DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

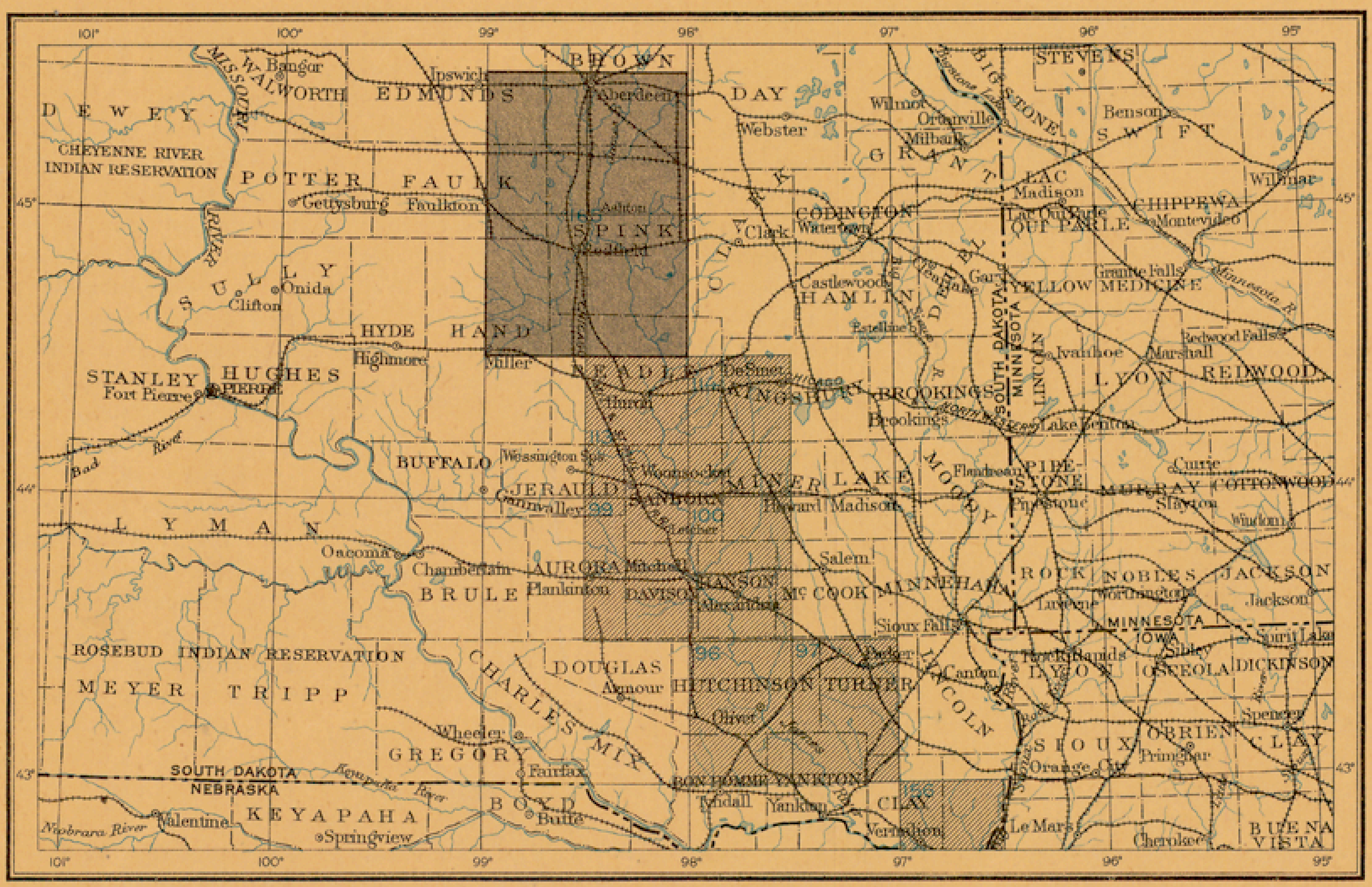
GEOLOGIC ATLAS
OF THE
UNITED STATES

ABERDEEN-REDFIELD FOLIO

NORTHVILLE, ABERDEEN, REDFIELD, AND BYRON QUADRANGLES

SOUTH DAKOTA

INDEX MAP



SCALE: 40 MILES = 1 INCH

ABERDEEN-REDFIELD FOLIO

OTHER PUBLISHED FOLIOS

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WASHINGTON, D. C.
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ABERDEEN-REDFIELD FOLIO
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GEOLOGIC ATLAS OF THE UNITED STATES.

