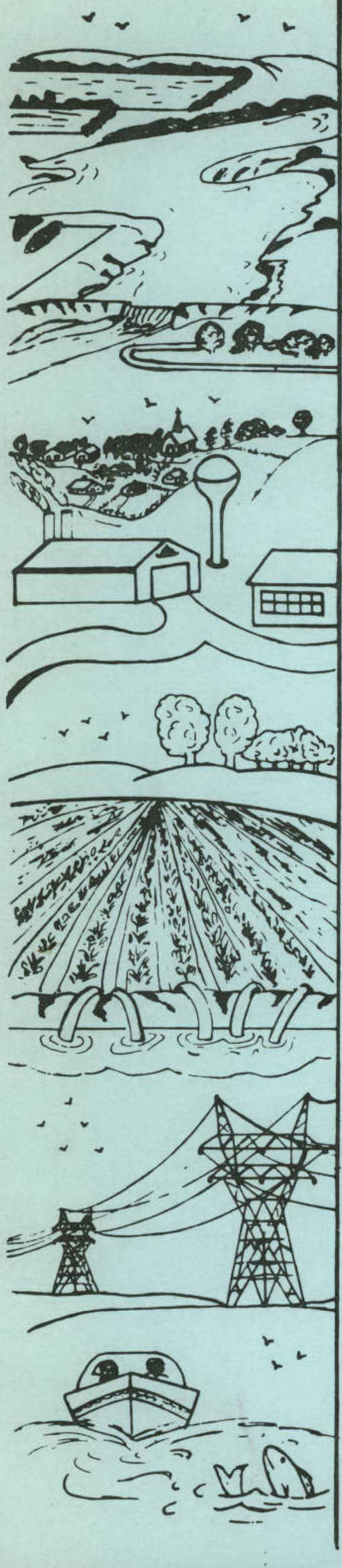

Ground-Water Resources of the Lawton Area Ramsey County, North Dakota

North Dakota Ground-Water Studies

No. 77

By

Charles E. Naplin

Ground-Water Geologist

Published By

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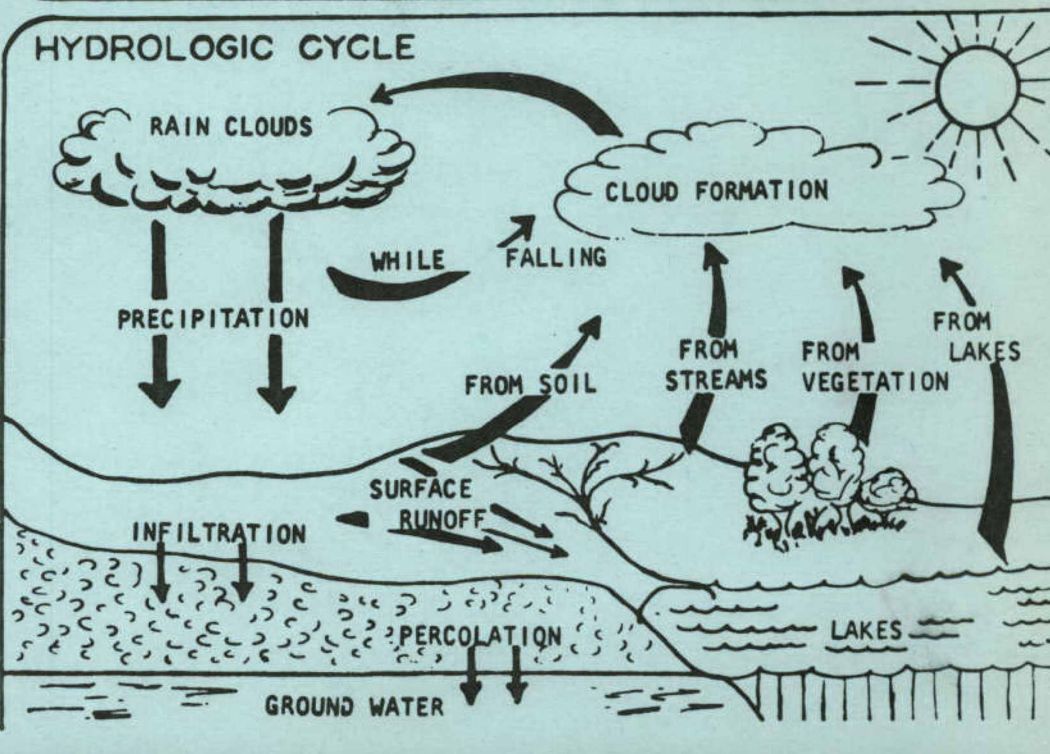

GROUND-WATER RESOURCES OF THE LAWTON AREA
RAMSEY COUNTY, NORTH DAKOTA
SWC PROJECT NUMBER 1542

NORTH DAKOTA GROUND-WATER STUDIES NUMBER 77

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INTRODUCTION

PURPOSE AND SCOPE

On February 12, 1971 the Lawton City Council passed a resolution requesting the North Dakota State Water Commission to conduct a ground-water survey for the city. The request was approved by the Water Commission on March 9, 1971 and the survey was conducted during June and July 1971.

The purpose of the survey was to locate a water source of adequate quantity and quality for the city. The investigation consisted of an inventory of existing wells in the area, test drilling, installation of observation wells, chemical analyses of water samples and this report.

ACKNOWLEDGEMENTS

Field work was under direct supervision of the author. Lewis Knutson and Hugh Jacobson accomplished the test drilling using a hydraulic-rotary drilling machine. Chemical analyses were performed by Garvin Muri, State Water Commission chemist, at the North Dakota State Laboratories in Bismarck. Special acknowledgement is extended to Mayor Albert J. Shereck and Alderman Kermit Lien for information concerning wells and collection of water samples.

LOCATION AND GENERAL FEATURES

The Lawton area, as described in this report, is located in eastern Ramsey County and is included in the Drift Prairie division of the Central Lowland physiographic province of North Dakota (fig. 1). The investigation covers an area of 72 square miles in parts of Tps. 155 and 156 N., Rs. 60 and 61 W.

