PLEISTOCENE GEOLOGY OF THE BEAUSEJOUR AREA, MANITOBA

A Thesis

Presented to

The Department of Earth Sciences

of

The University of Manitoba

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In Partial Fulfilment

of the Requirements for the Degree

of

Doctor of Philosophy

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by

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April, 1970

ABSTRACT

A study of the Beausejour Area was undertaken to determine the distribution, thickness, composition, and origin of the Pleistocene deposits.

Surficial deposits were delineated by traversing along available roads and by interpretation of air photographs. The stratigraphy was determined by test augering and compilation of water well logs. Laboratory procedures used to characterize the various deposits include textural analyses, pebble counts, heavy mineral studies, and x-ray diffraction of clay size fractions.

Glacial landforms in the area include the Belair and Milner Ridge end moraines, ground moraine, roches moutonnées, glacial flutings, and eskers.

Landforms associated with proglacial Lake Agassiz comprise strandlines, lacustrine clays, muds, and sandy silts, intersecting minor lineations, and ice push ridges.

The stratigraphic succession of Pleistocene deposits, from oldest to youngest, consists of Belair Drift, Libau Drift, and clay, mud, and sandy silt units of Lake Agassiz.

Investigations indicate that an ice advance from a northeast direction deposited the Belair Drift prior to 12,700 years B.P. The next ice advance came from a northwest direction. It overrode the Belair Drift and deposited the Libau Drift prior to 11,700 years B.P. As the northwest ice retreated, Lake Agassiz expanded into the area.

Lacustrine clay was deposited into Lake Agassiz until ice retreat in Ontario opened an eastern drainage outlet about 8,000 to 8,500

years B.P. At this time, Lake Agassiz was largely drained and the clay was subjected to subareal erosion. A re-advance of ice in Ontario closed the drainage outlet and as the level of Lake Agassiz rose, muds were deposited upon the clay.

Retreat of ice sheets in Ontario and Northern Manitoba caused the level of Lake Agassiz to recede again and sandy silt was deposited in shallow water of Lake Agassiz as a result of delta construction and offshore processes.

Disintegration of the ice sheet in the Nelson River basin opened northern drainage and Lake Agassiz drained about 7,300 years B.P.

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CHAPTER I

INTRODUCTION

PURPOSE OF THE INVESTIGATION

During the latter part of the Wisconsin Glacial Stage, Glacial Lake Agassiz covered about 200,000 square miles in the Provinces of Ontario, Manitoba, and Saskatchewan, and the States of Minnesota, North Dakota, and South Dakota (Fig. 8). Because no detailed surficial geology maps of southeastern Manitoba were available, a study of the Beausejour Area was undertaken to determine the distribution, thickness, composition, and origin of the glacial deposits. This information should aid in future interpretations of the history of Lake Agassiz.

LOCATION AND ACCESS

The Beausejour Area, composed of 55 townships (1980 square miles) or portions thereof, is situated in southeastern Manitoba (Fig. 1). The area is bounded on the west by the western edge of rge. 4 E. [1], the Red River, and the southeast shore of Lake Winnipeg; on the north by the Winnipeg River; on the east by the eastern edge of rge. 11 E.; and on the south by the southern boundary of tp. 11. Beausejour is situated

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[1] All ranges cited are east of the Principal Meridian

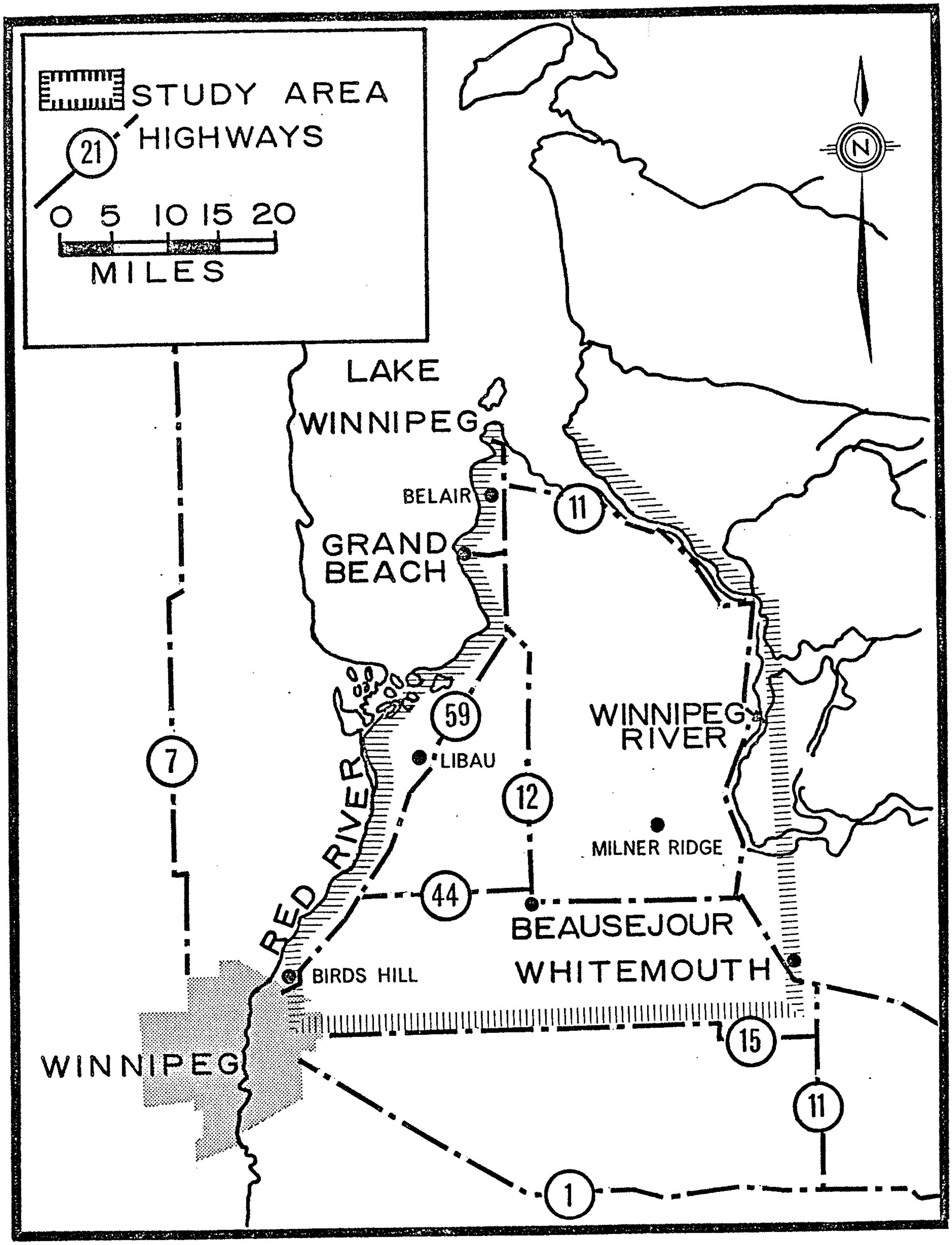

Fig. 1 Location map of the Beausejour Area

in the south central portion of the map area and is approximately 30 miles northeast of Winnipeg, Manitoba.

The area is well provided with road and railway facilities which include provincial trunk highway no's. 11, 12, 15, 44 and 59. Secondary roads at mile intervals are present in farming districts (about two-thirds of the area); non-farming districts have fewer roads which are mainly forestry access roads.

PREVIOUS WORK

Pioneer explorers who recognized beach structures related to Lake Agassiz include Keating (1925), Owen (1852), Hind (1859), Palliser (1893), Warren (1868), and Dawson (1875). The earliest comprehensive studies of Lake Agassiz were published by Upham (1895), Tyrrell (1896), and Leverett (1912). Johnston (1934) mapped the surficial geology of all but the northeast portion of the Beausejour Area, and in 1946 determined isobases for many of the Lake Agassiz beaches. However, no attempt was made to determine the glacial history of the Beausejour Area.

Since 1946, there have been numerous papers published on various aspects of Lake Agassiz and information from many of them is utilized within the thesis.

Elson (1966) presented a history of Lake Agassiz which includes at least four separate lake phases; sediments belonging to possibly all of these phases were mapped in a portion of the Winnipeg River Valley by McPherson (1968).

Soil maps by Ehrlich et al (1953) and Smith et al (1967) are available for the study area on a scale of 1 inch = 2 miles.

METHOD OF STUDY

During the initial stages of the study, a work map on a scale of 1 inch = 1 mile, was prepared from interpretations of soil maps and vertical aerial photographs. Field work was conducted in the summers of 1967 and 1968 using this preliminary map and airphoto mosaics of separate townships. Contacts between map units were modified and interpretations changed where necessary. Wherever possible, traverses were made along 1 mile intervals both in north-south and east-west directions. Elsewhere, the available roads were used as traverse lines. Foot traverses were made inside these areas when some important detail could not be obtained from the ordinary lines of traverse.

Sixty-eight drill holes with a total footage of 3,424 feet were drilled, using a truck mounted power auger during the summer of 1968. The auger, capable of penetrating to 100 feet, was used mainly to obtain stratigraphic information on till sheets, lake sediments, and end moraines.

After completion of the field work, a map of the surficial geology was prepared on a scale of 1 inch = 2 miles. The map is based on a detailed study of aerial photographs, field work, and laboratory analyses of samples.

Maps of bedrock topography, drift thickness, and lake sediment thickness were prepared using stratigraphic information obtained from drill holes and water well records. Drill hole data were also used to construct a series of stratigraphic sections.

Finally, an attempt was made to establish the glacial history of the area.

ACKNOWLEDGMENTS

This thesis was prepared under the supervision of Prof. E. Leith, Dr. D. Anderson, and Dr. J. Cherry, Department of Geology, the University of Manitoba, to whom the writer is indebted for guidance and constructive criticism. Dr. L. Clayton of the University of North Dakota read the manuscript and made useful suggestions. Dr. L. Clayton and Dr. S. Morin of the University of Illinois visited the study area and provided advice regarding field problems. The writer benefited greatly from discussions with Mr. S. Zoltai of the Canada Department of Forestry and Rural Development.

Mr. Barry Bannatyne, of the Manitoba Mines Branch, supplied maps and unpublished drilling data.

Valuable assistance regarding the drilling program was provided by Mr. L. Gray, Water Control and Conservation Branch, Province of Manitoba.

Drilling was done by Mr. C. Pearson, drafting by Mr. R. Pryhitko, and typing by Mrs. K. Korella; all of whom made useful suggestions.

Acknowledgment is made to members of the Department of Geology for their cooperation and interest in the project.

The study was supported by grants awarded to Prof. Leith and Dr. Anderson by the National Advisory Committee on Research in the Geological Sciences, and by a National Research Council of Canada Bursary awarded to the writer.

CHAPTER II

PHYSICAL GEOGRAPHY

CLIMATE

In relation to worldwide climatic conditions, the Beausejour Area is within the region Dfb. (Koppen and Geiger, 1936); an area which lies in the centre of the continent, a great distance from the oceans, and their modifying effect on temperatures. Summer temperatures are higher, winter temperatures lower, and the annual temperature range is much greater than the world average for the latitude. The mean monthly winter temperatures are below 32°F and the mean summer temperatures are above 50°F. Transition from winter to summer is abrupt, occurring normally in April. The change from summer to winter is usually in October.

Average yearly precipitation is 20 inches, but has ranged from 12.5 inches in 1961 to 26.9 inches in 1950 (Smith et al, 1967). About 14 inches of precipitation falls during the six months of May to October. Five inches of precipitation is received during the five winter months of November to March, mainly in the form of snow.

VEGETATION

Early in the study, it became apparent that a knowledge of vegetation distribution is essential to airphoto interpretation in the area. The following description of the vegetation will aid the reader in the interpretation of airphoto stereopairs in Chapter V.

Portions of the Grassland, Great Lakes, and Boreal Forest Regions occur in the Beausejour Area (Fig. 2).

In the Grassland Region, tall prairie grasses are most common, but aspen groves are plentiful around depressions or humid areas, and on northern and eastern slopes of higher areas and stream channels. Drier areas, such as steep ravines and gravel ridges, support oak trees in addition to aspen and poplar. Willow and poplar are frequently found in humid areas.

The Great Lakes' Forest Region is characterized by numerous swamps, extensive areas of sand, and granite outcrops. In the better drained depressions white and red pine are associated with white spruce, balsam, fir, elm, basswood, maple and oak. Poorly drained areas support black spruce, white cedar, and white birch. On the granitic outcrops, jack pine is common.

The Boreal Forest Region is subdivided into two sections in the area: the English River and Manitoba Lowlands Sections (Halliday, 1937).

The English River Section, occurring in the northeast portion of the Beausejour area, is relatively low relief country where Precambrian rocks are generally covered by Lake Agassiz sediments. Aspen and balsam poplar occur intermixed with white spruce, balsam fir and white birch. Black spruce and tamarack are found in the shallow swamps and jack pine is common in the sandy areas.

In the Manitoba Lowlands section, which occurs in the western portion of the area, the Paleozoic limestones are either near the surface or covered by calcareous till. The prevailing forest cover is aspen, black and balsam poplar, mixed with white spruce in well drained areas, and with tamarack and black spruce in poorly drained areas. Oak often occurs on gravel beaches and jack pine is common near limestone outcrops.

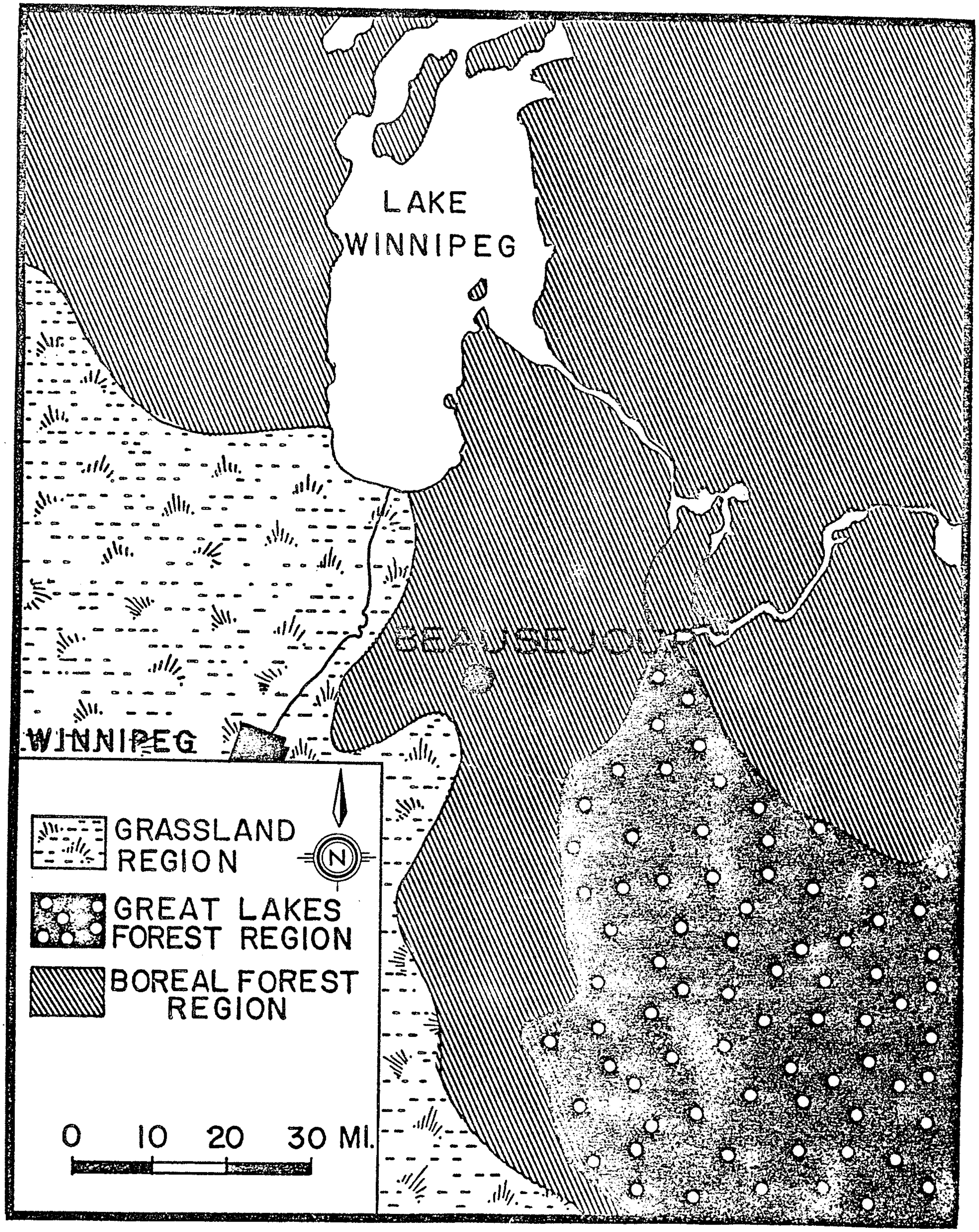

Fig. 2 Vegetation Regions in the Beausejour Area
(after Halliday, 1937)

SOILS

The Beausejour Area has been subdivided into three regional soil zones: the Black Earth Zone, the Rendzina Zone, and the Podzol (rock outcrops and peat) Zone (Fig. 3).

Several varieties of black earth soil are found, the main ones being: black earths developed on lacustrine clays, black earths with deeper profiles on sandy to silty lacustrine sediments, and black earths on calcareous till. In addition to the kind of parent material, the topography, position, and altitude vary considerably producing areas where black earth soils are interspersed with other soil types.

The Rendzina soils have developed primarily on calcareous till and are shallow, and dark in colour. Within the Rendzina Zone are local areas of gravelly soils developed on beaches, and peaty soils developed in depressions.

In the Podzol Zone, the predominance of rock outcrops, rather than soil development, is the outstanding characteristic. Podzol soils are developed where lacustrine sediments occur in areas between rock outcrops that are too well drained to produce tamarack swamps and moss peats.

Soil maps by Smith et al (1967), and Ehrlich et al (1953), were used extensively for field mapping and the final airphoto interpretation of the area.

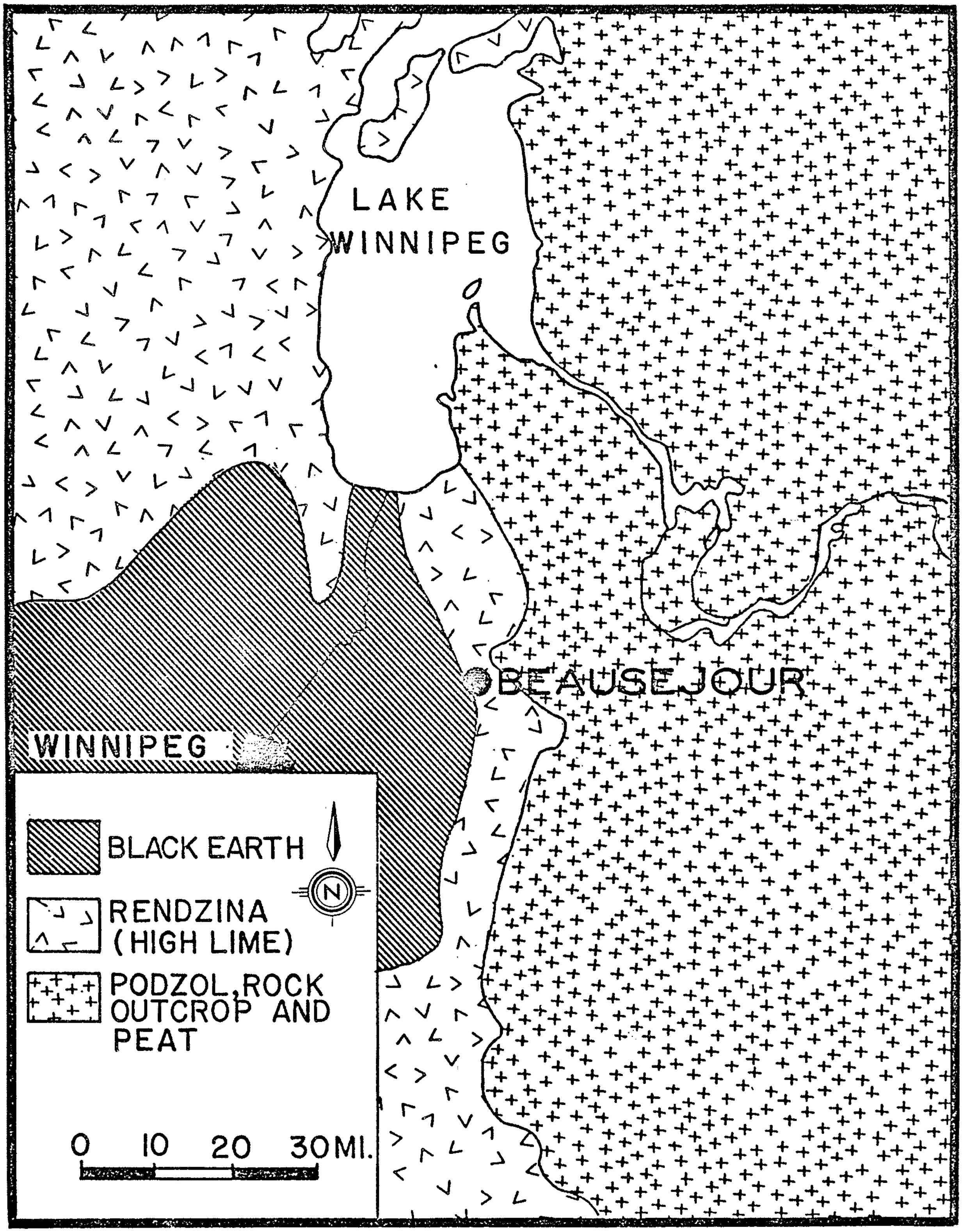

Fig. 3 Soil Zones in the Beausejour Area
(after Ellis, 1938)

DRAINAGE

The area is drained by the Winnipeg, Brokenhead, and the Red River Systems; the most extensive being the Winnipeg River system which includes the Whitemouth and Maskwa Rivers and Catfish and Jackfish Creeks (Fig. 7, in pocket).

The Winnipeg and Whitemouth Rivers drain approximately 43,480 square miles in the Lake of the Woods Area (Smith et al, 1967). They cross the area from south to north along the margin of the Precambrian Shield and flow through narrow, moderately drained clay plains.

The Brokenhead River flows from the swampy south-central portion of the area into Lake Winnipeg. The upper portion of the river, and a tributary, Hazel Creek, meander through poorly defined valleys and overflow their banks frequently. In the lower portions, the Brokenhead flows in and is confined within a well defined channel averaging more than ten feet in depth (Smith et al, 1967).

The southwestern portion of the area is drained by the Red River system, which includes Devil Creek. Both streams flow through well defined valleys developed in lake clays and glacial till. The Red River has developed an extensive delta where it flows into Lake Winnipeg.

PHYSIOGRAPHY

The Beausejour Area is situated within two major physiographic regions of Canada; the Canadian Shield in the northeast portion and the First

Prairie Level (also known as the Manitoba Lowlands) of the Interior Plains of Canada elsewhere. Smith et al (1967) and Ehrlich et al (1953) subdivided the Beausejour Area physiographically. However, modifications were made to these subdivisions because of different terminology used in the two reports (Fig. 4). The modified subdivisions are: the Red River Plain, Winnipeg Lake Terrace, and South-Eastern Lake Terrace Sections of the Manitoba Lowlands, and the Precambrian Drift Plain.

The Red River Plain Section is a flat, poorly drained, depressional area consisting of lacustrine clay and silt deposits. An extensive area of peat overlies these deposits in the Catfish Creek area.

The Winnipeg Lake Terrace Section is situated in the western portion of the area, and is usually above 800 feet in elevation.

The terrain varies from a gently undulating, modified, till plain in the Garson and Libau areas to irregular, hilly outwash and modified end moraine topography at Sand Hill, Grand Beach and Victoria Beach, and outwash topography near Birds Hill. Strandline features are present on many of the higher areas.

The South-Eastern Lake Terrace Section is located between the Red River Plain and the Precambrian Drift Plain. It occurs above an elevation of approximately 800 feet, and consists of a complex of landforms that have resulted from deposition of ground moraine, end moraine, glaciofluvial outwash, and lacustrine sediments.

A marginal portion of the Precambrian Drift Plain occurs along the eastern margin of the area. It is characterized by granitic rock outcrops, modified ground moraine, lacustrine clay, and peat deposits.

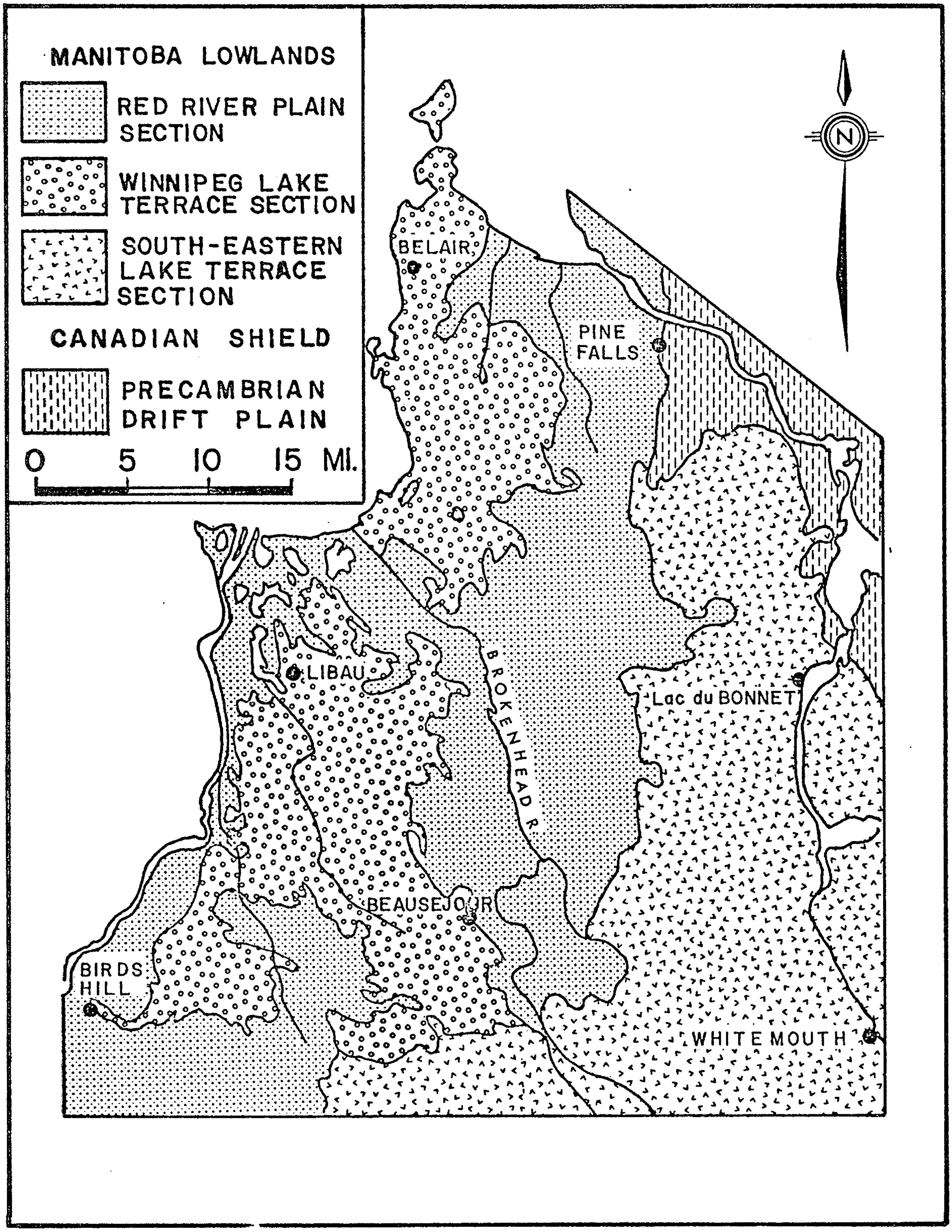

Fig. 4 Physiographic Subdivisions of the Beausejour Area
(modified after Ehrlich et al (1953), and Smith et al, 1967)

CHAPTER III

BEDROCK GEOLOGY

A review of both regional and local bedrock geology is relevant to the study of surficial geology for the following reasons:

1. Knowledge of the distributions of rock types in the bedrock is a prerequisite for the recognition of indicators of ice movement directions.
2. Surficial materials may resemble bedrock materials.
3. Most of the glacial drift in the Western Plains of Canada is local bedrock material (Bayrock, 1962).
4. Enquiry into the genesis of certain landforms and drainage patterns requires a knowledge of the geologic structure: for example, a portion of the western boundary of Lake Agassiz was controlled by an erosional escarpment in the bedrock.

The following description of bedrock geology is based on papers by Baillie (1952), Davies et al (1962), and Genik (1952).

REGIONAL BEDROCK GEOLOGY

The description of regional bedrock geology may be subdivided into two sections consisting of areas underlain by Precambrian rocks and areas where the Precambrian rocks are overlain by sedimentary rocks of Paleozoic, Mesozoic and Cenozoic ages (Fig. 5 and Table 1).

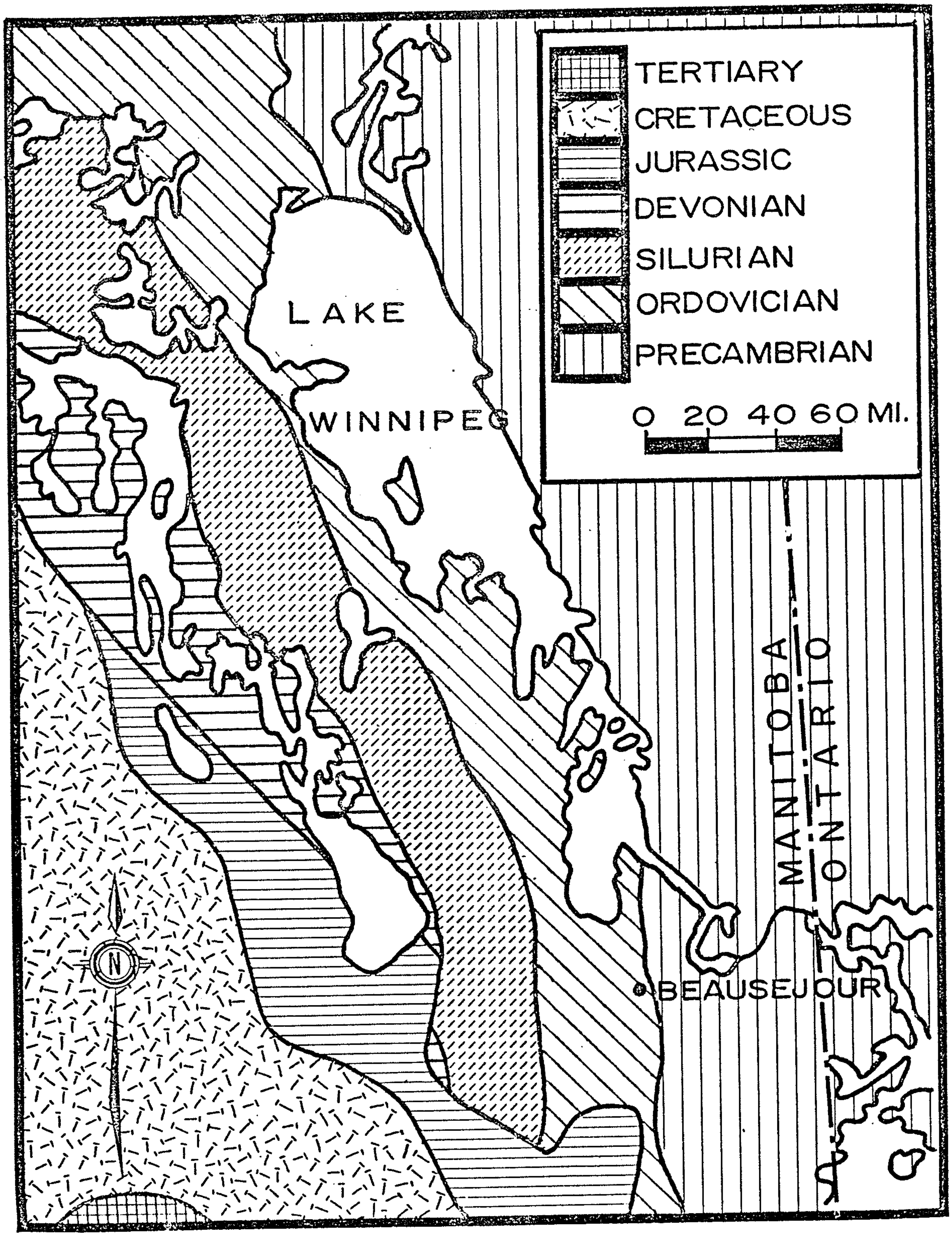

Fig. 5 Regional bedrock geology (modified from Davies et al, 1962)

TABLE 1

GEOLOGIC SYSTEMS IN MANITOBA *

Cenozoic	Palaeocene [1]	Shale, sandstone, minor lignite
Mesozoic	Cretaceous	Shale, bentonite, sandstone
	Jurassic	Shale, siltstone, dolostone anhydrite, gypsum
Paleozoic	Mississippian	Limestone, dolostone, shale siltstone, anhydrite, petroleum
	Devonian	Limestone, dolostone, shale, salt, potash
	Silurian	Dolostone, argillaceous dolostone, shale
	Ordovician	Dolostone, dolomitic dolostone, sandstone, shale
	Cambrian (?)	Glauconitic sandstone
Precambrian		Volcanic, sedimentary, metamorphic and intrusive rocks

* (modified from Davies et al, 1962)

The Precambrian rocks consist of extensive bodies of granite and granite gneisses containing smaller "belts" of highly folded and moderately metamorphosed volcanic and sedimentary rocks. Volcanic rocks consist of andesite, basalt, volcanic breccias, and metamorphosed equivalents, such as hornblende plagioclase schists and gneisses. Typical sedimentary rocks in the volcanic belts are quartzite, arkose, conglomerate, and greywacke.

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[1] Palaeocene is an epoch, other subdivisions in the column are periods.

Bodies of diorite, gabbro, and peridotite have intruded the volcanic and sedimentary rocks in most areas.

Paleozoic and Mesozoic rocks occur as northwest trending sedimentary belts with a shallow dip to the southwest. The thickness of the sequence ranges from 0 feet at the outcrop edge to over 5,000 feet in the south west corner of Manitoba. Paleozoic rocks are mainly limestones and dolostones, with smaller amounts of sandstone, shale, anhydrite and potash. Mesozoic rocks include mainly shales and sandstones. Cenozoic rocks are present at Turtle Mountain in southwestern Manitoba, and consist of sandstone and clay with thin seams of low rank coal.

LOCAL BEDROCK GEOLOGY

In the study area, the bedrock consists of Precambrian and Ordovician rocks (Fig. 6). The Precambrain rocks, mainly granites and granite gneisses of the Superior Province of the Canadian Shield, outcrop in the northeast portion of the area; elsewhere they are covered by drift and Ordovician rocks.

The Ordovician rocks, which dip gently to the southwest, are subdivided into two formations; the older, the Winnipeg Formation, and the younger, the Red River Formation.

The Winnipeg Formation trends north-northwest across the area, and is exposed in the study area at Victoria Beach (Genik, 1952). It consists of rounded, medium grained, quartz sand and green and purple shale containing interbedded sandstone. The upper portion of the formation frequently grades upward into arenaceous dolostone.

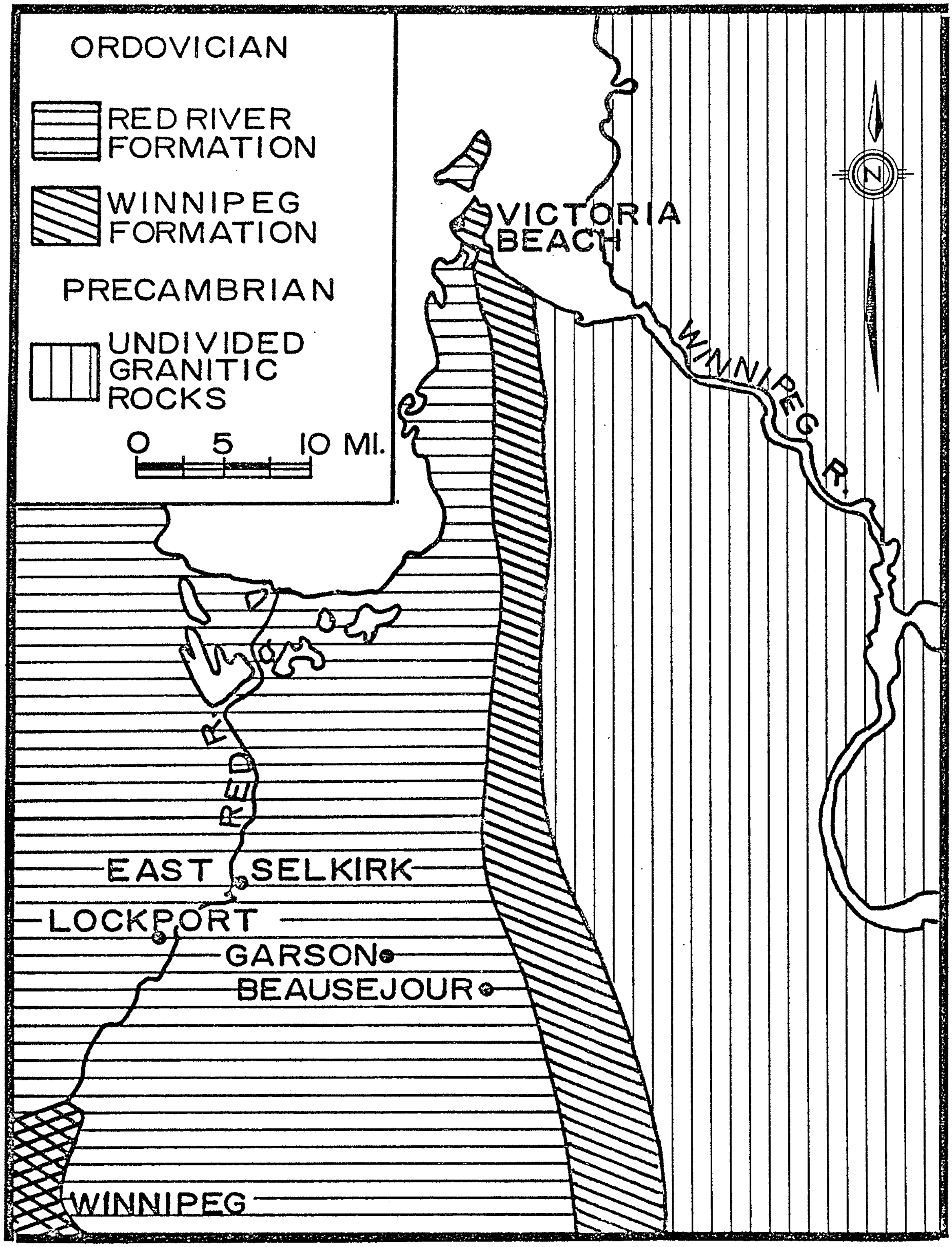

Fig. 6 Local bedrock geology (after Davies et al, 1962)

The Red River Formation occurs in the western portion of the Beausejour Area and outcrops at Lockport, East Selkirk, and Garson. It consists of mottled, dolomitic limestone containing cephalopods, gastropods, and compound corals, and bedded dolostone containing nodules of grey chert.

BEDROCK TOPOGRAPHY

The bedrock topography map(Fig. 7, in pocket) is based on data from topographic maps in areas of outcrops, 68 auger holes, and approximately 1,500 water wells.

The Precambrian granites and granite gneisses outcrop in the northeastern portion of the area at an elevation of about 850 feet [1]. To the west, they are covered by drift at an elevation of approximately 750 feet. The contact between the erosional edge of the Winnipeg Formation and the Precambrian rocks varies from 675 to 700 feet in elevation. Individual outcrops of granite frequently exhibit a surface relief of 50 feet, but auger holes adjacent to these outcrops indicate that some have a relief as great as 100 feet.

In the south central portion of the area, a low of 650 to 750 feet occurs in the surface of the Winnipeg Formation. This low parallels the present course of the Brokenhead River. The possibility exists that a buried channel, either preglacial or glacial, is present beneath the surface; however, the drift proved too thick for the drilling rig to penetrate. A compilation of lithologic logs from water wells indicates

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[1] Elevations cited are above sea level

the presence of gravel, sand and clay immediately above bedrock, but the deposits could be of either preglacial or glacial origin.