The Geological Survey is making a geologic atlas of the United States, which is being issued in parts, called folios. Each folio includes topographic and geologic maps of a certain area, together with descriptive text.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds—(1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those of the most important ones are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval*. Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

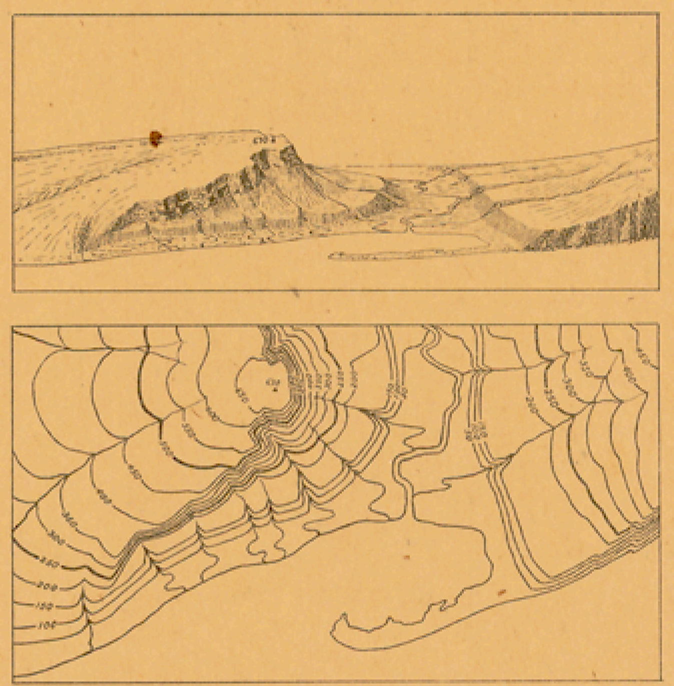


FIGURE 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay that is partly closed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle hill slope; that on the left is backed by a steep ascent to a cliff, or scarp, which contrasts with the gradual slope away from its crest. In the map each of these features is indicated, directly beneath its position in the sketch, by contour lines. The map does not include the distant portion of the view. The following notes may help to explain the use of contour lines:

1. A contour line represents a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contour lines are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above the sea—that is, this contour would be the shore line if the sea were to rise 250 feet; along the contour at 200 feet are all points that are 200 feet above the sea; and so on. In the space between any two contours are all points whose elevations are above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, and that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above the sea. The summit of the higher hill is marked 670 (feet above sea level); accordingly the contour at 650 feet surrounds it. In this illustration all the contour lines are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contour lines. The accentuating and numbering of certain of them—say every fifth one—suffices and the heights of the others may be ascertained by counting up or down from these.

2. Contour lines show or express the forms of slopes. As contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing around spurs or prominences. These relations of contour curves and angles to forms of the landscape can be seen from the map and sketch.

3. Contour lines show the approximate grade of any slope. The vertical interval between two contours is the same, whether they lie along a cliff or on a gentle slope; but to attain a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

A small contour interval is necessary to express the relief of a flat or gently undulating country; a steep or mountainous country can, as a rule, be adequately represented on the same scale by the use of a larger interval. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is in regions like the Mississippi Delta and the Dismal Swamp. For great mountain masses, like those in Colorado, the interval may be 250 feet and for less rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. For a perennial stream the line is unbroken, but for an intermittent stream it is broken or dotted. Where a stream sinks and reappears the probable underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are represented by appropriate conventional signs in blue.

Culture.—The symbols for the works of man and all lettering are printed in black.

Scales.—The area of the United States (exclusive of Alaska and island possessions) is about 3,027,000 square miles. A map of this area, drawn to the scale of 1 mile to the inch would cover 3,027,000 square inches of paper and measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and a linear mile on the ground by a linear inch on the map. The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to the inch" is expressed by the fraction $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; they are $\frac{1}{250,000}$, $\frac{1}{125,000}$, and $\frac{1}{62,500}$, corresponding approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale of $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale of $\frac{1}{125,000}$, about 4 square miles; and on the scale of $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map of the United States is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ represents one square degree—that is, a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ represents one-fourth of a square degree, and each sheet on the scale of $\frac{1}{62,500}$ one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, though they vary with the latitude.