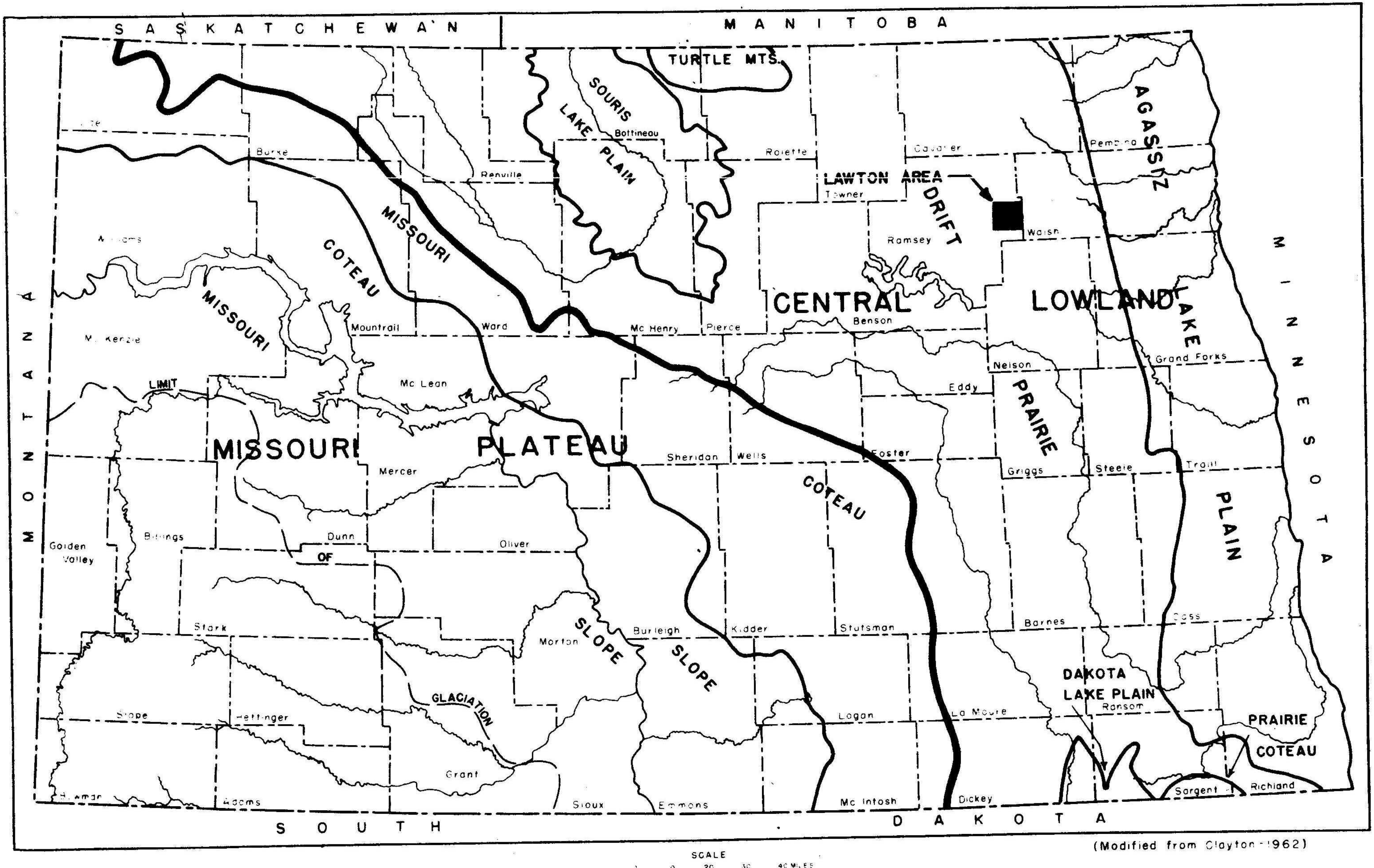


FIGURE 1-- MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE LAWTON AREA

Lawton (1970 population 123) is an agricultural community and is served by a branch line of the Burlington Northern Railroad and State Highway 1.

Lawton does not have a municipal water system. Water for drinking and culinary purposes is purchased from local farm residents, hauled to town, and stored in cisterns. Sewerage is disposed of through septic tanks and drain fields.

Climatological data, based on a 96-year period of record at the National Weather Service station in Devils Lake located 28 miles southwest of Lawton, show the average annual precipitation was 16.98 inches. A 67-year period of record at the same station indicates the average annual temperature was 38.8° F. (National Weather Service, 1971).

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is based upon the location of the well in the Federal system of rectangular surveys of public lands (fig. 2). The first number denotes the township north of the base line that passes laterally through the middle of Arkansas; the second number denotes the range west of the fifth principal meridian; the third number denotes the section in which the well is located. The letters a, b, c and d designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section and quarter-quarter-quarter section (10-acre tract). Consecutive terminal numerals are added if more than one well is located in a 10-acre tract. (Thus, well 156-60-15daa is in the NE¼NE¼SE¼ sec. 15, T. 156 N., R. 60 W.)

PREVIOUS INVESTIGATIONS

A general study of Ramsey County geology and ground-water resources was made by Simpson (1929, p. 189-196). The study includes a selected well

