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Pleistocene stratigraphy of the Red Lake Falls area, Minnesota

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University of North Dakota

PLEISTOCENE STRATIGRAPHY OF THE RED LAKE FALLS AREA, MINNESOTA

by

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This thesis, submitted by Kenneth L. Harris in partial fulfillment of the requirements for the Degree of Master of Science 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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Date April 9, 1973

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ABSTRACT

Seven formations are present along a 50-mile stretch of the Red Lake River in Pennington, Red Lake, and Polk Counties, Minnesota. Five formations are largely glacial sediment, and two are largely lacustrine sediment deposited during phases of Lake Agassiz.

The Gervais Formation (pre-Wisconsinan or early Wisconsinan) is mostly fluvial or lacustrine sediment modified by glacial ice of unknown source. The Marcoux Formation (pre-Wisconsinan or Wisconsinan) is largely sediment deposited by glacial ice that advanced from the northeast over the Canadian Shield. The St. Hilaire Formation (Wisconsinan) is mainly sediment deposited by glacial ice that advanced from a western or northwestern source. The Red Lake Falls Formation (late Wisconsinan) is mostly sediment deposited by glacial ice advancing from the north or northwest. The Wylie Formation (late Wisconsinan) is lacustrine sediment deposited during an early phase of Lake Agassiz. The Huot Formation (late Wisconsinan) is largely sediment deposited by glacial ice advancing from the north, down the axis of the Red River Valley. The Sherack Formation (Holocene) is lacustrine sediment deposited during the last phase of Lake Agassiz.

These formations are correlated with glacial sediment present in northwestern North Dakota, the subsurface of the Red River Valley, western Minnesota, and southwestern Minnesota.

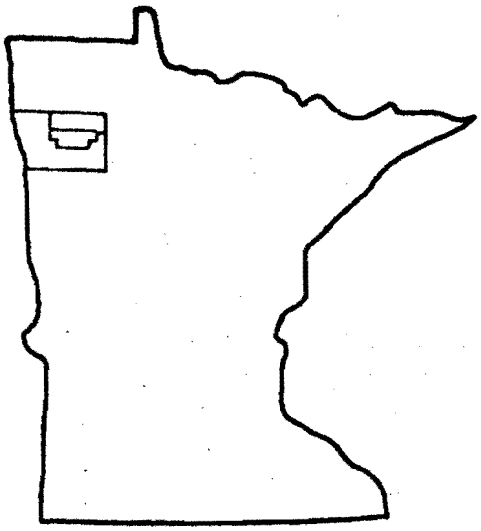
Introduction

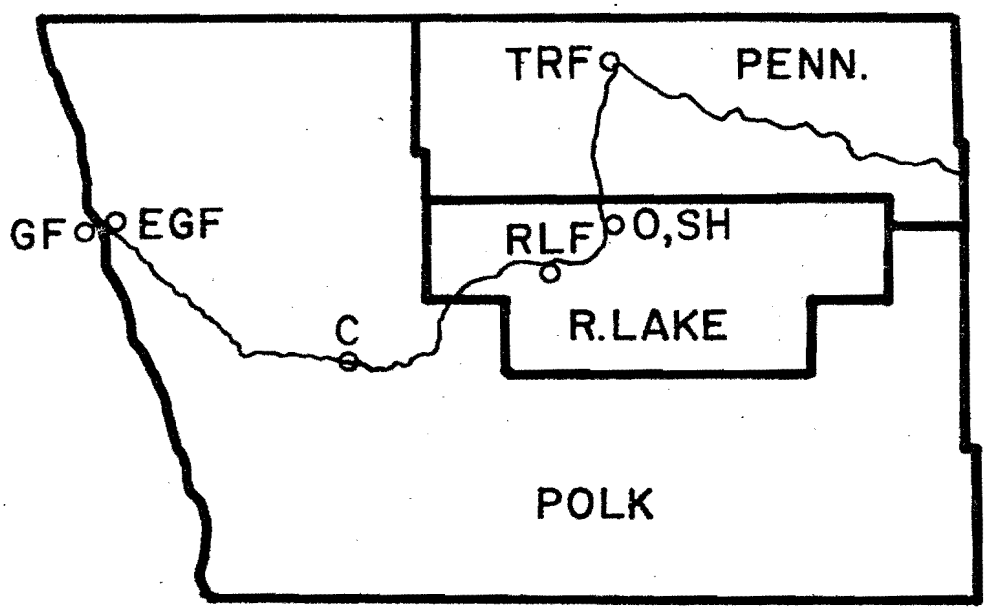
Area of Study

The area of investigation is located at the eastern edge of the Red River Valley in Pennington, Red Lake, and Polk Counties, Minnesota (Figure 1). In most places the local relief is only a few feet. Precambrian igneous and metamorphic rocks underlie the area. They are overlain by about 200 feet of Pleistocene sediment (Bidwell, Winter, and Maclay, 1970), most of which is glacial sediment. The surface sediment in the Red River Valley is mostly silt and clay deposited in the deep water of glacial Lake Agassiz. The Campbell Beach of Lake Agassiz crosses the Red Lake River three miles west of Red Lake Falls. The surface sediment east of Campbell Beach is largely wave-washed glacial sediment.

The cutbanks along a 50-mile reach of the Red Lake River from Thief River Falls to Fisher were studied in detail. The Red Lake River flows from its source, in lower Red Lake, west and south to the Red River of the North at East Grand Forks (Figure 1). Along its course it cuts a trench through the glacial sediment and Lake Agassiz sediment. The best exposures of late Quaternary sediment in the

Fig. 1.--Location of the Study Area




TRF
PENN.
GF
EGF
RLF
O,SH
C
R.LAKE
POLK

Red River Valley and adjacent areas are in the cutbanks of the Red Lake River.

Observations along the Red Lake River by A. M. Cvancara and W. L. Moore in the 1960's suggested the possibility of a detailed study of the river trench. Later work by S. R. Moran, Lee Clayton, and A. M. Cvancara at selected cutbank exposures indicated the need for further study.

Purpose of Study

The purpose of this study is to establish a workable stratigraphy for the Pleistocene sediment exposed along the trench of the Red Lake River. Knowledge of the stratigraphic framework will give insight into local groundwater flow patterns and serve as a basis for study of the Pleistocene history of the area.

Field Methods

Field work was completed during the 1971 field season. Methods employed included the location, description, measurement, and sampling of good cutbank exposures along the 50-mile reach of the Red Lake River trench. Thirty-six sections were measured, and 200 samples were collected to aid in the identification and definition of the lithostratigraphic units. Equipment and samples were transported from outcrop to outcrop by canoe.

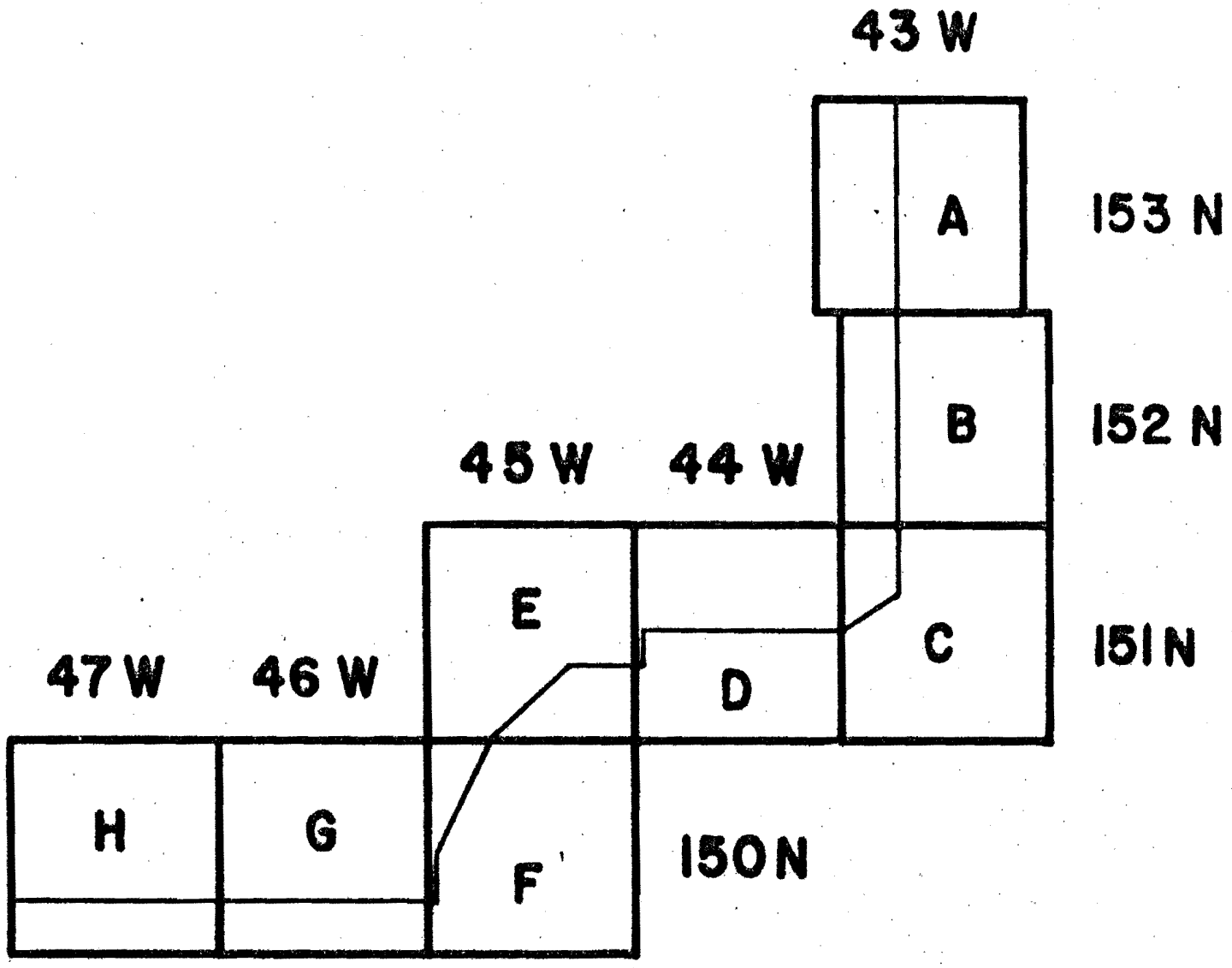
The study area was divided into townships for ease in

identification and relocation of exposures and samples collected (Figure 2). The townships were labeled A through H from north to west along the course of the river. Outcrops were numbered consecutively downstream within each township. Samples were referenced to river level and were numbered consecutively up the sampled sections.

Laboratory Methods

All samples were analysed for content of sand-size, silt-size, and clay-size material. Carbonate content of the material finer than 200-mesh was determined. Analyses were performed in the sediment laboratory of the North Dakota Geological Survey. Results were compiled, and means and standard deviations were calculated for each of the lithostratigraphic units present in the study area. Tabulation of the results of the analysis is included in Appendix I.

Fig. 2.--Location of townships A through H and cross-section location in the study area.


43 W
A
153 N
B
152 N
45 W
44 W
E
C
151 N
47 W
46 W
D
H
G
F
150 N

Lithostratigraphy

Seven distinct lithostratigraphic units are recognized in the study area. Five of these are of glacial origin and two are of lacustrine origin. The following discussion will be limited to general description, field recognition, and probable age of the formations encountered. The units will be discussed from oldest to youngest. A detailed discussion of the formations is included in Appendix II.

Gervais Formation

The Gervais Formation is unbedded, glacially modified fluvial or lacustrine sediment. The unit consists of very slightly pebbly, silty clay-loam (U.S.D.A. terminology). It is light olive-gray to dark gray. The Gervais contains abundant organic debris.

Field recognition of the Gervais Formation is made easy by the high silt content, dark color, and abundant organic debris. Logs, twigs, and wood fragments are present throughout the unit, but are much more abundant near the base of the exposed part of the formation. Rooted stumps appear near river level at the Three Creeks Section (Figure 3, No. 3). Other organic debris present includes mollusk fragments, carbon flakes, and insect fragments. All organic debris decreases in abundance upward, whereas pebbles and cobbles increase in abundance upward in the formation.

The Gervais Formation is pre-Wisconsinan or early Wis-

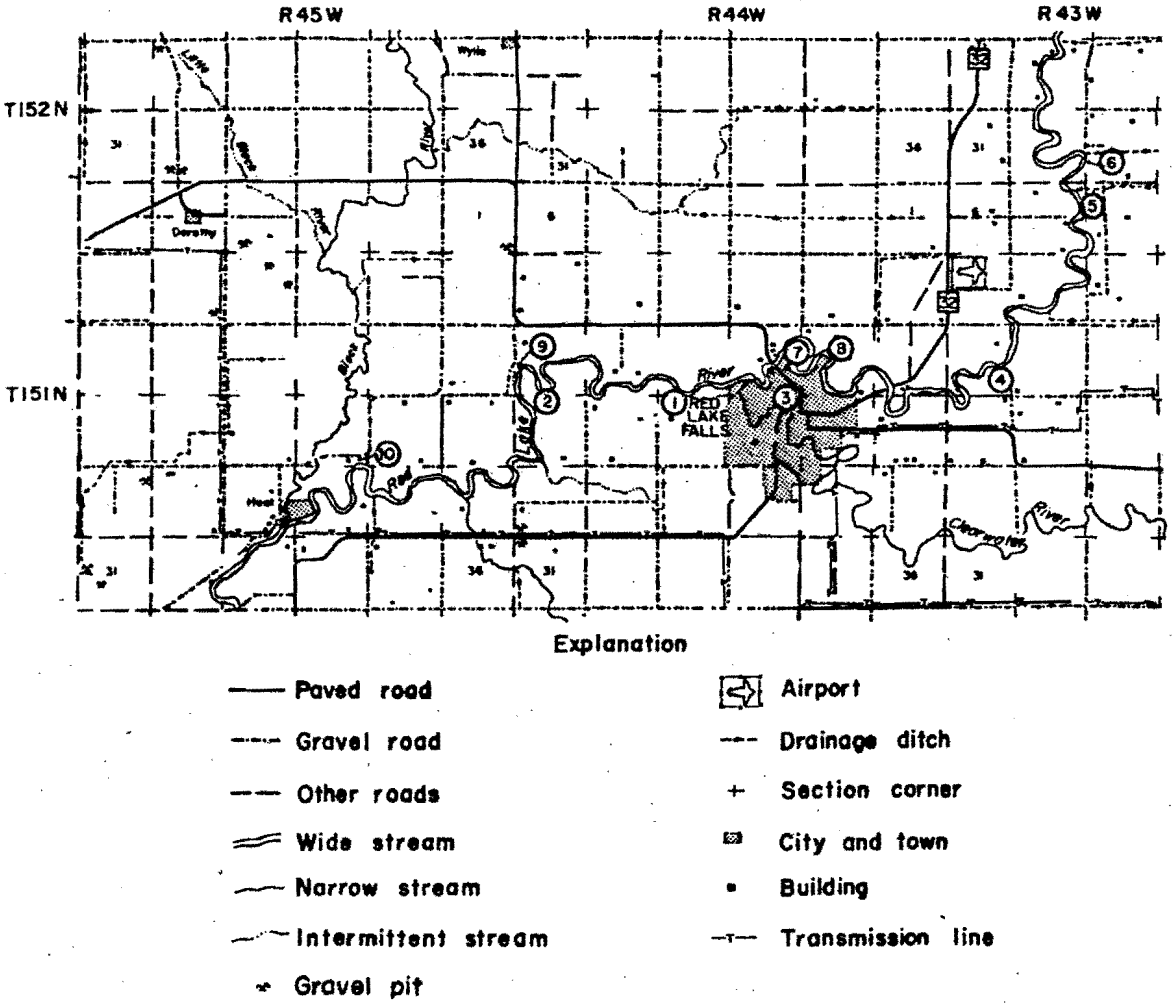


Fig. 3.--Map showing location of type and reference sections in the area of Red Lake Falls, Minnesota.

consinan in age.

Marcoux Formation

The Marcoux Formation consists largely of unbedded glacial sediment. The unit is very pebbly sandy-loam. is light gray in color.

Field recognition of the Marcoux is made possible b its sandy texture and characteristic pebble lithology. bles (4 to 64 mm.) in the Marcoux Formation are about 66 cent igneous and metamorphic rock types and 33 per cent bonate rock types. The sandy-loam ranges from friable i moist outcrops to extremely hard in dry outcrops. Outcr of the Marcoux Formation are generally associated with t presence of rapids in the Red Lake River because of the abundance of cobbles and boulders in the unit.

The Marcoux Formation is no younger than late Wisco sinan and is probably early Wisconsinan or older.

St. Hilaire Formation

The St. Hilaire Formation consists largely of unbedd glacial sediment. It is dark gray, pebbly loam.

Field recognition of the St. Hilaire Formation is m easy by its color, texture, and pebble lithology. It is the only formation in the study area consisting of dark pebble loam. The pebbles (4 to 64 mm.) are 40 per cent neous and metamorphic rock types, 40 per cent carbonate

types, 15 per cent shale, and about 5 per cent lignite. The presence of shale pebbles is a unique characteristic of the St. Hilaire Formation. The loam is friable in moist exposures and hard in dry exposures. It has a weak to strong secondary columnar jointing. The St. Hilaire is quite thin in the study area. Exposed thicknesses range from about 7 feet to 18 inches.

The age of the St. Hilaire Formation is unknown. It underlies the Red Lake Falls Formation, which is thought to be late Wisconsinan in age.

Red Lake Falls Formation

The Red Lake Falls Formation consists largely of unbedded glacial sediment. It is olive brown pebbly loam.

Field recognition of this formation is made possible by its color, texture, and pebble lithology. Pebbles (4 to 64 mm.) present are about 33 per cent igneous and metamorphic rock types and 66 per cent carbonate rock types. Numerous sand and gravel inclusions range from thin beds to channel fills with scoured bases. In dry outcrops the Red Lake Falls Formation stands nearly vertical and is quite hard. It has moderate to strong secondary columnar jointing.

The Red Lake Falls Formation is thought to be late Wisconsinan in age.

Wylie Formation

The Wylie Formation consists of laminated offshore lake sediment. It is largely interbedded silt and clay. Laminations range in thickness from a few millimeters to a few centimeters. The clay laminae thicken upwards. The silt laminae are olive brown, and the clay laminae are dark gray.

Field recognition of the Wylie Formation is made easy by its laminated nature, its stratigraphic position, and the dominance of the clay laminae. East of the Snake Curve Section (Figure 3, No. 9), the Wylie Formation is the only laminated unit exposed. West of the Snake Curve Section the Sherack Formation is also present. The Wylie is distinguished from it by the dominance of clay laminae and by its stratigraphic position above the Red Lake Falls Formation. The Wylie is thin, averaging about 3 feet thick; the Sherack is generally much thicker.

The Wylie Formation is late Wisconsinan in age and was probably associated with an early stage of glacial Lake Agassiz.

Huot Formation

The Huot Formation consists largely of unbedded glacial sediment. It is very slightly pebbly clay that is dark olive gray.

Field recognition of the Huot Formation is made possible by its texture, color, and pebble lithology. The Huot is the only exposed glacial sediment in the study area that is predominantly clay. Most of the pebbles present in the unit are limestone and dolomite. Small tan, calcareous, chalk-like inclusions are also present. This unit is extremely prone to slumping when moist and has been called the "slickensided clay." It is the surface unit east of the eastern edge of the Sherack Formation. The slumping of the Huot Formation is responsible for the generally poor quality of the outcrops downstream from Huot.

The Huot Formation is thought to be late Wisconsinan in age.

Sherack Formation

The Sherack Formation consists of laminated lake sediment. It is composed of interbedded silt and clay with minor amounts of silty sand. It is olive brown in outcrop.

Field recognition of the Sherack, in the study area, is made easy by its laminated nature, dominance of silt laminae, and its stratigraphic position above the Huot Formation. The silty nature of the Sherack is due to the location of the study area on the eastern margin of the Lake Agassiz basin. Subsurface borings indicate that the Sherack becomes considerably more clayey toward the axis of the Lake Agassiz basin (Moran, 1973).

The Sherack Formation is early Holocene in age. It was deposited during the last stage of Lake Agassiz.

Stratigraphic Interpretation

Stratigraphy

The stratigraphy along the Red Lake River trench is summarized by the general lithostratigraphic cross-section (Figure 4). The cross-section extends from Thief River Falls to Fisher. It shows the horizontal and vertical relationship of the seven lithostratigraphic units encountered over the entire length of the study area. In the northern section, from Thief River Falls to west of Red Lake Falls, the Red Lake River has cut down to stratigraphically lower units. West of Red Lake Falls, in reach D, the lowest stratigraphic unit, the Gervais Formation, is exposed. West of reach D the exposures along the river are progressively higher in the stratigraphic sequence.

The detailed stratigraphy along the Red Lake River is shown in Figure 5. The following discussion will progress from north to south and west along the detailed cross-section.