The atlas sheets, being only parts of one map of the United States, are not limited by political boundary lines, such as those of States, counties, and townships. Many of the maps represent areas lying in two or even three States. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet are printed the names of adjacent quadrangles, if the maps are published.

THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land and, by means of structure sections, their underground relations, so far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or magma, within these channels—that is, below the surface—are called *intrusive*. Where the intrusive rock occupies a fissure with approximately parallel walls it is called a *dike*; where it fills a large and irregular conduit the mass is termed a *stock*. Where molten magma traverses stratified rocks it may be intruded along bedding planes; such masses are called *sills* or *sheets* if comparatively thin, and *laccoliths* if they occupy larger chambers produced by the pressure of the magma. Where inclosed by rock molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. Where the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and as a rule contain, especially in their superficial parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows also are usually porous, owing to the expansion of the gases originally present in the magma. Explosive action, due to these gases, often accompanies volcanic eruptions, causing ejections of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

Sedimentary rocks.—Rocks composed of the transported fragments or particles of older rocks that have undergone disintegration, of volcanic ejecta deposited in lakes and seas, or of materials deposited in such water bodies by chemical precipitation are termed *sedimentary*.

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits of these are called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the kinds of deposit named may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind, and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is loess, a fine-grained earth; the most characteristic of glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*, and rocks deposited in such layers are said to be stratified.

The surface of the earth is not immovable; over wide regions it very slowly rises or sinks, with reference to the sea, and shore lines are thereby changed. As a result of upward movement marine sedimentary rocks may become part of the land, and most of our land areas are in fact occupied by rocks originally deposited as sediments in the sea.

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate and the more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

Metamorphic rocks.—In the course of time, and by various processes, rocks may become greatly changed in composition and in texture. If the new characteristics are more pronounced than the old such rocks are called *metamorphic*. In the process of metamorphism the constituents of a chemical rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressures, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structures may have been lost entirely and new ones substituted. A system of planes of division, along which the rock splits most readily, may have been developed. This structure is called *cleavage* and may cross the original bedding planes at any angle. The rocks characterized by it are *slates*. Crystals of mica or other minerals may have grown in the rock in such a way as to produce a laminated or foliated structure known as *schistosity*. The rocks characterized by this structure are *schists*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are many important exceptions, especially in regions of igneous activity and complex structure.

FORMATIONS.

For purposes of geologic mapping rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone. Where the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation contains one or more bodies of one kind, of similar occurrence, or of like origin. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics or origin.

When for scientific or economic reasons it is desirable to recognize and map one or more specially developed parts of a varied formation, such parts are called *members*, or by some other appropriate term, as *lentils*.

AGES OF ROCKS.

Geologic time.—The time during which rocks were made is divided into *periods*. Smaller time divisions are called *epochs*,

DESCRIPTION OF ABERDEEN-REDFIELD DISTRICT.

By J. E. Todd.

GEOGRAPHY.

GENERAL RELATIONS.

Eastern South Dakota forms a part of the Great Plains province, lying in the broad, indefinite zone in which these plains merge into the prairies of the Mississippi Valley. It is within the glaciated area and most of its surface features show the characteristics of a drift-covered region. The country is largely level, but also presents long rolling slopes rising 300 to 800 feet above the broad valleys. The principal elements of relief are massive ridges, or mesas, which are due to preglacial erosion. Many of these mesas are crowned or skirted by long ranges of low hills made up of morainal accumulations left by the ice along lines marking pauses of glacial advance and retreat. Further diversity of topography has been produced by the excavation of the valleys, especially that of Missouri River, which has cut a trench several hundred feet deep, for the most part with steeply sloping sides. Between the moraines there are rolling plains of till and level plains due to the filling of glacial lakes. The upper James River presents a notable example of this lake-bed topography. East of the Missouri, James River is the principal stream. It drains the broad James Valley and the adjacent coteau slope. The altitude of the region ranges from 1100 feet on Missouri River to 2000 feet on the summit of the eastern coteau.

LOCATION.