Test drilling with a larger rig and/or geophysical investigation would be necessary to determine the existence of a buried channel.

The Red River Formation, situated west of the Winnipeg Formation has an elevation ranging from 650 to 800 feet. A broad general high occurs where the rock outcrops at Garson. There is a depression of approximately ten feet in the bedrock surface beneath the Birds Hill esker-delta complex in tp's. 11 and 12, rge. 4 E.[1] The depression could have been there prior to deposition of the complex, perhaps influencing its deposition to some extent, or it could have been produced by stream erosion during deposition of the complex.

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[1] The depression does not show on Fig. 7, because of a 50 foot contour interval, but its presence is indicated by data from water wells.

CHAPTER IV

GLACIAL LAKE AGASSIZ

The following brief description of Glacial Lake Agassiz will provide the background material required to interpret many of the deposits in the Beausejour Area. For example, when beaches are described, the reader will be able to formulate his own views as to their significance and origin.

AREA

Glacial Lake Agassiz covered an area of approximately 200,000 square miles in the Provinces of Ontario, Manitoba, and Saskatchewan, and the States of Minnesota, North Dakota, and South Dakota (Fig. 8); however, the surface area of most phases did not exceed about 80,000 square miles at any one time (Elson, 1966).

AGE

The lake existed during the Wisconsin Stage of glaciation from approximately 12,400 to 7,300 years ago. The oldest date (12,400 ± 420 B.P.; Y-165, Science 122, 457) is on peat from below alluvial fill on the front of the Assiniboine delta, and is interpreted as representing an early event in Lake Agassiz. The time that the highest or Herman Beach was abandoned is 11, 740 B.P. (Y-1327; Wright and Ruhe, 1965, p. 39). The youngest date (7,270± 120 B.P.; G.S.C.-92, Radiocarbon 6, 170), on marine shells from an emerged beach at Churchill, Manitoba, indicates that Hudson Bay was free

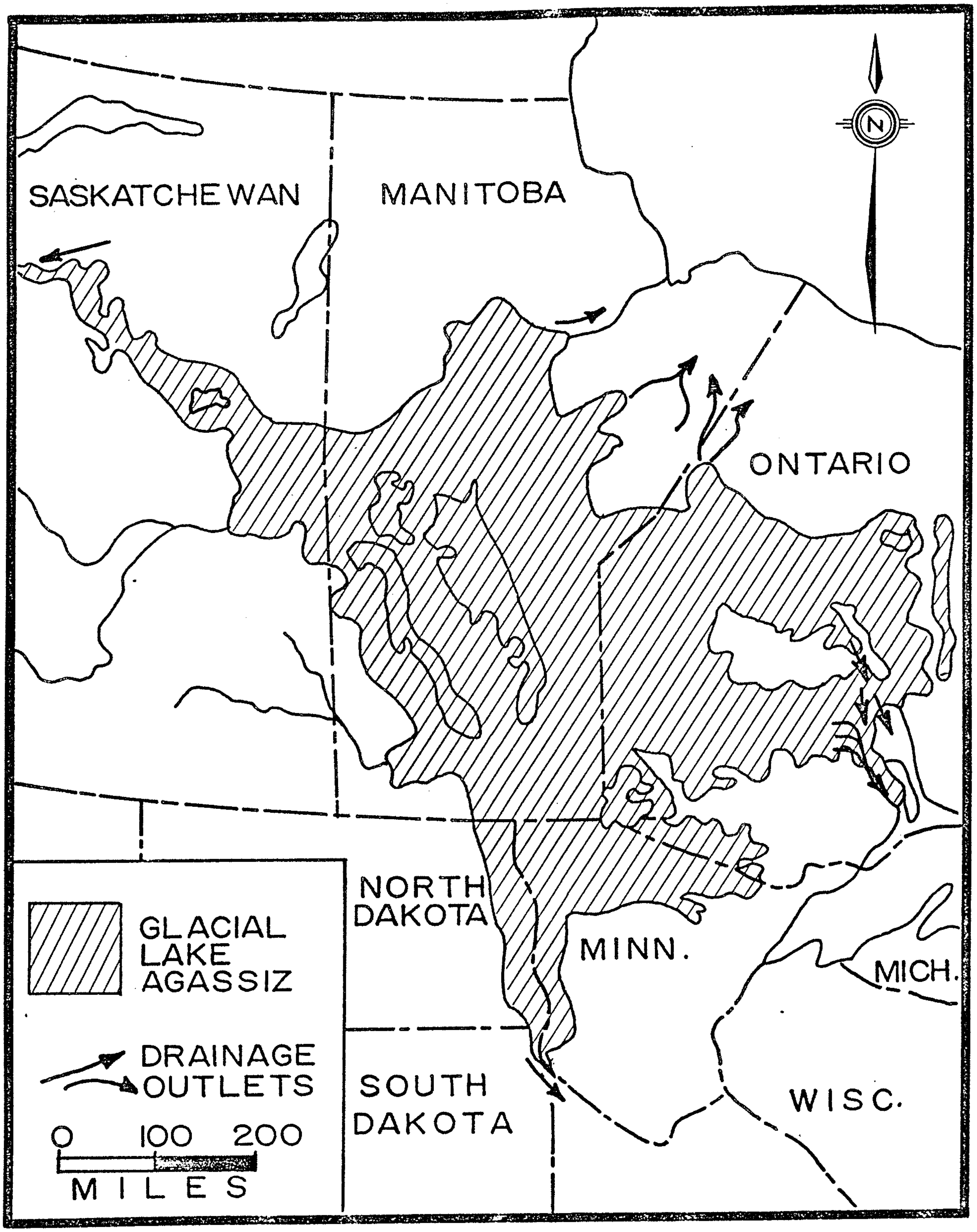


Fig. 8 Extent of Glacial Lake Agassiz (after Elson, 1966)

of ice at this time, so is a minimum age for the drainage of Lake Agassiz.

BOUNDARIES

In western Minnesota and along the escarpment (called Coteau des Prairies in the United States, and the Manitoba Escarpment in Canada), the lake boundary is characterized by well developed beach ridges, wave cut scarps and terraces. The northern lake limit in Manitoba and Ontario is poorly defined, being based on geological reports containing reference to lake clays and shoreline features (Elson, 1966). The eastern boundary is interpreted as the outer limit of well sorted sand resting on till or bedrock (Prest, 1963; Zoltai, 1965a, 1965b) except where strandline features are developed on end moraines or eskers (Elson, 1966).

DRAINAGE OUTLETS

Lake Agassiz had several drainage outlets that functioned during various stages of its history, depending on water level and the position of the ice margin on the northern and eastern side of the lake (Fig. 8).

The southern outlet crossed the Continental Divide where the States of North Dakota, South Dakota, and Minnesota meet. Drainage was via the Glacial River Warren (named by Upham, 1895), into the Mississippi River and eventually into the Gulf of Mexico. This outlet functioned intermittently during the highest water levels of Lake Agassiz (Matsch and

Wright, Jr., 1966).

The northwest outlet, at Flatstone Lake, Saskatchewan, drained via the Clearwater River into the Athabasca River, and through the McKenzie River system to the Arctic Ocean. It functioned simultaneously with the southern outlet during the high water Campbell phase of Lake Agassiz (Elson, 1966).

Eastward drainage was prevented until the ice margin had retreated nearly to the north end of Lake Nipigon. Drainage outlets in this area, from south to north, are the Dog River spillway, Kaiashk, Pillar-Armstrong, and Pikitigushi systems (Zoltai, 1966). Subsequent retreat of the ice opened a northeastern outlet into Lake Barlow-Ojibway. Final drainage of Lake Agassiz was into Hudson Bay via such rivers as Sachigo, Echoing, Hayes, Bigstone, Limestone and Nelson (Elson, 1966).

SEDIMENTARY DEPOSITS

The bedrock topography forms a number of partially closed basins in which most of the deep water sediments of Lake Agassiz accumulated (Fig.9); the Red River basin in the south being the major one. Counterclockwise from this are the Lake of the Woods-Rainy River, Wabigoon-Lac Suel, Sandy Lake, Grass River, and Sturgeon Weir basins.

All the basins have characteristic sediments related to certain stages of Lake Agassiz, because they functioned over different ranges of water levels (Table II). The Red River basin, which includes the Beausejour Area, has the widest range of water levels, and therefore, should contain the most complete record of the history of Lake Agassiz.

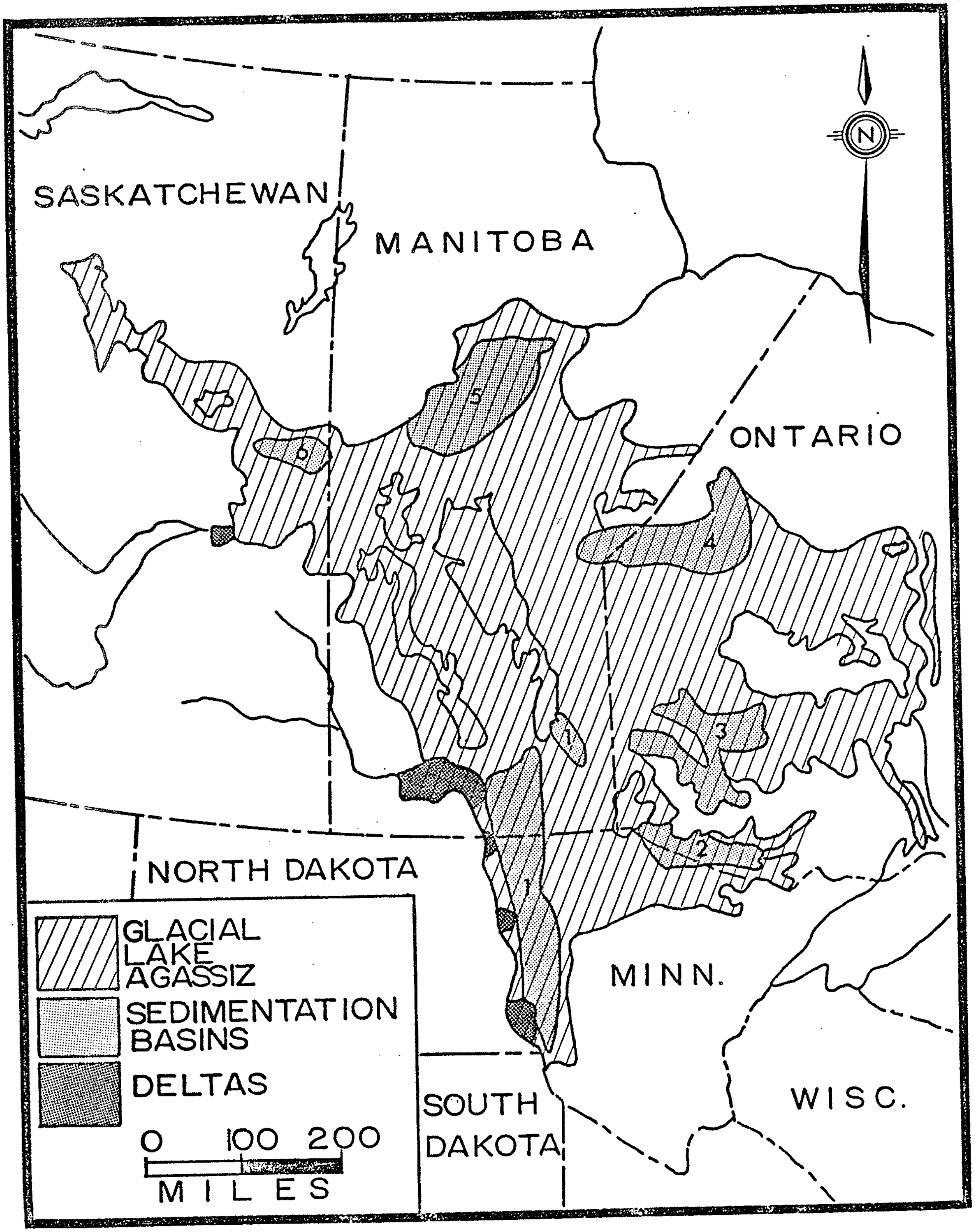
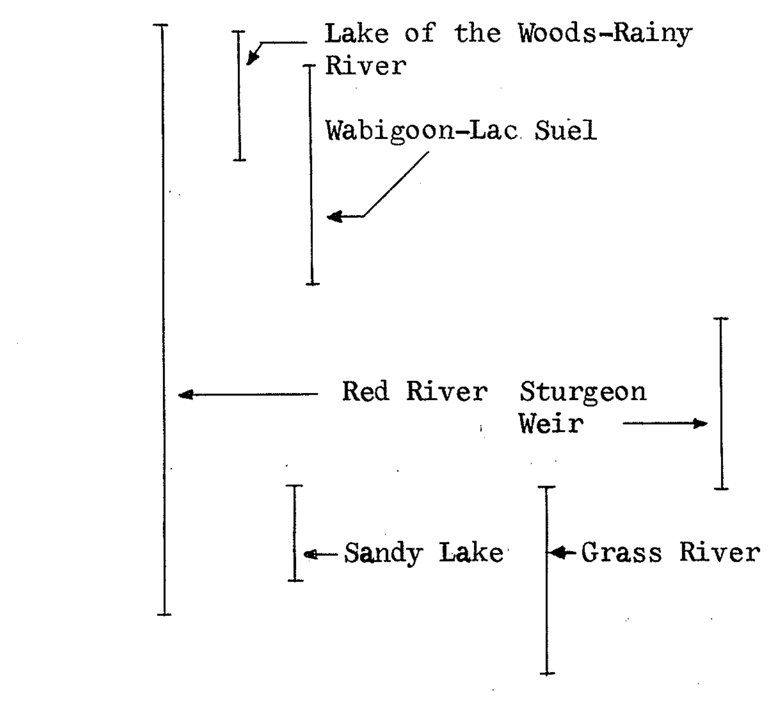


Fig. 9 Major sedimentation areas in Lake Agassiz (after Elson, 1966). Basins: 1 - Red River, 2 - Lake of the Woods-Rainy River, 3 - Wabigoon-Lac Suel, 4 - Sandy Lake, 5 - Grass River, 6 - Sturgeon Weir.

TABLE II

RANGE OF WATER LEVELS FOR MAJOR SEDIMENTARY BASINS OF LAKE AGASSIZ *

Water Planes	Elevation	Sedimentation Basins
Herman	1075-1400	
Norcross		
Tintah		
Campbell upper		
Campbell lower		
McCauleyville		
Blanchard		
Hillsboro		
Emerado		
Ojata		
Gladstone	840-1350	
Burnside		
Ossawa		
Stonewall		
Unnamed		
The Pas		
Lower Pas		
Gimli		
Grand Rapids		
Pipun		
L. Winnipeg	713	

* (data from Elson, 1966)

Several major deltas were deposited into Lake Agassiz at the front of the escarpment (Fig. 9); from south to north, they include the Sheyenne, Elk Valley, Pembina, Assiniboine, and Saskatchewan River deltas (the Saskatchewan River delta may have been deposited prior to Lake Agassiz). In all, 33 deltas have been described on the margins of Lake Agassiz, most of them deposited by short steep gradient streams on the face of the Manitoba escarpment (Elson, 1966).

About 55 water planes are represented by strandlines in the Lake Agassiz region. However, the water planes were not occupied in successively lower stages because the level of the lake fluctuated up and down with opening and closing of the various drainage outlets (Fig. 10). Beach ridges are the most common strandline forms in Lake Agassiz, but wave cut cliffs, terraces, spits, and tombolos are also present. The strandlines have higher elevations in the north because of isostatic uplift; hence, correlation of the beach ridges across large distances is difficult (Elson, 1966; Johnston, 1934; Kupsch, 1966).

Elson (1966) attempted to synthesize the evidence for Lake Agassiz into a step by step history and, in spite of limited data, provided a more complete understanding of Glacial Lake Agassiz.

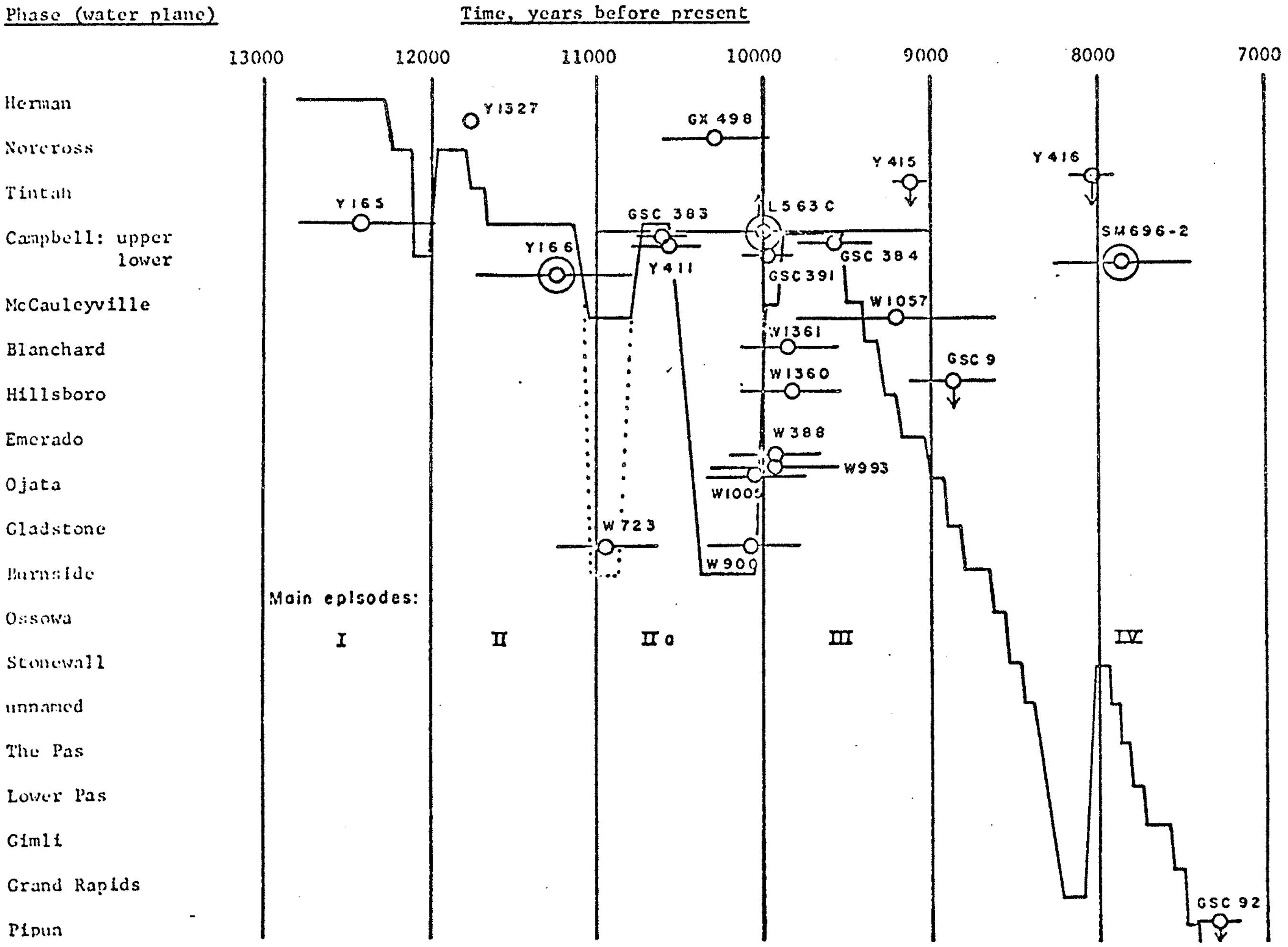


Fig. 10 Hypothetical sequence of water levels of Glacial Lake Agassiz (after Elson, 1966)
The numbers refer to radiocarbon dates (e.g. G.S.C. 383)

CHAPTER V

SURFICIAL GEOLOGY

SURFICIAL GEOLOGY MAP

A review of map formats used in the plains region (Cherry, 1966) revealed that information pertaining to lithology, morphology, and origin of glacial deposits is usually combined together in the legend.

Cherry stated: "In general lithology and morphology are much of the evidence upon which the interpretation of the origin is based. To maintain the usual procedure in presentation of scientific information, it appears desirable to separate the evidence from the interpretations."

The map legend used in this thesis (Fig. 11, in pocket) includes separate lithologic, morphologic, and genetic descriptions for each unit. This format enables persons who are using the map for applied purposes to view clearly the more objective information on lithology and morphology but still provides direct access to the subjective information on origins to those interested in the scientific aspects.

A problem in the description of glacial deposits is the confusion that exists in the terminology. For example, the Glossary of Geology and Related Sciences (American Geological Institute, 1957) gives four definitions for moraine and comments: "the term has been used in many different ways and its history is confused". Similar objections can be applied to many of the other terms. In an attempt to resolve this problem, all terminology will be defined within the thesis. The writer by no means assumes that his definition is the best one, but at least the reader will understand how each term is being used.

Problems involved in the choice of map units for the area are illustrated by the following specific example. Surficial deposits were formed primarily by:

1. a major ice advance from the northeast (these deposits are termed the Belair Drift [1]).
2. a major ice advance from the northwest (these deposits are termed the Libau Drift).
3. sedimentation and erosion in Lake Agassiz.

The Milner Ridge end moraine (part of the Belair Drift) occurs in the eastern portion of the Beausejour Area (Fig. 12). However, this end moraine is covered primarily by Libau Drift or Lake Agassiz beach deposits (illustrated by Fig. 41, in pocket). If the feature is called an end moraine on the map, any one who observes it in the field will question the interpretation. If the feature is called Libau Drift and/or Lake Agassiz beach deposits, the reader cannot visualize the extent of the Milner Ridge end moraine. In an attempt to solve this problem, the features observed directly on surface (i.e. Libau Drift and/or Lake Agassiz beaches) are utilized as map units (Fig. 11, in pocket)

This approach provides a map which can be used for practical purposes. On a second map (Fig. 12), the area is subdivided into broad genetic units. The extent of the Milner Ridge end moraine is indicated, but is described as having been modified by Libau Drift and/or Lake Agassiz processes. This second map provides a framework for discussion of the glacial history of the area.

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[1] The Drifts are formally defined in Chapter VI; they are mentioned here only to explain the choice of map units.

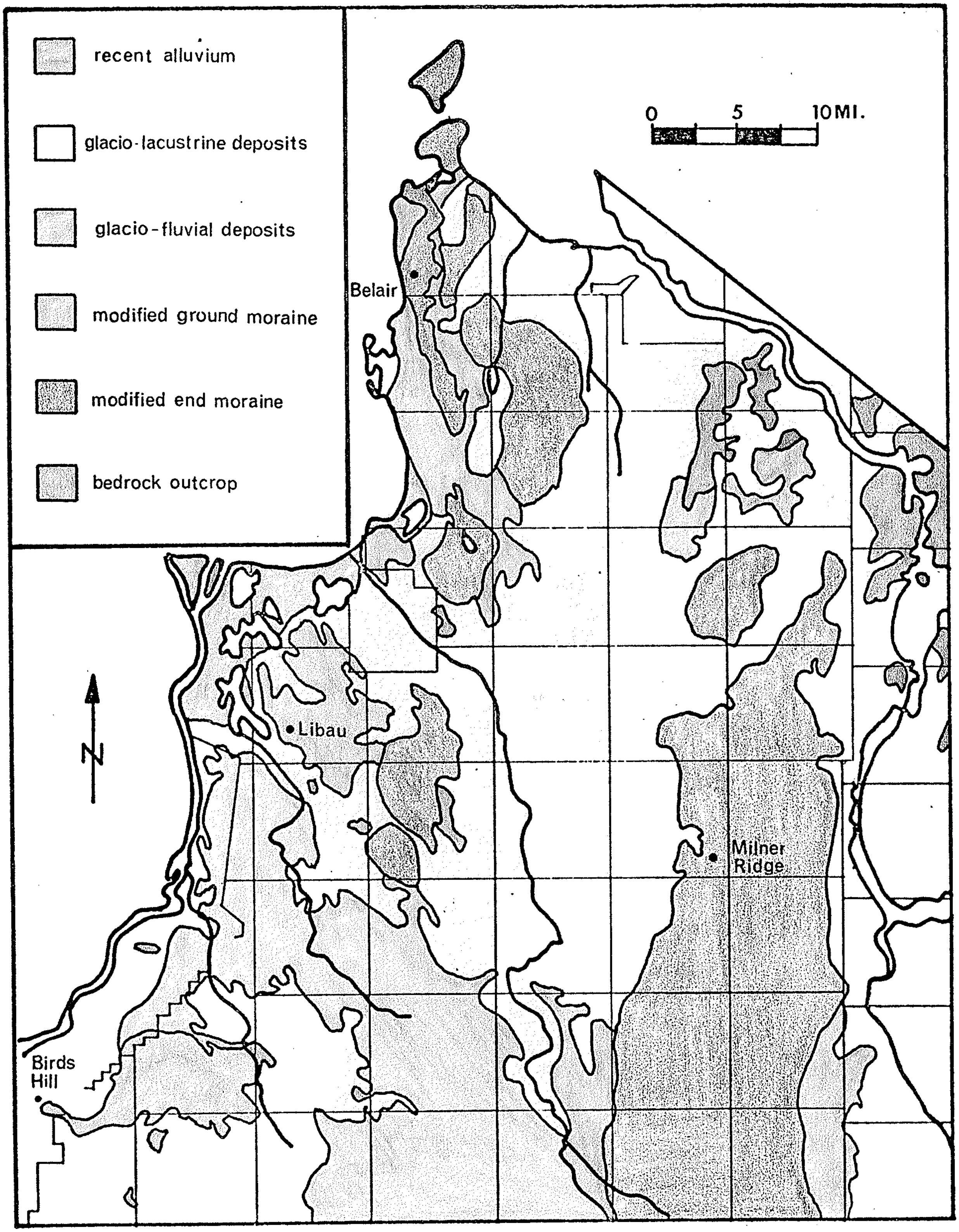

Fig. 12 Generalized surficial geology of the Beausejour Area

INDICATORS OF ICE MOVEMENT DIRECTION

The direction of ice movements in the area are indicated by striations on bedrock, striated boulders, roches moutonnées, crescentic gouges, and glacial flutings (Fig. 13).

Striations on Bedrock

Striations on outcrops of granite and granite gneisses indicate two major directions of ice advance. One ice advance is indicated by striations trending from N. 48° E. to N. 58° E. A different set of striations trending approximately N. 55° W. indicates a second ice advance. On most outcrops only northeast trending striations are present, however, both sets of striations are present on an outcrop in sec's. 33 and 34, tp. 15, rge. 11 E. The striations occur on opposite sides of a bedrock high; the northwest trending striations on the northwest side and the northeast trending striations on the northeast side (Fig. 14). In general, the northwest trending striations are finer and more poorly developed than the northeast ones. The relative ages of the striations are not apparent on the outcrop, but drift lithology and stratigraphy suggest that the northeast trending striations are older. Furthermore, the fineness of the northwest trending striations suggests that they would have been destroyed if they had been subjected to a major ice advance from the northeast.

Striated Boulders

In the southwest portion of the area, striated boulders occur within a calcareous till. The boulders, composed of limestone and dolostone have approximately horizontal, striated upper surfaces (Fig. 15).

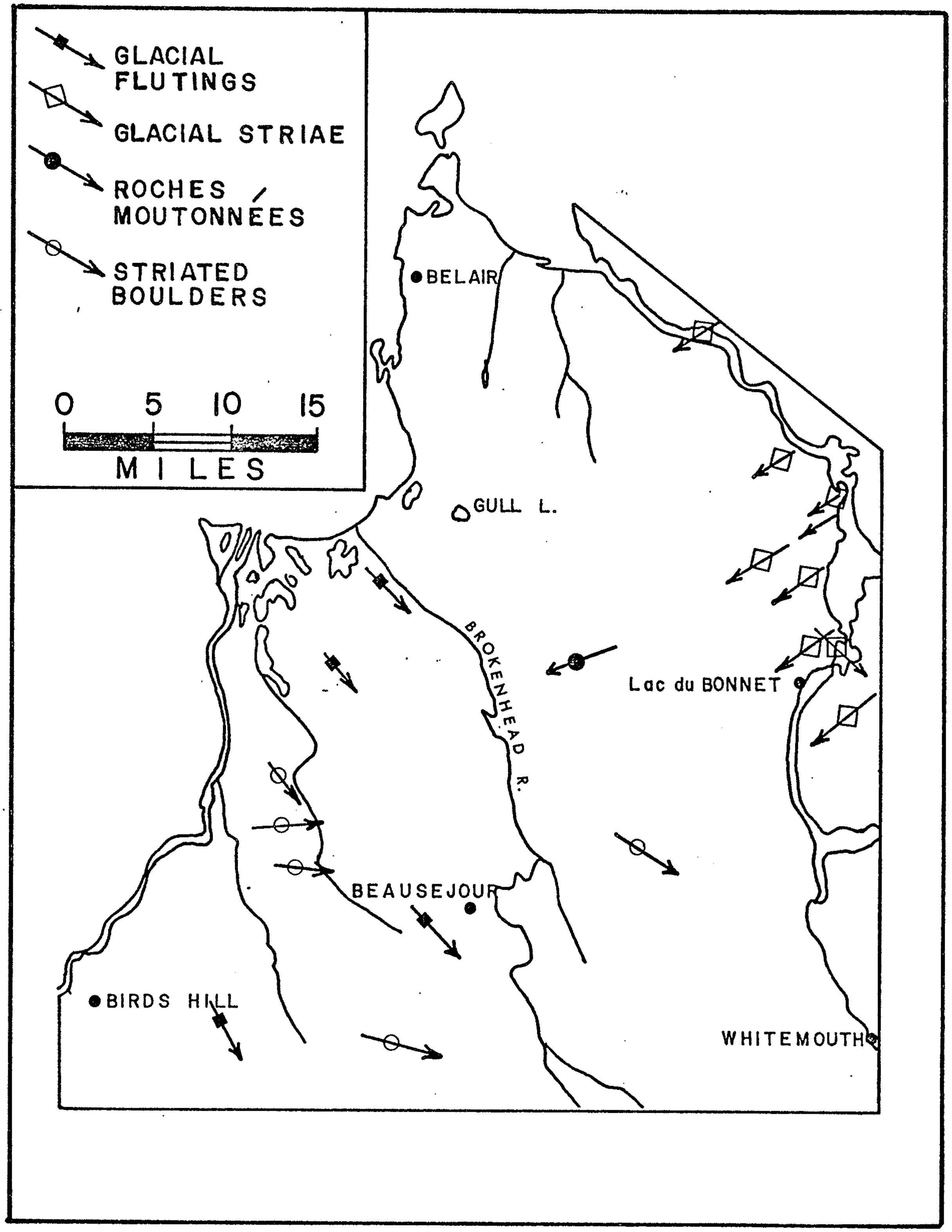

Fig. 13 Indicators of ice movement direction

The striations trend from northwest to west which is subparallel to direction of ice advance in that area as indicated by glacial flutings. The boulders do not occur in groups as in boulder pavements; no more than two were observed in a single section. The till above and below the boulders is identical, and no evidence of subareal erosion is present. Boulders of this type have not been reported in the literature except in groups as boulder pavements. Miller (1884) suggested that boulder pavements formed by the subglacial erosion of till contemporaneous with deposition. Gilbert (1898) and Holmes (1944) indicated boulder pavements may form by subareal erosion followed by a re-advance of ice. The origin of these striated boulders in the Beausejour Area is uncertain, but the writer's opinion is that as the glacier moved along, the boulders rotated until they attained stable positions that offered least resistance to glacier flow (i.e. horizontal positions). The upper surfaces then were abraded by debris-laden ice, and a striated facet was formed. This process could occur either subglacially or englacially, due to changes in the ability of the ice to transport various sizes of debris. Such changes could be caused by fluctuation in the regimen of the glacier. If this process occurred, the striations would approximate the direction of ice advance.

Roches Moutonnées

Roches moutonnées are glacially abraded bedrock outcrops having a comparatively gentle abraded slope on the side facing the ice advance (stoss side), and a somewhat steeper and rougher quarried slope on the lee side. They are commonly developed on granitic outcrops in the northeast portion of the Beausejour Area. The stoss side is on the

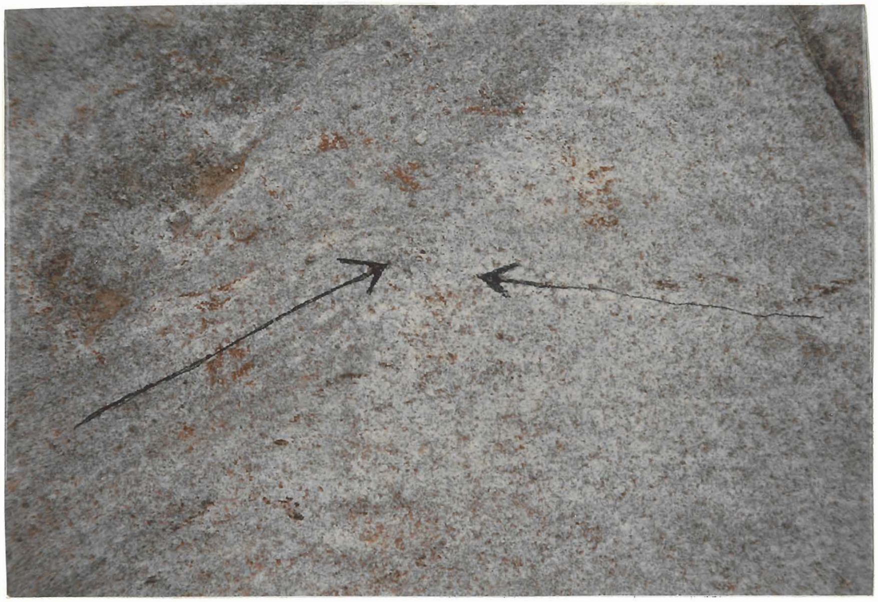

Fig. 14 Intersecting glacial striae on Precambrian granites

Fig. 15 Striated boulders in calcareous till

northeast side of the outcrops, and the lee side to the southwest indicating an ice advance from the northeast. No roches moutonnées formed by the northwest ice advance are present. The stoss sides result from glacial abrasion, whereas the lee side is probably steepened by plucking of the rock (Flint 1957; Thwaites, 1963).

Crescentic Gouges

Crescentic gouges are present on a granite outcrop in sec's 33 and 34, tp. 15, rge. 11 E. (Fig. 16). They are crescent shaped fractures oriented approximately at right angles to the direction of ice movement and are concave "upglacier". They consist of two fractures, the one with shallowest dip on the "upglacier" side. Crescentic gouges were produced by both northeast and northwest ice advances. They are believed to be formed by the sudden impact of a boulder, dragging of boulder along the rock surface (Dreimanis, 1953), or due to forces produced by the weight and motion of the glacier (Thwaites, 1963).

Fig. 16. Crescentic gouges on Precambrian granites near Lac du Bonnet.

Glacial Flutings

The word "fluting" has been used to describe parallel shallow grooves on till plains (Chapman & Putnam, 1951). In this report, the term "fluting" is used in its widest possible sense and includes low lying rock drumlins, as well as parallel ridges and grooves. The fact that drumlins — of a variety of forms — and flutings are gradational has been pointed out by several geologists (Smith, 1948; Gravenor, 1956; and Lemke, 1958).

Flutings are developed on modified ground moraine in the southwest portion of the Beausejour Area. They consist of low ridges of till trending N. 36° W. to N. 43° W., which indicates the direction of ice advance in that area. They have a relief of approximately 5 to 15 feet, width of 500 to 4,000 feet, and lengths of $\frac{1}{4}$ to 6 miles. In some instances, the flutings have a coalescing pattern.

Flutings developed near Libau have a preferred wave length(distance between ridge crests [1]) of 1,840 feet (Fig. 17a). Test drilling indicated that the till in the area is less than 50 feet thick, and that at least a portion of the ridges are underlain by bedrock highs.

Flutings developed near Garson have a preferred wave length of 3,430 feet (Fig. 17b). It is not known whether bedrock highs occur under the ridges, but the till is generally greater than 50 feet thick.

Wardlaw et al (1969) indicated that northwest trending flutings developed in till in the Interlake Area, Manitoba, are the reflection of

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[1] The values for wave length are only approximate because the ridge crests are difficult to delineate without precise surveying.

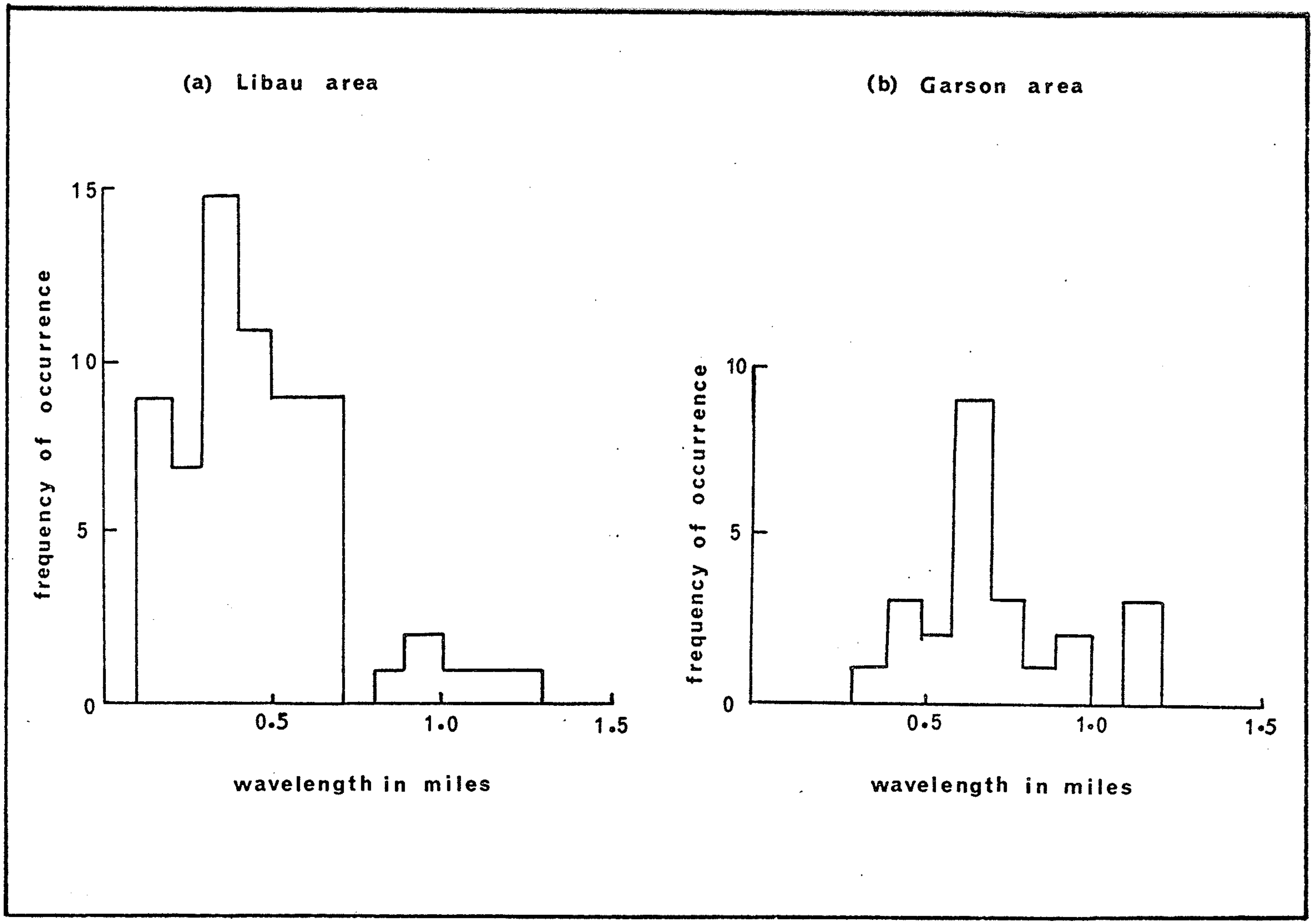

Fig. 17 Histograms indicating preferred wave lengths of glacial flutings in the Beausejour Area

"giant" ridges and grooves in bedrock. Because the flutings in the Beausejour Area have bedrock highs under at least some of the ridges, it is possible that they may also be a reflection of parallel ridges and grooves in bedrock. Flutings near Garson could have a larger preferred wave length than flutings at Libau because the till is thicker at Garson and would tend to mask many of the smaller ridges and grooves in the bedrock.