Reach A

Reach A (Figure 5A) is the northernmost reach in the study area. Three stratigraphic units are present here: the St. Hilaire, the Red Lake Falls, and the Huot Formations. The units are essentially flat lying and easily recognized.

The St. Hilaire Formation is the lowest stratigraphic

Fig. 4.--Generalized cross-section of lithostratigraphy along the Red Lake River, Minnesota.

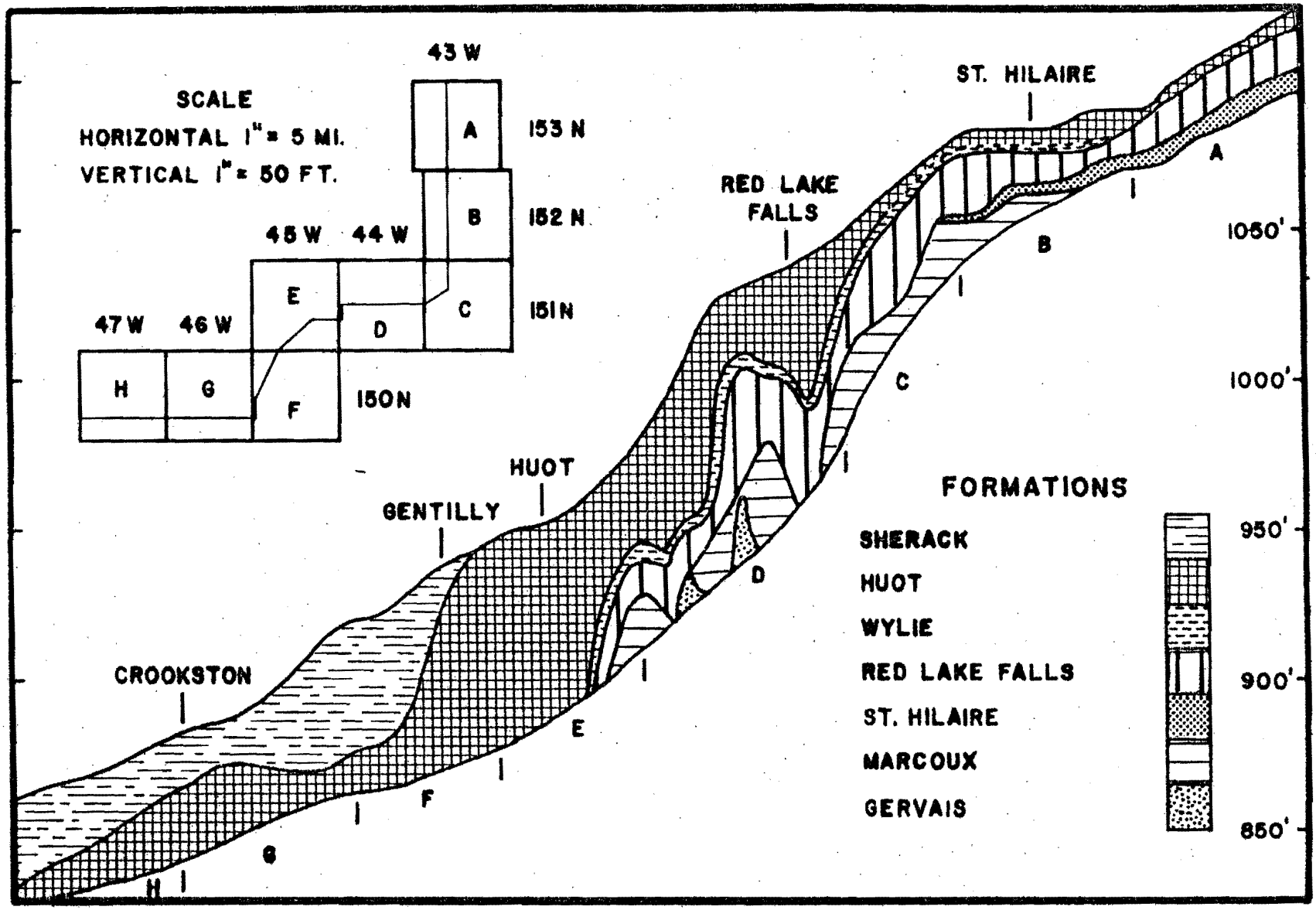

SCALE
HORIZONTAL 1" = 5 MI.
VERTICAL 1" = 50 FT.
43 W
A
153 N
B
152 N
48 W
44 W
E
D
C
151 N
47 W
46 W
H
G
F
150 N
ST. HILAIRE
RED LAKE FALLS
HUOT
GENTILLY
CROOKSTON
A
B
C
D
E
F
G
H
1050'
1000'
950'
900'
850'
FORMATIONS
SHERACK
HUOT
WYLIE
RED LAKE FALLS
ST. HILAIRE
MARCOUX
GERVAIS

Fig. 5.--Detailed lithostratigraphy along the Red Lake River, Minnesota. Figures 5A through 5G follow on pages 19 through 25.

LEGEND

Sherack Fm. . . . . .

Huot Fm. . . . . .

Wylie Fm. . . . . .

Red Lake Falls Fm. . . . .

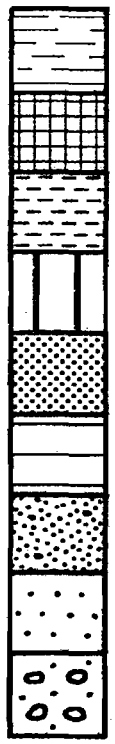
St. Hilaire Fm. . . . . .

Marcoux Fm. . . . . .

Gervais Fm. . . . . .

Sand . . . . . .

Sand and Gravel . . . . . .