The Northville, Aberdeen, Redfield, and Byron quadrangles, which make up the area considered in this folio, are located between meridians 98° and 99° west longitude and parallels 44° 30′ and 45° 30′ north latitude, the different quadrangles in the order named occupying respectively the northwest, northeast, southwest, and southeast quarters of the whole area. Each of them is a little less than 24$\frac{3}{4}$ miles in width and about 34.6 miles in length from north to south, the southern two covering about 850 square miles each, and the northern two 842 square miles each. They comprise nearly all of Spink County and portions of Faulk, Hand, Edmund, and Beadle counties.

This area is of especial interest because it extends across the junctions of the James Valley with the Turtle Creek valley and with another ancient valley entering from the west near the south line of Brown County, and because it includes a portion of the area once flooded by the remarkable ancient Lake Dakota. It contains also a notable irregularity or reentrant angle of the Antelope moraine, with its network of channels dating from the glacial period. Partly for the purpose of bringing out these unusual features with greater clearness, the four quadrangles are described together in a single folio.

RELIEF.

The region is in general flat and its features are those of subdued glacial topography. It is, however, more modified by fluvial and lacustrine action than some other portions of eastern South Dakota. Some moderately rough topography is shown in the moraine areas.

ALTITUDES.

The lowest point in the region, about 1230 feet above sea level, is on James River at the southern boundary of the Byron quadrangle. The highest points in that quadrangle, altitude 1425 feet, are in the north-central part of sec. 25, T. 115 N., R. 61 W. (Harrison Township), and the average altitude of the quadrangle is about 1300 feet.

In the Redfield quadrangle the lowest points are near its northeast corner in the valleys of Snake and Turtle creeks, which are about 1250 feet above sea level. The highest point is south of Miller, where an altitude of about 1595 feet is reached. Garfield Peak, in northern Howell Township, close to the western boundary of the quadrangle, rises to slightly above 1560 feet, and other peaks a few miles farther north are of the same general height. The most conspicuous prominence is Bald Mountain, which rises to an altitude of 1480 feet, or 180 feet above the surrounding lowland. The highest peak of this mountain is on the north side of sec. 21, T. 116 N., R. 65 W.

The Aberdeen quadrangle is much the flattest of all. Its lowest point, about 1250 feet above sea level, is on James River in the SW. $\frac{1}{4}$ sec. 25, T. 118 N., R. 64 W. Its highest point, with an altitude of about 1405 feet, is a sharp peak just south of the north line of Spink County, in the NW. $\frac{1}{4}$ sec. 2, T. 120 N., R. 160 W. The average altitude of the quadrangle is not far from 1300 feet, possibly 1310 feet.

The lowest point of the Northville quadrangle, elevation about 1255 feet, is where Snake Creek crosses its southern boundary near the southeast corner, in the SE. $\frac{1}{4}$ sec. 28, T. 118 N., R. 64 W. The highest point, about 1525 feet above sea level, is close to the northwest corner of the quadrangle. The average altitude is not far from 1400 feet.

PLAINS.

The surface of the four quadrangles presents several topographic divisions closely related to the geologic formations. The most extensive of these divisions is the nearly level plain of the James River valley, which has an average width of 19 miles. Its trend corresponds to the course of James River, being first to the south-southwest and then turning to the south-southeast near Redfield. Its width is about 20 miles north of Redfield, but from that point southward it narrows, at first rapidly and then more gradually, until it is less than 6 miles wide on the southern boundary of the area. This plain is largely covered by the deposits of Lake Dakota and its surface varies less than 15 feet in altitude except where the ancient and modern streams have excavated their shallow valleys. The general plain, which for many square miles is as level as a floor, slopes slightly downward near James River and toward a few other prominent channels. There are 733 square miles of this plain in the Aberdeen quadrangle, 400 in the Byron, 153 in the Northville, and 25 in the Redfield.

Another but less even plain, covering about 50 square miles, lies in the southwest-central part of the Redfield quadrangle. It extends from the central part of Linn Township (T. 116 N., R. 67 W.) to the northwest corner of Nance Township (T. 113 N., R. 65 W.) and in its widest portion is about 6 miles wide. This may be called the Wolf Creek plain.

In a few places the bottom and banks of James River are covered with gravel and bowlders. Below the mouth of Turtle Creek much of the river trough is lined with bowlders, but above that point the stream has in only a few places cut through the fine yellow silt deposited by Lake Dakota, and consequently bowlders and even pebbles are rare.