Gravenor and Meneley (1958) stated that any proposed origin for glacial flutings must take cognizance of the following facts:

1. flutings and drumlins are gradational features;
2. flutings are formed of till, stratified drift and bedrock;
3. flutings are regularly spaced, show well developed parallelism, and are up to several miles long;
4. preliminary fabric data indicate that there is a lineation of rock fragments parallel to the ridges and a foliation that dips away from the ridge tops.

They propose a periodic distribution of high and low pressure within the glacier to account for erosion in the lows and deposition on the highs, but could not explain the cause of such a pressure distribution. Westgate (1968) stated: "The exact mechanism whereby flutings are created is still a matter of conjecture."

Although the flutings in the Beausejour Area may be a reflection of ridges and grooves in bedrock, the reason for their preferred wave length is unknown.

END MORAINES

An end moraine has been defined as a glacial deposit whose topography is primarily the result of glacial deposition (by thrusting, shove, and dump) at the margin of an active glacier. In the Beausejour Area, the topography of the end moraines has been modified by an ice re-advance and by sedimentation and erosion in Lake Agassiz. The distinction between end moraine and associated outwash, both of which are sandy, is frequently impossible where sections are absent. The term "end moraine" as used in this thesis refers to a deposit whose topography was primarily the result of a glacial deposit whose topography was primarily the result of a glacial deposition at the margin of an active glacier, and has been modified by overriding ice and lake action. It may also include portions that were deposited by outwash from the ice margin.

There are two end moraines in the Beausejour Area, the Belair end moraine and the Milner Ridge end moraine.

Belair End Moraine

The Belair end moraine, named after the hamlet of Belair in sec. 9, tp. 19, rge. 7 E., extends discontinuously for approximately 40 miles in a north-south direction (Fig. 12). It probably extends northward under Lake Winnipeg as far as Black Island (Tyrrell, 1891). This moraine consists of 12 major topographic highs separated by intervening lower areas (Table III and Fig. 18, in pocket).

TABLE III

MAJOR TOPOGRAPHIC HIGHS OF THE BELAIR END MORAINE

Topographic High	Location	Approx. Area (Sq. Mi.)	Max. Relief of High (Feet)
1	tp.20 rge. 7 E.	3	50
2	tp.19 rge. 7 E.	2	150
3	tp.19 rge. 7 E.	3	125
4	tp.19 rge. 7 E.	2	50
5	tp.18 rge. 7 E.	6	125
6	tp.18 rge. 7 E.	2	125
7	tp.18 rge. 7 E.	6	100
8	tp.18 rge. 8 E.	7	150
9	tp.17 rge. 8 E.	19	200
10	tp.16 rge. 7 E.	6	100
11	tp.14 rge. 7 E.	17	100
12	tp.14 rge. 7 E.	5	50

Usually the highs are irregular in shape and ice contact slopes or outwash plains cannot be distinguished by topography alone. An exception occurs in sec's. 10 and 12, tp. 18, rge. 7 E., where a modified outwash plain slopes westward from a segment of the end moraine.

The end moraine complex is composed primarily of grayish yellow (5Y 8/4 wet)[1] medium to fine sand that is coarser with depth (Table IV).

TABLE IV

SIEVE ANALYSES OF SAND FROM BELAIR END MORAINE

Drill * Hole No.	Sample Depth (ft.)	% Very Coarse Sand	% Coarse Sand	% Med. Sand	% Fine Sand	% Very Fine Sand	% Silt + Clay
12	10	tr.	8	19	48	17	8
12	35	1	8	29	45	12	5
13	10	- -	1	15	76	7	1
13	25	tr.	4	41	50	4	1
19	10	- -	- -	24	67	7	2
19	30	- -	14	44	38	3	1

* (Locations of drill holes are give in Appendix I, and Fig. 40, in pocket)

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[1] All colour designations in this thesis are from a modified Munsell colour chart published by the National Research Council (1948), Washington, D.C.

The sand consists of quartz grains, minor amounts of granitic, volcanic and metasedimentary rock fragments, and heavy minerals, such as amphiboles, pyroxene, garnet, apatite and magnetite.

In places, beds less than one foot thick consisting of light olive gray (5Y 6/1 wet), silty to sandy lacustrine clay are interbedded with the sand. Unusually high concentrations of granitic cobbles and boulders are present in certain portions of the end moraine.

A light olive gray (5Y 6/1) sandy till, containing numerous granitic volcanic and metasedimentary rock fragments occurs beneath the sand. It could be either part of the end moraine or ground moraine associated with the same ice advance (the till is described in a later section).

Most of the material composing the end moraine is of local provenance having been derived from the Precambrian granitic rocks. An exception would be the volcanic and metasedimentary rocks. It is concluded that the end moraine was deposited by an ice advance from the northeast because of the trend of the end moraine, the presence of outwash on its western margin, the composition of the material, and northeast trending glacial striations, crescentic gouges, and roches moutonnées. A large portion of the end moraine is probably outwash sand deposited by streams flowing off the ice. The coarser sands would be deposited first, and as the ice margin receded, finer sand would be deposited on the coarser sand. On exposed ice slopes, large boulders would "bound" farther out from the ice margin and fine sediment would be deposited next to the ice. Thus, some initial irregularity of boulder concentration seems explained. This process has been observed to occur on the Barnes Ice Cap (Goldthwait, 1951).

The end moraine was deposited into a proglacial lake as evidenced by the beds of lacustrine clay in the sand. Because no dates are available to indicate the time of deposition of the Belair end moraine, it is not known whether this proglacial lake existed prior to Lake Agassiz or is an early stage of Lake Agassiz. However, the generalized picture of glaciation in adjoining areas suggests that this proglacial lake existed prior to formation of Lake Agassiz. This problem is discussed more fully in Chapter VII.

Milner Ridge End Moraine

The Milner Ridge end moraine, named after the hamlet of Milner Ridge in sec's. 12 and 13, tp. 14, rge. 9 E., extends for a distance of approximately 36 miles in a north-south direction in the study area (Fig. 12). Reconnaissance test drilling south of the study area indicated that it correlated with the Whitemouth moraine (as named by Elson, 1961).

Except for an isolated segment with an area of approximately 18 square miles in tp. 16, rge. 9 and 10, the end moraine is a continuous irregularly shaped high. The average relief of the end moraine is 100 to 150 feet; the maximum being 225 feet. The topography has been highly modified by an ice-re-advance and by sedimentation and erosion in Lake Agassiz. No ice contact slopes or outwash plains are evident. The end moraine is composed primarily of light olive gray (5Y 6/1 wet) medium to fine sand that is generally coarser with depth (Table V).

TABLE V

SIEVE ANALYSES OF SAND FROM THE MILNER RIDGE END MORAINE

Drill * Hole No.	Sample Depth (ft.)	% Very Coarse Sand	% Coarse Sand	% Med. Sand	% Fine Sand	% Very Fine Sand	% Silt + Clay
6	35-40	2	4	15	44	18	17
61	0-5	tr.	6	67	24	2	1
36	5	- -	2	27	56	13	2
36	60	18	19	25	18	11	9
38	15-30	7	40	41	8	2	2
38	80-85	8	12	25	14	19	22

The sand consists of quartz grains, minor amounts of granitic, volcanic and metasedimentary rock fragments, and heavy minerals such as amphiboles, pyroxene, garnet, apatite and magnetite.

Thin beds of light olive gray (5Y 6/1 wet) silty to sandy lacustrine clay are interbedded with the sand. Beneath the sand is a light olive gray (5Y 6/1 wet) sandy till similar to the till beneath the Belair end moraine. Unusually high concentration of granitic cobbles and boulders are present in certain areas of the Milner Ridge end moraine.

Because of the similarity in the Belair and Milner Ridge end moraines, it is concluded that the Milner Ridge end moraine was deposited by an ice advance from the northeast. The presence of large quantities of outwash indicates that it was deposited primarily by streams flowing off the glacier into a proglacial lake of unknown extent. It is likely that most of the material has been derived from the Precambrian granites.

The Milner Ridge end moraine situated to the east of the Belair end moraine is younger than the Belair end moraine because an ice advance from a northeast direction capable of depositing the Belair end moraine would have destroyed most evidence of previously deposited moraines. The Milner Ridge end moraine represents either a halt in the retreat or a minor re-advance of the ice sheet.

GROUND MORAINE

Ground moraine has been defined as glacial till deposited from the glacier on to the ground surface. Clayton (1962) defined ground moraine as relatively low relief, undulating (swell and swale) moraine that lacks transverse linear trends, and has a topography that is dominantly the result of subglacial lodgement of till. Although this type of topography is characteristic of ground moraine, it has not been proven that ground moraine consists primarily of lodgement till. It may actually consist mainly of till deposited by basal melting of the ice. Therefore, the writer prefers the first definition because it has less definite genetic implications.

There are two major till units in the study area, one being stratigraphically lower than the other or older.

The Lower Till

The lower till (probably an older ground moraine and part of the Belair Drift defined in Capter VI) is not exposed in the study area, but was intersected in 5 auger holes (no's. 3, 5, 12, 15, 35) at depths, ranging from 22 to 100 feet (Appendix I and Fig. 40, in pocket). It is directly overlain by outwash sand and/or end moraine associated with the same ice advance. It is not present in some areas, either because it has been removed by a later ice advance or was never deposited. Test drilling, south of the study area, indicates that the lower till is closer to the surface and more extensive. Future studies in that area should lead to increased knowledge of this deposit. Based on the limited data available, the characteristics of the lower till are as follows:

It is a light olive gray (5Y 6/1 wet) in colour and consists primarily of quartz and feldspar grains, clay materials, granitic, volcanic, and metasedimentary rock fragments, with a minor number of carbonate rock fragments. Grain size analyses [1] of 4 samples of the till are indicated on Figure 19. A complete list of sample locations and grain size analyses of both the upper and lower tills is presented in Appendix II. The average grain size of the 4 analyses is 49.8% sand, 31.7% silt, and 18.5% clay. Till of this grain size range may be called a loam till according to Elson's 1961 till classification triangle.

No pebble counts were conducted on the lower till because large enough quantities of uncontaminated samples of till were not available. However, general observations indicate that the content of carbonate pebbles is quite low. The heavy mineral assemblage consists primarily of amphibole, pyroxene, and garnet, with smaller amounts of apatite, and iron oxides, mainly magnetite.

The lower till is considered to have been deposited by an ice advance from the northeast because: (1) the mineralogical composition and heavy mineral suites indicate it has been derived primarily from acid igneous rocks which occur northeast of the area; (2) there are

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[1] Grain size analyses were performed according to the method outlined by Folk (1965) pp. 21-40.

directional indicators, such as roches moutonnées, striations, and crescentic gouges, indicating a major ice advance from that direction; (3) the association of this till with the Belair and Milner Ridge end moraines, whose mineralogical composition, and lobate form (on a regional scale) suggests deposition by a northeast ice lobe; (4) the lack of significant quantities of carbonate rock fragments which would most certainly be present if the ice had advanced from the northwest over the Paleozoic limestone and dolostones.

Test drilling indicates that the western limit of the lower till is marked by the Belair end moraine. It may have been deposited west of there and destroyed by the later northwest ice advance, because it was not protected by significant quantities of end moraine or outwash.

The Upper Till

The upper till (part of the Libau Drift defined in Chapter VI) is exposed at surface as ground moraine in many portions of the Beausejour Area, being most extensive in the southern and western portions of the area (Fig. 11, in pocket, and Fig. 20). It ranges in thickness from 0 to approximately 100 feet, 20 to 30 feet being average. It is thickest in topographically lower areas, where it is buried beneath Lake Agassiz sediments. The upper till has been eroded from many of the higher areas, but where present, is covered by 1 to 2 feet of wave modified till. The presence of flutings in the till near Libau and Beausejour indicates that it has not been extensively eroded in that area.

The till is usually light olive gray (5Y 6/1 wet) in colour, however, the till is yellowish gray (5Y 8/1 wet) where it occurs immediately above limestone or dolostone bedrock. In isolated localities

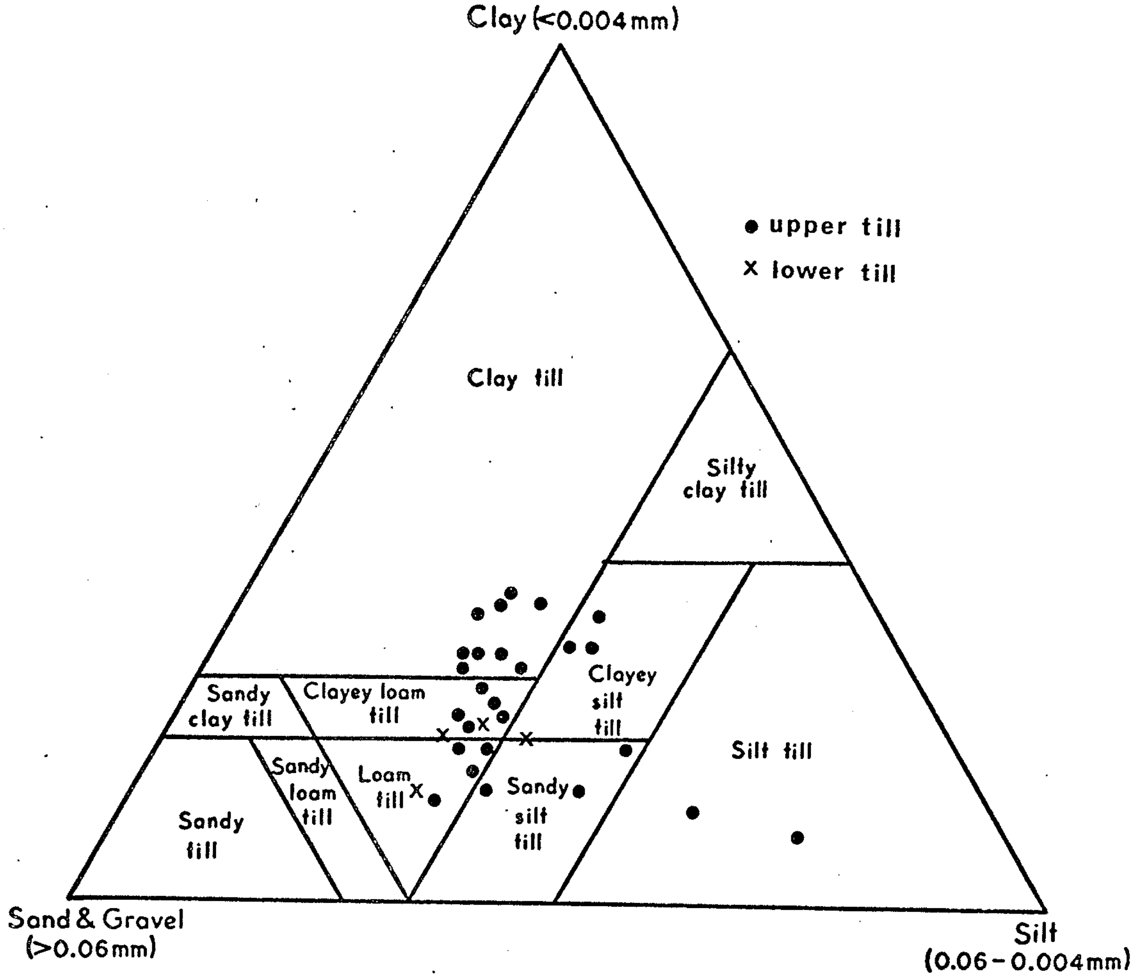

Fig. 19 Grain size analyses of till in the Beausejour Area (plotted on Elson's 1961 till classification triangle)

small glacio-fluvial and glacio-lacustrine deposits are interbedded with the till, but these are not considered extensive enough to be considered as evidence of two separate ice advances. They are interpreted as being due to meltwater flows within the ice and the result of slumping and flowing of till (flowtill of Hartshorn, 1958) incorporating these deposits.

Wicks (1965) conducted detailed studies of the mineralogy of this till in the Winnipeg Area (Table VI).

Fig. 20 Exposure of upper till on the shore of Lake Winnipeg (N.E. $\frac{1}{4}$, sec. 32, tp. 19, rge. 7 E.)

TABLE VI

QUANTITATIVE MINERALOGY OF THE UPPER TILL IN THE WINNIPEG AREA

Sample No.	Description	Wt. % dolomite	Wt. % calcite	Wt. % quartz	Wt. % feldspar	Wt. % illite-montorillonite	Wt. % organic matter
Y-39/6	till	38.2	11.0	13.9	14	20	0.5
Y-44	till near bedrock	48.1	10.7	17.1	17	5	0.4

Qualitative studies of the mineralogy of the upper till using binocular microscope and x-ray diffraction indicate that elsewhere in the study area the till consists mainly of dolomite, quartz, feldspar, calcite, and clay minerals. The relatively uniform mineralogy of the till in the Winnipeg Area is indicated by the CO_2 and quartz content (Table VII).

TABLE VII

CARBON DIOXIDE AND QUARTZ CONTENT OF THE UPPER TILL IN THE WINNIPEG AREA*

Sample No.	CO_2 (Wt. %)	Quartz (Wt. %)
Y-36/2	26.4	14.3
Y-36/6	21.1	13.0
Y-36/9	25.8	14.9
Y-37/1	24.1	16.7
Y-38	23.2	13.6
Y-39/6	23.0	15.5
Y-41/1	23.8	13.6
Y-42	23.5	14.4
Y-43/1	25.3	15.5
Y-44	27.6	18.8
Y-44/6	27.1	18.2
G-50	24.0	17.3
WR-1	26.3	12.3

* (data from Wicks, 1965)

Grain size analyses of 26 samples of the upper till are indicated on Figure 19. The average grain size of the 26 samples is 41.3% sand, silt 34.9%, and 23.8% clay. Till of this grain size may be called a clayey loam till.

Pebble counts of 10 samples of the upper till indicate that the majority of pebbles are limestones and dolostones (Table VIII). The relatively high percentage of igneous pebbles in the sample from tp. 15, rge. 8 E. is due to local granite bedrock being incorporated into the till.

TABLE VIII

PEBBLE COUNTS OF THE UPPER TILL IN THE BEAUSEJOUR AREA

Location	No. of Pebbles	% Limestones and Dolostones	% Acid Igneous Rocks and Gneisses	% Volcanic and meta-sedimentary
S.W.$\frac{1}{4}$,sec.33,tp.11,rge.5E	164	92	5	3
N.W.$\frac{1}{4}$,sec.18,tp.12,rge.8E	218	95	4	1
S.W.$\frac{1}{4}$,sec.5,tp.12,rge.10E	234	84	13	3
S.W.$\frac{1}{4}$,sec.17,tp.14,rge.7E	210	83	16	1
N.E.$\frac{1}{4}$,sec.13,tp.15,rge.8E	192	60	38	2
N.E.$\frac{1}{4}$,sec.32,tp.19,rge.7E	156	73	19	8
Hole 27 - depth 25'	223	85	12	3
Hole 31 - depth 45'	195	87	10	3
Hole 37 - depth 55'	186	86	13	1
Hole 57 - depth 17'	202	74	20	6

The heavy mineral assemblage of the upper till consists of amphibole and pyroxenes with lesser amounts of garnet, apatite and iron oxides. The gross mineralogy of the upper till indicates that it was derived primarily from the Paleozoic carbonates, with smaller contributions coming from Precambrian rocks, and perhaps, Cretaceous and Jurassic shales.

The upper till is considered to have been deposited by an ice advance from the northwest, because: (1) the trend of flutings and striated boulders within the till, as well as the trend of striations on bedrock indicate the ice advanced from a northwest direction; (2) the high carbonate content of the till suggests it was derived from the Paleozoic carbonate rocks, which occur primarily to the west of the area; (3) an esker near Birds Hill has a mineralogy similar to the till and was deposited by a stream flowing from an ice mass situated to the west of Birds Hill (Organ, 1952).

ESKERS

An esker may be defined as a sinuous ridge of sand and gravel deposited by a meltwater stream flowing in a channel or tunnel in glacial ice.

There are three eskers in the area, two near Birds Hill and one in tp. 13, rge. 5 E., three miles northeast of Gonor (Fig. 11, in pocket). The two near Birds Hill and an associated delta will hereafter be referred to as the Birds Hill complex. The westernmost esker of the complex, termed the Birds Hill esker consists of three major topographic highs. The first high begins near the town of Birds Hill and extends for approximately one mile in a southeasterly direction. It has a maximum relief of 50 feet and an average width of 1,200 feet. To the east, the second segment trends east-west for a distance of 2 miles, has a relief of 50 to 60 feet, and a width ranging from 1,000 feet in the western part to 1,500 feet to the east. The third major topographic high, situated northeast of the second one has a relief of about 50 feet, an area of three-quarter square miles, and trends in a northeast direction. The hill, at the easternmost limit, widens and flattens to become an elevated sandy plain covering approximately 16 square miles. The three major highs are connected by ridges having a relief of only 10 to 15 feet.

The second esker, called the Moose Nose Hill esker, situated south and east of the Birds Hill esker, trends approximately north-south. It also consists of three irregularly shaped topographic highs, but in this instance, the highs are separated (on surface) by low relief lake plain. However, test augering (Hole No's. 49 and 67, Appendix I) indicates that the hills are connected by sand and gravel deposits in the subsurface. The southernmost hill has an area of approximately one-half square mile and a relief of 50 feet. The second hill occurs three miles northeast and has an area of one square mile and a relief of 70 feet. The third hill occurs two-thirds of a mile north of the second, and has an area of one square mile and a relief of 60 feet. This third hill merges into the same sandy outwash plain as the Birds Hill esker.

Both eskers contain gravels and sands consisting of approximately seventy-five per cent limestone and dolostone rock fragments and smaller amounts of granite, granite gneiss, volcanic, and metasedimentary rock fragments, quartz grains, and heavy minerals. Organ (1952) found that many unstable heavy minerals are present, and that there is a progressive increase by weight of the heavy minerals closer to the outwash plain. This is likely due to the progressive breakdown of rock fragments and the subsequent release of heavy minerals with increased distance of transport.

Heavy minerals would also tend to be concentrated with sand size grains of light minerals, because they would have a similar weight.

In general, the bedding in the Birds Hill esker is horizontal and consists of layers of gravel or layers of gravel and sand. Cross bedding occurs within the layers and it slopes 15 to 30° to the east in the first two segments and 15 to 20° to the northeast in the third segment. Sometimes along the edges of the highs, the bedding dips away from the crest of the ridge.

In the Moose Nose Hill esker, the bedding is either horizontal or dipping at 10 to 30° to the north. Cross bedding within the layers also dips 10 to 30° to the north. On the edges of the hills, the bedding sometimes dips away from the crests of the ridges.

Organ (1952) conducted grain size analyses on 75 samples from the complex, and concluded that the gravels become finer toward the east and northeast until they merge into sands of the outwash plains. The writer observed that there is an overall decrease in grain size from west to east in the Birds Hill esker, and from south to north in the Moose Nose Hill esker, but there is also a decrease from coarse to fine gravel or sand within each major segment of the eskers.

Portions of both eskers are overlain by calcareous till, but the bedding in the underlying sand and gravel is not distorted. The till contains many lenses of sand and gravel and is often intercalated with contorted layers of clay. Although it is possible that the till was deposited by an ice re-advance over the eskers, as suggested by Upham (1910) and Organ (1952), it is more likely that the till is ablation till deposited as ice over a tunnel melted away, or a flowtill that slumped into a crack in the ice.

An underlying mass of till, similar in lithology to the upper till of the Libau Drift, occurs as a central core to the middle segment of the Birds Hill esker.

The eskers are overlain by fine outwash sands in some localities, especially the western portion of the Birds Hill esker. They were probably deposited upon the eskers as the ice margin retreated.

As mentioned previously, there is a slight depression of 10 to 15 feet in the bedrock surface below the Birds Hill complex. It is not known whether the depression was there prior to the eskers, perhaps influencing their deposition to some extent, or whether the depression originated by erosion caused by the esker streams. Future test drilling may provide an answer to this problem.

The origin of eskers has been a subject of much debate. The main points in question are whether eskers are formed by streams flowing in cracks in ice sheets that are open to the surface or whether they are formed in tunnels. Also, if the eskers were deposited in tunnels; were the tunnels near the base of the ice sheet, in the central portions, or near the surface. Most researchers recognize the multiple origins for eskers as indicated by Flint (1957) who stated: "It appears likely that many eskers, particularly the long ones, are subglacial tunnel deposits, that some were built headward in successive segments, each marked by a delta where the esker stream entered a glacial lake, and that others have been let down from superglacial and possibly englacial positions through very thin ice."

Upham (1910) suggested that Birds Hill esker was deposited by a superglacial stream flowing eastward from a glacial lobe situated immediately west of Birds Hill and the broad plain at the eastern end represents the delta or outwash plain.

Organ (1952) proposed that the Birds Hill esker was deposited by a stream flowing eastward in a crack in the ice, and indicated that the Moose Nose Hill deposit represents a second stream channel that flowed from south to north. He suggested that the overlying till was deposited by a minor re-advance of ice, and that the underlying core of till may have initiated the fissures in the ice front which defined the depositing streams. Both Upham (1910) and Organ (1952) agreed that the front of ice sheet marked the northwest boundary of Glacial Lake Agassiz, which was at the Herman stage (400 feet deep) during deposition of the Birds Hill complex. However, Upham felt that the complex was deposited on top of the ice sheet and let down 400 feet as the ice melted, and Organ believed that the complex was deposited in approximately its present position.

The writer agrees that the pattern of deglaciation in the area suggests that Lake Agassiz was at the Herman stage when the complex was deposited, but according to the uplift curves of Johnston (1934), the water was at least 600 feet deep at this time. The gradation from coarse to fine gravel within each major portion of the eskers suggests that they were deposited in segments as the ice retreated. However, a decrease in average grain size of each esker segment away from the west end of the Birds Hill esker and the south end of Moose Nose Hill esker suggests that the stream flow was greatest during the final stages of deposition of both eskers. This could result from development of a large network of tributary streams on the ice surface that could supply sediment to the eskers. The eskers were deposited near the base of the ice sheet because the bedding shows little evidence of being disturbed. The dip of the bedding away from the ridge crests along the edges of the eskers indicates that minor slumping occurred as supporting ice walls melted.

The question of whether the eskers were deposited in a crack in the ice (open to the surface) or a tunnel, or a combination of both remains unsolved because till overlying the eskers could be either ablation till or till that slumped into a crack in the ice. The central core of till underlying parts of the Birds Hill esker may have been "squeezed" up into a tunnel or fissure in the ice by the pressure of the ice sheet.

The depth of Lake Agassiz at the time the eskers were deposited is in question because of uncertainties in Johnston's (1934) uplift curves and the lack of dates for the time of deposition of the eskers. However, present data suggest a depth of 600 feet. Theakstone (1967) postulated that openings cannot exist below about 160 feet of ice, but the writer believes that an opening could exist at greater depths once it is initiated, provided that the hydrostatic pressure is sufficient enough. Streams capable of depositing the coarse gravel found in the eskers should have high enough velocities to allow deposition of the esker delta into 600 feet of standing water, and provide enough pressure to keep the tunnels open.

A third esker occurring 3 miles northeast of Gonor, was at one time completely buried by 5 to 15 feet of lake clay and calcareous till, but has since been exposed by quarrying. The esker trends approximately east-west, is one mile long, one-quarter mile wide, and at least 50 feet thick. It consists of gravel and sand that is coarsest in the western portions and finer to the east. Bedding is generally horizontal and contains cross bedding that dips 10 to 30° to the east. The mineralogical composition of the gravels and sands is remarkably similar to that of the Birds Hill complex suggesting that both deposits originated from the same major ice advance. The esker was probably deposited by a stream flowing from west to east in a tunnel or crack in the ice, and ending in Lake Agassiz. Any evidence of a delta at the eastern end of the esker would be buried beneath the lake clays.

SHORELINE FEATURES OF LAKE AGASSIZ

The section on shoreline features of Lake Agassiz will be divided into two parts: a description of the various shoreline features, and a discussion of the effect of post glacial uplift on these features.

Beach Ridges

A beach ridge may be defined as "a continuous mound of beach material behind the shore that has been heaped up by wave or other action", (American Geological Institute Glossary, 1957).

They are by far the most common shoreline landform in the Beausejour Area as well as in the Lake Agassiz basin.

Individual ridges range in length from a few hundred feet to slightly over 4 miles. Gaps separating the ridges range from a few hundred feet to tens of miles. Ridge widths are generally 100 to 1,000 feet, but near Milner Ridge, beach ridge complexes as wide as 4 miles occur. The height of the ridges ranges from approximately 2 to 30 feet with an average height being 5 to 15 feet. In many localities the ridges are symmetrical in profile and have smooth slopes. In other places, asymmetric ridges consisting of steep backshore slopes and more gentle foreshore slopes are present (Fig. 21).

Fig. 21 Asymmetric profile of a beach ridge near Birds Hill.

The altitude of the crests of individual beach ridges differ by as much as 10 feet. Essentially, all the ridges have developed on ground moraine and/or sandy end moraine.

The most noticeable feature of the stratification of beach ridge materials is the remarkable division into bedding. The thickness of the beds varies considerably. Some are no thicker than a single layer of fine sand grains, whereas other beds are a foot thick. The size of materials in the beaches varies from fine sand to boulders, but particles of different beds fall characteristically within different size ranges. The grain size distribution of material in different beds of a typical beach ridge is indicated in Table IX. There is considerable variation in graphic mean diameter of the particles of these beds which reflects varying wave action during deposition of the beach. Using the classification of Folk (1965), the sorting in the beds ranges from moderately to poorly sorted. This is mainly due to the poorly sorted nature of the glacial till from which beach material is derived. Because the beach represents only a temporary water level of Lake Agassiz, there was probably insufficient time for considerable reworking of sediment to take place. This would also tend to reduce sorting of the sediments. In general, the coarser beds are composed of granitic, volcanic, metasedimentary and carbonate rock fragments, and the finer beds of quartz grains and/or heavy minerals. Pierce et al (1956) conducted a heavy mineral study of a beach ridge near Vivian. Their results are summarized in Table X. It should be noted that they have lumped several laminae into single beds, and that frequently the heavy minerals, especially magnetite, may be concentrated into very thin laminae. They concluded from their study that although the percentage of each type of heavy mineral varies somewhat, the types of minerals found are the same. The heavy mineral suite is similar to the heavy mineral suite found in the tills of the Belair and Libau Drifts (as described by Elson, 1961). However, the relatively high percentage of garnet and magnetite indicate that considerable quantities of the heavy minerals in the beach were derived from the Belair Drift. The heavy minerals found in the beach are considered representative of other beaches in the study area, with

TABLE IX

GRAIN SIZE ANALYSES OF SAMPLES FROM UNNAMED BEACH

(loc. sec. 10, tp. 11, rge. 7 E)

% Weight Retained (ø Scale)	Bed Number							
	1	2	3	4	5	6	7	8
-2.0	8.70	11.05	0.00	0.82	5.06	1.27	3.14	53.40
-1.0	3.74	47.50	0.98	23.65	5.04	1.98	20.40	28.19
-0.5	2.49	25.55	1.76	29.50	3.26	2.87	17.75	5.24
0.0	3.80	7.24	6.24	21.80	3.49	6.92	16.50	2.76
0.5	4.14	2.18	13.18	12.76	4.89	14.00	12.52	1.78
1.0	6.15	1.28	27.21	6.24	14.00	27.00	13.56	1.46
1.5	21.10	1.42	25.95	2.27	38.70	32.85	10.91	2.05
2.0	32.00	0.96	15.21	1.28	22.45	10.09	2.78	1.78
2.5	16.65	0.64	8.20	0.68	2.84	1.27	0.47	2.62
3.0	0.98	0.31	1.07	0.17	0.08	0.14	0.25	0.18
3.5	- -	0.28	0.01	0.10	0.05	0.07	0.99	0.08
4.0	- -	0.25	0.00	0.09	0.02	0.07	0.09	0.08
<4.0	- -	1.34	0.01	0.58	0.05	0.36	0.47	0.08
Graphic Mean Diameter	1.12ø	-1.15ø	+1.05ø	-0.47ø	+0.92ø	+0.88ø	-0.14ø	-2.04ø
Inclusive * Graphic Skewness	-.43	+0.12	-0.06	+0.20	-0.56	-0.31	+0.06	+0.18
Inclusive * Graphic Standard Deviation	+1.31	+0.85	+0.72	+0.76	+1.04	+0.72	+1.07	+1.51

* Statistical parameters of grain size defined by Folk (1965)

the exception of a few beaches in the westernmost portion of the area where the Belair Drift is absent.

There are a number of types of bedding relationships present in the beach ridges of the area. These are illustrated in Figure 23. The most common type consists of beds with a very shallow dip toward the former water body (hereafter referred to as lakeward). In isolated localities, these beds appear horizontal (Fig. 22).

Fig. 22 Approximately horizontal bedding in a beach ridge

There are two relationships that exist between the beds in this type: (1) the surface truncating the underlying beds is the floor of deposition for the overlying beds; this surface dips lakeward more steeply than do the truncated beds. The result is a wedge between two erosion surfaces that thins lakeward (Fig. 23, type c); (2) the truncating surface dips lakeward less steeply than do the truncating laminae resulting in a wedge that thins landward (Fig. 23, type d). Both of these relationships are characteristic of foreshore deposits between the crest of the beach and the lake. Another type of bedding relationship consists of beds with a landward dip, truncated by an erosional surface of lakeward dip, and overlain by beds of lakeward dip having characteristics

TABLE X

HEAVY MINERAL ASSEMBLAGE OF A LAKE AGASSIZ BEACH RIDGE *

(location - sec. 29, tp. 10, rge. 8 E)

Thickness	Frequency	Per cent of Heavy Minerals		3 %
(ft.)	25%	10-25%	3-10%	
3 3/4	garnet magnetite	hornblende	epidote	rutile apatite staurolite hematite tremolite
$1\frac{1}{4}$	garnet	hornblende	epidote	hypersthene hematite limonite actinolite monazite tourmaline apatite rutile
3/4	garnet magnetite	hornblende	tourmaline epidote	rutile apatite staurolite hematite limonite hypersthene monazite
7	garnet magnetite	hornblende	epidote	tourmaline staurolite hematite apatite rutile hypersthene augite

* After Pierce et al (1956)

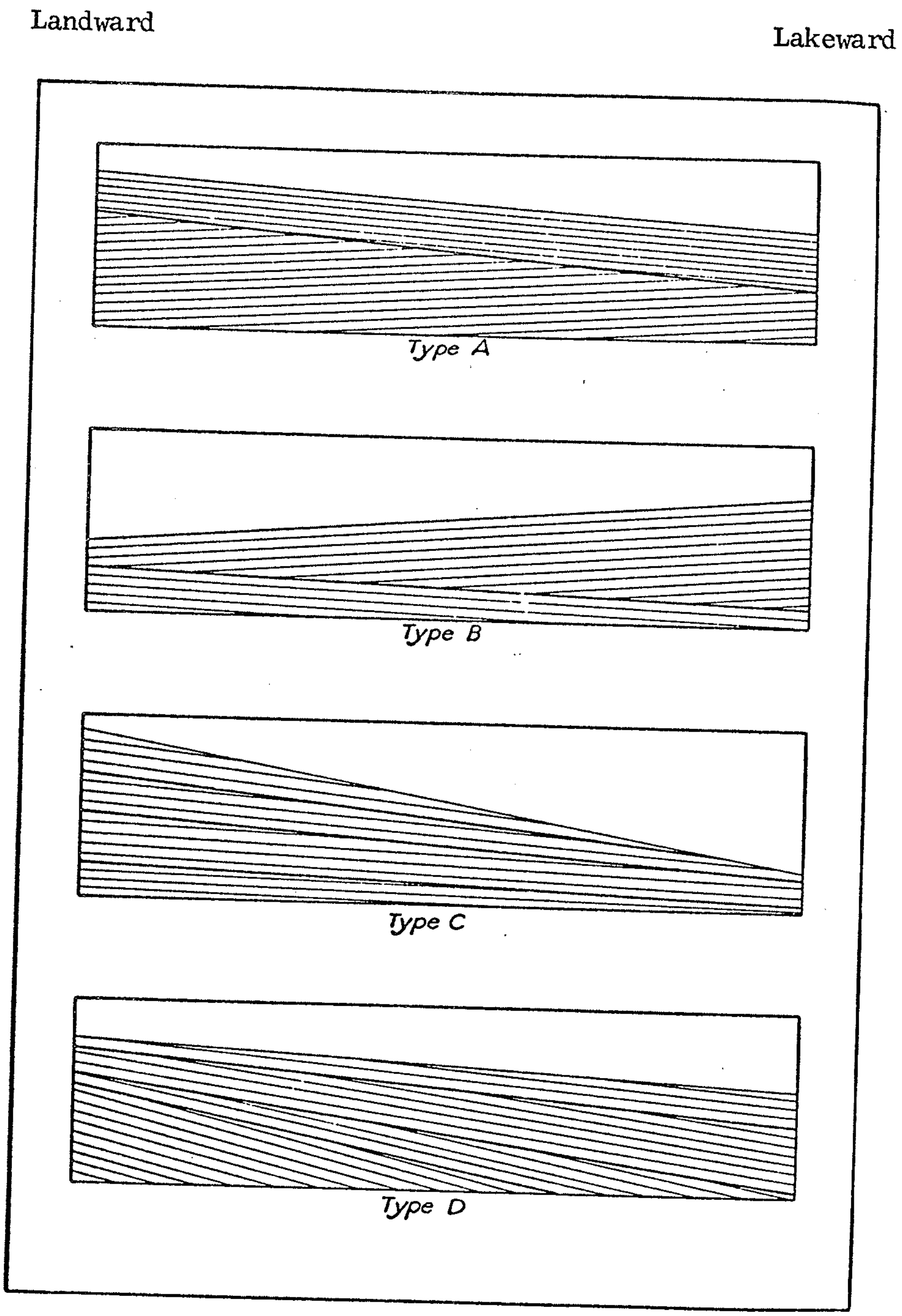

Fig. 23 Types of cross stratification in the beach ridges in the Beausejour Area (transverse cross sections)

of the first type of bedding (Fig. 23, type a). The lower beds are backbeach deposits and the upper ones are foreshore deposits (Fig. 24).

Fig. 24 Backbeach deposits overlain by foreshore deposits in a beach ridge near Pinawa.

Another type of bedding relationship consists of beds that slope gently lakeward overlain by landward sloping beds with or without an apparent erosion surface separating them (Fig. 23, type b). The lower beds are foreshore deposits, and the upper beds backshore deposits. Combinations of all these types of bedding relationships may occur in a single beach ridge.

An imbricate structure displayed by some of the pebbles in beach ridges is a useful criterion that can be used to determine the location of the former water body. On the forebeach, the imbrication is such that the pebbles are inclined down the slope of the bedding on foreshore beaches because the current moves both up and down, the former generally stronger, therefore, the currents strike the upper surface and have no lifting power. On the back beach, the currents flow downward so the equilibrium position of the pebbles is to be inclined into the slopes of the bedding (Twenhofel, 1950).

The various sizes and shapes of the beach ridges are the result of many factors; some of the more important being the slope of the coast; the fetch; the direction of wave attack; the type of material attacked by the waves; the frequency of storms and the duration of the water level. The fact that the majority of the beaches in the Beausejour Area are developed on ground moraine and/or end moraine indicates that a nearby source of sediment is essential for the formation of beach ridges.

The lithology of most of the beach ridge material resembles that of the Belair Drift. The heavy minerals are characteristic of acid igneous rocks with minor contributions coming from medium to high grade metamorphic rocks and mafic igneous rocks (Pierce et al, 1956). Exceptions are a number of beach ridges developed on calcareous Libau Drift.

