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Pleistocene geology of the Grand Forks-Bemidji area, northwestern Minnesota

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PLEISTOCENE GEOLOGY OF THE GRAND FORKS-BEMIDJI AREA,

NORTHWESTERN MINNESOTA

by

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This dissertation submitted by Kenneth L. Harris in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Permission

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Department Geology

Degree Doctor of Philosophy

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ABSTRACT

This is a report of a reconnaissance study of the Quaternary geology of an area in northwestern Minnesota. Surface geology was studied in an area extending from Grand Forks, North Dakota, in the northwest to Bemidji, Minnesota, in the southeast, an area of 10 723 square kilometres (4140 square miles). Near-surface stratigraphy was studied in the area of surface study and an adjacent area of equal size to the south.

Surface materials mapped range in age from Pleistocene to Holocene and include glacial, glaciofluvial, lacustrine, bog, eolian, and alluvial sediments.

Sixteen power-auger test holes, two measured sections along the Red Lake River, two composite sections from earlier drilling programs and surface exposures were used to characterize seven near-surface lithostratigraphic units in the area. From oldest to youngest they are unnamed unit 1, unnamed unit 2, the Marcoux Formation, and the St. Hilaire Formation. These units are largely glacial sediment and pre-Wisconsinan or Early Wisconsinan in age. The Red Lake Falls Formation and the Huot Formation are largely glacial sediment and Wisconsinan and latest Wisconsinan in age. The Sherack Formation is largely lacustrine sediment and is latest Wisconsinan and Holocene in age. The lithostratigraphic units present are differentiated by means of their texture and coarse-sand lithology.

During the Pleistocene an unknown number of glaciations occurred before the deposition of the glacial sediments of the oldest lithostratigraphic unit observed, unnamed unit 1. Three pre-Wisconsinan or Early Wisconsinan glaciers deposited the glacial sediments of unnamed unit 1, unnamed unit 2, and the Marcoux Formation over the entire area. Wisconsinan glaciers advanced into the area, flowed around the Itasca Highland, and retreated twice, depositing the glacial sediment of the St. Hilaire and Red Lake Falls Formations. The late Wisconsinan and Holocene lake sediments of the Argusville, Wylie, and Sherack Formations were deposited in Lake Agassiz during the retreat of the glacier that deposited the Red Lake Falls Formation and the advance and retreat of the glacier that deposited the Huot Formation. Lake Agassiz drained at about 9500 BP.

INTRODUCTION

Purpose of Study

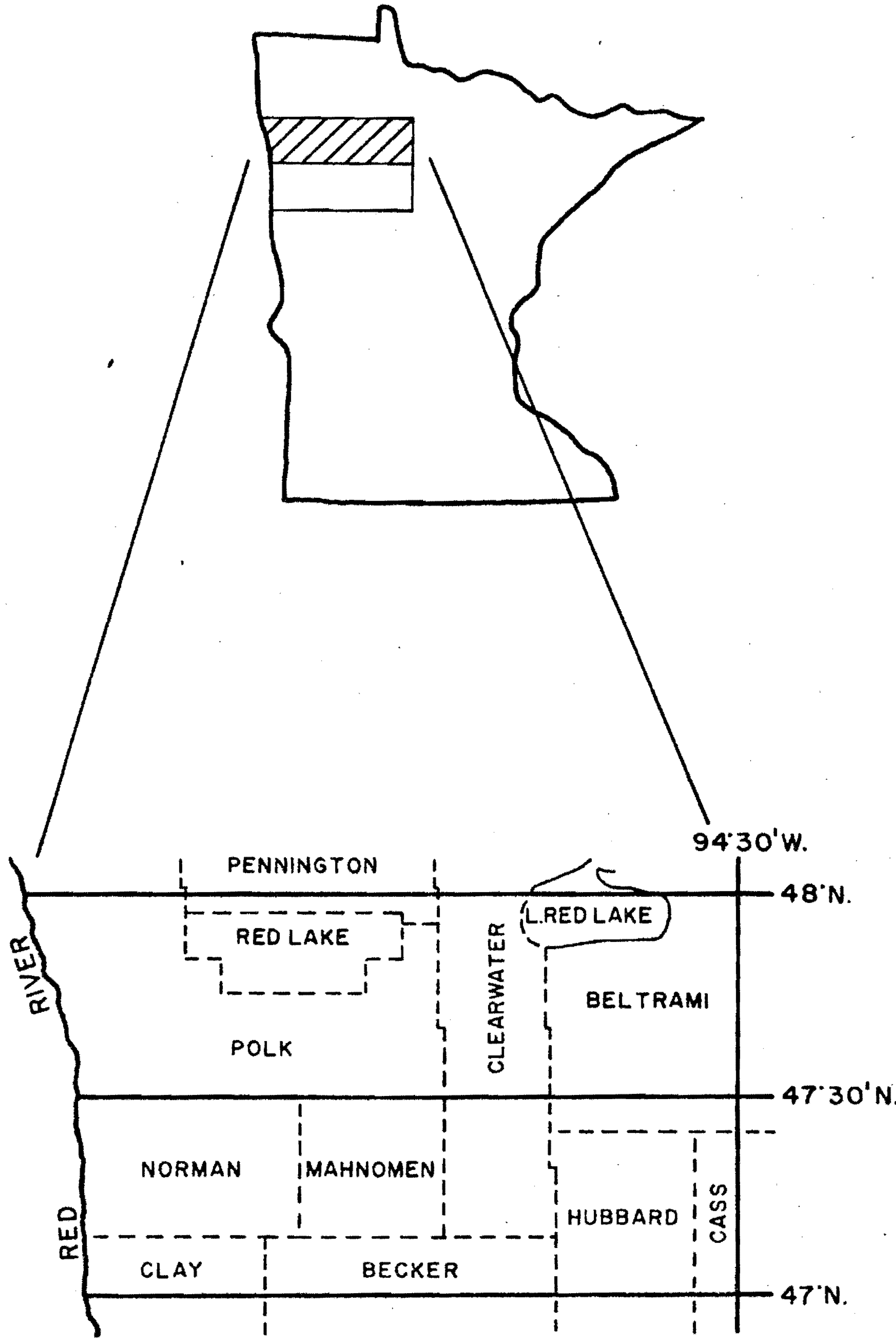
This report is a summary of a reconnaissance of the Quaternary geology of an area in northwestern Minnesota. The surface geology of the study area was mapped, and the near-surface stratigraphy was studied. The information and interpretations from this study and from other studies in adjacent parts of Minnesota, North Dakota, and Manitoba provide insight into the Pleistocene history of the Upper Midwest.

Area of Study

Two different areas are considered here: a surface study area and a subsurface study area. The Grand Forks-Bemidji area, the area of surface study, is located in northwestern Minnesota. It is bounded on the west by the Red River of the North and extends east to 94° 30' west longitude. The area is bounded on the north by 48° north latitude and extends to the south to 47° 30' north latitude (Figure 1). The area of surface study contains about 115 townships or about 10 723 square kilometres (4140 square miles). Parts of Polk, Pennington, Clearwater, and Beltrami Counties and all of Red Lake County are included in the study area.

The area of subsurface study in this report consists of the Grand Forks-Bemidji area and an adjacent area of equal size to the south. The subsurface study area is bounded on the west by the Red

Fig. 1. Location of the Grand Forks-Bemidji Area (cross-hatched) within the north half of the subsurface study area.


94°30'W.
PENNINGTON
48°N.
RED LAKE
L.RED LAKE
CLEARWATER
BELTRAMI
RIVER
POLK
47°30'N.
NORMAN
MAHNOMEN
HUBBARD
CASS
RED
CLAY
BECKER
47°N.

River of the North and extends east to 94° 30' west longitude. The subsurface study area is bounded on the north by 48° north latitutde and on the south by 47° north latitude (Figure 1).

The Grand Forks-Bemidji area contains a variety of geomorphic features. The Lake Agassiz plain and shoreline complex dominate the western and northern parts of the area. Collapsed glacial topography and outwash features are present in the central and eastern parts of the area.

The study area spans the boundaries between the prairie in the west, deciduous forest in the central part, and conifer-hardwood forest in the east.

Previous Work

Two early geologists who studied at least parts of the study area were Warren Upham and Frank Leverett. Warren Upham did reconnaissance geologic mapping of Minnesota from 1872 to 1895. He and H. H. Winchell, the first Minnesota State Geologist, published papers that dealt mainly with descriptions and interpretations of local landforms (Wright, 1972). Upham's major contribution to the understanding of the Pleistocene history of the region was his study of glacial Lake Agassiz (Upham, 1896).

Frank Leverett, a United States Geological Survey geologist, worked in Minnesota during the period from 1906 to 1912. Leverett's surficial maps of Minnesota are still the only surficial maps of the entire state (Leverett, 1915; Leverett and Sardeson, 1917; Leverett and Sardeson, 1919). Leverett summarized his work in a United States

Geological Survey professional paper, Quaternary geology of Minnesota and parts of adjacent states (Leverett, 1932).

A 1933 publication by C. C. Nikiforoff, a United States Department of Agriculture pedologist, produced reconnaissance soil maps of all the western Minnesota counties adjacent to the Red River of the North. Nikiforoff's soil maps accurately detail shoreline complexes of Lake Agassiz. Nikiforoff's contribution to an understanding of regional Pleistocene history was his alternate interpretation of the history of Lake Agassiz (Nikiforoff, 1947).

The glacial history of Minnesota has been summarized by H. E. Wright, Jr., in The Quaternary of the United States (Wright and Ruhe, 1965). A more recent summary in The Geology of Minnesota (Wright, 1972) uses a detailed stratigraphic study in southwestern Minnesota by Charles L. Matsch (1971).

Several stratigraphic studies of Pleistocene sediments have been conducted in the region. Mark M. Fenton has developed a stratigraphic framework for Quaternary sediments in southeastern Manitoba (Fenton, 1974). Similar studies have been done in northeastern North Dakota (Salomon, in press), the Red Lake River area of Minnesota (Harris, 1973), and the Red River Valley of North Dakota and Minnesota (Harris and others, 1974).

Concurrent with this study similar studies are being conducted by Donald K. Sackreiter (in preparation) in the south half of the subsurface study area, and Howard C. Hobbs (in preparation), in northeastern North Dakota. A detailed study of the stratigraphy of Lake Agassiz sediments is being conducted by B. Michael Arndt (in preparation).

Field Methods

Surface geology

Mapping of the surface geology began in the spring of 1973 and was completed by the fall of 1974. County highway maps, scale 1:126 720 (1 inch : 2 miles), from the Minnesota Department of Highways were used as base maps for the field study. Base maps for the preliminary and final versions of the surficials maps were United States Geological Survey 1° by 2° topographic maps, scale 1;250 000 (1 inch : 3.95 miles).

Stereoscopic aerial photographs were used to produce field maps of the study area. For the western half of the Grand Forks-Bemidji area Army Map Service aerial photographs, scale 1:58 940 (1 inch : 0.93 miles), flown in August 1952, were used. For the eastern half of the area aerial photographs from Mark Hurd Aerial Surveys, Inc., scale 1:86 400 (1 inch : 1.36 miles), flown in April 1969, were used. Soil maps were used where available to aid in lithologic interpretations of aerial photographs (Nikiforoff, 1933).

Field maps were field checked by driving most of the passable roads in the study area. Lithologic information was gathered by sampling surface exposures or by the use of a hand auger in areas of poor exposures.

A preliminary map was compiled at the final scale (1:250 000), and problem areas were again field checked.

Subsurface geology

Subsurface data used in this study were in part gathered in connection with a detailed study of the Pleistocene stratigraphy exposed along the Red Lake River, Minnesota (Harris, 1973). In addition to the measured sections in river cutbanks, five shallow power-auger test holes, as much as 24 metres (80 feet) deep, were drilled in 1971. These data were supplemented by six deep power-auger test holes, as much as 46 metres (150 feet) deep, and six shallow power-auger test holes in 1973 and 1974.

The field procedure used in all test drilling included the on-site description and collection of samples from power-auger cuttings. In general either a 1 metre (3 foot) or a 1.5 metre (5 foot) sample interval was used.

Laboratory Methods

Textural data

All surface and subsurface samples were analyzed for content of sand (2 mm to 1/16 mm), silt (1/16 mm to 1/256 mm), and clay (less than 1/256 mm). Textural analysis was conducted in the North Dakota Geological Survey sediment laboratory. Results were compiled, and means and standard deviations were calculated for each lithostratigraphic unit present in the study area. Tabulation of the results of the textural analysis for surface data is in Appendix I. Tabulation of the results of the textural analysis for subsurface data is in Appendix II.

Coarse-sand lithology

All surface and subsurface samples were analyzed for content of crystalline- and metamorphic-rock types, carbonate-rock types, and shale rock fragments in the coarse-sand (1 mm to 2 mm) fraction. The coarse-sand fraction was separated from the samples during textural analysis.

The proportion of each lithologic group was determined by studying individual sample fractions under a binocular microscope. Other material present in minor amounts in the coarse-sand fraction included lignite, wood, shell fragments, chert, sandstone, secondary carbonates, iron oxides, gypsum, and pyrite. The coarse-sand fractions counted ranged from 100 to 1500 grains but averaged about 400 grains. Tabulation of the results of coarse-sand lithology analysis for surface data is in Appendix I. Tabulation of the results of the coarse-sand lithology analysis for subsurface data is in Appendix II.

SURFACE GEOLOGY

Surface Map

The surface geology of the study area is presented on the map "Surficial sediments of the Grand Forks-Bemidji Area," (Plate 1). This map is a lithologic and genetic map of the surface sediments in the study area at a reconnaissance scale (1:250 000). The map units are descriptive lithologic units that are genetically interpreted in the legend.

Lithologic map units

Eight lithologic map units were used on the map. These include silt and clay; sand, silt, and clay; sand; sand and gravel; pebble-loam; sand overlying pebble-loam; peat overlying pebble-loam; and peat. These map units were chosen because they best describe the range of sediments encountered in the area mapped. Lithologic units less than 0.6 square kilometres (0.25 square miles) in area were not mapped. In general a minimum thickness of 1 metre (3 feet) was used as a mapping cutoff for these map units.

Silt and clay

This map unit indicates the location of material ranging from silty clay to clayey silt. The silt and clay contains little or no organic debris and is weakly to strongly laminated. This map unit is the dominant unit in the western part of the map. The silt and clay is interpreted to be offshore lake sediment deposited in the Lake Agassiz basin.

Sand, silt, and clay

The map unit indicates the location of variable amounts of interbedded sand, silt, and clay, and organic debris. It is generally poorly to moderately laminated. The sand, silt, and clay was deposited as fluvial overbank sediment in modern floodplains.

Sand

This map unit indicates the location of material that is mainly medium- to coarse-grained sand. The sand contains little or no organic debris and is variably bedded. In the western and northern parts of the study area, the sand is mostly of lacustrine origin and is associated with the Lake Agassiz shoreline complex. In the southern and eastern parts of the study area, the sand is mostly fluvial meltwater deposits. Small patches of eolian sand are present in the Fertile, Minnesota, area.

Sand and gravel

This map unit indicates the location of material ranging from sandy gravel to gravelly sand. It is variably bedded and sorted, and contains little or no organic debris. In the western and northern parts of the study area the sand and gravel is moderately to well sorted and is found in curved ridges associated with the Lake Agassiz shoreline complex. In the central and eastern parts of the study area the sand and gravel is generally poorly sorted and interpreted to be esker complexes and other outwash deposits.

Pebble-loam

This map unit indicates the location of a mixture of sand, silt, clay, pebbles, cobbles, and boulders in varying proportions. Pebble-loam is unbedded and unsorted. Pebble-loam is present in the south-central and northeastern parts of the study area. Here the topography ranges from undulating to hummocky due to the collapse of the glacial sediment. Pebble-loam is also present in the north-central part of the area where the topography is flat to undulating. Here the topography has been modified by the action of the waters of Lake Agassiz.

Sand over pebble-loam

This map unit indicates the location of variable amounts of sand overlying pebble-loam. The overlying sand is as much as a metre (3 feet) thick and covers more than one half of the surface area of the map unit. Sand overlying pebble-loam is present mainly in the western and north-central parts of the study area. Its occurrence is generally restricted to the shoreline complex of Lake Agassiz.

Peat over pebble-loam

This map unit indicates the location of variable amounts of peat overlying pebble-loam. The overlying peat is as much as a metre (3 feet) thick and covers more than one half of the surface area of the map unit. Peat overlying pebble-loam is presently mainly in the poorly drained lowlands in the north-central part of the study area.

Peat

This map unit indicates the location of dark brown or black partially decomposed and disintegrated organic material. Peat is deposited in shallow stagnant bogs and marshes. Accumulations of peat are found in poorly drained areas throughout the study area. They are most commonly found in the northern one-third and eastern one-half of the study area.

Genetic map units

Seven genetic map units are used on the surface map to indicate the interpreted origin of the descriptive map units. These units represent the results of the action of four geologic processes: glacial, fluvial, lacustrine, and eolian.

Alluvial sediment

This map unit indicates the location of interbedded sand, silt, clay and organic debris deposited as fluvial overbank sediment in modern floodplains. Alluvial sediment is poorly to moderately laminated.

Eolian sediment

This map unit indicates the location of wind-blown deposits of fine-grained sand. Areas of eolian deposits commonly contain stabilized dunes with some active blowouts.

Bog sediment

This map unit indicates the location of highly organic deposits accumulated in the shallow bogs and marshes common in poorly drained areas.

Lacustrine shoreline sediment

This map unit indicates the location of nearshore sediments and shoreline sediments. The topography of the lacustrine shoreline sediment is generally flat but includes curved ridges. The generally flat areas contain sand and gravel or sand overlying pebble-loam. The sediments are variably bedded and are moderately to well sorted. The curved ridges contain sand and gravel. They are variably bedded and are moderately to well sorted.

Lacustrine offshore sediment

This map unit indicates the location of lacustrine sediment deposited in an offshore environment. The resulting topography has very low relief. The sediment deposited in this environment is moderately to strongly laminated silty clay and clayey silt.

Glaciofluvial sediment

This map unit indicates the location of fluvial bedload sediment deposited by glacial meltwater in or near glacial ice. The glaciofluvial sediment includes eskers, collapsed esker complexes, outwash plains, and other meltwater deposits. Glaciofluvial sediment is largely sandy gravel or gravelly sand. It is variably bedded and variably sorted.

Glacial sediment

This map unit indicates the location of sediment deposited by glacial ice. The sediment was deposited directly by active glacial ice or by the melting of stagnant ice. The resulting topography is flat, undulating, rolling, or hummocky. The glacial sediment consists of pebble-loam with small amounts of sand and gravel.

Geomorphology

A variety of geomorphic features is present in the Grand Forks-Bemidji area. The study area is divided into four main provinces based on the occurrence of these features (Figure 2). The Lake-Plain Province dominates the western edge of the study area. The Shoreline-Complex Province is present in the western area and dominates the northern part of the study area. The Glacial-Upland Province dominates the south-central and southeastern parts of the study area. The Outwash Province is present in the southeastern part of the study area.

The Lake-Plain Province

The Lake-Plain Province is a low-relief plain. It is largely underlain by laminated silt and clay deposits in the Lake Agassiz basin (Figure 2). Geomorphological features in the province are subtle and best seen on aerial photographs. The most striking feature in the Lake-Plain Province is the flat lake plain itself. Other geomorphological features present have an average relief of about a metre. Some of the other features present include compaction ridges, intersecting lineations, and stream channels.

A compaction ridge may be seen in the Beltrami area of Polk County (Figure 3). The discontinuous ridge follows a sinuous course from southeast to northwest and is as much as 2 metres (7 feet) higher than the surrounding lake plain. The ridge is thought to be cored by bedload sediments of an ancestral Sand Hill River. These sediments were deposited before Lake Agassiz flooded for the last time. A veneer of lake sediment covers most of the ridge.

Fig. 2. Geomorphologic provinces of the Grand Forks-Bemidji Area.

1. Lake-Plain Province
2. Shoreline-Complex Province
3. Glacial-Upland Province
4. Outwash Province

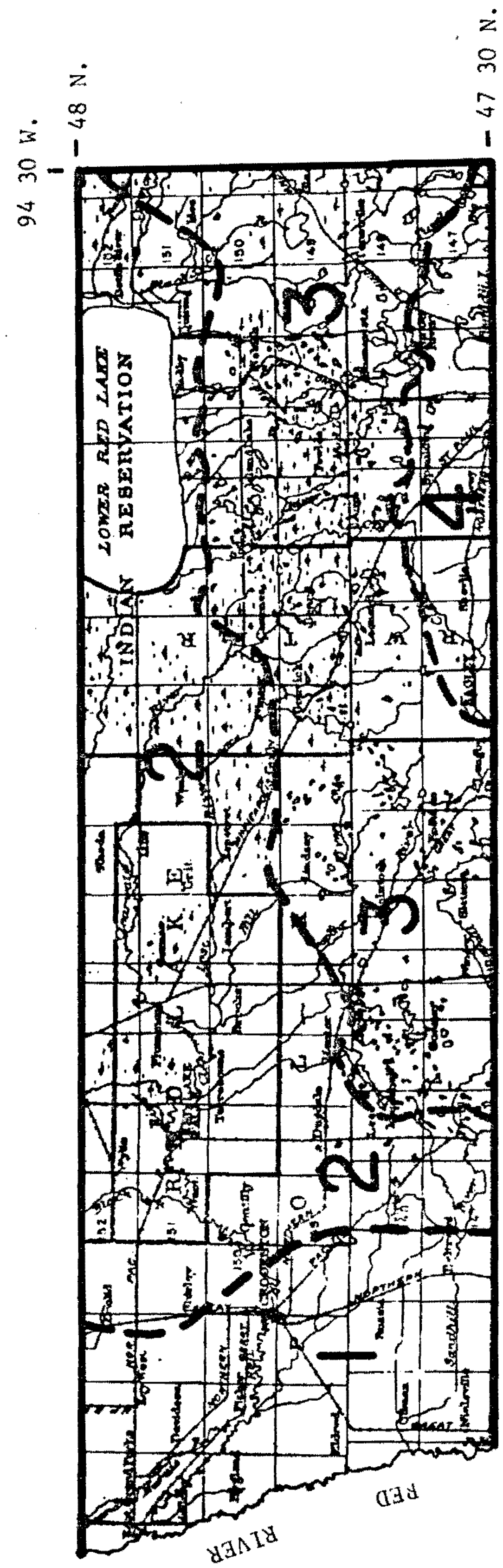
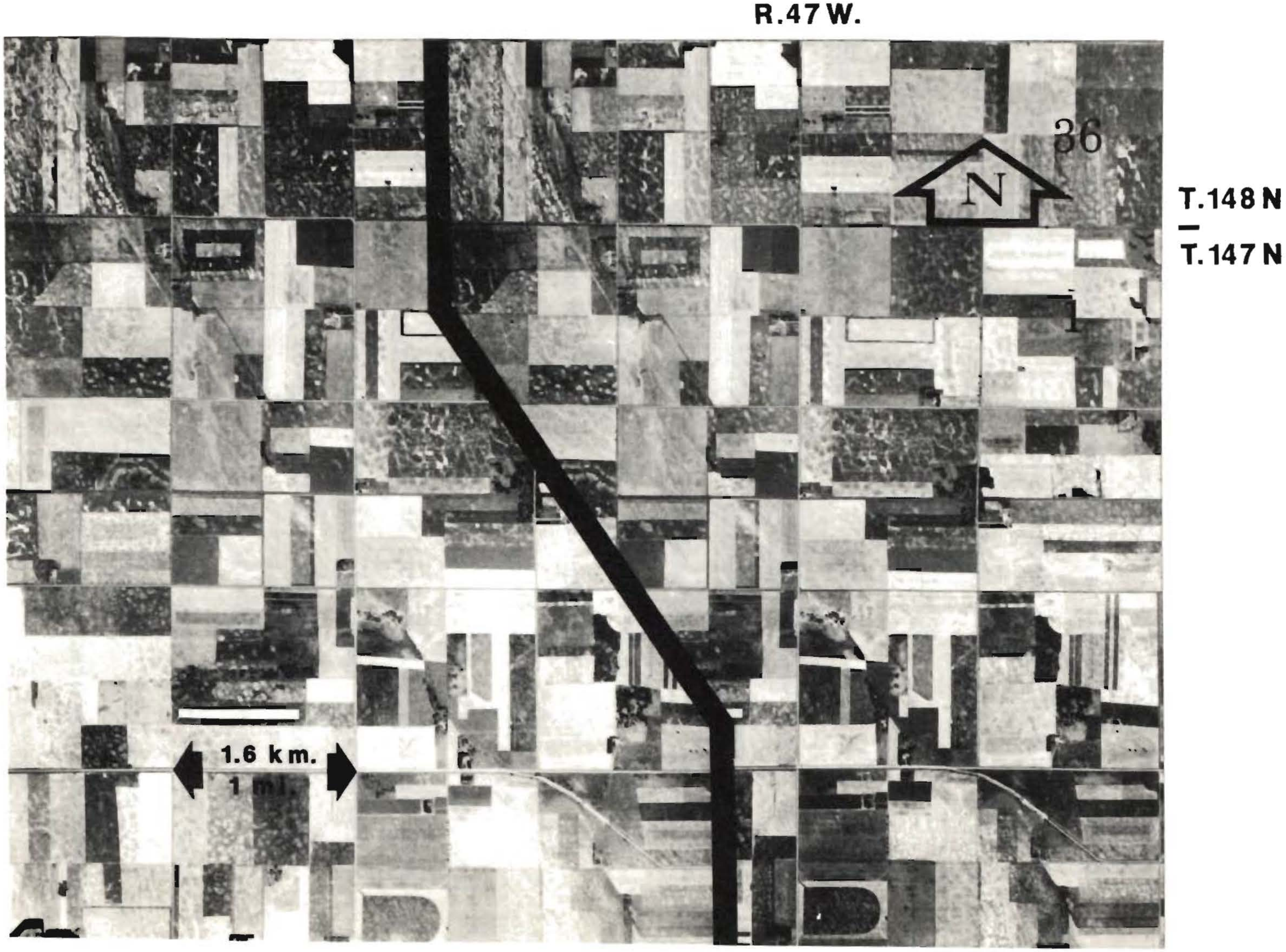

94 30 W.
48 N.
47 30 N.
LOWER RED LAKE
INDIAN RESERVATION
RED
RIVER

Fig. 3. Beltrami compaction ridge, Lake-Plain Province.


R.47 W.
36
N
1
T.148 N.
T.147 N.
1.6 km.
1 mi.

Intersecting lineations are commonly seen on the flat surface of the Lake-Plain Province. These lineations are low-relief ridges and grooves. Usually the lineations cannot be seen on the ground but are easily seen on aerial photographs (Figure 4). The lineations show a preferred northwest-southeast orientation. The intersecting lineations have been discussed by several authors since they were first observed by Horberg (1951). The most probable hypothesis is that the lineations are drag marks formed by floating lake ice during a shallow stage of Lake Agassiz (Clayton and others, 1965).

