ECONOMIC DEVELOPMENT ADMINISTRATION

TECHNICAL ASSISTANCE PROJECT

U.S. DEPARTMENT OF COMMERCE

NORTH DAKOTA GEOLOGICAL SURVEY

Wilson M. Laird, State Geologist

REPORT OF INVESTIGATION 48

Cement-Rock Possibilities in Paleozoic Rocks

of

EASTERN NORTH DAKOTA

by

Sidney B. Anderson

and

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1968

This technical assistance study was accomplished by professional consultants under contract with the Economic Development Administration. The statements, findings, conclusions, recommendations, and other data in this report are solely those of the Contractor and do not necessarily reflect the views of the Economic Development Administration.

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ACKNOWLEDGMENTS

This study was initiated by the North Dakota Resources Development Corporation (formerly the Stanton Industrial Center, Inc.). At the request of this group, the University of North Dakota entered into a contract with the Economic Development Administration, U. S. Dept. of Commerce, which provided a large share of the funds required to do the drilling. The balance of the funds required for the drilling program and the chemical analyses were provided by the North Dakota Economic Development Commission and the North Dakota Resources Development Corportion. X-ray analyses were provided by the North Dakota Geological Survey. The exploration program, laboratory analyses, and other technical aspects of the program were administered by the North Dakota Geological Survey in cooperation with the Department of Geology of the University of North Dakota.

ABSTRACT

An exploration drilling program was conducted in 1967 in eastern North Dakota in search for limestone suitable for the manufacture of portland cement. In this program eight tests were drilled with footage totaling 2640 feet; cored intervals totalled 800 feet. The primary objective in this program was the limestone of the Ordovician Red River formation. Several secondary objectives were also investigated; these included carbonates of the Ordovician Winnipeg and Stony Mountain formations and the Siluro-Ordovician Stonewall formation.

Two test holes were drilled in Pembina County and six were drilled in Grand Forks County. The most promising samples were obtained from test hole G.F.-3 near Manvel in Grand Forks County. In this hole a 40-foot cored interval (220-260 feet) averaged 85.6 percent calcium carbonate, although the magnesium carbonate content of 7.50 percent was somewhat higher than is desirable for the manufacture of portland cement.

To obtain a product containing an acceptable magnesium content, it is suggested that the Red River limestone be blended with the shaly limestone of the Niobrara Formation which crops out in western Grand Forks County. The Niobrara has a calcium carbonate content averaging only 61.0 percent in a 10-to-12 foot bed, but it has a low magnesium carbonate content averaging 1.4 percent over the same interval. A blend of the two limestones (Red River and Niobrara) should possess a permissible magnesium carbonate content, while keeping the calcium carbonate content well above the lower limits necessary for the manufacture of portland cement.

INTRODUCTION

Presently there is no cement plant located in the state of North Dakota; however, interest in the possibility of establishing a plant has persisted for many years. This interest has prompted the writing of several reports over the years concerning possible sources of cement rock in North Dakota. These have included reports on the White River limestone of Oligocene age in western North Dakota and the Niobrara Formation of Cretaceous age in eastern North Dakota. These reports concluded that the White River limestone deposits are too small and too discontinuous to warrant establishing a plant, and the calcium carbonate content of the Niobrara is too low for it to be used without blending with a purer limestone containing a higher percentage of calcium carbonate.

Heretofore, no reports have been published concerning the possibility of utilizing Paleozoic carbonates as a source rock for cement in North Dakota. In the course of this study, a total of eight test holes were drilled in eastern North Dakota. The drilling and coring totaled 2,640 feet, of which the coring totaled 800 feet. The primary objective was limestone of the Ordovician Red River Formation; secondary objectives were the limestones of the Ordovician Winnipeg and Stony Mountain Formations and the carbonates of the Siluro-Ordovician Stonewall Formation.

In the text, test holes Pembina 1 and Pembina 2 are referred to as P-1 and P-2; similarly, test holes Grand Forks 1, 2, 3, 4, 5, and 6 are referred to as GF-1, -2, -3, -4, -5, and -6.

Areas of Study

Three areas, all in extreme eastern North Dakota, were selected for this study. The first area is located in extreme northeastern North Dakota, about one mile north of Pembina in Pembina County (Figs. 1 and 2). The two other areas are both located in extreme east central North Dakota

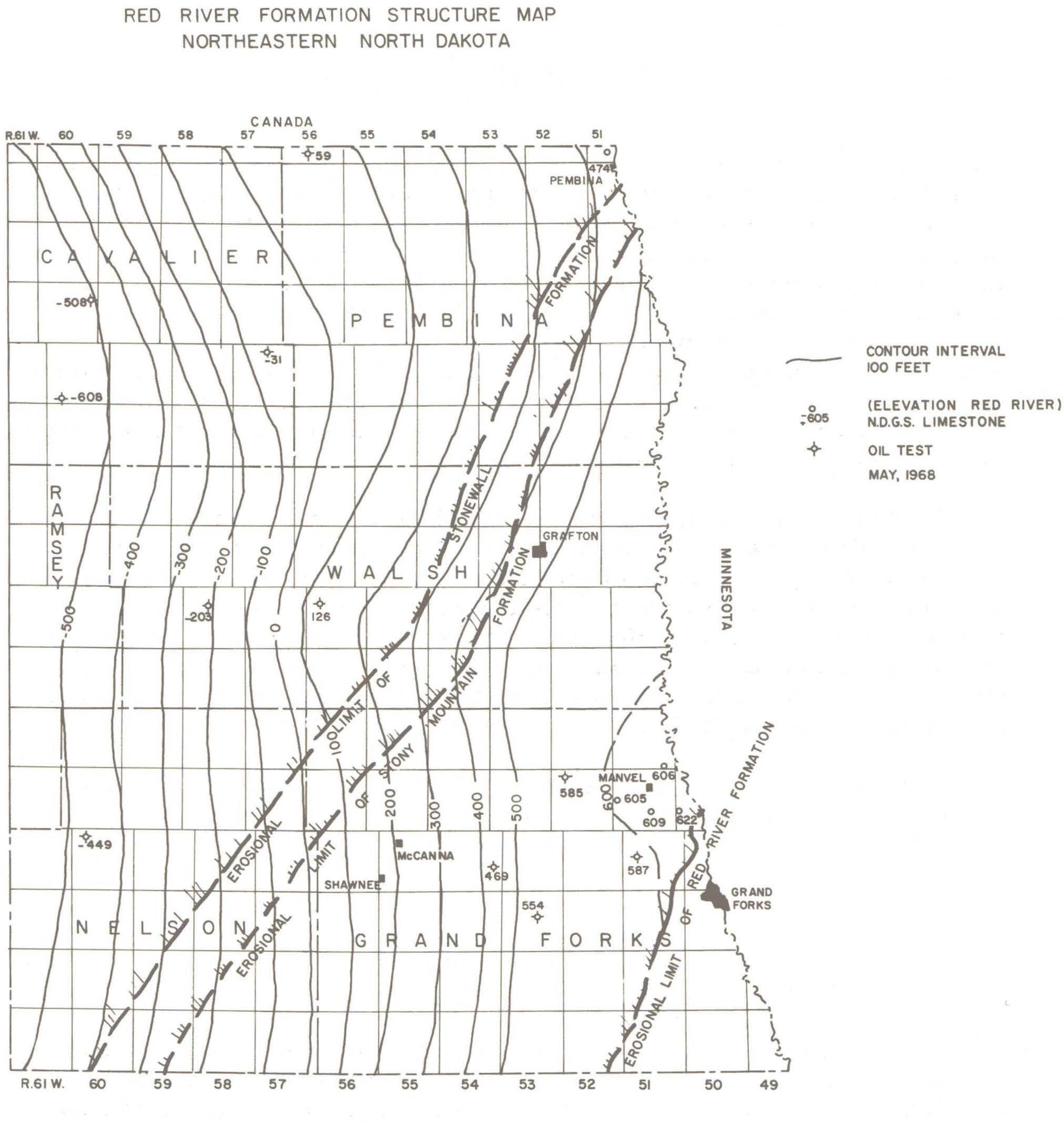

RED RIVER FORMATION STRUCTURE MAP
NORTHEASTERN NORTH DAKOTA
CANADA
MINNESOTA
CAVALIER
PEMBINA
RAMSEY
WALSH
NELSON
GRAND FORKS
PEMBINA
GRAFTON
MANVEL
McCANNA
SHAWNEE
GRAND FORKS
EROSIONAL LIMIT OF STONEWALL FORMATION
EROSIONAL LIMIT OF STONY MOUNTAIN FORMATION
EROSIONAL LIMIT OF RED RIVER FORMATION
CONTOUR INTERVAL 100 FEET
(ELEVATION RED RIVER) N.D.G.S. LIMESTONE
OIL TEST
MAY, 1968

FIGURE - I

RED RIVER FORMATION ISOPACH MAP OF NORTHEASTERN NORTH DAKOTA

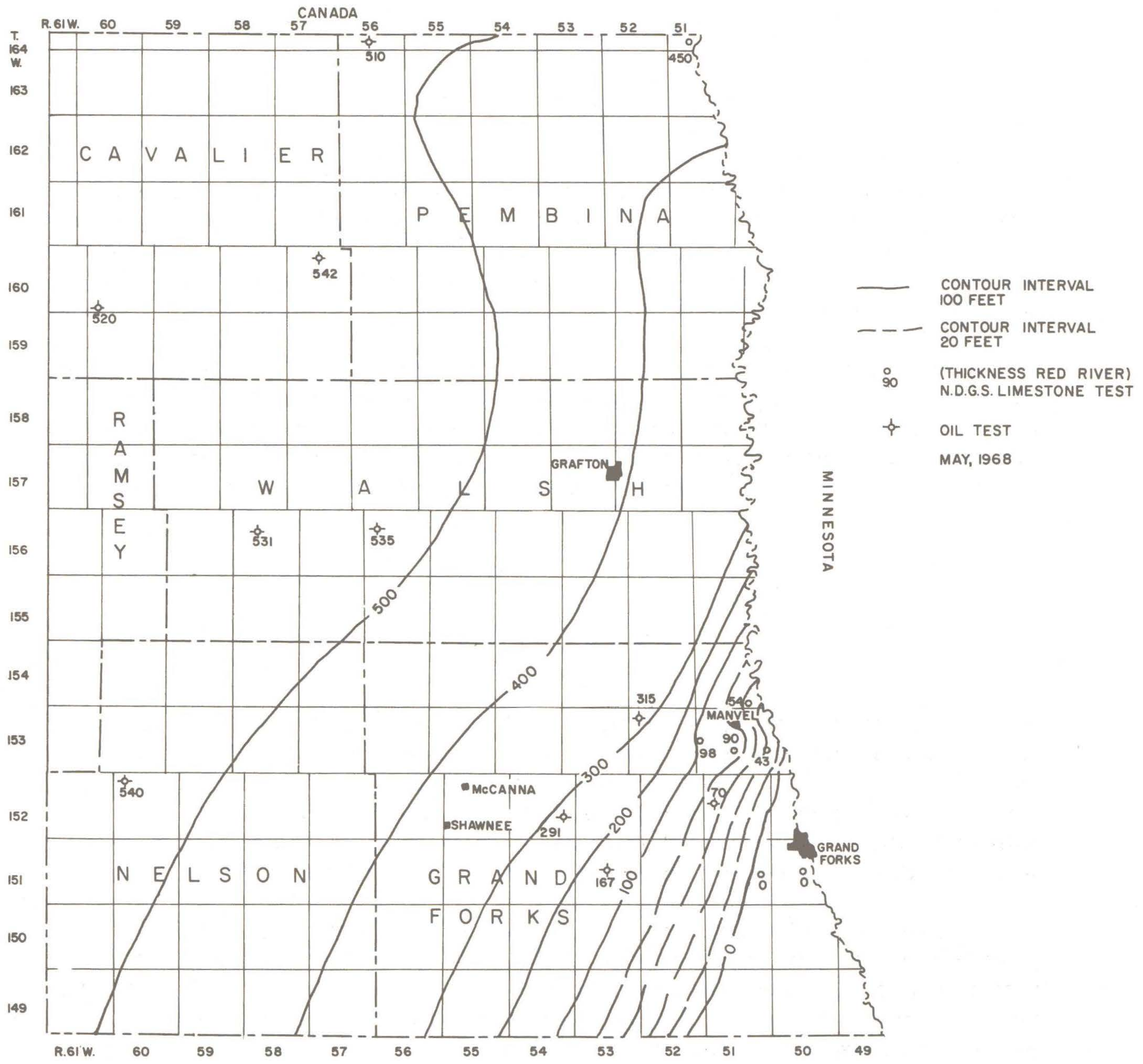


FIGURE - 2

in Grand Forks County (Figs. 1 and 2). The first of these areas is located in the vicinty of Manvel while the second is located immediately south of Grand Forks.

Regional Geologic Setting

The areas investigated lie wholly within the Lake Agassiz Plain District, Western Lake Section of the Central Lowland Province. All drill sites are within the boundaries of glacial Lake Agassiz. General geology is shown on geologic maps (Figs. 1 and 2, Plate 1) and on geologic cross sections (Plates 2 and 3).

Glacial-age deposits consisting of till and proglacial lake deposits directly overlie the bedrock in these areas. In all the areas drilled, except the two westernmost sites in the Manvel area, the bedrock is composed of sedimentary rocks of Ordovician age. In the two westernmost sites in the Manvel area, the bedrock is the Cretaceous Fall River Formation.

Methods of Study

The study was begun in the spring of 1967 by geologists of the North Dakota Geological Survey, utilizing subsurface information obtained from several sources. These include a gypsum test-drilling program in Pembina County; a cooperative water resources test-drilling program operated jointly by the North Dakota Water Commission, the U. S. Geological Survey, and the North Dakota Geological Survey; and oil test drilling.

From the information thus obtained, it was determined that the only possible sources of limestone of a grade suitable for use in the manufacture of Portland Cement, at reasonable depths, were in rocks of Ordovician age. Rocks of this age include carbonate sections in the Winnipeg and Red River Formations in Grand Forks County, and in the Red River, Stony Mountain, and Stonewall Formations in Pembina County.

Based on this information, tentative drill sites were selected in Pembina County near Pembina, and in Grand Forks County near Manvel and near Grand Forks. It was predicted that if limestone of a quality necessary for the manufacture of Portland Cement could be found it would be at depths of 200 to 500 feet.

Drill sites were spotted in road ditches or on quarter-line access approaches along road rights of way, except where specific permission was obtained to drill elsewhere. In all cases, township supervisors and/or adjacent landowners or the State Highway Department were contacted, and their approval received. Drilling was done with two truck-mounted rigs. Drag bits and rock bits were used in drilling through the glacial deposits, and coring was done with NX size bits (1 15/16 inch inside diameter). The holes were drilled 5 to 6 feet into the Paleozoic carbonate and casing was set before coring was commenced. Continuous cores were cut in the carbonate sections. Core recovery was in excess of 97 percent in the carbonate sections.

The drilling program began October 13, 1967, and was completed on December 1, 1967. Approximately 800 feet of section was cored. Electric logs, using a Widco logging unit, were run on all of the holes with the exception of P-2. In all of these holes, the logging sonde was lowered through the surface casing, and the carbonate section was logged. Following the pulling of the surface casing, logs were run on the till and lake clays section; however, this section began to cave as the casing was pulled so it was impossible to get a log of the entire glacial section.

In order to facilitate the analytical work on the cores, it was proposed that preliminary testing of the cores be done in the field using a Chittick Gasometric Apparatus. In a previous study conducted by the North Dakota Geological Survey in 1963, evaluating the Cretaceous Niobrara Formation for possible use as a cement rock, the Chittick apparatus was used and excellent results were obtained. By utilizing this method, it was felt that the better intervals could be delineated rapidly for further analysis by x-ray methods. Following x-ray analysis, the best sections were to be sent to a private laboratory for detailed chemical analysis. By utilizing these steps, it was felt that rapid results could be obtained.

Field testing was carried out on hole P-1 utilizing the Chittick apparatus. Coring on P-1 was discontinued at a depth of 505 feet on the basis of results obtained from the Chittick apparatus. However, following completion of P-1, it became evident that because of the cold weather the Chittick method was not practical as it was impossible to maintain anything approaching a constant temperature in the trailer which was used as a field laboratory. It was then decided that preliminary testing utilizing the Chittick apparatus would be continued in the office. Testing with the Chittick apparatus was resumed in the office; however, it was noted that some of the results did not appear to be reasonable. We then checked the apparatus using pure calcium carbonate comparing the results against samples obtained by coring. It was noted that greater amounts of carbon dioxide were generated from some of the core samples that were obviously dolomitic then from the calcium carbonate. Upon further testing with the apparatus, it was discovered that larger volumes of carbon dioxide gas are generated from carbonates containing magnesium than from calcium carbonate.

At the outset of the program, it was proposed that the initial testing be done using the Chittick apparatus with the more promising sections being tested further by x-ray methods. However, as a result of the unreliability of our Chittick results, systematic x-ray analysis of every third foot of core was undertaken.

PEMBINA AREA

General Statement

Paleozoic, Mesozoic, and Cenozoic deposits comprise the stratigraphic sequence in this area (Figs. 1 and 2, Plate 2). The Paleozoic deposits are the Ordovician Winnipeg, Red River, and Stony Mountain Formations and the Stonewall Formation of Siluro-Ordovician age. Overlying these deposits in much of the area, but absent in the area of the Pembina drill sites is a Mesozoic "red bed" section of questionable Jurassic age. The Cenozoic sediments are composed of glacial till and lake deposits; these directly overlie the "red bed" section in much of the area. However, in the area of the drill site, they directly overlie the Paleozoic sediments. Discussion of the sedimentary section will be restricted to those penetrated by the drill and in the order of penetration, i.e., surface to Red River.

