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Report of Investigation 41

THE NIOBRARA FORMATION

OF EASTERN NORTH DAKOTA;

ITS POSSIBILITIES FOR USE AS A CEMENT ROCK

by

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GRAND FORKS, NORTH DAKOTA

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This study was initiated by the North Dakota Economic Development Commission who provided funds to pay all drilling costs, chemical analyses and miscellaneous expenses of the program.

The project was outlined by Dr. Wilson M. Laird, State Geologist and the facilities of the North Dakota Geological Survey were made available for the project. During the fall of 1962, this included the aid of five other geologists in making field reconnaissance studies. In the spring of 1963, Miller Hansen, Assistant State Geologist, aided in choosing specific prospective areas for core hole investigation. He also aided in other preliminary preparations for the drilling program. Ted Freers, geologist, ably assisted the writer throughout preliminary field work and during the drilling program. Subsequent to the drilling program, Mr. Arthur Reesman made some mineral identifications using the X-Ray diffraction technique.

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ABSTRACT

The Niobrara Formation was cored in fourteen test holes, two near Edinburg, two near Park River and ten in the Shawnee-McCanna area. The stratigraphic thickness of Niobrara sampled by these cores was about 170 feet. Carbon dioxide analyses of the cores indicate that one ten foot zone, about 100 feet below the top of the Niobrara Formation, consistently analyzes higher than the rest of the Niobrara, although a few samples from above this zone approach the same quality. The calcium oxide content of this "high-lime" zone varies considerably. The highest analysis was 40.08 and the average is 34 to 35 percent calcium oxide. The magnesium oxide analyses of this zone ranged from 0.12 to 2.15 percent.

The drilling program indicates that in only one area, the Shawnee-McCanna area, can the "high-lime" zone be encountered at a depth of less than fifty feet. In that area the glacial drift composed of clayey till and boulders varies in thickness from seven to twenty feet. The "high-lime" zone is present at a depth of fifty feet or less in a band about a half mile wide and at least four miles long extending from Sec. 30, T. 152 N., R. 55 W. north-westward to Sec. 31, T. 153 N., R. 55 W. in Grand Forks County, North Dakota.

INTRODUCTION

General Statement

The Niobrara Formation has been of interest as a raw material for the manufacture of cement since Babcock first reported the occurrence of cement rock in northeastern North Dakota (1901). Largely as a result of his interest a plant was erected near Concrete, North Dakota in the early 1900's and a natural cement was produced using the Niobrara as the raw material. However, this plant soon closed in the wake of production and marketing difficulties.

Interest in a cement plant in North Dakota has continued, however, with the hope that either a better raw material might be found, or that with some beneficiation the Niobrara cement rock might be suitable for the manufacture of a Portland grade cement. It was this interest that prompted the present study.

Purpose of Study

The purpose of the present study was to make a thorough investigation of the cement rock qualities of the Niobrara Formation. Then, if a favorable raw material could be found, an attempt to locate an area where an economic prospect could be located would follow. Because the cement rock outcrops are scattered geographically and only partial sections are well exposed at any one locality the study was based on a core drilling program, preliminary field, and other studies.

Since the purpose was primarily economic, three main factors were considered in planning the drilling program:

1) To determine if some beds or zones in the Niobrara Formation are consistently higher in calcium carbonate than other beds or zones;
2) To find any such zone or zones as near to the surface as possible; and
3) To locate any such prospect as near to transportation facilities and markets as possible.

Area of Study

The area of study is a band about three to five miles wide in eastern North Dakota extending from the vicinity of Northwood, North Dakota north to near the Canadian border. The general geology, the areas of outcrop of the Niobrara and the Pierre Formations, and the areas of detailed investigations are shown on the location map (Fig. 1, in pocket).

Regional Geologic Setting

The area of study lies within the Western Lake Section of the Central Lowlands Province and along the border between two physiographic districts, the Drift Prairie District to the west and the Agassiz Lake Plain District to the east. The area is within the glaciated part of North Dakota and glacial drift is the surface material throughout the area of study. Outcrops are found only along the banks of some of the streams.

In the Agassiz Lake Plain District, glacial drift directly overlies the Niobrara Formation in the area of this investigation. The same relationship is true in the Drift Prairie District except where the surface elevations rise above about 1,280 feet above sea level. Above that elevation basal beds of the Pierre Formation lie between the glacial drift and the underlying Niobrara Formation except locally where glacial scour has removed them and glacial drift is relatively thick.

Methods of Study

The study began in the fall of 1962 when geologists of the North Dakota Geological Survey made reconnaissance studies of the area. In these studies,

outcrops of the Niobrara Formation and the contact between the Niobrara and Pierre Formations were noted. These preliminary studies indicated that the areas of interest would generally lie somewhere between 1,150 and 1,300 feet above sea level because it could be anticipated that the Niobrara Formation would be encountered directly underlying drift at those elevations.

In the spring of 1963, further reconnaissance studies of the topography of the area and specific areas for core hole investigations were made. Areas chosen were named after nearby towns and are referred to as the Edinburg, Park River, Lankin-Fordville, Shawnee-McCanna, and Northwood prospects.

The Edinburg, Lankin-Fordville, and Shawnee-McCanna prospects appeared to be the most favorable from the standpoint of transportation facilities. The Shawnee-McCanna area, being the most southerly of these three, was more favorably located in regard to markets. The Edinburg, Park River and Lankin-Fordville areas, due to the topography of these areas, seemed to offer the best prospects for developing adequate reserves with easily strippable overburden.

Since the outcrop sections are more numerous and the sections are better known in the northern areas, the drilling program began in the Edinburg area and proceeded southward. It was known from previous drill hole information in the area to the west of the prospective areas that the glacial drift, which is the surface material in this region, was generally thin (i.e., less than 50 feet thick) in most of that area. Therefore, the drilling program in each area generally began with a hole in the western part of the prospective area. This served two purposes; first it was closest to the areas of previous drill hole information, and secondly it was at the higher elevations in the area so it penetrated as much stratigraphic section of the Niobrara Formation as possible with the first hole. Future holes were then spotted on the basis of information regarding thickness of drift, depth to the zone of highest calcium carbonate of previous core holes, regional dip of the Niobrara Formation and surface elevations.

A critical part of the study involved the recognition of the zone or zones of highest calcium carbonate content as the drilling progressed. Therefore a rapid means of chemical analysis was a necessity. The method used was to determine the carbon dioxide content of the samples using a Chittick Gasometric Apparatus and then calculating the calcium carbonate content.

This method had previously been tested in the laboratory with samples of the Niobrara Formation of varying calcium carbonate content. The results using the Chittick apparatus checked closely to chemical analysis of the same samples. The method involves taking 0.85 grams of dry sample, adding ten milliliters of dilute sulphuric acid and then measuring the amount of carbon dioxide produced by the reaction. The temperature and pressure must be noted

and the beaker must be agitated so as to make sure that the reaction goes to completion. If proper care is taken in following the outlined procedures and if the temperature conditions are uniform, good results may be expected. It must be remembered, however, that the measurement is total carbonates, not just calcium carbonate. However, since our chemical analysis indicated that magnesium is a minor element in the Niobrara Formation the carbon dioxide analysis gave a good approximation of the calcium carbonate content of the Niobrara samples.

Test hole sites were generally spotted in road ditches along the road rights of way except where special permission was granted to drill elsewhere. Drilling was done with a truck mounted rig cutting an N X size core (about 2 inch diameter). Rock bits were used for drilling drift and continuous cores were cut through bedrock with core recovery nearly 100 percent in all test holes.

The drilling program began on May 6, 1963 and was concluded on June 11, 1963. Cores were sampled at two foot intervals and field tested for carbon dioxide content. The temperature variations under field conditions were such that although these results were satisfactory for relative calcium carbonate content, these results were not included in this report. All analyses listed in Table II were run in the laboratory subsequent to the drilling program.

Electrical logs, using a Widco logging unit, were run on most of the test holes. Core chips used for carbon dioxide analyses were examined with a binocular microscope. Appendix A lists the well locations, elevations of the drill sites and core descriptions. The electric logs are included in Appendix B.

Previous Studies

Babcock (1901, p. 20) first reported the occurrence of cement rock in northeastern North Dakota. Barry and Melstad (1908) made a more complete study of these deposits, including the general geology of the area and detailed descriptions of the Niobrara Formation at several localities. They also included a range of chemical analyses for a number of Niobrara samples and an analysis of the raw material used by the cement plant at Concrete. Their analysis of the raw material used by the plant is as follows (1908, p. 167):

	Percent
Calcium Carbonate	64.00
Silicon Dioxide	14.75
Alumina and Ferric Oxide	7.00
Magnesium Carbonate	Trace
Sulphur Trioxide	0.65

Powers (1946) restudied the cement rock possibilities of northeastern North Dakota. He revisited previously mentioned outcrops and contributed some chemical analyses of the Niobrara Formation.

The Lehigh Portland Cement Company (1960) investigated the possibilities of finding raw materials for the manufacture of cement in eastern North Dakota including investigations of the Niobrara Formation. Results of their investigations have not been released for public distribution.

STRATIGRAPHY

General Statement

The stratigraphic sequence in this area includes Paleozoic, Mesozoic and Cenozoic sedimentary deposits. However, the discussion will be limited to the stratigraphic units penetrated in the drilling program; namely the glacial drift, Pierre Formation and Niobrara Formation. These are discussed in the order in which they were penetrated by the drill, and, since the study is primarily concerned with the Niobrara, the glacial drift and the Pierre are only briefly discussed.

Glacial Drift

The number of holes drilled in this area makes generalizations concerning lithology and thickness of drift rather tenuous. However, the drift is variable in thickness, ranging from seven feet to ninety-four feet in the test holes drilled, and is generally thinner in the Drift Prairie District than in the Agassiz Lake Plain District.

The drift in the Drift Prairie District is generally composed of clayey till containing much gray shale incorporated from the bedrock of the region. Boulders are common and locally abundant. Thickness is generally less than fifty feet, but in some areas greater thicknesses were encountered.

Test holes in the Agassiz Lake Plain District were drilled only in the Edinburg and Park River prospective areas. In these holes, the drift near the surface is generally composed of fluviatile-lacustrine deposits of sand and gravel. Underlying the fluviatile-lacustrine deposits, some test holes encountered till similar in composition to that of the Drift Prairie District. Only one test hole (E-2) in the Agassiz Lake Plain District penetrated bedrock, and that hole was located near the western margin of the District. The other test holes were abandoned in drift, but were drilled to depths which were considered to be near the economic limits for stripping operations, and which should have penetrated the prospective zones of the Niobrara Formation, if those zones had been present at the drill site localities. Therefore, the thickness of drift in the Agassiz Lake Plain District was generally undetermined by the drilling program.

Pierre Formation

The Pierre Formation, of Upper Cretaceous age, is generally present conformably overlying the Niobrara Formation and unconformably underlying glacial drift in the area where surface elevations are more than 1,280 feet above sea level. Only the lower beds of the Pierre Formation are present in the area of study, the upper beds having been removed by erosion. One test hole, located in the Park River prospective area, encountered the lower 40 feet of the Pierre Formation.

The Pierre of the outcrop area is composed of medium gray (N5), non-calcareous, fissile shale with bentonitic layers, locally termed Fullers Earth beds, near the base. These Fullers Earth beds are excellent markers, being noted as alternating yellow and black bands on weathered surfaces, and the base of these beds mark the base of the Pierre Formation in this area.

In the PR-1 test hole, the Pierre is composed of medium gray (N5) to medium dark gray (N4), non-calcareous, sticky shale with a few thin bentonite layers from a depth of 18 to 51 feet. The Fullers Earth beds extend from a depth of 51 to 56 feet in this well and are noted as alternating bands of light gray (N7) and dark gray (N3) bentonites. The individual bands vary in thickness with the maximum thickness of any one band being about eight inches.

Niobrara Formation

The Niobrara Formation, of Upper Cretaceous age, is present throughout the area of study, conformably underlying the Pierre Formation where the Pierre is present and unconformably underlying glacial drift in the rest of the area. The lower contact was not encountered in the drilling program and was not observed in the surface studies.

All of the known outcrops near the prospective areas and some of the known outcrops north of the prospective areas are shown on the location map (Fig. 1). Most of these exposures have been mentioned in earlier reports, but one exposure in the Shawnee-McCanna area (SE NE Sec. 23, T. 152 N., R. 56 W.) is perhaps worthy of special mention as it extends southward the known outcrops in the area of study. At this locality a few feet of light gray (N7) to medium light gray (N6), calcareous shale containing abundant white specks is exposed in a roadcut on the north side of U. S. Highway 2. Chittick Gasometric analyses of several samples from this locality show a range of 45 percent to 56 percent calcium carbonate content for these samples.

The upper 25 feet of the Niobrara Formation is exposed in the NE NE of Sec. 24, T. 157 N., R. 57 W., Walsh County, North Dakota. The

Niobrara is composed of light gray (N7) to medium light gray (N6), calcareous shale containing abundant white specks at this locality. Gasometric Analyses (Table II, p. 37) of these samples ranged from about 37 percent to 66 percent, averaging 53 percent calcium carbonate, for the 25 foot interval. Another exposure, located in the NW NW of Sec. 19, T. 157 N., R. 56 W., Walsh County, North Dakota, exposes about 22 feet of Niobrara, but the upper contact, is not exposed. Gasometric analyses of samples of 18 feet of section at this locality ranged from about 36 percent to 62 percent, averaging 50 percent calcium carbonate.

Subsurface information is based on fourteen test holes, two in the Edinburg area, two in the Park River area, and ten in the Shawnee-McCanna area. One hole in the Park River area penetrated the Pierre-Niobrara contact at a depth of 56 feet. This hole (PR-1) was drilled to a depth of 169 feet, thus obtaining cores of the upper 113 feet of Niobrara. The upper 99 feet is composed of light gray (N7) to medium light gray (N6), slightly to very calcareous shale and generally contains abundant "white specks." Calcium carbonate content varies considerably in this interval, ranging from about 1 percent to 69 percent in the samples analyzed, (Table II, p. 29) and averaging 37.7 percent for the entire interval. The ten foot interval from 155 to 165 feet is composed of very light gray (N8), very calcareous shale which does not contain "white specks." Gasometric analyses (Table II, p.29) of this interval ranged from 48.1 percent to 69.9 percent averaging 61.5 percent. The interval from 165 to 169 feet is composed of medium gray (N5) to medium dark gray (N4), nearly non-calcareous shale.

A second hole in the Park River area (PR-2) penetrated Niobrara directly underlying drift and 107 feet of Niobrara was cored. The light gray (N7) to medium light gray (N6) shale containing abundant "white specks" extended from a depth of 23 feet to 108 feet, the very light gray, very calcareous, non-white specked shale extended from a depth of 108 to 118 feet. The shale from 118 to 130 feet is medium light gray (N6), slightly micaceous, slightly bentonitic, slightly calcareous, and does not contain white specks. Gasometric analyses of these samples (Table II, p. 30) ranged from 0 to 22.6 percent, averaging 12.5 percent calcium carbonate.

In test hole E-1, 132 feet of Niobrara was cored. The light gray (N7) to medium light gray (N6), white specked shale was encountered from 34 to 82 feet, and the very light gray (N8), non-white specked, very calcareous shale was encountered from a depth of 82 to 94 feet. Cores of the interval from 94 to 130 feet are composed of medium light gray (N6), slightly micaceous, slightly bentonitic, shale which does not contain white specks. Cores from 130 to 166 feet are composed of medium light gray (N6) to medium gray (N5), shale with common to abundant white specks. Gasometric analyses (Table II, p.28) show a range of 1.5 percent to 35 percent and an average of 12.9 percent calcium carbonate for the interval from 94 to 130 feet and a range of 11 to 47

percent with an average of 28.3 percent for the interval from 130 to 166 feet.

On the basis of this drill hole information, the Niobrara Formation may be subdivided into four lithologic units which are herein referred to in descending order as the:

1) upper white specks zone
2) high lime zone
3) non-white specked zone; and
4) lower white specks zone.

These are to be considered as informal units for convenience of reference only in the following discussion of specific areas and individual wells, although it is hoped that they may be useful in further field studies.

The thickness of the high lime zone is consistently about 10 feet throughout the area of study. Thicknesses of the other zones were not determined as the upper part of the upper white specks zone was missing at most localities and the test holes were generally stopped in the upper ten feet of the non-white specked zone.

The high lime zone is readily recognizable as it is consistently lighter colored than the overlying beds and generally contains stem-like concretionary structures. A three foot interval in the lower part of this zone is harder and consistently analyzes higher in calcium carbonate content than the rest of this zone.

Overlying the high lime zone is some light gray (N7) shale which contains few or no white specks, but which is included in the upper white specks zone on the basis of color and calcium carbonate content. Based on the test hole information this shale gradually thickens southward from about four feet near Edinburg to about six feet near Park River and to ten to fifteen feet in the Shawnee-McCanna area.

PROSPECTIVE AREAS

Edinburg

The Edinburg prospect is located in T. 158 N., R. 56 W., Walsh County, North Dakota. Five test holes with a total footage of 371 feet were drilled in this area. The location of test holes, general geology of the area and the line of cross section are shown on the location map (Fig.2).

A distinct topographic rise, commonly referred to as "the escarpment" marks the boundary between the Drift Prairie and Agassiz Lake Plain Districts.