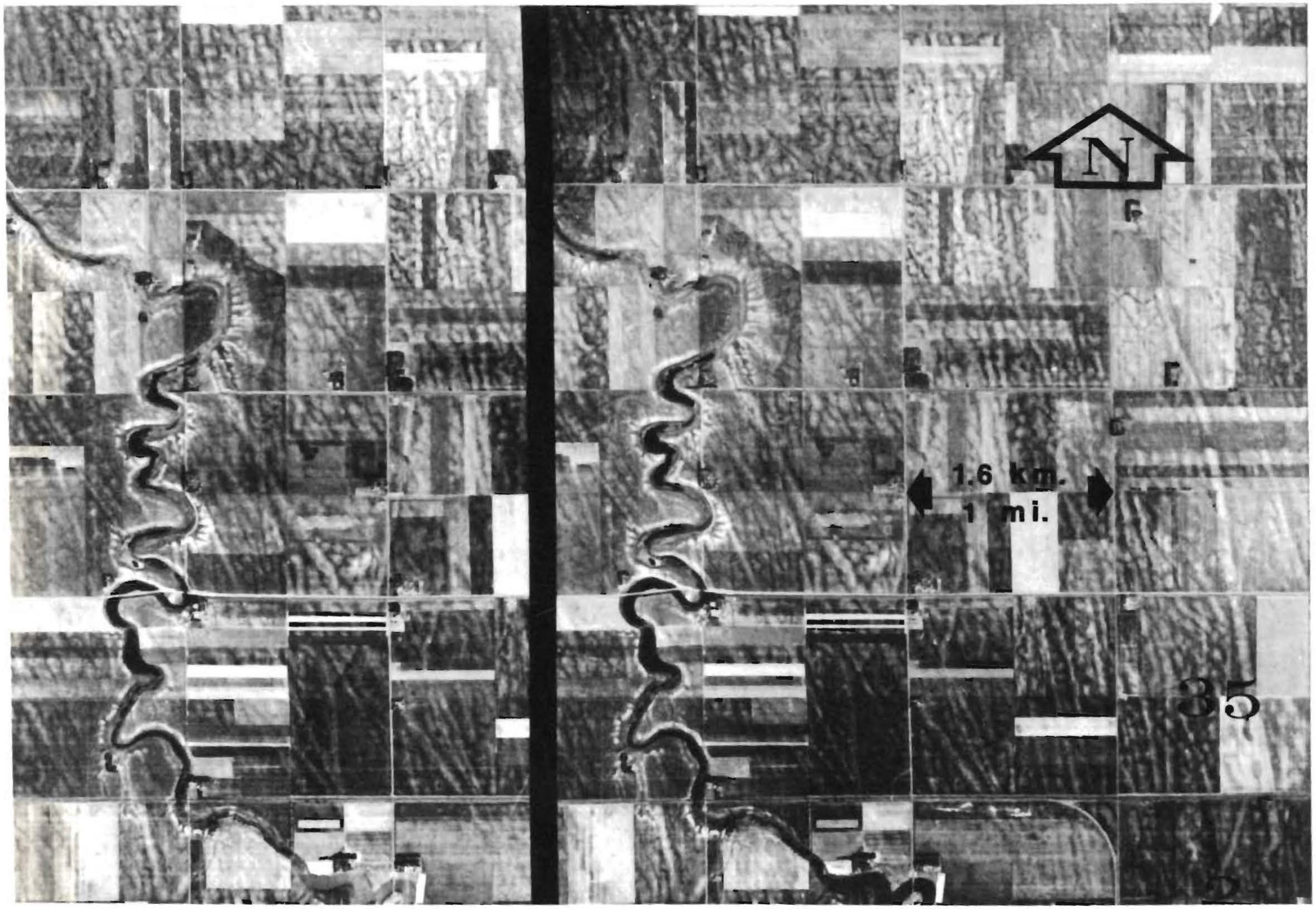
The Shoreline-Complex Province

The Shoreline-Complex Province (Figure 2) is a gently rolling to flat surface that has been shaped by lacustrine beach and nearbeach processes. The main geomorphologic features present in this province are beach ridges and wave-cut scarps. Other features include sand spits, peat bogs, lake basins, and river trenches.

The dominant features in the province are beach ridges (Figure 5). These features are curved ridges that rise as much as 5 metres (16 feet) above the surrounding land surface. The sediment in the ridges is moderately to well sorted sand and gravel. It is ripple cross-bedded to flat bedded. The beach ridges were formed at the margin of the glacial Lake Agassiz. The generally flat areas surrounding the beach ridges are composed of sand, sand overlying glacial sediment, and glacial sediment. The action of waves has reduced the relief on the glacial sediment exposed in the area, and a residual layer of stones on the surface is common.

Fig. 4. Intersecting lineations, Lake-Plain Province.

R.49 W.



T.152 N.
—
T.151 N.

Fig. 5. Beach ridges, Shoreline-Complex Province.

R.44 W.

T.149 N.

T.148 N.

Wave-cut scarps are present in the Shoreline-Complex Province. The most prominent and persistent wave-cut scarp is the Campbell scarp (Figure 6). This scarp trends from north to south through the province and for most of its length is cut into glacial sediment. The Campbell scarp marked the shoreline of Lake Agassiz at the Campbell level. The Herman scarp, another prominent scarp, marks the boundary between the Shoreline-Complex Province and the Glacial-Upland Province. It is best developed in the north-central and northeastern parts of the study area, where it is as much as 30 metres (100 feet) high. The Herman scarp marked the shoreline of Lake Agassiz at the Herman level.

The Glacial-Upland Province

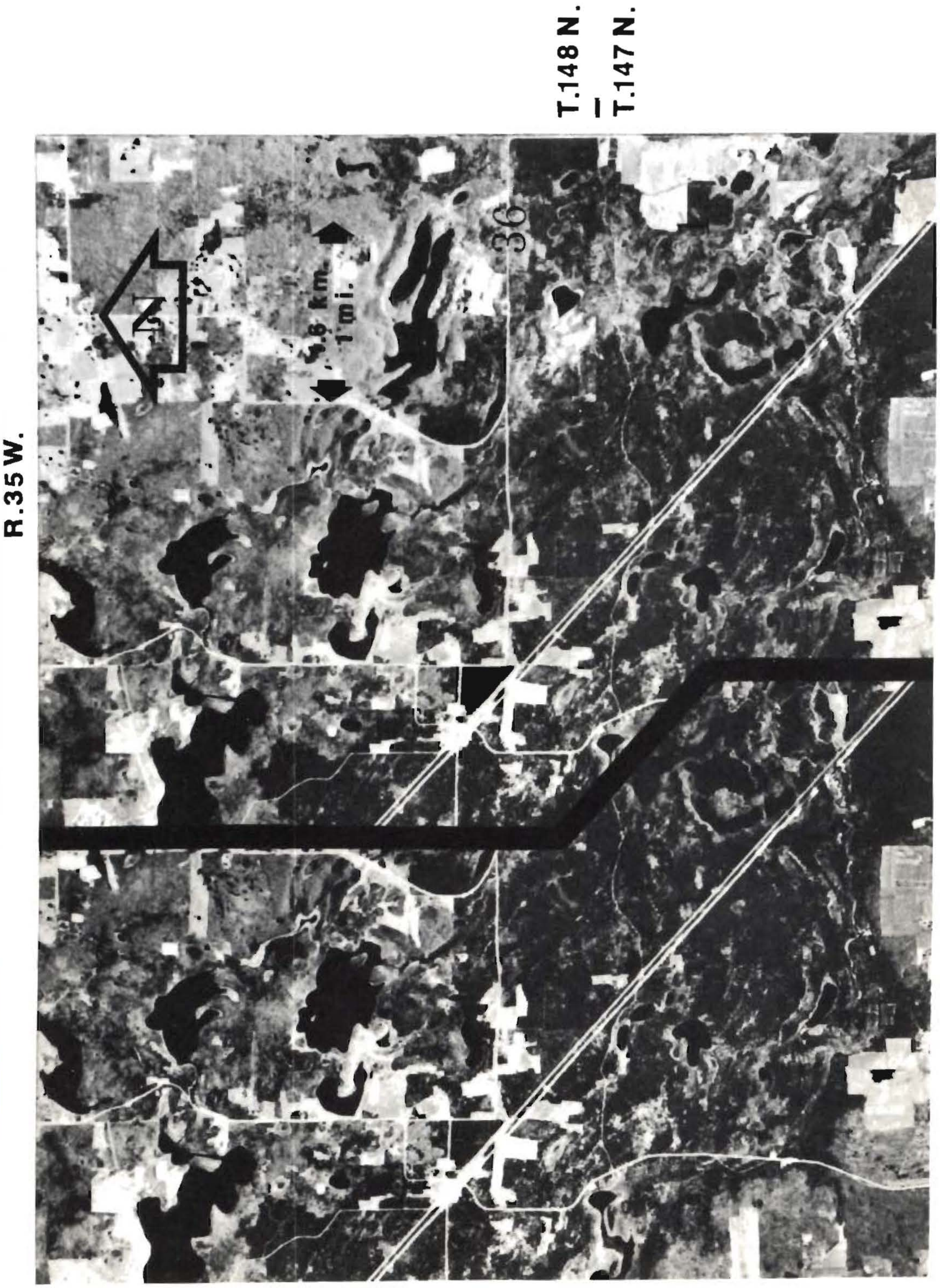
The Glacial-Upland Province is the largest province in the study area (Figure 2). It is an undulating to hummocky surface of collapsed glacial sediment. A variety of geomorphic features are present in the province. They include eskers, esker complex, meltwater channels, hummocky glacial sediment, lake basins, and scarps marking glacial-sediment margins.

Eskers and esker complexes are the most striking features in the Glacial-Upland Province (Figure 7). They are sinuous, discontinuous ridges and complexes of ridges. The sediment in the ridges is generally poorly sorted and variably bedded sand and gravel. The sediment contains flat-bedded units and both large- and small-scale cross-bedded units. These ridges consist of fluvial bedload sediment deposited by meltwater streams that flowed in or on the glacial ice. Esker complexes are scroll-like aggregates of eskers as much as 8 kilometres (5 miles) wide. Eskers and esker complexes are variably overlain by collapsed glacial sediment.

Fig. 6. Campbell scarp, Shoreline-Complex Province.


R.45 W. | R.44 W.
N
33
4
1.6 km
1 mi.
T.151 N.
T.150 N.

Fig. 7. Eskers and esker complex, Glacial-Upland Province. Photography by Mark Hurd Aerial Surveys.


R.35 W.
T.148 N.
T.147 N.
N
.6 km.
1 mi.
36

Meltwater channels are common throughout the province. They are usually associated with the discontinuous course of eskers and esker complexes. Most meltwater channels have been overridden and thus are poorly defined.

The most obvious meltwater channel in the province is the McIntosh Channel. It trends south and west from Trail to Fertile in Polk County (Figure 8). This channel averages about 1.6 kilometres (1 mile) wide over its 60 kilometre (36 mile) length. The average depth of the channel is about 10 metres (33 feet). The history and origin of the McIntosh Channel are discussed in detail by Moran and Clayton (in preparation). Moran and Clayton suggest that the channel was formed by glacial meltwater flowing north into Lake Koochiching, an early lake in the Agassiz basin. Later the channel drained meltwater south from Lake Koochiching into Lake Climax, another early lake in the Agassiz basin.

A discontinuous, generally obscure scarp marks the glacial-sediment margin at the boundary between the Glacial-Upland Province and the adjacent Outwash Province. A well developed section of this scarp is located about 8 kilometres (5 miles) northwest of Bagley in Clearwater County (Figure 9). The glacial sediment to the north of the scarp stands 15 metres (50 feet) above the adjacent outwash to the south. An esker complex trends southward toward the margin of the glacial sediment. At the glacial-sediment margin the esker complex was drained by a meltwater channel in the outwash sediment.

The relationship of the glacial-sediment margin to the areal distribution of lithostratigraphic units will be discussed in the stratigraphic interpretations section.

Fig. 8. McIntosh Channel, Glacial-Upland Province. Photography by Mark Hurd Aerial Surveys.

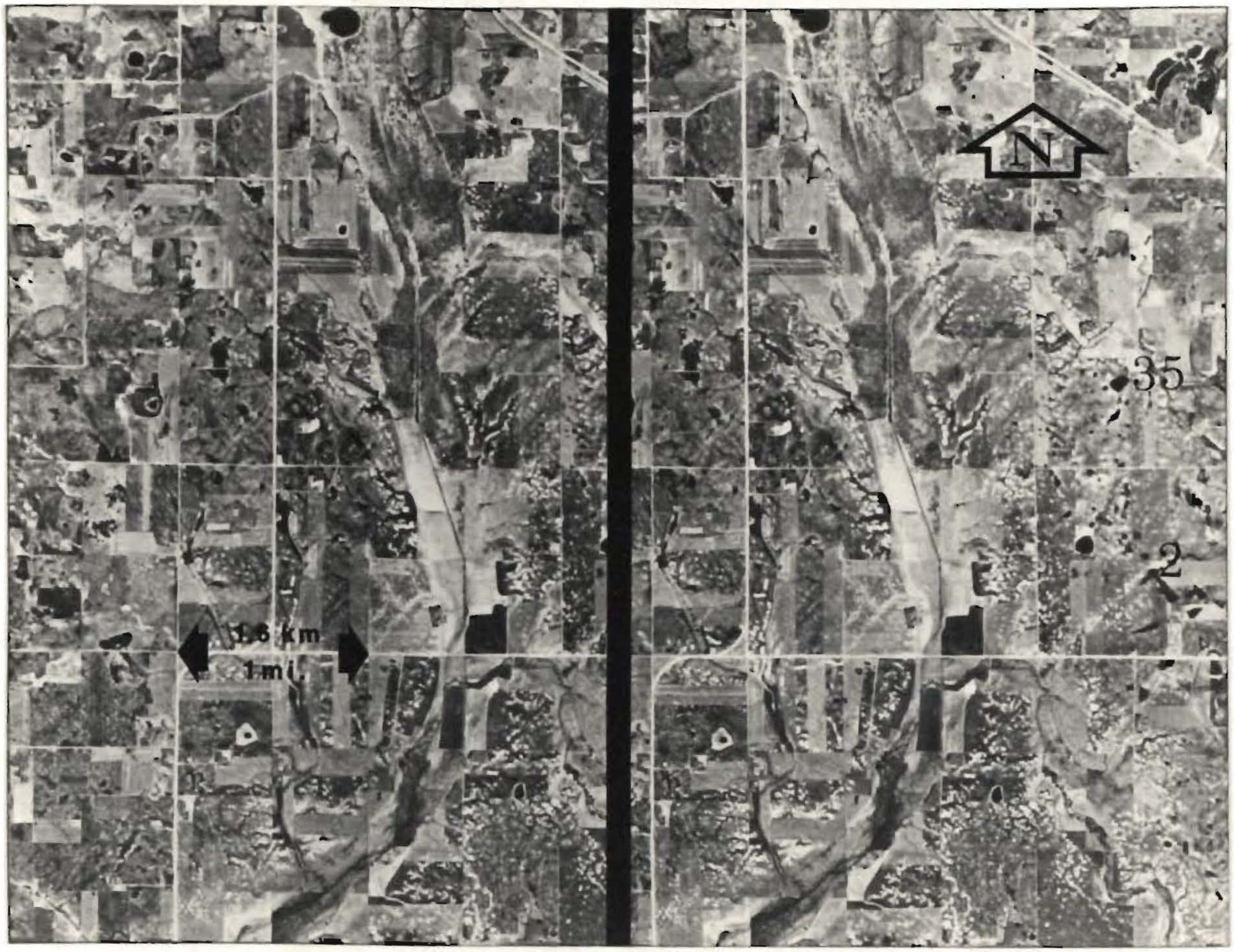
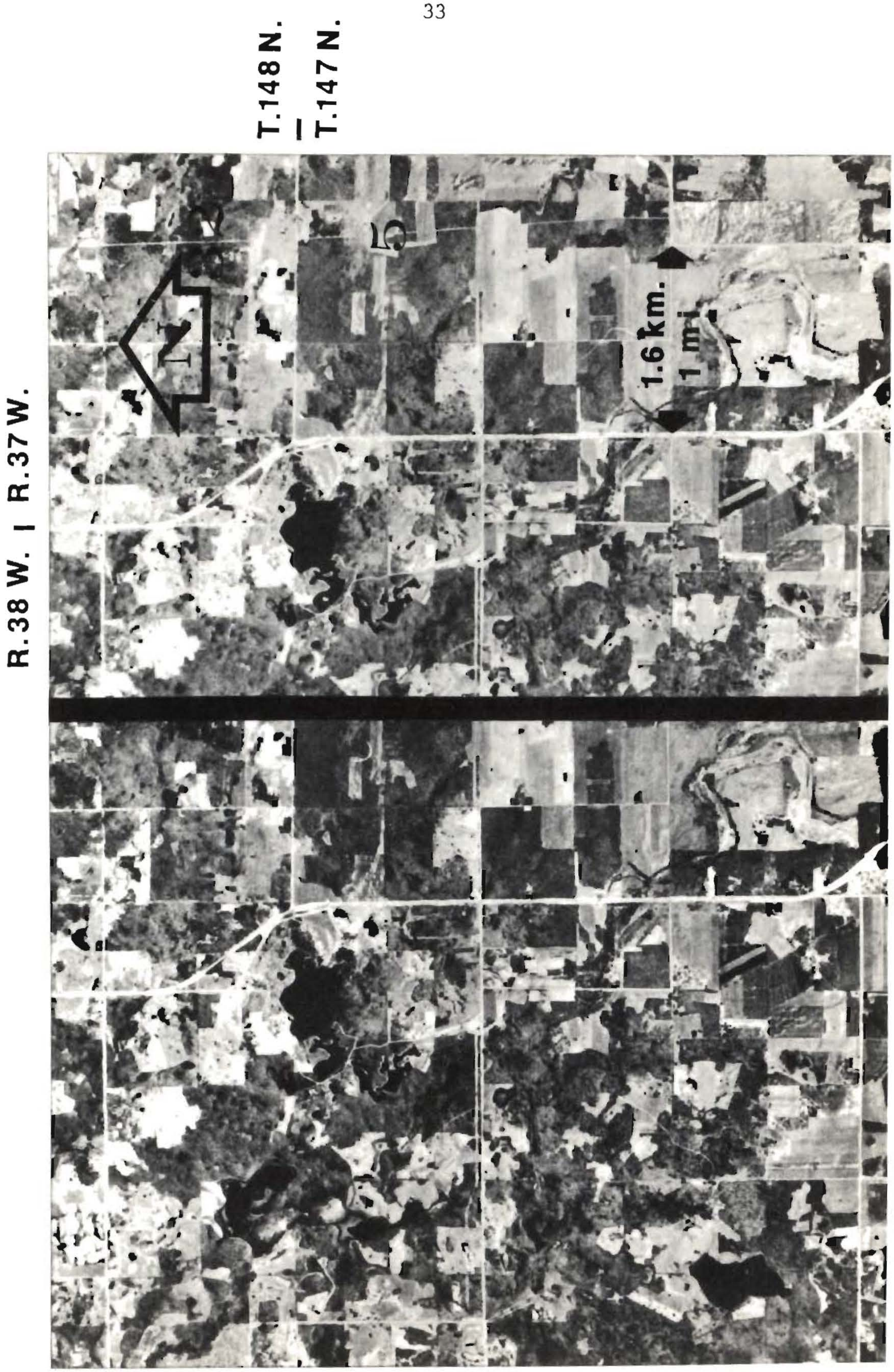

R.41 W.
N
35
2
1.6 km
1 mi
T.148 N.
T.147 N.

Fig. 9. Well developed scarp along the glacial-sediment margin near Bagley, Glacial-Upland Province. Photograph by Mark Hurd Aerial Surveys.


R.38 W. | R.37 W.
T.148 N.
T.147 N.
N
5
1.6 km.
1 mi

The Outwash Province

The Outwash Province is a flat to undulating surface of sand and gravel in the south-central and southeastern parts of the Grand Forks-Bemidji area (Figure 2). The major geomorphologic features present in this province are outwash plains, meltwater channels, eskers, and esker complexes.

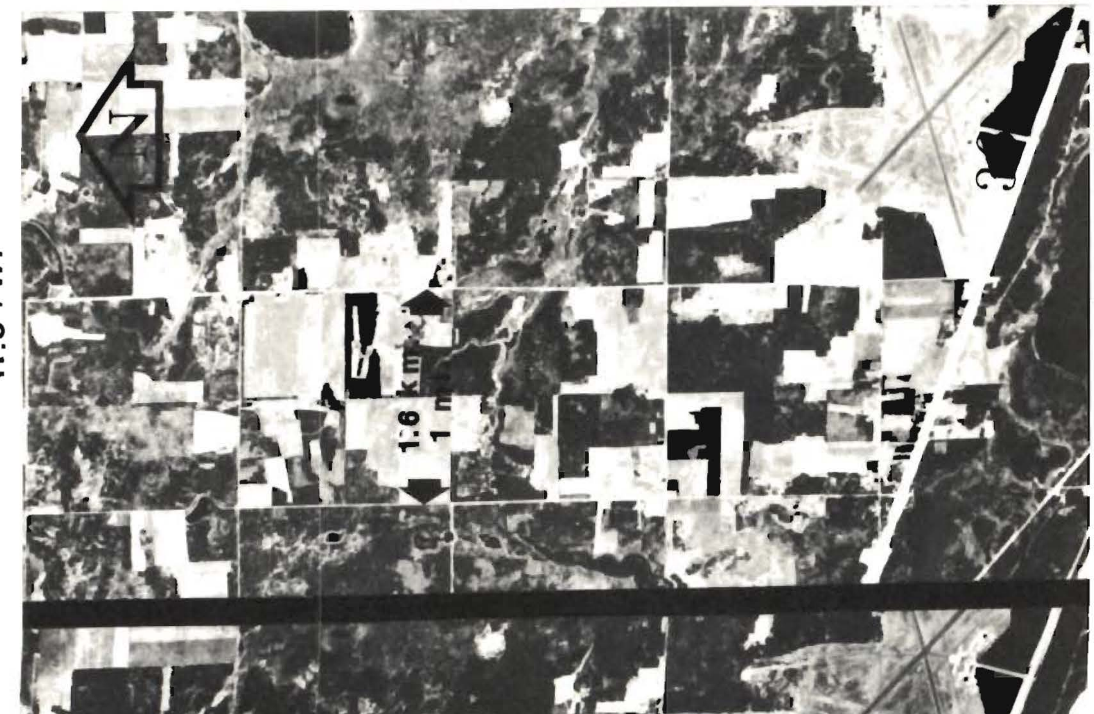
The outwash plains are generally flat areas of sand and gravel (Figure 10). They were deposited by glacial meltwater streams draining ice-marginal positions. The sediments in the outwash plains are variably bedded and moderately to well sorted. Bedding present includes mainly large and small scale cross-bedded units.

The meltwater channels, eskers, and esker complexes present in this province (Figure 10) are similar to those previously discussed in the Glacial-Upland Province. They consist of fluvial bedload sediment deposited by meltwater streams draining ice-marginal positions. The sediment is generally poorly to moderately sorted and variably bedded. The bedding ranges from flat-bedded units to large- and small-scale cross-bedded units.

Fig. 10. Outwash plain, Outwash Province. Photography by Mark Hurd Aerial Surveys.

T.147 N.

R.34 W.



SUBSURFACE GEOLOGY

The subsurface geology of the Grand Forks-Bemidji area and an area of equal size immediately to the south was studied. The subsurface study area and the location of the data points are shown in Figure 11.

Lithostratigraphic Units

Seven lithostratigraphic units are recognized in test holes and surface exposures in the subsurface study area. There are six units of glacial origin and one unit of lacustrine origin. These lithostratigraphic units were characterized by their texture, coarse-sand petrology, and stratigraphic position (Table 1). Samples from 16 power-auger test holes, two composite sections compiled from previous drilling programs, and two representative measured sections in the Red Lake River trench were used to characterize the lithostratigraphic units. Descriptive logs of all test holes, composite sections, and Red Lake River sections are contained in Appendix III. Tabulated textural and coarse-sand petrology data are presented in Appendix II. In addition to the seven lithostratigraphic units recognized in the test holes, five additional lithostratigraphic formations, recognized in earlier studies, are present in the subsurface in the western part of the study area. These lithostratigraphic units will be discussed from the oldest to youngest with respect to their distinguishing characteristics, source area, age, and correlation with the stratigraphic units of other workers in adjacent areas.

Fig. 11. Location of data points in area of subsurface study.

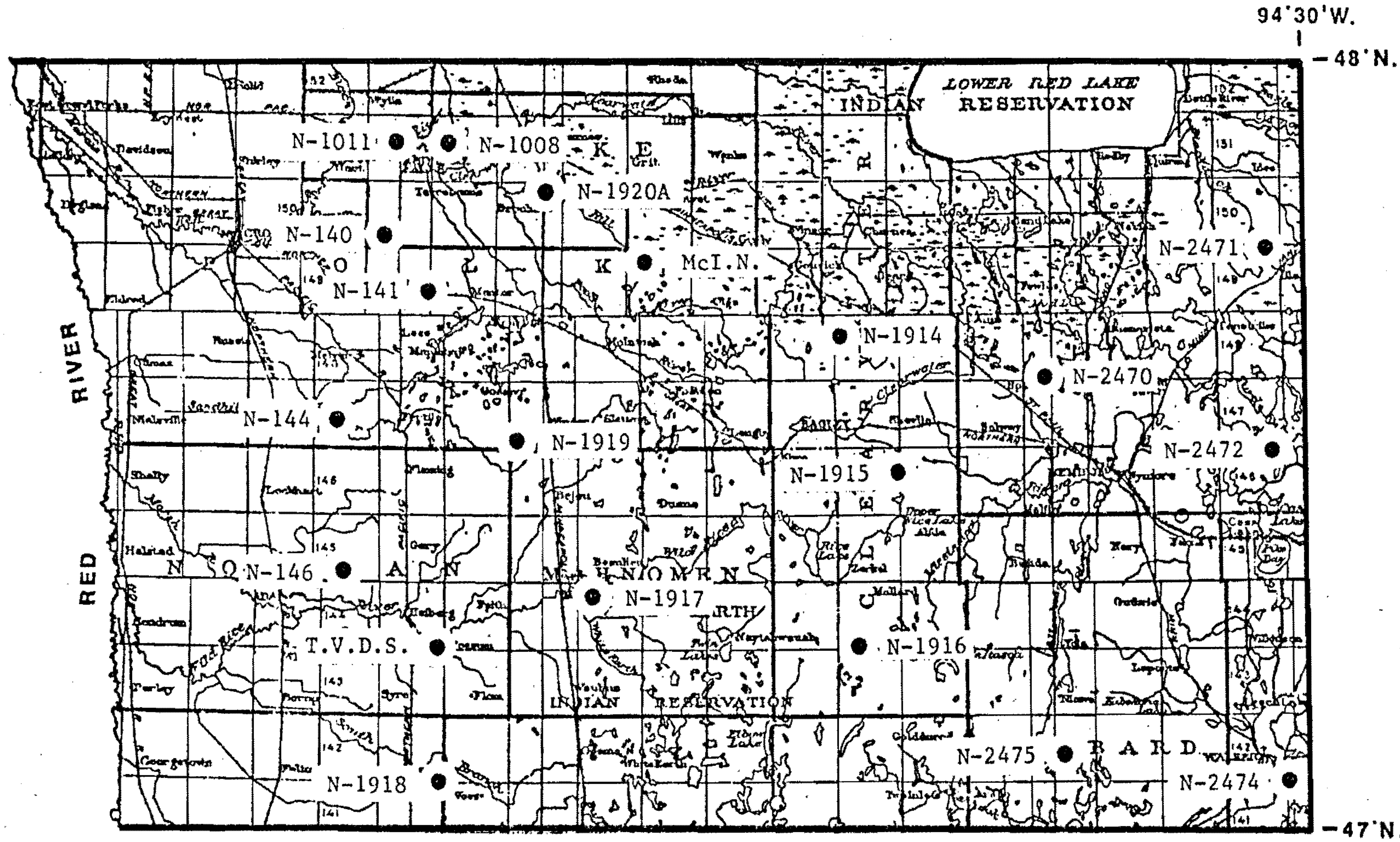

94°30'W.
48°N.
47°N.
LOWER RED LAKE
INDIAN RESERVATION
RED RIVER
N-1011
N-1008
N-1920A
N-140
McI.N.
N-141
N-2471
N-1914
N-2470
N-144
N-1919
N-2472
N-1915
N-146
N-1917
T.V.D.S.
N-1916
INDIAN RESERVATION
N-2475
N-1918
N-2474

Table 1. Summary of textural and coarse-sand petrology data for lithostratigraphic units.