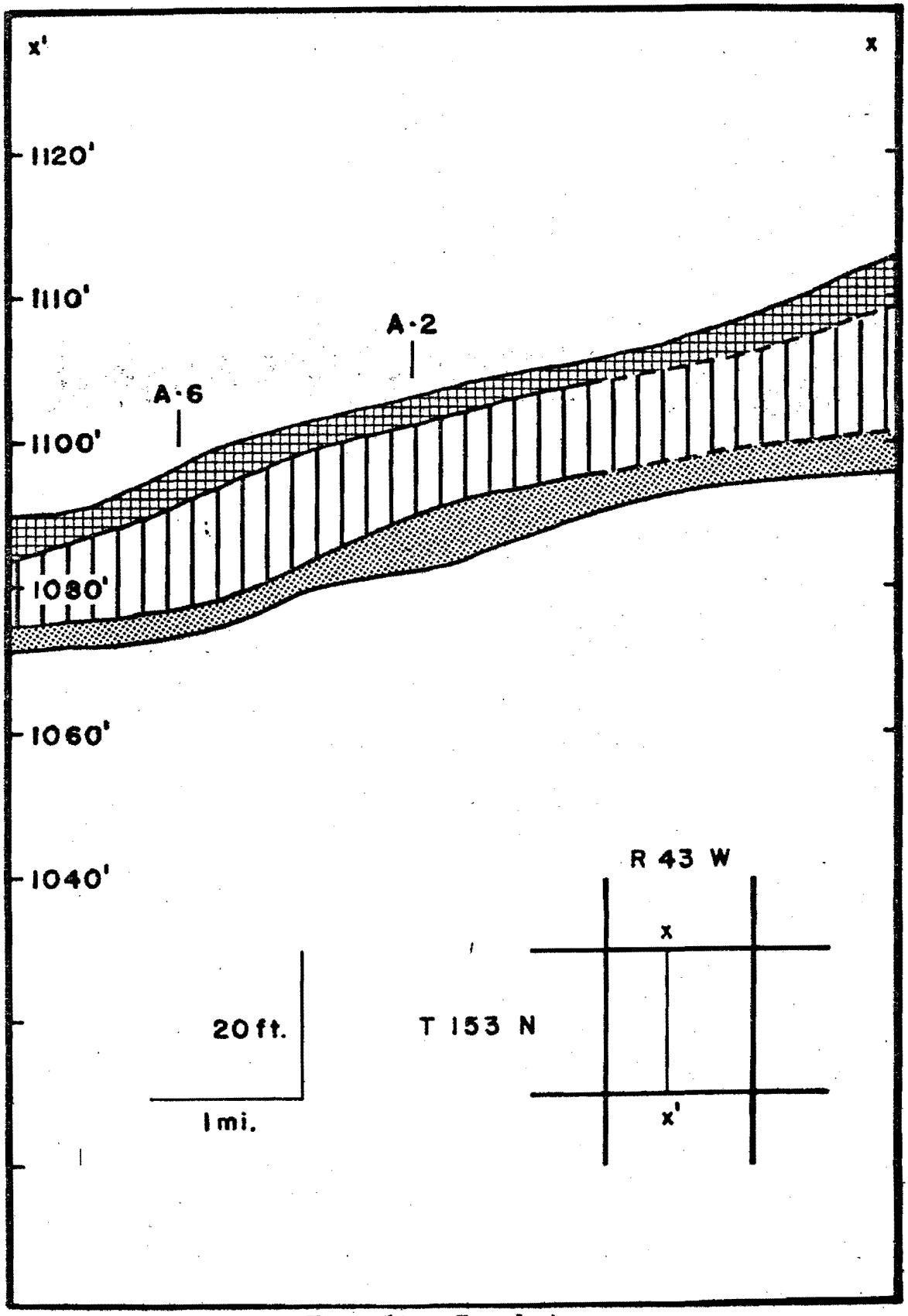


Fig. 5A.--Reach A

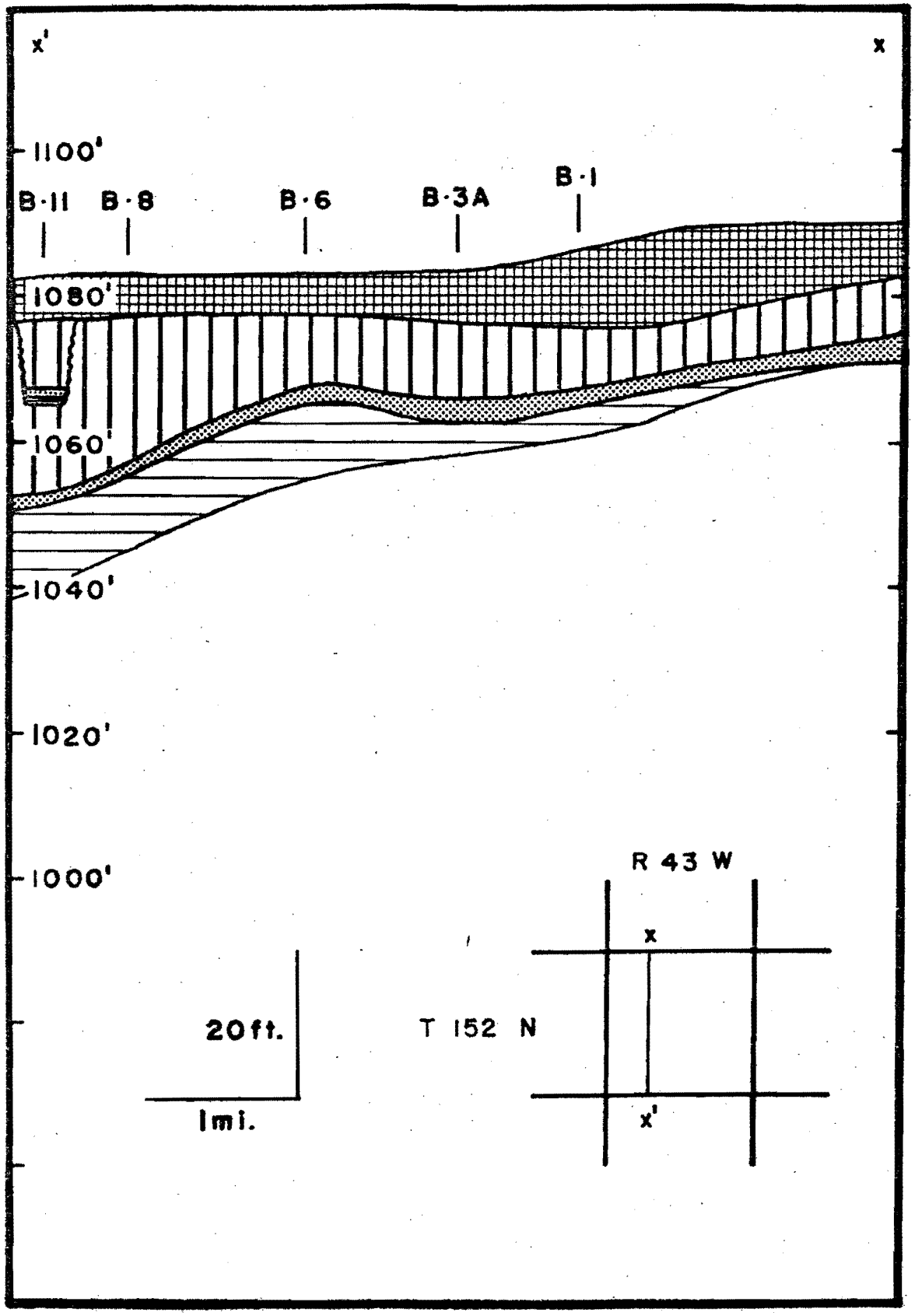


Fig. 5B.--Reach B

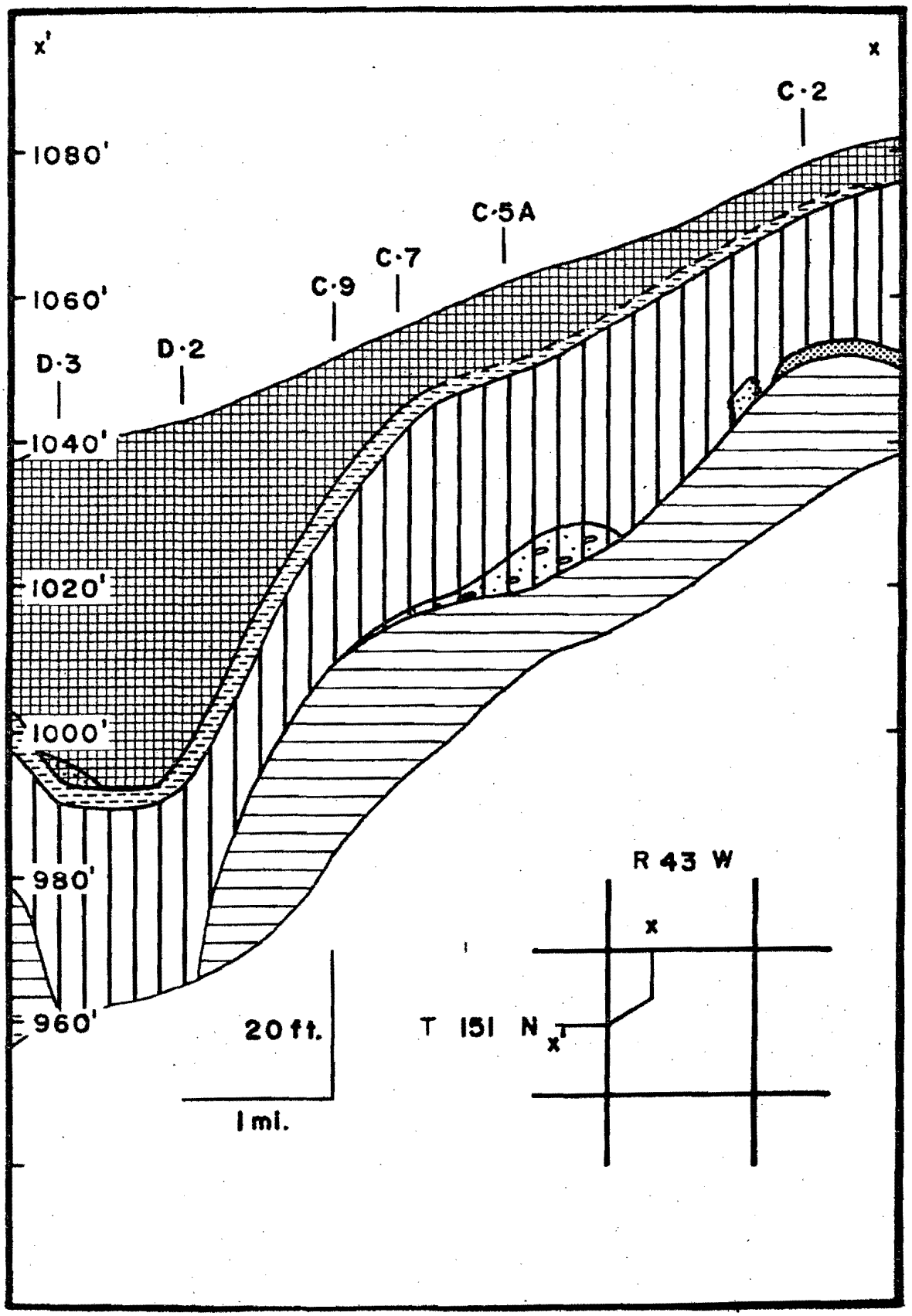


Fig. 5C.--Reach C

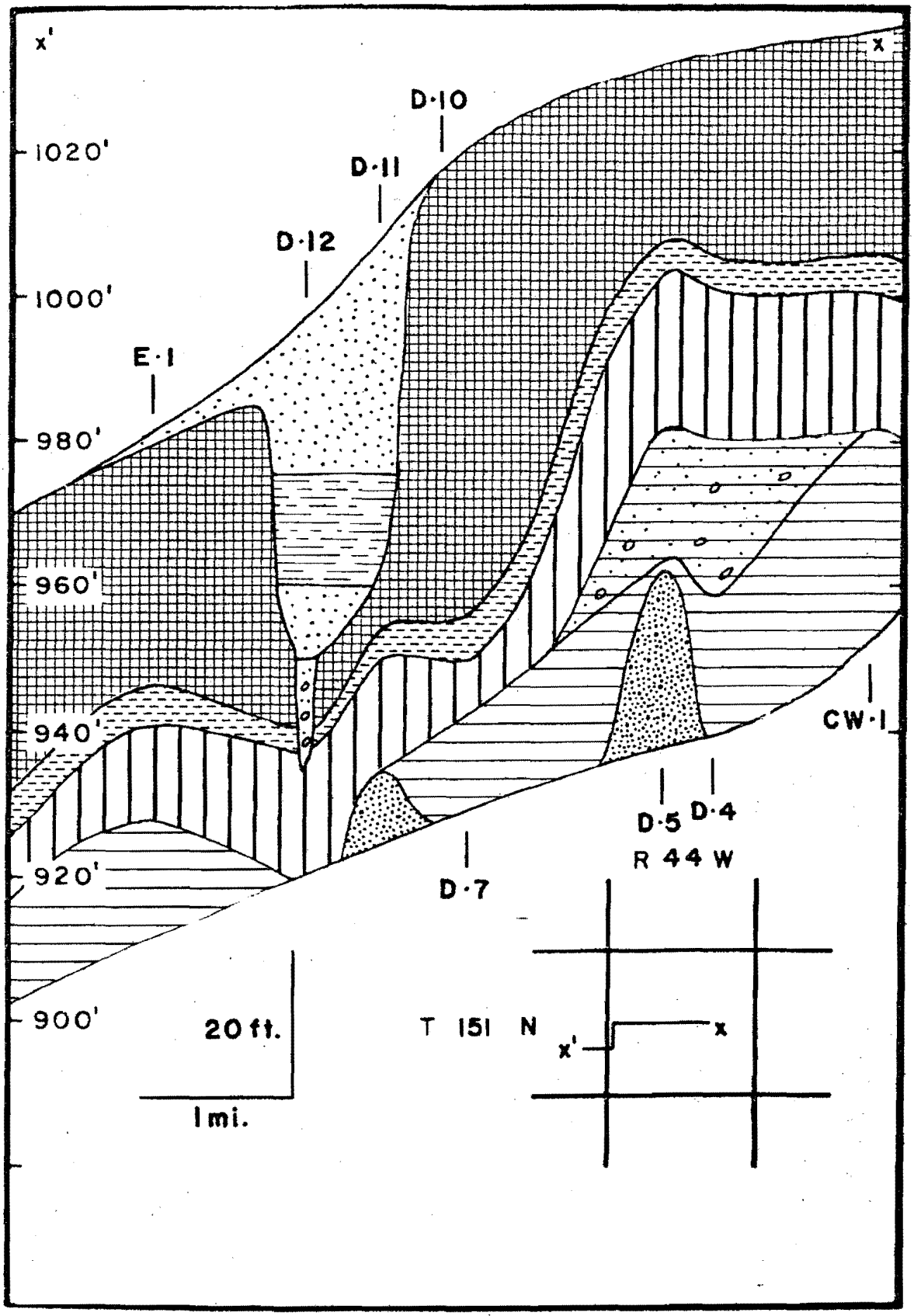


Fig. 5D.--Reach D

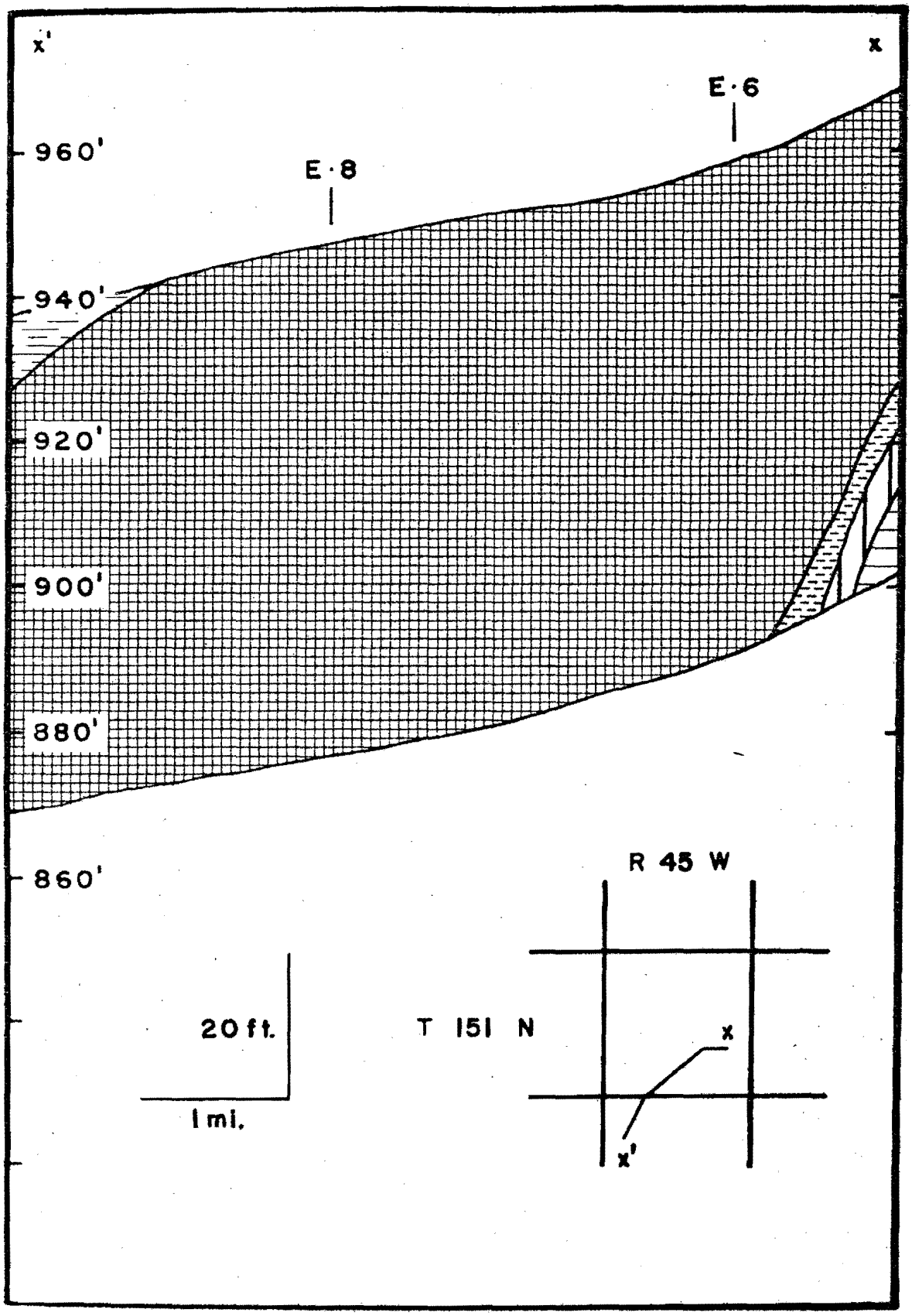


Fig. 5E.--Reach E

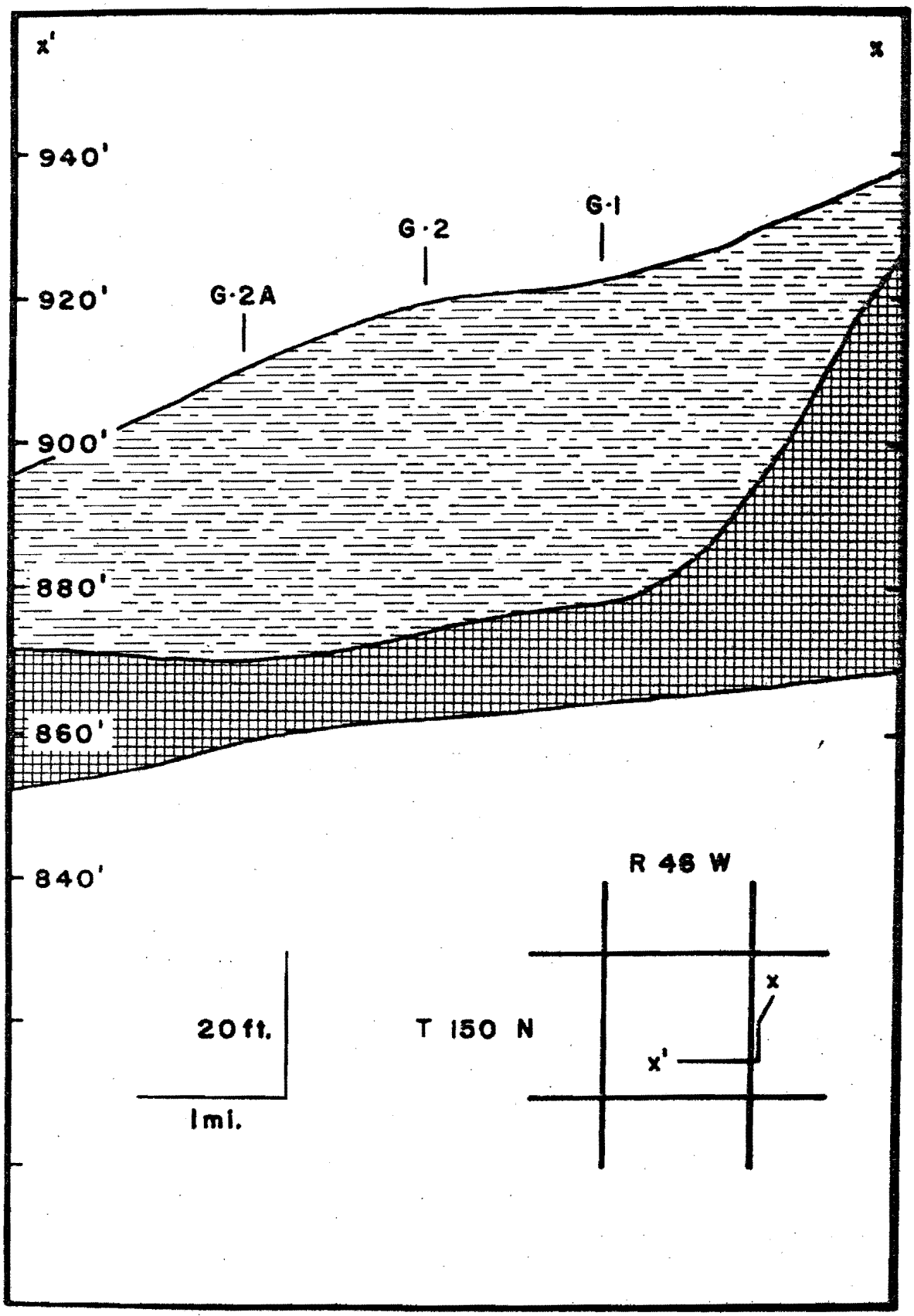


Fig. 5F.--Reach F

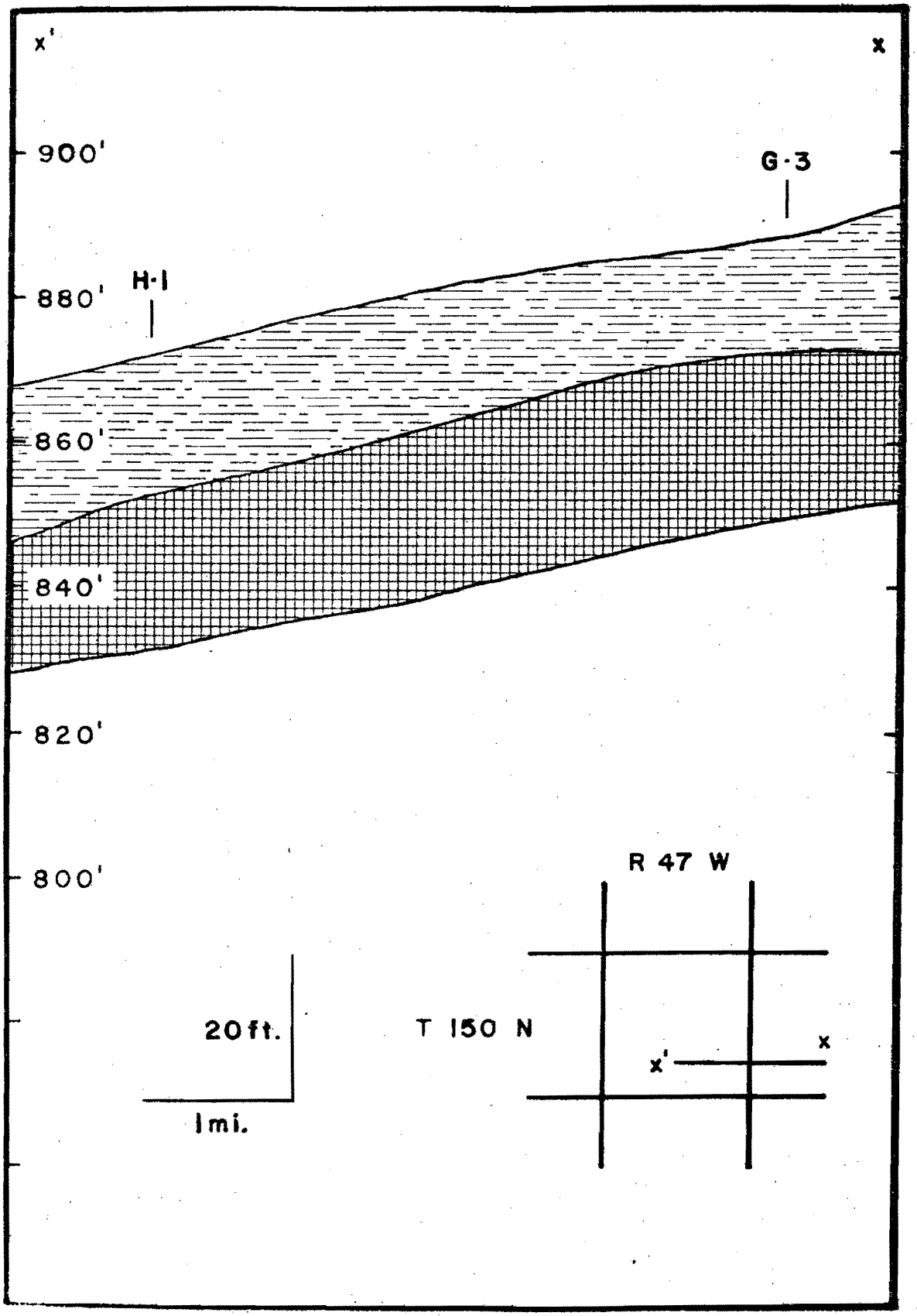


Fig. 5G.--Reach G

unit exposed in reach A. Here the pebbly loam is friable and is exposed from 2 to 7 feet above the river level. The base of the St. Hilaire has not been seen in this reach.

The Red Lake Falls Formation averages about 15 feet thick in reach A, is friable, and has poorly developed columnar jointing. The unit commonly has a 2-inch bed of interbedded silt and clay from 8 to 10 feet above the base of the unit. The laminated silt and clay bed marks the division between the lower member of the Red Lake Falls Formation and the upper member of the Red Lake Falls Formation as recognized by Salomon (1973) on the basis of coarse-sand lithology. No distinction is made between these two units in this report. Textural and carbonate analyses do not consistently distinguish between the two members of the Red Lake Falls Formation. Gross field characteristics are also essentially identical.

The lower contact of the Red Lake Falls is variable. In some places it is erosional and has sand and gravel at the contact. In other places the contact is gradational through a zone a few feet thick.

The Huot Formation is the surface unit in reach A. It is locally slumped and contains silt clasts. The silt clasts may indicate that the Wylie Formation was present before the Huot was slumped. The contact between the Huot and the Red Lake Falls Formations ranges from distinct to gradational.

Reach B

The stratigraphy of reach B is shown in Figure 5B. Here the river continues southward and has down-cut to expost another, lower stratigraphic unit.

The Marcoux Formation is the oldest unit exposed in reach B. It consists of light gray, sandy glacial sediment and is easily differentiated from the younger formations present. It outcrops at water level in the northern part of reach B, and up to 11 feet of the unit is exposed in the southern part of reach B. The base of the Marcoux is not exposed in this reach.

The base of the St. Hilaire Formation is above river level in reach B. The unit is typically thin and ranges from 18 inches to 3 feet thick. Its dark gray color makes it useful as a marker bed. The lower contact is generally sharp and is commonly marked by a cobble or sand and gravel concentration.

Columnar jointing is moderately to well developed in the Red Lake Falls Formation in reach B. The thickness of the unit ranges from about 8 to 23 feet. The lower contact of the Red Lake Falls is distinct to gradational through a few feet.

The Huot Formation is the surface unit in reach B. The contact between the Huot and the Red Lake Falls Formation is generally distinct and is marked by a 2-inch set of laminated silt and clay in some places. The laminated silt and

clay bed is laterally continuous for tens of feet.

A complication in the otherwise orderly stratigraphy occurs in the southern part of reach B. The Opernockity and Sleepy Hollow Sections (Figure 3, No. 6) contain a repetition of the normal Marcoux, St. Hilaire, and Red Lake Falls sequence. The surface unit, the Huot Formation, is present above the repeated section. The repetition of units is shown diagrammatically on the reach B cross-section (Figure 5B). The repeated section is interpreted to be the result of subglacial thrusting. The physical relationship between the Opernockity and Sleepy Hollow Sections give the thrust sheet minimum dimensions of 500 feet in width and 1000 feet in length.

Reach C

In reach C (Figure 5C) the oldest exposed unit is the Marcoux Formation. As much as 25 feet of the formation is exposed above river level, but it averages about 10 feet in exposed thickness. The Marcoux Formation is typically very pebbly and extremely hard in dry outcrops. The base of the Marcoux was not seen in reach C.

The St. Hilaire Formation is exposed only in the northern part of reach C. The Powerline Section is the southernmost exposure of the formation in the Red Lake River trench. Here it is about 3 feet thick and has a sharp lower contact.

Moderately to strongly columnar joints occur in the Red

Lake Falls Formation in reach C. It averages about 25 feet thick and reaches a maximum exposed thickness of 70 feet. The formation contains numerous sand and gravel inclusions in this area. The Red Lake Falls overlies the St. Hilaire Formation in the northern part of reach C, and overlies the Marcoux Formation in the southern part of the reach. The base of the Red Lake Falls Formation is marked by cobble or sand and gravel concentrations.

The Wylie Formation averages about 3 feet in thickness in reach C. It becomes thicker in the western part of the reach. The base of the Wylie is sharp to interbedded with the underlying Red Lake Falls Formation.

The surface unit in reach C is the Huot Formation. It is not seen in vertical outcrop but underlies hummocky, slumped areas above the cutbank exposures. The Huot overlies the Wylie Formation, and their contact is interbedded.

Reach D

The Gervais Formation, which is believed to be the oldest unit exposed along the Red Lake River, outcrops in two exposures in reach D (Figure 5D). Twenty feet of the Gervais is exposed at the Three Creeks Section (Figure 3, No. 1), where it contains abundant woody debris and logs as much as 6 inches in diameter. Here the Gervais Formation was penetrated by a hand auger to a depth of 15 feet without reaching its base. The unit has a minimum thickness of 35 feet at the Three Creeks Section. Thirteen feet of the Ger-

vais is exposed at the Moo Point Section (Figure 3, No. 2). Here the unit contains abundant disseminated woody debris.

The Marcoux Formation is exposed throughout most of reach D. Exposed thicknesses of the unit average about 20 feet. The maximum thickness is about 30 feet. The base of the Marcoux Formation is seen only at the Three Creeks Section. Here the contact is erosional and sharp with a concentration of cobbles. In the eastern part of reach D the Marcoux Formation consists predominantly of alternating fine, medium, and coarse-grained sand. The sand body averages about 20 feet thick. It is ripple cross-bedded to flat bedded and locally highly faulted. The sand body is placed within the Marcoux Formation because the heavy mineral assemblage of the sand is most closely associated with the heavy minerals found in the Marcoux Formation (Hobbs, in preparation).

Strongly developed columnar jointing is common in the Red Lake Falls Formation in reach D. The Red Lake Falls contains numerous sand and gravel inclusions, which range from thin beds to channel fills and contorted masses. The contact with the underlying Marcoux or Gervais Formations is generally sharp and marked by cobble concentrations.

The Wylie Formation is conspicuous in reach D. It is distinctly laminated and averages about 5 feet thick. Locally it is dominantly silt with some fine sand. Where the

Huot Formation has been extensively disrupted by mass movement the Wylie is also disrupted. The base of the Wylie Formation is generally interbedded with the underlying Red Lake Falls Formation.

In reach D, the Huot Formation is the surface unit except where it is overlain by shoreline sand and gravel (Figure 5D). It underlies the hummocky, wooded, upper part of the valley wall. Locally it is highly distorted and contains boulders of yellow-brown carbonate-rich glacial sediment of unknown source. As much as 60 feet of the Huot Formation is present in reach D. The Huot overlies the Wylie Formation. Their contact is gradational by interbedding and is locally highly disturbed.

There are two notable complications in the stratigraphic framework in reach D. The first is the 20-foot bed of alternating fine-grained, medium-grained and coarse-grained sand in the upper part of the Marcoux Formation. The unit is interpreted to be beach sand deposited along the shores of a lake occupying the ancestral Red River Valley before the Red Lake Falls Formation was deposited.

The second complication in the stratigraphy of reach D is the presence of a fluvial channel fill that was deposited before the Sherack Formation and after the Huot Formation (Figure 5D). The fluvial channel fill is exposed in cross-section in the Snake Curve South Section (Figure 3, No. 9). The channel has been eroded through the Huot and

Wylie Formations and is inset into the Red Lake Falls Formation. This exposure has been studied in detail by Moran, Clayton, and Cvancara (1971). Their interpretation is that the river eroded its channel across the Lake Agassiz plain before the time that the Sherack Formation was deposited. The plain was later flooded as an ice sheet blocked the northeastern outlets of Lake Agassiz and transgressive lake water deposited beach sand over the fluvial gravel in the channel. The lake continued to rise above the Campbell Beach level, and offshore sediment of the Sherack Formation filled the channel. The southern outlet of Lake Agassiz was eroded down to Precambrian granite at Browns Valley, Minnesota. The lake water dropped to a stable level determined by the Browns Valley granite. Water in the lake remained at this level, the Campbell level, until the northeastern outlets were reopened by the retreating ice.

Reach E

In reach E (Figure 5E) the lithostratigraphic units exposed in the Red Lake River trench become stratigraphically higher in a downstream direction. Within the first mile of reach E, the Marcoux, Red Lake Falls, and Wylie Formations have dropped below the river level. The Huot Formation is the principal unit exposed in this reach. In the last mile of reach E the Sherack Formation is present above the Huot. The contact is generally sharp between the Huot and Sherack Formations. It is locally marked by sand and gravel. The

quality of the outcrops is generally poor because of the tendency of the Huot to slump.

In one exceptionally large exposure, Schist Cliff Section (Figure 3, No. 10), the Huot Formation stands in a vertical outcrop 70 feet high. The usually slump-prone Huot is dry enough in the Schist Cliff Section to stand vertically; it weathers to light gray, brick-like blocks. Here the Huot contains boulder-sized inclusions of yellow-brown, carbonate-rich, glacial sediment. Some of the boulders are 15 feet in their long dimension.

Reaches F and G

Reaches F and G (Figures 5F and 5G) have a simple two-unit stratigraphy. The Huot Formation is exposed at river level in reaches F and G. It averages about 20 feet thick. The surface unit, the Sherack Formation, is offshore sediment of glacial Lake Agassiz; it laps over the Huot Formation. Where the contact between these units can be seen, it is generally sharp and erosional with sand and gravel present. The presence of the Huot Formation at river level results in extensively slumped river banks. Many of the farmsteads along this reach of the river are abandoned or endangered. Exposures are very poor.

Effect on Groundwater Flow

Groundwater flow is restricted to permeable, porous sediment. The layers of glacial sediment present along the Red Lake River are aquatards. They contain enough silt and clay to make them only slightly permeable. Only the more permeable sand and gravel bodies, which are present throughout the stratigraphic sequence, can be considered to be aquifers.

