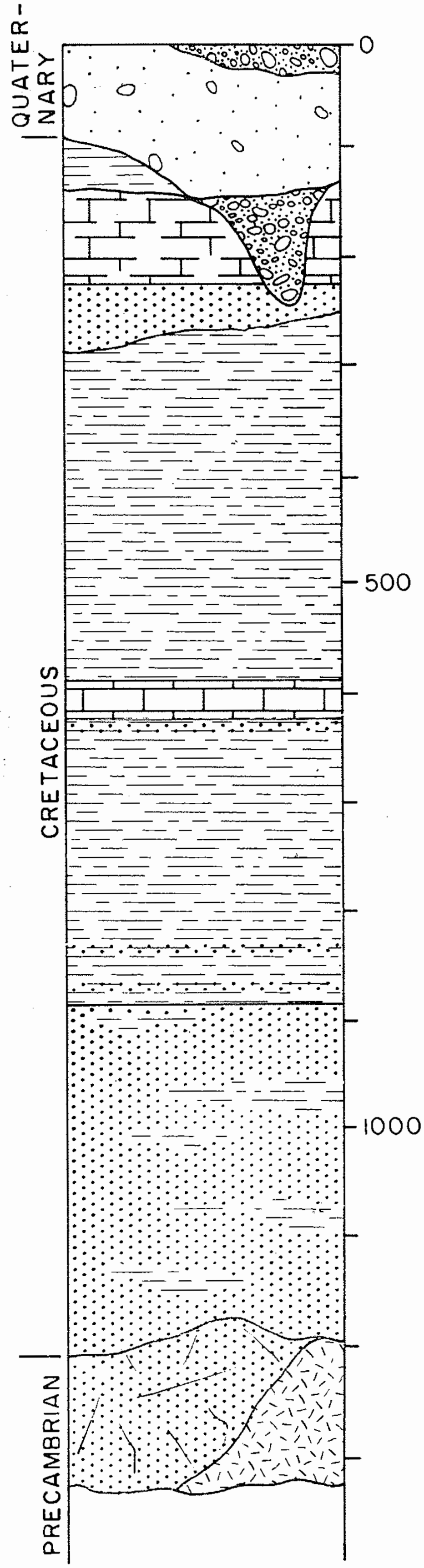

GEOLOGY AND GROUND WATER SUPPLIES IN SANBORN COUNTY SOUTH DAKOTA

by

Fred V. Steece,

South Dakota Geological Survey

and

Lewis W. Howells,

United States Geological Survey

Bulletin 17

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STATE OF SOUTH DAKOTA
Nils Boe, Governor

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by
Fred V. Steece, S.D.G.S., and Lewis Howells, U.S.G.S.

with sections on a

Magnetometer survey by Bruno C. Petsch, S.D.G.S., and on
Quality of water by Lewis Howells and Ralph L. Kilzer, U.S.G.S.

Prepared in cooperation with the
United States Geological Survey

Science Center
University of South Dakota
Vermillion, South Dakota
1965

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ABSTRACT

Sanborn County is in the central part of eastern South Dakota, in the James Basin division of the Central Lowland physiographic province. The area occupies 571 square miles and is drained by the James Basin.

Pleistocene glacial drift of early and late Wisconsin age and Recent sediments are the surficial deposits in the area. Cretaceous sedimentary rocks as much as 900 feet thick overlie the Precambrian Sioux Quartzite, the main basement rock of Sanborn County. The Cretaceous rocks are the Pierre Shale, the Niobrara Marl, the Carlile Shale, the Greenhorn Limestone, the Graneros Shale, and the Dakota Group.

A magnetometer survey revealed three anomalies in the county: a 500-gamma high in the northwestern part, a 400-gamma high in the south-central part, and an 800-gamma high in the central part. A magnetic low was mapped in the northeastern part of the county. The first two anomalies probably reflect undulations on the Precambrian surface; whereas the 800-gamma anomaly may be due to variation in the lithology of the basement rock. The remainder of the county has a magnetic intensity of approximately 300 gammas, which is normal for this part of South Dakota.

Ground water, sand and gravel, and rock comprise the mineral resources of the county.

An estimated 2,200,000 acre-feet of water is stored in two glacial-drift aquifers in western and northern Sanborn County. Although somewhat mineralized, the water has been successfully used for irrigation at three places. More than 20,000 acre-feet of water could be withdrawn annually from the two aquifers without exceeding average recharge. The Warren aquifer, which is recharged within and outside the county, contains water under water-table conditions where it is exposed and under artesian conditions where it is buried. The Floyd aquifer contains water under artesian conditions and probably receives recharge from the Coteau des Prairies east of Sanborn County.

The Niobrara Marl and Codell Sandstone Member of the Carlile Shale, the Carlile Shale, the Greenhorn Limestone, and the Dakota Group contain water under artesian pressure and are heavily developed for stock and domestic use. The Niobrara and Codell contain the most widely developed bedrock aquifer and supply water to more than 600 wells. Sandy zones in the Carlile Shale below the Codell Sandstone Member yield water to a few wells. The Greenhorn Limestone supplies water to 89 flowing wells. The Dakota Group discharges more than 4,500 acre-feet of water per year to nearly 600 flowing wells in Sanborn County.

More than 5,500 acre-feet of water per year is discharged by wells that penetrate bedrock aquifers. All bedrock aquifers discharge water to overlying aquifers either by natural hydraulic connections or through corroded well casings. The sources or areas of recharge of the bedrock aquifers are unknown.

Artesian pressures in bedrock aquifers have declined significantly since 1885 when pressure was high enough to cause most wells to flow. By 1961 wells penetrating the aquifer in the Niobrara and Codell flowed only in the lowest areas of the county. Wells that tap the Carlile Shale and Greenhorn Limestone flow in most of the county, but have very low pressures. Artesian pressure in the Dakota Group at Woonsocket decreased from 250 psi (pounds per square inch) in 1890 to 24 psi in 1961.

Rapid declines of artesian pressure and waste of water have resulted from the unrestricted flow of wells. More than 70 percent of the 5,500 acre-feet of water discharged by wells in 1961 from bedrock aquifers was wasted.

The quality of the ground water ranges from very poor to good. The poorest quality water is obtained from till or from very clayey drift, and the best quality water is obtained from clean sand in surface outwash. Water from the bedrock aquifers is generally poorer in quality than water from the major outwash aquifers.

The general range of quality of water in aquifers in Sanborn County may be summarized as follows:

Aquifer or water-bearing unit	Total dissolved solids (ppm) b/	Hardness (ppm)	Boron (ppm)	Percent sodium
Warren aquifer	670-2,000	50-886	0.07-0.67	17-70
Floyd aquifer	1,400-1,800	300-800	0.65-1.8	42-60
Niobrara Marl and Codell Sandstone Member of Carlile Shale	1,250-1,800	34-138	2.2-4.3	86-97
Greenhorn Limestone a/	1,500-1,860	68-1,030	0.79-6.2	23-98
Dakota Group	2,000-2,200	86-1,100	0.54-1.5	35-90

a/ Total range
b/ Parts per million

All aquifers yield water suitable for domestic and stock use, although the concentrations of some constituents may exceed the limits recommended by the U. S. Public Health Service for drinking water. The constituents most frequently in excess of recommended limits are total dissolved solids, chloride, fluoride, iron, and sulfate.

Only the Warren and Floyd aquifers yield water suitable for irrigation. Even this water should be used with care--salt tolerant crops should be grown and soil salinity control practiced.

Water from bedrock aquifers is unsuitable for irrigation because of high salinity, sodium, and boron.

INTRODUCTION

Purpose and Scope

During the decade 1952 to 1962, ground-water irrigation of conventional crops and sugar beets has increased in eastern South Dakota. The increase in irrigation has been accompanied by a growing need for information on shallow ground-water supplies. In addition, many towns and cities throughout the State need to expand existing water supplies or to obtain supplies of better quality.

The investigation of Sanborn County is the first in a series of studies conducted and financed jointly by the South Dakota State Geological Survey and the U. S. Geological Survey to determine the occurrence, quantity, and quality of ground water available for irrigation, industrial, domestic, and municipal supplies.

The quality of ground water was studied to determine the kinds and quantities of dissolved solids, to determine the relation between water quality and geology, to aid in understanding the hydrology of the aquifers, and to evaluate the suitability of the water for domestic, agricultural, and industrial uses.

Location and Extent

Sanborn County includes approximately 571 square miles near the center of the eastern half of South Dakota as shown on figure 1. The county is bordered on the north by Beadle County, on the northeast by Kingsbury County, on the east by Miner County, on the south by Hanson and Davison Counties, and on the west by Aurora and Jerauld Counties. Sanborn County is about 24 miles square. (See fig. 2.)

Previous Investigation

Sanborn County has been included in many geologic reports of regional scope. Chamberlin (1883) described the major morainic systems of South Dakota. The earliest investigations of ground-water resources that included Sanborn County were made by Nettleton (1892) and Darton (1896). Todd (1899) published a general description of the moraines of southeastern South Dakota, and later (Todd, 1903, 1904; Todd and Hall, 1903, 1904a) made geologic studies of four 30-minute quadrangles that included Sanborn County. Todd and Hall (1904b) studied the geology and water resources of part of the lower James River valley. Darton (1909) included Sanborn County in his general report on the geology and ground-water resources of South Dakota. The South Dakota State Planning Board (1937a) made an inventory of the water resources of the James River drainage basin and (1937b) a study of artesian well flow in South Dakota. Rothrock (1943, 1944) included Sanborn County in his general account of the geology and mineral resources of South Dakota, and in 1946 included Sanborn County in his reconnaissance study of the James Basin. Sanborn County was included in the area discussed by Gwynne (1951) in his description of

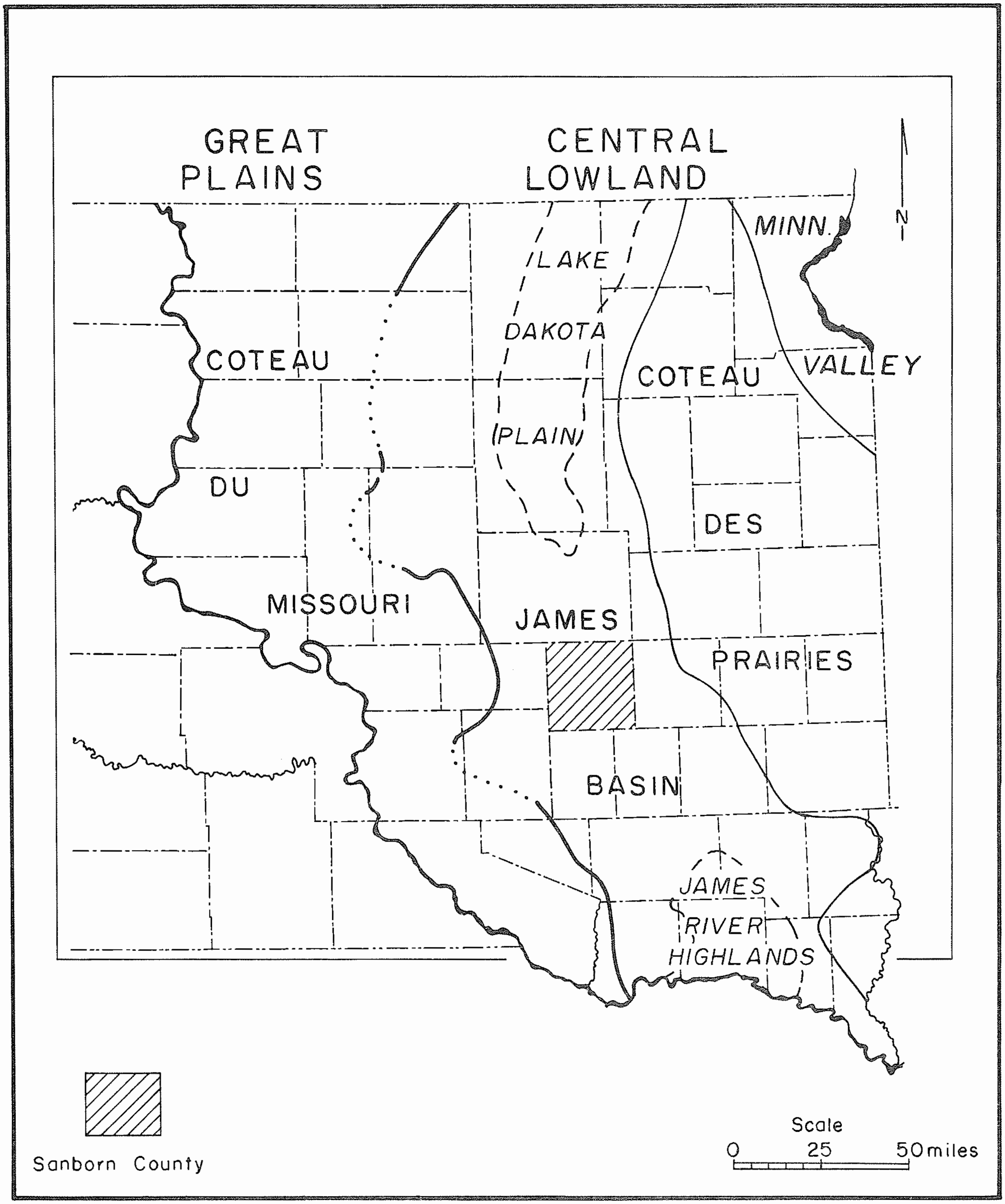

Figure 1. Index map of eastern South Dakota showing physiographic divisions and the location of Sanborn County. *(after Rothrock 1943 and Flint 1955.)*

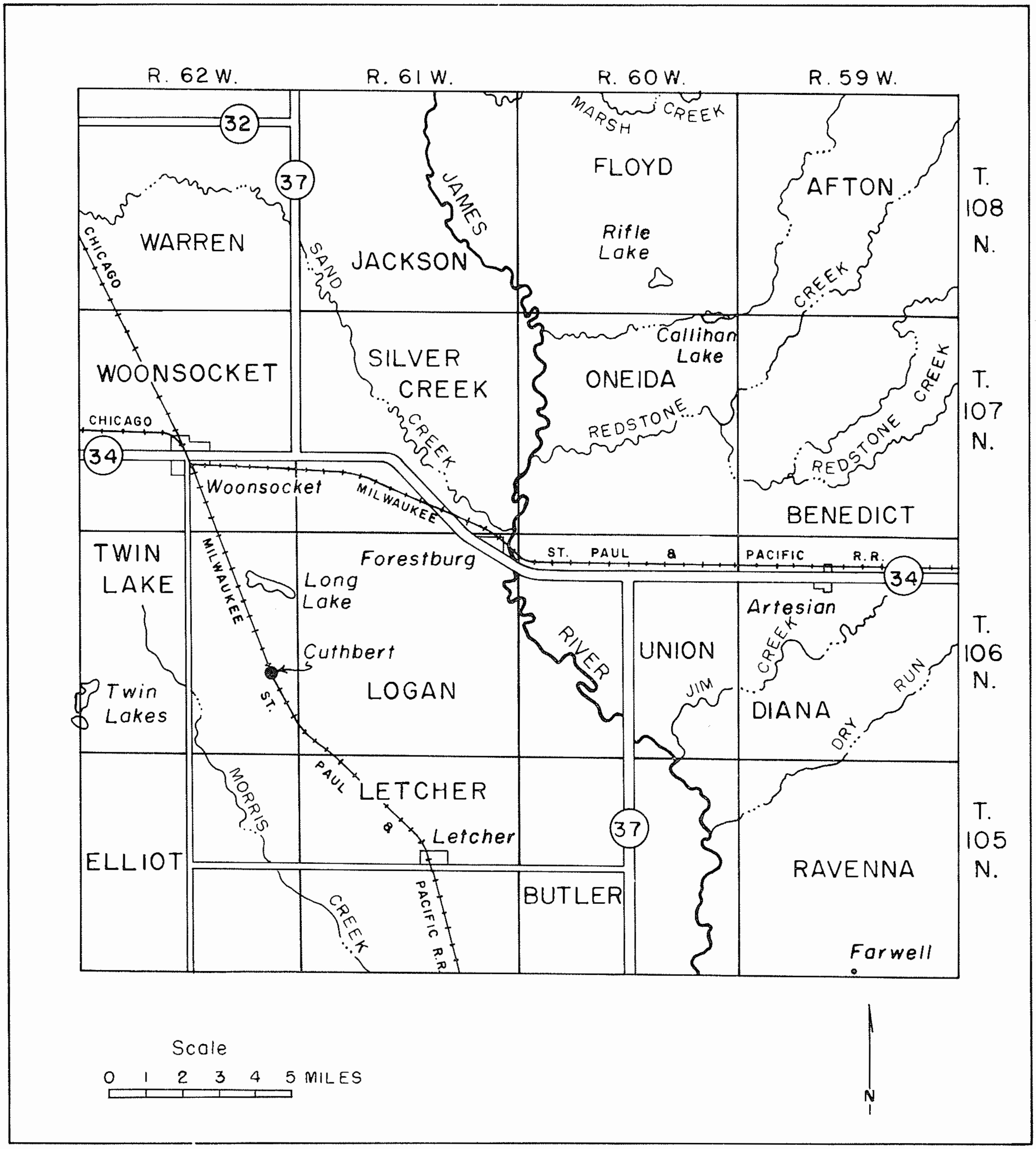

Figure 2. Map showing major cultural features and streams.

minor moraines in South Dakota and Minnesota. Barkley (1953) investigated artesian conditions on the flanks of the Sioux Ridge. Flint (1955) made a reconnaissance study of the glacial geology of eastern South Dakota.

Methods and Procedures

Geologic mapping was done in the summers of 1959 and 1960. Outcrop information was plotted on air photos (scale about 1:63,000) and was transferred to a base map of about the same scale. Outcrops were examined to obtain supplementary data. Surficial deposits were differentiated on the basis of topographic expression and lithology.

The thickness and lithology of the surficial deposits and the lithology of the bedrock were determined by studies of sample cuttings from 153 test holes; 33 of these were drilled with the South Dakota State Geological Survey's jeep-mounted auger primarily in the outwash deposits; 67 holes were drilled with the U. S. Geological Survey's truck-mounted auger for information on the glacial drift and bedrock; 36 rotary holes were drilled to bedrock by drillers under contract to the U. S. Geological Survey; and 17 holes were drilled at township corners by the South Dakota State Geological Survey's rotary rig to obtain bedrock information. Electric and gamma ray logs of some holes were made with the South Dakota State Geological Survey's electric logger. Samples of cuttings from the 36 contract test holes were collected at 5-foot intervals and bedrock cuttings were obtained from 16 of the South Dakota State Geological Survey holes. The samples were washed in the laboratory, examined with a binocular microscope, and described in detail.

The geology section of the report was written by F. V. Steece of the South Dakota State Geological Survey, and the hydrology section was written by Lewis Howells of the U. S. Geological Survey. Magnetic observations were made by B. C. Petsch of the South Dakota State Geological Survey. The quality-of-water section was written by Lewis Howells and R. L. Kilzer of the U. S. Geological Survey.

Ground magnetometer observations were made with a Schmidt type vertical ground magnetometer at intervals of 5 miles; closer spacing was used in an area just east of Forestburg. This network of observations probably outlines the major magnetic features in the county.

The diurnal (daily) magnetic variation was taken from repeated observations at a base station, and from daily magnetograms supplied by the Tucson Magnetic Observatory of the U. S. Coast and Geodetic Survey. All magnetic observations were made in fields or pastures, away from power lines, fences, and other possibly magnetic objects. The observations were plotted, and lines of equal magnetic intensity (isogams) were drawn on a map.

Information on water use, water levels, and artesian pressures was obtained by making a complete inventory of all rural and public water-supply wells. The inventory also provided information for selection of locations for test holes. Samples of water from 1,369 wells were tested in the field for specific conductance, hardness, and chloride, and samples from 93 wells and test holes were collected for complete laboratory analysis.

Aquifer discharge to flowing wells was estimated from well inventory data. Estimates of water use for pumped wells were based on the type of water system, number and kind of livestock, and number of people in a family. Per capita consumption of water was estimated as 70 gpd (gallons per day) in homes with inside plumbing and pressure systems, and 35 gpd in homes without inside plumbing and no pressure system. Livestock needs were estimated on the basis of maximum summer requirements as follows:

Chickens	6 gpd per 100 birds
Cattle	15 gpd per head
Hogs	2 gpd per head
Sheep	1 gpd per head

The quantity of water stored in glacial outwash aquifers was estimated from the map of water-saturated sand thickness using a specific yield value of 0.25. The specific yield estimate was based on the observed size composition of the outwash material.

Recharge to the Warren aquifer was estimated from weather records, stream-gauge readings at Huron and Forestburg, and from field observations of infiltration during heavy rainstorms.

Aquifer tests were made of five high-capacity wells--two irrigation wells in the Warren aquifer, and one irrigation well and two test wells in the Floyd aquifer. The aquifer tests were made by pumping the wells at a constant rate for 24 to 49 hours and observing the drawdown. After pumping stopped, observations were made of the recovery of water levels in the pumped wells and in two to four observation wells for each pumped well. The data on each test were analyzed to determine the coefficient of transmissibility and coefficient of storage of the aquifer. Pumping curves were drawn for each well.

Most laboratory analyses were made according to the methods described by Rainwater and Thatcher (1960). Field analyses were made with colorimetric test kits and resistance bridges.

Many technical terms commonly used in geology and hydrology are defined in the glossary, which begins on page 106.

Acknowledgments

This investigation was under the direction of Allen F. Agnew,[1/] State Geologist and Director of the South Dakota State Geological Survey, and John E. Powell, district engineer, Ground Water Branch, U. S. Geological Survey. The quality-of-water section was prepared under the supervision of D. M. Culbertston, district engineer, Quality of Water Branch, U. S. Geological Survey.

Glenn Miller and Wayne McDaniel provided information on wood samples for radiocarbon dating taken from a well on Mr. Miller's farm in Jerauld County. Laurence McElvain supplied information about wood samples

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1/ Resigned September 1, 1963.

used for radiocarbon dating, taken from a dugout on Mr. McElvain's farm in Miner County.

The writers wish to thank Meyer Rubin, U. S. Geological Survey, Washington, for supplying information on radiocarbon dates. They wish to thank W. R. Muehlberger, University of Texas, and S. S. Goldich, U. S. Geological Survey, Washington, for providing advance information on the date of Precambrian rocks in Sanborn County.

The South Dakota State Geological Survey wishes to thank M. M. Leighton for his helpful comments and suggestions on mapping the glacial geology of eastern South Dakota during several field conferences in South Dakota in 1957, 1960, and 1961, in which F. V. Steece and others of the South Dakota State Geological Survey staff took part.

Melvin Bergeleen and Lloyd Hinker, well drillers, generously supplied well logs and other information relating to Sanborn County and adjacent areas.

Dr. O. E. Olson, Station Biochemistry, South Dakota Agricultural Experimental Station, Brookings, South Dakota, made nine water analyses.

Jim D. Hammel, Clark Mulliner, Roy Alexander, Edward Naylor, and Richard Brown, of the State Geological Survey, and Herbert Bandelman and Jerry Stephens of the U. S. Geological Survey assisted in the field.

Many residents of Sanborn County aided measurably in the successful completion of this work, by providing valuable information and extending many courtesies.

Well-Numbering System

Wells and test holes in this report are numbered in accordance with the U. S. Bureau of Land Management's system of land subdivision. The first numeral of a well designation indicates the township, the second the range, and the third the section. Lowercase letters after the section number indicate the position of the well within the section, the first letter indicates the 160-acre tract, the second the 40-acre tract, the third the 10-acre tract, and the fourth the $2\frac{1}{2}$-acre tract. The letters a, b, c, and d are assigned to the tracts in a counterclockwise direction beginning in the northeast corner of each tract. For example, well 106-60-15da is in the $NE\frac{1}{4}SE\frac{1}{4}$ sec. 15, T. 106 N., R. 60 W. as shown in figure 3. If two or more wells are within the same tract, consecutive numbers beginning with 1 are added as suffixes to designate the order in which the wells are listed (such as 106-60-15da$_2$).

GEOGRAPHY

Physiography

Sanborn County is near the center of the James Basin division of the Central Lowland physiographic province (fig. 1). Although the total relief is only about 165 feet, a wide variety of topographic features are present in the county.

The James River trench, the outstanding topographic feature in the county, has an average width of half a mile and an average depth of 80

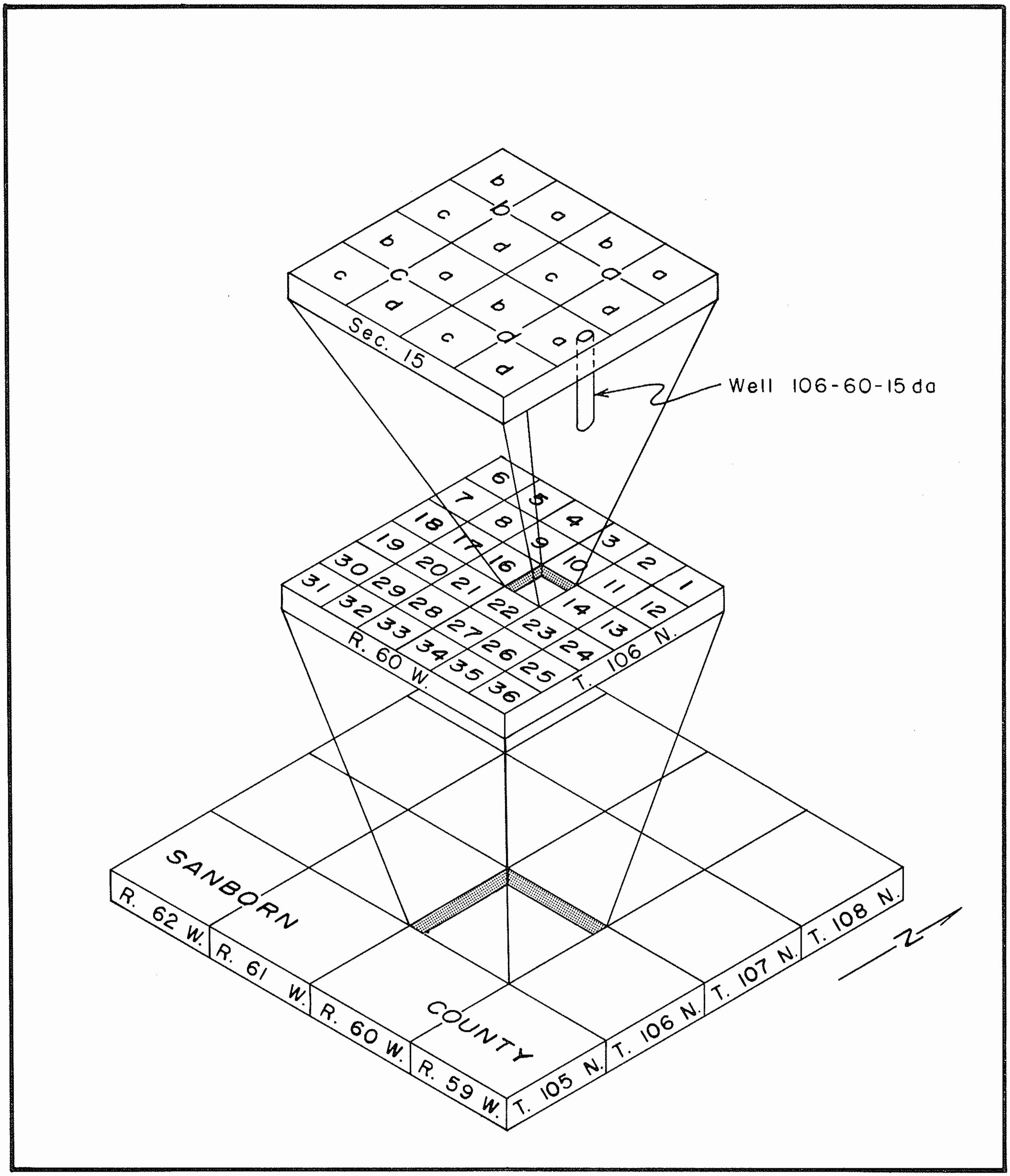

Figure 3. Diagram showing well-numbering system.

feet. (See pl. 1.) The James River enters Sanborn County from the north at an altitude of about 1,230 feet above sea level, and crosses the southern border at an altitude of about 1,210 feet. Thus the river falls only about 20 feet in its 40-mile traverse of the county.

Two terraces occur within the James River trench in Sanborn County. The lower terrace is partially eroded and is 10 feet above the flood plain, in secs. 7, 17, 18, 19, and 20, T. 107 N., R. 60 W. The upper terrace is fairly level and is about 60 feet above the flood plain in secs. 23, 24, and 25, T. 108 N., R. 61 W. and in sec. 30, T. 108 N., R. 60 W.

Although they are not major topographic features, the valleys of Sand, Marsh, Morris, Redstone, Jim, and Dry Run Creeks are conspicuous on the relatively flat uplands.

Except for two outwash plains, much of the northern three-fourths of the county is rolling to hilly and has internal drainage. The most prominent range of hills is the Pony Hills, which extend northwest from near Cuthbert into Jerauld County.

A broad flat plain occupies about 50 square miles north and east of Woonsocket. Near Forestburg this plain is locally overlain by sand dunes, reaching a height of 50 feet at John Brown's Mound (known also as Belcher's Mound--Judy and Robinson, 1953, p. 105). A second relatively flat plain adjacent to Morris Creek extends from southeastern Jerauld County to about 5 miles south of Cuthbert, where it merges with the narrow valley of Morris Creek. Two other small relatively flat areas are in the eastern part of the county--near Rifle and Callihan Lakes, and near Artesian.

The southern one-fourth of the county is nearly level to very gently undulating and is poorly drained. The surface is particularly flat south of Letcher where level terrain is visible for several miles.

Sanborn County is drained by the James River and its tributaries. The major tributaries, Sand, Morris, Marsh, Redstone, Jim, and Dry Run Creeks, are intermittent. Much of the end moraine area has poorly developed drainage; numerous small swales and potholes contain water during wet periods. Larger permanent bodies of water are recharged by artesian wells and are maintained for recreation. These include Twin Lakes, 7 miles southwest of Woonsocket, Rifle and Callihan Lakes, 8 miles northeast of Forestburg, Lake Prior at Woonsocket, and the lake at Letcher.

Climate

The climate of Sanborn County is subhumid and is characterized by long, cold winters and short, hot summers. For the period 1931 to 1955, the mean annual temperature at Forestburg was 46.4 degrees Fahrenheit. The highest temperature recorded was 116 degrees in 1934, and the lowest was -45 degrees in 1912. The growing season (consecutive days with the temperature above 32 degrees) is about 130 days, between May 15 and September 21 (Potas and Skow, 1959).

Most precipitation occurs as rain during the late spring and summer. The average annual precipitation at Forestburg for the period 1931 to 1955 was 20.31 inches. (See fig. 4.) The maximum precipitation was 36.4 inches in 1914, and the minimum was 11.77 inches in 1925.

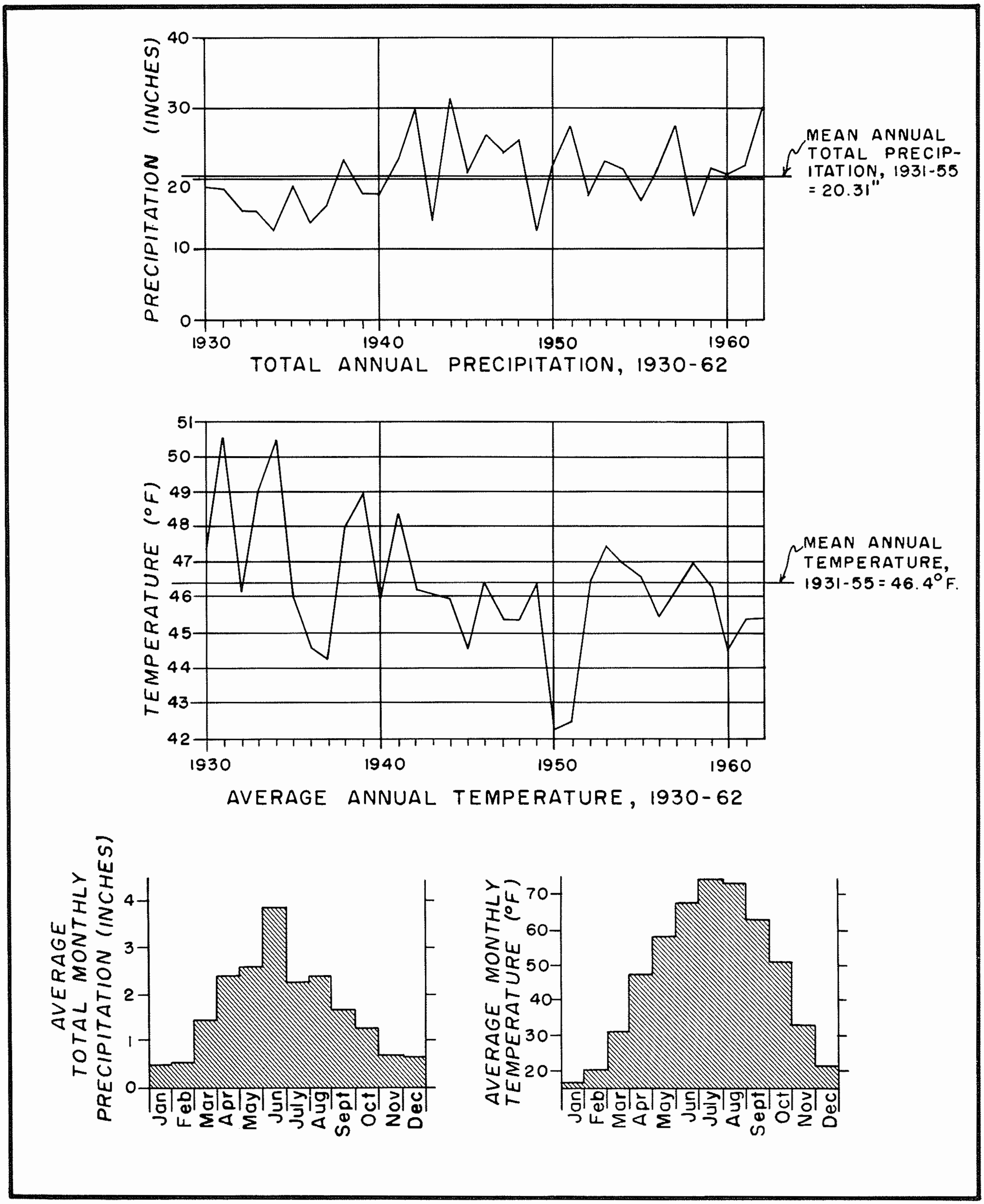

Figure 4. Precipitation and temperature at Forestburg, 1931-62. (Means based on period 1931-55.) From records of U.S. Weather Bureau.

History of County and Population

Sanborn County was settled as early as 1873, but was not organized until 1883. Woonsocket has been the county seat since 1884.

As many as 15 small settlements existed during the early days of the county, but most of these have long since been abandoned. Communities remaining are Woonsocket, Letcher, Artesian, Forestburg, Cuthbert, and Farwell; the last three are unincorporated.

The following table shows the populations of the communities in the county.

	Population (1960 census)
Woonsocket	1,035
Artesian	330
Letcher	296
Forestburg	150 a/
Farwell	7 b/
Cuthbert	2 c/

a/ 1950 census

b/ Census by Lewis Howells, June 1962

c/ Census by County Treasurer, March 1962

In 1890 the population of Sanborn County was 4,610. There was a slight decline in the following decade, then a sharp rise to an all time high of 7,877 in 1920. Since 1920 the number of residents has decreased steadily to the present population of 4,641 as shown in the following table.

Year	Population
1890	4,610
1900	4,464
1910	6,607
1920	7,877
1930	7,326
1940	5,754
1950	5,142a/
1960	4,641

Source: Potas and Skow, 1959

a/ White, 1961

Transportation

Hard-surfaced, all-weather highways in Sanborn County include the east-west State Route 34 and the north-south State Route 37. State Highway 32 in the northwest part of the county connects State Route 34 with Alpena in Jerauld County to the west. A hard-surfaced county road connects Woonsocket with Mount Vernon (Davison County) 25 miles to the south, and a similar county road passes through Letcher and connects the Woonsocket-Mount Vernon road with State Route 37, 5 miles east of Letcher. Graded gravel roads supplement these primary roads on most section lines, except near the James River. The river is bridged nine times in its traverse of the county.

Two lines of the Chicago, Milwaukee, St. Paul, and Pacific Railroad intersect at Woonsocket and provide rail service for the county. Commercial bus service is provided by the Jack Rabbit Lines. Several major truck lines serve Sanborn County, and small truckers handle local hauling and cattle marketing.

Agriculture and Soils

Agriculture is the principal industry in the county. The main crops are corn, oats, and alfalfa, and the chief livestock raised are cattle, hogs, sheep, and poultry. Seventy-eight percent of the cash farm income from 1952 to 1956 was from livestock and livestock products. The remaining 22 percent was from corn (12 percent), wheat (2 percent), and other crops (8 percent). These data are compared to the cash farm income for the State in the following table.

	Sanborn County (percent)	South Dakota (percent)
Cattle and calves	37	35
Hogs	28	18
Other livestock and livestock products............	13	16
Corn........................	12	9
Wheat	2	10
Other crops..................	8	12
	100	100

Source: Potas and Skow, 1959

Sanborn County production for 1959 and 1960 is shown in the following table.

Product	Harvested (acres)		Yield (bu./acre)		Value (dollars)	
	1959	1960	1959	1960	1959	1960
Corn	68,800	66,900	16.0	24.0	1,122,800	1,364,800
All wheat	2,130	2,720	6.9	19.9	28,800	100,600
Winter wheat	40	150	6.0	26.5	--	3,980
Durum wheat	190	70	6.5	19.5	--	--
Spring wheat	1,190	2,500	7.0	19.5	--	--
Oats	21,900	34,600	11.0	33.5	142,100	614,300
Barley	1,500	2,500	12.0	30.0	15,100	57,000
Rye	2,200	3,300	10.0	23.0	21,800	63,000
Flaxseed	150	40	4.0	10.0	1,800	1,100
Soybeans	150	130	10.0	11.0	2,900	2,700
Sorghum	5,400	3,700	23.5	32.5	99,000	81,800
All hay	68,600	61,200	0.73 a/	1.17 a/	1,025,000	1,114,400
Alfalfa hay	32,400	31,500	0.95 a/	1.60 a/	30,800	50,400
Wild hay	26,100	27,400	0.50 a/	0.70 a/	13,100	19,200
Irrigated corn	60	170	67.0	69.0	--	--
Irrigated alfalfa	30	20	2.7 a/	4.0 a/	--	--

Source: Potas, 1961

a/ Hay given in tons per acre.

In 1959, the land in Sanborn County was classified as follows: cropland, 60.2 percent; pasture, 36.2 percent; and other land, 3.6 percent. The following table shows these data.

	Acres	Percent
Urban and built-up	5,123	1.4
Ponds, lakes, etc.	2,348	0.6
Forest and woodland	2,206	0.6
Other non-farm use	1,025	0.3
Cropland, including alfalfa pasture	219,962	60.2
Pasture and range	132,185	36.2
All other	2,591	0.7
Total land area	365,440	100.0

Source: Maurice Van Walleghen, U. S. Dept. Agriculture, Soil Conserv. Service, Woonsocket, personal communication, 1961.

Livestock population in Sanborn County for January 1960 and 1961 is given in the following table.

	January 1, 1960		January 1, 1961	
	Number	Value (dollars)	Number	Value (dollars)
All cattle	41,000	5,544,800	42,100	6,166,300
Milk cows	1,800	355,400	1,700	342,100
Beef cows	16,700	2,688,700	17,300	3,010,200
Hogs	23,800	523,600	22,800	736,400
Sheep and lambs	22,500	382,500	21,600	339,900
All chickens	117,000	98,300	110,000	125,400

Source: Potas, 1961

The average value of farm land and buildings in Sanborn County from 1910 to 1959 is shown in the following table.

Year	Value per acre a/ (dollars)	Total value b/ (dollars)
1910	47.10	15,360,219
1915	57.00	--
1920	112.00	36,652,230
1925	57.50	19,565,810
1930	49.60	17,197,742
1935	22.30	7,132,520
1940	15.20	5,183,226
1945	22.80	8,271,148
1950	37.00	13,048,224
1954	46.20	16,291,104
1959	64.50	21,919,917 c/

a/ Potas, 1961

b/ Potas and Skow, 1959

c/ Calculated

The soils of Sanborn County are classified as follows: (1) black and very dark, grayish-brown loams and clay loams of the subhumid grasslands, (2) sandy soils of the subhumid grasslands, and (3) soils from alluvium (Westin and Buntley, 1962). In the first category the soils are deep, friable to firm, well-drained loams, light clay loams, and clay loams in association with clay pan soils on nearly level, to gently undulating, glacial drift plain. The soil series of this group include Bonilla, Houdek, Vienna, Cresbard, Cavour, Tetonka, Miranda, and Beadle. In the second category the soils are deep, friable to loose, excessively drained to somewhat poorly drained, sandy loams, loamy sands of glacial outwash plains, and wet sandy soils of the Hecla, Hamar, and Maddock series. The soils of the third category are poorly drained loams and silt loams of bottomlands and low terraces along the James River. Figure 5 shows the distribution of these groups as modified after Westin and Buntley (1962).

A critical factor of agriculture in Sanborn County is insufficient moisture. Prolonged drought or, as in 1959, lack of rainfall at critical times

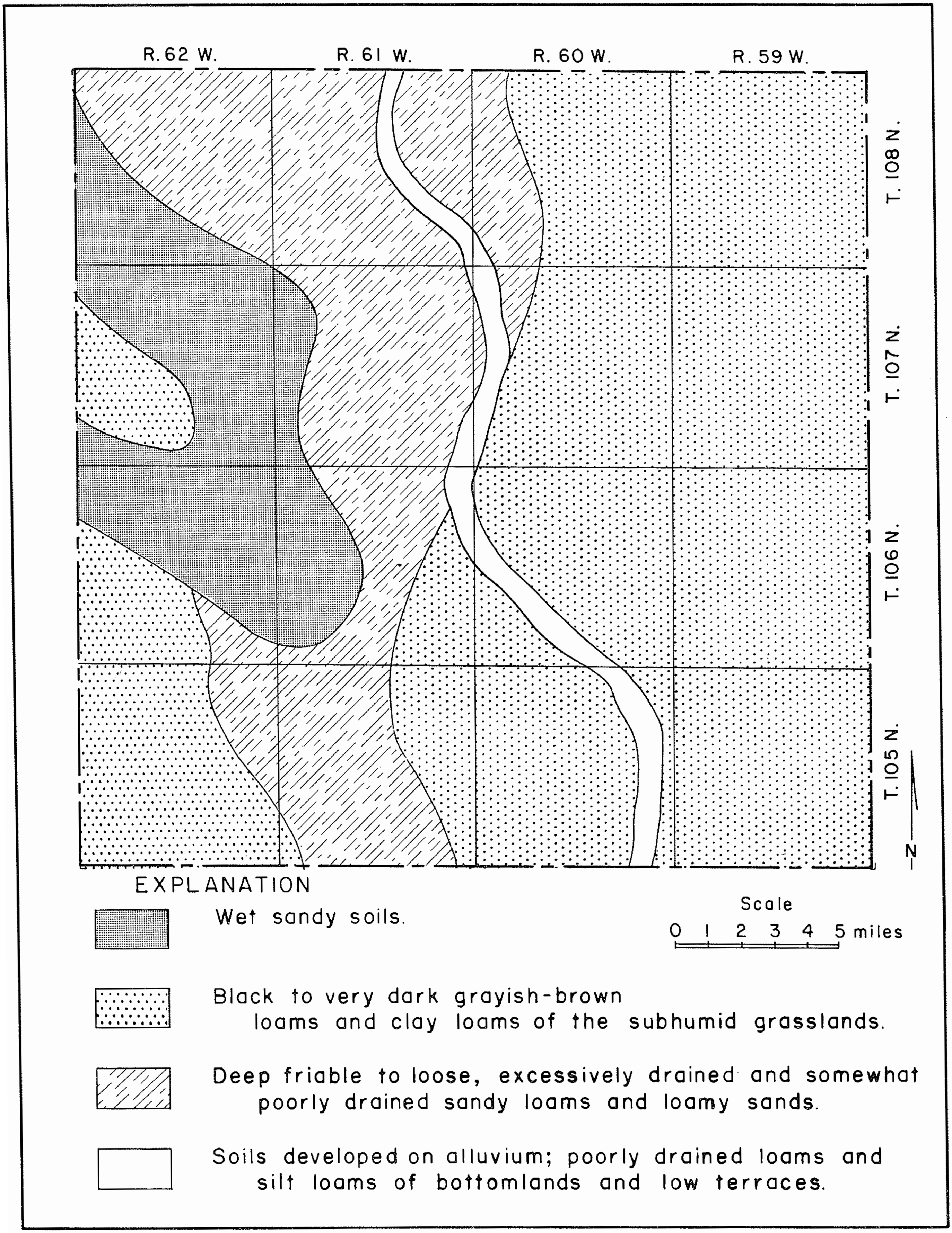

Figure 5. Soils of Sanborn County (modified after Westin and Buntley, 1962)

during the growing season, may damage crops or severely reduce yields. Many farmers are becoming interested in irrigation to supplement rainfall and thus save crops that otherwise might be lost.

The following table summarizes land capability and potential suitability for irrigation.

Land class	Acreage	Description
IIc	96,748	Deep soil, medium textured, moderately permeable substratum.
IIe	83,332	Same as IIc except slopes may be as much as 4 percent.
IIw	1,079	Same as IIc except for occasional flooding.
IIIe	376	Similar to Class II soils but has slopes from 4 to 8 percent.
$IIIs_2$	67,896	Shallow, sandy soils with till at 30 inches or less; moderate salinity hazard.
$IIIs_3$	11,683	Deep, silty, medium textured soils overlying gravel at 20-36 inches below land surface; severe salinity hazard.
IVw	39,794	Deep, moderately heavy soil, poorly drained.
V	38,524	Land subjected to flooding or high water table; slough bottoms.
VI	17,598	Land has steep slopes (over 9 percent); extreme salinity hazard; sandy soil too permeable to retain water.
Total	357,030	

Source: R. Stone and R. Pasco, U. S. Soil Conservation Service, and U. S. Bureau of Reclamation, Huron, personal communications, 1961.

Only land in Classes II and III can be considered as potentially irrigable land. Land in Class IV presents severe drainage problems. Most of Class V land is slough bottoms that are covered with water most of the summer. Class VI includes land that has slopes greater than 9 percent (some slopes exceed 19 percent), land that has excessive salinity hazard and, in Sanborn County, about 8,000 acres of sandy soil so permeable that its water-retaining ability is too low to permit good plant growth.

The total irrigable land in Sanborn County is 261,733 acres. If Class IV land could be economically drained, this total would be increased to 301,527 acres.

GEOLOGY

by Fred V. Steece

Stratigraphic Relations

Information on the stratigraphy of Sanborn County was obtained from a study of samples from shallow test holes, from electric and driller's logs of wells in and near the county, and from published material.

The stratigraphic nomenclature in this report conforms to that used by the South Dakota State Geological Survey. The classification and nomenclature of the rock units accord, for the most part, with that of the U. S. Geological Survey. The stratigraphic section for Sanborn County is summarized as follows:

- Quaternary System
  - Recent Series
    - Alluvium
    - Dune sand
  - Pleistocene Series
    - Wisconsin Glaciation
      - Late Wisconsin
      - Early Wisconsin
- Cretaceous System
  - Upper Cretaceous Series
    - Pierre Shale
    - Niobrara Marl
    - Carlile Shale
    - Greenhorn Limestone
    - Graneros Shale
  - Upper and Lower Cretaceous Series
    - Dakota Group
- Precambrian System
  - Sioux Quartzite
  - Older rocks

A generalized section of the surficial deposits is shown in table 1 and their distribution is shown on plate 1.

Table 1.--Generalized geologic section of the surficial deposits of Sanborn County.

Age			Deposit	Thickness (feet)	Description
Recent			Mainly Chernozem soils	0.5-2	Dark, deep, well-drained, friable loams and clay loams; some claypan soils; developed on nearly level to gently undulating glacial till and outwash plains; and dark, poorly drained loams and silt loams developed on alluvium.
Recent			Alluvium	0-10	Black humic clay; contains minor amounts of sand, silt, and gravel, stratified.
Pleistocene and Recent			Dune sand	0-50	Well-sorted fine to medium wind-blown sand; local dune topography.
Pleistocene and Recent			Loess	0-1	Buff silt to very fine sand; patchy.
Pleistocene	Wisconsin Glaciation	Late	Lake deposits	0-10	Local deposits of sand, silt, clay and marl; commonly gray and fossiliferous.
Pleistocene	Wisconsin Glaciation	Late	James River trench valley fill	0-40	Interbedded sand, silt, and clay, stratified.
Pleistocene	Wisconsin Glaciation	Late	Surface outwash	0-75	Poorly sorted to fairly well-sorted stratified sand and gravel; locally very fine sand and silt; averages about 30 feet.
Pleistocene	Wisconsin Glaciation	Late	Till	0-95	Olive-brown to olive-gray boulder clay; locally includes sand and gravel beds; averages 40 feet.
Pleistocene	Wisconsin Glaciation	Early	Buried outwash and till	0-115	Boulder clay, sand and gravel; recognized by oxidation zones and stratigraphic position below late Wisconsin deposits; till may be as much as 90 feet thick; outwash may be as much as 115 feet thick.

Surficial deposits: Quaternary System

Recent Series

Alluvium

The flood plains of the major streams and the beds of most lakes and ponds in Sanborn County are covered wholly or partly by alluvium. Alluvium averages 6 to 8 feet thick in the James River flood plain, but only 2 to 3 feet thick in the smaller stream valleys. As much as 10 feet of alluvium underlies what may be two ancient lake beds--one broad, flat tract near Rifle and Callihan Lakes, the other near Artesian (pl. 1). The alluvium is generally dark-colored, humic, clay-rich material that contains some silt and sand, and locally, gravel. As much as 5 feet of alluvium underlies the beds of small lakes and ponds throughout the county.

Dune sand

Wind-blown sand, derived from material composing the Woonsocket outwash, covers about 45 square miles of central Sanborn County. The sand is composed primarily of slightly frosted, well-rounded, fine to medium quartz grains. The sand deposit is thin throughout most of the area, commonly ranges from 2 to 29 feet in thickness, and averages about 15 feet. Near Forestburg, however, the wind-blown sand is thicker and has developed a dune topography. At John Brown's Mound, $2\frac{1}{2}$ miles northeast of Forestburg, it is as much as 50 feet thick. Wind-blown sand is brown to yellow when oxidized and grayish when unoxidized. In areas where the sand is thickest it is oxidized to an average depth of about 12 feet.

The distribution of the dune sand shown on the geologic map (pl. 1) differs in detail from that shown by Todd and Hall (1903 Geologic map, 1904a Geologic map) and by Flint (1955, pl. 1). The discrepancies arise because of the more detailed nature of the present report as compared with the earlier studies.

Wind-blown sand occurs in small scattered areas of the Woonsocket outwash plain, producing a gently undulating topography. The deposits are thin and difficult to delineate, and, therefore, are not shown on the geologic map (pl. 1). Near the mouth of Redstone Creek on the east side of the James River, isolated wind-blown sand areas are not shown on the map because of their sporadic distribution. Todd (1904, Geologic map) mapped "old stream deposits" along the east bluff of the James River trench in Sanborn County. Thin ($1\frac{1}{2}$ to 2 feet) scattered deposits of wind-blown sand and some loess were found in this area, but the deposits are too small to show on plate 1.

An interesting phenomenon is present in the dune-sand area several miles northwest of Forestburg where boulders occur on the surface of the wind-blown sand. The boulders may have been deposited by ice rafting during outwash deposition and later exposed by deflation of the surrounding finer grained material, or frost action may have brought the boulders to the surface. Some of these boulders show slight desert polish on the northwestern side.

