STATE OF SOUTH DAKOTA
Sigurd Anderson, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

NO. 74

ARTESIAN CONDITIONS
IN
EAST CENTRAL SOUTH DAKOTA

by

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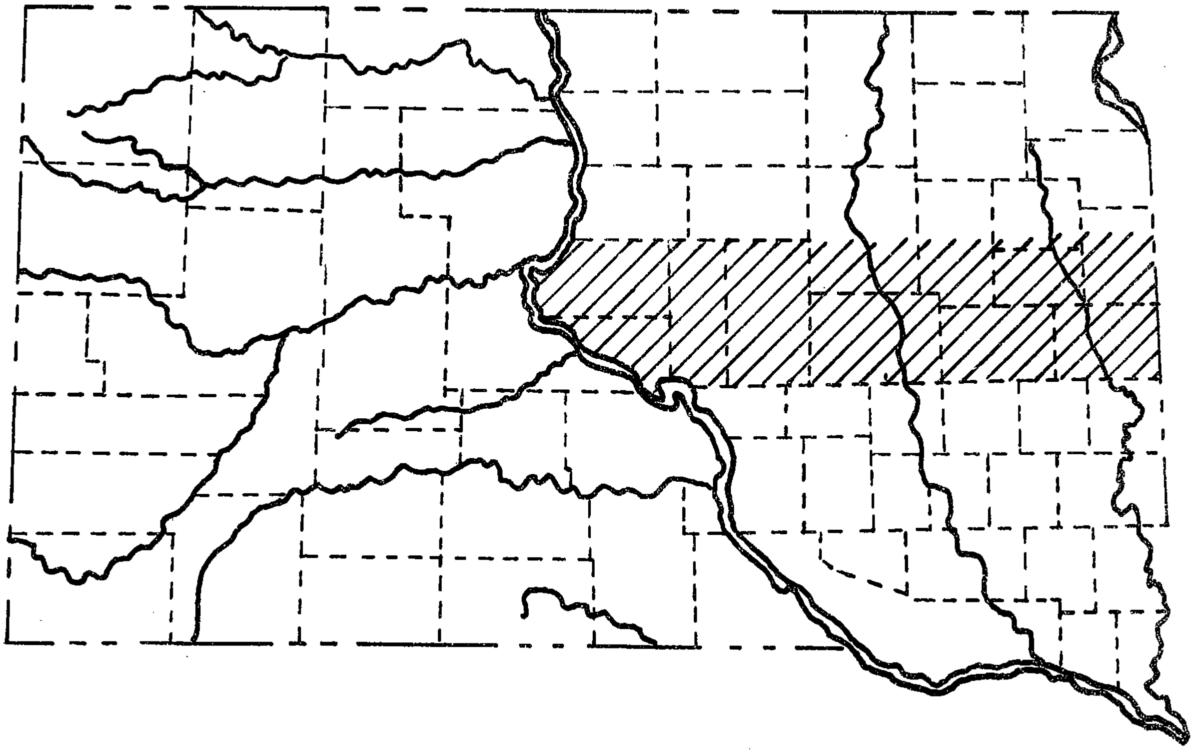
ARTESIAN CONDITIONS

IN

EAST CENTRAL SOUTH DAKOTA

INDEX MAP OF AREA



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INTRODUCTION

Location and Area

The region covered in this report includes Sully, Hughes, Hyde, Hand, Beadle, Kingsbury, Brookings, Hamlin, and the southern part of Spink, Clark, Codington and Deuel counties extending northward through and including Township 116 North. The south county lines of Hughes, Hyde, Hand, Beadle, Kingsbury, and Brookings counties form the southern extent of the area, while the northern limit of the area is formed by the north county lines of Sully, Hyde, and Hand counties. From the eastern extent of Hand county to the Minnesota line the northern limit of the area follows the line formed by the north boundary of T. 116 N. The area covered lies between the Missouri river, the western boundary, and the Minnesota-South Dakota state line, the eastern boundary.

The area covered by this report covers approximately 9,300 square miles or approximately 6,000,000 acres. The area is well supplied with transportation facilities and numerous large towns and cities, some of which are; Pierre, Onida, Miller, Highmore, Huron, DeSmet, Clark, Watertown, Brookings, Clear Lake, and Redfield.

Purpose and Method of Investigation

The primary purpose of making an investigation of this nature was to determine the height above sea level (the static level) to which the waters coming from the Dakota and Lakota sandstones would rise. Also the rate and amount of decline of the static level of the water in the past fifty years was determined.

Secondly the stratigraphy and structure of the area was investigated.

This investigation was made by a two man party consisting of Ronald L. Hale as field assistant and the author as geologist.

The method of investigation was conducted as follows: A brief history of each well including depth, date drilled, driller, location, etc. was obtained. The actual inspection of the well consisted of taking a temperature, pressure, rate of discharge, and elevation reading of the well. The temperature was obtained with a standard Taylor thermometer. The pressure was measured with a standard gauge on wells which were in good condition, otherwise an approximation of the pressure was made. A gallon measure and stop watch were used to determine the rate of discharge, as well as mathematical formulas, where the flow was too great to be determined with a gallon measure. The elevation of each well site was determined largely by the use of an altimeter, with levels carried from precise level bench marks near each well. Topographic maps were also used where the surface relief was gentle.

Since the amount of time required to check all the wells in the area would be too long, a well was measured every three to six miles to determine the piezometric gradient of the water level. In certain parts of the area where the surface elevation was higher above sea level than the piezometric head one encountered only pumped artesian wells. In this area a line was placed in the well to determine how far the water rose toward the surface. Many times, however, pumped wells cannot be measured by this method except by removing all the pump rods from the well. The information then had to be obtained from the well owners. This information was in some cases misleading for many times the well had not been pulled for two or three years. Another factor which tended to mislead was the amount of drawdown in the well. If the drawdown was large, more well rods had to be used to obtain a sufficient amount of water when the well was pumping steady, but if the drawdown was small the number of pump rods would nearly be an indication of how far the water would rise toward the surface. Thus, the number of feet of pump rods in the well had no bearing on the height to which the water would rise toward the surface unless one had an approximate idea as to what the drawdown actually was in feet.

In most cases this could not be obtained. Still another factor which made investigations difficult was that some wells produce from both the Dakota and Lakota sandstones thus giving a combined result of the two.

Previous Investigations

Few investigations of artesian water conditions have been carried on in this state, especially in the last forty years. The first investigation of artesian water in this particular region was made by Nettleton (1892), an engineer employed by the United States Department of Agriculture. He made a general investigation to determine pressures, depths, and flows of artesian wells in North and South Dakota during 1890 and 1891.

A more detailed study of the artesian basin in South Dakota was made for the United States Geological Survey by Darton (1896). Darton's preliminary report investigated the location of the water-bearing beds and the limits of the territory in which artesian flows were expected in South Dakota and adjoining states. Todd (1898) made several investigations of the geology and underground water resources in this state some of which are in the same regions covered by this report. Darton (1909) wrote a second report for the United States Geological Survey concerning artesian water. He investigated the geologic conditions that had a bearing on the occurrence of artesian water in South Dakota.

By comparing these investigations with the data obtained in the present survey it is possible to record the decline in head or water pressure during the past sixty years.

Acknowledgements

The author expresses appreciation for the help received from Mr. Bruno Petsch, who contributed all electric log data; Mr. Francis Buckmeier, who assisted the author during the latter part of June before the regular field season began; and Dr. E. P. Rothrock, under whose supervision this report was written.

Thanks is also given to the State Geological Survey staff who printed and assembled this report.

Appreciation is also expressed for the kind cooperation received from well drillers and well owners operating in the area, thus making this report possible.

GEOLOGY OF THE AREA

PROCEDURES FOR OBTAINING STRATIGRAPHIC INFORMATION

Examination of Well Samples

The information used for making well logs of subsurface formations of this area was interpreted from sample cuttings and from electric logs.

The cuttings collected from the different wells were studied with the aid of a microscope to determine the lithologic character of each formation. Since each formation has definite, distinguishing, lithologic characteristics, it is not extremely difficult to determine the thickness as well as the tops and bottoms of the formations. A description of each formation is made visually and with the aid of a microscope. Visually, one can determine the more diagnostic features as color, bedding, texture, and so forth, while microscopically the finer characteristics such as roundness of grains, character of cement holding grains together, crystalline properties of evaporites, and also the type of microscopic fossils (foraminifera, ostercods) can be determined. For example, the Niobrara formation is visually identified as a massive chalk rock. Microscopically, it can further be found to contain numerous foraminifera.

Electric Well Logging

In the last few years a new method of obtaining subsurface stratigraphic information has been employed. This method is electric well logging. The electric logger's principal purpose is to detect the contacts between formations, which directly gives one thicknesses of the formations encountered. To some extent, permeability or the amount of water carried in a formation can be determined as well as the chemical nature of this water. For this purpose the State Geological Survey owns a 2000 foot electric logger to obtain accurate subsurface data.

Before electric logging procedures can be started, the hole must be conditioned.

To do this the mud is circulated for some time to clear the hole of drill cuttings and any obstruction which might hinder the passage of the electrode into the hole. To start the logging operations, a stationary electrode is placed at the surface, usually in the mud pit at the most distant point possible from the well. A traveling electrode is then lowered into the hole by means of an insulated cable attached to a rotating spool. As the electrode assembly is lowered into the hole, an electric current is passed through the traveling electrode. The current then flows through the different formations to the surface where it is picked up by the stationary electrode, thus completing the electric circuit. The resistance that the electric current encounters when going through the different lithologic formations is then amplified in the instrument box and automatically recorded against depth on the right hand side of the recording drum. The spontaneous potential is a measure of secondary potential currents and not artificially induced currents as resistance is. Potential is recorded on the left hand side of the drum. This method of well logging is termed the one-electrode type and is the method now used by the South Dakota State Geological Survey. Other multiple-electrode methods can be used and are employed by most well logging companies such as the Schlumberger Well Surveying Corporation.

Some of the more fundamental principals of electric logging must be known in order to accurately interpret data about the formations traversed. A further and more detailed discussion of potential and resistance as well as their properties will then be attempted.

Potential

Potential is a measurement of electrical currents produced by natural and secondary reactions taking place within the earth. The only electrical method that is employed when a potential curve is made on the log is a phase of secondary potential. This phase is known as the electro-chemical phase. In a bore hole filled with water or drilling mud, the electro-kinetic phase of secondary potential, and natural potential produce no electric currents which are measurable by electric logging equipment. They can, however, be measured if the bore hole is dry, (i.e., has neither water nor drilling mud in it).

Since nearly all drilled holes of any depth contain water and drill mud, only the electro-chemical phase of secondary potential is to be considered.

Electro-chemical potential is the electromotive force generated at the contact of different media. In this case it is the force resulting from the difference in successive beds as well as the difference between the bed and the drilling mud or water. The difference in beds and mud give rise to a current which flows through the different beds and drill mud where it is picked up by the logging electrodes and recorded. The electro-chemical force is measured in millivolts, one millivolt being 0.001 volt.

Since the electromotive force varies in formations and at their contacts, it is then possible to determine to some extent their character and composition. For example, salt water sands or brackish water sands are usually more negative than the associated shales and clays. Fresh water sands, on the other hand, may be either more negative or more positive than the associated beds.

By making these potential measurements and plotting them in terms of depth, a potential graph is obtained. From this graph it is possible to pick out the contacts, thicknesses, and permeability, as well as the freshness of the water contained within the formation. An idealized potential graph is represented on the left side of Diagram No. 1, (pages 111-112).

Resistance

According to Guyod (1952), electrical resistance is a property common to all matter. The magnitude of the resistance of different substances, however, varies extremely. The range is considerably wider for resistance than for any other important physical property of matter. The resistance of a substance is, therefore, a very sensitive indicator which exhibits large variations for small changes.

The electrical conductivity is the property which characterizes the ability of a substance to transmit a current. In electric logging, however, the conductivity has been replaced by its reciprocal, the resistance, which can be defined as the property which tends to impede the flow of electricity through a substance. Actually in electric logging the "specific resistance" rather than the resistance is measured. The "specific resistance" is the resistance of a substance having a unit length and unit cross section at zero degrees centigrade. This property differs from resistance in that it is independent of shape and dimension and depends primarily upon the composition of the substance and its character. The effect of temperature is relatively small, but should be considered if accurate results are to be obtained.

In electric logging it is convenient to express resistance in ohmmeters (ohm/m) which gives values ranging from a fraction of an ohm to several thousand ohms. These measurements of resistance in ohmmeters, when plotted against depth, result in a resistivity or resistance graph. A graph of this type is shown of the right hand side of Diagram No. 1, (pages 111-112).

Electric Log

The combination of a potential graph and a resistance graph placed side by side constitute an electric log.

Application of Electric Logs

Electric logs give a complete and continuous record of the formations penetrated in the course of drilling a well. They are, therefore, one of the most useful tools available at the present time for subsurface work and correlation.

There are many applications to which electric logs can be applied. Only the first two of the four following classes will be discussed as these two are the only ones that have a bearing on this report.

1. Geological Problems
2. Investigations of Water Supplies
3. Data for Surface Exploration
4. Production Problems

Geological Problems

The electrical properties as stated earlier in this report are directly dependent on the amount, composition, and geometry of fluid, usually water, which the bed contains. Since each bed usually varies as to the amount and composition of the water contained therein, the electric log reflects the lithologic character of strata traversed. As the log is made in some detail and in terms of depth, the relative thickness and stratigraphic position can be determined with sufficient accuracy.

The average lithologic characters of a formation usually do not vary or change in short distances. Since this is true, electric logs taken in the same area and penetrating the same formations usually exhibit a pattern which is almost identical from well to well. By correlating these patterns, the tops and thicknesses of the beds can be determined and from this information accurate geologic mapping is made possible.

If the wells are shallow, as seismograph shot holes and shallow core holes, a shallow subsurface or surface map can be drawn. A map of this kind is important in exploration work, especially if the surface geology reflects deeper structures. If the surface geology does not reflect deeper structures, then deeper core holes must be drilled and logged to prepare new subsurface maps to work from. The location of exploratory wells can be determined from a map of this nature and this map is many times used when prospecting for petroleum. Numerous other geological problems can be solved from electric logs, such as bed indentification, research on sedimentation, *et cetera*.

Investigation of Water Supplies

Since the electrical characteristics of different rock formations is determined by the amount and composition of the water contained therein, electric logs which show these changes are a useful tool for the investigation of the water supplies of an area. In particular the electric log shows the exact depth and thickness of the water bearing formation and also shows whether the water is fresh or brackish.

STRATIGRAPHY

STRATIGRAPHIC SYSTEMS PRESENT

The rock formations that are present in this area belong to all four of the geologic groups. These groups are: the Cenozoic, Mesozoic, Paleozoic, and Pre-Cambrian. The following geologic time rock chart shows the groups, systems, and formations found at the surface and in the subsurface in this area.

TIME ROCK CHART

Group	System	Formation	
Cenozoic	Quaternary	Pleistocene (Glacial, stream and wind deposits)	SURFACE
	Tertiary	Oligocene-Miocene White River?	
Mesozoic	Cretaceous	Pierre	
		Niobrara	SUBSURFACE
		Carlile	
		Greenhorn	
		Graneros	
		Dakota	
		Fuson	
		Lakota	
	Jurassic	Sundance	
Paleozoic	Pennsylvanian	Minnelusa	
	Mississippian	Madison	
	Ordovician	Red River	
		Winnipeg	
Pre-Cambrian	Pre-Cambrian	Sioux and earlier granites & schists	

The Cenozoic group is divided into two systems; the Quaternary and the Tertiary. The Quaternary sediments, the youngest exposed, cover nearly the entire area except along the bluffs of the Missouri river. These sediments are mostly unconsolidated materials made up largely of glacial till. Some areas exhibit wind blown loess, while the large stream valleys exhibit alluvial deposits of silt, sand, and gravel. The Tertiary sediments are composed of ancient stream deposits of silt, sand, and stratified quartzite. There is an outcrop of these Tertiary (Oligocene-Miocene) sediments in the hills, six miles south of Ree Heights in Hand County.

The Mesozoic group is divided into three systems. In this area sediments representing the upper two systems are found. The Cretaceous deposits or sediments are composed of shales, sandstones, and limestones, and include the Pierre, Niobrara, Carlile, Greenhorn, Graneros, Dakota, Fuson, and Lakota as formations. The Jurassic sediments consist of shales and sandstones and include only the Sundance formation in this area.

The Paleozoic group is divided into seven different systems, three of which are represented in this area. The Pennsylvanian system includes only one formation, the Minnelusa sandstone. The Mississippian system also is represented by one formation, namely the Madison limestone. The Ordovician system is represented by two formations, the Red River shales, limestones, and dolomites, and the Winnipeg shale and sandstone.

The Pre-Cambrian sediments of this area are represented by only one formation, the Sioux Quartzite. The other Pre-Cambrian granites and schists are not considered a part of stratigraphy and will be discussed later under the heading CRYSTALLINE ROCKS OF THE AREA.

An accompanying geologic map of this area shows where the surface formations outcrop, while the panel diagram shows the subsurface formations encountered during drilling operations.

CENOZOIC GROUP

QUATERNARY SYSTEM

Pleistocene Deposits

Stream or Alluvial Deposits

Alluvial deposits composed of clays, silts, sands and gravels make up the floodplain of the Missouri, James, and Big Sioux rivers, as well as the floodplains of some of the larger creeks of the area.

Wind or Loessial Deposits

Loess is a wind blown deposit of fine clays. In some places along the Missouri river it covers the higher alluvial terraces. Although it is a fine, soft, unconsolidated sediment, it forms steep-walled slopes, since it is held firmly together by bentonite.

Glacial Deposits

Glacial till or boulder clay, as it is sometimes called, is an unstratified mixture of clay, sand, gravel, worn pebbles, and boulders, the boulders sometimes attaining a diameter of several feet.

The till or drift of this region exhibits the sag and swell surface to various degrees. This type of glacial topography is less pronounced in the eastern and western portion of the area where older drift is found. In the central part of the area, where younger till is found, the sag and swell surface is much more prominent.

Since the drainage is more mature on the older drift, the sharpness of the topography is decreased. Actually the drainage system throughout the area is poor and as a result numerous lakes and swamps are found.

The thickness of the drift varies appreciably over the area. It ranges from nothing along the banks of the Missouri river to approximately 350 to 400 feet on the high moranic deposits in the eastern portion of the area. Taking a mean for the area as a whole, the drift would probably average between 100-125 feet.

The terminal or end moraines of this region are numerous. The material or composition of the moraines differ little from glacial till except that it is usually more stony or bouldery. This character is due to the greater exposure to water action which has carried away much of the finer silt and clay leaving the coarser material in place.

In this area there are three principal moraines and two minor moraines.

The name Altamont was applied by Chamberlin (1883) to a moraine in eastern South Dakota which he supposed to be the outermost moraine of the latest (Wisconsin) glaciation. It was named after the village of Altamont in Deuel county. Later work, however, has shown this to be the Bemis moraine rather than the Altamont. The name Altamont has nevertheless persisted and is accepted as the name for the outermost moraine. In the eastern portion of this area the Altamont moraine runs southeastward along the west side of the Big Sioux river. In the western extent of the area it follows the east bank of the Missouri river through Sully and Hughes counties. From here it breaks eastward through Hyde and about one half of Hand county where it breaks south into the eastern part of Buffalo county. A spur of the Altamont moraine is also found in the very southeast corner of Hand county. The topography of the moraine is rough. It is composed essentially of clayey till with a few occasional gravel pockets.

