LATE QUATERNARY STRATIGRAPHIC NOMENCLATURE, RED RIVER VALLEY, NORTH DAKOTA AND MINNESOTA

NORTH DAKOTA GEOLOGICAL SURVEY
MISCELLANEOUS SERIES 52

LATE QUATERNARY STRATIGRAPHIC NOMENCLATURE RED RIVER VALLEY, NORTH DAKOTA AND MINNESOTA

By Kenneth L. Harris, Stephen R. Moran, and Lee Clayton

NORTH DAKOTA GEOLOGICAL SURVEY
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Ten new formations with type areas near Red Lake Falls, Minnesota, and Grand Forks, North Dakota, are described and formally named. These formations include the bulk of Late Quaternary sediments in the Red River Valley.

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ABSTRACT

Detailed study of Quaternary sediments in the Grand Forks, North Dakota, and Red Lake Falls, Minnesota, areas has led to the recognition of ten new formations.

The Gervais Formation is compact, light gray to reddish brown, sandy silt. It commonly contains abundant organic material. It is probably pond or swamp sediment that was partly modified by later glacial overriding.

The Marcoux Formation is light gray, very hard, very sandy pebble-loam. It is glacial sediment that was deposited by a southwestward-flowing glacier. It is either pre-Wisconsinan or earliest Wisconsinan in age.

The St. Hilaire Formation is dark gray to black, silty pebble-loam. It is glacial sediment that was deposited by a southeastward-flowing glacier. It is either Early Wisconsinan or pre-Wisconsinan in age.

The Red Lake Falls Formation is light gray to yellow brown, silty, sandy pebble-loam. It is glacial sediment that was deposited by a southward-flowing glacier. It is Late Wisconsinan in age.

The Wylie Formation is thinly laminated gray to yellow brown clay and silt. It is deep-water sediment deposited during the earliest phase of Lake Agassiz, about 13,500 B.P.

The Falconer Formation is light gray, soft, silty to clayey pebble-loam. It is glacial sediment that was deposited by a southward-flowing glacier. It is Late Wisconsinan in age and was deposited about 13,500 B.P.

The Huot Formation is dark gray, soft, slightly pebbly clay that contains abundant soft, silty, calcareous pebbles, cobbles, and boulders. It is glacial sediment that was deposited by the same glacier that deposited the Falconer Formation.

The Brenna Formation is dark gray, soft, obscurely laminated clay that contains locally abundant soft, calcareous, silty inclusions that are as much as 1 cm in diameter. It is deep-water lake sediment that was deposited in Lake Agassiz from about 12,000 to about 11,000 B.P.

The Poplar River Formation is sand, gravelly sand, and sandy gravel. It occurs in linear depressions inset into the upper part of the Brenna, Falconer, Huot, and Wylie Formations. It locally contains clam and snail shells and wood. It is fluvial channel sediment that was deposited from about 11,000 to about 9,900 B.P.

The Sherack Formation is light gray to olive brown, thinly laminated clay and silt. It locally contains wood, peaty material, and clam and snail shells near the base. It is dominantly deep-water lake sediment deposited in Lake Agassiz from about 9,900 to about 9,500 B.P.

framework for several studies that have been completed in the Grand Forks area (Harris, 1973; Salomon, 1973, in press) or are in preparation, and it is intended that they will serve as the basic stratigraphic framework for continuing studies of the geology of the entire Red River Valley.

Acknowledgments

Mark Fenton of the Geological Survey of Canada visited outcrops along the Roseau River in southeastern Manitoba and discussed correlation problems with us. Mike Arndt of the North Dakota Geological Survey visited outcrops throughout the area with us. His work on the deep-water sediments of Lake Agassiz has greatly aided us in tracing several of the units over long distances. Nena Salomon of the Department of Geology, University of North Dakota, has studied the late Quaternary stratigraphy in western Grand Forks, Walsh, and Pembina Counties. Her work has aided us in understanding stratigraphic relations in this area. H. C. Hobbs, Department of Geology, University of North Dakota, has been studying heavy minerals in the units along the Red Lake River. His discussions of correlation have been most helpful. Numerous other Quaternary geologists have visited key outcrops and helped us with their comments.

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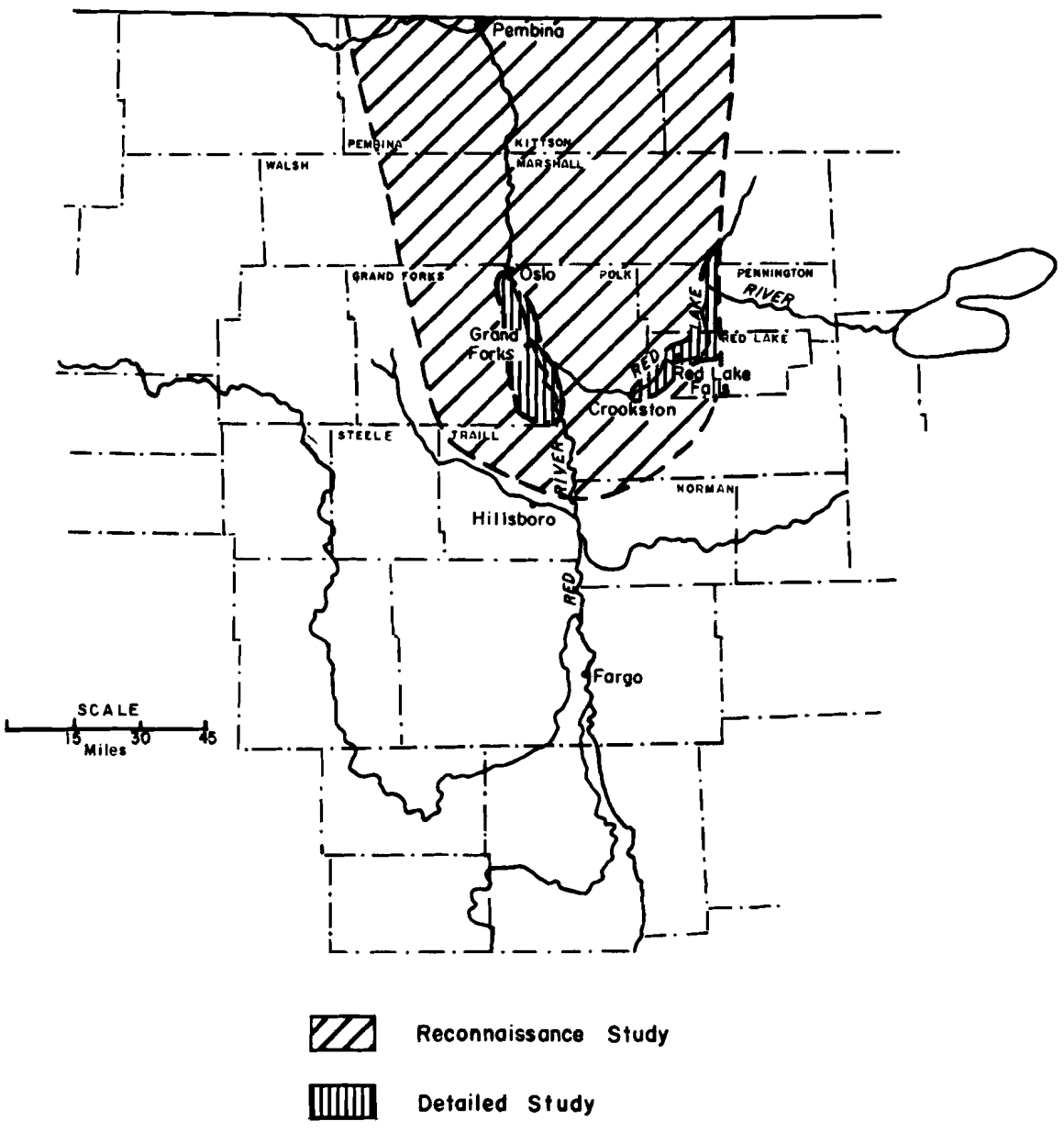

FIGURE 1. Location of the area covered by this report.