Lithostratigraphic unit	Characteristic	Texture			Coarse-sand lithology		
		Sd	Silt	Clay	Xtal.	CO_3	Sh.
Huot Fm. n = 4	Mean	8	34	57	59	35	6
	Standard Deviation	4.9	21.4	25.4	13.0	8.2	6.0
Red Lake Falls Fm. n = 15	Mean	37	42	21	58	37	5
	Median	37	42	20	56	38	4
	Mode	24,36 37,39	40	16,20, 29,31	53	33,43	4
	Standard Deviation	9.7	5.1	6.7	7.0	6.9	4.1
St. Hilaire Fm. n = 9	Mean	34	40	26	53	24	23
	Median	36	38	24	48	24	24
	Mode	–	37,38	23	–	24	24
	Standard Deviation	8.4	5.2	7.0	13.2	5.5	10.9
Marcoux Fm. n = 12	Mean	50	35	16	82	16	2
	Median	53.5	32	15.5	83	16	1
	Mode	55,57	32	11 15,16	83,87	16	0
	Standard Deviation	9.0	5.0	8.1	7.1	4.9	2.7
unnamed unit 2 n = 2	Mean	39	32	28	70	29	1
unnamed unit 1 n = 1	Mean	20	46	34	61	38	0

Unnamed unit 1

This unit consists of unbedded glacial sediment. It is pebbly, silty clay-loam.

Two metres (7 feet) of this unit is present in test hole N-1916 (Appendix III). Here the unit is composed of an average of 20% sand, 46% silt, and 34% clay. The coarse-sand fraction contains an average of 61% crystalline- and metamorphic-rock fragments, 38% carbonate-rock fragments, and no shale fragments (Table 1).

This unit is one of two unnamed units which are present beneath the Marcoux Formation. Unnamed unit 1 underlies unnamed unit 2 and is the oldest lithostratigraphic unit recognized in test holes made during this study. Unnamed unit 1 contains an average of 20% sand, less than any other units present except the Huot Formation. The amount of carbonate-rock fragments present in the coarse-sand fraction is greater than any other lithostratigraphic unit encountered in the study area. It contains an average of less than one percent shale fragments (Table 1).

The source area of this unit is unknown. The relatively high carbonate-rock fragment content suggests a north-northwesterly source area.

The age of unnamed unit 1 is unknown, but stratigraphic position suggests it is pre-Wisconsinan or Early Wisconsinan in age.

Unnamed unit 2

This unit consists of unbedded glacial sediment. It is pebbly clay-loam.

Unnamed unit 2 is found in test holes N-1915 and N-1916 (Appendix III). The unit averages about 4.5 metres (15 feet) thick. This unit is composed of an average of 39% sand, 32% silt, and 28% clay. The coarse-sand fraction contains an average of 70% crystalline- and metamorphic-rock fragments, 29% carbonate-rock fragments, and 1% shale fragments (Table 1).

Unnamed unit 2 is significantly sandier than the underlying unnamed unit 1 and significantly less sandy than the overlying Marcoux Formation. The coarse-sand fraction contains fewer carbonate-rock fragments than unnamed unit 1 and more than the Marcoux Formation. It contains an average of 1% shale (Table 1).

The source area of unnamed unit 2 is unknown. The ratio of crystalline- and metamorphic-rock fragments to carbonate-rock fragments suggests a north-northwesterly source area.

The age of unnamed unit 2 is unknown, but stratigraphic position suggests it is pre-Wisconsinan or Early Wisconsinan in age.

Marcoux Formation

The Marcoux Formation consists largely of unbedded glacial sediment. It is pebble-loam. A formal description of the unit is contained in Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota (Harris and others, 1974).

This unit is present in 13 test holes located throughout the area studied (Appendix III). Test holes rarely reached the base of the Marcoux Formation. An average thickness of 15 metres (50 feet) and a maximum thickness of 44 metres (146 feet) was encountered.

The Marcoux Formation is composed of an average of 50% sand, 35% silt, and 16% clay. The coarse-sand fraction contains an average of 82% crystalline- and metamorphic-rock fragments, 16% carbonate-rock fragments, and 2% shale fragments (Table 1).

The Marcoux Formation includes the surface glacial sediment throughout the southeastern part of the study area (Figure 12). In most of the subsurface the Marcoux Formation is overlain by the St. Hilaire Formation. In the Red Lake Falls area the St. Hilaire Formation is absent and the Marcoux is overlain by the Red Lake Falls Formation (Plate 2, Panel 1). The Marcoux Formation overlies unnamed unit 2.

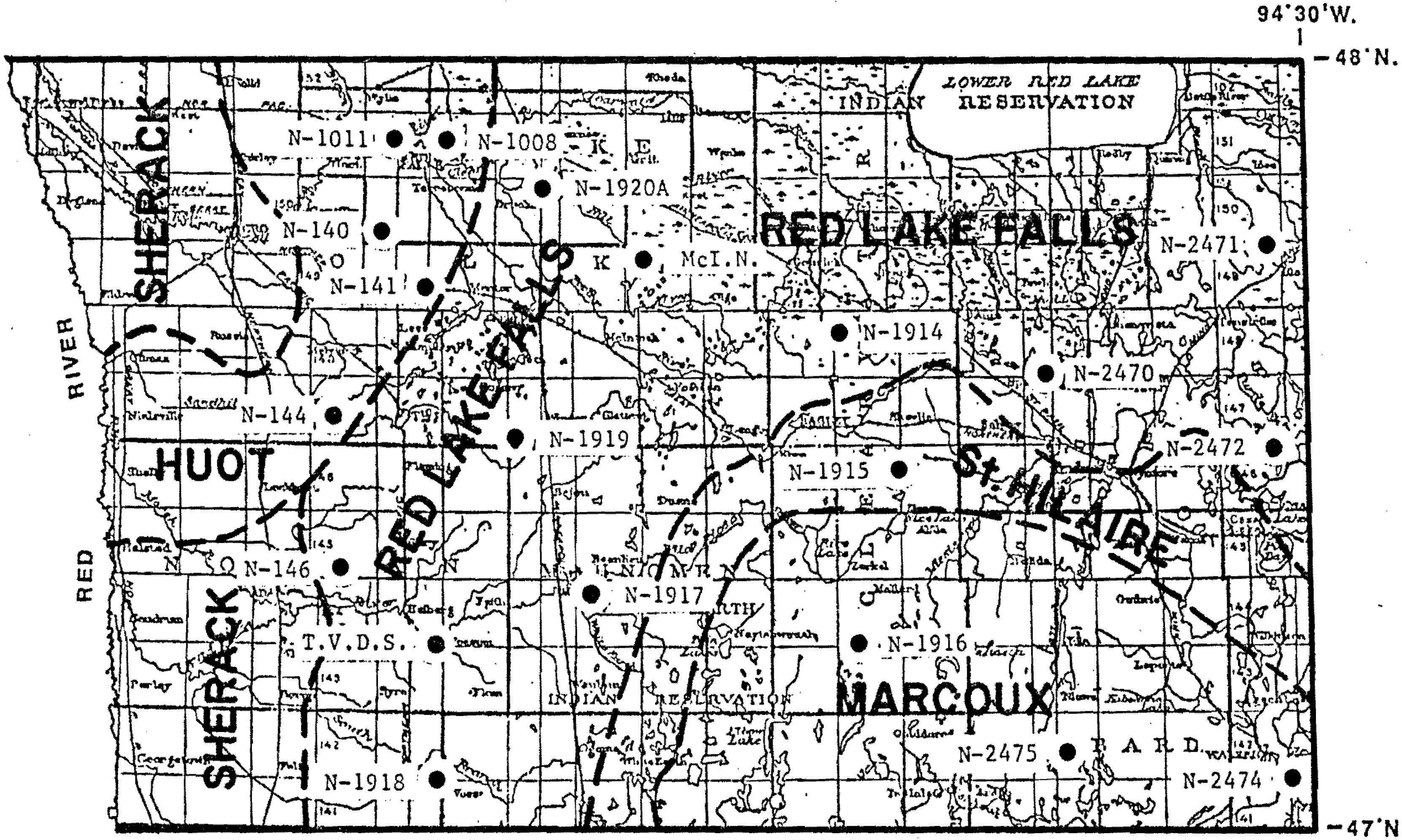
The characteristics that are most useful in identifying the Marcoux Formation are its relatively high sand content, abundant crystalline- and metamorphic-rock fragments in the coarse-sand fraction, and low shale content. The average sand content is 50%, higher than any other unit present. The coarse-sand fraction contains 82% crystalline- and metamorphic-rock fragments, more than any other unit present (Table 1).

The Marcoux Formation is thought to have a north-northeastern source area because the coarse-sand fraction contains a large portion of Canadian Shield type rocks.

The age of the Marcoux Formation is unknown, but stratigraphic position suggests that it is pre-Wisconsinan or Early Wisconsinan in age.

The Marcoux Formation is correlatiod with the Vang Formation in northeastern North Dakota (Hobbs, in preparation). It is also correlated with the Hawk Creek Till (Matsch, 1971) in the Minnesota River Valley of southwestern Minnesota (Harris and others, 1974) (Table 2).

Fig. 12. Surface exposure of the lithostratigraphic units in the area of subsurface study.



94°30'W.
48°N.
47°N.
LOWER RED LAKE
INDIAN RESERVATION
RED RIVER
SHERACK
HUOT
RED LAKE FALLS
St. HILAIRE
MARCOUX
N-1011
N-1008
N-1920A
N-140
N-141
McI.N.
N-2471
N-1914
N-2470
N-144
N-1919
N-1915
N-2472
N-146
N-1917
T.V.D.S.
N-1916
N-2475
N-2474
N-1918
INDIAN RESERVATION

Table 2. Correlation of lithostratigraphic units present in the subsurface study area with stratigraphic units of workers in some other areas.

NORTHEASTERN NORTH DAKOTA H. C. HOBBS (in preparation)	SOUTHEASTERN MANITOBA M. M. FENTON (1974)	NORTHWESTERN MINNESOTA M. M. FENTON (1974)	RED LAKE FALLS AREA MINNESOTA K. L. HARRIS AND OTHERS (1974)	STUDY AREA NORTHWESTERN MINNESOTA	SOUTHWESTERN MINNESOTA C. L. MATSCH (1971)
SD-SLT-CLY XTAL-CO_3-SH	SD-SLT-CLY XTAL-CO_3-SH	SD-SLT-CLY XTAL-CO_3-SH	SD-SLT-CLY XTAL-CO_3-SH	SD-SLT-CLY XTAL-CO_3-SH	SD-SLT-CLY XTAL-CO_3-SH
			Sherack Fm.	Sherack Fm.	
			Poplar River Fm.		
	Steinbach Till		Brenna Fm.		
	31-51-17				
	30-69-0				
Falconer Till	Marchand Till	Marchand Till	Huot Fm.	Huot Fm.	
29-33-38	42-43-15	41-42-17	6-23-71	8-34-57	
35-24-41	41-59-0	45-54-1		59-35-6	
			Wylie Fm.		
	Roseau Till	Roseau Till	U. Red Lake Falls Fm.		New Ulm Till
	32-50-18	37-41-23	35-41-24	Red Lake Falls Fm.	31-43-26
	34-66-0	32-62-5	51-34-13	37-42-21	27-23-45
				58-37-5	
Dahlen Fm.	Senkiw Till	Senkiw Till	L. Red Lake Falls Fm.		
32-35-33	59-29-11	48-38-14	44-36-20		
25-15-60	50-50-0	69-31-0	57-37-5		
	Tolstoi Till				
	25-53-22				
	28-72-0				
Gardar Fm.	Stuartburn Till	Stuartburn Till	St. Hilaire Fm.	St. Hilaire Fm.	Granite Falls Till
27-34-39	41-45-14	30-46-24	38-42-20	34-40-26	38-43-20
6-4-90	41-59-0	41-59-0	40-31-27	53-24-23	49-43-3
Vang Fm.			Marcoux Fm.	Marcoux Fm.	Hawk Creek Till
36-40-24			54-33-13	50-35-16	51-38-11
39-21-40			78-19-5	82-16-2	79-12- 1
Tiber Fm.	Woodmore Till			Unnamed Unit 2	
27-38-35	29-49-22			39-32-28	
15-27-58	27-73-0			70-29-1	
	Rosa Till	Rosa Till		Unnamed Unit 1	
	29-50-21	21-51-28		20-46-34	
	42-58-0	39-61-0		61-38-0	

St. Hilaire Formation

The St. Hilaire Formation consists largely of unbedded glacial sediment. It is a pebble-loam. A formal description of the unit is contained in Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota (Harris and others, 1974).

This unit is present in nine test holes located in all but the southeastern part of the area studied (Appendix III). An average thickness of 11 metres (36 feet) was encountered.

The St. Hilaire Formation is composed of an average of 34% sand, 40% silt, and 26% clay. The coarse-sand fraction contains an average or 53% crystalline- and metamorphic-rock fragments, 24% carbonate-rock fragments, and 23% shale fragments (Table 1).

The St. Hilaire Formation contains the surface glacial sediment in a narrow band from the south-central part of the area studies, toward Bagley and southeastward toward Leech Lake (Figure 12). The St. Hilaire Formation is overlain by the Red Lake Falls Formation throughout the northern and western parts of the area studied.

The characteristic most useful in distinguishing the St. Hilaire Formation from other units present is its high shale content. It contains an average of 23% shale fragments in the coarse-sand fraction, more than any other unit (Table 1).

The St. Hilaire Formation is thought to have a west-northwesterly source area. The shale fragments are thought to have come from the Pierre and Riding Mountain Formations in eastern North Dakota and southern Manitoba.

Based on stratigraphic position the St. Hilaire Formation is Wisconsinan or pre-Wisconsinan in age.

Fenton (1974) correlates his Stuartburn Till of southeastern Manitoba with the St. Hilaire. In northeastern North Dakota the St. Hilaire is correlated with the Gardar Formation (Hobbs, in preparation). The Granite Falls Till of southwestern Minnesota (Matsch, 1971) is thought to correlate with the St. Hilaire Formation (Table 2).

Red Lake Falls Formation

The Red Lake Falls Formation consists largely of unbedded glacial sediment. It is a pebble-loam. A formal description of the unit is contained in Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota (Harris and others, 1974).

This unit is present in 15 test holes located in all but the southeastern part of the area studied (Appendix III). An average thickness of 13 metres (42 feet) was encountered.

The Red Lake Falls Formation is composed of an average of 37% sand, 42% silt, and 21% clay. The coarse-sand fraction contains an average of 58% crystalline- and metamorphic-rock fragments (Table 1).

The Red Lake Falls Formation includes the surface glacial sediment throughout the central and northeastern parts of the area studied (Figure 12). In the northwestern part of the area it is overlain by the Huot Formation.

The characteristics of the Red Lake Falls Formation that distinguish it from other units are its stratigraphic position above the St. Hilaire Formation, its intermediate shale content (5%), and its loamy texture. Texturally the Red Lake Falls and St. Hilaire Formations are quite similar. The lower shale content of the Red Lake Falls easily distinguishes it from the St. Hilaire Formation. The

Red Lake Falls Formation is considerably sandier than the overlying Huot Formation (Table 1).

On the basis of coarse-sand lithology it is thought that the Red Lake Falls Formation had a source area to the north-northwest.

The Red Lake Falls Formation is thought to be Wisconsinan in age because of its stratigraphic position beneath the Huot Formation and its extensive surface exposure (Figure 12).

In some outcrops along the Red Lake River and some test holes, two subdivisions can be distinguished within the Red Lake Falls Formation. This distinction cannot be made consistently. No subdivision of the Red Lake Falls Formation is made in this report. Where the distinction is made, in the Red Lake Falls area, the lower unit is somewhat sandier and the upper unit is considerably more shaley (Harris and others, 1974).

In northeastern North Dakota the upper part of the Red Lake Falls Formation is correlated with the Dahlen Formation (Hobbs, in preparation). In southeastern Manitoba the lower part of the Red Lake Falls Formation is correlated with the Senkiw Till and the upper part of the Red Lake Falls Formation with the Roseau Till by Fenton (1974). In southwestern Minnesota the New Ulm Till of Matsch (1971) is correlated with the Red Lake Falls Formation (Table 2).

Huot Formation

The Huot Formation consists largely of glacial sediment. It is slightly pebbly, silty clay-loam. A formal description of the unit is contained in Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota (Harris and others, 1974).

This unit is present in three test holes and one of the measured sections along the Red Lake River (Appendix III). An average thickness of 4 metres (14 feet) is present.

The Huot Formation is composed of an average of 8% sand, 34% silt, and 57% clay. The coarse-sand fraction contains an average of 59% crystalline- and metamorphic-rock fragments, 35% carbonate-rock fragments, and 6% shale fragments (Table 1).

In exposure along the Red Lake River the Huot Formation is underlain by the Wylie Formation, a laminated silt and clay of lacustrine origin (Harris and others, 1974). The Huot Formation is the surface glacial sediment in a narrow band extending from the west-central part of the study area northeast through the Red Lake Falls area (Figure 12).

The Huot Formation is easily identified by its stratigraphic position, texture, and coarse-sand lithology. It overlies the Red Lake Falls Formation and contains less sand and more clay than any other unit present in the area of study. The Huot contains more carbonate-rock than any of the other units present, except the Red Lake Falls Formation and unnamed unit 1 (Table 1).

The Huot Formation was deposited by latest Wisconsinan glacial ice that flowed south in the Red River Valley. The Edinburg Moraine, a thickening of the Huot Formation, marks the southern limit of the Huot Formation (Arndt, in preparation).

The Huot Formation is the lateral equivalent of the Falconer Formation in the northern Red River Valley (Harris and others, 1974) and northeastern North Dakota (Hobbs, in preparation). In southeastern Manitoba the Huot and Falconer Formations are correlated with the Marchand Till (Fenton, 1974) (Table 2).

Sherack Formation

The Sherack Formation consists largely of laminated offshore lake sediment. It is composed of interbedded silt and clay. A formal description of the Sherack Formation is contained in Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota (Harris and others, 1974).

The Sherack Formation averages between 4.5 to 9 metres (15 to 30 feet) thick (Harris and others, 1974).

The Sherack Formation is easily distinguished from other lithostratigraphic units in the study area by its stratigraphic position and texture. In the southwestern part of the study area the Sherack is underlain by the Argusville Formation (Arndt, in preparation). In the northwestern part of the study area the Sherack is underlain by the Brenna Formation (Harris and others, 1974). The Argusville and Brenna Formations are massive, obscurely laminated clays of lacustrine origin. The Poplar River Formation occurs as scattered deposits of sand and gravel beneath the Sherack (Harris and others, 1974). The Sherack Formation is exposed on the surface throughout most of the western part of the study area, except where the Huot Formation is at the surface (Figure 12). The Sherack Formation is only wide-spread, conspicuously laminated lake sediment present in the study area. Its interbedded silt and clay easily distinguish it from other lithostratigraphic units encountered.

The Sherack Formation is latest Wisconsinan and Holocene in age. It was deposited as offshore sediment in the Agassiz basin between 10 000 and 9 500 BP (Harris and others, 1974).

No correlation of Lake Agassiz sediments is made in this paper. A detailed stratigraphic study of the Agassiz basin is being conducted by B. Michael Arndt (in preparation).

Stratigraphic Interpretations

The stratigraphy of the area is shown in a generalized cross-section that extends across the area from northwest to southeast (Figure 13). In general, progressively younger lithostratigraphic units lap up and around a local highland in the southeastern part of the area. This highland consists mainly of glacial sediment of the Marcoux Formation.

Seven detailed cross-sections (Figure 14) have been constructed from test holes, composite sections, and Red Lake River sections (Appendix III). These cross-sections substantiate and elaborate the generalized stratigraphic framework. Three east-west cross sections (Panels 1, 2, and 3) and four north-south cross-sections (Panels 4, 5, 6, and 7) are contained in Plates 2, 3, 4, and 5. These cross-sections contain the basic hole-to-hole correlations. As a matter of convention, sand and gravel units separating units of pebble-loam were placed in the formation containing the overlying pebble-loam.

The stratigraphic relationships of the Pleistocene sediments beneath the oldest lithostratigraphic unit encountered, unnamed unit 1, are unknown. Figure 13 shows that the total thickness of these sediments probably ranges from about 12 metres (40 feet) to about 60 metres

Fig. 13. Generalized stratigraphy of the subsurface study area.

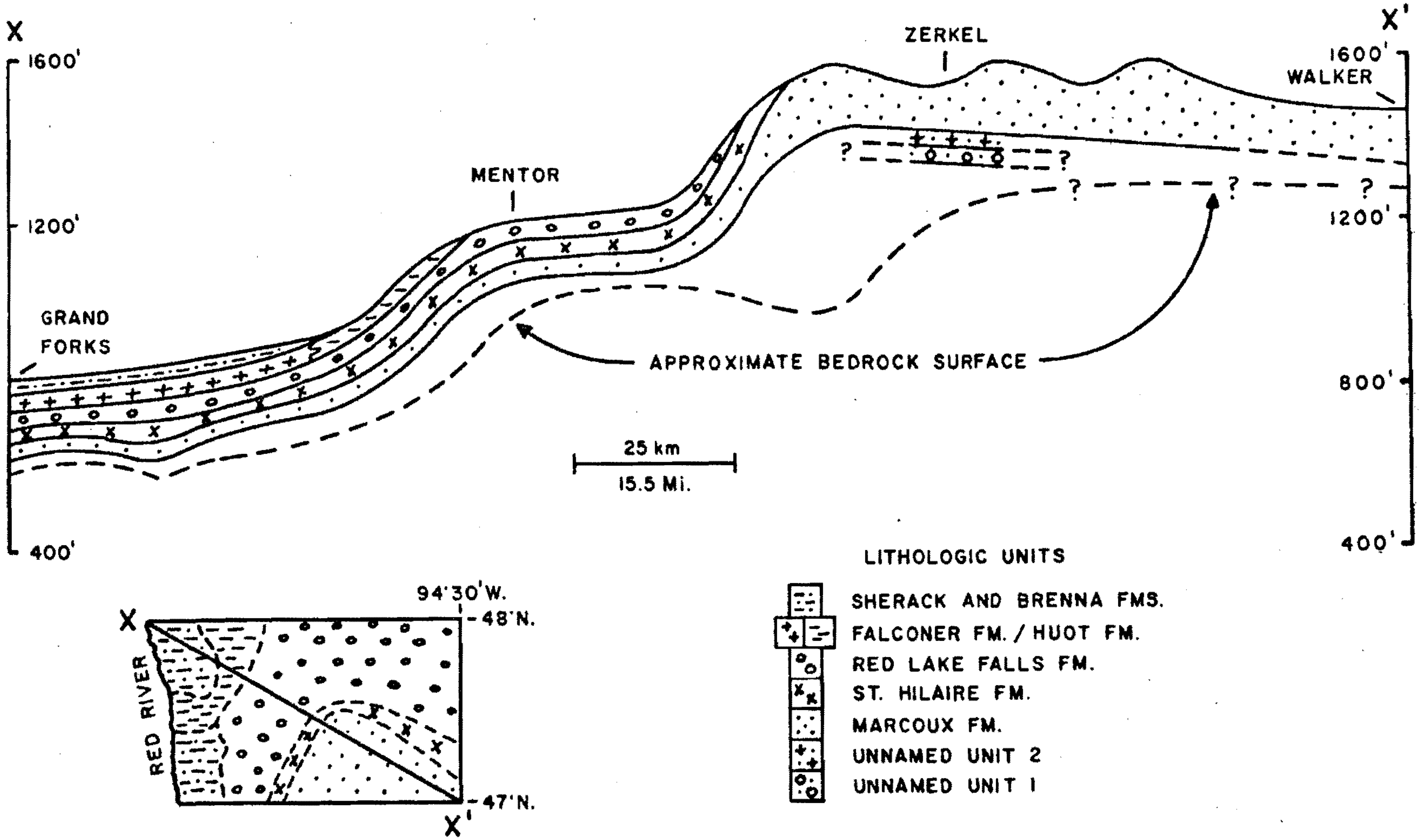
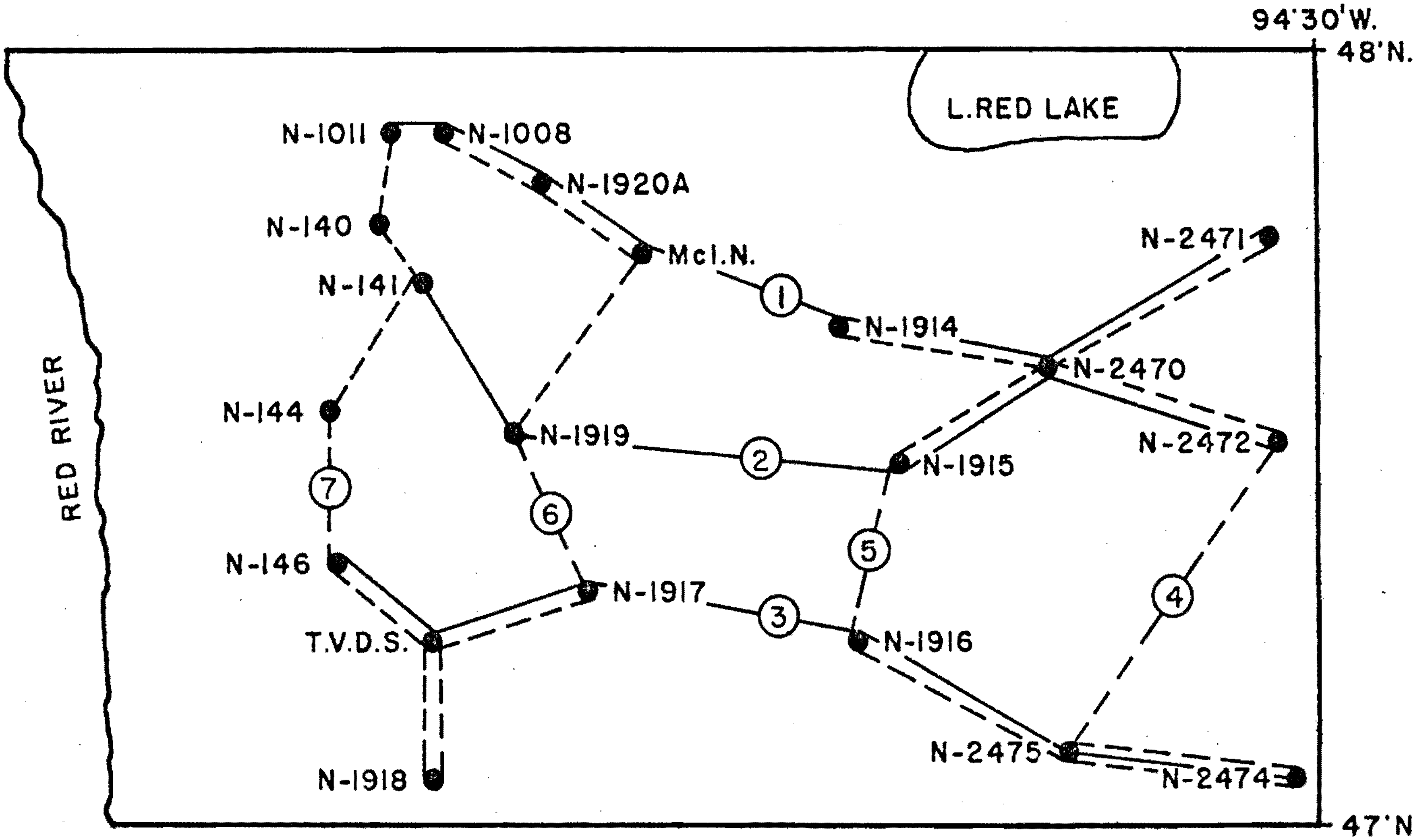

X
X'
1600'
1200'
800'
400'
GRAND FORKS
MENTOR
ZERKEL
WALKER
APPROXIMATE BEDROCK SURFACE
25 km
15.5 Mi.
94°30'W.
48°N.
47°N.
RED RIVER
LITHOLOGIC UNITS
SHERACK AND BRENNA FMS.
FALCONER FM. / HUOT FM.
RED LAKE FALLS FM.
ST. HILAIRE FM.
MARCOUX FM.
UNNAMED UNIT 2
UNNAMED UNIT 1

Fig. 14. Location and panel numbers of detailed cross-sections.