Fluvial sand and gravel is common on erosional contacts between layers of glacial sediment. It is generally thin, intermittent in distribution, and may not be laterally continuous. These bodies of sand and gravel may be only locally significant as aquifers. Fluvial sand and gravel also occur as channel fills. These channel fills may occur anywhere within the stratigraphic sequence. They may be inclusions within a layer of glacial sediment, inset into a layer of glacial sediment, or cut completely through a layer of glacial sediment. These channel fills are important as aquifers because they are for the most part interconnected with each other, both vertically and horizontally. The paths of these aquifers are sinuous, making the prediction of their location a problem. A buried channel-fill aquifer outcrops at the Snake Curve South Section (Figure 3, No. 9); a considerable amount of groundwater discharges into the Red Lake River from this aquifer.

Shoreline sand and gravel is also an important aquifer

along the Red Lake River. The sand of the Marcoux Formation exposed in the Three Creeks Section (Figure 3, No. 1) is interpreted to be shoreline sand. It is up to 20 feet thick and is probably widespread. Shoreline sand occurs at erosional contacts between layers of glacial sediment. Shoreline sediment is abundant along the margin of the Red River Valley.

Aquifers are mainly limited to erosional contacts between layers of glacial sediment. Their location is obscured by overlying layers of glacial sediment. Their areal distribution can only be determined by test drilling. Most of them contain dependable sources of water for domestic use.

History and Regional Correlation

The following discussion deals with the history and regional correlation of exposed formations in the study area. Inferences made are based on numerous regional field investigations and discussions with Pleistocene stratigraphers active in the mid-continent area.

Gervais Formation

The Gervais Formation is pre-Wisconsinan or early Wisconsinan in age (Figure 6). A radiocarbon date from a log in the unit indicates an age greater than 39,900 B.P. (I-5317). The source of the glacial ice which deposited the unit is unknown.

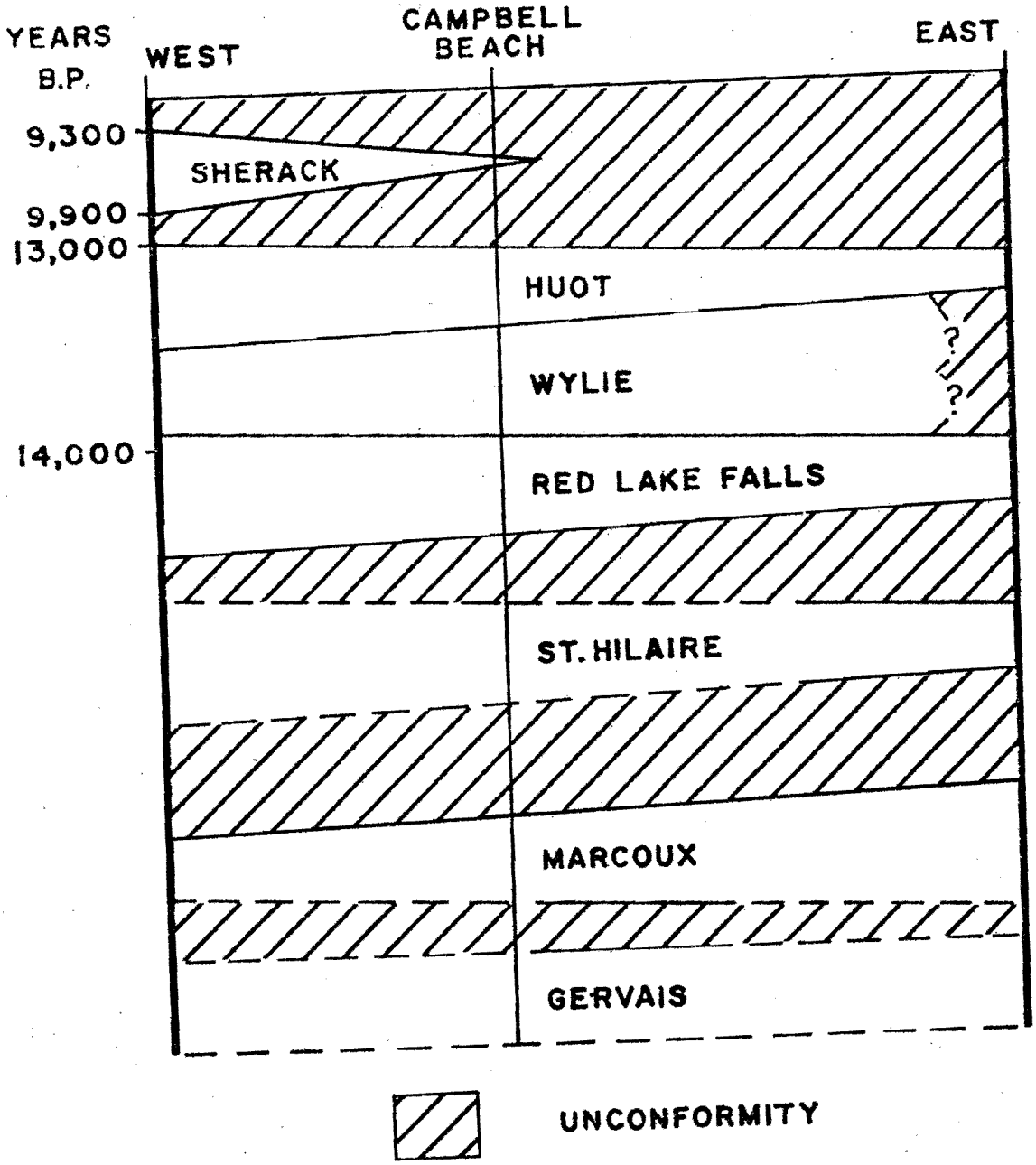


Fig. 6.--Schematic time-distance diagram showing periods of deposition of the formations in the study area.

The Gervais Formation may be correlative with a silt and sand unit encountered in well borings in the Lake Bronson, Minnesota, area (Moran, 1973). These borings range in depth from 90 to 140 feet and provide abundant organic material. Radiocarbon dates on the organic debris recovered have been greater than 19,000 B.P. (C-496), greater than 36,000 B.P. (W-102), greater than 38,000 B.P. (W-1028).

Marcoux Formation

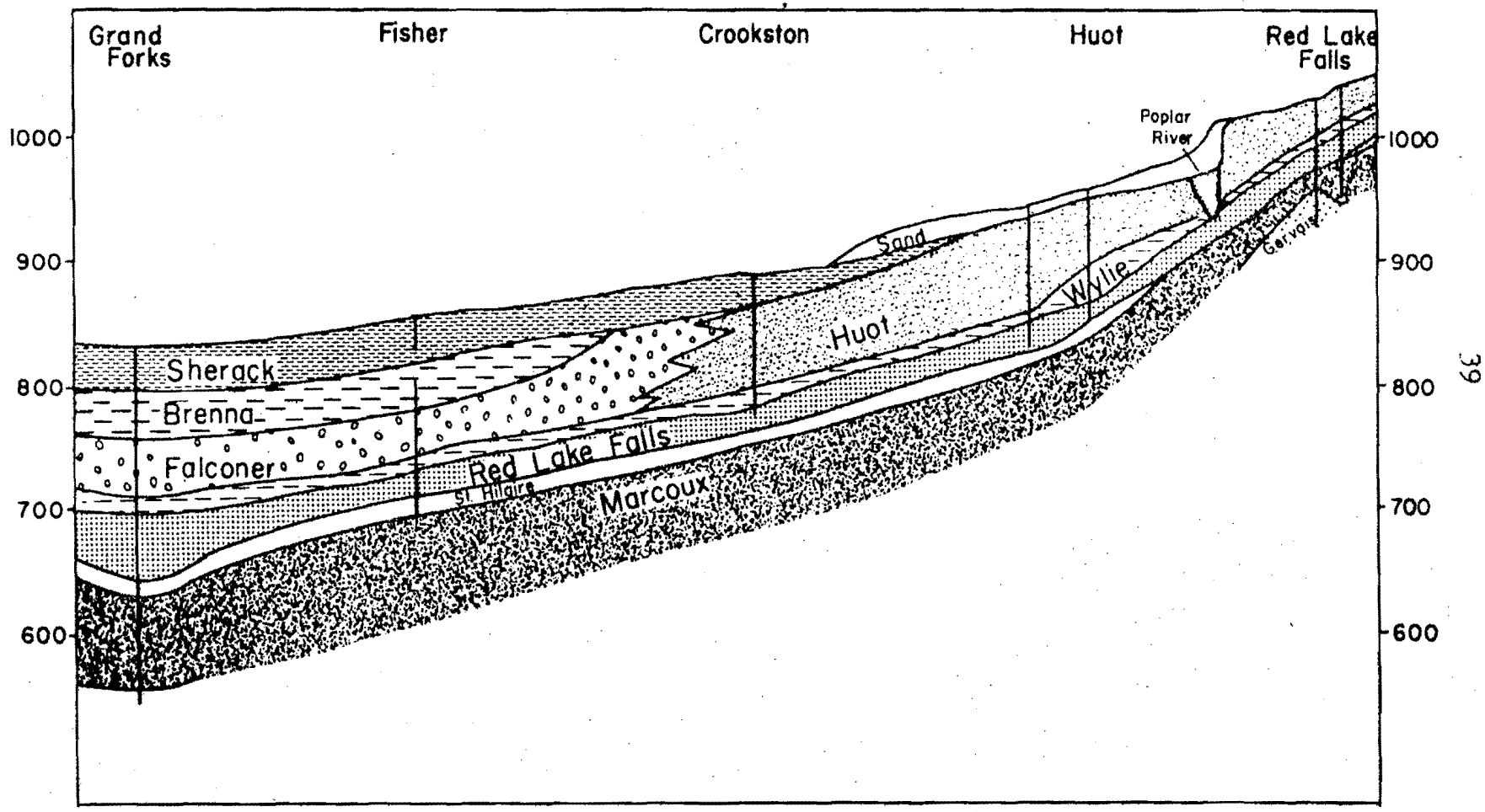
The Marcoux Formation underlies the St. Hilaire and Red Lake Falls Formations. The Red Lake Falls Formation is thought to be late Wisconsinan. The age of the Marcoux is unknown, but it is no younger than late Wisconsinan and is probably early Wisconsinan or older.

The glacial ice which deposited the pebbly loam of the Marcoux Formation is thought to have come from the Canadian Shield to the northeast, because of the dominance of igneous and metamorphic rock types.

The Marcoux Formation is probably correlative with the Hawk Creek Till in the New Ulm, Minnesota, area. Matsch (1971) describes the Hawk Creek Till as a sandy, clay-loam with a suite of rock fragments characteristic to the Lake Superior region.

Moran (1973) described a sandy loam in the Red River Valley and adjacent areas. This sandy loam has been traced from the Red River Valley subsurface to the Red Lake River trench (Figure 7). It correlates with the Marcoux Formation.

Fig. 7.--Generalized cross-section showing stratigraphic correlations from Grand Forks, North Dakota, to Red Lake Falls, Minnesota.


Grand Forks
Fisher
Crookston
Huot
Red Lake Falls
1000
900
800
700
600
Poplar River
Sand
Wylie
Huot
Sherack
Brenna
Falconer
Red Lake Falls
St Hilaire
Marcoux
Gervais

Salomon (1973) described a sandy lower till in northeastern North Dakota. It contains abundant crystalline pebbles and is easily distinguished from overlying, shale-rich glacial sediments. Salomon correlates the sandy lower till with the Marcoux Formation.

Regional reconnaissance along the eastern edge of the Red River Valley suggests correlation of the glacial sediment in the Marcoux Formation with glacial sediment exposed as far north as the Middle River, Minnesota. Glacial sediment possibly correlative with the Marcoux has also been observed in the Fort Ransom and Devils Lake areas of North Dakota (Moran, 1973).

St. Hilaire Formation

The St. Hilaire Formation underlies the Red Lake Falls Formation in the northern part of the study area. The Red Lake Falls Formation is thought to be late Wisconsinan. The age of the St. Hilaire Formation is unknown but is no younger than late Wisconsinan.

The glacial ice that deposited the St. Hilaire Formation came from the west or northwest. The St. Hilaire contains a large number of shale pebbles. The only known source of the shale pebbles is the Pierre Formation, which outcrops along the western margin of the Red River Valley.

The St. Hilaire Formation is also seen in outcrop at Heiberg, Minnesota, on the Wild Rice River. In northeastern

North Dakota the glacial sediment called Unit A by Salomon (1973) is similar to the St. Hilaire Formation in texture and minerology. It is correlated with the St. Hilaire Formation (Salomon, 1973).

Red Lake Falls Formation

The Red Lake Falls Formation is thought to be late Wisconsinan in age (Figure 6). It underlies the Wylie Formation which is late Wisconsinan in age.

Glacial ice that deposited the Red Lake Falls Formation advanced over the study area from the north or northwest. Pebbles contained in the Red Lake Falls Formation are dominantly limestone and dolomite. Lower Paleozoic rocks that subcrop in the northern part of the Red River Valley are thought to be the source of the limestone and dolomite pebbles.

The Red Lake Falls Formation is the surface sediment in much of the area outside of the Red River Valley. Salomon (1973) correlates the Gardar Formation and the Dahlen Formation of northeastern North Dakota with the Red Lake Falls Formation. The Gardar Formation is probably correlative with the Granite Falls till (Matsch, 1971) of southwestern Minnesota. The Dahlen Formation is probably correlative with the New Ulm till (Matsch, 1971) of southwestern Minnesota. The Red Lake Falls Formation has been recognized in the Red River Valley subsurface (Figure 7) by Moran (1973).

Wylie Formation

The Wylie Formation overlies the Red Lake Falls Formation from reach C west into the Red River Valley low-land (Figure 4). The Wylie is late Wisconsinan offshore lake sediment. It was deposited during an early phase of Lake Agassiz. The water was ponded by the retreating glacial ice that deposited the Red Lake Falls Formation.

The Wylie is present in the subsurface throughout the central part of the Red River Valley. It has been recognized in Traill, Grand Forks, and southern Walsh Counties, North Dakota, and Red Lake, Polk, and Norman Counties, Minnesota (Moran, 1973).

Huot Formation

The Huot Formation is late Wisconsinan in age (Figure 6). It was deposited at about 13,500 B.P. (Moran, 1973). The glacier that deposited the Huot Formation advanced southward down the axis of the Red River Valley to the Edinburg moraine.

The Huot Formation is laterally and chronologically equivalent to the Falconer Formation (Moran, 1973). The Huot is the surface unit in the study area from the Red Lake Falls area to west of Crookston and in an arcuate belt across the Red River Valley in Red Lake, Polk, and Norman Counties, Minnesota, and Traill County, North Dakota. This arcuate belt of Huot coincides with the morphologic feature known as the Edinburg moraine.

Sherack Formation

The Sherack Formation is Holocene lake sediment (Figure 6). It was deposited in the water of Lake Agassiz dammed by the retreating glacier that deposited the Huot Formation. Radiocarbon dates from wood at the base of the Sherack Formation are 9,930 ± 280 B.P. (W-388), 9,900 ± 400 B.P. (W-933), 9,730 ± 160 B.P. (I-5123C) and 9,650 ± 150 B.P. (I-5123).

The Sherack is present throughout the central part of the Red River Valley (Figure 7). It extends as far north as Winnipeg, Manitoba.

APPENDICES

Appendix I

TABULATED LABORATORY ANALYSES OF COLLECTED SAMPLES

This appendix contains a tabulated summary of laboratory analyses of collected samples. Table headings include sample number (reach, outcrop, and sample number), elevation, Munsell Soil Color, sand, silt and clay (percentage), and calcite and total carbonate (percentage). Also in this appendix are tables of outcrop locations and a summary of textural and carbonate analyses. All samples collected are available at the North Dakota Geological Survey. Section descriptions of type and reference sections are in Appendix III.

TABLE 1

TABULATED LABORATORY ANALYSES OF COLLECTED SAMPLES

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
A-2-1	4.5	1087.5	10YR 4/2	2.5Y 6/2	29	51	20	5.4	26.3	St. Hilaire
A-2-2	5.5	1088.5	10YR 3/1	2.5Y 6/2	30	49	21	5.0	25.8	St. Hilaire
A-2-3	8.5	1091.5	2.5Y 4/4	2.5Y 7/2	35	47	18	5.2	27.1	Red Lake Falls
A-2-4	10	1093	2.5Y 4/4	2.5Y 7/4	31	49	20	1.5	25.1	Red Lake Falls
A-6-1	1.5	1076.5	2.5Y 3/2	10YR 6/1	48	40	12	4.2	27.4	St. Hilaire
A-6-3	3	1078	2.5Y 4/4	10YR 6/3	66	26	8	5.0	26.9	Red Lake Falls
A-6-4	4	1080	2.5Y 4/4	2.5Y 7/4	35	47	18	5.4	27.2	Red Lake Falls
A-6-5	6.5	1081.5	2.5Y 4/4	2.5Y 7/4	35	49	16	4.1	25.7	Red Lake Falls
A-6-6	9.5	1084.5	2.5Y 4/4	2.5Y 7/4	33	47	20	6.7	28.1	Red Lake Falls
A-6-7	10.5	1085.5	2.5Y 4/4	2.5Y 7/4	31	40	29	5.0	27.1	Red Lake Falls
A-6-8	21.5	1096.5	2.5Y 4/4	2.5Y 7/2	23	38	39	4.9	25.5	Red Lake Falls
A-6-9	22.5	1097.5	2.5Y 4/2	10YR 7/1	3	29	68	8.3	26.7	Huot
A-6-10	24	1099	2.5Y 4/4	2.5Y 7/4	27	45	28	5.6	27.2	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
A-6-11	27.5	1102.5	10YR 4/2	10YR 6/1	8	22	70	13.2	26.9	Huot
B-1-1	4	1064	2.5Y 5/2	10YR 7/1	61	31	8	8.6	36.1	Marcoux
B-1-2	6.5	1066.5	2.5Y 4/2	2.5Y 6/2	37	42	21	5.4	26.4	St. Hilaire
B-1-3	10	1070	2.5Y 4/4	2.5Y 6/2	38	43	19	4.5	27.1	Red Lake Falls
B-1-3A	11	1071	2.5Y 4/4	2.5Y 7/2	38	47	15	5.5	27.1	Red Lake Falls
B-1-5	13	1073	2.5Y 5/4	2.5Y 7/2	28	47	25	5.8	26.3	Red Lake Falls
B-1-7	16	1076	2.5Y 4/4	2.5Y 7/2	6	51	43	1.4	23.3	Wylie
B-3-2	5	1065	2.5Y 3/2	10YR 7/1	41	40	19	8.8	35.6	Marcoux
B-3-3	6.5	1066.5	2.5Y 4/4	2.5Y 7/2	43	39	18	7.3	29.3	St. Hilaire
B-3-5	13	1073	2.5Y 5/4	2.5Y 7/2	38	39	23	4.8	28.0	Red Lake Falls
B-3-6	1.5	1061.5	2.5Y 4/4	10YR 7/1	35	40	25	9.2	35.6	Marcoux
B-3A-1	2.5	1060.5	2.5Y 5/2	5Y 6/1	50	39	11	9.2	16.4	Marcoux
B-3A-2	5	1063	10YR 4/1	5Y 6/1	48	40	12	8.8	29.3	St. Hilaire