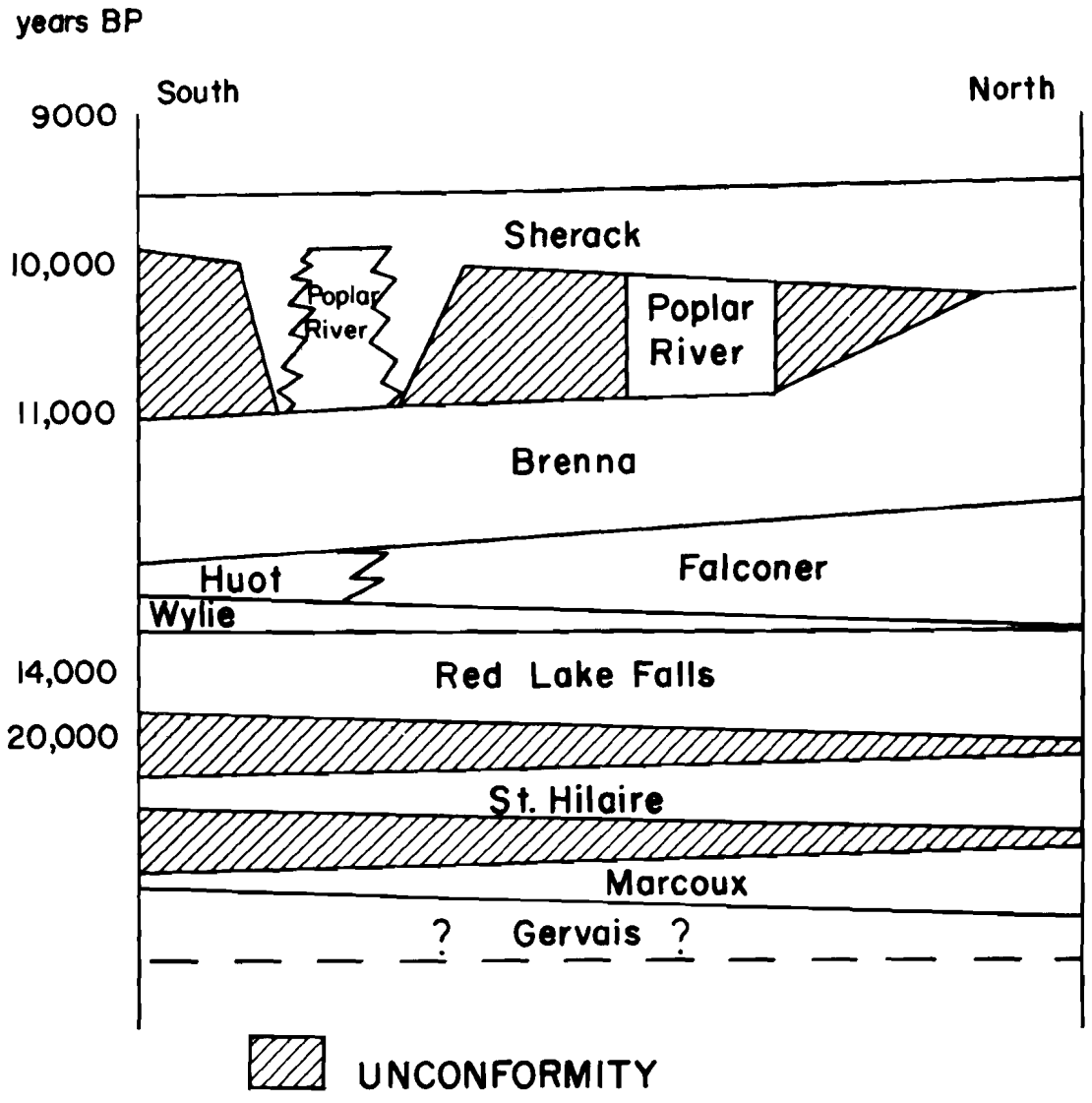

FIGURE 2. Schematic time-distance diagram showing periods of deposition of the formations defined in this report.

GERVAIS FORMATION (New)

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

Type area: The Red Lake Falls area of Minnesota (figs. 1 and 3).

Type section: Three Creeks Section*, NE¼NE¼NW¼ sec. 21, T. 151 N., R. 44 W. (section 1, fig. 3).

Reference section: Moo Point Section, NE¼NE¼NW¼ sec. 19, T. 151 N., R. 44 W. (section 2, fig. 3).

Description of unit: The Gervais Formation is unbedded, silty, very slightly pebbly clay-loam. It is light olive gray (5Y 6/2)** when dry and very dark gray (5Y 3/1) when moist. In outcrop, it tends to part or flake along joints that are oxidized to dark brown (7.5YR 3/2), giving the outcrop a brownish cast. Abundant wood chips, twigs, and logs up to 6 inches (150 mm) 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***. Calcareous material makes up about 15% of the minus 200 mesh fraction of the sediment.

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 (fig. 4). It is at least 40 feet (12.25 m) 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 sediment of the formation becomes progressively more homogeneous upward. The silt and clay was probably originally derived locally.

**All listed sections are described in the appendix.*
***Color designations throughout this report are from the Munsell Soil Color Chart.*
****All compositional data summarized in this report are contained in Harris (1973), or are on file at the North Dakota Geological Survey.*

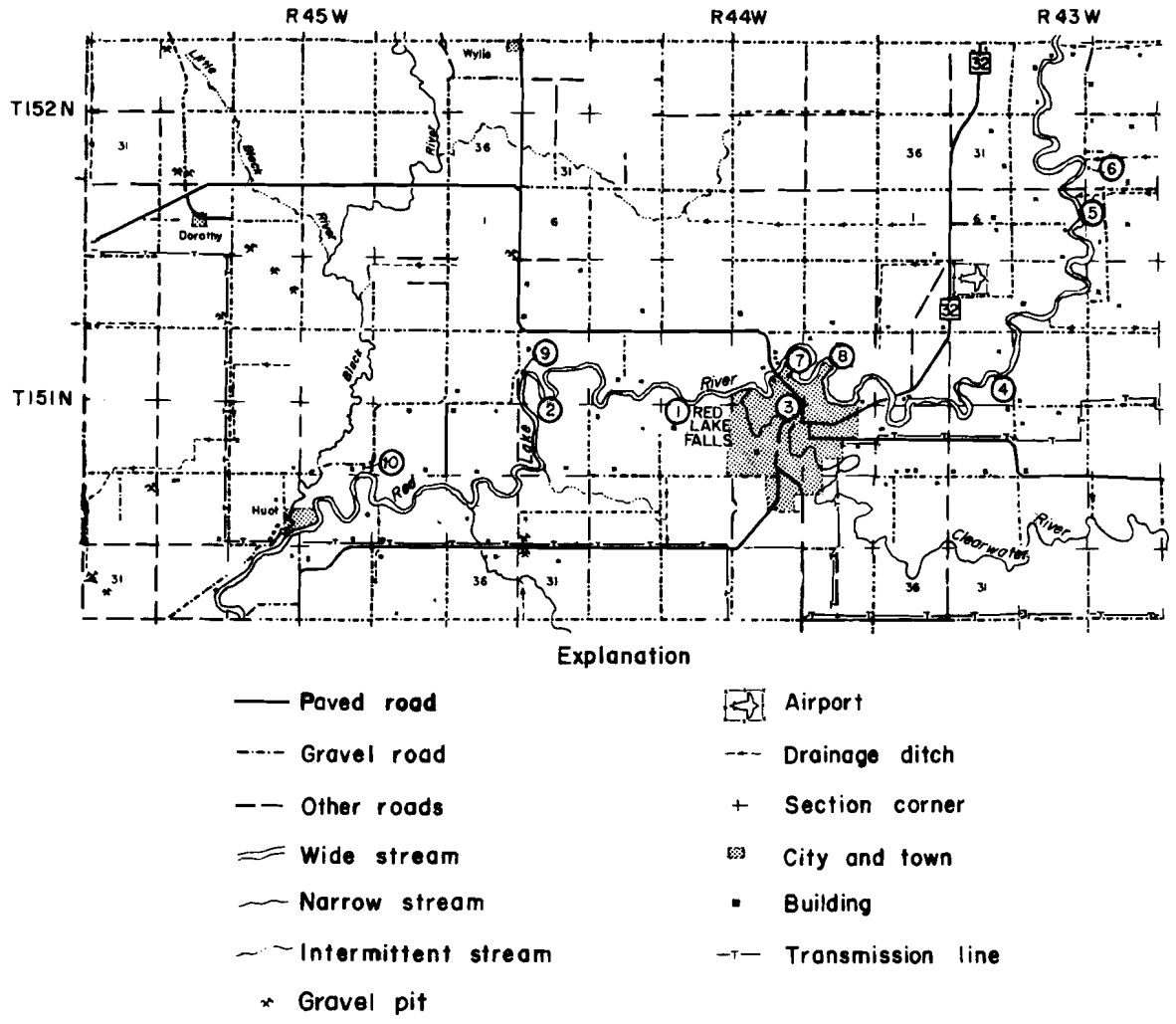

FIGURE 3. Map showing location of type and reference sections in the area of Red Lake Falls, Minnesota.