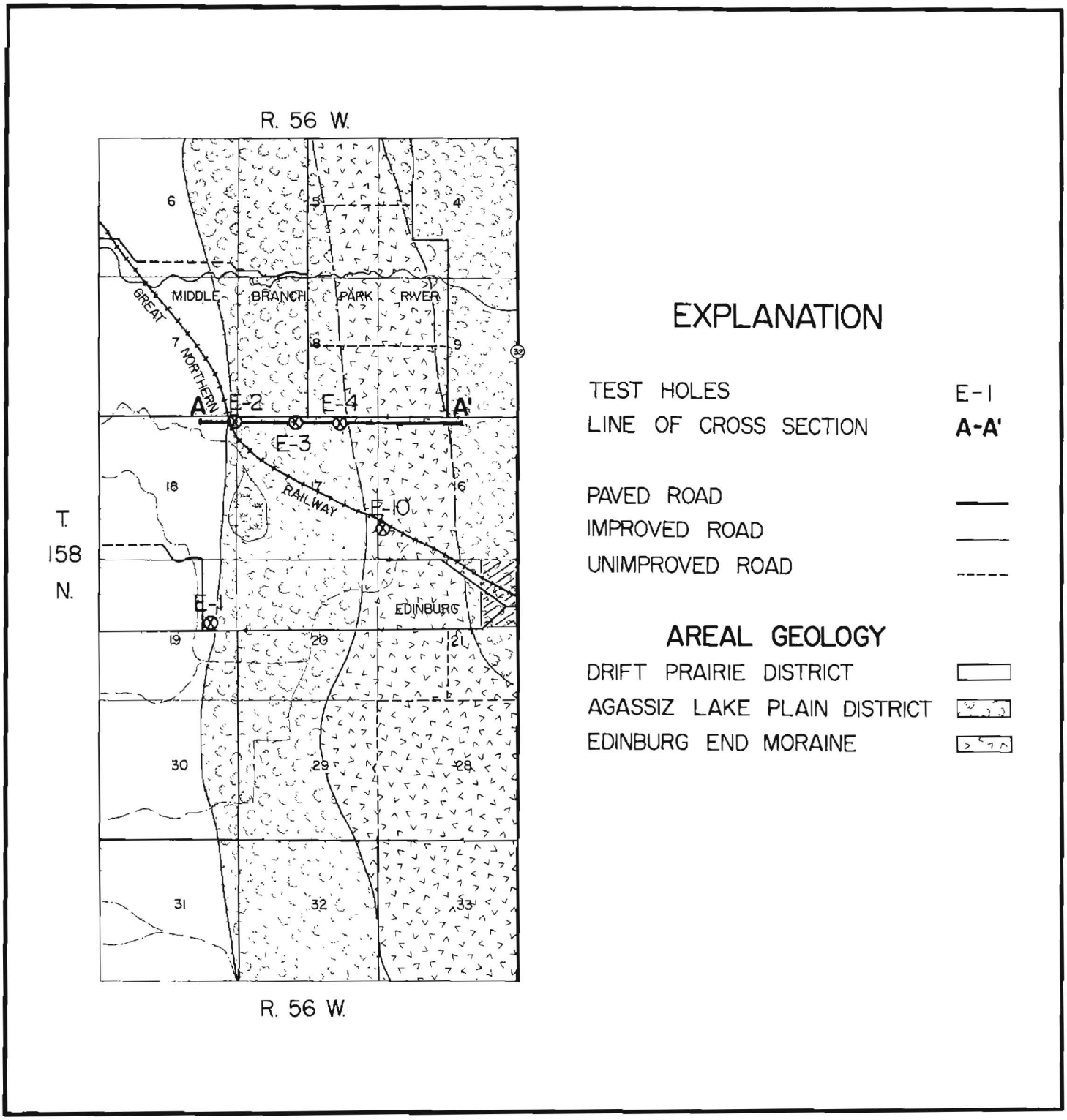

Figure 2 - Map of Edinburg prospective area showing test hole locations, general geology of area, and the line of cross-section.

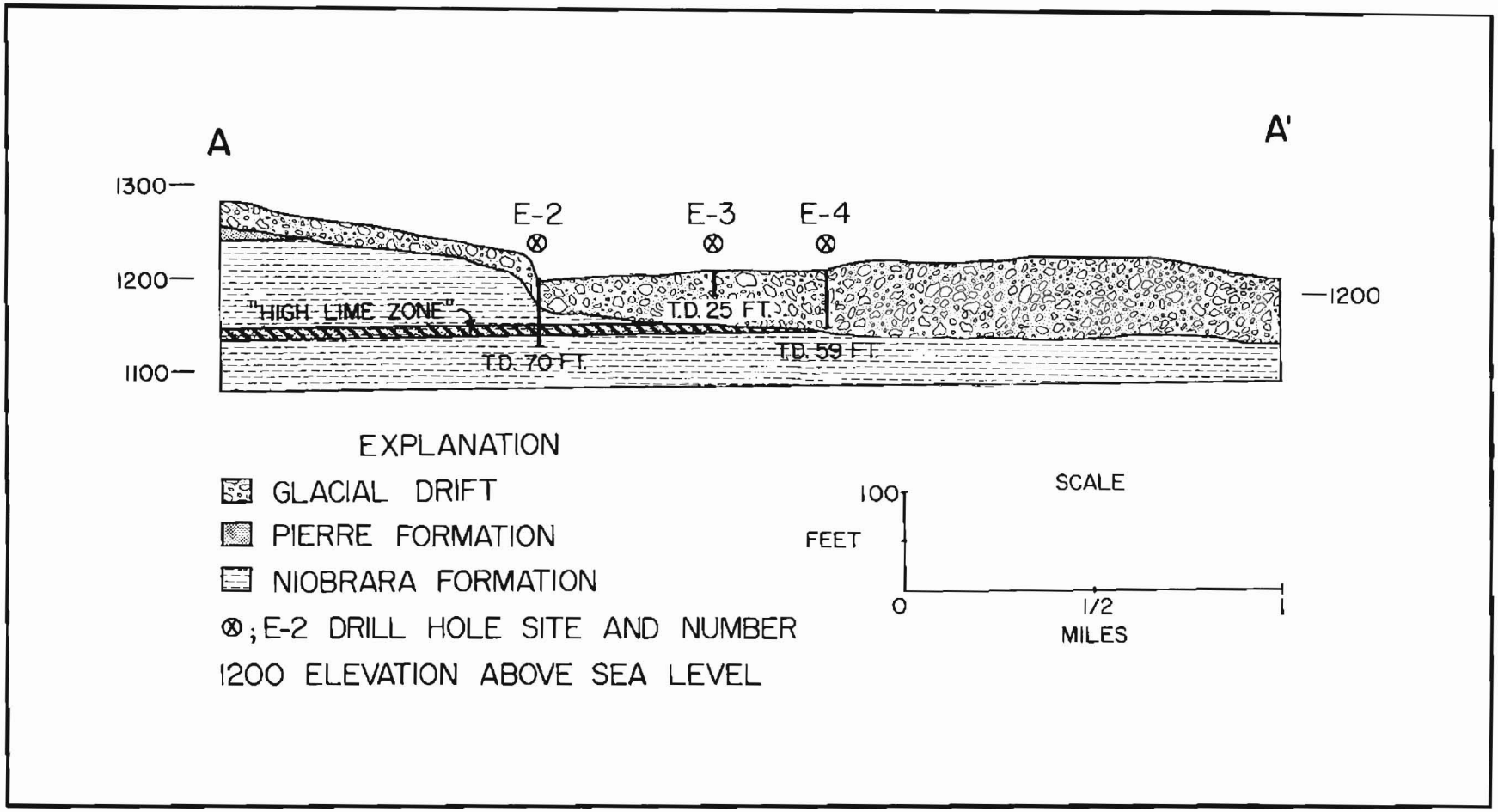

Figure 3 - Cross-section along the line A - A' showing geology of the Edinburg prospective area.

Surface elevations at the base of the escarpment are about 1,200 feet, rising in less than a quarter of a mile to about 1,250 feet and continuing to rise westward in the Drift Prairie District to elevations over 1,300 feet in another quarter to half mile. Surface elevations in the Agassiz Lake Plain District of this area vary from about 1,180 to 1,260 feet. The higher elevations are in the southeastern part of the area (Sections 28 and 33) where the Edinburg End Moraine is a prominent topographic feature. A northwest-southeast trending ridge in the eastern part of sections 5 and 8 and the western part of sections 9 and 16 may be a part of the Edinburg Moraine as the surface is marked by numerous boulders and the surface elevations rise to about 1,230 to 1,245 feet. Surface slopes are gradually westward from the Edinburg Moraine toward the escarpment and northeastward toward the Park River.

One hole (E-1, SE NE Sec. 19) was drilled in the Drift Prairie District. In this hole, the Niobrara Formation was penetrated directly underlying glacial drift at a depth of 34 feet. The hole was drilled to a total depth of 166 feet and was in the Niobrara Formation at total depth. The upper white specks zone was present from a depth of 34 to 82 feet, the high lime zone was present from a depth of 82 to 94 feet, the non-white specked zone was present from a depth of 94 to 130 feet, and the lower white specks zone was present from 130 to 166 feet.

One hole (E-2, NE NE Sec. 18) in the Agassiz Lake Plain District penetrated the Niobrara directly underlying the drift at a depth of 27 feet. This hole was drilled to a depth of 70 feet. The upper white specks zone was present from a depth of 27 to 47 feet, the high lime zone was present from a depth of 47 to 58 feet and the non-white specked zone was present from 58 to 70 feet.

Three other holes (E-3, E-4 and E-10) were drilled in the Agassiz Lake Plain District, but each of them was abandoned on boulders in the glacial drift. Hole E-4 (NW NE Sec. 17) was drilled to a total depth of 59 feet from a surface elevation of 1,219 feet. It should have been in the high lime zone at that depth if that zone were present at that locality. Hole E-10 (NW SW Sec. 16) was drilled to a total depth of 51 feet from a surface elevation of 1,202 feet. It should also have penetrated the high lime zone at that depth if the high lime zone were present at that locality.

The map (Fig. 2) and the cross section (Fig. 3) show an interpretation of the geology of the area based on limited field studies and the drill hole information. The drift is interpreted as being generally thin in the Drift Prairie District and near the escarpment in the Agassiz Lake Plain District. The drift thickens eastward from the escarpment, and in the test holes located about 3/4 of a mile and about one mile east of the escarpment the drift is at least 59 and 51 feet thick, but may be much thicker, since the bedrock was not encountered in these holes.

The high lime zone is present throughout the Drift Prairie District, but the depth to this zone is about 80 feet near the escarpment. Since the surface elevations rise westward and the Niobrara dips westward the depth to the high lime zone increases rapidly westward in the Drift Prairie District.

The high lime zone is present in the Agassiz Lake Plain District near the base of the escarpment at a depth of about 48 feet. However, eastward from the escarpment, where it had been anticipated that this zone might be found at shallower depths, erosion had removed these beds and glacial drift had been deposited.

In summary, the drilling program indicates that the thickness of drift and absence of the high lime zone in much of the Agassiz Lake Plain District eliminates that District as a prospective area. The depth to any zones of high calcium carbonate in the Drift Prairie District also makes that District unfavorable as an economic prospect. Therefore, no further drilling was done in the Edinburg area.

Park River

The Park River prospective area is located in T. 157 N., Rs. 56 and 57 W., Walsh County, North Dakota. Three test holes were drilled in this area with a total footage of 369 feet. The location of test holes, general geology of the area and the line of cross section are shown on the location map (Fig.4).

The boundary between the Drift Prairie District and the Agassiz Lake Plain District is a distinct topographic feature, but is not as abrupt as in the Edinburg area, rising westward at a rate of about 70 feet per mile in the map area. Two test holes were located in the Drift Prairie District where the drift was 18 and 23 feet thick. The third test hole, PR-3, located near the topographic break in slope marking the boundary between the two districts, penetrated 70 feet of drift without reaching bedrock.

The Niobrara Formation crops out at three localities within the map area, two along the Middle Branch of the Park River (NE NE of Sec. 24 and NW NW of Sec. 19) and one along a tributary of that stream (SW SE of Sec. 19). The Pierre-Niobrara contact is exposed in Section 24. Test Hole PR-1 (NE NE of Sec. 25), was located about one mile south of this exposure at an elevation of 1,313 feet. The hole was drilled to a depth of 169 feet, penetrating glacial drift from 0 to 18 feet, Pierre Formation from 18 to 56 feet and Niobrara Formation from 56 to 169 feet. In this well the upper white specks zone extends from 56 to 155 feet, the high lime zone extends from 155 to 165 feet and the non-white specked zone from 165 to 169 feet. Test hole PR-2 (NE NW of Sec. 30) was drilled to a depth of 130 feet, penetrating glacial drift from 0 to 23 feet and

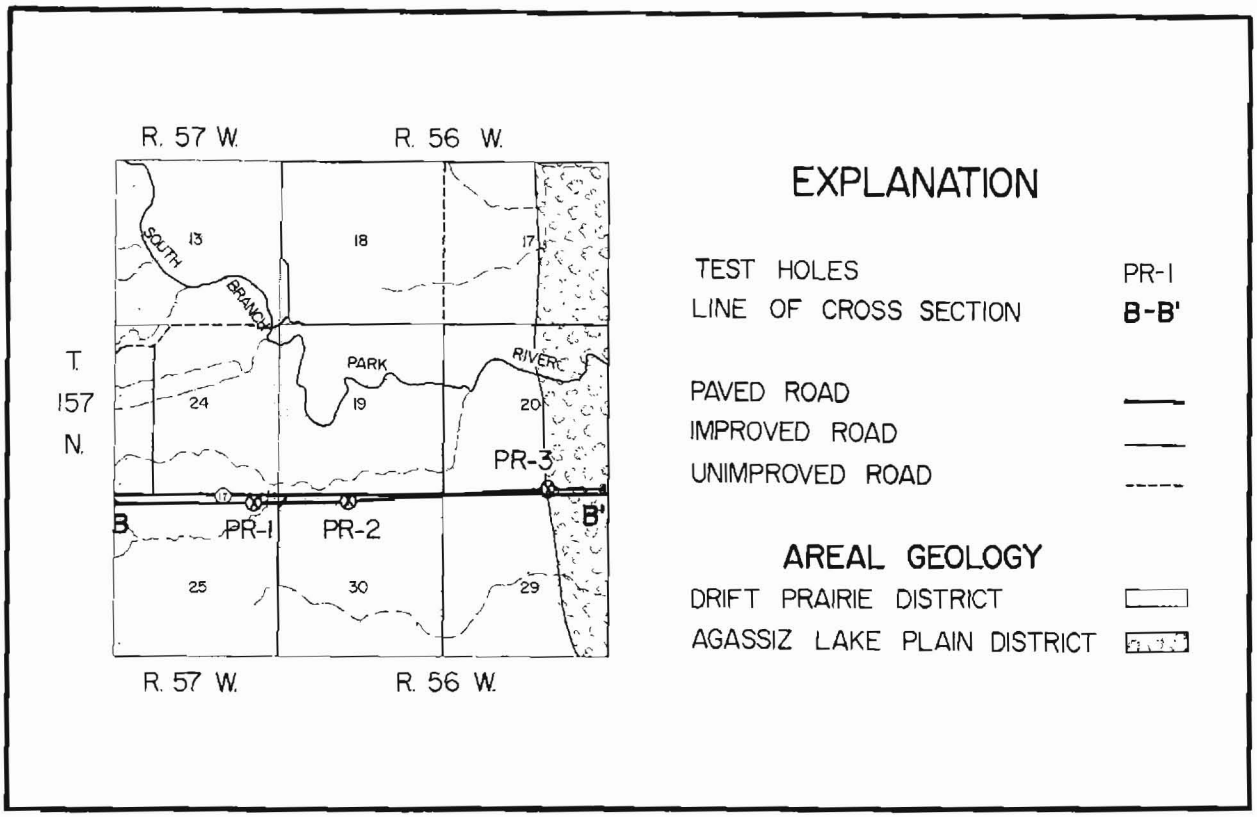

Figure 4 - Map of the Park River prospective area showing test hole locations, general geology of the area and the line of cross-section.