Stratigraphy

Glacial drift

The glacial deposits in the Pembina area are composed of lake sediments from proglacial Lake Agassiz and glacial till which underlies the lake sediments. The combined thickness of the lake sediments and till is 222 feet in test hole P-1. Of this gross thickness, the lake sediments occupy 125 feet and are composed of yellowish gray to olive gray silt and clay; the remaining thickness of 98 feet is composed of olive gray till with some glacial sand at the base.

Stonewall Formation

There is some dispute over the age of the Stonewall as to whether it is Silurian or Ordovician; therefore, it is generally listed as Siluro-Ordovician in age. In the Pembina area, it conformably overlies the Ordovician Stony Mountain and is overlain unconformably by glacial deposits or by Jurassic "red beds." The test hole P-1, it is overlain by glacial deposits. The Stonewall Formation in this area is composed of very light beige colored, fine grained, dense, hard dolomite. At drill site P-1, the thickness of the Stonewall is 30 feet.

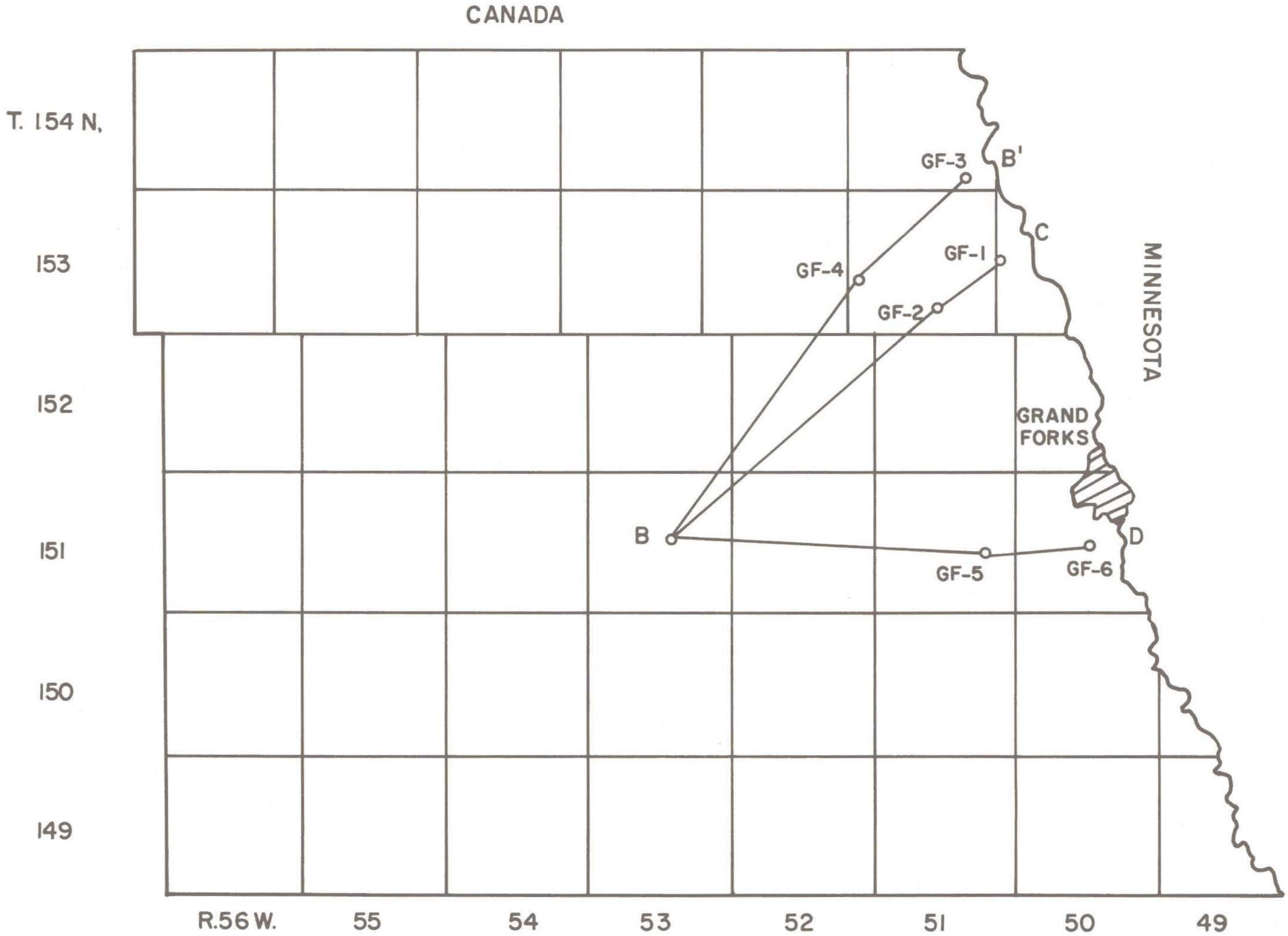
Stony Mountain Formation

The Stoney Mountain Formation is of Ordovician age and conformably overlies the Red River Formation in the Pembina area. In test hole P-1, the Stony Mountain Formation is composed of light colored greenish gray to buff, dense dolomite with small amounts of interbedded chert. Underlying the dolomite is a noncalcareous shale section, predominantly reddish brown in color, with some light greenish gray shale inclusions.

Red River Formation

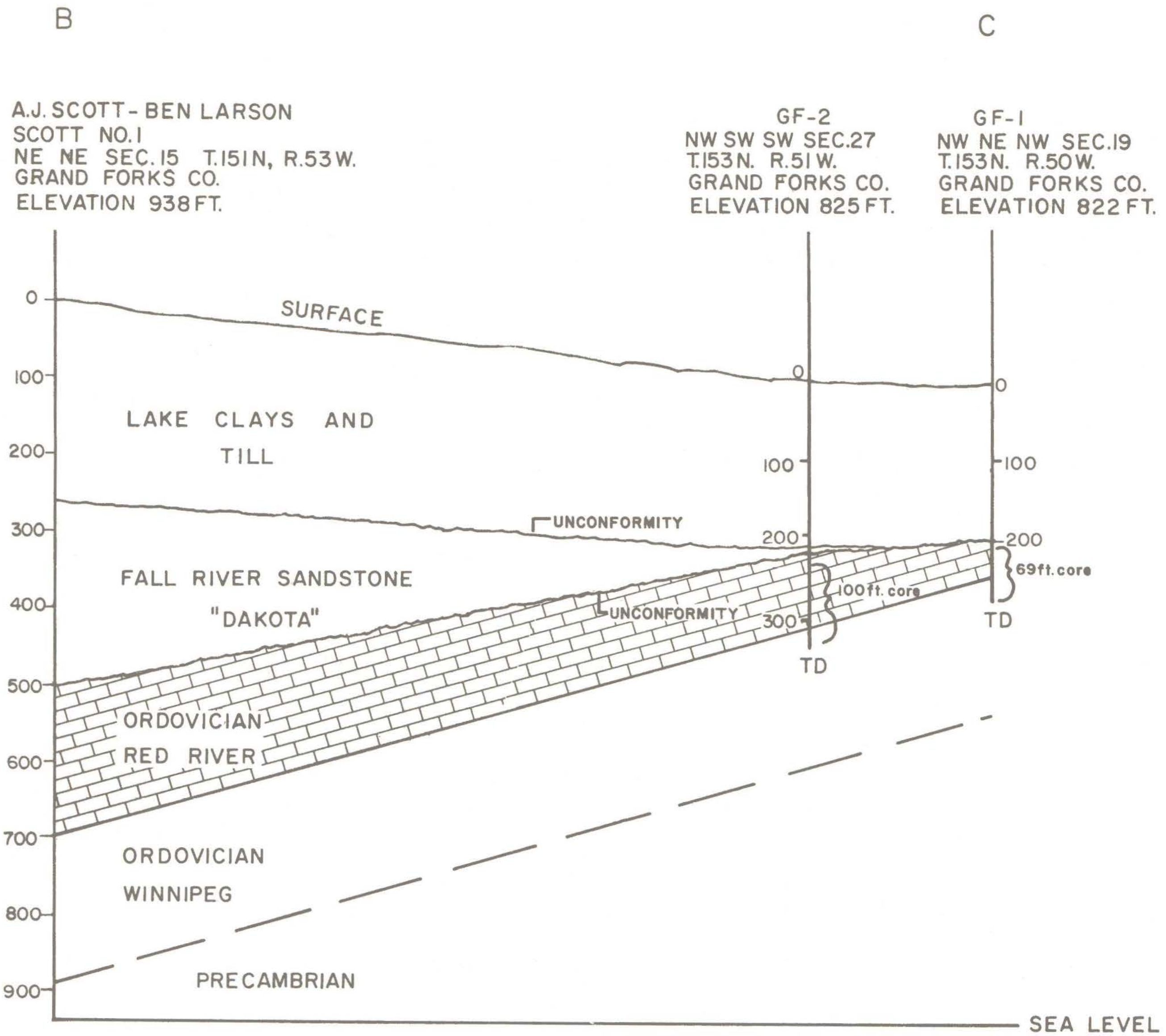
The Red River Formation is Ordovician in age and in the Pembina area is conformably overlain by the Stony Mountain Formation. Conformably underlying it is the Winnipeg Formation, also of Ordovician age; however, test hole P-1 did not penetrate the Winnipeg.

Test hole P-1 was originally scheduled to be drilled to a depth of 500 feet in order to evaluate the upper 150 feet of the Red River. However, the overlying Stonewall and Stony Mountain Formation were thinner than expected; therefore, when drilling was suspended at 505 feet a total of 197 feet of Red River has been cored. At this site, the upper 172 feet (308-480 feet)of the Red River is composed largely of light yellowish brown to light purple and cream colored mottled generally dense, fine grained limestone. A 28-foot section from 359 feet to 387 feet was encountered that had a good vugular porosity. From 480 feet to 505 feet, where the hole was bottomed, the Red River is medium light gray with slight purplish cast with medium dark gray banding and mottling, dense and rich in fossil fragments.



GRAND FORKS COUNTY NORTH DAKOTA CROSS SECTION LOCATION MAP
MAY, 1968

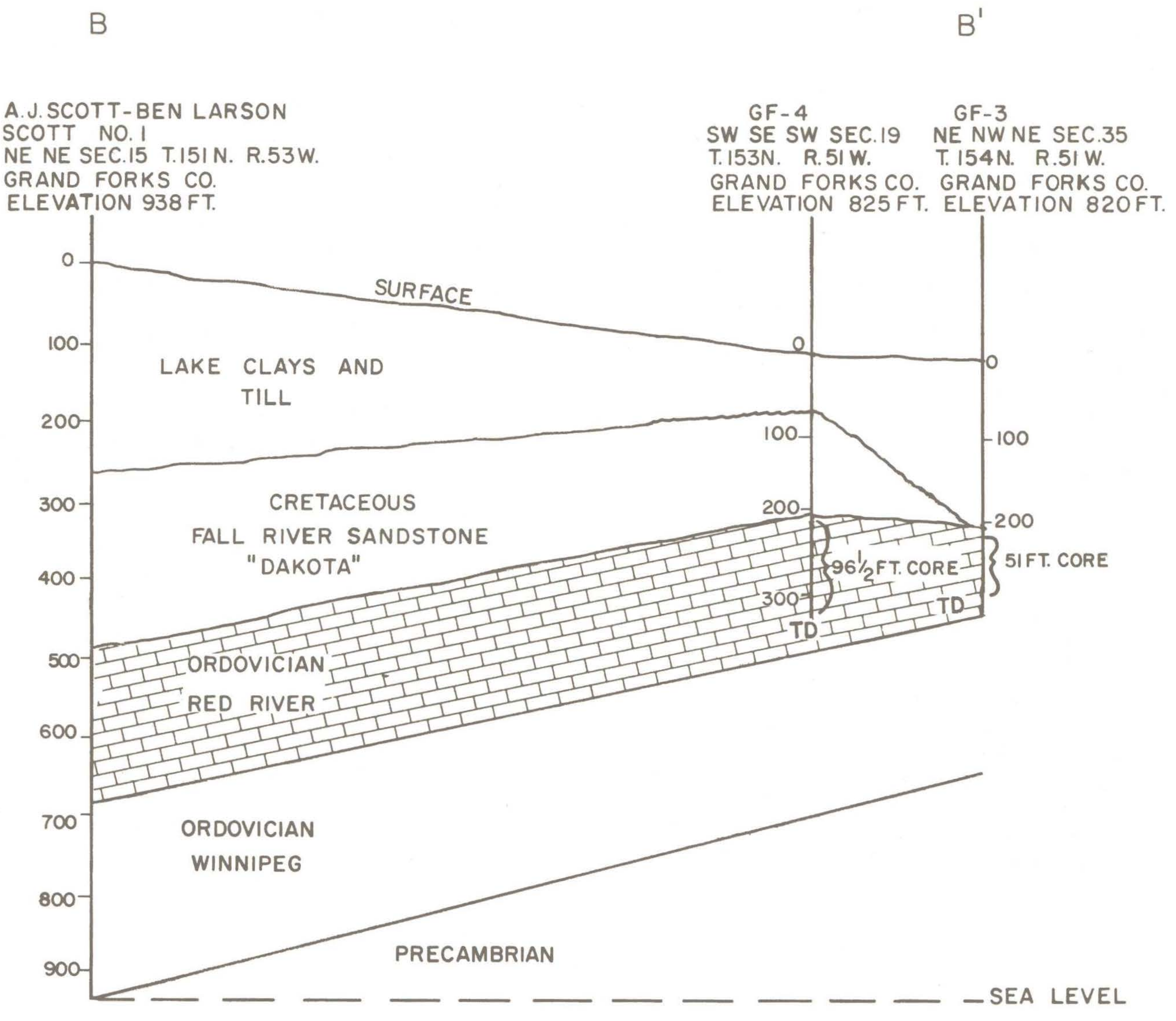
FIGURE-3



HORIZONTAL SCALE
1 inch = 2 1/2 Miles

CROSS SECTION SHOWING RED RIVER FORMATION
GRAND FORKS — MANVEL AREA
MAY 1968

FIGURE - 4



HORIZONTAL SCALE

1 inch = 2 1/2 Miles

CROSS SECTION SHOWING RED RIVER FORMATION
GRAND FORKS — MANVEL AREA
MAY, 1968

FIGURE-5

GRAND FORKS-MANVEL AREA

General Statement

As in the Pembina area, the stratigraphic sequence in this area is composed of Paleozoic, Mesozoic, and Cenozoic deposits; however, there are some differences. The Paleozoic section consists of the Ordovician Winnipeg Formation and the basal portion of the Ordovician Red River Formation. In this area, the upper three-fourths to four-fifths of the Red River Formation as well as the Ordovician Stony Mountain and Siluro-Ordovician Stonewall Formations have been removed by erosion. This is indicated on maps, Figures 1 and 2, Plate 1, and cross section Plate 3.

In test holes GF-2 and GF-4, the Mesozoic is represented by the Cretaceous Dakota Group sandstones (Fall River Formation) (Fig. 3, cross section location map and cross sections Figs. 4 and 5). The sandstone is absent in the two easternmost holes, GF-1 and GF-3, of the four tests drilled in the Grand Forks-Manvel area (Figs. 4 and 5).

Cenozoic deposition is represented by glaical till and lake deposits of proglacial Lake Agassiz. At drill sites GF-1 and GF-3, the glacial deposits directly overlie the limestone of the Red River Formation (Figs. 4 and 5). Discussion of the sediments will be restricted to those penetrated by the drill and in the order of penetration, i.e., surface to Red River.

Stratigraphy

Glacial drift

The glacial deposits in the Grand Forks-Manvel area are composed of sediments from proglacial Lake Agassiz and glacial till which underlies the lake sediments. The combined thickness of the lake sediments and till ranges from 80 feet in GF-4 to 214 feet in GF-3 (Fig. 5). The lake sediments make up approximately the upper 55 feet of the glacial sediments in the area with the underlying till comprising the remainder of the total. The lake sediments are generally yellowish gray to olive gray silt and clay, and the till is generally olive to dark olive gray. In the Red River prospective area (Plates 1 and 4), it is expected that the glacial sediments will range from about 200 to 220 feet in thickness.

In test holes GF-2 and GF-4, the glacial sediments overlie the Dakota Group sandstones (Fall River Formation) while in test holes GF-1 and GF-3, the glacial sediments directly overlie the Red River Formation (Figs. 4 and 5).

Cretaceous Dakota Group

Sandstone of the Cretaceous Dakota Group (Fall River Formation) is present in the two westernmost tests drilled in the Grand Forks-Manvel area. At site GF-2, the sandstone has a thickness of 6 feet while at site GF-4 the thickness is 140 feet (Figs. 4 and 5). T. E. Kelly of the U. S. Geological Survey (oral communication, May 1968) has stated that in this area a portion of the sandstone section assigned to the Dakota Group may in part have been reworked by glacial meltwater; however, it appears to be connected hydrologically to the Fall River.

The sandstone is generally fine grained quartz, light gray in color and is subangular to subround. In test hole GF-4 (Fig. 5), the upper 55 feet also contains some igneous and limestone fragments, indicating that this section may have been reworked by glacial meltwater.