Pleistocene Series

Nomenclature and age determination

Present knowledge of Pleistocene stratigraphy reveals four major periods of glaciation that occurred on the North American Continent, beginning as long ago perhaps as 1.5 million years (Ericson, and others, 1964). These glacial periods, from oldest to youngest, the Nebraskan, Kansan, Illinoian, and Wisconsin, were separated by interglaciations consisting of long, relatively warm periods of weathering, soil development, and nonglacial deposition. The three major interglaciations beginning with the oldest are the Aftonian, Yarmouth, and Sangamon.

Deposits of the Wisconsin Glaciation have long been known and studied by glacial geologists. Leverett (1929) recognized early, middle, and late Wisconsin deposits. Leighton (1933) believed there were four subdivisions of the Wisconsin, and accordingly he assigned them the names Iowan, Tazewell, Cary, and Mankato. Later Leighton and Willman (1950) added the Farmdale substage below the Iowan as earliest Wisconsin. Thwaites (1943) introduced the name Valders as the sixth Wisconsin substage. The Cochrane has been proposed as a seventh substage by Antevs (1925). Leighton (1960) proposed names for the periods of deglaciation or interstages between the Wisconsin substages as follows: Farm Creek, Gardena, St. Charles, Bowmanville, and Two Creeks.

Flint (1955) mapped the Pleistocene deposits of eastern South Dakota according to Leighton's (1933) subdivisions. He traced moraines and drift sheets of Cary and Mankato age into the James lobe of South Dakota from the Des Moines lobe of western Minnesota. However, Zumberge and Wright (1956) demonstrated that the drift at the Mankato type locality is older then the Two Creeks forest bed of Wisconsin and is probably of Cary age. Radiocarbon dates in the Des Moines lobe show that the lobe was at its maximum extent about 14,000 years ago and had retreated by about 11,800[a/] years ago leaving only 2,200 years for the ice to expand to its outer moraine (Bemis moraine, designated as Cary age by Flint), retreat into Canada, and readvance to the second moraine (Altamont moraine, designated as Mankato age by Flint). Thus, it appears that the Altamont, Gary, Antelope (see figure 6), and all moraines behind the Bemis are but recessionals of the Bemis ice sheet. These facts coupled with the fact that no deposits representing significant time breaks have been found in the Des Moines or James lobes between the above-mentioned morainal deposits suggest that one age of drift was deposited by an ice sheet which built multiple recessional moraines. However, the identification of this drift sheet becomes complicated by radiocarbon dates from Cary drift in Illinois (the type locality), which indicate that the Cary is older in the Lake Michigan lobe in Illinois than it is in the Des Moines and James lobes in South Dakota. Consequently, the drift of the James and Des Moines lobes may not correlate with the Cary drift of the Lake Michigan

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a/ Age of Two Creeks forest bed according to Broecker and Farrand, 1963.

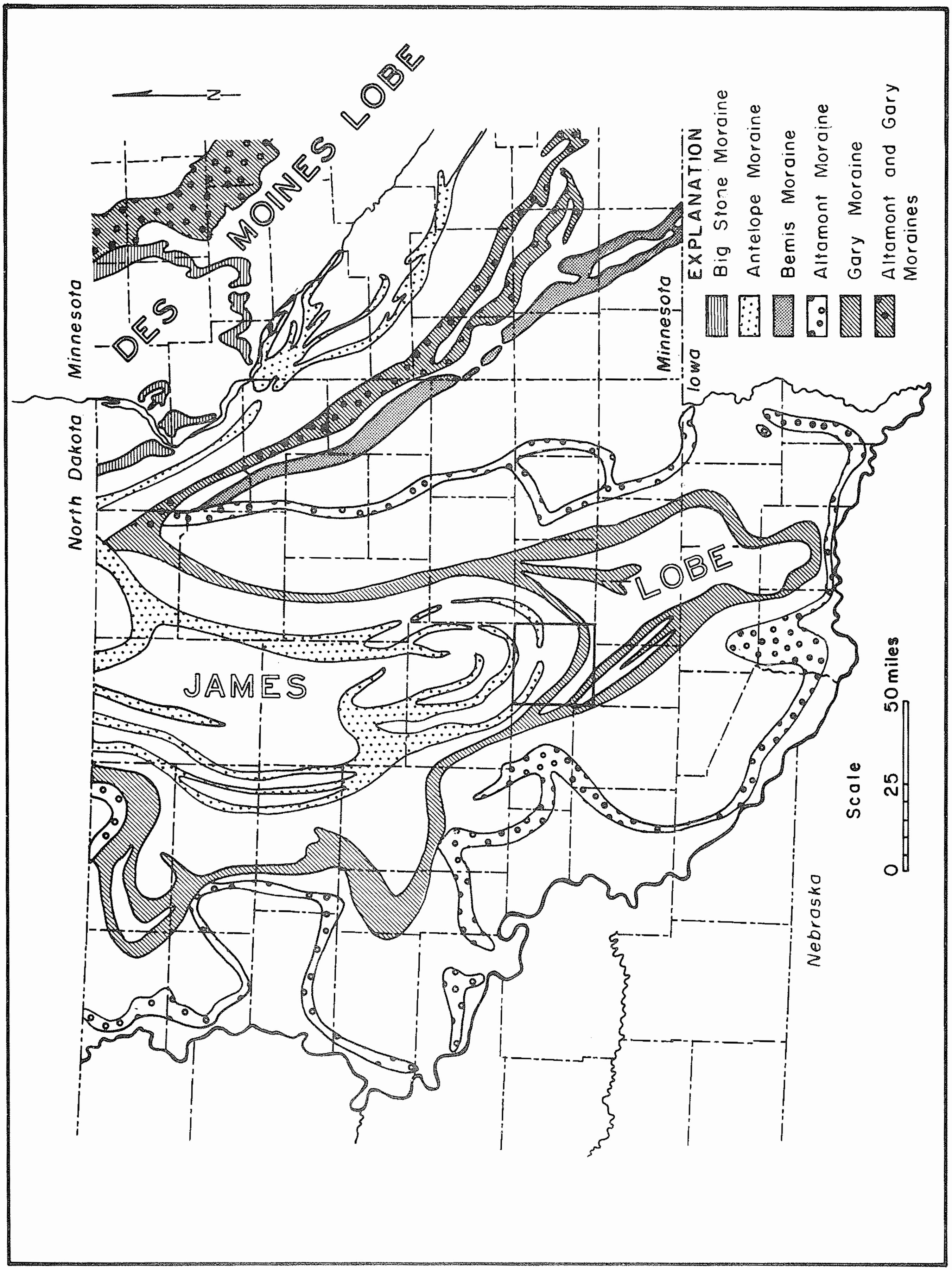

Figure 6. Map of eastern South Dakota and southwestern Minnesota showing major Wisconsin moraines.

lobe but may be a younger drift. To refer to this younger drift as Mankato would be ambiguous because this term has been used to denote both post-Two Creeks (Horberg, 1955) and pre-Two Creeks (Fries, Wright, and Rubin, 1961) events. Yet to refer to it as Valders also may be incorrect because Wright (1955) and Elson (1957) are of the opinion that the Valders never crossed the international boundary in the vicinity of western Minnesota.

Even in Leverett's day (1932), the break between Iowan drift and later Wisconsin deposits was recognized as a significant one. In eastern South Dakota, the Iowan drift surface (Flint, 1955) resembles the Illinoian surface more closely than it does any of the later Wisconsin deposits (Steece, Tipton, and Agnew, 1960). A radiocarbon date in the Iowan drift area near Brookings (sample W-115, from 180 feet deep in a well) (see figure 7) is older than 30,000 radiocarbon years (Rubin and Suess, 1955, p. 484). Thus it may be older than the Iowan of Iowa and comparable in age with the "early Wisconsin" in Ohio (Goldthwait, 1958); it certainly is not as old as the Illinoian of southeastern South Dakota (Steece, 1959a, b, and Tipton, 1959a, b).

In South Dakota therefore, the drift enclosed by the Bemis and Altamont moraines is designated as late Wisconsin age. The deposits between the Bemis moraine and the Illinoian drift border are referred to as early Wisconsin age. The terms early and late Wisconsin as used here do not necessarily have the same meaning as "early" and "late" Wisconsin of Leverett (1929) or "early Wisconsin" of Goldthwait (1958).

The Bemis moraine of the Des Moines lobe and the Altamont moraine of the James lobe each, and in places together, are terminal moraines that mark the farthest advance of ice associated with the two lobes. Radiocarbon dates from drift in the James lobe (fig. 7) indicate that the drift (Cary, of Flint, 1955) in southeastern South Dakota (samples Y-452[1], Y-595[2], and W-1189[3]) is approximately the same age as that (Mankato of Flint, 1955) in central eastern South Dakota (samples W-801[4] and W-987[5]); all five dates are between 12,050 and 12,760 radiocarbon years. Therefore, it is probable that the whole of the James lobe drift was deposited only shortly before Two Creeks time, that is, during the latter part of the Wisconsin Glaciation.

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1 Barendsen, Deevey, and Gralenski, 1957, p. 913.

2 Deevey, Gralenski, and Hoffren, 1959, p. 150.

3 Ives, Levin, Robinson, and Rubin, 1964, p. 48.

4 Rubin and Alexander, 1960.

5 Ives, Levin, Robinson, and Rubin, 1964, p. 48; wood from this same locality collected 9 years after sample W-987 was dated at 10,350±300 years B. P. (Sample W-983, Ives, Levin, Robinson, and Rubin, 1964, p. 48). Both samples were dated the same year. The anomaly probably arises due to the 9 years exposure of the wood in the well to different chemical conditions thus altering the original carbon content.

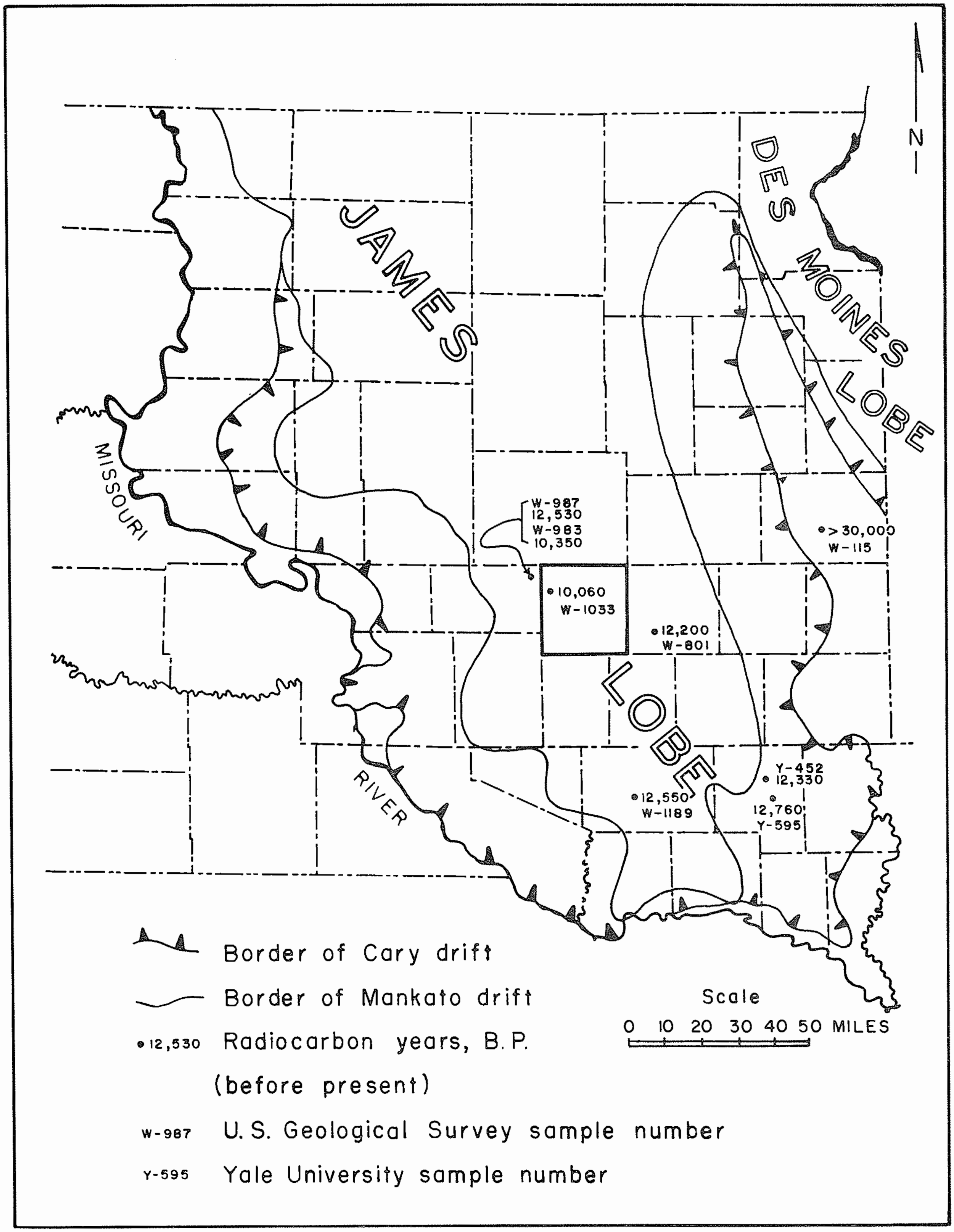

Figure 7. Map of eastern South Dakota showing approximate positions of Mankato and Cary drift sheets of Flint (1955) in relation to available radiocarbon dates.

Pleistocene and Recent

Late Wisconsin lake deposits.--Deposits of sand, silt, clay, and marl, which are too small to be shown at the scale of the geologic map (pl. 1), are scattered throughout the area of the Woonsocket Outwash Plain. Lacustrine materials also are found in a few low places such as swales on the till upland away from the outwash, commonly below 1 to 4 feet of black alluvial or colluvial fill. The lake deposits are locally fossiliferous, but in the absence of fossils these sediments are judged to be lacustrine because of their lithology.

Fossiliferous, light-gray, marly clay 1 foot in thickness, containing many Mullusca, Ostracoda, and Charophyta, overlies the Woonsocket Outwash Plain in SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 3, T. 107 N., R. 62 W. The marly clay occurs below 1$\frac{1}{2}$ feet of brownish-gray sandy clay and above at least 1 foot of dark olive-gray, iron-stained clay whose base is concealed. The types and relative abundance of the fossils found in the marly clay are shown in table 2.

Fossil-bearing lake sediments were found in road cuts at the center of the north line of sec. 36, T. 108 N., R. 61 W., and in the SW$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 36, T. 107 N., R. 61 W.; in test hole 107-62-35aaaa$_1$ at a depth of 2 to 3 feet; and in test hole 105-62-3cbbb in light, olive-gray silt at a depth of 2 to 5 feet and in yellowish-brown, silty clay at a depth of 5 to 10 feet.

Nonfossiliferous lake sediments were found in a hand auger boring in the NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 16, T. 107 N., R. 62 W., 4 feet deep; a road cut between secs. 31, and 32, T. 108 N., R. 62 W.; and hand auger borings at the center of the north line and in the northwestern corner of sec. 28, T. 107 N., R. 62 W., 2 to 4 feet deep.

The large alluvial flats near Rifle and Callihan Lakes and on Jim Creek in the vicinity of Artesian (pl. 1) contain late Wisconsin lake sediments. Alluvium in these areas was deposited either in ice-block basins or in segments of pre-existing drainage in the end moraine. This alluvium probably correlates with Recent alluvium and colluvium in numerous small closed depressions which dot the end moraine surface.

James River trench valley fill.--The valley fill of the James River trench is composed of about 75 feet of interbedded gravel, sand, silt, and clay. The uppermost 1 to 8 feet probably represents Recent alluvium and colluvium, and consists of black to dark-brown humic clay with sand and silt. The remainder is stratified brown to gray gravel, sand, silt, and clay, which is probably late Wisconsin in age.

Several small remnants of valley train outwash that occupied the trench prior to its removal by escaping waters from glacial Lake Dakota occur as terraces in the northern part of the county (pl. 1). Other remnants of this former outwash are found locally beneath the younger valley fill. (See logs of test holes 105-60-25cccd$_2$, 105-60-35ddbb, and 107-60-30baab, Appendix A.)

Table 2.--Fossils from lacustrine marl in SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 3, T. 107 N., R. 62 W. (S. Dak. Geol. Survey Paleo. sample (1) 20-9, Woonsocket north; U.S.G.S. Radiocarbon date sample W-1033; dated 10,060±300 years B.P. by Meyer Rubin, U.S.G.S., Washington; Ives, Levin, Robinson, and Rubin, 1964, p. 48.

	Abundant (75-85%)	Common (15-20%)	Rare (0-5%)
Gastropoda: (Snails)			
Valvata sincera (Say)	X		
V. tricarinata (Say)	X		
Amnicola limosa (Say)			X
Fossaria dalli (Baker)	X		
F. obrussa (Say)	X		
Stagnicola exilis (Lea)		X	
Helisoma anceps (Menke)			X
Planorbula armigera (Say)	X		
Gyraulus circumstriatus (Tryon)	X		
G. crista (Linne)		X	
G. parvis (Say)	X		
Aplexa sp.			X
Physa sp.			X
Pelecypoda: (Clams)			
**Musculium* sp.			X
Pisidium casertanum (Poli)			X
Ostracoda (Crustaceans)		X	
Charophyta (Algae)			X
Fish tooth			X

* Only embryonic (?) valves.

Wisconsin Glaciation

Late Wisconsin.--The surficial deposits of Wisconsin age in Sanborn County are till and outwash. The till is an unsorted unstratified mixture of rock fragments of various sizes in a clay-rich matrix; it is calcareous and yellowish-brown where oxidized (locally called yellow clay), and gray to olive-gray where unoxidized (locally called blue clay). The till is usually calcareous except where it is overlain by sandy soil, in which case it may be wholly or partly leached to a depth of several feet. The till in Sanborn County ranges from 12 to 95 feet, and averages about 40 feet in thickness.

Till results from the deposition of material that the ice erodes from the land surface. The material is carried on and incorporated into the ice; most of it is deposited when the rate of melting equals the rate of advance. In this case, the debris will form end moraines around the margin of the ice. Where the ice ceases its forward motion and becomes stagnant, the debris will form dead-ice moraine. If the ice has an active retreat and therefore does not stagnate, the debris is deposited in a more or less uniform blanket which constitutes ground moraine.

The area mapped as end moraine on plate 1 is part of a broad belt of recessional moraine formed by minor retreats and readvances of the ice as it occupied the center of the James lobe; it is therefore an end-moraine system (Flint, 1957, p. 131).

Todd (1903, 1904) and Todd and Hall (1903, 1904a) mapped the Gary moraine in nearly the same position as the end moraine border is shown on plate 1. In the same publications, Todd and Hall mapped the Antelope moraine through the northern part of Sanborn County.

End moraine mapped in Sanborn County probably represents a complex system of terminal moraines associated with the lateral moraines of late Wisconsin (Mankato of Flint, 1955, p. 118-119, and fig. 31) ice in the James lobe. The ice built lateral moraines, as it advanced down the James River basin, pushing against the Coteau des Prairies to the east and the Coteau du Missouri to the west. The terminal margin of the ice, unrestricted by the Coteau blockades, built end moraines at successive minor readvances. All of these minor retreats and readvances are not recorded in the lateral moraine systems because the ice was more or less continuously forced against the two Coteaux, whereas the ice terminus was free to fluctuate north and south with climatic changes. This resulted in generally north-south lateral moraines along the two Coteaux, and many minor ridges or sublinear masses of glacial drift representing end moraines; the latter are essentially arcuate and more or less perpendicular to the direction of ice movement. Because of this complexity, no attempt was made in this study to trace individual moraines, such as the Gary and Antelope, in Sanborn County.

End moraine, generally of low relief, constitutes the surface of about 50 percent of the northern three-quarters of Sanborn County; it is characterized by rolling to semirugged hummocky topography (photo 1), and by having internal drainage. The most prominent end moraine is the Pony Hills in the western part of the county (photo 2).

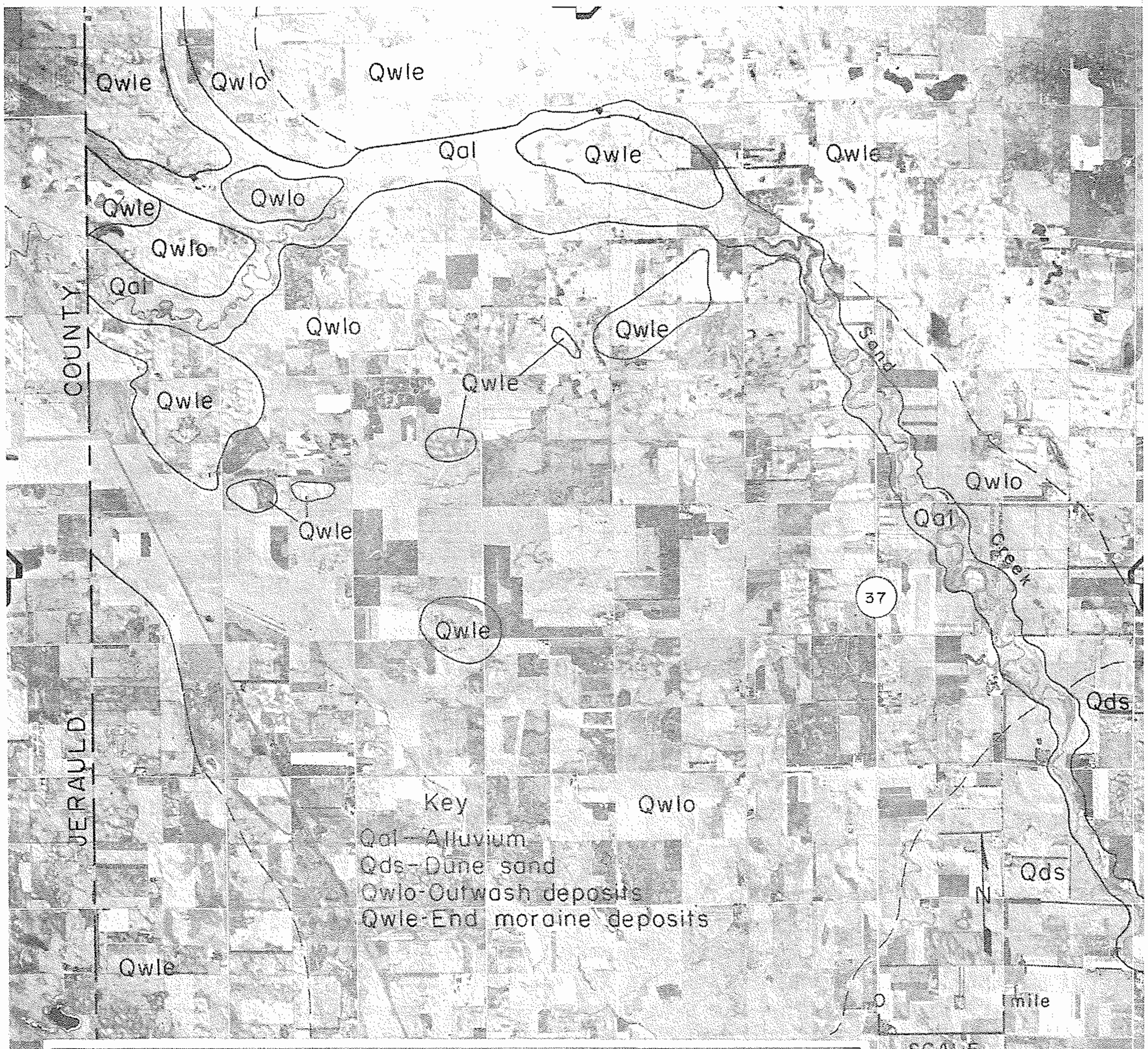

Photo I. Vertical air photo of northwestern Sanborn County showing geomorphic character of surficial deposits.

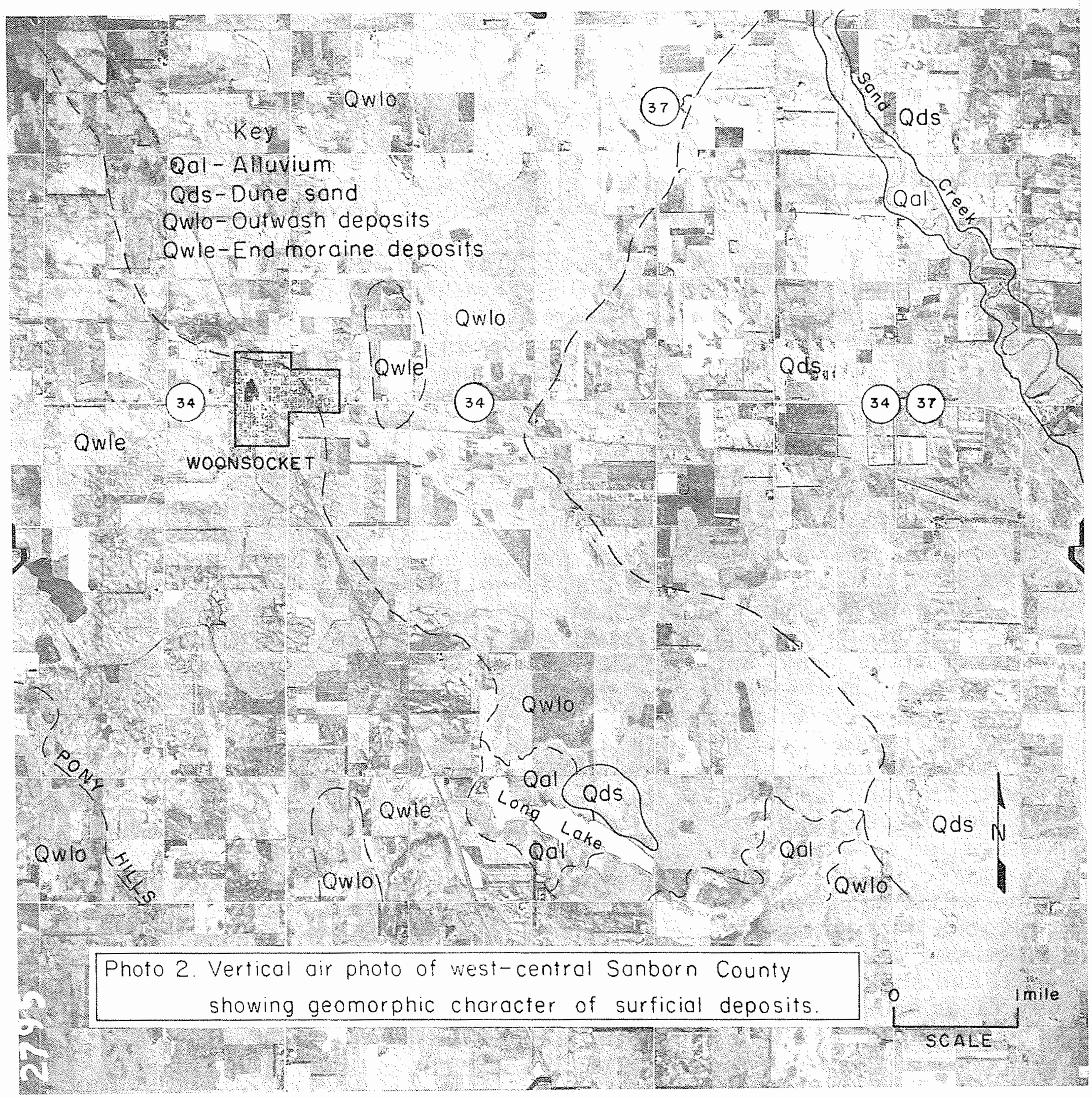

Photo 2. Vertical air photo of west-central Sanborn County showing geomorphic character of surficial deposits.

The margin of the end moraine is easily traced in all except the southeastern part of the county (photo 3). Although there is no thick accumulation of drift at the end moraine border east of the James River, the margin can be delineated (1) by the abundant small closed depressions on the end-moraine surface, and (2) by the sublineation of elongated depressions and small interdepression ridges that roughly parallel the end-moraine margin. This lineation is perpendicular to the direction of flow of the ice, which in this area was principally from the north-northwest, and is characteristic of the remainder of the end moraine in the county.

The ground moraine, which covers most of the southern quarter of the county, is characterized by an extremely flat surface that has relatively few closed depressions as compared to the end moraine. Local relief of the ground-moraine surface is less than 20 feet and is usually about 5 to 10 feet. The ground moraine is dissected by the James River, Morris Creek, and two smaller creeks, which flow southward out of the county.

Gwynne (1951) described features in extreme northwestern Sanborn County that resemble minor moraines, although they are less well developed than similar features south of Mitchell. Minor moraines in northwestern Sanborn County (secs. 6 and 7, T. 108 N., R. 62 W.) have northwest-southeast lineation. (Steece, 1963, in preparation.)

Topographic features left by the melting ice include ice-marginal meltwater channels, which probably resulted from streams flowing in ice crevasses near the ice margin (photo 3), and subaligned depressions and interdepression ridges formed by periodic oscillations of the glacial terminus. The ice-marginal meltwater channels are shallow linear topographic lows several hundred feet wide that range in length from $2\frac{1}{2}$ to $7\frac{1}{2}$ miles.

There are extensive deposits of glacial outwash in Sanborn County; they consist of poorly sorted to fairly well sorted sand and gravel with minor amounts of silt and clay. Usually outwash deposits are sorted and stratified by meltwater action; the suspended material is carried downstream and the coarser particles, mainly sand and gravel, are deposited near their source. In Sanborn County, the outwash deposits are predominantly fine to coarse sand with local gravel accumulations. However, fine sand, silt, and clay occur locally and probably represent accumulation in shallow lakes during the last stages of ice melting. Locally, the outwash is mantled by thin coarse loess as much as $1\frac{1}{2}$ feet thick.

The outwash material has a wide range in mineral composition. The finer part is composed of quartz sand with minor amounts of other minerals and rock fragments. The coarser part is composed chiefly of igneous rock fragments with lesser amounts of limestone, dolomite, and locally derived marl and shale pebbles. The depth of oxidation in the surface outwash averages about 13 feet and ranges from 10 to 25 feet. Surface-outwash deposits range from 0 to 75 feet in thickness, and average about 30 feet.

The surface of the Woonsocket Outwash Plain (called "The Forestburg-Woonsocket Outwash" by Rothrock, 1946, p. 19), in the northwest quarter of the county, contrasts strongly with that of the nearby end moraine. (See photos 1 and 2.) The plain, about 12 miles long in Sanborn County, ranges in width from $1\frac{1}{2}$ to $8\frac{1}{2}$ miles.

The northern border of the Woonsocket Outwash Plain is defined partly by the shallow flood plain of Sand Creek and partly by the flank of the end

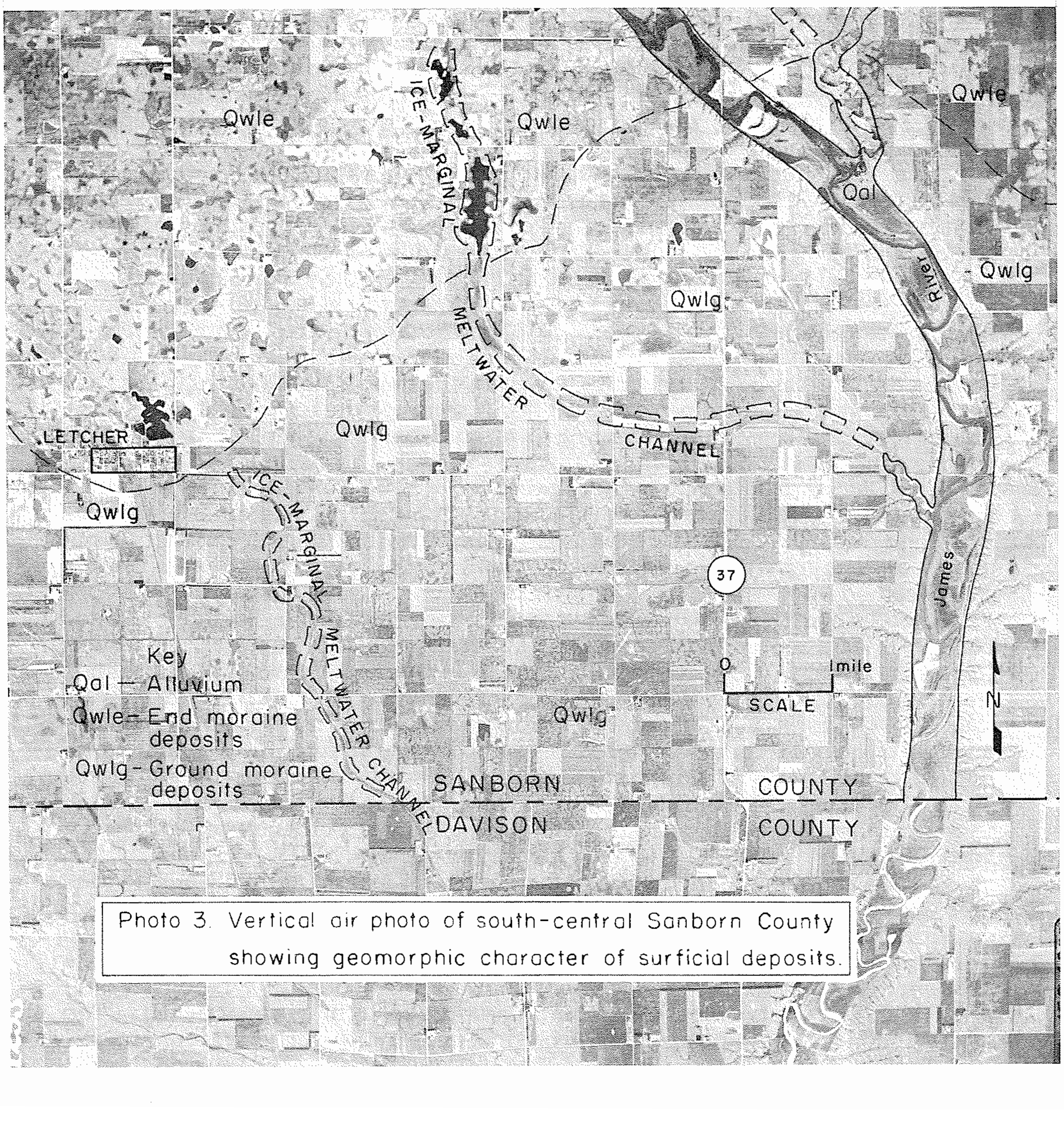

Photo 3. Vertical air photo of south-central Sanborn County showing geomorphic character of surficial deposits.

moraine in the northern part of the county. The western edge of the outwash plain is well defined except near Woonsocket. Near Long Lake, the plain is easily distinguished from the bordering till, but grades imperceptibly into the alluvial flat that extends southward from Long Lake (pl. 1). The eastern boundary of the outwash plain is partly obscured near Forestburg by windblown sand deposits, which are thicker in this area than farther north. Several outliers of till, probably end moraine remnants, stand as knobs above the outwash plain. These knobs are as much as 20 feet above the surrounding plain and occupy less than half a square mile in area (pl. 1).

In a few places, the Woonsocket Outwash is relatively thin which probably indicates the presence of buried morainal ridges. Figure 8, based mainly on drill-hole information, shows the inferred positions of these buried ridges. The till outliers shown in figure 8 and plate 1 represent the tops of these buried ridges that are not covered by the outwash.

A buried morainal ridge northeast of Woonsocket (fig. 8) may account for the fan shape of the northern half of the Woonsocket Outwash Plain. This ridge could have acted as a dam for the meltwater, backing it up over a wide area to the north and thus causing the deposition of silt, clay, and marl in low areas on the outwash plain; some of these deposits are fossiliferous. (See p. 28.) When the water became deeper, it flowed over the moraine dam and drained southward.

The Cuthbert Outwash Plain (Rothrock, 1946, p. 19), in the southwestern part of the county, about 12 miles long within the county, ranges from one-half to 3 miles in width. This outwash is less extensive but nearly as level as the Woonsocket Outwash Plain; its borders are generally well defined.

The Cuthbert Outwash is divided into two parts by a buried oxidized zone. In this report the upper part is hereinafter referred to as Cuthbert Outwash-2 and the lower part as Cuthbert Outwash-1. Cuthbert Outwash-2 may be considerably younger than the late Wisconsin surface drift surrounding it, for the depth of oxidation of the sands in test hole 106-62-33aaaa is only 10 feet as compared with the average depth of oxidation of the till of 20 feet. It would seem that if the outwash and till were of the same age, the sand would be oxidized to a greater depth than the till owing to the higher permeability of the sand. Additional evidence for a younger age of Cuthbert Outwash-2 is provided by test hole 106-62-21aaad, which shows 20 feet of sand and gravel presumably of late Wisconsin age (Cuthbert Outwash-1) which is oxidized to a depth of 15 feet. This lies on an unoxidized till presumed to be early Wisconsin age from information obtained from test hole 106-62-15cbbb about half a mile north of test hole 106-62-21aaad. Test hole 106-62-15cbbb shows oxidized late Wisconsin outwash (Cuthbert Outwash-2) overlying unoxidized late Wisconsin till. The late Wisconsin till is separated from the underlying early Wisconsin till by a 5-foot thick oxidized zone. Unoxidized basal early Wisconsin till overlies 60 feet of an older outwash of which the upper 15 feet is oxidized. Cross section D-D' (pl. 2) shows that the early Wisconsin till of test hole 106-62-15cbbb has been cut by outwash that is of late Wisconsin age (Cuthbert Outwash-1). The deeper oxidation of Cuthbert Outwash-1 may, however, indicate that it is early rather than late Wisconsin in age.

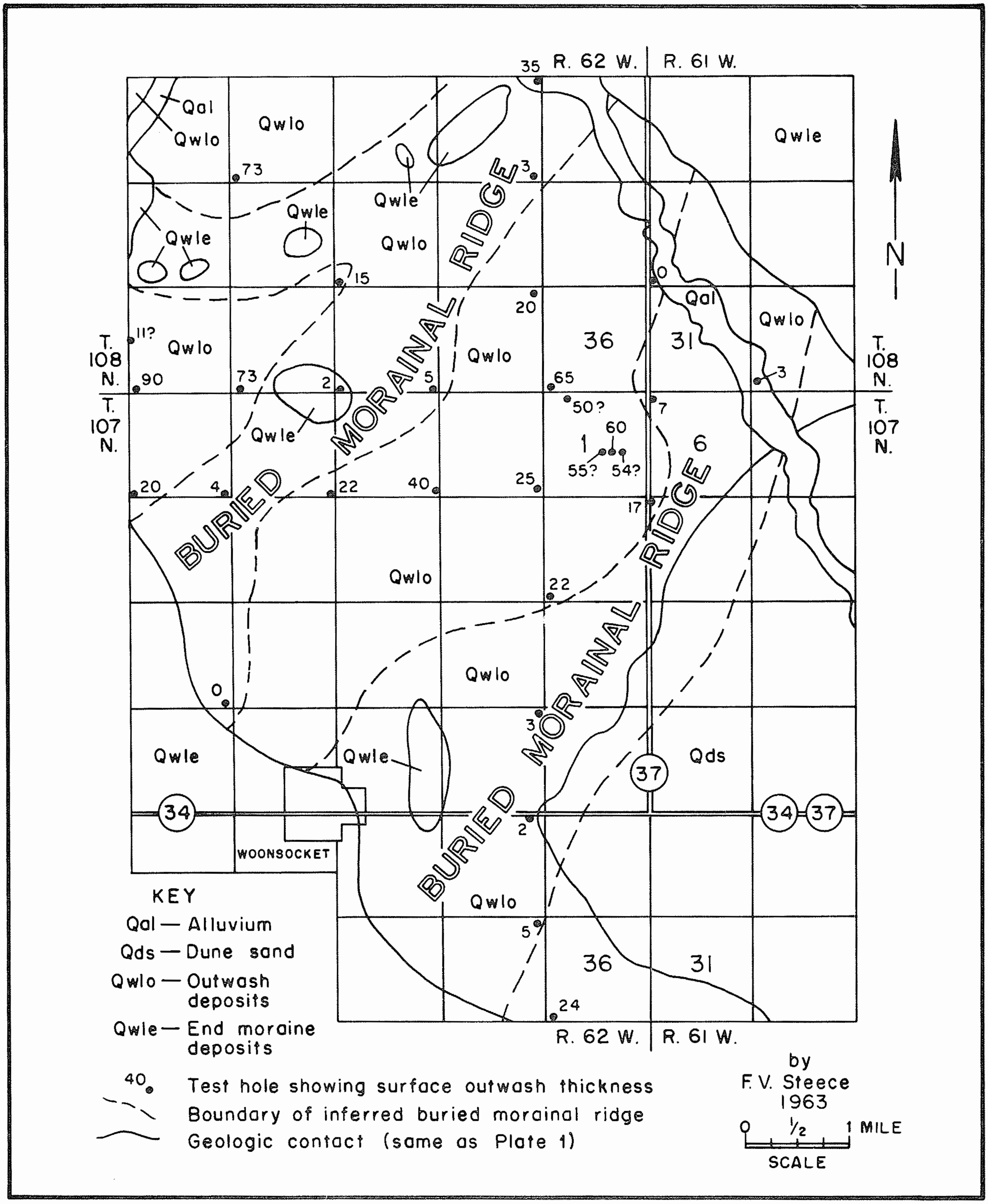

Figure 8. Map of a part of northwestern Sanborn County, showing positions of inferred buried morainal ridges.

Geomorphic evidence also indicates that the Cuthbert Outwashes-1 and -2 were deposited at different times. In cross section D-D' (pl. 2) Cuthbert Outwash-1 was deposited in a valley that was widened by as much as 1 to 1½ miles. It is interesting to note that the early Wisconsin outwash underlying the Cuthbert Outwash (cross section D-D') seems to have been deposited in the same general area, indicating perhaps that this marked the location of a significant stream course during all of the Wisconsin Glaciation.

The Woonsocket Outwash may also be divisible into upper and lower parts. Snails from lacustrine marl overlying the Woonsocket outwash sand and gravel have been dated at 10,060±300[a/] years B. P. (sample W-1033 dated by Meyer Rubin, U. S. Geological Survey; unpub., in files of S. Dak. Geol. Survey). This radiocarbon date may serve to date the Cuthbert Outwash-2 (and its equivalent of the Woonsocket Outwash) as late Wisconsin, probably post-Two Creeks age. The Cuthbert Outwash-1 (and its equivalent of the Woonsocket Outwash) is probably late Wisconsin (pre-Two Creeks) in age.

Early Wisconsin.--Lithologic information from 25 wells and test borings in Sanborn County disclosed two drifts older than late Wisconsin age. The two buried drift sheet deposits probably are early Wisconsin age but may be older.

Early and late Wisconsin deposits were penetrated by several test borings (pl. 3). In test boring 108-61-17aacc (Appendix A), the sequence of deposits from the surface downward includes late Wisconsin till, two early Wisconsin tills, and two early Wisconsin outwash deposits. All these are separated by oxidized zones except the lowest outwash and lowest till. A similar stratigraphic sequence is present in test hole 106-62-15cbbb in which late Wisconsin outwash and till, and early Wisconsin till and outwash lie in succession from the surface downward. Many other test holes and wells in the county penetrated similar stratigraphic sequences. (See Appendix A.)

In general, the early Wisconsin tills and outwash deposits appear to have about the same composition as those of the late Wisconsin deposits. The thicknesses of the early Wisconsin drifts vary greatly; therefore the average thicknesses of the deposits are unknown.

Buried outwash deposits.--About 80 percent of Sanborn County is underlain by buried outwash deposits, 90 percent of which is more than 10 feet thick. (See pl. 4 and fig. 9.) Several layers of buried outwash occur as shown in plate 2. The largest and most extensive buried outwash directly overlies the erosional surface on the Niobrara Marl and the Pierre Shale in most places in the northeastern half of the county (cross sections A-A' and E-E'). Many smaller outwash deposits are scattered throughout the county (pl. 2).

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a/ The date of this material may be anomalous as the shells were washed by the author with a solution containing sodium carbonate, which may have caused contamination of the carbon content of the shells.

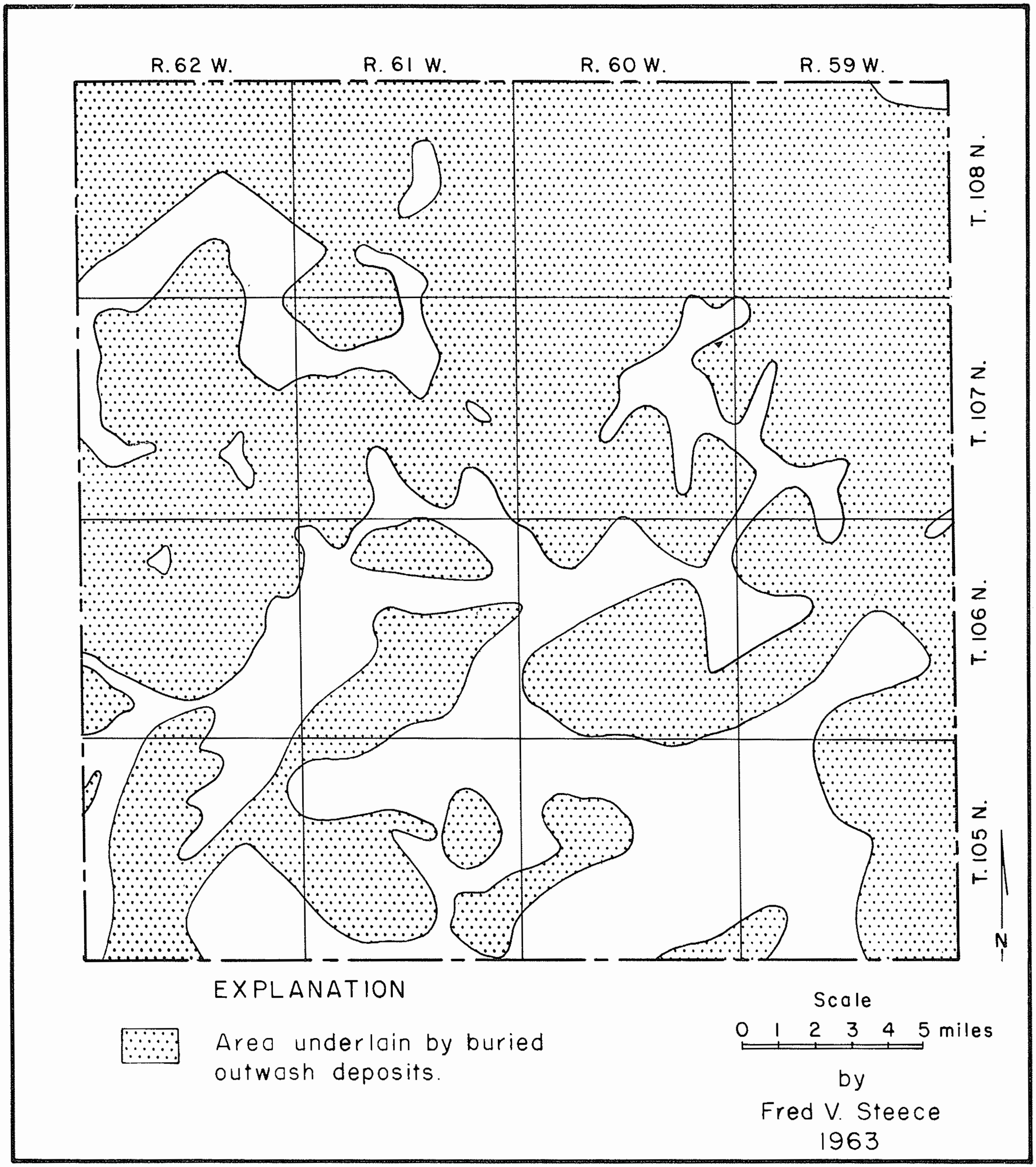


Figure 9. Map of Sanborn County showing distribution of buried outwash deposits more than 10 feet thick. (see Plate 4 for more detail)

The buried outwash deposits are composed predominantly of coarse sand to medium gravel and are similar in composition to surface outwash materials. The buried outwashes range in thickness from a few feet to about 100 feet, and average about 30 feet (pl. 3). The drift that overlies the buried outwash deposits has an average thickness of about 60 feet, although the range is from 13 to 140 feet.

The early and late phases of the Wisconsin Glaciation are represented by the buried outwash deposits. (See discussion of early Wisconsin drift, p. 36.) The thick extensive buried outwash in the northeastern half of the county, and several small sand and gravel beds, all in the lower and middle part of the surficial deposits, probably are early Wisconsin in age. The small sand and gravel stringers in the upper part of the drift are local and probably are interbedded with late Wisconsin till.

Bedrock

Cretaceous System

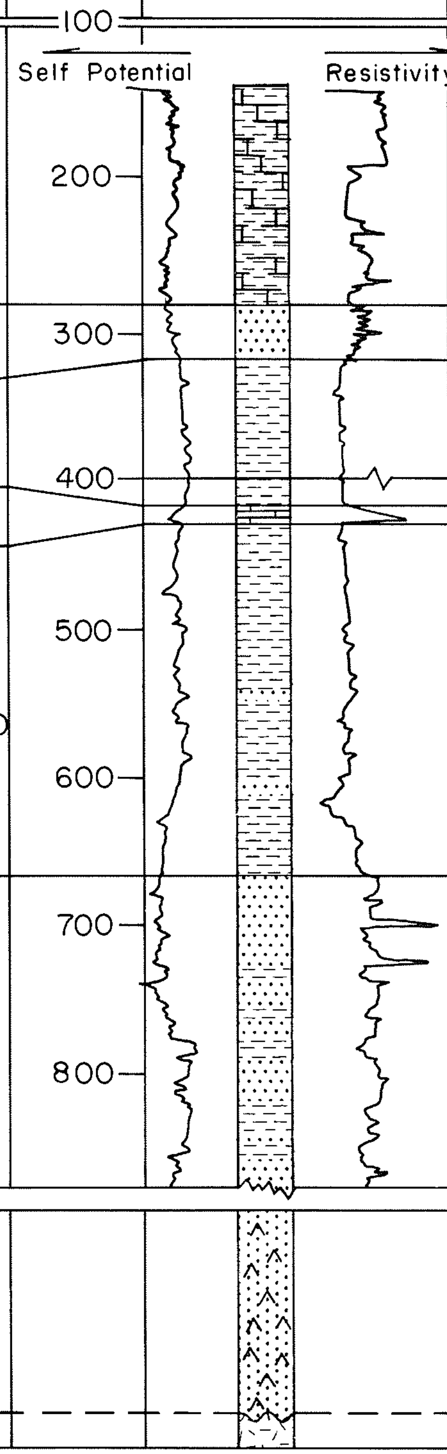
Cretaceous rocks consisting of sandstone, limestone, shale, and marl underlie Sanborn County. Although there are no bedrock outcrops, the entire Cretaceous sequence (fig. 10) has been penetrated by many wells. The general stratigraphic relations of the Cretaceous rocks are shown on plate 5. Most of the county is underlain by Niobrara Marl (pl. 6); however, a small area in the northeastern part is underlain by Pierre Shale and a small area in the southeast is underlain by the Codell Sandstone Member of the Carlile Shale.

The topographic high on the bedrock surface in the northeastern part of the county (pl. 6) corresponds generally to the area underlain by the Pierre Shale. This rise in the bedrock surface to the northeast reflects the core of the Coteau des Prairies, the western escarpment of which begins about 30 miles east of Sanborn County (fig. 1). A series of low elevations on the bedrock surface from south to north through the central part of the county appears to indicate an ancient (preglacial?) valley (pl. 6). The maximum relief on the bedrock surface is 250 feet.

Pierre Shale

The Pierre Shale is present only in the northeastern part of Sanborn County (pl. 6), where it consists of light to dark-gray fissile bentonitic clay-shale. The electric-log characteristics of the Pierre Shale are not always distinguishable from those of the overlying glacial drift, but are significantly different from the underlying Niobrara Marl. The Pierre ranges in thickness from 0 to 90 feet.