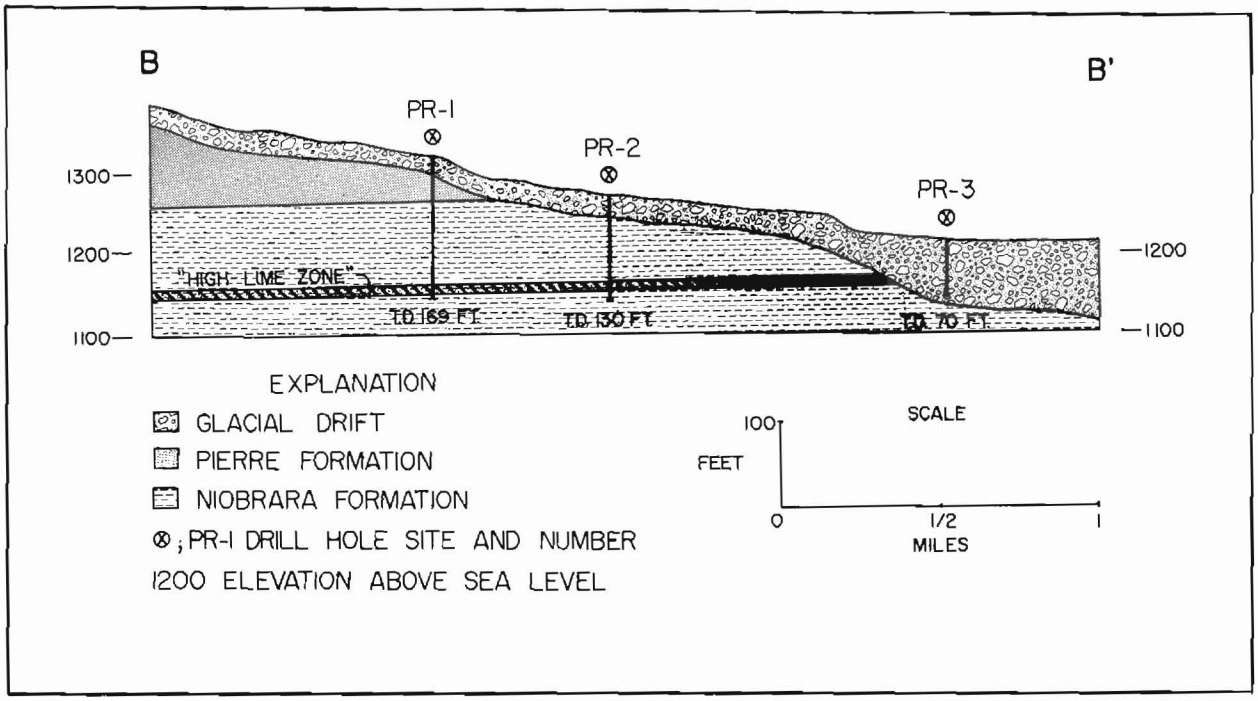

Figure 5 - Cross-section along the line B - B' showing geology of the Park River prospective area.

Niobrara from 23 to 130 feet. The upper white specks zone extended from 23 to 110 feet, the high lime zone from 110 to 119 feet and the non-white specked zone from 119 to 130 feet. Test hole PR-3 (SE SW of Sec. 20) was drilled to a depth of 70 feet, bottoming in glacial drift.

In summary, the Park River prospect is similar to the Edinburg prospect. The cross section (Fig. 5) shows that the zones of highest calcium carbonate in the Niobrara Formation are present in most of the Drift Prairie District, but are to deep to be of economic interest. Toward the east, where it had been anticipated that these zones might be found at shallower depths these zones have been removed by erosion and glacial drift has been deposited.

Lankin - Fordville

The Lankin-Fordville prospective area is located in Twps. 155 and 156 N., Rs. 56 and 57 W., Walsh County, North Dakota. The general geology of the area is similar to that of the Edinburg and Park River areas with the boundary between the Drift Prairie District and the Agassiz Lake Plain District being marked by a distinct break in topographic slope.

Test hole L-1 (SE SE Sec. 6, T. 155 N., R. 56 W.) was located in the Drift Prairie District at an elevation of 1,260 feet. This hole was drilled to a depth of 94 feet without encountering bedrock. This thickness of drift, based on the experience in the Edinburg and Park River areas, is unusually thick for this district, and since our experience in the areas to the north indicated that the drift generally thickens eastward, no further drilling seemed advisable in this area.

Shawnee - McCanna

The Shawnee-McCanna prospective area is located in Twps. 152 and 153 N., Rs. 55 and 56 W., Grand Forks County, North Dakota. Eleven test holes were drilled in this area with a total footage of 599.5 feet. The location of the test holes, general geology of the area, and the line of cross section are shown on the location map (Fig. 6).

The boundary between the Drift Prairie District and the Agassiz Lake Plain District is marked in this area by a gentle rise in surface elevations and scattered boulders on the surface in the Drift Prairie District. Elevations rise from about 1,160 feet to about 1,220 feet a mile west of the boundary. The test holes were all drilled in the Drift Prairie District. In seven test holes (S-1 to S-4, S-7, and S-10 to S-13) the drift ranged in thickness from 7 to 20 feet. One hole (S-5) encountered 34 feet of drift and one hole (S-6) penetrated 60 feet of drift without encountering bedrock.

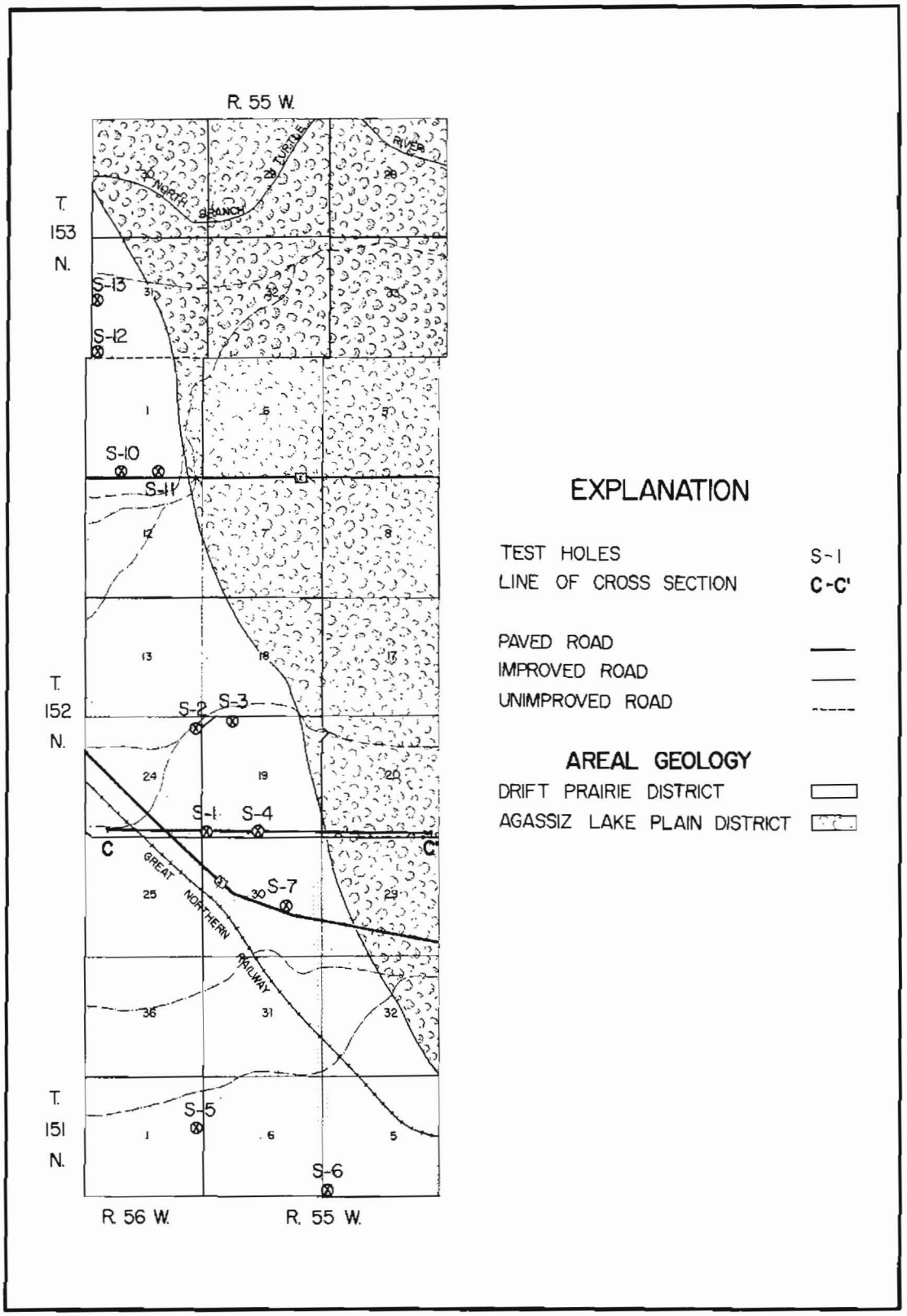

Figure 6 - Map of the Shawnee-McCanna prospective area showing test hole locations, general geology of the area and the line of cross-section.

In this area, immediately underlying the drift, the shale was weathered to a yellowish brown, soft, sticky shale. The thickness of this weathered zone varied from three to four feet in some test holes to seven and fourteen feet in others, being generally thickest where the drift is thinnest. Coring this weathered zone and seating surface casing in this zone was difficult, so the weathered zone was usually drilled with a rock bit, but in one hole (S-3) the weathered zone was cored. It is significant that no appreciable differences in percentages of any of the constituents were noted in chemical analyses (Table I, p.26) of the cores of the weathered zone (11-19 feet).

Most of the test holes penetrated part of the upper white specks zone, all of the high lime zone and were bottomed in the non-white specked zone. Four test holes (S-3, S-4, S-7 and S-11) encountered the high lime zone immediately below the drift or weathered zone. Test hole S-5 (SE NE of Sec. 1, T. 151 N., R. 56 W.) penetrated the most complete section, penetrating 76 feet of Niobrara. The upper white specks zone was present from 34 to 88 feet, the high lime zone was present from 88 to 99 feet and the non-white specked zone was present from 99 to 110 feet. The lower 30 feet of the upper white specks zone was also cored in five other test holes (S-1, 2, 10, 12, and 13).

The high lime zone is probably present in the prospective area throughout the Drift Prairie District north of U. S. Highway 2 where surface elevations exceed 1,175 feet. South of the highway, this zone is probably present in much of the Drift Prairie District also, but it was not present in test hole S-6 (SW SW Sec. 5, T. 151 N., R. 55 W.) where thick drift was encountered.

Present drainage patterns may reflect changes in the drift thickness pattern and were so interpreted on the isopach map (Fig.7). Thicknesses in the Drift Prairie District are based on test hole information, surface elevations and interpretation. Thicknesses in the Agassiz Lake Plain District are merely conjecture.

A map (Fig.8) was constructed to show the depth to the high lime zone based on the thickness of drift, depth to the high lime zone in the test holes, topography, and regional dip of the Niobrara. The most favorable prospect is one about a half mile wide and five miles long extending from the southeast quarter of Sec. 30, T. 151 N., R. 55 W., northwestward to the southwest quarter of Sec. 31, T. 153 N., R. 55 W. where the high lime zone is present at depths of 50 feet or less. Test hole S-7 is probably near the southeastern limit of this prospect based on test hole S-6, surface drainage, and location of transportation facilities. This prospect might be extended slightly by further drilling to the northwest, but the north branch of the Turtle River and the additional distance from transportation facilities probably limit the prospect in that direction.

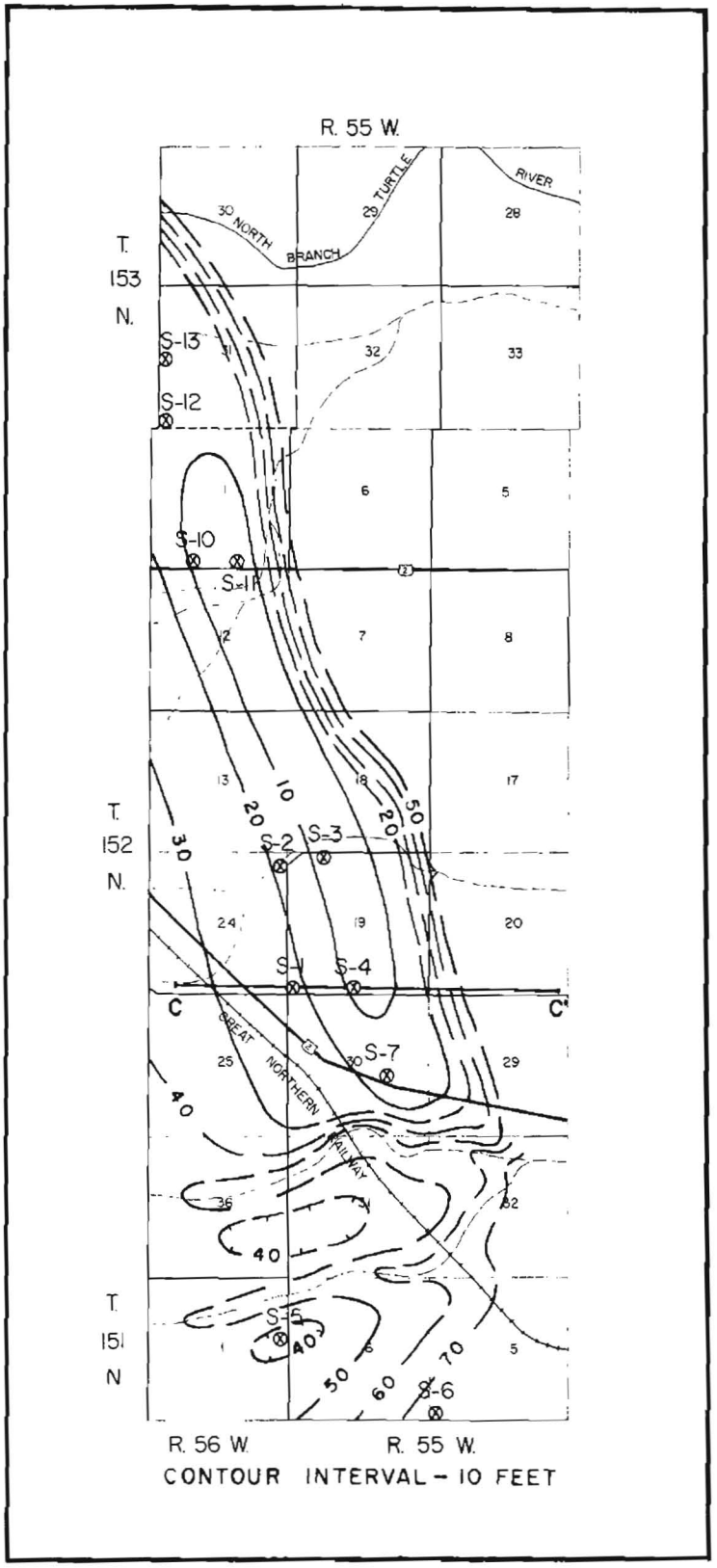

Figure 7 - Isopach map of glacial drift in the Shawnee-McCanna prospective area.

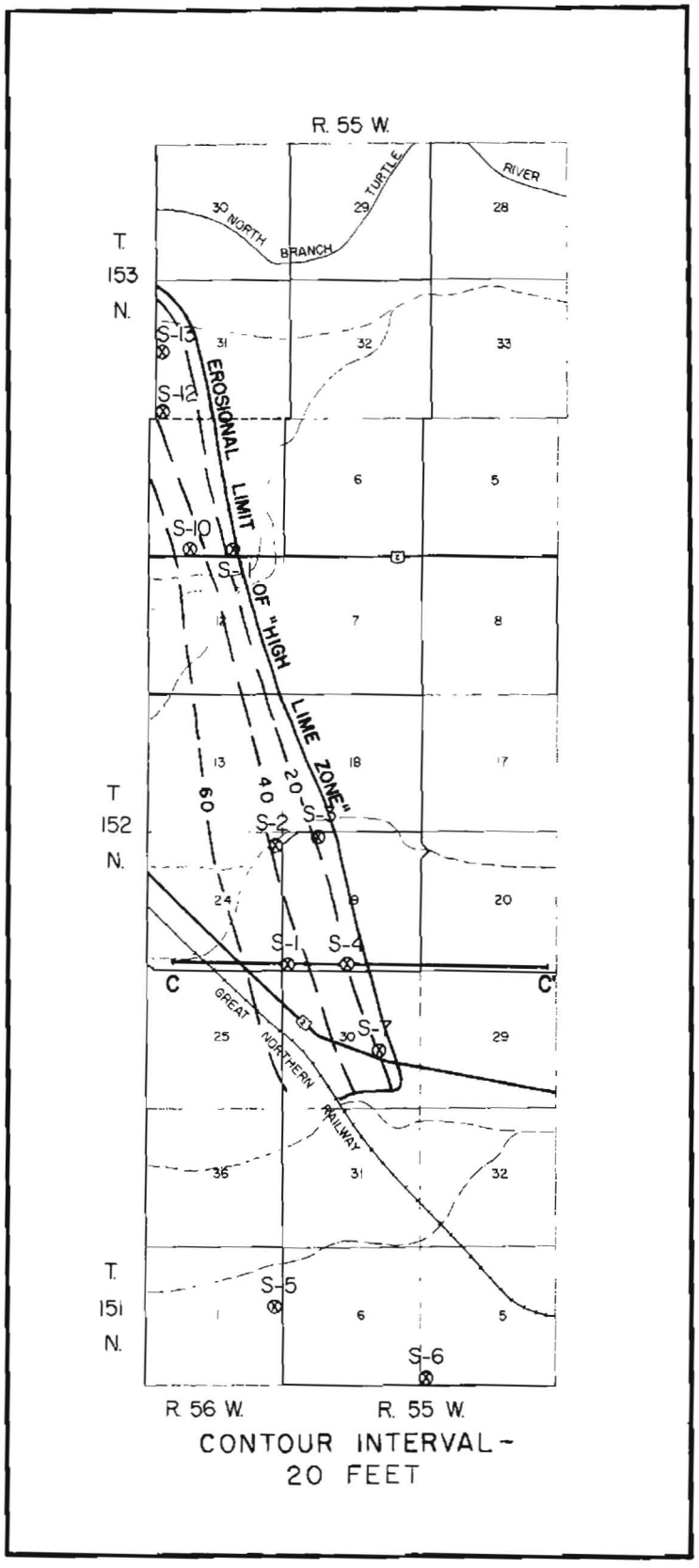

Figure 8 - Map of depth to the "high lime zone" of the Niobrara Formation in the Shawnee-McCanna area.