Red River Formation

The Ordovician Red River Formation in the Grand Forks-Manvel area is overlain unconformably by the Fall River Formation of the Dakota Group in test holes GF-2 and GF-4 (Figs. 4 and 5). In test holes GF-1 and GF-3, it is unconformably overlain by glacial deposits (Figs. 4 and 5). In this area, it conformably overlies the Winnipeg Formation. In holes GF-1, -2, -3, and -4 only the upper transitional portion of the Winnipeg was penetrated.

The Red River in this area is generally cream colored with some reddish to purplish mottling, fine grained, and fossiliferous.

Winnipeg Formation

The Ordovician Winnipeg Formation is overlain conformably by the Red River and unconformably overlies Precambrian granite in the Grand Forks-Manvel area. Only the upper portion of the Winnipeg was penetrated by the test holes GF-1, -2, -3, and -4. This portion is transitional with the overlying Red River and is composed of argillaceous limestone, cream colored with much purplish mottling and green shale inclusions. This unit becomes increasingly shaly with depth, finally grading into a green waxy shale.

GRAND FORKS AREA

General Statement

Two wells were drilled in this area (Location Map, Fig. 3 and Plate 1), GF-6 was located on the southern edge of the city of Grand Forks and GF-5 approximately 4 miles southwest of the city. In this area, the sedimentary section is represented only by Paleozoic and Cenozoic deposits, which are represented by the Ordovician Winnipeg Formation and the overlying glacial drift. The Ordovician Red River Formation has been eroded and the Cretaceous Fall River Formation is not present; however, the latter is present 3 to 4 miles west of GF-5 (Fig. 6 and Plate 1).

Stratigraphy

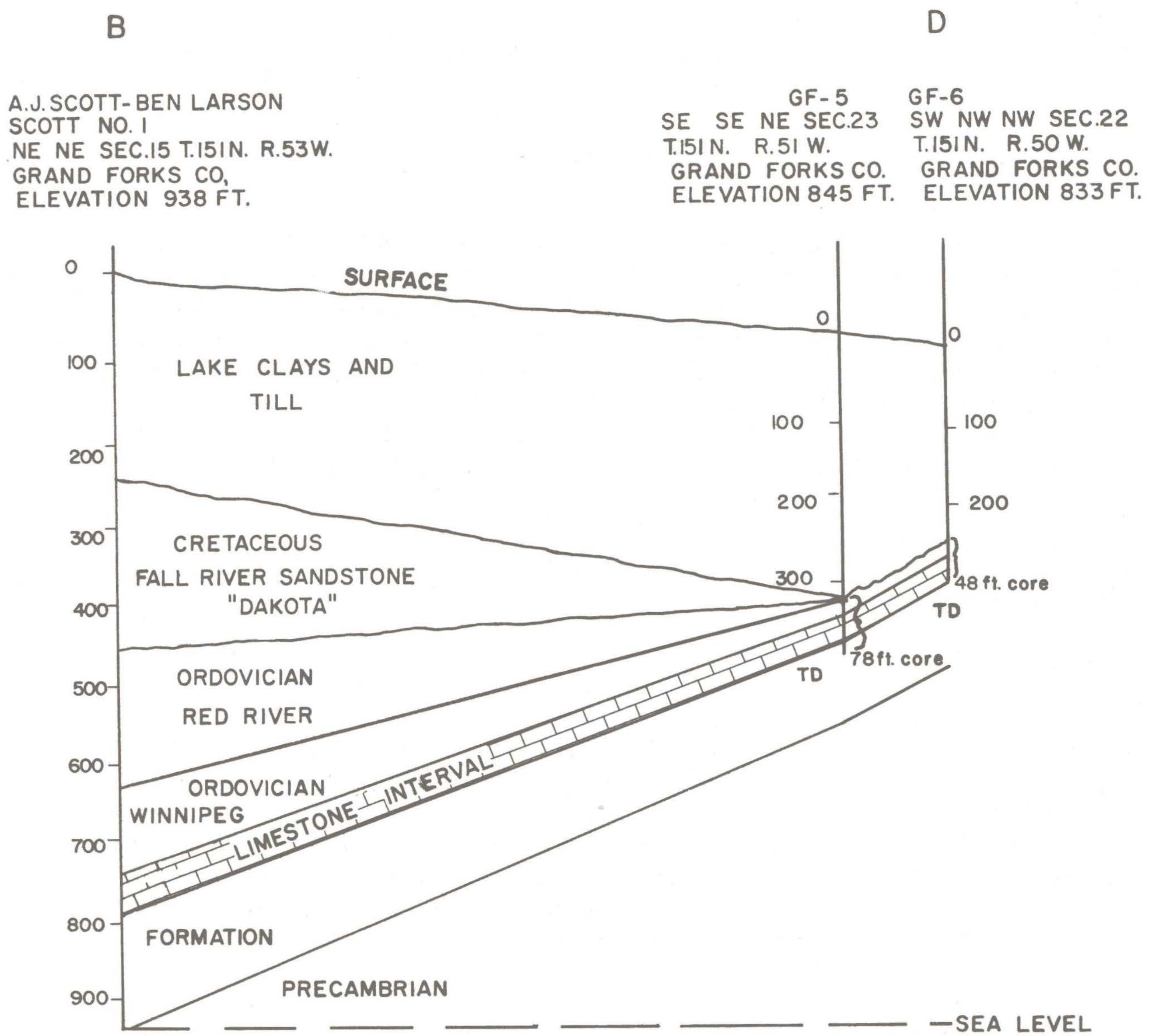
Glacial drift

In this area, the glacial drift ranges in thickness from 320 feet in GF-5 to 234 feet in GF-6. The abnormally thick section of drift in GF-5 appears to be due to infilling of a preglacial channel (Fig. 6).

Proglacial lake deposits range in thickness from 40 feet in GF-5 to 85 feet in GF-6 with the underlying till making up the remainder of the glacial drift. The lake deposits are yellowish gray to olive gray silt and clay. The till varies from olive gray and dark gray to very pale brown.

Winnipeg Formation

The Ordovician Winnipeg Formation is unconformably overlain by glacial drift in this area. The Red River Formation, which normally overlies it, has been eroded.



HORIZONTAL SCALE
1 inch = 2 1/2 miles

CROSS SECTION SHOWING WINNIPEG FORMATION
GRAND FORKS (SOUTH) AREA

MAY, 1968

FIGURE-6

The Winnipeg Formation is composed of three members in Grand Forks County, they are, in order of penetration by the drill, the Roughlock, the medial Icebox and the basal Black Island members. The Roughlock member is transitional with the overlying Red River Formation and is composed of shaly limestone and shale, becoming increasingly shaly toward the base. The Icebox member is composed of an overlying sandstone unit with some shale, a medial argillaceous limestone unit, and a basal shale unit. The sandstone ranges from 28 to 63 feet in thickness in wells where it is present; the limestone ranges from 22 to 57 feet in thickness. The basal shale unit ranges in thickness from 50 to 65 feet. Underlying this unit is the Black Island member; this unit, composed of sandstone, is the basal member of the Winnipeg.

The limestone unit of the Icebox is the interval of the Winnipeg with which this report is concerned. Drill sites GF-5 and GF-6 were selected to evaluate this interval because the usual overlying Red River Formation, as well as the Roughlock member and the sandstone unit of the Icebox, were thought to be absent. However, it was found that about 20 feet of the Icebox sandstone unit are present here in GF-5. The Icebox member is directly overlain by glacial drift (Fig. 6 and Plate 1).

The limestone section has a thickness of 40 feet in GF-5 and 37 feet in GF-6. The limestone is composed primarily of grayish purple, fine grained, dense, argillaceous limestone with some yellowish and reddish banding.

RESULTS AND RECOMMENDATIONS

Eight test holes were drilled for a total of 2640 feet in eastern North Dakota in a search for limestone suitable for Portland Cement. The primary objective was limestone in the Ordovician Red River Formation. Secondary objectives were carbonates of the Ordovician Winnipeg Formation and Stony Mountain Formation, and the Siluro-Ordovician Stonewall Formation. These zones were chosen because they occur at relatively shallow depths in eastern North Dakota and can be mined east of the edge of the water-bearing Dakota sandstone which can create severe mining problems. Cored intervals totaled 800 feet and are described in Appendix "A". In an initial x-ray study (Appendix "B") high-calcium sections of the cores were identified for more detailed study. Subsequent detailed x-ray and chemical studies of possible cement-rock zones are summarized in Appendices "B" and "C".

In the Pembina area, at test hole P-1, a high-calcium, low-magnesium zone is present at 487-505 feet depth. The secondary objectives in the Pembina area were eliminated from further consideration as cement rock, because the Stonewall Formation is nearly pure dolomite (test hole P-2), the Stony Mountain Formation is largely non-calcareous shale.

Four test holes were drilled in the Grand Forks-Manvel area, where the thickness of the Red River limestone ranged from 43 to 98 feet. Holes GF-2 and GF-4 had thicker limestone sections than GF-1 and GF-3; however, they were overlain by water-bearing Dakota sandstone. In GF-1 and GF-3, 43 and 54 feet, respectively, of Red River limestone subcrop beneath glacial deposits beyond the eastern limits of the Dakota sandstone. The most promising zone is the limestone in the Red River Formation in the Grand Forks-Manvel area (GF-3) where it occurs at a depth of 214-260 feet (GF-3) and is not overlain by Dakota sandstone. The secondary objective in the Grand Forks area was a 40- to 50-foot limestone bed, apparently a local lens in the Icebox member of the Ordovician Winnipeg Formation. This section was cored in GF-5 and GF-6, where it proved to be a dolomitic, clayey, low-calcite limestone (Appendix "B" and "C").

In the Grand Forks-Manvel prospect, the calcium carbonate content over a 40-foot cored interval (220-260 feet) averaged 85.6 percent in GF-3 (Appendix "C"). This is considerably higher than the 70 to 75 percent calcium carbonate required for Portland Cement. An additional upper six feet (214-220 feet) of this bed were drilled, rather than cored, to facilitate setting of surface casing; it is thought that the calcium carbonate content of this section is probably comparable to that of the cored interval. The average magnesium carbonate content of 7.50 percent over the same 40-foot interval was higher than desirable for manufacture of Portland Cement. Therefore, it would be necessary to blend the Red River limestone in the Grand Forks-Manvel deposit with other material to reduce the magnesium carbonate content to the maximum allowable 4 to 5 percent. The Cretaceous Niobrara Formation, a shaly limestone, may be suitable blending material. The Niobrara Formation is found in the Shawnee-McCanna prospect (Plate 4) at the surface in western Grand Forks County. A report covering this prospect was published by the North Dakota Geological Survey in 1964 as Report of Investigations Number 41, "The Niobrara Formation of Eastern North Dakota; Its Possibilities for Use as a Cement Rock" (Carlson, 1964). This report indicates that the Niobrara Formation is not suitable for use as a raw material for Portland Cement, but may be upgraded by blending with a limestone that contains a higher percentage of calcium carbonate. Appendix "C" contains chemical data from this report. A possible blend suggested by A. M. Cooley of the Chemical Engineering Department, University of North Dakota, is 2.3 parts of Niobrara, shaly limestone (comparable to that in S-2 test hole, Carlson, 1964) to 1 part of Red River limestone (comparable to that of GF-3 test hole) plus small additions of $CaSO_4$. Using an average producing interval of 40 feet for a section surrounding the GF-3 test hole, the reserves in place would be 3,500 tons per acre foot, 140,000 tons per acre, and 89,600,000 tons per 640 acres. The Niobara Formation at the Shawnee-McCanna prospect has a 10- to 12-foot high-lime zone in which 55 million tons have been outlined by drilling from the surface to depths of less than 50 feet. Chemical analyses from six test wells in the high-lime zone averaged 61.0 percent calcium carbonate and 1.4 percent magnesium carbonate. The S-2 test hole, which was used for calculating a possible raw mix, had 12 feet of high-lime zone from 34 to 46 feet which averaged 64.0 percent calcium carbonate and 1.1 percent magnesium carbonate. The Grand Forks-Manvel deposit is 28 air miles northeast of the Shawnee-McCanna deposit (Plate 4).

The city of Grand Forks has a population of 30,000, with an additional 15,000 in the East Grand Forks, Minnesota, area and 18,000 at

Grand Forks Air Force Base, 15 miles to the west, giving a total population in excess of 70,000. The combination of good water supply from the Red River of the North, good sources of natural gas and electricity, good industrial sites, and transportation facilities can make Grand Forks a favorable location for a cement plant. The Grand Forks-Manvel deposit is 15 miles north of Grand Forks, and the Shawnee-McCanna deposit is 30 miles west of Grand Forks. The Grand Forks-Manvel deposit is served by railraod, by U. S. Highway 81, and by North Dakota Highway 44, The Shawnee-McCanna deposit is served by railroad and by U. S. Highway 2.

In the original application to the Economic Development Administration for support of the drilling program, it was estimated that the area could support a cement plant with an annual capacity of 1 million barrels. At present there is no plant in North Dakota or the adjacent area of western Minnesota, apparently because there has been no known suitable raw material. The present report, pointing out the availability of suitable raw material, excellent transportation facilities, and sizeable market, suggests that the outlook for a cement industry in eastern North Dakota is favorable.

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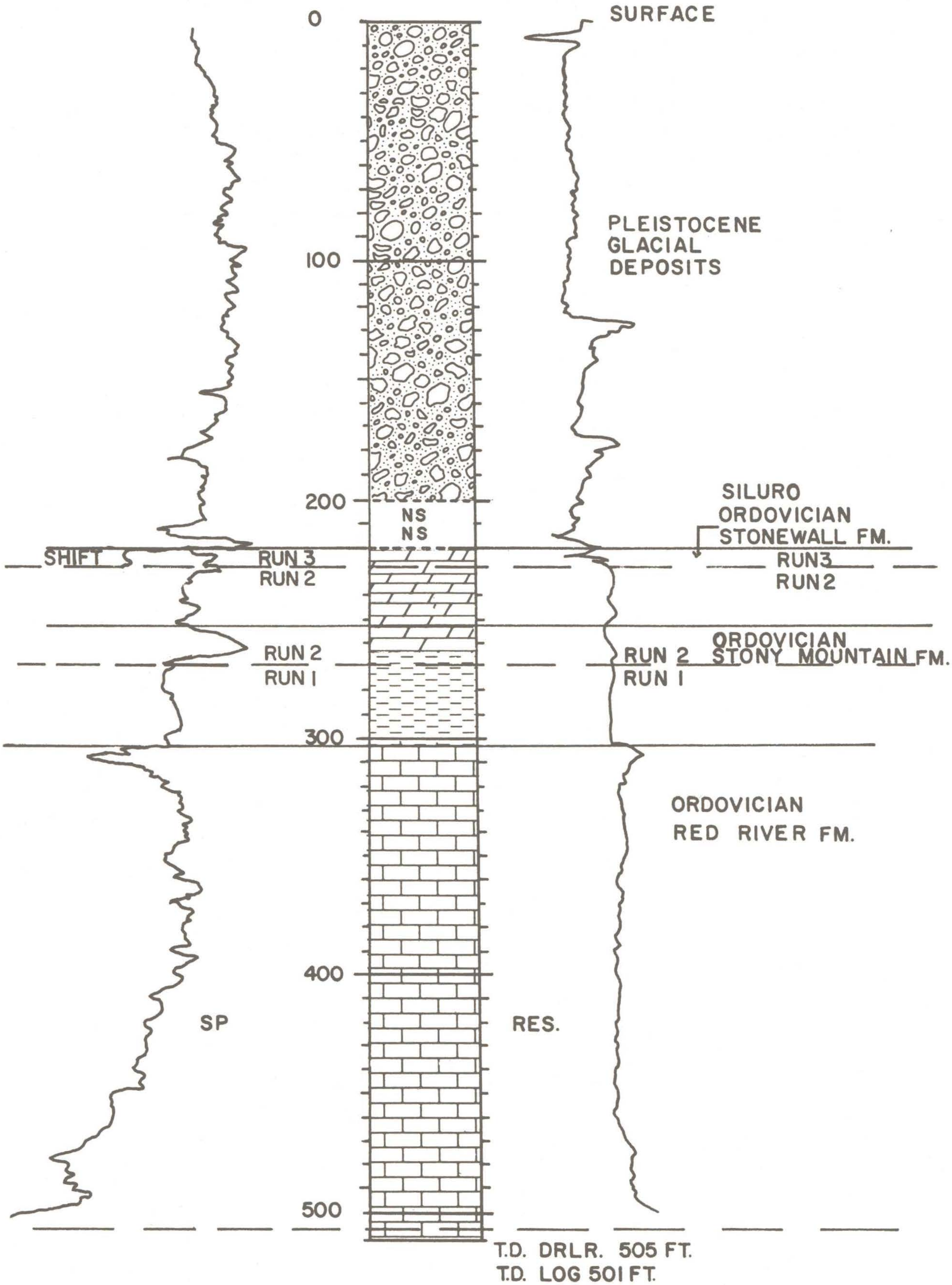
APPENDIX "A"

LITHOLOGIC DESCRIPTIONS

Test Hole P-1; Location - SE NW SE sec. 28, T. 164 N., R. 51 W., Pembina County, North Dakota. Elevation - 782. Total Depth - 505 feet driller, depth logger--501 feet.