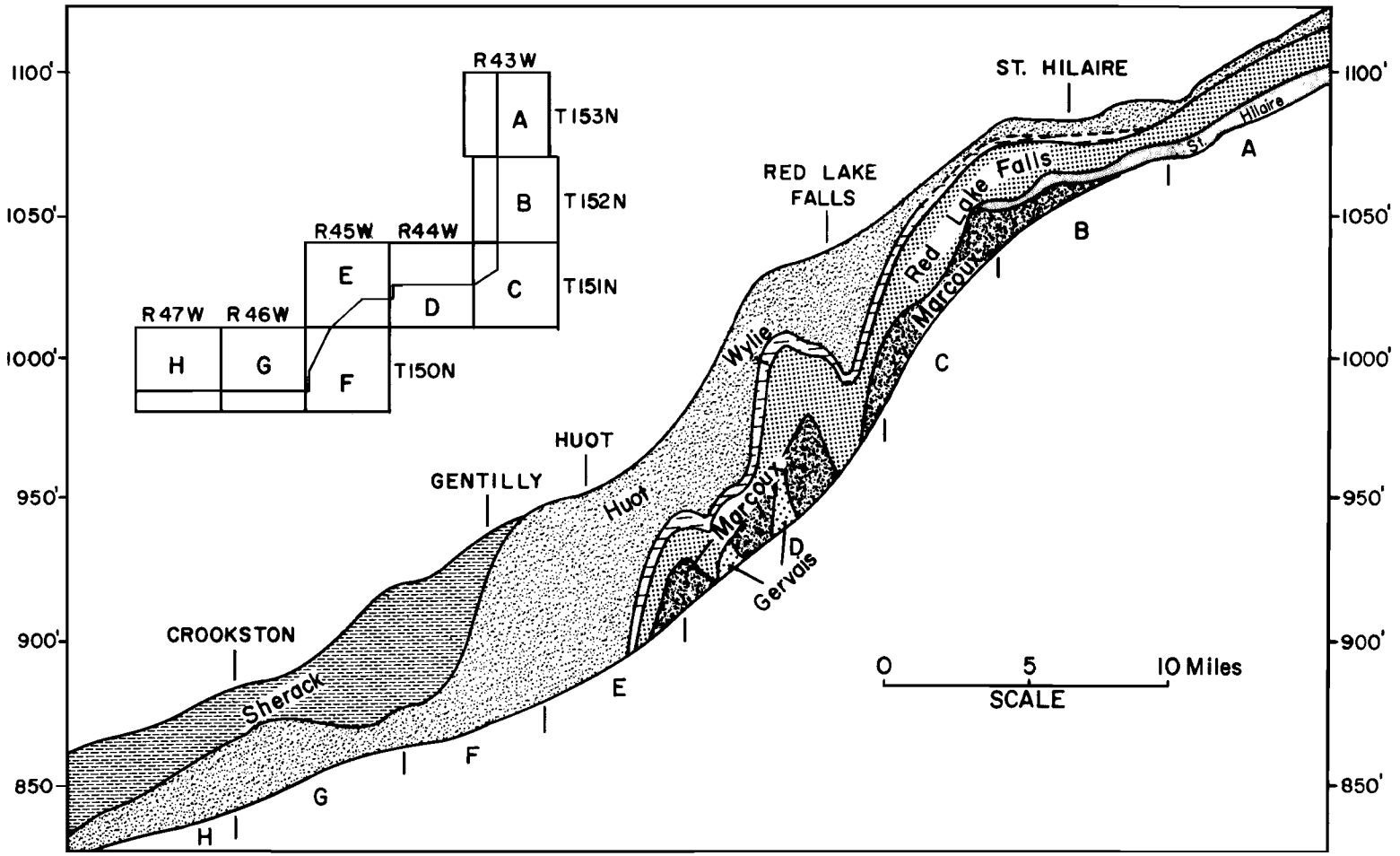

FIGURE 4. Generalized cross section along the Red Lake River in the Red Lake Falls, Minnesota, area.

Correlation: 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 (27.5 to 44.0 m) and produced abundant organic material. Radiocarbon dates on the organic debris recovered are: 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).

Age: 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).

MARCOUX FORMATION (New)

Source of 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, NE¼NE¼ sec. 22, T. 151 N., R. 44 W. (section 3, fig. 3).

Reference section: Needles Eye Section, SW¼NE¼SE¼ sec. 18, T. 151 N., R. 43 W. (section 4, fig. 3) and Damned House Section, SW¼NE¼SE¼ sec. 15, T. 151 N., R. 44 W. (section 7, fig. 3).

Description of unit: The Marcoux Formation is unbedded, very sandy pebble-loam. The formation is light gray (5Y 6/1) when dry and grayish brown (2.5Y 5/2) when wet. In weathered outcrops it is *extremely hard* and stands in nearly vertical slopes. It is weakly 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. The pebble loam of the Marcoux consists of 48% to 58% sand, 30% to 40% silt, and 8% to 18% clay. The abundant pebbles consist of roughly 2/3 igneous and metamorphic rock types and 1/3 limestone and dolomite. Shale pebbles occur only very rarely. The very coarse sand (1-2 mm) contains from 73% to 85% igneous and metamorphic rock types, from 12% to 26% limestone and dolomite, from 0% to 8% shale, and 1% to 2% miscellaneous rock types. Calcareous material makes up about 28% of the less than 200 mesh fraction of the sediment.

Nature of 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 (SE¼SE¼NE¼ sec. 5, T. 151 N., R. 43 W.), the Marcoux is overlain by the St. Hilaire Formation (fig. 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 (fig. 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 (5.2 m). 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 (32 km), from south of Thief River Falls to west of Red Lake Falls (fig. 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 (160 km). A sandy, pebble-loam believed to be the Marcoux Formation occurs throughout the Red River Valley (L. Froelich, personal communication; R. W. Schmid, personal communication; J. P. Bluemle, personal communication). 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 (0.15 to 8.25 m). Attempts to penetrate the Marcoux with a truck-mounted power auger have been frustrated by the large number of boulders and extreme hardness of the formation. Borings in the Grand Forks area penetrated as much as 64 feet (19.57 m) of the Marcoux Formation.

Differentation from other units: The most useful characteristic for distinguishing the Marcoux Formation from other late Quaternary formations is its texture. No other formation contains as much sand and as little clay as the Marcoux. The abundance of stones, predominance of igneous and metamorphic pebbles, hardness, and weak jointing are all characteristic of the Marcoux.

Origin: The Marcoux Formation is glacial sediment. The predominance of granitic and metamorphic rock types suggests that the glacier that deposited the Marcoux Formation advanced from the northeast across the Canadian Shield.

Correlation: Formation probably correlates with the Hawk Creek Till in the Minnesota River valley (Matsch, 1971). Both formations are very sandy, contain a mineral assemblage characteristic of areas to the northeast, and occur in the same stratigraphic position.

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

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, SE¼SE¼NE¼ sec. 5, T. 151 N., R. 43 W. (section 5, fig. 3).

Reference sections: Opernockity Section, SE¼NE¼SE¼ sec. 32, T. 152 N., R. 43 W. (section 6, fig. 3); Small Creek Section, SE¼SW¼SE¼ sec. 17, T. 152 N., R. 43 W.

Description of unit: The St. Hilaire Formation is unbedded pebble-loam. It is gray (5Y 5/1) when dry and very dark gray (10Y 3/2) when wet. Weak vertical joints are common and result in a moderately columnar structure. The pebble loam of the formation consists of 30% to 40% sand, 38% to 46% silt, and 15% to 29% clay. Pebbles and cobbles are abundant. Two groups of pebbles, igneous and metamorphic rock types, and limestone and dolomite,

occur in equal numbers and constitute most of the pebbles. Shale pebbles, which are conspicuously present, are about half as abundant as either of these groups. Lignite pebbles are commonly present in amounts as great as 5% of the total pebble fraction. The very coarse sand (1-2 mm) contains 37% to 44% igneous and metamorphic rock types, 27% to 36% dolomite and limestone, 20% to 35% shale, and 1% to 3% miscellaneous rock types. Calcareous material makes up about 25% of the sediment finer than 200 mesh.

Nature of contacts: The St. Hilaire 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 (0.46 m) of fine sand is present at the contact. The upper contact with the overlying Red Lake Falls Formation is sharp to gradational. 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 (6.11 m) of the formation is exposed. The St. Hilaire Formation is thought to extend throughout northeastern North Dakota, southern Manitoba, and northwestern Minnesota.

Differentation from other units: The St. Hilaire Formation is easily distinguished from the Marcoux and Red Lake Falls Formation 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 occurrence of appreciable quantities of shale in the pebble fraction suggests a western or northwestern source. The shale appears to be derived from the Pierre and Riding Mountain Formations in eastern North Dakota and southern Manitoba.

Correlation: It has not been possible to correlate the St. Hilaire Formation outside the Red River Valley.

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, NE¼NW¼ sec. 22, T. 151 N., R. 44 W. (section 3, fig. 3).

Reference sections: Needles Eye Section, SW¼NE¼SE¼ sec. 18, T. 151 N., R. 43 W. (section 4, fig. 3); Damned House Section, SW¼NE¼SE¼ sec. 15, T. 151 N., R. 44 W. (section 7, fig. 3).

Description of unit: The Red Lake Falls Formation is unbedded pebble-loam. It is brownish gray (2.5Y 6/2) when dry and olive brown (2.5Y 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 (7.5YR 6/6) stain. The Red Lake Falls Formation is hard and resistant to erosion in dry outcrops and is friable when moist.

Sand and gravel inclusions are 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.