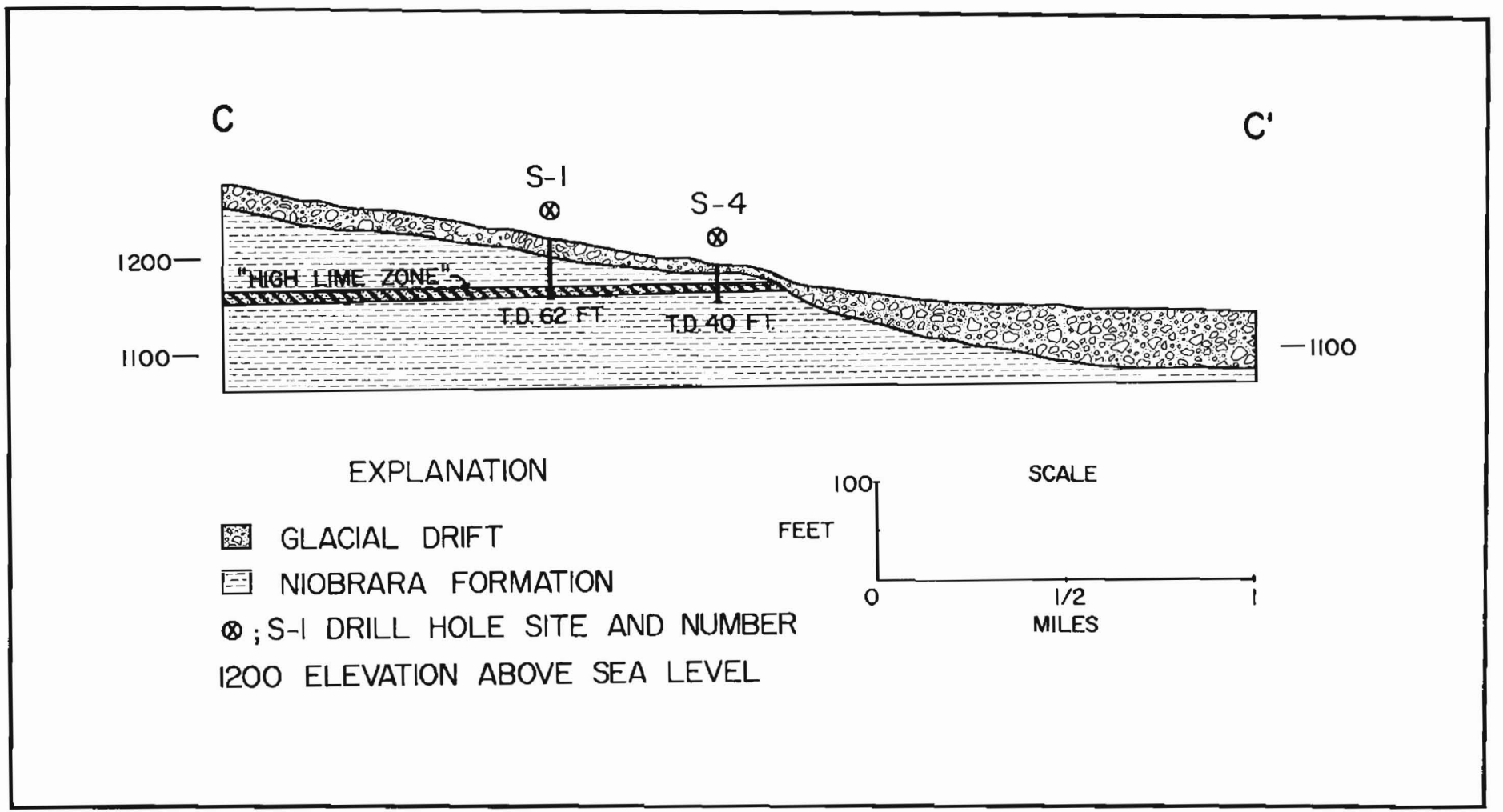

Figure 9 - Cross-section along the line C - C' showing geology of the Shawnee-McCanna prospective area.

The Shawnee-McCanna area is similar in some respects to the prospective areas to the north. The drift is generally thin in the Drift Prairie District and the boundary between the physiographic districts is an easily recognizable feature. However, as is shown on the cross section (Fig.9), this area differs from the northern prospective areas inasmuch as the high lime zone subcrops beneath the drift in the Drift Prairie District rather than in the Agassiz Lake Plain District. Thus, the high lime zone is present at relatively shallow depths over a sizeable area.

In summary, if the high lime zone were to prove to be a suitable raw material, this is the most favorable area as an economic prospect. If the entire ten foot interval were acceptable, a reserve of about 55 million tons is available at depths of less than 50 feet.

Northwood

The Northwood prospect is located in Twps. 149 to 150 N., R. 55 W., Grand Forks County, North Dakota. Two test holes were drilled in this area with a total footage of 120 feet. Both sites were located in the Drift Prairie District at elevations of about 1,260 feet and were drilled to depths of 60 feet without penetrating bedrock. Since these thicknesses of drift were considered to be excessive, particularly when the Shawnee-McCanna prospect was taken into consideration, this prospective area was abandoned.

ANALYTICAL PROCEDURES

Chemical Analyses

Complete analyses of the high lime zone were run on eight test holes, one in the Edinburg area (E-1), one in the Park River area (PR-1), and six in the Shawnee-McCanna area (S-1, 2, 3, 4, 10, and 11). These analyses were made for Fe, Si, Al, P, CaO, CO_2, MgO, S, Na_2O, K_2O and loss on ignition. A total of 68 samples were analyzed by the Lerch Brothers Laboratories in Hibbing, Minnesota and these results are listed in Table I.

Gasometric analyses for carbon dioxide content were run on most of the cores subsequent to the drilling program. Samples were taken at one foot intervals on most of the wells, but to conserve time, some cores were sampled at two foot intervals. In most cases only one run per sample was made, but a few samples were double checked. No samples were re-checked after the calculations were made. The results listed in Table II represent the gasometric measurement of carbon dioxide and its calculated equivalent in terms of calcium carbonate. For those samples for which chemical analyses were run by

Lerch Brothers, those determinations are included in Table II. Although some of the samples for gasometric analyses were taken subsequent to those for chemical analyses, comparisons of the results show that the gasometric method is a reliable instrument for rapid determinations. Half of the gasometric analyses agree within one percent of the chemical analyses and three fourths of the analyses agree within two percent. Only two determinations are more than three percent off, one being 3.9 percent and one being 4.7 percent off. In both cases the gasometric analyses were low and in general the gasometric determinations were slightly lower than the chemical analyses. This suggests that perhaps the reaction did not quite reach completion in some of the determinations, however, any errors should be on the conservative side in regard to the calculated calcium carbonate content.

The average analyses for the high lime zone for the eight test holes on which chemical analyses were run are as follows:

Test Hole	Depth	Chittick Gasometric $CaCO_3$	Lerch Analysis $CaCO_3$
E-1	82-93	60.91	61.08
PR-1	155-165	61.47	63.49
S-1	48-59	62.88	61.67
S-2	36-46	64.02	64.94
S-3	16-27	61.68	66.40
S-4	20-29	60.05	63.12
S-10	57-66	64.33	57.62
S-11	21-27	65.24	66.43

Test holes E-1, PR-1 and S-4 were analyzed at one foot intervals by both methods. Test holes S-1, S-2, S-3, S-10 and S-11 were analyzed at two foot intervals by Lerch Brothers and at one foot intervals by the gasometric methods. Gasometric analyses of the high lime zone in the other test holes are as follows:

Test Hole	Depth	$CaCO_3$
PR-2	110-118	62.31
S-5	87-98	63.66
S-7	21-31	62.02
S-12	38-47	61.91
S-13	37-46	63.85

In only two test holes did any other ten foot intervals show comparable calcium carbonate content. One of these was test hole E-1, where the interval

from 43 to 55 feet analyzed 62.67 percent calcium carbonate, and the other was test hole PR-2, where the interval from 76 to 86 feet analyzed 63.78 percent calcium carbonate. Both of these zones are in the upper white specks zone. In test hole E-1, the base of this zone lies 27 feet above the top of the high lime zone, whereas in test hole PR-2, the base of this zone lies 34 feet above the top of the high lime zone. Gasometric analyses of the upper white specks zone in test holes PR-1 and S-5 did not find any ten foot interval which approaches 60 percent calcium carbonate content, nor were any zones of high calcium carbonate noted in the upper white specks zone in the other holes drilled in the Shawnee-McCanna area.

X-Ray Diffraction Analyses

The X-Ray technique is usually used for mineral identification where the material is very fine grained and other methods of identification are unsatisfactory. Since the cement rock of the Niobrara falls into this category, five samples of the "high lime zone" were sent for analysis to Mr. Arthur Reesman, geologist at the University of Missouri, Columbia, Missouri. The following is a summary of the X-Ray data which he presented.

The procedure followed was to dissolve about 15 grams of sample in dilute hydrochloric acid. The results of the acid treatment are as follows:

Sample No.	Weight of Sample	Weight of Residue	Percent of Insoluble Residue
21	14.457 gms.	6.101 gms.	42
23	14.979 gms.	8.687 gms.	58
25	15.054 gms.	5.375 gms.	35
27	15.103 gms.	4.986 gms.	33
29	15.152 gms.	5.118 gms.	34

The insoluble residues were then put back in suspension. Since the clays showed a tendency to flocculate, calgon was added to aid in getting the residue into suspension. Oriented samples of clay were then made by running the clay suspension through a porous tile which tends to orientate the clays with reference to their basal cleavages. X-Ray analyses were then made using a Norelco X-Ray Spectrometer. Major peaks noted in the X-Ray analyses are shown in Table III (p. 38). The diffraction patterns obtained were reduced using a Kail Reflecting Projector and are presented with Mr. Reesman's comments in Appendix C (p. 54). Two runs were made on each sample, one unglycolated and one glycolated. The purpose of adding the glycol was to differentiate the montmorillonite from the rest of the clay minerals.

The samples examined were taken from test hole S-4, located in the SE SW of Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota. Sample numbers represent the depth of the core sample analyzed and the results are as follows:

Minerals Present

Sample 21 - Quartz, Kaolinite, Chlorite, Illite, Mica-Biotite ?, Montmorillonite.
Sample 23 - Quartz, Kaolinite, Chlorite, Illite, Mica-Biotite ?, Montmorillonite.
Sample 25 - Quartz, Kaolinite, Chlorite, Illite, Montmorillonite.
Sample 27 - Quartz, Kaolinite, Chlorite, Illite, Montmorillonite.
Sample 29 - Quartz, Kaolinite, Chlorite, Mica-Biotite ?, Montmorillonite.

X-Ray analysis can be used for quantitative analysis also, but this requires considerable time and therefore added expense, so these determinations were essentially qualitative, although some quantitative estimates can be made based on area under the curves. No estimates of actual percentages of each constituent were attempted, but he did estimate that quartz and kaolinite are present in about equal amounts in sample 21, and that quartz is present in about the same amount in each sample. Kaolinite was estimated to be only about half as abundant in sample 23 as in sample 21, and continues to decrease in abundance in samples 25 and 27, with a slight increase again in sample 29. No estimates of relative abundance of the other clay minerals were attempted.

SUMMARY

A total stratigraphic section of 182 feet of Niobrara Formation was cored in the drilling program. Analyses of these cores indicate that one ten foot interval about 100 feet below the top of the Niobrara Formation is consistent in physical and chemical properties and that this zone consistently analyzes higher than any other ten foot zone. Therefore, if the Niobrara is to be used as a raw material for cement, this zone would be the most suitable raw material. However, the gasometric analyses of this zone show an average calcium carbonate content of only about 63 percent. Since a Portland Grade Cement requires a calcium carbonate content of 80 percent, this material must either be beneficiated or upgraded by the addition of limestone before it would be a suitable raw material.

X-Ray analyses were run to determine the minerals present with the hope that this might be an aid to beneficiation. If the problems of beneficiation can be solved, or, if it is economically feasible to import limestone to upgrade the Niobrara, a deposit of about 55 million tons is available at a depth of less than 50 feet in the Shawnee-McCanna area. The prospect is located near a railroad,

and overburden would consist of seven to twenty feet of drift and thirty feet or less of shale.

The drilling program indicates that the high lime zone is probably not present at such shallow depths north of the Shawnee-McCanna area. Limited drilling in the Northwood area and other available information indicates generally thick drift in Steele, Griggs and Barnes Counties. Thus it is very unlikely that the high lime zone could be found at shallow depths in areas toward the south, either. Since the Shawnee-McCanna area combines the factors of the zone of highest calcium carbonate of the Niobrara Formation being at depths of less than 50 feet, the drift being thin (7 to 20 feet), and the prospect being near the railroad (within a half mile at the south end of the prospect) the project was terminated in this area. If the Shawnee-McCanna prospect is uneconomical, it is very unlikely that a better prospect can be found in the Niobrara of northeastern North Dakota.

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Powers, W. E., 1946, Cement rock and limestone deposits of North Dakota: North Dakota Geological Survey, open file report, p. 3-16.

Wilder, F. A., 1902, Statistics of mineral production: North Dakota Geological Survey, 2nd. Biennial Report, p. 30-31.

HOLE NO. E - 1; Location - SE NE Sec. 19, T. 158 N., R. 56 W., Walsh County, North Dakota

Depth	Total Fe	HF Si	Fus. A1203	Total P	CaO	C02	MgO	Loss on Ignition	S	Na20	K20
79	3.13	32.34	12.80	.072	24.56	19.40	.32	25.20	1.72	.47	1.02
80	2.57	28.58	11.80	.037	28.12	22.75	.34	27.25	1.30	.45	.95
81	4.74	27.36	12.36	.019	28.28	20.95	.34	24.60	1.60	.42	.84
82	2.89	23.40	11.48	.040	34.00	24.90	.41	26.32	1.35	.35	.96
83	2.82	22.94	11.08	.048	32.40	26.60	.40	27.84	1.27	.42	.67
84	1.93	19.90	10.16	.141	35.08	27.55	.72	31.08	.37	.28	.95
85	1.85	23.14	12.00	.072	33.60	25.70	.86	27.53	.27	.32	1.06
86	2.17	22.38	10.36	.035	34.00	27.70	1.62	28.32	.32	.32	.90
87	2.49	19.48	7.76	.098	35.52	29.75	2.00	31.52	.26	.26	.85
88	2.33	19.74	8.16	.046	36.72	29.70	1.84	31.00	.18	.36	.85
89	1.61	20.76	8.48	.073	36.92	28.50	1.92	29.42	.21	.35	.92
90	1.85	27.06	12.36	.057	29.36	22.70	1.20	27.14	.27	.46	1.22
91	5.87	22.60	9.10	.068	29.84	24.65	1.22	28.58	1.67	.32	.89
92	2.57	16.56	6.66	.071	38.24	31.10	2.06	32.68	.19	.26	.82
93	2.09	26.00	10.02	.086	32.08	26.40	1.25	27.31	.32	.37	1.16

HOLE NO. PR - 1; Location NE NE Sec. 25, T. 157 N., R. 57 W., Walsh County, North Dakota

155	2.01	22.22	9.34	.328	35.44	26.20	.29	29.20	.88	.37	.93
156	2.25	29.50	11.68	.060	29.36	22.65	.18	25.80	.96	.43	1.15
157	2.09	20.10	8.12	.134	36.88	27.60	.60	31.50	.77	.36	.87
158	2.97	17.68	7.18	.180	38.24	28.15	1.07	31.08	1.48	.32	.79
159	1.93	19.72	8.25	.214	36.52	29.55	1.10	31.26	.29	.28	.86
160	2.15	20.26	7.90	.039	34.80	29.90	2.00	31.48	.37	.27	.83
161	2.09	29.40	11.52	.070	29.84	21.80	.20	26.20	.32	.42	1.17
162	2.01	19.04	7.56	.069	38.80	29.50	.44	31.00	.26	.26	.80
163	2.33	17.80	7.35	.071	37.72	30.85	1.60	32.04	.23	.32	.80
164	2.41	16.60	6.75	.066	38.68	29.05	2.15	32.12	.29	.28	.72
165	2.49	17.80	7.74	.322	37.04	29.85	2.12	31.20	.22	.34	.75

TABLE I - CHEMICAL ANALYSES OF NIOBRARA SAMPLES

HOLE NO. S - 1; Location SW SW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota

Depth	Total Fe	HF Si	Fus. A1203	Total P	CaO	C02	MgO	Loss on Ignition	S	Na20	K20
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

TABLE I - Continued

Depth	Total Fe	HF Si	Fus. A1203	Total P	CaO	C02	MgO	Loss on Ignition	S	Na20	K20
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