NORTH DAKOTA GEOLOGICAL SURVEY TEST HOLE P-1

Location:	SE NW SE sec. 28, T. 164 N., R. 51 W. Pembina County, North Dakota
Elevation:	Ground 782 feet
Total Depth:	505 feet driller, depth logger--501 feet
Spud:	October 14, 1967
Completed:	November 2, 1967
Logged:	North Dakota Geological Survey Widco Electric Logger
Footage Cored:	305 feet

GLACIAL DRIFT

0 - 50	Silt, yellowish gray, iron stained, oxidized, shell fragment
50 - 55	Silt, as above, more clayey
55 - 125	Clay, dark olive gray, hard, dense
125 - 135	Till, dark olive gray, massive, hard
135 - 195	Till, as above, some yellowish silt
195 - 200	Sand, reddish, coarse grained, arkosic, appears to be granite wash
200 - 222	Coring, no recovery
222	SILURIAN-ORDOVICIAN STONEWALL FORMATION (Coring)
222 - 252	Dolomite, buff, fine grained, dense, hard, some small vugular porosity
252	ORDOVICIAN STONY MOUNTAIN FORMATION
252 - 254 1/2	Dolomite, very light greenish gray, argillaceous, dense, very fine grained, little interbedded chert at 254 feet

254 1/2 - 262	Dolomite, buff, fine grained, dense, hard, little interbedded chert
262 - 264	Drilled 262 - 264 feet Commenced coring at 264 feet again
264 - 269	Shale, purplish red to yellow ochre to medium light gray
269 - 270	Shale, dark reddish brown
270 - 272	Shale, light greenish gray to purplish red, varigated shale
272 - 307	Shale, dark reddish brown, some fractures with calcite filling, occasional light greenish gray shale inclusions
307 - 308	Limestone, medium light gray, breccia, dark reddish brown shale at 307 3/4 feet
308	ORDOVICIAN RED RIVER FORMATION
308 - 387	Limestone, light yellow brown with darker yellow brown mottles, fine grained with small calcite crystals and calcite replacement of crinoid fragments, some scattered vugular porosity, good vugular porosity and very fossiliferous, 359 - 387 feet
387 - 406	Limestone, light yellow brown to light purplish, fine grained, dense, appears somewhat earthy and argillaceous, fossiliferous
406 - 436	Limestone, light purplish to cream, fine grained, dense, appears earthy, somewhat argillaceous, some small intervals of yellow brown mottled limestone, fossiliferous
436 - 480	Limestone, yellow brown, mottled, fine grained, dense, appears argillaceous, occasional tripolitic chert inclusions, fossiliferous, earthy

480 - 505	Limestone, medium light gray with light purplish cast and medium dark gray banding and mottling, rich in fossil fragments
505	Total Depth

Dolomite	222 - 252 = 30 feet
Limestone	308 - 505 = 197 feet

NORTH DAKOTA GEOLOGICAL SURVEY TEST HOLE P-2

Location:	SE NW SE sec. 28, T. 164 N., R. 51 W. (150 feet northeast of P-1), Pembina County, North Dakota
Elevation:	Ground 785 feet
Total Depth:	266 feet driller, feet logged--none
Spud:	October 25, 1967
Completed:	November 1, 1967
Footage Cored:	36 feet

GLACIAL DRIFT

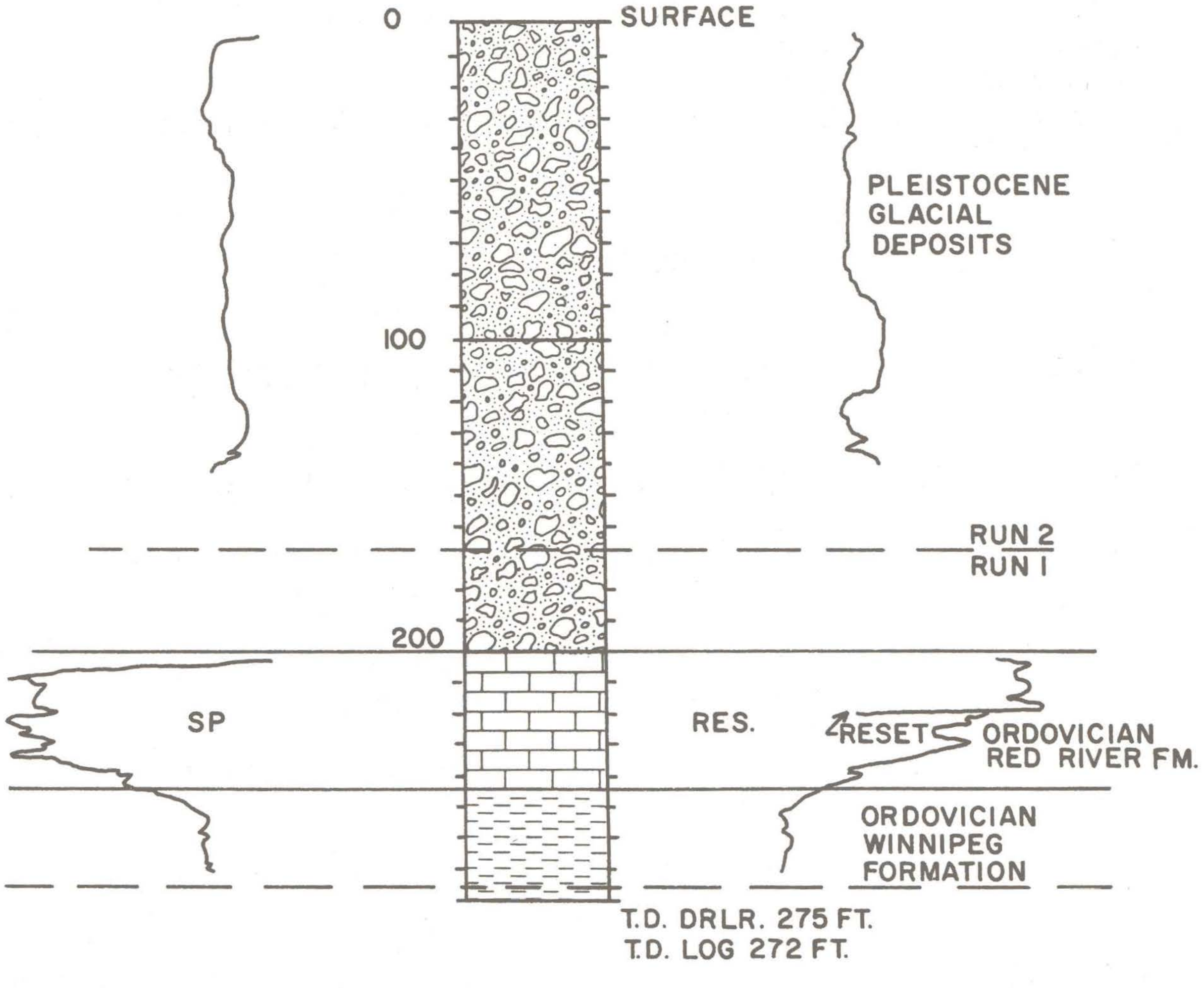
0 - 50	Silt, yellowish gray, iron stained, oxidized, shell fragment
50 - 55	Silt, as above, more clayey
55 - 125	Clay, dark olive gray, hard dense
125 - 135	Till, dark olive gray, massive, hard
135 - 195	Till, as above, some yellowish silt
195 - 200	Sand, reddish, coarse grained, arkosic, appears to be granite wash
200 - 225	No samples
225	SILURIAN-ORDOVICIAN STONEWALL FORMATION (Drilling)
225 - 233 1/2	No samples
233 1/2	Commenced coring
233 1/2 - 252	Dolomite, buff, fine grained, dense, hard, some small vugular porosity, fossiliferous
252	ORDOVICIAN STONY MOUNTAIN FORMATION

252 - 253	Sandstone, very fine grained, argillaceous, greenish-gray
253 - 256	Dolomite, buff, fine grained, some breccia, and chert
256 - 258 1/2	Dolomite, greenish-gray, argillaceous, grading to buff, fine grained, dense dolomite
258 1/2 - 266	Dolomite, buff, fine grained, dense with thin chert interbeds
266	Total Depth

Dolomite 225 - 252 = 28 feet

Limestone None

Test Hole GF-1; Location - NW NE NW sec. 19, T. 153 N., R. 50 W., Grand Forks County, North Dakota. Elevation - 822. Total Depth - 275 feet driller, depth logger--272.



NORTH DAKOTA GEOLOGICAL SURVEY TEST HOLE GF-1

Location:	NW NE NW sec. 19, T. 153 N., R. 50 W. Grand Forks County, North Dakota
Elevation:	Ground 822 feet
Total Depth:	275 driller, depth logger--272 feet
Spud:	November 6, 1967
Completed:	November 8, 1967
Logged:	North Dakota Geological Survey Widco Electric Logger
Footage Cored:	70 feet

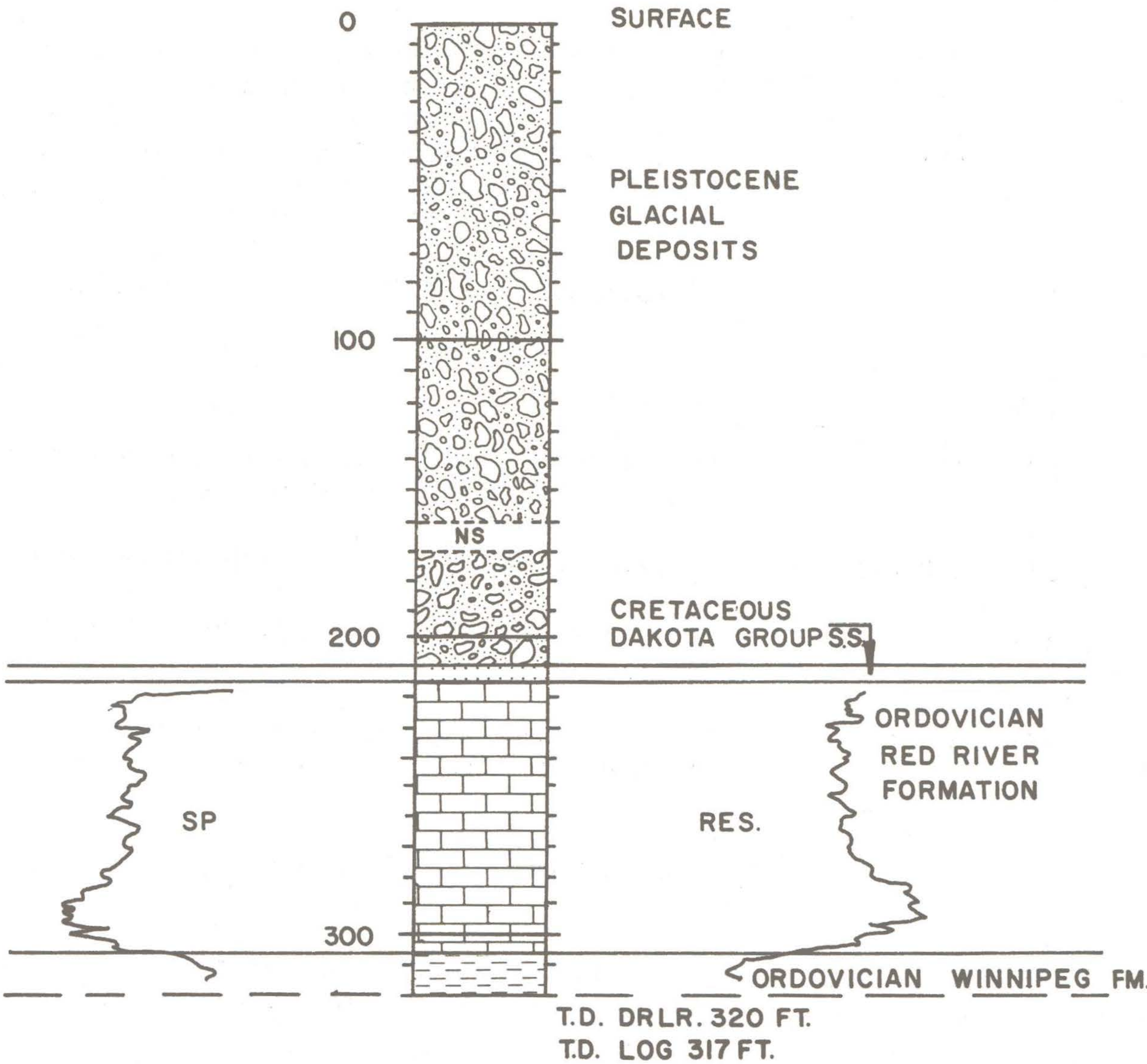
GLACIAL DRIFT

0 - 25	Silt, yellowish gray, iron stained, small fine sand, oxidized
25 - 45	Silt, as above, increase in sand, oxidized
45 - 55	Sand, light olive gray, silty, iron stained, unoxidized, much dark sand pebbles
55 - 75	Till, olive gray, very clayey, very hard, dense, iron stained, some bedding
75 - 80	Till, olive gray, primarily clay, few scattered sand grains and pebbles
80 - 100	Till, as above, yellowish gray, iron stained, oxidized, some bedding
100 - 110	Till, as above, olive gray, iron stained, unoxidized, some bedding
110 - 125	Silty clay, olive gray, bedded
125 - 135	Till, dark olive gray, clay, hard
135 - 145	Till, as above, yellowish gray, thin bedding, alternating dark olive gray and yellowish gray beds
145 - 150	Silt, light olive gray, sandy, sand grains angular to rounded
150 - 155	Sand, light olive gray, silty

155 - 170	Till, dark olive gray, very clayey, hard
170 - 185	Till, dark olive gray, sandy silt, increase in carbonate pebbles with depth, increase in sand grain size with depth
185 - 190	Sand, dark olive gray, silty, grain size fine to coarse, high percentage carbonate
190 - 200	Sand, light olive gray, fine, subangular to subround. No Dakota Sandstone.
200	ORDOVICIAN RED RIVER FORMATION (Drilling)
206	Commenced coring
206 - 214	Limestone, cream with some very pale reddish mottling, fine grained, slightly fragmental
214 - 222 1/2	Limestone, as above, but with darker red mottling
222 1/2 - 228 1/2	Limestone, as above, but dark red mottling increases
228 1/2 - 243	Limestone, purplish with occasional green inclusions, argillaceous
243	ORDOVICIAN WINNIPEG FORMATION
243 - 275	Limestone, purplish to greenish gray, very mottled, very shaly, becomes more shaly with depth, fossiliferous
275	Total Depth

Limestone 200 - 241 = 41 feet

Test Hole GF-2; Location - NW SW SW sec. 27, T. 153 N., R. 51 W., Grand Forks County, North Dakota. Elevation - 825. Total Depth - 320 feet driller, depth logger--317 feet.



NORTH DAKOTA GEOLOGICAL SURVEY TEST HOLE GF-2

Location:	NW SW SW sec. 27, T. 153 N., R. 51 W. Grand Forks County, North Dakota
Elevation:	Ground 825 feet
Total Depth:	320 feet driller, Depth logger--317 feet
Spud:	November 9, 1967
Completed:	November 15, 1967
Logged:	North Dakota Geological Survey Widco Electric Logger
Footage Cor ed:	100 feet

GLACIAL DRIFT

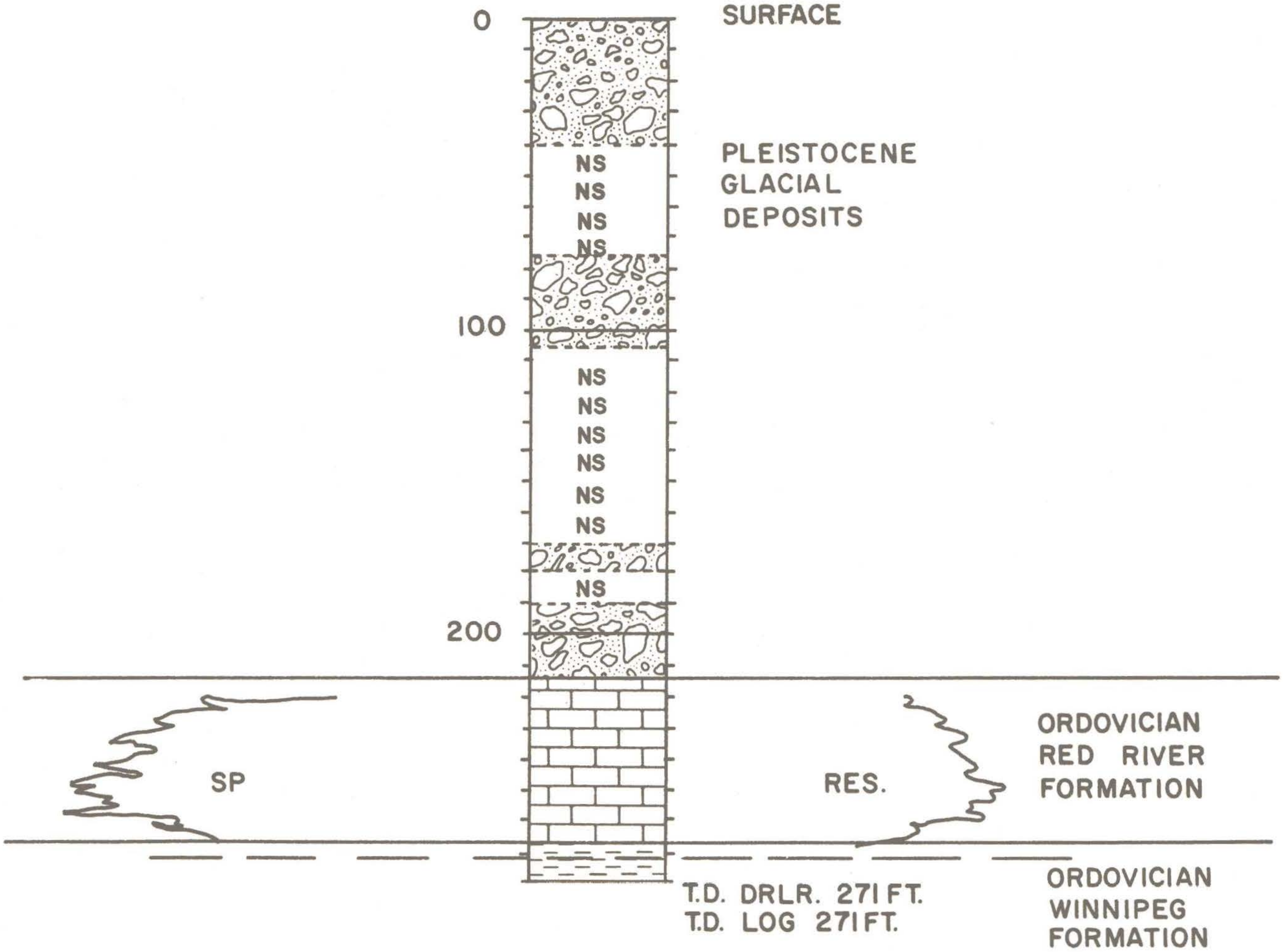
0 - 5	Clay, grayish black to black, silty, sandy, organic material
5 - 10	Clay, dark gray, sandy, some gravel, shell fragment
10 - 15	Clay and silt, yellowish gray, pebbly, oxidized
15 - 20	Silty sand, yellowish gray, subangular to subround
20 - 90	Sandy silt, yellowish gray, subangular to subround
90 - 95	Silt, yellowish gray, mostly quartz
95 - 125	Silty, light olive gray
125 - 135	Sand, light olive gray, mostly quartz, fine, good sorting
135 - 145	Sand, light olive gray, fine to medium grained, mostly quartz, subangular, good sorting
145 - 150	Sand, light olive gray, fine to medium grained, iron stained
150 - 160	Clay, dark olive gray, hard, uniform
160 - 170	No samples
170 - 190	Clay, dark olive gray, hard, uniform