In some outcrops two slightly different lithologies occur in the Red Lake Falls Formation. The differences are subtle enough that in most cases consistent field separation of the two units is not yet possible. The upper unit is generally more conspicuously jointed than the lower, more massive unit. The upper unit contains less sand, 32% to 42%, more silt, 36% to 46%, and about as much clay, 17% to 27%, as the lower unit; 39% to 49% sand, 34% to 40% silt, and 15% to 25% clay. The very coarse sand (1-2 mm) of the upper unit contains more shale, 10% to 15%, and less limestone and dolomite, 33% to 35%, than the lower unit, 0% to 4% shale and 38% to 52% limestone and dolomite. Both units contain about 50% igneous and metamorphic rock types. Calcareous material makes up a greater percentage of the minus 200 mesh fraction of the lower unit, 36%, than the upper unit, 28%. Pebbles, cobbles, and boulders are abundant in both units. The pebbles in the lower unit consist of about 2/3 limestone and dolomite; about 1/3 igneous and metamorphic rock types, and minor amounts of shale. The pebbles of the upper unit are similar but with a greater percentage of shale. The contact between the two units is commonly marked in some places by a cobble concentration similar to the solid, striated boulder pavement at the base of the formation. The cobbles making up this concentration are much smaller than in the basal pavement.

Nature of 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 (5.2 m) thick. A boulder pavement is present at the contact 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 (21.5 m) at Knife's Edge Section (NW¼NW¼SE¼ sec. 19, T. 151 N., R. 43 W.) to 7 feet (2.15 m) at the Stony Bench Section (NE¼NE¼NW¼ sec. 17, T. 152 N., R. 43 W.). The normal range of thickness is from 15 to 30 feet (4.6 to 9.2 m).

Differentation 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 sandier 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 composed predominantly of glacial sediment. In the Red Lake Falls area, minor amounts of lake and stream sediment are included in the formation. In the central part of the Red River Valley, in eastern Grand Forks County, as much as 20 feet (6.1 m) of laminated lacustrine clay lies between the 2 pebble-loam units of the formation in an area of several 10's of square miles. In some places, several 10's of feet of fluvial sand and gravel occur in the formation.

On the basis of pebble and sand-grain lithology we believe that the lower pebble-loam unit of the Red Lake Falls Formation was deposited by a glacier that advanced from the north. On the same basis we believe that the upper pebble-loam unit of the formation was deposited by a glacier that advanced from the northwest.

Correlation: The lower unit of the Red Lake Falls Formation correlates with the Granite Falls Formation of southwestern Minnesota (Matsch, 1971). The very similar appearance, texture, and pebble lithology of these two formations strongly suggests that they are correlative. Correlation of the lower unit of the Red Lake Falls Formation to the west into North Dakota is much less certain. Salomon (1973, in press) correlated the lower part of the formation with a very shaley till that is widespread in northeastern North Dakota. Although this correlation seems reasonable on the basis of available information on stratigraphic position and lateral continuity of the two units, the very abrupt change in lithology, from nearly no shale in the Red Lake Falls to 70% shale to the west, needs to be explored further before this correlation can be considered certain.

The upper unit of the Red Lake Falls Formation correlates with the New Ulm till of southwestern Minnesota (Matsch, 1971). The stratigraphic position and lithology of the two formations argues strongly for this correlation. Salomon (1973, in press) has correlated the upper unit of the Red Lake Falls with the surface till in northeastern North Dakota. Her correlation is based on stratigraphic position and pebble lithology.

Age: The age of the Red Lake Falls Formation is believed to be Wisconsinan. No evidence to support this assignment has been found in the Grand Forks area. Matsch (1971, p. 63-64) considers the Granite Falls Till to be Wisconsinan in age. Three radiocarbon dates from the New Ulm area were greater than 39,000 B.P. The upper part of the Red Lake Falls Formation can be dated with greater certainty. On the basis of radiocarbon dates below and above the formation in southwestern Minnesota and northwestern Iowa, the New Ulm Till can be dated as Late Wisconsinan. Ruhe (1969, p. 106, 201, 212) reported 2 dates of about 20,000 B.P. beneath till that Matsch (1972, p. 335) considered to be part of the New Ulm Till. Numerous radiocarbon dates from above the New Ulm Formation in southwestern Minnesota and Iowa indicate that deposition ceased about 14,000 B.P. (Matsch, 1971, p. 63). Dates in North Dakota are several thousand years younger, suggesting that the top of the formation is younger farther toward the north (Clayton, 1966).

WYLIE FORMATION (New)

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

Type section: Clearwater Section, NE¼NW¼ sec. 22, T. 151 N., R. 44 W. (section 3, fig. 3).

Reference section: Old Dam Section, SE¼NW¼ sec. 14, T. 151 N., R. 44 W. (section 8, fig. 3).

Description of unit: The Wylie Formation contains clay and silt that are generally thinly laminated. The clay is olive gray (5Y 5/2) when dry and dark gray (5Y 4/1) when wet. The silt is light brownish gray (2.5Y 6/2) when dry and olive brown (2.5Y 4/4) when wet. In outcrop, the formation is friable when dry and tough and plastic when moist. The silt laminae become thinner and the clay laminae become thicker upward. In most outcrops, the laminae range in thickness from a few millimeters to a centimeter.

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 (SW¼NE¼SE¼ sec. 22, T. 151 N., R. 43 W.) downstream to the area of the Schist Cliff Section (SE¼SE¼ sec. 22, T. 151 N., R. 45 W.). 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 (fig. 5).

The Wylie Formation ranges in thickness from less than 2 feet (0.6 m) to more than 7 feet (2.1 m). Average thickness of exposures is about 5 feet (1.5 m).

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

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

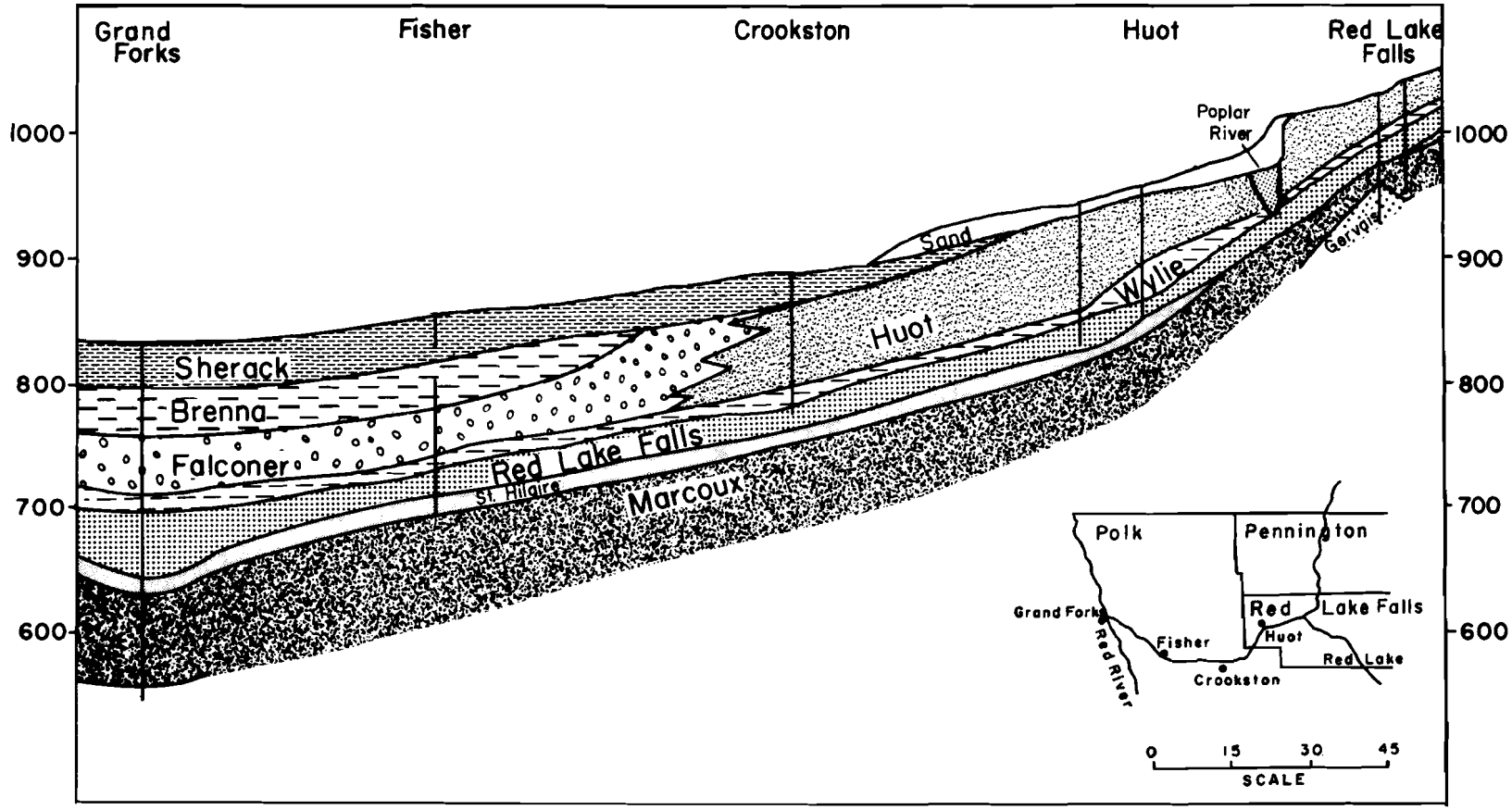

FIGURE 5. Generalized cross section showing stratigraphic correlations from Grand Forks, North Dakota, to Red Lake Falls, Minnesota.