TABLE I - Continued

HOLE NO. E - 1; Location - SE NE Sec. 19, T. 158 N., R. 56 W., Walsh County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
40	26.29	59.78	73		28.03	63.75	106	6.91	15.73
41	25.99	59.09	74		26.56	60.39	107	2.43	5.52
42	25.01	56.86	75		15.33	34.86	108	3.41	7.75
43	27.87	63.36	76		12.50	28.43	109	5.40	12.28
44	25.48	57.95	77		11.72	26.66	110	2.14	4.87
45	27.87	63.36	78		9.76	22.19	111	3.02	6.86
46	25.80	58.68	79	19.40	18.78	42.71	113	3.21	7.30
47	29.37	66.79	80	22.75	22.51	51.19	115	6.82	15.50
48	24.61	55.97	81	20.95	21.33	48.51	117	12.66	28.79
49	27.78	63.18	82	24.90	24.66	56.08	119	2.82	6.41
50	28.38	64.55	83	26.60	25.98	59.09	121	3.12	7.10
51	26.10	59.37	84	27.55	27.51	62.57	123	1.95	4.43
52	25.35	57.66	85	25.70	24.12	54.86	125	2.82	6.41
53	31.14	70.81	86	27.70	26.00	59.13	127	8.86	20.15
54	28.75	65.38	87	29.75	29.80	67.77	129	13.18	29.97
55	29.72	67.60	88	29.70	29.31	66.67	131	14.06	31.97
56	25.33	57.62	89	28.50	27.90	63.46	133	16.67	37.92
57	30.10	68.45	90	22.70	22.62	51.45	135	4.80	10.91
58	28.51	64.84	91	24.65	26.34	59.90	137	5.33	12.12
59	27.11	61.65	92	31.10	30.33	68.98	139	13.67	31.08
60	27.31	62.12	93	26.40	24.15	54.92	141	19.58	44.53
61	28.81	65.53	94		15.62	35.52	143	5.81	13.22
62	26.32	59.86	95		5.86	13.34	145	17.79	40.47
63	24.22	55.08	96		1.46	3.32	147	5.17	11.76
64	24.97	56.78	97		7.32	16.66	149	20.67	47.00
65	24.48	55.68	98		6.64	15.09	151	8.95	20.35
66	23.98	54.54	99		5.08	11.56	153	14.31	32.54
67	19.27	43.83	100		8.11	18.45	155	19.97	45.42
68	27.13	61.69	101		3.60	8.19	157	16.20	36.83
69	25.75	58.56	102		6.81	15.49	159	14.75	33.55
70	18.68	42.49	103		2.14	4.87	161	12.08	27.46
71	25.75	58.56	104		4.13	9.40	163	9.21	20.93
72	25.95	59.01	105		7.98	18.16	165	11.09	25.22

TABLE II - Chittick Gasometric Analyses of Niobrara Samples

HOLE NO. PR-1; Location - NE NE Sec. 25, T. 157 N., R. 57 W., Walsh County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$
56	19.97	45.42	100	13.88	31.56	142		26.80	60.93
58	30.11	68.49	102	12.02	27.33	144		25.40	57.76
60	30.51	69.39	104	8.77	19.95	146		26.01	59.16
62	0.19	0.43	106	12.31	27.99	148		24.82	56.43
64	26.60	60.48	108	11.03	25.09	149		12.85	29.22
66	27.29	62.05	110	12.66	28.79	150		14.43	32.81
68	0.29	0.66	112	12.80	29.11	151		17.59	39.99
70	21.04	47.85	114	14.77	33.58	152		14.23	32.36
72	19.50	44.36	116	13.79	31.35	153		22.33	50.78
74	27.31	62.12	118	12.70	28.88	154		15.65	35.60
76	15.12	34.39	120	14.47	32.90	155	26.20	25.68	58.40
78	26.72	60.76	122	11.37	25.87	156	22.65	21.15	48.10
80	11.15	25.35	124	13.58	30.89	157	27.60	26.54	60.35
82	9.78	22.23	126	13.38	30.42	158	28.15	28.14	64.00
84	9.49	21.58	127	13.68	31.11	159	29.55	27.54	62.62
86	11.16	25.39	129	13.04	29.65	160	29.90	28.34	64.45
88	12.92	29.39	130	12.35	28.10	161	21.80	21.35	48.55
90	11.79	26.81	132	25.18	57.26	162	29.50	28.85	65.61
92	12.77	29.04	134	23.07	52.47	163	30.85	29.84	67.85
94	12.51	28.46	136	23.67	53.82	164	29.05	30.74	69.91
96	10.38	23.60	138	24.97	56.78	165	29.85	29.16	66.31
98	11.02	25.06	140	23.72	53.94				

TABLE II - Continued

HOLE NO. PR-2; Location; NW NE Sec. 30, T. 157 N., R. 56 W., Walsh County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
24	8.77	19.94	58	24.13	54.87	92	23.54	53.53
25	25.04	56.94	59	18.34	41.72	93	14.62	33.25
26	26.50	60.27	60	19.72	44.85	94	25.44	57.86
27	27.18	61.81	61	19.82	45.09	95	17.43	39.63
28	11.30	25.68	62	25.43	57.83	96	24.24	55.12
29	25.43	57.83	63	22.69	51.59	97	22.84	51.95
30	25.13	57.15	64	24.84	56.49	98	20.64	46.93
31	19.09	43.43	65	23.87	54.29	99	25.85	40.35
32	17.96	40.84	66	26.12	59.41	100	28.45	64.69
33	18.44	41.93	67	22.31	50.74	101	31.45	71.53
34	25.82	58.72	68	24.66	56.08	102	21.04	47.85
35	26.30	59.82	69	26.42	60.09	103	26.53	60.34
36	21.94	49.89	70	27.79	63.19	104	20.71	47.09
37	23.29	52.97	71	27.20	61.85	105	13.77	31.31
38	21.73	49.43	72	26.03	59.20	106	23.32	53.04
39	22.50	51.18	73	28.96	65.86	107	16.09	36.59
40	22.31	50.74	74	26.74	60.82	108	14.88	33.83
41	25.60	58.23	75	25.83	58.75	109	15.28	34.75
42	22.31	50.74	76	29.25	66.51	110	23.94	54.46
43	22.11	50.29	77	28.95	65.85	111	25.54	58.08
44	16.29	37.06	78	30.82	70.08	112	28.56	64.96
45	19.40	44.12	79	24.62	56.00	113	28.86	65.62
46	21.14	48.09	80	28.95	65.85	114	29.78	67.73
47	27.34	62.17	81	27.87	63.38	115	25.87	58.84
48	9.69	22.03	82	25.21	57.34	116	29.18	66.35
49	19.20	43.67	83	27.57	62.70	117	29.79	67.76
50	24.71	56.20	84	30.13	68.53	118	25.07	57.02
51	26.17	59.53	85	28.26	64.27	119	8.53	19.39
52	24.04	54.67	86	26.88	61.12	120	.20	0.45
53	26.86	61.08	87	21.17	48.14	122	5.87	13.35
54	23.54	53.53	88	26.88	61.12	124	7.53	17.12

TABLE II Continued

HOLE NO. PR-2 Continued

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
55	21.78	49.52	89	26.99	61.39	126	0	0.00
56	23.15	52.64	90	27.48	62.49	128	9.94	22.60
57	25.11	57.10	91	23.44	53.32	130	6.49	14.76

HOLE NO. S-1; Location - SW SW Section 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. CO_2	Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$
24	23.84	54.22	37	31.57	71.79	48		28.43	64.65
25	24.78	56.36	38	23.67	53.82	50	28.35	28.03	63.75
26	18.28	41.57	39	21.74	49.44	51		27.94	63.55
27	22.35	50.82	40	26.01	59.16	52	22.35	19.70	44.81
28	21.74	49.44	41	25.70	58.44	53		25.63	58.28
29	23.97	54.51	42	27.41	62.33	54	25.75	27.53	62.61
30	23.56	53.58	43	26.61	60.51	55		28.74	65.37
31	15.43	35.08	44	26.00	59.13	56	29.50	28.74	65.37
32	21.93	39.88	45	27.01	61.43	57		29.54	67.19
33	23.55	53.57	46	20.10	45.71	58	31.10	28.74	65.37
34	23.75	54.02	47	22.21	50.52	59		28.64	65.13
35	21.96	49.95	49	30.15	68.57	60	27.20	22.51	51.19
36	23.27	52.92							

TABLE II - Continued

HOLE NO. S-2, Location - NE NE Sec. 24, T. 152 N., R. 56 W., Grand Forks County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$
20	20.34	46.27	30	25.90	58.89	34	27.00	26.80	60.95
21	21.74	49.44	31	21.91	49.84	36	30.20	29.78	67.73
22	22.43	51.01	32	26.80	60.95	38	27.75	25.81	58.69
23	22.26	50.62	33	26.11	59.38	40	25.45	26.46	60.18
24	30.99	70.48	35	25.02	56.90	42	31.25	30.51	69.39
25	24.10	54.82	37	27.30	62.09	43		29.32	66.68
26	25.90	58.89	39	25.61	58.24	44	30.70	28.03	63.75
27	19.72	44.85	41	28.64	65.13	45		28.63	65.12
28	26.10	59.37	48	4.62	10.51	46	30.60	28.23	64.20
29	25.90	58.89	49	3.10	7.05	47		26.35	59.93

HOLE NO. S-3, Location - NE NW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
11	25.67	58.39	17	31.20	28.73	65.34	32	6.01	13.67
12	25.87	58.84	18		28.59	65.01	34	9.88	22.47
13	18.69	42.50	19	25.40	24.56	55.85	36	8.91	20.25
14	23.60	53.66	20		19.77	44.97	38	7.34	16.70
15	22.23	50.56	21	27.35	27.14	61.72	40	2.95	6.70
16	28.76	65.41	22		26.44	60.14	42	2.95	6.70
26	28.87	65.66	23	31.50	29.51	67.12	44	0.30	0.69
28	23.98	54.54	24		26.44	60.14			
30	9.32	21.20	25	30.80	28.32	64.40			
			27	31.00	28.32	64.40			

TABLE II Continued

HOLE NO. S-4; Location - SE SW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota

Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$	Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
20	31.05	26.14	59.45	26	29.90	29.12	66.23	32	5.41	12.29
21	26.85	25.56	58.12	27	29.85	29.50	67.08	34	6.59	15.00
22	25.05	24.68	56.13	28	31.00	29.90	68.00	36	8.46	19.23
23	18.75	14.82	33.70	29	30.55	29.60	67.32	38	11.61	26.40
24	25.65	26.53	60.34	30		21.56	49.03	40	5.90	13.40
25	29.35	28.19	64.09	31	21.00	19.16	43.56			

HOLE NO. S-5; Location - SE NE Sec. 1, T. 151 N., R. 56 W., Grand Forks County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
44	25.15	57.18	66	22.08	50.21	88	30.49	69.34
45	22.91	52.11	67	24.28	55.23	89	27.46	62.45
46	23.32	53.04	68	17.06	38.78	90	25.96	59.04
47	20.68	47.04	69	20.37	46.32	91	25.37	57.70
48	22.04	50.12	70	21.36	48.58	92	24.97	56.78
49	23.76	54.03	71	16.46	37.43	93	28.19	64.11
50	24.67	56.09	72	21.86	49.72	94	28.51	64.84
51	23.38	53.17	73	22.53	51.23	95	29.52	67.13
52	17.53	39.86	74	22.12	50.30	96	29.12	66.23
53	24.59	55.92	75	28.18	64.08	97	29.72	67.60
54	19.85	45.14	76	28.87	65.66	98	28.41	64.61
55	22.26	50.62	77	25.58	58.19	99	24.13	54.87
56	23.57	53.61	78	24.58	55.89	100	3.58	8.12
57	20.35	46.28	79	23.17	52.69	101	10.02	22.78
58	22.16	50.40	80	26.37	59.98	102	0.60	1.35
59	25.58	58.19	81	26.37	59.98	103	8.43	19.15
60	20.75	47.20	82	25.87	58.84	104	9.92	22.55
61	25.78	58.64	83	22.37	50.89	105	9.22	20.97

TABLE II Continued

HOLE NO. S-5

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
62	22.76	51.75	84	27.36	62.24	107	10.97	24.94
63	24.04	54.67	85	17.97	40.87	109	10.97	24.94
64	22.84	51.95	86	21.37	48.59	110	5.78	13.14
65	16.36	37.20	87	28.16	64.04			

HOLE NO. S-7; Location - NW SE Sec. 30, T. 152 N., R. 55 W., Grand Forks County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
21	26.31	59.83	27	29.00	65.95	34	2.54	5.76
22	17.09	38.96	28	30.39	69.11	36	2.35	5.35
23	24.64	56.04	29	29.59	67.29	38	15.26	34.71
24	29.80	66.77	30	28.40	64.60	40	3.89	8.84
25	29.80	66.77	31	26.22	59.62			
26	29.60	67.32	32	8.24	18.74			

TABLE II Continued

HOLE NO. S-10; Location - SE SW Sec. 1. T. 152 N., R. 56 W., Grand Forks County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$
29	25.41	57.79	43	25.84	58.76	53	24.20	25.35	57.66
30	17.61	40.04	44	26.13	59.42	54		24.37	55.43
31	22.26	50.62	45	25.36	57.67	55	23.72	23.33	53.05
32	20.61	46.88	46	25.84	58.76	56		24.20	55.03
33	24.58	55.89	47	22.95	52.26	57	28.20	28.57	64.97
34	15.48	35.20	48	27.19	61.84	58		29.25	66.51
35	21.09	47.97	49	22.94	52.16	59	28.52	28.76	65.41
36	21.86	49.72	50	20.91	47.56	60		28.96	65.86
37	21.67	49.28	51	24.67	56.09	61	30.20	29.03	66.02
38	21.28	48.39	52	30.45	69.26	62		28.27	64.28
39	23.41	53.24				63	19.41	22.94	52.16
40	30.56	69.51				64		30.68	69.78
41	25.46	57.91	67	18.28	41.57	65	28.37	28.55	64.93
42	18.32	41.66	68	3.29	5.65	66		27.85	63.34

HOLE NO. S-11; Location - SW SE Sec. 1, T. 152 N., R. 56 W., Grand Forks County, North Dakota

Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$	Depth	Lerch CO_2	Chittick CO_2	Calc. $CaCO_3$
21	30.20	30.34	68.99	26		25.03	56.93
22		29.07	66.11	27	27.14	30.50	69.35
23	28.24	27.81	63.26	28		23.78	54.09
24		29.85	67.89	29		1.32	3.00
25	25.41	28.20	64.12	30		1.07	2.43

TABLE II Continued

HOLE NO. S-12; Location; SW SW Sec. 31, T. 153 N., R. 55 W., Grand Forks County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
21	31.64	71.95	31	21.53	48.96	41	28.30	64.36
22	22.87	52.02	32	25.25	57.42	42	28.10	63.91
23	21.47	48.83	33	29.75	67.65	43	20.88	47.49
24	25.64	58.31	34	26.62	60.54	44	27.81	63.26
25	26.13	59.42	35	27.01	61.43	45	19.28	43.84
26	24.48	55.68	36	26.22	59.62	46	30.39	69.11
27	26.24	59.69	37	24.66	56.08	47	29.21	66.43
28	22.72	51.67	38	28.71	65.29	48	10.58	24.05
29	25.64	58.31	39	29.47	67.03	49	7.55	17.16
30	22.51	51.19	40	30.05	68.34	50	8.23	18.73

HOLE NO. S-13; Location; NW SW Sec. 31, T. 153 N., R. 55 W., Grand Forks County, North Dakota

Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$	Depth	CO_2	Calc. $CaCO_3$
21	28.51	64.84	31	22.72	51.67	41	28.29	64.35
22	28.70	65.26	32	31.90	72.55	42	29.86	67.92
23	25.29	57.51	33	26.47	60.19	43	26.52	60.31
24	21.09	47.97	34	22.99	52.28	44	25.74	58.53
25	28.12	63.95	35	24.56	55.85	45	29.47	67.03
26	26.07	59.29	36	21.02	47.81	46	28.88	65.69
27	25.41	57.79	37	26.72	60.76	47	21.90	49.80
28	26.40	60.05	38	28.09	63.88	48	8.55	19.43
29	20.29	46.15	39	28.68	65.22	49	6.09	13.86
30	20.98	47.72	40	28.49	64.80	50	8.62	19.59

TABLE II Continued

SHAWNEE - MC CANNA OUTCROP; Location - SE NE Sec. 23, T. 152 N., R. 56 W., Grand Forks County, North Dakota

SAMPLE	CO_2	Calc. $CaCO_3$	SAMPLE	CO_2	Calc. $CaCO_3$	SAMPLE	CO_2	Calc. $CaCO_3$
OS-1	20.01	45.50	OS-2	24.63	56.01	OS-3	21.74	49.44

PARK RIVER OUTCROP; Location - NE NE Sec. 24, T. 157 N., R. 57 W., Walsh County, North Dakota

			18' above base	28.38	64.55	8' above base	25.13	57.14
24' above base	28.88	65.69	16' "	19.64	44.66	6' "	22.54	51.26
22' "	25.93	58.97	14' "	23.37	53.16	4' "	11.67	26.53
20' "	28.09	63.88	12' "	16.20	36.83	2' "	22.76	51.75
			10' "	23.36	53.13	base of Sec.	26.79	60.92

PARK RIVER OUTCROP; Location - NW NW Sec. 19, T. 157 N., R. 56 W., Walsh County, North Dakota

18' above base	15.60	35.48	14' above base	21.14	48.09	6' above base	27.08	61.59
16' "	15.60	35.48	12' "	25.80	58.68	4' "	27.38	62.26
			10' "	20.76	47.21	2' "	20.46	46.52
			8' "	18.68	42.49	base of Sec.	27.48	62.49

TABLE II Continued

Peak	Mineral	Peak	Mineral
1.82 A^{O}	Chlorite (205) & ($13\bar{6}$)	3.56 A^{O}	Kaolinite (002)
1.99 A^{O}	Kaolinite ($20\bar{3}$) & ($1\bar{3}2$)	4.35 A^{O}	Kaolinite (110)
2.00 A^{O}	Mica (probably Biotite)	4.96 A^{O}	Micas (002)
2.13 A^{O}	Kaolinite ($02\bar{3}$) & (041)	7.2 A^{O}	Kaolinite (001)
2.56 A^{O}	Illite	9.9+A^{O}	Micas (001) (Illite, Muscovite, Biotite, and unexpanded Montmorillonite, 10 A^{O} - 13 A^{O} Expanding Clays). (Montmorillonite).
3.34 A^{O}	Quartz (110)	13.8 A^{O}	Chlorite
3.50 A^{O}	Chlorite		

Table III - X-Ray Diffraction peaks noted, minerals present and their Miller indices.