Along the Missouri River about 60 miles west of Sanborn County, the Pierre has been divided into members (Searight, 1937) but none of these members has been identified in this county.



System and Series		Stratigraphic unit	Thickness (feet)	Description
Cretaceous	Upper Cretaceous	Niobrara Marl	0-80	Gray speckled calcareous clay-shale or marl; highly fossiliferous, mostly foraminifers; locally contains thin bentonite beds.
Cretaceous	Upper Cretaceous	Codell Sandstone Member	0-120	Chiefly gray shale, contains gypsum, pyrite, and coal; Codell Sandstone Member present in most of the county.
Cretaceous	Upper Cretaceous	Carlile Shale	90-380	
Cretaceous	Upper Cretaceous	Greenhorn Limestone	5-40	Grayish fragmental limestone; highly fossiliferous; may contain speckled marl beds.
Cretaceous	Upper Cretaceous	Graneros Shale	24-300	Chiefly gray shale containing pyrite and other concretions; contains thin interbedded sand layers.
Cretaceous	Upper and Lower Cretaceous	Dakota Group	91-350	Complex of interbedded sandstones and shales; probably includes sandstones and shales previously referred to as Dakota, Fuson and Lakota in this area; associated with "quartzite wash" near buried Sioux Ridge.
Precambrian		Sioux Quartzite	(?)	Pink to red silica cemented pure quartzose sandstone or orthoquartzite.
Precambrian		Rhyolite	(?)	Altered rhyolitic rock underlies Sioux Quartzite locally. (?)

Figure 10. Generalized columnar section of subsurface formations. Electric log is composite of well 108-59-21 abaa (from 136-400 feet.) and well 106-62-30 bbcd (from 400-880 feet.)

Niobrara Marl

The Niobrara Marl underlies the drift in most of Sanborn County. (See pl. 6.) The formation consists chiefly of marl of various shades of gray, and becomes sandy south of the county near the Sioux Ridge. It contains a luxuriant microfauna consisting mostly of Foraminifera. In wells in Sanborn County the Niobrara is as much as 80 feet thick, and averages about 40 feet. It is easily recognizable in drill cuttings as gray marl that contains shells of Foraminifera, giving it a white-speckled appearance. The formation gives a characteristic electric-log curve that is usually easy to differentiate from the overlying and underlying shale (fig. 10). Elsewhere in southeastern South Dakota, Bolin (1952) has divided the Niobrara into upper (Smoky Hill) and lower (Fort Hays) members, on the basis of Foraminifera. These members have not been identified in Sanborn County.

Carlile Shale

The Carlile Shale underlies all of Sanborn County. It consists mostly of light-gray to black shale interbedded with silt or sand layers. The character of the Carlile on electric logs is typical of marine shale. (See fig. 10.) The Carlile ranges in thickness from 90 feet in well 105-58-19bbba to 312 feet in well 105-61-1ddbb.

Locally, the Carlile includes the Codell Sandstone Member near its top. In test hole 105-60-15dddd$_1$ the Codell is 38 feet thick and consists of light-gray, moderately hard, medium sandstone. In test hole 105-60-31dddd it is $4\frac{1}{2}$ feet thick and consists of cemented fine sandstone. The Codell forms the bedrock in the southeastern part of the county and crops out along Firesteel Creek, about 5 miles south of Sanborn County. It ranges in thickness from 0 to 120 feet and averages about 45 feet (pl. 6). The Codell Sandstone Member is recorded on the resistivity scale of the electric log as a strong deflection to the right.

Greenhorn Limestone

The Greenhorn Limestone underlies all of Sanborn County and consists of 5 to 40 feet of marl or chalky shale that is locally interbedded with variable thicknesses of hard fragmental limestone. The formation is easily recognized in cuttings and on the electric log, where both the self potential and the resistivity curves show significant deviations at the top and bottom of the formation (fig. 10). The gamma-ray log also shows a distinctive curve for the Greenhorn Limestone.

The limestone contains abundant fragments of pelecypod shells which are easily identified with the aid of a microscope; the marl is normally gray and speckled with white microfossil shells.

Graneros Shale

The Graneros Shale, as discussed in this report, includes the shale sequence below the Greenhorn Limestone and above the Dakota Group. In Sanborn County the Graneros Shale is a light-gray to dark-gray clay-shale and sandy shale containing some hard layers, probably iron-sulfide or calcium carbonate-cemented sandstone. The Graneros ranges in thickness from 24 feet in well 105-58-19bbba to 260 feet in well 105-61-7addc. The Graneros thickens rapidly to the north and west, reflecting the northwestward drop of the Precambrian surface. (See p. 42.)

Dakota Group

The Dakota Group (Hansen, 1955, p. 17), used in this report as described by Steece (1958, p. 11), is a "thick sequence of Cretaceous sand, shale, and coal in extreme eastern South Dakota" which is between the Graneros Shale (above) and the Precambrian (below). In many wells it is difficult to distinguish the Dakota Group from the overlying Graneros Shale as both formations consist of interbedded sand and shale. An arbitrary rule for differentiating the Graneros and Dakota in Sanborn County is that the predominantly shale lithology below the Greenhorn Limestone constitutes the Graneros Shale and the predominantly sandstone lithology below the Graneros constitutes the Dakota Group.

In Sanborn County the Dakota Group is composed of white to gray quartzose sandstone cemented with pyrite and calcite and unconsolidated quartz sand. The quartz grains are usually very well rounded and very well sorted; accessory minerals and rock grains make up less than 5 percent of the rocks of this group. The sandstones and sands are interbedded with gray fissile shales of variable thickness. A very fine-grained, light-gray, quartzose sandstone was cored at a depth of about 698 feet in well 106-59-8cccb; this sandstone is very dense and tightly cemented with calcite. A core from the Dakota Group was recovered in well 107-60-3adaa$_2$ at a depth of 625 to 627 feet. The sandstone from this well is likewise a very fine quartzose light-gray and calcite-cemented dense rock. A small piece of core from the same well consists of dense noncalcareous gray shale, presumably interbedded with the sandstone. On the electric log the Dakota Group is recorded as a series of sharp outward deflections representing sandstone and by inward deflections representing shales which are usually thinner than the sandstone layers.

The Dakota Group is as much as 335 feet thick in well 107-60-3adda$_2$, 279 feet thick in well 106-62-30bbcd, 187 feet thick in well 105-61-7addc, and 92 feet thick in well 108-59-21abaa. In contrast, as mentioned above, the total Graneros-Dakota sequence occupies only 115 feet of section between the Greenhorn Limestone and the Sioux Quartzite in well 105-58-19bbba. The average thickness of the Dakota is probably about 220 feet. None of the first three wells cited above completely penetrated the Dakota Group, so the thicknesses are not maximum. It is apparent, then, that the rocks of the Dakota Group are thinner in the southeastern and northeastern parts of the county, reflecting buried Precambrian hills.

Precambrian System

Sioux Quartzite

The Sioux Quartzite (White, 1870) forms a prominent buried ridge (Sioux Ridge, Steece, 1962) that extends westward from southwestern Minnesota and southeastern South Dakota to central South Dakota; it constitutes most of the Precambrian basement rocks under Sanborn County. The topography developed on the formation in Sanborn County is uneven (fig. 11), and is the result of erosion during much of geologic time. The Sioux Quartzite is unconformably overlain by Cretaceous strata.

The Sioux is a hard, massive, pink, siliceous orthoquartzite that is bedded, crossbedded, and jointed. At the outcrop and in several wells in eastern South Dakota the quartzite is interbedded with pink to red siltstone and pink to pale-orange sericitic claystone known as pipestone, or catlinite. The Sioux locally may include coarse silica-cemented conglomerate of vein quartz, jasper, chert, and rock fragments.

The Sioux Quartzite is locally overlain by unconsolidated, somewhat weathered sand called "granite wash" or "quartzite wash" by drillers. The Sioux Quartzite is known to be more than 3,700 feet thick in south-central South Dakota (Bolin and Petsch, 1954).

Older rocks

The Sioux Quartzite overlies igneous rocks in parts of Sanborn County. In well 108-59-21abaa, rhyolite porphyry was penetrated at a depth of 675 feet (fig. 11); in well 108-59-22cccc4, about $1\frac{1}{2}$ miles to the southeast, schist and dark porphyry were penetrated at a depth of 680 feet. Lee (1958) examined a core of the rock recovered in the first well and identified it as "altered rhyolitic rock."

Structure

The structural geology of Sanborn County is fairly simple, as the county is located in the Stable Interior of North America. The structural relationships of the subsurface formations are shown on figure 12.

The Precambrian basement rocks control the geologic structure. In the southeastern and south-central parts of the county the Precambrian Sioux Quartzite reaches an altitude of 980 feet in well 105-59-15dddd and 902 feet in well 105-60-17cccd (no logs available, fig. 11). The Precambrian surface slopes gently northward for about 5 miles and then drops to less than 607 feet above sea level in well 106-59-9babc, which did not penetrate the basement rocks. The altitude of the Precambrian surface is less than 381 feet in well 107-60-26bcca, which likewise did not penetrate the basement rocks. In well 108-59-22cccc4 the Precambrian surface is porphyry at an altitude of 669 feet. In well 108-60-13aaab3 (no log available) the Precambrian surface is below an altitude of 229 feet, the lowest altitude in the county reached by wells that did not penetrate the Precambrian.

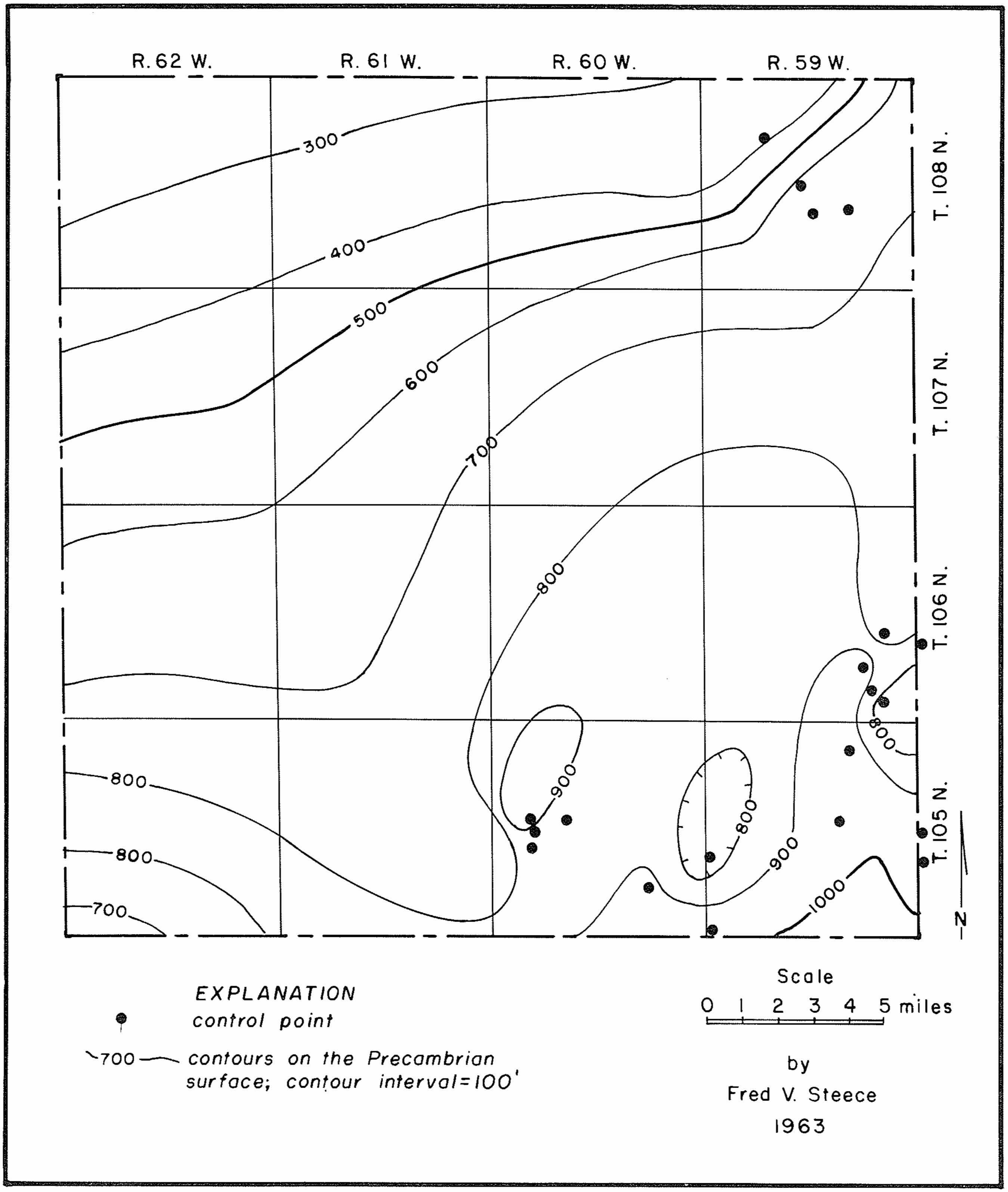


Figure 11. Generalized Precambrian surface in Sanborn County.

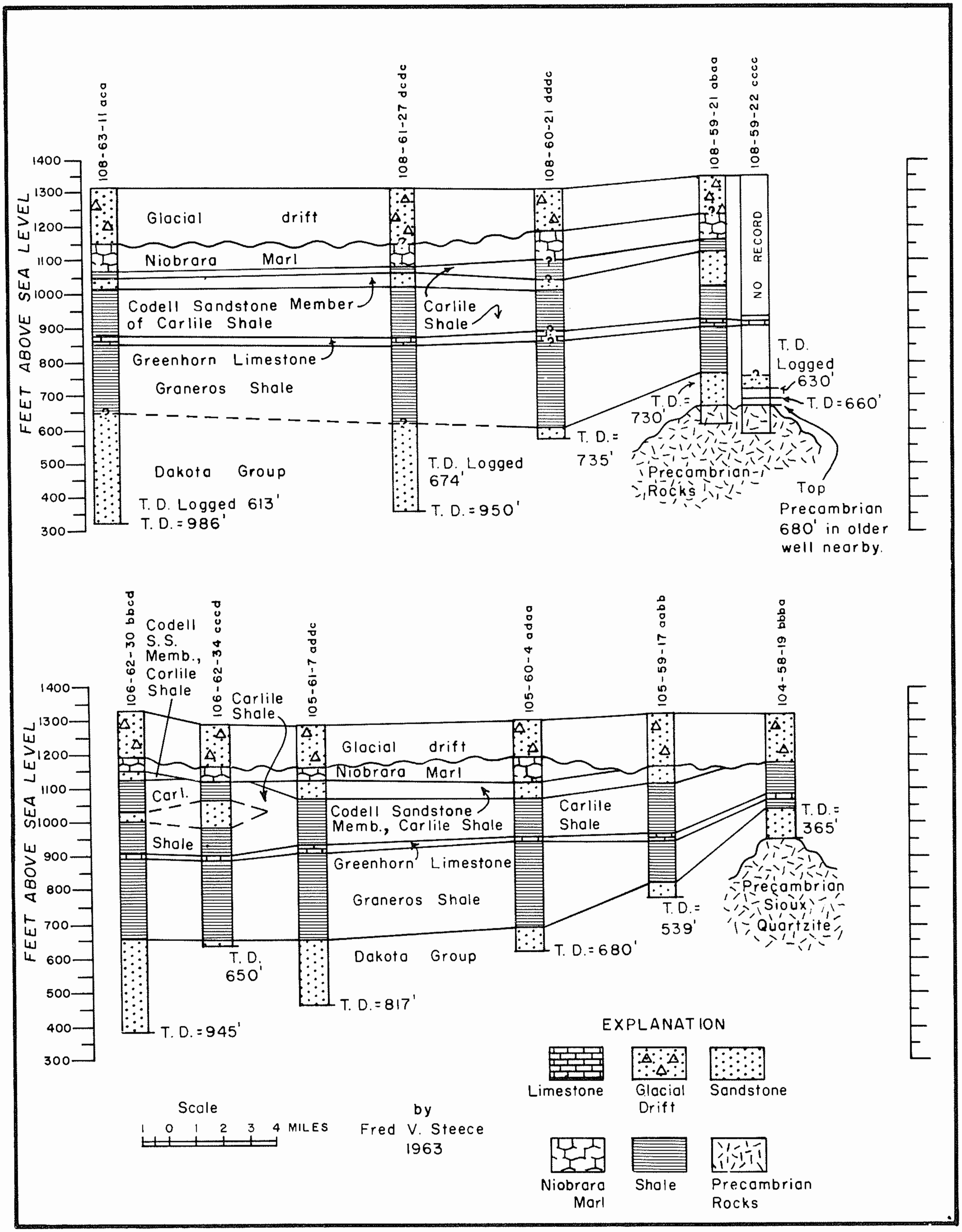


Figure 12. Diagram showing structural relations in Sanborn County. (see Pl. 6 for locations of wells.)

The structure of the Greenhorn Limestone (fig. 13) generally conforms to the structure of the Precambrian basement (fig. 11) in Sanborn County. The Greenhorn is high in the southeastern corner of the county and low in the southwestern and northern parts of the county. The Codell Sandstone Member of the Carlile Shale likewise rises to the southeast in Sanborn County.

Geologic History

Geologists for several decades have accepted the fact that the Sioux Quartzite lies on granitic rocks in eastern South Dakota and adjacent parts of Minnesota and Iowa. This age relationship has been verified recently by age determinations of Goldich and others (1959, 1961), who (1961, p. 146) have shown that the granite at Milbank, South Dakota (northeastern part of the State) is approximately 2.0 billion years old, and that pipestone in the Sioux Quartzite at Pipestone, Minnesota, is 1.2 billion years old (1959, p. 660). They believe that the date of 1.2 billion years is, in fact, the minimum age for the Sioux Quartzite, and that this date may actually indicate a time of folding rather than deposition. Further evidence that the Sioux Quartzite is underlain by older rocks is furnished by an age of 1.64±0.09 billion years1/ determined from a rhyolite porphyry core from well 108-59-21abaa (W. R. Muehlburger, University of Texas, written communication, 1963).

A relatively short period of geologic time (see the table "Geologic time scale" below) is represented in the sedimentary strata of Sanborn County. The events that occurred during the time between the late Precambrian and the Cretaceous (approximately 1 billion years!) must therefore remain unknown. It can only be inferred from evidence in surrounding areas that the Sioux Ridge was a positive area, and therefore subject to extensive erosion throughout most of this time.

Cretaceous seas probably occupied the land in much the same manner as the late Precambrian seas and must have been characterized by similar ecological conditions, for much of the Dakota Group consists of quartzose sandstone apparently deposited in a near-shore stable-shelf environment. Gries (1962, fig. 2) shows that sandstone of the Dakota Group is thickest in the central part of South Dakota adjacent to the Sioux Ridge, and thins westward where it interfingers with other lithologic units. The thick sand of the Dakota was deposited contemporaneously with shales and thin beds of sand west of Sanborn County. The interbedded shale of the Dakota Group in Sanborn County indicates that the Cretaceous seas were repeatedly

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1/ "The radiometric age date is the result of a cooperative dating program on buried basement rocks between the Crustal Studies Laboratory, the University of Texas, and the Isotope Geology Branch, U. S. Geological Survey. The grant to the University of Texas supporting this work is contract No. AF 49(638)-1115 of the Air Force Office of Scientific Research as part of the Advanced Research Projects Agency Project VELA UNIFORM."

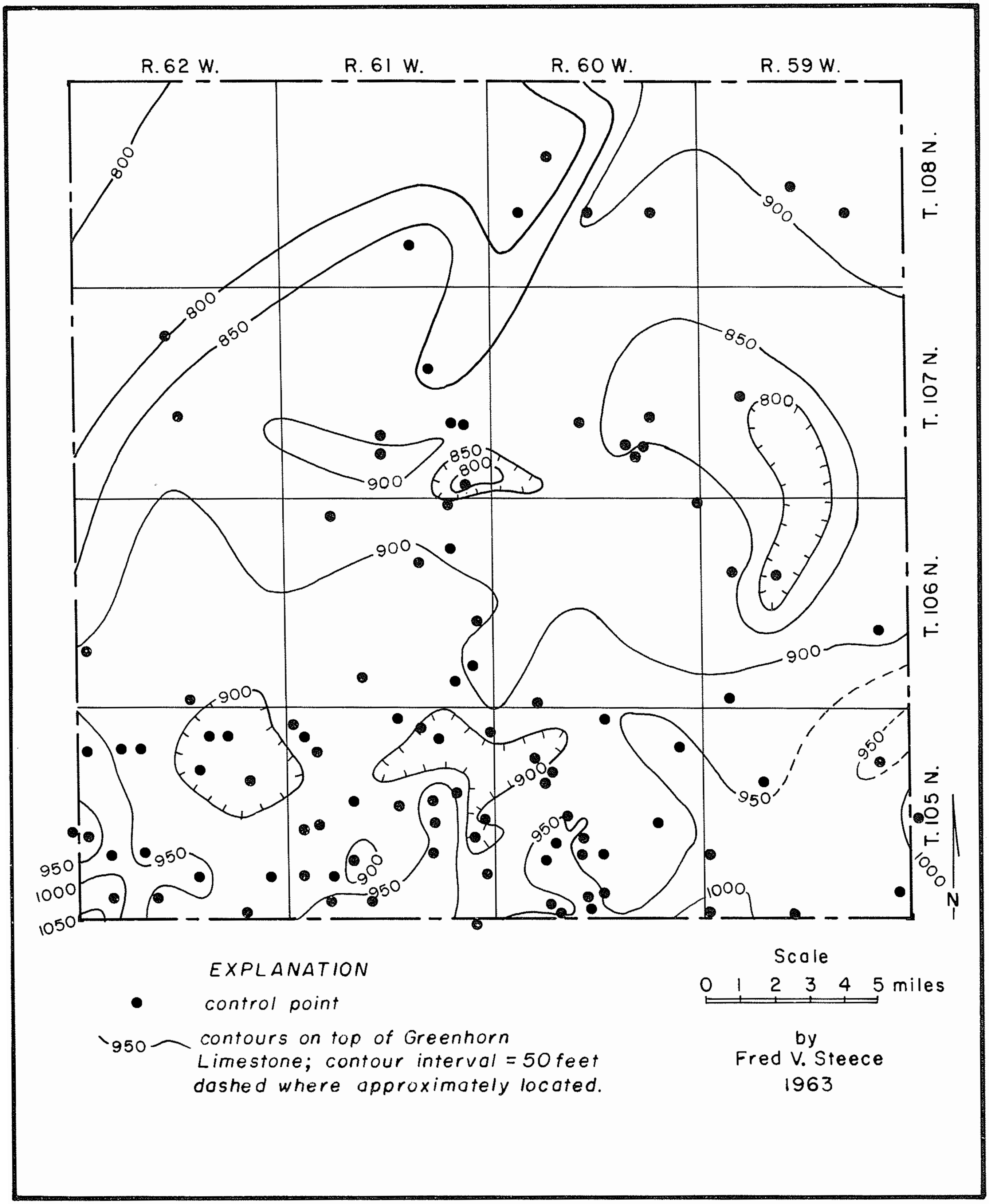


Figure 13. Structure contour map of Greenhorn Limestone in Sanborn County.

Geologic time scale (after Kulp, 1961, p. 1,111)

Era	Period		Epoch	Beginning of interval (million years ago)
Cenozoic		Quaternary		1 a/
		Tertiary		63
Mesozoic		Cretaceous	Late	90
			Early	135
		Jurassic		181
		Triassic		230
Paleozoic		Permian		280
	Carbon-iferous	Pennsylvanian		310
		Mississippian		345
		Devonian		405
		Silurian		425
		Ordovician		500
		Cambrian		600
		Precambrian		

a/ Emiliani, 1955, gives beginning of Pleistocene Epoch as about 600,000 years ago; Ericson, Ewing and Woolin, 1964, date beginning of Pleistocene Epoch at 1.5 million years ago.

transgressive and regressive. The shifting of the strand line continued during the deposition of the Graneros, resulting in similar interbedding of shallow and deep water sediments with shale being predominant.

Stable conditions prevailed during the deposition of the Greenhorn, when fragmental limestone and foraminiferal marl were laid down on the gently subsiding stable shelf.

Early during the deposition of the Carlile Shale, the sea inundated the land and gray shale was deposited. Late during the period of Carlile deposition, the sea was again regressive and deposited the Codell Sandstone Member.

The foraminiferal chalk and marl of the Niobrara Marl show the return of a gently subsiding stable-shelf environment to the Sanborn County area. The seas then deposited the Pierre Shale, which underwent considerable sculpturing during the remainder of the Cretaceous and all of the Tertiary Periods, and much of the Pleistocene Epoch. A great unconformity, representing a gap of about 80 million years, is apparent between the Cretaceous deposits and the glacial drift in Sanborn County.

The first gigantic continental ice sheet to advance over the northern Great Plains was that of the Nebraskan Glaciation, which ushered in the Pleistocene Epoch. The Kansan, Illinoian, and Wisconsin ice sheets followed the Nebraskan. Each ice advance was interrupted by long periods of weathering, erosion, and deposition called interglaciations which are, from oldest to youngest, the Aftonian, Yarmouth, and Sangamon. Whether Sanborn County was the scene of glaciation during all four of the ice ages is not known, but ice may have occupied Sanborn County during Nebraskan and Kansan times (Flint, 1955, p. 143).

Illinoian ice probably overrode Sanborn County, as the age of the present Missouri River is tentatively assigned by Warren (1952) and Flint (1955, p. 143) as Illinoian. There is no evidence of Illinoian drift remaining in Sanborn County, except for the possibility that the early Wisconsin drift (p. 36) may be Illinoian. The absence of pre-Wisconsin drift in Sanborn County may be due to the devastation of the pre-Wisconsin landscape by the thick Wisconsin ice sheets.

Early Wisconsin ice deposited till and thick outwash in Sanborn County. The thick early Wisconsin outwash, now buried, was dissected after its deposition by a stream flowing northward through Sanborn County. This newly cut trench was later filled with fine-grained alluvium causing a permeability barrier between the two outwash bodies east and west of the trench. Re-expansion of the early Wisconsin ice deposited more drift that covered the ancient channel. Large areas of early Wisconsin drift are preserved beneath the late Wisconsin drift surface in the county. Many of the features of the present-day drift surface, aside from Recent modifications, probably resulted from stillstands of the late Wisconsin ice in Sanborn County during the retreat of the ice to the north. Ice-marginal meltwater channels in the central and south-central parts of the county suggest temporary halts of this ice. The ice front receded to the northern part of the county, where its last stationary position is marked by the upper reaches of Sand Creek, west of the James River, and Redstone Creek, east of the river. The Woonsocket Outwash Plain was built by meltwater flowing southward from this ice front into a low area, which was blocked on the south by older moraines in the vicinity of Long Lake and by a morainal ridge east of Woonsocket. The waters that were ponded in this outwash plain cut through the morainal dam and flowed southward in the channel from Long Lake to Morris Creek, $3\frac{1}{2}$ miles west of Letcher. In the waning stages of the melting ice sheet, water moving slowly southward carried fine sand, silt, and clay onto the outwash plains, and deposited (about 8,110 B. C., Ives and others, 1964) stratified fossiliferous sediments in several small glacial lakes.

Dune topography was developed in the area near Forestburg as winds from the northwest swept across the newly deposited Woonsocket Outwash Plain, carrying fine materials to the east and depositing them as a sand blanket on the drift. Meanwhile, the late Wisconsin ice retreated farther to the north, and its meltwaters carried fine silts into glacial Lake Dakota. When the lake drained the lake waters flowed southward through Sanborn County, ultimately entering the Missouri River. The resultant flooding deposited local, fine-grained, fluvial material adjacent to the trench in Sanborn County, and more extensively in Beadle County (Hedges, in preparation). The James River deepened its trench to as much as 120 feet into the glacial drift. The torrent cut through the valley-train outwash that had previously been deposited in the valley, leaving only small remnants of sand and gravel as terraces in the northern part of the James River trench, and in places leaving sand and gravel in the bottom of the trench. Sediments were carried out of the Lake Dakota plain, and as much as 45 feet of this material was laid down in the trench of the James River in Sanborn County.

The present land surface of the county is the result of Recent erosion and deposition. Alluvial and colluvial materials have been deposited in the drainageways and in closed depressions, lakes, and ponds. The present-day surface features are being modified by wind and water.

Mineral Resources

Sand and Gravel

The Woonsocket Outwash Plain has an area of approximately 28,000 acres. The average thickness of the outwash deposits is about 30 feet; thus the volume of sand and gravel in this outwash plain is about 1,300,000,000 cubic yards. The Cuthbert outwash deposits have an area of about 16,200 acres, average about 35 feet in thickness, and contain about 900,000,000 cubic yards of sand and gravel. Two small terrace deposits along the James River valley have a total area of 730 acres, average 20 feet in thickness, and contain about 20 million cubic yards of sand and gravel. In addition, there is a vast amount of glacial sand and gravel in the buried outwashes in the county. The buried outwash is as much as 115 feet thick, but is not considered a potential economic source for sand and gravel because it is buried in most places beneath an average of 60 feet of glacial drift. The outwash deposits are mostly fine to coarse sand with some gravel, silt, and clay. The sand and gravel generally includes excessive amounts of locally derived rock fragments such as shale, chalk, and clay ironstone, making it unsuitable as concrete aggregate or for use as construction material. It may be used satisfactorily, however, as road metal and bituminous aggregate. In addition, some of the sand might be suitable as fine aggregate in concrete and plaster.

A small deposit of sand and gravel on a gravelly knoll in sec. 32, T. 108 N., R. 61 W., and another deposit in a part of the ice-marginal channel east of Forestburg, contain fairly good material that may be suitable for use as road metal and bituminous aggregate.

Much fine to medium well-sorted sand may be obtained from the area shown as dune sand on plate 1. The deposit has an area of about 28,000 acres, an average thickness of about 10 feet, and contains about 430,000,000 cubic yards of sand. The sand is cleaner where it is thickest, and could be used for mortar or plaster sand.

Rock

Boulders and cobbles characteristically litter the surface of many ridges of end moraine in the county. On the Pony Hills, boulders are abundant, and could be removed from the top few feet of the surface for use as riprap.

Oil and Gas

Oil and gas have not been found in commercial quantities in eastern South Dakota, despite the fact that many water wells and several oil tests penetrated the complete sedimentary sequence and reached the Precambrian basement.

Magnetometer Survey

by Bruno C. Petsch

The magnetometer survey of Sanborn County was made in July 1960, as part of the continuing study of the entire state of South Dakota.

Principles of Magnetometer Surveying

Theoretically, the earth itself is a natural magnet. The forces set up between the north and south magnetic poles are made up of four components: declination, inclination, horizontal intensity, and vertical intensity. The vertical component is the most satisfactory to measure because of ease and accuracy; its magnitude is a resultant of all forces that influence the magnetic field emanating from the crust of the earth. These forces are caused by paramagnetic, diamagnetic, and nonmagnetic substances in the Precambrian basement rocks, in overlying rocks, and at the ground surface.

In addition to changes in the earth's magnetic field caused by rock types and geologic structures, there is a gradual increase in the magnetic intensity toward the north magnetic pole. In South Dakota the vertical intensity increases about 8.7 gammas per mile north latitude, and 3.6

gammas per mile east longitude (Jordan and Rothrock, 1940). The application of this regional correction to a survey tends to result in a constant magnetic surface. Therefore an anomaly on this surface should reflect a geologic feature.

The vertical intensity of the terrestrial magnetic field is illustrated by contour lines (isogams) which connect points of equal value. Variations of intensity are recognized as positive and negative forces commonly known as magnetic highs and lows, or anomalies. The composite effect of the earth as a great magnet and the local variations in intensity that are caused by geologic features, determine the size and shape of anomalies. Magnetic anomalies are generally important when prospecting for oil and mineral deposits.

Magnetic surveys are made to discover general trends, which may then be investigated with more exact geological and geophysical surveys.

Possible causes of magnetic anomalies are: (1) differences in lithologic composition of the Precambrian basement rocks; (2) concentration of magnetic minerals in the overlying sedimentary rocks and the "granite wash," or conglomerate overlying the basement rocks; (3) deep-seated magnetic iron-bearing body; (4) changes in thickness of "red-bed" sections; (5) structure of the sedimentary formations; and (6) differences in depth and relief of the Precambrian surface.

It is advantageous to make magnetic surveys over areas where the geology is unknown. The solution of a magnetic problem is aided when comparison can be made with a problem that has been correctly interpreted in another area.

Magnetic Anomalies in Sanborn County

The arbitrary vertical magnetic intensity base selected for South Dakota is 500 gammas (Jordan and Rothrock, 1940, p. 10), as the true readings of 55,000 - 58,000 gammas are unwieldy in calculations. A low reading of 136 gammas was observed by Tullis (1942) 1 mile north of the northeast corner of Sanborn County (NE corner sec. 36, T. 109 N., R. 59 W., Beadle County). The readings in Sanborn County range from 174 gammas in the low mentioned above, to a high of 838 gammas, 4 miles east of Forestburg (fig. 14).

The outstanding anomaly in the county is the magnetic high 4 miles east of Forestburg. The summit is in the NE corner sec. 34, T. 107 N., R. 60 W. The anomaly slopes abruptly downward from the summit of 838 to a low of 292 gammas in 1 mile to the east, and from the summit to a low of 283 gammas in 2 miles to the west.

Two moderate highs with readings of 390 and 423 gammas trend northeast and northwest, respectively, and join in T. 106 N., R. 61 W., southwest of Forestburg. A high with a 543-gamma reading is about 6 miles northwest of Forestburg (fig. 14).

Geologic Interpretation

The slope of magnetic intensities apparently does not conform to the topography of the Precambrian surface, which slopes in a northwest direction across the county.

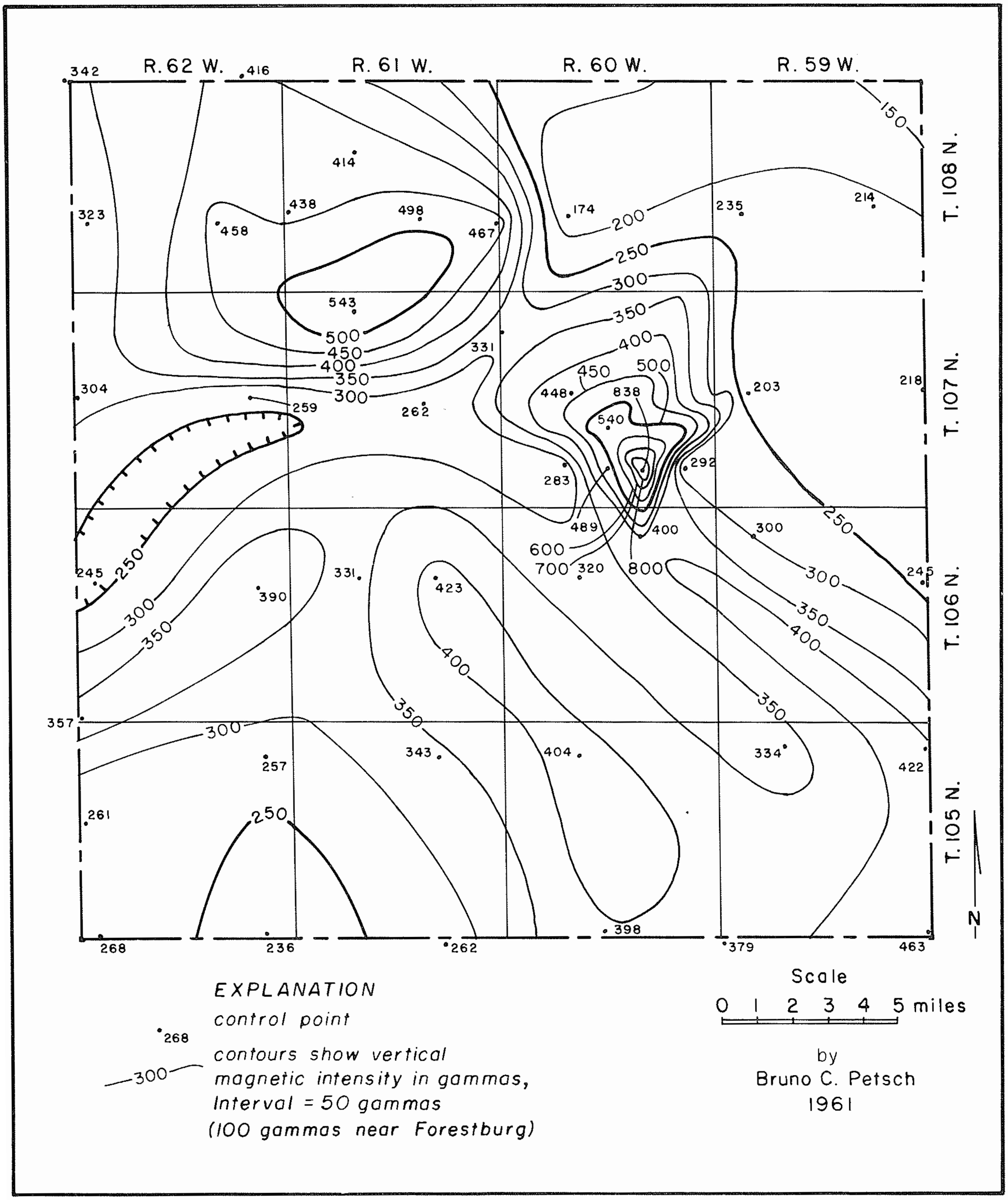


Figure 14. Map of Sanborn County showing magnetic anomalies.

The magnetic high 4 miles east of Forestburg could be caused by a mafic igneous mass intruded into a granite or quartzite, or by mafic dikes and sills intruded into sedimentary rocks. Near the Forestburg magnetic high, the glacial drift and sedimentary rocks are only 700 to 900 feet thick, which is not enough cover to shield any material that might be causing the magnetic high.

GROUND-WATER HYDROLOGY

by Lewis Howells

Occurrence of Ground Water

Principles of Occurrence of Ground Water

Principles that govern the occurrence of ground water have been discussed by many authors. Leopold and Langbein (1960) provide a simplified explanation; reports by Meinzer (1923a, b, 1949, p. 385-477), Tolman (1937), and Todd (1959) are more detailed.

Practically all ground water is derived from precipitation. Rain and meltwater from snow enter the ground by direct infiltration or by infiltration from streams and lakes. Ground water generally moves downward and laterally from areas of recharge to areas of discharge.

Ground-water discharge occurs by evapotranspiration, by seepage into surface-water bodies, and by discharge from wells or springs.

Any formation or stratum that will yield water in sufficient quantity to be important as a source of supply is called an aquifer. An aquifer is both a distribution system for transmission of water and a reservoir for storage. Water in an aquifer is in constant motion from areas of recharge to areas of discharge and is in transient storage.

The suitability of an aquifer as a source of water is governed by its permeability and volume and its capacity to store and ability to release water.

The amount of water that is stored in an aquifer is determined by the area and thickness of the aquifer, and by the porosities of the materials that form the aquifer. Porosity is the percent of open spaces in the material and is dependent upon several factors such as size, shape, degree of sorting, cementation, and compaction of the grains, and the number, size, and distribution of joints and fractures in the rock. Unconsolidated material such as clay, sand, and gravel is generally more porous than consolidated rocks such as sandstone and limestone.

The amount of water that an aquifer yields by gravity drainage may be much less than its porosity because part of the water is held in the pore spaces by molecular attraction between the water and the rock particles and some of the pores may not be connected. Small pores retain a greater proportion of the water than large pores. The volume of water, expressed as a fraction of a cubic foot, that will drain by gravity from 1 cubic foot of an aquifer is called the specific yield of the aquifer.

If the water in an aquifer is not confined by overlying impervious strata it is said to be under water-table conditions (fig. 15, well A). Under

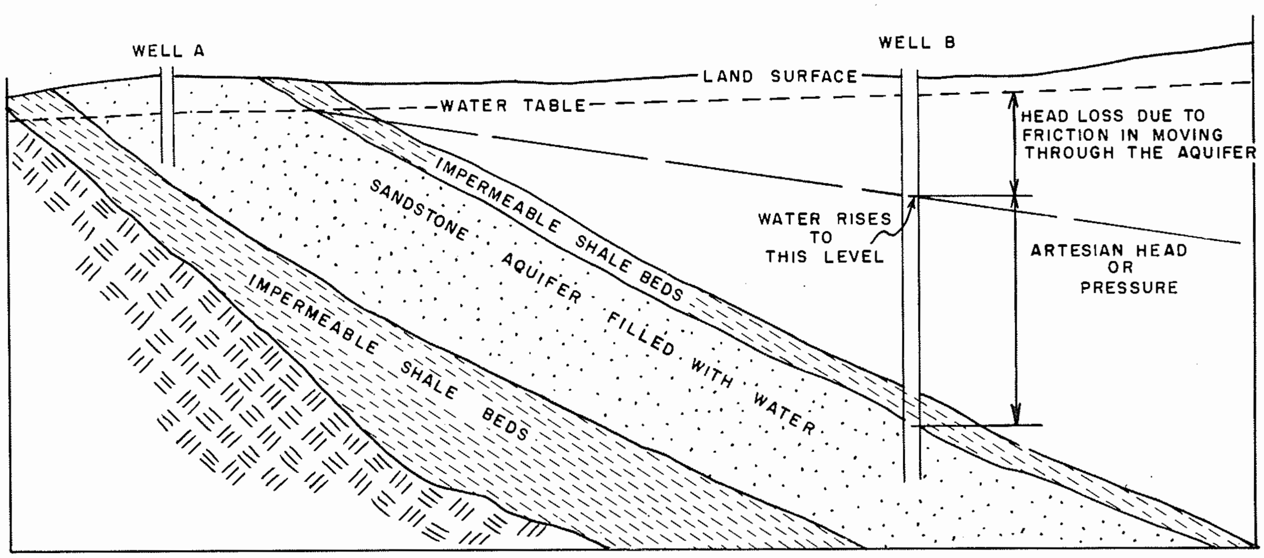


Figure 15. Diagram showing water-table and artesian conditions. Water-table aquifer at Well A. Artesian aquifer at Well B.

water-table conditions water can be obtained from storage in an aquifer by gravity drainage -- that is, by lowering the water level as by pumping from a well. The water table may be defined as the surface at which water will stand in a well that penetrates an unconfined aquifer.

The ability of a material to transmit water under pressure is called its permeability. Frictional resistance to the movement of water through material with relatively large pore spaces, such as coarse gravel, is not great and the material is said to be highly permeable. However, the resistance to the movement of water through small pore spaces, such as those in clay or shale, may be very great, and the material is said to be relatively impermeable. A bed or formation of relatively impermeable material is called an aquiclude. Permeability is quantitatively expressed as the coefficient of permeability and is defined, for field use, as the number of gallons of water per day that will pass through a cross-sectional area of 1 square foot under unit hydraulic gradient at the local temperature of the ground water.

Water is under artesian conditions if it is confined in an aquifer by overlying and underlying strata that are relatively less permeable than the aquifer (fig. 15, well B). Water in a well that penetrates an artesian aquifer will be raised by pressure to a level above the top of the aquifer. As in water-table aquifers, water can be obtained from artesian aquifers if the water level is lowered by pumping or if the hydrostatic pressure is lowered by natural flow. When water under artesian conditions is released from storage the aquifer remains saturated.

In most artesian aquifers, pressure is exerted on the water confined in the aquifer because the altitude of the area of recharge is above the top of the aquifer. Some artesian aquifers may derive part of their artesian head from the weight of overlying rock and yield some water from storage by expansion of the water; some water may be yielded by compression of the aquifer as the head is decreased.

The coefficient of storage (S) of an aquifer is the volume of water released from or taken into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.

The coefficient of storage of a water-table aquifer is essentially equal to the specific yield; however, for an artesian aquifer the coefficient of storage is generally much smaller than the specific yield. The quantity of water released from storage in a water-table aquifer in response to a change in head is attributed partly to gravity drainage and partly to compressibility of the water and of the material in the saturated zone.

The relation of the coefficient of permeability to porosity and to the rate of movement of ground water was illustrated by Wenzel and Fishel (1942, p. 11):

> "The material with the coefficient of permeability of 0.0002 consisted of 21 percent of clay, 44 percent of silt, and 35 percent of coarser grained material, but it had a porosity of 58.2 percent. Under a gradient of 10 feet to the mile the rate of movement of water through this clayey silt would be about 0.0004 inch a year or 1 foot in about 30,000 years. In the material with a coefficient of permeability of 90,000 about 90 percent of the grains

> were larger than 2 millimeters. The porosity was 38 percent. The rate of movement of water through this coarse material under a hydraulic gradient of 10 feet to the mile would be about 60 feet a day, or 1 mile in about 3 months. Under higher gradients the velocities through both the fine and coarse materials would be proportionally greater. . . most formations that are sufficiently water-bearing to be utilized by wells have coefficients that are whole numbers of two or more figures when expressed in Meinzer's units--that is, about 10. The yields of wells depend, of course, not only on the permeability of the formations they tap but also on the thickness of the formations, the draw-down of the water level, and the diameter and construction of the wells. For many places in the United States the physical and economic conditions are such that wells with moderate to high yields--100 gallons a minute or more--generally penetrate materials with coefficients of permeability of 100 or more."

Meinzer (1949, p. 449) noted that the natural rate of movement of water in aquifers generally is not greater than 5 feet a day and not less than 5 feet a year.

In glacial material similar to that in Sanborn County, Koopman (1957, p. 16) found coefficients of permeability ranging from 0.03 gpd per square foot for sandy and gravelly clay to 6 gpd per square foot for sandy clay, 0.3 to 15 gpd per square foot for very fine sand, and 380 gpd per square foot for gravelly sand.

The coefficient of transmissibility (T) is convenient to use in ground-water studies because it indicates a characteristic of the aquifer as a whole rather than of a small part. It is the average field coefficient of permeability of the aquifer multiplied by the aquifer thickness in feet.

The coefficients of transmissibility and permeability and the coefficient of storage may be determined by aquifer tests. An aquifer test may be made by pumping a well at a constant rate and measuring the drop in water level, or drawdown, in the pumped well and in nearby observation wells. The duration of pumping may vary from several hours to weeks depending upon the particular situation. When pumping stops, the recovery of the water level in the pumped well and observation wells is also measured. The data are analyzed and graphed and the coefficients of transmissibility (T) and storage (S) determined. As T and S largely determine the ability of the aquifer to store and transmit water, they can, when combined with other data under stated conditions, be used to predict water levels, to determine optimum well yields, and to design well fields. For an extended discussion of aquifer tests, see Ferris and others (1962).

Aquifers should be managed the same as surface-water reservoirs--inflow or recharge must balance outflow or natural discharge plus consumption over a period of time. If an aquifer is being used to its capacity, any increase in consumption must be balanced by a decrease in natural discharge, an increase in recharge, or both. Discharge of water through wells may reduce natural discharge in two ways--by lowering the water-table or piezometric surface and thus reducing evapotranspiration, or by intercepting water moving toward areas of natural discharge. Recharge to the aquifer must be adequate if the water supply is to last indefinitely because even a small rate of withdrawal will ultimately deplete the water in storage unless there is equal or greater recharge. Aquifers that are highly permeable but small in volume and that are surrounded by relatively impermeable material can be drained in a comparatively short time. High initial yield from a well may give the erroneous impression that a great volume of water is indefinitely available from an aquifer. Therefore, sufficient test drilling, aquifer tests, and related studies should be made to determine the physical characteristics of the aquifer before any substantial ground-water development is attempted.

Water-bearing Units of Quaternary Age

The aquifers in Sanborn County having the greatest potential are in deposits of Quaternary age. Two of these aquifers underlie more than half of the county. Locally significant aquifers are found in scattered deposits of permeable material in the drift and in the alluvium. Most of the potential for future development, however, lies in the Warren and Floyd aquifers.

Alluvium

Deposits of alluvium in Sanborn County generally are too thin or too clayey to serve as sources of ground water. Locally, however, the alluvium might supply some water for stock, particularly in the James River trench.

Glacial drift

The first wells in Sanborn County obtained water from aquifers in glacial drift. However, use of these aquifers decreased after residents learned that deep bedrock wells yield abundant flows of water, and by 1961 most wells tapped aquifers in the bedrock.

In Sanborn County the aquifers in glacial drift (fig. 16) are composed of hydraulically connected remnants of outwash and other glaciofluvial deposits from two or more glacial stades. Although the glaciofluvial material contains a high proportion of silt, fine sand, and clay, it also includes extensive amounts of coarse sand and gravel. Plate 1 shows the areas where deposits of outwash and dune sand are at the surface in Sanborn County. The geologic cross sections (pl. 2) show the thickness and extent of outwash deposits that are buried beneath a variable thickness of till; these deposits have no surface expression.

Figure 16 differs from figure 9 and plate 4 because it shows the total thickness of saturated sand and gravel, whereas figure 9 and plate 4 show the thickness of buried outwash.

The Floyd aquifer and the buried part of the Warren aquifer probably formed a single hydrologic unit at the time of deposition. Division of this unit into two parts may be the result of interstadial erosion by an "ancestral James River," continued by erosion of outwash deposits and deposition of till during the last glacial stade, and completed by erosion of the James River trench since the end of the last stade (p. 48).

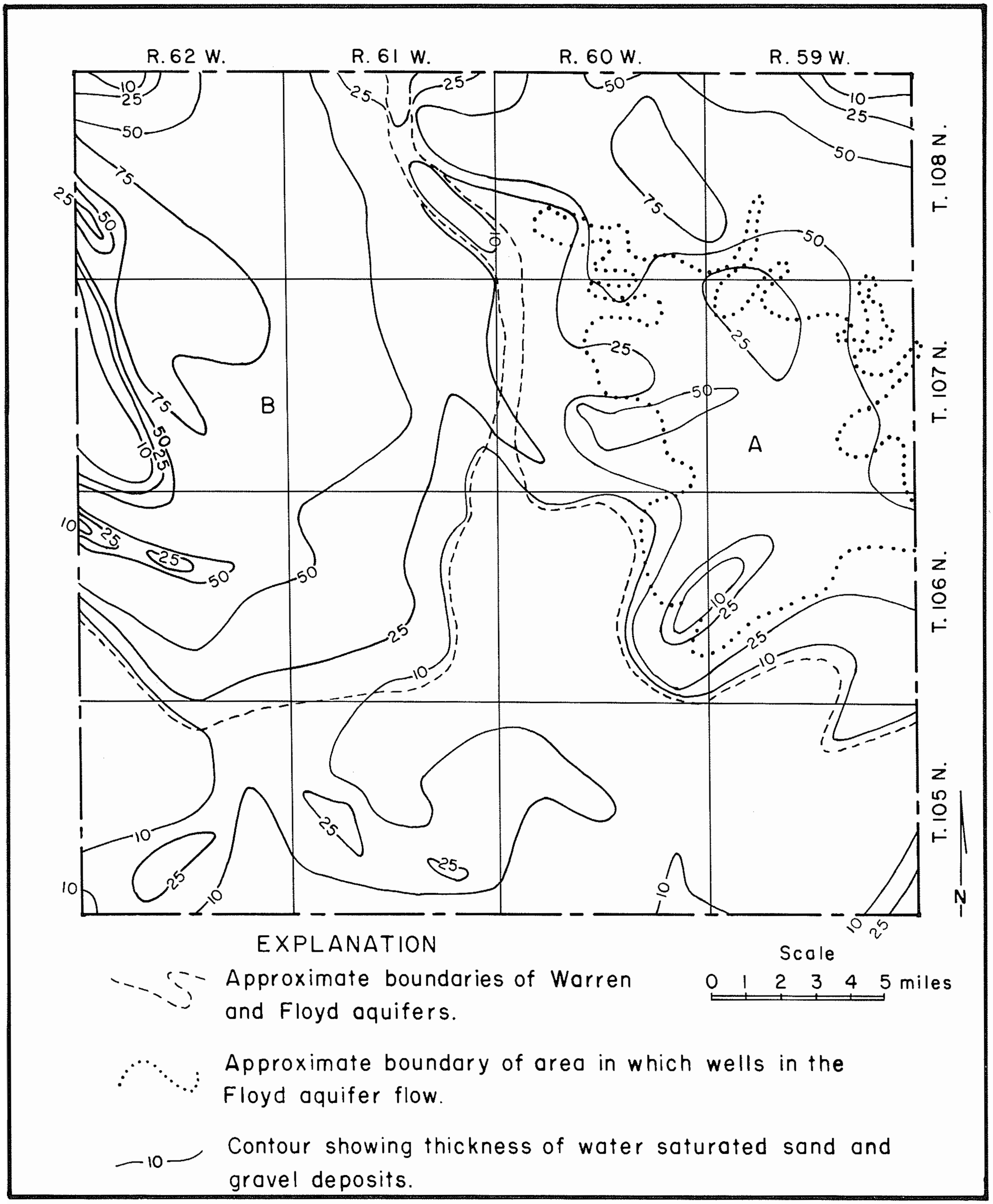


Figure 16. Map of Sanborn County showing thickness of water-saturated sand and gravel deposits. (A) Floyd aquifer, (B) Warren aquifer.