190 - 210	Till, dark olive gray, sand grains and pebbles
210	CRETACEOUS DAKOTA GROUP (Sandstone)
210 - 216	Sand, light olive gray, mostly quartz, subrounded to subangular, fine grained, nonglacial sand
216	ORDOVICIAN RED RIVER FORMATION (Drilling)
220	Commenced coring
220 - 231 1/2	Limestone, cream, with pale red to tan mottling, fine grained, dense, fossiliferous
231 1/2 - 237	Limestone, as above, mottling becomes darker red and more prominent, fossiliferous
237 - 261	Limestone, cream, very pale red to tan mottling, mottling is less prominent, fine grained, dense, fossiliferous
261 - 285	Limestone, cream, with pale reddish, to slightly purplish mottling, mottling is more prominent, fine grained, dense, fossiliferous
285 - 303 1/2	Limestone, cream, much purple mottling, mottling increases with depth, some small green shale inclusions between 295 - 300, fine grained, dense, fossiliferous
303 1/2 - 312	Limestone, cream with much purple mottling, argillaceous, fine grained, dense
306	ORDOVICIAN WINNIPEG FORMATION
312 - 320	Limestone, cream with much purple mottling, occasional green shale inclusions, argillaceous, becoming very shaly, becoming more shaly with depth, fine grained, fossiliferous

320	Total Depth

Limestone 216 - 303 1/2 = 87 1/2 feet

Test Hole GF-3; Location - NE NW NE sec. 35, T. 154 N., R. 51 W., Grand Forks County, North Dakota. Elevation - 820. Total Depth - 271 feet driller, depth logger--271 feet.



NORTH DAKOTA GEOLOGICAL SURVEY TEST HOLE GF-3

Location:	NE NW NE sec. 35, T. 154 N., R. 51 W. Grand Forks County, North Dakota
Elevation:	Ground 820 feet
Total Depth:	271 feet driller, depth logger--271 feet
Spud:	November 10, 1967
Completed:	November 13, 1967
Logged:	North Dakota Geological Survey Widco Electric Logger
Footage Cored:	51 feet

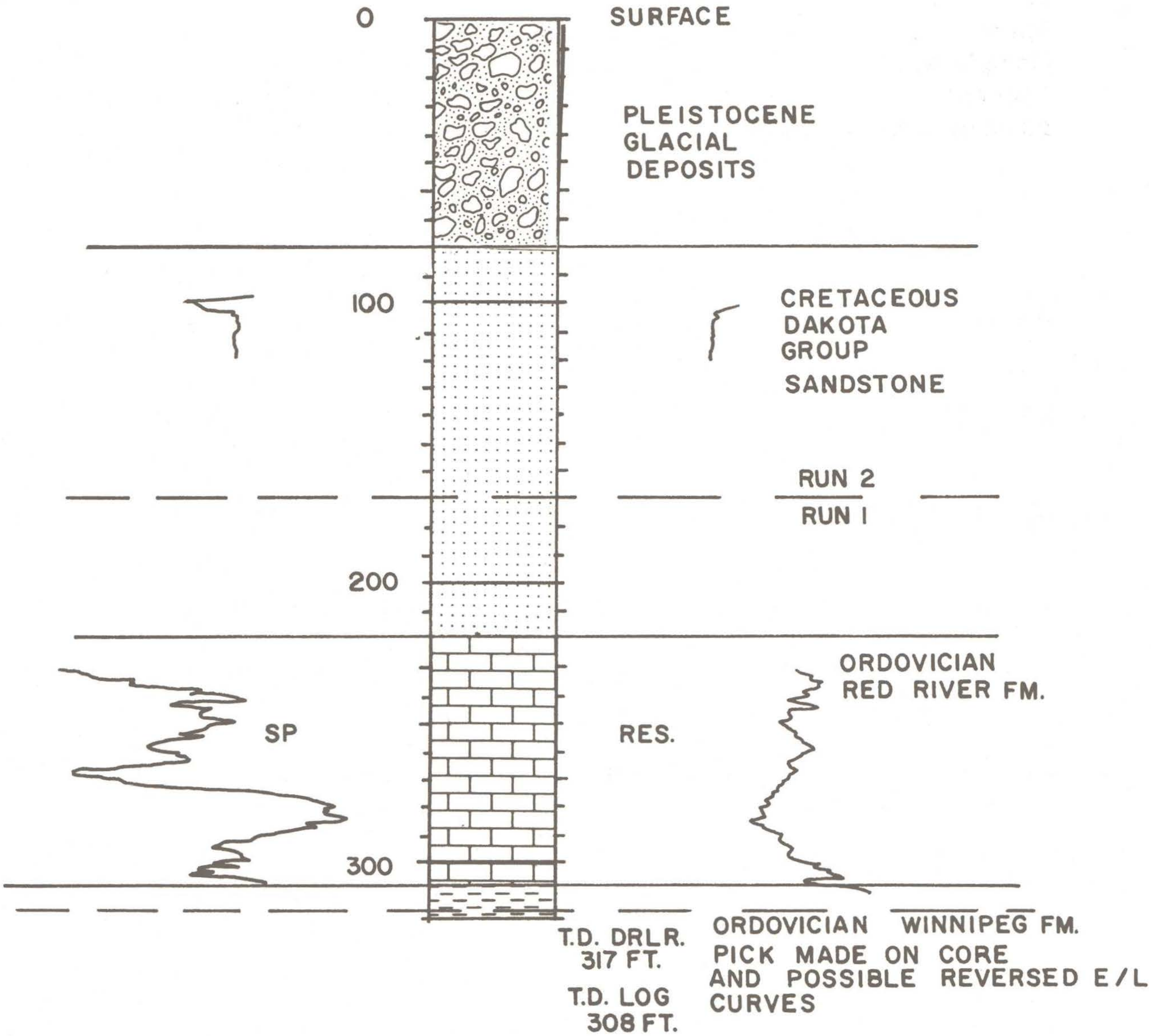
GLACIAL DRIFT

0 - 5	Clay, sandy loam, dark gray to black, organic material
5 - 25	Silt, yellowish gray, some sand grains, angular to subangular, iron stained, oxidized
25 - 30	Silt, as above, increase in sand
30 - 40	Silty clay, light olive gray, some sand, some iron stained, unoxidized
40 - 75	No samples
75 - 105	Clay, dark olive gray, dense, uniform, clean
105 - 170	No samples
170 - 180	Silty sand, light olive gray, subangular to subrounded
180 - 190	No samples
190 - 205	Silty sand, light olive gray, coarse, much limestone, angular to subangular
205 - 214	Sand, light olive gray, medium to coarse, mostly carbonate grains, angular to well rounded. No Dakota Sandstone
214	ORDOVICIAN RED RIVER FORMATION (Drilling)

220	Commenced coring
220 - 230 1/2	Limestone, cream with some very pale reddish mottling, fine grained, slightly fragmental, fossiliferous
230 1/2 - 255	Limestone, as above, but mottling increases and becomes somewhat darker reddish
255 - 260	Limestone, as above, with much purplish mottling, fossiliferous
260 - 270 1/2	Limestone, cream colored with green shale partings, becoming very shaly, fossiliferous
268	ORDOVICIAN WINNIPEG FORMATION (electric log pick)
270 1/2 - 271	Sandstone, gray, fine to medium coarse, subround, some frosted (Winnipeg sample top)
271	Total Depth

Limestone	214 - 260 = 46 feet
Shaly Limestone	260 - 270 1/2 = 10 1/2 feet
Total Limestone	214 - 270 1/2 = 56 1/2 feet

Test Hole GF-4; Location - SW SE SW sec. 19, T. 153 N., R. 51 W., Grand Forks County, North Dakota. Elevation - 825. Total Depth - 317 feet driller, depth logger--308 feet.



NORTH DAKOTA GEOLOGICAL SURVEY TEST HOLE GF-4

Location:	SW SE SW sec. 19, T. 153 N., R. 51 W. Grand Forks County, North Dakota
Elevation:	Ground 825 feet
Total Depth:	317 feet driller, depth logger--308 feet
Spud:	November 15, 1967
Completed:	November 18, 1967
Logged:	North Dakota Geological Survey Widco Electric Logger
Footage Cored:	112 feet

GLACIAL DRIFT

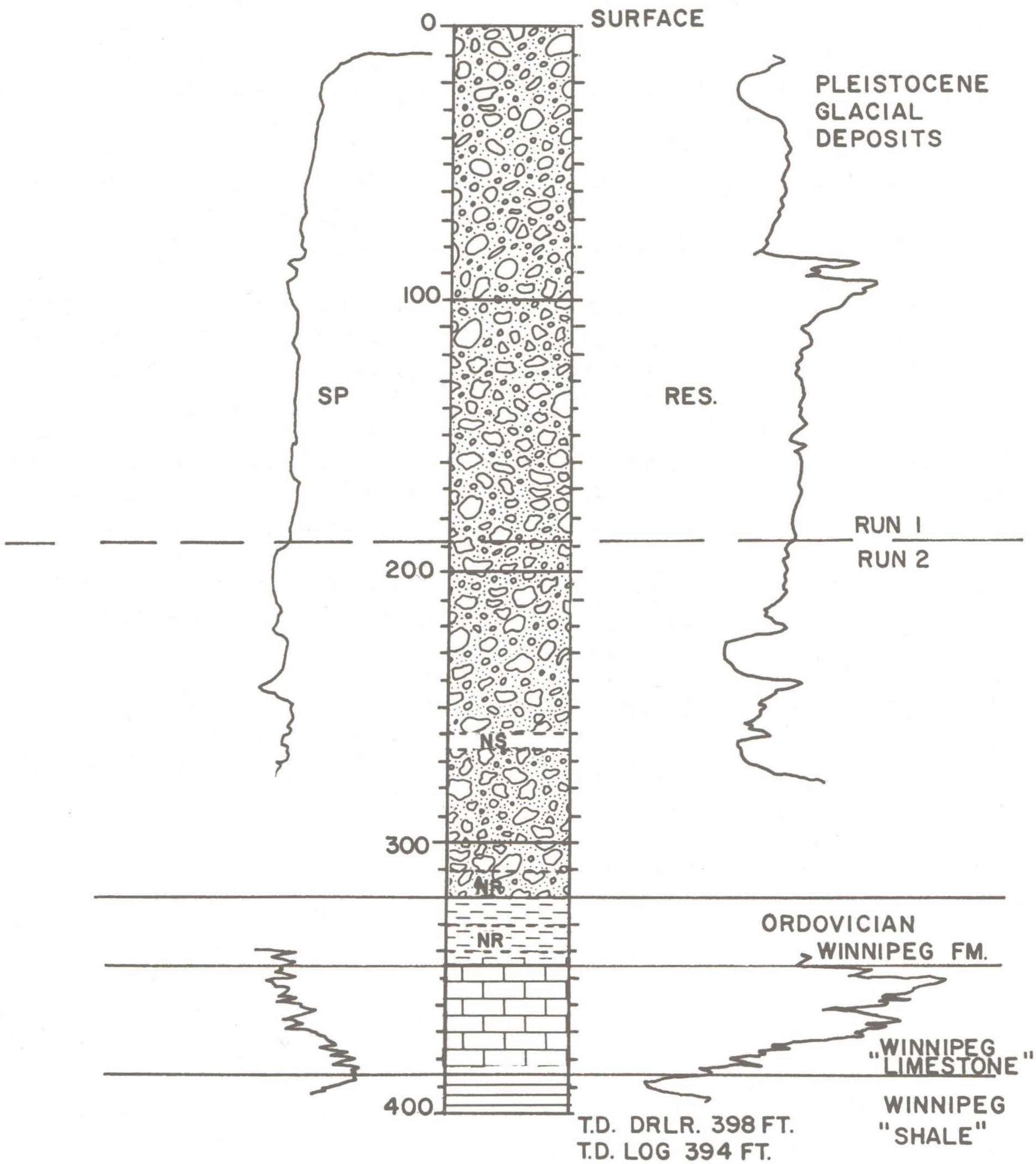
0 - 20	Silt, yellowish gray, sandy, iron stained, some organic material, oxidized, some gypsum crystals
20 - 45	Clay, dark olive gray, hard, clean, uniform, unoxidized, white calcareous specks
45 - 50	Clay, light olive gray, silty, medium soft, some sand grains
50 - 55	Clay, light olive gray, clean, uniform, soft
55 - 70	Till, dark olive gray, slightly sandy, medium hard, iron stained
70 - 80	Clay, light olive gray, hard, massive, dense, microthin beds

80	CRETACEOUS DAKOTA GROUP (Sandstone)
80 - 110	Sand, light olive gray, fine grained, mostly quartz, some limestone, some igneous, subangular to subround
110 - 135	Sand, light olive gray, very fine grained, mostly quartz, some limestone, some igneous, subangular to subround, some well rounded grains
135 - 180	Sand, light olive gray, very fine grained, mostly quartz with fraction black grains, fraction carbonate grains, subangular to subround

180 - 205	Sand, light olive gray, fine grained, quartz, subangular to subround
205 - 220 1/2	Coring, no recovery
220 1/2	ORDOVICIAN RED RIVER FORMATION (Coring)
220 1/2 - 225	Limestone, purplish-yellow brown, crystalline, dense, fine grained, in part fragmental, fossiliferous
225 - 257	Limestone, very pale yellow-brown to cream, fine grained, fragmental, fossiliferous, some purplish-yellow brown mottling, rare chert inclusions, purplish mottling 255- 257
257 - 275	Limestone, cream to buff, fragmental, with calcite crystals, fine grained, tan to purplish mottling, rare inclusions of chert, fossiliferous
275 - 300	Limestone, cream, earthy appearance, less fragmental than above, fine grained, dense, tan mottling, fossiliferous
300 - 317	Limestone, cream with much pink to purple mottling, fragmental, fine grained, dense, fossiliferous, bottomed near contact of Ordovician Winnipeg Formation
317	Total Depth

Limestone 220 1/2 - 317 = 96 1/2 feet

Test Hole GF-5; Location - SE SE NE sec. 23, T. 151 N., R. 51 W., Grand Forks County, North Dakota. Elevation - 845. Total Depth - 398 feet driller, depth logger--394 feet.