94°30'W.
48°N.
47°N.
L.RED LAKE
RED RIVER
N-1011
N-1008
N-1920A
N-140
N-141
Mcl.N.
N-1914
N-2471
N-2470
N-144
N-1919
N-1915
N-2472
N-146
N-1917
N-1916
T.V.D.S.
N-2475
N-2474
N-1918
1
2
3
4
5
6
7

(200 feet). The elevation of the undulating bedrock surface (Moran, 1975) rises from about 600 feet in the northwest to about 1300 feet in the southeast.

Little is known about unnamed units 1 and 2. The intermediate content of crystalline-rock fragments and the relatively high content of carbonate-rock fragments in the coarse-sand fraction (Table 1) suggests a north-northwesterly source area. It is thought that unnamed units 1 and 2 may be correlative with the glacial sediment of the Wadena drumlin field to the south of the subsurface study area (Sackreiter, in preparation).

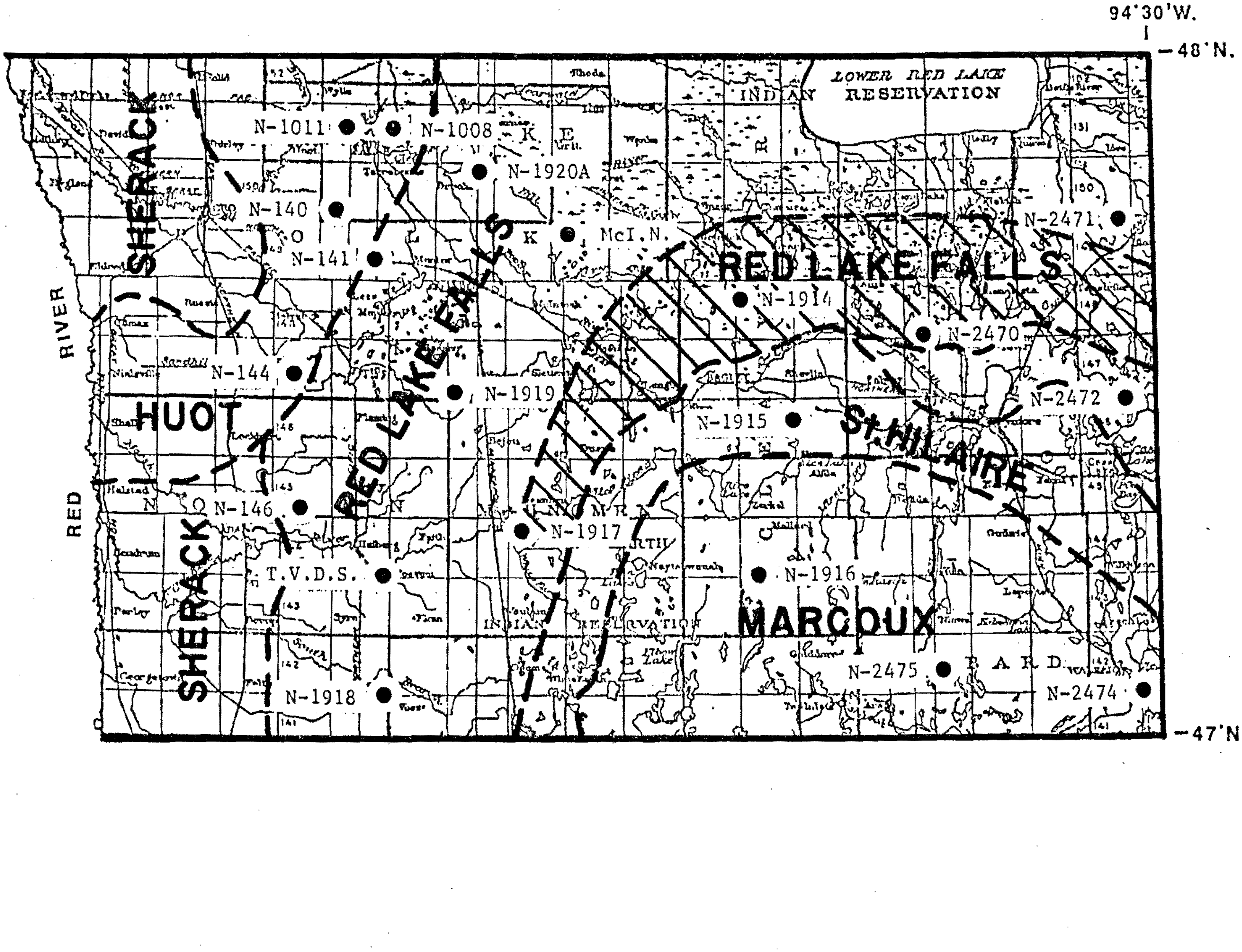
The surface glacial sediment in the Itasca Highland in the southeastern part of the subsurface study area is in the Marcoux Formation. Drill holes in the Itasca Highland often encountered repetitive interval of sand and gravel separated by intervals of glacial sediment of the Marcoux Formation. Buried oxidized glacial sediments were encountered in Test holes N-1915 and N-1916 (Plate 4, Panel 5). The repetitive buried oxidation zones and the sand and gravel units are interpreted as evidence of thrusting of glacial sediments near a glacial margin. The Itasca Highland is thought to be a morainic complex consisting largely of the Marcoux Formation.

The St. Hilaire Formation is thought to have been deposited by a single advance of glacial ice from the northwest. The sediment of the St. Hilaire Formation most often encountered in test holes is a homogeneous, shale-rich pebble-loam. Sand and gravel members of the formation are not uncommon. They are most common near the southeastern limit of the formation in the study area (Figure 13). These sand and gravel members are thought to be meltwater sediments deposited during the advance of the glacial ice that deposited the St. Hilaire Formation.

The Red Lake Falls Formation contains the surface glacial sediment throughout the central part of the subsurface study area (Figure 13). The extent of the glacial sediment of this formation in the subsurface study area is shown in Figure 13. In the Grand Forks-Bemidji area, the area of surface study, the southern limit of the glacial sediment of the Red Lake Falls Formation is marked by a discontinuous, generally obscure scarp. This discontinuous scarp marks the boundary between the Glacial-Upland Province, to the north, and the Outwash Province, to the south (Figure 2). A well developed scarp along the southern limit of the Red Lake Falls glacial sediment is located about 6 kilometres (4 miles) north of Bagley (Figure 9). Meltwater discharged along this glacial margin flowed into a major meltwater channel that followed a southwesterly course along the glacial margin. The present day Clearwater River flows in this channel in the Bagley area.

The surface sand and gravel in the Bemidji area (Plate 1) is thought to be Red Lake Falls outwash sediment. This sand and gravel extends north and west under the surface glacial sediment of the Red Lake Falls Formation (Plate 3, Panel 4; Plate 4, Panel 5). Figure 15 shows the approximate extent of the overridden sand and gravel. In this area the thickness of the surface glacial sediment is variable, but generally ranges from about 3 metres (10 feet) to about 12 metres (40 feet). Overridden meltwater channels and esker complexes are common in this area, and sand and gravel is commonly exposed at the surface. The sand and gravel underlying the surface glacial sediment is

Fig. 15. Surface exposure of lithostratigraphic units in the area of subsurface study. Cross-hatched area indicates the approximate extent of the overridden sand and gravel of the Red Lake Falls Formation.


94°30'W.
48°N.
47°N.
LOWER RED LAKE
INDIAN RESERVATION
SHERACK
HUOT
RED LAKE FALLS
St HILAIRE
MARCOUX
RED RIVER
N-1011
N-1008
N-1920A
N-140
N-141
McI.N.
N-2471
N-1914
N-2470
N-144
N-1919
N-2472
N-1915
N-146
N-1917
T.V.D.S.
N-1916
N-2475
N-2474
N-1918
INDIAN RESERVATION

thought to be overridden outwash sediment deposited along the margin of the glacier that deposited the Red Lake Falls Formation.

North and west of the overridden outwash sediments, the glacial sediments of the Red Lake Falls Formation may be divided into an upper shalier member and a lower sandier member in some test holes. This distinction is noted on the detailed cross-sections where it can be made (Plate 2, Panel 1; Plate 4, Panel 5, Panel 6; Plate 5, Panel 7). It is tempting to correlate the lower sandier member with the overridden outwash sediments, and the upper shalier member with the surface glacial sediment of the Red Lake Falls Formation. However, the distinction between the upper and lower members cannot be consistently made in the subsurface, and the surface data indicates the presence of a low-shale surface glacial sediment throughout the area of exposure of the Red Lake Falls Formation. For the purposes of this report the Red Lake Falls Formation remains undifferentiated. More detailed stratigraphy is needed to fully understand the relationship between the upper and lower members of the Red Lake Falls Formation.

A moderately to well sorted, fine- to medium-grained sand is found beneath the glacial sediment of the Red Lake Falls Formation in some places in the northern part of the study area. This sand is present in test holes N-1011 and N-1914 and in the McIntosh, North composite section (Plate 2, Panel 1). A similar sand is present beneath 1.5 metres (5 feet) to 3 metres (10 feet) of Red Lake Falls glacial sediment in a borrow pit (SW¼, SW¼, SE¼ section 17, T-150N, R-34W) and in numerous poorer exposures in several surrounding townships (T-150N, R-33W; T-150N, R-34W; T-150N, R-35W; T-150N, R-36W). A similar sand is present at the surface in sections 10, 11, 15, and

15 of T-150N, R-36W and along the southeastern and eastern margins of Lower Red Lake (Plate 1). Location of exposures and detailed distribution of the aand on tribal lands of the Red Lake Indian Reservation was not possible because access to the reservation to field check airphoto maps could not be gained. This apparently widespread sand unit is thought to be lacustrine shoreline sand associated, at least in part, with ponding of meltwater in the Agassiz basin before the deposition of the Red Lake Falls Formation.

QUATERNARY HISTORY

The Quaternary history of the area of study will be discussed event by event from oldest to youngest.

Glaciers advanced and retreated over the study area an unknown number of times, depositing the glacial sediment that probably occurs beneath the oldest glacial sediment present in test borings, unnamed unit 1 (Figure 13).

Glacial ice advanced over the study area and retreated twice, depositing the glacial sediment of unnamed units 1 and 2 (Figure 16). This glacial ice is thought to have flowed out of the Winnipeg lowland (Figure 17). The coarse-sand petrology of these units suggests a north-northwesterly source area (Table 1).

The glacial ice of the Rainy and Superior Lobes advanced over the study area from the northeast (Figure 17) and retreated, depositing the Marcoux Formation (Figure 16). The coarse-sand petrology of the Marcoux Formation (Table 1) suggests a northeasterly source area. How far south this ice lobe extended is not known, but it is thought to have extended at least to southwestern Minnesota. At its maximum extent the glacial ice of the Rainy and Superior Lobes is thought to have eroded the Wadena drumlin field in pre-existing glacial sediment. A recessional ice margin is thought to have formed the morainic complex in the Itasca Highland.

Glacial ice that deposited the St. Hilaire Formation advanced into the area of study during the Early Wisconsinan (Figure 16). The

Fig. 16. Schematic time-distance diagram showing periods of deposition of formations present in the study area.

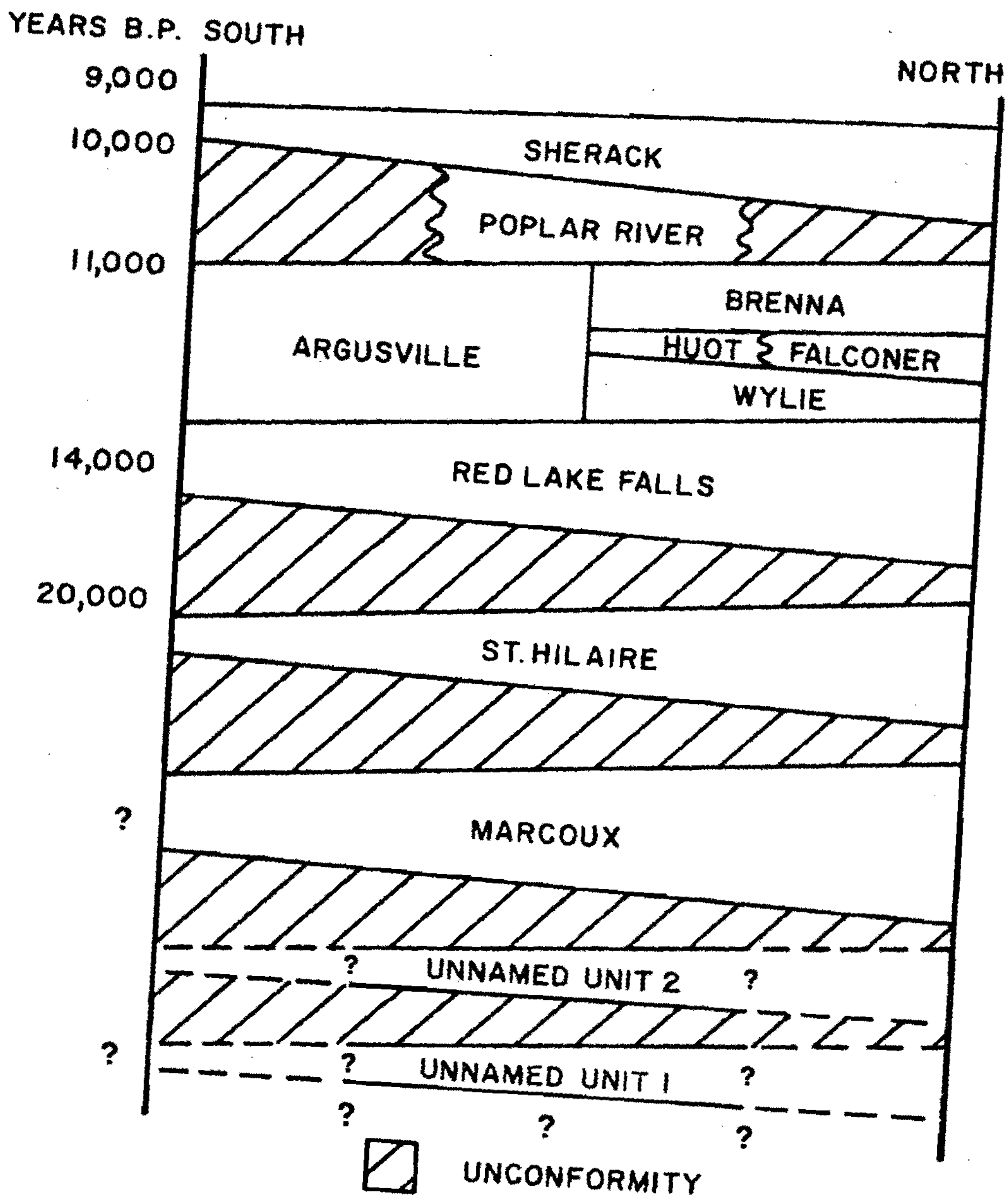

YEARS B.P.
SOUTH
NORTH
9,000
10,000
11,000
14,000
20,000
?
?
SHERACK
POPLAR RIVER
ARGUSVILLE
BRENNA
HUOT
FALCONER
WYLIE
RED LAKE FALLS
ST. HILAIRE
MARCOUX
UNNAMED UNIT 2
UNNAMED UNIT 1
UNCONFORMITY

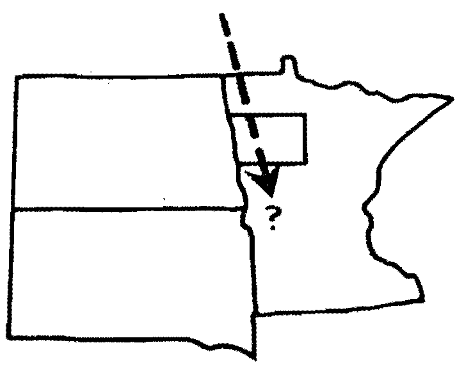
Fig. 17. Quaternary events in the study area and adjacent areas.

a. Pre-Wisconsinan advance of glacial ice from the Winnipeg lowland. Deposition of unnamed units 1 and 2.

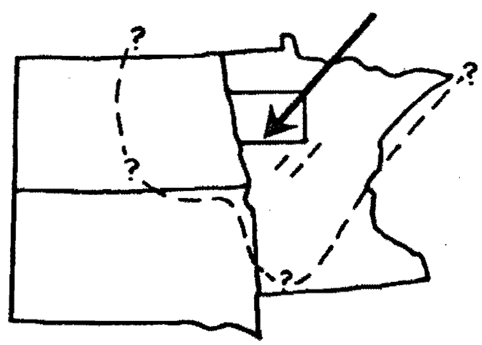
b. Pre-Wisconsinan advance of Rainy and Superior lobes from the northeast. Deposition of the Marcoux Formation (study area), Vang Formation (northeastern North Dakota), and Hawk Creek Till (southwestern Minnesota). Lines show position and orientation of Wadena drumlin field.

c. Early Wisconsinan advance of the Napoleon Glaciation from the northwest. Deposition of the St. Hilaire Formation (study area), Gardar Formation (northeastern North Dakota), Stuartburn Till (southeastern Manitoba), and Granite Falls Till (southwestern Minnesota).

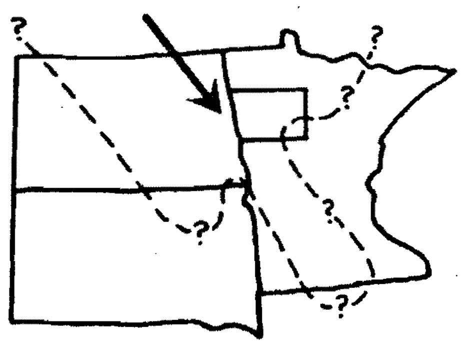
a.



b.



c.



coarse-sand petrology of the St. Hilaire Formation (Table 1) suggests a northwesterly source area. This glacial event is thought to be the Napoleon Glaciation in North Dakota (Clayton, 1962). The glacial ice was divided into two lobes by the Itasca Highland (Figure 17), an area ranging in elevation from 1500 to 2000 feet in the southeastern part of the study area. One large lobe flowed through the western part of the study area and south an unknown distance, down the Red River Valley (Figure 17). The other lobe flowed to the southeast around the Itasca Highland. How far southeast this lobe extended is unknown. The glacial ice of the Napoleon advance retreated from the area.

Glacial ice that deposited the Red Lake Falls Formation advanced into the study area during the Wisconsinan (Figure 16). The coarse-sand petrology of the Red Lake Falls Formation (Table 1) suggests a northwesterly source area and this glacial event is thought to be the Lostwood Glaciation (Clayton, 1972) in North Dakota. This glacial ice was divided into two lobes by the Itasca Highland (Figure 18). One large lobe flowed south down the Red River Valley and is thought to have deposited the bulk of the surface glacial sediment in western Minnesota. The other lobe flowed southeast around the Itasca Highland (Figure 18). How far southeast this lobe extended is unknown. The southern edge of the surface exposure of the Red Lake Falls Formation (Figure 15) marks the approximate position of the glacial ice margin as it flowed around the Itasca Highland. The glacial ice of the Lostwood advance retreated from the study area at about 14 000 BP (Harris and others, 1974).

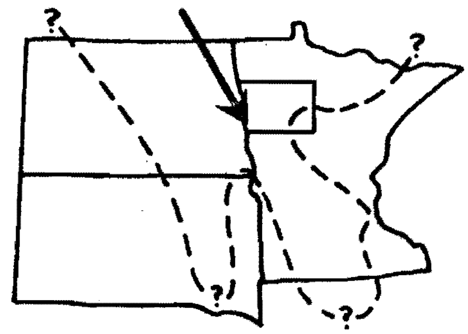
As the glacier margin retreated northward, a proglacial lake occupied the Agassiz basin (Figure 18). The lake sediment of the

Fig. 18. Quaternary events in the study area and adjacent areas.

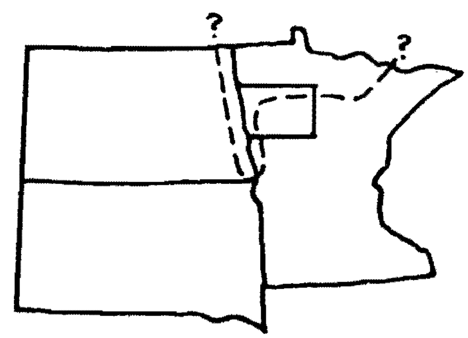
a. Wisconsinan advance of the Lostwood Glaciation from the northwest. Deposition of the Red Lake Falls Formation (study area), Roseau and Senkiw Tills (southeastern Manitoba), Dahlen Formation (northeastern North Dakota) and New Ulm Till (southwestern Minnesota).

b. Early phase of Lake Agassiz (Late Wisconsinan), deposition of the Wylie Formation (northern study area), lower Argusville Formation (southern study area), and Grunthal Formation (southeastern Manitoba).

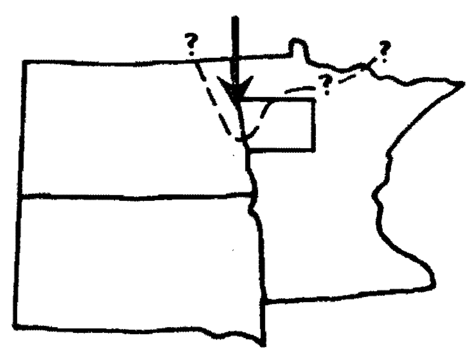
c. Late Wisconsinan Caledonia Advance from the north. Deposition of the Huot and Falconer Formations (study area and northeastern North Dakota) and Marchand Till (southeastern Manitoba).



a.



b.



c.

Wylie Formation (Harris and others, 1974) and the lower part of the Argusville Formation (Arndt, in preparation) were deposited in the Agassiz basin (Figure 15).

The Late Wisconsinan glacial ice of the Caledonia Advance deposited the Huot and Falconer Formations in the northwestern part of the study area (Figure 16). The southern extent of the Caledonia advance (Figure 18) is marked by the Edinburg Moraine. Arndt (in preparation) has shown that the Huot Formation thickens at this position. Deposition of the Edinburg Moraine occurred at about 13 000 BP (Harris and others, 1974).

Proglacial ponding continued in the Agassiz basin during the Caledonia advance. This phase of Lake Agassiz has been called the Lockhart Phase (Moran and Clayton, in preparation). The lake sediment of the Brenna Formation (Harris and others, 1974) and the upper part of the Argusville Formation (Arndt, in preparation) was deposited in the Agassiz basin between about 13 000 and 11 000 BP (Figure 16; Figure 19).

With the retreat of the glacial ice that deposited the Huot and Falconer Formations, the proglacial lake occupying the Agassiz basin drained. This low-water phase of the Lake Agassiz has been called the Moorhead Phase of Lake Agassiz (Moran and Clayton, in preparation). During the Moorhead Phase, about 11 000 to 10 000 BP streams deposited the sediment of the Poplar River Formation (Harris and others, 1974) on the lake plain (Figure 16; Figure 19).

A readvance of glacial ice to the north blocked a northeastern outlet of Lake Agassiz at about 10 000 BP (Harris and others, 1974). The Agassiz basin was again flooded during the Emerson Phase

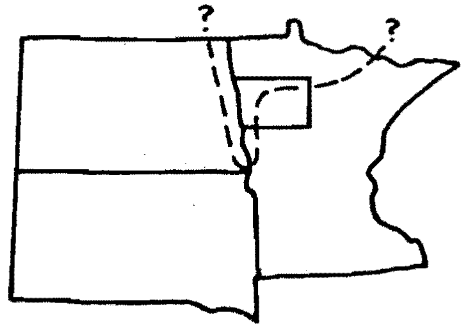
Fig. 19. Quaternary events in study area and adjacent areas.

a. Late Wisconsinan Lockhart Phase of Lake Agassiz. Deposition of the Brenna Formation (northern study area), upper Argusville Formation (southern study area), and lower Hazel Formation (southeastern Manitoba).

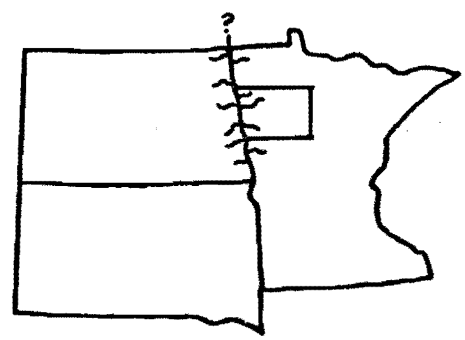
b. Latest Wisconsinan Moorhead Phase of Lake Agassiz. Deposition of the Poplar River Formation (study area) and upper Hazel Formation (southeastern Manitoba).

c. Early Holocene Emerson Phase of Lake Agassiz. Deposition of the Sherack Formation (study area) and upper Hazel Formation (southeastern Manitoba).

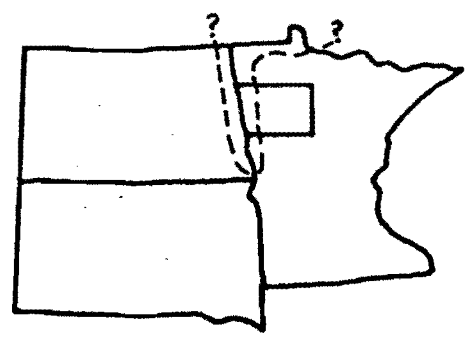
a.



b.



c.



of Lake Agassiz (Moran and Clayton, in preparation). The sediment of the Sherack Formation was deposited in the Agassiz Basin (Figure 16; Figure 19). The glacial ice retreated and Lake Agassiz was drained at about 9500 BP (Harris and others, 1974).

SUMMARY

Unconsolidated sediments, ranging from pre-Wisconsinan or Wisconsinan to Holocene in age, completely cover the bedrock of the area studied. Included are glacial, glaciofluvial, lacustrine offshore, lacustrine shoreline, bog, eolian, and alluvial sediments. The distribution of surficial sediments in the Grand Forks-Bemidji area is shown on Plate 1.

The study area may be divided into four geomorphic provinces on the basis of the presence of different geomorphic features. The very flat Lake-Plain Province dominates the western part of the study area. The Shoreline Province extends from the southwest to the northeast across the study area. The Glacial-Upland Province dominates the south-central and eastern parts of the study area. The Outwash Province is present in the southeastern part of the study area. Figure 2 shows the location of the geomorphic provinces in the study area.