Bedding in beaches results from a complex of variables, depending largely on variations in the transporting power of waves carrying particles of different sizes and specific gravities. Thompson (1937) in describing lamination in California beaches stated:

> "The observed uniform sorting of particles within a single laminae is the result of a finely balanced selecting process. An incoming wave brings to the slope of the beach all particles where size and specific gravity permit their being transported by that wave. The backwash of the same wave returns most of the material to the sea, but leaves on the beach those grains that cannot be returned to the sea by the backwash, whose transporting power is less than that of the incoming wave. Laminae are added to the upper foreshore as long as deposition by the swash of a certain wave exceeds erosion by the backwash

> of the same wave. However, the backwash tends to erode deposits of the swash more deeply at the lower than at the upper surface of the beach, so that the slope of the upper foreshore, and hence, the erosive power of the backwash, is gradually increased. When disposition by the swash is just balanced by erosion of the backwash of a wave, the slope of the beach is said to be at the "profile of equilibrium". The carrying power of the waves is so variable from day to day that this condition of equilibrium seldom prevails for long. Changes in height of water, due to tides and offshore or onshore winds, and changes in wave size, all enforce a continual modification of the profile of equilibrium and, hence, a corresponding change in size of grains that remain on the beach. Dark coloured laminae result from the fact that their dark constituent grains of high specific gravity are more difficult to transport than are those grains of lesser density that make up the light coloured laminae. When the transporting power of the swash of a wave carrying a load of both light and heavy grains decrease up the beach, heavy grains tend to settle to the bottom of the laminae deposited by that wave. In returning over the surface of the newly made laminae, the backwash of the same wave picks up most easily transported grains, but leaves a thin residual film. Hence, a dark laminae builds up by the addition of the residual film of heavy grains left by the backwash of one wave and those heavy grains that settle from the load of swash of the next succeeding wave."

The interval of time represented by a group of laminae is unknown because the time required to form a single laminae varies (Thompson, 1938). Also, a group of laminae includes intervals of non deposition and of erosion. During Lake Agassiz's existence, approximately 4,500 years, it produced 55 major strandlines. Hence, the maximum average duration of each beach was less than 80 years (not allowing for the time taken for the water level to change). Wide departures from this hypothetical average are certain (Elson, 1966). Different bedding relationships, in general, result from changes in the beach profile of equilibrium caused by the same factors that affect beach ridge size and shape. Most of the bedding relationships (i.e. foreshore deposits over backshore deposits), can be explained by migration of the beach crest back and forth during its development.

Wave Cut Cliffs and Surf Cut Terraces

A wave cut cliff is a cliff formed primarily by wave action. A surf cut terrace is a terrace cut to surf base (surf refers to the wave activity in the area between the shoreline and the outermost limit of breakers). The term "wave cut terrace" is not used because wave base is not the dominant process which controls terrace development (Dietz, 1963).

Cliffs and terraces are not a common strandline landform in the Beausejour Area, but they sometimes occur where slopes are steep. Also, beaches may change into low cliffs or terraces where the slope of the shore changes.

Two locations where well developed wave cut cliffs occur are sec. 29, tp. 16, rge. 10 E. (Fig. 25) and sec. 9, tp. 18, rge. 7 E. The first cliff has a relief of 75 to 100 feet. However, most of the relief existed prior to the development of the cliff because the cliff is developed on part of the Milner Ridge end moraine. A sandy, surf cut terrace slopes away from the base of the cliff and a beach ridge is present on the terrace. The second wave cut cliff has a relief of approximately 30 feet; it also has a sandy surf cut terrace that slopes away from its base. A large concentration of boulders occurs on the terrace near the base of the cliff. There are other smaller cliffs and terraces in the Beausejour Area, commonly from 5 to 15 feet high. These features are mapped as shoreline features (Fig. 11, in pocket).

Wave cut cliffs probably originate on relatively steep slopes, because in the Beausejour Area, the best developed ones occur on irregular slopes of end moraines. The main power of the wave is their ability to carry rock fragments and hurl them at the steep faces.

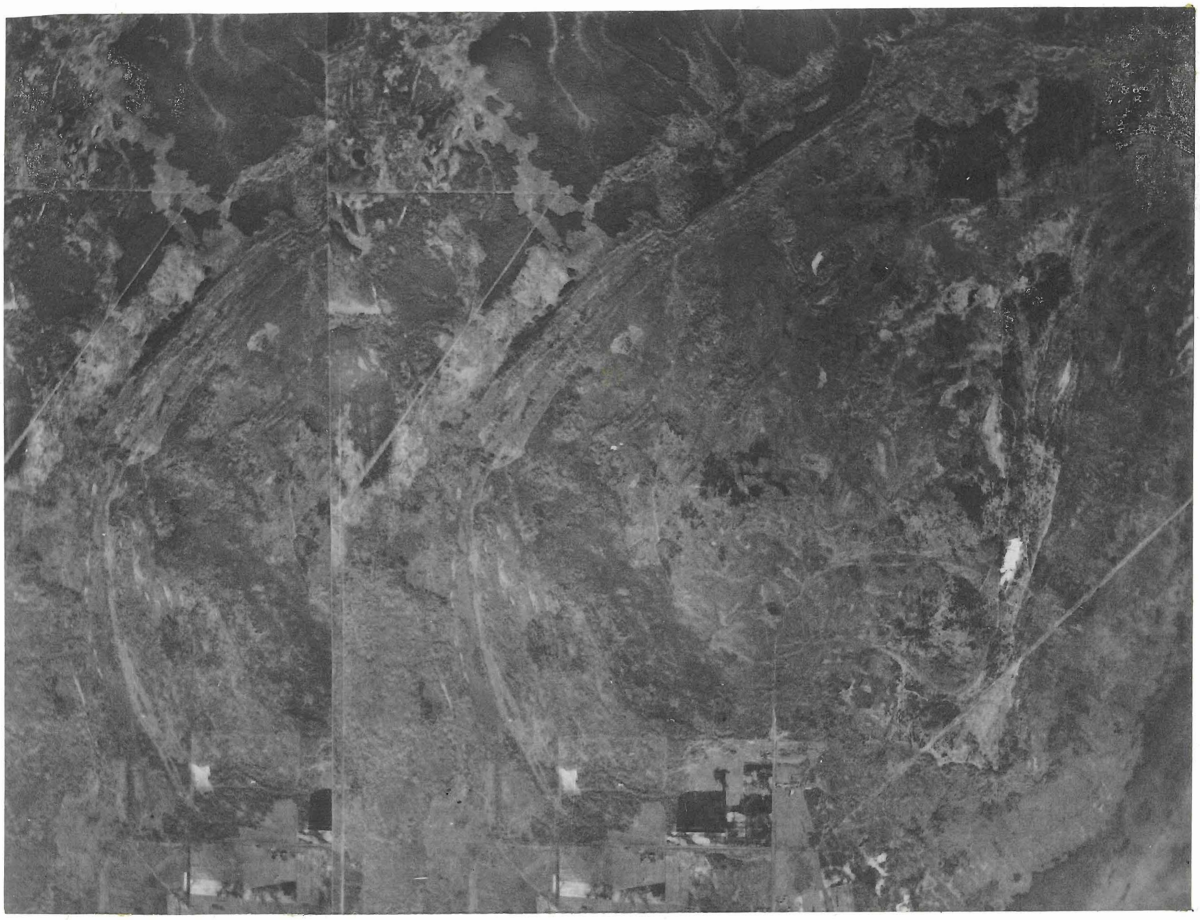

Fig. 25 Stereopair of shoreline features of Lake Agassiz location (tp. 16, rge's. 9 E and 10 E.)

Wave erosion cuts a notch in the edge of the sloping land and destroys the initial profile. Continued wave erosion soon pushes the notch so far inland that the unsupported overhanging material falls down under the influence of gravity. Terraces often develop in front of the cliffs. The terraces tend to be cut essentially at water level, but with continued cutting during stationary water level, they are cut somewhat deeper due to action of the surf. Beaches developed near the base of the cliffs are laid down in equilibrium with surf conditions (Dietz, 1963).

Spits

A spit can be defined as a ridge or embankment of sediment that is attached to the land at one end and terminated in open water at the other.

In the Beausejour Area, major spits are present in sec's. 15, 21, and 22; tp. 16, rge. 10 E; sec. 22, tp. 17, rge, 8 E; and sec's. 3 and 4, tp. 15, rge. 7 E. (Fig. 11, in pocket).

Smaller spits are developed on the end moraines in the area. The spits are usually 10 to 20 feet high, 500 to 1,000 feet wide, and one half mile long. The longest spit observed extends for 2½ miles. All the spits have developed on end moraines or ground moraine, as did the beach ridges in the area, hence the lithology of the spits and beaches is similar. However, the spits contain more sand and less coarse gravel than do the beach ridges. Many of the spits are curved in outline and can be called recurved spits. Opinions differ regarding the origin of spits. According to one view, a spit will be formed where a current passing a headland maintains a straight course, rather than conforming to the irregularities of the coastline. As a result, an embankment will be gradually built in the direction in which the current is moving. Changes in current directions account for recurved spits and hooks. The presently accepted theory of spit formation is that although currents may contribute sediment to them, they grow in the predominant direction of longshore sediment flow caused by waves, and their outlines are shaped largely by wave action (Bird, 1965)

Tombolos

A tombolo may be defined as a bar connecting an island with the mainland or with another island.

The only tombolo observed in the Beausejour Area is in sec's. 28 and 33, tp. 15, rge. 10 E. It is approximately a mile long and a quarter of a mile wide, and connects a granite outcrop to a calcareous till high. Tombolos, like spits, are believed to be produced largely by wave action. It is possible that the tombolos began to form as separate spits developed on the highs and eventually became connected.

Offshore Bars

Offshore bars are defined as submerged or emerged embankments of sand and gravel built on the lake floor by waves and currents.

Offshore bars are uncommon in the Beausejour Area, occurring only in tp. 12, rges. 7 and 8. They are 1 to $1\frac{1}{2}$ miles long, a few hundred feet to a mile wide, and 10 to 15 feet high. The area in which they are developed has a relatively shallow slope.

The upper portion of the bars consists of fine sand, although lower portions contain sand and gravel similar to the beach ridges. It is possible that the sand and gravel ridges were deposited offshore as a submerged bar near surf base. When the water level of Lake Agassiz receded, wave action was greatly reduced near the bar, and as a result, sand was deposited on top of the ridges.

THE EFFECT OF POST GLACIAL UPLIFT ON LAKE AGASSIZ STRANDLINES

In general, the strandlines of Lake Agassiz have a higher elevation in the north than in the south. Johnston (1946) considered this to be due to isostatic uplift during and after the existence of Lake Agassiz. Naturally, any postulated history of Lake Agassiz must take into account the effect of this uplift. The following section is divided into two parts. The first part is a discussion of the limitations of the uplift curves that have been constructed for the Lake Agassiz basin. In the second part, an attempt is made to correlate strandlines in the study area to strandlines developed elsewhere in the Lake Agassiz basin.

Johnston (1946) using data from his own work and data from Upham (1885), and Leverett (1932) correlated many of the Lake Agassiz strandlines and constructed 7 isobases [1] (Fig. 26). He then constructed a series of profiles for each strandline, drawn perpendicular to the isobases; from the profiles one can approximate the mode and amount of uplift that has taken place since formation of the strandlines. A modified version of these uplift curves is illustrated in Figure 27.

Ideally, if these curves are reliable, one can take an isolated segment of strandline in any portion of the lake basin, correct for uplift, and determine the stage of Lake Agassiz to which it belongs. However, there are pitfalls in this approach. Kupsch (1966) presented an excellent review of these pitfalls and the following discussion of them is based primarily on his paper.

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[1] Isobases are lines connecting points of equal deformation of old water planes, as shown by equal elevation of the beaches or other features that form records of the water planes at these points.

Fig. 26 Selected isobases for Lake Agassiz strandlines (after Johnston, 1946)

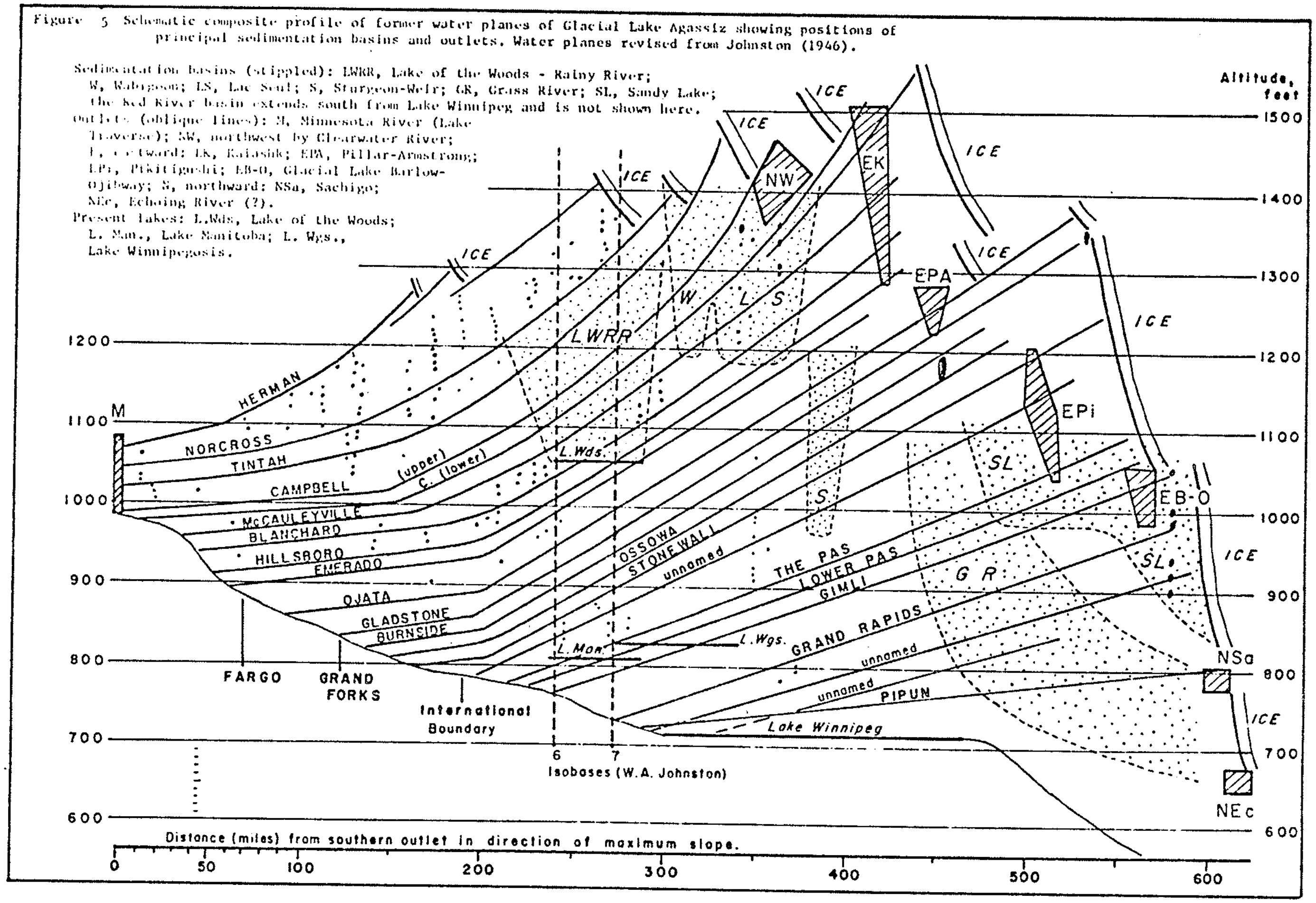
Figure 5 Schematic composite profile of former water planes of Glacial Lake Agassiz showing positions of principal sedimentation basins and outlets. Water planes revised from Johnston (1946).

Sedimentation basins (stippled): LWRR, Lake of the Woods - Rainy River; W, Wabigoon; LS, Lac Seul; S, Sturgeon-Weir; GR, Grass River; SL, Sandy Lake; the Red River basin extends south from Lake Winnipeg and is not shown here.
Outlets (oblique lines): M, Minnesota River (Lake Traverse); NW, northwest by Clearwater River; E, eastward: EK, Kaiashk; EPA, Pillar-Armstrong; EPi, Pikitigushi; EB-O, Glacial Lake Barlow-Ojibway; N, northward: NSa, Sachigo; NEc, Echoing River (?).
Present lakes: L.Wds, Lake of the Woods; L. Man., Lake Manitoba; L. Wgs., Lake Winnipegosis.

Fig. 27 Uplift curves for Lake Agassiz strandlines (after Elson, 1966)

Upham (1885) concluded that the strandlines were not level at their time of formation because the water surface should slope up toward the ice due to gravitational attraction, and that one-quarter or less of the changes of levels could be explained by this cause. Flint (1957) stated, "that such a distortion is minor if not negligible because subsidsence of the crust beneath the weight of the ice reduces the mass effective for distorting water levels."

The gradient of the surface of the lake undoubtedly changed considerably every time a different drainage outlet was functioning. However, this probably did not effect strandline elevations considerably.

The present elevation of abandoned strandlines provides only a minimum measure of the actual uplift that has taken place because, when the ice thinned, some uplift occurred before the development of Lake Agassiz and the attendant creation of strandlines (Kupsch, 1966). The amount of uplift could vary in different regions due to redistribution of sediment load caused by glacial erosion, and Lake Agassiz erosion and sedimentation. Furthermore, some of the uplift may have been due to deep seated tectonic activity and not to release of the ice load. This could particularly apply in the Hudson Bay region which has a history of tectonic instability (King, 1965).

When discussing the mechanisms involved in isostatic adjustment, the question arises that if the land surface were pushed down by the ice, where does the excess material go? Kupsch (1966) believed there should be a bulge in the land surface outside the margin of a glaciation, but there is no evidence for one. The writer believes that if a phase change at the Moho is proven to exist as postulated by Noble (1961), the bulge does not have to occur.

The dataupon which the uplift curves for Lake Agassiz are based have several limitations. Elevations were determined at the base of old shorecliffs, as well as the crests of beach ridges. The bases of old shorecliffs are probably the most accurate indicators of former water levels (Bird, 1965), but most of Johnston's work is based on elevations of beach crests. Upham (1885) stated, "The elevations of the crests of the beach ridges are commonly 5 to 15 feet or rarely 15 feet or more, above the level held by the lake when the beaches were heaped up by the waves, chiefly during storms." Where the sand and gravel ridges are bars, spits, and other similar features they were at or below water level and, not at a constant depth below that level. However, most of Johnston's work is based on beach crest, and although the water planes constructed may be about 10 feet too high, this error is probably consistent for all the water planes.

Kupsch (1966) stated that if one assumes the uplift curves are in error by plus or minus 10 feet, and new profiles are constructed, many of the isobases or nick points become rather indefinite. He suggested that a more objective manner of illustrating uplift would be to draw contours of equal uplift rather than isobases, and that these contours may be concentric to the area where the ice was thickest.

The question of whether warping on a large scale or only tilting of a block of the earth's crust occurred (Johnston, 1946) remains unanswered. Kupsch (1966) stated, "It is possible that only in some localities, failure of the crust along hinges occurred whereas others a slight bending or warping took place."

In spite of all these objections, it appears that the uplift curves may still provide a valid framework for historical discussion of Lake Agassiz. The writer feels that the former water levels may be incorrect by as much as 30 feet. (Elson suggests that it may be 10 to 20 feet, may be more); but because Lake Agassiz was greater than 600 feet deep in places, the uplift curves can provide a generalized picture of its history.

The elevations of the strandlines in the Beausejour Area were interpolated from 25 foot contour maps, using air photographs as a guide to the topography between the contours. These elevations are probably accurate to within 15 feet, and thus accurate enough to use the uplift curves which have a greater range of error. This approach is not completely satisfactory, but until the effects of post glacial uplift in the Lake Agassiz basin are reinterpreted, detailed profiling of the strandlines in the study area seems unwarranted.

The extent of the strandlines in the study area is indicated in Fig. 28. Individual strandline elevations have been corrected for uplift, and the most likely strandline to which they belong is indicated. Strandlines in the study area represent water planes from the Ojata down to the present level of Lake Winnipeg. In places where different strandlines are close together in elevation (i.e. the Pas, lower Pas, and Gimli), the identification of the strandline may be incorrect. However, the approximate phase of the lake's history is reasonably certain, and the strandlines can be used in a generalized discussion of the glacial history of the area which is included in Chapter VII.

OFFSHORE SEDIMENTS OF LAKE AGASSIZ

The Beausejour Area, located in the northern portion of the Red River sedimentary basin of Lake Agassiz, probably contains sediments belonging to all phases of Lake Agassiz, subsequent to and including the late stages of development of the Herman strandline (Elson, 1966).

The areal extent and thickness of these sediments was derived from field mapping, test drilling, and a compilation of water well logs (Fig.29). It proved difficult to distinguish certain sedimentary units in disturbed auger samples, and was impossible from interpretation of water well logs. However, the total thickness of lake sediments could be determined because of the contrast between these sediments and the underlying till and overlying recent alluvium.

Detailed studies by Wicks (1965) in Winnipeg, and by McPherson (1968) along the Winnipeg River from Lake Winnipeg to Seven Sisters Falls have established two control points where the stratigraphic sequence is well known. Using these points, together with data from field mapping and test drilling, it is possible to divide Lake Agassiz sediments in the study area into three major stratigraphic units (Table XI).

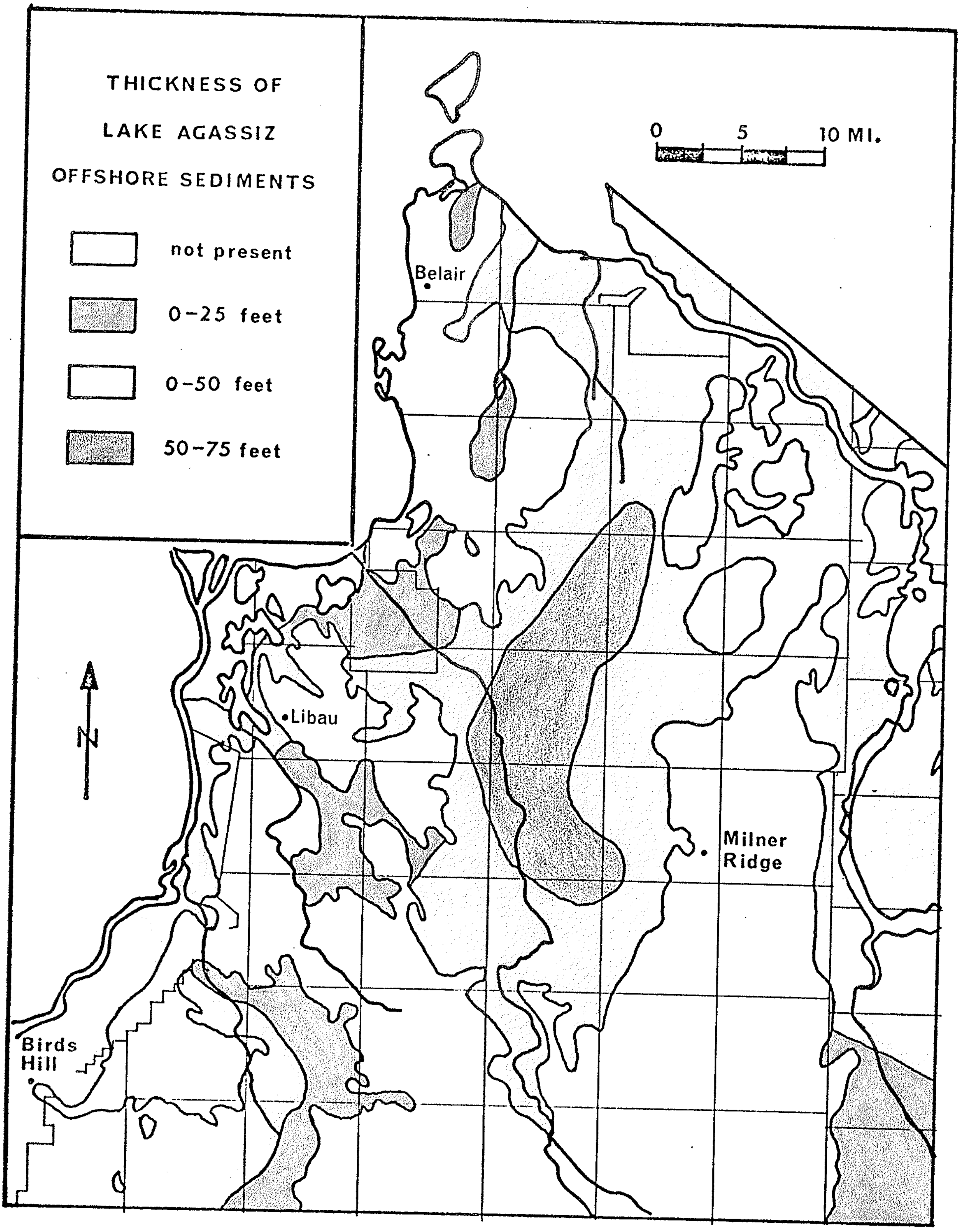

Fig. 29 Extent of Lake Agassiz offshore sediments in the Beausejour Area

TABLE XI

STRATIGRAPHIC SEQUENCE OF LAKE AGASSIZ SEDIMENTS IN THE BEAUSEJOUR AREA

Unit No.	Thickness (ft.)	Average Grain Size	Origin
3	0-15	sandy silt	glacio-fluvial and glacio-lacustrine deposit
			erosional unconformity
2	0-25	mud	glacio-lacustrine deposit
			erosional unconformity
1	0-35	clay	glacio-lacustrine deposit

Many of the Lake Agassiz deposits in the Beausejour Area consist of coarse grained light coloured layers which alternate with coarser grained dark coloured layers. Geologists often refer loosely to these sediments as varves. However, the American Geological Institute (1957) definitions of varves are (1) any sedimentary bed or lamination that is deposited within one year's time, (2) a pair of contrasting laminae representing seasonal sedimentation, as, summer (light) and winter (dark) within a single year. Although some of the sediments in the Beausejour Area may be true varves, many are probably not. The term alternating layers or laminations is used in this thesis to describe these sediments because it has not been proven that each couplet is an annual deposit.

The Glacio-Lacustrine Clay (Unit No. 1)

The clay unit is the most extensive of the sedimentary units. It is usually underlain by the calcareous upper till of the Libau Drift, but in a few places is underlain by sandy end moraine or Precambrian bedrock. In topographically low areas, the clay ranges from 20 to 35 feet in thickness and is overlain by the mud unit. The clay also occurs outside the boundaries of the main sedimentary basins of the Beausejour

Area, but only as isolated deposits less than 5 feet thick. The contact between the clay and the till is sometimes quite sharp. However, along portions of the Winnipeg River, the clay is separated from the till by a 1 to 2 foot bed, has a mineralogy similar to the till, and consists of alternating layers of sandy silt and silty clay with a thickness of one-half to 2 inches (Fig. 30). Wicks (1965) observed a minor amount of interfingering of clay and till in the Winnipeg area.

Fig. 30 Glacio-lacustrine deposit between the upper till and the clay unit

The contact between the clay and the overlying mud unit is an unconformity marked by numerous cut and fill structures. The lowest observed elevation of the unconformity corresponds approximately to the Grand Rapids water level of Lake Agassiz. Channels ranging in size from six feet to 250 feet in length and 2 to 5 feet in depth, have been cut into the clay and filled with mud.

Along the Winnipeg River, the clay unit can be divided into three beds. Bed 1, the lowest one, is 1 to 2 feet thick and consists of layers of grey-brown clay and buff silty clay, the layers ranging in thickness from 1 to 2 mm. at the base to 5 mm. at the top. Bed 2, ranges in thickness from 0 to 15 feet. Individual layers number 2 to 3 per inch, and consist alternately of buff silty clay and grey-brown clay. Three types of layering were observed in this bed. In one type, the coarse grained layer has a till-like appearance, and contains numerous angular silt balls, rock fragments and quartz grains. The fine grained layers are usually somewhat thinner and consist primarily of clay. A second type of layering consists of coarse grained silty layers that are ungraded and are either massive or sublaminated with thin accumulations of clay. The fine grained layers are massive clay. Silt balls, rock fragments, and quartz grains are common in these sediments, predominantly in the coarse grained layers. A third type of layering has a massive clay layer and vertical graded bedding in the coarse grained layer. However, this type is uncommon. Overlying this sequence, near Pine Falls, is a clayey silt stratum one-half foot thick, but it could not be traced for any appreciable distance. Bed 3 usually consists of alternating laminations of clay and silty clay numbering 10 to 20 per inch.

In some places, the laminations are so thin that the bed appears massive. In these sediments, the silty layers are ungraded, generally thinner than the clay layers, and either massive or contain fine sublaminations of clay within each silt layer. Silt balls, rock fragments, and quartz grains are uncommon in this bed.

In the Winnipeg area, the clay units can be subdivided into two beds (Wicks, 1965). The lower bed, called the blue grey clay, is 10 to 15 feet thick and is massive. Both silt balls and rock fragments are abundant in the lower portions of the bed, but they decrease in amount toward the top of the bed. The upper bed, called the brown clay bed, is from 10 to 15 feet thick, and is thinly laminated. Silt balls and rock fragments are uncommon in this bed. Wicks (1965) determined by quantitative mineralogy of the clay unit in the Winnipeg area by a combination of differential thermal analyses, x-ray powder photographs, and x-ray fluorescence (Table XII).

TABLE XII

QUANTITATIVE MINERALOGY OF THE CLAY UNIT IN THE WINNIPEG AREA *

Sample No.	Description	Wt. % Dolomite	Wt. % Quartz	Wt. % Calcite	Wt. % Feld-spar	Wt. % Illite-mont.	Wt. % Gypsum	Wt. % Organic Matter
Y-13	brown clay bed	4.7	2.7	2.9	3	85	tr.	1.9
Y-18	brown clay bed	6.2	3.3	3.9	3	80	tr.	1.9
Y-26/4	blue clay bed	10.3	5.3	4.8	5	75	tr.	1.8
Y-33	blue clay bed	15.1	5.6	5.7	6	65	tr?	1.1

* Modified from Wicks (1965)

McPherson (1968) determined the qualitative mineralogy of the clay unit along the Winnipeg River by x-ray diffraction, which indicated it is composed primarily of illite and montmorillonite or possibly interlayered illite-montmorillonite, dolomite, and quartz with minor amounts of kaolin, and/or chlorite, and minor feldspar.

The lithology of the clay unit in both areas is quite similar. In general, it may be said that the non-clay minerals increase with the depth, and this variation is well illustrated in the Winnipeg area by the carbon dioxide and quartz content of the clay unit (Table XIII).

TABLE XIII

CARBON DIOXIDE AND QUARTZ CONTENT OF THE LAKE AGASSIZ CLAY UNIT *

Sample No.	Bed	Carbon Dioxide Wt. %	Quartz Wt. %
Y-8/6	Brown Clay	4.6	tr.
Y-10		3.2	tr.
Y-11/2		3.2	tr.
Y-12	"	3.2	tr.
Y-13		3.0	tr.
Y-14		3.5	tr.
Y-15		3.3	tr.
Y-16		3.7	tr.
Y-17		3.3	tr.
Y-18	"	3.5	tr.
Y-19		4.7	tr.
Y-20/1		3.3	2.6
Y-21/6		3.6	3.1
Y-22	"	4.9	3.0
Y-23	Blue Grey Clay	4.4	3.3
Y-24		6.5	2.2
Y-25		6.6	3.9
Y-26/4		6.4	5.3
Y-27		10.3	5.8
Y-28/1		11.4	4.9
Y-29		8.6	4.4
Y-30		10.1	3.7
Y-31		11.2	3.4
Y-32		10.6	3.7
Y-33		9.6	5.6
Y-34		9.5	3.4
Y-35		12.9	4.7
Y-36		14.0	4.7
Bottom of clay unit			

* Modified from Wicks (1965)

Although the individual beds within the clay are not identical everywhere in the Beasejour Area, the clay unit is considered a distinct lithologic unit because (1) it is underlain by till and bedrock and is unconformably overlain by the mud unit; (2) throughout the area, the lower portion of the unit contains an abundance of silt balls, rock fragments, and quartz grains, and the upper portion is usually finely laminated; (3) the minerals present in the clay unit are consistent throughout the area.

The Glacio-Lacustrine Mud (Unit No. 2)

The mud unit is most extensive along the Winnipeg River and in the Catfish Creek area. It ranges from 0 to 25 feet in thickness, being thickest in topographically low areas. The mud uncomformably overlies the clay unit, and is overlain by the sandy silt unit in some localities and by the soil profile in others. The appearance of the mud unit on airphotos is shown on Fig. 31. The contact between the mud and sandy silt is generally an erosion surface with 2 to 5 feet of relief, but occasionally it does not appear to have undergone extensive erosion.

Along the Winnipeg River, the basal 1 to 5 feet of the mud unit consists of alternating layers of grey mud 1 to 2 inches thick and buff fine sand less than 2 mm. The central portion of the mud unit is 2 to 15 feet thick and consists of alternating layers, possibly varves, of silt and silty clay, usually one-half to 1 inch in thickness. The upper portions of the unit is 2 to 10 feet thick and has a faint indication of bedding, although it appears massive in most localities. It consists of mud that weathers with a characteristic blocky structure (Fig. 32).

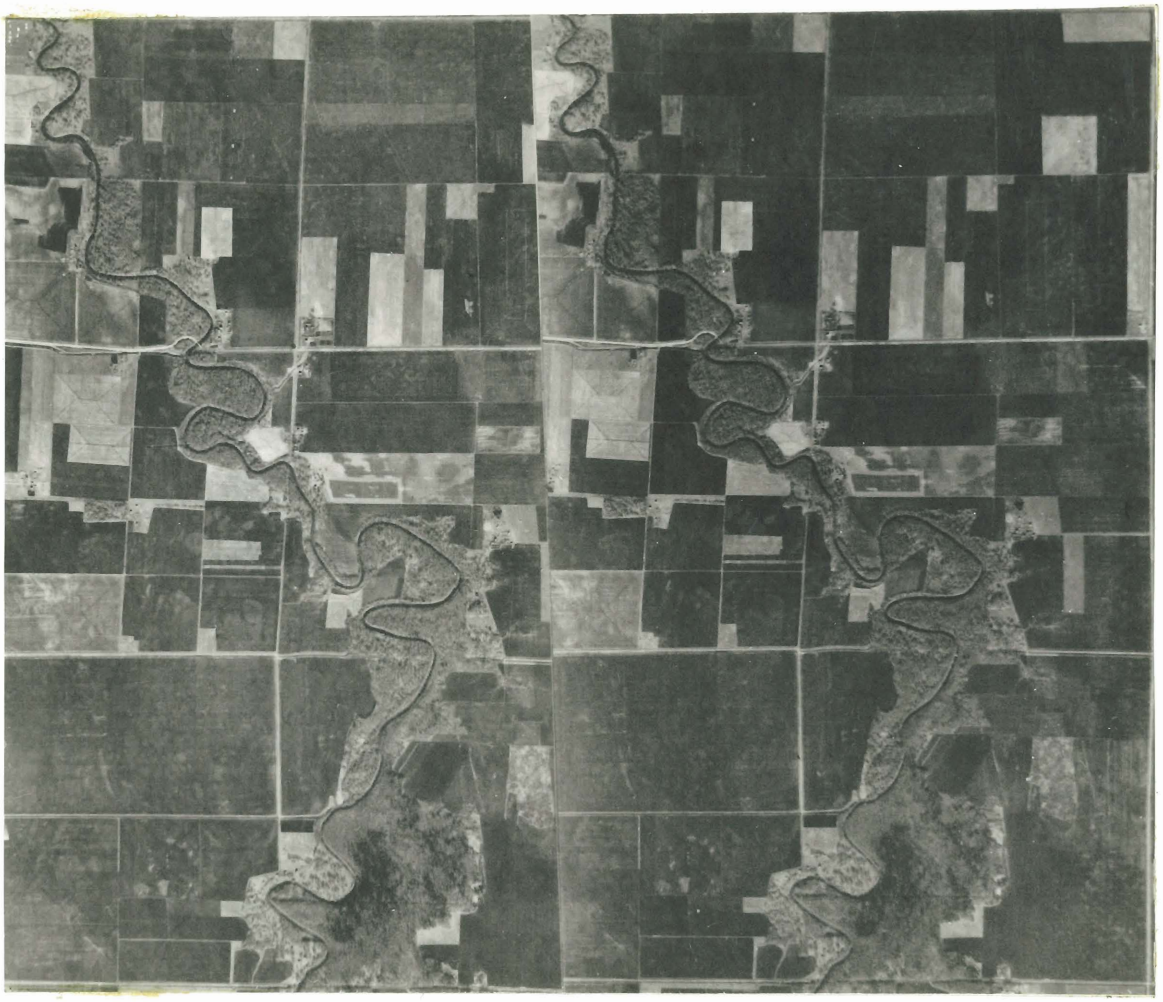

Fig. 31 Stereopair illustrating the airphoto pattern of the mud unit

Fig. 32 Blocky structure on the weathered surface of the mud unit

Concretions occur in the coarse grained layers of the laminated portion of the mud unit and their longest dimensions are parallel to the bedding. The concretions, consisting of dolomite and calcite, are usually a combination of ring and septarian concretions, although irregularly shaped ones are not uncommon. They are seldom greater than 2 inches in diameter and average approximately 1 inch in diameter.

In the Winnipeg area, the lower one foot of the mud unit consists of alternating layers of brownish yellow silt and medium brown clay. Each layer never exceeds one-half inch in thickness. Within each band a complex microstructure exists. The silt bands are composed of laminations of very fine silt with a few thin clay layers. Fine cross bedding is present in some of the silt bands. The upper portion of the unit has a distinctive greenish brown colour and consists of layers of silt and clay (Wicks, 1965). The qualitative mineralogy of the mud unit in the Winnipeg area is shown in Table XIV.

TABLE XIV

QUANTITATIVE MINERALOGY OF THE MUD UNIT IN THE WINNIPEG AREA *

Sample No.	Description	Wt. % Dolomite	Wt. % Calcite	Wt. % Quartz	Wt. % Feld-spar	Wt. % Illite-mont.	Wt. % Gypsum	Wt. % Organic Matter
Y-7	couplets of silt	2.7	1.7	1.8	2	90	nil	2.0
Y-8/1	lower silt bed	8.1	4.3	16.3	16	50	nil	2.6

* Modified from Wicks (1965)

Along the Winnipeg River, the unit consists of dolomite, quartz, and illite-montmorillonite, with smaller amounts of feldspar and kaolin, and/or chlorite (McPherson, 1968). In both localities, the clay mineral content is highest where the unit is well laminated.

The mud unit is considered to be a distinctive lithologic unit because (1) it is unconformably underlain by the clay unit and unconformably overlain by the sandy silt unit where it is present; (2) the unit is every where coarser grained at the bottom and finer near the top of the section, which suggests it is a transgressive sequence; (3) it is composed of the same suite of minerals in different localities.

The Glacio-Fluvial and Glacio-Lacustrine Sandy Silt (Unit No. 3)

The sandy silt unit is the least extensive of the three units, occurring mainly along portions of the Winnipeg River and in isolated localities elsewhere. It occurs in topographically low areas and ranges in thickness from 0 to 15 feet. It is unconformably underlain by the mud unit and overlain by the soil profile.

Along the Winnipeg River, the sandy silt unit is massive where it is thin (Fig. 33), but exhibits bedding in thicker sections.

Fig. 33 The sandy silt unit overlying the mud unit

Where bedding is present, it consists of alternating layers of brown silty clay and buff silty sand. The layers range in number from one-half to 10 per inch and average 2 per inch. One particular layer occurring in isolated localities is approximately 1½ feet thick and consists of cross bedded silty sand. Cross bedding and vertical graded bedding are present in many of the thinner sandy layers of the sandy silt unit. The direction of the cross bedding in different sections is variable and no definite trends could be established.

In the Winnipeg area, the unit is approximately 1 to 3 feet thick, finely laminated, and consists primarily of sand with only minor amounts of clay. The sandy silt consists of dolomite, quartz, and feldspar with minor amounts of calcite and clay minerals in the Winnipeg area (Wicks, 1965), and of dolomite and quartz with minor amounts of feldspar, calcite and clay minerals along the Winnipeg River (McPherson, 1968). It is considered to be a distinctive sedimentary unit because (1) it is unconformably underlain by the mud unit, and (2) it has a similar mineralogy and grain size in different localities.

Sedimentology of the Offshore Sediments of Lake Agassiz

Concretions

There are several possible origins for the concretions in the mud unit. Because many are ring concretions, it is possible that they formed around tree stems and subsequently were carried into the lake basin. Another alternative is that they formed within the lake basin either during or after sedimentation. The concretions always occur in the coarser silt layers, and could have been formed around nucleii when carbonate precipitated as a result of increasing temperature of the water during the summer (Burwash, 1938), or could be formed by carbonate precipitation from pore water after sedimentation in the lake had ceased.