The Gary moraine is the second principal moraine of this area. This moraine was named by Chamberlin (1883) after the town of Gary, Deuel county, South Dakota. This moraine, however, is now called the Gary and Altamont. The name Gary has persisted through continued usage and is still the name used for the moranic deposits of the second latest stage in Wisconsin glaciation. In the eastern half of the region the Gary moraine runs south and slightly to the east through the center of Clark and Kingsbury counties, while in the western part of the area it runs west through the northwest part of Hand county, thence on through the north part of Hyde county. It then swings south and then back east through the middle of Hyde and Hand counties. Just over the county line between Hand and Beadle counties it swings sharply to the southeast and runs out of Beadle county into the northeast corner of Jerauld county. The topography of the Gary moraine is much less rough than is the Altamont. It consists mainly of clayey till, thickly set with stones of all sizes. A few places are found where it is conspicuously gravelly.

The Antelope moraine named by Chamberlain (1883) lies in the central portion of the area and represents the latest stage in Wisconsin glaciation. This moraine is unusually irregular and complex to identify because it is so low and is divided or split up into many different fingers representing different intervals when the ice front remained stationary. Essentially there are three of these fingers on each side of the James river that merge together about straight east and west of Redfield. They extend down below the county line between Beadle and Sanborn counties. The topography of these moranic fingers is smooth and low. The till is essentially clayey with some scattered boulders.

The other two moraines are the Bemis and the Gary and Altamont. The Bemis moraine (Leverett, 1922) is an extremely bouldery moraine that was named after the village of Bemis, in Deuel county, South Dakota. It runs southeastward through Deuel county into Minnesota. The Gary and Altamont moraine is also a rocky, bouldery range of hills that runs southeastward through Deuel county paralleling the Bemis moraine on its eastern side. Actually the Gary and Altamont moraines are both separate moraines named by Chamberlin (1883), but in this area they appear physiographically as one moraine.

As the glacier retreated northward, an enormous amount of water was released by the melting of the ice. Little evidence is left to show that this water existed. The main physiographic feature which resulted from the drainage of this meltwater through the moraines was the glacial spillway or glacial channel. As the ice thinned and the water subsided these spillways or channels were partially filled with sand and gravel. Post glacial streams tended to occupy many of these old channels. Thus, as these later streams increased in size they began to erode away portions of this sand and gravel. As deeper trenching continued these streams left flat, broad, rock-floored terraces high above the present stream level. Some of these terraces are as much as 50 to 60 feet above the present stream and vary from one-fourth mile in width to nearly two miles. Many of these terraces are found along the James river. East of Huron, for example, two levels of terraces are found, one 40 feet and the other 60 feet above the present stream level. Many of the larger creeks, such as Pearl creek and Turtle creek follow these old glacial channels.

Glacial Lake Deposits

The very southern tip of glacial Lake Dakota extends only over the border into the area covered by this report. The deposits occupy much of the bottom of the James river valley at an altitude of about 1300 feet above sea level. Opposite Redfield the area is about twelve miles wide and just ten miles south the lake deposits fade into the till plain. The extent of the area can be easily seen on the accompaning geologic map. According to Rothrock (1943), the lake silt closely resembles the loess that covers extensive areas in southeast South Dakota and in Iowa and Nebraska. It consists mainly of very fine, clear, perfectly rounded, quartz sand. It differs from the loess in that it is less coherent, larger grained, and usually is lighter in color although the lower portion is usually a darker gray in color.

TERTIARY SYSTEM

Oligocene-Miocene Deposits

Evidence as to the existence of Tertiary formations in eastern South Dakota is meager. The only Tertiary deposits of this area are found high in the hills about six miles south of Ree Heights in Hand county. The exact character of these rocks is not definitely known as no detailed stratigraphic or correlative work has been done on them. From the general character of the rocks they have been called Oligocene-Miocene deposits. Fossil fish, Oligocene in age, have also been found. The thickness is not known. Doubtless much of eastern South Dakota was originally covered with Tertiary deposits, but the widespread glacial erosion destroyed nearly all evidences of these deposits.

MESOZOIC GROUP

CRETACEOUS SYSTEM

Pierre Formation

Distribution

The Pierre formation crops out along the bluffs of the Missouri river and can be traced up some of the larger tributaries of the Missouri. The formation thins to the east and is covered by glacial till except for a small area south of Doland where it is again seen at the surface.

Character

Taking the Pierre formation as an entire unit, it consists of gray shales, varying from light to dark in color with numerous bentonite beds, concretionary layers, and a few chalky beds. The Pierre has, however, been divided into members and the members in turn into smaller lithologic units called zones or facies. Since the geologic map accompanying this report shows the different members of the Pierre, the character of each member will be discribed. The members of the Pierre in descending order are; the Elk Butte, Mobridge, Virgin Creek, Sully, Gregory, and Sharon Springs. The undifferentiated Pierre is also included in this description. All members of the Pierre are present in the area covered by this report except the Elk Butte.

Elk Butte Member

The Elk Butte member was named by Searight, (1937) from exposures at Elk Butte, Corson county, South Dakota. It is the uppermost member of the Pierre and includes a thick series of dark gray shales lying between the calcareous Mobridge member and the overlying Fox Hills sandstone. It lies too high stratigraphically to be found in the area covered by this report.

Mobridge Member

The Mobridge member of the Pierre shale was named by Searight (1937) from beds exposed in Walworth and Corson counties near the town of Mobridge, South Dakota. As originally described, it includes beds of chalk, chalky shale, shale, sandy shale, and perhaps some thin sandstone beds. Emphasis, however, should be placed on its overall calcareous nature to distinguish it from other members of the Pierre formation. It underlies the Elk Butte and overlies the Virgin Creek, and is approximately 100 to 140 feet in thickness.

Virgin Creek Member

The Virgin Creek member was named by Searight (1937) from exposures on Virgin Creek in northeastern Dewey county, South Dakota. It lies between the overlying Mobridge and underlying Sully member. The Virgin Creek member is divisible on the basis of lithology into the upper and lower zones. The upper zone is composed of gray shales which weather to a gumbo. It carries numerous different types of small concretions as well as some larger limestone nodules in its upper portion. The lower zone consists of medium hard, gray shale which weathers silver and carries a large number of thin bentonite beds. The Virgin Creek member averages between 100-120 feet in thickness.

Sully Member

The Sully member of the Pierre shale was also named by Searight (1937) for exposures along the Missouri river bluffs in the western part of Sully county, South Dakota. This member is divided into four distinct lithologic units. The upper zone called the Verendrye consists of light to medium-dark shale which contains large, flat, iron-manganese, carbonate concretions in well defined layers. The concretions may reach a diameter of several feet but average about six inches. They are usually gray or greenish-gray on the interior but weather to a purplish black when exposed. Nearly 180 feet of this zone was measured at Ft.Pierre, South Dakota.

The Agency zone is a siliceous shale carrying only a few black, iron-carbonate concretions and bentonite beds.

The Oacoma zone consists of beds of gray shale separated by thin bands of bentonitic clay. The shale carries an abundant amount of iron-manganese, carbonate concretions which may have some commercial value, but as yet are only a prot ore.

The lower zone of the Sully member is known as the Crow Creek zone. This is divided into two facies, the lower sandstone zone which is composed of nearly white quartz grains cemented by calcium carbonate and the upper zone which consists of calcareous shale called marl. The sandstone bed is about one foot thick while the marl zone is six to eight feet thick.

Gregory Member

The Gregory member of the Pierre shale is divided into two distinct lithologic units; an upper zone consisting of light to dark shale and a lower zone composed of light gray chalk.

Sharon Springs Member

The Sharon Springs member likewise is divided into two distinct units based on paleontology rather than lithology. It was named by Elias (1931) for exposures around Sharon Springs, Wallace county, Kansas. The upper zone is a bluish-gray shale void of fish remains, while the lower zone is a dark gray, fissile, somewhat bituminous shale containing an abundance of fish scales and other fish remains.

On the geologic map accompanying this report, the Gregory and Sharon Springs members are grouped into one unit, the same symbol being used for both.

Undifferentiated Pierre

The undifferentiated Pierre, as shown on the geologic map, is not a member of the Pierre. It simply means that the outcrop has not been sufficiently studied to permit correlating it with the recognized Pierre.

Below is shown the succession of beds in some of the members of the Pierre formation near DeGrey, Hughes county, South Dakota.

Sequence of beds, Pierre Formation
exposed along DeGrey-Joe Creek
road, 1½ miles southeast of
Degrey, Hughes county, South Dakota.

Pierre Formation
  Sully Member
    Verendrye Zone

14. Shale, gray weathers to gumbo, numerous black sideritic concretions, not measured.

13.	Shale, yellowish gray, flaky, with large black concretionary zone at top	7' 10"

Oacoma Zone (upper)

12.	Shale, gray, hard, platey, with blue stained joints; many bentonites and iron-manganese concretions	33' 7"
11.	Bentonite, yellow, with biotite flakes (LMB).	6"

Lower (Agency)?

10.	Shale, light gray, somewhat papery, no visible bentonites or concretions; stands in steep outcrop	12' 4"
9.	Shale, gray, weathers to gumbo, contains few bentonites and scattered iron-manganese concretions	21' 0"
8.	Bentonite	6"
7.	Shale, as above	1' 0"
6.	Bentonite	6"
5.	Shale. Shale, as above	8' 8"
4.	Bentonite, slightly micaceous	6"
3.	Shale, as above	6' 2"

<u>Crow Creek Zone</u>

2.	Marl, light gray , with brown slabby sandstone at base.	14' 1"

<u>Gregory Member</u>

1.	Shale, brown to gray, many rusty brown concretions; layer of one foot gray septarian concretions about 37 feet below top to level of road. (hand leveled)	42' 0"
	TOTAL THICKNESS	138' 8"

Distinguishing and Drilling Characteristics

Since the Pierre is relatively a soft, plastic, bentonitic clay, the formation drills easily. Occasionally some difficulty is encountered when any great thickness of bentonite is struck or if a tough concretionary zone is encountered. Bentonite has the property of absorbing great quantities of water, which makes it swell considerably. If the swelling is great enough the hole being drilled may be closed off completely and in many cases the drilling tools have been "stuck" as a result of this heaving and swelling. Bentonite, on the other hand, is very useful in drilling operations as it makes its own drilling mud, thus saving the driller the expense and trouble of using commercial drilling mud.

Fossils and Age

The most common fossils found in the Pierre formation are clam shells belonging to the genus Inoceramus, identified by heavy corrugations of the shell. A few ammonites of the genera Acanthoscaphites, Baculites, and Placenticeras are also found. Micro-fossils belonging to the order Foraminifera can also be found, provided a microscope is used for study. Some marine reptile bones are found at the contact of the Verendrye and Oacoma facies of the Sully member. The age of the Pierre shale is upper Cretaceous and is the lower part of the Montana group.

Thickness

The Pierre formation varies greatly in thickness throughout the entire area. This is due to the fact that it is the topmost of the bedrock formations and has been subjected to extreme continental glacial erosion, as well as a minor amount of present stream erosion, in the area along the Missouri river. The maximum thickness is found in the western part of this area. The exposed section at Ft. Pierre is 139 feet in thickness, while the Hunt-School # 2 oil test in Hyde county penetrated 630 feet of Pierre shale.

Niobrara Formation

Distribution

The Niobrara formation is stratigraphically too low to crop out any where in the area concerned by this report. It will be included, however, since it is of importance to any one who desires to know the formations traversed before the artesian horizons are reached. The same is true for the remainder of the formations discussed. It does, however, underlie the Pierre formation over the entire area.

Character

The Niobrara chalk was named by Meek and Hayden (1861) from exposures along the Missouri river near the mouth of the Niobrara river in northeastern Nebraska. Lithologically the Niobrara formation varies from marl through chalky marl to chalk in the exposures in the southeast part of South Dakota. As one goes north it becomes more argillaceous (shaley) with a decrease in calcium carbonate ($CaCO_3$) material. In Kansas, the Niobrara has been divided into two distinct lithologic units; the upper or Smoky Hill member (Cragin, 1896) is soft chalk carrying numerous beds of bentonite, whereas the lower or Fort Hayes member (Mudge, 1876) is almost a limestone with only a few bentonitic beds. It is almost impossible to distinguish the Smoky Hill from the Fort Hayes in South Dakota. The differentiation is based on micro-paleontological studies rather than lithologic studies. Another characteristic of the

Niobrara formation is its relatively high resistance as measured by an electric logger. Since this is true it is usually very easy to pick the bottom and top of this formation, thus making it a valuable horizon for correlation.

Distinguishing and Drilling Characteristics

The Niobrara is sometimes mistaken for a shale, since it is a blue speckled color when it is fresh or unweathered. Upon weathering, it turns a buff to orange-white color. By simply dropping a drop of hydrochloric acid on the specimen, which causes it to bubble or effervesce as carbon dioxide is released, it is easily distinguished from a shale.

The Niobrara drills easily and usually gives the driller little trouble. It does, however, cave to some degree and if the caving is too great it must be cased off to keep the hole clean and also the samples clean if samples are being taken.

Fossils and Age

The most numerous fossils found in the Niobrara are micro-fossils called Foraminifera and Ostracods. The megascopic fossils are small cup shaped oysters (Ostrea congesta) usually found in clusters, and the larger clam shells of the genus Inoceramus. Sharks teeth, fish scales, skelton fish, and fish bones are also found throughout the formation.

The Niobrara chalk is upper Cretaceous in age and is placed in the Colorado group.

Thickness

The maximum thickness recorded from sample studies and electric logs of oil tests and water wells is 195 feet found in the Pierre Airport well just east of Pierre. The Niobrara thins to the east. In the Steptoe and Olson wells located in Hand county (see panel diagram for location of these wells and those to follow), the Niobrara is 60 and 70 feet thick respectively. In northwestern Beadle county it increases in thickness and is 115 feet thick in the Zybell well. East and south in Kingsbury county, at Oldham, it is nearly 90 feet thick. The average thickness over the area is between 90 and 100 feet.

Carlile Formation

Distribution

The Carlile formation does not crop out in this area but does underlie the entire region. The upper member of the Carlile, known as the Codell sandstone member, seems to be present only in the southern portion of Beadle county. It is not positively identified in any other part of the area.

Character

The Carlile formation was named by Gilbert (1896) for the excellent exposures near Carlile Station, 21 miles west of Pueblo, Colorado.

The Carlile shale, which is the uppermost formation of the Benton group, consists of gray to dark gray fissile shale with concretions, thin sandstones, and impure limestone layers. The concretions are mostly calcareous with some iron pyrite. An abundant amount of selenite or gypsum can be found throughout the formation. Since shales and clays are highly resistant, the "kicks" of the Carlile on the electric log are very slight. The fact that the Codell fails to show up as a sand on many of the electric logs may indicate that it is more argillaceous in this area.

Codell Member

Near the top of the Carlile is a sand member called the Codell sandstone. It was named by Bass (1926) for exposures in the bluffs along Saline Valley in Ellis county, Kansas. It consists of a fine angular to subangular quartz sand with a few of the grains frosted or etched. The farther north one finds this member the more argillaceous it becomes. It has been positively identified in only two wells in this area, they are the State Fair Grounds well at Huron and the Virgil City well. Many electric logs show some sand at the top of the Carlile but nothing upon which a thickness could be based.

Distinguishing and Drilling Characteristics

Stratigraphically the Carlile lies between two lime formations, the Niobrara above and the Greenhorn below. Thus, it is very easily recognized. The Codell sand usually lies immediately below the Niobrara, but many times is separated by a thin bed of shale. It is, however, the first major sand encountered in this area if it is present.

Since the Carlile is essentially a soft plastic clay, it drills easily. Only occasional trouble is encountered from the lime and pyrite concretions. This formation serves also as a source for drilling mud as it consists of a plastic clay and a few bentonites. It is not as excellent a drill mud as is that produced from the Pierre shale.

Fossils and Age

Fossils are abundant throughout the formation, especially in the upper portion. Fish scales, and skeletal remains are common. Invertebrate fossils as Inoceramus and Ostrea congesta are also present. Numerous cephlapods are also present. The Carlile is Cretaceous in age and is the uppermost formation in the Benton group.

Thickness

The Carlile shale has its maximum thickness in the Hunt-School Land # 2 well, Hyde county, where it is 290 feet. It thins to the east in Hand and Beadle counties. In the Oldham City well in Kingsbury county it is 190 feet thick and continues to thin as one goes east and north toward the high granite area around Milbank, South Dakota. It averages about 280 feet in the western part of the area and about 175 feet in the eastern portion of the area.

Greenhorn Formation

Distribution

The Greenhorn formation underlies almost the entire area covered by this report. It may, however, pinch out against the north flank of the Sioux Quartzite Ridge in extreme eastern portion of this region. It also seems to be missing in the north central portion of Beadle county. Two water wells logged in this area by the State Geological Survey, one in Sec. 32, T. 113 N., R. 62 W., and the other in Sec. 29, T. 112 N., R. 62 W., failed to give any indication on the log that the Greenhorn was present.

Character

The Greenhorn formation was named by Gilbert (1896) for exposures found near Greenhorn Station, 14 miles south of Pueblo, Colorado. The upper and lower portions of the formation are dominantly a light to dark gray, fissile, calcareous shale grading into a marl, while the middle portion is the typical Greenhorn, composed of a light gray, fine to medium grained calcarenite with a carbonate matrix, some pieces of molusk shells, and interbeds of light gray to brown calcareous shale. The calcarenite is composed chiefly of broken, angular to subangular <u>Inoceramus</u> shell fragments. There are a few bentonitic beds scattered throughout the formation. Below is given a section of exposed Greenhorn measured by E. J. Bolin and Raymond C. Barkley in February, 1952.

Succession of beds in the Greenhorn
Formation, Measured at Quarry 12.3
miles southeast of Westfield, on
Highway 12, Plymouth County, Iowa.

Greenhorn

8. Highly weathered, soft, buff and light blue to gray chalk . . . . .3'

7. Slabby, thin bedded, white limestone. Beds vary from $\frac{1}{4}$" to about 1" in thickness, contains abundant <u>Inoceramus</u> fragments and has iron staining on surface. . . . . .8.7'

6. Very hard, massive, white limestone, contains abundant <u>Inoceramus</u> fragments and has iron staining on surface . . . . .4.5'

5. Highly weathered, soft, buff and light blue-gray chalk, contains a 1" seam of bentonite 2.45 ft. below top . . . . . . .3.72'

4.	Black, slabby, calcareous shale	4'
3.	Chalk as above	3'
2.	Shale as above	5'
1.	Chalk as above, base of quarry.	3.14'
	TOTAL SECTION.	24.26'

Distinguishing and Drilling Characteristics

The Greenhorn lies comformably under the Carlile and comformably over the Graneros. It is an easy formation to identify in the field as well as on electric logs. It forms large broad flat buttes when found outcropping. On an electric log it makes very prominent "kicks" which easily distinguish it from other formations. The Greenhorn formation is not hard to drill but may slow down the drilling time as it is quite hard, especially the middle portion where the "limeshells" are very abundant.

Fossils and Age

Since the Greenhorn is essentially a calcarenite, it consists largely of shell fragments. Whole shells of the genus Inoceramus are abundant. The Greenhorn also contains shark teeth, fish scales, fish skeletons, and foraminifera. The age of the Greenhorn limestone is Cretaceous and it is the middle formation in the Benton group.

Thickness

The Greenhorn formation is approximately 50 feet thick in the western part of this area, and thins as one goes east to approximately 20 feet. The Greenhorn apparently thickens and thins locally as a result of differential compaction of the sediments over the Pre-Cambrian rocks.

Graneros Formation

Distribution

The Graneros formation underlies the entire area covered by this report.

Character

The Graneros formation was named by Gilbert (1896) for exposures along Graneros Creek, Colorado. It is a laminated, argillaceous or clayey gray shale, with very little limey or sandy material. There are a few iron-carbonate concretions varying from 2 to 6 inches in diameter scattered throughout the formation. Thin sand layers are also interspersed throughout.