Seven lithostratigraphic units are recognized in test holes in the subsurface study area. The bulk of the material in six units is of glacial origin, and the material in one unit is largely of lacustrine origin. Unnamed unit 1, unnamed unit 2, the Marcoux Formation, and the St. Hilaire Formation are largely glacial sediment and pre-Wisconsinan or Early Wisconsinan in age. The Red Lake Falls Formation is largely glacial sediment and Wisconsinan in age. The Huot Formation is largely glacial sediment and is latest Wisconsinan in age. The Sherack Formation is largely lacustrine sediment and is latest Wisconsinan and Holocene in age.

The lithostratigraphic units are recognized and distinguished by means of their texture, coarse-sand lithology, and stratigraphic position. The texture of the sediments is characterized by the portions of sand-, silt-, and clay-sized particles present. The coarse-sand lithology is characterized by the proportions of crystalline- and metamorphic-rock fragments, carbonate-rock fragments, and shale fragments present.

The younger units of glacial sediment lap upon and around a highland, cored by older glacial sediment, in the southeastern part of the subsurface study area. Figure 13 shows a generalized cross-section of the subsurface study area. Detailed cross-sections are included in Plates 2, 3, 4, and 5. Figure 15 shows the surface exposure of the lithostratigraphic units. Lake sediment of Lake Agassiz is present in the western part of the subsurface study area. The lithostratigraphic units present are correlated with units of other workers in the regions (Table 2).

The Quaternary history of the study area consists of an unknown number of glacial advances and retreats depositing the glacial sediment that underlies the oldest lithostratigraphic unit observed, unnamed unit 1. Glaciers advanced across the area and retreated three times depositing the glacial sediment of unnamed unit 1, unnamed unit 2, and the Marcoux Formation. Glaciers advanced into the area, flowed around the Itasca Highland, and retreated twice, depositing the glacial sediment of the St. Hilaire and Red Lake Falls Formations. During the treat of the glacier that deposited the Red Lake Falls Formation, a lake occupied the Agassiz basin. The sediments of the lower Argusville and the Wylie Formations were deposited in the basin. The glacial ice that deposited the Huot Formation advanced south down the Red River Valley. During its advance and retreat, water continued to be ponded in the Agassiz basin. The sediments of the upper Argusville and the Brenna Formations were deposited in the basin. Lake Agassiz drained and refilled. During the last phase of Lake Agassiz the Sherack Formation was deposited.

Suggestions for future workers include more detailed work in the area studied and similar studies in adjacent areas, particularly to the south and east, to obtain a more complete understanding of the Quaternary stratigraphy and history of the Upper Midwest.

In the area studied, deep test drilling to bedrock would provide information on the Quaternary sediments present below the oldest units described here.

Similar studies in adjacent areas would provide additional surface and subsurface information to increase our understanding of the areal extent and stratigraphic relationships of the lithostratigraphic units present. Correlations could be extended, and the Quaternary history of the region would be better understood.

APPENDIX I

TABULATED SURFACE DATA

TABULATED SURFACE DATA

This appendix contains a tabulated summary of laboratory analysis of surface samples (Table 3). Sample data are listed by townships. The townships are listed from west to east in each tier. The tiers are listed from north to south.

The table headings include N-number, location, surface elevation, sample depth, description, texture, and lithology. These headings are discussed below.

The N-number is a unique sample number in the North Dakota Geological Survey sample library.

The location of the sample site is given as the quarter of the quarter of the quarter (A is NE¼, B is NW¼, C is SW¼, and D is SE¼) of the section(S) in which it is located. The township in which the site is located is indicated by its township number (T) and range number (R).

The surface elevation of the sample site and sample depth are given in feet.

A description of the sample site is given in a nine character code of the form "ABBCCDEFF."
The "A" indicates that the sample is (1) or is not (0) from the upper unit present. The "B" indicates the thickness of the upper unit in feet. The "C" indicates the lithology of the upper unit (1 is gravel, 2 is sand, 3 is silt, 4 is clay, 5 is pebble-loam, 6 is peat). Silty sand would be listed as 32. The "D" is a slash that separates the upper unit from the lower unit. The "E" indicates that the sample is (1) or is not (0) from the lower unit. The "F" indicates the lithology of the lower unit as in "C" above. A sample site with 3 feet

of sand overlying pebble-loam that was sampled would have a description of "0 3 2/1 5."

The texture of the sample is given as the percentage content of sand (SD) silt (SLT), and clay (CLY).

The lithology of the coarse-sand fraction of the sample is given as the percentage content of crystalline- and metamorphic-rock fragments (XTAL), carbonate-rock fragments (CO_3) and shale fragments (SH).

N=	LOCATION 1/4	S	T	R	SURF. ELEV.	SAMP. DEPTH
1333	BBC	20	153	30	1210	9
1337	BBC	20	153	30	1210	3
1258	AAA	28	152	47	877	8
1269	DDD	11	152	45	1026	3
1267	BBB	27	152	44	1057	4
1288	CCC	35	152	43	1101	4
1294	AAA	19	152	42	1118	4
1298	DDD	5	152	42	1120	3
1292	DDC	25	152	42	1120	4
1293	AAA	27	152	42	1127	6
1291	CCC	27	152	42	1128	7
1299	AAA	10	152	42	1130	4
1313	AAD	26	152	41	1151	4
1312	AAA	32	152	40	1150	5
1322	AAA	15	152	39	1165	5
1323-2	AAA	1	152	32	1200	5
1323-1	AAA	1	152	32	1200	4
1351	CDD	22	152	31	1232	4
1336	CBD	16	152	30	1275	5
1335	DAB	26	152	30	1350	5
1339	BBC	34	152	30	1350	5
1255	DDC	36	151	47	892	3
1264	CCC	8	151	46	918	3
1272	AAA	4	151	44	1042	4
1284	AAA	14	151	42	1125	3
1301	BBB	32	151	41	1145	4
1302-2	CCC	27	151	41	1145	3
1302-1	CCC	27	151	41	1145	1
1302-3	CCC	27	151	41	1145	5
1303	AAA	35	151	41	1152	5

DESC.	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
115 5/0 0	38	31	31	56	42	2
115 5/0 0	35	43	22	62	33	4
0 834/1 5	13	35	52	36	59	5
0 2 5/1 5	18	32	50	41	53	6
1 4 5/0 0	9	13	78	41	56	3
1 4 5/0 0	17	34	49	55	36	9
1 4 5/0 0	32	40	28	46	40	14
0 2 5/1 5	29	36	35	50	38	12
1 4 5/0 0	33	34	33	51	32	18
0 212/1 5	9	42	49	49	39	12
0 2 2/134	3	34	63	47	42	10
0 3 2/1 5	31	45	24	46	41	14
1 4 5/0 0	33	28	39	48	38	14
1 5 5/0 0	35	30	35	50	37	13
0 1 6/1 5	33	34	33	50	37	14
0 2 5/1 5	41	33	26	62	35	3
0 221/1 5	20	32	48	61	39	0
1 4 5/0 0	32	33	35	48	46	6
0 2 2/1 5	28	32	40	72	2	26
1 5 5/0 0	33	32	35	55	40	5
1 5 5/0 0	33	27	40	56	33	11
0 3 2/1 5	26	33	41	35	60	4
1 3 5/0 0	26	34	40	44	55	1
0 3 5/1 5	15	34	51	60	39	1
1 3 5/0 0	30	36	34	56	30	14
1 4 5/0 0	31	41	28	29	45	26
1 234/0 5	7	21	72	46	15	39
1 2 5/034	11	29	60	67	30	3
1 1 5/0 0	43	30	27	54	36	10
0 423/1 5	38	41	21	59	34	8

N=	LOCATION 1/4 S T R	SURF. ELEV.	SAMP. DEPTH
1308	AAA 11 151 41	1155	4
1304	DDD 30 151 40	1155	5
1310	AAA 9 151 40	1160	5
1318	CCC 31 151 39	1160	5
1321-1	CCC 11 151 39	1165	2
1321-2	CCC 11 151 39	1165	10
1320-2	BBB 34 151 39	1168	5
1320-1	BBB 34 151 39	1168	3
1330	BBB 29 151 31	1250	5
1331-1	AAA 27 151 31	1325	1
1331-3	AAA 27 151 31	1325	3
1331-2	AAA 27 151 31	1325	2
1346	AAA 24 151 31	1355	5
1352	BBB 9 151 30	1330	4
1353	AAA 11 151 30	1350	5
1332	BAB 29 151 30	1380	3
2168	AAA 21 150 46	898	5
2167	AAA 3 150 46	932	4
2271	CCC 2 150 45	964	3
2274	CCD 34 150 45	1000	4
2272	DDD 14 150 45	1016	3
2270-2	AAA 12 150 45	1030	3
2270-1	AAA 12 150 45	1030	2
2273	DDD 13 150 45	1032	3
2269	CCC 4 150 44	1035	5
2268	DDD 2 150 44	1060	4
2266	CCC 26 150 42	1143	4
2169	ABA 16 150 41	1155	5
2170	ABA 14 150 41	1160	5
2171	AAA 18 150 40	1155	6

DESC.	TEXTURE			LITHOLOGY		
	SD	SLT	CLY	XTAL	CO3	SH
0 2 2/1 5	43	35	22	59	40	1
1 5 5/0 0	24	43	33	58	26	16
0 4 2/1 5	14	54	32	49	38	13
0 412/1 5	30	36	34	49	41	10
1 2 6/0 5	0	0	0	0	0	0
0 2 6/1 5	35	33	32	50	35	15
0 1 2/1 5	19	44	37	33	14	53
1 3 5/0 2	39	32	29	50	38	12
0 434/1 5	36	6	58	51	34	15
1 6 5/0 0	42	36	22	58	42	0
1 6 5/0 0	17	44	39	64	28	8
1 6 5/0 0	35	36	29	65	28	7
1 5 5/0 0	35	34	31	50	39	11
1 4 5/0 0	36	30	34	53	37	10
1 5 5/0 0	25	29	46	56	39	5
1 4 5/0 0	21	31	48	54	40	6
0 323/1 5	10	36	54	35	58	5
0 2 5/1 5	6	26	68	67	33	0
0 223/1 5	8	43	49	48	51	1
1 4 5/0 0	19	8	73	57	3	40
1 3 5/0 0	6	23	71	83	17	0
0 2 5/1 5	5	26	69	49	51	0
1 2 5/0 5	26	44	30	40	60	0
1 3 5/0 0	4	24	72	45	55	0
0 432/1 5	5	26	69	40	59	0
0 234/1 5	39	50	11	66	32	2
0 221/1 5	20	46	34	61	36	3
1 5 5/0 0	38	46	16	61	39	1
1 5 5/0 0	43	35	22	63	32	6
0 4 2/1 5	36	33	31	53	34	12

N=	LOCATION 1/4	S	T	R	SURF. ELEV.	SAMP. DEPTH
2172	AAB	31	150	40	1200	5
2188	CCC	5	150	39	1160	4
1319	AAA	5	150	39	1162	5
2187	DDD	3	150	39	1170	4
2186	DAD	15	150	39	1180	4
2189-2	CCB	29	150	39	1240	4
2189-1	CCB	29	150	39	1240	3
2184	DDD	11	150	38	1170	4
2185	CCC	32	150	38	1250	4
2193	BBB	17	150	37	1196	4
2196	BBB	31	150	36	1250	3
2197	BCC	36	150	36	1375	3
2201	BEB	27	150	34	1340	3
2203-2	DAD	33	150	34	1350	4
2203-1	DAD	33	150	34	1350	2
2202	DAA	26	150	34	1350	3
2207	DDD	15	150	32	1280	2
2210-1	DDD	36	150	31	1390	2
2210-2	DDD	36	150	31	1390	4
2166	AAA	36	149	45	912	3
2267	CCC	25	149	43	1175	4
2174	BCB	8	149	41	1190	5
2173	AAB	21	149	41	1205	4
2178	AAA	31	149	40	1261	5
2211	CCD	9	149	40	1262	4
2175	AAA	18	149	40	1266	5
2177	CCC	25	149	40	1278	3
2176	CCC	12	149	40	1302	3
2180	AAA	33	149	39	1236	5
2182-2	CCD	10	149	39	1300	9

DESC.	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
0 2 2/1 5	7	40	53	43	52	5
1 4 5/0 0	37	44	19	66	34	0
0 2 2/1 5	42	39	19	57	39	4
0 1 6/1 5	43	41	16	65	35	0
0 224/1 5	69	12	19	63	34	3
0 1 5/1 5	41	42	17	63	36	1
0 2 2/1 5	39	31	30	98	1	0
1 4 5/0 0	40	42	18	54	27	20
0 232/1 5	35	48	17	54	43	3
1 4 5/0 0	42	32	26	60	36	5
1 3 5/0 0	21	40	39	83	14	3
1 3 5/0 0	20	41	39	57	41	2
0 232/1 5	13	47	40	91	9	0
0 134/1 5	40	45	15	53	45	1
1 2 5/034	34	32	34	95	1	4
0 2 5/1 5	39	51	10	58	41	1
1 2 5/0 5	12	55	33	95	3	2
1 2 5/0 5	24	42	34	98	1	1
0 2 5/1 5	26	54	20	57	42	1
1 3 5/0 0	8	20	72	57	42	1
1 4 5/0 0	35	42	23	58	42	0
0 334/1 5	37	44	19	45	54	1
1 4 5/0 0	30	47	23	70	30	0
1 5 5/0 0	27	35	38	68	31	1
1 6 5/032	31	41	28	50	48	2
0 3 2/1 5	42	41	17	98	2	0
1 3 5/0 0	27	36	37	45	55	0
1 3 5/0 0	42	47	11	68	32	0
0 334/1 5	19	28	53	66	34	0
115 5/0 0	35	46	19	55	38	7

N=	LOCATION 1/4	S	T	R	SURF. ELEV.	SAMP. DEPTH
2182-1	CCD	10	149	39	1300	6
2179	AAA	36	149	39	1307	5
2183	AAA	12	149	39	1326	3
2181	DDD	17	149	38	1307	3
2194	BBB	3	149	37	1220	5
2195	BAA	11	149	37	1260	15
2192-3	CDC	15	149	37	1310	5
2192-2	CCC	15	149	37	1310	3
2192-1	CDC	15	149	37	1310	1
2190	AAA	27	149	37	1330	4
2191-1	CCC	25	149	37	1370	2
2191-2	CCC	25	149	37	1370	4
2198	AAC	8	149	36	1310	5
2200-2	AAA	2	149	35	1330	4
2200-1	AAA	2	149	35	1330	2
2199	CDC	32	149	35	1350	13
2205	BBB	25	149	35	1380	4
2206	CCC	34	149	35	1430	3
2204-2	ABD	16	149	34	1400	18
2204-1	ABD	16	149	34	1400	7
2208	DDD	3	149	32	1370	9
2209-1	CCC	8	149	32	1410	2
2209-2	CCC	8	149	32	1410	4
2265	CCC	17	148	45	948	5
2264	BBB	34	148	45	1000	5
2258	BBB	22	148	45	1020	6
2260	CDD	28	148	44	1147	5
2259	BBC	1	148	44	1180	4
2254	BBB	19	148	42	1203	3
2253	BCD	21	148	42	1220	4

DESC.	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
115 5/0 0	36	51	13	50	43	6
0 234/1 5	29	42	29	58	41	1
1 3 5/0 0	39	47	14	53	42	5
1 3 5/0 0	33	41	26	57	43	0
1 5 5/0 0	3	54	43	43	49	8
125 5/0 0	33	43	24	61	35	3
1 2 5/0 1	38	43	19	57	41	2
1 2 5/0 5	16	34	50	61	34	5
1 2 5/0 5	38	37	25	55	41	4
0 234/1 5	29	50	21	48	45	6
0 234/1 5	21	36	43	46	2	52
0 234/1 5	10	36	54	72	23	4
110 5/0 2	33	36	31	44	54	2
1 2 5/0 0	23	44	33	62	34	4
1 2 5/0 5	30	28	42	91	9	0
01223/1 5	26	38	36	46	53	1
0 2 2/1 5	27	37	36	63	36	1
1 3 5/0 0	22	46	32	66	23	11
0 3 5/0 0	29	47	24	55	45	0
115 5/0 5	31	46	23	55	43	2
0 3 5/1 5	32	40	28	57	40	3
0 1 2/1 5	40	37	23	98	2	0
0 2 5/1 5	35	51	14	54	44	2
0 321/1 5	1	9	90	40	45	15
1 5 5/0 0	3	29	68	58	42	0
1 8 5/0 0	5	24	71	56	40	3
0 232/1 5	34	49	17	61	39	0
1 4 5/0 0	47	46	7	59	40	1
0 2 5/1 5	31	44	25	57	42	1
1 4 5/0 0	40	54	6	62	35	3

N=	LOCATION 1/4	S	T	R	SURF. ELEV.	SAMP. DEPTH.
2249	AAA	34	148	42	1252	4
2248	DCB	10	148	41	1236	3
2243	BAB	7	148	40	1263	3
2241	DDD	11	148	40	1280	2
2242	BBA	21	148	40	1300	3
2240	ADD	35	148	40	1335	5
2238	AAA	28	148	39	1330	3
2237	CCC	26	148	39	1360	4
2230	BDD	21	148	38	1410	5
2231	AAA	21	148	38	1441	4
2234	DDD	31	148	38	1470	3
2232	AAA	12	148	38	1475	4
2233	AAA	26	148	38	1506	3
2224	BBB	11	148	37	1432	10
2225	BDB	16	148	37	1460	3
2223	CCC	23	148	37	1500	12
2165	CCC	19	148	37	1514	13
2226	BCC	21	148	37	1555	12
2220	AAA	18	148	36	1460	3
2214	DDD	36	148	36	1460	6
2218	CCC	14	148	36	1470	3
2215	DDD	24	148	36	1480	4
2219	BBB	11	148	36	1500	3
2216	DDD	12	148	36	1500	5
2164	AAA	11	148	35	1480	3
2163-2	CCC	10	148	35	1500	18
2163-1	CCC	10	148	35	1500	4
2159	BCC	1	148	34	1410	2
2156	DCA	27	148	33	1320	12
2157	BBC	11	148	33	1340	5

DESC.	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
1 4 5/0 0	31	48	21	56	44	0
0 3 5/0 0	21	53	26	39	61	0
0 232/1 5	38	40	22	58	42	0
1 4 5/0 0	32	48	20	56	44	0
1 3 5/0 0	31	50	19	54	44	2
1 5 5/0 0	28	44	29	54	44	2
1 3 5/0 0	21	53	26	54	45	0
0 323/1 5	30	48	22	54	45	1
1 5 5/0 0	18	44	38	46	51	4
0 234/1 5	23	43	34	58	41	1
1 3 5/0 0	16	53	31	53	46	1
0 323/1 5	24	54	22	63	35	2
110 5/0 0	20	50	30	89	11	0
0 221/1 5	27	54	19	62	30	8
1 3 5/0 0	42	44	14	86	14	1
115 5/0 0	9	49	42	48	51	1
113 5/0 0	11	40	49	44	48	9
115 5/0 0	19	50	31	55	39	6
1 3 5/0 5	24	40	36	67	30	3
0 2 5/1 5	52	18	30	88	12	0
1 8 5/0 0	18	52	30	55	39	5
0 2 5/1 5	44	39	17	66	32	2
1 4 5/0 0	10	47	43	50	42	8
1 4 5/0 0	14	37	49	57	30	13
0 134/1 5	29	35	36	63	31	7
0 8 5/1 5	13	36	51	59	29	13
1 8 5/0 5	15	37	48	45	50	5
1 334/0 0	6	62	32	70	0	30
0 2 5/1 5	22	52	26	67	19	14
1 5 5/0 0	29	35	36	93	2	5

N=	LOCATION 1/4	S	T	R	SURF. ELEV.	SAMP. DEPTH
2158	DDD	32	148	33	1350	2
2155	BAA	14	148	32	1410	5
2154	CCD	31	148	31	1400	4
2152-2	CCC	18	148	30	1380	21
2152-1	CCC	18	148	30	1380	9
2262	AAA	7	147	45	943	4
2263	CCC	2	147	45	1029	5
2257	DDC	27	147	44	1165	3
2261	CBB	24	147	44	1171	4
2256	AAA	6	147	43	1188	4
2255	BBB	36	147	43	1213	4
2250-2	DDD	22	147	42	1222	12
2250-1	DDD	22	147	42	1222	5
2251	AAA	29	147	42	1224	3
2252-2	CCC	9	147	42	1231	5
2252-1	CCC	9	147	42	1231	3
2247	DDD	5	147	41	1251	3
2246	DDD	27	147	41	1260	5
2245	CCC	14	147	41	1260	4
2244	BBB	22	147	40	1295	3
2239	DDD	11	147	40	1300	5
2236	DDD	26	147	39	1515	5
2229-2	DCC	15	147	38	1490	10
2229-1	DCC	15	147	38	1490	5
2228	DBA	36	147	38	1500	6
2227-2	CAD	25	147	38	1500	17
2227-1	CAD	25	147	38	1500	6
2235	ADD	19	147	38	1510	3
2222	CCC	14	147	37	1494	3
2212	ADD	25	147	36	1430	4

DESC.	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
1 3 5/0 1	57	30	13	75	25	0
1 5 5/0 0	14	36	50	46	54	1
1 4 5/0 0	45	39	16	86	5	9
125 5/0 0	32	50	18	64	31	5
125 5/0 0	34	52	14	66	25	9
0 232/1 5	2	16	82	62	38	0
0 332/1 5	36	54	10	66	34	0
1 3 5/0 0	35	50	15	64	36	0
1 4 5/0 0	21	65	14	68	32	1
1 4 5/0 0	31	45	24	55	41	4
1 4 5/0 0	32	53	15	53	47	0
115 5/0 0	16	68	16	52	44	4
115 5/0 0	11	65	24	53	47	0
1 3 5/0 0	24	60	16	53	46	1
1 5 5/0 0	19	66	15	53	45	2
1 5 5/0 0	18	64	18	56	44	0
0 2 3/1 5	38	42	20	58	42	0
0 323/1 5	36	49	15	52	45	3
0 334/1 5	38	49	13	46	53	1
1 7 5/0 0	24	47	29	49	43	8
1 5 5/0 0	37	44	19	61	39	0
1 6 5/0 0	44	50	6	74	23	3
115 5/0 0	19	51	30	47	44	9
115 5/0 0	18	53	29	99	0	0
1 9 5/021	42	45	13	85	15	0
0 4 5/1 5	18	53	29	47	44	9
0 421/1 5	61	28	11	98	2	0
1 3 5/0 0	23	44	33	51	44	5
1 3 5/0 0	41	36	23	79	18	4
0 2 5/1 5	41	41	18	82	14	4

N=	LOCATION 1/4	S	T	R	SURF. ELEV.	SAMP. DEPTH
2213	DDD	12	147	36	1470	4
2221	DAA	18	147	36	1490	6
2217	BCC	3	147	36	1500	4
2162	BAA	21	147	35	1440	3
2161	AAB	33	147	35	1450	3
2160	AAA	5	147	34	1430	4
2153-1	DDA	32	147	32	1370	3
2153-2	DDA	32	147	32	1370	5
2151	CCC	13	147	30	1310	4

DESC.	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
0 2 2/1 5	41	38	21	74	17	8
1 6 5/0 0	42	46	12	74	25	0
0 2 2/1 5	19	46	35	42	50	8
1 3 5/0 0	29	47	24	94	1	5
1 3 5/0 0	31	40	29	88	3	9
0 332/1 5	16	40	44	67	30	3
1 3 5/0 5	27	38	35	97	2	1
0 3 5/1 5	9	58	33	82	10	8
0 2 2/1 5	22	39	39	56	34	10

APPENDIX II

TABULATED SUBSURFACE DATA

TABULATED SUBSURFACE DATA

This appendix contains a tabulated summary of laboratory analysis of subsurface samples (Table 4), a tabulated summary of occurrence and site averages of lithostratigraphic units (Table 5), and a tabulated summary of means, medians, modes, and standard deviations of site averages for lithostratigraphic units (Table 6).

The table headings for Table 4 include N-number, location, sample depth, texture, and lithology. These headings are discussed below.

The N-number is a unique sample number in the North Dakota Geological Survey sample library.

The location of the sample site is given as the quarter of the quarter of the quarter (A is NE¼, B is NW¼, C is SW¼, D is SE¼) of the section(s) in which it is located. The township in which the site is located is indicated by its township number (T) and range number (R).

The elevation of the sample and the sample depth are given in feet.

The texture of the sample is given as the percentage content of sand (SD), silt (SLT), and clay (CLY).

The lithology of the coarse-sand fraction of the sample is given as the percentage content of crystalline- and metamorphic-rock fragments (XTAL), carbonate-rock fragments (CO_3), and shale fragments (SH).