Blocky Weathering of the Mud Unit

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

Varves and Alternating Layers in the Lake Agassiz Sediments

DeGeer (1912), suggested that varves were deposited by meltwater bottomflows in glacial lakes. However, Antevs (1925, 1951) advocated the hypothesis that the transportation of sediments took place in the upper water strata. Kuenen (1951) proposed turbidity currents as the cause of glacial varves and pointed out that sediment laden meltwater issuing from waning glaciers must have been heavier than the lakewater, and consequently, followed the bottom of glacial lakes and did not rise to the surface. This hypothesis is supported by field observations of stream flow into Lake Mead (Gould, 1951) and Lake Hazen (Deane, 1958), which demonstrated that sediment laden streams do plunge beneath the surface of the lake and continue along the bottom as turbid bottom flows.

Burwash (1938) suggested that the CO_2 content of the water is important in varve formation because the cold water has a greater capacity for the solution of gases. During the winter months a lake would be more acidic and be able to hold carbonates in solution; however, as the lake warmed in the summer, CO_2 would be released and calcium carbonate precipitated. Depth of water is believed to control the formation of varves. If the water is shallow, and subjected to wave action, any varves that may be forming would be destroyed. Lake Louise, Alberta, where varves are forming at the present time, is approximately 180 feet deep (Flint, 1957). Another factor that may affect varve formation is unusual concentrations of salts which act as electrolytes causing grains to flocculate.

The three types of alternating layers present in the clay unit (as described on page 82) can all be produced by continuous meltwater bottom flows and/or turbidity currents.

The first type consists of a coarse grained layer with a till-like appearance and contains silt balls, rock fragments, and quartz grains, and a fine grained layer consisting of clay. The coarse grained layer could be produced by a subaqueous mudflow, in which the sediment load is very high and size differentiation is greatly retarded (Lajtai, 1967). Subaqueous mudflows could be generated when glacial sediments are released upon calving of the ice front. The silt balls, rock fragments, and quartz grains may be transported by rolling along the bottom in turbulent suspension by a high density turbidity current, or by ice rafting. The fine grained layers would be deposited from a uniform clay suspension produced by the mudflow, as well as from previous more continuous bottom flows.

The most common type of sedimentation couplets in the clay unit consist of ungraded coarse grained layers that are massive or contain thin clay partings, and fine grained layers of clay. These couplets may be deposited by continuous bottom flows that vary in transporting power. Warm weather would result in increased melting, and, therefore, increased meltwater flow. The coarse grained layers would be deposited at this time by the bottomflow, and the clay partings would be deposited out of a uniform clay suspension produced also by the bottomflow. The clay partings must be unstable, as they have to survive erosion by subsequent high density flows, which could explain why they are relatively rare. The fine grained clay layer of each couplet would be deposited in cold weather as a result of decreased bottomflow.

Alternating layers consisting of a coarse grained layer which exhibits vertical graded bedding, and a massive clay layer could be formed from a single turbidity current, or by settling from a meltwater flow out over the surface of the lake. Lajtai (1967) indicated that such an overflow would only occur if the sediment load was extremely low, so that the formation of a significant number of couplets by this process is unlikely.

In summary, the alternating layers are most likely produced by meltwater bottomflows, their characteristics depending mainly on the proximity of the ice margin, and the supply of sediment from the glacier, which is controlled primarily by the rate of melting of the glacier. The varied origins of the layers indicate that they are not necessarily varves.

HISTORY OF LAKE AGASSIZ SEDIMENTATION IN THE BEAUSEJOUR AREA

The characteristics of the offshore sediments of Lake Agassiz in the Beausejour Area suggest that the following sequence of events occurred. During the late stages of development of the Herman strandline, the northwest ice lobe retreated from the Beausejour Area, the northeast ice lobe having already retreated from the area. Meltwater from the ice lobe carried sediments into the Red River basin, and resulted in deposition of the clay unit. There are not enough clay minerals in the Libau Drift to account for the entire clay unit; however, clay derived from weathering of the Precambrian rocks may have been carried into the area by the northeast ice lobe. Significant amounts of clay derived from the Cretaceous shales west of the Manitoba escarpment, could have been carried into Lake Agassiz by streams flowing off the Manitoba escarpment (Wicks, 1965). The Sheyenne, Elk Valley, Pembina and Assiniboine deltas were deposited during Herman time (Elson, 1966), and most of the clay could have been carried out farther east into the Red River basin. Sedimentation was greatest at this time, because of the large amounts of meltwater and the lack of vegetative cover to prevent erosion. This possibly explains why the clay is the most extensive of the sedimentary units. The high percentage of quartz grains, silt balls, and rock fragments in the lower portion of the unit suggests that the ice margin was relatively close at this time. The massive nature of the clay in the Winnipeg area may be due to reduced meltwater flow caused by a colder period which resulted in deposition of more fine material. The upper portion of the unit which is finely layered was probably deposited when the ice margin was more remote.

When the ice margin had retreated far enough, Lake Agassiz discharged through the Sandy Lake basin, probably into Glacial Lake Barlow-Ojibway (Elson, 1966). The water level dropped to slightly lower than the Grand Rapids water plane, and the clay unit was subjected to subareal erosion. A re-advance of ice to the Agutua moraine blocked the drainage outlet, and the level of Lake Agassiz rose gradually to a level between the Stonewall and the Pas water planes (Elson, 1966). As the water level rose, the coarse material of the lower portion of the mud unit was deposited in shallow water. Crossbedding in this material near Winnipeg may be the result of stream flow into the shallow lake basin.

The finer upper portion of the unit was deposited in deeper water when the lake level had risen further. The coarser material, which is higher in quartz and feldspar content and lower in clay minerals than the clay unit, was probably derived primarily from wave erosion of till and outwash. Smaller amounts of clay are probably due to a reduction in sediment contribution from both the northeast ice lobe and the Cretaceous shales. The fine material in the upper portion of the mud unit has a suite of minerals similar to the clay unit, so it was probably derived from a combination of wave erosion, meltwater flow from the ice margin, and stream flow off the Manitoba escarpment.

Further ice retreat then opened eastern and northern outlets and Lake Agassiz was gradually drained. As the water level fell, the sandy silt unit was deposited by streams flowing into shallow water and/or by offshore processes. This explains the erosion surface between the mud and the sandy silt, and the variable trend of the crossbedding in the sandy silt.

The sandy silt, consisting of dolomite, quartz, and feldspar was derived from wave and stream erosion of glacial till and sandy outwash. The rarity of clay minerals is due to the lack of significant contributions from the glacier margin and the Cretaceous shales. Elson (1966) postulated a minor rise of water level to account for the flat upper surface of the sandy silt unit along the Winnipeg River.

ICE PUSH RIDGES

An ice push ridge may be defined as a ridge or a mound of material pushed on to a shoreline by wind driven pack ice.

The only ice push ridge identified in the study area occurs immediately west of Belair. It forms a ridge approximately 10 feet high, 60 feet wide, and one-half mile long, and consists of unsorted material ranging in size from sand to boulders (Fig. 34)

Fig. 34 Ice push ridge west of Belair

The boulders, which are moderately well rounded, constitute a large percentage of the ridge. The ridge occurs on the crest of a Lake Agassiz beach complex, everywhere parallels the former shoreline, and has been subjected to wave action since its formation.

The deposit resembles an esker formed by high regime flow (Clayton, personal communication) [1], but is not believed to be one because (1) the trend of the ridge is approximately parallel to the ice frontal position, which is not usually the case with eskers; (2) the complete lack of eskers associated with the northeast ice advance suggests that the environment was not suitable for esker deposition; (3) the deposit is on the crest of a Lake Agassiz beach complex interpreted to have been developed when the ice margin was remote from the area.

The ridge is not thought to be an end moraine because (1) the high concentration of rounded boulders is not present in any of the end moraines in the area; (2) the deposit occurs on the crest of a Lake Agassiz beach complex. The high boulder concentration suggests that the boulders were pushed up into a ridge by wind driven lake ice.

Ice push ridges resulting from the pressure of floating ice driven by the wind are common around the modern lakes of the region (Elson, 1966). During the spring of 1969, spectacular ridges of ice were pushed on to the southwest shore of Lake Winnipeg by unusually strong winds (Fig. 35).

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[1] Dr. L. Clayton, Geology Department, The University of North Dakota

Fig. 35 Ridges of ice on the shoreline of Lake Winnipeg (Spring, 1969)

A boat house and a cottage were destroyed by the ice, but large quantities of boulders were not pushed into a ridge because the shore consisted only of sand. However, if the ice had been pushed over a boulder beach, the writer feels that an ice push ridge would have developed. Elson (1966) identified ice push ridges on the crest of the Eagle Finlayson moraine in Ontario. Accumulations of boulders averaging two and one-half feet in diameter form ridges, 3 to 10 feet high, up to 75 feet wide, and several miles long. Hume and Schalk (1964) indicated that ice push deposits occur on the northern Alaskan coast as mounds or ridges that are 2 to 15 feet high. However, they constitute only 1 to 2 per cent of the beach material above sea level. Tyrrell (1892) found evidence of ice push on the shoreline of Lake Winnipegosis.

Reports of ice push ridges on the Lake Agassiz strandlines are rare. This is probably because they are not a common shoreline form, they may be destroyed by subsequent wave action, and they can easily be interpreted as some other type of deposit.

INTERSECTING MINOR LINEATIONS

In portions of the Beausejour Area, intersecting low relief ridges and grooves exhibit a striking linear pattern on air photographs (Fig. 36).

Fig. 36 Airphoto of intersecting minor lineations near Gull Lake

Similar features occur on the Lake Agassiz plain in other areas of Manitoba, North Dakota, and Minnesota (Clayton et al, 1965). A summary of characteristics displayed by the lineations both in the Beausejour Area and elsewhere is:

1. They may be either ridges or grooves;
2. They are 25 to 75 feet wide, a few hundred feet to several miles long (the average length of 100 lineations in the Beausejour Area is 0.91 miles) and from 2 to 10 feet high;
3. On airphotos, the ridges stand out as light coloured areas and the depressions as dark areas; the contrast being due to differences in soils, soil moisture, and vegetation;
4. The lineations generally intersect at acute angles, and exhibit cross cutting relationships (i.e. some are definitely older than others);
5. Some of the lineations are curved;
6. The lineations are generally not visible on the ground. Investigation shows that there is no difference in composition between material forming the lineations and adjacent material;
7. Cross sections through some of the ridges exhibit folded, contorted, and jointed sediments (Horberg, 1951);
8. They are developed on lacustrine sediments as thick as 130 feet (Allison, 1932) and on wave eroded till. They are generally confined to the area below the Ossawa strandline. A few of the lineations continue without interruption across Lake Agassiz shorelines (Horberg, 1951);
9. A lineation in tp. 16, rge. 8 E. is overlain by a near shore sand deposit, which indicates that it formed prior to the draining of Lake Agassiz;
10. In tp. 11, rge. 12 E., a lineation is intersected by the Whitemouth River Valley, indicating that the river post dates formation of the lineation. In North Dakota, Horberg (1951) noted that some of the ridges are intersected by, and do not appear on a younger terrace fill along the Red River;
11. The trends of the ridges have remarkably consistent orientations. This is not readily apparent from airphotos, but is revealed when the strikes of individual lineations are plotted (Fig. 37).

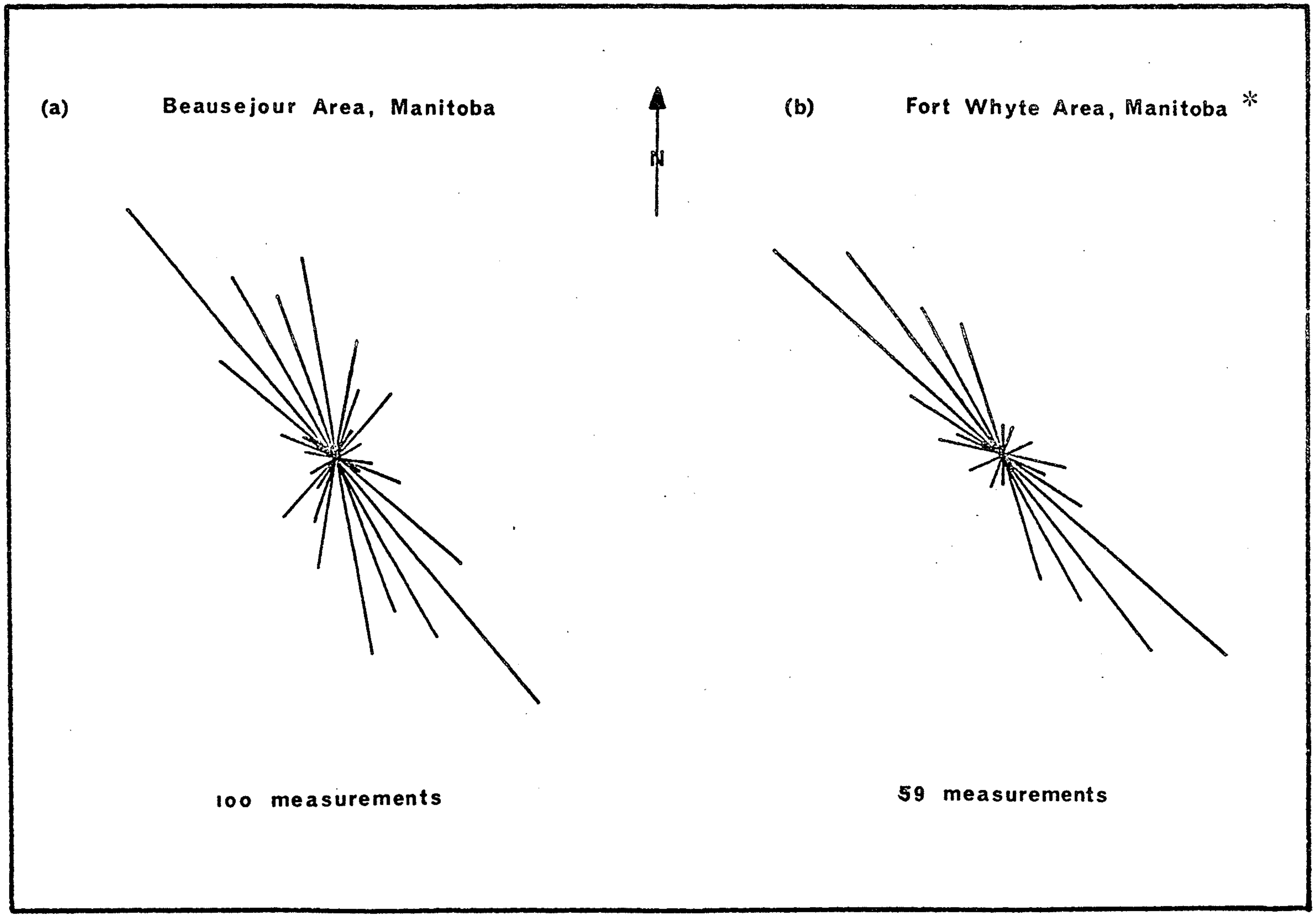

Fig. 37 Rose diagrams of the trends of minor lineations in the Red River basin of Lake Agassiz

* (after Fulton, 1959)

Numerous hypotheses have been proposed for the origin of these lineations. Horberg(1951) concluded that they represent tundra or permafrost patterned-ground because of their association with possible periglacial features. As an alternate hypothesis, he proposed that the ridges are fracture fillings formed in lake ice; Colton (1958) agreed with this alternate proposal. The first hypothesis "breaks down" because the lineations do not resemble any known present-day patterned ground in permafrost areas (Black, in Mollard, 1957). Furthermore, tundra conditions may not have existed following drainage of Lake Agassiz (Nikiforoff, 1952). The second hypothesis requires that fractures in grounded ice would be filled with sediment, while the intervening ice blocks would remain in the same position until they melted. Even if this occurred, the predominant northwest trend and length of the lineations is not explained. Nikiforoff (1952) proposed that the ridges formed by the natural processes of wave action and running water. However, wave action and running water could hardly produce the intersecting pattern. Also, no similar pattern is observed being produced by this method today (Clayton et al, 1965). Mollard (1957), Fulton (1959) and Elson (1961) proposed that this sort of pattern may be a reflection of a fracture pattern in the underlying bedrock. This theory, on first appearance, sounds attractive because the trend of jointing in the bedrock and tills in the Winnipeg area is approximately northwest (Render, personal communication)[1]. The joints and lineations also parallel isobases of

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[1] F. Render, Water Control and Conservation Branch, Dept. Mines and Natural Resources, Winnipeg, Manitoba

Lake Agassiz beaches (lines of equal uplift) suggesting that both the joints and lineations are related to isostatic uplift. However, the hypothesis fails because the reflection of joints through surficial material would not produce cross cutting lineations. Clayton et al (1965) proposed that the intersecting minor ridges were pushed up by floating lake ice and the minor grooves formed by dragging lake ice. Large flat bottomed sheets of lake ice would form a ridge where their edges pushed against the lake bottom. The long ridges, and probably most of the short ones, were not bulldozed up by the front edge of the sheet of ice, but were plowed up at the side of the sheet by the diagonal edge of the floe that was dragging bottom. Clayton et al (1965) stated:

> "The prevailing wind that produced the lineations on the bottom of Lake Agassiz was probably predominantly from the northwest and southeast. This would be expected under the present climatic conditions because the prevailing wind direction today during spring break-up is from these directions. However, climatic conditions could have been considerably different with the ice front at the north edge of Lake Agassiz. The presence of the best developed lineations on the west side of the lake plain and the poor development of those in the southern end of the basin suggest that the wind was predominantly from the southeast. It was blown from the south end of the lake on to the western shore farther north. Here, the slope of the shallow lake bottom was nearly perpendicular to the prevailing south-easterly wind direction, and the ridges several miles long could be formed because the ice dragged along the bottom in water of nearly constant depth. The curvature of the lineations was caused by a change in wind direction as the ice dragged lake bottom. Most of the curved lineations in the Lake Agassiz Plain are concave to the east of southeast, suggesting the occurrence at that time of the present tendency of strong southeasterly winds to change to the northwest as cold fronts pass."

Weber (1958) described a pattern of grooves in Great Slave Lake bottom sediments nearly identical to the pattern in the Lake Agassiz basin (Plate 1, in Clayton et al, 1965). The grooves were formed by ice floes driven shorewards by the prevailing winds. Tyrrell (1892) described similar grooves along the margins of Lake Winnipegosis. Stanley (1955) illustrated that shallow stone tracks in the Racetrack Plaza in California have resulted from the movement of wind driven ice.

POST GLACIAL DEPOSITS

Sand Dunes

Sand dunes are present on sandy end moraine and outwash in tp. 14, rge. 7 E., tp. 15, rge. 7 E., and tp. 19, rge. 7 E. The majority of the dunes are U-shaped, convex, and have steep leeward slopes. They are stabilized by vegetation, and usually occur in groups forming a complex pattern of ridges and basins. The sand is fine to medium grained and composed primarily of quartz grains with minor granitic, volcanic, and metasedimentary rock fragments. Most of the quartz grains are angular, frosted, and pitted. The dunes are similar to those described by Hack (1941), who classified them as parabolic dunes, and defined them as "long-scoop-shaped hollows, or parabolas, of sand with windward slopes, much more gentle than the leeward". Hack thought that parabolic dunes were formed where the wind removed sand from windward hollows and deposited it on leeward slopes. It would appear that they are not original dune forms, but rather forms produced by sand blowouts, and subsequent redisposition. The age of dune formation in the study area is unknown, but would have to be subsequent to the draining of Lake Agassiz (7,300 years B.P.).

Alluvium

Alluvium is not a common deposit in the study area, occurring only along the banks of the Brokenhead River, Hazel Creek, and the Red River (Fig. 11, in pocket). In some localities, alluvium extends over lake clays, but is too limited in extent to justify a separate map unit.

Areas of alluvium along Hazel Creek and the southern portion of the Brokenhead River are level to irregular, gently sloping and imperfectly to poorly drained. The alluvium is stratified, varies from fine sand to clay, and is generally high in silt. Numerous layers of organic matter occur in the stratified material. The alluvium is deposited where the streams meander through poorly defined valleys and flood the surrounding areas in the spring and/or during seasons of high rainfall (Ehrlich et al, 1953).

Alluvium on the Red River in the study area forms terraces about 5 to 10 feet below the lake plain, and as much as 20 feet above river level. The alluvium consists of silty clay, derived largely from the lake clays, and is rich in organic matter. Near Lockport, it contains fossils and archaeological material dating almost to historical times (MacNeish, 1958).

Horberg (1951) described similar alluvial deposits on the Red River in North Dakota, and concluded that they represent an old valley fill which is being trenched by the present streams. Horberg stated:

> "The terrace relations indicate (1) erosion of a valley somewhat wider than the present channel to a depth of at least 35 feet in the lake plain; (2) deposition of alluvium within the channel up to the level of the terrace; and (3) entrenchment to a depth of about 25 feet. On the basis of known regional history, the sequence of events may be

> explainable by changes in gradient resulting from isostatic uplift following glaciation. Rapid entrenchment immediately after drainage of the lake could have been followed by alluviation as isostatic uplift continued; and, as the rate of uplift diminished, normal headward erosion and adjustments of gradient may have caused cutting of the present stream."

Elson (1961) suggested that a drier climate beginning about 6,200 B.P. as well as a reduction in gradient due to crustal warping, caused the river to adjust to a smaller channel and partly fill the larger valley.

The Red River has deposited an extensive delta (approximately 60 square miles) where it empties into Lake Winnipeg (Fig. 11, in pocket). The river flows through several channels separated by alluvium, small lakes and marshland.

Peat Bogs

Peat bogs are common in the Beausejour Area; the most extensive ones being in the northern and eastern portions of the area (Fig. 11). In most areas the peat is underlain by lacustrine sediments. However, in some of the higher enclosed depressions till underlies the peat. The predominant forest cover in the bog is black spruce, but larch, willow, and alder are also present.

The bogs range in depth from less than 1 foot up to as much as 12 feet (Smith et al, 1967). No distinction is made as to thickness of the peat on the surficial geology map because these areas were not accessible to the drilling rig. In general, deeper bogs have a darker tone on air photographs, but this criterion is not always reliable so has not been used.

The bogs are complexes of fibrous to muck sedge peat, a fibrous mixed sphagnum-feathermoss peat, and a fibrous sphagnum peat. The fibrous to mucky sedge type occurs in the Catfish Creek area (Fig. 38), the mixed sphagnum-feather moss types occur in the southeastern portion of the area.

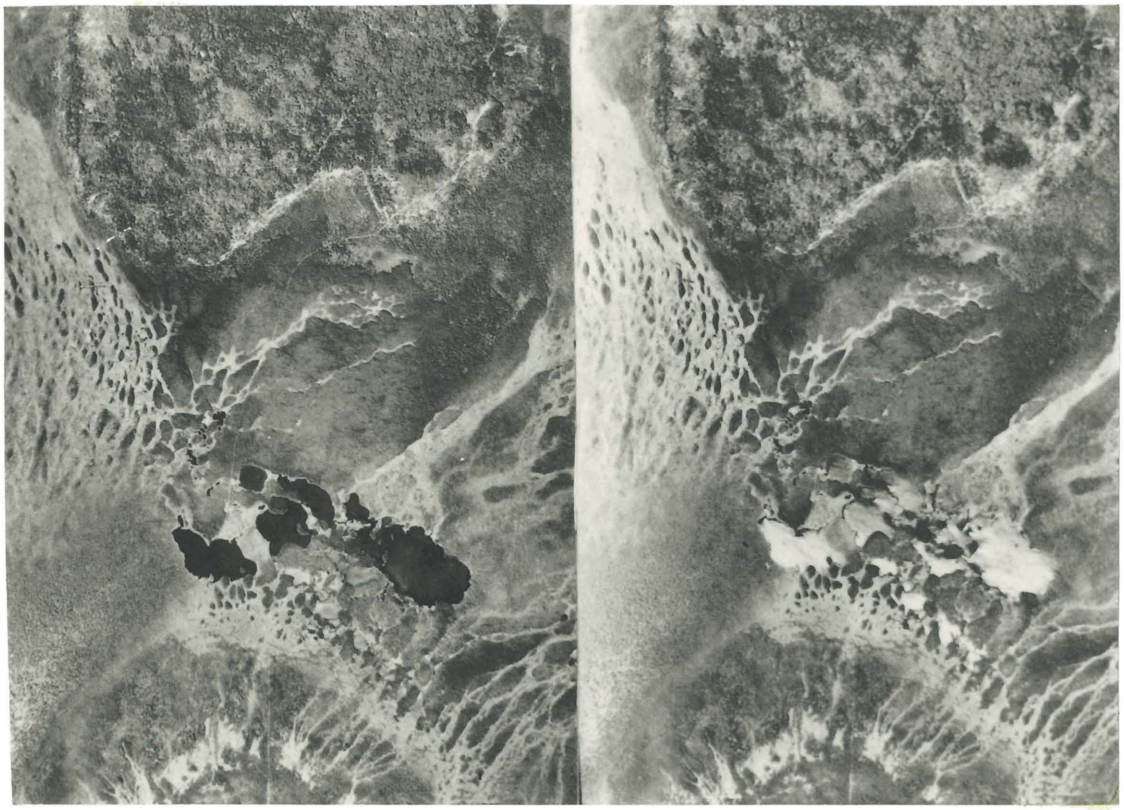

Fig. 38 Stereopair of peat bog in Catfish Creek Area

Smith et al (1967) proposed two origins for the peat deposits and stated:

> "The peat types found in the undrained rock bound depressions in the Precambrian drift plain, and in small enclosed basins in the South-Eastern Lake Terrace Area have been formed by a successional deposition of aquatic and semi-aquatic plants, reeds, sedges, mixed moss and herbaceous plants, forest vegetation and sphagnum moss. In most of the Lake Agassiz basin, peat formation is due to gradual paludification or expansion of peat over sloping poorly drained terrain."

The exact time of formation of these peat deposits is unknown, but they have developed since the drainage of Lake Agassiz prior to 7,270 ± 130 years B.P. (6SC-92). Dates from peat deposits in or near the Lake Agassiz basin range from 1,400 to 9,570 B.P. (Elson, 1966). This suggests there has probably been a gradual formation of peat deposits ever since the ice retreated from the area. Bannatyne (1964) indicated the possible economic value of many of the bogs as a source of peat moss.

CHAPTER VI

PLEISTOCENE STRATIGRAPHY IN THE BEAUSEJOUR AREA

The Pleistocene stratigraphic succession and drift thickness in the Beausejour Area has been determined by surface mapping, test drilling, and interpretation of water well logs. In this chapter, the stratigraphic succession will be formally defined, the drift thickness indicated by an isopach map, and the extent of the various units illustrated by a series of stratigraphic cross sections.

THE PLEISTOCENE STRATIGRAPHIC SUCCESSION

The Pleistocene deposits in the Beausejour Area can be subdivided into two major drifts as well as Lake Agassiz sediments. None of the formally named drifts described below is a lithostratigraphic unit as defined by the American Commission on Stratigraphic Nomenclature (1961, Art. 4, 4a, 4c, 4d) because they are differentiated by their topographic form, geographic position, and inferred geologic history. Stratigraphic subdivisions of the surface drifts are required for a future synthesis of the glacial history of Manitoba, and for the construction of a practical time - stratigraphic terminology. The morphostratigraphic unit of Frye and Willman (1960, 1962) is the most useful stratigraphic subdivision in the Beausejour Area and may be defined as a body of drift that is defined by its surface form and position, and consists of all the drift that is deposited from the glacial ice of a significant glacial advance. The basic unit is a drift, as used by Clayton (1962), rather than a moraine as used by Frye and Willman (1960, 1962).

There are several problems concerned with the use of morphostratigraphic units in the Beausejour Area. The Belair Drift is exposed on surface as the Belair and Milner Ridge end moraines. However, the surface form has been modified by an ice re-advance and by sedimentation and erosion in Lake Agassiz. In spite of this, the Belair Drift is still identified largely by the relict morphology it displays on surface. Therefore, the use of the term "Belair Drift" as a morphostratigraphic unit seems warranted. The Libau Drift is also identified largely by its relict surface morphology, even though the morphology has been modified by Lake Agassiz sedimentation and erosion. Another problem is that an end moraine is not associated with the Libau Drift so that the outer limit of the drift is uncertain. Future studies in adjacent areas may indicate that the till of the Libau Drift would be better defined as a rock-stratigraphic unit.

However, for the purpose of this study, the use of the drift units provides a useful means of stratigraphic separation of the glacial deposits.

Belair Drift

The Belair Drift is defined as the morphostratigraphic unit consisting of all the till and outwash of the Belair end moraine, and associated drift that was deposited by a significant glacial advance from a northeast direction, including the till and outwash of the Milner Ridge end moraine. The type area is designated as sec's. 2 and 11, tp. 19, rge. 7 E., located approximately two miles east of Belair (Fig. 11, in pocket).

The main basis for distinguishing the Belair Drift is its occurrence on surface as sandy end moraine or outwash, its characteristic mineralogy indicating it was derived primarily from acid igneous rocks, and its stratigraphic position in the subsurface being stratigraphically lower than Lake Agassiz sediments and Libau Drift.

Both the Belair and Milner Ridge end moraines, and their associated drifts are included in a single morphostratigraphic unit because both are interpreted as being deposited by the glacial ice of a single significant advance from a northeast direction. The Milner Ridge end moraine is not considered to represent a significant separate advance because it does not overlap any older end moraines, it is approximately parallel to the outer limit of advance of the glacial ice that deposited the Belair Drift, and both end moraines and associated outwash have similar lithology and topography.

The age of the Belair Drift is unknown, but test drilling south of the Beausejour Area, indicates that the Milner Ridge end moraine can be correlated with the Whitemouth end moraine (named by Elson, 1961), which may possibly correlate with the Vermilion end moraine (Fig. 39). Clayton (1966) suggested an age for the Vermilion moraine of greater than 12,700 years B.P.

Libau Drift

The Libau Drift is here defined as the morphostratigraphic unit consisting of all the drift deposited by a significant glacial advance from a northwest direction, which includes ground moraine, associated outwash, and the Birds Hill esker-delta complex (Fig. 11, in pocket). The type area is designated as sec's. 9, 10, 15, and 16 in tp. 15, rge. 6 E., which includes the town of Libau. The main basis for distinguishing the Libau Drift is that it contains a high percentage of limestone and dolostone fragments, and is stratigraphically lower than the Lake Agassiz deposits that formed since development of the Herman strandline. Possible minor ice re-advance may have occurred during deposition of the Libau Drift, but there is not enough evidence to warrant the naming of more than one drift.

The exact age of the Libau Drift is unknown; however, it is younger than the Belair Drift which it overrode. Lake Agassiz was in existence during retreat of the ice sheet which deposited the Libau Drift, and is interpreted to have been at the Herman stage during the deposition of the Birds Hill esker-delta complex. The Herman strandline was abandoned about 11,700 B.P. (Y-1327, Wright and Ruhe, 1965, p. 39), therefore, the ice frontal position at Birds Hill should be, at the most, a few hundred years older than this. It is possible that during the deposition of the Birds Hill complex that the ice frontal position may have corresponded to Elson's Brandon Phase (Fig. 39).

Lake Agassiz Sediments

The Lake Agassiz sediments cannot be included in the morphostratigraphic unit terminology because they are the result of deposition by meltwater from both the northwest and northeast ice advances, as well as stream deposition and wave erosion. It may be possible to apply formal stratigraphic names to the Lake Agassiz sediments in the Red River basin, upon completion of further investigations. However, the present data only warrant informal subdivisions of the deposits in the Beausejour Area into the clay unit, the mud unit, and the sandy silt unit as described in Chapter V. The exact age of these units is unknown.

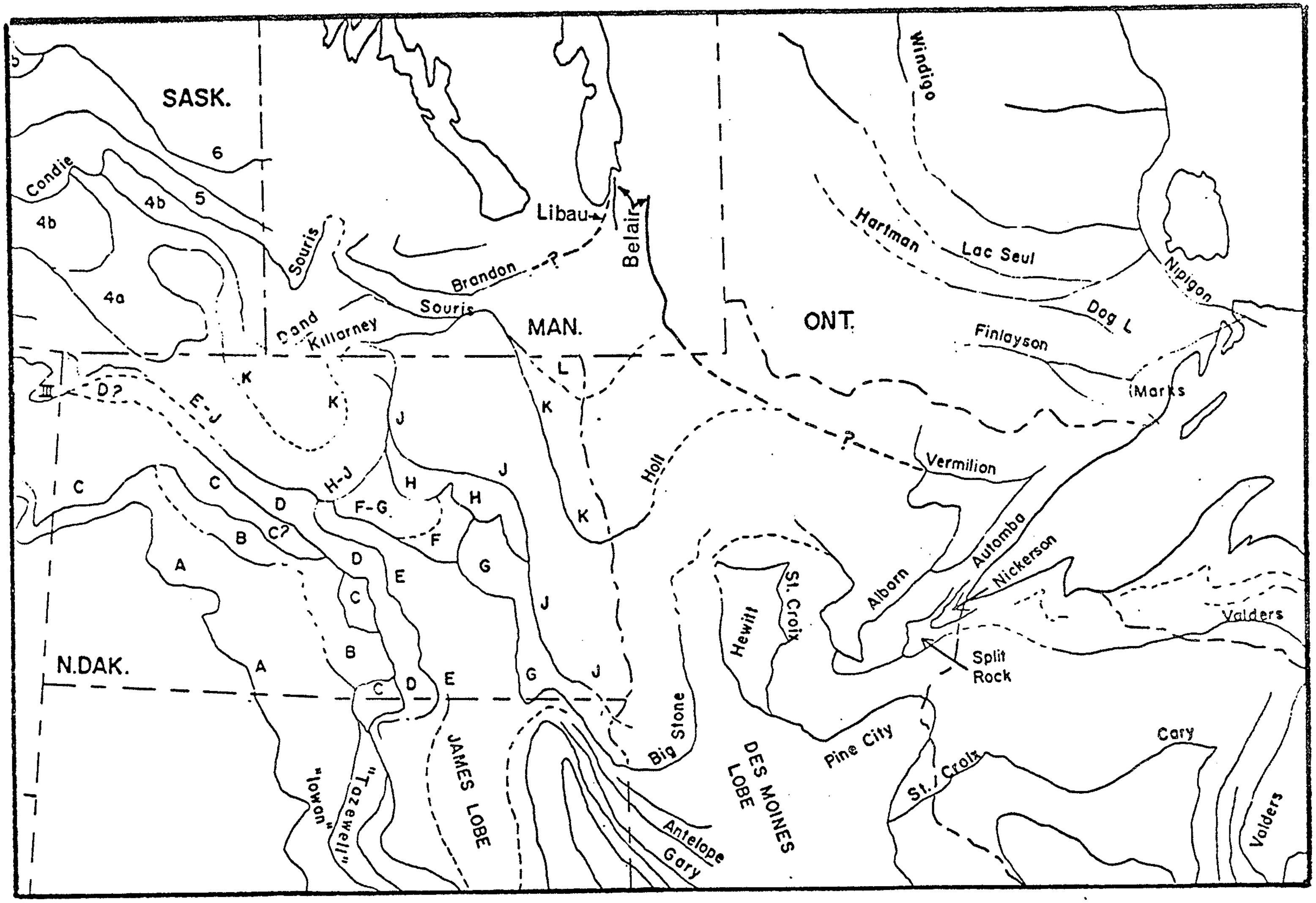

Fig. 39 Correlation of ice margin positions in the Beausejour Area to adjoining areas (modified from Clayton, 1966)

but Lake Agassiz existed from approximately 12,400 to 7,300 years ago (Elson, 1966). The clay unit is the oldest, being deposited during the time interval between the retreat of the northwest ice margin, until Lake Agassiz drained to the Grand Rapids water level about 8,000 to 8,500 years B.P. The mud unit and sandy silt units were deposited womewhere between this time and the drainage of Lake Agassiz about 7,300 years B.P. A suggested correlation of the Pleistocene stratigraphic succession in the Beausejour Area to other localities is shown in Table XV.

DRIFT THICKNESS

The drift thickness map for the Beausejour Area is based on data from topographic maps, 68 auger holes (Appendix I), and approximately 1,500 water well logs (Fig. 40, in pocket).

Areas where the drift is thickest are: (1) along the Belair end moraine where 150 to 200 feet of drift is common; (2) along the Milner Ridge end moraine where the drift averages 150 feet in thickness; (3) the Birds Hill esker-delta complex which consists of 100 to 150 feet of drift and (4) along the present course of the Brokenhead River where 100 to 150 feet of drift occupies a low in the bedrock surface. Drift is absent in many localities in the northeast portion of the area where Precambrian bedrock outcrops, and is less than 50 feet thick near Libau and at Garson Quarry. Isolated localities where bedrock is overlain by a thin cover of drift are at Lockport, East Selkirk, Victoria Beach, and the southwest side of Elk Island. Elsewhere in the Beausejour Area the drift is commonly 50 to 100 feet thick, and consists primarily of

TABLE XV

SUGGESTED CORRELATION OF PLEISTOCENE STRATIGRAPHY IN
THE BEAUSEJOUR AREA TO ADJOINING AREAS

	Wisconsin - Illinois (Frye, and others, 1965) Time - Stratigraphic Units (irregular time scale)	Southwestern Manitoba (Elson, 1958)	Beausejour Area (this report)		Northwestern Ontario (Zoltai, 1965)
Wisconinan Stage	Valderon Substage	Brandon	L. Agassiz	Sandy silt unit Mud unit Clay unit	Agutua Eagle Finlayson Rainy Lake
	Twocreekan Substage	Souris-Hind Dand Killarney		Libau Drift?	
	Woodfordian Substage			Belair Drift?	
	Farmdalian Substage				
	Altonian Substage				

Lake Agassiz sediments and Libau Drift.

A series of approximately east-west stratigraphic cross sections illustrate diagrammatically the drift thickness, surface topography, bedrock topography, and the extent of the various stratigraphic units (Fig. 41, in pocket). Correlation lines between auger holes are interpretive, but provide a generalized picture of the stratigraphy of the area.

CHAPTER VII

GLACIAL HISTORY OF THE AREA

Determination of the glacial history of the Beausejour Area is beset by several problems; the most critical being the lack of material suitable for age dating, the lack of detailed studies in adjacent areas, and a relatively poor understanding of the nature of post glacial uplift and its effect on Lake Agassiz strandlines. The history presented in this chapter indicates a generalized sequence of events that occurred in the area, but the correlation of these events to others outside of the area is for the most part conjectural.

EARLY GLACIATIONS

All evidence of glaciations prior to the northeast ice advance that deposited the Belair Drift was either destroyed or buried beneath the Belair Drift. Zoltai (1961) determined the glacial history of part of northwestern Ontario. He found evidence which suggests an early ice advance from a northwest direction. The calcareous nature of the till associated with the advance indicates that at least portions of the till may have been derived from the Paleozoic carbonate rocks of Manitoba. Therefore, it would be reasonable to assume that this glaciation also affected the Beausejour Area. At Piney, in southeastern Manitoba, there is a till (for which no lithologic descriptions are available) beneath the Belair Drift. However, the direction of ice advance responsible for its deposition is unknown (Little, 1968).

GLACIAL PHASES IN THE BEAUSEJOUR AREA

The generalized sequents of events that occurred in the area are described as seven separate phases and illustrated on Fig. 42 (in pocket.

Phase 1

The earliest discernible ice advance into the area came from a northeast direction. No evidence of this advance was found west of the Belair end moraine suggesting that the moraine marks the western limit of ice advance in the study area. The ice lobe was stationary long enough to allow deposition of the Belair end moraine (Fig. 42, Phase 1). The high percentage of outwash sand interbedded with lacustrine clay in the moraine, suggests that it was deposited into a proglacial lake. This lake probably existed prior to, and is not an early stage of Lake Agassiz because: (1) the Milner Ridge end moraine, which is younger than the Belair end moraine, is believed to correlate with the Vermilion moraine and Clayton (1962) indicated that the Vermilion moraine was deposited prior to the formation of Lake Agassiz; (2) strandlines of Lake Agassiz which occur in southeastern Manitoba would have been destroyed by the northwest ice advance which overrode the Belair Drift; (3) there does not seem to be sufficient time for the northwest ice advance to occur between the early stages of Lake Agassiz (12,300 years B.P.) and then retreat to the vicinity of Winnipeg by

Herman time (11,700 years B.P.).