Distinguishing and Drilling Characteristics

The Graneros lies comformably between the Greenhorn limestone above and the Dakota sandstone below. It presents no great problem for drillers as it is essentially a soft plastic clay. A few of the larger concretions sometimes interrupt drilling operations for a time. The Graneros as well as the Pierre and Carlile can be used for drilling mud.

Fossils and Age

According to Todd (1908), the Graneros formation carries very few fossils. A few reptile bones, pelagic foraminifera, *Inoceramus*, and fish scales have been found. The Graneros is upper Cretaceous in age and is the lowest formation in the Benton group.

Thickness

The formation varies in thickness throughout the area. In the western part of the area it averages around 200 feet, while in the central portion it is somewhat thicker being around 250 feet. In the eastern extent of the region it decreases to about 100 feet in thickness as it wedges out on the slope of the old Pre-Cambrian surface.

Dakota Formation

Distribution

The Dakota sandstone also underlies the entire region concerned but decreases in thickness in the eastern part of the region. It may even pinch out against the Pre-Cambrian rocks in the southeast portion of the area.

Character

The Dakota formation was named by F. B. Meek and F. V. Hayden (1861) for exposures found in the hills back of the town of Dakota, Dakota county, Nebraska.

The Dakota is a yellowish, reddish and occasionally a white sandstone with alternations of varicolored shales, siltstones, and occasional lignite beds. Carbonaceous material is usually found all through the formation. Some of the lithologic changes can be seen in the following detailed section.

Succession of beds in the Dakota
formation measured below the mouth
of Aowa Creek, Dixon Co., Nebraska.
Todd (1908)

<u>Dakota</u>

6.	Sandstone, soft, porous, rust colored. . . .	10.0'
5.	Clay, dark with thin sandstone layers. . .	2.5'
4.	Sandstone, nodular, rust colored	1.0'
3.	Clay, dark, sandy at base.	1.0'
2.	Sandstone, with layers of iron concretions	4.5'
1.	Sandstone, dark, rust colored, with shaly layers	25.0'
	TOTAL SECTION . . .	44.0'

Succession of beds in the Dakota
formation measured on the east
bluff of the Big Sioux River, Stone
Park, Plymouth Co. Sioux City, Iowa.
Tester (1931)

<u>Dakota</u>

7.	Sandstone, yellow to buff and gray, fine to medium-grained, friable. 3" seam of impure lignite 3' below top.	10-11'

6.	Shale, fissile, gray to black, carbonaceous, with thin sandstone layers.	8-9'
5.	Sandstone, gray to buff, fine grained, cross-bedded, and plant fragments	7-8'
4.	Sandstone, medium to fine grained, some clay pebbles	3-4'
3.	Shale, gray turning to brown at lower contact. Carbonaceous and fissile in upper part	5-6'
2.	Siltstone, with many thin alternating layers of shale and in irregular zones, buff to brown, grains are angular, iron stained	7-8'
1.	Sandstone, with thin shale layers, sand is gray, medium to fine grained, 1 to 1½ foot zone of iron carbonate concretions at top	5-6'
	TOTAL SECTION.	45-52'

Distinguishing and Drilling Characteristics

When artesian wells were first drilled into this formation the drillers tried to divide the Dakota into different flows. As can be seen from the log of the Fred Meyer artesian well, (diagram No. 1), there are a great number of separate sands that could be termed flows if each were eased off separately. Now, however, the drillers have abandoned the idea of individual flows in the Dakota and have disignated the Dakota sandstone as the first artesian horizon or first flow.

The Dakota lies conformably between the Graneros shale above and the Fuson shale below, except where the Dakota lies unconformably on Pre-Cambrian rocks in the eastern part of the area. The Dakota is essentially a loose porous sand containing various amounts of water. It should be stated, however, that since the Dakota sandstone is a typical shoreline deposit, it is not always a loose porous sand but changes rapidly over short distances, becoming more compact and usually more shaly. Actually in some areas the sandstone-shale ratio is very high, that is, there is more shale in the Dakota formation than there is sandstone. On the whole it is easy to drill, but occasionally the drill encounters iron pyrite concretions which are very hard and hold up drilling operations for a short time.

Fossils and Age

The Dakota formation contains an abundance of carbonaceous material, consisting of charcoal, plant fragments and leaves. The flora found consist mainly of dicotyledonous plants. The fauna is mostly of the fresh water molluscan type. The Dakota sandstone is middle Cretaceous in age.

Thickness

Since the Dakota is essentially a stream and shore line deposit, it varies tremendously in thickness. In this area it does not thicken or thin in any definite direction, but thickens and thins locally. It is about 40 feet thick on an average in the western part of the area and increases to between 100-150 feet around Huron and then decreases to about 50 feet in thickness in the eastern part of the area.

Fuson Formation

Distribution

The Fuson formation underlies much of the area but may be stratigraphically pinched out over the southeast portion of this area.

Character

The Fuson shale was named by Darton (1901) for excellent exposures in Fuson Canyon on the east flank of the Black Hills. It is composed of fine grained, thin beds of sand, and massive varicolored shales mixed with a large amount of bentonite. An interesting character found in the Fuson is the great number of manganese pellets that are present. These are small manganese-iron concretions varying in color from light tan to deep purple, and are persistant from the Black Hills eastward. They are a great help in the identification of this shale.

Distinguishing and Drilling Characteristics

The most distinguishing feature about the Fuson shale is that it serves as an impermeable horizon between the Dakota and Lakota sandstones, which are the two artesian horizons with which this report is concerned. Since it contains manganese pellets in some abundance, it is easily identified in well cuttings. If one is not careful, however, he will miss these pellets, for they appear like sand grains. Usually a magnifying lens must be used to spot them. As the Fuson is highly bentonitic, it presents some problems in drilling. It slacks and sweels readily and if the hole is not cased up soon after drilling operations cease it may close the hole off.

Fossils and Age

No fossils have been found in this area, but small pieces of carbonized wood and thin bands of lignitic material have been encountered during drilling operations. The Fuson is middle Cretaceous in age.

Thickness

The Fuson varies in thickness as have some of the preceding formations. It is only 25 feet thick in the Pierre Airport well, but increases to about 100 feet in the eastern part of the region.

Lakota Formation

Distribution

The Lakota sandstone underlies most of this region except in southeastern part of the area where it pinches out against the northern flank of the Sioux Quartzite Ridge.

Character

The Lakota formation was named by Darton (1899) after one of the tribal divisions of the Sioux Indians. It is mainly a sandstone, which is hard, buff to red, coarse grained, cross bedded, and massive with partings of shale. Locally it has some lignite beds and other carbonaceous horizons.

Distinguishing and Drilling Characteristics

The Lakota sandstone lies comformably under the Fuson formation and unconformably on the Sundance sand in the western part of this area. In the eastern part of the area the Lakota lies unconformably on the Pre-Cambrian quartzites, schists and granites. It has essentially the same drilling characteristics as the Dakota sandstone does, but on the whole is a little harder. Numerous hard streaks, bearing iron pyrite concretions, make drilling more difficult.

Fossils and Age

Neither invertebrate nor vertebrate fossils occur in any abundance in this formation. Carbonaceous material and seams of lignite are common. Fossil fern trees called cycadeoids have been found in the Lakota formation north of Edgemont in the Black Hills. It is middle Cretaceous in age.

Thickness

The Lakota also varies in thickness throughout the region. At the Bureau of Reclamation well at Watertown, it is approximately 70 feet thick and lies unconformably on the Pre-Cambrian surface. In the State Fair Grounds well at Huron it is about 200 feet in thickness and lies unconformably on Pre-Cambrian rocks. In the Olson and Hunt-School Land wells it is approximately 140 feet in thickness and lies unconformably on the Sundance sandstone, while in the Pierre Airport well east of Pierre it has only a thickness of 20 feet. Thus, from west to east it thins, thickens, and then thins again.

JURASSIC SYSTEM

Sundance Formation

Distribution

The Sundance sandstone is known to be present in only two wells; the Pierre Airport and the Hunt-School Land # 2. Unauthentic reports by three well owners who reside in Hand county say that their wells are in the Sundance. If the depths given were correct, it is highly possible that the Sundance formation is present in this region. The Sundance probably pinches out against the Pre-Cambrian rocks in western Spink and Beadle counties.

Character

The Sundance formation was named by Darton (1899) for exposures found near the town of Sundance in the Black Hills. It is composed of gray to green marine shales, bentonitic clays, and glauconitic sandstone with some gray to cream colored limestones. It carries some water usually under high pressure.

Distinguishing and Drilling Characteristics

The most distinguishing feature about the Sundance formation in this region is that it is the first formation penetrated in drilling operations that carries the bright green iron mineral called glauconite in any abundance. Glauconite may be found in some of the earlier Cretaceous formations but only in small amounts. The Sundance lies unconformably under the Lakota sandstone and unconformably on the Minnelusa sandstone and

Pre-Cambrian rocks of the area. It is not a difficult formation to drill since it is composed largely of sands. Occasionally hard limestone beds are encountered which made drilling difficult.

Fossils and Age

The Sundance formation carries a molluscan fauna of which Belemnites densus is the form usually found. Ostracods are the principal microfossil found. It is upper Jurassic in age.

Thickness

The thickness of the Sundance formation varies greatly in this region. In the Pierre Airport well, it is approximately 500 feet thick, while in the Hunt-School Land # 2, it diminishes to about 100 feet. It continues to decrease in thickness to the east where it pinches out against the Pre-Cambrian surface.

PALEOZOIC GROUP

PENNSYLVANIAN SYSTEM

Minnelusa Formation

Distribution

As the accompanying panel diagram shows, the Minnelusa formation is present in only two wells, one of which is the Pierre Airport and the other in the Hunt-School Land # 2 in Hyde county. Baker (1952), however, introduced the formation known as the Millstone grit as the sand found in place of the Minnelusa in the Hunt-School Land # 2 well. In earlier reports, this term was applied by geologists to the basal conglomerate and coarse sands of the Pennsylvanian series in the eastern and central states. Here it was considered to be associated with the Pottsville. The extent to which the Minnelusa formation spreads eastward is indefinite and doubtful. It probably pinches out against the Pre-Cambrian rocks in a northeasterly direction through the southeast part of Hyde county and the northwest part of Hand county.

Character

The Minnelusa formation was named by Winchell (Ludlow, 1875) for the Indian name of the valley in which it was discovered. It consists mainly of white and reddish sandstone with some calcareous cement and local limestone beds in the medial and lower portion of the formation. The base is usually characterized by bright red shales with layers of white limestone.

Distinguishing and Drilling Characteristics

The Minnelusa sandstone lies unconformably between the Sundance sandstone above and the Pre-Cambrian below except where it lies conformably on the Madison limestone in the very western portion of this area. It does carry some artesian water. The coarser grained sands in the Minnelusa which have been called the Millstone grit by Mr. Baker do on occasion carry much artesian water under high pressure as was the case in the Hunt-School Land # 2 well in northwest Hyde county. The only drilling problems presented in the Minnelusa are the hard limey layers in the upper portion and water under high pressure in the lower portion.

Fossils and Age

Relatively few fossils are obtained from the Minnelusa sandstone. Brachiopods of the genera *Spirifer* and *Composita* are most common. It is lower Pennsylvanian in age.

Thickness

The Minnelusa is 200 feet thick in the Pierre Airport well. In the Hunt-School Land # 2 well where the Millstone grit is included it is 350 feet in thickness. It averages nearly 200 feet throughout the western portion of this area.

MISSISSIPPIAN SYSTEM

Madison Formation

Since the Madison formation is found only in the Pierre Airport well in this region, it will be treated in less detail than the preceding formation. The older formations which follow the Madison, excluding the Pre-Cambrian rocks, will be discussed only briefly as they are found only in the Hunt-School Land # 2 well.

The Madison formation underlies the western part of Sully and Hughes counties. It is mostly a fine grained, massive, light gray to buff colored limestone with numerous caverns and geodes lined with calcite crystals, (Darton, 1925). It carries some water and presents little difficulty in drilling unless a large cavern is struck or unless a thick bed of chert is encountered. Fossil corrals and brachiopods are most prevalent in the Madison limestone. It is lower Mississippian in age. The only thickness recorded in the area covered by this report is 75 feet in the Pierre Airport well.

ORDOVICIAN SYSTEM

Red River Formation*

The Red River formation is found in this area only in the Hunt-School Land # 2 well in Hyde county. It probably extends into this region only as far as northern Sully and Hyde counties. Its middle portion is a pink to buff colored dolomite with large rhombs and many vugs. It drills rather hard, has numerous fossils, and is 100 feet thick in this well. The lower portion of the Red River formation is a fine-textured, light gray to pinkish dolomitic limestone with streaks of clay. It carries some water under pressure, and drills rather hard. It has few fossils, and is 70 feet thick in this well. It is Middle Ordovician in age.

Winnipeg Formation*

The Winnipeg formation is divided into two distinct lithologic units. The upper unit called the Winnipeg shale is found in northern Sully and Hyde counties. It is a light gray to green, mottled, bentonitic shale and siltstone with a few sandy horizons. It drills with ease and is not fossiliferous. It is 120 feet thick in the Hunt-School Land well. The lower unit is known as the Winnipeg sandstone. In this area it is known to be present in the western part of Hughes

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* The names Red River and Winnipeg have only recently been introduced into South Dakota, being brought in by the different oil geologists to correlate with wells drilled north of South Dakota. The names used by C. L. Baker in logging wells for the State Geological Survey were as follows: For the Red River, the names Trenton, Decorah, and Platteville were used, while for the Winnipeg shale, the term Black River, which is actually a group name rather than a formation name, was employed. For the Winnipeg sandstone the name St. Peter was used.

county. It is essentially a well sorted, medium textured, clear, quartz sand with only a few fossils. It carries some water and drills easily. About ten feet of Winnipeg sandstone was penetrated in the Pierre Airport well before drilling operations ceased. The Winnipeg formation is Middle Ordovician in age.

PRE-CAMBRIAN GROUP

PRE-CAMBRIAN SYSTEM

Sioux Formation

Distribution

One of the most prominent features of the eastern part of this state is the Sioux Quartzite Ridge that runs west-northwest from Sioux Falls, through Mitchell, then south of Pierre and on west of Pierre for a short distance.

In the area covered by this report the north flank of this ridge extends northward to about the center of Hughes, Hyde, Hand, Beadle, and Kingsbury counties. A trough runs northwestward through Kingsbury county. East of the trough the Sioux quartzite broadens out and extends to about the middle of Clark and Deuel counties and just reaches across the borderline of Hamlin and Codington counties.

Character

The Sioux quartzite is a sedimentary rock consisting predominantly of fine, well sorted, rounded, iron coated, pink grains of quartz cemented into an impervious sandstone by silica. As the cementing material is structurely stronger than the quartz grains, the rock breaks through the grains rather than around them as ordinary sandstones do. It exhibits ripple marks and mud cracks indicating shallow water or shoreline deposition. In certain areas coarse grained conglomeratic quartzite is found.

Distinguishing and Drilling Characteristics

Since the quartzite is a very hard sediment due to the cementation by silica, it is almost impossible to drill it by jetting or rotary drilling machines. The best method of drilling the quartzite is to use the heavy cable tool rig which crushes and smashes up the rock. Rotary bits with the exception of the diamond bit soon wear out and even the diamond bit will last only a short time.

Fossils and Age

Since no fossils have been found in the Sioux quartzite, its age cannot be determined by paleontological methods. On the basis of indirect evidence it is probably Pre-Cambrian in age. Some stratigraphers have, on the basis of lithology, correlated the Sioux with the Baraboo quartzite in Wisconsin, which is overlain directly and uncomformably by Cambrian sediments.

Thickness

According to Dr. Brewster Baldwin, (1951), who wrote his doctor's thesis on the Sioux formation, the actual thickness of the Sioux is not known. It was found that in the Split Rock Creek section in Minnehaha county, South Dakota, that the formation was approximately 2700 feet thick with neither the top nor the base of it being exposed. He also found that in the Rock County Basin, Minnesota, some 5250 feet are present according to structural sections. Another evidence as to the thickness of the Sioux formation is the Wagner City well, where 3800 feet of the Sioux was penetrated. The well was finished, however, in Sioux quartzite. It can thus be concluded that the Sioux formation is easily a mile thick and may be much thicker.

CRYSTALLINE ROCKS OF THE AREA

PRE-CAMBRIAN GROUP AND SYSTEM

Igneous Rocks

Granite

Distribution and Character

Granite has been reported from the Pierre Airport well in Hughes county and in the State Fair Grounds well at Huron. The granite from the Pierre Airport well is a dark gray, finely crystalline granite which carries the minerals quartz, plagioclase, biotite, some hornblende and augite. The granite found in the Huron well is a light gray, fine textured rock composed mostly of quartz and plagioclase. Some hornblende, biotite and augite are present in small quantities.

Distinguishing and Drilling Characteristics

Granite presents the same problem in drilling as does the Sioux Quartzite. Since granite is made up of interlocking crystals of many different minerals, it usually breaks up with more ease than does the quartzite which is tightly cemented. Jetting and rotary rigs still have considerable trouble and heavy cable tool rigs should be used if the granite is to be penetrated to any depth.

Fossils and Age

Fossils have never been found in any type of granite rock. For that matter, they have not been found in any type of igneous rock. Since this is true, this section entitled Fossils and Age will be excluded from the rock descriptions which follow. The only method used to determine the age of igneous and metamorphic rocks is their relative position with later sediments. Since stratified sediments have not been found below the basement floors of granite, the granites are assumed to be the oldest rocks.

Thickness

This section on thickness will also be excluded from the following rock descriptions as no boring has ever penetrated any of the granite or metamorphic rocks in its entire thickness.

Diabase

Distribution and Character

The Hunt-School Land # 2 well in Hyde county is the only well in this area which was drilled a short distance into diabase. Diabase actually belongs to the granitoid group, but usually contains more of the dark colored minerals and is thus termed a diabase. The specimen from this well has an ophitic texture and was found to contain augite, chlorite, labradorite and magnetite in its mineral suite.

Distinguishing and Drilling Characteristics

Diabase is as difficult to drill as granite. If anything, it is usually a little tougher as it is finer grained and the crystals are more interlocking.

Metamorphic Rocks

Serpentine

Distribution and Character

The U. S. Bureau of Reclamation well at Watertown encountered serpentine at a depth of 1300 feet, and is the only well in this area in which this type of metamorphic rock was found. The specimen was composed of olive-green serpentine with lesser amounts of magnetite, chlorite, biotite and muscovite.

Distinguishing and Drilling Characteristics

Metamorphic rocks of this type are usually much easier to drill than are granites or diabase. They usually have a platy or schisty structure, which is not difficult to break. They are, however, tougher to drill than are the stratified shales, sandstones, and limestones.

Quartz-Chlorite Schist

Distribution and Character

The Motley well in Sec. 7, T. 115 N., R. 61 W., Spink county, struck quartz-chlorite schist. Another well in Sec. 26, T. 115 N., R. 62 W., Spink county, drilled by the Huron Drilling Company, Huron, South Dakota, also struck this type of rock. These are the only two wells which have encountered this type of rock. The sample contained an abundance of green chlorite, clear quartz, and lesser amounts of plagioclase and chloritized biotite.

Distinguishing and Drilling Characteristics

This is slightly harder to drill than is the serpentine as it contains more quartz, but is easier to drill than the granites as it is characterized by a platy structure.

STRUCTURAL CONDITIONS

INTRODUCTION

The structural features of this area consist mostly of very gentle folds, minor flexures, and shallow troughs. There is no sharp structural feature to be found anywhere in this area. The over-all regional dip is north-northwest, and is very low. In the eastern portion of the area, in Brookings, Hamlin, and Kingsbury counties the dip of the Greenhorn limestone is about 30 feet to a mile, while in the north and western part of the area it drops down to less than a foot a mile, which is essentially flat lying.