N=	LOCATION 1/4	S	T	R	SAMP. ELEV.
140	AAA	30	150	44	1034
140	AAA	30	150	44	1029
140	AAA	30	150	44	1024
140	AAA	30	150	44	1019
140	AAA	30	150	44	1017
141	BBB	25	149	44	1137
141	BBB	25	149	44	1134
141	BBB	25	149	44	1129
141	BBB	25	149	44	1124
141	BBB	25	149	44	1119
141	BBB	25	149	44	1114
144	DDD	17	147	45	950
144	DDD	17	147	45	945
144	DDD	17	147	45	940
144	DDD	17	147	45	935
144	DDD	17	147	45	930
144	DDD	17	147	45	925
144	DDD	17	147	45	920
144	DDD	17	147	45	915
144	DDD	17	147	45	910
144	DDD	17	147	45	905
146	DDA	28	145	45	948
146	DDA	28	145	45	946
146	DDA	28	145	45	944
146	DDA	28	145	45	940
146	DDA	28	145	45	934
1008	CAD	18	151	43	1045
1008	CAD	18	151	43	1042
1008	CAD	18	151	43	1039
1008	CAD	18	151	43	1036

SAMP.	TEXTURE			LITHOLOGY		
DEPTH	SD	SLT	CLY	XTAL	CO3	SH
6	10	37	53	49	41	10
11	17	40	43	39	46	15
16	32	37	31	58	37	5
21	44	41	15	63	34	4
23	42	42	16	63	34	3
13	37	41	22	48	50	2
16	10	69	21	65	35	0
21	12	44	44	72	28	0
26	6	62	32	64	36	0
31	54	33	13	57	40	3
36	51	32	17	50	46	4
6	9	24	67	70	30	0
11	6	47	47	62	27	11
16	41	45	14	51	46	4
21	42	38	20	57	40	3
26	43	37	20	56	41	3
31	42	44	14	56	39	5
36	41	45	14	53	45	2
41	34	47	19	49	50	1
46	30	58	12	52	41	7
51	3	76	21	0	0	0
7	16	67	17	55	42	3
9	36	48	16	51	46	2
11	41	43	16	50	48	2
15	41	44	15	24	5	71
21	31	50	19	44	55	1
6	28	34	38	56	29	15
9	34	47	19	48	31	20
12	35	40	25	54	32	14
15	35	42	23	0	0	0

N=	LOCATION 1/4	S	T	R	SAMP. ELEV.
1008	CAD	18	151	43	1033
1008	CAD	18	151	43	1030
1008	CAD	18	151	43	1027
1008	CAD	18	151	43	1024
1008	CAD	18	151	43	1021
1008	CAD	18	151	43	1016
1008	CAD	18	151	43	1013
1008	CAD	18	151	43	1010
1008	CAD	18	151	43	1007
1008	CAD	18	151	43	1004
1008	CAD	18	151	43	1001
1011	BCD	16	151	44	1006
1011	BCD	16	151	44	999
1011	BCD	16	151	44	995
1011	BCD	16	151	44	989
1011	BCD	16	151	44	983
1011	BCD	16	151	44	980
1011	BCD	16	151	44	957
1914	CBB	18	148	37	1455
1914	CBB	18	148	37	1450
1914	CBB	18	148	37	1445
1914	CBB	18	148	37	1440
1914	CBB	18	148	37	1435
1914	CBB	18	148	37	1430
1914	CBB	18	148	37	1425
1914	CBB	18	148	37	1390
1914	CBB	18	148	37	1385
1914	CBB	18	148	37	1380
1914	CBB	18	148	37	1370
1914	CBB	18	148	37	1365

SAMP. DEPTH	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
18	36	46	18	51	31	18
21	34	38	28	52	35	13
24	35	36	29	51	34	16
27	36	44	20	51	31	18
30	41	45	14	56	33	11
35	55	39	6	86	14	0
38	52	37	11	84	16	0
41	56	36	8	88	12	0
44	58	20	22	89	10	0
47	59	32	9	0	0	0
50	60	30	10	87	13	0
12	2	6	92	0	0	0
19	28	32	40	49	30	21
23	36	34	30	51	35	14
29	40	33	27	59	34	7
35	45	33	22	53	44	4
38	43	32	25	54	44	2
61	53	32	15	68	32	0
10	71	22	7	86	14	0
15	23	50	27	68	28	4
20	24	50	26	57	37	6
25	13	57	30	57	40	4
30	12	48	40	50	45	5
35	12	56	32	47	43	10
40	16	68	16	55	27	18
75	43	40	17	53	25	22
80	36	44	20	49	25	26
85	29	40	31	55	21	25
95	53	22	25	81	17	2
100	53	33	14	75	24	1

N=	LOCATION 1/4 S T R	SAMP. ELEV.
1914	CBB 18 148 37	1360
1914	CBB 18 148 37	1355
1914	CBB 18 148 37	1340
1914	CBB 18 148 37	1335
1914	CBB 18 148 37	1330
1914	CBB 18 148 37	1327
1914	CBB 18 148 37	1323
1914	CBB 18 148 37	1320
1914	CBB 18 148 37	1310
1915	CCD 12 146 37	1565
1915	CCD 12 146 37	1560
1915	CCD 12 146 37	1555
1915	CCD 12 146 37	1550
1915	CCD 12 146 37	1545
1915	CCD 12 146 37	1540
1915	CCD 12 146 37	1535
1915	CCD 12 146 37	1530
1915	CCD 12 146 37	1525
1915	CCD 12 146 37	1520
1915	CCD 12 146 37	1515
1915	CCD 12 146 37	1510
1915	CCD 12 146 37	1505
1915	CCD 12 146 37	1500
1915	CCD 12 146 37	1495
1915	CCD 12 146 37	1490
1915	CCD 12 146 37	1485
1915	CCD 12 146 37	1483
1915	CCD 12 146 37	1480
1915	CCD 12 146 37	1478
1915	CCD 12 146 37	1475

SAMP.	TEXTURE			LITHOLOGY		
DEPTH	SD	SLT	CLY	XTAL	CO3	SH
105	48	38	14	74	24	2
110	50	21	29	81	18	1
125	13	72	15	76	24	1
130	61	14	25	83	16	1
135	68	25	7	84	16	0
138	33	37	30	67	30	3
142	50	45	5	83	16	0
145	82	14	4	83	16	1
155	81	0	19	85	15	0
5	29	47	25	67	14	19
10	21	58	21	75	15	10
15	40	49	11	76	17	7
20	44	32	24	81	13	6
25	0	0	0	82	17	0
30	47	34	19	83	17	0
35	32	53	15	88	12	0
40	0	0	0	86	14	0
45	52	38	10	86	14	0
50	51	39	10	86	14	0
55	53	34	13	82	18	0
60	47	41	12	86	14	0
65	88	7	5	75	25	0
70	61	19	20	38	11	0
75	53	23	18	88	12	0
80	64	17	19	90	9	0
85	71	11	18	82	18	0
87	50	32	18	88	11	1
90	57	31	12	89	11	0
92	49	36	15	88	12	0
95	59	26	15	87	13	0

N=	LOCATION 1/4 S T R	SAMP. ELEV.
1915	CCD 12 146 37	1470
1915	CCD 12 146 37	1468
1915	CCD 12 146 37	1455
1915	CCD 12 146 37	1441
1915	CCD 12 146 37	1440
1915	CCD 12 146 37	1435
1915	CCD 12 146 37	1430
1915	CCD 12 146 37	1425
1915	CCD 12 146 37	1425
1915	CCD 12 146 37	1420
1916	BCC 28 144 37	1710
1916	BCC 28 144 37	1705
1916	BCC 28 144 37	1700
1916	BCC 28 144 37	1695
1916	BCC 28 144 37	1690
1916	BCC 28 144 37	1685
1916	BCC 28 144 37	1680
1916	BCC 28 144 37	1675
1916	BCC 28 144 37	1670
1916	BCC 28 144 37	1665
1916	BCC 28 144 37	1657
1916	BCC 28 144 37	1655
1916	BCC 28 144 37	1650
1916	BCC 28 144 37	1647
1916	BCC 28 144 37	1635
1916	BCC 28 144 37	1630
1916	BCC 28 144 37	1625
1916	BCC 28 144 37	1615
1916	BCC 28 144 37	1610
1916	BCC 28 144 37	1605

SAMP. DEPTH	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
100	60	19	21	85	15	0
102	61	5	34	88	12	0
115	82	6	12	0	0	0
129	64	25	11	90	10	0
130	62	17	21	87	13	0
135	38	27	35	71	28	1
140	36	29	35	73	26	1
145	36	37	27	72	27	1
145	34	34	32	70	28	3
150	34	33	33	68	29	3
10	49	35	16	83	17	0
15	51	30	19	83	17	0
20	74	20	6	86	14	0
25	50	24	26	85	15	0
30	47	33	20	83	16	0
35	45	42	13	84	16	0
40	54	29	17	86	14	0
45	49	36	15	84	16	0
50	39	44	17	83	17	0
55	38	46	16	82	17	0
63	34	49	17	84	16	0
65	49	36	15	78	22	0
70	41	46	13	83	17	0
73	43	43	14	83	17	0
85	83	11	6	0	0	0
90	85	9	6	83	17	0
95	42	41	17	89	11	0
105	42	39	19	84	16	0
110	78	22	0	80	20	0
115	60	33	7	79	21	0

N=	LOCATION 1/4	S	T	R	SAMP. ELEV.
1916	BCC	28	144	37	1595
1916	BCC	28	144	37	1587
1916	BCC	28	144	37	1583
1916	BCC	28	144	37	1576
1916	BCC	28	144	37	1572
1916	BCC	28	144	37	1570
1916	BCC	28	144	37	1567
1916	BCC	28	144	37	1565
1917	CCD	6	144	41	1215
1917	CCD	6	144	41	1210
1917	CCD	6	144	41	1205
1917	CCD	6	144	41	1198
1917	CCD	6	144	41	1192
1917	CCD	6	144	41	1190
1917	CCD	6	144	41	1185
1917	CCD	6	144	41	1180
1917	CCD	6	144	41	1175
1917	CCD	6	144	41	1170
1917	CCD	6	144	41	1165
1917	CCD	6	144	41	1162
1917	CCD	6	144	41	1160
1917	CCD	6	144	41	1150
1917	CCD	6	144	41	1149
1917	CCD	6	144	41	1142
1917	CCD	6	144	41	1140
1917	CCD	6	144	41	1135
1917	CCD	6	144	41	1133
1917	CCD	6	144	41	1125
1917	CCD	6	144	41	1120
1917	CCD	6	144	41	1117

SAMP. DEPTH	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
125	86	14	0	0	0	0
133	72	23	5	86	14	0
137	46	35	18	76	24	0
144	39	29	32	65	35	0
148	27	44	29	64	35	0
150	14	48	38	52	47	1
153	24	41	35	69	31	0
155	14	50	36	61	39	1
10	24	47	29	58	41	1
15	4	81	15	51	32	17
20	57	29	14	56	36	8
27	29	33	38	38	33	29
33	26	39	35	33	24	44
35	34	38	28	44	31	25
40	27	41	32	39	32	29
45	19	52	29	50	24	26
50	29	40	31	46	29	25
55	20	45	35	45	34	21
60	23	67	10	49	29	22
63	25	39	36	46	32	22
65	57	29	14	54	30	16
75	36	44	20	76	17	6
76	19	50	31	45	31	24
83	32	38	30	62	24	14
85	23	49	28	76	18	6
90	34	43	23	86	12	2
92	24	40	36	82	17	1
100	57	16	27	88	12	0
105	39	37	24	87	12	1
108	4	72	24	79	19	2

N=	LOCATION 1/4	S	T	R	SAMP. ELEV.
1917	CCD	6	144	41	1115
1917	CCD	6	144	41	1087
1917	CCD	6	144	41	1085
1917	CCD	6	144	41	1083
1917	CCD	6	144	41	1077
1918	BCB	36	142	44	1165
1918	BCB	36	142	44	1160
1918	BCB	36	142	44	1158
1918	BCB	36	142	44	1155
1918	BCB	36	142	44	1150
1918	BCB	36	142	44	1145
1918	BCB	36	142	44	1135
1918	BCB	36	142	44	1134
1918	BCB	36	142	44	1130
1918	BCB	36	142	44	1122
1918	BCB	36	142	44	1120
1918	BCB	36	142	44	1115
1918	BCB	36	142	44	1110
1918	BCB	36	142	44	1105
1918	BCB	36	142	44	1100
1918	BCB	36	142	44	1096
1918	BCB	36	142	44	1095
1918	BCB	36	142	44	1085
1918	BCB	36	142	44	1080
1918	BCB	36	142	44	1075
1918	BCB	36	142	44	1070
1918	BCB	36	142	44	1065
1918	BCB	36	142	44	1060
1918	BCB	36	142	44	1055
1918	BCB	36	142	44	1050

SAMP.	TEXTURE			LITHOLOGY		
DEPTH	SD	SLT	CLY	XTAL	CO3	SH
110	0	76	24	0	0	0
138	46	25	29	86	14	0
140	42	32	26	89	11	0
142	23	50	27	88	12	0
148	38	40	22	86	14	0
5	30	37	33	50	37	13
10	34	36	30	50	38	11
12	23	41	36	48	41	10
15	15	54	31	46	31	23
20	49	29	22	51	27	22
25	30	49	21	61	29	10
35	45	35	20	70	28	1
36	44	41	15	74	24	2
40	17	58	25	69	28	4
48	44	42	14	60	20	21
50	4	58	38	63	23	13
55	55	33	12	53	26	21
60	58	28	14	70	28	2
65	64	27	9	73	22	5
70	6	77	17	61	28	11
74	37	30	33	48	26	26
75	13	46	41	42	25	33
85	29	48	23	73	25	2
90	30	34	36	47	28	24
95	16	43	41	33	25	42
100	25	36	39	32	21	47
105	16	44	40	33	20	46
110	28	33	39	36	26	37
115	26	33	41	34	24	42
120	38	36	26	51	27	22

N=	LOCATION 1/4 S T R	SAMP. ELEV.
1918	BCB 36 142 44	1050
1918	BCB 36 142 44	1050
1918	BCB 36 142 44	1050
1919	BCB 29 147 42	1220
1919	BCB 29 147 42	1215
1919	BCB 29 147 42	1210
1919	BCB 29 147 42	1205
1919	BCB 29 147 42	1200
1919	BCB 29 147 42	1195
1919	BCB 29 147 42	1190
1919	BCB 29 147 42	1185
1919	BCB 29 147 42	1180
1919	BCB 29 147 42	1175
1919	BCB 29 147 42	1173
1919	BCB 29 147 42	1171
1919	BCB 29 147 42	1169
1919	BCB 29 147 42	1165
1919	BCB 29 147 42	1160
1919	BCB 29 147 42	1155
1919	BCB 29 147 42	1150
1919	BCB 29 147 42	1145
1919	BCB 29 147 42	1140
1919	BCB 29 147 42	1135
1919	BCB 29 147 42	1132
1919	BCB 29 147 42	1129
1919	BCB 29 147 42	1109
1920-A	ABB 11 150 42	1118
1920-A	ABB 11 150 42	1112
1920-A	ABB 11 150 42	1110
1920-A	ABB 11 150 42	1107

SAMP.	TEXTURE			LITHOLOGY		
DEPTH	SD	SLT	CLY	XTAL	CO3	SH
120	33	42	25	66	26	8
120	37	30	33	53	24	23
120	33	33	34	65	27	9
5	32	42	26	62	37	1
10	33	45	22	61	37	2
15	20	49	31	40	57	3
20	26	47	27	49	49	2
25	26	44	30	51	47	2
30	34	40	26	46	48	6
35	12	50	38	60	37	3
40	20	43	37	57	41	2
45	16	46	38	52	44	5
50	1	27	72	0	86	14
52	36	43	21	42	34	24
54	30	34	36	44	32	24
56	21	46	33	53	44	4
60	40	31	29	40	35	25
65	44	44	12	43	35	22
70	50	18	32	81	19	0
75	25	42	33	31	28	41
80	46	42	12	67	29	4
85	42	35	23	51	24	25
90	31	42	27	33	12	55
93	38	45	17	70	19	11
96	39	47	14	83	15	2
116	31	55	14	38	27	36
8	4	65	31	21	14	65
14	38	46	16	57	36	7
16	38	45	17	50	38	12
19	30	54	16	59	30	11

N=	LOCATION 1/4 S T R	SAMP. ELEV.
1920-A	ABB 11 150 42	1099
1920-A	ABB 11 150 42	1097
1920-A	ABB 11 150 42	1090
1920-A	ABB 11 150 42	1087
1920-A	ABB 11 150 42	1084
1920-A	ABB 11 150 42	1083
1920-A	ABB 11 150 42	1081
1920-A	ABB 11 150 42	1078
1920-A	ABB 11 150 42	1076
1920-A	ABB 11 150 42	1074
1920-A	ABB 11 150 42	1071
1920-A	ABB 11 150 42	1069
1920-A	ABB 11 150 42	1068
1920-A	ABB 11 150 42	1061
1920-A	ABB 11 150 42	1059
1920-A	ABB 11 150 42	1056
1920-A	ABB 11 150 42	1054
1920-A	ABB 11 150 42	1052
2470	BBB 28 148 34	1485
2470	BBB 28 148 34	1481
2470	BBB 28 148 34	1457
2470	BBB 28 148 34	1451
2470	BBB 28 148 34	1446
2470	BBB 28 148 34	1438
2470	BBB 28 148 34	1436
2470	BBB 28 148 34	1431
2470	BBB 28 148 34	1426
2471	CDD 34 150 31	1356
2471	CDD 34 150 31	1351
2471	CDD 34 150 31	1346

SAMP. DEPTH	TEXTURE SD	SLT	CLY	LITHOLOGY XTAL	CO3	SH
27	39	44	17	55	34	10
29	38	45	17	55	37	8
36	40	41	19	62	32	6
39	38	38	24	54	40	6
42	37	46	17	60	34	5
43	38	45	17	52	45	3
45	40	38	22	58	38	5
48	37	5	54	56	35	9
50	32	49	19	52	43	5
52	37	46	17	49	46	5
55	38	43	19	56	37	7
57	39	44	17	79	20	2
58	28	50	22	61	35	4
65	34	55	21	44	51	5
67	38	42	20	50	46	4
70	36	44	20	46	50	4
72	37	46	17	50	47	3
74	35	47	18	44	52	4
4	46	44	10	78	22	0
9	54	37	9	77	17	7
33	48	36	16	78	13	9
39	44	34	22	65	26	8
44	47	34	19	77	18	5
52	56	32	12	80	16	3
54	59	30	11	80	17	3
59	55	33	11	84	14	2
64	57	32	11	83	16	1
4	36	44	20	65	33	2
9	36	43	21	65	33	1
14	4	75	21	0	0	0

N=	LOCATION 1/4	S	T	R	SAMP. ELEV.
2471	CDD	34	150	31	1341
2471	CDD	34	150	31	1336
2471	CDD	34	150	31	1331
2472	BAB	11	146	31	1346
2472	BAB	11	146	31	1341
2472	BAB	11	146	31	1336
2472	BAB	11	146	31	1331
2472	BAB	11	146	31	1326
2472	BAB	11	146	31	1321
2472	BAB	11	146	31	1286
2474	AAD	1	141	31	1446
2474	AAD	1	141	31	1441
2474	AAD	1	141	31	1439
2475	CB	15	142	34	1576
2475	CB	15	142	34	1572
2475	CB	15	142	34	1566
2475	CB	15	142	34	1561

SAMP.	TEXTURE			LITHOLOGY		
DEPTH	SD	SLT	CLY	XTAL	CO3	SH
19	7	69	25	0	0	0
24	3	71	26	0	0	0
29	4	69	26	0	0	0
4	70	27	3	72	22	7
9	50	35	15	75	16	9
14	27	40	34	63	26	10
19	13	66	21	80	15	5
24	11	69	20	71	21	8
29	4	70	25	0	0	0
64	25	59	16	86	12	1
4	17	45	38	0	0	0
9	35	35	30	89	11	0
11	56	30	14	90	9	1
4	15	66	19	0	0	0
8	62	30	7	87	13	0
14	63	29	8	90	10	0
19	57	35	8	90	10	0

Table 5. Occurrence and site averages of lithostratigraphic units.

	Huot Fm.			Red Lake Falls Fm.			St. Hilaire Fm.			Marcoux Fm.			unnamed unit 2			unnamed unit 1		
	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh
N-140	14	38	48	39	40	21												
	44	44	12	61	35	4												
N-141	9	58	32	52	32	15												
	67	33	0	54	43	4												
N-144	8	36	57	39	45	16												
	66	28	6	53	43	4												
N-146				37	46	16												
				50	48	2												
N-1008				36	42	22				57	32	11						
				52	32	16				87	13	0						
N-1011	2	6	92	38	33	29				53	32	15						
				53	37	10												
N-1914				17	52	31	36	41	23	55	28	17						
				56	39	6	52	24	24	80	19	1						
N-1915							25	52	23	54	31	15	36	32	32			
							71	14	14	87	13	0	71	28	2			
N-1916										47	37	16	42	32	25	20	46	34
										83	16	0	70	30	0	61	38	0
N-1917				24	47	29	28	44	28	36	38	27						
				58	41	1	45	30	26	84	14	2						
N-1918				32	42	26	24	37	39	35	40	26						
				58	31	11	36	24	40	65	28	8						
N-1919				24	45	31	38	37	24	38	46	16						
				53	44	3	44	32	24	76	17	6						

	Huot Fm.			Red Lake Falls Fm.			St. Hilaire Fm.			Marcoux Fm.			unnamed unit 2			unnamed unit 1		
	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh	Sd Xtal	Slt CO_3	Cly Sh
N-1920A				37	43	20												
				55	40	6												
N-2470				50	40	10	46	35	19	57	32	11						
				78	20	4	73	19	7	82	16	2						
N-2471				36	44	20												
				65	33	2												
N-2472							27	40	34									
							63	26	10									
N-2474										46	32	22						
										90	10	0						
N-2475										61	31	8						
										89	11	0						
McI.N.				42	40	18	37	38	25									
				59	38	3	43	27	30									
T.V.D.S.				48	39	13	45	38	17	55	37	8						
				62	33	5	48	23	29	83	16	1						

Table 6. Means, medians, modes, and standard deviations for site averages of lithostratigraphic units.

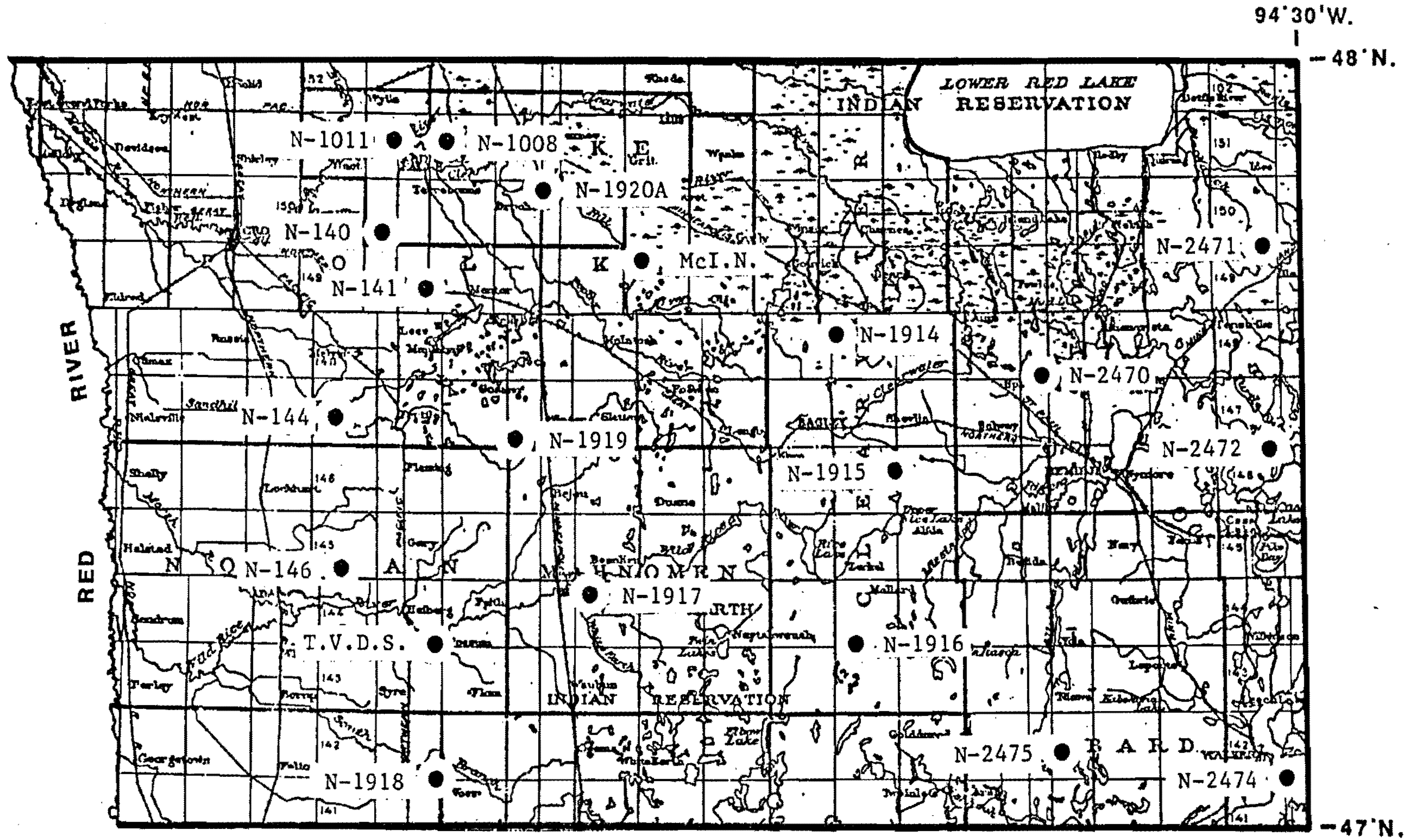
Lithostratigraphic unit	Characteristic	Texture			Coarse-sand lithology		
		Sd	Silt	Clay	Xtal.	CO_3	Sh.
Huot Fm. n = 4	Mean	8	34	57	59	35	6
	Standard deviation	4.9	21.4	25.4	13.0	8.2	6.0
Red Lake Falls Fm. n = 15	Mean	37	42	21	58	37	5
	Median	37	42	20	56	38	4
	Mode	24,36 37,39	40	16,20, 29,31	53	33,43	4
	Standard Deviation	9.7	5.1	6.7	7.0	6.9	4.1
St. Hilaire Fm. n = 9	Mean	34	40	26	53	24	23
	Median	36	38	24	48	24	24
	Mode	-	37,38	23	-	24	24
	Standard Deviation	8.4	5.2	7.0	13.2	5.5	10.9
Marcoux Fm. n = 12	Mean	50	35	16	82	16	2
	Median	53.5	32	15.5	83	16	1
	Mode	55,57	32	11 15,16	83,87	16	0
	Standard Deviation	9.0	5.0	8.1	7.1	4.9	2.7
unnamed unit 2 n = 2	Mean	39	32	28	70	29	1
unnamed unit 1 n = 1	Mean	20	46	34	61	38	0

APPENDIX III

SECTION DESCRIPTIONS

This appendix includes section descriptions for power-auger test holes, Red Lake River sections, and composite sections used in the subsurface study area. A map indicating the location of these sections is included.

Fig. 20. Location of data points in area of subsurface study.


94°30'W.
48°N.
47°N.
LOWER RED LAKE
INDIAN RESERVATION
RED RIVER
N-1011
N-1008
N-1920A
N-140
N-141
McI.N.
N-2471
N-1914
N-2470
N-144
N-1919
N-2472
N-1915
N-146
N-1917
T.V.D.S.
N-1916
N-2475
N-2474
N-1918
INDIAN RESERVATION

N-140

Power-auger Test Hole

NE¼, NE¼, NE¼, sec. 30, T. 150 N., R. 44 W.

Elevation 1040 feet

Section description by K. L. Harris

Depth in Feet	Elev. in Feet	Description
0-4	1040-1036	Road Fill.
Huot Formation		
4-15	1036-1025	Clay; silty; slightly pebbly; olive brown; contains tan, pebble-sized, calcareous inclusions; glacial sediment.
Red Lake Falls Formation		
15-24	1025-1016	Pebble-loam; sandy, silty; crystalline and carbonate pebbles; yellow brown; glacial sediment.

N-141

Power-auger Test Hole

NW¼, NW¼, N W¼, sec. 25, T. 149 N., R. 44 W.

Elevation 1150 feet

Section description by K. L. Harris

Depth in Feet	Elev. in Feet	Description
0-12	1150-1138	Sand; fine to medium grained; brown.
Huot Formation		
12-28	1138-1122	Pebble-loam; silty, clayey; glacial sediment.
Red Lake Falls Formation		
28-44	1122-1106	Pebble-loam; sandy, silty; glacial sediment.

N-144

Power-auger Test Hole

SE¼, SE¼, SE¼, sec. 17, T. 147 N., R. 45 W.

Elevation 956 feet

Section description by K. L. Harris

Depth in Feet	Elev. in Feet	Description
0-4	956-952	Road Fill.
Huot Formation		
4-14	952-942	Clay; silty; slightly pebbly; olive gray; glacial sediment.
Red Lake Falls Formation		
14-49	942-907	Pebble-loam; silty, sandy; crystalline and carbonate pebbles; yellow brown; glacial sediment.
49-54	907-902	Silt; sandy; yellow brown.

N-146

Power-auger Test Hole

SE¼, SE¼, NE¼, sec. 28, T. 145 N., R. 45 W.

Elevation 955 feet

Section description by K. L. Harris

Depth in Feet	Elev. in Feet	Description
0-4	955-951	Sand; gray white; limonitic stains.
Red Lake Falls Formation		
4-22	951-933	Pebble-loam; silty, sandy; yellow brown; jointed; limonitic stains on joints; glacial sediment.

N-172

Twin Valley Dam Site

Composite Section

SW¼, sec. 26, T. 144 N., R. 44 W.

Elevation 1105 feet

Section description by K. L. Harris

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-35	1105-1070	Pebble-loam; sandy, silty; carbonate and crystalline pebbles; yellow brown; glacial sediment.
St. Hilaire Formation		
35-80	1070-1025	Pebble-loam; sandy, silty; carbonate, crystalline, and shale pebbles; gray; glacial sediment.
80-100	1025-1005	Sand.
Marcoux Formation		
100-150	1005-955	Pebble-loam; sandy; crystalline and carbonate pebbles; light gray; glacial sediment.