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, NE¼NW¼ sec. 22, T. 151 N., R. 44 W. (section 3, fig. 3).

Reference section: Snake Curve Section, NW¼SW¼ sec. 18, T. 151 N., R. 44 W. (section 9, fig. 3); Schist Cliff Section, SW¼SE¼ sec. 22, T. 151 N., R. 45 W. (section 10, fig. 3).

Description of unit: The Huot Formation is unbedded slightly pebbly clay. It is gray (5Y 5/1) when dry and very dark grayish brown (2.5Y 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 in size from less than 2 mm to more than 1 cm. 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. The very coarse sand (1-2 mm) contains 40% to 45% igneous and metamorphic rock types, 50% to 55% limestone, and dolomite calcareous material makes up 25% of the minus 200 mesh fraction of the sediment.

Nature of 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 (fig. 5). 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 (fig. 6). 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 (0.9 to 4.6 m) of the formation are exposed in most outcrops. However, as much as 70 feet (21.4 m) of the Huot Formation is exposed in the Schist Cliff Section. As much as 100 feet (30.6 m) of the Huot Formation is present in the central part of the Red River Valley.

Differentiation from other units: The Huot Formation can be easily distinguished from other formations in the region by its texture, pebble content, unbedded, blocky structure, and color. The Brenna 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.

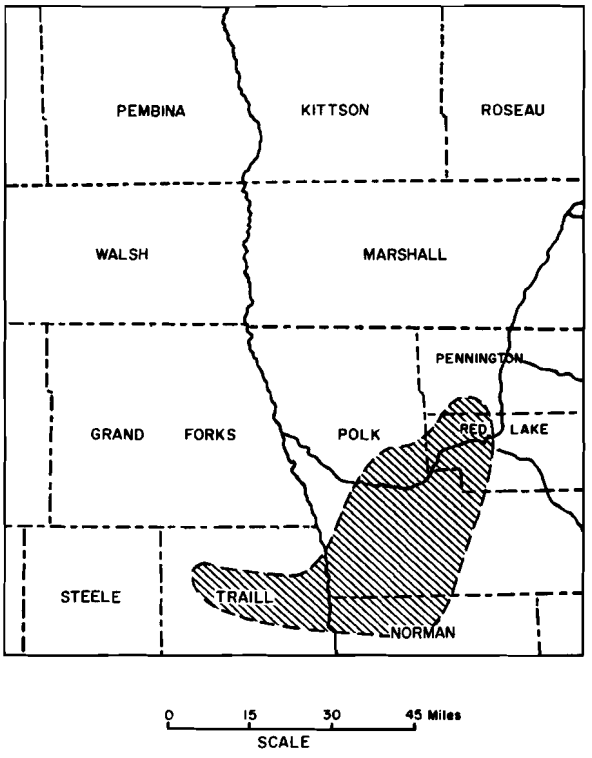

FIGURE 6. Map of the distribution of the Huot Formation.

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

Correlation: The Huot Formation is laterally and chronologically equivalent to the Falconer Formation in the central and western part of the Red River Valley.

Age: No radiocarbon dates are available to unambiguously date the Huot Formation. Two dates that can be related to the time of deposition of the Edinburg Moraine which lies along the outer margin of the Falconer Formation suggest a minimum age of 13,500 or 12,800 B.P. for deposition of the formation (Moran and Clayton, in preparation).

FALCONER FORMATION (New)

Source of name: Falconer Township, Grand Forks County, North Dakota.

Type area: The city of Grand Forks, North Dakota.

Type section: Boring No. 3, Witmer Hall, University of North Dakota, SE¼SE¼SE¼ sec. 5, T. 151 N., R. 50 W. (fig. 7).

Reference sections: North Dakota State Water Commission (NDSWC) Testhole 2430, NE¼SE¼SE¼ sec. 29, T. 152 N., R. 50 W.; NDSWC Testhole 2431, NE¼NE¼NE¼ sec. 22, T. 151 N., R. 50 W.; NDSWC Testhole 2433, SE¼NE¼SE¼ sec. 26, T. 151 N., R. 50 W.; NDSWC Testhole 2609, SE¼SE¼SE¼ sec. 36, T. 152 N., R. 51 W. (fig. 7).

Description of unit: The Falconer Formation consists of silty, clayey pebble-loam. It is light gray (5Y 6/1) when dry and commonly appears conspicuously silty. Beds of sand or gravel occur locally, but they are nowhere a significant constituent of the formation. Contorted beds of silt a few millimeters thick are locally abundant, especially in the upper part of the formation. In the Grand Forks area the Falconer Formation contains about 15% to 20% sand, 35% to 45% silt, and 35% to 45% clay. Calcareous material makes up 25% to 30% of the minus 200 mesh fraction of the sediment.

The Falconer Formation is sandier and less clayey north of Grand Forks. In northern Walsh County, North Dakota, the formation contains about 25% to 30% sand, 40% to 45% silt, and 25% to 35% clay. South of Grand Forks the sand content decreases and the clay content increases. In northern Traill County the formation contains 10% to 15% sand, 30% to 40% silt, and 50% to 60% clay. The Falconer Formation becomes progressively sandier and less clayey toward the west in Grand Forks and Walsh Counties, North Dakota, and toward the east in Polk, Pennington, and Marshall Counties, Minnesota.

Nature of contacts: The Falconer Formation is probably gradational with the underlying laminated clay of the Wylie Formation and the overlying obscurely laminated to unbedded clay of the Brenna Formation, although neither contact has been observed. The Brenna Formation becomes sandier and more pebbly downward toward its contact with the Falconer Formation. The contact between the Huot Formation, the clayey lateral equivalent of the Falconer Formation, with the Wylie Formation is gradational by interbedding in many outcrops. Laterally the Falconer Formation is completely gradational with the Huot Formation in Red Lake, Polk, and Norman Counties, Minnesota, and in central Traill County, North Dakota (fig. 5). The two formations have been differentiated because they look very different; material containing less than about 10% to 12% sand and more than about 55% clay looks like a slightly pebbley clay, whereas material containing more sand and less clay looks like pebble-loam ("till").

Regional extent and thickness: The Falconer Formation occurs throughout much of the northern half of the Red River Valley in North Dakota and Minnesota (fig. 8). It has been traced from its southern margin in central Traill County, North Dakota, as far north as Pembina County, North Dakota. It is believed to be present at least as far north as Roseau River in southern Manitoba, but this correlation is not certain. Neither the western boundary nor the eastern boundary north of Red Lake Falls, Minnesota, is known. The formation is as much as 100 feet (30.6 m) thick in northern Traill County, a few miles north of its southern limit. It thins progressively northward to less than 10 feet (3.1 m) in northern Walsh County.

Differentiation from other units: The Falconer Formation may be differentiated from both the Red Lake Falls and Huot Formations by its texture. The Falconer Formation is considerably less sandy and more clayey (about 20% sand, 40% silt, 40% clay) than the Red Lake Falls Formation (40% sand, 40% silt, 20% clay), and more sandy and less clayey than the Huot Formation (5% sand, 25% silt, 70% clay).