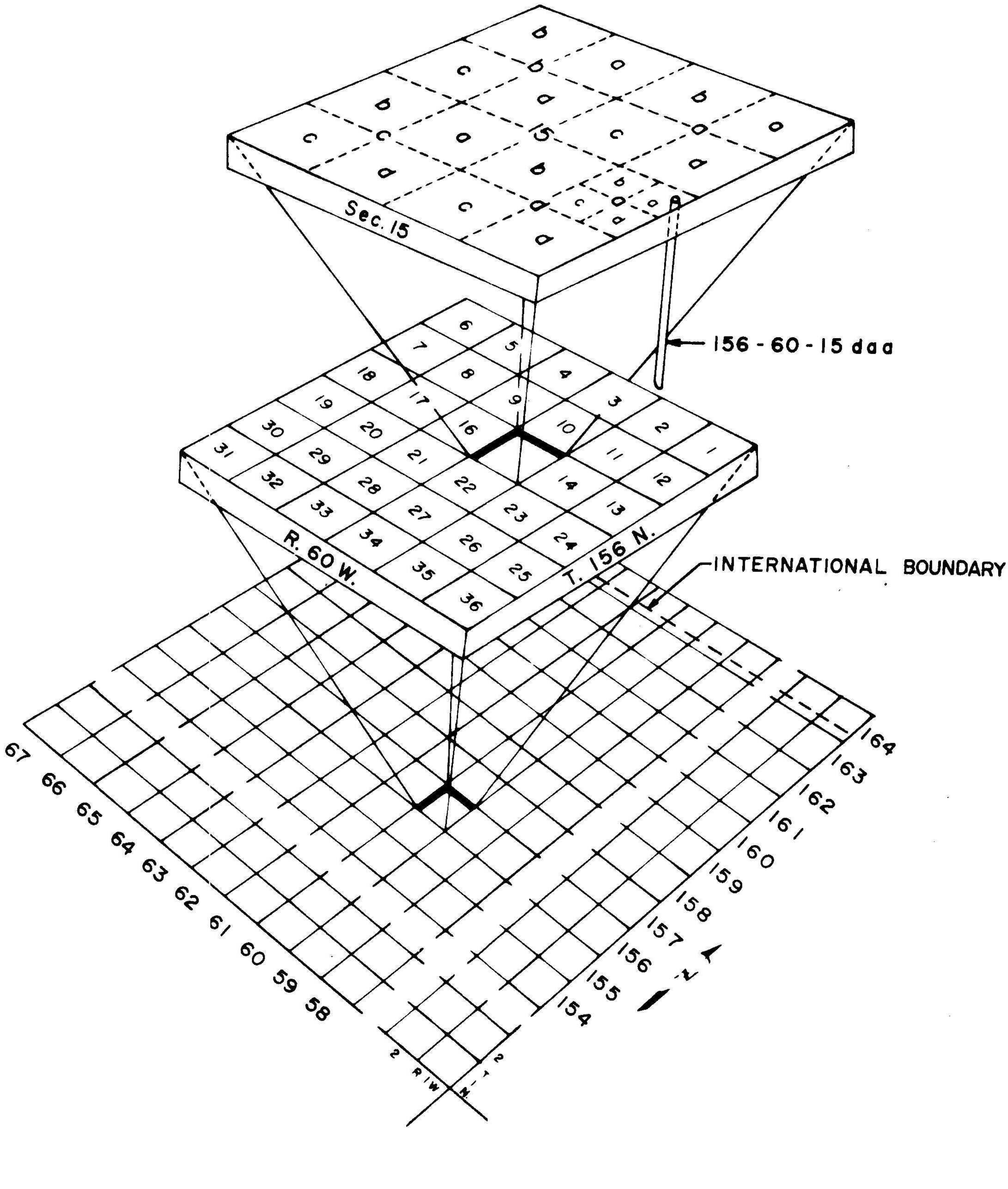


FIGURE 2 -- DIAGRAM SHOWING WELL-NUMBERING SYSTEM

inventory and chemical analyses. Paulson and Akin (1964) described a 920 square mile area around the city of Devils Lake in a comprehensive report titled the "Ground-Water Resources of the Devils Lake Area, Benson, Ramsey, and Eddy Counties, North Dakota."

PRINCIPLES OF GROUND-WATER OCCURRENCE

All ground water is derived from precipitation. After the precipitation falls to the earth's surface, part runs off to streams, part evaporates, and part infiltrates into the soil. A large portion of the precipitation infiltrating into the soil is returned to the atmosphere by evaporation and transpiration with the remainder percolating downward to the zone of saturation.

Various types of rocks possess the ability to store ground water within their porous structure. These deposits are called aquifers when they will yield water to wells in sufficient quantity to be of importance as a source of water supply.

The water table is the upper surface of the zone of saturation. Water-table conditions exist when an aquifer is not confined by impermeable beds and the ground water is relatively free to move in response to gravity.

A water-bearing stratum confined by impermeable beds is considered an artesian or confined aquifer. The water level in a well completed in a confined aquifer will rise above the top of the aquifer.

Ground-water movement is generally very slow and may be only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the deposits through which ground water moves and by the hydraulic gradient.

WATER QUALITY

All water occurring on the earth's surface or underground contains dissolved solids. Water begins to dissolve mineral material as it falls to the surface as precipitation and continues to take on solids as it infiltrates through the ground to the zone of saturation. Dissolved constituents in ground water vary in type and concentration depending upon the composition of rocks with which ground water comes into contact. Other factors such as the duration of contact with rock material, temperature, pressure, and gases in solution also determine the nature and concentration of dissolved material.

The following summary gives the significance of various constituents of water for domestic or municipal water supply in North Dakota (Schmid, 1965):

Silica (SiO_2)

Silica has no physiological or esthetic significance.

Iron (Fe)

Iron concentration over 0.3 mg/l (milligrams per liter) may cause staining of laundry and fixtures; over 0.5 mg/l may be tasted by persons not accustomed to this type of water. Iron removal systems are available.

Manganese (Mn)

Manganese produces black staining when present in amounts exceeding 0.05 mg/l.

Calcium (Ca) and Magnesium (Mg)

Calcium and magnesium are the primary causes of hardness. Over 125 mg/l magnesium may have a laxative effect on persons not accustomed to this type of water.

Sodium (Na)

No physiological or esthetic significance results from sodium except for persons on salt-free diets. It does have an effect on the irrigation usage of water.

Potassium (K)

Small amounts of potassium are essential to plant and animal nutrition.

Bicarbonate and Carbonate (HCO_3 and CO_3)

These constituents have no definite significance in natural water. There are, however, certain standards to be maintained in water treatment plants. A water with high bicarbonate content will tend to have a flat taste.

Sulfate (SO_4)

The U.S. Public Health Service limit is set at 250 mg/l for sulfate, however, a survey by the North Dakota Department of Health survey indicates no laxative effect is noticed until sulfates reach 600 mg/l. Sulfate is classified as follows:

0 to 300 mg/l - low

300 to 700 mg/l - high

over 700 mg/l - very high

Chloride (Cl)

Chloride concentration over 250 mg/l chloride may have a salty taste to some persons. Humans and animals may become accustomed to higher concentrations.

Flouride (F)

Flouride helps prevent tooth decay within the limits of 0.9 to 1.5 mg/l in North Dakota. Higher concentrations cause mottled teeth.

Nitrate (NO_3)

Over 45 mg/l nitrate can be toxic to infants. Larger concentrations can be tolerated by adults. Nitrate in excess of 200 mg/l may have a deleterious effect on livestock health.

Boron (B)

Boron has no physiological or esthetic significance.

Total Dissolved Solids

A limit of 500 to 1,000 mg/l of total dissolved solids is set by the U.S. Public Health Service, but persons may become accustomed to water containing 2,000 mg/l or more total dissolved solids. They are classified as follows by the North Dakota State Department of Health:

0 to 500 mg/l - low

500 to 1,400 mg/l - average

1,400 to 2,500 mg/l - high

over 2,500 mg/l - very high

Hardness

Hardness increases soap consumption but can be removed by a water-softening system. The following is a general hardness scale for North Dakota established by the North Dakota State Department of Health:

0 to 200 mg/l as ($CaCO_3$) - low

200 to 300 mg/l - average

300 to 450 mg/l - high

over 450 mg/l - very high

Specific Conductance is an electrical indication of total dissolved solids measured in micromhos per centimeter at 25° C. It is used primarily for irrigation analyses.

Percent Sodium and Sodium Adsorption Ratio (SAR) indicate the sodium hazard of irrigation water.

pH

Should be between 6.0 and 9.0 for domestic use.

GROUND WATER IN PREGLACIAL ROCKS

Greater than 2,500 feet of sedimentary rocks underlie the glacial drift of the Lawton area (table 1). These rocks consist of limestone, dolostone, sandstone, and shale, with shale and limestone being the predominant rock types. Rocks of pre-Cretaceous age are too deep and contain water that is too highly mineralized to be an economical source of potable water. The Fall River and Pierre Formations of Cretaceous age are potential aquifers, however, and contain water that is moderately to highly mineralized.

FALL RIVER FORMATION

The Fall River Formation underlies the Cretaceous shales in the Lawton area at a depth of about 1,200 feet. Oil tests indicate that the formation consists mostly of fine-to coarse-grained, quartzose sandstone with thin shale interbeds and ranges in thickness from 50 feet (Bakke #1 156-58-9ba) to 90 feet (Wolfe #1 158-62-33cb). Little is known about the quality of water in the Fall River Formation at Lawton. However, the water is very likely similar to that of the Dakota Group Sandstones in other sections of North Dakota and is probably high in sodium and may contain in excess of 2,500 mg/l dissolved mineral solids (Robinove and others, 1954).

Several years ago the city of Devils Lake used water from a 1,470 foot well for fire protection and their municipal sewer system (Simpson, 1929 p. 192). The well was completed in sandstone of the Dakota Group, presumably the Fall River Formation, and initially flowed at more than 40 gpm (gallons per minute). The water contained 3,835 mg/l total dissolved solids and was of the sodium chloride sulfate type. The concentration of dissolved minerals limits the use of this type of water for domestic purposes without proper treatment.