Outwash extending under the James River north of Forestburg between the Floyd and Warren aquifers contains a high proportion of silt and clay and has very low permeability.

Warren aquifer.--The Warren aquifer occupies parts of Beadle, Jerauld, and Sanborn Counties and underlies about 190 square miles of western Sanborn County. The aquifer is composed of buried outwash deposits and the Woonsocket and Cuthbert surface outwash deposits. Visual examination of material recovered from 65 test holes indicates that about 40 percent of the material in the aquifer is mixed silt to medium sand, about 25 percent silt and fine sand to gravel, and about 35 percent medium sand to gravel. The Warren aquifer has a maximum known thickness of 85 feet (test hole 108-62-21cccc).

In 1961 the Warren aquifer contained an estimated 1,200,000 acre-feet of water in transient storage. Water levels in the aquifer ranged from 3 to 12 feet below land surface in most of the area south of Sand Creek. North of Sand Creek water levels in the aquifer ranged from 12 to 65 feet below land surface. The depth to water was greatest near the junction of Sand Creek and the James River.

In the fall of 1962 aquifer tests were made at two irrigation wells completed in the Warren aquifer. The aquifer-test data are summarized below:

Well location	Depth to top of aquifer (ft)	Pumping rate (gpm)	Material	Coef. of transmissibility (T) (gpd/ft)	Coef. of storage (S)
107-62-1dba	40	215	Poorly sorted; ranges from coarse gravel to silt.	22,500	2.0×10^{-4}
108-61-17aacc	71	485	Clean, well-sorted medium to fine sand (42 feet thick).	50,000	1.7×10^{-5}

The values obtained for coefficient of storage (S) indicate that the water in the aquifer is under artesian head. Under water-table conditions S would probably be between 0.1 and 0.3. The effect of variations in the value of T may be seen by comparing the drawdown in each well after 10 days of pumping at 500 gpm. (See figs. 17 and 18.) In well 107-62-1dba, for example, the drawdown would be 51.0 feet but in well 108-61-17aacc it would be only 25.6 feet.

The aquifer data from the test at irrigation well 107-62-1dba are summarized in figure 17, a drawdown curve, which shows the drop in water level in the well, at pumping rates of 250 and 500 gpm (gallons per minute) for pumping durations of as much as 95 days. Drawdown for pumping rates

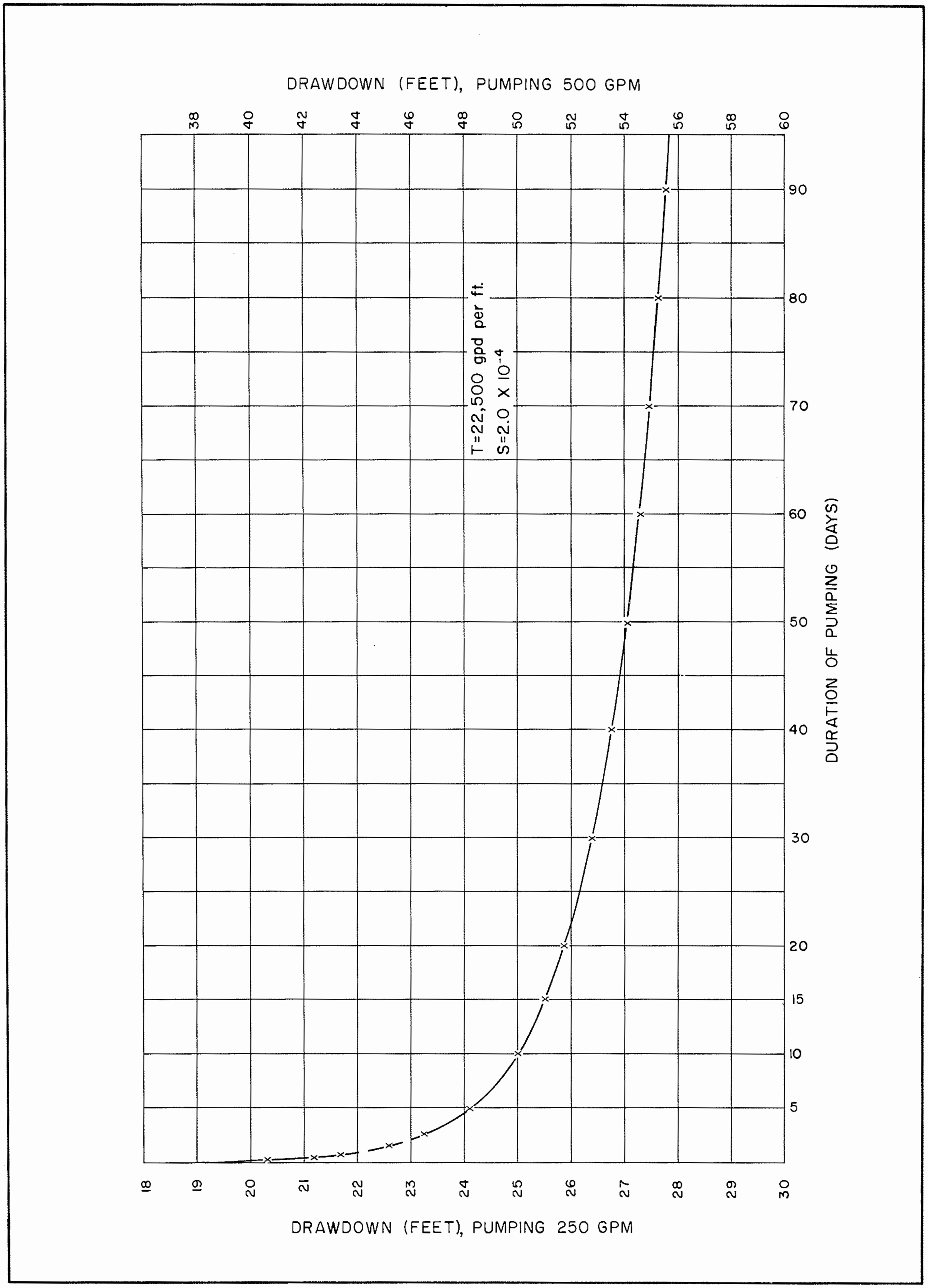


Figure 17. Projected time-drawdown curve for irrigation well 107-62-1 dba.

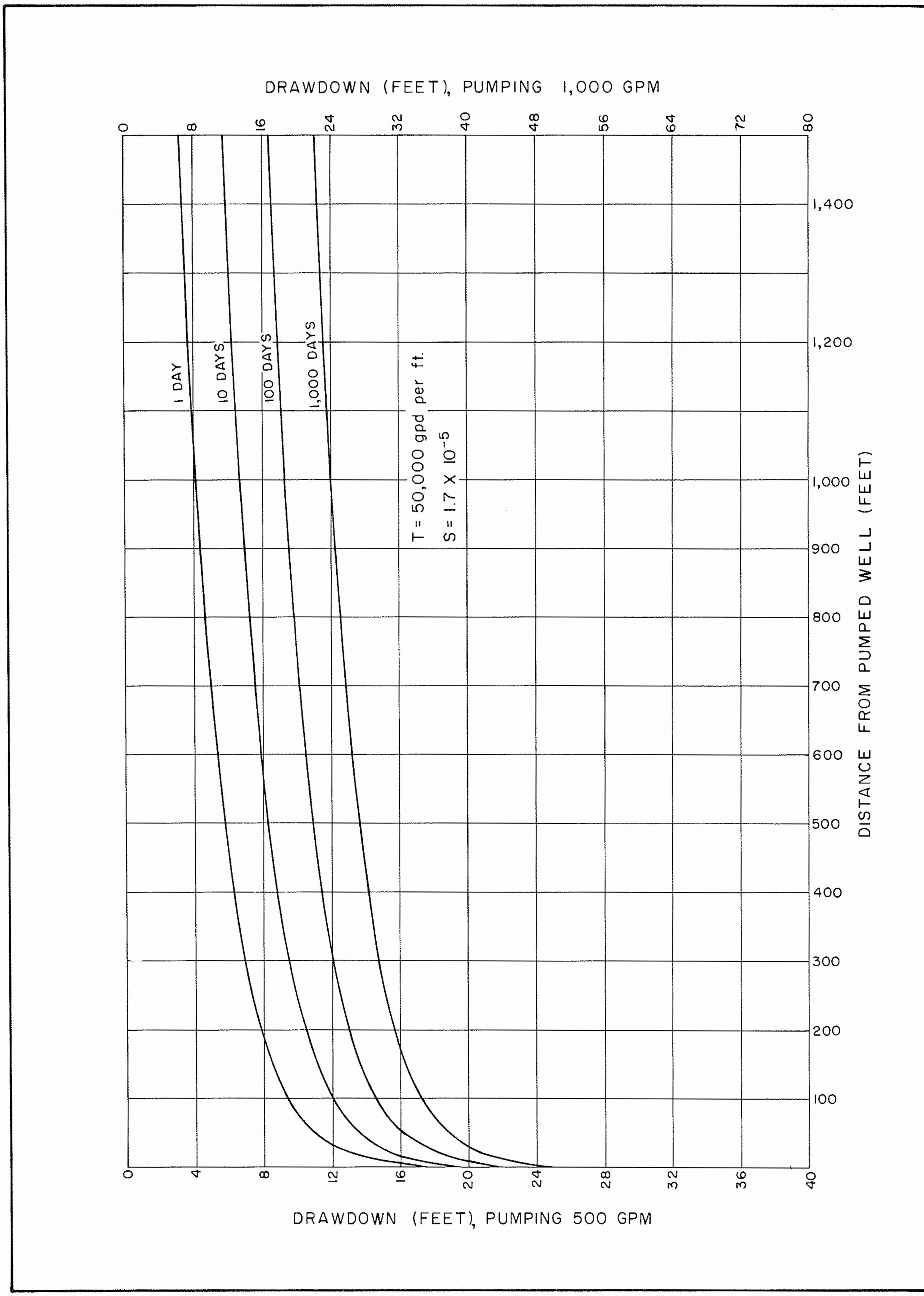


Figure 18. Projected distance-drawdown curves for irrigation well 108-61-17aacc.

other than those shown may be determined easily, as drawdown is proportional to pumping rate--for example, if the pumping rate is doubled, the drawdown is doubled.

Figure 18, a pumping curve for well 108-61-17aacc, shows the drop in water level in the aquifer within 1,500 feet of the well, at pumping rates of 500 and 1,000 gpm, for pumping durations of as many as 1,000 days. Drawdowns for other rates of pumping are determined as discussed for figure 18.

Floyd aquifer.--The Floyd aquifer underlies more than 180 square miles of northeastern Sanborn County. The first drilled well in the county penetrated this aquifer at the town of Diana (now Artesian) in 1886. It obtained a large flow of water from a sand and gravel layer 100 feet below the land surface at the base of the glacial drift. In the decade after 1886, many settlers drilled wells to obtain water from this aquifer.

The Floyd aquifer contains a greater proportion of coarse material than does the Warren aquifer. Visual examination of samples from 46 wells and test holes indicates that about 25 percent of the aquifer is silt to medium sand, about 30 percent silt to gravel, and about 45 percent medium sand to gravel. The aquifer is covered by 25 to 100 feet of till and has a maximum known thickness of 83 feet.

A thin permeable zone at the top of the Niobrara Marl contains water from the Floyd aquifer throughout much of the area where this aquifer and the Niobrara are in contact. Wells that top the Floyd are often drilled and cased several feet into underlying permeable bedrock to prevent sand and silt in the outwash from entering the well; in this way, the top of the bedrock acts as a screen. If a well were drilled and cased 10 to 50 feet deeper into the bedrock, water would come from an aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale and would differ greatly in quality from water in the Floyd aquifer. In this area, the Floyd aquifer is separated from the aquifer in the Niobrara and Codell by a few feet of impermeable chalky shale.

The artesian head in the Floyd aquifer is high enough to cause water to flow from wells in parts of six townships (fig. 16). Earlier studies (Todd, 1899, p. 125, 1903, 1904; Todd and Hall, 1903, 1904a, b) noted that the pressure at the land surface was low (about $5\frac{1}{2}$ psi at Artesian) but yields often were large (as much as 150 gpm). Heavy demand and rapid withdrawals by the early settlers, aggravated by several severe droughts, resulted in a decrease of artesian head and a significant decline in yields from flowing wells. During this investigation, the highest artesian pressure measured was 5 psi, but for most wells it was less than 2 psi. Yields from flowing wells ranged (1961) from less than 0.1 to 60 gpm and averaged 2.8 gpm. Most of the flowing wells were stock wells and had unrestrained flows.

The Floyd aquifer is filled to capacity in Sanborn County and is estimated to contain more than 1,000,000 acre-feet of recoverable water in transient storage; specific yield is assumed to be 0.25. In 1961 depths to water in areas where wells in the aquifer did not flow ranged from land surface to 45 feet below land surface.

In 1962 aquifer tests were made at two test wells and one irrigation well tapping the Floyd aquifer. Aquifer test data are summarized below and in figures 19, 20, and 21.

Location	Depth to top of aquifer (ft)	Pumping rate (gpm)	Material	Coef. of transmissibility (T) (gpd/ft)	Coef. of storage (S)
108-59-29bbab	62	302	Well-sorted layers of fine gravel to medium sand (42 feet thick).	59,000	$5.8x10^{-4}$
107-58-7cbd	45	796	Well-sorted layers of fine gravel to coarse sand (53 feet thick).	62,000	$3.9x10^{-4}$
106-59-13ddca	91	613	Coarse gravel to coarse sand (9 feet thick).	233,000	$4.6x10^{-3}$

The large coefficient of transmissibility (T) determined in the test at well 106-59-13ddca is especially noteworthy as the aquifer is only 9 feet thick at the well.

Local sand deposits.--Small lenses or beds of sand and gravel in the glacial drift occur locally in Sanborn County. These small sand and gravel bodies vary in thickness and area and are often in hydraulic contact with the underlying aquifer in the Niobrara and Codell.

Till.--The composition and hydrologic properties of till in Sanborn County are much like those of its main source rock, the Pierre Shale. The till, which contains a high proportion of clay, is relatively impermeable and is an aquiclude.

Water-bearing units of Cretaceous age

Cretaceous rock units that underlie Sanborn County and contain one or more aquifers are the Niobrara Marl, Carlile Shale, Greenhorn Limestone, and Dakota Group. The remaining two units, the Pierre Shale and Graneros Shale, locally may furnish meager supplies of highly mineralized water from sandy or fractured zones elsewhere in South Dakota, but they are not aquifers in Sanborn County. The stratigraphic relations of the water-bearing units are shown in figure 22.

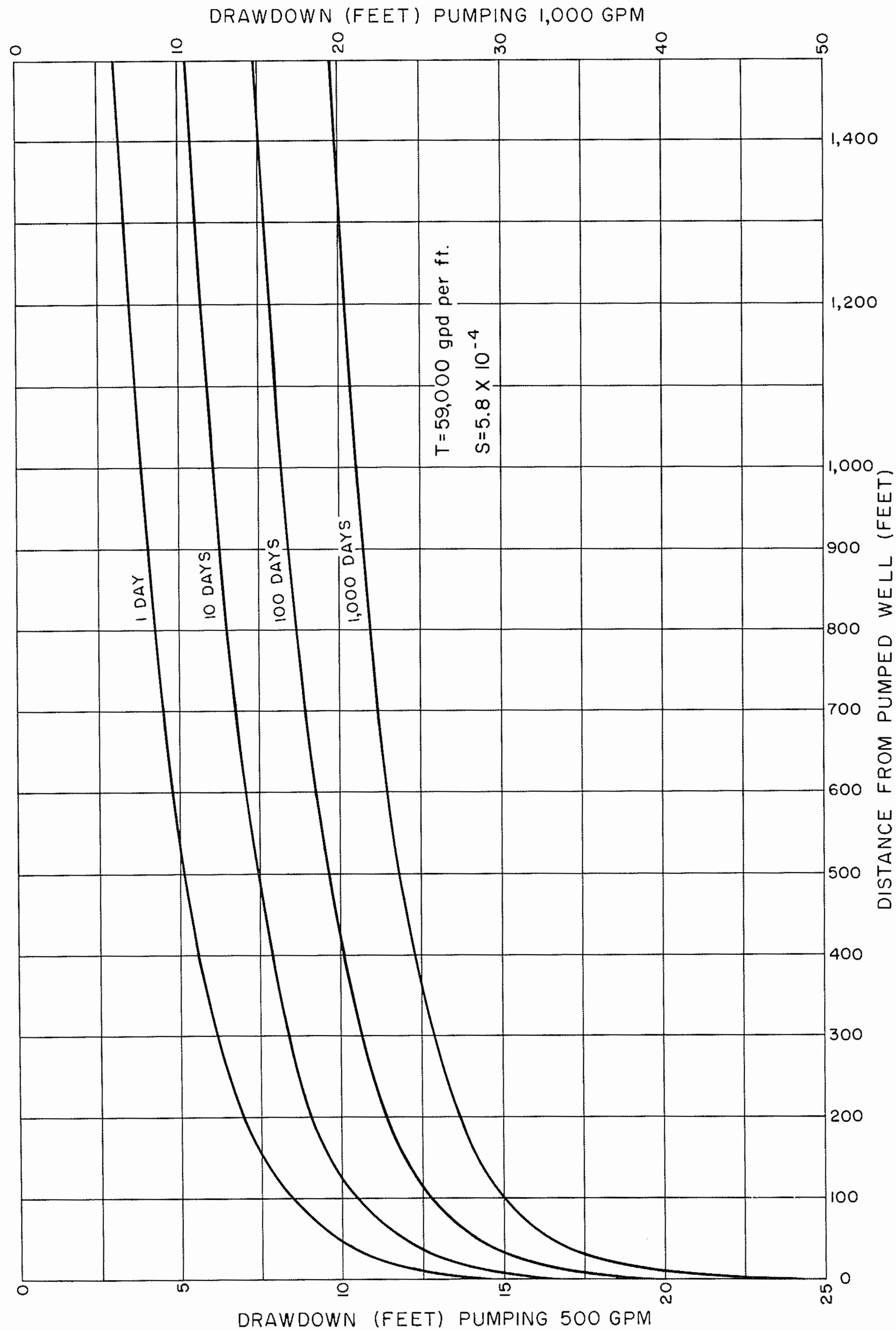


Figure 19. Projected distance-drawdown curves for aquifer test well 108-59-29 bbab.

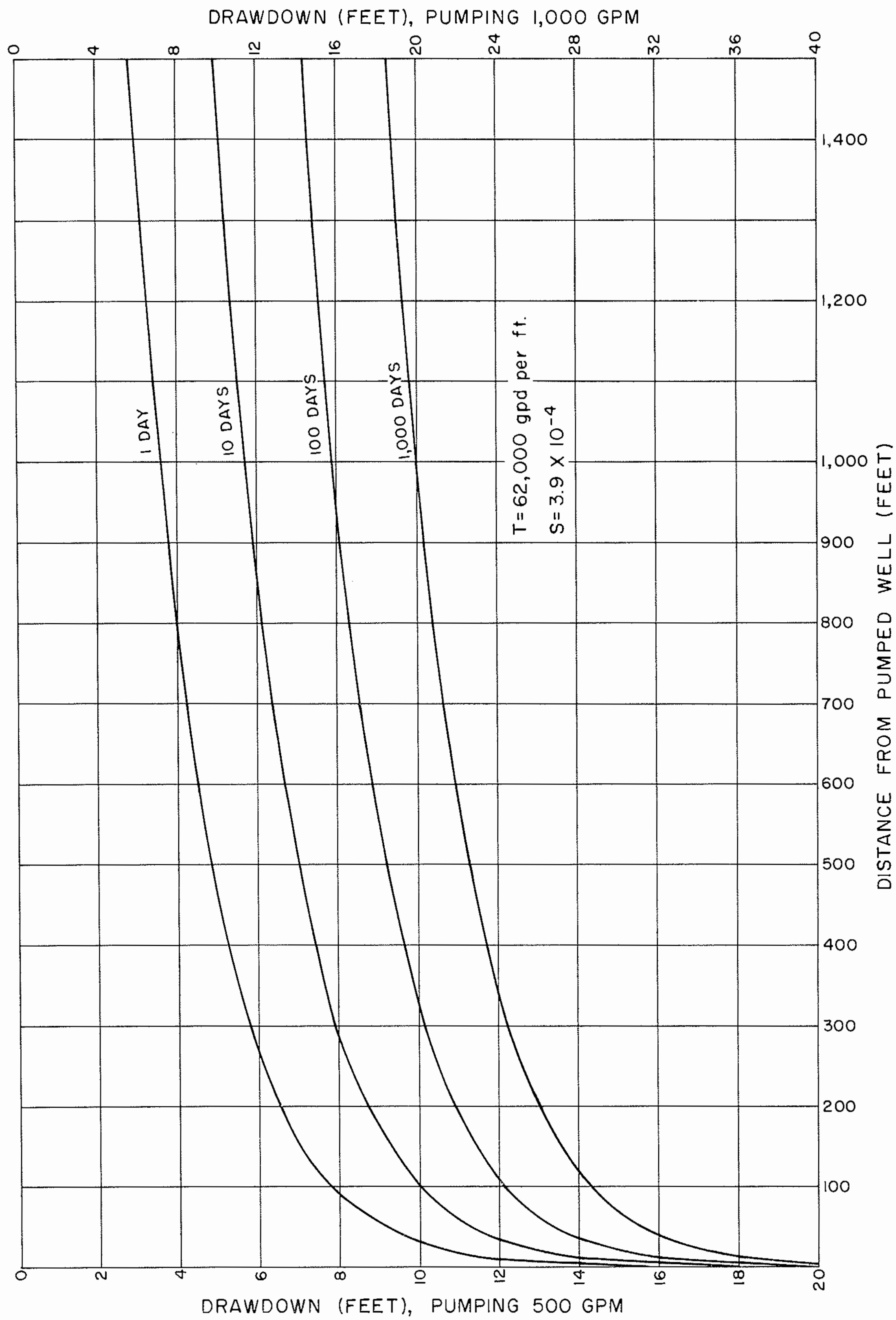


Figure 20. Projected distance-drawdown curves for aquifer test 107-58-7cbd.

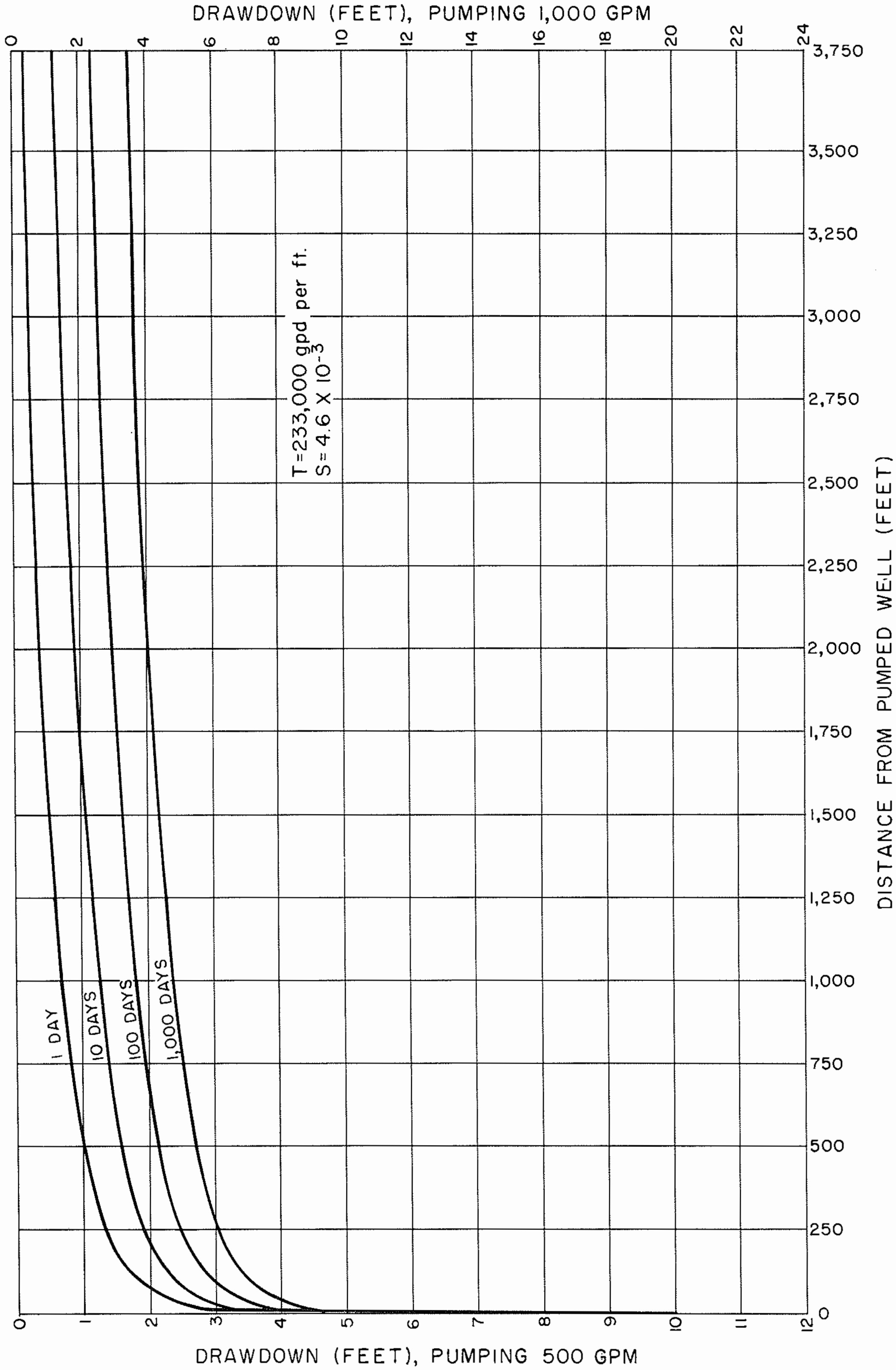


Figure 21. Projected distance-drawdown curves for irrigation well 106-59-13 ddca.

System	Series	Geologic Unit	Thickness (Feet)	Section	Water-Bearing Unit	Aquifer Material	Hydrologic Characteristics
Quaternary	Pleistocene and Recent	Alluvium and Glacial Drift	30-200		Surface Outwash Deposits	Sand and gravel; may contain much silt or clay.	Hard, fresh to saline water. Water table conditions.
					Local Sand Lenses		Soft, saline water locally under artesian pressure.
					Buried Outwash Deposits		Hard, saline water under artesian pressure. Wells may flow.
Cretaceous	Upper Cretaceous	Pierre Shale	0-90				Local permeable zones throughout Niobrara Marl yield water to wells. Unit is mainly an aquiclude.
		Niobrara Marl	0-80		Niobrara Marl and Codell Sandstone Member	Dark-blue to tan or light-gray chalky shale; may contain sand zones. White to rusty-brown sandstone; loose to well cemented fine sand and gravel.	Codell Sandstone Member and a permeable zone at or near the base of Niobrara Marl may yield soft, saline water under artesian pressure. Wells flow at lower altitude. Water hard in Southeast part of county.
		Codell Sandstone Member	(0-120)				
		Carlile Shale	90-380		Carlile Shale	Sand and permeable sandy shale zones below Codell Sandstone Member.	May yield soft, saline artesian water. Wells flow in some areas. Unit is mainly an aquiclude.
		Greenhorn Limestone	5-40		Greenhorn Limestone	Fossiliferous calcareous shale; locally sandy.	Porous zone near middle of formation may yield soft, saline water to flowing wells. Water hard in southeast part of county.
		Graneros Shale	24-300			Sand and permeable sandy shale zones; thicker and more extensive in the southern part of the county.	May yield soft, saline artesian water. Wells might flow in some areas. Unit is mainly an aquiclude.
	Upper and Lower Cretaceous	Dakota Group	91-350		Dakota Group	Fine to coarse-grained quartz sandstone; loose to well cemented with calcium carbonate and silica. Interbedded with dark shale.	Permeable sandstones yield soft to very hard saline water to flowing wells.
Precambrian		Sioux Quartzite					Aquiclude.
		Igneous and Metamorphic Rocks					

Figure 22. Generalized stratigraphic column in Sanborn County showing water-bearing units and some of their hydrologic properties.

Niobrara Marl and Codell Sandstone Member of Carlile Shale

In Sanborn County the Codell Sandstone Member of the Carlile Shale and a permeable zone at or near the base of the Niobrara Marl are a single hydrologic unit. In the southern part of the county the Codell Sandstone Member is in contact with a porous, permeable zone near the base of the Niobrara. Elsewhere in the county a light-blue to black shale zone in the Carlile separates the Codell and Niobrara.

The aquifer in the Niobrara and Codell contains water that is under artesian pressure. Seventy years ago most wells completed in this aquifer flowed and had high pressures. Records of wells drilled in the 1880's and 1890's reveal that many wells had initial flows of 100 to 300 gpm and pressures as high as 35 psi. In 1961, however, wells in the aquifer flowed only in the James River trench, Sand Creek and Morris Creek valleys, and parts of T. 106 N., R. 62 W., and T. 105 N., R. 62 W. Elsewhere in the county, water levels in the aquifer ranged from 2 to 60 feet below land surface. The greatest depths to water were near the trench of the James River north of Forestburg.

Carlile Shale

In the interval between the base of the Codell Sandstone Member and the top of the Greenhorn Limestone, the Carlile Shale may contain one or more zones of water-bearing sandstone or very sandy shale. These zones are more numerous and are thickest in the southern half of Sanborn County.

Greenhorn Limestone

The Greenhorn Limestone underlies all of Sanborn County and supplies water to flowing artesian wells. According to drillers' reports the aquifer, locally known as the "mud flow," is a porous calcareous or sandy shale zone near the middle of the formation. Unpublished information in the files of the U. S. Geological Survey indicates that artesian pressure in the aquifer is low and has decreased since 1890.

Dakota Group

The Dakota Group underlies all of Sanborn County and is an important artesian aquifer. Its sandstones yield water to flowing wells everywhere in the county except for small areas in the northeastern and southeastern parts, where the Precambrian basement rock is close to the land surface.

Well logs and water analyses indicate that the Dakota may contain three aquifers. The first, or shallowest aquifer, and the third, or deepest aquifer, contain dissimilar types of water. The second aquifer contains water intermediate in character. Wells completed in the topmost aquifer yield small to moderate flows of water at low pressure; those in the intermediate one yield somewhat larger flows of water at higher pressure; and those in the lowest aquifer yield moderate to large flows of water at high pressure. The upper aquifer occupies an increasingly thicker section of the Dakota Group north of Woonsocket and supplies much of the water from the Dakota in the northern part of the county. The third aquifer occupies an increasingly thicker section of the Dakota south of Woonsocket, and may supply most of the water from the Dakota Group in the southern part of the county.

The sandstone beds of the Dakota in Sanborn County are composed of very fine to coarse quartz sand cemented with calcium carbonate. Tightly cemented zones have low permeability, but uncemented or loosely cemented zones may be very permeable. Meinzer (1929, p. 163) reported coefficients of permeability of 57, 69, and 81 gpd per square foot for the Dakota Group at Canton, South Dakota, 100 miles east-southeast of Woonsocket.

Artesian pressures in the Dakota have declined rapidly since 1890. At Woonsocket, initial pressures of both the first and second aquifers were reported to have been 250 psi at land surface; by 1892 pressure in the first aquifer had dropped to 130 psi and in the second had decreased to 180 psi. Near Letcher, pressures in the first aquifer were reported to have decreased 10 to 30 psi from 1890 to 1892. In 1961 artesian pressures in the Dakota in Sanborn County ranged from about 3 to 33 psi.

Pressure measurements have been made on several wells in Woonsocket during the last 70 years. Figure 23 shows the decrease in pressure in 5 closely spaced wells since 1888. All wells tapped the same sandstone and were the same depth. The change in slope of the pressure time curve at about the year 1925 may indicate a change of major hydrologic significance; perhaps the decline in pressure had been enough to permit compaction of the aquifer and the dewatering of the confining and contained shale beds.

A rapid decrease in artesian pressure and an accompanying decrease in production has been caused by unrestricted and uncontrolled flows from wells that tap the Dakota.

Seventy years ago many flowing wells had yields of several hundred to a thousand gallons per minute, but few new wells today flow as much as 100 gpm and most flow less than 50 gpm. A Woonsocket city well (fig. 24) drilled in 1890 reportedly had an initial flow of 2,750 gpm. In 1961 a well within 500 feet of the site of the original well and of the same depth and diameter, had a flow of only 130 gpm. In 1891 a well near Letcher had a measured initial flow of 4,000 gpm. New wells in the Letcher area have initial flows of 5 to 60 gpm. Artesian pressures probably will continue to decrease and wells that tap the Dakota Group eventually may stop flowing.

Water-bearing Units of Precambrian Age

In some parts of South Dakota the Precambrian Sioux Quartzite yields water to wells from fractures or joints, lenses of porous sand, or small deposits of "granite wash." No wells in Sanborn County receive water from this source.

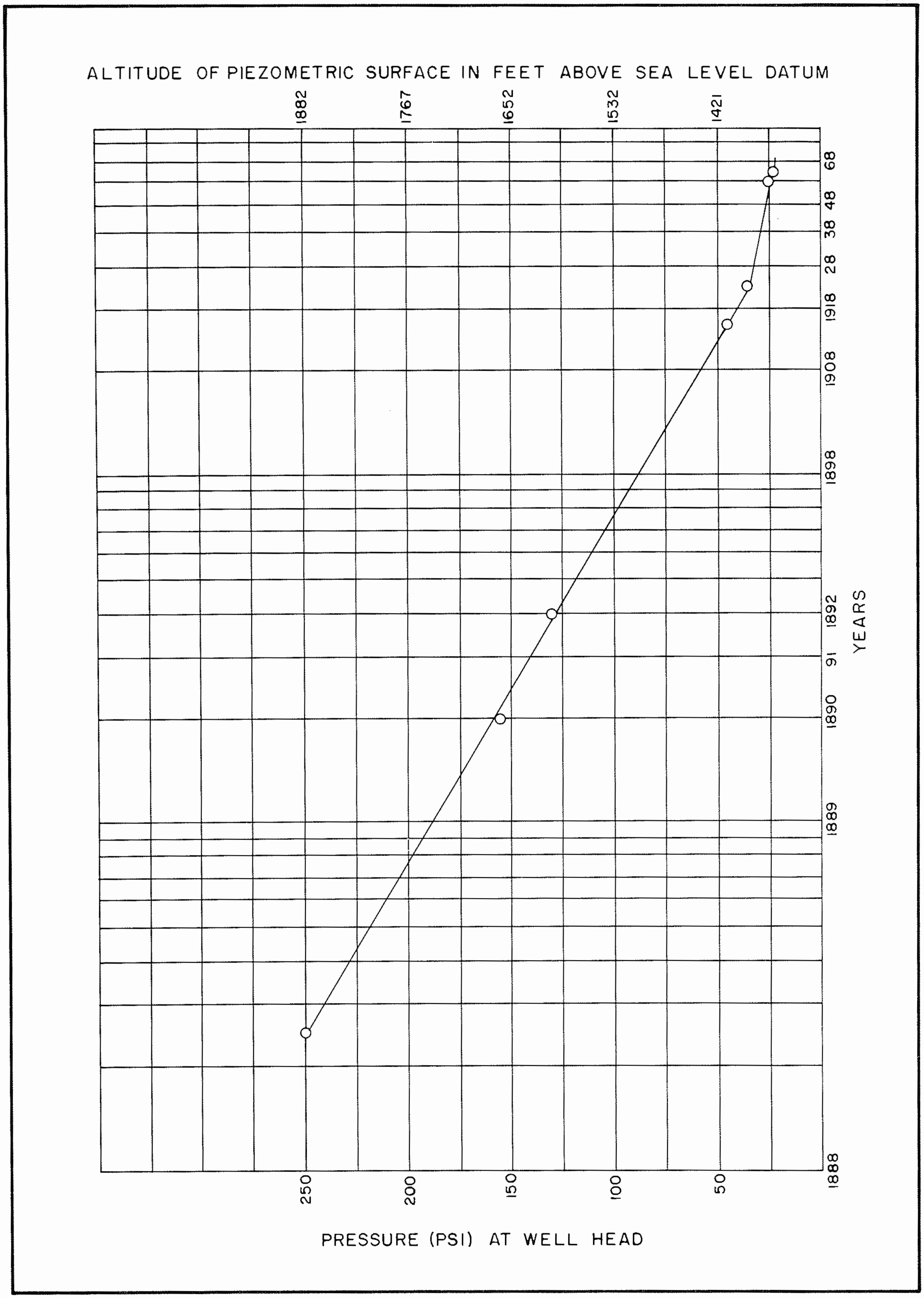


Figure 23. Decrease of artesian pressure in the top aquifer in the Dakota Group since 1888 at Woonsocket, South Dakota.

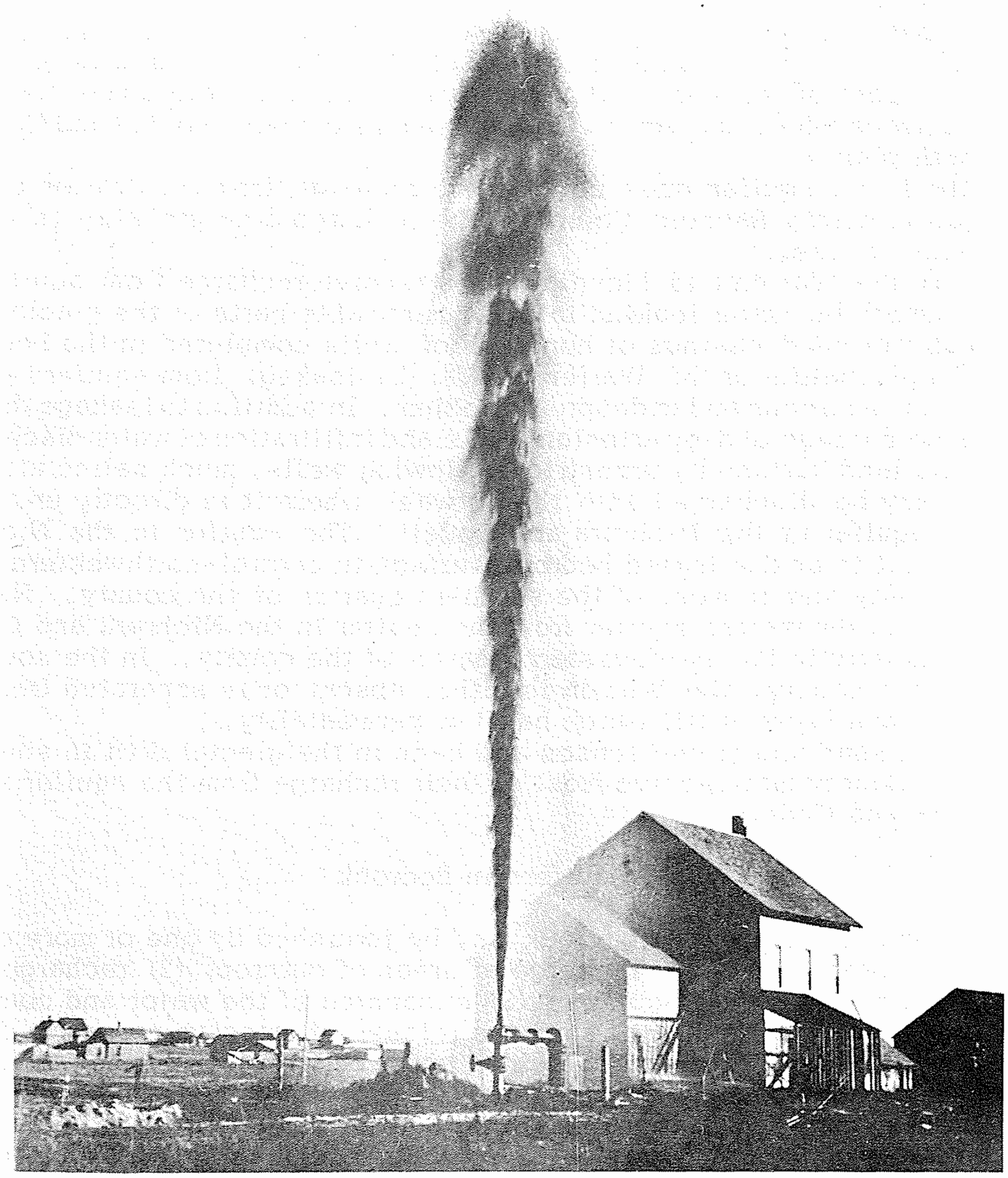


Figure 24. Artesian Well at Woonsocket, 1909. (Photo by N. H. Darton)

Recharge

Aquifers in Glacial Drift

Aquifers in glacial drift, where they are exposed, are recharged by infiltration of precipitation. The Warren aquifer has two areas of recharge in Sanborn County--the outwash plain and dune sand areas south of Sand Creek between Woonsocket and Forestburg, and the outwash plain along Morris Creek west of Cuthbert. (See pl. 1.) When recharge is great, as it is in years of above-normal precipitation, the water table may reach the land surface where the aquifer is exposed in the Woonsocket and Cuthbert outwash plains.

The Floyd aquifer does not receive recharge from infiltration of precipitation within Sanborn County. The recharge area probably is to the northeast or east.

Both the Warren and Floyd aquifers receive recharge from aquifers in the bedrock by water leaking into the permeable parts of the glacial drift through corroded casings of hundreds of wells completed in the bedrock.

Contamination of the Warren aquifer by leakage from aquifers in the bedrock is a serious and widespread problem. In addition to leakage through corroded casings of deep artesian wells and infiltration of water discharged onto the land surface by unrestricted flowing wells, much saline artesian water may be discharged into the outwash where it is directly underlain by the aquifer in the Niobrara and Codell. The aquifer in the Niobrara and Codell is at the buried bedrock surface in central-northwestern Sanborn County and in most of the southern quarter of the county. Natural recharge to the Warren aquifer from the aquifer in the Niobrara and Codell occurs mostly in the northwestern quarter of the county. In the southern part of the county, the Warren is either absent or is separated from the bedrock by a layer of till which has low permeability.

Local sand and gravel lenses and beds in the glacial drift in southern Sanborn County may receive most of their recharge from the aquifer in the Niobrara and Codell.

Aquifers in Bedrock

Water from aquifers in bedrock may be furnished by one or more of the following processes: (1) recharge at areas of outcrop; (2) recharge from overlying or underlying aquifers; (3) expansion of the water and compaction of the aquifer, resulting from the release of artesian pressure; or (4) dewatering of confining and contained shale beds by compaction resulting from the release of artesian pressure.

The major source of recharge to the aquifer in the Niobrara and Codell is not known. Recharge may occur as water is released by compaction of the Codell Sandstone Member and the shale of the Carlile. Outcrops of the Niobrara Marl and the Codell Sandstone Member of the Carlile Shale probably are not areas of recharge. In exposures in the Black Hills the Niobrara Marl and the equivalents of the Codell Sandstone Member of the Carlile Shale have low permeability and the outcrops are small and poorly situated with respect to surface drainage. It is evident that the outcrop of the Niobrara Marl in the Missouri River trench is not a major recharge area because the piezometric surface of water in the aquifer in some nearby areas of eastern South Dakota is above the level of the river.

The aquifer in the Niobrara and Codell probably is not recharged by overlying aquifers. East, west, and locally to the north of Sanborn County, it is overlain by the Pierre Shale, which serves as a barrier to downward movement of water. The recharge area could not be to the south because the piezometric surface of water in the aquifer is higher than the land surface south of Sanborn County.

The aquifer in the Niobrara and Codell receives some artificial recharge from the Greenhorn Limestone and Dakota Group in Sanborn County and adjacent areas. Casings of hundreds of deep wells have corroded and permitted water from the Greenhorn and Dakota to flow into the Niobrara and Codell.

Water analyses and well logs indicate that the aquifer in the Niobrara and Codell receives some natural recharge from the aquifer in the Dakota Group where the two aquifers are hydraulically connected along the slope and crest of the buried Sioux Ridge south of Sanborn County.

Quality-of-water data indicate that the sandy zones in the Carlile Shale below the Codell Sandstone Member are recharged by the Greenhorn Limestone or Dakota Group. (See table 3 and Appendix B.)

The Greenhorn Limestone may yield water by compaction and dewatering of the confining shale beds, but in southeastern Sanborn County it receives recharge from the third or lowest aquifer in the Dakota Group. Well logs and water analyses show that the Greenhorn and Dakota merge near the crest of the Sioux Ridge and that they merge or are in hydraulic contact over other highs on the Precambrian surface. (See figs. 11 and 12.) In northeastern Sanborn County and in other areas of South Dakota to the north, the Greenhorn may receive recharge from the topmost aquifer in the Dakota Group.

The Dakota Group may yield water by compaction of the aquifer, by dewatering of confining and contained shale beds, or by recharge from deeper aquifers where they contain water under greater artesian pressure than the Dakota.

Discharge

Well Discharge

Discharge of water by wells in Sanborn County in 1961 is summarized in the following tables.

Type of well	No. of wells	Estimated production	
		Million gallons per day	Acre-feet per year
Flowing	840	4.39	4,910
Nonflowing artesian	729	1.48	1,660
Water-table	27	0.02	17
TOTAL	1,596	5.89	6,587

Water-bearing unit	No. of wells	Estimated production	
		Million gallons per day	Acre-feet per year
Dakota Group	593	4.03	4,514
Greenhorn Limestone	89	0.21	234
Carlile Shale	4	0.02	17
Niobrara Marl and Codell Sandstone Member of Carlile Shale	616	0.70	780
Glacial drift - flowing	102	0.61	681
Glacial drift - nonflowing	109	0.26	291
Undetermined	83	0.06	70
TOTAL	1,596	5.89	6,587

About 230,000 gpd or 260 acre-feet of water was discharged by wells that produced from the Warren aquifer in 1961. Eighty percent of this, or 216 acre-feet, was pumped from irrigation well 108-61-17aacc. Most of the 43 wells that tapped this aquifer were stock or emergency wells and had only seasonal or intermittent use. A second irrigation well (107-62-1dba) was drilled in 1962 and produced about 55 acre-feet of water during the year.

During 1961, 160 wells in the Floyd aquifer discharged about 630,000 gpd or 710 acre-feet of water. Ninety-six percent (605,000 gpd) of the total discharge came from the 102 flowing wells that tapped the aquifer. In 1962, a newly completed irrigation well (106-59-13ddca) produced about 60 acre-feet of water.

The aquifer in the Niobrara and Codell supplied an estimated 700,000 gpd or 780 acre-feet of water to more than 600 wells in 1961. One of the major reasons the aquifer is the most heavily developed in Sanborn County is the desire for soft water for domestic use. More than 50 percent of the domestic supplies are obtained from the aquifer in the Niobrara and Codell.

The permeable zones in the Carlile Shale below the Codell Sandstone Member and the Greenhorn Limestone are minor aquifers in Sanborn County. In 1961 the permeable zones in the Carlile supplied about 15,500 gpd or 17.4 acre-feet of water from four flowing wells and the Greenhorn supplied about 209,000 gpd or 234 acre-feet from 89 flowing wells.

In Sanborn County, the Dakota Group yields more water to wells than all other aquifers combined. In 1961 the 593 wells that tapped the Dakota flowed about 4,030,000 gpd or 4,500 acre-feet of water.

Leakage and Natural Discharge

Evaporation and transpiration account for most of the natural groundwater discharge from the Warren aquifer. Except in spring, when a high-water table may result in numerous temporary seeps and springs, discharge to lakes and springs is slight and there is no base flow in streams; in years of low rainfall even the James River has no flow. Only two small perennial springs (NE$\frac{1}{4}$SW$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$, sec. 12, T. 106 N., R. 61 W., and SW$\frac{1}{4}$SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$, sec. 9, T. 108 N., R. 61 W.), both discharging water from the Warren aquifer, were observed during the field investigation.

The Floyd aquifer apparently has little natural surface discharge in Sanborn County. The 25 to 100 feet of relatively impermeable till that covers the aquifer reduces evapotranspiration to a small amount and the well inventory disclosed no permanent springs or seeps.

Natural discharge from the aquifer in the Niobrara and Codell occurs primarily in northwestern and southern Sanborn County. The aquifer apparently crops out in a buried valley in the bedrock surface in the northwest and central parts of the county; thus water from the aquifer in the Niobrara and Codell may be discharged to the overlying Warren aquifer. In much of the southern quarter of Sanborn County the aquifer in the Niobrara and Codell is in contact with drift and locally may discharge water into sand beds and lenses in the till.

The Carlile Shale and Greenhorn Limestone have no known natural discharge in Sanborn County. The Greenhorn discharges water into overlying aquifers by leakage through hundreds of corroded well casings.

The aquifers in the Dakota Group discharge water to overlying aquifers in southeastern Sanborn County and adjacent areas, where they merge with or are hydraulically connected to overlying aquifers on the slope and crest of the Sioux Ridge. The Dakota also discharges water to overlying aquifers through hundreds of corroded well casings.

Aquifer Potential

Aquifers in Glacial Drift

Aquifers in Quaternary deposits underlie more than 70 percent, or 400 square miles, of Sanborn County and have a much greater potential for future development than aquifers in bedrock. The Warren and Floyd aquifers not only contain more water in transient storage than the other aquifers (an estimated 2,200,000 acre-feet), but also contain the only water that is of suitable quality for irrigation. The Warren might support annual withdrawals of as much as 15,000 acre-feet, or as much water as would be supplied by about 70 wells equal in capacity to irrigation well 108-61-17aacc (850 gpm).

Potential sustained yields of wells in the Floyd aquifer cannot be determined without additional investigation. Greater development of the Floyd aquifer would result in a decrease in artesian pressure and wells that now flow would have to be pumped. Unless the artesian head is lowered considerably, however, the aquifer will remain essentially saturated and will continue to yield water to pumped wells.

Irrigation wells or other high-capacity wells can be developed in the glacial drift if they are favorably located and carefully constructed. Test holes should be drilled at the site of a proposed well to determine the thickness and texture of the aquifer. Samples of water should be collected from each test hole and analyzed to determine whether the water is of suitable chemical quality for the proposed use. When a high-capacity well is installed, careful construction and proper development are necessary to prevent the well screen from plugging or the aquifer from sealing with fine material near the well screen.

Local sand lenses and beds in the glacial drift may be an important future source of stock and domestic water, but the water they contain is unsuitable for irrigation.

Aquifers in Bedrock

Water yielded to wells by aquifers in bedrock may be permanently lost from storage. As a group, these aquifers may receive little or no recharge, and extensive withdrawal of water might constitute "mining" of the supply.

The aquifer in the Niobrara and Codell could supply much more water for domestic and stock needs than it did in 1961. There is little large-scale waste of this water because the wells usually do not flow. Continued or increased development may gradually lower the artesian head in the aquifer and result in increased pumping lifts. Also, substantial withdrawal may change the water quality by inducing greater recharge from other aquifers.