APPENDIX A

The surface was drilled with rock bits and the description of cuttings are from the drillers log with slight modifications. Continuous cores were cut through the bedrock. These descriptions are based on binocular microscope study of chips used for carbon dioxide analysis plus hand lens inspection of the full cores.

Elevations of locations were surveyed in with a level from the nearest benchmark available with the exception of test holes E-1 and E-10. These elevations were determined with an altimeter. In the case of the Park River test holes and test holes S-1 to S-5 in the Shawnee area only a few shots were necessary to determine each elevation. However, for test holes S-7, and S-10 through S-13 it required carrying levels for 3/4 of a mile to as much as 2 1/2 miles.

Test Hole E-1; Location - SE NE Sec. 19, T.158 N., R. 56 W., Walsh County, North Dakota. Elevation - 1243. Total Depth - 166 feet.

LITHOLOGY

0-34 Glacial drift; Clay, sand and gravel.

NIOBRARA FORMATION

34-41 Shale, medium gray (N5) to light gray (N7), intermingled; the light gray shale is very calcareous and contains "white specks;" the medium gray shale is moderately bentonitic, contains no white specks but is still calcareous.

41-68 Shale, light gray (N7), contains abundant white specks, is very calcareous.

68-70 Shale, light gray (N7), contains a few white specks, is very calcareous.

70-74 Shale, light gray (N7), contains abundant white specks, is very calcareous.

74-75 Shale, light gray (N7), white specks inconspicuous, still very calcareous.

75-82 Shale, light gray (N7), white specks common to abundant, very calcareous, scattered pyrite.

82-83 Shale, very light gray (N8), white specks inconspicuous, very calcareous, moderately bentonitic.

83-86 Shale, very light gray (N8), white specks inconspicuous, very calcareous.

86-89	Shale, as above, some pyrite in stemlike concretions.
89-92	Shale, very light gray (N8), no white specks, very calcareous, slightly bentonitic.
92-94	Shale, very light gray (N8), no white specks, very calcareous, slightly micaceous, slightly bentonitic.
94-95	Shale, light gray (N7), contains a few white specks, some shell fragments, slightly micaceous, slightly bentonitic, moderately calcareous.
95-97	Shale, medium gray (N5), contains pyrite nodules, slightly micaceous, slightly calcareous.
97-99	Shale, medium light gray (N6), contains abundant white specks, very calcareous, slightly micaceous, slightly bentonitic.
99-112	Shale, medium light gray (N6), no white specks, slightly micaceous, slightly bentonitic, moderately calcareous.
112-116	Shale, medium light gray (N6), no white specks, slightly micaceous, moderately calcareous.
116-118	Shale, as above and shale, medium light gray (N6), contains abundant white specks, very calcareous.
118-128	Shale, medium light gray (N6), no white specks, slightly micaceous, moderately calcareous.
128-130	Shale, medium light gray (N6), no white specks, slightly micaceous, moderately bentonitic, contains some fish scales ?, moderately calcareous.
130-138	Shale, medium light gray (N6), contains abundant white specks, very micaceous, very calcareous, some fragments of sharks teeth and fish scales.
138-140	Shale, medium gray (N5), white specks inconspicuous, moderately calcareous.
140-148	Shale, medium light gray (N6), white specks common to abundant, micaceous, moderately calcareous.
148-150	Shale, medium light gray (N6), contains abundant white specks, very calcareous.
150-166	Shale, medium gray (N5), contains abundant white specks, very calcareous.

Test Hole E-2; Location - NE NE Sec. 18, T. 158 N., R. 56 W., Walsh County, North Dakota. Elevation - 1201. Total Depth - 70 feet.

LITHOLOGY

0-27	Glacial drift.

NIOBRARA FORMATION

27-40	Shale, light gray (N7), contains abundant white specks, very calcareous.
40-41	Shale, light gray (N7) to medium light gray (N6), no white specks, slightly bentonitic, very calcareous.

41-43	Shale, light gray (N7), a few to common white specks, very calcareous.
43-47	Shale, light gray (N7), white specks inconspicuous, very calcareous.
47-59	Shale, very light gray (N8), no white specks, very calcareous.
59-60	Shale, very light gray (N8), no white specks, very calcareous, slightly micaceous, contains a few shell fragments.
60-62	Shale, light gray (N7) to medium light gray (N6), no white specks, slightly micaceous, slightly bentonitic, contains a few pyrite nodules.
62-64	Shale, medium gray (N5), no white specks, slightly micaceous, slightly bentonitic, slightly calcareous.
64-68	Shale, medium light gray (N6), contains a few white specks, slightly micaceous, slightly bentonitic, moderately calcareous.
68-70	Shale, medium gray (N5), no white specks, slightly micaceous, slightly bentonitic, slightly calcareous.

Test Hole PR-1; Location - NE NE Sec. 25, T. 157 N., R. 57 W., Walsh County, North Dakota. Elevation - 1313. Total Depth - 169 feet.

LITHOLOGY

0-18	Glacial drift.

PIERRE FORMATION

18-51	Shale, medium dark gray (N4) to medium gray (N5), a few thin bentonite layers.
51-56	Fullers Earth beds, alternating dark gray (N3) and light gray (N7) bands of bentonite.

NIOBRARA FORMATION

56-57	Shale, medium gray (N5), slightly bentonitic.
57-62	Shale, light gray (N7), contains abundant white specks, very calcareous.
62-64	Shale, medium light gray (N6) to light gray (N7), bentonitic, contains small pyrite nodules, non-calcareous.
64-68	Shale, light gray (N7), contains abundant white specks, very calcareous.
68-70	Shale, medium gray (N5), slightly bentonitic, non-calcareous.
70-72	Shale, light gray (N7), contains abundant white specks, very calcareous.
72-74	Shale, as above, with a thin, slightly micaceous, medium gray (N5), bentonitic layer and a thin yellowish gray band of bentonite.
74-76	Shale, light gray (N7), contains abundant white specks, very calcareous.
76-78	Shale, as above; and shale, medium light gray (N6), slightly micaceous, slightly bentonitic, white specks inconspicuous, very calcareous.
78-148	Shale, light gray (N7), contains abundant white specks, very calcareous.

148-149 Shale, medium gray (N5), no white specks, slightly bentonitic, moderately calcareous.
149-152 Shale, medium light gray (N6) to light gray (N7), no white specks, very calcareous, slightly bentonitic.
152-155 Shale, light gray (N7), white specks inconspicuous, slightly bentonitic, very calcareous, scattered shell fragments.
155-161 Shale, very light gray (N8), no white specks, very calcareous, scattered pyrite nodules and stemlike concretions.
161-165 Shale, very light gray (N8), no white specks, very calcareous, slightly bentonitic, scattered pyrite, slightly micaceous.
165-169 Shale, medium gray (N5), slightly micaceous, contains pyrite nodules, slightly calcareous.

Test Hole PR-2; Location NW NE Sec. 30, T. 157 N., R. 56 W., Walsh County, North Dakota. Elevation - 1273. Total Depth - 130 feet.

LITHOLOGY

0-23 Glacial drift.

NIOBRARA FORMATION

23-26 Shale, medium light gray (N6) to light gray (N7), contains some white specks, very calcareous, slightly bentonitic, slightly micaceous.
26-30 Shale, light gray (N7), contains abundant white specks, very calcareous.
30-31 Shale, medium gray (N5), no white specks, moderately calcareous; and Shale, as above.
31-47 Shale, light gray (N7), contains abundant white specks, very calcareous.
47-48 Shale, light gray (N7), contains abundant white specks, very calcareous, slightly bentonitic.
48-78 Shale, light gray (N7), contains abundant white specks, very calcareous.
78-79 Shale, medium light gray (N6), no white specks, very calcareous, moderately bentonitic.
79-88 Shale, light gray (N7), contains abundant white specks, very calcareous.
88-89 Shale, as above and some Shale, medium light gray (N6), moderately bentonitic, no white specks, very calcareous.
89-93 Shale, light gray (N7), contains abundant white specks, very calcareous.
93-94 Shale, as above; with a thin micaceous layer.
94-101 Shale, light gray (N7), contains abundant white specks, very calcareous.
101-105 Shale, as above; with scattered shell fragments.
105-106 Shale, medium light gray (N6), no white specks, moderately calcareous, slightly bentonitic.
106-107 Shale, light gray (N7), no white specks, very calcareous, contains scattered pyrite nodules.

107-110 Shale, as above, but slightly micaceous.
110-119 Shale, very light gray (N8), no white specks, very calcareous, some pyrite nodules and stemlike concretions, slightly micaceous, slightly bentonitic, moderately calcareous.
119-130 Shale, medium light gray (N6), no white specks, slightly micaceous, slightly bentonitic, moderately calcareous.

Test Hole S-1; Location - SW SW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1219. Total Depth - 62 feet.

LITHOLOGY

0-22 Glacial drift.

NIOBRARA FORMATION

22-29 Shale, light gray (N7), contains abundant white specks, very calcareous.
29-30 Shale, as above, with some shell fragments.
30-31 Shale, light gray (N7), contains abundant white specks, very calcareous.
31-32 Shale, light gray (N7), contains some white specks, very calcareous.
32-33 Shale, light gray (N7), contains abundant white specks, very calcareous.
33-42 Shale, light gray (N7), white specks inconspicuous, very calcareous.
42-45 Shale, light gray (N7), white specks inconspicuous, very calcareous, scattered ironstone, stemlike concretions.
45-47 Shale, light gray (N7), white specks inconspicuous, slightly bentonitic, slightly micaceous, very calcareous.
47-48 Shale, light gray (N7) to medium light gray (N6), white specks inconspicuous, slightly bentonitic, very calcareous.
48-51 Shale, very light gray (N8), white specks inconspicuous, slightly bentonitic, very calcareous, scattered pyrite in form of stemlike concretions.
51-53 Shale, light gray (N7), white specks inconspicuous, slightly micaceous, slightly bentonitic, very calcareous.
53-59 Shale, very light gray (N8), no white specks, very calcareous, scattered pyrite in form of stemlike concretions.
59-60 Shale, light gray (N7), no white specks, very calcareous, scattered shell fragments, moderately bentonitic, a few pyrite nodules.
60-62 Shale, medium gray (N5).

Test Hole S-2; Location NE NE Sec. 24, T. 152 N., R. 56 W., Grand Forks County, North Dakota. Elevation - 1207. Total Depth - 49.5 feet

LITHOLOGY

0-19.5 Glacial drift; clay till.

NIOBRARA FORMATION

19.5-21 Shale, yellowish gray (5Y 8/1), some white specks, very calcareous,

moderately bentonitic.

21-24 Shale, light gray (N7), common white specks, very calcareous, slightly bentonitic.

24-25 Shale, light gray (N7), white specks common, very calcareous, slightly micaceous.

25-28 Shale, light gray (N7), white specks common, very calcareous, slightly bentonitic.

28-33 Shale, light gray (N7), white specks inconspicuous, very calcareous, moderately bentonitic.

33-35 Shale, light gray (N7), abundant white specks, very calcareous.

35-45 Shale, very light gray (N8), no white specks, very calcareous, scattered pyrite in form of stemlike concretions, slightly bentonitic.

45-47 Shale, very light gray (N8), no white specks, very calcareous, scattered shell fragments, slightly micaceous.

47-48 Shale, as above; slightly bentonitic.

48-49 Shale, medium light gray (N6), no white specks, non-calcareous, slightly micaceous, slightly bentonitic.

49-49.5 Interbedded shale, medium light gray as above and light gray (N7), contains some white specks, moderately calcareous, contains some pyrite nodules.

Test Hole S-3; Location - NE NW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1184. Total Depth - 48 feet.

LITHOLOGY

0-7 Glacial drift; clayey till.

NIOBRARA FORMATION

7-13 Shale, yellowish gray (5Y 6/1) to light gray (N7), white specks inconspicuous, very calcareous.

13-14 Shale, as above; with numerous small crystals of recrystallized, colorless calcite.

14-20 Shale, very light gray (N8), white specks inconspicuous, very calcareous, some iron staining.

20-21 Shale, as above except for heavy iron staining.

21-23 Shale, very light gray (N8), white specks inconspicuous, very calcareous, scattered light iron stain, shell fragments at 22.

23-29 Shale, very light gray (N8), no white specks, very calcareous.

29-31 Shale, medium light gray (N6), contains a few white specks, moderately calcareous.

31-47 Shale, medium light gray (N6), contains a few white specks, numerous mica flakes, slightly bentonitic, moderately calcareous.

47-48 Shale, very light gray (N8), micaceous, very bentonitic.

Test Hole S-4; Location - SE SW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1187. Total Depth - 40 feet.

LITHOLOGY

0-8	Glacial drift; clayey till with boulders.

NIOBRARA FORMATION

8-20	Shale; soft, sticky, not cored.
20-22	Shale, very light gray (N8), white specks inconspicuous, very calcareous.
22-29	Shale, very light gray (N8), no white specks, very calcareous, some ironstone stemlike concretions.
29-31	Shale, light gray (N7) to medium light gray (N6), no white specks, slightly bentonitic, moderately calcareous.
31-33	Shale, medium light gray (N6), contains some white specks, slightly bentonitic, moderately calcareous, some pyrite nodules.
33-37	Shale, medium light gray (N6), contains some white specks, slightly micaceous, slightly bentonitic, moderately calcareous.
37-40	Shale, as above; with scattered shell fragments.

Test Hole S-5; Location - SE NE Sec. 1, T. 151 N., R. 56 W., Grand Forks County, North Dakota. Elevation - 1264. Total Depth - 110 feet.

LITHOLOGY

0-34	Glacial drift; clayey till.

NIOBRARA FORMATION

34-44	Shale; no recovery.
44-76	Shale, light gray (N7), contains abundant white specks, very calcareous.
76-85	Shale, light gray (N7), white specks inconspicuous, very calcareous.
85-88	Shale, light gray (N7), white specks inconspicuous, very calcareous, micaceous, moderately bentonitic.
88-90	Shale, light gray (N7) to very light gray (N8), no white specks, very calcareous, contains ironstone stemlike concretions.
90-95	Shale, light gray (N7), contains a few white specks, very calcareous, some ironstone stemlike concretions.
95-97	Shale, light gray (N7) to very light gray (N8), no white specks, very calcareous, slightly micaceous, some ironstone stemlike concretions.
97-100	Shale, very light gray (N8), no white specks, very calcareous, scattered ironstone concretions, slightly micaceous.

100-103	Shale, medium gray (N5), no white specks, slightly micaceous, slightly bentonitic, contains some pyrite nodules, slightly calcareous.
103-106	Shale, medium light gray (N6), contains some white specks, slightly micaceous, moderately bentonitic.
106-109	Shale, as above; with scattered shell fragments and pyrite nodules.
109-110	Shale, medium dark gray (N4), no white specks, slightly micaceous, slightly bentonitic, slightly calcareous.

Test Hole S-7; Location - NW SE Sec. 30, T. 152 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1192. Total Depth - 40 feet.

LITHOLOGY

0-18.5	Glacial drift; clayey till, boulders and sand.

NIOBRARA FORMATION

18.5-20	Shale, no core recovery.
20-22	Shale, very light gray (N8), no white specks, very calcareous, slightly bentonitic.
22-24	Shale, very light gray (N8), no white specks, very calcareous, slightly micaceous, moderately bentonitic.
24-27	Shale, very light gray (N8), no white specks, very calcareous.
27-30	Shale, very light gray (N8), no white specks, very calcareous, some ironstone stemlike concretions.
30-32	Shale, very light gray (N8), no white specks, very calcareous, slightly micaceous, moderately bentonitic.
32-34	Shale, medium light gray (N6), micaceous, slightly bentonitic, no white specks, slightly calcareous, contains a few pyrite nodules.
34-37	Shale, medium gray (N5), micaceous, slightly bentonitic, slightly calcareous, no white specks.
37-40	Shale, medium light gray (N6), contains some white specks, scattered shell fragments, slightly micaceous, slightly bentonitic.