NORTH DAKOTA GEOLOGICAL SURVEY TEST HOLE GF-5

Location:	SE SE NE sec. 23, T. 151 N., R. 51 W. Grand Forks County, North Dakota
Elevation:	Ground 845 feet
Total Depth:	398 feet driller, depth logger--394 feet
Spud:	November 16, 1967
Completed:	November 25, 1967
Logged:	North Dakota Geological Survey Widco Electric Logger
Footage Cored:	78 feet

GLACIAL DRIFT

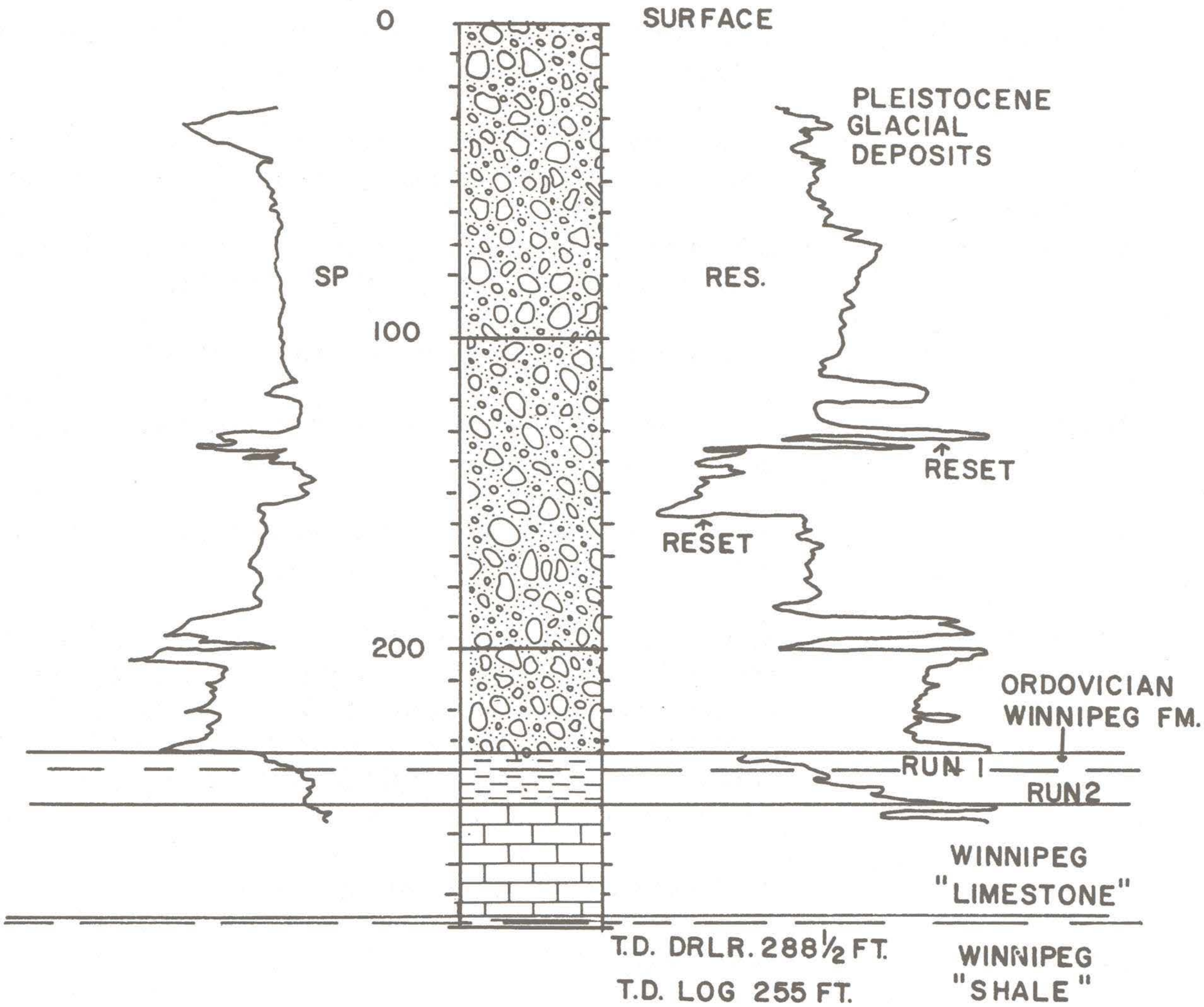
0 - 10	Silt, yellowish gray, some sand, iron stained
10 - 30	Silt, as above, less sand, mottled appearance, some bedding, oxidized
30 - 35	Silt, as above, sandy, oxidized
35 - 40	Silt, olive gray, unoxidized
40 - 55	Till, olive gray, very clayey, some bedding, some pebbles, may possibly be lake sediments because of bedding
55 - 60	Till or lake beds, as above, some material oxidized, some carbonaceous material
60 - 65	Till, olive gray, silty clay, pebbles, some iron staining
65 - 75	Till, as above, light olive gray
75 - 85	Clay, olive gray, few sand grains, hard, dense clay, as above, becoming sandy
85 - 90	Sands, silts, clays interbedded, olive gray, some iron staining
90 - 95	Till, olive gray, clayey sandy silt, some iron staining

95 - 125	Till, as above, light olive gray
125 - 155	Till, light olive gray, silty clayey sand, quartz, limestone
155 - 170	Till, light olive gray, sandy silt
170 - 175	Till, light olive gray, clayey silt, slightly sandy, iron stained
175 - 210	Till, light olive gray, sandy silt, iron stained
210 - 215	Silty sand, light olive gray
215 - 225	Sand, light olive gray, mainly quartz, some carbonate, subangular to round, very fine to fine grained
225 - 255	Sand, as above, medium grained
255 - 260	Sand, as above, silty, iron stained
260 - 265	No samples
265 - 270	Silt, light olive gray, sandy, iron stained
270 - 280	Sand, light olive gray, subangular, mostly carbonates and igneous, iron stained
280 - 300	Silt, light olive gray, sandy, iron stained
300 - 310	Sand, light olive gray, silty, iron stained. No Dakota Group Sandstone
310 - 320	Coring, no recovery
320	ORDOVICIAN WINNIPEG FORMATION (Sandstone, Coring)
320 - 330	Sandstone (Recovery 2 feet), gray, medium fine to fine grained, rounded quartz, trace of glauconite, partly silty, calcareous cement
330 - 340	No recovery (Sandstone section)

340 - 341	Shale, green, non-calcareous, contains very small pyrite crystals visible under scope
341 - 341 1/2	Shale, reddish, non-calcareous, very small darker red mottles visible under scope
341 1/2 - 344	Shale, reddish-purple, with greenish mottling, calcareous, shell fragments
344 - 345 1/2	Shale, yellowish-ochre, with slight reddish banding, calcareous, becoming more reddish near base
345 1/2 - 352	Limestone, alternating yellowish and reddish banding, very argillaceous, shell fragments
352 - 379 1/2	Limestone, grayish-purple, fine, dense
379 1/2 - 385 1/2	Limestone, alternating gray to grayish purple, very argillaceous, blocky
385 1/2 - 388	Shale, reddish gray alternating to gray, calcareous, blocky, some conodont fragments
388 - 395 1/2	Shale, reddish to medium light gray to medium gray (388 - 388 1/2, small light gray, mottles appear to be burrows). Small light colored mottling in short sections, non-calcareous except occasional mottles, conodont fragments, slightly silty, shale appears carbonaceous from 390 - 392
395 1/2 - 398	Limestone, light gray, shaly, silty
398	Total Depth

Limestone 345 1/2 - 385 1/2 = 40 feet

Test Hole GF-6; Location - SW NW NW sec. 22, T. 151 N., R. 50 W., Grand Forks County, North Dakota. Elevation - 833. Total Depth - 288 1/2 feet driller, depth logger--255 feet.



NORTH DAKOTA GEOLOGICAL SURVEY TEST HOLE GF-6

Location:	SW NW NW sec. 22, T. 151 N., R. 50 W. Grand Forks County, North Dakota
Elevation:	Ground 833 feet
Total Depth:	288 1/2 feet driller, depth logger--255 feet
Spud:	November 21, 1967
Completed:	December 2, 1967
Logged:	North Dakota Geological Survey Widco Electric Logger
Footage Cored:	48 feet

GLACIAL DRIFT

0 - 15	Clay and silts, yellowish gray to light olive gray, oxidized
15 - 85	Clay and silt, olive gray to dark olive gray, unoxidized
85 - 105	Till, olive gray, sandy, silty clay, small shale pebbles, small iron staining
105 - 110	Same as above, becoming more sandy
110 - 115	Silt to sand, very pale brown, very fine, occasional organic fragments
115 - 120	Sand, very pale brown, fine to medium subangular, quartz, clear
120 - 130	Till, very pale brown, sandy, shale pebbles
130 - 135	Sand, very pale brown, fine to silty, iron stained
135 - 145	Till, dark gray, very clayey, dense, hard, very few small pebbles
145 - 151	Sand, pale yellow, fine subangular to subround mostly quartz, few shale or clay fragments
151 - 188	Till, dark gray, very clayey, dense, hard, very few small pebbles

188 - 205	Sand, light gray, fine to medium, subangular, quartz carbonates, basic and acid igneous, percentage quartz increases with depth, becomes finer with depth
205 - 210	Till, dark gray, very clayey, dense, hard, very few small pebbles
210 - 234	Sand, light gray, fine to medium, subangular to subround, mostly quartz, shell fragments at 230 - 235. No Dakota Group Sandstone
234	ORDOVICIAN WINNIPEG FORMATION (Shale, Drilling)
234 - 239 1/2	Shale, reddish, calcareous, drilling
239 1/2	Commenced coring
239 1/2 - 249 1/2	Shale, yellowish ochre with reddish purple mottling, calcareous, reddish purple mottling somewhat more calcareous, some greenish gray shale inclusions at 240 1/2. Yellowish shale has darker yellow banding, indicates bedding
249 1/2 - 250	Shale, gray, calcareous
250 - 267	Limestone, purplish-gray, some bands more purplish, argillaceous, fossiliferous, very fine grained, dense
267 - 285	Limestone, grayish-purple, somewhat more gray than above, small mottles may be borings, argillaceous, fossiliferous, concoidal fractures, very fine grained, dense
285 - 287	Limestone, as above, somewhat more platy, more argillaceous
287 - 288 1/2	Shale, grayish-red, blocky and platy, calcareous, conodont fragments
288 1/2	Total Depth

Limestone 250 - 287 = 37 feet

APPENDIX "B"

X-RAY ANALYSES OF CEMENT-ROCK CORES

by

F. R. Karner

METHOD

Mineralogy was determined by x-ray diffraction. Two studies, an initial survey and a more detailed analysis, were made. Volume percentages of minerals present in the samples were determined using relationships developed by Alexander and Klug (1948) and modified by Leroux et. al. (1953) to:

$$X_1 = \frac{I_1}{(I_1)o} \quad \frac{\mu s^*}{\mu 1^*}$$

where

X_1 = weight fraction of component 1 (or volume fraction)

μ 1* = mass absorption coefficient of component 1

μ s* = mass absorption coefficient of powder sample

I_1 = intensity diffracted at a definite Bragg angle 2θ by a crystalline component 1

$(I_1)o$ = intensity diffracted at a definite Bragg angle 2θ by pure crystalline component 1

This formula shows that the weight percent of component 1 is equal to the ratio of the intensities of the diffraction peaks for component 1 in the sample and pure component 1 after correction for absorption by multiplying by a factor, i.e., the ratio of absorption coefficients for the sample and pure component 1. Leroux, et. al. (1953) further established the following relationship in order to experimentally determine the absorption correction:

$$\frac{\mu s^*}{\mu 1^*} = \frac{\rho 1 \log {}^{T_s/T_o}}{\rho_s \log {}^{T_s/T_o}}$$

where

ρ 1 = apparent density of a pure sample of component 1

ρ s = apparent density of a sample containing weight fraction X_1 of component 1

T_o = intensity of incident x-ray beam

T_1 = intensity transmitted by pure sample of component 1

T_s = intensity transmitted by sample containing weight fraction X_1 of component 1

The following machine conditions were used for the x-ray analyses:

X-ray Generator (Philips constant potential 50KV-50ma No. 12215)
X-ray Tube (Machlett Cu tube-short anode 32112) 46KV, 19 ma.
Diffractometer (Philips high angle 42272/1)
 1^o 2θ/minute scan speed (2^o 2θ/minute for initial survey),
 1^o divergence and anti-scatter slits,
 .006" receiving slit,
 Ni filter,
 back-loaded rotating sample holder.
Detector (Philips scintillation-transistorized 52572) 1.0 KV.
Circuit Panel (Philips 12206/53), Bristol recorder
 PHA, width 9V, level 7V,
 linear scale,
 1 sec time constant,
 2×10^3 counts/sec (or greater) full scale (5×10^3 counts/sec for initial survey),
 30"/hr chart speed.

INITIAL STUDY

Representative chips for 231 samples from carbonate-rich sections of the cores were crushed to a coarse powder (approximately 75 microns particle diameter and finer). X-ray diffractometer charts of the samples were overlaid on a calibrated chart and mineral amounts read from peak heights. Pure mineral values used are given in Table 1. These are generally derived from empirical standards described below and have been corrected for an estimated sample mass absorption coefficient of 61. Mineral amounts were read to the nearest part per ten except for amounts less than one part per ten which are given as C (about 5 percent) or T (peak present but amount is less than about 2 1/2 percent). Results given in Table 2 show samples which have relatively high calcite values and were used to select sections of the cores for further study. Dolomite and clay values in Table 2 are high and calcite values low when compared to more accurate determinations in Table 4.

Table 1. Pure mineral intensities corrected for sample with mass absorption coefficient of 61 and peak positions used in initial study of cores.

Mineral	20 (degrees)	Pure Mineral Intensities (counts per second)
Quartz	26.6	5730
K-Feldspar	27.6	1500
Plagioclase	28.0	2580
Calcite	29.4	7380
Dolomite	31.0	5100
Clay	34.9	108

Table 2. Results of initial x-ray diffraction study of cores. Amounts are given in parts per ten. T = trace. C = common, about five percent. Asterisks indicate calcite-rich intervals.

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar	Plagioclase
Pembina No. 1						
226	-	5	T	4	2	T
232	T	1	-	9	T	-
237	-	9	T	T	-	T
240	-	9	T	C	-	T
245	-	9	-	T	-	T
248	-	9	1	T	-	T
252	-	10	T	T	-	T
257	-	10	-	C	-	T
260	-	10	-	T	-	T
266	T	2	5	2	1	-
269	1	2	5	1	1	-
272	-	3	5	2	C	C
276	4	C	3	2	C	T
307	5	3	1	1	T	T
310	2	8	T	T	-	C
313	2	8	T	T	-	C
316	5	4	T	C	-	T
319	3	7	T	T	-	T
322	7	1	1	T	-	-
325	6	3	-	C	-	T
328	6	3	-	C	-	T
331	8	2	T	T	-	-

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar	Plagioclase
Pembina No. 1						
334	4	5	1	1	-	T
337	1	9	T	T	-	T
340	1	8	-	T	-	C
343	3	6	1	T	-	T
347	2	8	-	T	-	T
350	6	2	1	T	-	-
353	5	5	T	T	-	-
356	2	8	-	T	-	C
359	2	8	1	T	-	T
362	5	5	T	T	-	T
365	C	9	-	T	-	C
368	1	8	-	T	-	C
371	4	6	T	T	-	T
374	4	6	-	T	-	T
377	1	9	-	T	-	T
380	1	9	-	T	-	T
383	4	5	T	T	-	-
389	1	9	-	C	-	C
392	1	7	T	C	-	C
395	1	6	-	3	-	C
398	1	9	-	C	-	C
401	2	8	T	C	-	C

Table 2, continued.

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar	Plagioclase
Pembina No. 1						
404	1	8	1	C	-	T
407	2	7	T	C	-	T
410	3	7	T	C	-	T
413	2	8	T	C	-	T
416	1	9	-	C	T	C
419	3	6	T	C	-	T
422	3	6	-	T	-	T
425	5	4	1	C	-	T
428	3	7	T	C	-	T
431	1	9	-	C	-	T
434	2	8	T	C	T	T
437	4	5	T	1	-	T
440	2	8	T	C	-	T
443	4	6	T	T	-	T
446	2	8	-	C	-	T
449	3	5	1	2	-	T
452	4	6	-	1	-	-
455	5	5	-	C	-	-
458	5	3	T	C	-	-
461	5	4	1	T	-	-
464	2	7	T	T	-	T
467	4	5	1	C	-	-
470	4	5	T	C	-	-
473	6	4	T	C	-	-
*476	10	T	-	T	-	-
*479	3	5	1	C	T	T
*482	9	C	1	T	-	-
*487	6	4	T	C	-	-
*490	8	1	1	T	T	T
*493	9	1	-	T	T	-
*496	6	3	1	C	T	T
*499	6	2	1	C	T	T
*502	6	4	T	C	-	-
*505	9	3	T	T	-	-
Pembina No. 2						
234	-	10	T	T	-	T
237	-	-	-	10	-	-
240	-	9	1	C	-	T
243	-	10	-	C	-	T
246	-	10	-	T	-	T
249	-	10	-	T	-	T
252	-	1	2	6	-	2
258	-	8	1	C	-	C
261	-	8	1	T	-	C
266	-	9	1	T	-	C
Grand Forks No. 1						
*206	6	4	T	T	-	-
*209	7	3	T	T	-	-
*212	7	2	1	T	-	-
*215	7	2	1	T	-	-
*218	5	4	T	C	T	-
*221	6	3	T	T	-	-
*224	8	2	-	T	-	-
*227	6	4	-	T	-	-
230	2	3	3	1	C	-
234	6	3	1	C	T	-
236	6	3	1	C	T	-
239	6	2	1	C	C	-
242	3	2	3	C	C	-
245	7	2	T	C	T	-
248	6	2	1	C	C	-
251	2	2	4	1	1	-
254	5	1	3	C	C	-
257	2	2	5	1	1	-
260	7	2	T	C	C	-
263	4	1	3	1	C	-
266	3	2	4	C	C	-
269	2	2	4	1	1	-
272	2	1	5	1	C	-
275	2	3	4	1	1	-
Grand Forks No. 2						
220	7	3	T	C	T	C
223	4	5	T	C	-	T
227	4	4	1	C	-	T
230	2	8	T	C	-	T
233	6	2	1	T	-	-
236	4	5	1	C	-	T
239	5	4	T	T	-	-

Table 2, continued.