N-505, 506, 520, 521

McIntosh Channel, North

Composite Section

Elevation 1300 feet

Section description by K. L. Harris

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-24	1300-1276	Pebble-loam; sandy, silty; crystalline and carbonate pebbles; minor

		shale pebbles; yellow brown; glacial sediment.
24-75	1276-1225	Silt; sandy.
75-125	1225-1175	Sand.
St. Hilaire Formation		
125-150	1175-1150	Pebble-loam; silty, sandy; carbonate, crystalline, and shall pebbles; gray; glacial sediment.
Marcoux Formation		
150-155	1150-1145	Pebble-loam; sandy; crystalline and carbonate pebbles; light gray; glacial sediment.

N-1008

Red Lake River Section

SW¼, NE¼, SE¼, sec. 18, T. 151 N., R. 43 W.

Elevation 1051 feet

Section description by K. L. Harris

Depth in Feet	Elev. in Feet	Description
Wylie Formation		
0-6	1051-1045	Clay and silt; thinly laminated; clay is olive gray; silt is light brownish gray; laminae thicken upward; sharp lower contact.
Red Lake Falls Formation		
6-35	1045-1016	Pebble-loam; clayey; unbedded; columnar jointing; hard; pale olive; up to 1 foot of gravel present at sharp lower contact; glacial sediment.
Marcoux Formation		
35-56	1016-995	Pebble-loam; sandy; unbedded; hard; light gray; abundant pebbles,

cobbles, and boulders; lower contact not exposed; glacial sediment.

N-1011

Red Lake River Section

NW¼, SW¼, SE¼, sec. 16, T. 151 N., R. 44 W.

Elevation 1018 feet

Section description by K. L. Harris

Depth in Feet	Elev. in Feet	Description
Huot Formation		
0-13	1018-1055	Clay; slightly pebble; unbedded; gray; contains tan, pebble-sized, calcareous inclusions; sharp lower contact; glacial sediment.
Wylie Formation		
13-18	1005-1000	Clay and silt; thinly laminated; clay is olive gray; silt is light brownish gray; laminae thicken upward; gradational lower contact.
Red Lake Falls Formation		
18-26	1000-992	Pebble-loam; silty, clayey; unbedded; friable; light brownish gray; glacial sediment.
26-38	992-980	Pebble-loam; sandy, silty; unbedded; light brownish gray; sharp lower contact; glacial sediment.
Marcoux Formation		
38-60	980-958	Sand; alternating fine and medium grained; flat-bedded to ripple cross-bedded; jointed; limonitic stains; gravel from 56-60 feet.
60-78	958-940	Pebble-loam; sandy; unbedded; friable; light gray; lower contact not exposed; glacial sediment.

N-1914

Power-auger Test Hole

SW¼, NW¼, NW¼, sec. 18, T. 148 N., R. 37 W.

Elevation 1465 feet

Section description by S. R. Moran, K. L. Harris, and D. K. Sackreiter

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-40	1465-1425	Pebble-loam; silty, clayey; carbonate and crystalline pebbles; minor shale pebbles; glacial sediment.
40-56	1425-1409	Sand; fine grained; gray.
St. Hilaire Formation		
56-83	1409-1382	Pebble-loam; sandy; lower 3 feet silty; abundant carbonate pebbles; glacial sediment.
83-83	1382-1380	Sand; medium grained; wet.
85-80	1380-1376	Pebble-loam; silty; contains abundant carbonate pebbles; interbedded, slightly pebbly silt; glacial sediment.
89-95	1370-1323	Pebble-loam; silty; very stony at 95 feet; glacial sediment.
Marcoux Formation		
95-142	1370-1323	Pebble-loam; very sandy; abundant carbonate pebbles; thin pea gravel at 110 feet; glacial sediment.
142-156	1323-1309	Sand; silty; few pebbles; very hard.

N-1915

Power-auger Test Hole

SW¼, SW¼, SE¼, sec. 12, T. 146 N., R. 37 W.

Elevation 1570 feet

Section description by S. R. Moran, D. K. Sackreiter, and K. L. Harris

Depth in Feet	Elev. in Feet	Description
St. Hilaire Formation		
0-8	1570-1562	Pebble-loam; silty, clayey, brown; glacial sediment.
8-13	1562-1557	Pebble-loam; sandy; reddish brown; glacial sediment.
13-18	1557-1552	Sand; fine-grained, silty; yellow brown.
Marcoux Formation		
18-57	1552-1513	Pebble-loam; silty; crystalline and carbonate pebbles; yellow brown; sandy zone 40 to 50 feet; glacial sediment.
57-61	1513-1509	Pebble-loam; silty, sandy; gray; glacial sediment.
61-71	1509-1499	Sand; slightly gravelly.
71-84	1499-1486	Pebble-loam; sandy; yellow brown; glacial sediment.
84-85	1486-1485	Sand; gravelly.
85-95	1485-1475	Pebble-loam; sandy; yellow brown; glacial sediment.
95-102	1475-1468	Sand; gray.
102-105	1468-1465	Pebble-loam; sandy; gray; glacial sediment.
105-128	1465-1442	Sand; gray.

128-140	1442-1430	Pebble-loam; yellow brown shale pebbles present; glacial sediment.
Unnamed unit 2		
140-150	1430-1420	Pebble-loam; reddish brown; crystalline, carbonate, and reddish volcanic pebbles present; glacial sediment.

N-1916

Power-auger Test Hole

NW¼, SW¼, SW¼, sec. 28, T. 144 N., R. 37 W.

Elevation 1720 feet

Section description by S. R. Moran, D. K. Sackreiter, and K. L. Harris

Depth in Feet	Elev. in Feet	Description
Marcoux Formation		
0-31	1720-1689	Pebble-loam; sandy, silty; abundant stones; glacial sediment.
31-34	1689-1686	Sand; gravelly.
34-62	1686-1658	Pebble-loam; sandy, silty; blue gray; wood at 45 feet; glacial sediment.
62-63	1658-1657	Silt; brown.
63-73	1657-1647	Pebble-loam; sandy, silty; carbonate and crystalline pebbles; brown; glacial sediment.
73-85	1647-1635	Sand; coarse to medium grained; gravelly 80 to 85 feet.
85-105	1635-1615	Sand; medium to fine grained; wood fragments at 95 feet.
105-106	1615-1614	Pebble-loam; glacial sediment.
106-116	1614-1604	Gravel; sandy.
116-134	1604-1586	Sandy gray.

Unnamed unit 2		
134-148	1586-1572	Pebble-loam; sandy; glacial sediment.
Unnamed unit 1		
148-156	1572-1564	Pebble-loam; silty; very hard; stony; greenish gray; glacial sediment.

N-1917

Power-auger Test Hole

SW¼, SW¼, SE¼, sec. 6, T. 144 N., R. 41 W.

Elevation 1225 feet

Section description by S. R. Moran, D. K. Sackreiter, and K. L. Harris

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-15	1225-1210	Pebble-loam; silty; glacial sediment.
15-30	1210-1195	Gravel; sandy; coarse-grained; 20 to 30 feet, fine-grained.
St. Hilaire Formation		
30-76	1195-1149	Pebble-loam; silty; abundant shale pebbles; gray; glacial sediment.
Marcoux Formation		
76-108	1149-1117	Pebble-loam; sandy; stony; light gray; glacial sediment.
108-136	1117-1089	Silt; light gray.
136-150	1089-1075	Pebble-loam; very sandy; stony; very hard; glacial sediment.

N-1918

Power-auger Test Hole

NW¼, SW¼, NW¼, sec. 36, T. 142 N., R. 44 W.

Elevation 1170 feet

Section description by S. R. Moran, D. K. Sackreiter, and K. L. Harris

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-15	1170-1155	Pebble-loam; silty, clayey; brown; glacial sediment.
15-16	1155-1154	Silt; sandy; greenish gray.
16-36	1154-1134	Pebble-loam; sandy, silty; carbonate, crystalline, and shale pebbles; gray; sand at 36 feet; glacial sediment.
36-48	1134-1122	Pebble-loam; sandy; glacial sediment.
48-53	1122-1117	Sand; fine-grained; light gray.
53-56	1117-1114	Silt; laminated; light gray.
56-62	1114-1108	Sand; gravelly.
62-68	1108-1102	Sand; fine-grained; abundant lignite below 65 feet.
68-74	1102-1096	Silt; sandy; interbedded pebble-loam.
St. Hilaire Formation		
74-116	1096-1054	Pebble-loam; silty, sandy; dark gray; abundant shale pebbles, lignite present; glacial sediment.
Marcoux Formation		
116-120	1054-1050	Pebble-loam; sandy; light gray; very hard.

N-1919

Power-auger Test Hole

NW¼, SW¼, NW¼, sec. 29, T. 147 N., R. 42 W.

Elevation 1225 feet

Section description by S. R. Moran and K. L. Harris

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-25	1225-1200	Pebble-loam; sandy; carbonate pebbles predominate; yellow brown to light gray; glacial sediment.
25-45	1200-1180	Pebble-loam; silty, clayey; light gray; silt bed at 35 feet; glacial sediment.
St. Hilaire Formation		
45-50	1180-1175	Sand and silt; interbedded clay.
50-51	1175-1174	Clay; minor interbedded sand.
51-52	1174-1173	Silt.
52-62	1173-1163	Pebble-loam; silty to sandy; stony; glacial sediment.
62-68	1163-1157	Sand; fine-grained.
68-87	1157-1138	Pebble-loam; sandy, silty; abundant shale pebbles; glacial sediment.
Marcoux Formation		
87-91	1138-1134	Pebble-loam; very hard; abundant cobbles; glacial sediment.
91-117	1134-1108	Pebble-loam; sandy; fewer pebbles; very hard at 116 feet; glacial sediment.

N-1920A

Power-auger Test Hole

NE¼, NW¼, NW¼, sec. 11, T. 150 N., R. 42 W.

Elevation 1126 feet

Section description by S. R. Moran and K. L. Harris

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-3	1126-1123	Road Fill.
3-6	1123-1120	Sand and gravel; coarse.
6-42	1120-1084	Pebble-loam; silty, sandy; carbonate and crystalline pebbles, minor shale pebbles; gray; glacial sediment.
42-75	1084-1051	Pebble-loam; sandy; carbonate and crystalline pebbles, minor shale pebbles; stony; cobble concentration 42 to 47 feet; glacial sediment.

N-2470

Power-auger Test Hole

NW¼, NW¼, NW¼, sec. 28, T. 148 N., R. 34 W.

Elevation 1490 feet

Section description by D. K. Sackreiter and B. M. Arndt

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-12	1490-1487	Pebble-loam; silty; carbonate and crystalline pebbles; yellow brown; glacial sediment.
12-17	1478-1473	Sand and gravel.
17-19	1473-1471	Sand; medium to coarse-grained; clean

19-33	1471-1457	Sand and gravel.
St. Hilaire Formation		
33-50	1457-1440	Pebble-loam; sandy, silty; carbonate and crystalline pebbles dominant; shale pebbles present; lignite present; wood fragments present; gray; glacial sediment.
Marcoux Formation		
50-64	1440-1426	Pebble-loam; sandy; carbonate and crystalline pebbles dominant; shale pebbles present; gray; glacial sediment.

N-2471

Power-auger Test Hole

SW¼, SE¼, SE¼, sec. 34, T. 150 N., R. 31 W.

Elevation 1360 feet

Section description by D. K. Sackreiter and B. M. Arndt

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-9	1360-1351	Pebble-loam; silty, sandy; carbonate and crystalline pebbles; yellow brown; glacial sediment.
9-29	1351-1331	Clay; black; wet.

N-2472

Power-auger Test Hole

NW¼, NE¼, NW¼, sec. 11, T. 146 N., R. 31 W.

Elevation 1350 feet

Section description by D. K. Sackreiter

Depth in Feet	Elev. in Feet	Description
Red Lake Falls Formation		
0-9	1350-1341	Sand and gravel.

St. Hilaire Formation

9-19	1341-1331	Pebble-loam; sandy, silty; crystalline and carbonate pebbles dominant; shale pebbles present; glacial sediment.
19-37	1331-1313	Silt; clayey; lignite fragments.
37-39	1313-1311	Gravel; sandy; cobbles.
39-64	1311-1286	Sand; medium to coarse-grained; minor lignite present.

Marcoux Formation

64	1286	Pebble-loam; silty, sandy; glacial sediment.

N-2474

Power-auger Test Hole

NE¼, NE¼, SE¼, sec. 1, T. 141 N., R. 31 W.

Elevation 1450 feet

Section description by D. K. Sackreiter and K. L. Harris

Depth in Feet	Elev. in Feet	Description
0-12	1450-1438	Pebble-loam; silty, sandy; crystalline and carbonate pebbles; yellow brown; glacial sediment.
12-20	1438-1430	Gravel; sandy intervals.
20-64	1430-1386	Sand; medium-grained; yellow brown; dry.

N-2475

Power-auger Test Hole

SW¼, SW¼, NW¼, sec. 15, T. 142 N., R. 34 W.

Elevation 1580 feet

Section description by D. K. Sackreiter and K. L. Harris

Depth in Feet	Elev. in Feet	Description
Marcoux Formation		
0-22	158 - 1558	Pebble-loam; sandy, silty; crystalline and carbonate pebbles; yellow brown; glacial sediment.
22-28	1558-1552	Sand and gravel; very stony at 26 feet; stopped by cobbles at 28 feet.

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REFERENCES

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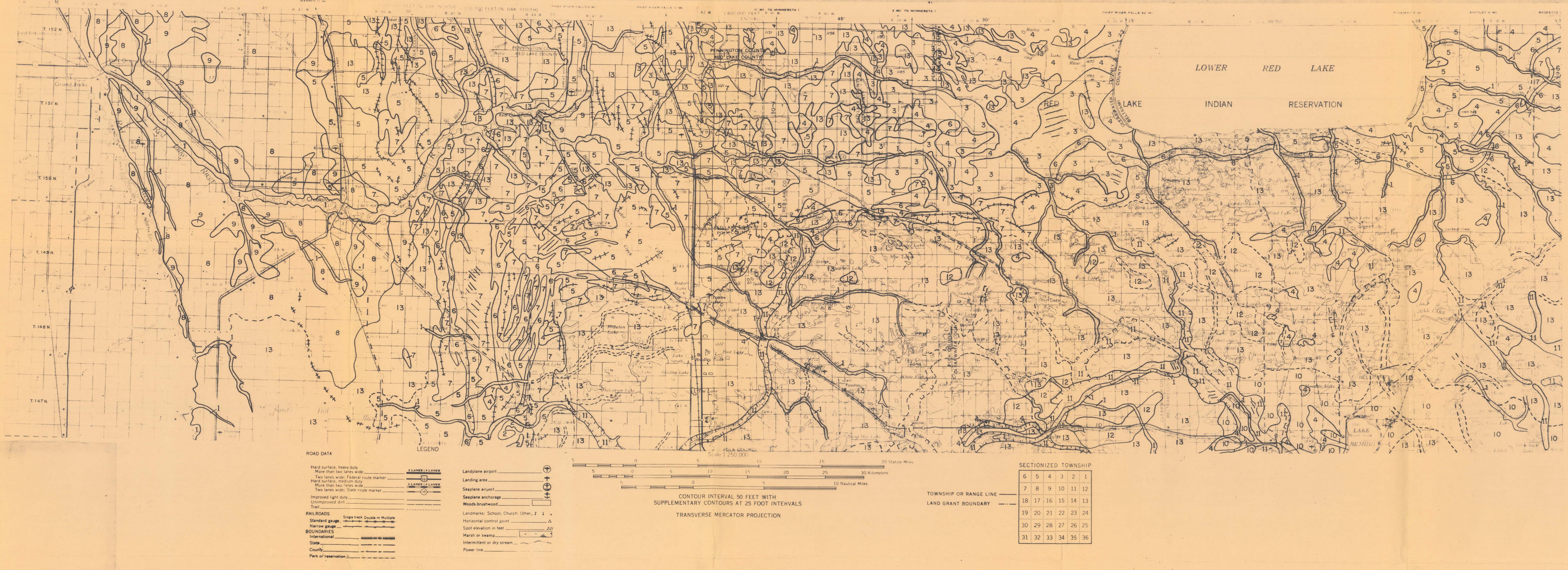
Harris, K. PhD 1975

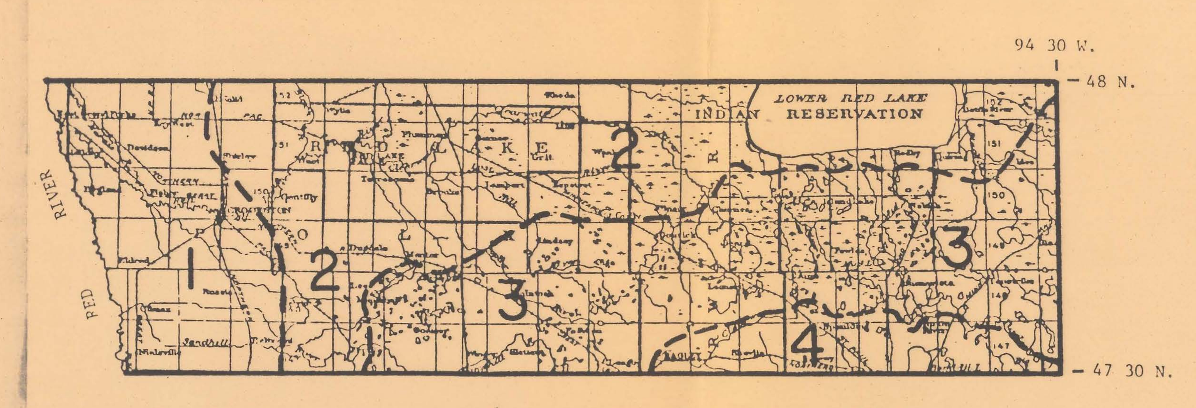
Plate I

SURFICIAL SEDIMENTS OF THE GRAND FORKS – BEMIDJI AREA



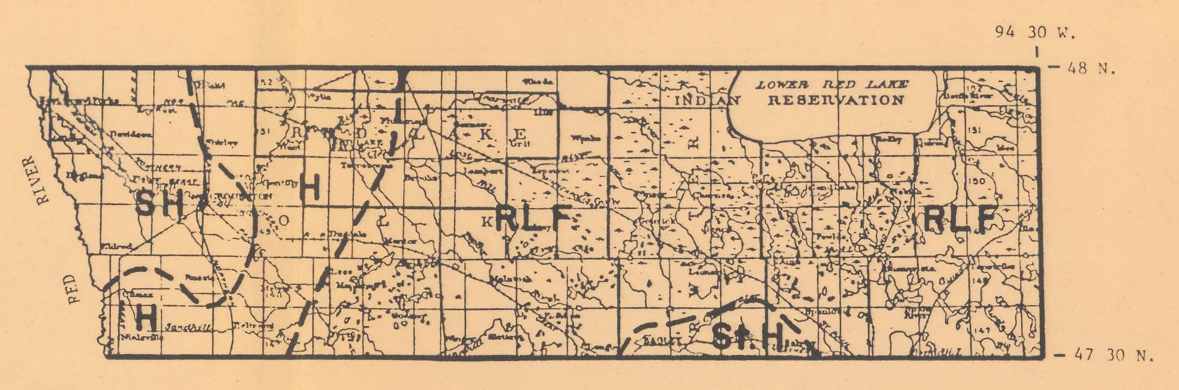
LITHOLOGIC UNITS / GENETIC UNITS	SILT AND CLAY	SAND SILT AND CLAY	SAND	SAND AND GRAVEL	PEBBLE-LOAM	SAND OVER PEBBLE-LOAM	PEAT OVER PEBBLE-LOAM	PEAT
ALLUVIAL SEDIMENT		1						
EOLIAN SEDIMENT			2					
BOG SEDIMENT							3	4
LACUSTRINE SHORELINE SEDIMENT			5	6		7		
LACUSTRINE OFFSHORE SEDIMENT	8	9						
GLACIOFLUVIAL SEDIMENT			10	11		12		
GLACIAL SEDIMENT					13			

MAP UNIT	DESCRIPTION
1	More than a metre of variable amounts of interbedded silt, clay, and organic debris.
2	More than a metre of well sorted, cross-bedded, fine-grained sand.
3	Less than a metre of peat overlying pebble-loam.
4	More than a metre of peat.
5	More than a metre of moderately to well sorted, variably bedded sand.
6	More than a metre of poorly sorted, generally flat-bedded sand and gravel.
7	Less than a metre of moderately to well sorted, variably bedded sand and overlying pebble-loam.
8	More than a metre of laminated silt and clay.
9	More than a metre of laminated sand, silt, and clay.
10	More than a metre of variably bedded, variably sorted sand.
11	More than a metre of variably bedded, poorly sorted sand and gravel.
12	Less than a metre of variably bedded, variably sorted sand overlying pebble-loam.
13	More than a metre of unbedded, unsorted pebble-loam. Pebble-loam contains variable amounts of boulders, cobbles, pebbles, sand, silt, and clay.



GEOMORPHIC PROVINCES OF THE GRAND FORKS-BEMIDJI AREA.

1. Lake-Plain Province
2. Shoreline-Complex Province
3. Glacial-Upland Province
4. Outwash Province



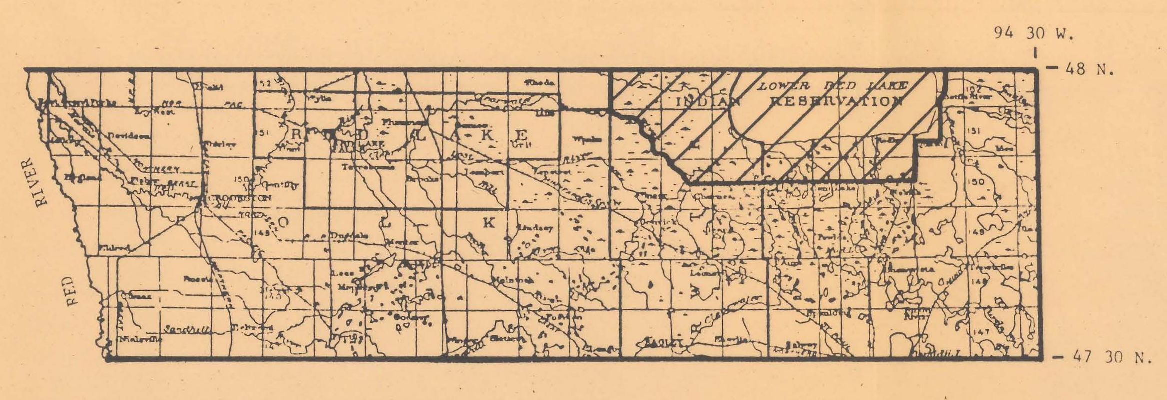
SURFACE EXPOSURE OF LITHOSTRATIGRAPHIC UNITS IN THE GRAND FORKS-BEMIDJI AREA.

SH ------ Sherack Formation

H ------- Huot Formation

RLF ----- Red Lake Falls Formation

St. H --- St. Hilaire Formation



MAP RELIABILITY

--- Aerial photography only

--- Aerial photography and field checking

MAP SYMBOLS

-continuous scarp

-discontinuous scarp

-discontinuous channel or complex of curved ridges

-surface lineations

-curved ridge

MAP UNIT BOUNDARIES

-confident boundary (± .5Km)

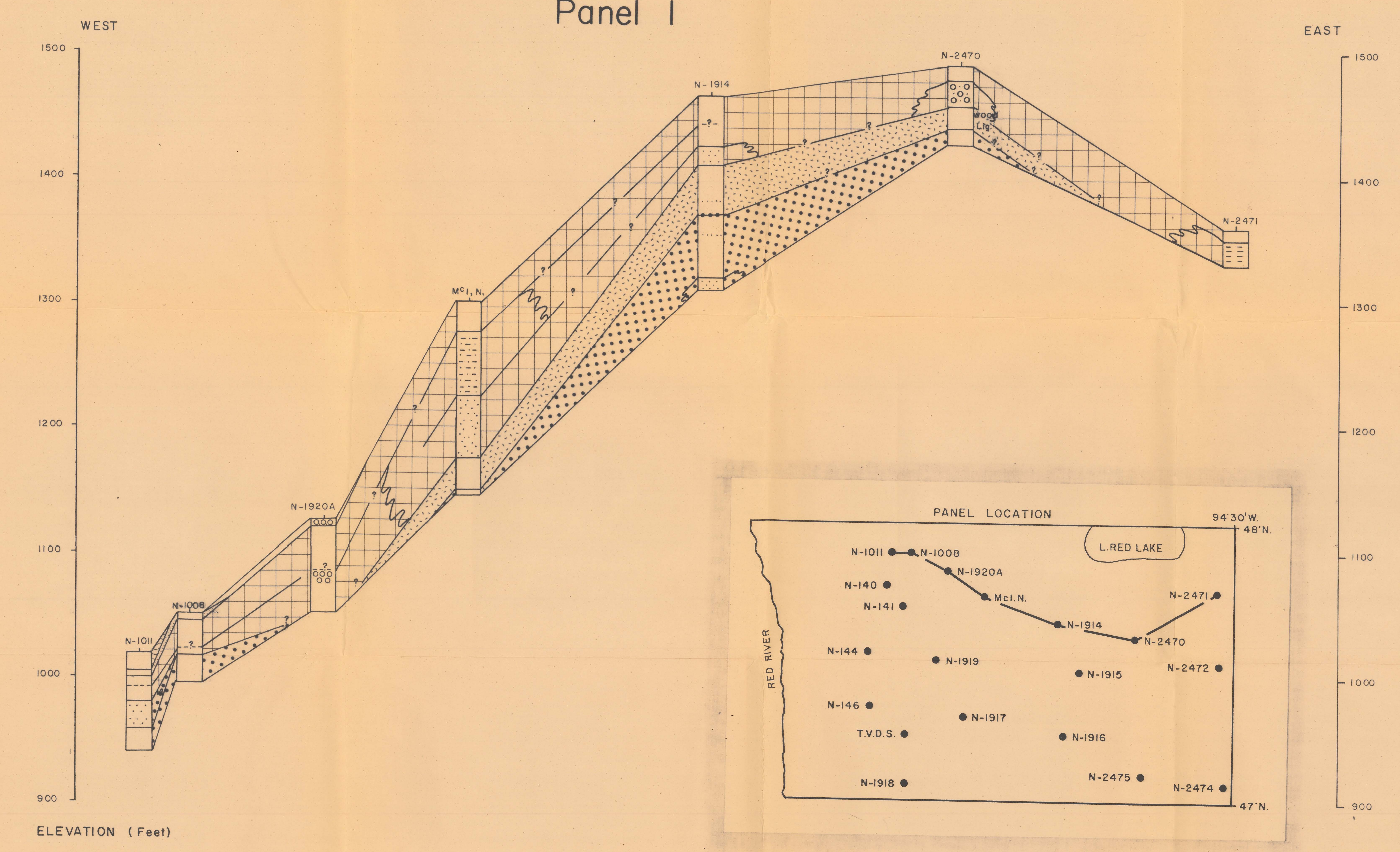
-approximate boundary (± 1Km)

-uncertain boundary (>1Km)

Harris K. PhD. 1975

PLATE 2

Panel 1



LITHOSTRATIGRAPHIC UNITS

- HUOT FORMATION
- WYLIE FORMATION
- RED LAKE FALLS FORMATION
- ST. HILAIRE FORMATION
- MARCOUX FORMATION
- UNNAMED UNIT 2
- UNNAMED UNIT 1

SYMBOLS

- CLAY
- SILT
- SAND
- SAND AND GRAVEL
- COBBLES
- APPROXIMATE CONTACT
- CONTACT
- OXIDIZED ZONE

HORIZONTAL SCALE

8 km
5 Mi.