Although the Greenhorn Limestone has small potential, it could supply more water to wells than it did in 1961. Water from the Greenhorn often contains much suspended clay and is, therefore, unsuitable for either domestic or stock supply. Many residents prefer to drill deeper wells to the Dakota Group.

The Dakota Group could furnish all the stock and domestic water supplies of Sanborn County for many years if the water were not wasted. In 1961 the total estimated consumption of water from all aquifers for domestic and stock use in Sanborn County was 940,000 gpd (1,100 acre-feet), about one-fourth the discharge of the Dakota in the county (p. 73).

Management

Proper management of ground-water resources is necessary for fullest realization of an aquifer's potential, and for maintenance and conservation of existing water supplies. The procedures of proper management may differ for different aquifers. In general, however, information is required about the recharge, discharge, storage, and physical characteristics of the aquifer, and on the chemical characteristics and intended use of the water. Some aquifers resemble surface reservoirs in that outflow (water yielded by the aquifer) is replaced by inflow (infiltration of precipitation). Other aquifers resemble coal mines or oil pools in that discharged water is replaced very slowly, if at all, and is "mined." The water in such an aquifer is a dwindling resource.

The Warren aquifer resembles a reservoir that has been filled with sand and gravel. The walls, floor, and dam of the reservoir are impermeable till or shale and streambeds and draws function as spillways when the water table is high. Most ground-water recharge occurs from November to May as a result of infiltration of rain and snow melt where the aquifer is exposed. As the ground-water reservoir fills, the water table rises to the land surface and water discharges into spillways through many temporary seeps and springs. Average runoff into the James River from the area underlain by the Warren aquifer is estimated to be more than 3,000 acre-feet per year for the period 1950-59 (Wells, 1960).

Good management of the Warren aquifer would entail lowering the water table so that the depth to water is greater during the summer. Although no more water should be removed in periods of great demand than could be replaced by recharge, a drop in water table during times of high demand would increase the amount of space available to store water in the spring, and some of the water now discharged to the James River could be salvaged. A second result of lowering the water table would be a reduction in evapotranspiration, which constitutes most of the natural discharge from the shallow water table. A third possible result of lowering the water table is an increase in value of land now water-logged because of high ground-water levels during the planting season.

The Floyd aquifer, which resembles a roofed or covered reservoir, presents a different management problem. Evapotranspiration losses from it are low because of the 25 to 100 feet of overlying till. Estimates of the potential sustained yield of this aquifer would require additional investigation in adjacent Miner and Kingsbury Counties to locate the recharge area and to determine the rate of recharge to the aquifer.

The aquifers in Cretaceous rocks may not be subsurface reservoirs with constantly renewed supplies of water, but may resemble mines or oil pools in that water is "mined" or removed from storage more rapidly than it is replaced. "Mined" aquifers represent a diminishing resource and their potential is very limited. The quantity of water in storage in the bedrock aquifers is large, however, and if properly managed, could last for many years. Good management of a depletable or vanishing resource makes the maximum use compatible with the least waste.

More than 70 percent of the 5,500 acre-feet of water discharged to wells in 1961 by aquifers in Cretaceous rocks was wasted by unrestricted flow from wells. Almost 3,700 acre-feet (93 percent) of the wasted water was discharged from the Dakota Group. About 50 percent of the well discharge from the Greenhorn Limestone was wasted. Needless waste of water since 1885 has resulted in rapid decline of artesian pressure and decreased yield from wells and, if continued, eventually may result in cessation of flow. In 1961 the total discharge of all wells in Sanborn County tapping the Dakota was 2,800 gpm--only 50 gpm more than the discharge of one well at Woonsocket in 1890 and 1,200 gpm less than the initial flow of a well at Letcher in 1890.

Poor construction of wells that tap artesian aquifers may result in uncontrolled flow with consequent waste of water and contamination of other aquifers by leakage. Poor well construction and its results were reported by Nettleton (1892, p. 58-59) for the Woonsocket city well:

> "***large quantities of sand, shale, and a tough, tenaceous clay were thrown out of the well. It is estimated that at least 100 car loads--say 2,000 cubic yards--of this material were brought up with the water before the flow could be shut off. ***The bore is cased to what is commonly called the cap rock, 680 feet below the surface, ***. *** The casing is open at its lower end, and rests upon a stratum of hard rock only 4 feet thick. ***Similar discharge of large quantities of sand and shale occurred from the nearby mill well which was drilled to the second flow."

Davis, Dyer, and Powell (1961) reported on many other poorly constructed or wild wells in eastern South Dakota.

Public Supplies

The towns in Sanborn County that have public water supplies are Woonsocket, Forestburg, Artesian, and Letcher. Sanborn County and the South Dakota Department of Game, Fish, and Parks also have public wells. The wells furnishing the public water supplies are described below. Additional information on the quality of public supplies is included in table 3.

Woonsocket

Two wells within the city limits on the west side of Lake Prior are completed in the Dakota Group and are used to maintain the level of the lake. Well 107-62-21dcac at the bathhouse is 775 feet deep, penetrates the second aquifer, and yields about 15 gpm. Well 107-62-21dcdb about 100 yards to the south, is 735 feet deep, taps the first aquifer, and yields about 130 gpm. Lake Prior is used for recreation and as an emergency fire-fighting supply.

Woonsocket, which chlorinates its water, is the only town in the county that furnishes treated water to its residents. The municipal water system is supplied by two wells, each 163 feet deep, which produce from the aquifer in the Niobrara and Codell. The North Well (107-62-28aaba$_2$) has an 8-inch casing and is equipped with a 200 gpm turbine pump. The South Well (107-62-28aacb), used on a standby basis, has a 6-inch casing and is equipped with a 150 gpm turbine pump. The water is treated by a gas-feed chlorinator and is stored in a 60,000-gallon elevated tank.

Metered consumption of water for the years 1958-60 was as follows:

1958	11,970,000 gallons
1959	14,380,000 gallons
1960	14,110,000 gallons

Most residents supplement the public supply with water from private wells that produce from the aquifer in the Niobrara and Codell.

A fifth city well (107-61-21dccd) was drilled in 1958 to supply the public school. The well, which was capped in 1960, taps the aquifer in the Niobrara and Codell at a depth of 160 feet.

Forestburg

Forestburg has two public supply wells. Well 106-61-1bbcc$_2$ is 140 feet deep and is cased with 3- and 2-inch diameter pipe; it taps the aquifer in the Niobrara and Codell and furnishes water to the public school. Well 106-61-1bbcc$_1$ is 705 feet deep, has 4- and $2\frac{1}{2}$-inch casing, and flows 60 gpm of water from the Dakota Group. The well in the Dakota provides 33 families with water for domestic use and also is used for fire protection. Many other private wells in Forestburg tap the aquifer in the Niobrara and Codell.

Artesian

The city of Artesian has three public wells. The school well (106-59-9bdba) taps an aquifer in the Dakota Group at a depth of 760 feet. The well is equipped with a pump to supply additional water when the 3 gpm flow is not sufficient to supply the school's needs. A pumped well (106-59-4cdca) furnishes about 400,000 gallons of water per year to the municipal swimming pool and is reported to be 275 feet deep. This well taps the aquifer in the Niobrara and Codell and can be pumped at 75 gpm for extended periods. The third well (106-59-9bada) is 850 feet deep, taps an aquifer in the Dakota Group, has 4- to $2\frac{1}{2}$-inch casing, and is reported to flow 20 gpm. Water from this well supplies a 35,000-gallon storage tank, which is used for fire protection. All domestic water supplies are obtained from individual or cooperative wells that tap either the aquifer in the Niobrara and Codell or the Dakota Group.

Letcher

The town of Letcher has three public wells which produce from aquifers in the Dakota Group. The school well (105-61-15dcdc) is 700 feet deep, has 3-inch casing, and flows an estimated 15 gpm. The swimming pool well (105-61-15dbd) is reported to be 806 feet deep, has 3- to 2-inch casing, flows 18 gpm and is used for fire fighting as well as for recreation. The well at the city hall (105-61-15dcaa) is 780 feet deep, has 3- to 2-inch casing, and is reported to flow 3 gpm. Domestic water supplies are obtained from private wells completed in the aquifer in the Niobrara and Codell or the Dakota Group.

Sanborn County

Sanborn County has two wells, both of which supply county facilities and are completed in the aquifer in the Niobrara and Codell. Well 107-62-28abab, north of the courthouse in Woonsocket, is 158 feet deep, is equipped with a piston pump and is used as an emergency supply for the courthouse. Well 107-62-28aaa, about 160 feet deep, supplies water for the county maintenance shop.

South Dakota Department of Game, Fish, and Parks

The Department of Game, Fish, and Parks has four wells in Sanborn County. Well 107-61-35cdad is 140 feet deep and furnishes drinking water at the roadside park near Forestburg; it is equipped with a hand-operated cylinder pump and obtains water from the aquifer in the Niobrara and Codell. Well 107-61-35cddd, 300 yards to the south, is 25 feet deep and yields water of very poor quality from the Warren aquifer; this water is not used for drinking. The remaining two wells (106-62-30bd and 106-62-30bbcd) of the Department are at Twin Lakes and are used to maintain the water level of the lakes. Both wells tap aquifers in the Dakota Group, are 760 and 945 feet deep, and flow 50 and 67 gpm respectively. The shut-in pressure on the 945-foot well was 18.2 psi in April 1961.

Summary of Ground-Water Conditions

Aquifers in the glacial drift underlie more than 70 percent of Sanborn County. They average about 45 feet in thickness and are estimated to contain more than 2,300,000 acre-feet of water in storage. In general, these aquifers have a high proportion of fine-grained material, but locally they are sufficiently permeable to yield large amounts of water to wells. Aquifers in the glacial drift are recharged by infiltration of precipitation in Sanborn County and adjacent areas. Natural discharge to lakes, rivers, or streams is small. The Warren aquifer, however, discharges much water by evapotranspiration.

The till in Sanborn County is relatively impermeable and is not an aquifer. Alluvium in stream valleys and drainageways is too thin or too fine-grained to serve as an aquifer except locally in the James River trench.

Artesian aquifers in rocks of Cretaceous age underlie the entire county. The aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale of Late Cretaceous age, however, has been removed by glacial erosion from small areas in the south. Aquifers in Cretaceous rocks probably do not receive much recharge but yield water from storage.

The first aquifer in bedrock below the glacial drift is in the Niobrara and Codell. Although the artesian head has declined since 1885, water levels in wells that penetrate the aquifer range from land surface to a depth of 65 feet. Wells that tap the aquifer in the Niobrara and Codell may flow in the James River trench and in other low areas of the county. In northwestern and southern Sanborn County, the aquifer discharges water into the overlying glacial drift.

Sandy zones in the Carlile Shale below the Codell Sandstone Member may yield water to wells in some parts of the county. These zones probably receive recharge from the Greenhorn Limestone or Dakota Group.

The aquifer in the Greenhorn Limestone receives recharge from aquifers of the Dakota Group. Wells completed in the Greenhorn yield small flows of water at low pressure and some of them may discharge water to overlying aquifers through corroded well casings.

The Dakota Group contains three or more zones of permeable sandstone that yield water to wells. Natural discharge from aquifers of the Dakota Group may be an important source of recharge for overlying aquifers in southeastern Sanborn County. The Dakota also discharges water to overlying aquifers through hundreds of corroded well casings. Yield and artesian pressure of wells completed in the Dakota Group have greatly decreased in the last 70 years.

CHEMICAL QUALITY OF WATER

by Lewis Howells and R. L. Kilzer

Ground water is never pure. It may contain dissolved organic and inorganic substances, dissolved gases, colloids, sediment, and bacteria and other organisms. The ability of ground water to dissolve various substances usually depends upon the acidity of the water; acidity mainly depends upon the amount of carbon dioxide dissolved in the water. In general, the more acid the water, the greater its ability to dissolve material. Other factors that may determine the chemical content of ground water are temperature, pressure, chemical composition of rocks through which the water moves, amount of water available, rate of movement of the water, and geologic environment.

The chemical quality of ground water in Sanborn County was studied by analyzing water samples from wells that tap the principal aquifers. Laboratory analyses were made of 93 water samples, and an additional 1,183 water samples were tested in the field. The following table shows the number and types of analyses made of samples of water from each aquifer.

Aquifer or water-bearing unit	Chemical Analyses Complete	Partial	Field	Total
Till or mixed till and outwash	1	0	0	1
Warren aquifer	17	10	33	60
Floyd aquifer	12	1	128	141
Other glacial drift and alluvium	1	0	5	6
Niobrara Marl and Codell Sandstone Member of Carlile Shale	20	1	375	396
Permeable zone in Carlile Shale below Codell Sandstone Member	1	0	3	4
Greenhorn Limestone	5	0	74	79
Dakota Group	20	4	518	542
Undetermined	0	0	47	47
TOTAL	77	16	1,183	1,276

Field analyses included measurement of specific conductance with a resistance bridge and determination of hardness, chloride, and pH with colorimetric tests.

The results of laboratory analyses are given in table 3 and the sample locations are shown in figure 25.

Temperature, concentration of dissolved matter, specific conductance, hardness, percent sodium, sodium-adsorption ratio, and water type are some of the properties of water that determine its suitability for various uses.

Temperature is an important characteristic of water. Water temperature probably reflects aquifer temperature if a well flows more than 1.5 gpm or is pumped at a rate of at least 3 gpm for 5 minutes prior to measurement.

Concentrations of dissolved matter in water are expressed as parts per million (ppm) or as equivalents per million (epm). A "part per million" is a unit used to express the concentration by weight of a substance, usually as grams of constituents per million grams of solution. An "equivalent per million" is a unit used to express the concentration of a substance in terms of the unit chemical combining weight (atomic weight divided by valence); one epm of positive ions (cations) will react with one epm of negative ions (anions). Parts per million are converted to equivalents per million by multiplying by the following factors:

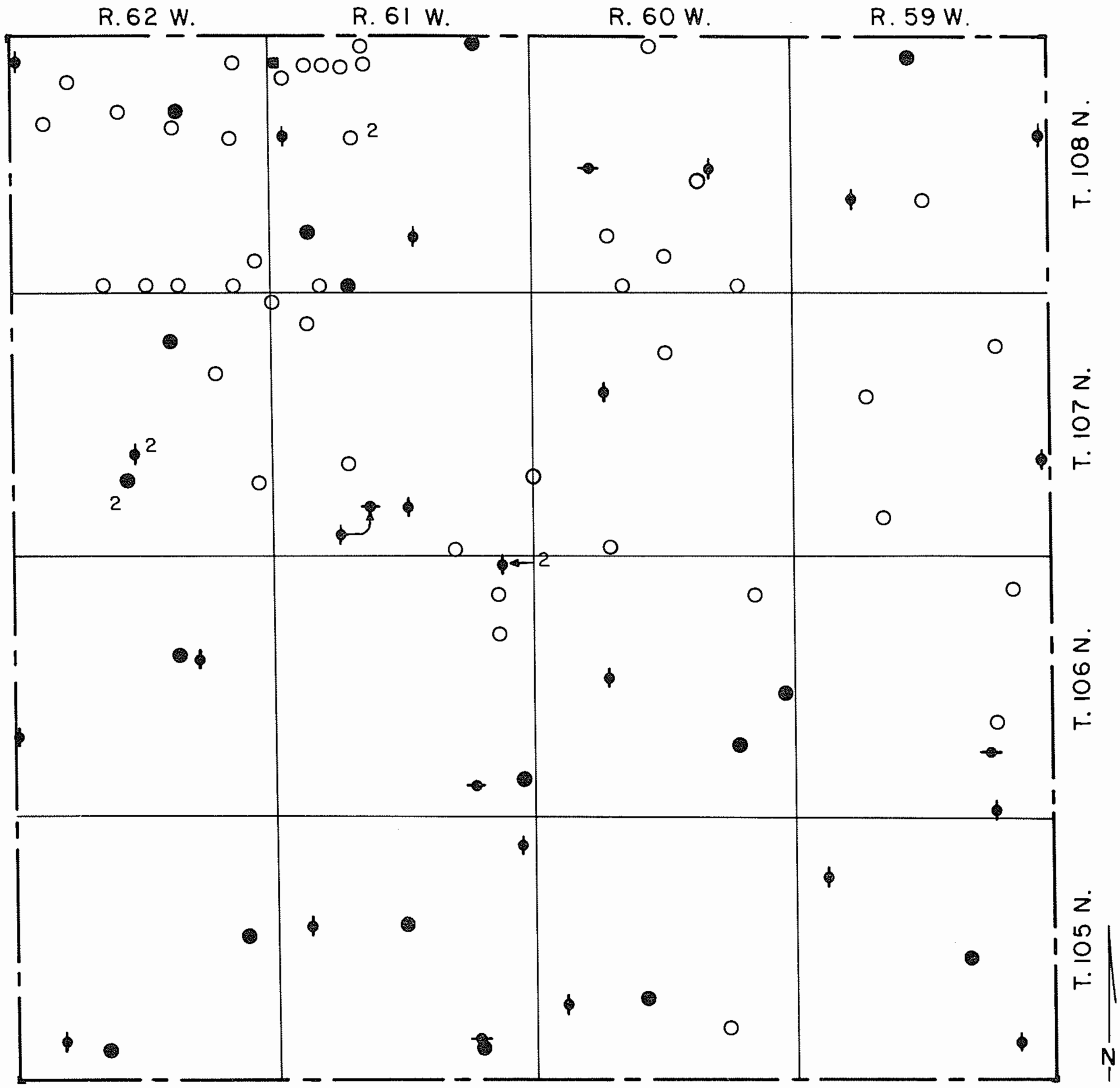
Table 3.--Chemical analyses of ground water, Sanborn County, S. Dak.
(Results in parts per million except as indicated)

Well and test hole number	Date of collection	Depth (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium (%Na)	Sodium adsorption ratio (SAR)	Specific conductance (micromhos per cm)	pH
James River alluvium																									
105-60-25cccd2*	9-14-60a	117	..	....	.....	....	100	53.5	240	4.0	230	0	550	70	1.0	10.0	....	1,260	.....	470	.....	52	....	2,000	...
Glacial till																									
108-62-34cccc	9-12-60a	75	..	....	.....	....	341	766	2,800	12.0	560	0	8,500	500	1.4	2.0	....	13,500	.....	4,000	.....	60	19.2	20,500	...
Floyd aquifer																									
106-59-1ccba	9-23-60	135	50	26	1.1	0.37	67	133	249	14	263	0	965	74	0.7	0.0	0.96	1,660	1,790	715	499	42	4.1	2,250	7.4
106-59-23ddd	4-11-61	125	47	4.4	0.12	0.13	143	45	267	16	86	0	923	101	0.4	0.1	0.65	1,540	1,670	544	473	51	5.0	2,170	7.4
106-60-1ccabl	9-23-60	110	50	20	0.39	0.01	35	100	344	14	314	0	890	88	0.4	0.0	1.2	1,650	1,740	497	240	59	6.7	2,340	7.5
107-59-11abaa	4-11-61	75	47	28	1.4	1.3	295	69	375	14	274	0	1,550	35	0.2	0.0	1.4	2,510	2,670	1,020	795	44	5.1	3,120	7.4
107-59-17addd	4-11-61	120	48	21	0.37	0.12	152	40	348	12	288	0	935	92	0.5	0.7	1.8	1,750	1,860	542	306	58	6.5	2,430	8.0
107-59-33bbbc	4-11-61	120	48	22	0.79	0.03	181	48	265	13	277	0	925	72	0.5	0.3	1.1	1,660	1,780	649	422	46	4.5	2,240	7.9
107-60-10bcac	7-5-61	...	44	28	2.1	0.51	75	24	400	11	334	0	782	90	0.6	0.8	1.8	1,580	1,640	284	10	74	10	2,340	7.5
108-59-29bbab	8-21-62	104	50	28	1.0	2.7	166	50	438	13	343	0	1,030	157	0.5	0.3	2.5	2,060	2,160	620	330	60	7.7	2,870	2.7
108-60-4addd	4-11-61	120	46	18	1.0	0.09	120	25	346	11	298	0	783	98	0.5	7.3	2.2	1,560	1,600	403	159	64	7.5	2,210	7.4
108-60-27cccc2	9-14-60a	117	..	....	.....	....	301	207	580	8.0	310	0	2,200	160	1.3	3.0	....	3,770	.....	1,600	.....	44	6.3	5,700	...
108-60-29dab2	4-11-61	120	40	16	.....	....	74	19	.....	....	401	0	.....	...	0.5	.....	....	......	1,520	263	0	..	....	2,270	8.0
108-60-33cccb	7-7-49	60	49	26	.....	....	156	49	295	13	441	0	800	56	0.4	11	1.2	1,630	1,720	591	229	51	5.3	2,240	7.2
108-60-35dddc	9-22-60	132	49	25	1.5	0.31	43	111	306	13	252	0	930	77	0.4	0.1	1.4	1,630	1,750	562	355	53	5.6	2,320	7.3
Warren aquifer																									
106-61-1cccc	12-15-58	20	..	29	0.20	....	86	29	18	2.0	309	0	93	3.5	0.3	22	0.11	......	434	334	81	10	0.4	662	7.3
106-61-12caca	4-11-61	Spring	45	29	1.5	0.67	103	56	57	6.7	451	0	222	8.9	0.4	1.8	0.18	......	721	486	116	20	1.1	1,040	7.4
107-60-30bcb	8-17-48	114	51	12	7.5	....	10	14	366		588	20	208	97	0.4	10	1.8	1,030	1,030	82	0	91	18	1,520	8.3
107-61-6bbbb	9-13-60a	77	..	....	.....	....	76.2	34	150	6.0	410	0	175	25	0.7	8.0	....	880	.....	330	.....	49	3.6	1,350	...
107-61-6dddd	12-15-58	22	..	30	1.3	....	116	67	54	4.0	412	0	332	9.4	0.6	0.8	0.13	......	840	565	227	17	1.0	1,150	7.1
107-61-35cddd	4-11-61	25	42	16	13	2.3	708	322	415	8.1	336	0	3,650	2.4	0.9	3.3	0.20	5,310	5,510	3,090	2,810	23	3.2	5,160	7.1
107-62-11ddad2	4-11-61	25	45	21	0.09	1.3	205	119	381	25	549	0	1,250	26	0.6	122	0.48	2,420	2,530	1,000	550	45	5.2	3,050	8.1
107-62-25aaaa1	8-17-48	12	63	12	2.3	....	25	6.2	8.0	3.2	108	0	12	4.0	0.2	2.6	0.07	......	136	107	18	16	0.4	214	8.0
108-61-4bcba1	7-7-49	80	52	....	.....	....	.....	.....	.....	....	612	0	564	65	...	.....	....	......	.....	664	162	44	4.1	2,170	7.5
108-61-4ccd	6-4-47	80	..	23	.....	....	146	61	291	16	658	0	616	60	0.6	3.8	0.67	1,540	1,530	616	76	50	5.1	2,180	7.4
108-61-5cddd1	7-7-49	40	50	....	.....	....	.....	.....	.....	....	668	0	560	102	...	.....	....	......	.....	444	0	65	7.9	2,130	7.8
108-61-5dcd1	7-7-49	85	48	....	.....	....	.....	.....	.....	....	532	0	3,220	183	...	.....	....	......	.....	2,800	2,360	40	7.0	5,180	7.3
108-61-6ddcd1	7-7-49	55	50	....	.....	....	.....	.....	.....	....	596	0	508	68	...	.....	....	......	.....	552	63	68	9.9	1,980	7.8
108-61-7babb1	7-7-49	40	50	....	.....	....	.....	.....	.....	....	556	0	630	86	...	.....	....	......	.....	780	324	38	3.5	2,230	7.4
108-61-17aacc	7-6-61	140	50	30	3.7	0.25	115	0.2	302	12	656	0	354	49	0.3	0.5	0.39	1,190	1,190	288	0	68	7.7	1,760	8.1
108-61-17addd	7-7-49	73	50	....	.....	....	.....	.....	.....	....	672	0	364	44	...	.....	....	......	.....	297	0	70	8.2	1,710	7.5
108-61-32cccc	9-13-60a	95	..	....	.....	....	80.2	31.6	250	6.0	360	0	300	125	0.8	2.0	....	1,160	.....	330	.....	62	6.1	1,850	...
108-62-1ccc1	6-4-47	48	..	20	0.20	....	554	347	78	23	386	0	2,250	78	1.2	295	0.59	3,840	4,250	2,810	2,490	6	0.6	4,080	7.4
108-62-8baab2	6-3-47	38	..	25	4.9	....	278	135	247	14	545	0	1,220	54	0.1	15	0.93	2,260	2,510	1,250	803	30	3.0	2,760	8.1
108-62-9dcd	7-6-49	30	49	....	.....	....	.....	.....	.....	....	592	0	834	57	...	.....	....	......	.....	886	401	39	3.8	2,290	7.6
108-62-13bcc2	4-11-61	34	49	22	1.7	0.77	424	168	173	20	426	0	1,530	81	0.2	39	0.17	2,670	2,940	1,750	1,400	17	1.8	3,100	8.0
108-62-15aadd	7-6-49	25	50	....	.....	....	.....	.....	.....	....	536	0	800	52	...	.....	....	......	.....	556	116	59	6.8	2,440	7.6
108-62-18aab	7-6-49	20	49	....	.....	....	.....	.....	.....	....	548	0	644	55	...	.....	....	......	.....	384	0	68	8.4	2,030	7.6
108-62-33cccc	9-9-60a	75	..	....	.....	....	28	31.6	210	6.0	330	0	250	20	0.6	6.0	....	880	.....	200	.....	69	6.5	1,350	...
108-62-34ddaa	7-6-49	40	50	....	.....	....	.....	.....	.....	....	652	0	258	130	...	.....	....	......	.....	50	0	95	27	1,840	7.8
108-62-36adaa3	4-11-61	12	48	27	0.09	0.00	143	103	76	24	580	0	109	61	0.7	373	0.32	1,200	1,410	780	304	17	1.2	1,780	8.2
108-62-36cccc	9-12-60a	87	..	....	.....	....	104	72.9	240	7.0	130	10	850	25	1.3	5.0	....	1,440	.....	560	.....	48	3.1	2,100	...
Aquifer in the Niobrara and Codell																									
105-59-23bcbb2	9-23-60	140	54	26	1.3	1.7	202	56	315	21	212	0	1,100	122	0.5	0.0	1.1	1,950	2,060	734	560	47	5.1	2,570	7.5
105-60-28aada2	9-21-60	166	54	12	0.72	0.15	46	13	560	14	472	0	899	63	0.8	7.7	4.1	1,850	1,880	168	0	87	19	2,640	7.6
105-61-15cbd	9-21-60	160	54	16	0.39	0.04	45	13	471	12	520	0	649	98	0.8	6.9	2.6	1,570	1,600	166	0	85	16	2,310	7.6
105-61-35aaad1	4-11-61	157	..	25	0.93	0.00	84	22	605	16	476	0	1,140	45	0.4	9.0	2.3	2,180	2,230	302	0	80	15	3,030	8.0
105-62-13cddc1	9-21-60	120	56	9.3	0.15	0.00	13	3.0	546	12	768	0	239	253	1.4	5.3	4.3	1,460	1,470	45	0	95	35	2,330	7.8
105-62-33bccb1	9-21-60	140	..	12	0.05	0.00	21	6.4	475	11	648	0	317	203	1.0	5.9	4.2	1,380	1,400	79	0	92	23	2,190	7.7
106-60-24aacc	4-11-61	130	47	11	0.18	0.05	43	11	475	10	362	0	743	93	0.9	0.1	2.6	1,570	1,620	154	0	86	17	2,330	7.4
106-60-26adad	9-23-60	140	56	9.2	0.22	0.00	28	8.3	500	11	432	0	699	97	1.3	7.8	4.3	1,580	1,610	104	0	90	21	2,360	7.9
106-61-36aaaa	9-21-60	138	51	8.6	0.01	0.00	12	5.4	573	9.7	594	0	632	110	1.3	5.9	4.3	1,650	1,670	52	0	95	35	2,460	8.2

Table 3.--Chemical analyses of ground water, Sanborn County, S. Dak.--Continued

Well and test hole number	Date of collection	Depth (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium (%Na)	Sodium adsorption ratio (SAR)	Specific conductance (micromhos per cm)	pH
Aquifer in the Niobrara and Codell--Continued																									
106-62-15adb	9-21-60	132	50	9.3	0.05	0.02	11	2.6	565	8.1	723	0	374	219	1.0	0.0	3.8	1,550	1,560	38	0	96	40	2,450	7.9
107-60-32dddd2	9-22-60	143	54	18	0.31	0.23	30	8.0	465	10	517	0	568	87	1.3	5.6	3.7	1,450	1,480	108	0	89	19	2,170	7.9
107-61-20ddd	7-7-49	170	52	23	.....	....	16	4.3	487	8.0	761	0	288	124	1.2	5.6	....	1,340	1,420	58	0	94	28	2,160	7.5
107-62-10abaa2	7-6-49	165	52	15	.....	....	11	2.8	399	14	568	0	312	80	1.0	6.5	....	1,130	1,170	39	0	94	28	1,790	7.4
107-62-28aaba2	3 -55b	163	..	....	0.1	0.6	13	3	484		708	..	349	85	0.9	11	....	.....	c 1,370	48	.....	..	.....	.....	7.6
107-62-28aacb	7 -56b	163	..	....	0.1	0.0	19	4	437	30	717	..	372	96	0.7	0.0	....	.....	c 1,380	66	.....	..	.....	.....	8.0
107-62-28ab	9-8-47	160	..	11	0.03	....	1.3	1.2	466	13	680	0	338	86	0.6	8.0	....	1,260	1,250	8	0	97	72	1,900	7.8
108-59-4daa	9-22-60	155	54	9.0	0.10	0.10	15	4.3	628	6.9	167	0	1,090	128	1.7	9.0	1.2	1,980	2,010	55	0	96	37	2,910	7.6
108-61-2adba3	7-7-49	160	50	9.6	.....	....	11	2.0	432	6.8	628	0	90	255	1.4	11	....	1,130	1,180	36	0	96	32	1,970	7.5
108-61-30daaa	7-7-49	160	50	....	.....	....	.....	....	...	....	576	0	4.8	804	...	....	....	.....	.....	144	0	91	25	3,330	7.4
108-61-32dddd	7-7-49	150	51	12	.....	....	7.0	2.6	535	4.4	686	43	154	289	1.4	10	....	1,400	1,470	28	0	97	44	2,410	8.4
108-62-10dddd2	9-21-60	220	53	14	0.10	0.05	21	6.7	729	8.1	622	0	42	826	0.9	4.7	2.2	1,960	1,930	80	0	95	35	3,390	7.7
Greenhorn Limestone																									
105-61-35aaad2	9-21-60	365	55	8.7	3.5	0.15	313	82	159	20	148	0	1,200	63	2.4	0.0	0.79	1,930	2,100	1,120	999	23	2.1	2,360	6.8
106-59-26dbb	9-23-60	410	52	8.5	0.81	0.05	57	62	469	15	170	0	1,140	107	2.2	0.2	1.9	1,960	2,030	396	257	71	10	2,880	7.1
106-61-35aacc	9-21-60	350	54	7.8	2.2	0.01	14	3.6	688	8.6	248	0	1,220	83	3.0	0.3	3.6	2,160	2,190	50	0	96	42	3,100	7.2
107-61-28cdc2	9-21-60	400	54	7.7	0.94	0.00	9.3	1.2	699	6.3	713	0	817	104	3.4	0.3	6.2	2,010	2,060	28	0	98	57	3,000	7.8
108-60-20baaa1	9-8-47	500	..	9.0	0.92	....	1.4	0.5	694	16	787	41	556	162	3.6	0.5	....	1,870	1,890	6	0	98	123	2,840	8.2
Carlile Shale																									
108-61-6cccc1	7-7-49	400	50	8.0	.....	....	15	5.2	983	10	805	0	552	665	1.2	11	....	2,650	2,720	59	0	97	56	4,370	7.8
Dakota Group																									
105-59-7adda1	9-23-60	550	57	9.0	2.0	0.09	291	54	271	20	162	0	1,220	147	2.4	0.0	0.63	2,100	2,200	948	815	38	3.8	2,670	7.3
105-59-36bad	9-23-60	600	56	8.1	3.5	0.10	320	47	250	21	164	0	1,200	131	2.3	0.0	0.56	2,060	2,190	991	857	35	3.5	2,640	7.6
105-60-30addc	9-21-60	542	58	11	1.7	0.07	262	48	256	19	155	0	1,190	67	2.4	0.0	0.55	1,930	2,040	850	723	39	3.8	2,480	7.0
105-61-1ddbb	9-21-60	657	58	9.9	0.98	0.09	124	34	412	18	111	0	1,190	67	1.6	0.2	1.0	1,910	2,010	448	357	66	8.4	2,630	6.6
105-61-18daa2	9-21-60	830	58	8.4	6.6	0.12	394	36	163	20	157	0	1,230	66	2.5	0.0	0.54	2,000	2,130	1,130	1,000	23	2.1	2,410	6.8
105-62-32bbcb1	9-21-60	742	59	11	2.2	0.10	409	75	107	21	170	0	1,290	79	2.6	0.0	0.26	2,080	2,210	1,330	1,190	15	1.3	2,440	7.0
106-59-35ddcb	9-23-60	545	54	9.2	3.4	0.05	277	54	259	19	169	0	1,180	126	2.2	0.0	0.74	2,010	2,100	914	775	36	3.7	2,610	7.2
106-60-17ddbb	9-23-60	734	61	8.8	3.0	0.07	203	29	363	17	156	0	1,200	91	1.6	0.0	0.99	1,990	2,060	625	497	55	6.3	2,660	7.4
106-61-1bbbc1	11- -54b	750	..	....	2.0	0.0	164	46	335		173	..	1,030	77	2.4	0.0	....	.....	c 2,170	605	.....	..	7.2	.....	...
106-61-1bbbd	1952d	705	..	7	0.4	....	167	49	411		167	..	1,220	72	1	...	....	.....	c 2,080	618	481	59	.....	.....	7.5
106-62-14bda1	9-21-60	594	55	9.0	0.37	0.07	55	13	543	15	118	0	1,190	67	1.2	0.1	1.5	1,950	1,990	190	93	85	17	2,810	6.7
106-62-30bbcd	5-9-60	945	62	9.2	1.9	0.16	373	92	127	19	165	0	1,290	85	2.5	0.1	0.27	2,080	2,170	1,310	1,180	17	1.5	2,460	6.9
107-59-24ddba2	9-23-60	1,020	61	8.8	4.7	0.08	283	50	285	20	165	0	1,220	149	2.4	0.0	0.81	2,100	2,190	913	778	40	4.1	2,760	7.3
107-60-17aca	9-22-60	700	58	8.4	0.23	0.06	54	13	576	11	180	0	1,210	77	2.0	0.0	1.5	2,040	2,090	188	40	86	18	2,990	7.6
107-61-27cdc2	10-14-60	735	61	11	0.00	0.01	156	35	405	17	159	0	1,190	83	1.9	0.0	0.90	1,980	2,070	533	403	61	7.6	2,690	7.4
107-61-28cdc	9-8-47	750	..	8.0	3.3	....	158	45	422	19	137	0	1,230	86	2.4	0.2	....	2,040	2,090	579	467	60	7.6	2,610	7.2
107-62-21dcac	9-8-47	775	..	12	0.95	....	212	58	316	22	142	0	1,200	74	2.8	0.2	....	1,970	2,050	762	646	47	5.0	2,240	7.1
107-62-21dcdb	9-21-60	735	60	12	1.3	0.07	230	59	272	20	158	0	1,200	75	2.0	0.0	0.62	1,950	2,080	817	687	41	4.1	2,500	7.6
108-59-13adad1	9-22-60	1,015	58	9.2	0.18	0.01	36	9.5	605	10	200	0	1,070	162	2.4	0.0	1.5	2,000	2,030	129	0	90	23	2,950	7.7
108-59-20cddb	5-11-60a	730	60	....	.....	....	44.1	34	600	13	130	0	1,250	80	2.4	7.0	....	2,160	.....	250	.....	83	.....	3,000	...
108-60-23bbba1	9-22-60	959	61	9.3	1.0	0.09	206	56	347	20	168	0	1,160	172	1.8	0.0	0.90	2,060	2,140	745	607	49	5.5	2,780	7.2
108-61-18bdcc1	9-8-47	760	..	10	2.9	....	28	8.2	653	16	213	0	1,170	98	2.8	6.2	....	2,100	2,110	104	0	92	28	2,940	7.4
108-61-27dcdc2	1952d	950	62	66	130	....	275	72	216		157	..	1,260	136	3	....	....	.....	c 2,280	982	857	32	3.0	.....	...
108-62-6cdd1	1952d	717	..	6	1.4	....	241	69	332		161	..	1,250	104	2	....	....	.....	c 2,200	885	753	45	4.9	.....	...

a Analysis by Station Biochemistry, Agr. Exp. Sta., S. Dak. State Coll., 1960. Some values rounded to fewer significant figures.
b Analysis by S. Dak. Dept. of Health, 1959. Some values rounded to fewer significant figures.
c Temperature on evaporation unknown.
d Analysis from Tullis and others, 1954. Some values rounded to fewer significant figures.
* Sample contained clay in suspension.



EXPLANATION

Geologic unit in which well is finished

○	Glacial drift
●	Niobrara Marl and Codell Sandstone, Member of Carlile Shale.
■	Carlile Shale
-●-	Greenhorn Limestone
♦	Dakota Group
2	Number of samples collected

Scale

0 1 2 3 4 5 miles

Figure 25. Map of Sanborn County showing locations of wells sampled for complete quality of water analysis.

Constituent	Factor	Constituent	Factor
Calcium (Ca)	0.04990	Carbonate (CO_3)	0.03333
Magnesium (Mg)	0.08224	Sulfate (SO_4)	0.02082
Sodium (Na)	0.04350	Chloride (Cl)	0.02820
Potassium (K)	0.02558	Fluoride (F)	0.05263
Bicarbonate (HCO_3) ...	0.01639	Nitrate (NO_3)	0.01613

Parts per million are converted to grains per gallon (gpg) by dividing parts per million by the factor 17.1.

Specific conductance is a measure of the ability of a unit cube of water to conduct an electric current and is expressed in micromhos per centimeter (umhos/cm) at 25° Celcius (centigrade). Although the specific conductance of water depends upon the amounts and types of ions in solution, and varies with temperature, it can be used to estimate the total concentration of dissolved solids. The following factors, determined from the ratio of total solids to specific conductance in complete chemical analyses from each aquifer, were used to convert specific conductance to total dissolved solids:

Aquifer or water-bearing unit	Factor
Warren aquifer	0.68
Floyd aquifer	0.74
Niobrara Marl and Codell Sandstone Member of Carlile Shale	0.65
Greenhorn Limestone	0.70
Dakota Group	
1st zone	0.71
2d zone	0.77
3d zone	0.88

Hardness is reported as parts per million of $CaCO_3$ and includes concentrations of all hardness-causing constituents in the sample.

Percent sodium (% Na) and sodium-adsorption ratio (SAR) of water are of great importance in determining the suitability of water for irrigation. Percent sodium is the ratio of sodium to total cations (calcium, magnesium, sodium, and potassium) in epm expressed as a percentage. The SAR is an empirical value (U. S. Salinity Laboratory Staff, 1954) used to determine and compare the sodium hazard of irrigation waters and is based upon the base exchange reactions and sodium adsorption of soils. The SAR is determined by the following relation where ion concentrations are expressed in epm:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

Water type indicates the cation and anion having concentrations in excess of 50 percent of the total cation and anion concentrations, respectively. For example, water from well 106-60-26adad (table 3) contains 500 ppm sodium and 699 ppm sulfate, 91 and 56 percent of the cations and anions, respectively, and is, therefore, called a sodium sulfate water. Waters in which one cation and anion do not predominate are considered mixed types and identified by the names of all the important cations and anions.

In any aquifer local conditions may cause the quality of water from some wells to differ greatly from the quality of water usually obtained from the aquifer. Such conditions include contamination by surface pollution and leakage from another aquifer through the corroded casing of a nearby well. About 15 percent of the chemical analyses appear to be affected by such conditions. The 85 percent range, or the range in concentration of a chemical constituent based on the 85 percent of the analyses closest to the mean, probably represents the actual water quality in the aquifer.

Aquifers and Water-bearing Units of Quaternary Age

Water temperatures, measured at the well head, ranged from 44° to 53°F. Almost all wells deeper than 25 feet had water temperatures of 49° to 50°F, slightly higher than the mean annual temperature of 46.4°F.

Although the till in Sanborn County is not an aquifer, a sample of water from till was obtained from test hole 108-62-34cccc. The water was very saline (13,500 ppm total dissolved solids) and was not suitable for domestic or agricultural use.

Although the well inventory disclosed no wells that obtained water from alluvium, a water sample was taken for analysis from test hole 105-60-25cccd$_2$, which penetrated 39 feet of alluvium in the James River flood plain. The water contained 1,260 ppm total dissolved solids and had a hardness of 470 ppm. Water from a properly constructed well probably would be of better quality than is indicated by the analysis because the sample contained some clay in suspension.

Quality of water from the Floyd and Warren aquifers is summarized in the following table and in figure 26.

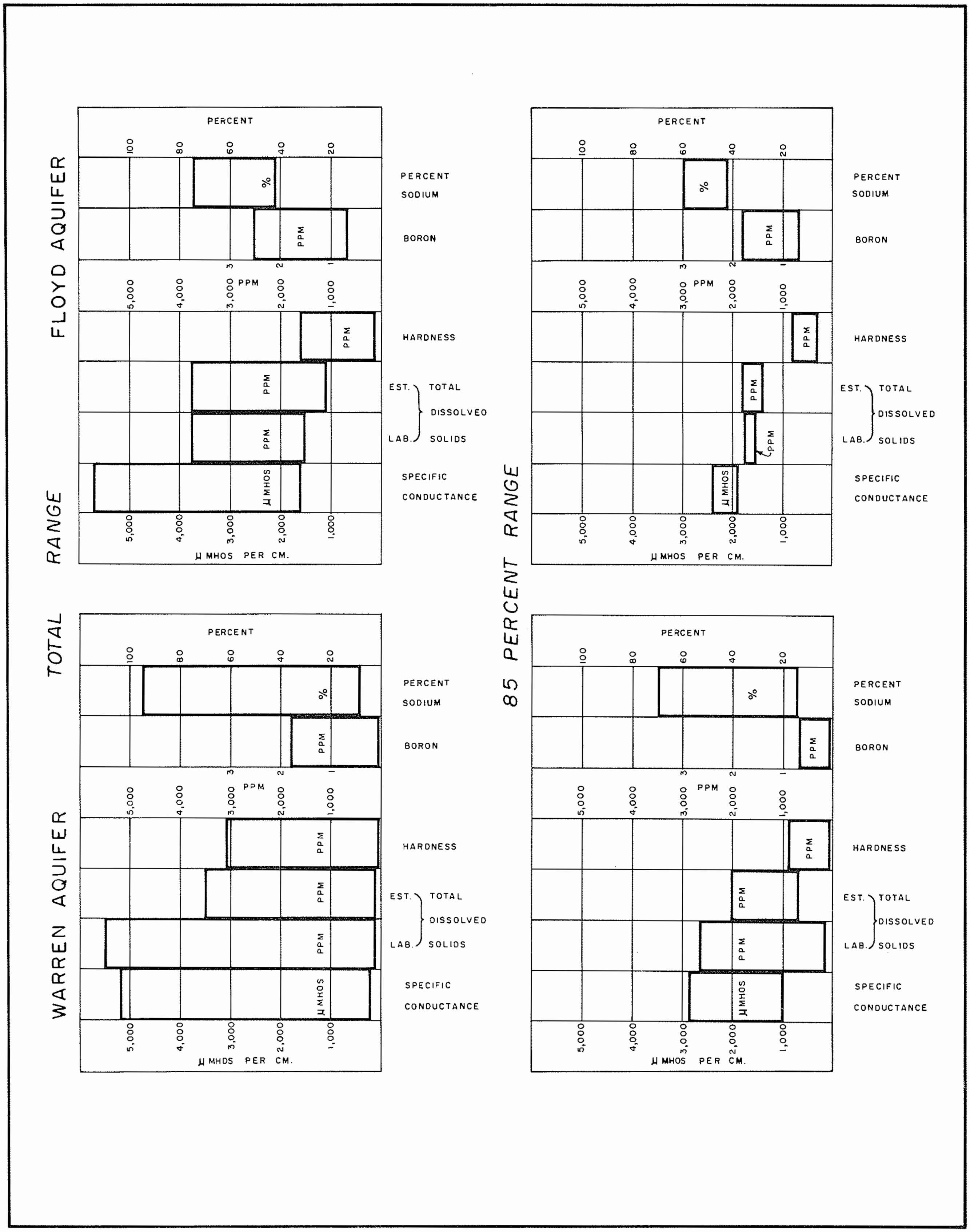


Figure 26. Diagram comparing water quality in the Floyd and Warren aquifers.

Property	Total range		85 percent range	
	Warren	Floyd	Warren	Floyd
Specific conductance (µmhos/cm)	214-5,180	1,600-5,700	980-2,870	1,900-2,030
Total dissolved solids (ppm):				
Laboratory	136-5,510	1,540-3,700	136-2,670	1,540-1,750
Estimated 1/	145-3,510	1,100-3,770	670-2,000	1,400-1,800
Hardness (ppm)	50-3,090	120-1,600	50-886	300-800
Boron (ppm)	0.07-1.8	0.65-2.5	0.07-0.67	0.65-1.8
Percent sodium	9-95	42-74	17-70	42-60

1/ Estimated from specific conductance. See p. 85.

The quality of water varies widely in the Warren aquifer. Shallow wells completed in clean dune sand yield water of good quality but wells completed in clayey parts of the aquifer may yield water of very poor quality. Some wells completed a few feet above the bedrock surface in central and northwestern Sanborn County yield water similar in character to water from the aquifer in the Niobrara and Codell, suggesting recharge of the Warren by the aquifer in the Niobrara and Codell.

Water in local sand and gravel deposits in till strongly resembles water from the aquifer in the Niobrara and Codell in its chemical characteristics. The water is soft to moderately hard, saline, and of the sodium sulfate type.

Water-bearing Units of Cretaceous Age

The quality of water from wells completed in the major aquifers in bedrock is summarized in the following table and in figure 27.

Water temperature, measured at the well head during the field investigation, generally increased with aquifer depth. In flowing wells completed at the same depth, temperatures tended to increase with an increase in the rate of flow up to about 10 gpm.

Property	Total range			85 percent range		
	Niobrara Marl and Codell Sandstone Member of Carlile Shale	Greenhorn Limestone	Dakota Group	Niobrara Marl and Codell Sandstone Member of Carlile Shale	Greenhorn Limestone	Dakota Group
Specific conductance (µmhos/cm)	1,470-3,770	2,340-3,270	1,930-3,330	1,930-2,790	2,400-3,000	2,400-2,970
Total dissolved solids (ppm):						
Laboratory	1,130-1,980	1,870-2,160	1,910-2,280	1,370-1,960	....	1,930-2,160
Estimated	960-2,450	1,460-2,040	1,700-2,360	1,250-1,800	1,500-1,860	2,000-2,200
Hardness (ppm)	8-976	51-1,180	51-1,387	34-138	68-1,030	86-1,100
Boron (ppm)	1.1-4.3	0.79-6.2	0.26-1.5	2.2-4.3	....	0.54-1.5
Percent sodium	47-97	23-98	15-92	86-97	.....	35-90
Temperature (° F)	52-60	58-62	58-67	.....	.....	.....

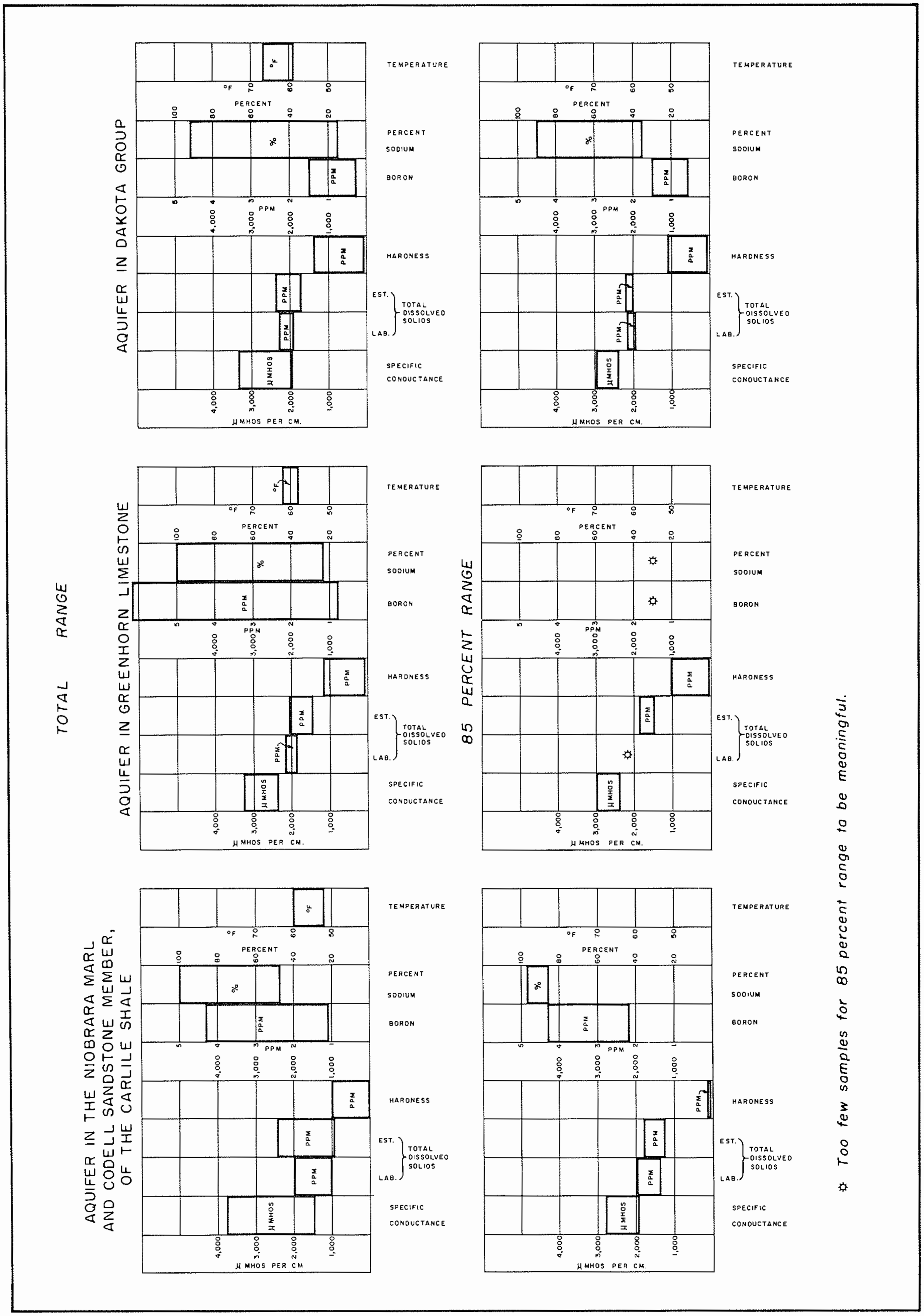


Figure 27. Diagram comparing water quality in the major aquifers in bedrock.

Although water from the aquifer in the Niobrara and Codell is relatively uniform in quality throughout much of Sanborn County (fig. 28), there are several significant variations in quality (Howells, 1965a, b); (1) in the southeastern corner of the county the aquifer yields hard to very hard water, similar to water from the lowest part of the Dakota Group; (2) in the northeastern and northwestern corners of the county the aquifer yields water high in chloride and total solids; and (3) on the southern and eastern sides of the buried bedrock valleys in central and northwestern Sanborn County (pl. 6) the aquifer yields hard to very hard water.