Test Hole S-10; Location - SE SW Sec. 1, T. 153 N., R. 56 W., Grand Forks County, North Dakota. Elevation - 1210. Total Depth - 68 feet.

LITHOLOGY

0-8	Glacial drift; clayey till.

NIOBRARA FORMATION

8-20	Shale, drilled with rock bit.
20-29	Shale, no core recovery.

29-38	Shale, light gray (N7), contains abundant white specks, very calcareous.
38-39	Shale, light gray (N7), white specks inconspicuous, moderately calcareous, moderately bentonitic.
39-40	Shale, light gray (N7), white specks inconspicuous, very calcareous.
40-42	Shale, light gray (N7), common white specks, very calcareous.
42-43	Shale, light gray (N7), white specks inconspicuous, moderately calcareous.
43-49	Shale, light gray (N7), white specks inconspicuous, very calcareous, slightly bentonitic.
49-50	Shale, light gray, abundant white specks, very calcareous.
50-52	Shale, light gray (N7), white specks inconspicuous, very calcareous, slightly bentonitic.
52-60	Shale, very light gray (N8), no white specks, very calcareous, scattered ironstone stemlike concretions.
60-62	Shale, very light gray (N8), no white specks, very calcareous, scattered shell fragments.
62-66	Shale, very light gray (N8), no white specks, very calcareous, slightly bentonitic.
66-67	Shale, light gray (N7), no white specks, slightly bentonitic, very calcareous, scattered shell fragments, micaceous.
67-68	Shale, medium gray (N5), no white specks, slightly calcareous, moderately bentonitic.

Test Hole S-11; Location - SW SE Sec. 1, T. 152 N., R. 56 W., Grand Forks County, North Dakota. Elevation 1179. Total Depth - 30 feet.

LITHOLOGY

0-8	Glacial drift; clayey till.

NIOBRARA FORMATION

8-20	Shale; drilled with rock bit.
20-22	Shale, very light gray (N8), no white specks, very calcareous, scattered ironstone concretions.
22-23	Shale, very light gray (N8), no white specks, very calcareous, slightly bentonitic.
23-27	Shale, very light gray (N8), no white specks, very calcareous.
27-28	Shale, very light gray (N8), no white specks, very calcareous, micaceous, slightly bentonitic.
28-29	Shale, mottled, light gray (N7) and medium light gray (N6), no white specks, very calcareous, micaceous.
29-30	Shale, medium dark gray (N4), non-calcareous, slightly bentonitic, scattered pyrite.

Test Hole S-12; Location - SW SW Sec. 31, T. 153 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1202. Total Depth - 50 feet.

LITHOLOGY

0-16.5 Glacial drift; clayey till.

NIOBRARA FORMATION

16.5-20 Shale; drilled with rock bit.
20-22 Shale, very light gray (N8), white specks, inconspicuous, very calcareous.
22-23 Shale, light gray (N7), common white specks, very calcareous, slightly bentonitic.
23-30 Shale, light gray (N7), white specks inconspicuous, very calcareous, slightly bentonitic.
30-31 Shale, medium light gray (N6), no white specks, very calcareous, moderately bentonitic.
31-37 Shale, light gray (N7), white specks inconspicuous, very calcareous, slightly micaceous, scattered ironstone stemlike concretions.
37-41 Shale, light gray (N7), no white specks, very calcareous, slightly bentonitic, scattered pyrite.
41-45 Shale, very light gray (N8), no white specks, very calcareous, scattered pyrite nodules and stemlike concretions.
45-46 Shale, light gray (N7), no white specks, very calcareous.
46-48 Shale, very light gray (N8), no white specks, very calcareous.
48-49 Shale, mottled, light gray (N7) with a little medium gray (N5), no white specks, very calcareous, slightly micaceous, slightly bentonitic.
49-50 Shale, mottled, medium gray (N5) with a little light gray (N7), micaceous, slightly bentonitic, slightly calcareous.

Test Hole S-13; Location - NW SW Sec. 31, T. 153 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1192. Total Depth - 50 feet.

LITHOLOGY

0-16 Glacial drift; clayey till.

NIOBRARA FORMATION

16-20 Shale, drilled with rock bit.
20-23 Shale, light gray (N7) to yellowish gray (5Y 8/1), no white specks, very calcareous, moderately bentonitic.

23-28	Shale, light gray (N7), white specks inconspicuous, very calcareous.
28-29	Shale, light gray (N7), white specks common, very calcareous.
29-31	Shale, light gray (N7), white specks, inconspicuous, micaceous, slightly bentonitic.
31-32	Shale, light gray (N7), a few white specks, very calcareous.
32-40	Shale, light gray (N7), no white specks, very calcareous, scattered pyrite nodules and stemlike concretions.
40-45	Shale, very light gray (N8), no white specks, very calcareous, scattered pyrite nodules and stemlike concretions.
45-47	Shale, as above; with scattered shell fragments.
47-48	Shale, light gray (N7), no white specks, very calcareous, micaceous.
48-50	Shale, medium light gray (N6), no white specks, moderately calcareous, micaceous, moderately bentonitic, scattered shell fragments and pyrite.

Test Hole E-4; Location - NW NE Sec. 17, T. 158 N., R. 56 W., Walsh County, North Dakota. Elevation - 1219. Total Depth - 59 feet.

LITHOLOGY

0-59	Glacial drift; clayey till, boulders and sand.

Test Hole E-10; Location - NW SW Sec. 16, T. 158 N., R. 56 W., Walsh County, North Dakota. Elevation - 1202. Total Depth - 51 feet.

LITHOLOGY

0-51	Glacial drift; clayey till, sand and boulders.

Test Hole PR-3; Location - SW SE Sec. 20, T. 157 N., R. 56 W., Walsh County, North Dakota. Elevation - 1217. Total Depth - 70 feet.

LITHOLOGY

0-70	Glacial drift; sand , boulders and gravel.

Test Hole S-6; Location - SW SW Sec. 5, T. 151 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1214. Total Depth - 60 feet.

LITHOLOGY

0-60	Glacial drift; clayey till, boulders and sand.

Test Hole S-8; Location - NW NE Sec. 30, T. 150 N., R. 55 W., Grand Forks

County, North Dakota. Elevation - 1280 (from Larimore topo sheet). Total Depth - 61 feet.

LITHOLOGY

0-61 Glacial drift; sand and clayey till with boulders.

Test Hole S-9; Location - SW SE Sec. 5, T. 149 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1260 (from Larimore topo sheet). Total Depth - 62 feet.

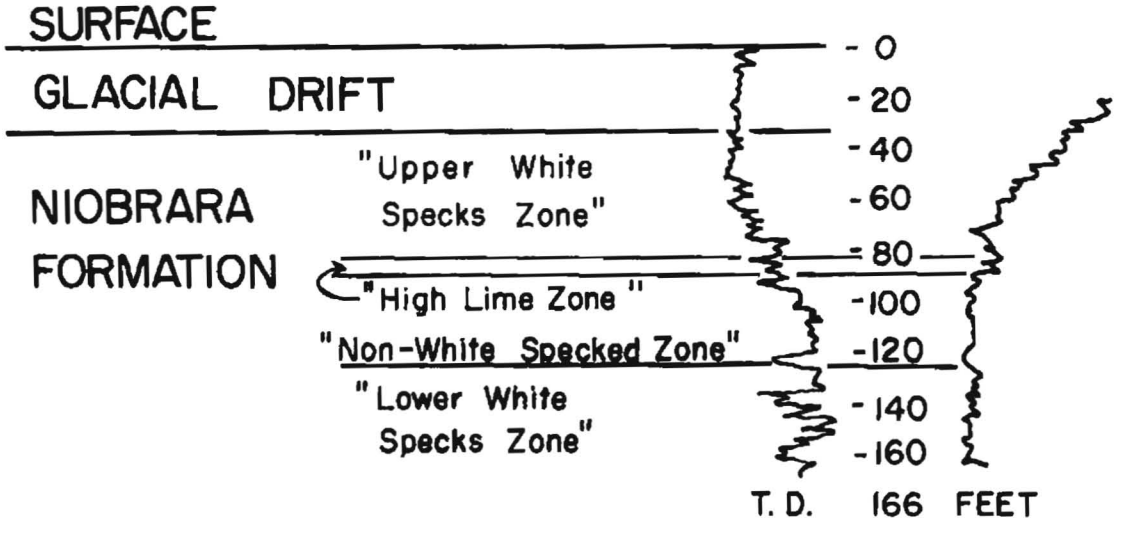
LITHOLOGY

0-62 Glacial drift; sand and clayey till with boulders.

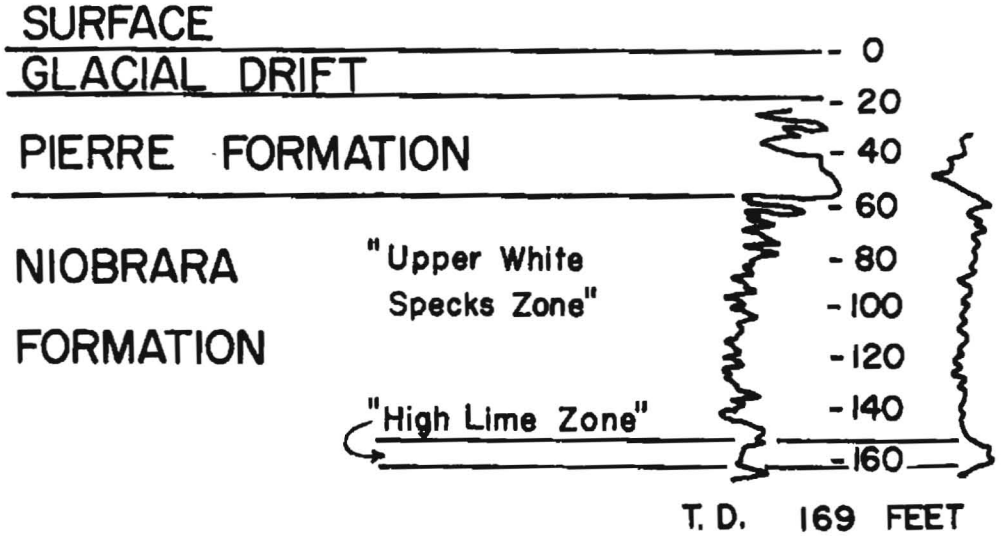
APPENDIX B

Widco electric logs of test holes.

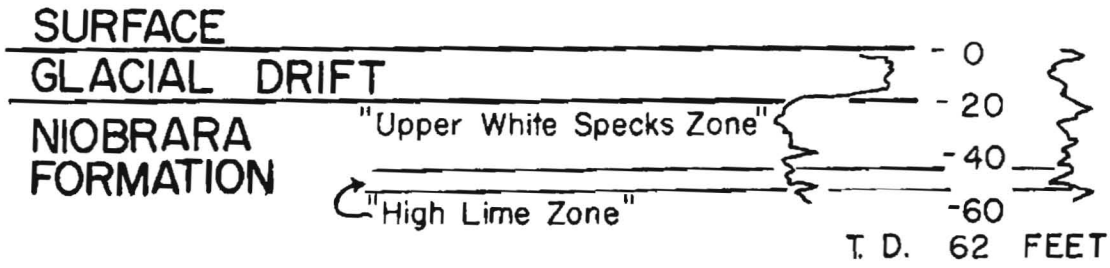
Test Hole E-1; Location - SE NE Sec. 19, T. 158 N., R. 56 W., Walsh County, North Dakota. Elevation - 1243. Total Depth - 166 feet.



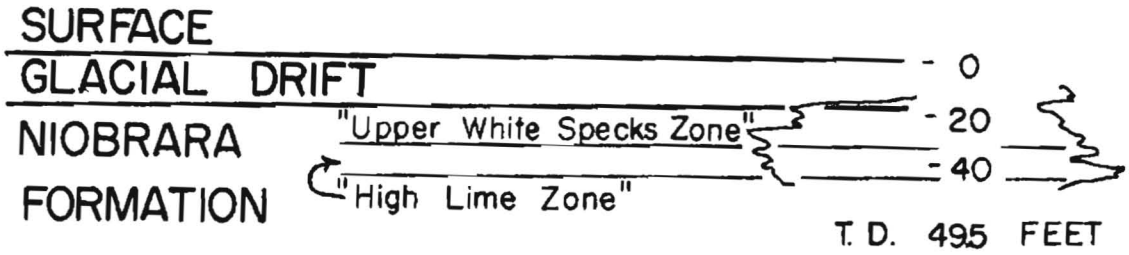
Test Hole PR-1; Location - NE NE Sec. 25, T. 157 N., R. 57 W., Walsh County, North Dakota. Elevation - 1313. Total Depth - 169 feet.



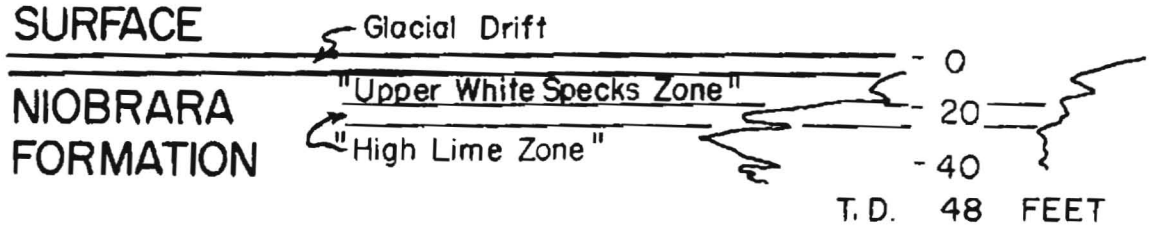
Test Hole S-1; Location - SW SW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1219. Total Depth - 62 feet.



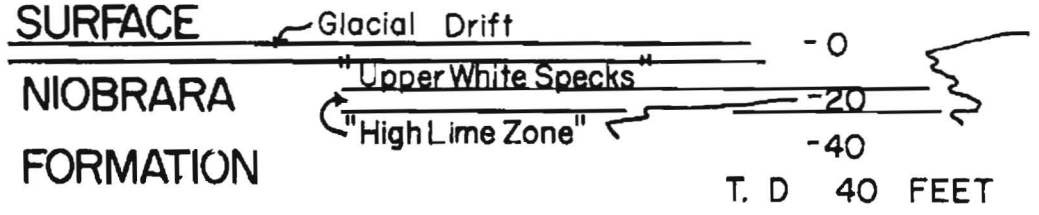
Test Hole S-2; Location - NE NE Sec. 24, T. 152 N., R. 56 W., Grand Forks County, North Dakota. Elevation - 1207. Total Depth - 49.5 feet.



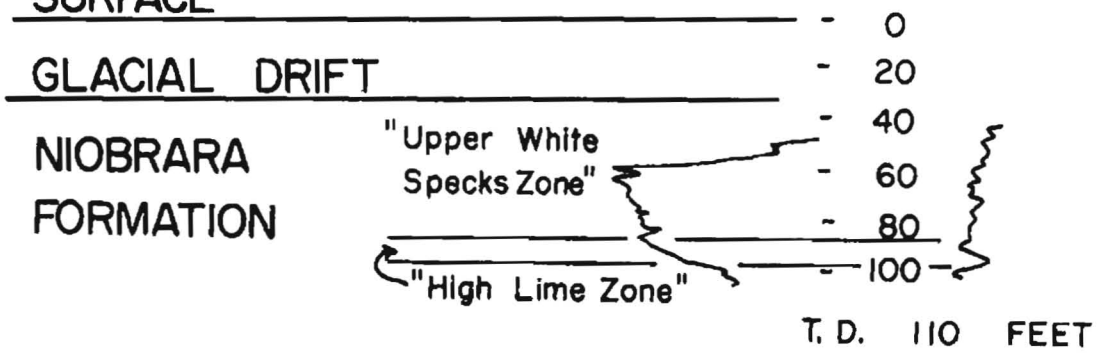
Test Hole S-3; Location - NE NW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1184. Total Depth - 48 feet.



Test Hole S-4; Location - SE SW Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota. Elevation - 1187. Total Depth 40 feet.