Phase 2

The northeast ice lobe then retreated until it restabilized at, or readvanced to the vicinity of the Milner Ridge and deposited the Milner Ridge end moraine (Fig. 42, Phase 2). The high percentage of outwash sand interbedded with lake clay in the moraine suggests that it also was deposited into a proglacial lake, probably the same lake that the Belair end moraine was deposited into but with a greater eastern extent. The ice then receded northeastward an unknown distance.

Phase 3

The next ice advance to affect the area, came from a northwest direction and deposited the calcareous Libau Drift. The eastern limit of this advance is uncertain but Zoltai (1961) found calcareous till resting on "granitic" till as far east as Fort Francis, Ontario. Clayton (personal communication) [1]found evidence for a calcareous till overriding the Vermilion moraine in Minnesota. These calcareous tills could possibly belong to the same ice advance as the Libau Drift. This ice advance must have occurred prior to the formation of the Herman strandline of Lake Agassiz, otherwise it would have destroyed many of the strandlines.

Phase 4

As the northwest ice lobe retreated, Glacial Lake Agassiz developed northward. The lower portion of the clay unit is interpreted as having been deposited near the receding ice margin because it contains a high percentage of silt balls and rock fragments. The ice stabilized near Birds Hill long enough to allow deposition of the Birds Hill esker-delta

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[1] Dr. L. Clayton, Geology Department, The University of North Dakota

complex (Fig. 42, Phase 4). At this time, the ice margin portion may have corresponded with the Brandon phase (Fig. 39), but further studies west of Winnipeg will be required before the correlation can be proven. During this phase, Lake Agassiz is interpreted to have been at its highest or Herman level, because the northeastern ice lobe had not receded far enough in Ontario to open eastern drainage outlets (Elson, 1966). Following deposition of the Birds Hill complex, the northwestern ice receded from the Beausejour Area, except perhaps for minor fluctuations.

Phase 5

The remaining phases of the history of the area are concerned with Glacial Lake Agassiz, the level of which was controlled by ice advances and retreats outside of the Beausejour Area. Therefore, the events described in the phases are based primarily on the work of Elson (1966). Subsequent to development of the Herman strandline, Elson postulated several fluctuations of water level that were controlled mainly by the opening and closing of eastern drainage outlets.

During this time the Beausejour Area was completely covered by water, except for a single period when the level dropped to about the Burnside strandline (Fig. 42, Phase 5). After the low water phase, the water rose to the lower Campbell strandline and remained stable for 200 to 500 years.

Phase 6

Northward retreat of the northeast ice margin west of Lake Nipigon, opened a series of successively lower outlets, and the level of Lake Agassiz dropped in a series of steps to about the Grand Rapids water plane (Fig. 42, Phase 6). At the end of this time, Lake Agassiz was probably discharging into glacial Lake Barlow-Ojibway (Elson, 1966). During the time the water level was dropping the strandlines from Ojata down to about the Pas levels were developing in the Beausejour Area. The lowest observed elevation of the unconformity on the surface of the clay unit in the study area suggests that it was developed when the water was at the Grand Rapids level.

Phase 7

The final phase in the history of the Beausejour Area occurred when an northeast ice advance blocked the outlet to glacial Lake Barlow-Ojibway, and stabilized at the Agutua moraine (Elson, 1966). Lake Agassiz again rose to a level between the Stonewall and the Pas water planes, and the mud unit was deposited in the Beausejour Area (Fig. 42, Phase 7). Ice retreat then reopened the eastern outlet to the Barlow-Ojibway basin, and the water level dropped to the Gimli strandline (Elson, 1966).

Melting of the ice sheet in the North opened lower drainage outlets and as the water level dropped, the sandy silt unit was deposited upon the mud unit in the Beausejour Area. Finally, Lake Agassiz drained into Hudson Bay prior to 7,300 years B.P. (Elson, 1966).

The glacial history inferred from a study of the surficial deposits in the Beausejour Area may be summarized as follows: Ice advanced into the area from a northeast direction and the Belair Drift was deposited. An ice advance from the northwest, overrode the Belair Drift and deposited the Libau Drift. As the ice retreated, Lake Agassiz came into existence and during its history, the clay, mud, and sandly silt units were deposited in the Beausejour Area.

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APPENDIX 1

LITHOLOGIC DESCRIPTION OF DRILL HOLES

Hole No. 1

Location N.W.$\frac{1}{4}$, sec. 11, tp. 11, rge. 5 E.

Depth (ft.)	Description	Interpretation
0-15	light olive gray (5Y 6/1 wet) lake clay with minor silty lenses	Lake Agassiz mud unit
15-24	light olive gray (5Y 6/1 wet) lake clay, minor granules	Lake Agassiz clay unit
24-65	light olive gray (5Y 6/1 wet) calcareous till, silty numerous carbonate rock fragments; water table 49'.	Libau Drift
65	Bedrock	

Hole No. 2

Location N.W.$\frac{1}{4}$. sec. 11, tp. 11, rge. 7 E

Depth (ft.)	Description	Interpretation
0-17	dark yellowish brown (10Y 4/2 wet) oxidized silty gravel, subrounded carbonate rock fragments	beach deposit
17-21	medium dark gray (N4 wet) clayey silt	beach deposit
21-31	dark yellowish brown (10Y R 4/2 wet), oxidized silty gravel, subrounded carbonate rock fragments	beach deposit
31	too bouldery to drill	

Hole No. 3

Location N.W.$\frac{1}{4}$. sec. 32, tp. 10, rge. 10 E

Depth (ft.)	Description	Interpretation
0-12	light olive gray (5Y 6/1 wet) oxidized quartz sand, minor granitic and volcanic rock fragments	shoreline deposit
12-22	light olive gray (5Y 6/1 wet) clayey silt	lake sediment

Hole No. 3 (cont.)

22-31	light olive gray (5Y 6/1 wet) calcareous silty till, numerous granitic and volcanic rock fragments	Belair Drift
31	total depth, too bouldery to drill	

Hole No. 4 Location N.W.$\frac{1}{4}$, sec. 26, tp. 11, rge. 11 E

Depth (ft.)	Description	Interpretation
0-7	yellowish gray (5Y 8/1 wet) oxidized quartz sand	Lake Agassiz sandy silt unit
7-13	light olive gray (5Y 5/2 wet) lake clay, sandy lenses	Lake Agassiz mud or sandy silt unit
13-26	olive gray (5Y 4/1 wet) lake clay	Lake Agassiz clay unit
26-36	light olive gray (5Y 6/1 wet) calcareous silty till, numerous carbonate rock fragments	Libau Drift
36	total depth, too hard to drill	

Hole No. 5 Location S.E.$\frac{1}{4}$, sec. 3, tp. 13, rge. 10 E

Depth (ft.)	Description	Interpretation
0-30	pale yellowish brown (10Y R 6/2 wet) oxidized, fine, quartz sand, water table 25 ft.	shoreline deposit
30-72	light brown (5Y R 6/4 wet) medium to coarse sand composed of quartz grains, and granitic, volcanic, and carbonate rock fragments, a few pebbles	Belair Drift
72-90	light olive gray (5Y 6/1 wet) calcareous silty till with carbonate, volcanic, and granitic pebbles	Belair Drift
90	total depth, too hard to drill	

Hole No. 6 Location S.E.$\frac{1}{4}$, sec. 22, tp. 13, rge. 9 E

Depth (ft.)	Description	Interpretation
0-7	pale yellowish brown (10Y R 6/2) oxidized silty quartz sand, minor pebbles. Water table at 7 ft.	shoreline deposit
7-83	quicksand, no good samples, but all fine quartz sand	Belair Drift
83-85	drilled like till with boulders - no samples	?
85	total depth, too hard to drill	

Hole No. 7 Location S.W.$\frac{1}{4}$, sec. 18, tp. 14, rge. 10 E

Depth (ft.)	Description	Interpretation
0-25	pale yellowish brown (10Y R 6/2) calcareous well rounded, coarse gravel with numerous granitic and carbonate cobbles and pebbles, stratified with some layers coarser grained than others	beach deposit
25-30	greyish yellow (5Y 8/4 wet) calcareous quartz sand	beach deposit
30-45	Same as 0-25	beach deposit
45	total depth, too bouldery to drill	

Hole No. 8 Location S.W.$\frac{1}{4}$, sec. 14, tp. 15, rge. 10 E

Depth (ft.)	Description	Interpretation
0-5	pale yellowish brown (10Y R 6/2 wet) silty sand	Lake Agassiz sandy silt unit
5-15	moderate olive brown (5Y 4/4 wet) lake clay silty lenses	Lake Agassiz mud unit
15-33	light olive gray (5Y 5/2 wet) laminated lake clay, numerous silty lenses and carbonate rock fragments	Lake Agassiz clay unit

Hole No. 8 (cont.)

33-55	light olive gray (5Y 6/1 wet) clayey, silty till, more silty with depth	Libau Drift
55	total depth, too hard to drill	

Hole No. 9 Location N.W.¼, sec. 5, tp, 16, rge. 10 E

Depth (ft.)	Description	Interpretation
0-11	light olive gray (5Y 5/2 wet) lake clay with silty pockets, granitic rock fragments	Lake Agassiz clay unit
11-17	light olive gray (5Y 6/1 wet) calcareous silty till, carbonate and volcanic rock fragments	Libau Drift ?
17	granite	

Hole No. 10 Location S.W.¼, sec. 17, tp. 18, rge. 10 E

Depth (ft.)	Description	Interpretation
0-17	light olive gray (5Y 6/1 wet) laminated lake clay, numerous silt lenses and rock fragments	Lake Agassiz clay unit
17-26	light olive gray (5Y 6/1 wet) calcareous silty till, granitic and volcanic rock fragments	Libau Drift ?
26	granite bedrock or boulder	

Hole No. 11 Location S.W.¼, sec. 36, tp. 17, rge. 9 E

Depth (ft.)	Description	Interpretation
0-13	pale yellowish brown (10Y R 6/2 wet) clayey, calcareous, lake sand to sandy clay, minor granitic rock fragments	Lake Agassiz sandy silt or mud unit
13-44	light olive gray (5Y 6/1 wet) lake clay, minor rock fragments	Lake Agassiz clay unit

Hole No. 11 (cont.)

44-46	Olive gray (5Y 4/1 wet) slightly calcareous, clayey till, granitic rock fragments	Libau Drift?
46	granite bedrock or boulder	

Hole No. 12 Location S.W.¼, sec. 25, tp. 16, rge. 7 E.

Depth (ft.)	Description	Interpretation
0-35	light brownish gray (5Y R 6/1 wet)	wave washed outwash
35-82	Interbedded sand (as above) and light olive gray (5Y 6/1 wet) sandy clay	Belair Drift
82-90	light olive gray (5Y 6/1 wet) sandy silty till, numerous granitic rock fragments	Belair Drift

Hole No. 13 Location S.W.¼, sec, 16, tp. 17, rge. 8 E.

Depth (ft.)	Description	Interpretation
0-100	pale yellowish brown (10Y R 6/2 wet) quartz sand - water table at 60 ft. a few pebbles at 100 feet	Belair Drift

Hole No. 14 Location N.W.¼, sec. 9, tp. 19, rge 8 E.

Depth (ft.)	Description	Interpretation
0-15	light olive gray (5Y 6/1 wet) calcareous lake clay	Lake Agassiz clay unit
15-96	light olive gray (5Y 6/1 wet) quartz and granitic sand with interbedded sandy clay. Sand is slightly coarser with depth	Belair Drift

Hole No. 15 Location N.W.$\frac{1}{4}$, sec. 15, tp. 19, rge. 7 E.

Depth (ft.)	Description	Interpretation
0-7	dark yellowish orange (10Y R 6/6 wet) oxidized quartz sand	nearshore deposit
7-85	light olive gray (5Y 6/1 wet) quartz and granitic sand interbedded with olive gray (5Y 4/1 wet) clay containing lenses of silt and minor rock fragments	Belair Drift
85-100	light olive gray (5Y 6/1 wet) calcareous sandy to silty till with numerous volcanic and granitic rock fragments	Belair Drift

Hole No. 16 Location N.W.$\frac{1}{4}$, sec. 16, tp. 18, rge. 7 E.

Depth (ft.)	Description	Interpretation
0-11	grayish orange (10Y R 7/4 wet) oxidized, calcareous, quartz sand, minor granitic pebbles	nearshore deposit
11	total depth, too rocky to drill	

Hole No. 17 Location S.W.$\frac{1}{4}$, sec. 4, tp. 18, rge. 7 E.

Depth (ft.)	Description	Interpretation
0-10	dark yellowish orange (10Y R 6/6 wet) gravelly, calcareous sand, rounded granitic and carbonate rock fragments	beach deposit
10-26	grayish orange (10Y R 7/4 wet) calcareous quartz sand, minor pebbles	Belair or Libau Drift
26-31	light olive gray (5Y 6/1 wet) calcareous silty till, granitic volcanic and carbonate rock fragments	Belair or Libau Drift

Hole No. 18 Location S.W. $\frac{1}{4}$, sec. 12, tp. 18, rge. 7 E

Depth (ft.)	Description	Interpretation
0-7	light olive gray (5Y 6/1 wet) lake clay, silty fragments and carbonate rock fragments	Lake Agassiz clay unit
7-27	pale yellowish brown (10 Y R 6/2 wet) calcareous, silty till, carbonate rock fragments	Libau Drift
27	boulders or bedrock	

Hole No. 19 Location S.W. $\frac{1}{4}$, sec. 16, tp. 15, rge. 7 E

Depth (ft.)	Description	Interpretation
0-25	grayish orange (10Y R 7/4 wet) oxidized quartz sand	Belair Drift
25-100	grayish yellow (5Y 8/4 wet) and granitic sand, hard drilling at 97 ft., water table at 30 ft.	Belair Drift

Hole No. 20 Location S.W. $\frac{1}{4}$, sec. 4, tp. 14, rge. 7 E

Depth (ft.)	Description	Interpretation
0-10	grayish orange (10Y R 7/4 wet) pebbly, carbonate gravel, water table 10 ft.	beach deposit
10-40	no samples on auger, drilled like stratified sand and gravel	beach deposit
40-80	light olive gray (5Y 6/1 wet) slightly calcareous quartz sand, a few rocks near bottom	Belair Drift
80	too wet to drill	

Hole No. 21 Location N.W. $\frac{1}{4}$, sec. 12, tp. 13, rge. 7 E

Depth (ft.)	Description	Interpretation
0-5	moderate yellowish brown (10Y R 5/4 wet) sandy silt	Lake Agassiz sandy silt unit

Hole No. 21 (cont.)

5-20	olive gray (5Y 4/1 wet) lake clay, numerous silt pockets	Lake Agassiz clay unit
20-48	light olive gray (5Y 6/1 wet) calcareous, silty till, granitic and carbonate rock fragments	Libau Drift
48	total depth, too rocky to drill	

Hole No. 22 Location S.E. ¼, sec. 20, tp. 14, rge. 8 E

Depth (ft.)	Description	Interpretation
0-30	pale yellowish brown (10Y R 6/2 wet) sandy silt to clayey silt	Lake Agassiz mud or sandy silt unit
30-72	medium dark gray (N5 wet) lake clay	Lake Agassiz clay unit
72-93	light olive gray (5Y 6/1 wet) calcareous, silty till, carbonate and granitic rock fragments	Libau Drift
93	total depth, too hard to drill	

Hole No. 23 Location N.W. ¼, sec. 18, tp. 16, rge. 7 E

Depth (ft.)	Description	Interpretation
0-4	light olive gray (5Y 6/1 wet) lake clay, silty lenses, minor rock fragments	Lake Agassiz clay unit
4-12	light olive gray (5Y 6/1 wet) clayey to silty calcareous till?	Libau Drift ?
12-15	pale yellowish brown (10Y R 6/2 wet) calcareous sand	Libau Drift
15-18	light olive gray (5Y 6/1 wet)lake clay, numerous silty fragments	Libau Drift
18-25	drilled like stratified sediment, no samples	Libau Drift

Hole No. 23 (Cont.)

25-28	grayish orange (10Y R 7/4 wet) calcareous, silty till, numerous carbonate rock fragments	Libau Drift
28	total depth, too rocky to drill	

Hole No. 24 Location S.W. ¼, sec. 25, tp. 15, rge. 6 E

Depth (ft.)	Description	Interpretation
0-11	yellowish gray (5Y 7/2 wet) sandy silt	Lake Agassiz silt unit
11-33	light olive gray (5Y 5/2 wet) silty clay, numerous calcareous rock fragments	Lake Agassiz mud or clay unit
33-38	yellowish gray (5Y 8/1 wet) calcareous silty till, carbonate rock fragments	Libau Drift
38	total depth, too hard to drill	

Hole No. 25 Location S.W. ¼, sec. 20, tp. 14, rge. 6 E

Depth (ft.)	Description	Interpretation
0-8	road fill	
8-14	light olive gray (5Y 6/1 wet) lake clay, silt pockets and carbonate rock fragments	Lake Agassiz clay unit
14-35	pale yellowish brown (10Y R 6/2 wet) calcareous silty till, numerous rock fragments	Libau Drift
35	total depth, too hard to drill	

Hole No. 26 Location S.W. ¼, sec. 31, tp. 13, rge. 6 E

Depth (ft.)	Description	Interpretation
0-10	grayish orange (10Y R 7/4 wet) carbonate, gravelly, sandy silt	wave washed till?
10	total depth, too rocky to drill	

Hole No. 27 Location N.W. $\frac{1}{4}$, sec. 24, tp. 13, rge. 5 E

Depth (ft.)	Description	Interpretation
0-6	light olive gray (5Y 5/2 wet) lake clay, silty lenses	Lake Agassiz clay unit
6-23	light olive gray (5Y 5/2 wet) calcareous, silty till, calcareous pebbles and cobbles	Libau Drift
23	carbonate bedrock or boulder	

Hole No. 28 Location S.E. $\frac{1}{4}$, sec. 32, tp. 12, rge. 6 E

Depth (ft.)	Description	Interpretation
0-11	light olive gray (5Y 6/1 wet) lake clay, silt pockets and minor rock fragments	Lake Agassiz clay unit
11-17	yellowish gray (5Y 8/1 wet) calcareous, silty till, numerous carbonate rock fragments	Libau Drift
17	bedrock or boulder	

Hole No. 29 Location S.E. $\frac{1}{4}$, sec. 4, tp. 12, rge. 6 E

Depth (ft.)	Description	Interpretation
0-18	medium dark gray (N5 wet)lake clay numerous silty lenses and rock fragments	Lake Agassiz clay unit
18-28	medium dark gray (N5 wet) massive lake clay	Lake Agassiz clay unit
28-41	light olive gray (5Y 6/1 wet) calcareous sandy to silty till, carbonate rock fragments	Libau Drift
41-49	medium dark gray (N5 wet) massive clay	Libau Drift
49-55	light olive gray (5Y 6/1 wet) calcareous, sandy to silty till, carbonate rock fragments	Libau Drift

Hole No. 30 Location N.E. $\frac{1}{4}$, sec. 9, tp. 11, rge. 6 E

Depth (ft.)	Description	Interpretation
0-20	light olive gray (5Y 6/1 wet) lake clay, silty lenses, minor rock fragments	Lake Agassiz clay unit
20-24	pale yellowish orange (10Y R 8/6 wet) calcareous quartz sand	Lake Agassiz deposit
24-38	pale yellowish orange (10Y R 8/6 wet) calcareous silty till, numerous carbonate rock fragments	Libau Drift
38	total depth, boulder or bedrock	

Hole No. 31 Location N.E. $\frac{1}{4}$, sec. 23, tp. 11, rge. 4 E

Depth (ft.)	Description	Interpretation
0-41	moderate olive brown (5Y 4/4 wet) lake clay, silt pockets, minor rock fragments	Lake Agassiz clay unit
41-49	yellowish gray (5Y 7/2 wet) calcareous silty till, numerous carbonate rock fragments	Libau Drift

Hole No. 32 Location S.E. $\frac{1}{4}$, sec. 28, tp. 12, rge. 5 E

Depth (ft.)	Description	Interpretation
0-30	yellowish gray (5Y 7/2 wet) oxidized calcareous, silty till, numerous carbonate rock fragments	Libau Drift
30	boulder or bedrock	

Hole No. 33 Location S.E. $\frac{1}{4}$, sec. 21, tp. 12, rge. 7 E

Depth (ft.)	Description	Interpretation
0-68	yellowish gray (5Y 8/1 wet) bedded quartz sand	Lake Agassiz deposit

Hole No. 33 (cont.)

68-78	medium light gray (N6 wet) sandy to silty, calcareous till, numerous carbonate rock fragments	Libau Drift
78	total depth, too hard to drill	

Hole No. 34

Location S.E. $\frac{1}{4}$, sec. 20, tp. 12, rge. 8 E

Depth (ft.)	Description	Interpretation
0-6	light olive gray (5Y 6/1 wet) lake clay, numerous silty lenses and rock fragments, water table 4 ft.	Lake Agassiz clay unit
6-13	yellowish gray (5Y 7/2 wet) calcareous sandy to silty till, numerous carbonate rock fragments	Libau Drift
13-59	yellowish gray (5Y 5/2 wet) calcareous sandy silt, numerous quartz grains	Libau Drift
59-70	light olive gray (5Y 5/2 wet) calcareous silty till, carbonate and a few volcanic rock fragments	Libau Drift
70	total depth, too hard to drill	

Hole No. 35

Location S.W. $\frac{1}{4}$, sec. 3, tp. 11, rge. 8 E

Depth (ft.)	Description	Interpretation
0-8	medium dark gray (N5 wet) lake clay, silty lenses	Lake Agassiz clay unit
8-15	light olive gray (5Y 6/1 wet) calcareous sandy to silty till?	Libau Drift
15-63	yellowish gray (5Y 8/1 wet) calcareous, quartz sand (layered)	Belair Drift?
63-70	light olive gray (5Y 6/1 wet) calcareous silty till, numerous granitic and carbonate rock fragments	Belair Drift
70	total depth, too hard to drill	

Hole No. 36 Location S.E. $\frac{1}{4}$, sec. 29, tp. 12, rge. 9 E

Depth (ft.)	Description	Interpretation
0-5	pale yellowish orange (10Y R 8/6 wet) oxidized, quartz sand	nearshore deposit
5-63	grayish orange (10Y R 7/4 wet) quartz sand, minor pebbles, probably till near bottom	Belair Drift
63	total depth, too rocky to drill	

Hole No. 37 Location N.W. $\frac{1}{4}$, sec. 9, tp. 12, rge. 10 E

Depth (ft.)	Description	Interpretation
0-5	grayish orange (10Y R 7/4 wet) calcareous sandy silt	wave washed till
5-59	grayish orange (10Y R 7/4 wet) calcareous silty to clayey till, carbonate rock fragments	Libau Drift
59	total depth, too rocky to drill	

Hole No. 38 Location S.E. $\frac{1}{4}$, sec. 17, tp. 11, rge. 10 E

Depth (ft.)	Description	Interpretation
0-3	grayish orange (10Y R 7/4 wet) gravelly sand	nearshore deposit
3-5	very pale orange (10Y R 8/2 wet) sandy silt	nearshore deposit
5-77	grayish orange (10Y R 7/4 wet) gravelly quartz sand with granitic and volcanic fragments, water table 15 ft., bedded	Belair Drift
77-85	same as 5-77, except more rock fragments	Belair Drift
85	total depth, too rocky to drill	

Hole No. 39 Location N.E. $\frac{1}{4}$, sec. 17, tp. 12, rge 11 E

Depth (ft.)	Description	Interpretation
0-4	pale yellowish brown (10Y R 6/2 wet) silty lake clay	Lake Agassiz mud unit
4-12	medium dark gray (N4 wet) massive, lake clay	Lake Agassiz clay unit
12-85	light olive gray (5Y 6/1 wet) calcareous, silty till, minor carbonate rock fragments	Libau Drift
85	total depth, too rocky to drill	

Hole No. 40 Location N.E. $\frac{1}{4}$, sec. 7, tp. 14, rge. 11 E

Depth (ft.)	Description	Interpretation
0-13	yellowish gray (5Y 8/1 wet) sandy silt	Lake Agassiz sandy silt unit
13-55	light olive gray (5Y 6/1 wet) calcareous silty till, minor boulders	Libau Drift
55	total depth, too hard to drill	

Hole No. 41 Location N.E. $\frac{1}{4}$, sec. 13, tp. 15, rge. 10 E

Depth (ft.)	Description	Interpretation
0-3	light olive gray (5Y 6/1 wet) lake clay, silty pockets	Lake Agassiz clay unit
3-28	light olive gray (5Y 6/1 wet) calcareous, silty till	Libau Drift
28	total depth	

Hole No. 42 Location N.E. ¼, sec. 4, tp. 17, rge. 11 E

Depth (ft.)	Description	Interpretation
0-12	medium dark gray (N5 wet) lake clay silty lenses and rock fragments	Lake Agassiz clay unit
12-13	yellowish gray (5Y 8/1 wet) calcareous silty till or lake sediment	Libau Drift ?
13	total depth, granite bedrock	

Hole No. 43 Location N.E. ¼, sec. 30, tp. 17, rge. 11 E

Depth (ft.)	Description	Interpretation
0-20	light olive gray (5Y 6/1 wet) laminated sandy silt, minor clay	Lake Agassiz sandy silt unit
20-55	light olive gray (5Y 6/1 wet) laminated silty clay	Lake Agassiz mud unit
55	total depth	

Hole No. 44 Location S.W. ¼, sec. 3, tp. 19, rge. 10 E

Depth (ft.)	Description	Interpretation
0-7	light olive gray (5Y 6/1) lake clay	Lake Agassiz clay unit
7	total depth, bedrock	

Hole No. 45 Location S.W. ¼, sec. 3, tp. 19, rge. 10 E

Depth (ft.)	Description	Interpretation
0-10	yellowish gray (5Y 8/1 wet) sandy silt	Lake Agassiz sandy silt unit
10-55	light olive gray (5Y 6/1 wet) lake clay, numerous silty lenses	Lake Agassiz mud or clay unit
55	total depth	

Hole No. 46 Location N.E. $\frac{1}{4}$, sec. 27, tp. 17, rge. 7 E

Depth (ft.)	Description	Interpretation
0-14	yellowish gray (5Y 8/1 wet) oxidized quartz sand	lake sediment
14-18	medium dark gray (N5 wet) lake clay, silty lenses and minor rock fragments	Lake Agassiz clay unit
18-55	light olive gray (5Y 6/1 wet) calcareous, quartz sand to sandy gravel, numerous granitic, volcanic, and carbonate rock fragments, almost appears like till in places	Belair Drift

Hole No. 47 Location N.E. $\frac{1}{4}$, sec. 8, tp. 10, rge. 12 E

Depth (ft.)	Description	Interpretation
0-5	peat	
5-13	yellowish gray (5Y 7/2 wet) sandy silt	Lake Agassiz sandy silt unit
13-31	pale yellowish brown (10Y R 6/2 wet) calcareous, silty till, carbonate rock fragments	Libau Drift
31	total depth	

Hole No. 48 a, b, c. Location N.E. $\frac{1}{4}$, sec. 9, tp. 15, rge. 6 E

Depth (ft.)	Description	Interpretation
a		
0-6	medium dark gray (N5 wet) lake clay, minor silty lenses, numerous rock fragments	Lake Agassiz clay unit
6-14	yellowish gray (5Y 8/1 wet) calcareous silty till, carbonate and minor granitic rock fragments	Libau Drift
b		
0-12	calcareous till as in 48 a	Libau Drift

Hole No. 48 (cont.)

c

0-17	medium dark gray (N5 wet) silty lake clay, numerous rock fragments	Lake Agassiz clay unit
17-25	yellowish gray (5Y 8/1 wet) calcareous silty till, carbonate and minor granitic rock fragments	Libau Drift
	All holes end in bedrock	

Hole No. 49 Location S.W. $\frac{1}{4}$, sec. 32, tp. 11, rge. 5 E

Depth (ft.)	Description	Interpretation
0-38	light olive gray (5Y 6/1 wet) lake clay	Lake Agassiz mud or clay unit
38-73	yellowish gray (5Y 6/1 wet) sandy gravel, carbonate with minor granitic rock fragments	Libau Drift
73-78	yellowish gray (5Y 8/1 wet) calcareous, silty till, carbonate and granitic rock fragments	Libau Drift
78	total depth, too rocky to drill	

Hole No. 50 Location S.W. $\frac{1}{4}$, sec. 25, tp. 15, rge. 11 E

Depth (ft.)	Description	Interpretation
0-3	road fill	
3-5	yellowish gray (5Y 8/1 wet) sandy silt	Lake Agassiz sandy silt unit
5-14	olive gray (5Y 4/1 wet) lake clay	Lake Agassiz clay unit
14-30	light olive gray (5Y 6/1 wet) calcareous, silty till, numerous carbonate and granitic rock fragments	Libau Drift
30	total depth, granite bedrock	

Hole No. 51 Location S.W. ¼, sec. 14, tp. 16, rge. 10 E

Depth (ft.)	Description	Interpretation
0-3	road fill	
3-5	yellowish gray (5Y 8/1 wet) sand	nearshore deposit
5-10	drilled like till, no sample	
10	total depth, boulder or bedrock	

Hole No. 52 Location N.W. ¼, sec. 1, tp. 13, rge. 11 E

Depth (ft.)	Description	Interpretation
0-5	road fill	
5-44	olive gray (5Y 4/1 wet) lake clay	Lake Agassiz mud or clay unit
44	total depth, boulder or bedrock	

Hole No. 53 Location S.W. ¼, sec. 18, tp. 13 rge. 10 E

Depth (ft.)	Description	Interpretation
0-5	pale yellowish orange (10Y R 8/6 wet) calcareous, quartz sand	nearshore deposit
5-85	light olive gray (5Y 6/1 wet) quartz and granitic sand, interbedded with olive gray (5Y 4/1 wet) clay	Belair Drift

Hole No. 54 Location N.E. ¼, sec. 7, tp. 15, rge. 6 E

Depth (ft.)	Description	Interpretation
0-5	road fill	
5-20	light olive gray (5Y 6/1 wet) lake clay, some silt	Lake Agassiz mud unit
20-38	medium gray (N6 wet) lake clay	Lake Agassiz clay unit

Hole No. 54 (cont.)

38-53	yellowish gray (5Y 8/1 wet)	Libau Drift
53	total depth	

Hole No. 55 Location N.E.$\frac{1}{4}$, sec. 32, tp. 16, rge. 7 E.

Depth (ft.)	Description	Interpretation
0-8	light olive gray (5Y 6/1 wet) lake clay, silt pockets, minor rock fragments	Lake Agassiz clay unit
8-10	pale yellowish orange (10Y R 8/6 wet) calcareous, silty till, carbonate and granitic rock fragments	Libau Drift
10	total depth, bedrock or boulder	

Hole No. 56 Location N.W.$\frac{1}{4}$, sec. 10, tp. 17, rge. 7 E.

Depth (ft.)	Description	Interpretation
0-18	pale yellowish brown (10Y R 6/2 wet) sandy to clayey silt	Lake Agassiz sandy silt unit?
18-33	light olive gray (5Y 6/1 wet) lake clay, numerous silty pockets	Lake Agassiz mud or clay unit
33-56	light olive gray (5Y 6/1 wet) calcareous, silty till, numerous carbonate and granitic rock fragments	Libau Drift
56	total depth, bedrock	

Hole No. 57 Location N.W.$\frac{1}{4}$, sec. 26, tp. 18, rge. 9 E.

Depth (ft.)	Description	Interpretation
0-15	olive gray (5Y 4/1 wet) lake clay, minor silt lenses, and rock fragments	Lake Agassiz clay unit
15-17	light olive gray (5Y 6/1 wet) calcareous, silty till	Libau Drift
17	total depth, bedrock	

Hole No. 58 Location N.E.¼, sec. 26, tp. 18, rge. 7 E

Depth (ft.)	Description	Interpretation
0-34	yellowish gray(5Y 8/1 wet) calcareous quartz sand	Belair Drift
34-77	medium dark gray (N5 wet) sandy lake clay, interbedded with light brownish gray (5Y 6/1 wet) quartz sand with granitic and volcanic pebbles	Belair Drift
77	total depth, too hard to drill	

Hole No. 59 Location N.W.¼, sec. 5, tp. 17, rge. 9 E.

Depth (ft.)	Description	Interpretation
0-10	light olive gray (5Y 6/1 wet) sandy silt	Lake Agassiz mud or sandy silt unit
10-60	medium dark gray (N5 wet) lake clay	Lake Agassiz clay unit
60-70	light olive gray (5Y 6/1 wet) calcareous silt, carbonate, granite, and volcanic rock fragments	Libau Drift

Hole No. 60 Location S.W.¼, sec. 6, tp. 14, rge. 9 E.

Depth (ft.)	Description	Interpretation
0-25	yellowish gray (5Y 8/1 wet) sandy silt	Lake Agassiz sandy silt unit
25-60	medium dark gray (N5 wet) lake clay minor pebbles near 60 ft.	Lake Agassiz clay unit
60	total depth	

Hole No. 61 — Location N.E. $\frac{1}{4}$, sec. 30, tp. 12, rge. 9 E

Depth (ft.)	Description	Interpretation
0-10	light olive gray (5Y 6/1 wet) oxidized, quartz sand	nearshore deposit
10-80	medium gray (N6 wet) sandy clay and interbedded sand as above with granitic and volcanic rock fragments	Belair Drift
80	total depth, too hard to drill	

Hole No. 62 — Location S.W. $\frac{1}{4}$, sec. 1, tp. 13, rge. 6 E

Depth (ft.)	Description	Interpretation
0-16	yellowish gray (5Y 7/2 wet) clayey sand, minor rock fragments	wave washed till
16-25	light olive gray (5Y 6/1 wet) calcareous silty till, numerous carbonate rock fragments	Libau Drift
25	bedrock	

Hole No. 63 — Location N.E. $\frac{1}{4}$, sec. 34, tp. 13, rge. 5 E

Depth (ft.)	Description	Interpretation
0-10	pale yellowish orange (10Y R 8/6 wet) calcareous silt, minor rock fragments	lake deposit
10-18	grayish orange (10Y R 7/4 wet) calcareous, quartz sand	lake deposit?
18-24	very pale orange (10Y R 8/2 wet) calcareous silty to sandy till, numerous carbonate rock fragments	Libau Drift

Hole No. 64 — Location N.W. $\frac{1}{4}$, sec. 31, tp. 12, rge. 5 E

Depth (ft.)	Description	Interpretation
0-28	olive gray (5Y 3/2 wet) lake clay minor silty pockets and rock fragments	Lake Agassiz clay unit

Hole No. 64 (cont.)

28-40	yellowish gray (5Y 7/2 wet) calcareous silty till, numerous carbonate rock fragments	Libau Drift
40	total depth	

Hole No. 65 Location N.E. 1/4, sec. 8, tp. 11, rge. 7 E

Depth (ft.)	Description	Interpretation
0-15	pale yellowish orange (10Y R 8/6 wet) calcareous silty till, numerous carbonate rock fragments, minor granitic rock fragments	Libau Drift
15	total depth, too bouldery to drill	

Hole No. 66 Location S.W. 1/4, sec. 1, tp. 11, rge. 7 E

Depth (ft.)	Description	Interpretation
0-15	pale yellowish orange (10Y R 8/6 wet) oxidized, calcareous, silty till, numerous carbonate, minor granitic rock fragments	Libau Drift
15-85	grayish orange (10Y R 7/4 wet) unoxidized calcareous till (as above)	Libau Drift

Hole No. 67 Location S.W. 1/4, sec. 19, tp. 11, rge. 5 E

Depth (ft.)	Description	Interpretation
0-5	road fill	
5-12	olive gray (5Y 4/1 wet) silty to sandy clay	Lake Agassiz mud unit
12-29	olive gray (5Y 4/1 wet) lake clay minor silt lenses	Lake Agassiz clay unit
29-55	rounded sand and gravel composed of mainly carbonate and minor granitic and volcanic rock fragments	Libau Drift

Hole No. 67 (cont.)