Wells that tap permeable zones of the Carlile Shale yield soft saline water, except in southeastern Sanborn County where the water is very hard.

The Greenhorn Limestone yields soft to moderately hard, saline, low-chloride, sodium sulfate water except in the southeastern part of the county where it yields hard to very hard water similar to that from the lowest part of the Dakota Group. Because water from the Greenhorn frequently contains clay in suspension, the aquifer locally is known as the "mud flow."

The Dakota Group yields water of both the sodium sulfate and calcium sulfate types; the total dissolved solids, sulfate, chloride, and fluoride concentrations are fairly uniform throughout the county, but the concentrations of other constituents vary widely. Three kinds of water in the Dakota are: (1) soft to moderately hard, high-boron, sodium sulfate water whose specific conductance generally is greater than 2,700 µmhos/cm; (2) very hard (more than 800 ppm), low-boron, calcium sulfate water whose specific conductance generally is less than 2,500 µmhos/cm; and (3) water intermediate in quality to the other two types.

Permeable sandstone at or near the top of the Dakota may yield water of the soft, sodium sulfate type, particularly in the northern part of the county. The lowest sandstone of the Dakota yields very hard water of the calcium sulfate type in the northern part of the county, but all permeable sandstone in the Dakota may yield water of this type in southernmost Sanborn County. Water of intermediate quality occurs in permeable sandstone near the middle of the Dakota Group in northern Sanborn County, but occurs in permeable sandstone at the top of the Dakota in the south-central part of the county.

Water Quality and Use

Domestic Use

Water for domestic use should be free not only of harmful bacteria, but also of objectionable taste and odor. Standards for drinking water have been established by the U. S. Public Health Service (1962) and adopted by the American Water Works Association as criteria of quality for all public water supplies in the United States. Almost all of the public water supplies in South Dakota exceed the standards. The State Department of Health has recommended modified standards for South Dakota.

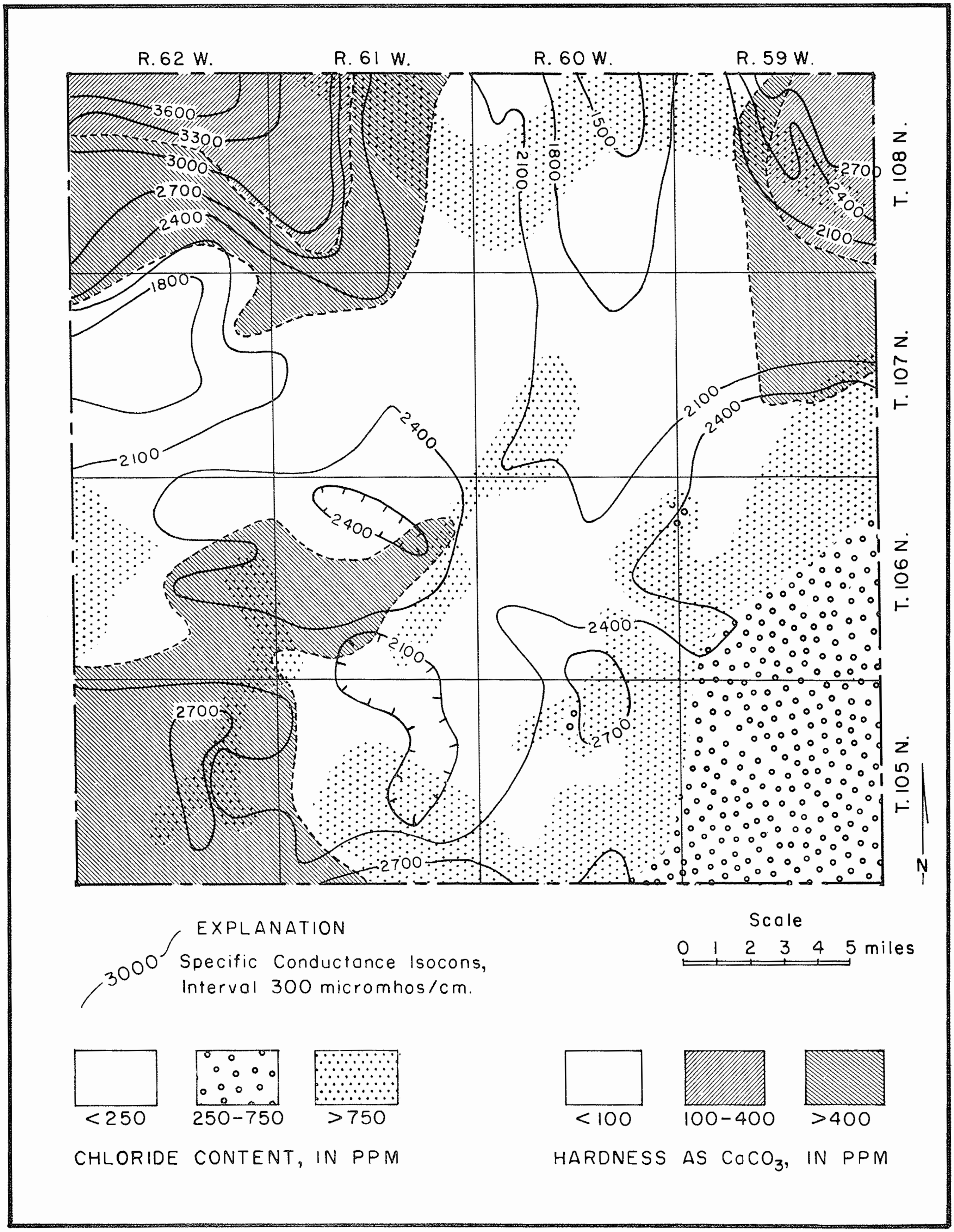


Figure 28. Map of Sanborn County showing chloride content, hardness, and specific conductance of water from the aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale.

The standards that pertain to chemical constituents are as follows:

Constituent	U.S. Public Health Service recommended maximum concentration[a] (ppm)	S. Dak. Dept. of Health Standards modified for S. Dak.[b] (ppm)
Chloride................	250	250
Fluoride	1.3[c]	0.9-1.7
Iron	0.3	0.3
Manganese	0.05	0.05
Nitrate	45[d]	45
Sulfate	250	500
Total dissolved solids ...	500	1,000

a/ Should not be exceeded where other more suitable supplies are or can be made available.

b/ Written communication, Feb. 5, 1962.

c/ For Sanborn County; limit varies for different parts of the United States.

d/ In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

Total dissolved solids

Only five water samples, all from the Warren aquifer, met the U. S. Public Health standards for total dissolved solids. All other samples exceeded the recommended limit. High dissolved-solids content of water is not in itself necessarily harmful; any effects depend upon the individual constituents that comprise the dissolved solids. Some dissolved mineral matter is desirable, otherwise the water would have the flat taste characteristic of distilled water.

Chloride

The recommended limit of chloride concentration of 250 ppm was exceeded in 103 water samples--97 from the aquifer in the Niobrara and Codell (all from the northern part of the county), four from the Dakota

Group, and one each from the till and a permeable zone in the Carlile Shale. High concentration of chloride may impart an undesirable taste to the water.

Fluoride

Concentrations of fluoride ranged from 0.1 to 3.6 ppm. Fluoride concentrations were less than the recommended maximum of 1.3 ppm in water from the aquifers in the Quaternary rocks and in most water from the aquifer in the Niobrara and Codell. Most samples of water from the Dakota Group and the Greenhorn Limestone, however, contained more than 1.3 ppm fluoride. Concentrations of fluoride in excess of 1.3 ppm in drinking water may cause dental fluorosis or "mottled enamel" in children's teeth (Smith and others, 1931).

Iron

Most of the water samples, except those from the aquifer in the Niobrara and Codell, contained more than the 0.3 ppm maximum concentration recommended for iron. A high concentration of iron is undesirable because it will cause yellow or reddish-brown stains on laundry and plumbing fixtures, form deposits on food during cooking, and impart an unpleasant taste to water.

Manganese

Some water samples from each aquifer contained manganese in excess of the recommended limit of 0.05 ppm. Higher concentrations of manganese may cause gray or black stains on porcelain, enamel, and fabrics.

Nitrate

Three samples, all from wells in the glacial drift, contained more than the recommended 45 ppm limit of nitrate; all three wells are shallow and probably are contaminated by barnyard seepage. Nitrate is an end product of decomposition of barnyard seepage or other organic substance; consequently, significant concentrations of nitrate may indicate contamination by seepage from such material, or from organic fertilizer. Water containing a high concentration of nitrate, if used for preparing infant feeding formulas, may cause methemoglobinemia, a disease characterized by certain blood changes and cyanosis (Welsh and Thomas, 1960).

Sulfate

Nine water samples, four from the Warren aquifer and five from the aquifer in the Niobrara and Codell, contain less than the 250 ppm maximum for sulfate. High concentrations of sulfate have cathartic effects on some people; however, many people who drink water with high sulfate content develop a tolerance to it. Sulfate concentrations as high as 1,000 ppm are considered harmless by some investigators (Moore, 1950).

Hardness

Hardness usually is related to the soap-consuming power of water and ordinarily is considered undesirable. It results in formation of scum when soap is added, causes an excessive consumption of soap, and may cause deposition of scale in water pipes, heaters, and boilers. Calcium and magnesium are the constituents that are usually responsible for hardness of water. The U. S. Geological Survey has adopted the following hardness standard:

Hardness as $CaCO_3$ (ppm)	Rating	Evaluation
0- 60	Soft	Suitable for many uses with no treatment
61-120	Moderately hard	Usable except in some industries
121-180	Hard	Softening required by laundries
181+	Very hard	Requires softening for most uses

Municipal Use

Forestburg and Woonsocket were the only communities in Sanborn County that had public water-supply systems in 1961. Water from well 106-61-1bbbd2 at Forestburg is very hard and contains concentrations of sulfate, iron, fluoride, and dissolved solids that exceed U. S. Public Health Service standards. Water from wells 107-62-28aaba and 107-62-28aacb at Woonsocket, contains concentrations of sulfate and dissolved solids that exceed the standards, but the water is soft to moderately hard.

Agricultural Use

Livestock

Water used for livestock consumption is subject to the same general quality limitations as that used for human consumption. Livestock, however, can tolerate a greater amount of dissolved solids than humans. The following maximum tolerances of some farm animals to dissolved solids have been published (Officials of the Department of Agriculture, 1950).

Animal	Maximum dissolved solids (ppm)
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,000
Adult sheep	12,900

Except for water from the till, almost all samples of water from Sanborn County were satisfactory for consumption by livestock.

Irrigation

Characteristics that determine the suitability of water for irrigation are: (1) The total dissolved-solid content; (2) the amount of boron; (3) the relative amounts of certain dissolved constituents; and (4) the chemical changes that may take place in the soil and water after the water has been applied.

High concentrations of dissolved solids in irrigation water may adversely affect plant growth. The tolerances of common crops to the amount of dissolved solids in water are shown in table 4 (U. S. Salinity Laboratory Staff, 1954, p. 67).

Boron.--Boron is essential to proper plant growth and nutrition, but a small excess over the needed amount is toxic to some plants. Plants are classified as sensitive, semitolerant, and tolerant to boron. Scofield (1936) stated that irrigation water should contain less than 1.00 ppm boron if used on sensitive crops, less than 2.00 ppm if used on semitolerant crops, and less than 3.00 ppm if used on tolerant crops. Boron tolerances of some common crops are listed in table 5 (U. S. Salinity Laboratory Staff, 1954, p. 67).

Sodium hazard.--The proportion of sodium relative to calcium and magnesium in the water (sodium hazard) may be of critical importance in determining the suitability of water for irrigation. If soil that contains exchangeable calcium or magnesium ions is irrigated with water in which sodium ions greatly outnumber the other cations, the calcium and magnesium of the soil will tend to be replaced with sodium. Soil that has a high content of exchangeable sodium is undesirable for agriculture as it tends to deflocculate or "puddle," develop a hard crust, and become nearly impermeable to water. If irrigation is continued long enough, the tilth and permeability of the soil may be seriously impaired. The effect becomes important when the percent sodium rises considerably above 50 (Wilcox, 1948).

Sodium Carbonate.--"Black alkali" or sodium carbonate may form in soils by evaporation of some types of water. The pH of "alkali" soils is high and has a serious effect on soil fertility by causing many plant nutrients to form insoluble compounds and, hence, to be unavailable for absorption by crops.

Table 4.--Relative tolerance of crop plants to amount of total dissolved solids.

(Within each group the least tolerant plants are placed at the top of the column.)

Sensitive	Moderately tolerant	Tolerant
	Fruit crops	
Stawberry	Cantaloupe	
Peach	Grape	
Apricot		
Almond		
Plum		
Prune		
Apple		
Pear		
	Vegetable crops	
Green beans	Cucumber	Spinach
Celery	Squash	Asparagus
Radish	Peas	Kale
	Onions	Garden beet
	Carrot	
	Potato	
	Sweet corn	
	Lettuce	
	Cauliflower	
	Bell pepper	
	Cabbage	
	Broccoli	
	Tomato	
	Forage crops	
Ladino clover	Sour clover	Birdsfoot trefoil
Red clover	Tall meadow catgrass	Barley (hay)
Alsike clover	Smooth brome	Western wheat grass
Meadow foxtail	Big trefoil	Canada wildrye
White Dutch clover	Reed canary	Saltgrass
	Blue gamma	Alkali sacaton
	Orchardgrass	
	Oats (hay)	
	Wheat (hay)	

Table 4.--continued

Sensitive	Moderately tolerant	Tolerant
	Forage crops--continued	
	Rye (hay) Alfalfa Sudan grass Dallis grass Strawberry clover Perennial ryegrass Yellow sweet clover White sweet clover	
	Field crops	
Field bean	Castorbean Sunflower Flax Corn (field) Sorghum (grain) Oats (grain) Wheat (grain) Rye (grain)	Rape Sugar beet Barley (grain)

Table 5.--Relative tolerance of crop plants to boron.

(The least tolerant plants are placed at the top of the columns.)

Sensitive	Semitolerant	Tolerant
Thornless blackberry	Lima bean	Carrot
Apricot	Bell pepper	Lettuce
Peach	Pumpkin	Cabbage
Cherry	Zinnia	Turnip
Persimmon	Oats	Onion
Apple	Milo	Broadbean
Pear	Corn	Gladiolus
Plum	Wheat	Alfalfa
American elm	Barley	Garden beet
Navy bean	Field pea	Sugar beet
English walnut	Radish	Asparagus
Black walnut	Sweet pea	
	Tomato	
	Potato	
	Sunflower (native)	

Residual sodium carbonate is the amount of carbonate and bicarbonate, expressed in epm, that would remain in solution if all the calcium and magnesium were precipitated as carbonate. Eaton (1950) concluded that carbonate and bicarbonate concentration must exceed calcium and magnesium concentration by more than 1.25 epm before soil structure will deteriorate.

Classification.--Ground water is classified as to its suitability for irrigation on the basis of four properties (U. S. Salinity Laboratory Staff, 1954, p. 76-82). These are salinity hazard (total dissolved solids), sodium hazard, boron concentration, and residual sodium carbonate.

A diagram for classifying irrigation waters according to salinity hazard and sodium hazard is shown in figure 29. Salinity-hazard and sodium-hazard classes are indicated by the letters "C" and "S", respectively, and a subscript of 1 to 4; the higher the sodium hazard, the higher the subscript. Thus, water classified as C_1-S_1, under average conditions, is more suitable for irrigation than water classified as C_4-S_4.

Water from aquifers in rocks of Cretaceous age is unsuitable for irrigation because it has a high or very high salinity hazard and much of it has a very high sodium hazard, high residual sodium carbonate, or high boron content.

Irrigation ratings of water from aquifers in glacial drift are summarized in table 6.

Industrial

No nonagricultural industrial use is made of water in Sanborn County; however, abundant supplies of water are available for use by industry.

Conclusions

Ground water in Sanborn County generally contains from 1,000 to 2,500 ppm dissolved solids, of which sulfate is the major constituent. All aquifers supply water that is suitable for domestic use, although the limits recommended by the U. S. Public Health Service for total dissolved solids, sulfate, and fluoride are exceeded by water from many wells. Except in the southeastern part of the county, the aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale, and the aquifer in the Greenhorn Limestone yield soft water. The top aquifer in the Dakota Group yields soft water in some parts of the county. The lower aquifers in the Dakota Group and the Warren and Floyd aquifers generally yield very hard water.

None of the aquifers in bedrock yields water that is suitable for irrigation owing to high salinity, high sodium hazard, high residual sodium carbonate, or high boron content. Water from the Warren and Floyd aquifers has been used successfully for irrigation, although it may be considered borderline in quality. The Floyd aquifer contains more saline water than the Warren, but if considerable care is used in application, if salt-tolerant crops are grown, and if soil salinity control practices are used, the water from both aquifers can be used for irrigation.

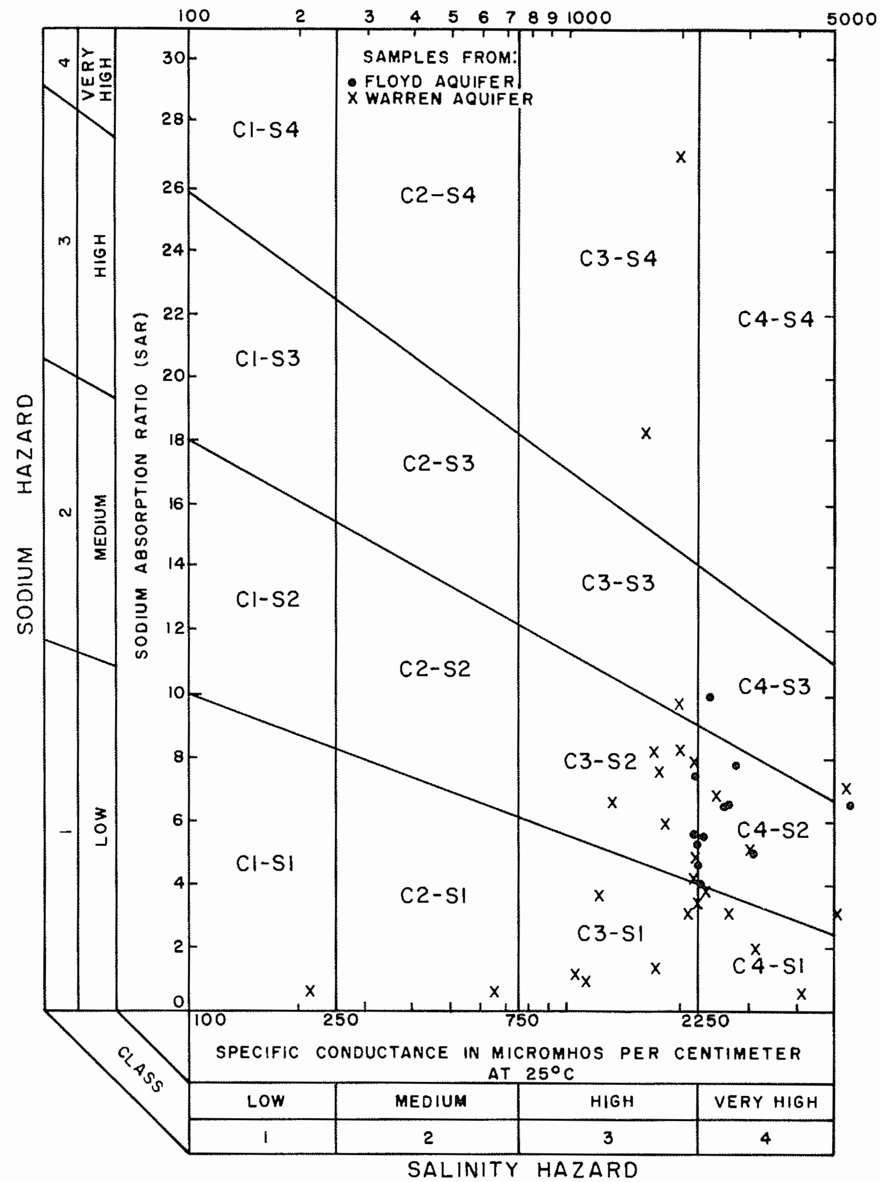


Figure 29. Diagram for classifying irrigation waters, showing classification of water samples from the Floyd and Warren aquifers.

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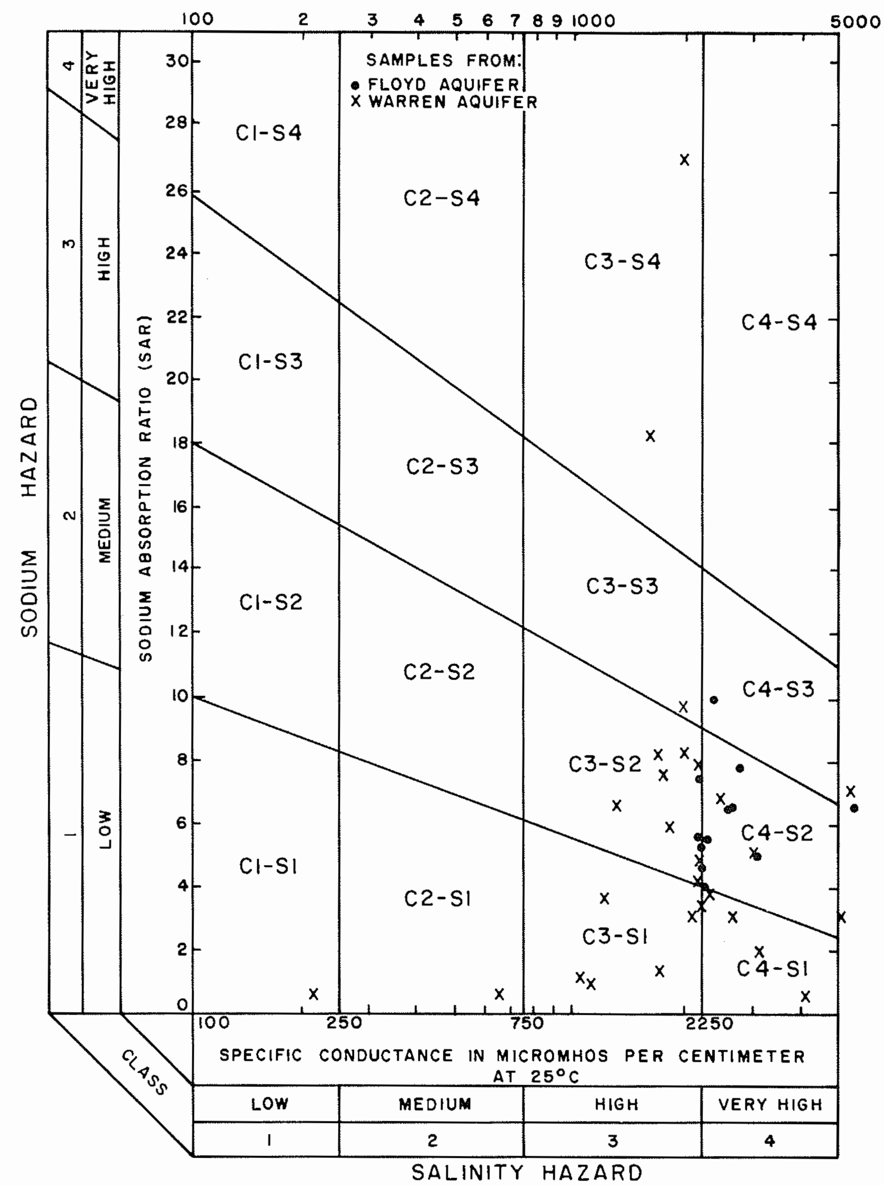

Figure 29. Diagram for classifying irrigation waters, showing classification of water samples from the Floyd and Warren aquifers.

Table 6.--Classification for irrigation of water from aquifers and water-bearing units of Quaternary age.

Well location	Salinity and sodium hazards (U.S. Salinity Laboratory Staff, 1954)	Boron rating for semitolerant crops (Scofield, 1936)	Residual sodium carbonate (Eaton, 1950)
	Alluvium along James River		
$105\text{-}60\text{-}25cccd_2$	$C_3 - S_2$	.....	0
	Floyd aquifer		
106-59-1ccba	$C_4 - S_2$	Good	0
106-59-23ddd	$C_3 - S_2$	Excellent	0
106-60-1ccab	$C_4 - S_2$	Good	0
107-59-11abaa	$C_4 - S_2$	Permissible	0
107-59-17addd	$C_4 - S_2$	Permissible	0
107-59-33bbbc	$C_3 - S_2$	Good	0
107-60-10bcac	$C_4 - S_3$	Permissible	0
108-59-22cccc	$C_4 - S_3$	Unsuitable	0
108-59-29bbab	$C_4 - S_2$	Doubtful	0
108-60-4addc	$C_3 - S_2$	Doubtful	0
108-60-27cccc	$C_4 - S_2$	.....	0
$108\text{-}60\text{-}29dab_2$	C_4	.....	1.32
108-60-33cccb	$C_3 - S_2$	Good	0
108-60-35dddc	$C_4 - S_2$	Permissible	0
	Warren aquifer		
106-61-1cccc	$C_2 - S_1$	Excellent	0
106-61-12caca	$C_3 - S_1$	Excellent	0
107-61-6bbbb	$C_3 - S_1$	.....	1.60

Table 6.--continued

Well location	Salinity and sodium hazards (U.S. Salinity Laboratory Staff, 1954)	Boron rating for semitolerant crops (Scofield, 1936)	Residual sodium carbonate (Eaton, 1950)
	Warren aquifer--continued		
107-61-6dddd	$C_3 - S_1$	Excellent	0
107-61-35cddd	$C_4 - S_2$	Excellent	0
107-62-11ddad$_2$	$C_4 - S_2$	Excellent	0
107-62-25aaaa$_1$	$C_1 - S_1$	Excellent	0
108-61-4bcba	$C_3 - S_1$	.....	0
108-61-4ccd	$C_3 - S_2$	Good	0
108-61-5cddd$_1$	$C_3 - S_2$	.....	0.07
108-61-5dcd	$C_4 - S_3$	.....	0
108-61-6ddcd	$C_3 - S_3$	.....	0
108-61-7babb$_1$	$C_3 - S_1$	.....	0
108-61-17aacc$_2$	$C_3 - S_2$	Excellent	4.99
108-61-17addd	$C_3 - S_2$	.....	5.07
108-61-32cccc	$C_3 - S_2$	.....	0.60
108-62-1ccc$_1$	$C_4 - S_1$	Excellent	0
108-62-8baab$_2$	$C_4 - S_1$	Good	0
108-62-9dcd	$C_4 - S_1$	.....	0
108-62-13bccc	$C_4 - S_1$	Excellent	0
108-62-15aadd$_1$	$C_4 - S_2$	.....	8.67
108-62-18aab	$C_3 - S_2$	.....	1.30
108-62-33cccc	$C_3 - S_2$	.....	2.60

Table 6.--continued

Well location	Salinity and sodium hazards (U.S. Salinity Laboratory Staff, 1954)	Boron rating for semitolerant crops (Scofield, 1936)	Residual sodium carbonate (Eaton, 1950)
	Warren aquifer--continued		
108-62-34ddaa	C_3 - S_4	.....	9.69
108-62-36adaa	C_3 - S_1	Excellent	0
108-62-36cccc	C_3 - S_1	.....	0

GLOSSARY OF GEOLOGIC AND HYDROLOGIC TERMS

Acre-foot.--A unit for measuring the volume of water; is equal to the quantity of water required to cover 1 acre to a depth of 1 foot and is equal to 43,560 cubic feet or 325,851 gallons. The term commonly is used in measuring volumes of water used or stored.

Altitude.--The vertical distance between a point and a datum surface, such as sea level.

Andesite.--A volcanic rock composed essentially of andesine and one or more dark-colored minerals such as pyroxene, hornblende, or biotite.

Aquiclude.--A bed or formation of relatively low permeability that serves as a barrier to the movement of ground water.

Aquifer.--A formation, group of formations, or part of a formation that can serve as a useful source of water.

Aragonite.--A mineral composed of calcium carbonate; similar to the mineral calcite.

Artesian.--Refers to ground water under sufficient pressure to rise above the top of the aquifer containing it.

Artesian head.--Artesian pressure, expressed as the height above the base of the overlying confining bed, to which water from an artesian aquifer would rise in a tightly cased well that had no discharge. May sometimes be given with reference to some datum, as "artesian head of 10 feet above land surface".

Basin.--The drainage or catchment area of a stream or lake.

Bedrock.--Any solid rock underlying the looser materials of the earth's surface.

Bentonite.--A clay formed by the decomposition of volcanic ash and largely composed of the clay minerals montmorillonite and beidellite.

Calcite.--A mineral composed of calcium carbonate; similar to aragonite; a very common mineral; the principal constituent of limestone.

Chalk.--A very soft, white to light-gray, porous, friable limestone composed of the shells of floating microorganisms and some bottom dwelling forms in a mass of microscopic calcite crystals.

Charophyta.--A class of nonmarine aquatic plants of phylum Thallophyta; stonewarts.

Chernozem soils.--(Tschernosem) A very black soil, rich in humus and carbonates, that forms under cool and temperate, semiarid climatic conditions.

Chert.--A compact form of silica composed of chalcedonic or opaline silica; of organic or precipitated origin; hornstone.

Clay ironstone.--A clayey carbonate of iron; heavy, compact and fine grained; occurs in nodules or concretions.

Claystone.--A rock composed largely of clay; sometimes bound together by iron carbonate; hardened clay similar to shale but having no fissility.

Coefficient of permeability.--The number of gallons of water per day that will pass through a cross-sectional area of 1 square foot of material under a unit hydraulic gradient at a temperature of 60° F. The field coefficient of permeability is the same, except that it is given at the local temperature of ground water.

Loess.--A homogeneous, nonstratified, unconsolidated deposit consisting predominantly of silt with small amounts of very fine sand and/or clay; eolian in origin.

Magnetic anomaly.--Any departure from the normal magnetic field of the earth as a whole. May be high or low, subcircular, ridge- or valley-like, or linear or dikelike.

Magnetometer.--An instrument used for measuring magnetic intensity; in ground magnetic prospecting usually an instrument for measuring the vertical intensity.

Marcasite.--A mineral, iron sulfide, similar to pyrite; white iron pyrites.

Marl.--A calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells. Also calcareous deposits of lakes which contain 30 to 90 percent of calcium carbonate.

Mollusca.--The phylum of invertebrate (having no backbone) animals that includes the gastropods (snails), pelecypods (oysters, clams), and cephalopods (squids, octopuses).

Orthoquartzite.--A clastic sedimentary rock composed of silica-cemented quartz sand.

Ostracoda.--A subclass of the Crustacea in the phylum Arthropoda; popularly called Ostracods.

Ostracods.--Minute crustaceans, inhabiting both fresh and salt water, with bean-shaped bivalve shells completely enclosing the body. Shells are molted several times as individuals grow.

Outlier.--An isolated mass or remnant of rock detached from the main body of rock by erosion.

Oxidation.--Process of combining with oxygen; an increase in positive valence or decrease in negative valence.

Oxidized zone.--That portion of a deposit which has been subjected to the action of surface waters carrying oxygen, carbon dioxide, etc.

Paramagnetic.--Pertaining to materials that are attracted by a magnetic field.

Permeability.--The property of soil or rock to permit a fluid to pass through it. This depends not only on the number and volume of the openings and pores, but also on how these openings are connected one to another.

Physiography.--The study of the surface of the earth -- its physical form and the processes and forces that mold and change that surface.

Piezometric surface.--An imaginary surface that coincides everywhere with the static level of water in the aquifer. It is the surface to which water from a given aquifer will rise under its full head.

Pipestone (Catlinite).--Indurated sericitic claystones and siltstones; deposits in southeastern South Dakota, southwestern Minnesota, and northwestern Iowa are interbedded with Sioux Quartzite. Used by the Dakota Indians for making pipes, tools, and ornaments.

Porosity.--The amount of voids or pores in rock or soil. Porosity is usually expressed as the percent of pore space in the total volume of the material.

Porphyry.--Rock that contains conspicuous, large crystals in a fine-grained groundmass or matrix.

Positive.--An arch, or high area, of a craton (a relatively stable portion of the earth's crust) that persistently tends to stand higher than surrounding areas.

Pyrite.--A mineral, iron sulfide, similar to marcasite. Cubic crystals; brass-yellow; hardness 6 to $6\frac{1}{2}$; ore of sulfur; called fool's gold.

Quartz.--A mineral, silicon dioxide (silica), having hexagonal crystals and a Mohs hardness of 7; most abundant mineral in earth's crust.

Quartzite.--1. A granulose metamorphic rock consisting essentially of quartz. 2. Sandstone cemented by silica which has grown in optical continuity around each fragment.

Quartzose.--A term applied to sands, sandstones, and grits composed mainly of quartz, and in which the component particles are distinct.

Radiocarbon dating.--Determination of the age of a material by measuring the proportion of the isotope C^{14} (radiocarbon) in the carbon it contains. The method is suitable for the determination of ages of as much as 30,000 years.

Recharge.--Addition of water to the zone of saturation or to an aquifer; also, the quantity of water added to an aquifer.

Rhyolite.--A rock which is the extrusive equivalent of a granite; composed mainly of quartz and alkalic feldspar.

Riprap.--Rock or broken rock used for protection of bluffs or structures exposed to wave action.

Saline water.--Water containing more than 1,000 ppm of dissolved solids. For the purpose of comparison, sea water has about 35,000 ppm of dissolved solids.

Salinity.--The concentration in water of dissolved solids in parts per million or parts per thousand. No distinction is made as to the composition of the dissolved solids.

Salinity hazard.--The injury-causing potential (to soil or crops) of the total dissolved solids in water. The four classes of salinity hazard are based upon the specific conductance of water.

Sandstone.--A cemented or otherwise compacted detrital sedimentary rock composed predominantly of sand-size quartz grains.

Schist.--A medium or coarse-grained metamorphic rock with sub-parallel orientation of the micaceous minerals which dominate its composition.

Sericite.--A fine-grained variety of mica; occurs in small scales, especially in schists.

Series.--A time-stratigraphic unit ranked next below a system.

Shale.--A laminated sedimentary rock, in which the constituent particles are predominantly of the clay grade.

Siliceous.--Of or pertaining to silica; containing silica, or partaking of its nature.

Siltstone.--A very fine-grained consolidated fragmental sedimentary rock composed predominantly of particles of silt grade.

Sodium hazard.--The injury-causing potential (to soil or crops) of the sodium ions dissolved in water. The four classes of hazard are based upon the sodium-adsorption ratio (SAR).

Soft water.--Water with hardness less than 60 ppm (about $3\frac{1}{2}$ grains per gallon) reported as $CaCO_3$.

Soil association.--The principal soil mapping unit; a group of defined and named taxonomic soil units occurring together in an individual and characteristic pattern over a geographic region.

Soil series.--A group of soils having soil horizons similar in characteristics and arrangement in the soil profile, and developed from a particular type of parent material.

Solodization.--Process of change from Solonetz to Soloth soils by leaching.

Solonchak.-- Light-colored, flocculated, salty soils; lack prismatic or blocky structures.

Solonetz.--Deflocculated, jelly-like, strongly alkaline soils; have definite columnar structure when dry, column tops usually rounded.

Specific conductance.--The electrical current conducted by 1 cubic centimeter of a substance at a specified temperature.

Specific yield.--The ratio of the volume of water that will drain by gravity from a saturated rock to the total volume of the rock.

Stade.--A climatic episode within a glaciation during which a secondary advance of glaciers took place.

Strand.--A beach; the portion of the shore between high and low water.

Stratification.--Layering of rock produced by deposition of sediments in beds or layers (strata), laminae, and other essentially tabular units.

Surficial.--Characteristic of, pertaining to, formed on, situated at, or occurring on the earth's surface; especially alluvial or glacial deposits lying on the bedrock.

System.--The fundamental unit of world-wide time-stratigraphic classification of Phanerozoic rocks; contains strata deposited during the corresponding geologic period.

Terrace.--A relatively flat, horizontal or gently inclined surface, usually long and narrow, that is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side; when typically developed is steplike in character.

Texture.--Geometric aspects of the component particles of a rock, including size, shape, and arrangement.

Topography.--The physical features of the land surface, especially the relief and contour.

Transmissibility.--See coefficient of.

Unconformity.--A surface of erosion or nondeposition that separates younger strata from older rocks.

Uncontrolled.--When applied to a flowing well, the term means that the well is flowing out of control and that it could not easily be brought under control. The term "uncontrolled" is used exclusively to refer to cratered wells having no visible casing or to wells in which water is rising outside, as well as inside, the casing.

Unrestrained.--When applied to a flowing well, the term means that the well is flowing at full capacity but that the flow might be restricted by the addition of a valve at the well head.

Valley.--An elongate depression in the earth's surface, usually with an outlet, ordinarily occupied by a stream or river.

Water table.--The upper surface of the zone of saturation, except where that surface is formed by an impermeable boundary.

Weathering.--The group of processes whereby rocks on exposure to the weather change in character, decay, and finally crumble into soil.

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APPENDIX A.--LOGS OF WELLS AND TEST HOLES IN SANBORN COUNTY, AND VICINITY

Well or test hole location: See page 9.

Drilled: Letter before year: a, about; b, before. Letter after year designates source of data and well driller as follows: A, South Dakota State Geological Survey jeep-mounted auger; B, South Dakota State Geological Survey rotary drill; C, South Dakota Water Resources Commission; D, U. S. Geological Survey truck-mounted auger; E, U. S. Geological Survey contract rotary drilling; F, U. S. Bureau of Reclamation; G, Commercial well driller; s, samples taken at 5-foot intervals.

Elevation: To the nearest foot; obtained by instrument or from U. S. Geological Survey New Series Topographic Quadrangle Maps, or U. S. Bureau of Reclamation reconnaissance topographic maps (5-foot contour interval).

Geologic unit: Qu, Pleistocene and Recent undifferentiated; Qal, alluvium; Qds, dune sand; Qld, lake deposit; Qwl, late Wisconsin drift; Qwe, early Wisconsin drift; Kp, Pierre Shale; Kn, Niobrara Marl; Kc, Carlile Shale; Kcc, Codell Sandstone Member of Carlile Shale; Kg, Greenhorn Limestone; Kgs, Graneros Shale; Kd, Dakota Group; p€s, Precambrian Sioux Quartzite; p€u, Precambrian undifferentiated.

Location of wells and test holes shown on Plate 7.

HANSON COUNTY

Test hole 104-59-1aaaa — Elevation 1,311 feet
Drilled 1960, B

Geologic unit	Material	Depth below land surface (feet)
Qu	Clay, buff, sandy	0- 16
	Clay, gray, sandy	16-110
	Gravel, fine to medium	110-147
Kn	Marl, very light-gray (N8) to light olive-gray (5Y 6/1), silty, highly calcareous, foraminiferal	147-150 T.D.

DAVISON COUNTY

Test hole 104-62-6aaaa — Elevation 1,353 feet
Drilled 1954, F

Qu	Silt, clayey, sandy	0- 8
	Till, silty clay, oxidized	8- 35
	Till, silty clay to clayey silt, unoxidized	35- 55
	Sand, fine, and silt	55- 60
	Till, clayey silt	60- 79
	Sand, fine and silt	79- 85
	Till, clayey silt	85-119
	Sand, fine and silt	119-126
	Till, silty clay	126-133
Kn	Chalkstone, light-gray	133-135 T.D.

MINER COUNTY

Well 105-58-19bbba — Elevation 1,320 feet
Drilled 1952, G

Electric Log tops (below 148 feet) and some information from Driller on field copy of Electric Log (from 0 to 148 feet):

Qu	Glacial drift (probably till from E-Log)	0-104
Qwe	Gravel containing coal	104-146
Kc	Carlile Shale (no Codell Sandstone Member present)	146-236
Kg	Greenhorn Limestone (cored 235 to 240)	236-250
Kgs	Graneros Shale	250-274
Kd	Dakota Group (cored 300 to 305)	274-350
	Sand, pink (quartzite wash)	350-365
p€s	Top Sioux Quartzite	365 T.D.

SANBORN COUNTY

Well 105-59-17aabb — Elevation 1,309 feet
Drilled 1958, G

Geologic unit	Material	Depth below land surface (feet)
	Unreported	0-155
Kcc	Sand	155-205
Kc	Shale, sticky	205-344
	Sand, hard	344-350
Kg	Shale; contains sand streaks and shells	350-370
Kgs	Shale; sand at bottom	370-390
	Sand; contains shells; shale at bottom	390-430
	Shale; sand at bottom	430-440
	Shale; sand at top	440-496
Kd	Sand	496-539 T.D.

SANBORN COUNTY

Well 105-60-4adaa3* — Elevation 1,296 feet
Drilled 1959, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Clay, yellow	0- 21
	Clay, blue	21-112
Kn	Chalk rock; top part soft	112-180
Kcc	Sand and sandrock	180-230
Kc	Shale	230-345
Kg	Rock, hard; caprock; "dirty flow"	345-350
	Shale; shells	350-502
	Rock, hard	502-502½
	Shale	502½-610
Kd	Sand; flowed 4 gpm at 627 feet; 6 gpm at 632 feet	610-634
	Shale	634-672
	Sand rock; flowed 40 gpm	672-680 T.D.

* Log is a composite of two wells, one drilled in 1889 and the other in 1959.

SANBORN COUNTY

Test hole 105-60-15dddd$_1$ — Elevation 1,295 feet
Drilled 1954, F

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil zone, silty clay	0- 3
	Till, silty clay, oxidized; sandy zone 10 to 11 feet	3- 35½
	Till, sandy silt and clay, oxidized	35½- 37
	Till, very silty and sandy, oxidized	37- 38
	Till, clayey silt, oxidized	38- 40
	Till, silty clay, unoxidized; sandy 96 to 98 feet	40-122
Kcc	Sandstone, light-gray, medium grained, moderately cemented to friable; very hard 147½ to 150 feet	122-150
	Wash sample: Too hard to core; used rock bit; driller reported shale at 156 feet	150-160
Kc	Shale, gray, with thin silt lenses	160-165 T.D.

SANBORN COUNTY

Test hole 105-60-25cccd$_2$ — Elevation 1,211 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qal	Soil	0- 1
	Clay, dark-gray; wet below 7 feet	1- 17
	Sand, very fine, to silt; very easy drilling	17- 35
	Sand and silt, slightly coarser; easy drilling	35- 37
Qwl	Gravel	37- 39
Kc	Shale, light-gray to blue-gray; abundant grains and pebbles of marcasite; some rounded quartz grains	39-112
	No sample. Very easy drilling; sand(?)	112-117 T.D.

SANBORN COUNTY

Test hole 105-60-31dddd — Elevation 1,301 feet
Drilled 1954, F

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, silty clay, oxidized, humified to 2 feet; concentration of salts at 4 to 6½ feet; partly unoxidized from 28 to 31 feet	0- 31
	Till, silty clay, unoxidized; sandy till from 37 to 85 feet; water-laid sand from 42 to 43 feet; coal from 64 to 65 feet; water-laid silt from 82 to 85, 105 to 106, 109 to 110, and 113 to 115 feet; thin oxidized zone at 61 feet; very pebbly from 121 to 125½ feet	31-125½
Kcc	Sandstone, fine, cemented, contains marcasite (as cement?)	125½-130
	Clay, light-gray to black, laminated with fine sand and silt	130-135 T.D.

Summary of Stratigraphy:

Pleistocene	
Late Wisconsin till	0- 61
Oxidized zone of early and late Wisconsin tills	61
Early Wisconsin till	61-125½
Carlile Shale	125½-135

SANBORN COUNTY

Test hole 105-60-35ddad — Elevation 1,215 feet
Drilled 1962, F

Qal	Clay, dark-brown to black, soft, wet	0- 10
	Clay, dark-brown, soft, wet	10- 20
	Clay, gray, soft	20- 33
	Sand, grayish-brown, fine	33- 39½
Qwl (?)	Sand, and gravel, brown; large boulders 43 to 45 feet	39½- 45 T.D.

SANBORN COUNTY

Test hole 105-60-35ddbb — Elevation 1,215 feet
Drilled 1962, F

Geologic unit	Material	Depth below land surface (feet)
Qal	Clay, grayish-black, soft	0- 10
	Clay, blue-green; soft	10- 20
	Clay, gray, soft, sandy layers	20- 30
	Clay, gray, soft	30- 44
Qwl (?)	(Valley fill?), sand, fine, gray	44- 60 T.D.

SANBORN COUNTY

Test hole 105-60-36dddd — Elevation 1,301 feet
Drilled 1961

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, dark brownish-black clay	0- 2
	Till, yellowish-brown oxidized clay	2- 18
	Till, medium to dark blue-gray clay	18- 47
	Sand, coarse, gravel, medium; some shale pebbles and lignite	47- 62
	Till, medium-gray, sandy	62-135
	Gravel	135-140
Kc	Clay and shale, dark to medium olive-gray, silty, some has speckled appearance; some brown fine cemented sandstone chips (Kcc?)	140-160 T.D.

SANBORN COUNTY

Well 105-61-1ddbb
Drilled 1961, B

Elevation 1,301 feet

Geologic unit	Material	Depth below land surface (feet)
Qu	Drift	0-132
Kn	Chalkstone	132-158
Kc	Shale	158-205
Kcc	Sand	205-250
Kc	Shale	250-390
	Shale; sand streaks	390-400
	Shale, sticky	400-430
	Shale	430-470
Kg	Shale, sticky; hard shells at 475 and 482 feet	470-490
Kgs	Shale	490-500
	Shale; sand streaks; a few shells	500-510
	Shale; hard shells	510-570
	Shale; hard shells at 575 feet; sand streaks at top	570-580
	Shale; hard shells at 588 feet	580-590
	Shale; sand streaks	590-600
	Shale	600-610
	Shale; a few thin sand streaks	610-620
Kd	Sand	620-633
	Shale	633-640
	Sand	640-650
	Shale	650-657 T.D.

SANBORN COUNTY

Test hole 105-61-3dddd
Drilled 1961, D

Elevation 1,290 feet

Qu	Till(?), sandy silt, yellow-brown	0- 5
	Till, very sandy; little clay, yellow-brown	5- 10
	Till, more clay, dark yellow-brown	10- 15
	Till, sandy and silty, dark-brown	15- 20
	Till, dark-gray	20- 40
	Till, darker	40- 55
	Till, little material coarser than clay; very hard drilling below 90 feet	55-145
Kn	Shale, light-gray; harder drilling	145-152 T.D.

SANBORN COUNTY

Well 105-61-7addc
Drilled 1957, G

Elevation 1,288 feet

Geologic unit	Material	Depth below land surface (feet)
Qu	Drift	0-125
Kn	Chalk	125-160
Kc	Shale; some sand	160-210
	Shale, sticky	210-350
Kg	Shale, sticky; hard shells	350-360
	Limestone	360-370
Kgs	Shale, sticky	370-410
	Shale; a few shells	410-490
	Shale, brittle	490-500
	Shale	500-550
	Sand; hard shells	550-565
	Shale	565-630
Kd	Sand	630-635
	Shale	635-650
	Sand	650-655
	Shale; sand streaks	655-678
	Sand	678-682
	Shale; sand streaks	682-698
	Sand	698-710
	Shale; some sand	710-720
	Shale?	720-730
	Shale	730-757
	Sand	757-774
	Shale, sticky	774-790
	Sand	790-817 T.D.

SANBORN COUNTY

Well 105-61-14ccba — Elevation 1,295 feet
Drilled b1903

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, clay, and yellow till	0- 30
	Sand and gravel	30- 52
	Till, blue	52-147
	Gravel	147-148
Kn and Kc	Chalk	148-323
Kg(?)	Sandstone; flow (also reported as limestone)	323-330
Kgs(?)	Shale	330-505
Kd	Sandstone, hard; some shale; slight flow from 505-506 feet and 514 feet	505-514
	Shale, hard; (also reported as soapstone lignite and sandstone)	514-551
	Sandstone, hard; some shale; strong flow of 70 gpm	551-577
	Sandstone; water	577-578 T.D.

SANBORN COUNTY

Well 105-61-23bbb — Elevation 1,303 feet
Drilled 1894, G

Qu	Topsoil	0 - 1
	Clay, yellow	1 - 30
	Clay, blue	30 - 90
	Sand and gravel, water	90 -100
Kn	Chalk	100 -140
	Sand, with water	140 -140½
	Chalk	140½-170½
Kcc	Sandstone	170½-197½
Kc	Shale with pyrite	197½-297½
Kg	Sandstone	297½-313½
Kgs	Shale with pyrite	313½-513½
Kd	Caprock	513½-521½
	Sandstone; 125 gpm flow	521½-562
	Unreported	562 -580 T.D.

SANBORN COUNTY

Test hole 105-61-31cccc — Elevation 1,308 feet
Drilled 1961, B

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, buff, sandy clay	0- 22
	Till, gray, sandy clay	22- 88
Kn	Marl, light-gray (N7), silty, sandy, contains foraminifers; strongly calcareous; bentonitic	88-100 T.D.

SANBORN COUNTY

Test hole 105-61-32dddd — Elevation 1,308 feet
Drilled 1954, F

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, clayey silt, oxidized; contains thin layers of water-laid silt from 2-3 feet; concentration of salts from 3 to 5 feet; mostly unoxidized from 32 to 35 feet	0- 35
	Till, clay silt to silty clay, unoxidized; very sandy from 87 to 90 feet	35- 99
Kn	Chalkstone, gray to light-gray	99-105 T.D.

SANBORN COUNTY

Test hole 105-61-35bbbb — Elevation 1,305 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
	Till, silty and sandy	2- 40
	Silt, sand, and gravel	40- 44
	Till, silty	44- 87 T.D.

SANBORN COUNTY

Test hole 105-61-36cccc — Elevation 1,307 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, yellow-brown, oxidized	0- 18
	Till, blue-gray, unoxidized	18- 60 T.D.

SANBORN COUNTY

Test hole 105-61-36dadd — Elevation 1,312 feet
Drilled 1961, B

Geologic unit	Material	Depth below land surface (feet)
Qu	(Till) clay, buff, sandy and pebbly........	0- 23
	(Till) clay, gray, sandy and pebbly	23- 87
	Gravel, medium	87- 92
	(Till) clay, gray, sandy	92-110
	(Till) clay, gray, very silty and sandy	110-137
Kcc	Siltstone, medium-gray (N5) and very fine sandstone, medium-gray (N5); weakly calcareous, micaceous	137-160 T.D.

SANBORN COUNTY

Test hole 105-62-3cbbb — Elevation 1,296 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, slightly sandy silt, brownish-gray (5YR 4/1); leached	0- 2
Qld	Silt, light olive-gray (5Y 6/1), calcareous; snail shells <u>Valvata tricarinata</u> (Say), <u>Helisoma anceps</u> (Menke)	2- 5
	Silt, yellowish-gray (5Y 7/2), highly calcareous, loess-like; unidentified snail shell fragments	5- 15
Qwl	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized, highly calcareous	15- 71
	Sand, coarse, and gravel, fine...........	71- 79
	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized....................	79-102
Kn	Siltstone, medium light-gray (N6) to medium-gray (N5), calcareous; abundant foraminifers. Drills much harder....	102-107 T.D.

Remarks: The bit sample was composed of light-gray (N7), highly calcareous marl, containing abundant foraminifers.

SANBORN COUNTY

Test hole 105-62-3cccc — Elevation 1,300 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, light olive-gray (5Y 6/1), oxidized, silty, calcareous	0- 5
	Till, yellowish-gray (5Y 7/2), silty	5- 18
	Till, dark olive-gray, unoxidized	18- 35
	Till, dark olive-gray, unoxidized; gravel and coarse sand	35- 80
	Till, dark olive-gray, unoxidized; gravel and coarse sand; thin layers of fine gravel and coarse sand	80- 95
	Till, dark-gray, unoxidized	95-100
Kn	Siltstone, medium- to dark-gray; gypsum	100-105
	Siltstone, light-gray; Foraminifera	105-120 T.D.