Panel 2

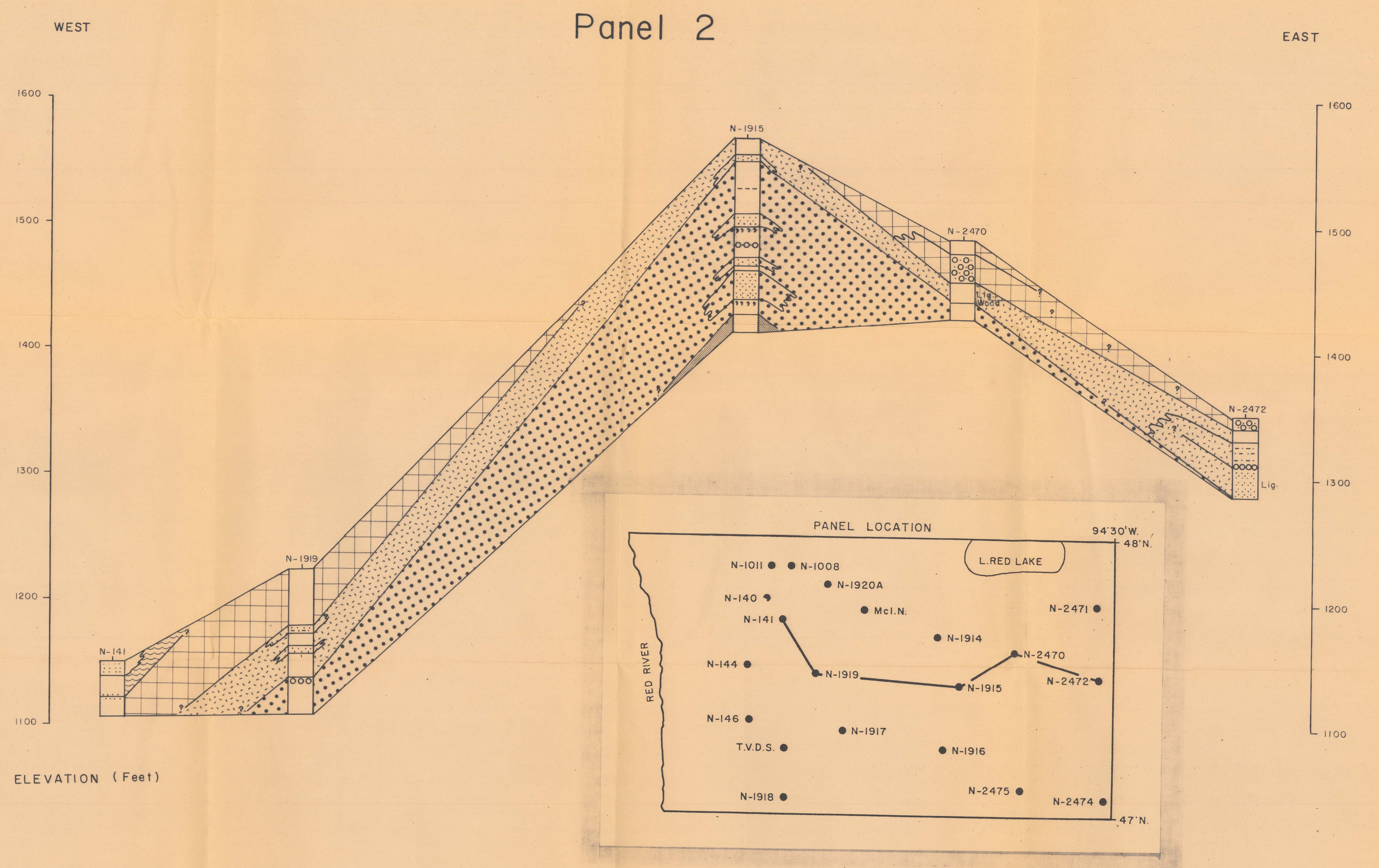


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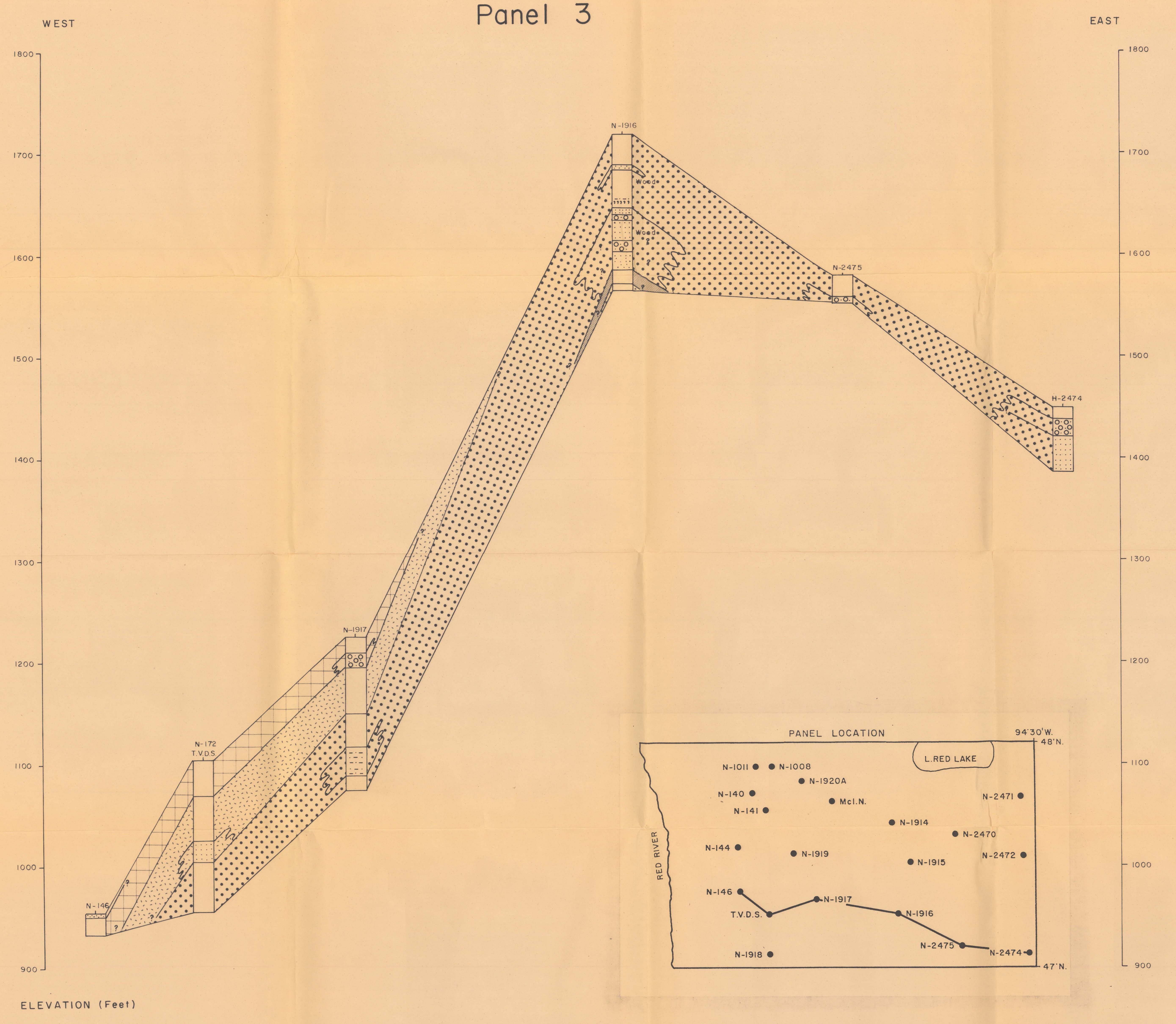
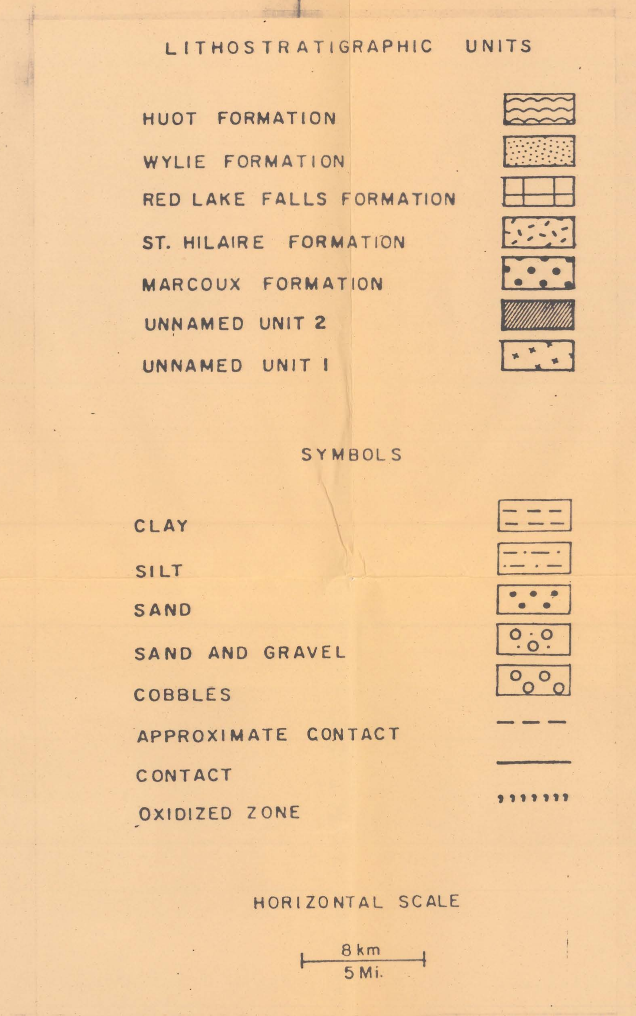
PLATE 3





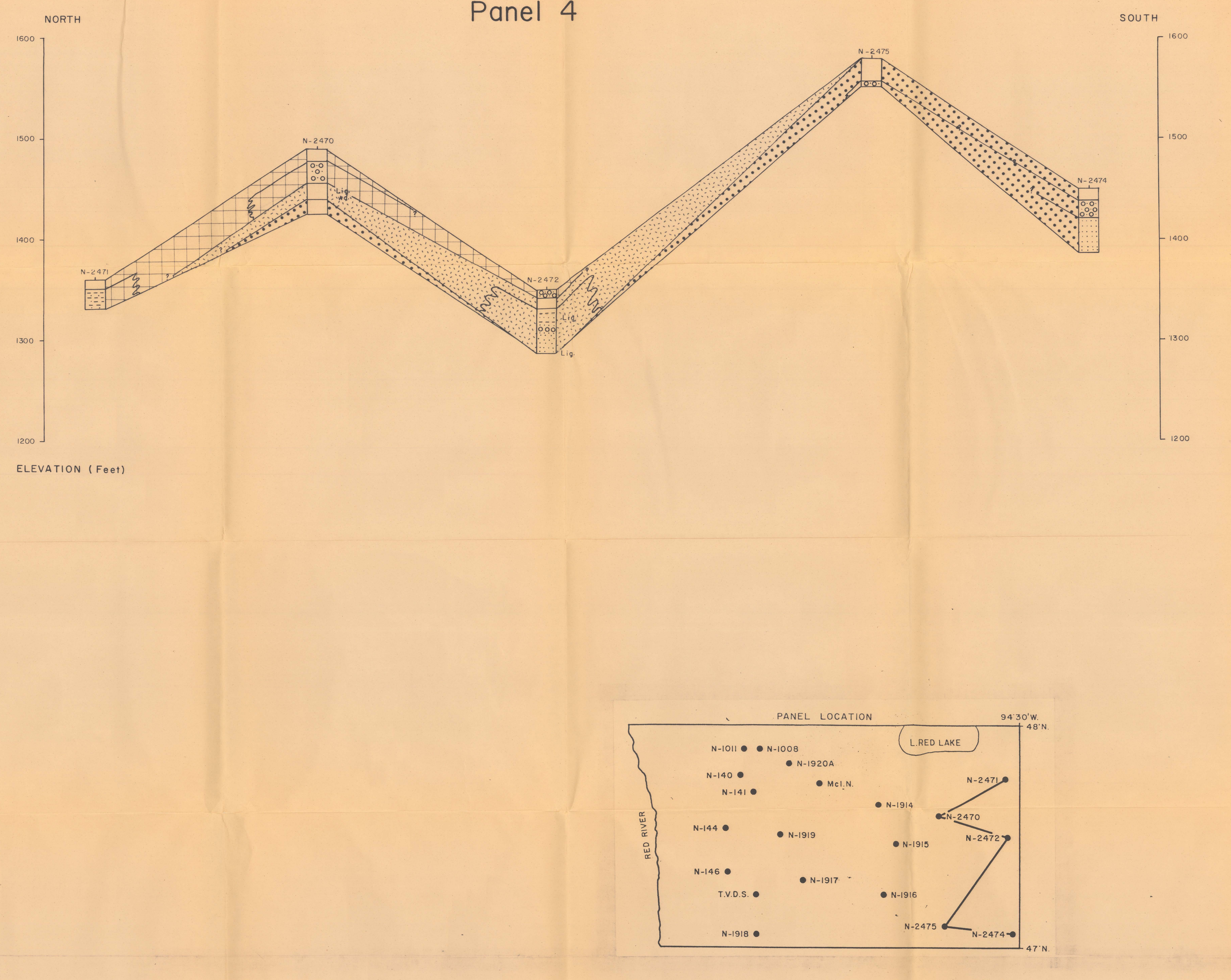


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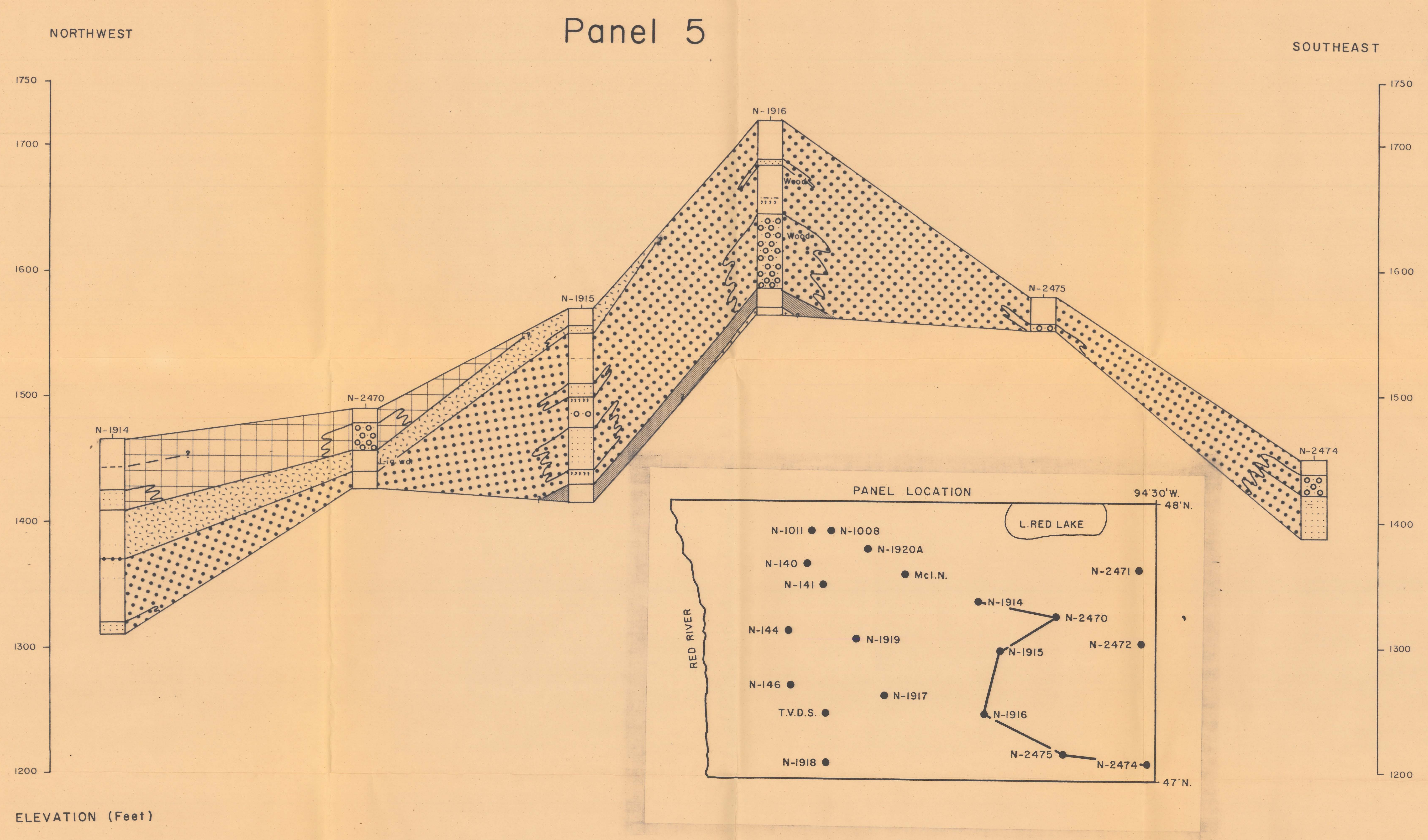
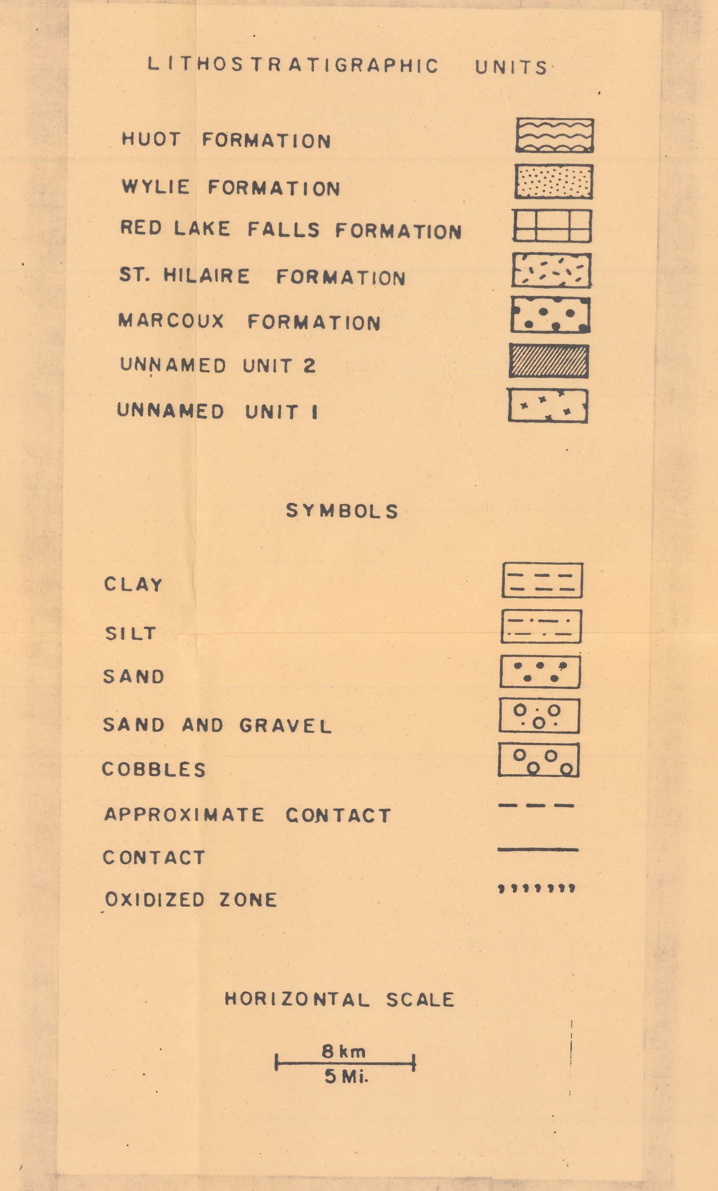
PLATE 4





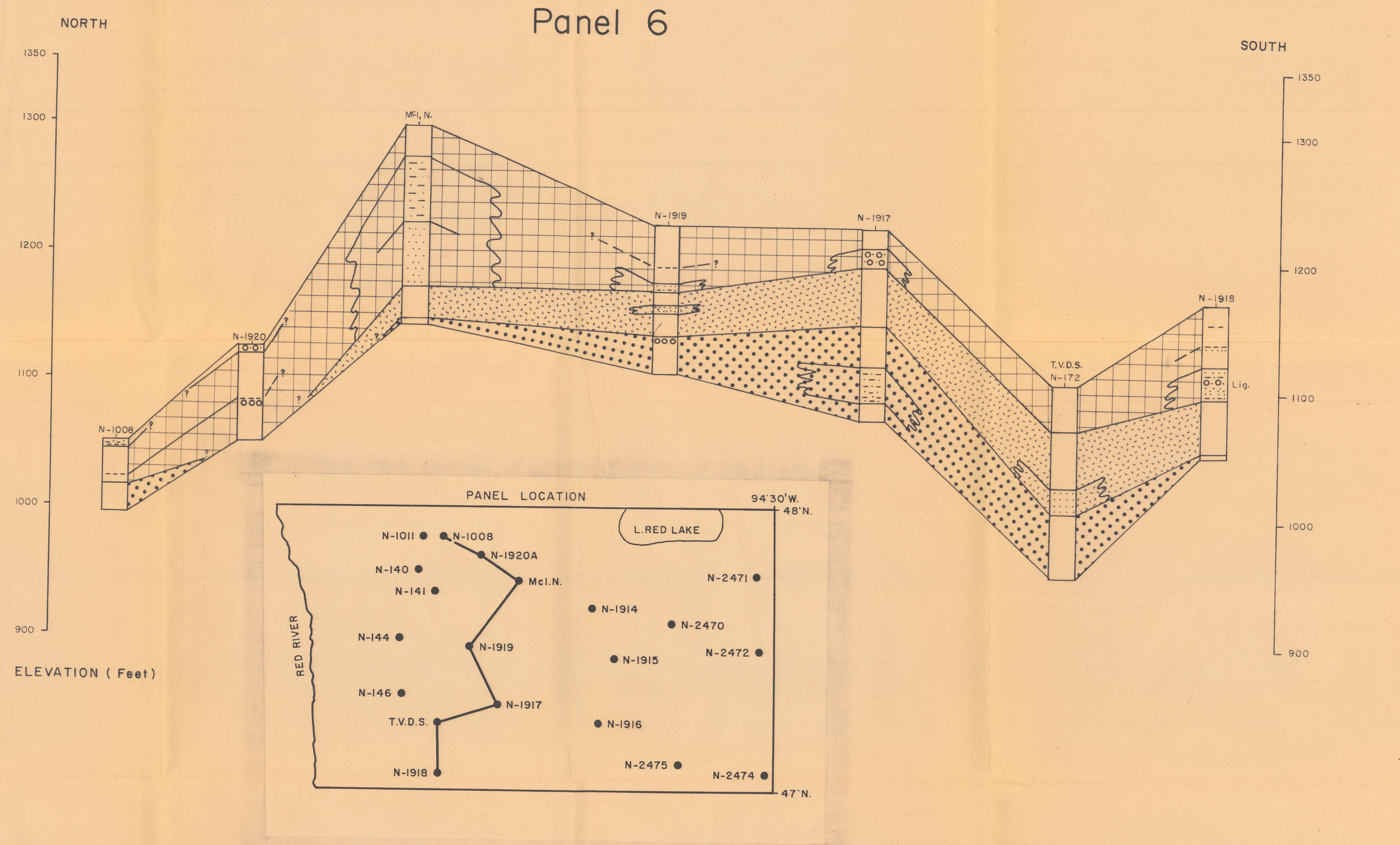


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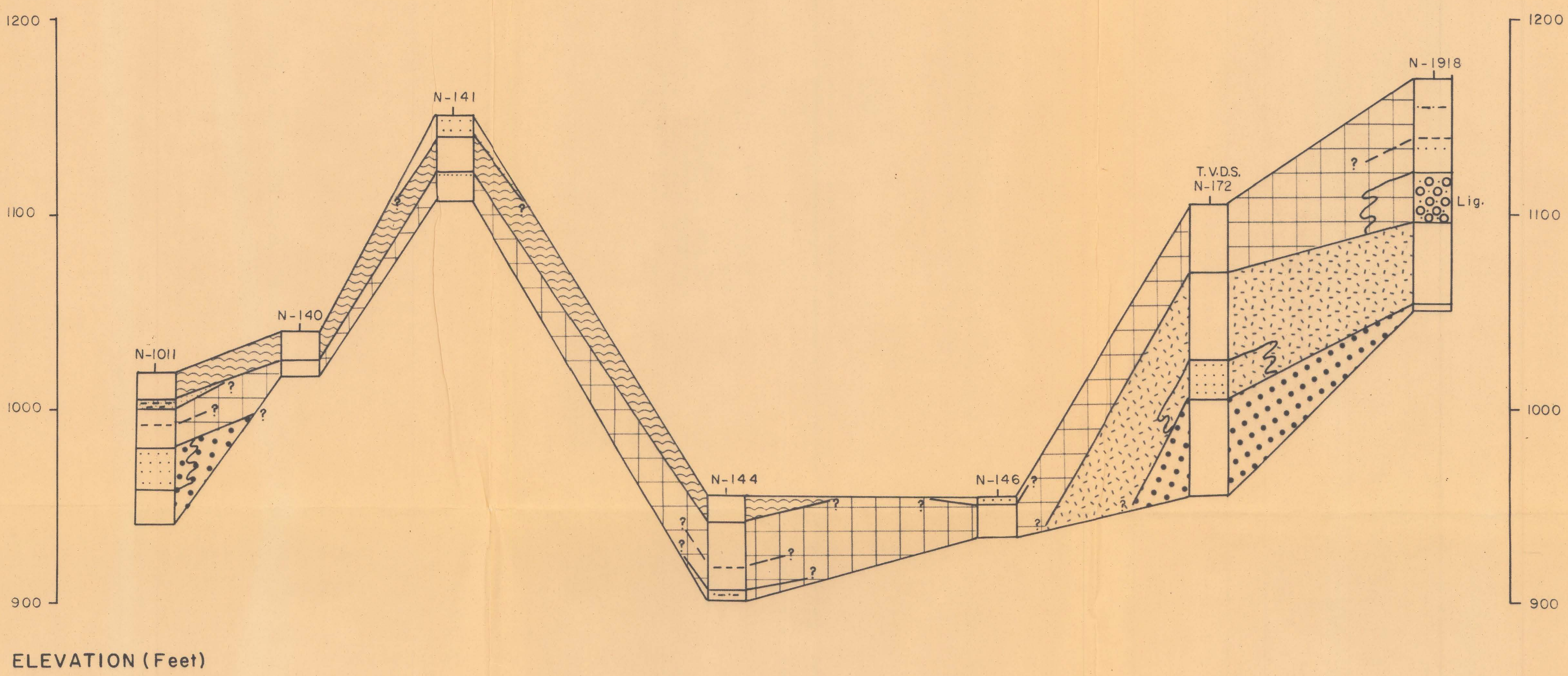
PLATE 5

Panel 7



LITHOSTRATIGRAPHIC UNITS

- HUOT FORMATION
- WYLIE FORMATION
- RED LAKE FALLS FORMATION
- ST. HILAIRE FORMATION
- MARCOUX FORMATION
- UNNAMED UNIT 2
- UNNAMED UNIT 1

SYMBOLS

- CLAY
- SILT
- SAND
- SAND AND GRAVEL
- COBBLES
- APPROXIMATE CONTACT
- CONTACT
- OXIDIZED ZONE

HORIZONTAL SCALE

8 km
5 Mi.

PANEL LOCATION