TABLE 1 -- Generalized stratigraphic column in the Lawton area

System	Formation	Lithology	Approximate stratigraphic interval (feet below land surface)	Thickness (in feet)
Tertiary	Glacial drift	Boulder clay (till) sand and gravel, cobbles, boulders	0-70	70
Cretaceous	Pierre Niobrara Greenhorn Belle Fourche Mowry Fall River	Shale Calcareous shale Calcareous shale, limestone Shale Shale Sandstone, shale interbeds	70-425 425-825 825-900 900-1050 1050-1200 1200-1330	1,230
Jurassic	Piper	Siltstone, limestone	1330-1550	220
Triassic ?				
Devonian ?		Limestone, dolostone shale	1550-1600	50
Silurian	Interlake	Limestone, dolostone	1600-1750	150
Ordovician	Stoney Mountain Red River Winnipeg	Limestone, dolostone Limestone, dolostone Limestone, shale	1750-2700 ?	950
Precambrian		Granite	2700 ?	Unknown

(Extrapolated from N.D. Geol. Survey Oil Well Circulars)

PIERRE FORMATION

The Pierre Formation directly underlies the glacial drift in the Lawton area. Drill cuttings indicated the Pierre is a hard medium-dark-gray to grayish-black noncalcareous shale. It is the only bedrock formation presently being utilized as a source of water supply.

The Pierre has low hydraulic conductivity with ground-water movement and storage occurring along joints and fractures in the upper part of the formation. Test drilling indicates that fracturing and jointing in the Pierre is not as well developed in the Lawton area as it is in other parts of northeastern North Dakota. Recharge to the fractured zone occurs as seepage through the overlying glacial drift.

Several farm wells are completed in the Pierre Formation in this area and generally exceed 100 feet in depth. Well yields are low and water quality is usually poor.

Three water analyses from the Pierre indicate the water is of the sodium chloride bicarbonate type (table 2). Chloride and total dissolved solids content averaged 1,040 mg/l and 2,600 mg/l, respectively. The water is low to average in hardness but not desirable for drinking or culinary purposes.

GROUND WATER IN THE GLACIAL DRIFT

The surficial glacial drift in the Lawton area is ground moraine. This glacial landform is characterized by low relief and gently undulating topography. Drainage is poorly developed and numerous potholes and swampy depressions dot the landscape (pl. 1).

Ground moraine is composed primarily of till. Till is a heterogeneous mixture of clay, silt, sand, gravel, cobbles, and boulders. These materials were deposited directly by glacial ice with little or not transportation by water. Till encountered below the water table is colloquially referred to as "blue clay." Above the water table, weathering and oxidation processes chemically alter the material, and it is a yellowish color. Till ranges in thickness from 12 feet in test hole 8036 (155-60-17ddd) to 69 feet in test hole 8030 (156-61-23bbb). The average thickness is about 33 feet. Till in the Lawton area is composed primarily of extremely fine-grained clay and silt and is, therefore, relatively impermeable.

TILL-ASSOCIATED AQUIFERS

Many shallow wells in the Lawton area are completed in isolated bodies of sand and gravel associated with the till. These wells yield small quantities of water for domestic and livestock use. Test drilling indicates that till-associated aquifers are thin, local in areal extent, and located at varying depths within the till. Water levels commonly rise above the tops of the aquifers. Till-associated aquifers are usually only a few feet in thickness and limited in areal extent. Well yields from these deposits are small and frequently inadequate.

Water quality reflects the infiltration and accumulation of dissolved solids as ground water percolates down through the surrounding till. Two water analyses from wells within the city limits indicate sulfate and total dissolved solids content average 1,805 mg/l and 3,890 mg/l, respectively. A nitrate concentration of 173 mg/l in one well (156-60-28acd) suggests possible contamination from nearby septic tanks. This water is extremely hard and unsuitable for domestic use.

ICE-CONTACT AQUIFERS

Kames and eskers are ice-contact deposits of sorted sand and gravel that are associated with ground moraine in the Lawton area. These surficial deposits occur at random over the landscape and are easily distinguishable on aerial photographs.

A kame is a conical or irregularly-shaped hill composed of sand and gravel formed in contact with glacial ice. Numerous kames occur in the Lawton area. Test hole 5993 (155-60-8aaa) was drilled on a kame and penetrated 10 feet of oxidized gravel from 6 feet to 16 feet below land surface. Several gravel pits near Lawton have been excavated from kame deposits. Locally, kames contain minor aquifers and yield water to individual domestic and stock wells.

Eskers are elongate ridges composed of sand and gravel that formed as meltwater tunneled under a decaying ice sheet. Plate 2 shows the location of eskers in the study area. These features are commonly a few hundred feet in width and several hundred feet in length. They trend in a general south-southeasterly direction and lie parallel to the general direction of glacial drainage.

Sand and gravel comprising esker deposits range in thickness from 6 feet in test hole 5996 (156-60-14dcc) to 17½ feet in test hole 8029 (156-61-34aaa). The predominant material is medium-to coarse-grained, gravelly sand that is slightly oxidized. Exposures of an esker 3½ miles west of Lawton indicate that thin layers of silty clay and occasional blocks of till may be encountered in these deposits.

Eskers contain the primary glacial drift aquifers in the Lawton area. They are easily recharged because their surficial position allows rapid infiltration of precipitation to occur. However, the eskers are topographically higher than the surrounding ground moraine and gravity drainage and seepage cause ground-water discharge to adjacent marshy areas.

During winter months, recharge is minimal and water levels decline several feet. When spring runoff occurs water levels rise rapidly in response to the downward percolation of ground water. Periods of heavy precipitation in summer months can be correlated with a significant rise in water levels.

Chemical quality of ground water is generally good. Total dissolved solids from 4 samples ranged in concentration from 195 mg/l to 783 mg/l and averaged 427 mg/l. The water is of the calcium bicarbonate type and is low to very high in hardness.

Water for drinking and culinary purposes is hauled to residents of Lawton by tank truck from two shallow commercial wells completed in an ice-contact deposit located in 156-60-29bc. It is reported that additional water must be occasionally obtained from farm wells during winter months to supplement the commercial supply.

SUMMARY

The Lawton area consists of 72-square miles in eastern Ramsey County and is in the Drift Prairie division of the Central Lowland physiographic province of North Dakota. The average annual precipitation is 16.98 inches and the average temperature is 38.8° F. Drainage is poorly developed with numerous potholes and swampy depressions scattered at random over the landscape.

Sandstone of the Fall River Formation underlies the entire Lawton area and may be encountered at a depth of about 1,200 feet. Information on the chemical quality of water from this formation is undetermined in the study area. However, it would be similar in quality to the 1,470 foot well at Devils Lake that yields water with a high degree of mineralization.

The Pierre Formation is the only bedrock aquifer that has been developed in the Lawton area. Several farm wells are completed at depths greater than 100 feet. Low well yields and generally poor water quality are characteristic of this formation.

Glacial drift in the Lawton area has several localized aquifers consisting of sand and gravel associated with it. These aquifers are classified as till-associated deposits and ice-contact deposits.