SANBORN COUNTY

Test hole 105-62-10bccc — Elevation 1,310 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, and till, yellowish-gray (5Y 7/2), oxidized, calcareous	0- 13
	Gravel and sand	13- 15
	Till, olive-gray, unoxidized, silty, highly calcareous; gravel and sand	15- 45
	Till, unoxidized	45-100
Kn	Shale, dark-gray, highly calcareous	100-110
	Shale, light-gray to medium-gray (N7 to N6), highly calcareous; Foraminifera (bit sample)	110-120 T.D.

SANBORN COUNTY

Test hole 105-62-10cccc — Elevation 1,302 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil; oxidized, yellowish-gray (5Y 7/2), sandy till, highly calcareous...	0- 12
	Sand, coarse to very fine; gravel	12- 15
	Till, oxidized, yellowish-gray (5Y 7/2), highly calcareous	15- 17
	Gravel and sand.........................	17- 18
	Till, oxidized; unoxidized till...........	18- 25
	Till, unoxidized; oxidized till...........	25- 30
	Sand and gravel mixed with some olive-gray unoxidized, silty till	30- 55
	Till, unoxidized; sand and gravel.........	55- 75
	Till, unoxidized; sand and gravel; dark-gray shale particles; more sand and gravel from 85 to 100 feet	75-100
	Till, unoxidized; sand and gravel, black shale fragments. Drilling much harder at 102 feet	100-105
Kn	Clay, medium-gray, calcareous; some sand and black shale particles; marl particles containing Foraminifera	105-115 T.D.

Remarks: Little marl present in samples. Drilling stopped when drilling mud changed from medium-gray to very light-gray and light-gray cuttings began to show.

SANBORN COUNTY

Test hole 105-62-16daad — Elevation 1,302 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil; oxidized, yellowish-gray (5Y 7/2) till	0- 5
	Till, oxidized, light olive-gray (5Y 6/1); some gravel from 7 to $8\frac{1}{2}$ feet	5- 20
	Till, medium olive-gray (5Y 5/1), unoxidized	20- 85
	Till, medium olive-gray (5Y 5/1), unoxidized, gravel and sand, dark-gray to black shale particles. Drilling harder below 90 feet	85- 95
	Till, unoxidized, and light-gray shale; abundant rounded fine gravel and coarse sand and chips of calcite. Drilling much harder	95-100
Kn	Shale, light-gray (N6), highly calcareous; Foraminifera	100-110 T.D.

SANBORN COUNTY

Test hole 105-62-21aaaa — Elevation 1,301 feet
Drilled 1954, F

Qu	Clay, silt, and sand; probably water-laid; impermeable	0- 4
	Till, silty clay, oxidized; very sandy from 9 to 10 feet	4- 15
	Till, silty clay, unoxidized	15- 76
	Silt; some clay; water-laid; impermeable	76- 80
	Till, silty clay, unoxidized; very sandy from 87 to 88 and 98 to 100 feet	80-105
	Sand, fine; much silt and clay; water-laid; slightly permeable	105-111
Kn	Clay, silt, and sand, fine	111-115
	Shale, gray, soft; some silt	115-125 T.D.

SANBORN COUNTY

Test hole 105-62-28aada — Elevation 1,313 feet
Drilled 1961, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, yellow-brown, oxidized	0- 15
	Till, dark-gray, unoxidized, sandy	15- 80
	Sand, fine; some clay..................	80- 90
	Till..................................	90-117
Ancient alluvium?	Silt, dark-gray to black, sandy; contains some clay; noncalcareous; gravelly zone from 117 to 122 feet..........	117-152 T.D.

SANBORN COUNTY

Test hole 105-62-31cccd$_2$ — Elevation 1,354 feet
Drilled 1961, B

Qu	Clay, buff, sandy......................	0- 22
	Clay, gray, silty and sandy	22- 70
	Sand, coarse	70- 72
	Clay, gray, sandy and pebbly...........	72-105
	Clay, gray, very sandy; many coal fragments	105-131
Kn	Clay, light-gray (N7), foraminiferal, strongly calcareous, sandy, silty; few fragments of speckled marl; sand and gravel cavings; some coal fragments and pyrite...........................	131-140 T.D.

SANBORN COUNTY

Test hole 105-62-34cccc$_1$ — Elevation 1,329 feet
Drilled 1954, F

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, clayey silt, oxidized; much water-laid silt, clay, and "rock flour" in top 10 feet; humified from 0 to 2 feet	0 - 20
	Till, clayey silt, unoxidized	20 - 30
	Sand, medium to coarse, and gravel	30 - 33½
	Till, clayey silt to silty clay	33½- 50
	Silt, and sand, fine to medium; water-laid; permeable; oxidized from 50 to 53 feet; very silty from 53 to 54½ feet	50 - 60
	Till, silty clay, unoxidized; clay and silt, water-laid from 67½ to 70½, 74 to 75, 90 to 91, and 94 to 95 feet; sand from 82 to 83 feet	60 -104½
Kn	Chalkstone, light-gray, argillaceous	104½-110 T.D.

Summary of Stratigraphy:

Late Wisconsin till	0 - 50
Oxidized zone of early and late Wisconsin tills	50 - 53
Outwash of early Wisconsin till	53 - 60
Early Wisconsin till	60 -104½
Niobrara Marl	104½-110 T.D.

MINER COUNTY

Test hole 106-58-31cccc Elevation 1,343 feet
Drilled 1961, E

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, clayey, dark-brown	0- 2
Qwl	Till, silty, oxidized	2- 4
	Till, yellowish-brown, oxidized; calcium carbonate zone from 4 to 5 feet; rock at 10 feet	4- 15
	Till, clayey, gray, unoxidized	15- 20
	Till, sandy, gray, unoxidized; rock at 73½ feet	20- 75
	Till, sandy, gray; some sand, coarse	75- 95
Qwe	Till, sandy, brown to gray; some sand, coarse	95-100
	Till, sandy, gray, unoxidized	100-115
	Till, gray, unoxidized; much sand, medium to coarse	115-135
	Sand, fine to gravel, medium; abundant rounded shale pebbles; coal fragments; some clay, light-gray	135-145
Kn	Siltstone, light olive-gray, weakly calcareous; shale, silty, light-gray, fissile, slightly calcareous; coal, no foraminifers	145-150 T.D.

SANBORN COUNTY

Well 106-59-8cccb — Elevation 1,308 feet
Drilled 1960, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Clay, yellow (till)	0- 25
	Clay, dark, soft; (till), rock at 60 feet	25- 96
	Sand	96-108
	Clay (till)	108-134
Kn	Chalk	134-195
Kc	Clay, gummy	195-230
Kcc	Sandstone; very hard from 234 to 235 feet	230-240
Kc	Shale	240-252
	Sandstone	252-267
	Shale and sandstone streaks	267-270
	Shale	270-290
	Shale, gummy	290-450
Kg and Kgs	Shale (seep of water at 540 feet); some hard shells from 526 to 567 feet	450-605
Kd	Sand	605-612
	Shale	612-616
	Sandstone	616-617
	Clay, gummy; some hard shells	617-640
	Shale; hard shell at 666 feet	640-670
	(Sandstone) rock, very hard; cored	670-677
	Sandstone; flow 6 gpm	677-700 T.D.

MINER COUNTY

Well 106-59-9babc — Elevation 1,315 feet
Drilled 1902, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil and yellow clay	0- 13
	Clay, blue	13- 63
	(Till?) shale, dark; hard water at 123 feet	63-123
Kp (?)	Shale, dark; contains pyrite	123-154
Kn (?)	Limestone	154-159
	Shale	159-197
	Limestone	197-204
Kc (?)	Shale, dark; contains pyrite	204-238
Kcc (?)	Limestone; soft water	238-242
Kc (?)	Shale, dark; contains pyrite	242-250
Kc, Kg, & Kgs	Shale, dark	250-675
Kd	Sandstone; 50 gpm flow at 675 to 680 feet; 120 gpm flow at 708 feet	675-708 T.D.

MINER COUNTY

Test hole 106-59-12aaaa | Elevation 1,315 feet
Drilled 1961, E

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 5
	Till, oxidized	5- 15
	Till, sandy, coarse, oxidized	15- 25
	Till, sandy, gray, unoxidized	25- 64
	Sand	64- 75
	Sand, coarse	75- 80
	Sand	80-105
Kn	Marl, medium light-gray (N6) to light olive-gray (5Y 6/1), speckled, calcareous; some sand cavings	105-140 T.D.

SANBORN COUNTY

Test hole 106-59-13dddd | Elevation 1,318 feet
Drilled 1961, D

Qu	Soil	0- 1
	Till, sandy (coarse to medium); dark-brown, red-brown below 3 feet	1- 5
	Till, gravelly, dark-brown	5- 8
	Sand, coarse, gravel, medium, clayey, dark red-brown	8- 10
	Sand, fine to gravel, fine, yellow-brown, poorly sorted, poorly rounded; mostly coarse sand	10- 15
	Till, clay to very sandy clay, dark-gray	15- 95
	Sand, fine to medium; gravel	95-125
Kn	Shale, light-gray, calcareous	125-152 T.D.

SANBORN COUNTY

Well 106-59-17aaa$_2$ Elevation 1,318 feet
Drilled a1894, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Glacial drift	0-130
Kn	Chalk	130-140
	Shale	140-190
Kcc	Sandstone	190-235
Kc, Kg, & Kgs	Shale	235-530(?)
	Flow at 530	530(?)-(?)
Kgs	Shale	(?)-630
Kd	Sandstone, flow	630-635
	Shale	635-690
	Rock, drilled 3/4 inch per hour	690-692' 4" T.D.

SANBORN COUNTY

Well 106-59-18aaad$_1$ Elevation 1,312 feet
Drilled 1960, G

Qu	Clay, yellow	0- 20
	Clay, gravelly	20- 35
	Clay, dark; blasted rock at 120	35-130
Kp	Shale, sandy, or clay	130-144
Kn	Chalkrock	144-205
Kc	Clay	205-240
Kcc	Sand	240-252
	Sandrock	252-259
	Shale	259-264
	Unreported	264-268
	Soft sandrock	268-272
	Sand streaks and shale	272-280
Kc	Clay, blue	280-420
Kg and Kgs	Shale containing hard shells	420-611
Kd	Sandrock	611-628
	Shale	628-662
	Sandrock	662-669
	Shale	669-688
	Sandrock, hard	688-695
	Sand	695-699
	Shale	699-745 T.D.

SANBORN COUNTY

Well 106-59-24cbb$_1$ Elevation 1,328 feet
Drilled 1958, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Drift	0-135
	Unreported	135-140
Kn	Chalk	140-200
Kc	Unreported	200-210
Kcc	Sand	210-265
Kc	Shale, sticky	265-435
Kg (?)	Sand	435-440
Kgs	Shale, hard, sticky	440-567
Kd	Sand, good	567-610 T.D.

SANBORN COUNTY

Well 106-61-1cccc Elevation 1,278 feet
Drilled 1957, C

Qu	Topsoil, sandy	0- 7
	Gravel	7-17
	Clay, blue	17-20 T.D.

SANBORN COUNTY

Test hole 106-61-3dddd — Elevation 1,284 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qds	Soil, sandy	0- 2
Qwl	Clay, sand, and gravel	2- 5
	Till, very sandy, oxidized; some gravel	5- 18
	Till, gray, unoxidized; some gravel	18- 25
Qwe	Gravel	25- 77
	Sand	27- 29½
	Clay	29½- 30½
	Sand, very fine to medium	30½- 38
	Till, blue-gray, unoxidized	38- 80
	Clay, sand, and gravel interlayered	80- 85
	Clay	85- 87
	Sand and gravel	87- 89
	Clay; sand and gravel streaks	89-100
	Till, blue-gray, unoxidized	100-105
	Clay; sand and gravel streaks	105-122
	Sand	122-124
Kn	Marl, very light-gray (N8), highly calcareous; clay, silty, light olive-gray (5Y 6/1), calcareous; foraminifers	124-130 T.D.

SANBORN COUNTY

Well 106-61-10dddd — Elevation 1,283 feet
Drilled 1959, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Sand	0- 15
	Clay	15-126
Kn	Chalkrock; first 20 feet very soft	126-170
Kc	Shale	170-220
Kcc	Sandrock	220-230
	Shale	230-356
Kg (?)	Sandrock	356-372
Kgs	Shale	372-540
Kd	Sand; flow 15 gpm	540-556
	Shale	556-558 T.D.

SANBORN COUNTY

Well 106-61-11acdd — Elevation 1,277 feet
Drilled 1959, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Clay	0- 21
	Sand; blasted rock at 20 feet	21- 35
	Clay	35-150
Kn	Chalk rock	150-210
Kc	Shale	210-240
Kcc	Sand rock, soft	240-270
Kc	Shale	270-385
Kg	Sand rock; slight flow	385-392
Kgs	Shale and hard shells	392-577
Kd	Sand; flow 15 gpm	577-590 T.D.

SANBORN COUNTY

Test hole 106-61-23bbbb — Elevation 1,284 feet
Drilled 1961, Es

Qds	Sand	0- 7
Qwl	Clay, light-gray, shaly, highly calcareous	7- 9
	Sand	9- 14
	Clay, sandy	14- 17
	Sand	17- 20
	Clay, sand, and gravel	20- 39
	Clay, sandy	39- 55
	Clay, less sandy	55- 60
	Till, blue-gray, unoxidized	60- 70
	Till, sandy, blue-gray, unoxidized	70- 75
	Till, less sandy, blue-gray, unoxidized	75- 86
	Till, gravelly and sandy, blue-gray, unoxidized	86- 95
	Clay, very sandy, gravelly	95-110
	Till, sandy, unoxidized	110-122
	Sand	122-129
	Till, light olive-gray (5Y 6/1), unoxidized	129-130
Kn	Marl, slightly silty, light-gray (N7), highly calcareous; some chalk, bentonitic, white (N9), calcareous; foraminifers	130-142 T.D.

SANBORN COUNTY

Test hole 106-61-27dddd — Elevation 1,290 feet
Drilled 1961, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, sandy, yellow-brown	0- 5
	Till, sandy, dark-brown	5- 25
	Till, sandy, dark-gray	25- 30
	Till, slightly sandy, dark blue-gray	30- 95
	Sand, coarse; gravel	95-108
	Till (?); hard drilling	108-120
Kn	Shale, light-gray, calcareous	120-152 T.D.

SANBORN COUNTY

Test hole 106-62-10cbbc — Elevation 1,296 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, sandy silt, yellowish-gray (5Y 7/2) to grayish-yellow (5Y 8/4), oxidized	0- 15
	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized	15- 20
	Sand, fine to medium, and gravel, fine; silty; calcareous; some till	20- 25
	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized	25- 85
	Sand, fine to medium; gravel	85-100
	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized	100-110
	Sand, medium to coarse; gravel; some till	110-120
	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized	120-140
Kn	Marl, light-gray (N7), speckled; abundant foraminifers	140-155 T.D.

SANBORN COUNTY

Test hole 106-62-15cbbb — Elevation 1,294 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qwl	Sand, very fine, to gravel, fine to medium; yellowish-gray (5Y 7/2), oxidized	0- 20
	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized; pebbly	20- 35
Qwe	Till, sandy silt, yellowish-gray (5Y 7/2) to light olive-gray, oxidized; pebbly	35- 40
	Till, sandy silt, light olive-gray, unoxidized	40- 90
	Sand, and gravel, coarse; some till	90- 95
	Sand, and gravel, coarse; color becoming more yellowish	95-100
	Sand and gravel, gray	100-130
	Sand, fine to medium; some gravel	130-150
	* Probable top of Niobrara Marl	135
Kn	Marl, light-gray, speckled	150-155 T.D.

* Based on loss of circulation from 135 to 145 feet.

SANBORN COUNTY

Test hole 106-62-16aaad — Elevation 1,304 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qwl	Till, sandy clay, yellowish-gray, (5Y 7/2), oxidized, calcareous; some coarse material	0- 10
	Till, sandy clay, grayish-orange (10YR 7/4) to yellowish-gray (5Y 7/2), oxidized, calcareous; some coarse material	10- 20
	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized, calcareous; some coarse material	20- 30
Qwe	Sand, fine to medium, and gravel, silty, gray; some till	30- 45
	Till, sandy silt, light olive-gray (5Y 6/1), unoxidized, calcareous	45-140
Kn	Clay, very light-gray (N8); some till	140-145 T.D.

SANBORN COUNTY

Well 106-62-19dddd Elevation 1,312 feet
Drilled 1961, G

Geologic unit	Material	Depth below land surface (feet)
Qwl	(Till); clay, gravelly, yellow; loose rocks	0- 20
	(Till); clay, dark	20- 39
	(Till); clay, dark, soft	39- 79
Qwe	(Till); clay, sandy, light-colored	79-111
	Sand	111-123
	(Till?); soft mud	123-132
Kn	Shale, sandy	132-138
	Chalk	138-160 T.D.

SANBORN COUNTY

Well 106-62-21aaad Elevation 1,289 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qwl (Cuthbert outwash-2)	Sand, fine to coarse, silty, yellowish-gray (5Y 7/2) to pale yellowish-brown (10YR 6/2), oxidized, calcareous; some coarse material	0- 15
	Sand, fine to coarse, silty, light olive-gray (5Y 7/2); gravel	15- 20
(Cuthbert outwash-1)	Sand, medium to coarse, brownish-gray, oxidized, clean, quartzose; rock at 24 feet	20- 25
	Sand, medium to coarse, brownish-gray, oxidized, clean, quartzose; gravel	25- 45
	Sand, medium to coarse, silty, gray, unoxidized, clean, quartzose; gravel	45- 75
Qwe	Till, light olive-gray (5Y 6/1), unoxidized, calcareous; sand and gravel	75- 90
	Sand, fine to coarse, clayey, silty; abundant shale pebbles	90-135
Kn	Marl, light-gray (N8) to medium light-gray (N6), calcareous, speckled; foraminifers	135-140 T.D.

SANBORN COUNTY

Test hole 106-62-27cbbb | Elevation 1,291 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qld	Silt, sandy, yellowish-gray (5Y 7/2), oxidized, calcareous	0- 14
Qwl (Cuthbert outwash-2?)	Sand, coarse, to gravel, silty, light olive-gray (5Y 6/1), unoxidized, calcareous.....................	14- 20
	Sand, medium to coarse, silty, light olive-gray (5Y 6/1), unoxidized.................................	20- 30
	Sand, coarse, and gravel, fine; silty	30- 40
(Cuthbert outwash-1?)	Gravel, fine to medium, silty	40- 70
Qwe	Till, silty, light-gray (N7); gravel	70- 85
	Sand, coarse, and gravel, fine; some till.............................	85-110
	Till, sandy, light-gray (N7), unoxidized, calcareous.....................	110-125
Kn	Marl, light olive-gray (5Y 6/1), speckled.............................	125-128 T.D.

SANBORN COUNTY

Well 106-62-30bbcd Elevation 1,320 feet
Drilled 1959, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Clay, yellow	0- 20
	Clay, blue, and sand	20- 40
	Clay, blue; pebbles	40- 60
	Clay, blue, and sand; rocky	60- 80
	Sand; gravelly below 120 feet	80-137
Kn	Chalk, dark to white	137-176
Kcc	Sand, white	176-190
	Sand and shale, interlayered	190-200
Kc	Shale, blue	200-245
	Sand	245-260
	Shale, sandy	260-270
	Shale; sand streaks	270-290
	Shale, sticky; rock at 315 feet	290-330
	Shale, hard	330-350
	Shale, gray	350-370
	Shale, black, hard	370-390
	Shale; sand streaks	390-425
Kg	Limestone (electric log - 420 to 430 feet)	425-450
Kgs	Shale, black, sticky	450-490
	Shale; sand streaks	490-510
	Shale	510-530
	Shale, gray; sand streaks	530-550
	Shale, sticky; sand streaks between 590 and 610 feet	550-630
Kd	(Electric log top at 666 feet)	
	Shale, hard; sand streaks	630-740
	Sandstone	740-760
	Shale	760-770
	Sand	770-780
	Shale	780-786
	Sandstone	786-800
	Shale; sand streaks	800-860
	Sandstone; thin shale bands	860-945 T.D.

SANBORN COUNTY

Test hole 106-62-33aaaa — Elevation 1,288 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu (Cuthbert outwash)	Soil, sandy silt, dark-brown to black	0- $2\frac{1}{2}$
	Sand, fine to coarse, silty, pale yellowish-brown (10YR 6/2)	$2\frac{1}{2}$- 5
	Silt, sandy, yellowish-gray (5Y 7/2), calcareous	5- 13
	Sand, very fine, silty, light olive-gray (5Y 6/1), calcareous	13- 25
	Sand, coarse, silty, light olive-gray (5Y 6/1), slightly calcareous.......	25- 40
	Silt, sandy, light olive-gray (5Y 6/1), slightly calcareous.....................	40- 45
	Sand, silty, light olive-gray (5Y 6/1), slightly calcareous.....................	45- 50
	Till, sandy silt, light olive-gray, calcareous	50- 90
	Sand, silty, light olive-gray; gravel.....	90-121
Kn	Marl, medium light-gray (N6), speckled, highly calcareous............	121-124 T.D.

SANBORN COUNTY

Test hole 106-62-33addd — Elevation 1,288 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil; sand, light olive-gray (5Y 6/1) to pale yellowish-brown (10YR 6/2), calcareous; gravel	0- 5
	Till, sandy clay-silt, pale yellowish-brown (10YR 6/2), calcareous...........	5- 16
	Sand	16- 19
	Till, blue-gray, unoxidized	19- 22
	Sand, fine to coarse, gray; gravel; some till..............................	22- 25
	Sand, fine to coarse, clayey, silty; coal...	25- 40
	Till, sandy clay-silt, light olive-gray (5Y 6/1)	40- 60
	Sand, fine to coarse, and gravel, fine; some till.............................	60- 83
	Till, sandy clay-silt, light olive-gray (5Y 6/1)	83-104
Kn	Marl, sandy, medium light-gray (N6) to greenish-gray (5G 6/1), calcareous; foraminifers	104-108 T.D.

SANBORN COUNTY

Test hole 106-62-33dddd — Elevation 1,291 feet
Drilled 1960, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil; silt, pale yellowish-brown (10YR 6/2), weakly calcareous	0- 2 (?)
	Till, sandy silt, yellowish-gray (5Y 7/2) to light olive-gray (5Y 6/1), oxidized, highly calcareous	2 (?)- 13
	Till, sandy clay-silt, light olive-gray (5Y 6/1), unoxidized, calcareous; sandy and gravelly	13- 20
	Till, sandy clay-silt, slightly darker than light olive-gray (5Y 6/1), unoxidized, calcareous; gravelly from 20 to 21 feet	20- 90
	Sand, fine to coarse; gravel; some till	90-100
Kn	Siltstone, sandy, light olive-gray (5Y 6/1) to light-gray (N7); calcareous; foraminifers	100-112 T.D.

SANBORN COUNTY

Well 106-62-34cccd$_1$ — Elevation 1,290 feet
Drilled 1956, G

Geologic unit	Material	Depth below land surface (feet)
	Unreported	0-120
Kn	Chalkstone	120-160
Kc	Shale	160-220
	Shale; sand streaks	220-300
Kc	Shale, sticky	300-350
	Unreported	350-380
Kg	Greenhorn Limestone; hard shell at 384 feet	380-390
Kgs	Unreported; hard shell at 488 feet	390-490
	Shale; hard shell at 492 feet	490-495
	Sand	495-500
	Shale, sticky	500-550
	Shale, sticky; sandy between 555 and 560 feet	550-560
	Unreported	560-630
Kd	Sand	630-650 T.D.

MINER COUNTY

Test hole 107-58-6cccc — Elevation 1,343 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, light-brown, oxidized	0- 10
	Till, light-brown, oxidized; gravel	10- 15
	Till, oxidized; till, dark blue-gray, unoxidized	15- 20
	Till, unoxidized	20- 23
	Sand	23- 25
	Till, unoxidized	25- 48
	Clay and sand	48- 50
	Clay, sand, and gravel	50- 64
	Sand and gravel	64-104
	Sand	104-115
Kp	Shale, medium olive-gray (5Y 5/1), moderately calcareous; marcasite	115-129 T.D.

MINER COUNTY

Test hole 107-58-7cbd$_1$ — Elevation 1,328 feet
Drilled 1962, E

Geologic unit	Material	Depth below land surface (feet)
Qal	Clay, silty, dark-brown	0- 13
	Sand, fine to coarse, and gravel, fine to coarse; brown; clayey	13- 19
Qwl	(Till); clay, sandy and gravelly; dark-brown, oxidized, soft	19- 22
	(Till); clay, sandy and gravelly, gray, unoxidized, soft	22- 44
	Sand, fine to coarse, clayey	44- 52
	Sand, medium to coarse, and gravel, fine	52- 59
	Sand, fine to coarse, and gravel, fine; clean	59- 62
	Gravel, fine to coarse, clean	62- 65
	Sand, medium to coarse, and gravel, fine to coarse; clean	65- 67
	Gravel, fine to coarse	67- 70
	Sand, coarse to very coarse	70- 72
	Gravel, fine to coarse; cobbles from 74 to 77 feet, and 79 to 80 feet	72- 80
	Sand, gravelly, clayey	80- 84
	Gravel, fine to very coarse	84- 87
	Sand, fine, clayey	87- 89
	Sand, very coarse, and gravel, medium	89- 97 (?)
Kp	Shale, black, waxy, bentonite, noncalcareous	97-117 T.D.

MINER COUNTY

Test hole 107-58-18cccc — Elevation 1,337 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
	Till, light-brown, oxidized	2- 15
	Till, oxidized; till, dark-gray to blue-gray, unoxidized	15- 20
	Till, unoxidized; sandy streaks	20- 53
	Clay(?), (very few cuttings)	53- 60
	Sand, very fine to coarse; clay; gravel	60- 81
	Sand, medium to coarse	81- 85
	Sand, medium to very coarse	85- 94
	Sand and gravel	94-100
	Sand, medium to very coarse, and gravel	100-110
	Sand and gravel	110-125
	Sand and gravel, clayey; coal	125-130
Kp	Shale, slightly silty, light-gray (N7) to medium light-gray (N6), fissile, very slightly calcareous, highly bentonitic, some with dull sheen; light bluish-gray montmorillonite; selenite; prismatic calcite. Sand streaks from 140 to 145 feet	130-155 T.D.

SANBORN COUNTY

Well 107-59-7aadd — Elevation 1,310 feet
Drilled 1961, G

Geologic unit	Material	Depth below land surface (feet)
Qwl	(Till); clay, soft; rock at 43 feet	0- 44
	(Till); clay, gummy	44- 75
Qwe	(Till); clay, sandy, light-colored, oxidized	75- 85
	Sand	85- 98
Kn	Shale, sandy, soft	98-122 T.D.

SANBORN COUNTY

Well 107-59-20bbbb — Elevation 1,306 feet
Drilled 1955, G

Geologic unit	Material	Depth below land surface (feet)
	Unreported	0-250
Kcc	Sand	250-280
Kc	Shale, sticky	280-295
	Sand	295-300
	Shale; sand streaks; shells	300-320
	Shale	320-460
	Shale, soft	460-500
Kg	Shale, sandy	500-520
Kgs	Shale, soft	520-660
	Shale, hard, brittle	660-700
Kd	Shale, sandy	700-710
	Sand, good	710-730
	Shale, hard, sticky	730-750
	Sand rock	750-760
	Sand rock; shale stringers	760-770
	Sand rock	770-790
	Shale; hard shells	790-810
	Shale; sand streaks	810-860
	Shale, sticky	860-870
	Sand rock	870-880
	Rock, hard	880-890
	Sand rock	890-930 T.D.

SANBORN COUNTY

Test hole 107-59-25dddd — Elevation 1,330 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- $3\frac{1}{2}$
	Till, light- to medium-brown, oxidized; gritty below 4 feet.......................	$3\frac{1}{2}$- 10
	Till, oxidized; till, dark blue-gray, unoxidized; selenite crystals	10- 15
	Till, unoxidized, gritty	15- 29
	Gravel	29- 32
	Sand...	32- 34
	Till, unoxidized..........................	34- 55
	Clay, sand streaks	55- 64
	Gravel	64- 65
	Sand, coarse, and gravel; lignite; till....	65- 80
	Sand, medium to coarse, and gravel; clay, lignite..................................	80- 85
	Sand, fine to coarse, and gravel; clay, lignite..................................	85- 95
	Sand, coarse, and gravel, fine...........	95-100
	Sand, fine to coarse, and gravel; clay; lignite	100-120
	Sand, fine to coarse; clay; lignite	120-124
Kp	Clay; sand, fine to coarse, and gravel; lignite; probably Pierre Shale	124-130
	Drills like shale; sand, coarse, and gravel cavings...........................	130-135
	Few cuttings; sand, fine; cavings	135-150
Kn	Marl, light olive-gray (5Y 6/1), speckled, clay, white (N9), bentonitic...	150-160 T.D.

SANBORN COUNTY

Well 107-60-3adda2 — Elevation 1,301 feet
Drilled 1961, Gs

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 1
	Sand	1- 20
	Clay, sand, and gravel	20- 52
	Clay and gravel, coarse	52- 55
	Clay, gravelly and sandy	55- 83
	Sand and gravel; lignite	83-118
Kn	Clay, light-gray	118-120
	Shale, chalky, light-gray	120-165
Kc	Shale, blue	165-193
Kcc	Sand, fine; rock	193-225
Kc	Shale, sandy, blue-gray to dark-blue, pyritic; shell fragments	225-417
	Gravel, lignitic	417-419
Kg	Shale, sandy, light- to dark-gray; calcite; shell fragments	419-430
Kgs	Shale, sandy, silvery to light-gray, calcareous; lignite; pyrite; mud flow reported, 0.9 gpm measured about 450 feet	430-490
	Shale, sandy, light- to dark-gray, pyritic; lignite; calcite; shell fragments	490-527
	Sand	527-529
	Shale, very soft	529-555
	Shale, sandy, light- to dark-gray; lignite; shell fragments	555-595
Kd	Sandstone laminae, hard	595-600
	Sand	600-612
	Shale, light- to medium-gray, non-calcareous; some fossils	612-685
	Sand	685-704
	Shale, dark-gray	704-845
	Sand	845-846
	Shale, sandy, bluish-gray	846-882½
	Sand	882½-930 T.D.

SANBORN COUNTY

Well 107-60-26bcca — Elevation 1,305 feet
Drilled 1955, G

Geologic unit	Material	Depth below land surface (feet)
Qu and Kn	No comment in driller's log	0-220
Kcc	Sand	220-280
Kc	Shale	280-300
	Sand	300-317
	Shale, sticky	317-450
Kg	Shale; sand streaks	450-460
Kgs	Shale, soft	460-550
	Shale; sandy	550-560
	Shale; many hard shell spots	560-620
	Shale, sand top, sand streaks	620-640
	Shale; sand top; some shells	640-710
Kd	Sand rock	710-735
	Mostly shale	735-750
	Shale	750-760
	Sand rock	760-780
	Shale; sand bottom	780-820
	Sand; shale bottom	820-840
	Shale; sand bottom	840-870
	Shale; sandy streaks	870-885
	Sand	885-895
	Shale	895-905
	Sand	905-924 T.D.

SANBORN COUNTY

Well 107-60-27ddad — Elevation 1,294 feet
Drilled 1961, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, sandy	0- 1
	(Till?), clay, gravelly, yellow	1- 10
	(Till?), clay, dark; rocks	10- 50
	(Till?), clay, gummy, soft	50-125
	Sand and gravel	125-145
	Sandrock, hard; blasted rock at 149 feet	145-146
	Unreported	146-151
Kn	Chalk	151-197
Kcc	Sand; hard shells; some clay	197-232
Kc	Clay	232-245
	Sand	245-269
	Shells	269-275
	Sand	275-285
	Clay, gummy	285-380
	Shale	380-440
Kg	Shale; hard shells at 440 feet; mud flow at 484, 1 gpm	440-484
Kgs	Shale; hard shells	484-609
	Sandstone; 2 gpm flow	609-617
	Shale, hard shells	617-712
Kd	Sandstone; 3 gpm flow	712-718
	Shale	718-726
	Sandstone; no water	726-728
	Shale; hard shells; sand at 805 feet	728-805
	Shale	805-845
	Sandstone	845-860
	Shale	860-864 T.D.

SANBORN COUNTY

Test hole 107-60-30baab — Elevation 1,229 feet
Drilled 1961, E

Geologic unit	Material	Depth below land surface (feet)
Qal	Soil, dark-brown to black, and alluvium; clay, silt, and some sand	0- 5
	Clay, sandy and silty, black	5- 10
	Clay, slightly sandy, tan-gray	10- 35
	Sand, fine, well-sorted	35- 40
	Sand, medium to gravel	40- 49
	Sand, fine to coarse	49- 75
Qwl (?)	Till (?), sandy	75- 87 T.D.

SANBORN COUNTY

Test hole 107-61-6bbbb — Elevation 1,288 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, sandy	0- 3
	Sand, fine to medium; gravel	3- 7
	Till, very sandy, oxidized	7- 9
	Till, unoxidized; gravel	9- 13
	Till, unoxidized	13- 15
	Clay, and silt, sandy, interlayered	15- 20
	Till, silty, and silt, sandy, interlayered; medium to coarse sand below 65 feet	20- 72
	Till, tough, dense	72- 77 T.D.

SANBORN COUNTY

Test hole 107-61-23bbbb — Elevation 1,290 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 1
	Sand, very fine to medium, brown to black; till, oxidized	1- 17
	Sand and gravel	17- 19
	Till, gray, unoxidized; sand and gravel streaks	19- 42
	Sand and gravel	42- 44
	Till, gray, unoxidized	44- 63½
	Gravel (to ½-inch diameter)	63½- 64
	Till, blue-gray, unoxidized; gravel; angular shale fragments	64- 70
	Gravel; boulders(?)	70- 75
	Till, blue-gray, unoxidized	75- 78
	Gravel	78- 80
	Sand, very fine to very coarse; lignite	80- 83
	Gravel	83- 84
	Sand and gravel; till(?) layers	84- 98
	Gravel; hard drilling	98-100
Kn	Marl, light-gray (N7), speckled, strongly calcareous; foraminifers	100-118 T.D.

SANBORN COUNTY

Test hole 107-61-28aaaa — Elevation 1,288 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qds	Silt to sand, medium, brown, well-sorted, well-rounded, frosted	0- 8
	Silt to sand, medium, gray, well-sorted, well-rounded, frosted	8- 18
	Silt to sand, medium; clay	18- 22
Qwl	(Till?), clay, sandy, silty, brown, oxidized; olive-gray, unoxidized below 42 feet.........................	22- 47
Qwe	Silt to sand, medium, clayey, gray......	47- 57
	Silt to sand, fine, olive-gray...........	57- 67
	Till(?), sandy silt; hard drilling	67- 74
	Rocks; could not penetrate with auger....	74- 77 T.D.

SANBORN COUNTY

Test hole 107-61-35bcc — Elevation 1,283 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Sand, fine to medium; shale fragments from 10 to 25 feet	0- 25
	Sand, fine to medium; clay, gray........	25- 29
	Till, sandy, gray, unoxidized	29- 35
	Till, sandy, gray, unoxidized; gravel....	35- 40
	Till, sandy, and gravelly, blue-gray, unoxidized...........................	40- 55
	Till, blue-gray, unoxidized	55- 65
	Till, very sandy, blue-gray, unoxidized...........................	65- 75
	Sand and gravel.......................	75- 84
	Till, blue-gray, unoxidized	84- 90
	Sand and gravel.......................	90- 93
	Till, blue-gray, unoxidized	93- 99
	Sand	99-101
	Till, blue-gray, unoxidized	101-105
	Till, very sandy and gravelly, blue-gray, unoxidized......................	105-115
Kn	Marl, light olive-gray (5Y 6/1); speckled, strongly calcareous; shell fragments; coal	115-135 T.D.

SANBORN COUNTY

Test hole 107-62-2dddd — Elevation 1,292 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qwl	Soil	0- 1
	Sand, dark reddish-brown	1- 7
	Sand, medium, to gravel, fine, yellow-brown	7- 12
	Silt to sand, coarse, brown, interlayered with silty, sandy gray till	12- 60
	Till, gray, unoxidized; tough drilling	60- 70 T.D.

SANBORN COUNTY

Test hole 107-62-12cccc — Elevation 1,292 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qwl	Sand, very fine to medium; silt	0- 7
	Sand, fine to coarse	7- 17
	Sand, very fine to medium, gray; silt and clay	17- 22
	Silt to sand, medium; interbedded with unoxidized till	22- 49
	Till, gray, unoxidized; silt and sand	49- 65
	Till, gray, unoxidized, tough; hard drilling	65- 70 T.D.

SANBORN COUNTY

Well 107-62-21dbdb — Elevation 1,308 feet
Drilled 1890, G

Geologic unit	Material	Depth below land surface (feet)
Qu	(Till), clay, yellow	0- 25
	Till, blue	25- 45
	Sand	45- 58
	Hardpan	58- 65
	Sand	65- 95
Qu and Kn	Hardpan and gravel; soft water at 160 feet	95-165
Kn and Kc	Shale; pyrite	165-412
Kg (?)	Sandstone	412-436
Kgs	Shale; pyrite	436-637
	Limestone	637-645
	Shale; flow near top	645-690
Kd	Hard rock	690-692
	Shale	692-697
	Sandstone; flows at top and middle	697-775 T.D.

SANBORN COUNTY

Test hole 107-62-23aaaa — Elevation 1,294 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, silty	0- 3
	Till, silty, gray-brown, oxidized	3- 15
	Till, silty, gray-brown to gray; unoxidized	15- 35
	Till, gray, unoxidized	35- 40
	Till, silty, gray, unoxidized	40- 53
	Sand, very fine to medium, silty; clay	53- 77
	Till, gray, unoxidized	77- 84 T.D.

SANBORN COUNTY

Test hole 107-62-26aaaa — Elevation 1,294 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
	Till, sandy silt, yellow-brown, oxidized	2- 15
	Till, sandy silt, oxidized	15- 22
	Till, sandy silt, gray, unoxidized	22- 42
	Clay, silt, and sand	42- 47
	Silt and sand, very fine to coarse	47- 57
	Till, silty, gray, unoxidized	57- 70
	Silt and sand, very fine to very coarse	70- 83
	Till, unoxidized; hard drilling	83-117 T.D.

SANBORN COUNTY

Test hole 107-62-35aaaa[1] — Elevation 1,287 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 1
Qld	Clay, light-tan to cream, soft, many small snail shells	1- 5
Qwl	Till, sandy silt, oxidized	5- 17
	Till, sandy silt, gray, unoxidized	17- 20
Qwe	Sand, medium, silty	20- 27
	Till, sandy silt, gray, unoxidized	27- 61
	Sand, very fine to coarse, silty; thin clay layers	61- 73
	Till, unoxidized, tough; hard drilling	73- 75 T.D.

SANBORN COUNTY

Test hole 107-62-36cccc — Elevation 1,287 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
Qwl	Till, sandy silt, brown, oxidized	2- 5
	Sand, fine to very coarse, brown; gray-brown below 9 feet	5- 17
	Silt and sand, very fine to coarse; interbedded with till, sandy silt, gray, unoxidized	17- 24
	Till, sandy, gray, unoxidized; hard drilling	24- 49
Qwe	Silt and sand, very fine to coarse; brownish-gray, oxidized	49- 68
	Till, sandy-gravelly clay, gray, unoxidized; very hard drilling	68- 75 T.D.

MINER COUNTY

Test hole 108-58-30cccc — Elevation 1,333 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 4
	Sand	4- 9
	Rock	9- 10
	Sand	10- 13
	Clay	13- 15
	Clay and sand, interbedded	15- 37
	Sand, coarse, clayey	37- 60
	Sand, fine; lignite; clay and sand layers from 67 to 70 feet	60- 85
	Sand, fine to coarse; lignite	85- 92
Kp	Shale, silty, medium dark-gray (N4), bentonitic, noncalcareous; montmorillonite, medium bluish-gray (5B 5/1); coal, pyrite; prismatic calcite	92-105 T.D.

SANBORN COUNTY

Test hole 108-59-7cccc | Elevation 1,321 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, yellowish-brown, oxidized	0- 5
	Till, oxidized; sand, coarse............	5- 22
	Till, gray, unoxidized	22- 25
	Sand, fine to coarse, clayey	25- 72
	Clay, gray; sand......................	72- 75
	Sand, fine to medium; gravel	75- 80
	Sand, fine to medium, clayey...........	80-105
	Sand, fine to medium, fairly well-sorted	105-117
Kn	Clay, light-gray (N7), highly calcareous, bentonitic; foraminifers	117-120 T.D.

Remarks: 0 to 60 feet from first hole, abandoned because of caving sand. 60 to 120 feet from second hole nearby.

SANBORN COUNTY

Test hole 108-59-9cccc | Elevation 1,319 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Sand, fine to medium, clayey, brown	0- 11
	Till, brown, oxidized; rock at 12 feet	11- 13
	Till, gray, unoxidized	13- 18
	Clay, silty, dark blue-gray	18- 20
	Till, gray, unoxidized	20- 40
	Till, gray, unoxidized; sand, coarse	40- 45
	Sand, coarse, and gravel; till; lignite below 50 feet.........................	45- 59
	Sand, fine to coarse, and gravel; till, lignite................................	59- 60
	Sand, coarse, and gravel; rocks from 84 to 85 feet	60-100
	Sand and gravel, medium..............	100-105
Kn	Clay, silty, light-gray (N7), highly calcareous, bentonitic; foraminifers	105-110 T.D.

SANBORN COUNTY

Test hole 108-59-10dddd$_2$ Elevation 1,351 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qwl	Till, yellow-brown, oxidized	0- 18½
	Till, gray, unoxidized	18½- 30
	Till, gray, unoxidized, sandy...........	30- 35
Qwe	Sand, coarse, and gravel; clay..........	35- 40
	Till, unoxidized; sand and gravel........	40- 55
	Sand, gravel, and till.................	55- 72
	Sand, fine, and gravel; lignite	72- 75
	Sand and gravel, coarse; lignite.........	75- 85
	Sand and gravel, coarse; lignite; some clayey, fine sandy till(?)	85- 95
	Till, dark-gray, unoxidized; sand	95-127
Kn	Shale, light-gray, calcareous...........	127-129 T.D.

SANBORN COUNTY

Test hole 108-59-12aaab Elevation 1,363 feet
Drilled 1961, Es

Qwl	Till, yellow-brown, oxidized	0- 18
Qwe	Sand, coarse	18- 20
	Till, gray, unoxidized, and sand, coarse	20- 25
	Sand, medium; till......................	25- 30
	Clay and silt, gray	30- 35
	Sand and till...........................	35- 40
	Till, gray, unoxidized; sand and gravel ..	40- 52
Kp	Shale, silty, medium dark-gray (N4), fissile, noncalcareous; montmorillonite, light bluish-gray (5B 7/1); pyrite..............................	52- 59 T.D.

SANBORN COUNTY

Test hole 108-59-13dddd — Elevation 1,368 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Till, clayey, brown, oxidized	0- 24
	Till, gray, unoxidized; some sand	24- 46
	Sand, medium to coarse; lignite	46- 70
	Sand, coarse, and gravel, fine	70- 75
	Sand, very coarse; gravel from 80 to 81 feet	75- 81
	Sand, fine to medium	81-105
Kp	Shale, bentonitic, medium light-gray (N6) to light olive-gray (5Y 6/1), non-calcareous	105-107 T.D.

SANBORN COUNTY

Well 108-59-21abaa — Elevation 1,343 feet
Drilled 1956, G

Geologic unit	Material	Depth below land surface (feet)
Qu	Electric log tops:	
	Glacial drift(?); (surface casing from 0 to 136 feet)	0-110(?)
Kn	Niobrara Marl	110(?)-188
Kc	Carlile Shale	188-224
Kcc	Codell Sandstone Member of Carlile Shale	224-324
Kc	Carlile Shale	324-424
Kg	Greenhorn Limestone	424-439
Kgs	Graneros Shale	439-583
Kd	Dakota Group	583-675
p€u	Altered rhyolite	675-730 T.D.

SANBORN COUNTY

Well 108-59-22cccc$_4$ — Elevation 1,349 feet
Drilled 1952, G

Geologic unit	Material	Depth below land surface (feet)
	Electric log tops:	
	Surface casing	0-417
Kc	Carlile Shale	417-426
Kg	Greenhorn Limestone	426-438
Kgs and Kd	Graneros Shale and Dakota Group	438-660 T.D.
	An older well nearby records the following:	
	Top Precambrian rocks	680
	Chlorite schist, cored	740
	Dark porphyry, cored	776 T.D.

SANBORN COUNTY

Aquifer test well 108-59-29bbab — Elevation 1,311 feet
Drilled 1962, E

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- $2\frac{1}{2}$
Qwl	Sand, medium to gravel, medium (brown?) to rusty, oxidized	$2\frac{1}{2}$- 6
	(Till), silty-sandy clay, yellow-brown to light-brown, oxidized	6- 12
	(Till), sandy-gravelly clay, medium- to blue-gray, unoxidized	12- 17
	(Till), silty-sandy clay, medium blue-gray, unoxidized	17- 23
Qwe	(Till), silty-sandy clay; medium-brown to brownish-gray, oxidized; some pebbles	23- 30
	(Till), silty-sandy clay, medium blue-gray, unoxidized; some pebbles	30- 34
	Sand and gravel, clayey(?)	34- 37
	(Till), silty-sandy clay, medium to dark blue-gray, unoxidized; some pebbles	37- 62
	Sand, fine to gravel, fine, brown, oxidized; coarse from 80 to 99 feet	62-104
Kn	Shale, light-gray, highly calcareous	104-105 T.D.

SANBORN COUNTY

Test hole 108-60-8dddd — Elevation 1,323 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil and till, brown, oxidized	0- 5
	Till, brown, oxidized	5- 25
	Till, gray, and sand, coarse	25- 40
	Till, dark bluish-gray, and silt	40- 45
	Till, gray; sand, coarse; silt	45- 50
	Till, gray; silt	50- 60
	Sand, fine to coarse; clay	60- 74
	Boulder	74- 75
	Sand, fine to coarse, and gravel; clay; boulder at 98 feet	75-110
	Till; some sand	110-115
Kn	Shale, light-gray (N7), calcareous; foraminifers	115-130 T.D.

SANBORN COUNTY

Test hole 108-60-10dddd — Elevation 1,324 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil and till, brown, oxidized	0- 5
	Till, yellowish-brown, oxidized	5- 10
	Till, yellowish-brown, oxidized; sand, fine to medium........................	10- 20
	Sand, fine to coarse; clay; boulders from 25 to 30 feet	20- 30
	Till, gray, unoxidized; sand and gravel ..	30- 50
	Till, gray, unoxidized; clay, silty, dark-gray	50- 60
	Sand, coarse, and gravel, fine; lignite ..	60-105
	Sand, fine to very coarse	105-124
Kn	Shale, slightly silty, light-gray (N7), strongly calcareous; foraminifers........	124-129 T.D.

SANBORN COUNTY

Well 108-60-21dddc — Elevation 1,308 feet
Drilled 1961, G

Qu	(Till) clay, yellow	0- 20
	(Till) clay, blue, gravelly..............	20- 84
	Sand(?)..............................	84- 97
	(Till) clay...........................	97-102
	Sand	102-116
Kn	Shale, sandy, mixed with chalk (probable top of Niobrara Marl at 125 feet; losing circulation below 125 feet)	116-140
Kn and Kc	Chalk, white; rock 8 inches thick at 265 feet (top of Carlile Shale at approximately 210(?) feet, by interpolation)	140-265
Kcc	Sand	265-298
Kc	Shale; rock 2 inches thick at 325 feet....	298-360
Kc and Kg	Shale, hard; rocks at 400, 442, and 445 feet; Greenhorn Limestone probably about 420 to 445 feet..............	360-445
Kgs	Shale, soft; rocks at 552, 582, 595, 610, 620, and 627 feet	445-702
Kd	Sand; flow 6 gpm......................	702-734
	Shale................................	734-735 T.D.

SANBORN COUNTY

Test hole 108-60-27cccc$_2$ — Elevation 1,300 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
	Till, oxidized	2- 12
	Till, unoxidized	12- 32
	Sand, fine to coarse	32- 50
	(Till), sandy-silty clay	50- 60
	Till, unoxidized	60- 65
	Silt; clay and sand	65- 70
	Till, unoxidized	70- 90
	Silt, to sand, coarse	90-112
	Till, tough; hard drilling	112-117 T.D.

SANBORN COUNTY

Test hole 108-60-32cddd — Elevation 1,291 feet
Drilled 1961, B

Geologic unit	Material	Depth below land surface (feet)
Qwl	Clay, sandy, buff	0- 15
	Clay, sandy, gray	15- 31
Qwe	Gravel, medium	31- 35
	Clay, sandy, gray	35- 39
	Sand, coarse, and gravel, medium	39- 60 T.D.

SANBORN COUNTY

Well 108-60-35dddc — Elevation 1,299 feet
Drilled 1959, G

Geologic unit	Material	Depth below land surface (feet)
Qu	(Till), clay	0- 47
	Sand	47- 48
	(Till), clay	48- 95
	Sand	95-103
Kn	Chalkrock	103-122 T.D.

SANBORN COUNTY

Test hole 108-61-7cccc — Elevation 1,302 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qwl	Till, brown, oxidized	0- 12
	Till, gray, unoxidized	12- 14
Qwe	Clay, orange-brown	14- 15
	Till, gray, unoxidized; sand, fine, gray at 23 feet; sand stringers from 25 to 30 feet	15- 30
	Sand, coarse, and clay	30- 35
	Till, gray, unoxidized; some sand, very coarse, and gravel	35- 58
	Sand, fine	58- 87
	Sand, coarse; lignite; boulder at 91 feet	87- 95
	Sand, fine; lignite	95-105
	Sand, coarse	105-128
Kn (?)	Shale, silty, bentonitic, noncalcareous	128-130 T.D.

SANBORN COUNTY

Test hole 108-61-10addd — Elevation 1,283 feet
Drilled 1961, Es

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil and till, sandy, brown, oxidized	0- 5
	Till, clayey, brown, oxidized	5- 10
	Till, brown, oxidized; sand	10- 25
	Till, light-gray, unoxidized	25- 30
	Till, dark-gray, unoxidized; gravel near bottom of interval	30- 60
	Till, dark-gray, unoxidized; sand	60- 65
	Sand, medium to coarse, and gravel	65- 70
	Sand	70- 75
	Clay, sand, and gravel	75- 80
	Sand, very fine to coarse, and gravel; lignite	80-110
Kn	Marl, medium light-gray, speckled, highly calcareous; foraminifers. Non-bentonitic; negative reaction to benzidine test	110-124 T.D.

SANBORN COUNTY

Test hole 108-61-10cddd — Elevation 1,227 feet
Drilled 1961, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 3
Qal	Silt to sand, fine, dark-brown; some clay and sand, medium	3- 12
	Silt to sand, fine, brownish-gray to grayish-black	12- 26
Qwl	Till, silty, medium-gray	26- 40
Qwe	Till, clay, chalky, brownish-gray	40- 46(?)
Kn (?)	Shale(?)	46(?)- 74
Kn	Shale(?), brownish-gray	74- 81
	Shale(?), light-gray, tough	81- 87 T.D.

SANBORN COUNTY

Test hole 108-61-13aaba — Elevation 1,318 feet
Drilled 1961, Es

Qu	Soil and till, brown, oxidized	0- 5
	Till, clayey, brown, oxidized	5- 28
	Till, gray, unoxidized	28- 30
	Till, dark bluish-gray, unoxidized	30- 60
	Till, dark bluish-gray, unoxidized, some sand	60- 86
	Sand	86- 90
	Sand and gravel; clay	90-100
	Clay, sand, fine to coarse, and gravel; boulder at 108 feet	100-110
	Sand, coarse, and gravel, coarse	110-115
	Sand, medium(?), and gravel	115-125
	Sand, fine to coarse	125-130
	Sand, very coarse, and gravel	130-140
	Sand and gravel, coarse	140-155
Kn	Marl, speckled, calcareous; foramifers; lignite; pyrite	155-158 T.D.