Grand Forks No. 2

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar	Plagioclase
242	5	5	-	T	-	-
245	5	3	1	T	-	-
248	5	3	1	T	-	-
251	5	3	1	T	-	-
254	4	3	2	C	-	-
*257	6	2	1	T	-	-
*260	7	1	1	T	-	-
*263	6	2	1	T	-	-
*266	5	3	1	T	-	-
269	5	4	T	T	-	T
271	6	2	1	T	-	T
274	6	3	1	T	-	-
277	5	3	1	T	-	-
280	5	3	1	T	-	-
283	5	3	1	T	-	-
286	6	2	1	T	-	-
289	6	2	1	T	-	-
292	3	6	1	C	T	-
296	6	4	T	C	T	-
299	3	4	2	1	C	-
302	4	3	2	C	T	-
305	1	5	2	1	C	-
308	7	1	1	C	T	-
311	5	2	2	C	T	-
314	5	1	2	1	C	-
317	2	2	5	1	C	-
320	3	2	3	1	C	-

Grand Forks No. 3

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar	Plagioclase
*220	9	C	-	T	-	-
*223	8	2	1	T	-	-
*226	7	4	T	T	-	-
*229	7	3	1	T	-	-
*232	6	3	1	C	-	-
*235	6	3	1	T	-	-
*238	4	5	T	C	T	-
*241	8	2	-	T	-	-
*244	7	3	-	T	-	-
*247	7	2	1	C	-	-
*250	7	2	1	T	-	-
*253	8	1	1	T	-	-
*256	4	3	2	C	-	-
*259	5	3	1	C	C	-
268	6	3	-	C	C	-
271	5	2	2	C	C	-

Grand Forks No. 4

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar	Plagioclase
*221	10	C	-	T	-	-
*224	5	5	T	T	-	T
*227	7	3	-	T	-	-
230	4	6	T	C	-	T
233	2	7	1	C	-	T
236	3	5	1	C	-	T
239	3	5	1	C	-	C
242	3	5	1	C	-	T
245	6	3	T	C	-	-
248	4	4	1	C	-	T
251	3	5	1	C	-	T
254	4	5	1	C	-	T
257	3	6	1	C	-	T
260	4	4	1	C	-	T
263	3	7	T	T	-	C
266	5	4	1	T	-	-
269	5	5	T	T	-	-
272	3	6	1	T	-	T
275	5	5	T	T	-	-
278	9	1	T	T	-	-
281	5	4	1	T	-	-
284	4	5	1	T	-	T
287	3	6	1	T	-	T
290	8	2	T	T	-	-
293	4	6	T	T	-	T
296	3	7	T	C	-	T
299	7	3	-	T	-	-
302	4	6	-	C	-	-
305	7	2	1	T	-	-
308	6	3	1	T	-	-
311	4	6	1	T	-	-
314	5	3	1	C	-	-

Table 2, continued.

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar	Plagioclase
Grand Forks No. 5						
325	C	1	-	7	1	1
341	T	T	8	C	2	-
344	5	-	5	T	T	-
347	5	T	5	T	C	-
350	4	T	6	T	C	-
353	4	C	4	C	1	-
356	4	2	3	T	C	-
359	2	2	5	T	C	-
362	5	3	1	-	C	-
365	3	2	5	T	C	-
368	5	2	2	T	C	-
371	3	4	3	T	C	-
374	6	1	3	T	C	-
377	2	3	5	T	C	-
380	7	1	2	-	T	-
383	2	3	5	T	C	-
386	2	1	6	C	1	-
389	C	C	4	3	2	-
392	-	C	5	2	2	-
395	C	C	5	2	2	-
398	2	2	5	C	C	-
Grand Forks No. 6						
240	3	-	6	C	1	-
243	5	-	5	T	C	-
246	5	-	5	T	C	-
*249	4	-	5	T	C	-
*252	6	-	4	T	C	-
*255	4	3	2	T	C	-
258	8	2	-	T	-	-
261	3	5	2	T	C	-
264	3	4	2	T	C	-
267	5	5	-	T	C	-
270	3	5	2	T	C	-
273	2	4	3	T	C	-
276	3	4	3	T	C	-
279	3	3	3	C	C	-
282	5	2	2	C	C	-
285	5	3	2	C	C	-

DETAILED STUDY

Splits of 51 samples including those selected for chemical analysis were subjected to detailed x-ray analysis. Subsamples were ground for three minutes in a Spex 8000 Mixer Mill resulting in an average particle size of about forty microns. X-ray diffractometer charts of the samples were overlaid on a calibrated chart and mineral percentages determined from peak heights. The 2θ positions of the peaks and the one hundred percent intensities used (corrected to a theoretical mass absorption coefficient of 60) are given in Table 3. One hundred percent intensities were determined empirically. A standard sample (U.N.D. 1901) was used for quartz. Averages determined for two optically analyzed perthites from granite (F. R. Karner, 238, 272) were used for plagioclase and K-feldspar, since the feldspar in our samples is of unknown, probably detrital, origin. Clay values are typical for the illite-rich clay expected in these samples. Calcite and dolomite one hundred percent intensities are typical for carbonates of approximately average particle size and crystallinity. Corrections for these minerals were made according to peak widths at one-half peak height (Karner, in preparation). Broad peaks require low one hundred percent values and narrow peaks require higher values. Calcite peak widths had mean values suggesting use of intensities comparable to those for carbonates of somewhat smaller than average particle size.

Results of the detailed study in Table 3 give mineral percentages recalculated to one hundred percent in order to correct for the initial assumption of a mass absorption coefficient of 60 and also for errors in determinations of mineral percentages. The median pre-correction total was eighty-nine percent. A spot check of five samples at or close to the median showed that 88 percent of the correction was attributable to the absorption adjustment and 12 percent to error. Comparison with chemical data indicates average accuracies of about 10 percent of the amount present except in amounts less than 5-10 percent. X-ray determined dolomite and clay are consistently slightly high and calcite slightly low.

The dolomite (211) peak at 30.99° 2θ was generally displaced about 0.1° toward lower 2θ values indicating significant substitution of iron for magnesium, or up to about 30 mole percent $CaFe(CO_3)_2$ (Rosenberg, 1967). This partially accounts for higher x-ray-determined dolomite than chemically determined $CaMg(CO_3)_2$.

One typical sample (GF-3, 220-221) was treated with dilute HCl to remove calcite and dolomite. The 5.9 weight percent insoluble residue was then x-rayed as a randomly oriented packed powder and as oriented, water-sedimented aggregates for study of the clay fraction. The residue consisted of approximately 50 percent clay, illite apparently with a high content of the 2M polymorph (Velde and Hower, 1963), 25 percent quartz, 15 percent K-feldspar, minor celestite ($SrSO_4$), probable minor strontianite ($SrCO_3$), and possibly a hydrated calcium chloride formed during acid treatment.

Gypsum and anhydrite peaks were not present on the diffractometer charts although these minerals were expected to be present in minor amounts in at least some of the samples. Very small amounts (less than one percent) may have been masked in the untreated samples and absent or dissolved in the acid-treated sample.

Table 3. Pure mineral intensities corrected for sample with mass absorption coefficient of 60 and peak positions used in detailed studies of cores.

Mineral	2θ (degrees)	Pure Mineral Intensity (counts per second)
Clay	19.9	230
Quartz	26.7	6700
K-Feldspar	27.6	1740
Plagioclase	28.0	2900
Calcite	29.4	4300
	47.5	525
	48.5	525
Dolomite	31.0	4240
	50.5	510
	51.1	510

Table 4. Results of detailed x-ray diffraction study of cores. Amounts are given as weight percentages. T = trace.

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar
Pembina No. 1					
475-480	59	30	5	4	2
480-483	68	21	5	4	2
487-490	70	18	5	5	2
490-495	72	15	6	5	2
493-494	75	15	6	3	1
495-500	74	13	6	5	2
500-505	75	12	6	5	2
Pembina No. 2					
234-235	1	97	-	1	1
Grand Forks No. 1					
206-212	67	25	5	2	1
212-218	70	21	5	2	2
Grand Forks No. 2					
255-260	65	24	5	3	3
260-265	69	21	5	3	2
Grand Forks No. 3					
220-221	71	21	4	2	2
221-222	78	12	7	3	1
222-223	72	18	5	3	2
Grand Forks No. 3					
223-224	76	15	6	2	1
224-225	72	14	6	4	4
225-226	73	17	6	3	1
226-227	70	21	4	3	2
227-229	70	21	5	2	2
229-231	72	19	6	2	1
231-233	61	28	6	3	2
233-235	70	19	6	3	2
235-237	71	20	6	2	1
237-239	74	18	5	2	1
239-241	73	15	7	3	3
241-242	71	19	6	2	2
242-243	79	11	6	2	2
243-244	77	13	6	2	2
244-245	79	12	5	2	2
245-246	74	16	6	2	2
246-247	65	24	6	3	2
247-248	69	20	5	3	3
248-249	73	17	6	2	2
249-250	73	17	6	2	2
250-251	78	15	5	2	1
251-252	77	13	6	2	2
252-253	68	18	6	4	5
253-254	79	12	5	2	2
254-256	75	14	5	4	2
256-258	73	15	6	3	3
258-260	76	12	6	3	3
241-253	72	20	4	2	2

Table 4, continued.

Depth (ft.)	Calcite	Dolomite	Clay	Quartz	K-Feldspar
Grand Forks No. 4					
221-223	68	25	5	2	1
223-225	63	29	5	2	1
Grand Forks No. 5					
371-372	57	20	17	1	5
380-381	50	16	29	1	4
Grand Forks No. 6					
249-250	57	3	33	1	6
252-253	59	3	31	2	5
255-256	44	23	28	1	4

SUMMARY OF X-RAY DATA

1. Initial study indicated the following as potential high calcium-low magnesium zones suitable for further chemical and x-ray study:

   a) P-1 476-505 feet.
   b) GF-1 206-227 feet.
   c) GF-2 257-266 feet.
   d) GF-3 220-259 feet.
   e) GF-4 221-227 feet.
   f) GF-6 249-255 feet.

2. Initial study indicated P-2 234-266 feet contained zones consisting of nearly pure dolomite.

3. Detailed study showed that the most favorable high-calcium-low-magnesium zones were P-1 487-505 feet and GF-3 220-260 feet.

4. Both favorable zones contain about 70-75 percent calcite, $CaCO_3$; 15-20 percent ferroan dolomite, Ca, (Mg, Fe) $(CO_3)_2$; Mg: Fe about 4:1; 5 percent illite, approximately K Al_4 (Si_7AlO_{20}) $(OH)_4$; 2-5 percent quartz, SiO_2; 1-2 percent K-feldspar, (K, Na) $AlSi_3O_8$; and minor celestite, $SrSO_4$ and strontianite, $SrCO_3$. P-1 487-505 feet has slightly more calcite and quartz and less dolomite than GF-3 220-260 feet.

REFERENCES

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Rosenberg, P. E., May-June, 1967, Subsolidus Relations in the system $CaCO_3$-$MgCO_3$-$FeCO_3$ between 350° and 550°: Am. Min. v. 52, p. 787-796.

Velde, B. and Hower, J., 1963, Petrological significance of illite polymorphism in Paleozoic sedimentary rocks: Am. Min. v. 48, p. 1239-1254.

APPENDIX "C"

CHEMICAL ANALYSES OF CEMENT-ROCK CORES

In sampling Pembina-Manvel-Grand Forks cores for chemical analysis, a uniform slice, about 1/5 of the total core, was taken along the length of the desired interval, generally one foot. This sample, about 150-200 grams, was reduced to powder and chips less than one half cm in diameter in a jaw crusher and split into two parts in a Jones-type sample splitter. One split was crushed to less than 75 microns in a porcelain mortar and split into two parts, about 75 grams for chemical analysis and about 15 grams for x-ray analysis.

CHEMICAL ANALYSES OF CEMENT-ROCK CORES

Analysts: N. D. Berlin, A. S. McCreath and Son, Inc., Harrisburg, Pa. (Pembina 1, Grand Forks 1, 2, 3, 4); Lerch Brothers, Inc., Hibbing, Minnesota (Grand Forks 5, 6). $CaCO_3$ and $MgCO_3$ calculated from oxides (Lamar, 1967, p. 84).

P-1
Location: NW SE sec. 28, T. 164 N., R. 51 W., Pembina County, North Dakota

Depth	CaO	MgO	CO_2	$CaCO_3$	$MgCO_3$
475-480	44.06	6.07	41.60	78.647	12.692
480-483	45.54	4.59	40.45	81.288	9.597
487-490	46.50	3.41	40.15	83.002	7.130
490-495	46.88	3.44	40.45	83.680	7.193
495-500	47.20	2.91	40.00	84.252	6.084
500-505*	47.80	2.52	40.40	85.323	5.269

*SiO_2 5.80, Al_2O_3 .96, Fe_2O_3 1.37, SO_3 less than 0.02, P_2O_5 0.096, Na_2O 0.13, K_2O 0.80, F 0.016, H_2O 0.10, Loss on Ignition 40.58

GF-1
Location: NW NE NW sec. 19, T. 153 N., R. 50 W., Grand Forks County, North Dakota

206-212	47.70	4.02	41.95	85.144	8.405
212-218	47.90	3.93	41.55	85.501	8.217

GF-2
Location: NW SW SW sec. 27, T. 153 N., R. 51 W., Grand Forks County, North Dakota

255-260	47.72	3.50	41.15	85.180	7.318
260-265	48.32	3.47	41.55	86.251	7.255

GF-3
Location: NE NW NE sec. 35, T. 154 N., R. 51 W.,
Grand Forks County, North Dakota

Depth	CaO	MgO	CO_2	$CaCO_3$	$MgCO_3$
220-221*	48.78	3.62	41.75	87.072	7.569
221-222	50.42	2.56	41.90	89.999	5.352
223-224	48.21	3.43	41.65	86.054	7.172
225-226	48.43	3.41	41.30	86.447	7.130
227-229	47.87	3.49	41.15	85.447	7.297
229-231	48.01	3.83	41.30	85.697	8.008
231-233	46.06	5.45	41.40	82.217	11.395
233-235	48.15	3.82	41.70	85.947	7.987
235-237	48.49	3.84	42.05	86.554	8.029
237-239	48.30	3.68	41.65	86.215	7.694
239-241	48.85	3.21	41.50	87.197	6.712
241-253**	48.13	3.57	41.10	85.912	7.464
244-245	49.32	3.03	41.75	88.036	6.335
249-250	48.20	3.97	41.25	86.037	8.301
254-256	46.70	3.86	40.15	83.359	8.071
256-258	46.53	3.17	39.35	83.056	6.628
258-260	47.21	3.15	39.65	84.269	6.586

*SiO_2 3.78, Al_2O_3 0.70, Fe_2O_3 0.20, SO_3 less than 0.02, P_2O_5 0.047, Na_2O 0.07, K_2O 0.45, F 0.017, H_2O 0.39

**SiO_2 4.20, Al_2O_3 0.79, Fe_2O_3 0.46, SO_3 less than 0.02, P_2O_5 0.140, Na_2O 0.07, K_2O 0.55, F 0.024, H_2O 0.38, Loss on Ignition 41.79

GF-4
Location: SW SE SW sec. 19, T. 153 N., R. 51 W.,
Grand Forks County, North Dakota

221-223	48.76	4.28	43.10	87.036	8.949
223-225	48.52	4.82	43.10	86.608	10.078

GF-5
Location: SE SE NE sec. 23. T. 151 N., R. 51 W.,
Grand Forks County, North Dakota

Depth	CaO	MgO	CO_2	$CaCO_3$	$MgCO_3$
371-372	35.40	2.73	35.56	63.19	5.71
380-381	31.80	3.03	31.10	56.76	6.34

GF-6
Location: SW NW NW sec. 22, T. 151 N., R.50 W.,
Grand Forks County, North Dakota

249-250	32.40	0.93	28.74	57.83	1.94
252-253	35.00	0.93	29.76	62.47	1.94
255-256	33.00	4.00	32.08	58.90	8.36

Depth	Total Fe	HF Si	Fus. Al2O3	Total P	CaO	CO2	MgO	Loss on Ignition	S	Na2O	K2O
HOLE NO. S - 1; Location SW SW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota											
48	2.64	17.12	8.42	.084	36.88	27.30	.28	30.96	.98	.33	.98
50	2.80	18.44	9.40	.067	35.76	28.35	.24	30.28	1.40	.36	.95
52	2.88	26.92	12.95	.049	27.76	22.35	.44	26.20	1.16	.51	1.30
54	2.40	22.22	10.69	.077	32.48	25.75	.44	29.96	.59	.37	1.09
56	2.92	16.80	8.72	.046	35.64	29.50	1.30	31.64	.78	.29	.84
58	2.64	15.50	10.78	.200	36.40	31.10	1.20	32.20	.30	.36	.81
60	2.40	19.82	9.73	.109	35.20	27.20	.64	30.64	.67	.37	.99
HOLE NO. S - 2; Location NW NW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota											
34	3.36	18.40	9.06	.038	34.44	27.00	.28	31.28	2.40	.32	.92
36	2.00	14.80	7.56	.080	38.88	30.20	.72	33.48	.83	.24	.82
38	2.08	20.62	12.22	.058	33.04	27.75	.20	29.84	1.12	.33	1.03
40	1.78	23.88	10.15	.054	32.80	25.45	.28	29.16	.83	.30	1.00
42	2.08	16.50	7.38	.076	38.40	31.25	.80	33.92	.27	.25	.80
44	1.77	16.80	7.56	.123	36.08	30.70	1.08	33.20	.21	.31	.83
46	1.93	16.86	7.82	.081	38.00	30.60	.32	33.32	.15	.29	.85
HOLE NO. S - 3; Location NE NW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota											
17	2.25	15.38	7.00	.105	39.04	31.20	.20	35.00	.14	.18	.77
19	1.93	22.94	6.08	.040	32.24	25.40	1.48	31.24	.13	.30	1.09
21	1.85	19.40	9.07	.073	34.84	27.35	.56	31.44	.14	.27	.98
23	1.61	15.34	6.98	.036	38.96	31.50	1.44	33.68	.44	.18	.78
25	2.49	16.54	7.56	.219	36.92	30.80	1.36	32.96	.29	.22	.80
27	2.09	16.10	7.46	.054	39.12	31.00	.60	33.36	.34	.19	.76

Chemical analyses of the Niobrara Formation, Shawnee-McCanna area. Reprinted from Carlson (1964).