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
B-3A-3	8.5	1066.5	2.5Y 4/2	2.5Y 6/2	44	39	17	8.2	31.0	Red Lake Falls
B-3A-4	14	1072	2.5Y 4/4	5Y 7/3	37	43	20	5.6	25.5	Red Lake Falls
B-3A-5	17	1075	2.5Y 4/4	2.5Y 7/2	36	42	22	9.0	29.5	Red Lake Falls
B-3A-6	19.5	1077.5	2.5Y 5/2	2.5Y 6/2	28	34	38	13.0	30.2	Wylie
B-6-2	4	1064	2.5Y 4/2	10YR 7/1	53	34	13	9.4	38.0	Marcoux
B-6-4	6	1066	2.5Y 4/4	2.5Y 7/4	36	45	19	5.3	26.7	St. Hilaire
B-6-5	11	1071	2.5Y 4/4	2.5Y 7/4	34	43	23	5.2	25.2	Red Lake Falls
B-6-6	14	1074	2.5Y 4/4	2.5Y 7/4	38	43	19	4.5	27.1	Red Lake Falls
B-6-7	18.5	1078.5	2.5Y 4/4	2.5Y 7/4	21	48	31	11.2	30.5	Wylie
B-8-1	1	1046	2.5Y 5/2	10YR 7/1	55	35	10	7.3	26.3	Marcoux
B-8-2	4	1049	10YR 3/1	5Y 5/1	35	40	25	6.3	25.4	St. Hilaire
B-8-3	5	1050	5Y 3/1	5Y 6/1	46	41	13	6.5	31.5	Red Lake Falls
B-8-4	7.5	1052.5	2.5Y 4/2	5Y 6/2	52	36	12	9.7	39.7	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
B-8-5	8.5	1053.5	2.5Y 3/2	10YR 6/1	52	36	12	9.4	37.2	Red Lake Falls
B-8-6	12	1057	2.5Y 5/4	2.5Y 6/2	46	41	13	2.4	22.8	Red Lake Falls
B-8-10	14	1059	2.5Y 3/2	2.5Y 6/2	33	47	20	5.3	24.8	Wylie
B-11-1	5	1045	2.5Y 5/2	5Y 6/1	55	36	9	5.0	25.9	Marcoux
B-11-2	7	1047	2.5Y 5/2	2.5Y 7/2	56	34	10	7.4	26.4	Marcoux
B-11-3	9	1049	2.5Y 4/2	5Y 6/1	58	32	10	6.2	24.5	Marcoux
B-11-4	11	1051	2.5Y 5/2	5Y 6/1	58	32	10	5.0	24.8	Marcoux
B-11-5	12	1052	10YR 3/1	5Y 5/1	32	43	25	6.0	25.9	St. Hilaire
B-11-6	13	1053	2.5Y 4/2	2.5Y 6/2	53	32	15	9.5	38.5	Red Lake Falls
B-11-7	15	1055	2.5Y 4/2	2.5Y 6/2	52	35	13	11.6	39.4	Red Lake Falls
B-11-8	17	1057	2.5Y 5/2	5Y 6/1	51	37	12	9.1	38.0	Red Lake Falls
B-11-9	19	1059	2.5Y 5/2	5Y 6/1	45	38	17	9.1	40.6	Red Lake Falls
B-11-10	21	1061	2.5Y 5/2	2.5Y 6/2	52	34	14	8.7	39.7	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
B-11-11	23	1063	2.5Y 4/2	5Y 6/1	48	39	13	13.6	37.8	Red Lake Falls
B-11-12	24.5	1064.5	2.5Y 5/2	2.5Y 7/2	49	35	16	11.6	37.7	Red Lake Falls
B-11-13	25.5	1065.5	2.5Y 4/2	2.5Y 6/2	56	37	7	7.2	36.0	Marcoux
B-11-14	26.5	1066.5	2.5Y 5/3	2.5Y 6/2	27	34	39	8.7	36.7	St. Hilaire
B-11-15	28	1068	2.5Y 4/2	5Y 6/1	44	37	19	9.9	38.0	Red Lake Falls
B-11-16	30	1070	2.5Y 4/4	2.5Y 7/2	45	41	14	7.4	36.5	Red Lake Falls
B-11-17	32	1072	2.5Y 4/4	2.5Y 7/2	43	37	20	11.0	35.1	Red Lake Falls
B-11A-1	3	1048	5Y 4/1	5Y 6/1	57	35	8	6.2	24.5	Marcoux
B-11A-2	4	1049	10YR 2/1	5Y 5/1	36	41	23	4.1	17.9	St. Hilaire
B-11A-3	7	1052	2.5Y 4/2	5Y 6/1	50	36	14	9.8	41.5	Red Lake Falls
B-11A-6	15	1060	2.5Y 4/2	5Y 6/1	50	36	14	11.0	37.9	Red Lake Falls
B-11A-7	21.5	1066.5	7.5YR6/4	7.5Y7/2	38	44	18	15.7	58.5	St. Hilaire
B-11A-8	23.5	1068.5	2.5Y 4/4	2.5Y 7/2	33	60	7	5.6	25.9	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total*	
C-2-19	6	1033	2.5Y 5/2	2.5Y 7/2	51	40	9	6.5	26.3	Marcoux
C-2-18	8	1035	5Y 4/2	5Y 6/1	47	43	10	5.8	25.5	Marcoux
C-2-17	11	1038	2.5Y 4/2	2.5Y 6/2	52	35	13	7.2	24.6	Marcoux
C-2-15	15	1042	2.5Y 4/2	5Y 6/1	58	32	10	5.8	23.7	Marcoux
C-2-13B	18	1045	10YR 3/1	5Y 5/1	37	37	26	9.0	30.2	St. Hilaire
C-2-13A	18.5	1045.5	10YR 3/1	5Y 5/1	30	38	32	6.1	29.3	St. Hilaire
C-2-12	20	1047	2.5Y 4/2	5Y 6/1	51	32	17	8.2	35.8	Red Lake Falls
C-2-23	20.5	1047.5	2.5Y 4/2	5Y 6/2	50	33	17	9.6	36.8	Red Lake Falls
C-2-11	22	1049	2.5Y 4/2	5Y 6/1	43	41	16	9.6	38.6	Red Lake Falls
C-2-22	23	1050	2.5Y 4/2	5Y 6/1	46	38	16	11.7	38.2	Red Lake Falls
C-2-10	24	1051	2.5Y 4/2	5Y 6/2	43	43	14	2.0	30.1	Red Lake Falls
C-2-21	25	1052	2.5Y 5/4	2.5Y 7/2	47	37	16	10.5	37.5	Red Lake Falls
C-2-8	26	1053	2.5Y 3/2	5Y 6/1	31	53	16	11.2	36.2	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
C-2-20	28	1055	10YR 3/3	5Y 6/1	36	46	18	10.5	34.8	Red Lake Falls
C-2-7	30	1057	10YR 3/2	5Y 6/1	41	43	16	10.8	34.3	Red Lake Falls
C-2-6	32	1059	2.5Y 5/4	2.5Y 7/2	46	38	16	9.6	32.9	Red Lake Falls
C-2-5	34	1061	2.5Y 5/4	2.5Y 7/2	45	40	15	10.4	34.8	Red Lake Falls
C-2-4	37	1064	2.5Y 5/4	2.5Y 6/4	44	39	17	7.6	30.2	Red Lake Falls
C-2-3	39	1066	2.5Y 4/4	2.5Y 6/4	34	43	23	5.6	26.6	Red Lake Falls
C-2-2	42	1069	2.5Y 4/4	2.5Y 6/4	38	40	22	3.0	25.7	Red Lake Falls
C-2-1	45	1072	2.5Y 5/4	5Y 7/3	30	46	22	6.6	26.1	Red Lake Falls
C-5A-1	7	1017	5Y 4/2	5Y 6/1	53	35	12			Marcoux
C-5A-2	9	1019	5Y 4/2	5Y 6/1	54	34	12	5.5	22.0	Marcoux
C-5A-9	9	1019	5Y 4/2	5Y 6/1	66	27	7	4.7	21.3	Marcoux
C-5A-3	11	1021	2.5Y 5/4	2.5Y 7/2				3.2	18.0	Red Lake Falls
C-5A-4	13	1023	2.5Y 5/2	5Y 7/1	49	35	16	10.6	42.4	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
C-5A-5	15	1025	2.5Y 4/2	5Y 6/1	51	36	13	12.8	43.3	Red Lake Falls
C-5A-11	16	1026	2.5Y 5/2	2.5Y 7/2	57	33	10	4.9	19.4	Red Lake Falls
C-5A-6	18	1028	5Y 4/2	5Y 6/1	48	38	14	10.6	38.5	Red Lake Falls
C-5A-6A	18	1028	2.5Y 4/4	2.5Y 6/2	49	34	17	10.6	38.0	Red Lake Falls
C-5A-7	21	1031	2.5Y 4/4	2.5Y 7/2	40	44	16	9.4	28.4	Red Lake Falls
C-5A-8	34	1044	2.5Y 4/4	2.5Y 7/2	35	44	21	6.1	28.5	Red Lake Falls
C-7-1	6	1001	2.5Y 4/4	5Y 6/1	60	30	10	6.0	22.4	Marcoux
C-7-2	9	1004	2.5Y 5/2	5Y 6/1	59	32	9	5.2	21.3	Marcoux
C-7-3	12	1007	2.5Y 5/2	5Y 7/1	58	20	22	3.7	29.3	Marcoux
C-7-4	15	1010	2.5Y 4/2	2.5Y 6/2	56	36	8	5.5	25.0	Marcoux
C-7-5	18	1013	2.5Y 4/2	5Y 6/1	52	37	11	4.9	24.8	Marcoux
C-7-6	21	1016	2.5Y 4/2	2.5Y 7/2	55	39	6	7.5	26.0	Marcoux
C-7-8	26	1021	5Y 3/1	5Y 6/1	41	45	14	7.4	30.3	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
C-7-9	29	1024	5Y 3/1	5Y 6/1	36	44	20	5.7	26.8	Red Lake Falls
C-7-10	32	1027	5Y 3/1	5Y 6/1	35	36	29	5.4	25.4	Red Lake Falls
C-7-11	35	1030	2.5Y 4/4	2.5Y 6/4	34	38	28	6.8	26.4	Red Lake Falls
C-7-12	38	1033	2.5Y 4/2	5Y 6/3	36	46	18	5.2	26.8	Red Lake Falls
C-7-13	41	1036	2.5Y 6/4	2.5Y 4/4	35	42	23	6.9	26.4	Red Lake Falls
C-7-14	44	1039	2.5Y 4/4	5Y 6/3	35	40	25	6.7	26.5	Red Lake Falls
C-7-15	47	1042	2.5Y 4/4	5Y 7/3	34	47	19	5.1	30.3	Red Lake Falls
C-7-16	50	1045	5Y 6/4	5Y 7/3	28	34	38	7.5	26.8	Wylie
C-10-2	6	986	5Y 4/1	5Y 6/1	44	41	15	8.7	44.0	Red Lake Falls
C-10-3	12	992	2.5Y 4/2	2.5Y 6/2	43	34	23	10.0	35.4	Red Lake Falls
C-10-4	32	1012	5Y 4/1	5Y 6/1	43	45	12	7.4	35.9	Red Lake Falls
C-10-5	44	1024	2.5Y 5/4	2.5Y 7/2	43	42	15	7.5	31.0	Red Lake Falls
C-10-6	50	1030	2.5Y 5/4	2.5Y 7/2	44	35	21	9.1	31.6	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
C-10-7	58	1038	2.5Y 5/4	2.5Y 7/2	25	47	28	8.1	28.0	Red Lake Falls
C-10-1	66	1046	2.5Y 4/2	2.5Y 5/2	29	52	19	5.6	25.6	Red Lake Falls
D-1-2	21	991	5Y 3/1	5Y 6/1	36	52	12	7.7	29.2	Red Lake Falls
D-1-3	27	997	5Y 3/1	5Y 6/1	35	54	11	5.0	26.5	Red Lake Falls
D-1-4	32	1002	2.5Y 4/2	2.5Y 6/2	38	45	17	5.7	26.8	Red Lake Falls
D-2-1	1	966	2.5Y 3/2	5Y 6/1	42	36	22	8.8	32.9	Red Lake Falls
D-2-2	6	971	2.5Y 4/2	5Y 6/1	43	39	18	11.1	35.7	Red Lake Falls
D-2-3	8	973	2.5Y 4/4	2.5Y 7/2	43	38	19	8.3	35.6	Red Lake Falls
D-2-4	16	981	2.5Y 4/4	2.5Y 7/2	42	38	20	11.1	35.8	Red Lake Falls
D-2A-1	18	980	5Y 4/2	5Y 6/1	53	34	13	7.9	29.5	Marcoux
D-2A-2	20	982	5Y 4/2	5Y 6/1	53	37	10	5.4	27.3	Marcoux
D-2A-3	21	983	5Y 3/1	5Y 6/1	34	45	21	6.5	28.7	Red Lake Falls
D-2A-4	23	985	5Y 3/1	10YR 6/1	37	45	18	5.7	28.7	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
D-2A-6	55	1017	2.5Y 3/2	5Y 6/2	27	53	20	3.9	25.0	Red Lake Falls
D-3-2	3	963	10YR 3/2	5Y 6/1	41	42	17	8.2	34.6	Red Lake Falls
D-3-3	6	966	10YR 3/3	2.5Y 6/2	43	38	19	8.2	33.2	Red Lake Falls
D-3-4	9	969	10YR 3/2	5Y 6/2	43	39	18	10.5	34.5	Red Lake Falls
D-3-5	12	972	5Y 4/2	5Y 6/2	42	39	19	7.4	33.2	Red Lake Falls
D-3-8	26	986	2.5Y 4/2	2.5Y 6/2	36	43	21	6.1	27.2	Red Lake Falls
D-3-7	29	989	5Y 4/2	5Y 7/2	19	43	38	6.8	26.1	Red Lake Falls
D-3A-1	9	964	5Y 5/2	5Y 6/1	50	38	12	5.4	29.0	Marcoux
D-3A-2	12	967	5Y 5/2	5Y 7/1	51	38	11	7.4	30.1	Marcoux
D-3A-3	15	970	5Y 5/2	5Y 6/1	48	42	10	8.0	30.6	Marcoux
D-3A-4	18	973	2.5Y 4/2	5Y 6/1	51	39	10	7.4	29.7	Marcoux
D-3A-5	21	976	2.5Y 4/2	5Y 6/1	50	38	12	8.3	30.5	Marcoux
D-3A-6	24	979	2.5Y 5/2	5Y 6/1	51	38	11	6.1	31.6	Marcoux

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
D-3A-7	26	981	2.5Y 4/2	5Y 6/1	50	37	13	10.0	37.2	Marcoux
D-3A-9	30	985	5Y 3/1	5Y 5/1	37	42	21	6.3	27.9	Red Lake Falls
D-3A-10	32	987	2.5Y 3/2	2.5Y 5/2	40	42	18	4.4	26.1	Red Lake Falls
D-3A-11	40	995	2.5Y 3/2	2.5Y 5/2	38	43	19	6.6	28.0	Red Lake Falls
D-3A-12	46	1001	2.5Y 4/2	2.5Y 6/2	36	46	18	4.7	33.2	Red Lake Falls
CW-1-1	44	999	10YR 3/3	5Y 6/3	36	41	23	4.8	27.4	Red Lake Falls
CW-1-2	41	996	2.5Y 4/2	2.5Y 6/2	36	40	24	5.2	29.2	Red Lake Falls
CW-1-3	38	993	2.5Y 3/2	5Y 6/1				11.2	41.0	Red Lake Falls
CW-1-4	35	990			37	38	25	8.6	41.2	Red Lake Falls
CW-1-5	32	987	5Y 3/1	5Y 6/1	32	41	27	12.8	40.1	Red Lake Falls
CW-1-6	27	982	2.5Y 5/4	2.5Y 7/2	12	72	16	5.6	38.7	Marcoux
CW-1-7	23	978	2.5Y 4/4	5Y 6/3	51	16	33	6.0	30.7	Marcoux
CW-1-8	20	975	2.5Y 5/4	2.5Y 7/2	50	34	16	5.4	30.1	Marcoux

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
CW-1-9	17	972	2.5Y 5/4	5Y 6/3	53	33	14	5.6	30.4	Marcoux
CW-1-10	14	969	2.5Y 4/2	5Y 7/2	55	31	14	6.8	30.5	Marcoux
CW-1-11	11	966	5Y 5/2	5Y 6/2	53	32	15	5.8	29.3	Marcoux
D-4-1	19	947	5Y 4/2	5Y 6/1	53	32	15	3.7	35.7	Marcoux
D-4-2	40	980	2.5Y 5/2	2.5Y 7/2	43	32	25	10.3	34.5	Red Lake Falls
D-4-3	43	983	2.5Y 4/2	5Y 6/1	45	33	22	9.1	33.2	Red Lake Falls
D-4-4	49	989	2.5Y 4/4	5Y 6/3	40	33	27	5.7	27.2	Red Lake Falls
D-4-5	55	995	2.5Y 4/4	5Y 7/3	36	34	30	6.2	26.3	Red Lake Falls
D-4-6	59	999	2.5Y 4/4	5Y 7/3	28	32	40	5.1	27.5	Red Lake Falls
D-4-7	61	1001	2.5Y 5/6	5Y 7/3	17	51	32	5.9	28.4	Wylie
D-4-8	62	1002	2.5Y 3/2	5Y 5/1	0	25	75	3.0	26.1	Wylie
D-4-9	66	1006	2.5Y 5/2	2.5Y 7/2	2	6	92	4.7	26.3	Huot
D-5-1	3	943	5Y 3/1	5Y 6/1	16	48	36	4.1	32.2	Gervais

TABLE 1--Continued

Sample No.	Foot Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
D-5-2	6	946	5Y 3/1	5Y 6/1	21	45	34			Gervais
D-5-3	9	949	5Y 3/1	5Y 6/2	20	47	33	4.5	19.8	
D-5-4	12	952	5Y 6/2	5Y 6/2				4.9	17.7	Gervais
D-5-5	15	955	5Y 3/1	5Y 6/2	20	47	33	3.7	18.6	Gervais
D-5-6	18	958	5Y 3/1	5Y 6/2	22	48	30	3.7	17.3	Gervais
D-5-7	21	961	5Y 3/1	5Y 6/2	18	48	34	4.4	18.7	Gervais
D-5-8	24	964	5Y 3/1	5Y 6/2	18	46	36	5.0	20.2	Gervais
D-5-9	24.5	964.5	2.5YR3/2	5Y 6/1	20	43	37	5.9	28.6	Gervais
D-5-10	25.5	965.5	5Y 5/1	5Y 6/1	50	35	15	4.1	39.7	Marcoux
D-5-16	45	985	2.5Y 4/2	2.5Y 6/2	44	31	25	9.5	35.3	Red Lake Falls
D-5-17	47	987	2.5Y 4/2	2.5Y 6/2	42	29	29	6.9	29.0	Red Lake Falls
D-5-18	47	987	2.5Y 4/2	2.5Y 6/2	46	31	23	7.3	33.7	Red Lake Falls
D-5-19	50	990	2.5Y 4/2	2.5Y 6/2	48	29	23	6.5	31.0	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
D-5-20	53	993	2.5Y 4/2	2.5Y 6/2	43	28	29	5.4	32.7	Red Lake Falls
D-5-21	56	996	2.5Y 4/2	2.5Y 6/2	38	32	30	5.1	25.5	Red Lake Falls
D-5-22	59	999	2.5Y 4/2	2.5Y 6/2	38	35	27	5.2	36.5	Red Lake Falls
D-5-23	61	1001	2.5Y 4/4	2.5Y 6/2	19	42	39	3.9	24.8	Red Lake Falls
D-5-24	65	1005	2.5Y 4/4	2.5Y 7/2	20	42	38	6.1	26.9	Red Lake Falls
D-7-1	11	941	2.5Y 5/2	5Y 7/1	51	28	21	5.7	24.7	Marcoux
D-7-2	16	946	10YR 3/2	5Y 6/1	37	31	32	6.6	27.3	Red Lake Falls
D-8A-2	5	933	5Y 3/1	5Y 6/1	41	33	26	7.3	30.2	Red Lake Falls
D-8A-1	17	945	5Y 3/1	5Y 6/1	39	38	23	7.3	29.1	Red Lake Falls
D-10-1	6	931	10YR 3/3	2.5Y 5/2	40	34	26	6.1	28.2	Marcoux
D-10-2	9	934	5Y 3/1	10YR 6/1	37	33	30	6.1	26.5	Marcoux
D-10-3	11	936	2.5Y 4/2	2.5Y 6/2	20	44	36	4.5	24.2	Red Lake Falls
D-10-4	14	939	2.5Y 3/2	2.5Y 5/2	30	35	35	3.7	23.5	Red Lake Falls

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
D-10-5	25	950	2.5Y 3/2	2.5Y 6/2	8	22	70	6.9	28.1	Huot
D-11-1	6	929	2.5Y 3/2	2.5Y 5/2	14	52	34	4.9	18.7	Gervais
D-11-2	9	932	2.5Y 3/2	2.5Y 6/2	15	54	31	3.0	16.6	Gervais
D-11-3	12	935	2.5Y 3/2	2.5Y 6/2	13	52	35	3.3	22.9	Gervais
D-11-4	15	938	2.5Y 3/2	2.5Y 6/2	40	37	23	6.9	29.6	Red Lake Falls
D-11-5	18	941	2.5Y 3/2	2.5Y 6/2	42	39	19	3.6	26.9	Red Lake Falls
D-11-6	21	944	2.5Y 4/2	5Y 6/1	36	41	23	7.0	29.2	Red Lake Falls
D-11-7	24	947	2.5Y 3/2	5Y 5/2	37	38	25	6.0	26.4	Red Lake Falls
D-11-8	27	950	10YR 3/2	5Y 5/1	38	38	24	5.1	31.1	Red Lake Falls
D-11-9	31	954	2.5Y 4/4	5Y 6/3	19	46	35	6.1	29.8	Wylie
D-11-10	33	956	2.5Y 3/2	5Y 5/1	2	30	68	5.2	26.2	Huot
D-11-11	35	958	2.5Y 4/2	5Y 6/1	16	30	54	7.7	34.9	Huot
D-11-12	38	961	5Y 3/1	5Y 6/1	1	12	87	6.2	22.6	Huot