The contours shown on the geologic map accompanying this report are drawn on top of the Greenhorn limestone. These sea level elevations of wells, on which the contours were based, were determined by subtracting the depth to the Greenhorn formation from the surface or ground elevation of each well that was studied from samples or by electric log.

There are only a few structural features that will be considered in this report. They are: the Sioux Quartzite Ridge, Overlaps and Unconformities, and Minor Flexures.

SIOUX QUARTZITE RIDGE

The dominant structural feature that affects this area is the Sioux Quartzite Ridge. The crest of this ridge does not run through the area concerned by this report, but runs easterly from a point west of Pierre, through Sioux Falls and on into Minnesota. The north flank of this ridge extends about half the way into this area and is the most prominent structural feature of the region. The old surface of this flank is characterized by innumerable hills and valleys, now buried by later sediments. This feature is born out by the results of all the wells drilled in this area. The depth to the quartzite is very variable and changes rapidly as one encounters these buried hills and valleys.

Brewster Baldwin made a study of the Sioux Quartzite rocks that outcropped in the southeastern portion of the state around Sioux Falls. His studies showed that the sediments were laterally extensive and have been gently warped, tilted, and jointed at some period in the past. The dips of the beds were low and the direction of the dips varied within short distances.

OVERLAPS AND UNCONFORMITIES

Since the Sioux Quartzite Ridge remained high until mid-Cretaceous times, it tended to serve as a barrier to deposition. Thus, all the sediments deposited before mid-Cretaceous times were pinched out against the north flank of the ridge. The oldest sediment known to the area is the Winnipeg sandstone found in the Pierre Airport well. It lies unconformably upon granite just off the flank of the ridge. Since the topography of the Sioux Quartzite Ridge is very irregular, it is rather difficult to determine just where these sediments pinch out, for not enough control on the subsurface has been obtained.

The fact that the Winnipeg sand (Ordovician) is found in the Pierre Airport well and not in the Hunt-School Land #2 well may be due to secular upwarpings of the southwest portion of the Pre-Cambrian nucleus from early Paleozoic to mid-Cretaceous times, as the Winnipeg shale, which directly overlies the Winnipeg sand, is found in the Hunt-School Land well. The Red River formation, also Ordovician in age, is found in the Hunt-School Land well. Another interesting fact is that no where in this area has the Jurassic Morrison formation been encountered, but the Sundance which underlies the Morrison and is Jurassic in age is present far to the east in relatively great thicknesses. This also tends to substantiate the fact that the Pre-Cambrian nucleus was being uplifted during this time. The very fact that the Sundance is a sandstone or near shoreline deposit would also tend to prove structural movements in the

Pre-Cambrian complex, for the sea would have to be shallower for the deposition of sandstone than it would for shale. Therefore, the sea would have to be deeper for the deposition of the Morrison shale, but this shale is not present.

It may then be said that the overlaps and unconformities occuring from early Paleozoic to mid-Cretaceous times were a result, in part, of secular upwarpings of the Pre-Cambrian basement and alternate periods of advancement and retreatment of the sea, while the overlaps and unconformities from mid-Cretaceous time to the time when the great seas withdrew from the continent were a result of alternate advancing and retreating of the sea, for these later Cretaceous sediments lie conformably upon each other except where they pinch out against the north flank of the Sioux Quartzite Ridge.

MINOR FLEXURES

Although there has probably been some structural movement in the region, especially in its western portion, it has been on the whole very slight. The structure map on the Greenhorn limestone shows folds, troughs, and one small anticlinal dome along with other anticlinal trends. They are, however, extremely gentle and suggest that the sediments were differentially compacted upon the irregular Pre-Cambrian surface. The differential compaction of the beds can easily be seen in the eastern portion of the area where the flank of the Sioux Ridge is more prominent and is closer to the surface. It seems that the irregularity of the contours diminish in Hyde county and the sediments seem to lie more flat as they start their more uniform dip into the Dakota basin lying to the north and west. This idea of differential compaction over the Pre-Cambrian surface is realized to its greatest extent when a contour map on the top of the Greenhorn is superimposed on top of a contour map on the top of the Pre-Cambrian surface. In numerous places the axis of the troughs and other structures follow the same general pattern.

As seen from the contour map on the Greenhorn limestone, one of the most significant of the subsurface structural features of the area, is the plunging anticline found in Kingsbury county. Its axis runs from the northwest corner to southeast corner of Kingsbury county and thence into Lake county where it comes to the crest of the Sioux Ridge and the Greenhorn limestone is finally pinched out. It plunges to the northwest and fades away into a broad, flat trough. It has a dip of about 30 feet to the mile on an average. The dip increases decidedly to about 50 feet as the top of the ridge is approached. The trough follows the anticline up both sides and on the western side it is extremely flat and is divided into two fingers, one paralleling the anticline and the other running northeasterly through the western portion of Beadle county. There is another anticlinal trend that extends up into the eastern part of Hand county with its axis running northeasterly. It is very, very gentle with a maximum dip of about 10 feet to the mile. In the southern half of Spink county there is an anticlinal dome with a very small dip and a closure of about 50 feet. This dome may actually be a part of the anticlinal trend in Kingsbury county but is more apt to be part of the very gentle anticlinal trend that runs northeasterly through the southern half of Hand county.

As stated before, the western portion of the area exhibits very little structure, but rather indicates the break off as the sediments start to dip gently toward the north and west into the Dakota basin.

From the character of the structures found in the eastern part of the region, which are incidently confined almost entirely to the south half of the area covered by this report, it is fairly evident that they are a result of the differential compaction of the sediments over the top of north flank of the Sioux Quartzite Ridge that extends into the area.

ARTESIAN CONDITIONS IN EAST CENTRAL SOUTH DAKOTA

METHODS OF DETERMINING THE STATIC WATER LEVEL IN OBSERVATION WELLS

Wells that flow due to a hydrostatic head have a static water level which is above the surface of the ground. The height of the static level of the water in a well of this type may be measured by two methods. First it can be measured by an altitude gauge which converts the pressure that the water in the well exerts directly into the number of feet above the ground to which the water will rise. This type of instrument is extremely delicate and must be calibrated frequently. The other method, which was the one used on this survey, is to measure the shut-in or closed pressure of the well with a standard water pressure gauge connected to a pitot tube* and then multiply the pressure in pounds per square inch by the constant, 2.31 feet per pound per square inch. The pounds per square inch cancel leaving one with the number of feet above the well that the static level will reach. This method involves only one extra step, mathematical computation, and the pressure gauge is much more capable of taking rougher abuse. If for example, a well had a closed pressure of 10 pounds, the height of the static column of water above the ground or point from which it was measured would be 23.1 feet, disregarding the small frictional losses that lower the actual value somewhat.

Another method can be used to measure the hydrostatic head on a well, and was occasionally used on this survey. One simply connects a hose to the outlet pipe and then raises this hose until the water ceases to flow over the top. By measuring the distance between the outlet and the top of the hose, the height of the static column is obtained. This method can be used best on wells

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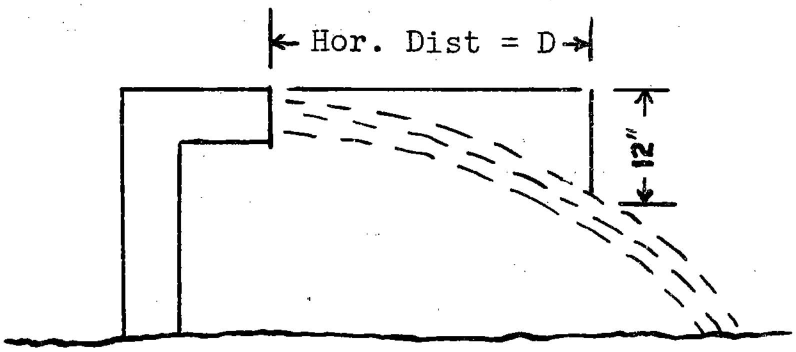
* A pitot tube is a small tube bent to a 90 degree angle near its lower end and calibrated to measure the pressure in pounds per square inch.

which do not have a hydrostatic head of over eight feet, for this is about as high as a man can reach without the help of a step ladder or something similar to stand on.

In non-flowing wells the standard method of obtaining the static level of the water is to let a line down into the well until the top of the water column is reached. The line is then pulled up and measured. The number of feet that the water surface lies below the ground surface is then known. In many cases this could not be done as the well owner did not particularly care about having the pump and pump rods removed from his well. It also was time consuming, as it is not an easy job to remove the pumping equipment from a well. In pumped wells then, the only way of determining how high the static level of the water was, was to ask the well owner. In many incidents his information was close to correct as was born out when each well was plotted on the piezometric map. Wells of this nature which were unreliable were disregarded when the piezometric map was drawn.

METHODS OF DETERMING THE RATE OF DISCHARGE

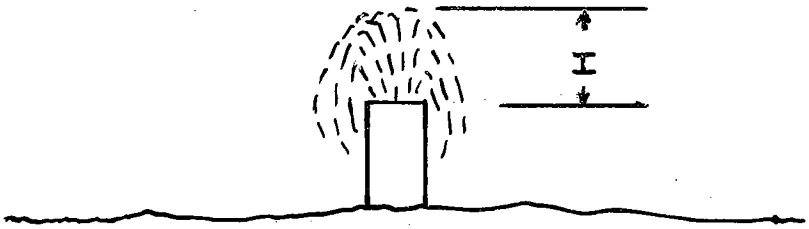
The most accurate way to obtain the rate of discharge on wells is to use a gallon measure or any convenient measure and determine the time it takes to be filled. On this survey a stop watch was used to determine the time. By taking several readings and averaging the results, a relatively accurate reading is arrived at. There are occasions, however, where a standard sized measure and a stop watch cannot be used, for the rate of discharge is too great. If a gallon measure is used as it was on this survey, it is extremely difficult to measure a well which flows over 30 gallons a minute by this method. In these cases a formula was used to measure the flow. There are two principal formulas which can be applied to find the rate of discharge. The first applies to wells having a horizontal outlet and the second to wells with a vertical outlet. A diagram and an example of how flow is computed from a horizontal and vertical pipe (Bennison 1947) is shown on the next page.



Flow From Full Horizontal Pipe

EXAMPLE:

Horizontal Distance (D) = 30"
Diameter of Pipe = 6"
Area of Pipe (A) = πr^2
= $3.1416 \times (3)^2$
= 28.9 sq. in.
Quantity of water per minute = $1.015 \times A \times D$
= $1.015 \times 28.9 \times 30$
= 880 gal/min.



Flow From Vertical Pipe

EXAMPLE:

Head (H) = 9"
Diameter (D) = 3"
Quantity of water per minute = $5.6\ H \times (D)^2$
= $5.6\ 9 \times (3)^2$
= 251.2 gal/min.

This last example of vertical flow can be used on pipes at any angle if they are flowing full.

METHODS OF DETERMINING THE ALTITUDE OF THE WELL

Altitude can be determined in a variety of different ways. Only two methods, however, were used on this survey. Nearly all the work was done with a Paulin altimeter. This instrument depends upon the variation of air pressure with altitude and measures these barametric changes directly in feet. It is calibrated in two foot intervals and should be corrected with a known altitude or elevation before a reading is taken on a well. It is essentially a very sensitive instrument and no reading should be attempted when weather conditions are unstable as they are before a thunder storm. Correction must be made for temperature and time between stations to obtain more accurate results.

The other method used to obtain ground elevations was topographic maps. These are simple to read and interpret and are accurate to within less than five feet. They were used only when the altimeter could not be used and when the surface topography was very gentle.

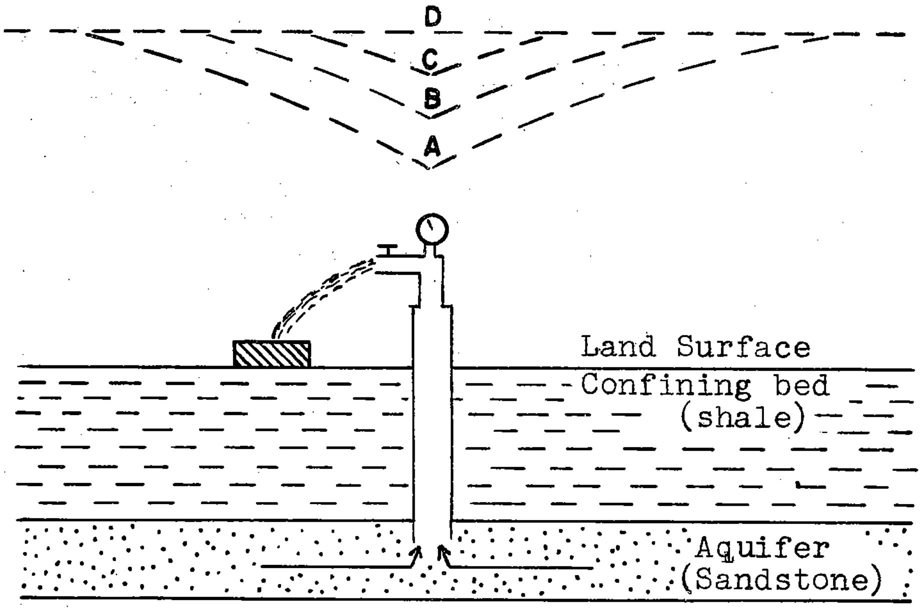
CONDITIONS AFFECTING THE PRODUCTION OF ARTESIAN WELLS

Drawdown

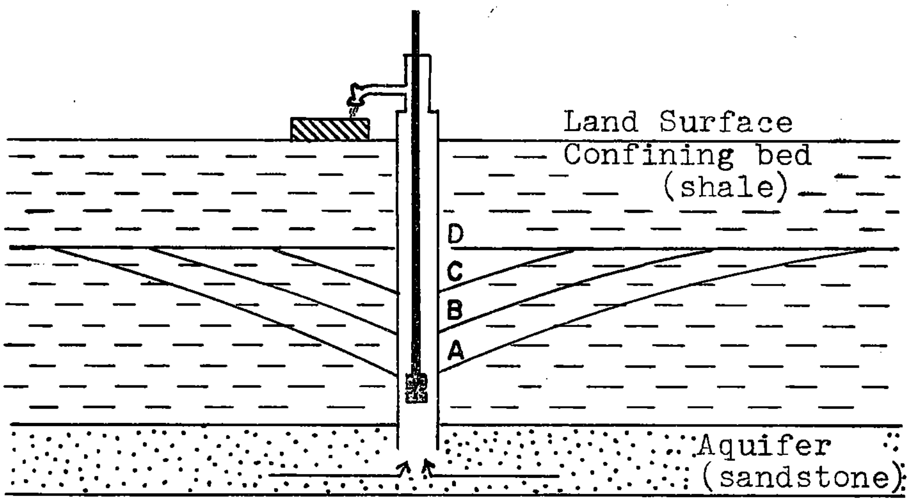
Whether a well is yielding water by pumping or through artesian pressure, there is a loss or reduction in pressure of the water in the well. This reduction in pressure causes a subsequent lowering of the water level and is designated as drawdown. Drawdown, however, is rather a difficult action to comprehend, but can be simplified by saying that it is the distance the water level drops in a well when the confined pressure of the artesian aquifer is released. If the well is closed up and is yielding no water, then the pressure increases as drawdown decreases until the normal static pressure and level exerted by the artesian horizon is reached. This situation is realized nearly every day in wells that are being pumped, since the piezometric head or height of the static level of the water in pumped wells is lower than the surface of the ground. Drawdown occurs in pumped wells only when they are extracting water. When the well is no longer pumping, the pressure exerted by the water in the well begins to increase and the recovery of the original static level of the water begins. The complete recovery of the pressure varies with different wells and will vary accordingly with the permeability of the aquifer, the length of time the well has been yielding water, and numerous other factors too technical to mention. Thus, after a well is pumped it may take several hours, days, or even weeks for the static level of the water to recover its original position. Measurements made in pumped and flowing wells from the Dakota sandstone indicate that the recovery is relatively rapid from this formation.

The same conditions are true for flowing wells as they are for pumped wells, except that the drawdown is continuous in flowing wells and the flow has to be shut off to obtain the drawdown of the well. The drawdown in a flowing well is more difficult to realize than in a pumped well, as the piezometric head is above the surface of the ground. This actually makes the drawdown a hypothetical, conical depression in the water level which lies suspended in the air above the well.

The diagrams on the following page may help to clarify drawdown in pumped and flowing wells.



Drawdown in a Flowing Well



Drawdown in a Pumped Well

In the above diagrams the bottom dashed line (A) indicates the level of the water or maximum drawdown while the well is flowing or being pumped. The other three dashed lines (B, C, and D) represent the static level of the water during three successive stages of recovery of pressure after the well has been closed or when pumping has ceased.

Drawdown is easily measured in both pumped and flowing wells. It can be measured by a pressure gauge in flowing wells after it is closed and by dropping a line down the well in pumped wells immediately after the pumping is discontinued.

The above discussion of drawdown has been concerned with its characteristic action in only one well at a time. Actually, however, drawdown is the hydrologic property which has reduced the piezometric head throughout the entire region. Let us assume a rather impossible case. Whereas the recovery of drawdown is fairly rapid in one particular well, it would be extremely slow if the recovery of the drawdown for the region as a whole were attempted. Every single well drilled into the artesian basin would have to be closed until all the pressures of the wells equalized. This would take many, many years and could not be realized because of the great need for the water. The people of this area and adjoining areas are now realizing that unless some control is introduced to stop this relatively rapid decline in the level of the water or increase in "regional" drawdown, there will be a serious shortage of water. One of the large factors will be the decrease in flowing wells and a proportional increase in pumped wells. Many farmers of the area are now attempting to save their supply of water by reducing the flow of their wells to meet only their immediate demands. Others, however, continue to let their wells run full force with the greatest share of the water running down the nearby slopes into the creeks and rivers where it does them or no one else much good.

Atmospheric Pressure

Atmospheric pressure does have a slight effect on the pressure exerted by the water in artesian wells. Seasonal changes can be noticed if the well is watched closely. During the winter season the average atmospheric pressure is higher causing a decrease in pressure exerted by the water in the well. Since the pressure is reduced,the velocity is also and so is the rate of flow. During the summer season the atmospheric pressure is usually lower and the water in the well exerts more pressure, thereby giving a slight increase in volumetric production.

Atmospheric pressure seems to affect wells in other ways. Before an approaching storm, wells many times start to flow small quantities of mud and sand. This is explained by the sudden increase in pressure of the water in the well due to the sudden decrease of atmospheric or barametric pressure.

No exact figures are known as to how much the atmospheric pressure changes the static level of the water, but observations made by E. P. Rothrock and T. W. Robinson, Jr. (1938) in pumped wells in west central South Dakota indicated it varied as much as 2.5 feet.

Gas Lift

In the western portion of this area, particularly in Sully and Hughes counties there are moderate to large amounts of gas mixed with the water. In these wells that contain gas, the height of the static level of the water is higher than it actually would be if no gas were present. The resulting water and gas mixture has a lower specific gravity than water alone and hence serves as a bouyant force holding the water up. In some cases it may even increase the rate of production to a slight extent. The static level of the water in these wells is then higher than it actually should be and has been recorded on the piezometric map as such. No attempt was made to correct for this effect as the primary purpose of this survey was to determine the altitude of the static level of the water and not its level after corrections for gas lift, atmospheric pressure, and other factors were considered.

GENERAL GROUND WATER CONDITIONS

The availability, preservation, and conservation of ground water are dominant factors that determine the relative prosperity of any region. In this area the availability of ground water is unquestioned. The preservation and conservation of ground water, however, is definitely a problem and must sooner or later receive considerable attention as the comparison between N. H. Darton's survey and the present survey will show.