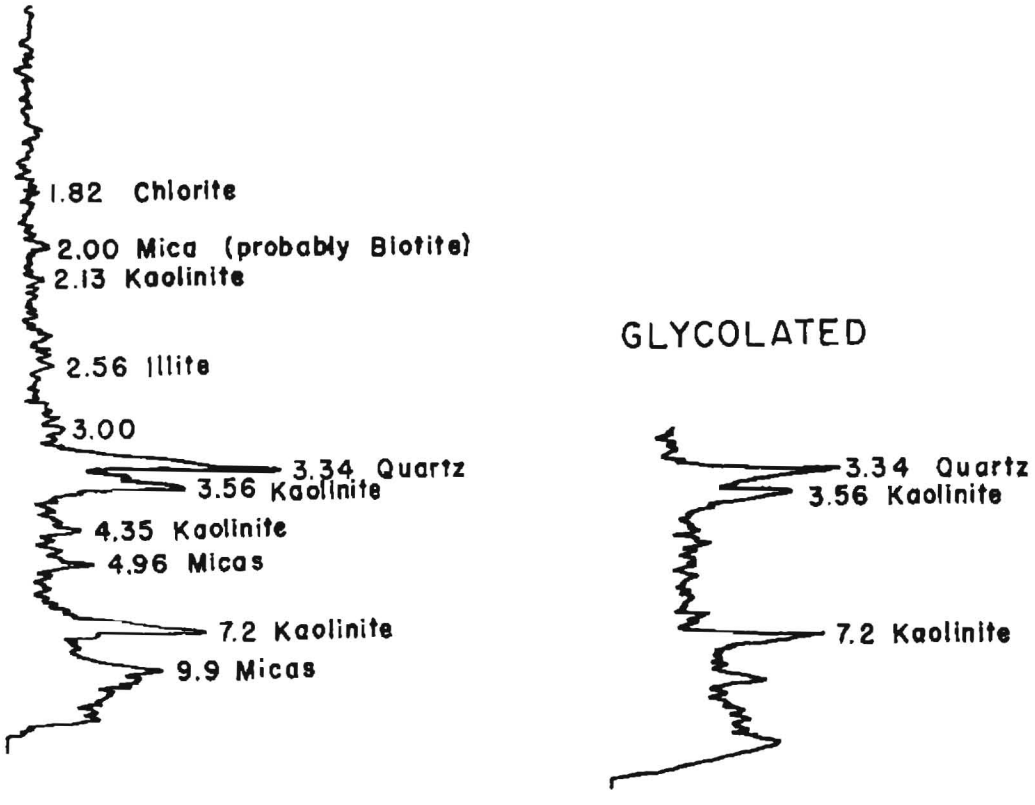
Test Hole S-5; Location - SE NE Sec. 1, T. 151 N., R. 56 W., Grand Forks County, North Dakota. Elevation - 1264. Total Depth - 110 feet.



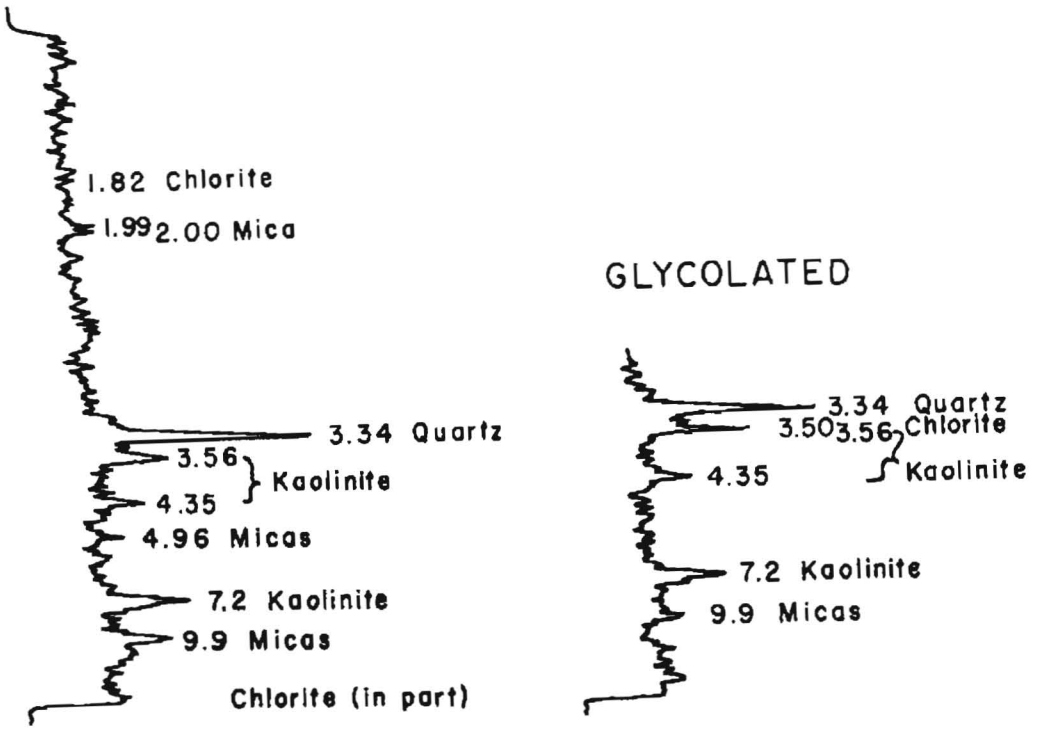
APPENDIX C

The samples are from test hole S-4, located in the SE SW of Sec. 19, T. 152 N., R. 55 W., Grand Forks County, North Dakota and the number refers to the depth in that test hole. Mr. Reesman, geologist at the University of Missouri, Columbia, Missouri, ran the X-Ray determinations and the comments opposite the peaks on the curves are Mr. Reesman's. His original X-Ray diffraction patterns of the Norelco X-Ray spectrometer were reduced to about one-fourth of their original size.

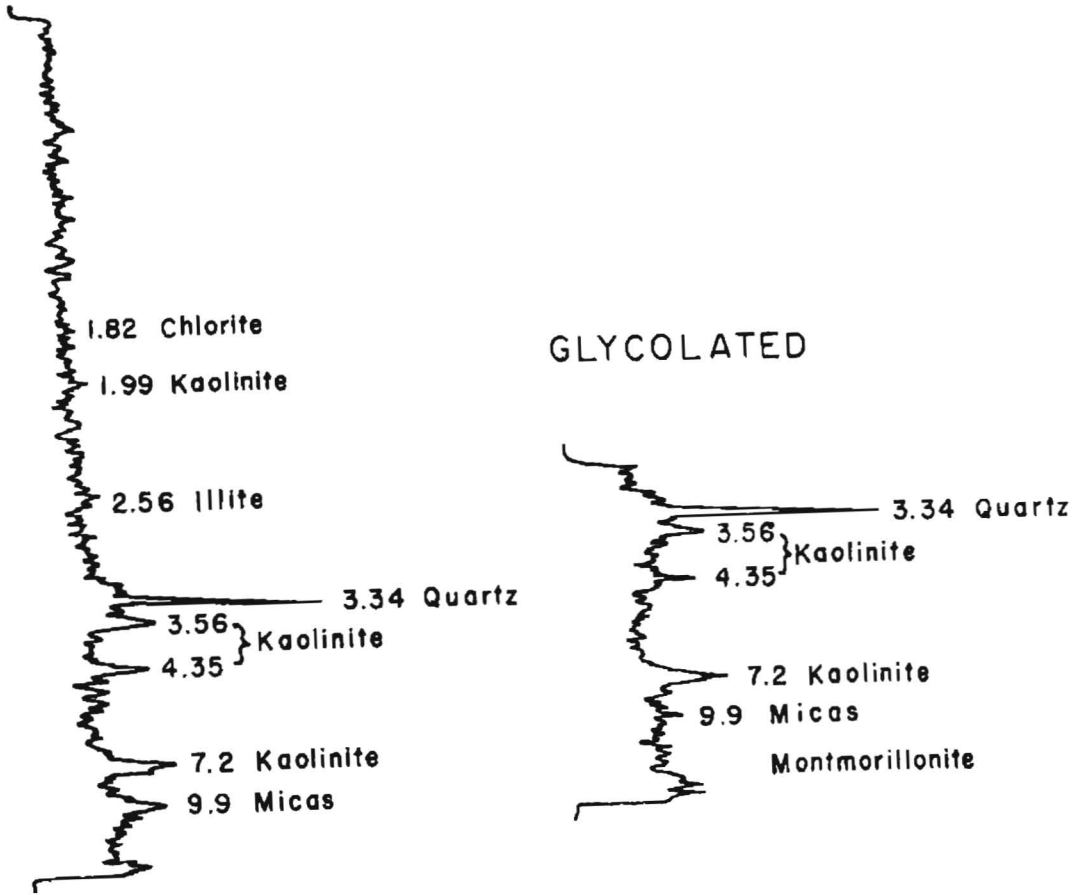
SAMPLE NUMBER 21



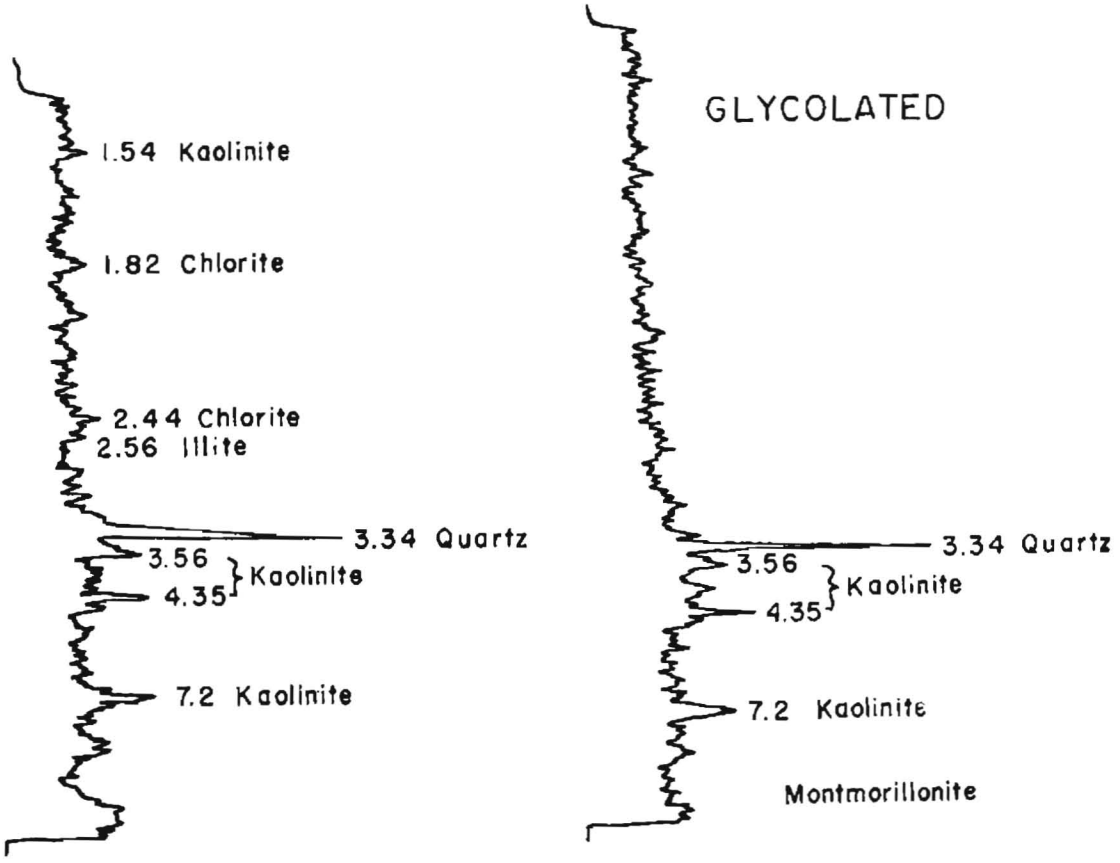
SAMPLE NUMBER 23



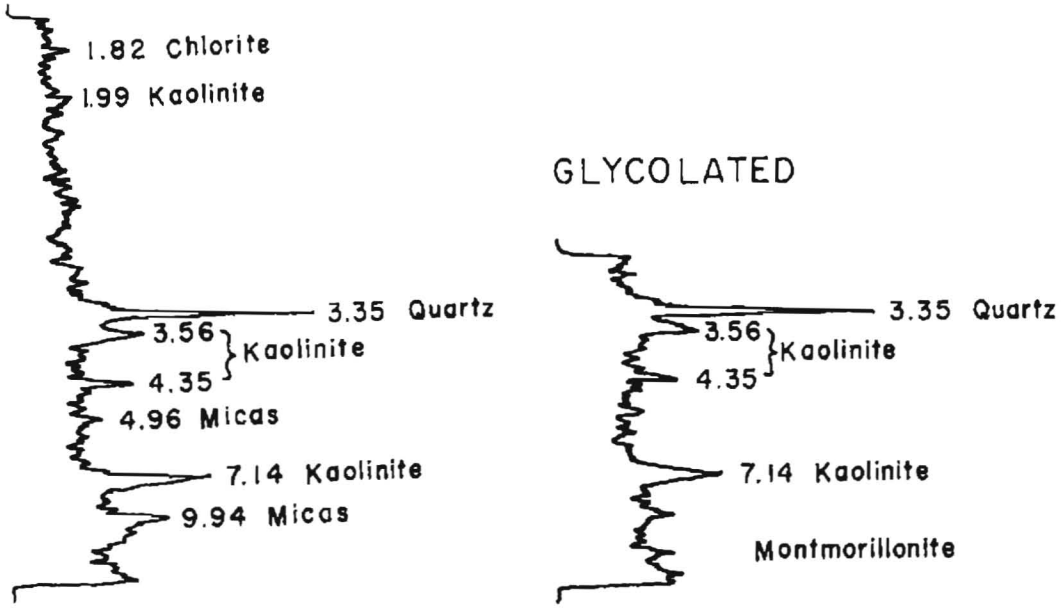
SAMPLE NUMBER 25

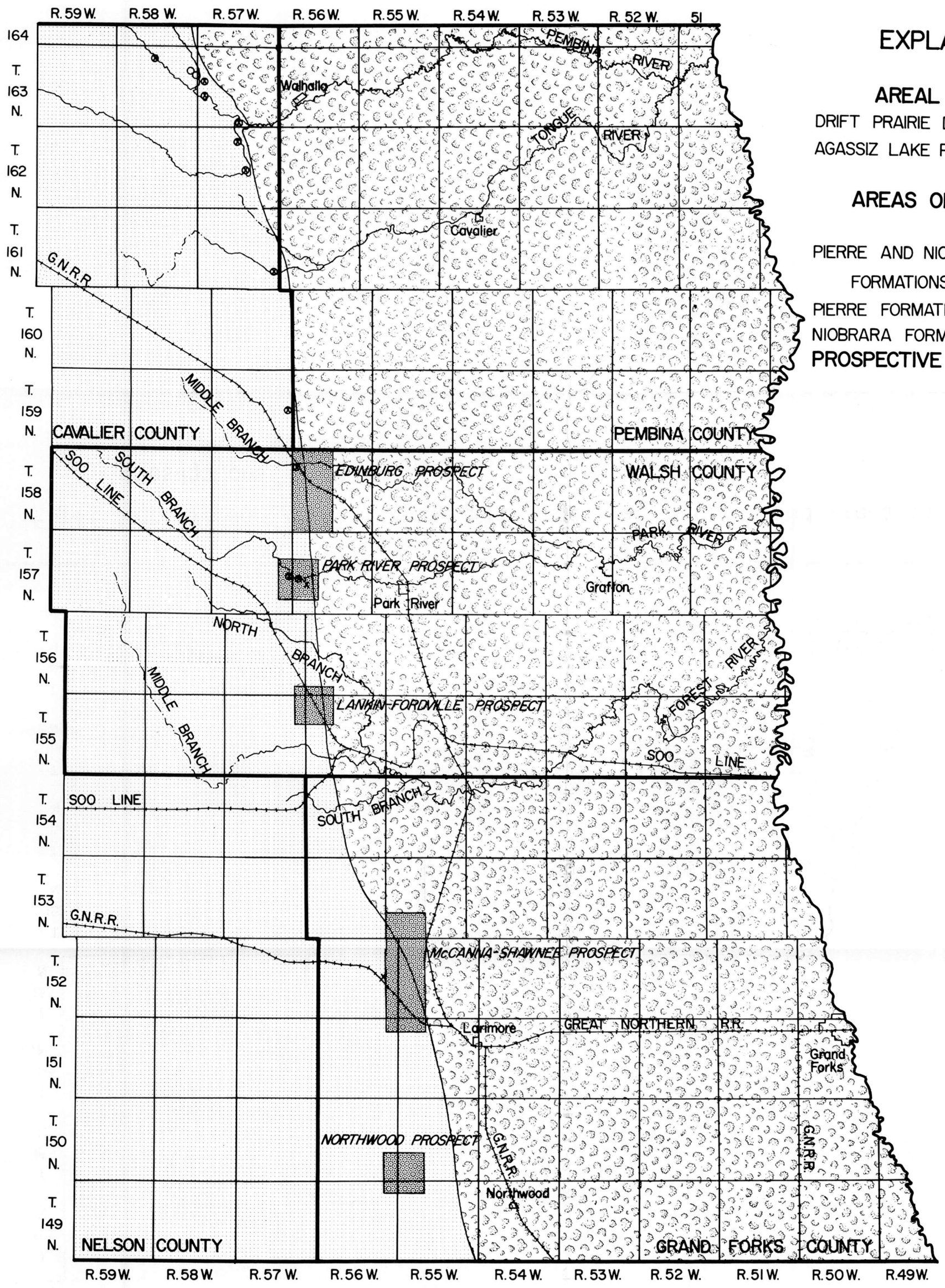


SAMPLE NUMBER 27



SAMPLE NUMBER 29





EXPLANATION

AREAL GEOLOGY

DRIFT PRAIRIE DISTRICT

AGASSIZ LAKE PLAIN DISTRICT

AREAS OF OUTCROP

PIERRE AND NIOBRARA FORMATIONS ⊗

PIERRE FORMATION ○

NIOBRARA FORMATION x

PROSPECTIVE AREAS

Fig. 1 — Map showing area of study, general geology of area, and areas of detailed investigations.