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
D-12-1	6	926	2.5Y 4/2	2.5Y 6/2	41	35	24	5.1	28.4	Red Lake Falls
D-12-2	9	929	2.5Y 4/2	2.5Y 5/2	37	34	29	4.7	33.2	Red Lake Falls
D-12-3	11	931	2.5Y 4/2	2.5Y 6/2	39	36	25	5.6	27.3	Red Lake Falls
D-12-4	13	933	2.5Y 4/2	2.5Y 7/2	13	43	44	5.0	24.1	Red Lake Falls
D-12-5	16	936	2.5Y 3/2	2.5Y 7/2	9	26	65	5.7	24.0	Red Lake Falls
D-12-6	25	945	2.5Y 3/2	5Y 5/1	8	20	70	4.8	25.8	Huot
D-12-7	28	948	2.5Y 3/2	5Y 5/1	8	17	75	7.0	30.7	Huot
D-12-8	31	951	5Y 3/1	5Y 5/1	8	21	71	3.9	27.0	Huot
D-12-9	33	953	5Y 3/1	5Y 5/1	7	18	75	5.6	27.5	Huot
E-1-1	6	919	5Y 3/1	5Y 6/1	51	35	14	5.0	22.3	Marcoux
E-1-2	9	922	5Y 4/1	5Y 6/1	52	25	23	5.4	24.4	Marcoux
E-1-3	12	925	2.5Y 4/2	5Y 6/1	53	30	17	3.9	24.0	Marcoux
E-1-4	14	927	5Y 4/1	5Y 6/1	51	28	21	5.2	22.3	Marcoux

TABLE 1--Continued

Sample No.	Feet Above Water Level	Elevation	Color		Texture			Carbonate		Formation
			Wet	Dry	Sand	Silt	Clay	Calcite	Total	
E-1-5	16	929	2.5Y 4/4	5Y 6/1	43	31	26	9.2	39.2	Red Lake Falls
E-1-6	17	930	5Y 4/1	5Y 6/1	41	34	25	11.2	43.8	Red Lake Falls
E-1-7	19	932	2.5Y 4/2	2.5Y 6/2	43	33	24	8.1	31.1	Red Lake Falls
E-1-8	22	935	2.5Y 3/2	2.5Y 5/2	38	35	27	5.7	27.0	Red Lake Falls
G-3-1	3	852	2.5Y 3/2	5Y 5/1	7	16	77	7.3	26.3	Huot
G-3-2	9	858	2.5Y 3/2	5Y 6/1	8	20	72	6.1	28.9	Huot
G-3-3	15	864	5Y 3/1	5Y 6/2	7	18	75	6.9	25.5	Huot
G-3-4	20	869	2.5Y 3/2	5Y 6/1	7	16	77	7.5	27.5	Huot

TABLE 2

SUMMARY OF TEXTURAL AND CARBONATE ANALYSES

Formation	TEXTURE						CARBONATE			
	Sand		Silt		Clay		Calcite		Total	
	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Huot	6.7	3.6	19.8	6.5	73.4	8.6	6.8	2.2	22.5	4.3
Red Lake Falls	40.3	6.9	39.3	5.7	20.4	5.8	7.3	2.5	31.4	5.1
St.Hilaire	36.1	6.6	41.6	4.5	22.2	7.2	7.0	3.0	24.8	7.6
Marcoux	52.8	5.4	34.4	4.6	12.8	6.0	6.3	1.5	28.1	5.1
Gervais	17.9	3.0	48.2	3.3	33.9	2.1	4.3	.8	14.3	5.4

TABLE 3

LOCATION OF MEASURED SAMPLE SECTIONS

Reach/ Outcrop	Name	Location
A-2		NW/4, SE/4, NE/4, Sec. 20, T 153 N, R 43 W
A-6	Fisherman's Curve Section	SW/4, SW/4, SE/4, Sec. 29, T 153 N, R 43 W
B-1	Stony Bench Section	NE/4, NE/4, NW/4, Sec. 17, T 152 N, R 43 W
B-3		NE/4, SE/4, SW/4, Sec. 17, T 152 N, R 43 W
B-3A	Small Creek	SE/4, SW/4, SE/4, Sec. 17, T 152 N, R 43 W
B-6		NE/4, NE/4, NW/4, Sec. 29, T 152 N, R 43 W
B-8	Befuddlement Bar Section	SW/4, NE/4, SE/4, Sec. 32, T 152 N, R 43 W
B-11	Opernockity Section	SE/4, NE/4, SE/4, Sec. 32, T 152 N, R 43 W
B-11A	Sleepy Hollow Section	NE/4, NE/4, SE/4, Sec. 32, T 152 N, R 43 W
C-2	Powerline Section	SE/4, SE/4, NE/4, Sec. 5, T 151 N, R 43 W
C-5A		W/2, SE/4, SE/4, Sec. 7, T 151 N, R 43 W
C-7	Needles Eye Section	SW/4, NE/4, SE/4, Sec. 18, T 151 N, R 43 W
C-10	Knifes Edge Section	NW/4, NW/4, SE/4, Sec. 19, T 151 N, R 43 W
D-1		N/2, SE/4, NW/4, Sec. 24, T 151 N, R 44 W
D-2		SW/4, NW/4, SE/4, Sec. 13, T 151 N, R 44 W

TABLE 3--Continued

Reach/ Outcrop	Name	Location
D-2A		NW/4, NE/4, NE/4, Sec. 23, T 151 N, R 44 W
D-3	Old Dam Section	SE/4, NW/4, Sec. 14, T 151 N, R 44 W
D-3A	Damned House Section	SW/4, NE/4, SE/4, sec. 15, T 151 N, R 44 W
CW-1	Clearwater Section	NE/4, NE/4, Sec. 22, T 151 N, R 44 W
D-4		NW/4, SW/4, SE/4, Sec. 16, T 151 N, R 44 W
D-5	Three Creeks Section	NE/4, NE/4, NW/4, Sec. 21, T 151 N, R 44 W
D-7		NW/4, NW/4, NW/4, Sec. 20, T 151 N, R 44 W
D-8A	Fossil Plate Section	SE/4, NW/4, SW/4, Sec. 17, T 151 N, R 44 W
D-10		NW/4, NE/4, SW/4, Sec. 18, T 151 N, R 44 W
D-11	Moo Point Section	N/2, NE/4, NW/4, Sec. 19, T 151 N, R 44 W
D-12	Snake Curve North Section	NW/4, SW/4, Sec. 18, T 151 N, R 44 W
E-1		NE/4, SE/4, SE/4, Sec. 24, T 151 N, R 44 W
E-6	Schist Cliff Section	SE/4, SE/4, Sec. 22, T 151 N, R 45 W
G-3	Convent Cut Section	SW/4, SE/4, SE/4, Sec. 32, T 150 N, R 46 W

Appendix II

DETAILED DESCRIPTION OF LITHOSTRATIGRAPHIC UNITS

This appendix includes detailed discussions of lithostratigraphic units exposed along the Red Lake River trench.

GERVAIS FORMATION (New)

Source of name: Gervais Township, Red Lake County, Minnesota.

Type area: The Red Lake Falls area of Minnesota.

Type section: Three Creeks Section, NE 1/4, NE 1/4, NW 1/4, Sec. 21, T 151 N, R 44 W (Appendix III).

Reference section: Moo Point Section, NE 1/4, NE 1/4, NW 1/4, Sec. 19, T 151 N, R 44 W (Appendix III).

Description of unit: The Gervais Formation is unbedded, silty, very slightly pebbly clay-loam. It is light olive gray (5 Y 6/2) (Munsell Soil Color Chart) when dry and very dark gray (5 Y 3/1) when moist. In outcrop, it tends to part or flake along joints that are oxidized to dark brown (7.5 YR 3/2), giving the outcrop a brownish cast. Abundant wood chips, twigs, and logs up to 6 inches across occur in the Gervais Formation. Fragments of mollusk shells, insects, carbon flakes and green moss are also present. Abundance of all organic material decreases upward, and the abundance of pebbles increases upward. A few cobbles are present near the upper contact. Though not abundant, sand lenses a few

millimeters thick are present with increasing abundance upward.

The Gervais Formation contains 15% to 21% sand, 45% to 51% silt, and 32% to 36% clay. It contains about 15% total carbonate material finer than 200-mesh.

Nature of contacts: At the Three Creeks Section, the contact of the Gervais Formation with the overlying Marcoux Formation is sharp, and cobbles are concentrated along the contact. At the Moo Point Section, the Marcoux Formation is absent and the Gervais Formation is in sharp to gradational contact with the Red Lake Falls Formation. Cobbles are concentrated at the contact here also. The lower contact of the formation has not been observed, and its nature is unknown.

Regional extent and thickness: The Gervais Formation is exposed at only two known outcrops in the Red Lake River valley (Figure 4). The Gervais Formation is at least 40 feet thick at the Three Creeks Section.

Differentiation from other units: The Gervais Formation is overlain by the Marcoux Formation at the Three Creeks Section and by the Red Lake Falls Formation at the Moo Point Section. It may be differentiated from both of these formations on the basis of its finer texture, darker color, and the presence of organic debris.

Origin: The Gervais Formation probably consists of glacially modified fluvial or lacustrine sediment. The homogenizing effect of the reworking increased upward through

the formation. The silt and clay was probably derived locally.

Age and correlation: The Gervais Formation is Early Wisconsinan or pre-Wisconsinan in age. A radiocarbon date obtained from a log near the base of the Three Creeks Section is greater than 39,900 B.P. (I-5317).

The Gervais Formation may be correlative with a silt and sand unit found in well borings in the Lake Bronson, Minnesota, area. These borings ranged in depth from 90 to 140 feet and produced abundant organic material. Radiocarbon dates on the organic debris recovered have not been finite: greater than 19,000 B.P. (C-496, greater than 36,000 B.P. (W-102), greater than 36,000 (W-498), and greater than 38,000 (W-1028).

MARCOUX FORMATION (New)

Source of the name: Marcoux Corners, Red Lake County, Minnesota, located on the Red Lake Falls 15-minute quadrangle.

Type area: Red Lake Falls area, Minnesota.

Type section: Clearwater Section, NE 1/4, NE 1/4, Sec. 22, T 151 N, R 44 W (Appendix III).

Reference sections: Needles Eye Section, SW 1/4, NE 1/4, SE 1/4, Sec. 18, T 151 N, R 43 W (Appendix III); and Damned House Section, SW 1/4, NE 1/4, SE 1/4, Sec. 15, T 151 N, R 44 W (Appendix III).

Description of unit: The Marcoux Formation is unbedded, very sandy pebble-loam. It contains 48% to 58% sand, 30% to 40% silt, and 8% to 18% clay. Total carbonate material finer than 200-mesh is 28%. The formation is light gray (5Y 6/1) when dry and grayish brown (2.5 Y 5/2) when wet. In weathered outcrops it is extremely hard and stands in nearly vertical slopes. It is not conspicuously jointed. Pebbles, cobbles, and boulders are abundant in this formation. Rapids along the Red Lake River are generally associated with outcrops of the Marcoux Formation. Pebble lithology is about 66% igneous and metamorphic rock types and 33% limestone and dolomite. Shale pebbles are rare.

Nature of the contacts: The lower contact of the formation has been seen only at the Three Creeks Section, where the Marcoux Formation overlies the Gervais Formation. Here the contact is sharp. Cobbles are concentrated at the contact.

North of the Powerline Section (Figure 9, No. 5), the Marcoux is overlain by the St. Hilaire Formation (Figure 4). The contact between these formations is sharp and generally marked by a boulder pavement. Where the boulder pavement is absent, a bed of sand as much as 18 inches thick is commonly present.

South and west of the Powerline Section, the Marcoux is overlain by the Red Lake Falls Formation (Figure 4). The contact between these formations is sharp and marked by a

bed of sand or sand and gravel ranging in thickness from a few inches to 17 feet. A boulder pavement is present in some outcrops but is not common.

Regional extent and thickness: The Marcoux Formation is exposed in the Red Lake River trench for a distance of about 20 miles, from south of Thief River Falls to west of Red Lake Falls (Figure 4). It has been seen in outcrop from Florian, in Marshall County, Minnesota, to Ulen, in Clay County, Minnesota, a distance of about 100 miles. Subsurface investigators in the Red River Valley also report a sandy, pebble-loam believed to be the Marcoux Formation (Moran, 1973). The Marcoux Formation is thought to extend from north of the Canadian border throughout northwestern Minnesota and eastern North Dakota.

Exposed thicknesses of the Marcoux Formation range from 6 inches to 27 feet. Attempts to penetrate the formation with truck-mounted power auger have been frustrated by its high boulder content and extreme hardness. Borings in the Grand Forks area encountered as much as 64 feet of the Marcoux Formation.

Differentiation from other units: The most useful characteristic for distinguishing the Marcoux Formation from other stratigraphically similar formations is its texture. No other formation has its high sand and low clay content. The abundance of stones, predominance of igneous and metamorphic pebbles, hardness, and weak jointings are also use-

ful criteria.

Origin: The Marcoux Formation is glacial sediment. Predominance of granitic and metamorphic rock types in the formation suggests a northeastern source area.

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

The Marcoux Formation probably correlates with the Hawk Creek till in the Minnesota River valley (Matsch, 1971).

ST. HILAIRE FORMATION (New)

Source of name: The village of St. Hilaire in Pennington County, Minnesota, located on the Thief River Falls 7.5 minute quadrangle.

Type section: Powerline Section, SE 1/4, SE 1/4, NE 1/4, Sec. 5, T 151 N, R 43 W (Appendix III).

Reference sections: Opernockity Section, SE 1/4, NE 1/4, SE 1/4, Sec. 32, T 152 N, R 43 W (Appendix III); Small Creek Section, SE 1/4, SW 1/4, SE 1/4, Sec. 17, T 152 N, R 43 W (Appendix III).

Description of unit: The St. Hilaire Formation is unbedded pebble-loam. It is gray (5 Y 5/1) when dry and very dark gray (10 Y 3/2) when wet. Weak vertical joints are common and result in a moderately columnar structure. The formation contains abundant pebbles and cobbles. Pebble lithology is about 40% igneous rock types, 40% limestone and dolomite, 15% shale, and 5% lignite fragments.

The St. Hilaire Formation consists of 30% to 40% sand, 38% to 46% silt, and 15% to 29% clay. Total carbonate material finer than 200-mesh is 25%.

Nature of the contacts: The St. Hilaire Formation overlies the Marcoux Formation in the Red Lake Falls area. The contact between them is sharp, and typically there is a cobble concentration or boulder pavement present. In some places as much as 18 inches of fine sand is present at the contact.

The upper contact with the overlying Red Lake Falls Formation is sharp to diffuse. Discontinuous and contorted sand beds are commonly present.

Regional extent and thickness: In the Red Lake River valley the St. Hilaire Formation is exposed only from Thief River Falls, south to the Powerline Section. In this area the unit is from 1 to 4 feet thick. Its characteristic dark color makes it a useful stratigraphic marker.

The St. Hilaire Formation thickens to the south. At the Twin Valley Section on the Wild Rice River near Heiberg, Minnesota, 20 feet of the formation is exposed.

The St. Hilaire Formation is thought to extent throughout northeastern North Dakota, southern Manitoba, and northwestern Minnesota.

Differentiation from other units: The St. Hilaire Formation is easily distinguished from the Marcoux and Red Lake Falls Formations by pebble lithology and color. The Marcoux

Formation contains predominantly igneous and metamorphic pebbles, and the Red Lake Falls Formation contains largely limestone and dolomite pebbles. Neither of these formations contains appreciable shale or lignite, and both are lighter in color than the dark gray St. Hilaire. The Huot and Gervais Formations contain significantly less sand than the St. Hilaire Formation.

Origin: The St. Hilaire is glacial sediment. The pebble lithology suggests a western or northwestern source; the glacial ice moved across outcrops of shale of the Pierre and Riding Mountain Formations in eastern North Dakota and southern Manitoba.

Age: The age of the St. Hilaire Formation is unknown, but stratigraphic position suggests that it is Wisconsinan or pre-Wisconsinan in age.

RED LAKE FALLS FORMATION (New)

Source of name: The city of Red Lake Falls, Red Lake County, Minnesota, located on the Red Lake Falls, Minnesota, 15-minute quadrangle.

Type section: Clearwater Section, NE 1/4, NW 1/4, Sec. 22, T 151 N, R 44 W (Appendix III).

Reference sections: Needles Eye Section, SW 1/4, NE 1/4, SE 1/4, Sec. 18, T 151 N, R 43 W (Appendix III); Damned House Section, SW 1/4, NE 1/4, SE 1/4, Sec. 15, T 151 N, R 44 W (Appendix III).

Description of unit: The Red Lake Falls Formation is unbedded, pebble-loam. It is brownish gray (2.5 Y 6/2) when dry and olive brown (2.5 Y 4/4) when wet. Vertical joints result in a strong columnar structure in dry, weathered outcrops, and oxidation along the joints produces a reddish yellow (7.5 YR 6/6) stain. The Red Lake Falls Formation is quite hard and resistant to erosion in dry outcrops and is friable when moist.

Sand and gravel inclusions are quite common; these include thin beds a few millimeters thick, channel fills, and contorted masses. Thin beds of laminated silt and clay as much as a few inches thick may be laterally persistent for tens of feet.

Pebbles, cobbles, and boulders are abundant. Pebble lithology is about 65% limestone and dolomite, and 30% igneous and metamorphic rock types, and about 5% shale.

The Red Lake Falls Formation is made up of 34% to 46% sand, 33% to 45% silt, and 14% to 26% clay. Total carbonate material finer than 200-mesh is 31%.

Nature of the contacts: North of the Powerline Section the Red Lake Falls Formation overlies the St. Hilaire Formation. The contact between these formations is sharp to diffusely graded. The Marcoux Formation underlies the Red Lake Falls Formation south of the Powerline Section. The contact between these formations is sharp, with sand and gravel commonly present. The sand and gravel ranges from a few inches to 17 feet thick. A boulder pavement is present at the con-

tact in some outcrops.

The upper contact of the Red Lake Falls Formation is a gradual interbedding with the overlying Wylie Formation. The Red Lake Falls Formation commonly becomes less sandy and more clayey near its upper contact. Where the Wylie Formation is absent, there is a diffuse contact with a contorted silty, pebbly clay containing silt inclusions. This is probably a subaqueous mud flow deposit made up of material derived from the Red Lake Falls and Wylie Formations. At several locations the upper contact of the Red Lake Falls Formation is an erosional surface overlain by Holocene fluvial sediment.

Regional extent and thickness: The Red Lake Falls Formation is exposed along the Red Lake River trench from Thief River Falls to near Huot. It is present in surface exposures in northwestern Minnesota from the Canadian border to the Wild Rice River. It is present in the subsurface throughout the Red River Valley and is believed to extend westward into North Dakota.

The Red Lake Falls Formation ranges in thickness from at least 70 feet at Knifes Edge Section (Table 3) to 7 feet at the Stony Bench Section (Table 3). The normal range of thickness is from 15 to 30 feet.

Differentiation from other units: The Red Lake Falls Formation can be distinguished from similar units on the basis of texture, pebble lithology, and color. It is sand-

ier than either the silty Gervais or Falconer Formations, or the clayey Huot Formation. It is lighter in color than both the Gervais and Huot Formations. Pebble lithology distinguishes the Red Lake Falls from the Marcoux Formation, and color distinguishes it from the St. Hilaire Formation, which is much darker.

Origin: The Red Lake Falls Formation is glacial sediment deposited by a glacier advancing from the north.

Age: The age of the Red Lake Falls Formation is unknown. It is thought to be Late Wisconsinan on the basis of a tentative correlation with glacial sediment of known age in nearby areas.

WYLIE FORMATION (New)

Source of the name: The village of Wylie, Red Lake County, Minnesota, located on the Red Lake Falls 15-minute quadrangle.

Type section: Clearwater Section, NE 1/4, NW 1/4, Sec. 22, T 151 N, R 44 W (Appendix III).

Reference section: Old Dam Section, SE 1/4, NW 1/4, Sec. 14, T 151 N, R 44 W (Appendix III).

Description of unit: The Wylie Formation contains clay and silt that are generally thinly laminated. The clay is olive gray (5 Y 5/2) when dry and dark gray (5 Y 4/1) when wet. The silt is light brownish gray (2.5 Y 6/2) when dry and olive brown (2.5 Y 4/4) when wet. In outcrop, the for-

mation is friable when dry and tough and plastic when moist. The silt laminae become thinner and the clay laminae become thicker upward. The laminae range from a few millimeters to a centimeter thick in most outcrops.

Nature of contacts: The lower contact of the Wylie Formation with the Red Lake Falls Formation is gradual and interbedded. This contact is locally highly contorted.