Actually, ground water conditions in this area and for that matter, in all of eastern South Dakota may be divided into two distinct subdivisions. These subdivisions are; the shallow subsurface ground water found in the unconsolidated, unstratified glacial drift and the deeper subsurface ground water found in the stratified and consolidated sedimentary formations.

Strange, as it may seem, there are a number of artesian wells (wells that flow) found in the glacial drift. A small number were found in the southwestern portion of Clark county. A larger number of flowing shallow wells were found in eastern Hamlin and eastern Deuel counties. The rest of the wells in the shallow subsurface are all pumped.

The origin of the conditions which seem to favor a flowing shallow well is not too well established. It is known, however, that in glacial deposits there are numerous buried gravel channels and lenses of gravel that contain enormous supplies of water under slight pressure. It must also be remembered that these channels and lenses many times do not lie horizontal, but are tilted upwards towards the crest of the moraine. If a well is drilled into one of these gravel horizons where the elevation of the ground at the well is lower than the highest elevation in the gravel channel or lens, then a flowing well may be the result. It is almost impossible, however, to tell whether a well will flow when it is drilled, for lithologic changes in the glacial drift and gravel horizons are much more rapid than in stratified beds. As a result these changes may prevent the well from flowing.

Wells of this type are usually characterized by small flows, low pressures, and cold relatively hard water. Even though this is usually the case one well located in the NE¼NW¼ Sec. 12, T. 114 N., R. 59 W., on the east flank of the Antelope Moraine in Clark county, had a pressure of 10 pounds and was flowing 30 gallons a minute. The water was relatively hard and had a temperature of 52 degrees. As a whole, however, they are usually small and last only a short time. A flowing shallow well depends largely upon surface water conditions for its supply of water and may quit flowing completely during dry periods or at least the volume of water discharged will diminish greatly.

In the deeper subsurface formations there are five recognized artesian aquifers. In order of their depth below the surface, they are; the Codell sandstone, the Dakota sandstone, the Lakota sandstone, the Sundance sandstone, and the Minnelusa sandstone. All five of these artesian horizons are not found throughout this region. The Codell seems to be most persistent in the southern and middle portion of Beadle county. The Dakota and Lakota formations are found throughout the entire area except possibly in the southeast corner of the area where they probably pinch out against the Sioux Quartzite Ridge. The Sundance and Minnelusa sandstones extend only a short way east into this area as they are stratigraphically pinched out against the Pre-Cambrian rocks in Hyde and Hand counties. All of these formations except the Codell sandstone member of the Carlile shale crop out in a wide area encircling the Black Hills. There are a number of sands in the Carlile shale that outcrop in the Black Hills, but none definitely correlated with the Codell sandstone of southern and eastern South Dakota. In the Black Hills these formations have a very steep outward dip that carries them far beneath the adjoining plains in a relatively short distance where they are buried under a thick section of impermeable shales and clays.

In the Black Hills where these formations are exposed, the sandstones receive water, part of which comes from annual rainfall and the other part from creeks and streams that flow across the exposed rocks. There is some thought that the Dakota may receive some of its water supply from the Sioux Quartzite Ridge. This is very possible, but the amount received is no doubt small as compared with the amount received from the Black Hills region. It is also believed that part of the water found in the Dakota may be connate water, that is, water that remained in the formation after overlying sediments were deposited. The direction of movement of the water in the sandstones is outward and down dip from the Black Hills as well as eastward across the adjoining plains.

The map accompanying this report shows the approximate head of the Dakota and Lakota sandstones as surveyed in 1953. This piezometric head or water level is shown by contours and is the height above sea level that the water will rise in wells that tap these horizons. An interesting thing to remember is that the movement of the water is always in the direction that the piezometric surface slopes, that is, from higher to lower levels. It should also be stated that the piezometric map may deviate somewhat from the actual pressure or level to which the water will rise, for interpolation cannot always be exact, especially in areas which are far from wells on which measurements were obtained. Since the pressure of the water in the well is decreasing somewhat each year, the piezometric head lowers periodically, thus making the piezometric map valid for only a relatively short period of time. Forecasts or estimations made after a few years will have some error which must be accounted for before a well is drilled.

ARTESIAN WATER IN THE CODELL MEMBER OF THE CARLILE FORMATION AND THE SUNDANCE AND MINNELUSA FORMATIONS

Codell Member

Origin of Water

The Codell sandstone receives much of its head and source of water supply from the Sioux Quartzite Ridge area. It is highly possible, however, that it receives part of its head and water supply from the Black Hills and Colorado regions. According to C. L. Baker (1953), the Codell is present in the form of a siltstone in the Marigold-Dunn well in Pennington county. If this is true, then it is highly probable that the Codell or its equivalent is present in the Black Hills, thereby substantiating the fact that some of the head and water supply of the Codell is derived from the west. It, no doubt, receives some replenishment from creeks which run across the outcrops in Davison county. Likewise, it may receive some water through percolating actions, as it does in the Ft. Randall area where it is known that the Codell lies close below the base of the Missouri river alluvial sands.

Quality of Water

The Codell sandstone or "tubular horizon" as it is called by well drillers, is a minor contributor to ground water supplies in this area. Only a very few wells are producing from this horizon. The quality of the water varies from soft to hard depending upon the area one is in. Since no analyses were obtained of Codell water, it cannot be said just how soft or hard the water actually is.

Sundance Formation

Origin of Water

There is little doubt that the water found in this sandstone is received through rainfall and replenishment by creeks flowing across the outcrops in the Black Hills as well as the eastern flank of the Rocky Mountains. Some of the water may be connate, but only a small portion.

Quality of Water

No specific water analyses were taken of the water found in the Sundance sandstone. Field observation, however, indicated it to be a warm, very hard water.

Minnelusa Formation

Origin of Water

The Minnelusa sandstone also receives its water supply from the Black Hills and Rocky Mountain regions, as well as a small amount which may be connate water.

Quality of Water

No wells were checked in this area that were flowing or being pumped from the Minnelusa sandstone. Consequently, little information is known as to the quality of the water. In the Black Hills region, it is usually potable and soft but does have an excessive amount of fluorine in the water which causes a dental defect known as "mottled enamel". This defect is usually greatest in children and is characterized by a brown pitted surface of the teeth.

ARTESIAN WATER IN THE DAKOTA SANDSTONE

Origin of Water

As stated earlier in this section of the report, the Dakota sandstone receives much of its water supply and piezometric head from the Black Hills region. However, thought must be given to the area near the Sioux Quartzite Ridge, for this structural feature may produce part of the water supply and head existing in the eastern part of the state. Part of the supply may be connate water, but it is the author's opinion that only a small amount would be of this origin.

Quality of Water

The quality of the water coming from the Dakota sandstone varies from soft to hard throughout the entire area. It cannot definitely be stated as to what quality the water will be in any specific region. In general, however, the areas most likely to yield soft or hard water can be determined. Before this is attempted, however, it should be stated that throughout North Dakota, Minnesota, and South Dakota the upper portion of the Dakota formation yields a softer water than does the lower. Also, it should be mentioned that the character and quality of the water changes from place to place and in successive strata in the same place.

In the western portion of this area in Sully, Hughes, Hyde, and the southern three-fourths of Hand counties, the Dakota waters are soft to medium soft except for a few wells discharging harder water in the vicinity of Stephen and Agar. In the western half of Sully and Hughes counties, the water must be classified as unpotable, simply for the reason that it carries varying amounts of inflammable gas and is extremely saline. In Hyde and Hand counties where the water is less saline and contains lesser amounts of gas, the water can be used for drinking and culinary purposes although it is almost unbearable if one is not used to it. In no area, however, was the water found to be unfit for watering livestock. Livestock seem to do well on water of this kind since it contains so many salts. In the northern one-fourth of Hand county, the Dakota water becomes harder, but still is characterized by small amounts of gas and extreme salinity. Throughout the rest of the area covered by this report, the waters from the Dakota are fairly soft except for a rather large area in the northern part of Beadle county and a very small area about six miles south of Cavour in eastern Beadle county. The larger area extends along a line through Wessington, Bonilla, Hitchcock, and then southeastward toward Broadland where it swings northeastward again toward Bryon Lake. This area is about four miles wide near Wessington, but widens to about ten miles as the line swings through Bonilla, Hitchcock, and Broadland. It is about five miles wide north of Bryon Lake. The only well reporting gas in the eastern section of this region was a well in the SW$\frac{1}{4}$ of Sec. 17, T. 112 N., R. 57 W., in Kingsbury county. This well, however, is situated on the higher portion of the anticlinal structure that projects northwestward into Kingsbury county, which explains why gas occurred in this well.

On an average, the artesian waters of the Dakota sandstone contain too much flourine which is injurious to the teeth if it is present in too large a quantity. It has been established that water should contain between 1 and 1.5 parts per million and/or not more than 2 parts per million of flourine. Any more than this results in the destroying of the enamel covering the teeth provided the water is drunk regularly. Chemical analyses run on water from the Dakota sandstone have given results as high as 4 parts per million of flourine. This water should not be used for drinking purposes if it can be avoided.

Also, it should be mentioned that water coming from the Dakota is usually not suited for extensive irrigation projects. On the whole this water contains too much sodium as well as sulphates and chlorides which result in injuries to crops. Occasionally a well was checked that had a lesser amount of these harmful chemicals present in its water. These waters could then be used for irrigating and were many times used to water the family garden plot. An interesting fact that is almost always true with artesian water in this region is that the softer the water the poorer it is for irrigating.

The temperature of the Dakota water varies locally, but regionally it decreases from the Missouri river eastward to the Minnesota-South Dakota state line. The highest temperature recorded was 88 degrees in a well in northwest Hughes county while the lowest recorded was 58 degrees in Beadle county. These temperatures refer to flowing wells as the temperatures in pumped wells are much lower, since the water has more of a chance to cool off on its way to the surface.

Piezometric Surface of the Dakota Formation

The location and number of all artesian wells checked in this area are found on the accompanying Piezometric Map (in folder) and in Table No. IV.

As seen from the contours on the Piezometric Map, the general slope of the piezometric head of the Dakota is from west to east except along the Missouri river where the contours show a northeast to southwest slope. The high hydrostatic head in the eastern part of Hughes and southern half of Hyde counties is due mostly to the fact that this area is almost void of artesian wells, that is, few wells have been drilled into the artesian horizons in this area. Since less water has been withdrawn from the formation, the pressure has remained higher and therefore the height of the water level also is higher. The contours in the northwestern part of Sully county do not conform to either general slope. This area, however, is characterized by wells with large amounts of gas which tend to increase the piezometric head. Since this increase is not uniform, the contours bend in different directions in this area.

The steepest gradient of the water level is found along the Missouri river where it slopes toward the river at about 90-100 feet per mile. From here eastward it rises until the 1850 contour line is reached in Hyde county. Here it starts a slow gradual descent of about

10-20 feet per mile until the James river is reached. Then the water level rises until it is 1550 feet above sea level in eastern Clark and Kingsbury counties.

Decline in Head of the Dakota Formation

The map (page 73) and Table No. 1 (page 72) show a comparison between Darton's (1909) survey and the present survey in 1953. To estimate the decline in head on the map the present contour lines can be subtracted from Darton's contours, while the Table gives the decline of head in feet in the same relative location. It should be remembered, however, when using the Table that the elevation of the well curb was not considered. Since in some areas the ground elevation changes rapidly, the actual decline in head may be either higher or lower than that recorded in Table No. I. It serves to show, however, a relative comparison; a comparison incidently which in every case shows that the piezometric head of the Dakota formation has lowered considerably.

As determined from the map there has been a considerable drop in head in the area along the Missouri river. This drop may be contributed to many different factors. Probably the most outstanding factor is that flowing wells are obtained only in the Missouri river valley, while on the bluff of the Missouri, pumped wells are obtained. Since the majority of the people would rather have a flowing well than a pumped well, hundreds of wells were drilled in the valley whereas only a few were drilled on the bluffs. As a result the head was reduced tremendously in this relatively narrow belt along the Missouri river while it remained high along the bluffs. Another factor contributing to the decrease in head of this area is that a number of "wild" wells are present. These are wells that discharge enormous volumes of water which is not used for any specific purpose. There has been an attempt made in the last few years to have these wells plugged, but as yet only a small number have been plugged.

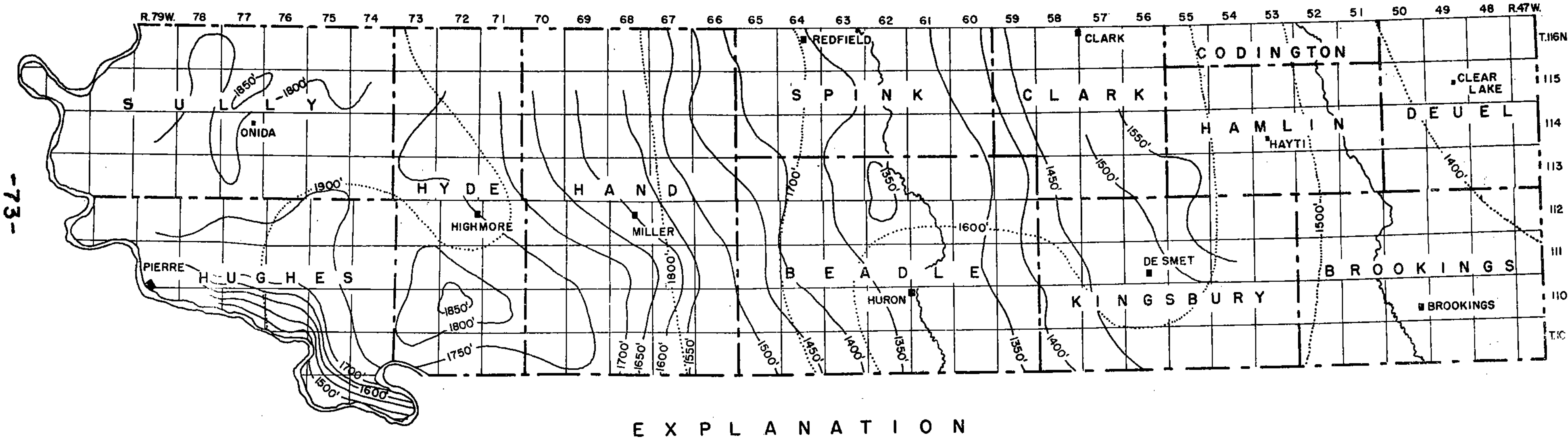
As seen from Table No. I, the greatest decline in head has occurred in T. 116 N., R. 64 W., in Spink county, where a decline of 385 feet was recorded.

COMPARISON OF DARTON'S SURVEY IN 1909 TO PRESENT SURVEY IN 1953

TABLE NO. I

	DARTON'S SURVEY		PRESENT SURVEY		
Location	Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)	Decline (ft) Since 1909
Beadle County					
T109N-R62W	785-916	289	920	67	222
T110N-R60W	930	231	800+	32	199
T111N-R64W	930	316	900+	48	268
T112N-R60W	779	277	800	9	268
T112N-R62W	793-817	116	850	16	100
T112N-R63W	601-870	138-270	840	12	126-258
T113N-R60W	810	265	855	8	257
T113N-R63W	890	231?	900	6	225?
Spink County					
T115N-R61W	1050	201	1000+	48	153
T116N-R64W	964	407	1000	22	385
T114N-R62W	909	346	900	44	306
Hand County					
T112N-R67W	1272	92	1260	-90	182
T112N-R69W	1207	139	1180	4	135
T113N-R67W	1140	296	1100	58	238
Hyde County					
T113N-R72W	1552	28	1434	-72	100
Sully County					
T116N-R78W	1595	150	1610	-60	210
Hughes County					
T112N-R74W	1453	62	1400	-13	75
Kingsbury County					
T109N-R58W	906	46	900	-5	51
T109N-R57W	925	46	960	-40	86
T110N-R57W	970	18	995	-115	133
T110N-R58W	1115	154	982	-7	161
T112N-R57W	1120	35	1040	-120	155
T112N-R58W	1000	92	1100	-25	117

COMPARISON OF DARTONS SURVEY TO THE PRESENT SURVEY



E X P L A N A T I O N

……1600…… Piezometric head surveyed by Darton in 1909

—1350— Piezometric head surveyed in 1953

ARTESIAN WATER IN THE LAKOTA FORMATION

Origin of Water

The origin of the water supply and piezometric head of the Lakota sandstone is from the Black Hills and Rocky Mountain regions. A small amount of the water supply and head may be due to connate water. It is not believed that any appreciable amount of the water supply or head is received from the Sioux Quartzite Ridge as the Lakota formation pinches out too far down the flanks of this ridge.

Quality of Water

The quality of water from the Lakota sandstone varies from soft to hard, but as a rule it is somewhat harder than the Dakota water is. It varies from one region to another and in successive strata in the same place as the Dakota does. Since fewer Lakota wells were checked, it is more difficult to outline the area that produce soft or hard water. As a whole the Lakota produces a medium soft to slightly hard water throughout the entire region except for smaller areas which are known to produce hard water. The largest of the two areas that produce hard water extends from a point about three miles south of Miller eastward to Vayland where it trends northeastwardly towards Tulare. From Tulare it trends slightly more eastward to Frankfort where it runs out of this area. This area is not more than eight miles nor less than two miles in width in any part of the area. The other area exhibiting some hard water is small and is located about five miles west and slightly north of Huron. Wells producing from the Lakota in the western portion of the region covered by this report usually produce a softer water, but the water usually contains varying amounts of gas and is extremely saline.

The other qualities of the Lakota water are nearly the same as was described for the Dakota water. It is too high in fluorine content and is not recommended for extensive irrigating purposes, although it might be slightly better for irrigating than the Dakota water is.

The temperature likewise decreases as one goes east from the Missouri river. The highest temperature measured in a flowing well producing from the Lakota sandstone was 91 degrees in a well in Hughes county, while the lowest temperature recorded was 58 degrees in Spink county.

Piezometric Surface of the Lakota Formation

The piezometric head of the Lakota formation follows the same general pattern as the head of the Dakota, that is, it slopes from west to east. There is, however, much less drop in pressure along the Missouri river in the Lakota than there is in the Dakota, but the slope remains the same. The high area in western Hyde and Hughes counties follows the same general outline as the high on the Dakota water level. The greatest gradient of the water level is found in western Beadle county where it drops about 15 feet per mile. It levels out in the middle portion of Beadle county and continues to fall until the James river is reached. East of the James river the gradient of the piezometric head increases until it is about 1500 feet above sea level in western Clark and Kingsbury counties.

Decline in Head of the Lakota Formation

It is rather hard to determine just how far the head of the Lakota formation has decreased, for no accurate records were kept on wells in this formation during the early nineteen hundreds. It has, however, decreased throughout the entire area. Probably the greatest decrease would occur in Beadle and Spink counties where more wells have been drilled into the formation. No doubt, the decline in head in this region would be 200 or more feet on an average. The decline along the Missouri river is probably not too great since fewer Lakota wells have been drilled in this area.

DEVELOPMENT OF THE WELL

The process of developing a well is many times one of the greatest difficulties faced by the well driller. To develop a well properly, requires long study and experience on the part of the driller. The drillers in this area, however, do not do much extensive developing of the wells. The usual procedure followed by most drillers, is to merely perforate the casing that will encounter the water sands. This is usually sufficient in most cases. If numerous shales or clays are interbedded with the water sands, then it is usually wise to develop the well further. This is usually done by placing a screen in the bottom of the well and packing gravel or coarse sand around it. This prevents the shales and clays from coming into the well with the water and lengthens the life of the well by preventing it from becoming clogged shut.

The use of electric logs in furthering the development of a well is very important. If an electric log is run on a well after it is drilled, it can be determined with comparative ease just where the casing should be perforated or where a screen should be placed.