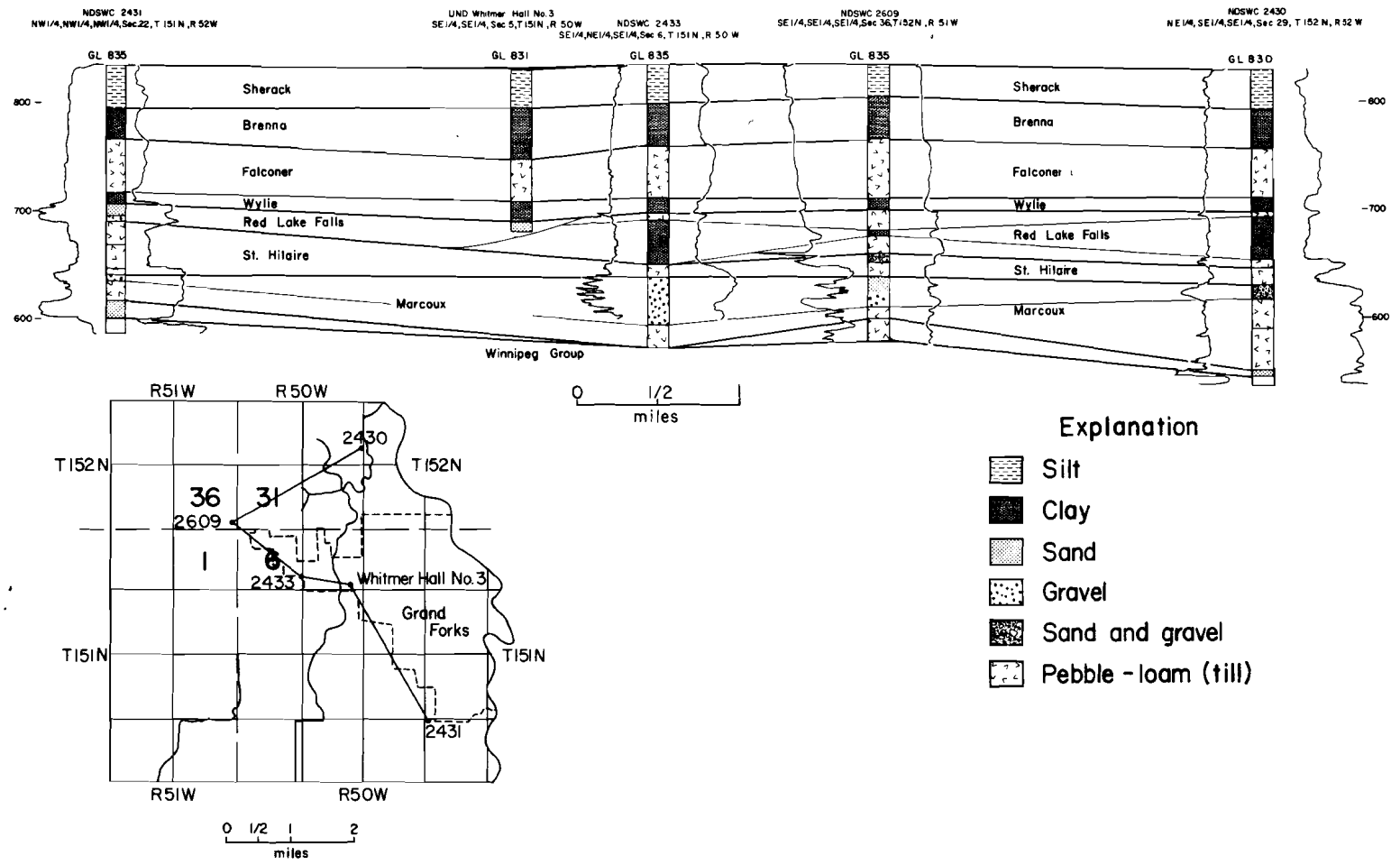

FIGURE 7. Cross section showing correlations of type and reference sections for the Falconer, Brenna, and Sherack Formations at Grand Forks, North Dakota.

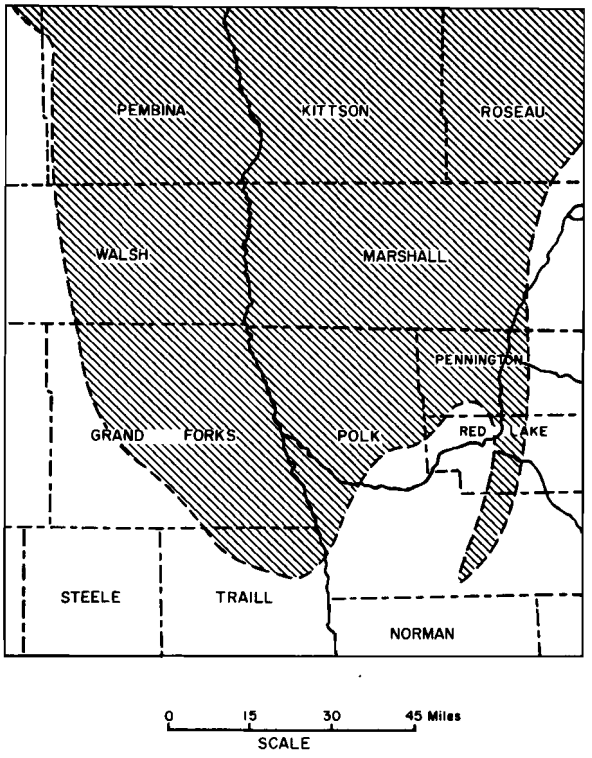

FIGURE 8. Map of the distribution of the Falconer Formation.

Toward its eastern, western, and northern edges the Falconer becomes increasingly similar to the Red Lake Falls Formation. Where the Wylie Formation or sand and gravel of the Falconer Formation are absent between these two formations, their differentiation is difficult. We consider it probable that the Falconer and Red Lake Falls Formations grade into one another somewhere in southern Manitoba.

Origin: The Falconer Formation is glacial sediment deposited as a result of a readvance of the generally retreating Late Wisconsinan glacier. The gradational change in texture of the formation is the result of the incorporation of clayey offshore sediment as the glacier advanced into Lake Agassiz. The Edinburg Moraine in Traill, Grand Forks, and Walsh Counties, North Dakota, marks the limit of this glacial advance.

Correlation: The Falconer Formation is laterally equivalent to the Huot Formation.

Age: The Falconer Formation was deposited during latest Wisconsinan time. The Formation was deposited prior to 12,800 B.P. Richie and Lichti-Federovich (1968) reported a date of 12,800±350 B.P. (I-1682) from the base of a pond near Brandon, Manitoba, located north of a moraine probably correlative with the Edinburg Moraine (Clayton, 1966).

BRENNA FORMATION (New)

Source of name: Brenna Township, Grand Forks County, North Dakota.

Type area: The city of Grand Forks, North Dakota.

Type section: Boring No. 3, Witmer Hall, University of North Dakota, SE¼SE¼SE¼ sec. 5, T. 151 N., R. 50 W. (fig. 7).

Reference sections: NDSWC Testhole 2430, NE¼SE¼SE¼ sec. 29, T. 152 N., R. 50 W.; NDSWC Testhole 2431, NE¼NE¼NE¼ sec. 22, T. 151 N., R. 50 W.; NDSWC Testhole 2433, SE¼NE¼SE¼ sec. 6, T. 151 N., R. 50 W.; NDSWC Testhole 2609, SE¼SE¼SE¼ sec. 36, T. 152 N., R. 51 W. (fig. 7); Boring 68-12M Oslo Dike, U. S. Army Corps of Engineers, NE¼SE¼SE¼ sec. 31, T. 155 N., R. 50 W.

Description of the unit: The Brenna Formation consists of clay that is dark gray to black (5Y 4/1 to 5Y 2/1) when wet. It is generally obscurely laminated to unbedded but locally contains more conspicuously laminated beds. It contains small, white, silty, calcareous fragments that range in size from 1 mm to 30 mm. Pebbles of hard carbonate and crystalline rocks occur infrequently within the unit. The clay is highly plastic and has a characteristic slick appearance. It is nearly impossible to break a sample of this material without it shearing to produce a slickensided surface. The clay is very weak and generally has a shear strength of less than 500 psf (Moran, 1972). It has a high liquid limit and water content (Rominger and Rutledge, 1952; Moran, 1972). Except for the calcareous white specks, the formation contains sand-sized material only near its base.

Nature of contacts: The contact of the Brenna Formation with the unbedded silty pebble-loam of the underlying Falconer Formation has not been observed; it is believed to be conformable and gradational. Sand is present in the lower part of the Brenna Formation and decreases in abundance upward. Similarly, the clay content of the Falconer Formation increases upward toward the contact.

The upper contact of the Brenna Formation with the light gray, thinly laminated clay of the Sherack Formation is an erosional unconformity, except in the central part of the Red River Valley north of Grand Forks, where it is conformable. The upper 5 to 10 feet (1.5 to 3.1 m) of the Brenna Formation is generally considerably harder, has greater shear strength, lower water content, and lower liquid limit than the remainder of the formation (Rominger and Rutledge, 1952; Moran, 1972). Rominger and Rutledge (1952) ascribed this change in the properties of the unit to dessication during sub-aerial exposure.

Regional extent and thickness: The Brenna Formation has been traced from its southern edge in extreme southern Grand Forks County, North Dakota, as far north as the international boundary. It is believed to extend at least as far north as Winnipeg, Manitoba. The Brenna Formation occurs only in the central part of the Red River Valley (fig. 9). It is everywhere overlapped by the Sherack Formation and is exposed only in artificial excavations and a few river banks throughout the area (fig. 5). The Brenna Formation is as much as 150 feet (45 m) thick in Pembina County, North Dakota.

Differentation from other units: The Brenna Formation looks very much like the Huot Formation, but may be differentiated from it by the greater sand and pebble content of the

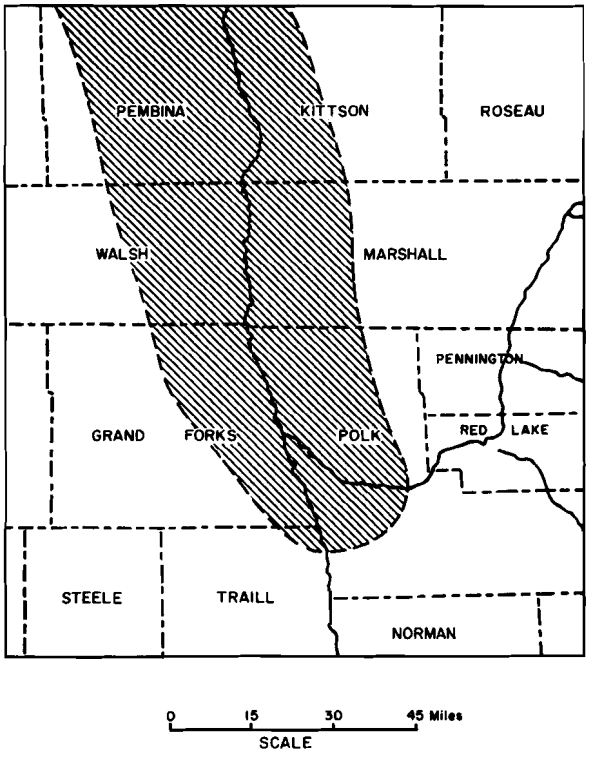

FIGURE 9. Map of the distribution of the Brenna Formation.