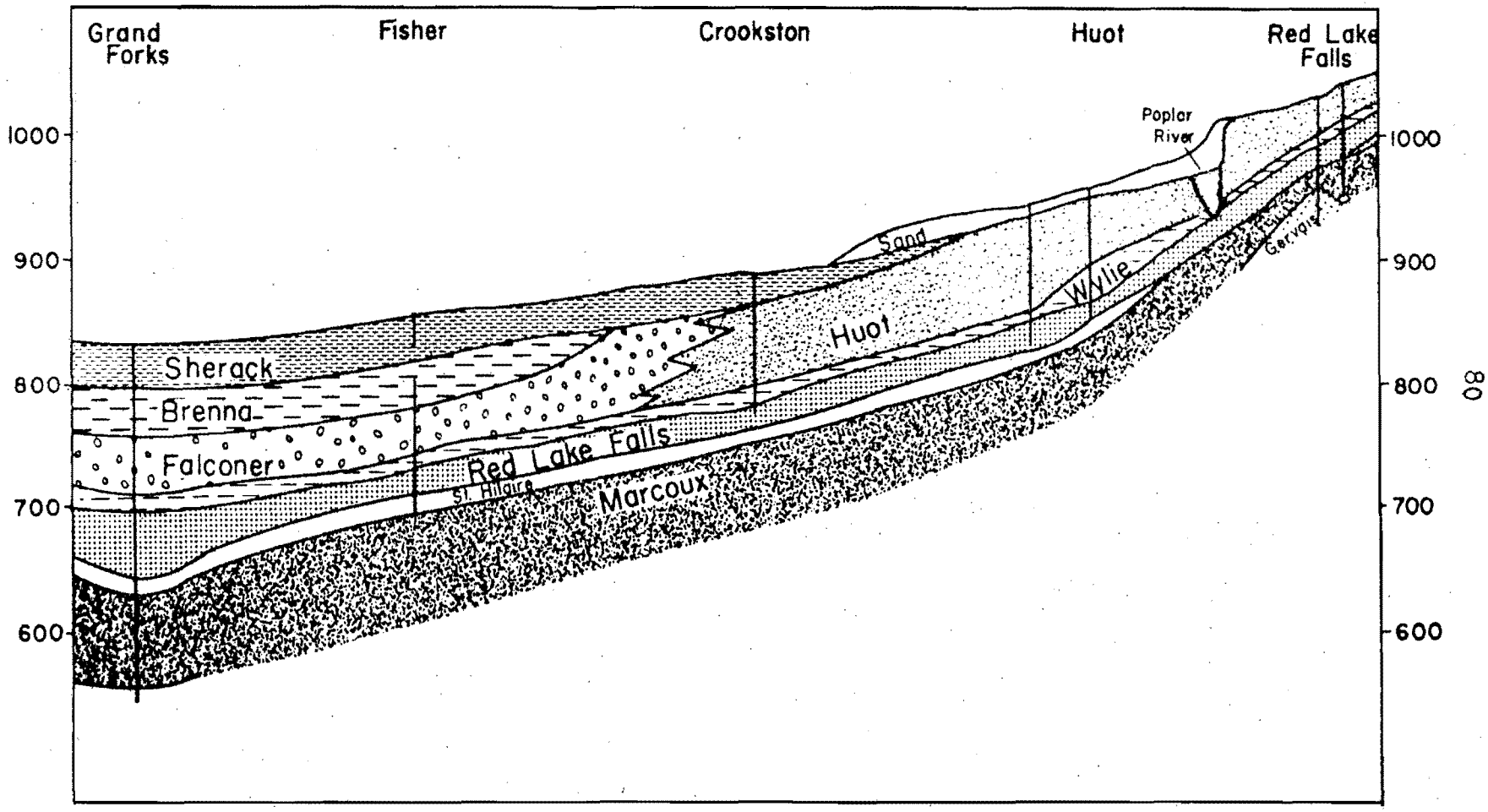
The upper contact with the overlying Huot Formation is gradually interbedded or diffuse. Locally the contact is highly contorted, and boulder-sized masses of glacial sediment are present.

The upper contact of the Wylie Formation with the Falconer Formation has not been observed. It is believed to be similar in nature to the contact with the Huot Formation.

Regional extent and thickness: On the Red Lake River the Wylie Formation is exposed from the Needles Eye Section (Figure 9, No. 4) downstream to the area of the Schist Cliff Section (Figure 9, No. 10). It is exposed at the surface north of Red Lake Falls beyond the eastern limit of the Huot Formation. The Wylie Formation is discontinuously present beneath the Huot or Falconer Formations throughout the central part of the Red River Valley in Traill, Grand Forks, and southern Walsh Counties, North Dakota, and in Norman and Polk Counties, Minnesota (Figure 8).

The Wylie Formation ranges in thickness from less than 2 feet to more than 7 feet. Average thickness of exposures

Fig. 8.--Generalized cross-section showing stratigraphic correlations from Grand Forks, North Dakota, to Red Lake Falls, Minnesota.


Grand Forks
Fisher
Crookston
Huot
Red Lake Falls
1000
900
800
700
600
Poplar River
Sand
Wylie
Huot
Sherack
Brenna
Falconer
Red Lake Falls
St Hilaire
Marcoux
Gervais
80

is about 5 feet.

Differentiation from other units: The Wylie Formation can be distinguished from all other named formations in the Grand Forks area except the Sherack Formation by its distinct laminations. The Sherack Formation is separated stratigraphically from the Wylie Formation by the Brenna and Falconer or Huot Formations (Moran, 1973). Where these are present, the distinction can be readily made.

Origin: The Wylie Formation is lacustrine sediment. Deposition occurred in an ice-marginal lake during the retreat of the ice sheet that deposited the Red Lake Falls Formation and the advance of the ice sheet that deposited the Huot and the Falconer Formations.

Age: The Wylie Formation is Late Wisconsinan in age. It was deposited during an early phase of Lake Agassiz.

HUOT FORMATION (New)

Source of name: The hamlet of Huot, Red Lake County, Minnesota, located on the Red Lake Falls 15-minute quadrangle.

Type section: Clearwater Section, NE 1/4, NW 1/4, Sec. 22, T 151 N, R 44 W (Appendix III).

Reference section: Snake Curve Section, NW 1/4, SW 1/4, Sec. 18, T 151 N, R 44 W (Appendix III); Schist Cliff Section, SW 1/4, SE 1/4, Sec. 22, T 151 N, R 45 W (Appendix III).

Description of unit: The Huot Formation is unbedded, slightly pebbly clay. It is gray (5 Y 5/1) when dry and very dark grayish brown (2.5 Y 3/2) when wet. The formation is very hard and blocky when dry and very plastic when moist. The high clay content of the Huot Formation causes it to slump in outcrop, so most exposures are poor. Slickensides typically occur on shear faces in the Huot Formation.

The Huot Formation contains limestone pebbles and cobbles and numerous tan, chalky inclusions that range from sand to pebble in size. A few pebbles of igneous rock are also present. Locally, boulder-size inclusions of a highly calcareous, pale-yellow glacial sediment are present.

The Huot Formation is composed of 4% to 9% sand, 14% to 26% silt, and 62% to 84% clay. Total carbonate material less than 200-mesh is 23%.

Nature of the contacts: The lower contact of the Huot Formation with the Wylie Formation is gradually interbedded to diffuse and locally is highly contorted. Boulder-size silt inclusions are associated with the areas of local disturbance.

The upper contact, where the Huot is overlain by the Poplar River or Sherack is sharp and erosional. The contact with the Brenna has not been seen, but is believed to be gradational.

Regional extent and thickness: The Huot Formation is

present in the Red Lake River valley from Red Lake Falls to west of Crookston, where it is overlapped by the Sherack Formation (Figure 8). It is at the surface in the area north and west of Red Lake Falls and in an arcuate belt a few miles wide across the Red River Valley. Because the Huot Formation is the surface unit in exposures west of Red Lake Falls and generally is prone to slumping, its exposed thickness is variable. From 3 to 15 feet of the formation are exposed in most outcrops. However, as much as 70 feet of the Huot Formation is exposed in the Schist Cliff Section. As much as 100 feet of the Huot Formation is present in the central part of the Red River Valley.

Differentiation from other units: The Huot Formation can easily be distinguished from other formations in the region by its texture, pebble content, unbedded, blocky structure, and color. The Brenna (Moran, 1973) is the only formation resembling the Huot. They may be distinguished by the higher sand and pebble content of the Huot and the presence of obscure laminations in the Brenna.

Origin: The Huot Formation is glacial sediment deposited by ice moving southward down the Red River Valley.

Age and correlation: The Huot Formation is Late Wisconsinan; it was deposited about 13,500 B.P. It is laterally and chronologically equivalent to the Falconer Formation.

SHERACK FORMATION (New)

Source of name: The village of Sherack in Polk County, Minnesota, located on the Warren 15-minute quadrangle.

Type area: The Grand Forks area in eastern North Dakota and northwestern Minnesota.

Type section: Boring 68-12M, Oslo Dike, U.S. Army Corps of Engineers, at Oslo, Minnesota, NE 1/4, SE 1/4, SE 1/4, Sec. 31, T 155 N, R 50 W (Appendix III).

Reference sections: Boring No. 3, Witmer Hall, University of North Dakota, SE 1/4, SE 1/4, SE 1/4, Sec. 5, T 151 N, R 50 W; NDSWC Testhole 2430, NE 1/4, SE 1/4, SE 1/4, Sec. 29, T 152 N, R 50 W; NDSWC Testhole 2431, NE 1/4, NE 1/4, NE 1/4, Sec. 22, T 151 N, R 50 W; NDSWC Testhole 2433, SE 1/4, NE 1/4, SE 1/4, Sec. 6, T 151 N, R 50 W; NDSWC Testhole, 2609, SE 1/4, SE 1/4, SE 1/4, Sec. 36, T 152 N, R 51 W (Appendix III).

Description of the unit: The Sherack Formation consists of laminated clay, silty clay, and silt, and minor amounts of sand. It is siltier toward its eastern and western margins and more clayey in the central part of the Red River Valley. The laminations are generally only a few millimeters thick, but some of the silty beds are locally several centimeters thick. In some places the bedding has been deformed into folds a few feet high and several feet across. The Sherack Formation is light gray when unoxidized and yellowish gray to olive brown when oxidized. Pieces of abraded wood are commonly found in the lower few feet of the forma-

tion. Locally the lower few feet of the formation contain considerable organic matter or beds of peat. Snail and small clam shells occur locally along the eastern and western edges of the unit. Above the base, the formation contains little or no organic matter.

Nature of contacts: The lower, unconformable contact of the Sherack Formation is sharply marked by an abrupt change from light gray, laminated clay to the dark gray, obscurely laminated to unbedded clay of the Brenna Formation. Where the Sherack Formation conformably overlies the Poplar River Formation, the contact is gradational by interbedding. The base of the Sherack Formation is placed where sand beds make up most of the sequence. The transition zone is generally no more than a few feet thick.

The Sherack Formation either occurs at the surface or is overlain unconformably by the Walsh Formation (Bluemle, in press). The contact between the Sherack Formation and the Walsh Formation is marked by a change from thinly laminated, inorganic clay to thick bedded or unbedded clay, silt, or loam containing disseminated organic matter.

Regional extent and thickness: The Sherack Formation extends throughout the central part of the Red River Valley in North Dakota and Minnesota. It extends at least as far north as Winnipeg, Manitoba. The formation is generally between 15 and 30 feet thick. The formation is thickest in Grand Forks County and thins northward.

Differentiation from other units: The Sherack Formation can be differentiated from the Walsh Formation by the absence of disseminated organic matter. The bedding in the Walsh Formation is generally thicker and the boundaries between individual strata are much less distinct than in the Sherack Formation, which is characterized by thin, sharply defined laminations.

Differentiation of the Sherack and Brenna Formations is generally not difficult because of the darker color, more obscure laminations, included white calcareous specks, and characteristic slickensided surfaces of the Brenna. Where the Sherack Formation is thin enough that oxidation extends down into the Brenna Formation, their separation is more difficult.

In most of the Grand Forks area, the Sherack Formation is separated from the Wylie Formation by the Brenna, and Falconer or Huot Formation, and there is no problem in their differentiation. In the Red Lake Falls area, laminated clay occurs at the surface, beyond the limit of the Huot Formation. In the absence of the intervening stratigraphic units it is not possible to tell from the characteristics of the clay whether it is part of the Sherack or Wylie Formation. This clay is included in the Wylie Formation because its lowest contact is conformable with the Red Lake Falls Formation.

Origin: The Sherack Formation consists largely of off-

shore sediment deposited in Lake Agassiz. The organic silt and beds of peat that occur locally at the base of the unit were deposited in shallow water, in the back-swamp area of deltas, or along river floodplains.

Age and correlation: Most of the Sherack Formation is Holocene and was deposited in Lake Agassiz about 9,900 to about 9,500 B.P. However, the lower part of the formation in some areas was deposited in latest Wisconsinan time, as early as 11,000 B.P. Radiocarbon dates from the base of the Sherack are 9,930 ± 280 B.P. (W-388), 9,900 ± 400 B.P. (W-993), 9,730 ± 160 B.P. (I-5123C), and 9,650 ± 150 B.P. (I-5123). The last two dates were from the same piece of wood.

Appendix III

This appendix includes descriptions of type and reference sections for lithostratigraphic units exposed along the Red Lake River. A location map is included of these exposures in the study area.

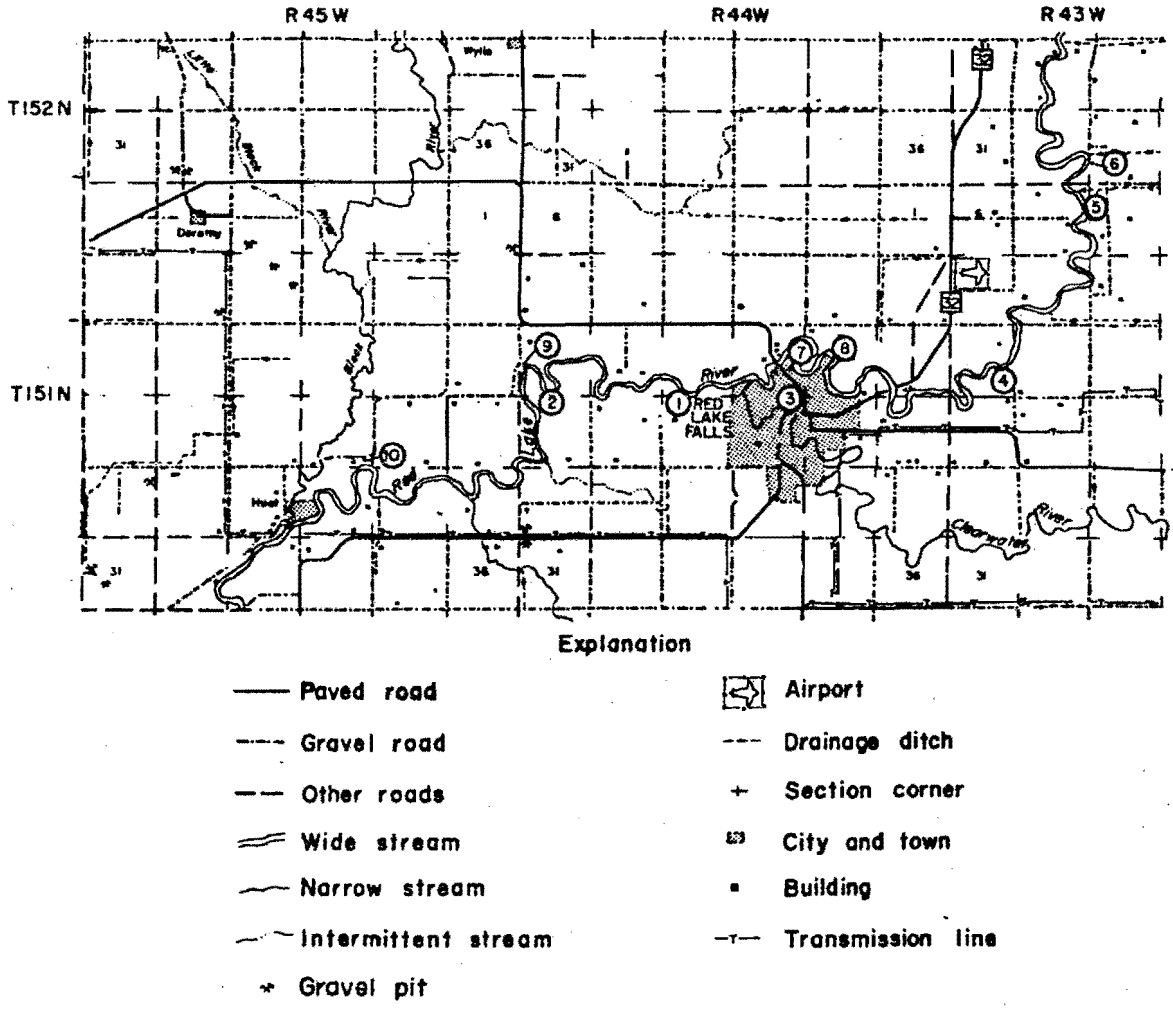


Fig. 9.--Map showing location of type and reference sections in the area of Red Lake Falls, Minnesota.

DESCRIPTION OF STRATIGRAPHIC SECTIONS AND TESTHOLES*

THREE CREEKS SECTION*

NE 1/4, NE 1/4, NW 1/4, Sec. 21, T 151 N, R 44 W

Section 1 - Figure 9

Depth in Feet	Elev. above Sea Level	Description
Huot Formation		
0-15	1023-1008	Clay; very slightly pebbly; unbedded; gray (5Y 5/1 dry); contains tan, pebble-sized, calcareous inclusions; highly slumped; gradational contact with Wylie Formation.
Wylie Formation		
15-19	1008-1004	Clay and silt; thinly laminated; clay is olive gray (5Y 5/2 dry); silt is light brownish gray (2.5Y 6/2 dry); laminae thicken upward; gradational contact with Red Lake Falls Formation.
Red Lake Falls Formation		
19-25	1004- 998	Pebble-loam; clayey; unbedded; friable; light brownish gray (2.5Y 6/2 dry); lower contact gradational; laminated clay at contact.
25-41	998- 982	Pebble-loam; unbedded; friable; light brownish gray (2.5Y 6/2 dry); abundant sand inclusions; sharp contact with Marcoux Formation.

*Cores and/or samples of these sections are stored at the North Dakota Geological Survey, Grand Forks, North Dakota.

Depth in Feet	Elev. above Sea Level	Description
Marcoux Formation		
41-58.6	982-964.5	Sand, alternating fine and medium grained; flat-bedded to ripple cross-bedded; jointed; limonitic stains; gradational lower contact.
58.5-59	964.5-964	Pebble-loam; sandy; unbedded; friable; light gray (5Y 6/1 dry); lower contact is sharp; cobbles common at contact.
Gervais Formation		
59-85	964-938	Clay-loam; silty; very slightly pebbly; unbedded; friable; light olive-gray (5Y 6/2 dry); wood chips, twigs and logs abundant near base; pebbles and sand-lens inclusions increase upward; mollusk fragments and charcoal flakes present; lower contact not exposed.

MOO POINT SECTION

NE 1/4, NE 1/4, NW 1/4, Sec. 19, T 151 N, R 44 W

N1C17 Section 2 - Figure 9 D-11

Depth in Feet	Elev. above Sea Level	Description
Huot Formation		
0-13	968-955	Clay; very slightly pebbly; unbedded; gray (5Y 5/1 dry); contains pebble-sized, tan, calcareous inclusions; upper 6 feet highly slumped with boulder-sized inclusions of pebbly, silty loam; lower contact gradational.
Wylie Formation		
13-15	955-953	Clay-loam; silty; unbedded; pale olive (5Y 6/3 dry); sharp lower contact.
15-17	953-951	Clay and silt; thinly laminated; clay is olive gray (5Y 5/2 dry); silt is light brownish gray (2.5Y 6/2 dry); ripple cross-bedded medium-grained sand is also present; lower contact gradational.
Red Lake Falls Formation		
17-32	951-936	Pebble-loam; unbedded; friable; brownish gray (2.5Y 6/2 dry); sharp lower contact with cobble concentration.
Gervais Formation		
32-45	936-923	Clay-loam; silty; very slightly pebbly; unbedded; friable; light brownish gray (2.5Y 6/2 dry); wood fragments and twigs present; persistent, intermittent, 2-inch sand-lens at 931 feet; lower contact not exposed.