An electric log should be run on all wells, but especially wells owned by cities or towns where it is extremely important that the water be clear and void of foreign particles such as fine sand, silt or clay. The presence of foreign particles may result in serious mechanical difficulties with pumping equipment, water lines, and plumbing utilities.

CONSERVATION OF PRESENT WATER RESOURCES

The conservation of both shallow subsurface ground water found largely in the glacial drift, and deeper subsurface ground water located in the stratified sedimentary formations is definitely becoming a problem in this area as well as all other areas in the State. It seems that people, on the whole, are reluctant about conserving any natural resources until the actual time of the crisis occurs. This has invariably been the case with the natural resource, ground water. Well owners throughout the region have continued to draw water from both ground water horizons overabundantly and without cause for the past sixty to seventy years. At first no appreciable decline was noticed, for the number of wells drilled was small and the spacing of the wells was scattered. As more wells were drilled in the same area, a decline in head or pressure of the wells was noticed, but still no action was taken on the well owners part.

The State Legislature in 1924 enacted a law pertaining to the regulation and conservation of artesian waters in the State. In brief, it provided that for every quarter section of land a flow of 25 gallons a minute be allowed free, but any amount over this was to be taxed by the State. It also provided that well owners could count other quarter sections to one well if the well owner owned this land. Also, it provided that a valve be placed on every well capable of delivering more than 25 gallons a minute so that the flow could not exceed this amount unless all taxes for that specified amount were paid for that specific year. This law, however, may be termed a "blue" law as it has never been enforced to any extent. Numerous wells checked this summer were flowing over 25 gallons a minute and yet no valves were present to control the discharge of the water. Whether or not the taxes were paid was not considered.

As far as conserving the ground water supplies of this region, there is little one can do to conserve shallow subsurface water, for this supply is dominantly insured by climatic conditions. A period of drouth will cause the shallow subsurface supplies to diminish, while a period of abundant precipitation will cause an increase.

Possibly the only precaution which should apply in this case is that the well owners pump only the amount of water needed to meet their demands. Pumped wells, whether they be from the shallow subsurface waters or from artesian aquifers, are in a sense conserving some of the water, for the amount of water wasted from a pumped well is negligible as compared to a flowing well.

There are a number of ways, however, by which ground water from the deeper subsurface or artesian horizons can be conserved. Since defective well construction and casing corrosion are one of the chief causes for the decline in head throughout the region, they will be considered first. Defective well construction results in the underground leakage of water from one permeable horizon to another. If then a well is constructed poorly, as is the case where a small casing is put into a large hole, the water may force its way up the outside of the casing and escape into other horizons. This can be curbed only by more care in the construction of the well. Casing corrosion also results in the underground leakage of the water. Wells with poor casing may be recased but if this seems inadvisable the old well should be plugged before a new well is drilled nearby. This is hardly ever practiced and as a result these old wells are still withdrawing a lot of water which never reaches the surface where it could be used advantageously.

"Wild" wells which flow unrestricted the year around also cause a depletion in the supply of water available. The depletion, however, is more local, but affects this local region severely. Not too much trouble is experienced from this type of well in this region as there are only a few present. In the area to the south of this, however, they are quite abundant along the Missouri river.

Perhaps the factor that has reduced the piezometric head more than any of the factors mentioned above, is the fact that nearly all the flowing wells in this area and all other areas in this State are not controlled. Many of the wells are flowing more than 10 gallons a minute which is much more water than is needed for the ordinary farm purposes.

A well flowing 10 gallons a minute will provide 14,400 gallons a day if it is allowed to run constantly. Actually it is the author's opinion that 4500 gallons a day or 3 gallons a minute would be sufficient for any farm or agricultural need other than extensive irrigation. It is not too difficult to realize then, just how the water supply is decreased when there are hundreds and hundreds of wells in the area flowing 50-100 gallons a minute and even more than this.

The artesian basin can be roughly compared to a barrel which is being filled with water at a certain rate, as small holes are being punched in its sides. There seems to be no appreciable decline as the first holes are punched, but as the number of holes increase the water level starts dropping, for the amount of water running into the barrel is less than the amount being taken out. Consequently, as this procedure continues, the barrel becomes almost empty except for the few holes in the very bottom of the barrel which drain the small amount of water coming into the barrel. The holes at the bottom can be compared to flowing wells, while those on the side of the barrel can be compared to pumped wells.

This simple comparison serves to show the need for regulation and control of those wells already drilled into the artesian basin. Unless some measures are taken to control the wells, there is no hope that the artesian basin will become equalized or the piezometric head become stable until nearly all the flowing wells have quit flowing and only pumped wells remain.

With only pumped wells in the region, the amount of water taken out will be much less. As a result the water level will build up slightly and extremely slowly until some of the original head and pressure are recovered. This, however, represents years and years of work, work which if started now rather than later will prevent all this from happening.

TABLE NO. II

ANALYSES OF WATER FROM WELLS IN EAST CENTRAL SOUTH DAKOTA
From State Geological Survey Files

County----Hughes
Location--SE$\frac{1}{4}$, Sec. 8, T. 112 N., R. 76 W.
Owner-----City of Blunt
Depth-----1400 feet (Lakota)
Date------1/18/54

	Parts per Million
Total Solids	2129
Chlorides (Cl)	837
Sulfates (SO_4)	324
Silica (SiO_2)	14
Calcium (Ca)	102
Magnesium (Mg)	33
Alkalinity	
Phenolphthalein	14
Methyl Orange	215
Total Hardness (as $CaCO_3$)	390
Fluorine (F)	1.2
Iron (Fe)	Trace
Manganese (Mn)	None
Sodium (Na)	630

County----Hughes
Location--SW$\frac{1}{4}$, Sec. 6, T. 109 N., R. 75 W.
Owner-----Tony Etzkorn
Depth-----836 feet (Dakota)
Date------1/18/54

	Parts per Million
Total Solids	3172
Chlorides (Cl)	1203
Sulfates (SO_4)	8
Silica (SiO_2)	14
Calcium (Ca)	26
Magnesium (Mg)	20
Alkalinity	
Phenolphthalein	39
Methvl Orange	818
Total Hardness (as $CaCO_3$)	143

Flourine (F)	1.2
Iron (Fe)	None
Manganese (Mn)	None
Sodium (Na)	1092

County----Hand
Location--SE¼, Sec. 32, T. 113 N., R. 66 W.
Owner------Howard Snodgrass
Depth------1263 feet (Lakota)
Date-------1/18/54

	Parts per Million
Total Solids	2351
Chlorides (Cl)	315
Sulfates (SO$_4$)	1125
Silica (SiO$_2$)	13
Calcium (Ca)	215
Magnesium (Mg)	52
Alkalinity	
Phenolphthalein	None
Methyl Orange	141
Total Hardness (as CaCO$_3$)	750
Fluorine (F)	2.8
Iron (Fe)	1.4
Manganese (Mn)	None
Sodium (Na)	453

County-----Hughes
Location--SE¼, Sec. 3, T. 109 N., R. 76 W.
Owner------George A. Schmitt
Depth------816 feet (Dakota)
Date-------1/18/54

	Parts per Million
Total Solids	3131
Chlorides (Cl)	1445
Sulfates (SO$_4$)	7
Silica (SiO$_2$)	19
Calcium (Ca)	21
Magnesium (Mg)	11
Alkalinity	
Phenolphthalein	72
Methyl Orange	651
Total Hardness (as CaCO$_3$)	98
Fluorine (F)	0.6
Iron (Fe)	Trace

Manganese (Mn)	None
Sodium (Na)	1182

County-----Sully
Location--NE¼, Sec. 23, T. 113 N., R. 77 W.
Owner------Emil Johnson (Dakota)
Depth------1495 feet
Date-------1/18/54

	Parts per Million
Total Solids	2027
Chlorides (Cl)	404
Sulfates (SO_4)	806
Silica (SiO_2)	19
Calcium (Ca)	58
Magnesium (Mg)	19
Alkalinity	
Phenolphalein	10
Methyl Orange	150
Total Hardness (as $CaCO_3$)	223
Fluorine (F)	1.4
Iron (Fe)	Trace
Manganese (Mn)	None
Sodium (Na)	729

County-----Spink
Location--SE¼, Sec. 10, T. 116 N., R. 61 W.
Owner------Jullian Remily
Depth------1070 feet (Lakota)
Date-------1/18/54

Total Solids	2188
Chlorides (Cl)	190
Sulfates (SO_4)	999
Silica (SiO_2)	9
Calcium (Ca)	10
Magnesium (Mg)	4
Alkalinity	
Phenolphthalein	None
Methyl Orange	330
Total Hardness (as $CaCO_3$)	42
Fluorine (F)	4
Iron (Fe)	7.9
Manganese (Mn)	None
Sodium (Na)	751

TABLE NO. III

LOGS OF WELLS IN EAST CENTRAL SOUTH DAKOTA

Hughes County

NE¼, Sec. 35, T. 111 N., R. 79 W.....Pierre Airport # 1.
Altitude.........1708 feet

Pierre shale	0-550'
Niobrara chalk	550-690
Carlile shale	690-1010
Greenhorn lime	1010-1060
Graneros shale	1060-1410
Dakota sand	1410-1500
Fuson shale	1500-1520
Lakota sand	1520-1530
Sundance sand	1530-2125
Minnelusa lime	2125-2260
Madison limestone	2260-2335
Winnipeg sandstone	2335-2370
Granite (dark gray)	at 2370

Hyde County

NE¼, Sec. 24, T. 116 N., R. 73 W.....Hunt-School Land # 2.
Altitude........1880 feet

Glacial drift	0-140'
Pierre shale	140-760
Niobrara chalk	760-905
Carlile shale	905-1200
Greenhorn limestone	1200-1250
Graneros shale	1250-1525
Dakota sandstone	1525-1560
Fuson shale	1560-1660
Lakota sandstone	1660-1805
Sundance sandstone	1805-1915
Millstone grit	1915-2265

Red River.................2265-2435
Winnipeg shale............2435-2555
Pre-Cambrian (diabase)....2555-2618

Hand County

SE¼, Sec. 19, T. 114 N., R. 69 W................Steptoe
Altitude.......1613 feet

Glacial drift.............0-208'
Pierre shale...........208-520
Niobrara chalk..........520-584
Carlile shale...........584-828
Greenhorn limestone.....828-860
Graneros shale..........860-1180
Dakota sandstone.......1180-1220
Fuson shale............1220-1280
Lakota sandstone.......1280-1373

SE¼, Sec. 33, T. 112 N., R. 68 W..................Olsen
Altitude.........1683 feet

Glacial drift..............0-230'
Pierre shale............230-574
Niobrara chalk..........574-646
Carlile shale...........646-852
Greenhorn limestone.....852-880
Graneros shale..........880-1190
Dakota sandstone.......1190-1230
Fuson shale............1230-1275
Lakota sandstone.......1275-1435
Probably Jurassic at bottom?

NE¼, Sec. 29, T. 110 N., R. 68 W..........Sheldon-Reese
Altitude.......1970 feet

Glacial drift..............0-280'
Pierre shale............280-752
Niobrara chalk..........752-845
Carlile shale...........845-1048
Greenhorn limestone....1048-1077
Graneros shale.........1077-1410
Dakota sandstone.......1410-1532

NE¼, Sec. 35, T. 110 N., R. 66 W. .... Palmer
Altitude........1664 feet

Glacial drift	0-122'
Pierre shale	122-510
Niobrara chalk	510-623
Carlile shale	623-768
Greenhorn limestone	768-782
Graneros shale	782-1140
Dakota sandstone	1140-1225
Fuson shale	1225-1226

SE¼, Sec. 32, T. 113 N., R. 66 W. .... Snodgrass
Altitude........1444 feet

Glacial drift	0-78'
Pierre shale	78-340
Niobrara chalk	340-430
Carlile shale	430-636
Greenhorn limestone	636-666
Graneros shale	666-968
Dakota sandstone	968-1089
Fuson shale	1089-1141
Lakota sandstone	1141-1262

Spink County

NW¼, Sec. 34, T. 116 N., R. 61 W. .... Wurz
Altitude........1300 feet

Glacial drift	0-88'
Pierre shale	88-202
Niobrara chalk	202-260
Carlile shale	260-500
Greenhorn limestone	500-530
Graneros shale	530-830
Dakota sandstone	830-864
Fuson shale	864-884
Lakota sandstone	884-952

NE¼, Sec. 26, T. 115 N., R. 64 W. .... Schmidt
Altitude .... 1325 feet

Glacial drift	0-120'
Pierre shale	120-210
Niobrara chalk	210-334
Carlile shale	334-466
Greenhorn limestone	466-480
Graneros shale	480-822
Dakota sandstone	822-953
Fuson shale	953-974
Lakota sandstone	974-1024
Pre-Cambrian (chlorite schist)	1024-1085

Beadle County

NE¼, Sec. 22, T. 109 N., R. 63 W. .... Meyer
Altitude .... 1344 feet

Glacial drift	0-100'
Pierre shale	100-210
Niobrara chalk	210-300
Carlile shale	300-494
Greenhorn limestone	494-522
Graneros shale	522-820
Dakota sandstone	820-920
Fuson shale	920-946
Lakota sandstone	946-1043

NE¼, Sec. 12, T. 113 N., R. 65 W. .... Zybell
Altitude .... 1362 feet

Glacial drift	0-92'
Pierre shale	92-266
Niobrara chalk	266-380
Carlile shale	380-542
Greenhorn limestone	542-570
Graneros shale	570-872
Dakota sandstone	872-923
Fuson shale	923-1055
Lakota sandstone	1055-1122

Probably Jurassic at bottom

NE¼, Sec. 32, T. 110 N., R. 63 W.........Virgil City Well
Altitude........1343 feet

Glacial drift	0-74'
Pierre shale	74-228
Niobrara chalk	228-308
Carlile shale	308-572
"Codell sandstone"	340-360
Greenhorn limestone	572-596
Graneros shale	596-830
Dakota sandstone	830-860
Fuson shale	860-980
Lakota sandstone	980-1120

SE¼, Sec. 3, T. 112 N., R. 57 W.................Glanzer
Altitude........1393 feet

Surface pipe	0-280'
Niobrara chalk	280-360
Carlile shale	360-572
Greenhorn limestone	572-600
Graneros shale	600-840
Dakota sandstone	840-903

SE¼, Sec. 32, T. 113 N., R. 62 W................Tschetter
Altitude........1316 feet

Glacial drift	0-150'
Pierre shale	150-170
Niobrara chalk	170-250
Carlile shale	250- ?
Greenhorn limestone	? - ?
Graneros shale	? -772
Dakota sandstone	772-910

NE¼, Sec. 27, T. 113 N., R. 59 W..................Waldner
Altitude........1413 feet

Glacial drift and Pierre shale	0-330'
Niobrara chalk	330-400
Carlile shale	400-618
Greenhorn limestone	618-650
Graneros shale	650-890
Dakota sandstone	890-1004

SE¼, Sec. 36, T. 111 N., R. 62 W.......State Fair Grounds
Altitude........1250 feet

Glacial drift	0-90'
Pierre shale	90-225
Niobrara chalk	225-250
Carlile shale	250-470
"Codell sandstone"	260-370
Greenhorn limestone	470-500
Graneros shale	500 750
Dakota sandstone	750-850
Fuson shale	850-960
Lakota sandstone	960-1151
Granite (light gray)	1151-1178

Kingsbury County

SW¼, Sec. 27, T. 111 N., R. 58 W.................Cadwell
Altitude........1480 feet

Glacial drift	0-124'
Pierre shale	124-332
Niobrara chalk	332-410
Carlile shale	410-628
Greenhorn limestone	628-650
Graneros shale	650-880
Dakota sandstone	880-984

SW¼, Sec. 22, T. 109 N., R. 54 W.........Oldham City Well
Altitude........1719 feet

Glacial drift	0-408'
Pierre shale	408-590
Niobrara chalk	590-620
Carlile shale	620-870
Greenhorn limestone	870-905
Graneros shale	905-1002
Dakota sandstone	1002-1110?
Fuson shale	1110?-1142?
Lakota sandstone	1142?-1300

Hamlin County

SE¼, Sec. 17, T. 113 N., R. 55 W........Bryant City Well
Altitude......1845 feet

Glacial drift............	0-370'
Pierre shale...........	370-732
Niobrara chalk..........	732-870
Carlile shale...........	870-1054
Greenhorn limestone...	1054-1088
Graneros shale.........	1088-1246
Dakota sandstone......	1246-1360

Codington County

SE¼, Sec. 3, T. 116 N., R. 52 W...........Bureau of Rec.
Altitude.......1813 feet

Surface pipe............	0-518'
Pierre shale...........	518-822
Niobrara chalk..........	822-861
Carlile shale...........	861-938
Greenhorn limestone....	938-953
Graneros shale..........	953-1064
Dakota sandstone.......	1064-1090
Fuson shale............	1090-1224
Lakota sandstone.......	1224-1274
Pre-Cambrian (Serpentine).......	1274-1299

TABLE NO. IV

ARTESIAN WELLS CHECKED IN EAST CENTRAL SOUTH DAKOTA

Hughes County

No.	Owner & Location	Date Drilled	Depth (ft.)	M.P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
368	Bob Hood NW¼ S22-T112N-R80W	Old Well	App. 1400	1738			6
369	W. H. Smith SW¼ S5-T111N-R78W		1580	1795		1735	
370	D. B. Garber NW¼ S2-T111N-R78W	1908	1600	1806		1736	
371	Eldon Hawkins Estate NE¼ S21-R111N-R78W		1400	1725	11.5	1752	4
372	Eltor Mattheis NW¼ S31-T112N-R78W		1580	1802		1742	
373	Lucy S. Pietris NE¼ S32-T112N-R78W		1580	1809		1769	1.7
374	William Luecke SW¼ S19-T112N-R78W		App. 1670	1815		1777	
375	Irvin Korkow NW¼ S1-T110N-R77W	1915	???? 2200	1713	App. 10	1736	6
376	West of Rousseau NW¼ S22-T110N-R77W			1470	Over 5	1481	3.2
377	Pete Metzinger SW¼ S29-T111N-R77W		1800	1715	2	1720	.85
378	Elmer Unruh NW¼ S13-T111N-R77W		App. 1800	1744	App. 6	1758	1.3

* Measuring point, Altitude above sea level.
** Height of Piezimetric head above sea level.