55-57	yellowish gray (5Y 8/1 wet) calcareous silty till, numerous carbonate rock fragments	Libau Drift
57	total depth, too hard to drill	

Hole No. 68 Location N.E. 1/4, sec. 21, tp. 12, rge. 6 E

Depth (ft.)	Description	Interpretation
0-13	olive gray (5Y 4/1 wet) lake clay, minor rock fragments	Lake Agassiz clay unit
13-22	yellowish gray (5Y 8/1 wet) calcareous silty till, numerous carbonate rock fragments	Libau Drift
22	total depth, hit a boulder	

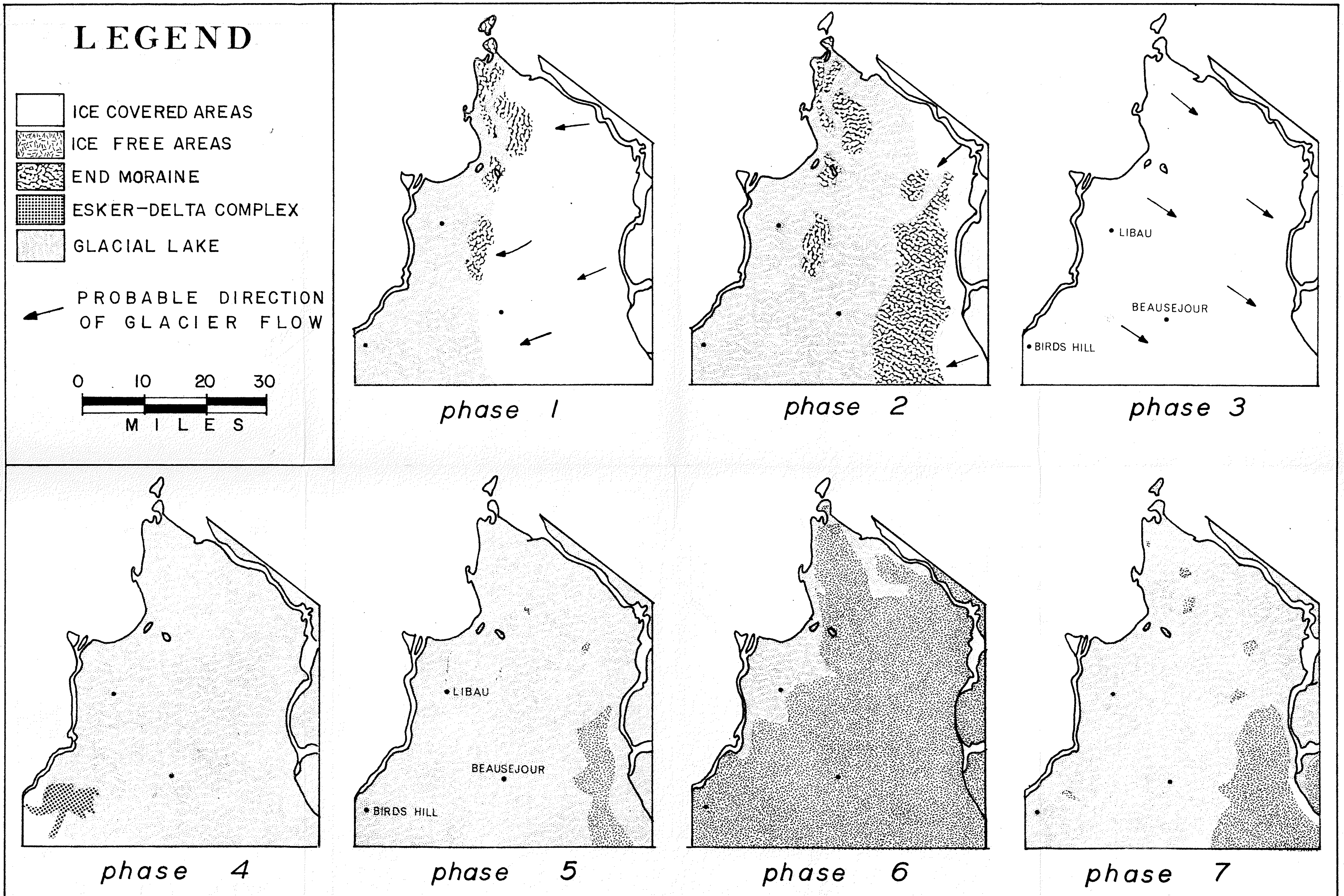
APPENDIX II

GRAIN SIZE ANALYSES OF THE UPPER AND LOWER TILL IN THE BEAUSEJOUR AREA

Hole No.	Depth	Description	% Sand	% Silt	% Clay
3	25	lower till *	57.3	29.6	13.1
5	80	"	43.7	36.3	20.1
12	85	"	47.1	32.3	20.6
15	90	"	51.3	28.6	20.1
1	50	upper till **	34.1	30.7	35.2
8	45	"	44.1	30.0	25.9
10	20	"	40.8	29.3	29.3
21	45	"	30.1	58.5	11.4
22	85	"	21.2	70.1	8.7
24	35	"	56.8	31.8	11.4
27	20	"	50.1	30.2	19.7
30	35	"	29.2	36.9	33.9
32	25	"	49.1	30.3	20.6
34	65	"	33.2	47.4	19.4
37	50	"	44.6	32.6	22.8
39	80	"	40.3	46.1	13.6
40	50	"	45.4	27.4	27.2
41	25	"	41.4	24.5	34.1
48 b	20	"	50.7	35.4	13.9
50	25	"	39.6	27.2	33.2
54	45	"	50.2	34.9	14.9
55	10	"	47.4	33.9	18.7
56	50	"	43.2	27.7	29.1
57	15	"	44.6	27.2	28.2
63	20	"	49.0	28.4	22.6
64	35	"	44.3	31.9	23.8
65	10	"	34.1	36.2	29.7
66	80	"	31.0	38.9	30.1
67	55	"	38.1	26.9	35.0
68	20	"	40.1	32.6	27.3

* the lower till is part of the Belair Drift

** the upper till is part of the Libau Drift



phase 1

phase 2

phase 3

phase 4

phase 5

phase 6

phase 7

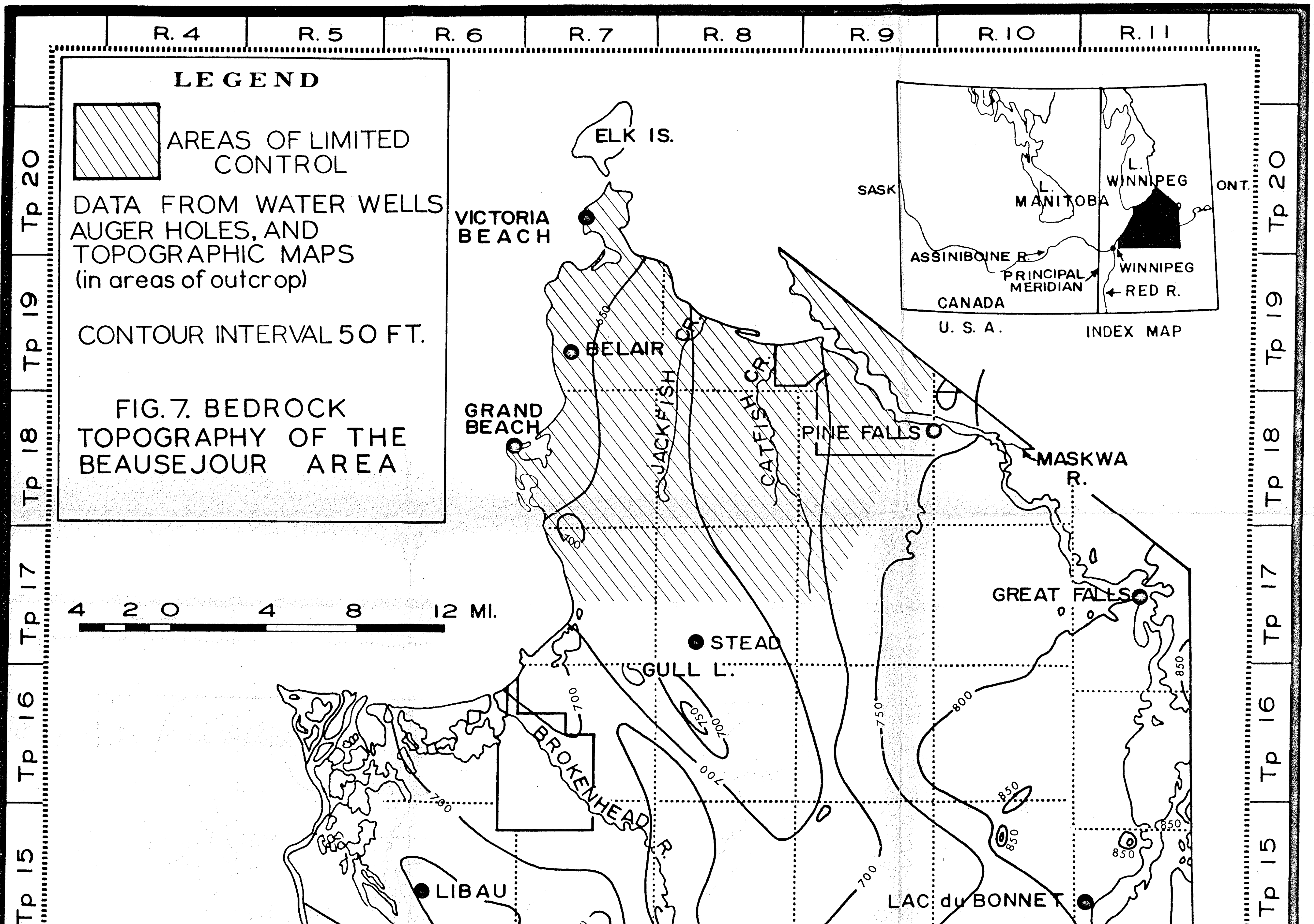
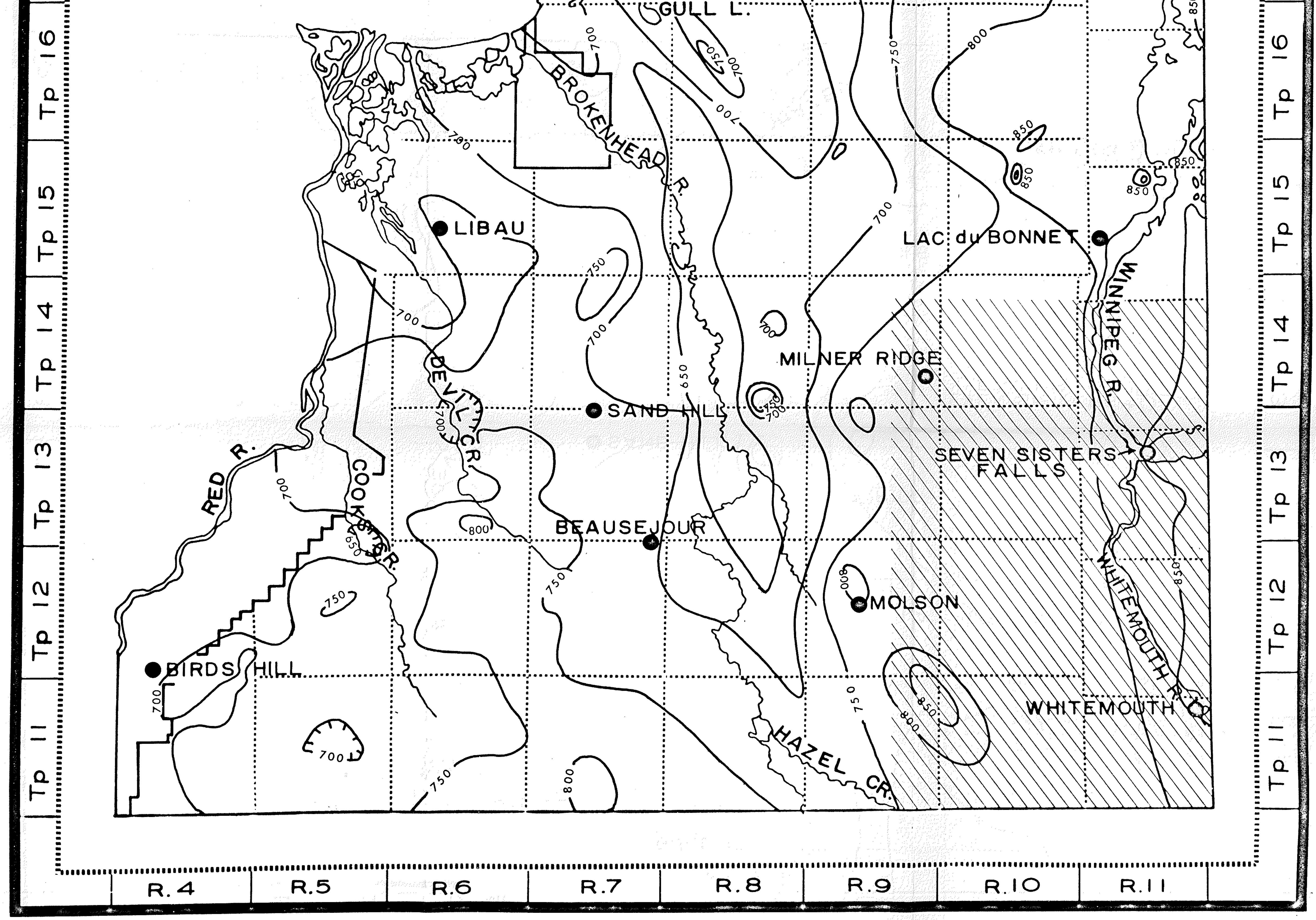


FIG. 7. BEDROCK TOPOGRAPHY OF THE BEAUSEJOUR AREA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BROKENHEAD R.
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LAC du BONNET
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MILNER RIDGE
SAND HILL
DEVIL CR.
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RED R.
COOKS CR.
BEAUSEJOUR
MOLSON
BIRDS HILL
WHITEMOUTH R.
WHITEMOUTH
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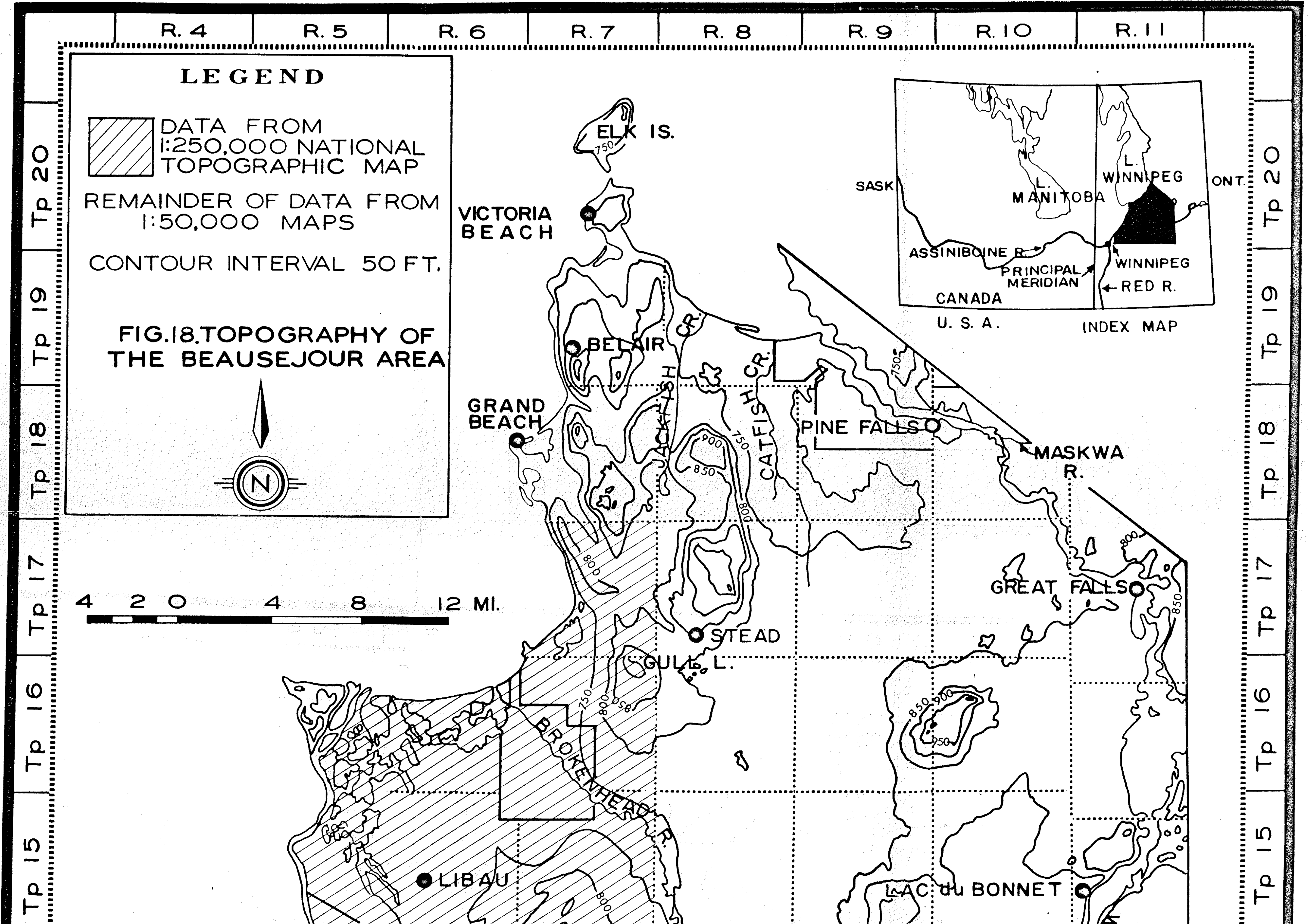
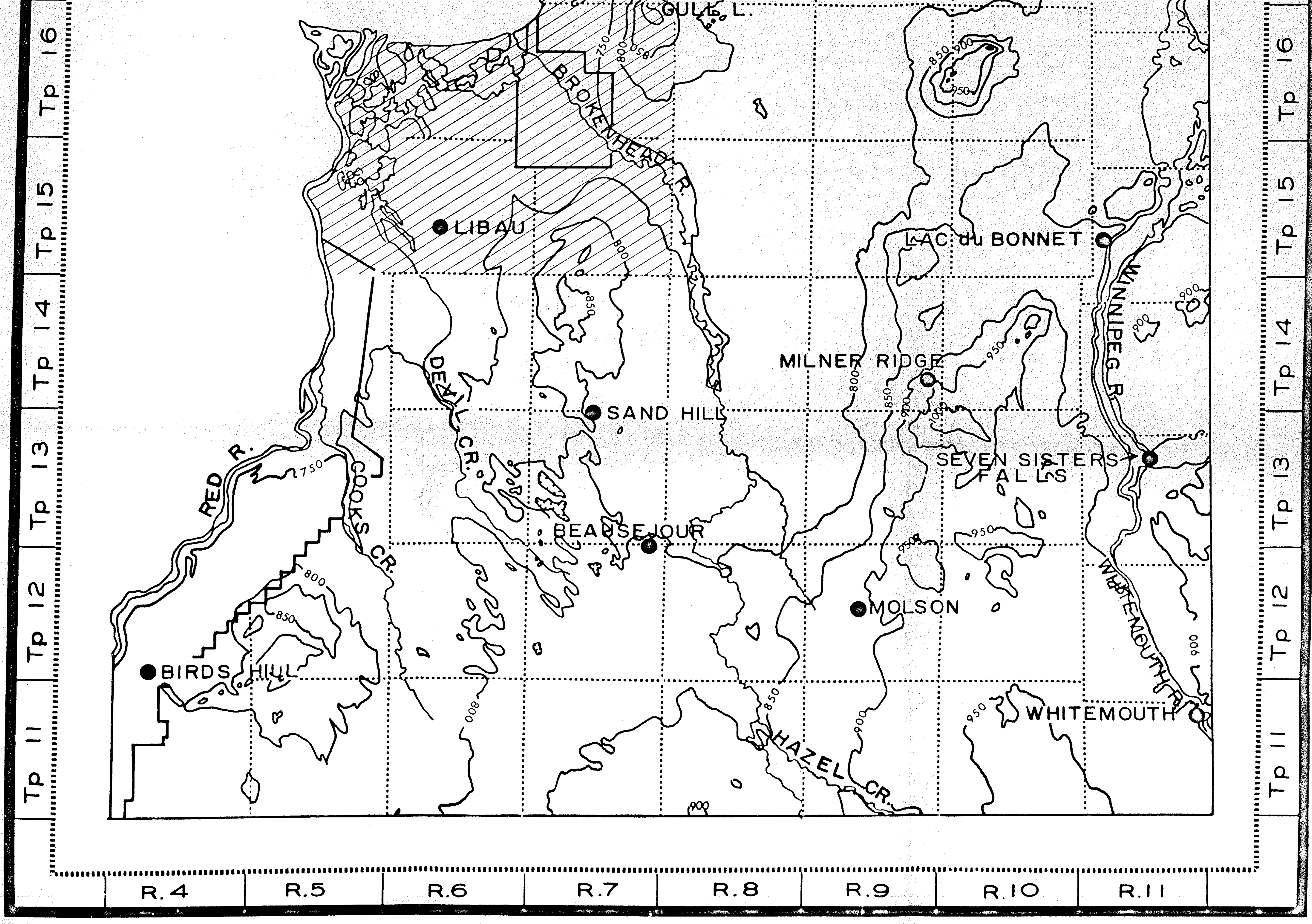


FIG. 18. TOPOGRAPHY OF THE BEAUSEJOUR AREA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RED R.
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ENE

silt, and sandy silt

eline deposits

outwash sand (Belair Drift)

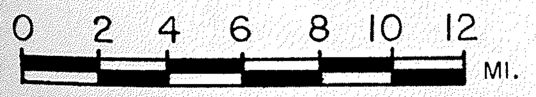
ICIAN

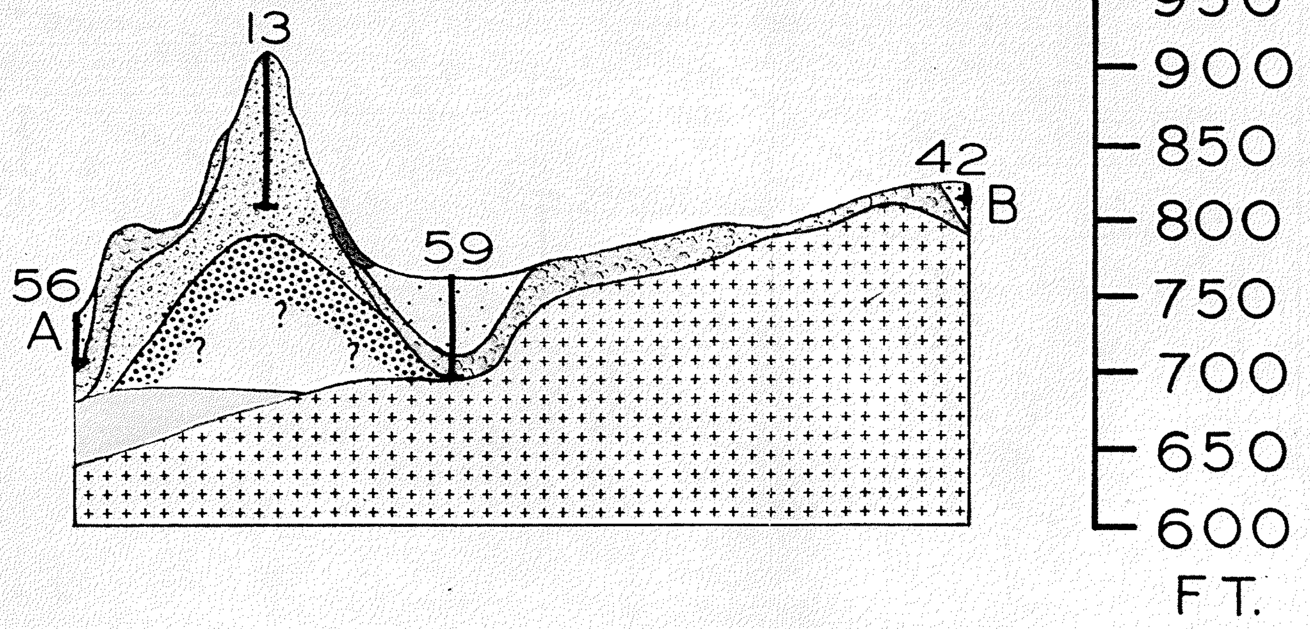
ation–dolomitic limestone, dolomite

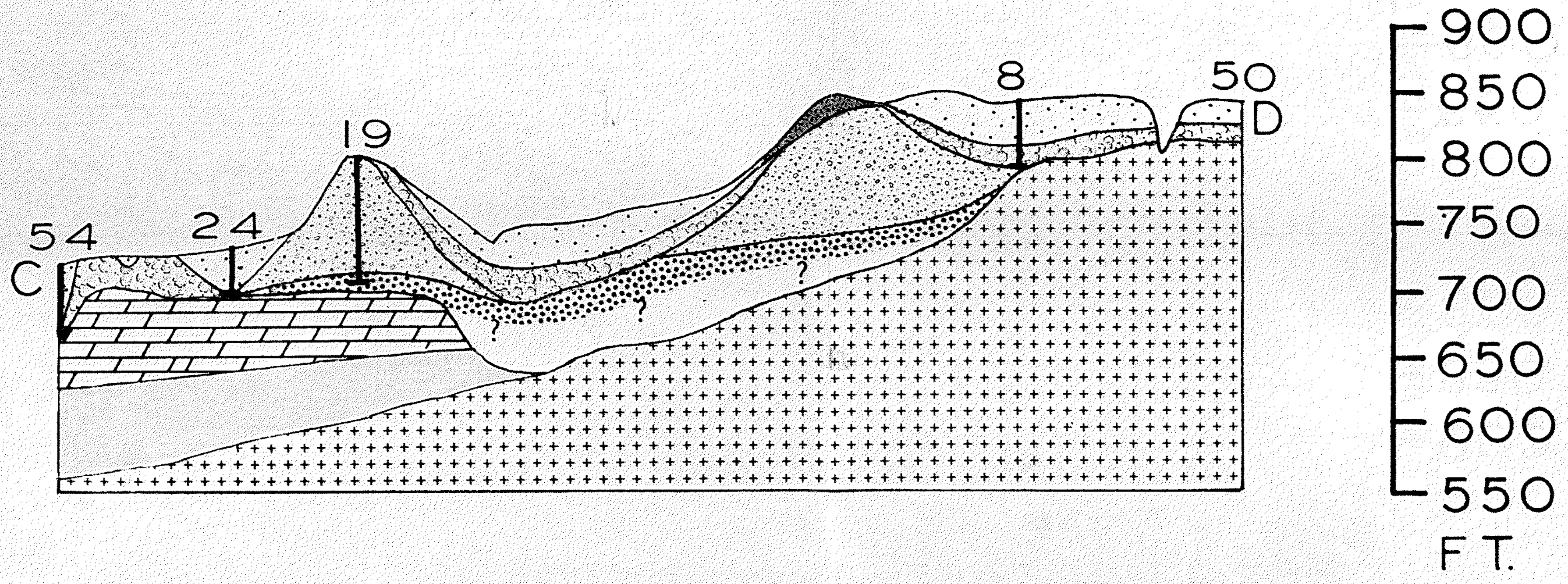
ation– quartzose sandstone, shale

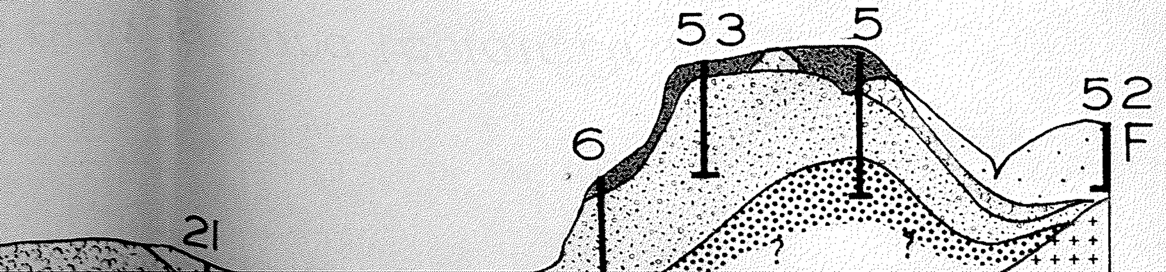
BRIAN

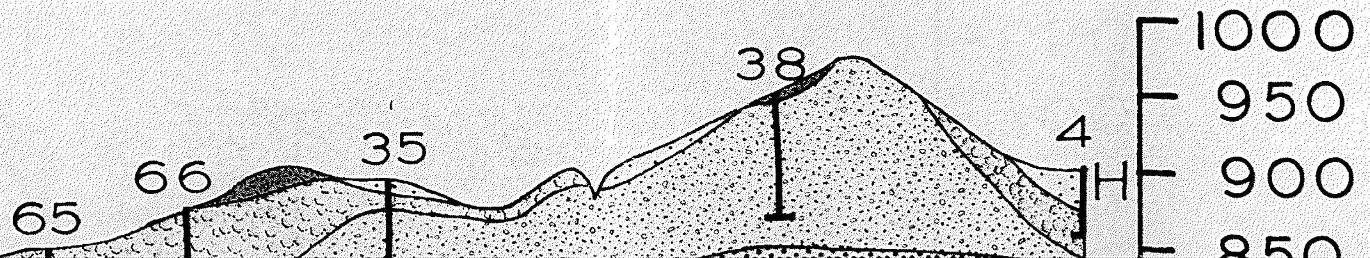
e gneiss











PLEISTOCENE

- ⁘ Lake Agassiz clay, silt, and sandy silt
- ▩ Lake Agassiz shoreline deposits
- ▒ till (Libau Drift)
- ░ end moraine and outwash sand (Belair Drift)
- ▓ till (Belair Drift)

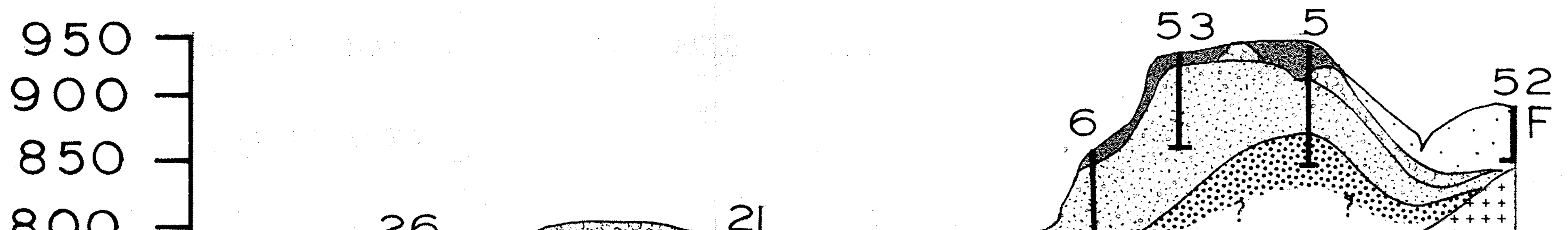
ORDOVICIAN

- ▤ Red River Formation–dolomitic limestone, dolomite
- ☐ Winnipeg Formation– quartzose sandstone, shale

PRECAMBRIAN

- ✚ granite, granite gneiss
- ⊥ auger hole

0 2 4 6 8 10 12 MI.



▨ till (Libau Drift)

▨ end moraine and outwash sand (Belair Drift)

▨ till (Belair Drift)

ORDOVICIAN

▨ Red River Formation–dolomitic limestone, dolomite

▨ Winnipeg Formation– quartzose sandstone, shale

PRECAMBRIAN

▨ granite, granite gneiss

⊥ auger hole

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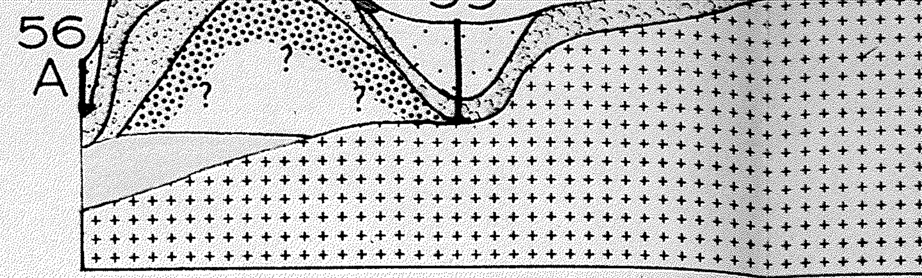