The till-associated deposits occur as confined bodies of sand and gravel within the glacial drift and are thin and very limited in areal extent. Well yields are small and often inadequate. Water quality is usually poor and indicates the infiltration and accumulation of dissolved minerals as ground water percolates down through the surrounding glacial till.

Ice-contact deposits consisting of kames and eskers occur at random in the Lawton area. Kames are conically-shaped hills of oxidized sand and gravel. The eskers are linear ridges of sand and gravel that may contain some clay. Several eskers were investigated by test drilling and found to be very limited in areal extent. Sand and gravel ranged in thickness from 6 feet to 17½ feet. Water quality is of the calcium bicarbonate type and generally low in dissolved solids. The surficial nature of these deposits permits the rapid infiltration of precipitation. However, the limited areal extent, small storage capacity, and wide annual fluctuation of water levels indicate these aquifers are not capable of sustained yields without continuous recharge.

A solution to Lawton's water supply problem would be to complete a well in the Fall River Formation. The Fall River sandstone is the largest source of water in the Lawton area. However, the water is highly mineralized.

A water sample collected from a well completed in this formation at Devils Lake contained 3,835 mg/l total dissolved solids. Some method of desalting, perhaps electrodialysis or reverse osmosis, would be required to reduce the dissolved solids to an acceptable level. Even though desalting is relatively expensive, it could be a means of providing an adequate supply of good quality water to city residents.

TABLE 2 -- CHEMICAL ANALYSES

(Analytical results are in milligrams per liter except where indicated)

AQUIFERS Owner or designation	Location	Depth of well (feet)	Temp.(°F)	Date of collection	(SiO_2)	(Fe)	(Mn)	(Ca)	(Mg)	(Na)	(K)	(HCO_3)	(CO_3)	(SO_4)	(Cl)	(F)	(NO_3)	(B)	Total dissolved solids	Total hardness as $CaCO_3$	Total hardness Noncarbonate	Percent sodium	S.A.R.	Specific conductance	pH
TILL-ASSOCIATED AQUIFERS																									
City of Lawton	156-60-28 acd	45	48	7-20-71	25	0	0.30	280	331	1050	57	813	0	2270	849	0.2	173	0.09	5270	2060	1390	52	10	7030	7.7
Farmers Union Oil Co.	156-60-28 daa	30	–	8-3-72	24	0.08	0.03	295	190	158	11	551	0	1340	31	0.4	110	0.11	2510	1520	1070	18	1.8	2790	7.7
PIERRE FORMATION																									
Thor Thompson	155-60-8 cdc	80	–	8-4-72	22	0.09	0.09	34	14	940	12	763	0	148	1020	0.4	70	2.6	2420	144	0	93	34	4580	7.7
Kermit Lien	156-60-28 dbb	92	–	1971	26	0.24	0.13	53	41	1130	15	721	0	86	1510	0.4	5.5	3.3	3190	301	0	88	28	5630	7.7
Richard Stevens	156-61-14 ddd	50	–	8-3-72	23	0.08	0.05	22	8.8	793	10	756	0	301	590	0.5	72	2.4	2190	91	0	94	36	3620	8.0
ICE-CONTACT AQUIFERS																									
Clinton Swanson	156-60-29 bcd	20	43	7-20-71	25	0	0.03	60	30	15	19	315	0	31	5.9	0.2	18	0.44	309	274	16	11	0.4	548	7.9
Test hole 5990	156-60-29 ccb	15	43	7-21-71	24	0	0.01	84	59	95	3.3	308	0	360	9.1	0.3	29	0.04	783	453	200	31	1.9	1140	7.9
Test hole 8029	156-61-34 aaa	18	46	7-21-71	25	0	0.01	34	20	10	1.7	198	0	31	12	0.3	2.5	0.09	195	166	4	12	0.3	337	7.5
Test hole 5987	156-61-35 aaa	14	41	6-17-71	26	0.03	0.17	91	31	8	5	335	0	83	3.2	0.4	1	0	422	353	78	5	0.2	669	7.8

TABLE 2 - CHEMICAL ANALYSES

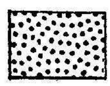
TABLE 3 - LOGS OF TEST HOLES

The following test hole logs are a summary of data from the driller's logs, geologist's sample descriptions and electric logs.

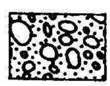
Grain-size classification is C. K. Wentworth's scale from Pettijohn (1957).

Test holes are called observation wells when they have been completed with $1\frac{1}{4}$ inch diameter plastic casing. Well depths, screened aquifer intervals and water levels are so designated.

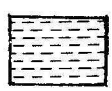
Explanation of Lithologic Symbols



Sand and Gravel



Till



Shale

155-60-8aaa

Test Hole 5993

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Topsoil, sandy, silty, pebbly, dark-brown	1	1
	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, slightly cohesive, moderately plastic, oxidized (till) ----------------------	5	6
	Gravel, sandy, moderately clayey, fine to coarse, poorly sorted, angular to rounded, oxidized --------------------	10	16
	Clay, silty, slightly sandy, pebbly, moderate-yellowish-brown, moderately plastic, cohesive, oxidized (till) ----	12	28
	Clay, silty, slightly sandy, pebbly, olive-gray, moderately cohesive, slightly plastic (till) --------------	4	32
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous not fractured ------------------------	8	40

155-60-17ddd

Test Hole 8036

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Topsoil, silty, clayey, grayish-black -------	1	1
	Clay, silty, moderately sandy, pebbly, occasional cobbles, moderate-yellowish-brown, cohesive, slightly plastic, oxidized (till) --------------------------	11	12
Pierre Formation:			
	Shale, siliceous, grayish-black to black, indurated, noncalcareous, not fractured ---	8	20

155-60-14ddd

Test Hole 8037

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, brownish-black	1	1
	Clay, silty, slightly sandy, pebbly, moderate-yellowish-brown, cohesive, slightly plastic, oxidized (till)	11	12
	Clay, silty, slightly sandy, pebbly, olive-gray, moderately cohesive, plastic, calcareous (till)	6	18
Pierre Formation:			
	Shale, siliceous, grayish-black to black, indurated, noncalcareius, not fractured	22	40

155-61-1ddd

Test Hole 8034

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, brownish-black	1	1
	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, cohesive, slightly plastic, oxidized (till)	21	22
	Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, moderately cohesive, moderately plastic, calcareous (till)	18	40
Pierre Formation:			
	Shale, siliceous, grayish-black to black, indurated, noncalcareous	20	60

155-61-10ddc

Test Hole 8035

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Topsoil, silty, clayey, sandy, brownish-black	1	1
	Clay, silty, moderately sandy, pebbly, a few cobbles and boulders, moderate-yellowish-brown, cohesive, slightly plastic, oxidized (till)	7	8
	Shale, gravelly, sandy, grayish-black to black with dark-yellowish-brown iron-staining on outer surface of angular fragments, fractured and reworked (till)	9	17
Pierre Formation:			
	Shale, siliceous, grayish-black to black, indurated, noncalcareous, not fractured	23	40