No.	Owner & Location	Date Drilled	Depth (ft.)	M.P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
379	K. Stewart NW¼ S20-T112N-R77W		1460	1818		1718	
380	J. A. Wies SW¼ S12-T112N-R77W		App. 1400	1761		1761	
381	George A. Schmitt #1 SE¼ S3-T109N-R76W	1944	816	1432	18	1474	18
382	George A. Schmitt #2 NE¼ S34-T110N-R76W	1948	910	1490	26	1549	3.8
383	Ray Byrum SE¼ S25-T110N-R76W	1947	860	1450	9	1471	2
384	Ernest Stewart SW¼ S3-T111N-R76W	1923	1200	1730	8	1749	6
385	Karl L. Graf SE¼ S20-T111N-R76W	1948	1150	1670	23	1746	4
386	Henry Lauing SE¼ S29-T112N-R76W	1922	1385	1723	App. 4	1732	1.5
387	City Well at Blunt SE¼ S8-T112N-R76W	1900	1400	1615	3	1622	2
388	Carl Albright SW¼ S25-T112N-R76W	1929	1400	1744	3	1751	2
389	Robert Hirsch NW¼ S15-T108N-R75W		App. 1100	1590	14	1622	1.7
390	Tom Hanson SW¼ S8-T108N-R75W	1930	App. 1200	1538	15	1573	1.3
391	Ted Schenegge NE¼ S4-T108N-R75W	1947	1250	1699			2
392	Tony Etzkorn SW¼ S6-T109N-R75W	1947	836	1422	25	1480	4
393	Leonard McDowell NW¼ S16-T109N-R75W	1947	1296	1698	App. 12	1724	8
394	C. L. Hyde SW¼ S1-T109N-R75W		1460	1696	10.5	1721	4.8

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
395	Harold Hansen SE¼ S28-T109N-R75W	1928	? 1340	1688	15	1723	
396	Oliver Oleson NE¼ S14-T110N-R75W	1949	1330	1731	6.5	1746	1.7
397	Herman Traxinger SW¼ S1-T111N-R75W		1800	1878		1800	3
398	Miles Robbins SE¼ S24-T111N-R75W		1400	1743	App. 8	1761	3
399	Harold Peitc SW¼ S5-T112N-R75W		1376	1721	App. 7	1737	4.6
400	Art Garrity NW¼ S26-T112N-R75W		1452	1763		1763	
401	Solomon Mehrer NW¼ S2-T112N-R75W	1909	1300	1729		1729	.4
402	B. A. Gregg NE¼ S23-T108N-R74W	Feb. 1953	1025	1503	Over 60	App. 1641	40
403	W. W. Feller SE¼ S20-T110N-R74W		App. 1500	1876		1791	
404	Wayne Berke SW¼ S26-T110N-R74W		1720	2004		1704	1.4
405	Mehrer Bros. NE¼ S15-R111N-R74W		1600	1935		1755	1.2
406	Ewald Mattheis SE¼ S9-T112N-R74W		1400	1783		1769	
407	Elmer Hoffman NW¼ S4-T112N-R74W	1951	1557	1765	6.5	1780	10

Sully County

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
408	Waitt Bros. NW¼ S12-T113N-R81W	1913	1600	1792		1784	

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/in
409	Waitt Bros. SW¼ S14-T113N-R80W	Old Well	App. 1700	1769	App. 9	1780	8.6
410	Florence Zebroski NW¼ S13-T115N-R80W			1902		1817	
411	Albert C. Trumble SW¼ S9-T113N-R79W	1953	App. 1600	1777	10	1799	3
412	D. Barton SE¼ S32-T113N-R79W	1901	1565	1744			
413	Frank Fagner SE¼ S6-T114N-R79W	1950	1660	1866		1795	3
414	Joe McGuire SE¼ S13-T114N-R79W	1942	App. 1400	1798		1793	
415	George C. Trumble SW¼ S35-T114N-R79W	Old Well	1500	1761	6	1775	3.7
416	C. E. Swenson SW¼ S8-T115N-R79W	1917	1792	1819		1779	
417	John Newman NE¼ S12-T115N-R79W			1887		1807	2
418	John Sutton Ranch NW¼ S8-T116N-R79W	1946	1260	1545		1545	.25
419	W. H. Becker SE¼ S23-T116N-R79W	1948	1638	1841		1801	4
420	Ed Wagner NE¼ S12-T116N-R79W	Old Well	1610	1821		1803	3
421	Charles Luecke SW¼ S7-T113N-R78W	1942	App. 1500	1786		1770	
422	Leland Warne NE¼ S15-T113N-R78W	1912	1475	1784		1772	
423	Albert Lomheim SE¼ S10-T115N-R78W	1944	1596	1874		1794	
424	D. G. Martin NE¼ S30-T115N-R78W	1947	1578	1873		1823	3.5

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
425	J. Cavenaugh SW¼ S3-T116N-R78W	1909	1615	1874		1814	3
426	E. F. Wittler NE¼ S25-T116N-R78W	1915	App. 1600	1863		1798	2.5
427	Emil Johnson NE¼ S23-T113N-R77W	1945	1495	1763	2.5	1769	2.1
428	H. D. Baker SE¼ S18-T113N-R77W	Very Old	App. 1500	1823		1823	.1
429	F. J. Sack SE¼ S6-T114N-R77W		App. 1700	1841		1841	.1
430	Onida City Well #1 SE¼ S2-T114N-R77W	1933	1558	1874		1734	90
431	Onida City Well #2 SE¼ S2-T114N-R77W	1911	1558	1874		1734	60
432	R. B. Walker SW¼ S17-T114N-R77W	Old Well		1844		1794	3
433	Boyd Chipman SE¼ S14-T115N-R77W	1902		1868	3	1875	.5
434	Vern Pearson SW¼ S26-T116N-R77W	Old Well	App. 1600	1866		1801	3
435	Alvin Joachin SE¼ S2-T116N-R77W	1935	1700	1899		1804	
436	Morton Sorenson NE¼ S9-T113N-R76W	1928	1700	1766		1736	
437	F. D. Albertus NE¼ S34-T113N-R76W		1650	1737	6	1751	3.1
438	J. A. Moore NE¼ S31-T113N-R76W	June 1953	1423	1736	App. 15	1770	28
439	B. A. Klingbil SW¼ S2-T114N-R76W	1933	1558	1851		1761	3
440	Henry Smith NE¼ S29-T114N-R76W	Old Well	1430	1803		1787	

No.	Owner & Location	Date Driller	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
441	A. C. Brehe NW¼ S33-T116N-R76W	Old Well	App. 1600	1835		1820	
442	Edwin Archer SE¼ S13-T116N-R76W		1600	1850		1850	.86
443	G. C. Reynolds SW¼ S3-T113N-R75W	Nov. 1945	1420	1713	33	1789	35
444	August Lappe SW¼ S34-T113N-R75W	1924	1440	1733	App. 10	1756	9
445	Alvin S. Thomas NW¼ S10-T114N-R75W			1761	1	1763	1.2
446	Monroa Shoup SW¼ S17-T115N-R75W	1917	1700	1954		1774	3.2
447	Sam G. Hofer SW¼ S23-T115N-R75W	1914	1588	1883		1808	
448	Pete Peterson NE¼ S29-T113N-R74W	1922	1700	1729	23	1783	3.2
449	Ronald Riveness SW¼ S11-T113N-R74W		App. 1500	1763		1761	1

Hyde County

No.	Owner & Location	Date Driller	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
450	Max Kusser NE¼ S6-T109N-R73W	1923	App. 1100	1773	13	1803	12
451	Theodore Filbey NW¼ S3-T111N-R73W	1916	1600	2022		1822	
452	Fred Wemmering NW¼ S10-T112N-R73W	1916	1470	1796	-	1796	
453	Sam Dalton SE¼ S20-T113N-R73W	Old Well	1500	1803		1763	
454	L. A. Larson NE¼ S26-T113N-R73W	1911	1565	1822		1762	

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
455	Wilbur Goehring SE¼ S10-T113N-R73W	1943		1782		1742	
456	John Konrad NE¼ S35-T109N-R72W	1928	1280	1742		1742	
457	Stephen Mission NW¼ S14-T109N-R72W	1948	1430	1835		1745	65
458	W. H. McKelvey SE¼ S5-T110N-R72W	1916	1707	2102		1882	
459	L. Hanson SE¼ S5-T112N-R72W	Old Well	App. 1500	1880		1876	
460	J. Naughton SW¼ S25-T113N-R72W	1910	1434	1802		1730	
461	Walter L. Ashdown SW¼ S17-T113N-R72W	1951	1480	1793		1763	8
462	Joe Stransky SE¼ S21-T114N-R72W	1909	1340	1727		1727	.66
463	Melvin Meeker NW¼ S23-T114N-R72W	1911	1340	1707			3.5
464	NE¼ S2-T114N-R72W			1714		1714	
465	Elmer Larson NE¼ S8-T114N-R72W	1919	1400	1722		1722	
466	L. J. Ankrum SW¼ S35-T114N-R72W	June 1951	1420	1700	7	1716	2.5
467	H. E. Simonette NE¼ S19-T115N-R72W	1908	1556	1885		1885	
468	Leo J. Thompkins NE¼ S10-T112N-R71W	Dec. 1942	1490	1815		1715	3
469	Floyd Dittman SE¼ S33-T113N-R71W	Dec. 1950	1480	1783		1713	
470	Floyd Gatlin SE¼ S9-T113N-R71W	1921	1475	1685			

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
471	Charles Clemmet SE¼ S28-T114N-R71W	1942	1407	1674	12	1702	4.6
472	Raymond Carlson SW¼ S4-T114N-R71W			1682	22	1733	9

Hand County

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
473	John Renner NW¼ S2-T112N-R70W	April 1949	1300	1694		1674	4
474	T. J. Poindexter NW¼ S3-T113N-R70W	1936	1336	1634	20	1680	
475	Erwin Kost SE¼ S23-T113N-R70W	1946	1345	1646	14	1678	8
476	Frank Nolz NE¼ S20-T114N-R70W	Old Well	App. 1400	1644	1	1646	.66
477	Richard Mardinmass NE¼ S32-T115N-R70W	Old Well	1420	1683		1648	3
478	Frank & Harry Kenaston SE¼ S28-T109N-R69W		1275	1872		1752	3.3
479	Myron Waring NE¼ S13-T110N-R69W	Old Well	App. 1250				
480	Leland Taylor SW¼ S11-T110N-R69W	1909	App. 1600				1
481	Glen Smith SE¼ S12-T112N-R69W	1917	1180	1612	1.5	1616	.86
482	James Manning SE¼ S3-T113N-R69W	Old Well	1170	1571	2	1576	.9
483	Walter Danielson NW¼ S22-T113N-R69W	1908	1180	1591	11	1616	3.5
484	C. C. Shaefer SW¼ S11-T114N-R69W	Old Well		1581	App. 2	1586	1.3

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
485	Ted Hellwueg NW¼ S18-T114N-R69W			1626	1	1627	.5
486	George Steptoe NW¼ S19-T114N-R69W	Feb. 1950	1578	1625			28
487	William Froning NE¼ S27-T115N-R69W	1918	1326	1582		1582	.25
488	Frank Shaefer NE¼ S15-T115N-R69W	1944	1405	1585	App. 25	1635	10
489	Roy Yearous NE¼ S21-T111N-R68W	July 1948	1448	1936		1746	2.5
490	Nels Jacobsen NW¼ S9-T111N-R68W	Sept. 1952	1380	1726		1616	4
491	Alvie Haberling SE¼ S20-T112N-R68W	Nov. 1949	1305	1632		1630	
492	Walter Brown SW¼ S1-T113N-R68W	Aug. 1948	1064	1484	30	1553	2.3
493	Olsen Bros. SE¼ S26-T113N-R68W	May 1951	1124	1480	40	1572	10
494	Emil Roester SW¼ S29-T113N-R68W	Old Well	1120	1568	15	1603	15
495	Robert Ames NE¼ S30-T114N-R68W	July 1949	1221	1545	11	1570	1.2
496	Percy Williams SW¼ S2-T114N-R68W			1440	24	1495	7
497	Leonard Naber NW¼ S29-T115N-R68W	1949	1500	1533	App. 10	1550	45
498	John Weideman SE¼ S3-T116N-R68W	Feb. 1948	1195	1462	4	1472	3
499	Lawrence Davis NE¼ S32-T116N-R68W	Old Well		1525	App. 25	1583	4
500	F. Welch NW¼ S25-T111N-R67W		App. 1600	1802		1552	

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
501	Gilbert W. Collins SE¼ S8-T112N-R67W	Old Well		1540	6	1554	1.5
502	C. E. Roberts NE¼ S3-T112N-R67W	Nov. 1948	1138	1492	10.5	1517	6
503	Laurence Parmerly SW¼ S26-T112N-R67W	Feb. 1953	1260	1638		1548	6
504	Earl Horn SW¼ S15-T113N-R67W	1925	1100	1444	25	1502	3
505	Ed Fechner SE¼ S28-T114N-R67W	1918	App. 1100	1404	App. 35	1485	8
506	Ernest Clemet SE¼ S3-T114N-R67W	Old Well		1410	30	1479	15
507	Gorden Strasburg SE¼ S16-T115N-R67W	June 1953	1090	1441	26	1501	2.2
508	Frank & Peter Joyce NE¼ S12-T115N-R67W	Old Well		1396	App. 34	1474	2.6
509	Albert Johnson NE¼ S36-T110N-R66W	Dec. 1952	1060	1560		1527	4
510	U. G. Harris SW¼ S3-T111N-R66W	1947	1072	1483	App. 25	1540	2.4
511	Drap Sievers SW¼ S35-T111N-R66W	Old Well	App. 1400	1507	5	1519	3
512	Jim Garner NE¼ S29-T112N-R66W	1941	1100	1481	9.5	1503	1
513	Gerald McGirr NE¼ S23-T112N-R66W	June 1953	985	1423	24	1478	12
514	Kai Beck NE¼ S12-T112N-R66W	1918	900	1427	22	1478	3.3
515	Howard Snodgrass SE¼ S32-T113N-R66W	Sept. 1952	1263	1444	43	1543	4.3
516	Harold Carr SE¼ S18-T113N-R66W	1906	1150	1422	App. 35	1503	30

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
517	J. E. Jones SE¼ S32-T114N-R66W	April 1949	1010	1413	34	1487	4.3
518	A. D. Yada NE¼ S18-T114N-R66W	Old Well		1418	41	1512	2.7
519	G. Bottom SE¼ S14-T114N-R66W	1952	1218	1380	75	1553	45
520	Caroline Maron SW¼ S26-T115N-R66W	1921	1140	1377	30	1446	3
521	Russel Anderson SW¼ S30-T115N-R66W	Old Well		1383	App. 15	App. 1438	3.7
522	August Schmidt NW¼ S13-T115N-R66W	Oct. 1950	1240	1345	App. 80	App. 1529	
523	Clarence Mullenberg NW¼ S12-116N-R66W	Old Well	App. 1000	1364	1	1366	.8
524	Armin Schneider NW¼ S19-T116N-R66W	Old Well		1383	App. 30	1452	
525	John Becker SW¼ S18-T116N-R66W	Old Well		1414	19	1458	6.6
	Spink County						
526	Frank Hague NW¼ S22-T114N-R65W			1364	8	1382	1.8
527	Brundt Ost SE¼ S25-T114N-R65W	1910	980	1356	22	1407	1.4
528	R. W. Jessen NE¼ S28-T115N-R65W	1952		1328	20	1374	1.5
529	Ralph Zarnecke SW¼ S2-T115N-R65W			1322	6.5	1337	1
530	Benefit Life Ins. Co. NW¼ S31-T116N-R65W	1942	990	1355	20	1401	10

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
531	Arlo Becker NE¼ S3-T116N-R65W	1945	1200	1360		1354	5.2
532	Bernard Hardy NE¼ S18-T116N-R64W	1928	1000	1346	12	1374	5
533	Frank Otoe SW¼ S7-T114N-R64W	1951	1000	1347	22	1398	20
534	Albert Neitzel NE¼ S10-T114N-R64W	1933	944	1326	.5	1327	1
535	Albert Neitzel NE¼ S10-T114N-R64W	1906	860	1340	App. 10	1363	2
536	Lyle Christensen SE¼ S27-T114N-R64W	Old Well	App. 900	1324	App. 21	1372	6
537	Jim Dorty SE¼ S19-T115N-R64W	1948	1180	1326	19	1369	3
538	Robert McCone SE¼ S3-T115N-R64W	1929	1100	1320	2.5	1326	.66
539	Dan Letz SW¼ S19-T116N-R64W	Old Well	App. 1000	1320	9.5	1342	1.7
540	Ray Cole Jr. NE¼ S19-T114N-R63W	Old Well		1344		1338	4
541	Leslie Hoeloel NW¼ S26-T114N-R63W	1948	App. 850	1305	App. 16	1342	6
542	Petersmeyer Bros. NE¼ S31-T115N-R63W	1947	930	1320	6	1334	4.1
543	Petersmeyer Bros. NE¼ S31-T115N-R63W	1905	997	1322	5	1334	1
544	Elmer Lips SE¼ S26-T115N-R63W	Old Well		1304	20	1350	2.4
545	Chester Meyer SE¼ S3-T115N-R63W	1906	840	1304	App. 20	1350	2
546	Rudolph Brink SW¼ S6-T116N-R63W	Old Well	975	1300	19	1344	5

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
547	Grace Morey NW¼ S30-T116N-R63W	Old Well	1200	1294	10	1317	5.1
548	Dewey Scott SW¼ S14-T116N-R63W	1913	App. 850	1278	20	1324	3.2
549	Herbert Stellmacher SW¼ S5-T114N-R62W			1288	App. 20	1334	2.4
550	E. J. Schneider SE¼ S32-T114N-R62W	Old Well		1303	18	1344	1.7
551	Peter Anderson SE¼ S28-T114N-R62W	1930	900	1283	19	1327	3.1
552	J. R. Hofer SE¼ S25-T114N-R62W	1935		1306	9.25	1327	3
553	Spink Colony NW¼ S28-T115N-R62W	1947	910	1284	9	1305	5
554	John Frenz SE¼ S8-T116N-R62W	Old Well	App. 950	1284	13	1313	.66
555	Joe Tschetter NW¼ S14-T114N-R61W	1906	App. 930	1308	App. 15	App. 1340	4.5
556	Peter Gross NE¼ S15-T114N-R61W	1941	App. 850	1312	11	1337	4.3
557	Earl Knickrehm SE¼ S34-T114N-R61W	1909	812	1313	19	1357	2.9
558	W. J. Pullman SW¼ S6-T114N-R61W	Old Well		1303	18	1344	3.2
559	Katie Hofer SW¼ S23-T115N-R61W	Old Well		1315	10	1338	6
560	Paul P. Hofer NW¼ S17-T115N-R61W	Old Well	App. 1000	1307	21	1355	3.7
561	George Sullivan SE¼ S7-T116N-R61W	Old Well		1285	13	1315	.5
562	Jullian Remily SE¼ S10-T116N-R61W	1953	1070	1348		1338	2

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
563	Martin Ballersley SE¼ S34-T116N-R61W	1920	960	1316	App. 10	1339	
564	Bert Mason NW¼ S30-T116N-R61W	Old Well	App. 1000	1291	15	1326	12
565	Harry Burrish NW¼ S33-T115N-R60W			1347	2	1352	5
566	Earl Paul NE¼ S8-T116N-R60W	1940	1060	1368		1368	
567	George Barkemy NE¼ S23-T116N-R60W	1911	910	1390	4	1399	.75
568	Otto Heer NE¼ S32-T116N-R60W	1943	1153	1365		App. 1340	
	Beadle County						
569	Hollingsworth Ranch SE¼ S4-T109N-R65W	Aug. 1953	915	1473	14	1505	20
570	Wylie Davis SE¼ S15-T110N-R65W	Old Well		1412	17	1450	2
571	Vernon Hedge NW¼ S33-T111N-R65W	1948	???? 1500	1410	17	1449	8.6
572	M. McKelvey SW¼ S15-T112N-R65W	1941	960	1382	App. 35	1463	12
573	John Bonebrake NW¼ S5-T112N-R65W			1414	26	1474	6.6
574	E. Kavenaugh SW¼ S19-T113N-R65W	1913	900	1420	25	1478	15
575	Harold Hurm SW¼ S24-T113N-R65W	New Well	App. 1000	1330	26	1388	6
576	Erwin Fromm NW¼ S1-T109N-R64W	1903	830	1383	18	1424	.8