Huot and the presence of obscure laminations in the Brenna. The Brenna Formation is separated from the Wylie Formation by the pebble-loam of the Falconer Formation. The light gray color, the laminations, and the absence of the small white specks in the Sherack Formation differentiate it from the Brenna Formation. The Brenna Formation can be differentiated from the Falconer Formation by the light gray color, complete lack of bedding, higher sand and pebble content, greater hardness, and greater strength of the Falconer.

Origin: The Brenna Formation consists of clay that was deposited in deep water in Lake Agassiz. It is probable that some glacial mud-flow sediment is included in the lower few feet of the formation.

Age: The Brenna Formation was deposited during latest Wisconsinan time, between about 13,000 and 11,000 B.P. In the north-central part of the Red River Valley, deposition of the Brenna Formation continued until about 10,000 B.P.

POPLAR RIVER FORMATION (New)

Source of name: Poplar River in Red Lake County, Minnesota, located on the Brooks 7½-minute quadrangle.

Type area: Red Lake Falls, Minnesota, area.

Type section: The Snake Curve Section, SW¼NW¼SW¼ sec. 18, T. 151 N., R. 44 W. (section 9, fig. 3).

Reference section: The Poplar River Formation occurs extensively in the Fargo, North Dakota, area. However, no reference section is designated there at this time.

Description of the unit: The Poplar River Formation consists largely of fine- to coarse-grained sand. Minor amounts of gravel occur near the base of the formation near the edges of the Red River Valley. In the central part of the Valley, the member consists entirely of sand. The gravel in the Poplar River Formation is generally flat bedded. The sand and gravelly sand contain both large- and small-scale crossbedding. Mussel shells, small clam shells, snail shells, and wood occur locally in the Poplar River Formation (Moran, Clayton, and Cvancara, 1971).

Nature of contacts: The basal and lateral contacts of the Poplar River Formation are sharp and erosional. The upper contact of the Poplar River Formation with the overlying Sherack Formation is gradational by interbedding. The contact is placed where sand ceases to be a significant constituent of the section and clay beds are abundant.

Regional extent and thickness: The Poplar River Formation occurs throughout the Red River Valley, but it is not laterally extensive. It occurs as narrow, trough-shaped, linear bodies, from a few hundred feet to a mile (1.6 km) wide, that are inset into the top of the Brenna, Falconer, Huot, and Wylie Formation. The greatest extent of the Poplar River Formation is in the Fargo area, south of the area being considered here. Figure 10 shows the location of known occurrences of the Poplar River Formation in the Red River Valley.

The Poplar River Formation is generally only a few feet to a few tens of feet thick, but it reaches thicknesses in excess of 100 feet (30.6 km) in the Fargo area.

Differentiation from other units: The sand and gravel of the Poplar River Formation make it readily distinguishable from the Sherack, Brenna, Falconer, and Wylie Formations. The Gervais Formation is differentiated from the Poplar River Formation by stratigraphic position as well as by its compactness and disseminated organic matter.

The Poplar River Formation may be confused with sand and gravel of the Red Lake Falls Formation. In the central part of the Red River Valley the presence of the Brenna, Falconer, Huot, and Wylie Formations between the Poplar River Formation and these other bodies of sand and gravel prevent confusion. However, on the margin of the Valley, where these intervening units are absent, differentiation may be difficult. The principal means of recognizing the Poplar River Formation on the margin of the Valley is its occurrence in linear trough-shaped bodies inset into the underlying material; most, although not all, of other sand and gravel occurs as sheets or ridged linear bodies located on, but not inset into, the Red Lake Falls Formation.

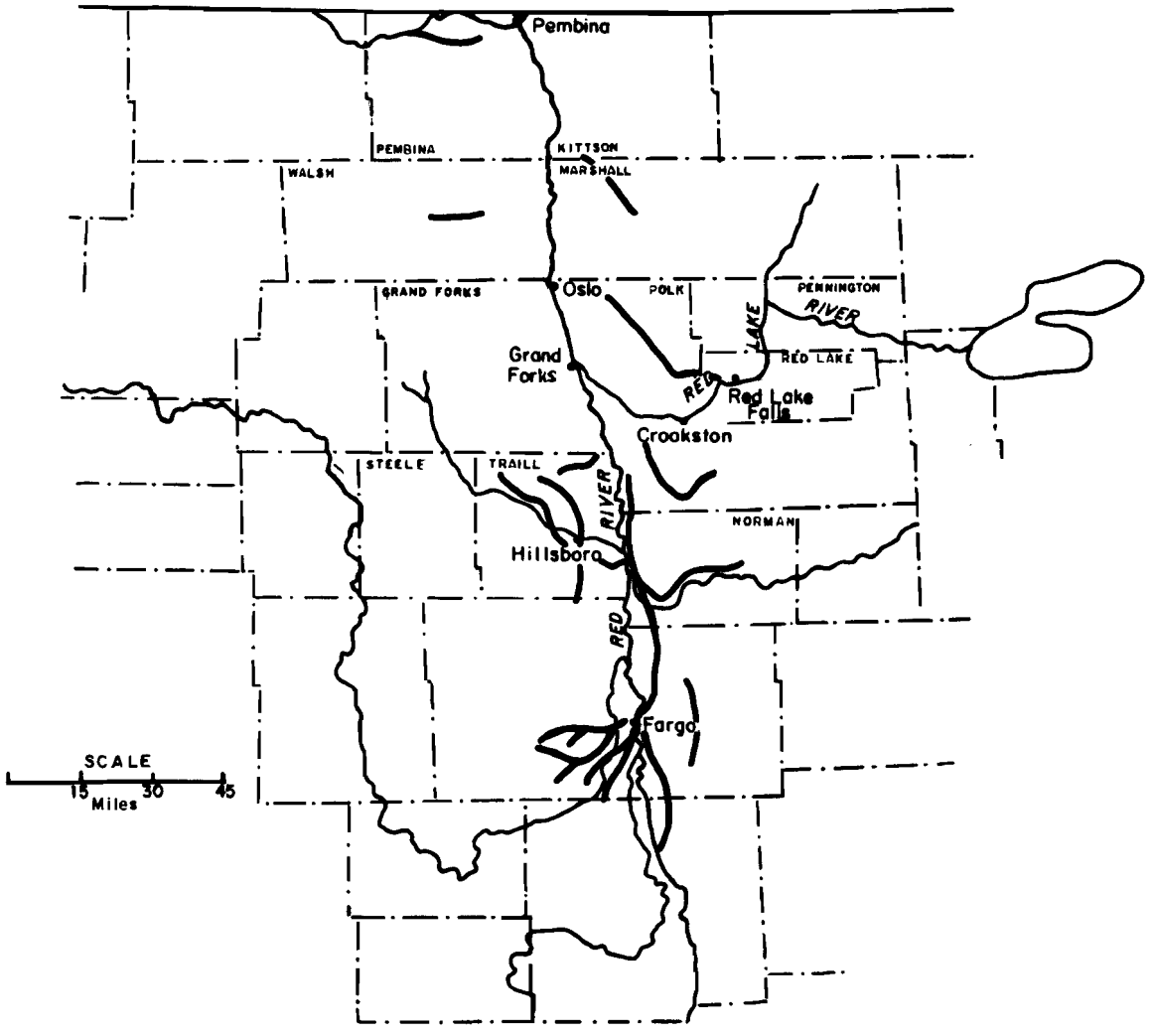

FIGURE 10. Map of the distribution of the Poplar River Formation.

Origin: The Poplar River Formation consists of fluvial channel sediment and some near-channel overbank sediment.

Age: Most of the Poplar River Formation was deposited on the unconformity at the upper surface of the Brenna Formation. It is largely latest Wisconsinan in age; it was deposited between 11,000 and 9,900 B.P., during a low-water phase of Lake Agassiz. The upper part of the formation is locally very earliest Holocene. A conifer log collected near the base of the formation in the Snake Curve Section was radiocarbon dated at 9,890±150 B.P. (I-4853).

Some of the Poplar River Formation may be considerably older than the remainder of the unit; it is thick, coarse-grained sand and gravel that occurs in the central part of the Red River Valley in Clay County, Minnesota, in Cass and Traill Counties, North Dakota, and in Marshall and Kittson Counties, Minnesota. It extends downward through the clay that is equivalent to the Wylie and Brenna Formation and is inset into the Red Lake Falls Formation. The exceptional thickness and coarse grain size of this part of the formation suggests that it was deposited by streams carrying considerably more water and sediment than those that deposited the remainder of the Poplar River Formation. Winter (1967) suggested that it formed within or adjacent to glacial ice. If this is the case, this part of the Poplar River Formation is only slightly younger than the Red Lake Falls Formation and is older than the Wylie Formation. If further study confirms that this part of the Poplar River Formation is, in fact, associated with the Red Lake Falls Formation and, therefore, that it is stratigraphically below the Wylie Formation, it will be removed from the Poplar River Formation.