156-60-8bcc

Test Hole 8032

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, brownish-black	1	1
	Clay, silty, moderately sandy, pebbly, a few cobbles and boulders, moderate-yellowish-brown, moderately cohesive, slightly plastic, oxidized (till)	18	19
	Clay, silty, slightly sandy, pebbly, olive gray, cohesive, slightly plastic, calcareous (till)	10	29
Pierre Formation:			
	Shale, siliceous, grayish-black to black, indurated, noncalcareous, not fractured	11	40

156-60-11ccc

Test Hole 5997

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, grayish-black-------	1	1
	Clay, silty, moderately sandy, pebbly, a few cobbles and boulders, moderate-yellowish-brown, slightly cohesive, moderately plastic, oxidized (till) ----------------	19	20
	Clay, silty, slightly sandy, pebbly, occasional cobbles and boulders, olive-gray, cohesive, slightly plastic, calcareous (till) -----------------------	12	32
Pierre Formation:			
	Shale, siliceous, grayish-black to black, noncalcareous, not fractured ------------	8	40

156-60-14dcc

Test Hole 5996

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, dark-brown --	1	1
	Gravel, sandy, clayey, fine to coarse, angular to rounded, poorly sorted, mostly carbonates, well oxidized ----------------	6	7
	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, slightly cohesive, moderately plastic, oxidized (till) --	15	22
	Clay, silty, slightly sandy, pebbly, gravelly, olive-gray, cohesive, moderately plastic (till) ---------------------	10	32
Pierre Formation:			
	Shale, siliceous, grayish-black to black, noncalcareous, not fractured -------------	8	40

156-60-19ccc

Test Hole 8033

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, brownish-black	1	1
	Clay, silty, moderately sandy, pebbly, a few cobbles and boulders, moderate-yellowish-brown, cohesive, slightly plastic, oxidized (till)	21	22
	Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, moderately plastic, calcareous (till)	20	42
Pierre Formation:			
	Shale, siliceous, grayish-black to black, indurated, noncalcareous, not fractured	18	60

156-60-20ccd

Test Hole 5991

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, dark-brown	1	1
	Clay, silty, moderately sandy, pebbly, a few cobbles, moderate-yellowish-brown, slightly cohesive, moderately plastic, oxidized (till)	15	16
	Clay, silty, slightly sandy, pebbly, a few cobbles and boulders, olive-gray, cohesive, moderately plastic, calcareous (till)	24	40
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous, not fractured	20	60

156-60-21aaa

Test Hole 5998

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, grayish-black	1	1
	Clay, silty, moderately sandy, pebbly, a few cobbles, moderate-yellowish-brown, slightly cohesive, moderately plastic, oxidized (till)	19	20
	Clay, silty, slightly sandy, pebbly, olive gray, cohesive, moderately plastic, calcareous (till)	5	25
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous, not fractured	15	40

156-60-24ccc

Test Hole 5995

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, sandy, gravelly, silty, dark-brown	1	1
	Sand, slightly gravelly, slightly clayey, fine to very coarse-grained, moderately well-sorted, subrounded, oxidized	11	12
	Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, moderately plastic, calcareous (till)	12	24
Pierre Formation:			
	Shale, siliceous, grayish-black to black, noncalcareous, brittle to moderately soft, not fractured	16	40

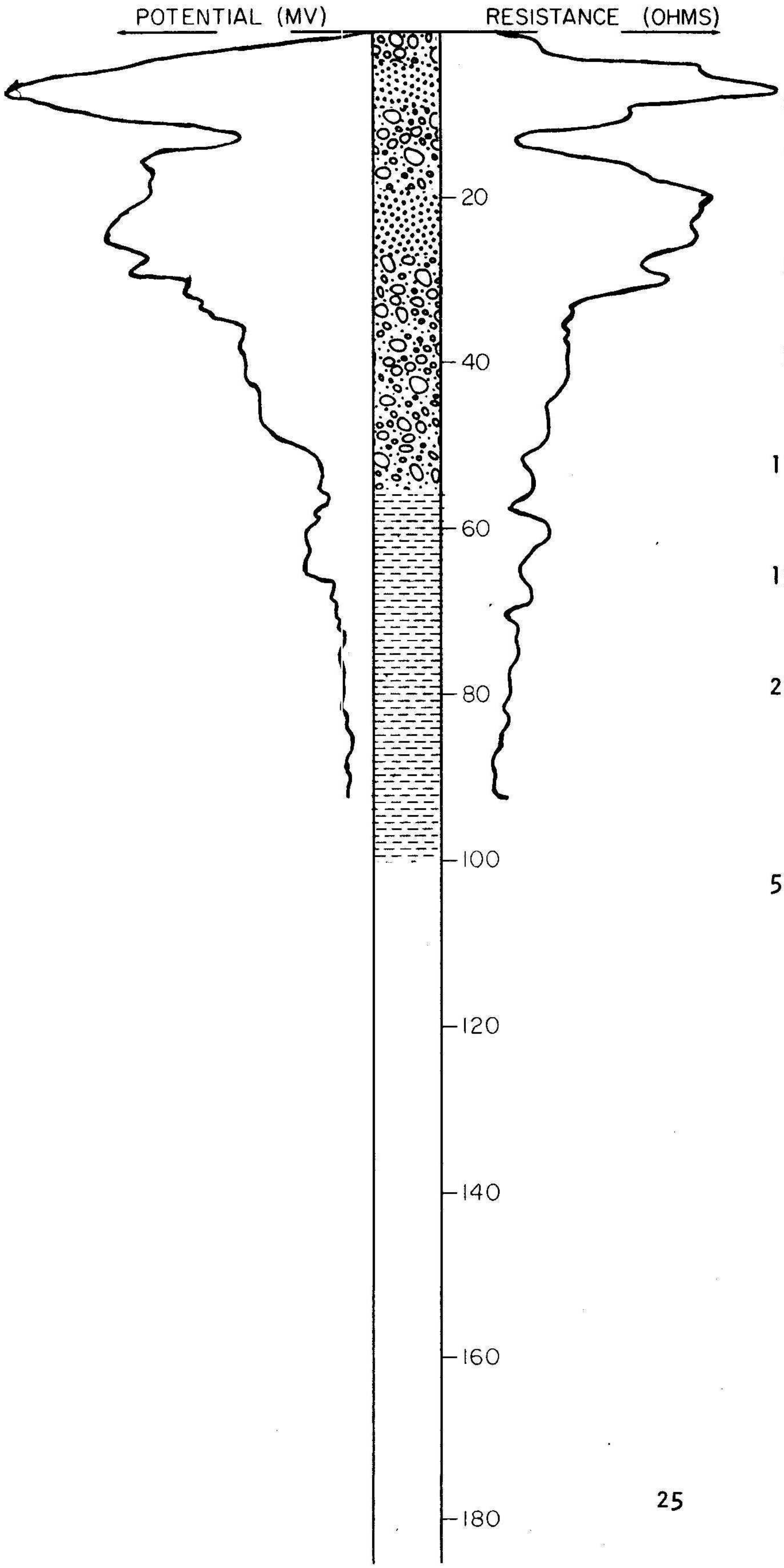
TEST HOLE 8038

LOCATION: 156-60-28acd

DATE DRILLED: July, 1971

ELEVATION: (FT, MSL)