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
577	Emanuel Bauder SW¼ S25-T109N-R64W	New Well		1354	24	1409	4
578	Edward R. Peterson NE¼ S14-T110N-R64W	Old Well		1361	21	1409	6
579	Robert McBride NW¼ S29-T110N-R64W	1949		1408	23	1461	4.8
580	Frank Klaschen SE¼ S27-T111N-R64W	Old Well		1332	27	1393	3
581	Jullius Frank NW¼ S14-T111N-R64W	1948	900	1349	21	1397	2.3
582	Carl Larson NW¼ S6-T111N-R64W	1949	925	1387	3.75	1396	2.5
583	H. M. Fichstead SE¼ S30-T111N-R64W	1922	App. 1100	1404	26	1464	10
584	Art Witthoeff NW¼ S27-T112N-R64W	1943	864	1350	21	1398	5
585	Otto Johannsen NW¼ S2-T112N-R64W	1492	915	1342	22	1393	5.5
586	Vern Wharrie SE¼ S7-T112N-R64W	1948		1342	13	1372	4.1
587	Don Jockhick SW¼ S2-T113N-R64W	Old Well	App. 900	1334	App. 25	1393	3
588	Fred M. Meyer NW¼ S26-T109N-R63W	1951		1356	38	1443	5.5
589	Charles Reilly SW¼ S23-T110N-R63W	Old Well		1341	App. 25	1398	3.8
590	Kenneth Langbehn NW¼ S33-T111N-R63W	Old Well	App. 700	1304	7.25	1321	.6
591	Joe P. Pullman SE¼ S9-T111N-R63W	July 1953	805	1318	App. 25	1376	6
592	Milton Brock NE¼ S28-T112N-R63W	1938	840	1334	App. 5	1346	3

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
593	Kenneth Huizenger NE¼ S34-T113N-R63W	1951	App. 900	1328	2.5	1333	3.7
594	Max Lips NW¼ S10-T113N-R63W	1921	App. 900	1327	3.5	1333	2
595	Ernest Baruth NW¼ S28-T109N-R62W	1936	920	1340	29	1407	4.3
596	A. H. McDowell NE¼ S24-T109N-R62W	Dec. 1945	770	1316	7.5	1333	5.5
597	Mark Walters NW¼ S33-T110N-R62W	Old Well		1345	11	1370	3.8
598	Ed Kotas SW¼ S35-T111N-R62W	1950	800	1286	20	1332	2.8
599	Fred Miedema SE¼ S31-T111N-R62W	1951	App. 900	1311	App. 35	1392	12
600	Francis Thomas NE¼ S7-T111N-R62W			1305	23	1357	2.3
601	Alvin Schnathorst SW¼ S25-T112N-R62W	1952	850	1301	7	1317	2.8
602	R. Stierly NE¼ S30-T112N-R62W	Old Well		1306	15	1341	5.5
603	Chris J. Gross NE¼ S12-T113N-R62W	April 1910	777	1295	14	1327	7.1
604	W. G. Wheiting NW¼ S8-T113N-R62W	Old Well	App. 850	1308	20	1354	6
605	Ferd Tschetter SE¼ S32-T113N-R62W	July 1952	910	1316	28	1380	10
606	Ed Arbeitei SE¼ S16-T109N-R61W	1950	??? 406	1296	22	1347	3.3
607	John Schroder NW¼ S30-T110N-R61W	May 1950	950	1295	22	1346	15
608	Mrs. D. W. Vance SE¼ S10-T110N-R61W			1303	5	1315	1

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pres-sure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
609	George Tobin SW$\frac{1}{4}$ S35-T110N-R61W	Old Well		1301	18	1342	2
610	William Cronin SW$\frac{1}{4}$ S19-T111N-R61W	1953	810	1287	9	1308	5.2
611	E. J. Allbee NW$\frac{1}{4}$ S5-T111N-R61W	1951	855	1303	9	1324	4
612	George Verhelst NW$\frac{1}{4}$ S26-T111N-R61W	Old Well		1309	11	1334	1.1
613	Dan Schmeichel Jr. SW$\frac{1}{4}$ S14-T112N-R61W	1951	???? 1000	1276	App. 40	1368	15
614	John Greenan SW$\frac{1}{4}$ S31-T113N-R61W	1908	850	1296	Over 20	1342	6
615	Charlie Anderson SW$\frac{1}{4}$ S23-T113N-R61W	Old Well		1304	19	1348	2.8
616	NE$\frac{1}{4}$ S10-T113N-R61W			1302	12	1330	6
617	H. J. Henkley NE$\frac{1}{4}$ S5-T109N-R60W	1910	App. 700	1324	10	1347	8
618	Kenneth Bloom NE$\frac{1}{4}$ S33-T109N-R60W			1324	3	1331	6
619	R. E. Barton SE$\frac{1}{4}$ S7-T110N-R60W	1948	App. 800	1308	App. 14	1340	4.4
620	Richard Moeller SE$\frac{1}{4}$ S21-T111N-R60W			1315	App. 15	1350	5.5
621	A. R. Evans SW$\frac{1}{4}$ S25-T112N-R60W			1352	3.5	1360	3
622	F. F. Robinson SE$\frac{1}{4}$ S31-T112N-R60W	Old Well	800	1315	4	1324	8.6
623	George Sthal NW$\frac{1}{4}$ S4-T112N-R60W	Old Well		1329	1	1331	.6
624	Joshua J. Hofer NW$\frac{1}{4}$ S9-T113N-R60W	1952	900	1337		1327	6

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
625	David M. Tschetter NW¼ S1-T113N-R60W	1952	855	1348	3.5	1356	3.3
626	Herman Dubra NE¼ S30-T109N-R59W	Sept. 1952	878	1340	2	1344	2.4
627	Spencer Spriggs SE¼ S24-T109N-R59W			1382	3	1389	.36
628	Frank S. McDonald NW¼ S7-T110N-R59W			1324	21.5	1374	1.8
629	C. H. Nenaven SW¼ S29-T110N-R59W	Old Well	800	1336	3	1343	.52
630	Arlo McMillian NE¼ S35-T110N-R59W			1380	2.5	1386	1.2
631	D. J. Fast NW¼ S26-T111N-R59W	Old Well		1393	1	1395	2.3
632	R. B. Hill NE¼ S18-T111N-R59W	March 1953	800	1362	1.5	1365	7.5
633	J. A. Glanzer SE¼ S3-T112N-R59W	July 1952	903	1393	7.5	1410	6
634	Marvin H. Walters SE¼ S31-T113N-R59W	1952	1080	1366		1355	
635	Sam Walters NW¼ S23-T113N-R59W	Old Well	App. 800	1394		1374	

Kingsbury County

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
636	Cecil Goss SE¼ S22-T109N-R58W	1910	App. 900	1408		1403	
637	Alex McGeachy NW¼ S7-T110N-R58W	1910	982	1402		1395	
638	Gerald Strub NW¼ S23-T110N-R58W	1922	960	1466		1431	2.4

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
639	SW¼ S30-T110N-R58W			1384	7	1400	6
640	Lyman Parkhurst NW¼ S7-T111N-R58W	Old Well		1440		1420	.5
641	W. D. Allen NW¼ S35-T111N-R58W	1919		1507		1432	2.7
642	John Fox Jr. SW¼ S5-T112N-R58W	1950	???? 1500	1493		1463	.75
643	Henry Martens NW¼ S27-T112N-R58W	Old Well	1100	1516		1491	.66
644	Bart Wallace NE¼ S29-T109N-R57W	1925	960	1458		1418	4.1
645	William Reese SW¼ S5-T109N-R57W	Jan 1952	965	1494		1439	
646	Francis Peckenpaugh SW¼ S13-T109N-R57W	1912	App. 1150	1537		1487	2.2
647	Walter Wurl SE¼ S26-T110N-R57W	May 1952	995	1595		1480	2.5
648	D. C. Fitts NE¼ S26-T111N-R57W	1951	1140	1684		1484	
649	John Knudson NW¼ S1-T111N-R57W	1912	1256	1780		1500	
650	Albert Muilenberg NE¼ S7-T112N-R57W	Jan. 1952	1040	1599		1479	
651	William Thaden SW¼ S17-T112N-R57W	1944	1300	1634		1304	2
652	Wallace Brown SE¼ S24-T109N-R56W	June 1952	1130	1720		1480	1.5
653	Alfred Larson SE¼ S21-T112N-R56W	1910	1250	1735		1500	
654	Ben Buer SE¼ S15-T109N-R55W	Jan. 1953	990	1690		1475	

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
655	Mary Buer NE¼ S3-T109N-R55W	1923	1050	1705		App. 1500	
656	Lake Preston City Well NE¼ S1-T110N-R55W	1950	1157	1719		1454	50
657	Erwin Town Well	1911	1313	1874		1574	8
658	Oldham City Well SW¼ S22-T109N-R54W	1951	1050	1720		1460	30

Clark County

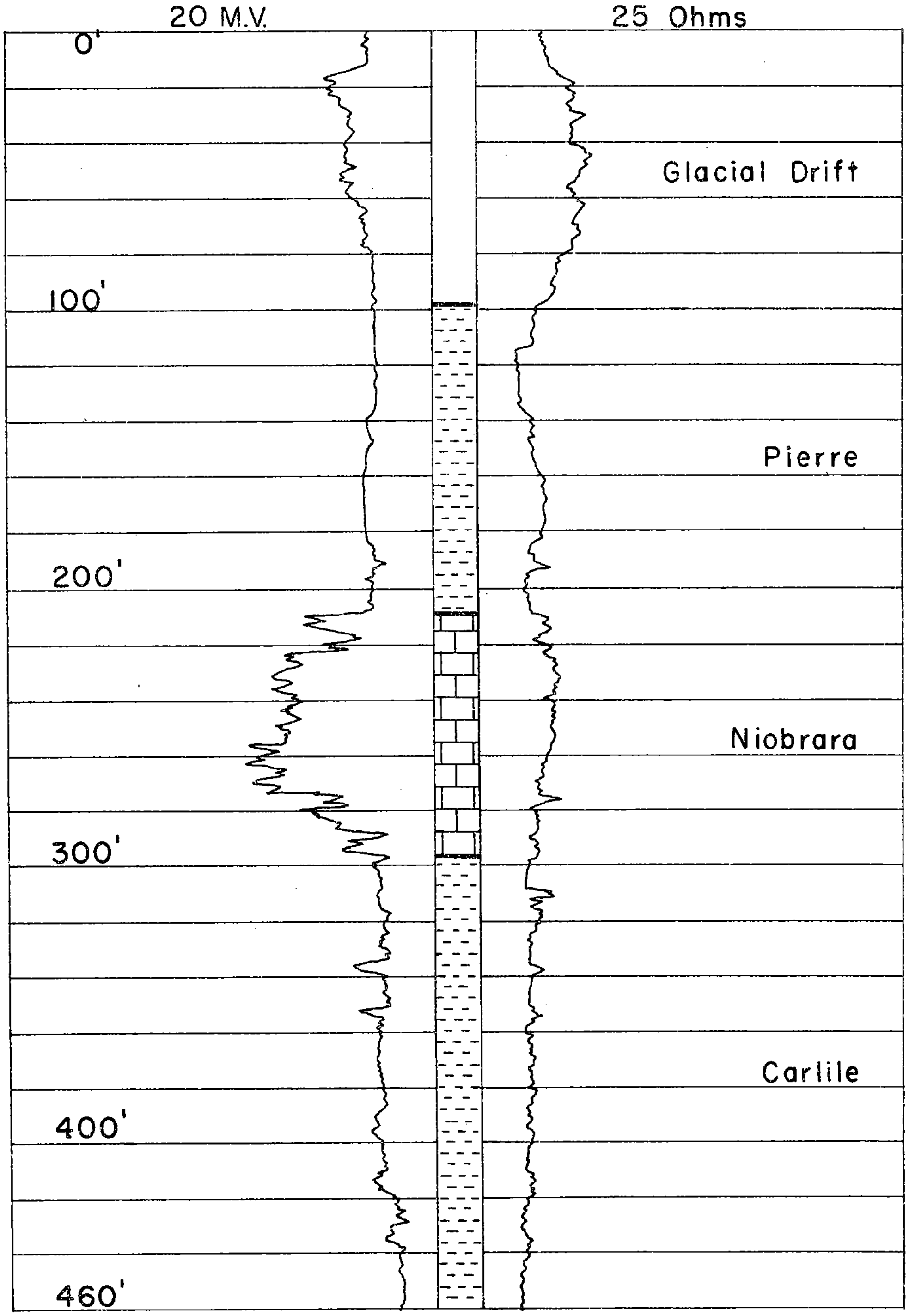
No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
659	David G. Hofer SE¼ S29-T114N-R59W	Old Well	800	1404		1394	
660	H. A. Falkenberg SW¼ S20-T115N-R59W	1922	1000	1436		1416	
661	George Bethke NW¼ S6-T115N-R59W		900	1406	3	1413	.33
662	Henry Hass SE¼ S9-T116N-R59W	1945	1054	1487		1476	2
663	Ivan Graves SW¼ S22-T116N-R59W	1945	1054	1484		1476	1
664	Floyd Batian NE¼ S6-T113N-R58W	Old Well	999	1507		1455	1.8
665	Clarence Warkenthien NE¼ S27-T113N-R58W	1936	1100	1563		1503	2
666	NE¼ S25-T114N-R57W	Nov. 1952	1363	1760		1620	
667	Iver O. Spilde NE¼ S9-T113N-R56W	1920	1320	1832		1532	
668	George Grensberg NE¼ S5-T113N-R56W	1944	1307	1803		1588	

No.	Owner & Location	Date Drilled	Depth (ft.)	M. P. Alt.*	Pressure (lbs.)	Piez. Head**	Rate Discharge Gal/Min
669	William Multhuf SW¼ S15-T114N-R56W	1926	1275	1841		1626	.75
	Hamlin County						
670	Bryant Well (city)	1953	1366	1845		1545	37
671	Robert Fuhr SW¼ S21-T113N-R55W	Nov. 1952	1323	1818		1518	3.8
672	John P. Corey NW¼ S23-T113N-R55W	Old Well	1260	1813		1538	1

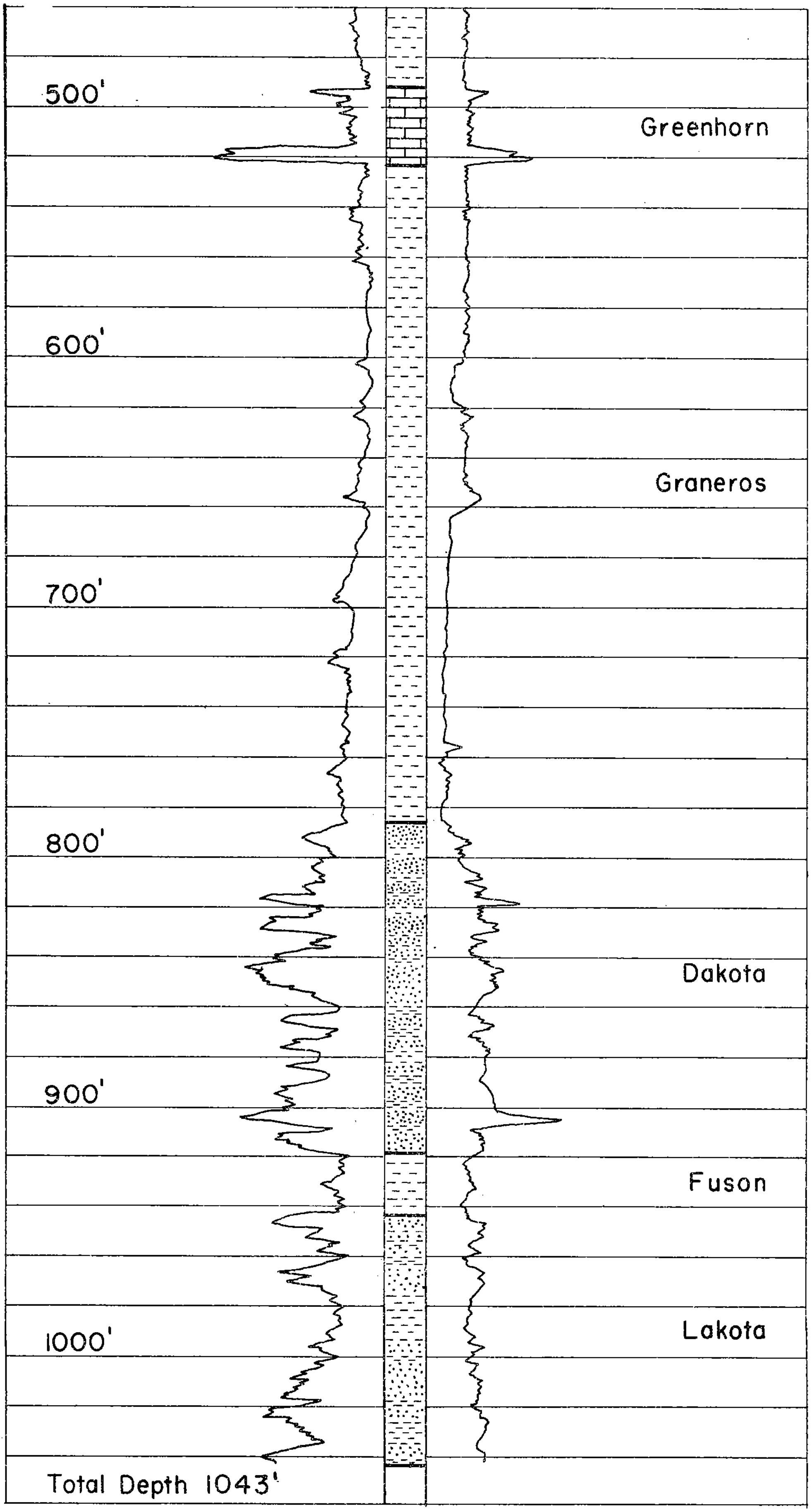
FRED MEYER WATER WELL
N.E. Sec. 22, T. 109 N., R. 63 W.
Beadle County, Elevation 1344'
Drilled by Huron Drilling Co.
Electric Log by Bruno Petsch
DIAGRAM NO. 1

LEGEND

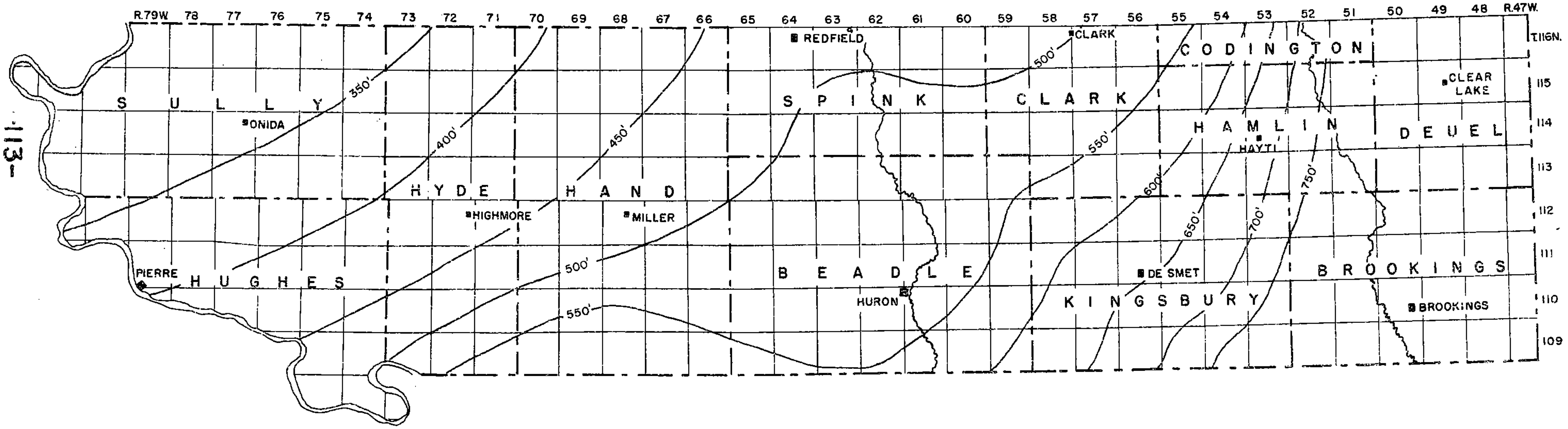
▤ Shale ▒ Sandstone ⊞ Chalk ▦ Limestone



Continuation of Fred Meyer Log



STRUCTURAL CONTOUR MAP ON THE TOP OF THE DAKOTA SANDSTONE



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