SHERACK FORMATION (New)

Source of name: The village of Sherack in Polk County, Minnesota, located on the Warren, Minnesota, 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, NE¼SE¼SE¼ sec. 31, T. 155 N., R. 50 W.

Reference sections: Boring No. 3, Witmer Hall, University of North Dakota, SE¼SE¼SE¼ sec. 5, T. 151 N., R. 50 W.; NDSWC Testhole 2430, NE¼SE¼SE¼ sec. 29, T. 152 N., R. 50 W.; NDSWC Testhole 2431, NE¼NE¼NE¼ sec. 22, T. 151 N., R. 50 W.; NDSWC Testhole 2433, SE¼NE¼SE¼ sec. 6, T. 151 N., R. 50 W.; NDSWC Testhole 2609, SE¼SE¼SE¼ sec. 36, T. 152 N., R. 51 W. (fig. 7).

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 formation. 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 clay ceases to be the dominant lithology and 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, 1973). 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 (fig. 11). It extends at least as far north as Winnipeg, Manitoba. The formation is generally between 15 and 30 feet (4.6 and 9.2 m) 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 Formation 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 surface 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 lower 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: Most of the Sherack Formation is Holocene and was deposited in Lake Agassiz from 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 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.

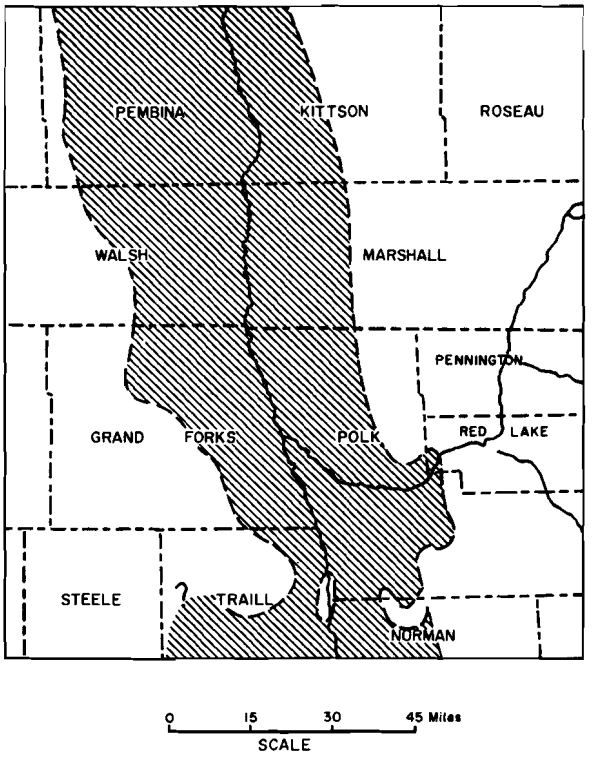

FIGURE 11. Map of the distribution of the Sherack Formation.

DESCRIPTION OF STRATIGRAPHIC SECTIONS AND TESTHOLES

Three Creeks Section*

NE¼NE¼NW¼ sec. 21, T. 151 N., R. 44 W.

Left bank of Red Lake River

Section 1 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation 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.
Marcoux Formation		
41-58½	982-964½	Sand, alternating fine and medium grained; flat bedded to ripple cross-bedded; jointed; limonitic stains; gradational lower contact.

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

58½-59	964½-964	Pebble-loam; sandy; unbedded; friable; light gray (5Y 6/1 dry); lower contact is sharp; cobbles are 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

NE¼NE¼NW¼ sec. 19, T. 151 N., R. 44 W.

Section 2 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation 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 crossbedded 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

NE¼NE¼ sec. 22, T. 151 N., R. 44 W.

Right bank of Clearwater River

Section 3 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation 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	982-955	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

SW¼NE¼SE¼ sec. 18, T. 151 N., R. 43 W.

Left bank of Red Lake River

Section 4 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation 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

SE¼SE¼NE¼ sec. 5, T. 151 N., R. 43 W.

Left bank of Red Lake River

Section 5 - Figure 3

Section described by K. L. Harris, S. R. Moran, Lee Clayton.

Depth in Feet	Elevation 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

SE¼NE¼SE¼ sec. 32, T. 152 N., R. 43 W.

Left bank of Red Lake River

Section 6 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation 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		
11-23½	1065-1052½	Pebble-loam; unbedded; friable; light brownish gray (2.5Y 6/2 dry); abundant sand lenses; gradational lower contact.
St. Hilaire Formation		
23½-24½	1052½-1051½	Pebble-loam; unbedded; friable; gray (5Y 5/1 dry); sand and gravel inclusions abundant at sharp lower contact.
Marcoux Formation		
24½-36	1051½-1040	Pebble-loam; sandy; unbedded; friable; light gray (5Y 6/1 dry); lower contact not exposed.

Damned House Section

SW¼NE¼SE¼ sec. 15, T. 151 N., R. 44 W.

Left bank of Red Lake River

Section 7 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation Above Sea Level	Description
Wylie Formation		
0-7	1015-1008	Silt; sandy; pebbly; 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	984-981	Sand; silty; flat-bedded to ripple crossbedded; 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.

Old Dam Section

SE¼NW¼ sec. 14, T. 151 N., R. 44 W.

Right bank of Red Lake River

Section 8 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation 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

NW¼SW¼ sec. 18, T. 151 N., R. 44 W.

Right bank of Red Lake River

Section 9 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation 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	939-932	Clay; silty; pebbly; unbedded; friable; light olive gray (2.5Y 7/2 dry); strong columnar jointing; gradational lower contact; silt bed at base.
28-40	932-920	Pebble-loam; unbedded; hard; light brownish gray (2.5Y 6/2 dry); lower contact not exposed.

Snake Curve South Section

SW¼NW¼SW¼ sec. 18, T. 151 N., R. 44 W.

Right bank of Red Lake River

Section 9 - Figure 3

Section described by S. R. Moran and Lee Clayton.

Depth in Feet	Elevation Above Sea Level	Description
0-15	992-977	Sand; fine grained; well sorted; thin bedded, contains ripple cross bedding; a layer of pebbles and cobbles about 6 inches thick occurs at the top of the sand; the lower contact of the sand is gradational.
Sherack Formation		
15-30	977-962	Silt; thinly laminated; contains some beds of clay and very fine sand; both upper and lower contacts are 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 are abundant near the base; lower 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 the 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 the gravel of the Poplar River Formation but gradational with the clay of the Wylie Formation both north and south of the measured section.

Schist Cliff Section

SE¼SE¼ sec. 22, T. 151 N., R. 45 W.

Right bank of Red Lake River

Section 10 - Figure 3

Section described by K. L. Harris.

Depth in Feet	Elevation 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

SE¼SW¼ sec. 17, T. 152 N., R. 43 W.

Section described by K. L. Harris.

Depth in Feet	Elevation 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.

Witmer Hall Boring No. 3

SE¼SE¼SE¼ sec. 5, T. 151 N., R. 50 W.

Core described by S. R. Moran.

Depth in Feet	Elevation 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 an average of 16% sand, 46% silt and 38% clay; the total carbonate content is 25.1% (5.5% calcite, 19.6% dolomite); contains 14% kaolinite and chlorite, 17% illite, and 68% montmorillonite.
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.

U. S. Army Corps of Engineers

Oslo Dike Boring 68-12M

NE¼SE¼SE¼ sec. 31, T. 155 N., R. 50 W.

Core described by S. R. Moran.

Depth in Feet	Elevation 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; silt; clayey; 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.
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

NE¼SE¼SE¼ sec. 29, T. 152 N., R. 50 W.

Sample description and electric-log interpretation by S. R. Moran.

Depth in Feet	Elevation 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	692-654	Clay; dark greenish gray to olive black; unoxidized.
176-183	654-647	Pebble-loam; gray (5Y 6/1 dry); unoxidized; poor samples.
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 (10YR 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

NW¼NW¼NW¼ sec. 22, T. 151 N., R. 50 W.

Sample description and electric-log interpretation by S. R. Moran.

Depth in Feet	Elevation Above Sea Level	Description
Sherack Formation		
0-16	835-819	Silt; clayey; light gray (2.5Y 7/2 dry); oxidized.
16-40	819-795	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.
60-68	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.
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

SE¼NE¼SE¼ sec. 6, T. 151 N., R. 50 W.

Sample description and electric-log interpretation by S. R. Moran.

Depth in Feet	Elevation 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 26.5% (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.

196-220	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

SE¼SE¼SE¼ sec. 36, T. 152 N., R. 51 W.

Sample description and electric-log interpretation by S. R. Moran.

Depth in Feet	Elevation 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.
St. Hilaire Formation		
183-196	652-639	Pebble-loam; gray (5Y 5/1 dry); unoxidized.
196-212	639-623	Sand and gravel.
Marcoux Formation		
212-232	623-603	Pebble-loam; sandy, very poor samples.
232-240	603-595	Pebble-loam; sandy; gray; very poor samples.
240-251	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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