Depth	Total Fe	HF Si	Fus. Al2O3	Total P	CaO	CO2	MgO	Loss on Ignition	S	Na2O	K2O
HOLE NO. S - 4; Location SE SW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota											
20	2.89	13.52	6.77	.084	40.08	31.05	.48	33.96	.28	.26	.70
21	3.13	20.64	8.78	.067	34.32	26.85	.48	30.76	.45	.28	1.03
22	3.05	21.90	11.53	.071	32.61	25.05	.52	28.68	.94	.31	1.08
23	3.53	30.52	12.25	.078	22.12	18.75	1.72	25.24	1.99	.40	1.38
24	2.89	22.39	9.56	.066	33.20	25.65	.72	29.92	.75	.37	1.06
25	1.77	16.12	7.74	.030	39.36	29.35	1.00	31.92	.77	.29	.71
26	2.97	16.84	6.79	.091	38.40	29.90	1.44	31.84	.61	.25	.79
27	2.81	15.54	6.14	.058	39.08	29.85	1.60	33.24	.28	.28	.85
28	3.13	15.42	7.02	.046	36.96	31.00	1.72	33.54	.24	.30	.82
29	2.57	15.96	7.40	.057	37.04	30.55	1.64	33.24	.20	.33	.87
31	2.17	27.90	12.93	.128	26.36	21.00	1.00	26.82	.31	.50	1.84
HOLE NO. S - 10; Location SE SW Sec. 1, T. 152 N., R. 56 W., Grand Forks County, North Dakota											
53	2.20	22.70	9.90	.047	28.24	24.20	.12	29.52	.74	.39	1.16
55	2.56	24.22	11.63	.103	25.92	23.72	.14	28.68	.94	.39	1.20
57	1.92	17.36	7.84	.073	33.08	28.20	.14	32.24	.71	.32	1.18
59	1.94	18.12	8.56	.072	29.28	28.52	.12	32.40	.31	.28	.94
61	1.90	16.80	7.77	.063	32.24	30.20	.28	33.64	.25	.29	1.32
63	2.40	31.02	13.70	.058	23.44	19.41	.16	25.36	.46	.48	1.53
65	1.84	18.30	9.74	.095	35.36	28.37	.40	32.32	.17	.28	1.14
HOLE NO. S - 11; Location SW SE Sec. 1, T. 152 N., R. 56 W., Grand Forks County, North Dakota											
21	1.86	14.96	8.71	.039	38.44	30.20	.43	32.76	.29	.16	.80
23	1.80	16.68	10.02	.045	35.60	28.24	.37	33.44	.21	.18	.88
25	2.16	17.96	9.11	.058	32.40	25.41	.40	32.52	.33	.18	.94
27	2.04	17.16	9.40	.090	34.88	27.14	.48	33.20	.21	.41	1.11

Chemical analyses of the Niobrara Formation, Shawnee-McCanna area. Reprinted from Carlson (1964).

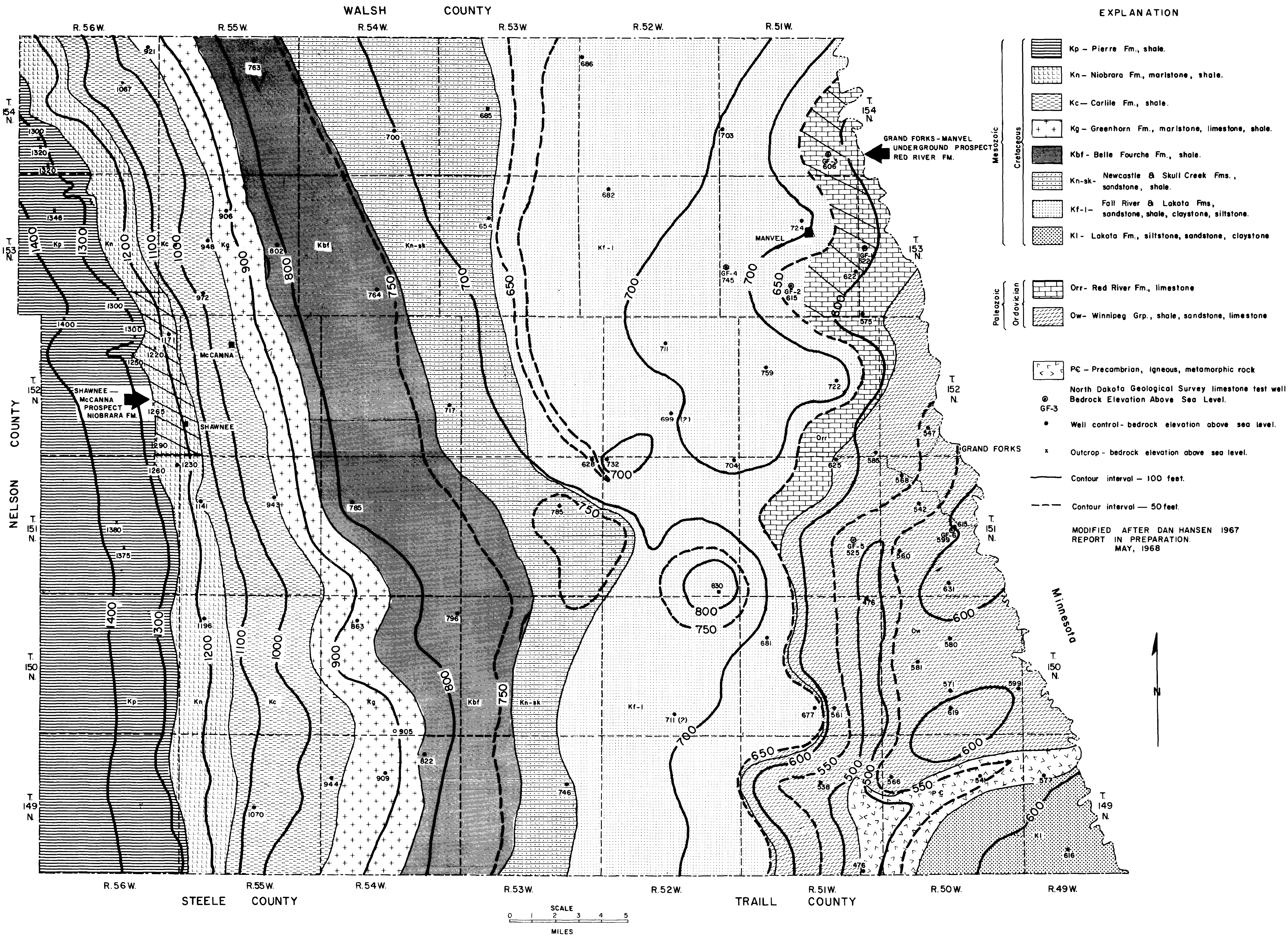
SELECTED REFERENCES

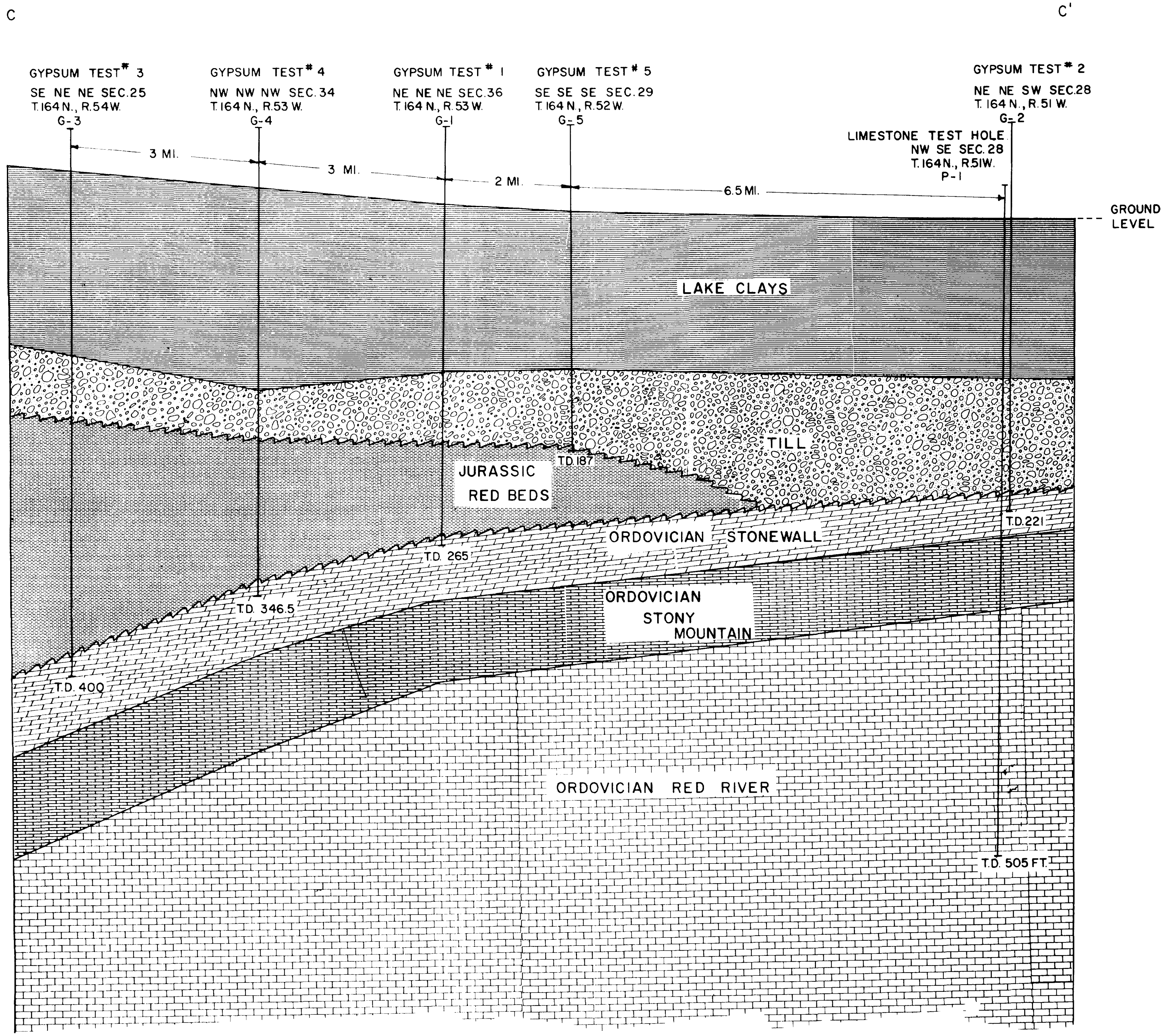
Carlson, C. G., 1964, The Niobrara Formation of eastern North Dakota; its possibilities for use as a cement rock: N. D. Geol. Survey, Rept. of Inv. 41, p. 26-27.

Lamar, J. E., 1967, Handbook on limestone and dolomite for Illinois quarry operators: Illinois State Geol. Survey, Bull. 91, p. 84.

BEDROCK GEOLOGIC MAP OF GRAND FORKS COUNTY, NORTH DAKOTA SHOWING CEMENT—ROCK PROSPECTS

STRUCTURE ON BEDROCK

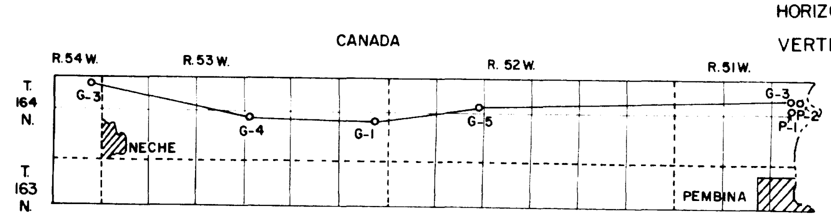




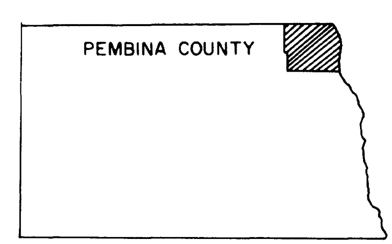
WEST-EAST CROSS SECTION PEMBINA COUNTY
NORTH DAKOTA

HORIZONTAL SCALE: 1" = 1 MI.
VERTICAL SCALE: 1" = 50 FT.

MAY 1968



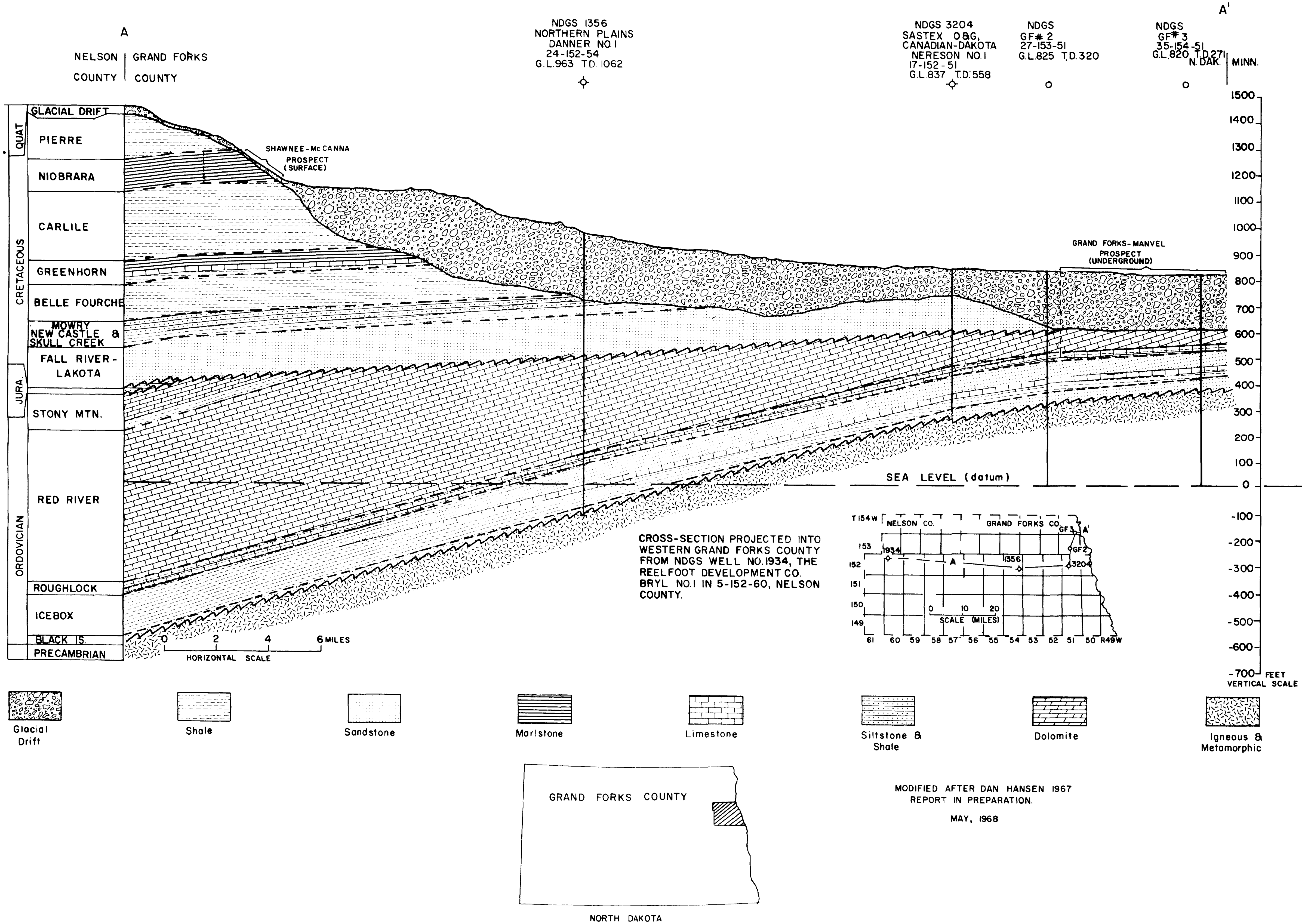
PORTION OF NORTHEASTERN PEMBINA COUNTY INDEX MAP



NORTH DAKOTA

PLATE-2

GEOLOGIC CROSS SECTION — — — — GRAND FORKS COUNTY, NORTH DAKOTA SHOWING CEMENT—ROCK PROSPECTS



MODIFIED AFTER DAN HANSEN 1967
REPORT IN PREPARATION.

MAY, 1968

PLATE-3