CLEARWATER SECTION

NE 1/4, NE 1/4, Sec. 22, T 151 N, R 44 W

N1122 Section 3 - Figure 9 Cw-1

Depth in Feet	Elev. above Sea Level	Description
Huot Formation		
0-14	1020-1006	Clay, very slightly pebbly; unbedded; gray (5Y 5/1 dry); contains abundant tan, pebble-sized, calcareous inclusions; lower contact interbedded; highly slumped.
Wylie Formation		
14-19	1006-1001	Clay and silt; thinly laminated; clay is olive gray (5Y 5/2 dry); silt is light brownish gray (2.5Y 6/2 dry); laminae thicken upward; interbedded lower contact.
Red Lake Falls Formation		
19-38	1001- 982	Pebble-loam; unbedded; friable; light brownish gray (2.5Y 6/2 dry); weak columnar jointing; abundant sand and gravel lenses; sharp lower contact.
Marcoux Formation		
38-65	982- 995	Pebble-loam; sandy; unbedded; hard; light olive gray (5Y 6/2 dry); high carbonate concentration upper 1 to 2 feet; lower contact not exposed.

NEEDLES EYE SECTION

SW 1/4, NE 1/4, SE 1/4, Sec. 18, T 151 N, R 43 W

Section 4 - Figure 9

Depth in Feet	Elev. above Sea Level	Description
Wylie Formation		
0-6	1051-1045	Clay and silt; thinly laminated; clay is olive gray (5Y 6/2 dry); silt is light brownish gray (2.5Y 6/2 dry); laminae thicken upward; sharp lower contact.
Red Lake Falls Formation		
6-35	1045-1016	Pebble-loam; clayey; unbedded; columnar jointing; hard; pale olive (5Y 6/3 dry); up to 1 foot of sand and gravel present at sharp lower contact.
Marcoux Formation		
35-56	1016- 995	Pebble-loam; sandy; unbedded; hard; light gray (5Y 6/1 dry); abundant pebbles, cobbles and boulders; lower contact not exposed.

POWERLINE SECTION

SE 1/4, SE 1/4, NE 1/4, Sec. 5, T 151 N, R 43 W

Section 5 - Figure 9

Depth in Feet	Elev. above Sea Level	Description
Red Lake Falls Formation		
0-28	1082-1054	Pebble-loam; unbedded; friable; light gray (5Y 6/1 dry); abundant sand lenses present; lower contact gradational; cobble, sand, and gravel concentrations occur at contact.
St. Hilaire Formation		
28-30	1054-1052	Pebble-loam; clayey; unbedded; friable; gray (5Y 5/1 dry); sharp lower contact.
Marcoux Formation		
30-47	1052-1035	Pebble-loam; sandy; unbedded; hard; light gray (2.5Y 6/2 dry); lower contact not exposed.

OPERNOCKITY SECTION

SE 1/4, NE 1/4, SE 1/4, Sec. 32, T 152 N, R 43 W

Section 6 - Figure 9

Depth in Feet	Elev. above Sea Level	Description
Red Lake Falls Formation		
0-9	1076-1067	Pebble-loam; unbedded; friable; light gray (2.5Y 7/2 dry); abundant sand lenses; lower contact gradational.
St. Hilaire Formation		
9-10	1067-1066	Pebble-loam; clayey; unbedded; friable; gray (5Y 6/1 dry); sand and gravel inclusions abundant at sharp lower contact.
Marcoux Formation		
10-11	1066-1065	Pebble-loam; sandy; unbedded; friable; light brownish gray (2.5Y 6/2 dry); lower sharp, but laterally irregular.
Red Lake Falls Formation		
11-23.5	1065-1052.5	Pebble-loam; unbedded; friable; light brownish gray (2.5Y 6/2 dry); abundant sand lenses; gradational lower contact.
St. Hilaire Formation		
23.5-24.5	1052.5-1051.5	Pebble-loam; unbedded; friable; gray (5Y 5/1 dry); sand and gravel inclusions abundant at sharp lower contact.

Depth in Feet	Elev. above Sea Level	Description
Marcoux Formation		
24.5-36	1051.5-1040	Pebble-loam; sandy; unbedded; friable; light gray (5Y 6/1 dry); lower contact not exposed.

DAMNED HOUSE SECTION

SW 1/4, NE 1/4, SE 1/4, Sec. 15, T 151 N, R 44 W

Section 7 - Figure 9 D-34

Depth in Feet	Elev. above Sea Level	Description
Wylie Formation		
0-7	1015-1008	Silt; sandy; pebble; unbedded; sharp lower contact.
7-10	1008-1005	Clay and silt; thinly laminated; clay is olive gray (5Y 6/2 dry); silt is light brownish gray (2.5Y 6/2 dry); lower contact gradational and interbedded.
Red Lake Falls Formation		
10-31	1005- 984	Pebble-loam; unbedded; friable; grayish brown (2.5Y 5/2 dry); sharp lower contact.
31-34	984- 955	Sand; silty; flat-bedded to ripple cross-bedded; jointed; limonitic stains; sharp lower contact.
Marcoux Formation		
34-60	981- 955	Pebble-loam; sandy; unbedded; hard; light gray (5Y 6/1 dry); lower contact not exposed.

A 1025 OLD DAM SECTION D-3

SE 1/4, NW 1/4, Sec. 14, T 151 N, R 44 W

Depth in Feet	Elev. above Sea Level	Description
Huot Formation		
0-3	1000-997	Clay; slightly pebbly; unbedded; gray (5Y 5/1 dry); contains tan, pebble-sized, calcareous inclusions; sharp lower contact.
Wylie Formation		
3-8	997-992	Silt and sand; fine-grained; ripple cross-bedded to flat-bedded; interbedded lower contact.
8-10	992-990	Clay and silt; thinly laminated; clay is olive gray (5Y 5/2 dry); silt is light brownish gray (2.5Y 6/2 dry); interbedded lower contact.
Red Lake Falls Formation		
10-40	990-960	Pebble-loam; unbedded; light olive gray (5Y 6/2 dry); strong to weak columnar jointing; frequent channel scours with cross-bedded sand and gravel fill; lower contact not exposed.

SNAKE CURVE NORTH SECTION

NW 1/4, SW 1/4, Sec. 18, T 151 N, R 44 W

N 1018 Section 9 - Figure 9 D-12

Depth in Feet	Elev. above Sea Level	Description
Sherack Formation		
0-5	960- 955	Silt and clay; laminated with some sand in lower laminae; light yellowish brown (2.5Y 6/4 dry); gradational lower contact.
Huot Formation		
5-20	955- 940	Clay; slightly pebbly; unbedded; gray (5Y 5/1 dry); contains tan, pebble-sized, calcareous inclusions; lower contact gradational.
Wylie Formation		
20-21	940- 939	Clay and silt; thinly laminated; clay is olive gray (5Y 5/2 dry); silt is light brownish gray (2.5Y 6/2 dry); lower contact gradational and interbedded.
Red Lake Falls Formation		
21-28	938- 932	Clay; silty; pebbly; unbedded; friable; light olive gray (2.5Y 7/2 dry); lower contact gradation and interbedded.
28-40	932- 920	Pebble-loam; unbedded; hard; light brownish gray (2.5Y 6/2 dry); lower contact not exposed.

SNAKE CURVE SOUTH SECTION

SW 1/e, NW 1/4, SW 1/4, Sec. 18, T 151 N, R 44 W

Section 9 - Figure 9

Depth in Feet	Elev. above Sea Level	Description
Sherack Formation		
15-40	977-962	Silt; thinly laminated; contains some beds of clay and very fine sand; both upper and lower contacts gradational.
Poplar River Formation		
30-40	962-952	Sand; fine-grained; thin bedded; contains ripple cross-bedding; contains a few interbeds of silt and clay; shells of gastropods and small bivalves abundant near the base; contact is gradational.
40-55	952-937	Sand; gravelly, grading downward into sandy gravel; gravel is flat-bedded and sand has dune cross-bedding; shells of gastropods and small bivalves are abundant at top of the unit, large mussels occur throughout the unit, and a large conifer log was exposed near the base; the lower contact is sharp.
Red Lake Falls Formation		
55-70	937-922	Pebble-loam; silty, sandy; hard; columnar jointing; stands in vertical cliffs; lower 5 to 10 feet above the river are covered; upper contact is sharp with gravel of Poplar River Formation but gradational with clay of Wylie Formation both north and south of measured section.

SCHIST CLIFF SECTION

SE 1/4, SE 1/4, Sec. 22, T 151 N, R 45 W

Section 10 - Figure 9

Depth in Feet	Elev. above Sea Level	Description
Huot Formation		
0-67	960-893	Clay; very slightly pebbly; unbedded; gray (5Y 5/1 dry); contains pebble-sized, tan, calcareous inclusions; contains boulder-sized inclusions of light colored pebbly loam; lower contact not exposed.

SMALL CREEK SECTION

SE 1/4, SW 1/4, Sec. 17, T 152 N, R 43 W

Depth in Feet	Elev. above Sea Level	Description
Wylie Formation		
0-2	1078-1076	Loam; clayey; bedding is highly disrupted; light brownish gray (2.5Y 6/2 dry); contains abundant silt clasts; lower contact laminated and interbedded.
Red Lake Falls Formation		
2-12	1076-1066	Pebble-loam; unbedded; friable; light brownish gray (2.5Y 6/2 dry); lower contact gradational.
St. Hilaire Formation		
12-16	1066-1062	Pebble-loam; unbedded; friable; gray (5Y 6/1 dry); lower contact sharp; cobble concentration at base.
Marcoux Formation		
16-20	1062-1058	Pebble-loam; sandy; unbedded; friable; gray (5Y 6/1 dry); lower contact not exposed.

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Witmer Hall Boring No. 3

SE 1/4, SE 1/4, SE 1/4, Sec. 5, T 151 N, R 50 W

Depth in Feet	Elev. above Sea Level	Description
Sherack Formation		
0-20	831-811	Clay; silt, clayey silt, and silty clay; thinly laminated; ripple cross-bedding in some coarse silt beds; brown to olive (5Y 4/3 wet) near base, only coarser beds are oxidized; finer beds are gray.
20-36	811-795	Clay, silt, clayey silt and silty clay; thinly laminated; black to dark gray (5Y 2/1 to 5Y 4/1 wet); dark gray to light gray (5Y 4/1 to 5Y 6/1 dry).
Brenna Formation		
36-84	795-747	Clay, obscurely laminated to unbedded; slick; sticky; soft; contains white to tan coarse sand and small pebble-sized grains of chalky shale and limestone; from 75 feet to 84 feet pebbles become more abundant; very dark gray (5Y 3/1 wet), dark gray to gray (5Y 4/1 to 5Y 5/1 dry).
Falconer Formation		
84-123	747-708	Pebble-loam; unbedded; hard; few pebbles; very dark gray (5Y 3/1 wet) to gray or light gray (5Y 5/1 or 5Y 6/1 dry); contains average of 16% sand, 46% silt and 38% clay; total carbonate content is 25.1% (5.5% calcite, 19.6% dolomite); contains 14% kaolinite and chlorite, 17% illite, and 68% montmorillonite.

Depth in Feet	Elev. above Sea Level	Description
Wylie Formation		
123-141	708-690	Clay; unbedded to obscurely bedded; very dark gray to dark gray (5Y 3/1 to 5Y 4/1 wet).
141-150	690-681	Sand; fine-grained; grayish brown.

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Oslo Dike Boring 68-12M

NE 1/4, SE 1/4, SE 1/4, Sec. 31, T 155 N, R 50 W

Depth in Feet	Elev. above Sea Level	Description
Walsh Formation		
0-3	811-808	Clay, silty; brown to tan; interbedded with gravelly clay; brown, calcareous, artificial fill.
3-12	808-799	Clay, silty; brown to tan; contains scattered plant fragments and some beds of organic material; locally secondary carbonate occurs; fluvial sediment.
Sherack Formation		
12-34	799-777	Clay, silty; thinly laminated; olive brown (2.5Y 4/4 wet); contains silt interbeds; some silt beds are cross-bedded; oxidized.
34-46	777-765	Clay, silty; clayey silt and clay; very dark gray (5Y 3/1 wet); laminated with unbedded subzones; cross bedding occurs in thicker silt beds throughout the interval; lamination less evident in lower 5 feet; some slick, unlaminated beds toward the base.
Brenna Formation		
46-52	765-759	Clay; obscurely laminated; very dark gray (5Y 3/1 wet); slickensided surfaces developed readily by shearing.

Depth in Feet	Elev. above Sea Level	Description
Brenna Formation		
52-112	759-699	Clay; unbedded to obscurely laminated; laminations are commonly irregular and lenticular; very dark gray (5Y 3/1 wet); soft; slickensides characteristic of entire section; soft, white, gray and brown, silty, calcareous pebbles abundant in upper 5 to 10 feet and continue to be present but in considerably reduced numbers throughout the unit; a few hard carbonate pebbles also present.
Falconer Formation		
112-118	699-693	Pebble-loam; silty, clayey; gray (5Y 6/1 dry); contains 17% sand, 43% silt, and 40% clay; total carbonate content is 29.6% (5.4% calcite and 24.2% dolomite).

NDSWC Testhole 2430

NE 1/4, SE 1/4, SE 1/4, Sec. 29, T 152 N, R 50 W

Depth in Feet	Elev. above Sea Level	Description
Sherack Formation		
0-17	830-813	Clay; silty; and silt; laminated; yellowish gray; oxidized.
17-37	813-793	Clay; silty; and silt; laminated; light gray; unoxidized.
Brenna Formation		
37-74	793-756	Clay; obscurely laminated to unbedded; gray to dark gray; contains white calcareous specks.
Falconer Formation		
74-118	756-712	Pebble-loam; silty; light gray (5Y 6.5/1 dry); unoxidized; contains 18% sand, 53% silt, and 29% clay; total carbonate content is 26.9% (5.5% calcite and 21.4% dolomite).
Wylie Formation		
118-133	712-697	Clay; gray; unoxidized.
Red Lake Falls Formation		
133-138	697-692	Pebble-loam; gray; unoxidized; poor samples.
138-176	692-659	Clay; dark greenish gray to olive black; unoxidized.
176-183	654-647	Pebble-loam; gray (5Y 6/1 dry); unoxidized; poor samples.

Depth in Feet	Elev. above Sea Level	Description
St. Hilaire Formation		
183-199	647-631	Clay; slightly pebbly; gray (5Y 6/1 dry); unoxidized; may be till.
199-214	631-616	Gravel; fine- to coarse-grained; poorly sorted; sandy; contains clay and silt beds.
Marcoux Formation		
214-240	616-590	Pebble-loam; sandy; light gray (10 YR 6/1 dry); contains 55% sand, 26% silt, and 19% clay; total carbonate content is 31.3% (9.9% calcite and 21.4% dolomite).
240-278	590-552	Pebble-loam; sandy; light gray (10YR 6/1 dry); contains 63% sand, 23% silt, and 14% clay; total carbonate content is 24.0% (6.9% calcite and 17.1% dolomite).
278-284	552-546	Sand; very poor samples.
Winnipeg Group		
284-292	546-538	Clay; pale reddish-brown to dusky red; silty; thin, very light gray limestone interbedded with clay.
292-295	538-535	Sandstone; dark reddish brown; medium-grained; well sorted; well rounded; calcium carbonate and iron-oxide cement.

NDSWC Testhole 2431

NE 1/4, NE 1/4, NE 1/4, Sec. 22, T 151 N, R 50 W

Depth in Feet	Elev. above Sea Level	Description
Sherack Formation		
0-16	835-819	Silt; clayey; light gray (2.5Y 7/2 dry); oxidized.
16-40	819-794	Clay; silty; laminated; light gray (5Y 6/1 dry); unoxidized.
Brenna Formation		
40-60	795-775	Clay; unbedded; gray (5Y 4.5/1 dry); unoxidized; contains white calcareous specks.
60-88	775-767	Clay; unbedded; pebbly; gray (5Y 6/1 dry); unoxidized; contains white calcareous specks.
Falconer Formation		
68-118	767-717	Pebble-loam; silty; light gray (5Y 6/1 dry); unoxidized; contains 12% sand, 46% silt, and 42% clay; total carbonate content 22.8% (5.3% calcite and 17.5% dolomite).
Wylie Formation		
118-128	717-707	Clay; light gray (5Y 6/1 dry); unoxidized.
Red Lake Falls Formation		
128-143	707-692	Sand; fine-grained at the top; grading downward into coarse to very coarse-grained at the base; pale yellowish brown.
143-148	692-687	Gravel; fine to medium-grained; poorly sorted.

Depth in Feet	Elev. above Sea Level	Description
St. Hilaire Formation		
148-166	687-669	Pebble-loam; light gray (5Y 6/1 dry); unoxidized; poor samples.
166-188	669-647	Pebble-loam; light gray (5Y 6/5/.5 dry); unoxidized; poor samples.
188-194	647-641	Pebble-loam; light gray (2.5Y 7/1 dry); poor samples.
194-200	641-635	Gravel; fine to medium grained; poorly sorted.
Marcoux Formation		
200-220	635-615	Pebble-loam; sandy; light brownish-gray (10YR 6.5/2 dry); unoxidized; contains 51% sand, 34% silt, and 15% clay; total carbonate content 28.1% (9.3% calcite and 18.8% dolomite).
220-236	615-599	Sand; fine grained; well sorted.
Winnipeg Group		
236-244	599-591	Shale; pale reddish brown; dusky red becoming yellow downward; noncalcareous at top; calcareous at base.
244-252	591-583	Limestone; grayish red; microcrystalline.

NDSWC Testhole 2433

SE 1/4, NE 1/4, SE 1/4, Sec. 6, T 151 N, R 50 W

Depth in Feet	Elev. above Sea Level	Description
Sherack Formation		
0-18	835-817	Silt; clayey and clay; laminated; pale yellow (2.5Y 7/3 dry); oxidized.
18-36	817-799	Clay; silty; laminated; light gray (5Y 6/1 dry); unoxidized.
Brenna Formation		
36-76	799-759	Clay; unbedded to obscurely laminated; slick; gray (5Y 5/1 dry); unoxidized; contains calcareous white specks.
Falconer Formation		
76-124	759-711	Pebble-loam; light gray (5Y 6/1 dry); unoxidized; contains 13% sand, 44% silt, and 43% clay; total carbonate content is 25.5% (6.0% calcite and 20.5% dolomite).
Wylie Formation		
124-138	711-697	Clay; light gray (10YR 6/1 dry); unoxidized.
Red Lake Falls Formation		
138-144	697-691	Pebble-loam; light gray (5Y 6/1 dry); unoxidized; poor samples.
144-185	691-650	Clay; light gray (5Y 6/1 dry); unoxidized.
185-196	650-639	Pebble-loam; sandy; light gray (5Y 6.5/1 dry); poor samples.

Depth in Feet	Elev. above Sea Level	Description
196-200	639-615	Gravel; sandy; very fine to fine grained; poorly sorted.
220-228	615-607	Pebble-loam; brownish gray to olive gray; sandy to very gravelly; very poor samples.
228-241	607-594	Gravel; sandy; very fine to fine grained; poorly sorted.
Marcoux Formation		
241-262	594-573	Pebble-loam; light gray (10YR 6/1 dry); unoxidized; contains 46% sand, 31% silt, and 23% clay; total carbonate content is 27.3% (9.8% calcite and 17.5% dolomite).
262-267	573-568	Gravel; sandy; mottled gray; fine to very coarse grained; poorly sorted.
Winnipeg Group		
267-279	568-556	Shale; variegated green-gray red; noncalcareous.
279-294	556-541	Sandstone; dark reddish brown; fine; well-sorted; very clayey; iron-oxide cement.

NDSWC Testhole 2609

SE 1/4, SE 1/4, SE 1/4, Sec. 36, T 152 N, R 51 W

Depth in Feet	Elev. above Sea Level	Description
Sherack Formation		
0-14	835-821	Clay; silty; laminated; yellowish brown to yellowish gray; oxidized.
14-30	821-805	Clay; silty; laminated; light gray (5Y 6/1 dry); unoxidized.
Brenna Formation		
30-69	805-766	Clay; obscurely laminated to unbedded; gray; unoxidized; contains white calcareous specks.
Falconer Formation		
69-124	766-711	Pebble-loam; silty; light gray (5Y 6/1 dry); unoxidized; contains 15% sand, 47% silt and 38% clay; total carbonate content is 25.4% (5.8% calcite and 19.6% dolomite).
Wylie Formation		
124-134	711-701	Clay; gray; unoxidized.
Red Lake Falls Formation		
134-174	701-661	Pebble-loam; gray (5Y 6/1 dry); unoxidized; contains 38% sand, 36% silt, and 26% clay; total carbonate content is 26.1% (6.7% calcite and 19.4% dolomite); contains a bed of clay from 153 feet to 158 feet.
174-183	661-652	Gravel.

Depth in Feet	Elev. above Sea Level	Description
St. Hilaire Formation		
183-196	652-639	Pebble-loam; gray (5Y 5/1 dry); unoxidized.
196-212	639-627	Sand and gravel.
Marcoux Formation		
212-232	627-203	Pebble-loam; sandy; very poor samples.
232-242	603-595	Pebble-loam; sandy; gray; very poor samples.
242-251	595-584	Pebble-loam; sandy; gray; very poor samples.
Winnipeg Group		
251-257	584-578	Clay; silty; reddish brown; very calcareous.

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