DEPTH: 100 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0 - 1	Topsoil, silty, clayey, pebbly, brownish-black
1 - 4	Clay, very silty, moderately sandy, pebbly, dusky-yellow to moderate-yellowish-brown, cohesive, plastic oxidized (till)
4 - 9	Gravel, sandy, fine to coarse, angular to rounded, poorly sorted, well oxidized
9 -11	Clay, silty, sandy, pebbly, moderate-yellowish-brown, cohesive, moderately plastic, oxidized (till)
11 -19	Clay, silty, slightly sandy, pebbly, cobbles, boulders, olive-gray, cohesive, slightly plastic, calcareous (till)
19- 27	Sand, moderately gravelly, fine- to very coarse-grained, mostly medium- to coarse-grained, subangular, mostly shale
27 -55	Clay, silty, slightly sandy, pebbly, numerous angular shale fragments, occasional cobbles and boulders, medium-dark-gray, cohesive, slightly plastic, calcareous (till)

Pierre Formation

55 -100	Shale, siliceous, grayish-black to black, indurated, noncalcareous, not fractured

156-60-29ccb

Test Hole 5990

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, very sandy, clayey, dark-brown	1	1
	Sand, slightly gravelly, fine- to very coarse-grained, mostly medium- to coarse-grained, subangular to subrounded, moderately well-sorted, slightly oxidized	14	15
	Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, moderately plastic, calcareous (till)	10	25
Pierre Formation:			
	Shale, siliceous, grayish-black to black, noncalcareous, not fractured	15	40

Observation well
Depth 15 feet
Screened interval 12-15 feet
Water level 3.80 feet measured June 18, 1971

156-60-29cdd

Test Hole 5992

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, brownish-black	1	1
	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, slightly cohesive, moderately plastic, oxidized (till)	19	20
	Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, moderately plastic, calcareous (till)	21	41
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous, not fractured	19	60

156-60-29daa

Test Hole 5983

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, grayish-black	1	1
	Clay, silty, moderately sandy, pebbly, a few cobbles, moderate-yellowish-brown, slightly cohesive, moderately plastic, oxidized (till)	14	15
	Clay, silty, slightly sandy, pebbly, occasional cobbles and boulders, olive-gray, cohesive, moderately plastic, calcareous (till)	29	44
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous, very slightly fractured	16	60

156-60-30dcd

Test Hole 5985

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Topsoil, silty, clayey, sandy, grayish-black	1	1
	Clay, silty, moderately sandy to sandy, pebbly, dusky-yellow, slightly cohesive, moderately plastic, oxidized (till)	4	5
	Sand, fine- to coarse-grained, slightly clayey, subangular, poorly sorted, oxidized	1	6
	Clay, moderately sandy, pebbly, moderate-yellowish-brown, cohesive, plastic, oxidized (till)	3	9
	Clay, silty, slightly sandy, pebbly, olive-gray, moderately cohesive, slightly plastic, calcareous (till)	2	11
	Sand, moderately gravelly, fine- to very coarse-grained, subangular to rounded, fair sorting	2	13
	Clay, silty, moderately sandy, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic, calcareous (till)	7	20
	Sand, gravelly, fine- to very coarse-grained, subangular, fair sorting	1	21
	Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, moderately plastic, calcareous (till)	14	35
Pierre Formation:			
	Shale, siliceous, grayish-black to black, very slightly fractured, noncalcareous	25	60

156-60-31aaa

Test Hole 5984

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, grayish-black ------	1	1
	Clay, silty, moderately sandy, pebbly, dusky-yellow to moderate-yellowish-brown, slightly cohesive, plastic, oxidized (till) -------------------------	11	12
	Clay, silty, slightly sandy, pebbly, occasional cobbles, olive-gray, cohesive, moderately plastic, calcareous (till) ----	13	25
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous, very slightly fractured -----------------	15	40

156-60-35bab

Test Hole 5994

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, dark-brown --	1	1
	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, slightly cohesive, plastic, oxidized (till) --------	14	15
	Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, moderately plastic, calcareous (till) -----------------------	5	20
	Sand, fine- to coarse-grained, subrounded, fair sorting ----------------------------	2	22
Pierre Formation:			
	Shale, siliceous, grayish-black to black, noncalcareous, not fractured -------------	18	40

156-61-11aaa

Test Hole 8031

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, sandy, clayey, brownish-black	1	1
	Clay, silty, moderately sandy, pebbly, occasional cobbles and boulders, moderate-yellowish-brown, moderately cohesive, slightly plastic, oxidized (till)	25	26
	Clay, silty, slightly sandy, pebbly, a few cobbles and boulders, olive-gray, cohesive, moderately plastic, calcareous (till)	28	54
Pierre Formation:			
	Shale, siliceous, grayish-black to black, indurated, noncalcareous, not fractured	6	60

156-61-23bbb

Test Hole 8030

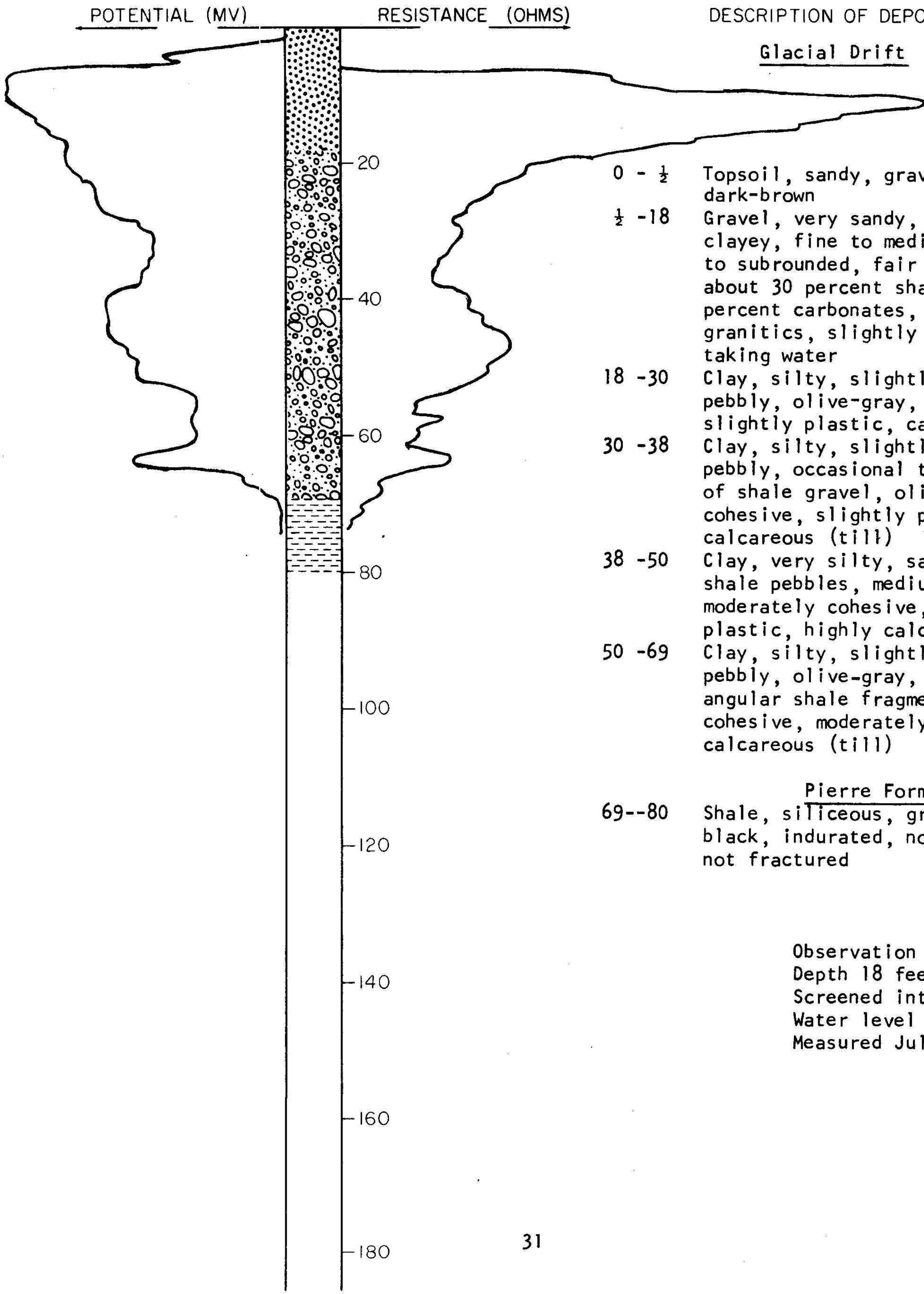
Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, sandy, gravelly, clayey, dark-brown	1	1
	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, cohesive, slightly plastic, oxidized (till)	7	8
	Sand, silty, clayey, very fine- to coarse-grained, subangular, well oxidized	7	15
	Clay, very silty, slightly sandy, pebbly, moderate-yellowish-brown, cohesive, slightly plastic, oxidized (till)	11	26
	Clay, silty, slightly sandy, a few thin sand lenses, boulders, cobbles, olive-gray, moderately cohesive, plastic, calcareous (till)	40	66
Pierre Formation:			
	Shale, siliceous, grayish-black to black, indurated, noncalcareous, not fractured	14	80