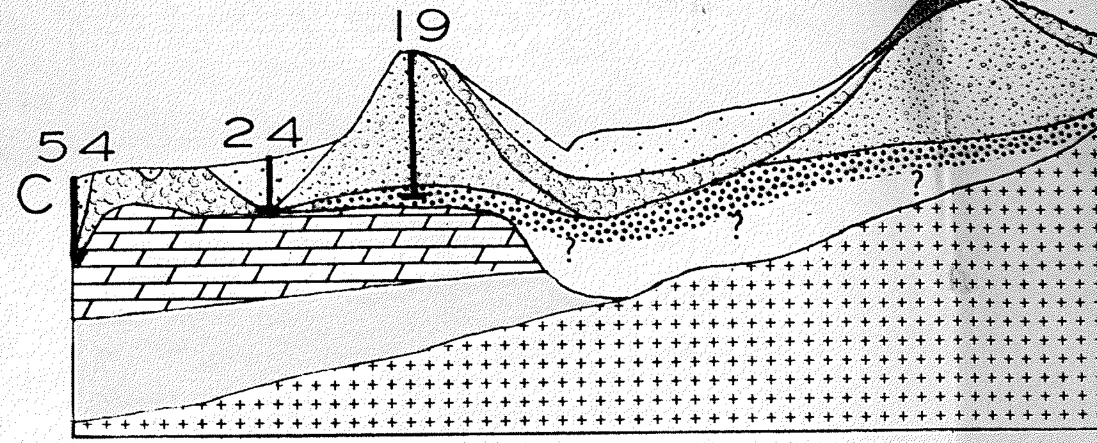

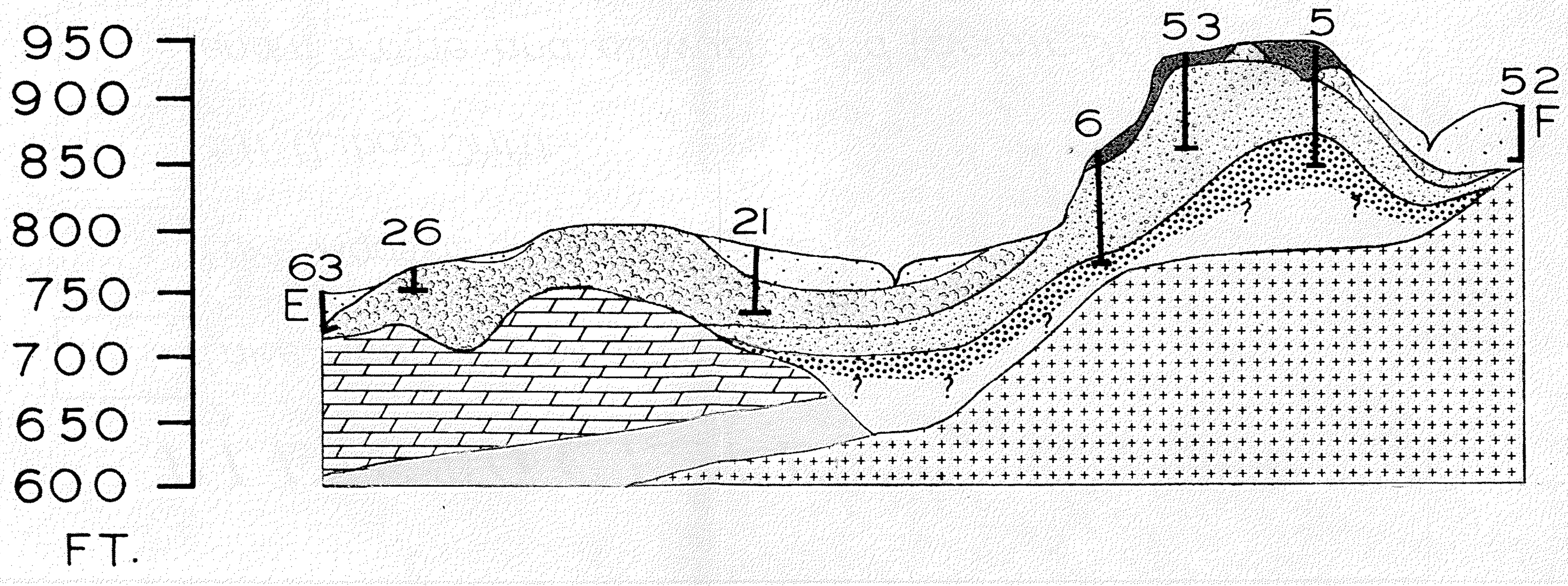

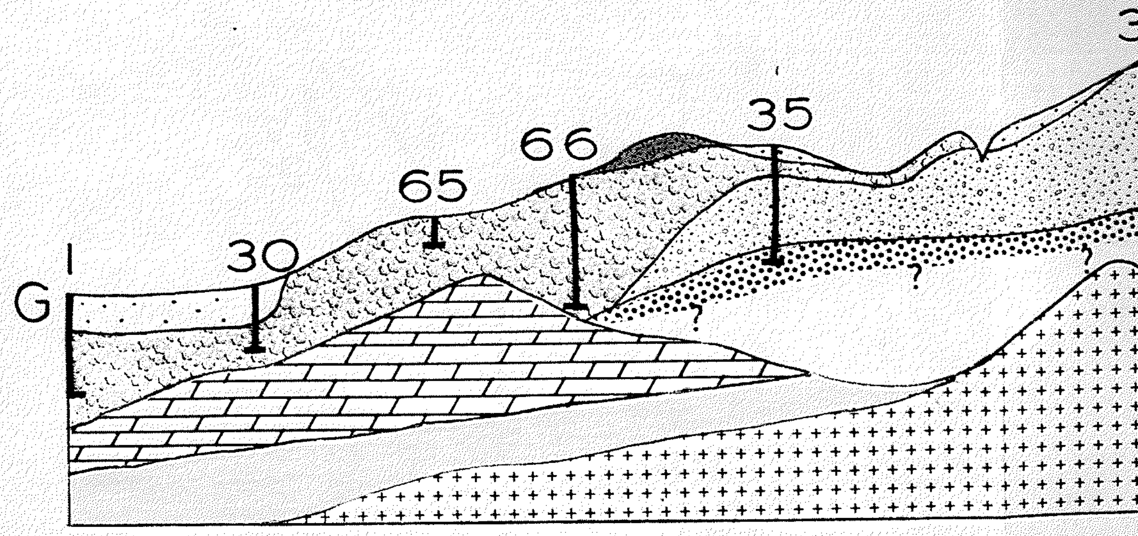

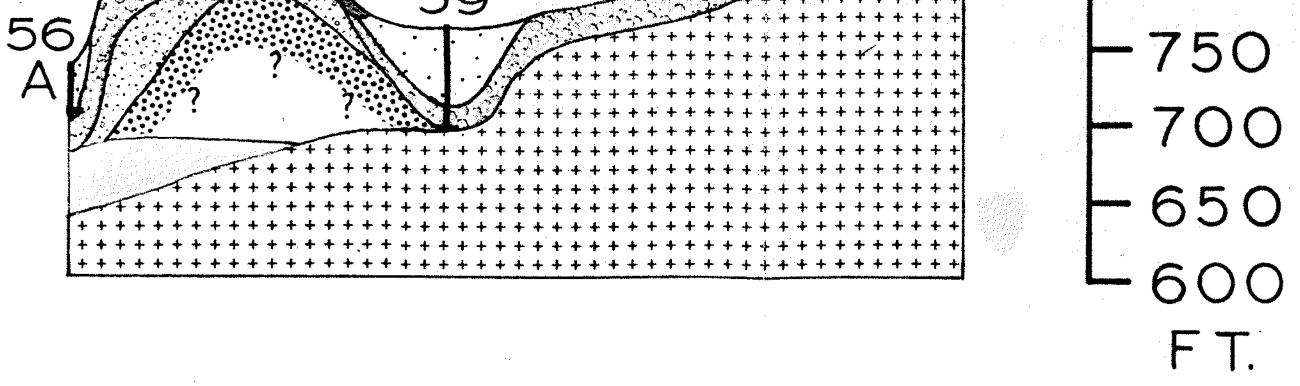
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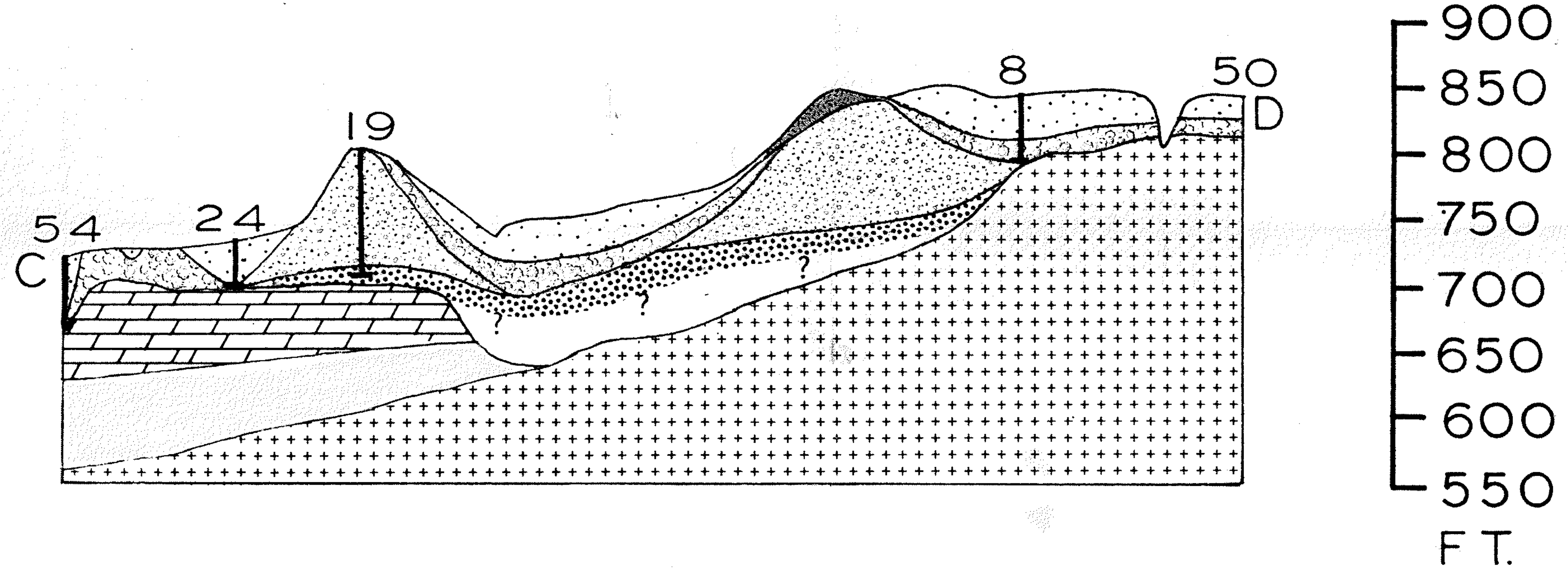
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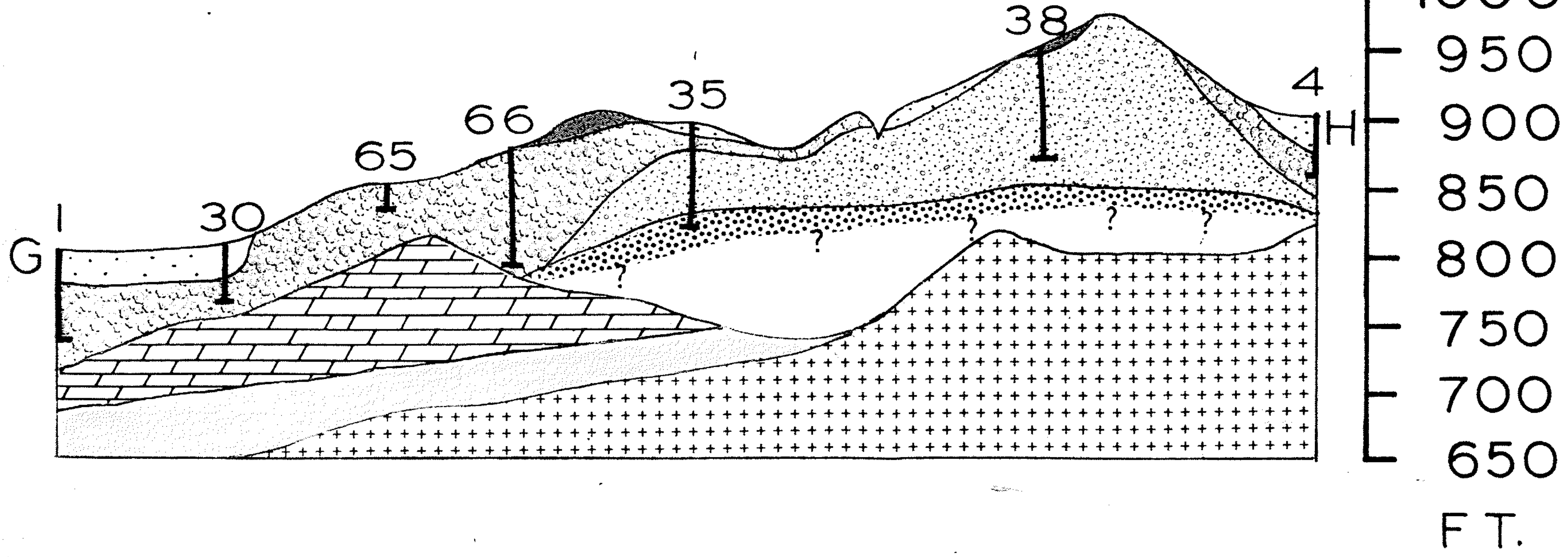
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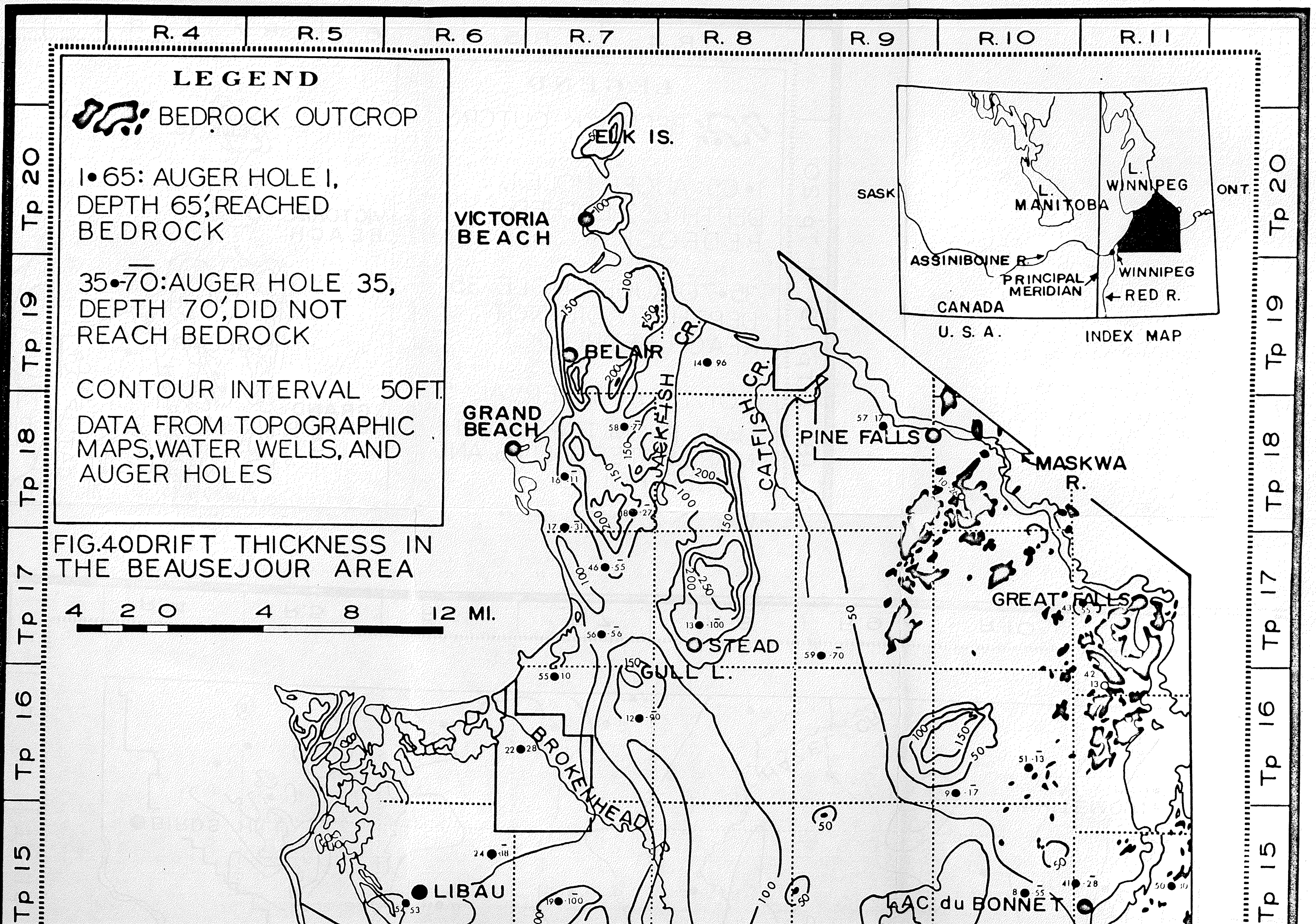
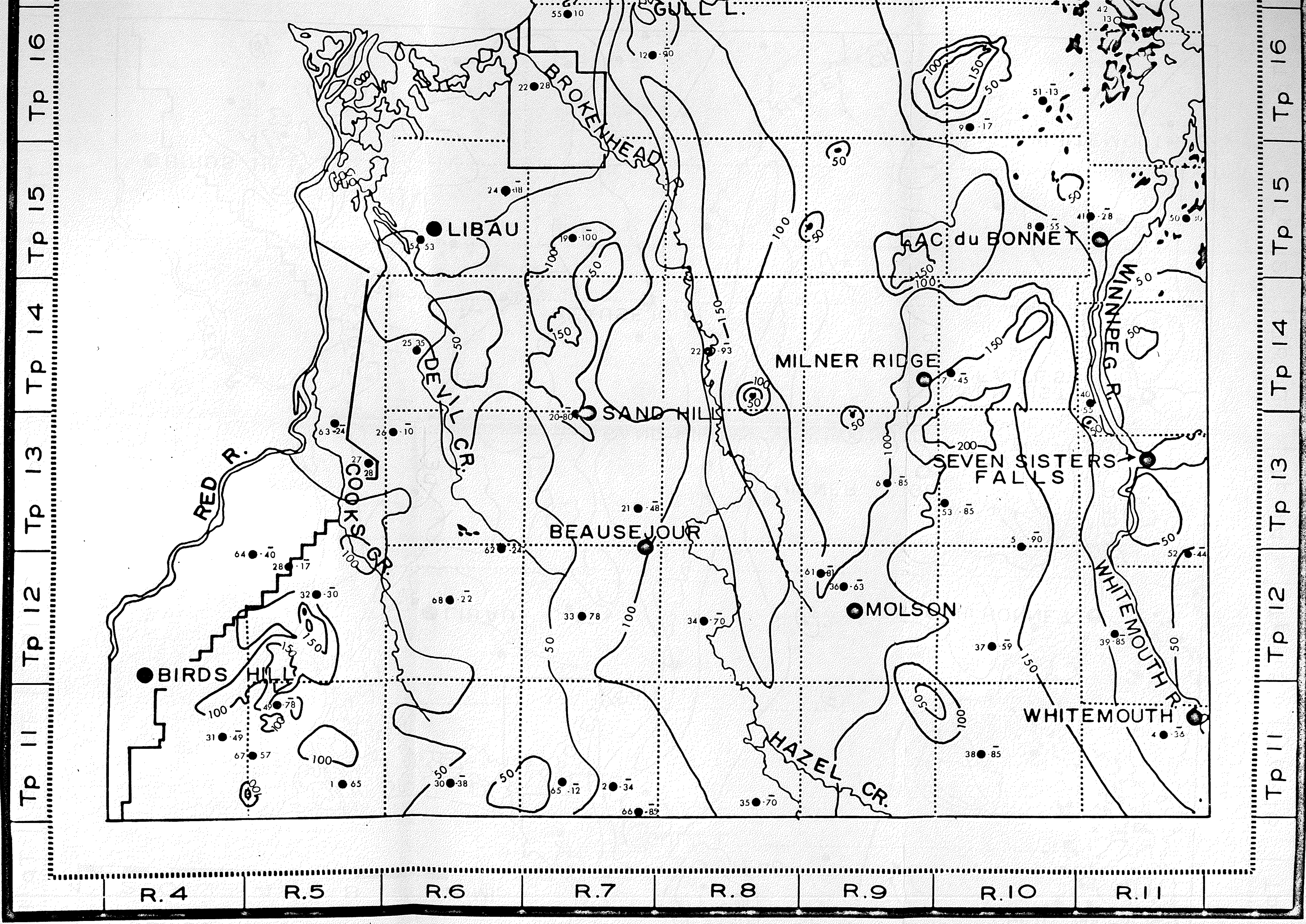


FIG.40 DRIFT THICKNESS IN THE BEAUSEJOUR AREA



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MILNER RIDGE
SAND HILL
DEVIL CR.
RED R.
COOKS CR.
SEVEN SISTERS FALLS
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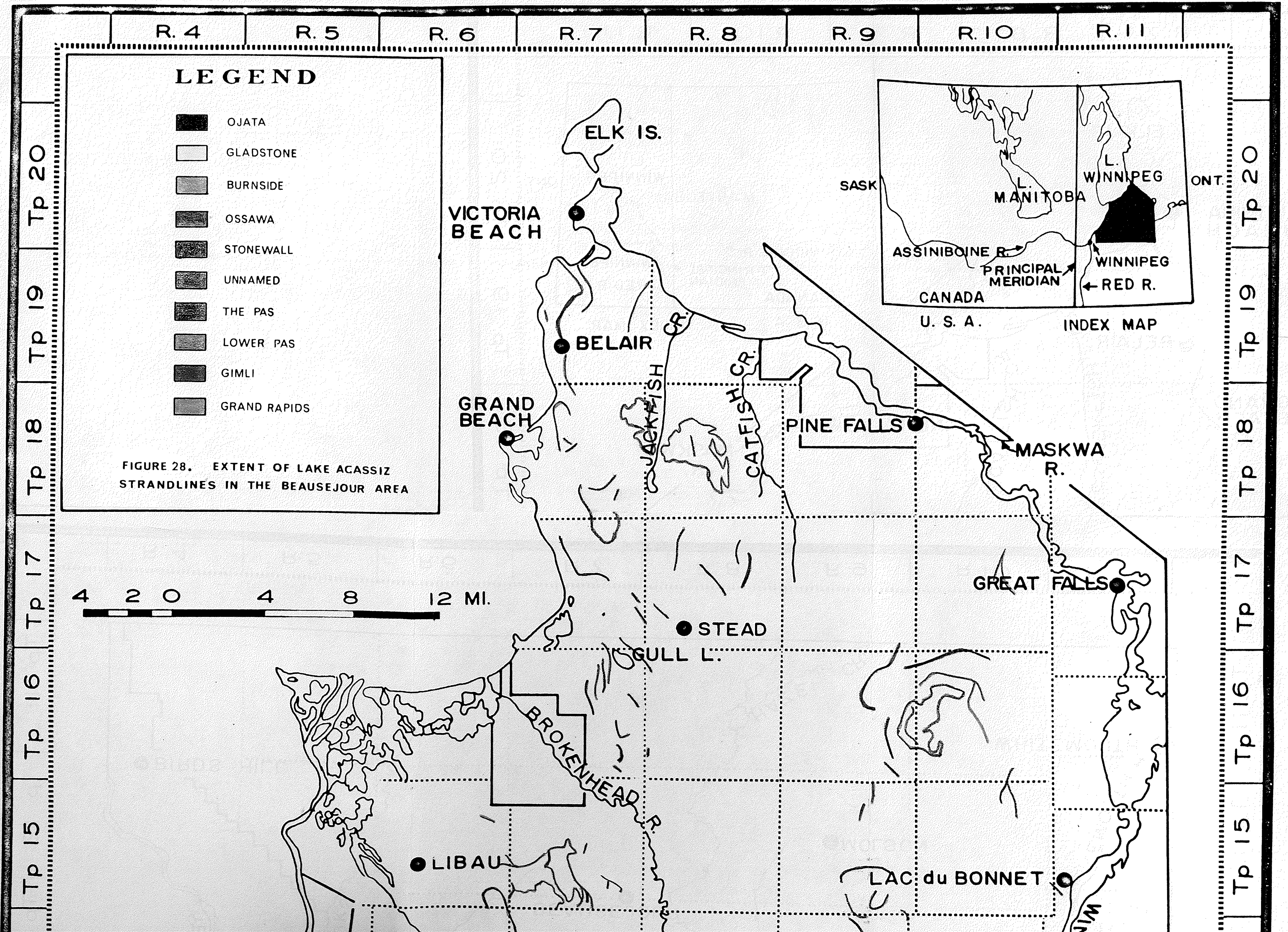
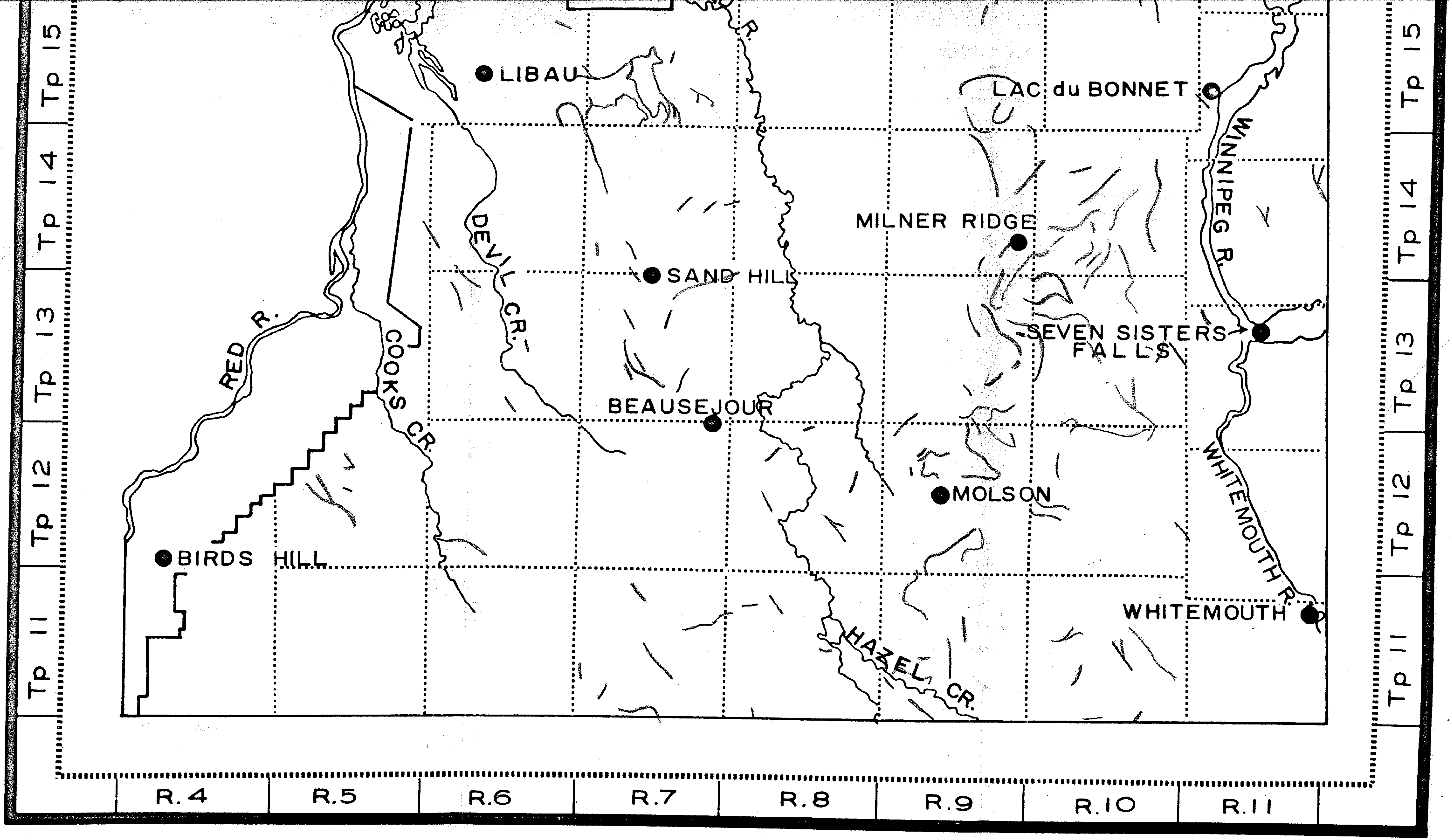


FIGURE 28. EXTENT OF LAKE AGASSIZ STRANDLINES IN THE BEAUSEJOUR AREA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RED R.
COOKS CR.
SEVEN SISTERS FALLS
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WHITEMOUTH R.
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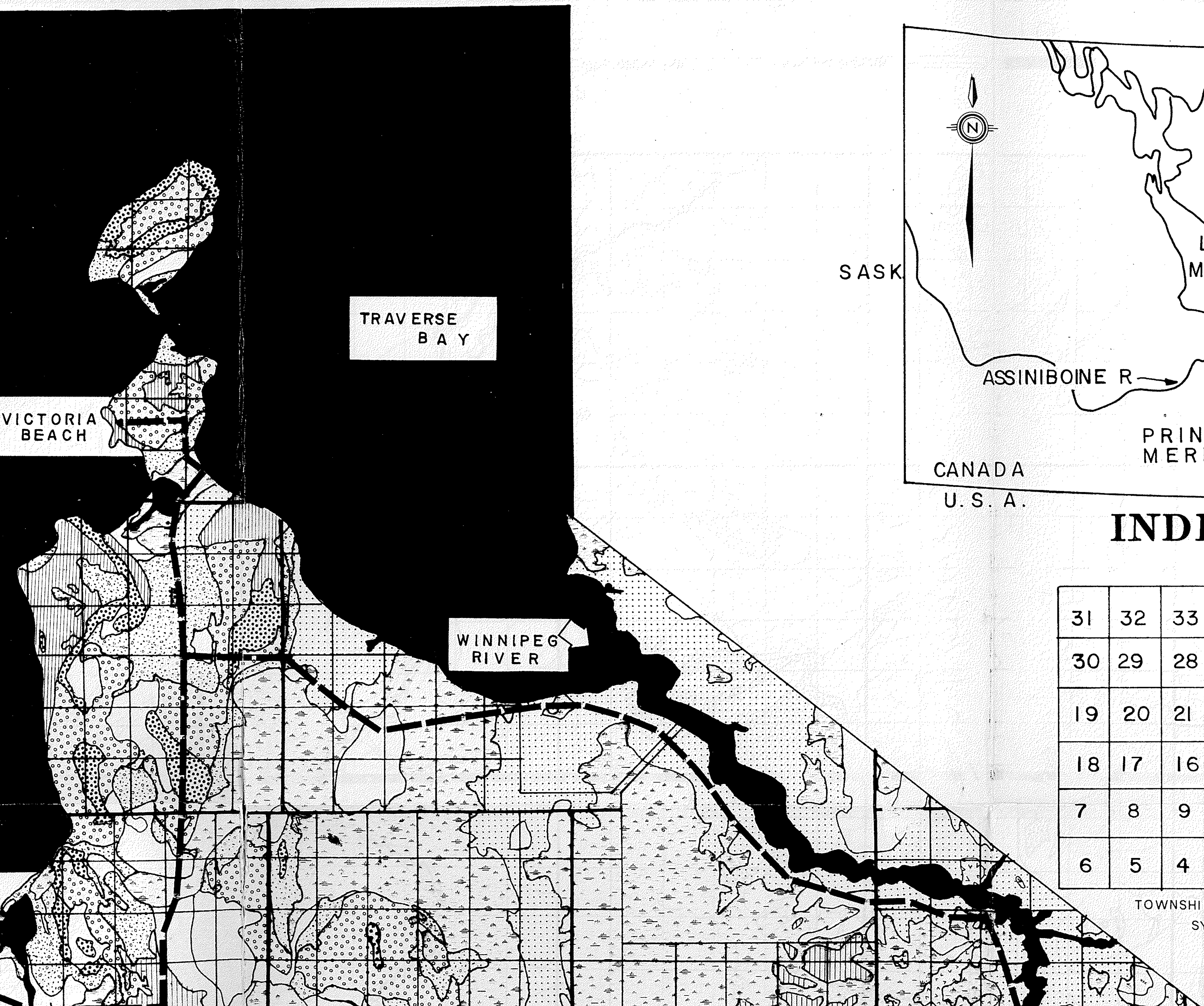
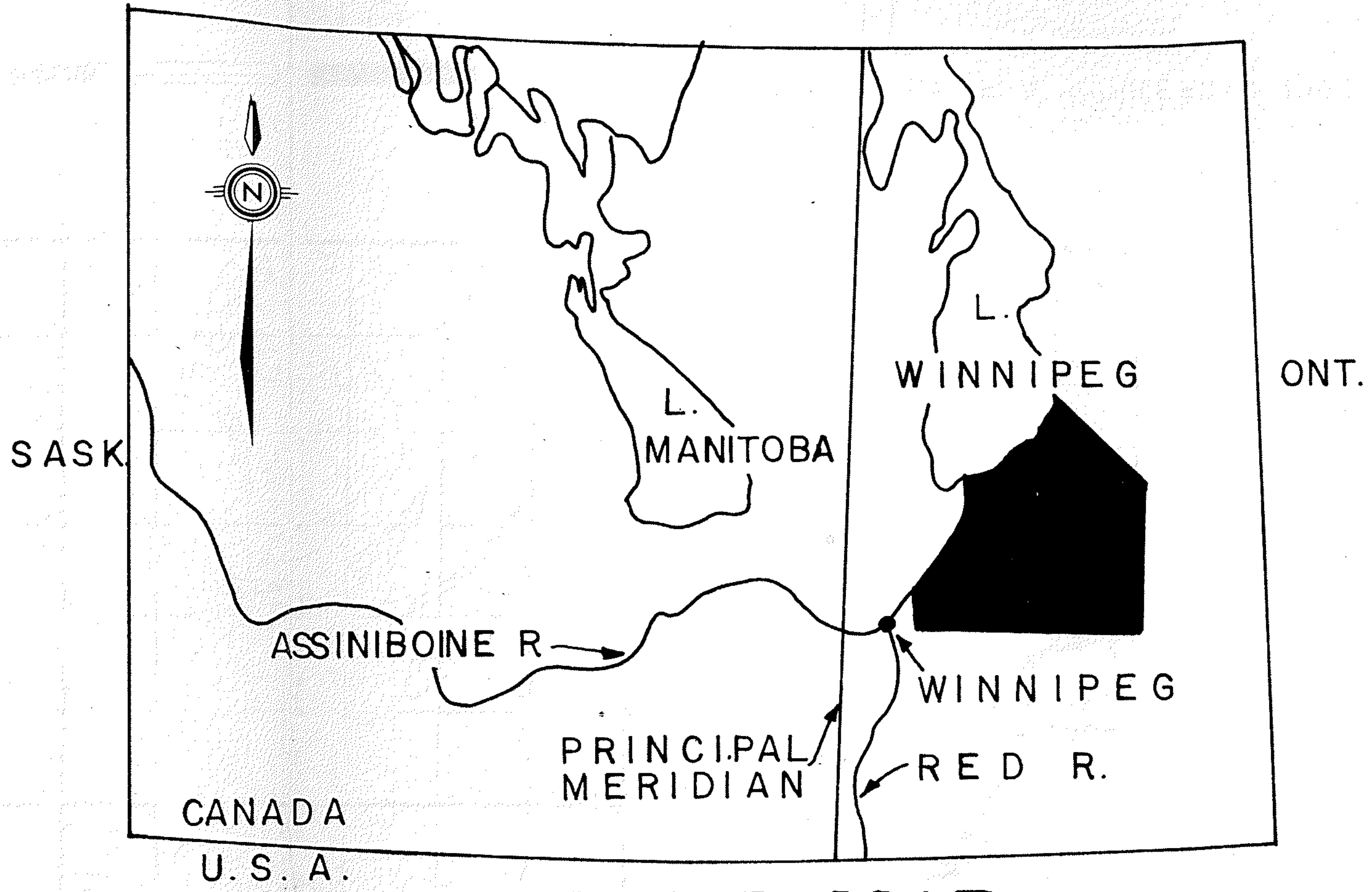


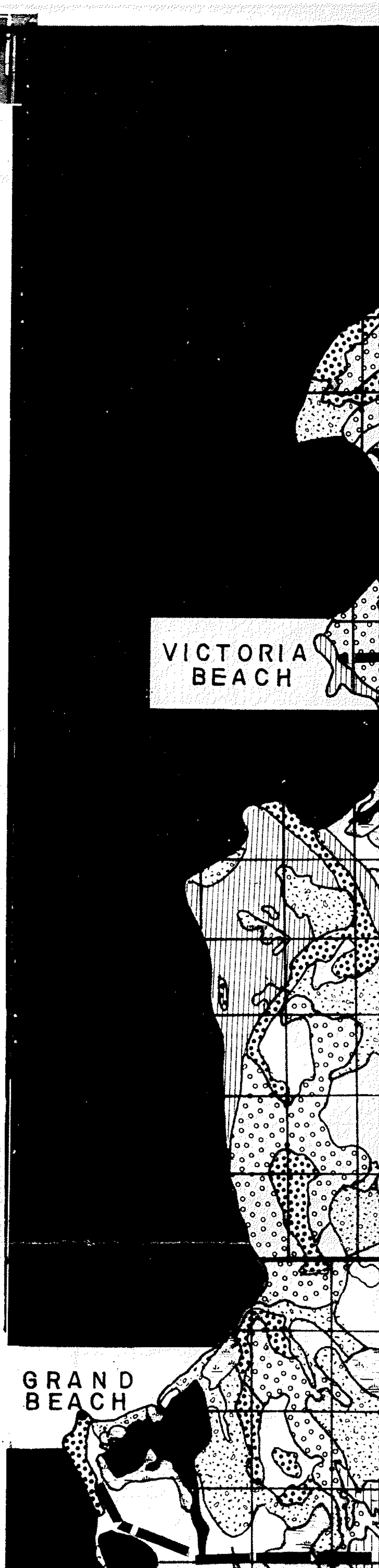


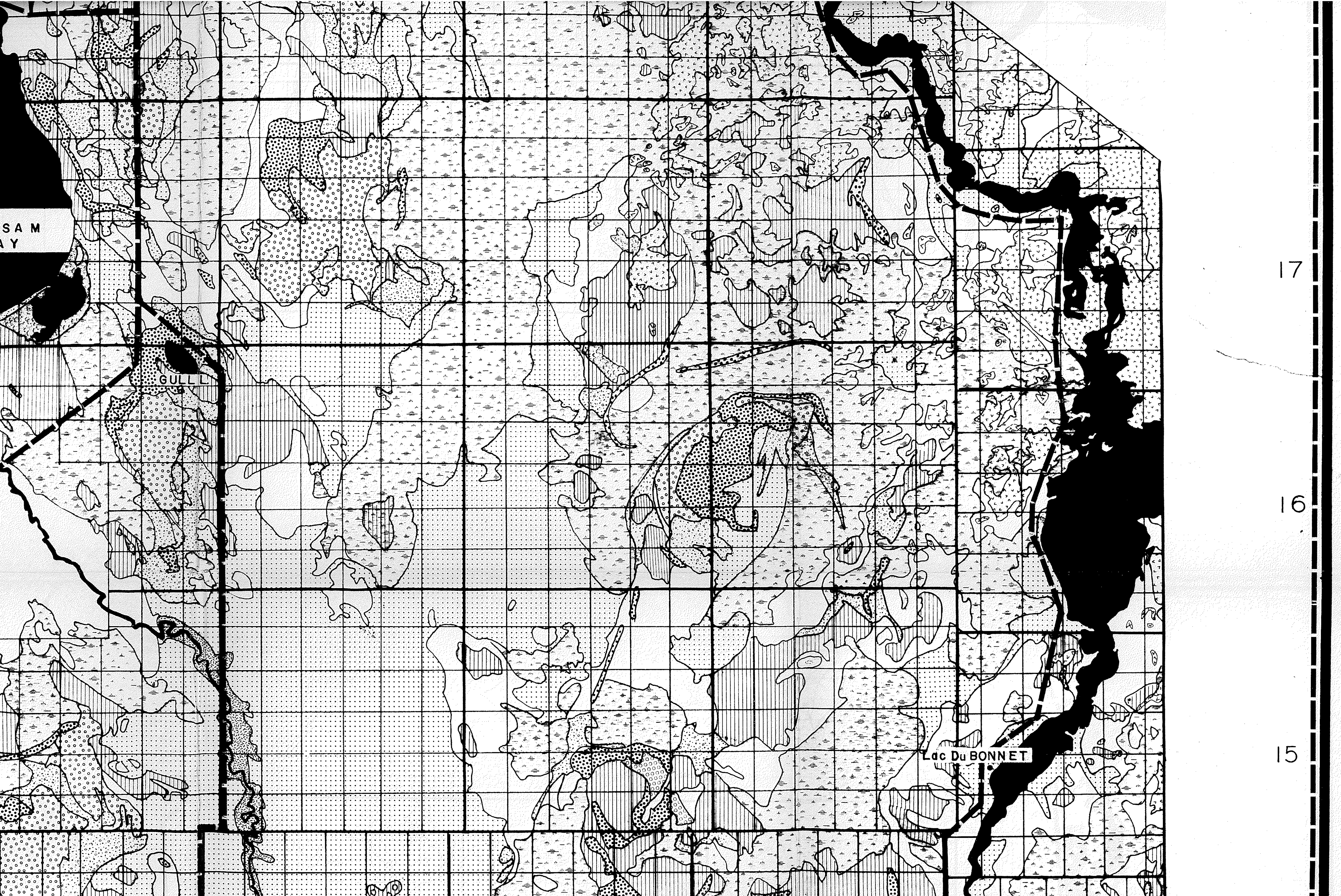
INDEX MAP

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

TOWNSHIP NUMBERING SYSTEM

	LITHOLOGY	MORPHOLOGY	INTERPRETATION
▨	Fibrous to muck sedge peat, mixed sphagnum - feathermoss peat, and sphagnum peat.	Depressed areas. Level to gentle slopes Relief < 5 feet	Peat deposits developed gradually since final retreat of the ice sheet.
▨	Stratified fine sand, silt, and clay containing layers of organic matter.	Narrow linear areas along streams, terraces and rolling topography, moderate slopes. Relief < 25 feet.	Alluvium deposited by streams since drainage of Lake Agassiz.
▨	Stratified fine sand, silt, and clay containing layers of organic matter	Estuarine swampy area, level to gentle slopes. Relief <5 feet.	Delta deposited by the Red River since drainage of Lake Agassiz.
▨	Sand and minor gravel composed of quartz grains and granitic and carbonate rock fragments.	Irregularly shaped moderately rolling areas, gentle to moderate slopes. Relief generally less than 15 feet.	Nearshore deposits of Lake Agassiz, may include minor terraces, spits, and offshore bars.
▨	Stratified sand and gravel composed mainly of granitic and carbonate rock fragments and quartz grains, local boulder concentrations.	Irregular, long narrow ridges, asymmetric to symmetrical gentle to moderate slopes. Relief 2 - 30 feet. Average 5 - 15 feet.	Lake Agassiz beach ridges and beach ridge complexes, minor spits and offshore bars.
▨	Mud and sandy silt, frequently laminated, consisting primarily of dolomite, feldspar, quartz and clay minerals.	Irregular shaped almost level to moderately rolling areas, gentle slopes. Relief < 10 feet.	Lake Agassiz mud and sandy silt units.
▨	Clay, frequently varved, primarily illite-montmorillonite with rock fragments and till balls.	Irregular shaped, almost level areas, gentle slopes. Relief < 5 feet.	Lake Agassiz clay unit
▨	Till, primarily carbonate pebbles, cobbles, and boulders in a silty matrix, frequently overlain by thin lacustrine sediments.	Swell and swale topography, preferred alignment of flutings, NW-SE., moderate slopes. Relief < 25 feet, generally 5 - 10 feet.	Ground moraine of Libau Drift modified by Lake Agassiz erosion and deposition.

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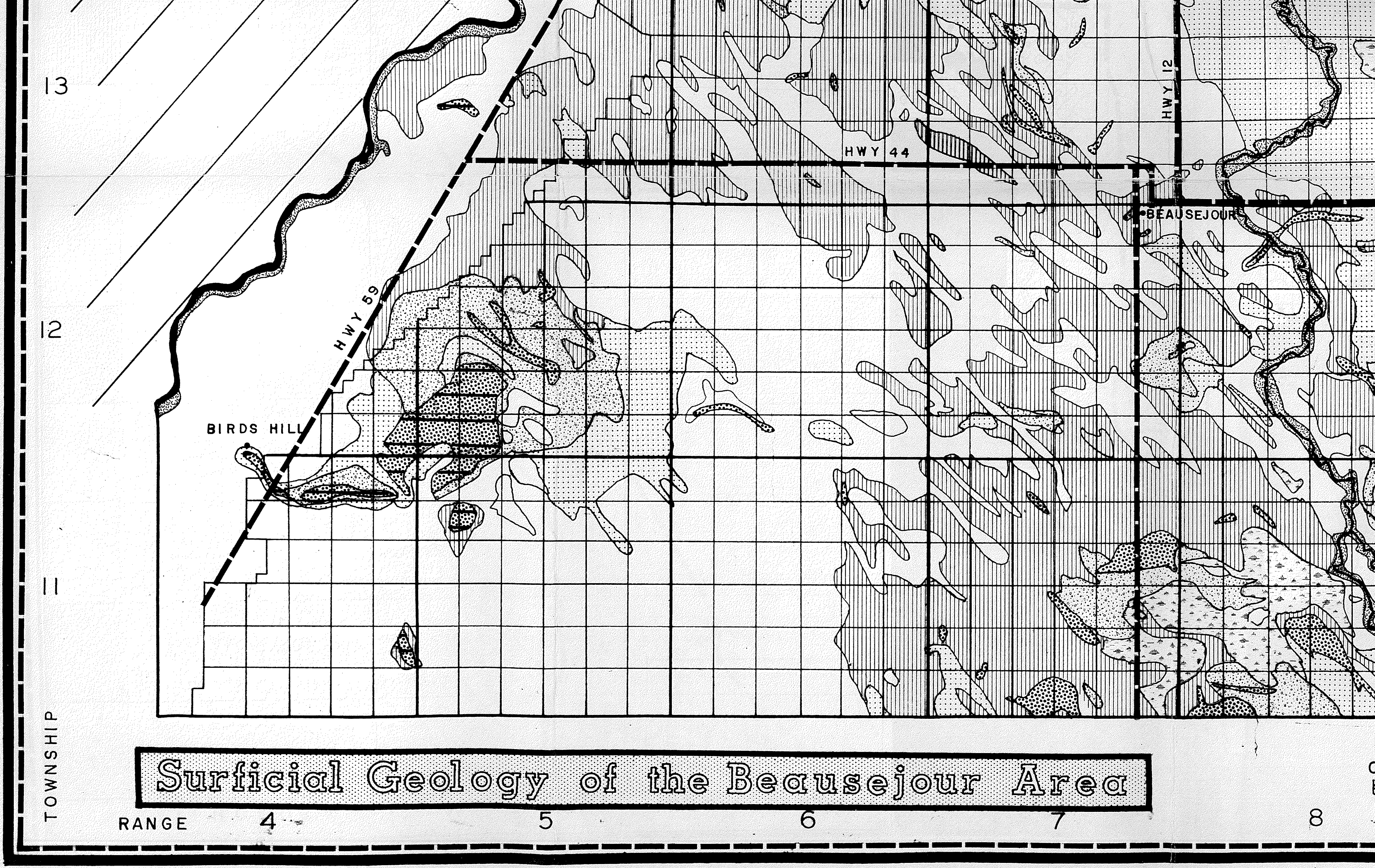
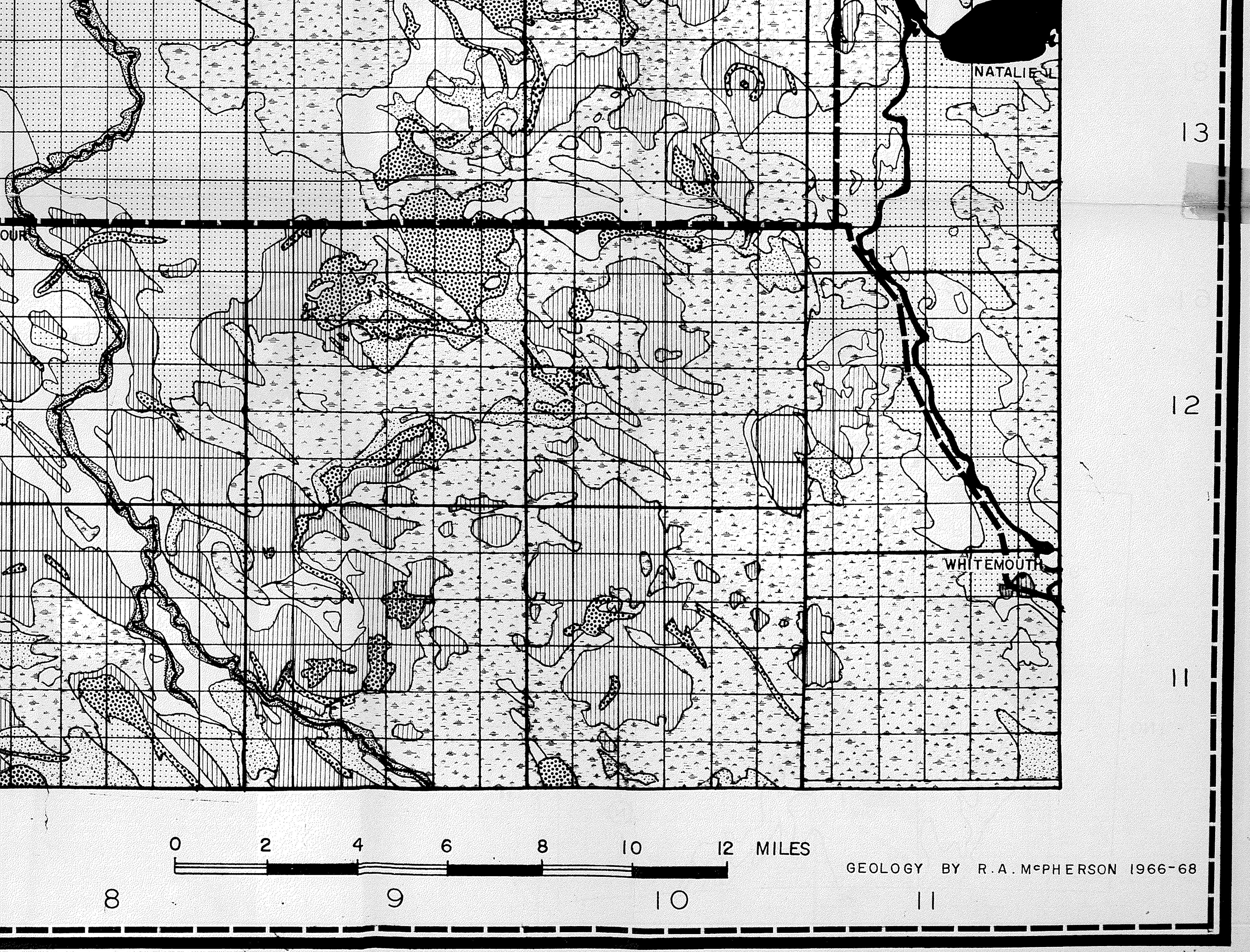
▨	Stratified sand and gravel deposits, composed primarily of carbonate rock fragments and quartz grains, frequently overlain by sand and/or till.	Irregular shaped topographic highs frequently elongate with a relief of 50 - 60 feet separated by intervening lows with a relief of < 10 feet, moderate to steep slopes.	Esker-delta complex of Libau Drift modified by Lake Agassiz erosion and deposition.
▨	Medium to fine quartz sand containing granitic, volcanic, and metasedimentary rock fragments. Contains local concentrations of granitic boulders, and lenses of till. Cross-bedding in some areas.	Irregular shaped topographic highs, moderate to steep slopes. Relief 50 - 200 feet, minor parabolic dune forms.	End moraine and outwash of Belair Drift, modified by ice re-advance and Lake Agassiz erosion and deposition and aeolian action.
▨	Granite and granitic gneiss frequently overlain by a thin cover of drift or peat deposits.	Irregular shaped outcrops, sometimes modified to asymmetric ridges by north-east ice advance, relief < 50 feet.	Precambrian bedrock modified by glaciation.



Surficial Geology of the Beausejour Area



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