Remarks: Even though the fragments of marl are few, the top of the Niobrara Marl is believed to be at 155 feet.

SANBORN COUNTY

Well 108-61-17aacc$_2$ — Elevation 1,300 feet
Drilled 1962, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, silty-sandy clay, medium-brown	0- 1
	(Till), silty-sandy clay, medium-brown	1- 10
	Sand, fine to very coarse, clayey, medium-brown	10- 12
	(Till), silty-sandy clay, medium-brown	12- 22
	Sand, fine to medium, silty, medium- to light-brown	22- 27
	(Till), silty-sandy clay, medium-brown	27- 37
	Sand, clayey, medium grayish-brown	37- 40
	(Till), silty-sandy clay, medium-gray, unoxidized	40- 47
Qwe	Sand, fine to medium, clayey, medium grayish-brown, oxidized(?)	47- 52
	(Till), silty-sandy clay, medium-gray	52- 63
	Sand, fine to medium, grayish-brown	63- 65
	(Till?), clay and sand interbedded	65- 71
	Sand, fine to medium, clean, well-sorted, well-rounded, dark-brown, oxidized	71-113
	(Till), silty-sandy clay, medium dark-gray	113-127 T.D.

Remarks: Niobrara Marl penetrated at 142 feet in well 78 feet south-southeast of this well.

SANBORN COUNTY

Test hole 108-61-26bbbb — Elevation 1,301 feet
Drilled 1961, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, brownish-black	0- 2
	Till, yellowish-brown, oxidized; dark-brown below 7 feet and grayish-brown below 23 feet	2- 34
	Till, medium- to dark-gray, unoxidized; very hard drilling	34- 83
	Till, silty, medium- to dark-gray, unoxidized	83-101
	Silt to sand, very coarse	101-124
	Sand, medium to gravel	124-135
Kn	Shale, medium tannish-gray, calcareous	135-152 T.D.

SANBORN COUNTY

Well 108-61-27dcdc2 — Elevation 1,309 feet
Drilled 1952, G

Geologic unit	Material	Depth below land surface (feet)
	Electric log tops (not logged below 674 feet):	
	Surface casing	0-176
Kn	Niobrara Marl	160(?)-232
Kc	Carlile Shale	232-252
Kcc (?)	Codell Sandstone Member of Carlile Shale	252-290
Kc	Carlile Shale	290-438
Kg	Greenhorn Limestone	438-460
Kgs and Kd	Graneros Shale and Dakota Group	460-950 T.D.

SANBORN COUNTY

Well 108-61-31ddcd — Elevation 1,280 feet
Drilled 1961, G

Geologic unit	Material	Depth below land surface (feet)
Qu	(Till), clay	0- 32
	Sand	32- 48
	(Till), clay, soft	48-160
Kn	Shale, sandy	160-170
	Chalk	170-206 T.D.

SANBORN COUNTY

Test hole 108-61-32cccc — Elevation 1,275 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qal	Sand	0- 3
Qwl	Till, silty and sandy, oxidized	3- 6
	Till, unoxidized; hard drilling	6- 30
Qwe	Sand, fine to medium; some silt	30- 57
	Sand, medium and gravel	57- 62
	Sand, medium	62- 65
	Sand, medium to coarse and gravel	65- 66
	Sand, medium to coarse; stopped by boulder	66- 95 T.D.

Remarks: Rocky zone from 3 to 7 feet.

SANBORN COUNTY

Test hole 108-61-33cccc — Elevation 1,292 feet
Drilled 1960, D

Qu	Soil	0- 1
	Till, sandy-gravelly clay	1- 38
	Silt and sand	38- 68
	Till	68- 75 T.D.

SANBORN COUNTY

Test hole 108-61-33dddd — Elevation 1,299 feet
Drilled 1960, D

Qu	Soil, silty	0- 3
	Till, silty	3- 14
	Till	14- 60 T.D.

SANBORN COUNTY

Test hole 108-61-35cccc — Elevation 1,290 feet
Drilled 1961, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, brownish-black	0- 1
	Till, yellowish-brown, oxidized	1- 20
	Sand, medium, light-brown; clay and fine sand	20- 34
	Clay, silty and sandy	34- 37
	Till, silty, medium-gray, unoxidized	37-100
	Sand, medium to coarse; gravel	100-104
	Till, unoxidized; hard drilling	104-141
Kn (?)	Bedrock; no sample	141-142 T.D.

SANBORN COUNTY

Test hole 108-62-11cccc — Elevation 1,300 feet
Drilled 1961, D

Qal	Sand, medium to gravel, red-brown to gray-brown	0- 17
Qwl and Qwe	Till, sandy and gravelly, gray-brown to black; dark-gray to blue-gray below 20 feet	17-105
Qwe	Sand and gravel	105-117
	Sand	117-130
	Till, gravelly, calcareous; hard drilling	130-152 T.D.

SANBORN COUNTY

Test hole 108-62-16bbbb — Elevation 1,312 feet
Drilled 1961, D

Qu	Soil, sandy silt, black	0- 2
Qld	Silt, slightly sandy, yellow; yellow-brown below 5 feet	2- 7
Qwl	Till(?), clayey-sandy silt, yellow-brown	7- 15
Qwe	Sand, fine to gravel, clayey, yellow-brown; gray, more clay below 19 feet	15- 69
	Till, sandy, gray	69-141
Kn	Shale, dark gray-black, calcareous	141-152 T.D.

SANBORN COUNTY

Test hole 108-62-23aaaa — Elevation 1,293 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
	Sand, fine to medium	2- 5
	Clay, sand, and gravel, medium-brown	5- 9
	Till, medium- to dark-brown, oxidized	9- 15
	(Till), clay, very sandy, light-gray, unoxidized	15- 35
	Till, silty and sandy, unoxidized	35- 41
	Till, unoxidized	41- 72 T.D.

SANBORN COUNTY

Test hole 108-62-23dddd — Elevation 1,294 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 3
	Till, silty	3- 14
	Silt to sand, medium, light-brown	14- 17
	Till, gray, unoxidized	17- 87 T.D.

SANBORN COUNTY

Test hole 108-62-31cccc — Elevation 1,326 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 1
	Till, slightly silty and sandy from 35 to 42 feet	1- 75
	Till, tough; hard drilling	75- 77 T.D.

SANBORN COUNTY

Test hole 108-62-32cccc — Elevation 1,312 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, fine to medium sandy silt	0- 7
	Gravel, very coarse	7- 9
	Sand, fine; gravel	9- 12
	Sand, medium	12- 15
	Sand, medium to coarse; boulders	15- 30
	Sand, medium to gravel, fine	30- 48
	Till, clay	48- 51
	Sand, fine to coarse	51- 66
	Sand, very fine, silty	66- 73
	Sand, fine to medium, very silty	73- 83
	Sand, very fine to fine, very silty	83- 90
	Till, hard	90- 99 T.D.

Remarks: Rocky zone from 15 to 30 feet and below 98 feet.

SANBORN COUNTY

Test hole 108-62-33cccc — Elevation 1,305 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 3
	Sand, very fine to coarse; some silt and gravel	3- 12
	Silt to sand, fine; some thin clay layers; medium to very coarse sand near bottom of interval	12- 73
	Till, tough; hard drilling	73- 75 T.D.

SANBORN COUNTY

Test hole 108-62-34cccc — Elevation 1,305 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
	Till, oxidized	2- 13
	Till, unoxidized; boulders from 23 to 25 feet	13- 25
	Silt and sand	25- 70
	Till; boulders at 72 to 75 feet	70- 75 T.D.

SANBORN COUNTY

Test hole 108-62-34dddd Elevation 1,303 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
	Sand, fine to medium; silt and some gravel from 5 to 7 feet	2- 7
	(Till), silty-sandy clay	7- 17
	Sand, fine to medium; some silt	17- 21
	(Till), silty-sandy clay	21- 28
	Silt and sand, fine to medium; some clay	28- 38
	(Till), silty clay	38- 42
	Silt and sand, fine; some clay	42- 70 T.D.

SANBORN COUNTY

Test hole 108-62-35aaaa Elevation 1,297 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qwl	Soil, silty and sandy; sand increasing downward	0- 4
	Sand, very fine to medium, brown	4- 12
	Sand and clay, gray, unoxidized	12- 20
	Till, gray, unoxidized	20- 28
	Till, very silty, unoxidized	28- 35
	Till, silty and sandy, unoxidized	35- 45
	Till, silty and sandy, unoxidized; easy drilling	45- 54
Qwe	Till, gray-brown, oxidized; hard drilling	54- 77 T.D.

SANBORN COUNTY

Test hole 108-62-36cccc Elevation 1,295 feet
Drilled 1960, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 2
	Till, sandy clay	2- 3
	Sand, fine to coarse	3- 27
	Silt; some clay and fine sand	27- 35
	Silt, sand, and gravel	35- 39
	Silt and sand, very fine to medium; clayey below 65 feet	39- 86
	Till	86- 87 T.D.

JERAULD COUNTY

Test hole 108-63-1aadd — Elevation 1,343 feet
Drilled 1961, B

Geologic unit	Material	Depth below land surface (feet)
Qwl	(Till), sandy clay, buff, oxidized.....	0- 25
Qwe	Sand, coarse to very coarse..........	25- 39
	(Till), very sandy clay, gray, unoxidized.........................	39-132
Kn	Clay, silty, sandy, light-gray (N7), highly calcareous; foraminifers.......	132-140 T.D.

JERAULD COUNTY

Well 108-63-11aca — Elevation 1,322 feet
Drilled 1961, G

Geologic unit	Material	Depth below land surface (feet)
	Electric log tops:	
	Surface casing......................	0-150
Qu	Glacial drift........................	0-165
Kn	Niobrara Marl......................	165-245
Kc	Carlile Shale......................	245-265
Kcc	Codell Sandstone Member of Carlile Shale..............................	265-295
Kc	Carlile Shale......................	295-435
Kg	Greenhorn Limestone...............	435-460
Kgs	Graneros Shale.....................	460-660(?)
Kd	Dakota Group......................	660(?)-986(?) T.D.

JERAULD COUNTY

Test hole 108-63-12dddd — Elevation 1,306 feet
Drilled 1961, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil, sandy, silt, black..............	0- 2
	Sand, silty, brown; clay.............	2- 6
	Till, gravelly and sandy, dark-brown dark blue-gray below 9 feet...........	6- 58
	Sand, very fine to medium, well-sorted, gray..............................	58- 94
	Till(?); harder drilling than sand......	94-108
	Sand(?)............................	108-124
	Sand(?) and gravel..................	124-140
	Sand, fine to very coarse, subangular to subrounded; gravel................	140-152 T.D.

JERAULD COUNTY

Test hole 108-63-26add$_2$ — Elevation 1,320 feet
Drilled 1960, Ds

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 3
Qwl	Till, yellowish-brown, oxidized	3- 13
	Sand, medium-brown	13- 16
	Till, brown, oxidized	16- 19
	Till, medium-gray, unoxidized	19- 40
Qwe	Soil zone (?); clay, dark reddish-brown	40- 42
	Till, yellowish-brown to brown, oxidized	42- 44
	Till, dark-gray to blue-gray, unoxidized	44- 47 T.D.

Remarks: Wood fragments found between 41 and 43 feet; U. S. Geological Survey radiocarbon sample number W-983 dated at 10,350±300 yr. B.P.; sample W-987 dated at 12,530±350 yr. B.P., was wood from a well drilled in 1951, 1½ feet south of this hole.

BEADLE COUNTY

Test hole 109-59-36dddd — Elevation 1,371 feet
Drilled 1961, D

Geologic unit	Material	Depth below land surface (feet)
Qu	Soil	0- 1
	Till, sandy clay	1- 13
	Sand, medium to coarse	13- 15
	Till, gravelly clay	15- 25
	Till, very sandy clay	25- 50
	Till, sandy clay	50- 56
Kp	Shale, blue-black to black, noncalcareous; very hard drilling	56- 70 T.D.

APPENDIX B.--RECORD OF SELECTED WELLS AND TEST HOLES

Well location: See figure 3.

Owner: SDGFP, South Dakota Department of Game, Fish, and Parks; SDGS, South Dakota Geological Survey; SDWRC, South Dakota Water Resources Commission; USBR, U. S. Bureau of Reclamation; USGS, U. S. Geological Survey.

Year drilled: a, about; b, before.

Aquifer or water-bearing unit: Qf, Floyd; Qw, Warren; Knc, Niobrara Marl and Codell Sandstone Member of Carlile Shale; Kc, lower part of Carlile Shale; Kg, Greenhorn Limestone; Kd, Dakota Group.

Method of lift: C, centrifugal pump; P, piston pump; Cy, cylinder pump; J, jet pump; T, turbine pump. Yield: F, natural flow in gallons per minute; Fs, slight flow; Fu, undetermined flow; e, estimated; m, measured; r, reported; >, more than; <, less than.

Use of water: D, domestic; S, stock; I, irrigation; PS, public supply; T, test hole; O, observation well; N, none.

Remarks: Fx, formerly flowed at land surface; Fs, flowed slightly.

Location of wells and test holes shown on Plate 7.

APPENDIX B.--RECORD OF SELECTED WELLS AND TEST HOLES

Well location	Owner	Year completed	Reported depth (feet)	Diameter of casing (inches)	Named aquifer or water-bearing unit	Method of lift and yield	Use of water	Water temperature at well (°F)	Specific conductance (micromhos per centimeter)	Date of visit or measurement	Altitude of land surface (feet)	Field Test: Hardness	Field Test: Chloride	Field Test: pH	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
							BEADLE COUNTY								
109-59-36dddd	USGS	1961	60	.....	...	...	T	....	.....	11-27-61	1,371	.....	...	...	See log. Water level measured 6.5 feet below land surface.
							DAVISON COUNTY								
104-62-6aaaa	USBR	1954	135	.....	...	...	T	....	.....	1954	1,352	.....	...	...	See log.
							HANSON COUNTY								
104-59-1aaaa	SDGS	1961	150	.....	...	...	T	....	.....	10-27-61	1,311	.....	...	...	See log. Water level measured 13.2 feet below land surface.
							JERAULD COUNTY								
108-63-1aadd	SDGS	1961	140	.....	...	...	T	....	.....	10-21-61	1,343	.....	...	...	See log. Water level measured 28 feet below land surface.
108-63-11aca	City of Alpena	1961	986	.....	Kd	F	PS	....	.....	....	1,322	.....	...	...	See log.
108-63-12dddd	USGS	1961	152	.....	...	...	T	....	.....	10-17-61	1,306	.....	...	...	See log. Water level measured 9.0 feet below land surface.
							MINER COUNTY								
105-58-19bbba	L. Chave	1952	365	2	Kd	F 1e	D,S	....	.....	1952	1,308	.....	...	...	See log.
106-58-31cccc	USGS	1961	150	.....	...	...	T	....	.....	7-18-61	1,343	.....	...	...	See log. Water level measured 19.3 feet below land surface.
107-58-6cccc	USGS	1961	129	.....	...	...	T	....	.....	7-24-61	1,343	.....	...	...	See log.
107-58-7cbd1	USGS	1962	85	14	Qf	T	T	50	2,830	10- 9-62	1,328	1,061	62	7.8	See log. Aquifer test well. Water level measured 11.20 feet below land surface.
107-58-18cccc	USGS	1961	155	.....	...	...	T	....	.....	7- 3-61	1,337	.....	...	...	See log. Water level measured 6.0 feet below land surface.
108-58-30cccc	USGS	1961	105	.....	...	...	T	....	.....	7-24-61	1,333	.....	...	...	See log.
							SANBORN COUNTY								
105-59-7adda1	J. Rubendall	1952	550	2	Kd	F 20.0m	D,S	57	2,670	8- 1-60	1,305	948	147	7.3	See chemical analysis.
105-59-15dddd	R. Mitchell	a1912	333	2	Kg	Fs	S	....	2,630	8- 1-60	1,326	1,061	166	7.7	
105-59-17aabb	W. Cope	1958	539	2½	Kd	F 10.0	D,S	56.5	2,530	5-31-60	1,309	993	166	7.3	See log.
105-59-23bcbb2	D. Morgan	1960	140	4	Knc	Cy	D,S	....	2,570	6- 8-60	1,327	734	122	7.5	See chemical analysis. Water level reported 75 feet below land surface.
105-59-36bad	M. Schmit	1955	600	2	Kd	F 14e	S	56	2,640	5-31-60	1,317	991	131	7.6	See chemical analysis.
105-60-4adaa3	A. Stekel	1959	680	2,1¼	Kd	F 20r	S	....	2,580	8- 3-59	1,296	668	105	7.6	See log. Water level reported 72 feet below land surface 1-24-59.
105-60-15dddd1	USBR	1954	165	.....	...	...	T	....	.....	....	1,295	.....	...	...	See log.
105-60-17cccd	W. Welch	1919	440	.....	Kd	F 0.15m	S	57	.....	7-21-59	1,307	.....	...	...	
105-60-25cccd2	USGS	1960	117	.....	...	...	T	....	2,000	9-14-60	1,211	470	70	...	See log and chemical analysis. Water level measured 4.7 feet below land surface.
105-60-28aada2	E. Ruml	1955	166	3	Knc	J	D,S	54.5	2,640	7-29-60	1,304	168	63	7.6	See chemical analysis. Water level reported 88 feet below land surface in 1955.
105-60-30addc	R. Titus	1942	542	3,1¼	Kd	F 5e	S	58	2,480	7-13-59	1,308	850	67	7.0	See chemical analysis.
105-60-31dddd	USBR	1954	135	.....	...	...	T	....	.....	....	1,301	.....	...	...	See log.
105-60-35ddbb	USBR	1962	60	.....	...	...	T	....	.....	1962	1,215	.....	...	...	See log.

Appendix B.--Record of selected wells and test holes--continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
							SANBORN COUNTY--Continued								
105-60-35ddad	USBR	1962	45	.....	...	...	T	....	.....	1962	1,215	.....	...	...	See log.
105-60-36dddd	SDGS	1961	160	.....	...	...	T	....	.....	10-27-61	1,301	.....	...	...	See log. Water level measured 13.2 feet below land surface.
105-61-1ddbb	S. Fitak, Jr.	1958	657	3,2	Kd	F 9.0m	S	58	2,630	10-16-59	1,291	448	67	6.6	See log and chemical analysis.
105-61-3dddd	USGS	1961	152	.....	...	...	T	....	.....	10-17-61	1,290	.....	...	...	See log. Water level measured 11.2 feet below land surface.
105-61-7addc	W. Parker	1957	817	$1\frac{1}{2}$	Kd	F 25.0	S	54	2,280	10-15-59	1,288	1,233	87	7.2	See log.
105-61-14ccba	F. Blindauer	b1903	578	2	Kd	...	...	....	.....	....	1,295	.....	...	...	See log.
105-61-15cbd	A. Hurban	1952	160	.....	Knc	J	D	54	2,310	1-17-60	1,305	166	98	7.6	See chemical analysis. Water level reported 30 feet below land surface in 1952.
105-61-15dbd	Town of Letcher	1936	806	3,2	Kd	F 18.0m	N	60	2,450	5- 2-56	1,288	616	125	7.7	Initial flow reported 55 gpm. Maintains level of municipal swimming pool and lake.
105-61-15dcaa	Town of Letcher	1940	780	3,2	Kd	F 3e	D,PS	....	.....	1-12-62	1,290	.....	...	...	Supplies city hall and several stores.
105-61-15dcdc	Letcher School	1921	700	3	Kd	F 15e	D,PS	....	2,470	12-27-61	1,303	514	125	7.7	
105-61-18daa2	A. Larimer	1946	830	3,2	Kd	F 20e	S	58	2,410	7-24-59	1,315	1,130	66	6.8	See chemical analysis.
105-61-23bbb	D. Swank	1894	580	3,2	Kd	...	...	....	.....	....	1,303	.....	...	...	See log. Flow reported 300 gpm in 1894.
105-61-31cccc	SDGS	1961	100	.....	...	...	T	....	.....	10-27-61	1,308	.....	...	...	See log. Water level measured 8.3 feet below land surface.
105-61-32dddd	USBR	1954	105	.....	...	...	T	....	.....	....	1,308	.....	...	...	See log.
105-61-35aaad1	J. Hoffman	1951	157	3	Knc	Cy	D,S	....	3,030	10-19-59	1,306	302	45	8.0	See chemical analysis.
105-61-35aaad2	J. Hoffman	a1942	a365	$1\frac{1}{2}$	Kg	F 1.0m	S	55	2,360	10-19-59	1,306	1,120	63	6.8	See chemical analysis.
105-61-35bbbb	USGS	1960	87	.....	...	...	T	....	.....	9-21-60	1,305	.....	...	...	See log.
105-61-36cccc	USGS	1960	60	.....	...	...	T	....	.....	9-21-60	1,307	.....	...	...	See log. Dry hole.
105-61-36dadd	SDGS	1961	160	.....	...	...	T	....	.....	10-27-61	1,298	.....	...	...	See log. Water level measured 15.0 feet below land surface.
105-62-3cbbb	USGS	1960	107	.....	...	...	T	....	.....	7-16-60	1,296	.....	...	...	See log.
105-62-3cccc	USGS	1960	120	.....	...	...	T	....	.....	7-16-60	1,300	.....	...	...	See log.
105-62-10bccc	USGS	1960	120	.....	...	...	T	....	.....	7-15-60	1,310	.....	...	...	See log.
105-62-10cccc	USGS	1960	115	.....	...	...	T	....	.....	7-15-60	1,302	.....	...	...	See log.
105-62-13cddc1	A. Berg	1957	120	3	Knc	J	D	....	2,330	10- 6-59	1,285	45	253	7.8	See chemical analysis. Water level reported 17 feet below land surface in 1957.
105-62-16daad	USGS	1960	110	.....	...	...	T	....	.....	7-15-60	1,302	.....	...	...	See log.
105-62-21aaaa	USBR	1954	125	.....	...	...	T	....	.....	....	1,301	.....	...	...	See log.
105-62-28aada	USGS	1961	152	.....	...	...	T	....	.....	10-18-61	1,313	.....	...	...	See log. Water level measured 5.6 feet below land surface.
105-62-31cccd2	SDGS	1961	140	.....	...	...	T	....	.....	10-27-61	1,354	.....	...	...	See log. Water level measured 25.2 feet below land surface.
105-62-32bbcb1	W. Mathis	1959	742	$1\frac{1}{4}$	Kd	F 7.5m	S	59	2,440	9-28-59	1,356	1,330	79	7.0	See chemical analysis. Copper casing.
105-62-33bccb1	M. Uhre	1955	140	3	Knc	Cy	D,S	....	2,190	9-28-59	1,338	79	203	7.7	See chemical analysis. Water level reported 26 feet below land surface in 1955.
105-62-34cccc	USBR	1954	110	.....	...	...	T	....	.....	....	1,329	.....	...	...	See log.
106-59-1ccba	L. Weabee	1956	135	$2\frac{1}{2}$	Qf	F 18m	S	50	2,250	2-10-60	.....	715	74	7.4	See chemical analysis.
106-59-4cdca	City of Artesian	1930	265	.....	Knc	Cy	PS	51	.....	7- 7-59	.....	.....	...	...	Furnishes water for municipal swimming pool.
106-59-8cccb	K. McKillop	1960	700	$2,1\frac{1}{4}$	Kd	F 3.5m	S	58	2,700	9-11-61	1,308	188	138	7.8	See log. Initial flow reported 12 gpm.
106-59-9babc	City of Artesian	1902	708	$6,2\frac{1}{2}$	Kd	Fu	PS	60	.....	....	.....	.....	...	...	See log. Initial flow reported 125.
106-59-9bada	City of Artesian	1949	850	$4,2\frac{1}{4}$	Kd	F 20r	PS	....	.....	2- 6-60	1,315	.....	...	...	Initial flow reported 25 gpm.
106-59-9bdba	Artesian School	1924	760	$1\frac{1}{4}$	Kd	F 3e, P	PS	....	.....	8- 7-59	1,315	.....	...	...	
106-59-12aaaa	USGS	1961	140	.....	...	...	T	....	.....	7-18-61	1,315	.....	...	...	See log. Water level measured 3.2 feet below land surface.
106-59-13ddca	R. Threadgold	1962	100	18	Qf	T	I	49	2,250	9-10-62	1,318	856	162	7.5	Aquifer test well. Water level measured 0.40 feet above land surface.
106-59-13dddd	USGS	1961	152	.....	...	...	T	....	.....	10-18-61	1,318	.....	...	...	See log. Water level measured 5.6 feet below land surface.
106-59-17aaaa2	R. Peer	a1894	692	2	Kd	Fu	D,S	54	2,740	9-17-59	1,318	325	122	7.9	See log.
106-59-18aaad1	K. McKillop	1960	745	.....	Kd	...	N	....	.....	....	1,312	.....	...	...	See log.
106-59-23ddd	E. Hein	1955	a125	.....	Qf	Cy	S	49	2,170	9-28-59	.....	544	101	7.4	See chemical analysis. Water level reported 15 feet below land surface in 1955.

Appendix B.--Record of selected wells and test holes--continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
							SANBORN COUNTY--Continued								
106-59-24cbb1	E. Hein	1958	610	2	Kd	F 4.0m	D,S	....	2,790	9-28-59	1,328	223	140	7.6	See log. Initial flow reported 5 gpm.
106-59-26dbb	R. Hamm	1954	410	2	Kg	F 1.0	S	52	2,880	7-27-60	1,315	396	107	7.1	See chemical analysis. Initial flow reported 15 gpm.
106-59-35ddcb	A. Scott	1955	545	2	Kd	F 6.0m	S	54	2,610	7-25-60	1,320	914	126	7.2	See chemical analysis.
106-60-1ccab1	D. Jones	1958	110	2½	Qf	F 3.5m	S	50	2,340	4-26-60	.....	497	88	7.5	See chemical analysis. Initial flow reported 10 gpm.
106-60-17ddbb	L. Smith	a1954	734	3	Kd	F 6.4m	S	61	2,660	8- 5-59	1,290	625	91	7.4	See chemical analysis.
106-60-24aacc	M. Schmit	1959	130	3	Knc	F 2.2m	S	50	2,330	9-11-59	1,290	154	93	7.4	See chemical analysis.
106-60-26adad	D. Trusty	1956	140	4	Knc	J	D,S	....	2,360	9- 9-59	1,291	104	97	7.9	See chemical analysis. Water level reported 49 feet below land surface in 1955.
106-61-1bbcc1	Town of Forestburg	1952	750	4,2½	Kd	F 60r	PS	....	.....	10-27-59	1,277	605	77	...	See log and chemical analysis.
106-61-1bbcc2	Forestburg School	1934	140	3,2	Knc	Cy	PS	....	2,450	1-10-62	1,280	68	250	7.8	Water level reported 41 feet below land surface on November 30, 1961.
106-61-1bbbd	Town of Forestburg	....	705	4,2½	Kd	...	PS	....	.....	....	.....	.....	...	...	See chemical analysis.
106-61-1cccc	SDWRC	1957	20	1¼	...	...	T,O	....	.....	1958	1,278	.....	...	...	See log and chemical analysis. Water level measured 10.88 feet below land surface.
106-61-3dddd	USGS	1961	130	...	...	...	T	....	.....	6-27-61	1,284	.....	...	...	See log.
106-61-10dddd	H. Peterson	1959	558	2½,1½	Kd	F 8.6m	S	57	2,800	10-27-59	1,283	68	96	7.8	See log. Initial flow reported 10 gpm.
106-61-11acdd	W. Burrill	1959	590	2½,1½	Kd	F 12.0m	S	58	2,960	4-27-60	1,277	86	105	8.2	See log. Initial flow reported 15 gpm.
106-61-12caca	A. Kundert	....	Spring	...	Qw	F 10	D,S	....	1,040	4-27-60	1,240	486	89	7.4	See chemical analysis.
106-61-23bbbb	USGS	1961	142	...	...	...	T	....	.....	6-27-61	1,284	.....	...	...	See log.
106-61-27dddd	USGS	1961	152	...	...	...	T	....	.....	10-17-61	1,290	.....	...	...	See log. Water level measured 10.8 feet below land surface.
106-61-35aacc	A. Zoss	a1895	350	1½	Kg	F 0.75m	S	54	3,100	10-20-59	1,300	50	83	7.2	See chemical analysis.
106-61-36aaaa	A. Zoss	1957	138	2½	Knc	Cy	S	50.5	2,460	10-20-59	1,276	52	110	8.2	See chemical analysis. Water level reported 40 feet below land surface in 1957.
106-62-10cbbc	USGS	1960	155	...	...	...	T	....	.....	7-20-60	1,296	.....	...	...	See log.
106-62-14bda1	E. Larson	1911	594	1	Kd	F 3.0m	S.	55	2,810	11- 1-59	1,315	190	67	6.7	See chemical analysis.
106-62-15adb	M. Nielson	1959	135	2	Knc	F 3.2m	S	50	2,450	10-28-59	1,290	38	219	7.9	See log and chemical analysis. Initial flow reported 9 gpm. Water level reported 2 feet above land surface on September 2, 1959.
106-62-15cbbb	USGS	1960	155	...	...	...	T	....	.....	7-19-60	1,294	.....	...	...	See log.
106-62-16aaad	USGS	1960	145	...	...	...	T	....	.....	7-20-60	1,304	.....	...	...	See log.
106-62-19dddd	E. Larson	1961	160	2½,2	Knc	Cy	S	51.0	2,110	9-11-61	1,312	120	158	7.7	See log. Water level reported 22 feet below land surface on July 28, 1961.
106-62-21aaad	USGS	1960	140	...	...	...	T	....	.....	7-20-60	1,289	.....	...	...	See log.
106-62-27cbbb	USGS	1960	128	...	...	...	T	....	.....	7-19-60	1,291	.....	...	...	See log.
106-62-30bbcd	SDGFP	1959	945	2 7/8	Kd	F 50.0m	PS	62	2,460	4-14-61	1,319	1,310	85	6.9	See log and chemical analysis. Maintains lake level. Water level measured 41.77 feet above land surface on April 14, 1961.
106-62-30bd	SDGFP	a1930	760	8,6	Kd	F 50e	PS	....	.....	11- 1-59	1,314	.....	...	...	Maintains lake level.
106-62-33aaaa	USGS	1960	124	...	...	...	T	....	.....	7-19-60	1,288	.....	...	...	See log.
106-62-33addd	USGS	1960	108	...	...	...	T	....	.....	7-19-60	1,288	.....	...	...	See log.
106-62-33dddd	USGS	1960	112	...	...	...	T	....	.....	7-18-60	1,291	.....	...	...	See log.
106-62-34cccd1	R. Vetter	1956	650	3,1½	Kd	F 4.0	S	....	2,260	10- 7-59	1,290	1,061	96	7.7	See log. Initial flow reported 45 gpm.
107-59-7aadd	V. Olson	1961	122	2	Knc	Fs	...	....	.....	1-10-62	.....	.....	...	...	See log. Water level reported 1.5 feet below land surface on October 31, 1961.
107-59-11abaa	G. Williams	1954	75	2	Qf	F 1.1m	S	48	3,120	5- 9-60	.....	1,020	35	7.4	See chemical analysis. Initial flow reported 2 gpm.
107-59-17adaa1	A. Strand	1959	120	2½	Qf	Cy	D,S	....	.....	5- 2-60	.....	.....	...	...	Fx until 1960.
107-59-17addd	A. Strand	1959	120	2	Qf	...	S	49	2,430	5- 2-60	1,304	542	92	7.4	See log and chemical analysis. Fx until 1961.
107-59-20bbbb	O. A. Olson	1955	930	3,2	Kd	Fu	D,S	....	2,500	5- 2-60	1,306	1,096	149	7.1	See log. Initial flow reported 60 gpm.
107-59-24ddba2	D. Jones	a1958	1,020	3,2	Kd	F 7.9m	D,S	61	2,760	5-31-60	.....	913	149	7.3	See chemical analysis.
107-59-25dddd	USGS	1961	158	...	...	...	T	....	.....	7-12-61	1,330	.....	...	...	See log.
107-59-33bbbc	R. Hazen	1957	120	2	Qf	F 4.8m	D,S	50	2,240	5- 4-60	.....	648	72	7.9	See chemical analysis. Initial flow reported 15 gpm.
107-60-3adda2	C. Talley	1961	930	4,2	Kd	F 42.8m	S	62.5	2,520	10- 4-61	1,301	942	212	7.1	See log. Water level measured 78.96 feet above land surface on October 4, 1961.

Appendix B.--Record of selected wells and test holes--continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
							SANBORN COUNTY--Continued								
107-60-10bcac	J. Burg	....	.....	$1\frac{1}{4}$	Qf	F 1.2m	S	44	2,340	4-27-60	1,300	284	90	7.5	See chemical analysis.
107-60-17aca	O. Schefsky	1959	700	2	Kd	F 13.3m	S	58	2,990	3- 3-60	1,285	188	77	7.6	See chemical analysis.
107-60-26bcca	O. McKillop	1955	924	$3,1\frac{1}{2}$	Kd	F 4.0m	S	58	2,430	5- 3-60	1,305	1,079	175	7.2	See log. Initial flow reported 35 gpm.
107-60-27ddad	K. McKillop	1961	864	$2,1\frac{1}{4}$	Kd	F 6.0m	D,S	60	2,500	9-11-61	1,294	993	225	7.5	See log. Initial flow reported 25 gpm.
107-60-30baab	USGS	1961	87	...	...	...	T	....	.....	....	1,232	.....	...	...	See log.
107-60-30bcb	H. Briggs	1937	114	$2\frac{1}{2},2$	Qw	Cy	D	51	1,520	5-31-60	1,243	82	97	8.3	See chemical analysis. Water level measured 15 feet below land surface June 18, 1947.
107-60-32dddd2	S. Brakke	1958	143	$2\frac{1}{2}$	Knc	J	D,S	....	2,170	4-26-60	1,285	108	87	7.9	See log and chemical analysis. Water level reported 63 feet below land surface on October 26, 1958.
107-61-6bbbb	USGS	1960	77	...	...	...	T	....	1,350	9-13-60	1,288	330	25	...	See log and chemical analysis. Water level measured 9.2 feet below land surface.
107-61-6dddd	SDWRC	1957	22	$1\frac{1}{4}$	Qw	...	O	....	.....	12-15-60	1,283	.....	...	...	See chemical analysis. Water level measured 11.09 feet below land surface.
107-61-20ddd	R. Schmidt	....	170	3	Knc	Cy	S	52	2,160	10-17-60	1,285	58	124	7.5	See chemical analysis.
107-61-23bbbb	USGS	1961	118	...	...	...	T	....	.....	6-26-61	1,290	.....	...	...	See log.
107-61-27cdb	D. Jones	1957	735	2	Kd	F 30m	S	61	2,690	8-30-60	1,285	533	83	7.4	See chemical analysis. Water level measured 40.15 feet above land surface on April 14, 1961.
107-61-28aaaa	USGS	1960	77	...	...	...	T	....	.....	10-11-60	1,288	.....	...	...	See log. Water level measured 7.9 feet below land surface.
107-61-28cdc2	D. Fredericks	1955	400	3,2	Kg	F 3.0m	D,S	56	3,000	9- 6-60	1,293	28	104	7.8	See chemical analysis.
107-61-35bcc	USGS	1961	135	...	...	...	T	....	.....	....	1,283	.....	...	...	See log.
107-61-35cdad	SDGFP	1955	148	4	Knc	Cy	PS	....	2,350	8-30-60	1,285	68	183	8.3	See log. Water level reported 32 feet below land surface in June 1955. Picnic area water supply.
107-61-35cddd	SDGFP	1957	25	6	Qw	Cy	PS	....	5,160	8-30-60	1,280	3,090	2	7.1	See chemical analysis; not used for drinking. Water level reported 10 feet below land surface in September 1957.
107-62-1dba	J. Warren	1962	147	18	Qw	T	I	49	2,380	11-13-62	1,295	685	88	7.0	See log and aquifer test well. Water level measured 13.77 feet below land surface.
107-62-2dddd	USGS	1960	70	...	...	...	T	....	.....	10- 6-60	1,292	.....	...	...	See log. Water level measured 4.8 feet below land surface.
107-62-10abaa1	J. Jensen	....	165	3	Knc or Qw	Cy	S	52	1,790	8-23-60	1,302	39	80	7.4	See chemical analysis.
107-62-11ddad2	R. Patterson	a1955	25	2	Qw	Cy	S	....	3,050	8-23-60	1,295	1,000	26	8.1	See chemical analysis.
107-62-12cccc	USGS	1960	70	...	...	...	T	....	.....	10- 6-60	1,292	.....	...	...	See log. Water level measured 6.7 feet below land surface.
107-62-21dbdb	"Mill Well"	1890	775	...	Kd	...	...	....	.....	....	1,308	.....	...	...	See log.
107-62-21dcac	Town of Woonsocket	1916	775	$2,1\frac{1}{2}$	Kd	F 20e	PS	....	2,240	1-10-62	1,305	762	74	7.1	See chemical analysis. Maintains lake level.
107-62-21dccd	Town of Woonsocket	1958	160	4,3	Knc	J	PS	....	.....	8-24-58	.....	.....	...	...	School well. Water level reported 9.5 feet below land surface. Well capped in 1960.
107-62-21dcdb	Town of Woonsocket	1954	735	6,4	Kd	F 130e	PS	....	2,500	12- 3-61	1,305	817	75	7.6	See chemical analysis. Maintains lake level. Water level measured 55.36 feet above land surface on December 3, 1961.
107-62-21ddcc	Town of Woonsocket	1888	725	6	Kd	...	...	....	.....	....	.....	.....	...	...	See log. Stopped flowing in 1896. Initial flow reported 2,750 gpm at 250 psi by Nettleton (1892).
107-62-23aaaa	USGS	1960	84	...	...	...	T	....	.....	10- 6-60	1,294	.....	...	...	See log.
107-62-25aaaa1	E. Weatherford	....	12	24	Qw	...	N	....	214	8-17-48	.....	107	4	8.0	See chemical analysis. Water level reported 6 feet below land surface.
107-62-26aaaa	USGS	1960	117	...	...	...	T	....	.....	10- 7-60	1,294	.....	...	...	See log. Water level measured 17.0 feet below land surface.
107-62-28aaa	Sanborn County	....	160	$2\frac{1}{2}$	Knc	Cy	PS	....	.....	11-18-61	1,305	.....	...	...	
107-62-28aaba2	Town of Woonsocket	1932	163	8	Knc	T	PS	....	.....	1-10-62	.....	48	84	7.6	See chemical analysis. Main city well.
107-62-28aacb	Town of Woonsocket	1922	163	6	Knc	T	PS	....	.....	1-10-62	1,305	66	96	8.0	See chemical analysis. Auxiliary city well (summer).
107-62-28ab	Unknown	....	160	...	Knc	...	D	....	.....	9- 8-47	.....	.....	...	...	See chemical analysis.
107-62-28abab	Sanborn County	1929	158	$2\frac{1}{2},1\frac{1}{4}$	Knc	P	PS	....	.....	11-18-61	1,305	.....	...	...	Emergency supply for courthouse.
107-62-35aaaa1	USGS	1960	75	...	...	...	T	....	.....	10- 7-60	1,287	.....	...	...	See log. Water level measured 6.68 feet below land surface.

SANBORN COUNTY--Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
107-62-36cccc	USGS	1960	75	...	...	...	T	....	.....	10- 7-60	1,287	.....	...	...	See log. Water level measured 2.4 feet below land surface.
108-59-4daa	H. Headlee	1953	155	3,2	Knc	Cy	D,S	....	2,910	5-12-60	.....	55	128	7.6	See chemical analysis. Water level reported 22 feet below land surface in 1953.
108-59-7cccc	USGS	1961	120	...	...	...	T	....	.....	7- 8-61	1,321	.....	...	...	See log.
108-59-9cccc	USGS	1961	110	...	...	...	T	....	.....	7-11-61	1,319	.....	...	...	See log.
108-59-10dddd2	USGS	1961	129	...	...	...	T	....	.....	7-10-61	1,351	.....	...	...	See log.
108-59-12aaab	USGS	1961	59	...	...	...	T	....	.....	7-11-61	1,363	.....	...	...	See log.
108-59-13adadl	D. DeJong	1954	1,015	3,2	Kd	F 7.5	D,S	58	2,950	5-11-60	.....	129	162	7.7	See chemical analysis. Initial flow reported 30 gpm.
108-59-13dddd	USGS	1961	107	...	...	...	T	....	.....	6-30-61	1,368	.....	...	...	See log.
108-59-20cddb	J. Effling	1959	730	2,1½	Kd	F 9.7m	S	60	3,000	5-11-60	1,307	250	80	7.7	See chemical analysis. Water level measured 29.72 feet above land surface on April 14, 1961.
108-59-21abaa	J. Grassel	1956	730	3,2	Kd	F 1.1m	S	....	2,940	5-12-60	1,343	68	158	7.8	See log.
108-59-22cccc4	J. Austerman	1952	690	2	Kd	...	N	....	.....	....	1,349	.....	...	...	See log.
108-59-29bbab	USGS	1962	104	14	Qf	T	T	49	2,550	8-21-62	1,311	616	158	7.8	See chemical analysis. Aquifer test well. Water level measured 4.95 feet below land surface.
108-60-4addd	A. Newman	1945	120	3,2	Qf	Cy	S	50	2,210	5-23-60	1,319	403	98	7.4	See chemical analysis. Water level reported 22 feet below land surface in 1945.
108-60-8dddd	USGS	1961	130	...	...	...	T	....	.....	7- 6-61	1,323	.....	...	...	See log.
108-60-10dddd	USGS	1961	126	...	...	...	T	....	.....	7- 6-61	1,324	.....	...	...	See log.
108-60-13aaab3	M. Wormstadt	1930	1,092	2½,1½	Kd	F 0.2m	S	....	2,790	5-17-60	.....	257	289	7.8	Initial flow reported 5 gpm.
108-60-20baal	A. Edwards	....	a500	2	Kg	F 5.0m	D,S	....	2,840	5-24-60	1,316	6	162	8.2	See chemical analysis.
108-60-21dddc	G. Crandell	1961	735	4,2	Kd	F 4.0m	D,S	60	2,730	12-27-61	1,310	171	188	7.8	See log. Initial flow reported 6 gpm.
108-60-23bbbal	A. Hollander	1951	959	1½	Kd	Fu	D,S	....	2,780	5-10-60	1,317	745	172	7.2	See chemical analysis. Drilled to 755 feet in 1951, flow reported 7 gpm; later drilled to 959 feet, flow reported 32 gpm at 40 psi. Copper casing.
108-60-27cccc2	USGS	1960	117	...	...	...	T	....	5,700	9-14-60	1,300	1,600	160	...	See log and chemical analysis.
108-60-29dab2	E. Pearson	1955	120	2	Qf	F 0.5m	S	49.5	2,270	5-24-60	1,302	263	219	8.0	See chemical analysis. Initial flow reported 3 gpm.
108-60-32cddd	SDGS	1961	60	...	...	...	T	....	.....	10-27-61	1,291	.....	...	...	See log. Water level measured 8.5 feet below land surface.
108-60-33cccb	J. Spellburg	a1944	60	3	Qf	Cy	D,S	49	2,240	5-24-60	1,304	591	56	7.2	See chemical analysis.
108-60-35dddc	K. Davison	1959	122	2	Qf	F 8.7m	S	50	2,320	5- 3-60	1,299	562	77	7.3	See log and chemical analysis. Initial flow reported 12 gpm at 1 foot above land surface; water level reported 2 feet above land surface January 16, 1959.
108-61-2adba3	S. Pearson	....	160	...	Knc	N	N	50	1,970	7- 7-47	1,299	36	255	7.5	See chemical analysis.
108-61-4bcbal	W. Hegg	b1910	80	2	Qw	J	D,S	52	2,170	10-20-60	1,294	664	65	7.5	See chemical analysis. Water level reported 25 feet below land surface.
108-61-4ccd	T. Hegg	....	80	30	Qw	...	N	....	2,180	10-20-60	1,298	616	60	7.4	See chemical analysis. Water level measured 20 feet below land surface.
108-61-5cdddl	E. Fenske	....	40	18	Qw	Cy	S	50	2,130	10-20-60	1,296	444	102	7.8	See chemical analysis. Water level reported 25 feet below land surface in 1947.
108-61-5dcdl	E. Fenske	....	85	24	Qw	Cy	S	48	5,180	10-20-60	1,296	2,800	183	7.3	See chemical analysis. Water level reported 30 feet below land surface in 1947.
108-61-6ccccl	C. Hegg	....	400	...	Kc	Fs	N	50	2,650	6- 5-47	1,307	59	665	7.8	See chemical analysis.
108-61-6dcdl	W. Kukuk	....	55	18	Qw	Cy	S	50	1,980	10-20-60	1,296	552	68	7.8	See chemical analysis. Water level reported 30 feet below land.
108-61-7babbl	G. Johannsen	....	40	36	Qw	...	N	50	2,230	6- 5-47	1,308	780	86	7.4	See chemical analysis. Water level reported 30 feet below land surface in 1947.
108-61-7cccc	USGS	1961	130	...	...	...	T	....	.....	7- 1-61	1,302	.....	...	...	See log.
108-61-9aadc	C. Hegg	....	Spring	...	Qw	F 3e	S	49	1,610	10-20-60	1,250	291	105	7.8	
108-61-10addd	USGS	1961	124	...	...	...	T	....	.....	7- 5-61	1,283	.....	...	...	See log.

Appendix B.--Record of selected wells and test holes--continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
SANBORN COUNTY--Continued															
108-61-10cddd	USGS	1961	87	...	...	...	T	.....	.....	10-14-61	1,227	.....	...	...	See log.
108-61-13aaba	USGS	1961	158	...	...	...	T	.....	.....	7- 5-61	1,318	.....	...	...	See log.
108-61-17aacc	W. Brosnan	1956	169	16	Qw	...	I	.....	1,760	11-28-62	1,300	288	49	8.1	See log and chemical analysis. Aquifer test well. Water level measured 27.12 feet below land surface.
108-61-17addd	W. Brosnan	1936	73	8	Qw	J	D,S	50	1,710	11-12-60	1,304	297	44	7.5	See chemical analysis. Water level reported 35 feet below land surface.
108-61-18bdcc1	H. Hegg	1918	a760	2	Kd	...	...	.....	2,940	10-20-60	1,322	104	98	7.4	See chemical analysis. Flowed until 1948.
108-61-26bbbb	USGS	1961	152	...	...	...	T	.....	.....	.....	1,301	.....	...	...	See log.
108-61-27dcdc2	M. Loring	1952	950	2½,1½	Kd	F 30r	S	63	2,620	10-20-60	1,309	1,061	275	7.2	See log and chemical analysis. Initial flow reported 60 gpm and 32 psi.
108-61-30daaa	F. Furguson	....	...	2	Knc	Cy	N	50	3,300	10-20-60	1,303	144	804	7.4	See chemical analysis.
108-61-31ddcd	G. Fuerst	1961	206	3,1½	Knc	Cy	S	56.5	2,100	9-11-61	1,285	68	375	7.8	See log. Water level reported 5 feet below land surface on March 30, 1961.
108-61-32cccc	USGS	1960	95	...	...	...	T	.....	1,850	9-13-60	1,275	330	125	...	See log and chemical analysis. Water level measured 6.7 feet below land surface.
108-61-32dddd	W. Brosnan	....	a150	3	Knc or Qw	Cy	D,S	51	2,410	6-19-60	1,298	28	289	8.4	See chemical analysis.
108-61-33cccc	USGS	1960	75	...	...	...	T	.....	.....	9-13-60	1,292	.....	...	...	See log.
108-61-33dddd	USGS	1960	60	...	...	...	T	.....	.....	9-14-60	1,299	.....	...	...	See log. Dry hole.
108-61-35cccc	USGS	1961	142	...	...	...	T	.....	.....	10-15-61	1,290	.....	...	...	See log.
108-62-1ccc1	Nielson Estate	....	48	36	Qw	J	N	.....	4,080	8-29-60	1,325	2,490	78	7.4	See chemical analysis. Water level measured 35.5 feet on June 4, 1947 and 49.8 feet below land surface on December 12, 1956.
108-62-6cddd1	J. Simms Estate	1944	717	3,2	Kd	F 1.0m	...	.....	.....	6-30-47	.....	885	104	...	See chemical analysis.
108-62-8baab2	C. Robeson	....	38	18	Qw	Cy	D,S	.....	2,760	6- 3-47	1,314	1,225	54	8.1	See chemical analysis.
108-62-9dcd	H. Craft	....	30	24	Qw	Cy	N	.....	2,290	8-28-60	1,308	886	57	7.6	See chemical analysis. Water level measured 14.55 feet below land surface on June 27, 1947.
108-62-10dddd2	E. Nelson	1951	220	3,2	Knc	P	D,S	53	3,390	8-29-60	1,299	80	826	7.7	See chemical analysis. Water level reported 8 feet below land surface.
108-62-11cccc	USGS	1961	152	...	...	...	T	.....	.....	10-11-61	1,300	.....	...	...	See log.
108-62-13bcc2	L. Grace	1922	34	18	Qw	Cy	S	.....	3,100	8-29-60	1,310	1,750	81	8.0	See chemical analysis. Water level reported 28 feet below land surface.
108-62-15aadd	J. Lutter	....	25	24	Ow	Cy	S	50	2,440	6-27-47	1,298	556	52	7.6	See chemical analysis. Water level measured 10.85 feet below land surface on June 27, 1947.
108-62-16bbbb	USGS	1961	152	...	...	...	T	.....	.....	10-17-61	1,312	.....	...	...	See log. Water level measured 9.0 feet below land surface.
108-62-18aab	E. Lillie	....	20	20	Qw	Cy	...	.....	2,030	6- 9-47	1,303	384	55	7.6	See chemical analysis. Water level measured 0.9 feet below land surface.
108-62-21cccc	USGS	1961	152	...	...	...	T	.....	.....	10-17-61	1,303	.....	...	...	See log. Water level measured 5.8 feet below land surface.
108-62-23aaaa	USGS	1960	87	...	...	...	T	.....	.....	10- 5-60	1,293	.....	...	...	See log. Water level measured 14.8 feet below land surface.
108-62-23dddd	USGS	1960	72	...	...	...	T	.....	.....	10- 5-60	1,294	.....	...	...	See log. Water level measured 10.45 feet below land surface.
108-62-31cccc	USGS	1960	77	...	...	...	T	.....	.....	9-21-60	1,326	.....	...	...	See log. Dry hole.
108-62-32cccc	USGS	1960	99	...	...	...	T	.....	.....	9-21-60	1,312	.....	...	...	See log. Water level measured 9.9 feet below land surface.
108-62-33cccc	USGS	1960	75	...	...	...	T	.....	1,350	9- 9-60	1,305	200	20	...	See log and chemical analysis. Water level measured 8 feet below land surface.
108-62-34cccc	USGS	1960	75	...	...	...	T	.....	20,500	9-12-60	1,305	4,000	500	...	See log. Water level measured 16.1 feet below land surface.
108-62-34ddaa1	W. & A. Lynch	....	40	2	Qw	Cy	N	.....	1,840	7- 2-47	1,304	50	130	7.8	See chemical analysis. Water level reported 9 feet below land surface.
108-62-34dddd	USGS	1960	70	...	...	...	T	.....	.....	9-12-60	1,303	.....	...	...	See log. Water level measured 9.0 feet below land surface.
108-62-35aaaa	USGS	1960	77	...	...	...	T	.....	.....	10- 6-60	1,297	.....	...	...	See log. Water level measured 9.5 feet below land surface.
108-62-36adaa3	L. Gilbertson	....	12	2½	Qw	Cy	S	.....	1,780	8-29-60	1,292	780	61	8.2	See chemical analysis.
108-62-36cccc	USGS	1960	87	...	...	...	T	.....	2,100	9-12-60	1,295	560	25	...	See log and chemical analysis. Water level measured 6.1 feet below land surface.