LOCATION: 156-61-34aaa

DATE DRILLED: July 20, 1971

ELEVATION: (FT, MSL)

DEPTH: 80 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0 - ½ Topsoil, sandy, gravelly, clayey, dark-brown

½ -18 Gravel, very sandy, slightly clayey, fine to medium, angular to subrounded, fair sorting, about 30 percent shale, 40 percent carbonates, 30 percent granitics, slightly oxidized, taking water

18 -30 Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, slightly plastic, calcareous (till)

30 -38 Clay, silty, slightly sandy, pebbly, occasional thin layers of shale gravel, olive-gray, cohesive, slightly plastic, calcareous (till)

38 -50 Clay, very silty, sandy, a few shale pebbles, medium-gray, moderately cohesive, slightly plastic, highly calcareous (till)

50 -69 Clay, silty, slightly sandy, pebbly, olive-gray, numerous angular shale fragments, moderately cohesive, moderately plastic, calcareous (till)

Pierre Formation

69--80 Shale, siliceous, grayish-black to black, indurated, noncalcareous, not fractured

Observation well
Depth 18 feet
Screened interval 15-18 feet
Water level 7.27 feet
Measured July 21, 1971

156-61-35aaa

Test Hole 5987

Formation	Lithology	Thickness	Depth
		(feet)	
Glacial Drift:			
	Topsoil, silty, clayey, sandy, brownish-black	1	1
	Sand, slightly gravelly, fine- to very coarse-grained, mostly medium- to coarse-grained, subangular to subrounded, moderately well-sorted, taking water -----	13	14
	Clay, silty, moderately sandy, pebbly, olive-gray, cohesive, moderately plastic, calcareous (till) ---------------------------	12	26
	Sand, slightly clayey, very fine- to medium-grained, subrounded ---------------------	5	31
	Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, moderately plastic, calcareous (till) --------------	24	55
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous, not fractured ---------------------------	25	80

Observation well
Depth 14 feet
Screened interval 11-14 feet
Water level 3.30 feet measured June 17, 1971

156-61-35abb

Test Hole 5988

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, brownish-black	1	1
	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, slightly cohesive, plastic, oxidized (till)	11	12
	Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, moderately plastic, calcareous (till)	19	31
	Sand, slightly gravelly, very clayey, silty, fine- to coarse-grained, subrounded	6	37
	Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, slightly plastic, calcareous (till)	11	48
Pierre Formation:			
	Shale, siliceous, grayish-black to black, noncalcareous, not fractured	12	60

156-61-36bab

Test Hole 5989

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Topsoil, silty, clayey, pebbly, dark-brown	1	1
	Clay, silty, moderately sandy, pebbly, a few cobbles, moderate-yellowish-brown, moderately cohesive, slightly plastic, oxidized (till)	13	14
	Clay, silty, slightly sandy, pebbly, occasional cobbles, olive-gray, cohesive, moderately plastic, calcareous (till)	27	41
Pierre Formation:			
	Shale, siliceous, grayish-black to black, noncalcareous, very slightly fractured, brittle to moderately soft	19	60

156-61-36bbb

Test Hole 5986

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Topsoil, sandy, pebbly, silty, dark-brown --	1	1
	Sand, slightly gravelly, slightly clayey, fine- to very coarse-grained, fair sorting, subangular to rounded, taking water ------	13	14
	Clay, very sandy, silty, olive-gray, slightly cohesive, slightly plastic, calcareous (glaciofluvial sediment) ------	6	20
	Sand, slightly gravelly, fine- to coarse-grained, subangular, fair sorting --------	2	22
	Clay, very sandy, silty, olive-gray, cohesive, slightly plastic, calcareous (glaciofluvial sediment) ----------------	2	24
	Sand, fine- to coarse-grained, subrounded --	1	25
	Clay, very sandy, silty, medium-gray, cohesive, slightly plastic, calcareous (glaciofluvial sediment) ----------------	2	27
	Sand, fine- to medium-grained, subrounded --	1	28
	Clay, silty, moderately sandy, pebbly, olive-gray, cohesive, moderately plastic, calcareous (till) -----------------------	7	35
	Sand, clayey, fine- to coarse-grained, subrounded ------------------------------	2	37
	Clay, silty, very sandy, pebbly, cobbles, olive-gray, cohesive, slightly plastic, calcareous (till) -----------------------	18	55
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous, very slightly fractured -----------------	25	80

156-61-36ddd

Test Hole 5999

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Road fill, silty, clayey, brownish-black	3	3
	Clay, very silty, moderate-yellowish-brown, slightly cohesive, plastic, laminated, oxidized (glaciofluvial sediment)	12	15
	Clay, very silty, olive-gray, slightly cohesive, plastic, laminated (glaciofluvial sediment)	9	23
	Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, plastic, calcareous (till)	11	34
Pierre Formation:			
	Shale, siliceous, grayish-black to black, brittle to moderately soft, noncalcareous, not fractured	6	40

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