Along the southern portion of the valley appear numerous terraces, the highest of which is about 50 feet above the stream; another lies about 40 feet above. These two are usually covered with bowlders. Other terraces lying 30, 15, and 8 feet above the stream are more sandy; the last is the alluvial flood plain. East and southeast of Aberdeen a few high isolated island-like masses rise out of the wide bottom lands. Most of these masses are connected with one side of the valley by terraces; some, however, are surrounded by the alluvial flood plain. One of these outliers is east of Warner, another southeast of Mellette, and a third in the southwest corner of T. 119 N., R. 63 W.

UPLANDS.

The east side of the James Valley plain terminates in a slope which rises along a line trending slightly east of north. A short distance southwest of Doland this slope is comparatively abrupt, rising to a sharp ridge with peaks attaining altitudes of over 1400 feet in the northern half of the Byron quadrangle; but it is less marked toward the south, where its steepness diminishes and it trends somewhat more to the east. In general this slope rises to the crest of a ridge whose surface is gently undulating and lies at an altitude 50 to 60 feet higher than the plain on the west. In the Aberdeen quadrangle the slope is more regular and its surface is nearly even except that it is covered more or less with scattered knolls and low ridges from 5 to 15 or 20 feet in height.

On the west side of the James Valley plain there is a gentle upward slope which about midway in the Redfield quadrangle gives place to the Wolf Creek plain already mentioned. Most of the sloping surface is nearly smooth, but it presents many low knolls rising in general from 5 to 10 feet and rarely attaining 20 feet above the surrounding slope except in the Redfield Hills described farther on. There are also numerous basins and lake beds, most of them being of small extent, though some cover several square miles. Most of them are very shallow, some being scarcely noticeable except for the larger grasses occupying them. Others are 20 to 40 feet deep, with sharp outlines and steep banks. Few contain water much of the time, except those that receive drainage from unusually extensive catchment areas. These basins are further described under the heading "Lakes." There are also numerous well-defined channels, some of which are shallow and wide while others have abrupt banks and are 15 to 25 feet in depth. These channels usually lead southward.

The features above described have a rudely parallel arrangement corresponding to that of the moraines shown on the areal geology map, but the relief is so slight that only the channels are readily recognized.

South and southeast of Redfield there is an irregular area of little more than 18 square miles, extending about 7 miles from north to south, with peaks rising 50 or 60 feet above the surrounding plain. This area is known as the Redfield Hills. Two or three hilly areas also extend southward from this group of hills along the line between the Byron and Redfield quadrangles, and another lies 3 to 5 miles farther west. About 7 miles west of the north end of the Redfield Hills is a short isolated ridge known as Bald Mountain.

Another small area of exceptional topography is on the slope north and northeast of Miranda. It presents numerous shallow, flat-bottomed channels, depressed 10 to 20 feet below the general surface, that are believed to be the work of old springs now nearly dried up.

DRAINAGE.

The principal drainage features of the area treated in this folio are James River, various creeks, springs, and lakes, and overflows at times of unusually great precipitation.

STREAMS.

The general drainage is southward to Missouri River, but in the Redfield quadrangle most of the streams flow to the east and northeast. The three most important streams are James River and Snake and Turtle creeks. These are the only streams having running water all the year; the last two flow for only a few miles above their mouths. Timber Creek flows for 10 miles or more and Dry Run and Foster Creek for 2 or 3 miles near their mouths. Many of the intermittent streams have water holes along their courses which afford fairly good water for stock or even for domestic use if kept free from contamination.

James River is the main stream and follows a somewhat irregular course from north to south with a notable deflection to the southeast between the mouth of Turtle Creek and Frankfort. Its fall is less than 35 feet in the whole distance of about 80 miles, and its most rapid descent is in its easterly course, where in places it is considerably obstructed by bowldery bars. The trough in which the river flows is about 30 feet deep east of Aberdeen and about 65 feet deep south of Byron Lake. In the northern portion of the Aberdeen quadrangle the river bottom or flood plain is in some places more than 2 miles wide and rather marshy, but in the main it is less than half a mile in width. The greater width of the valley at the north seems to be due partly to the ease with which the stream erodes the lacustrine silt. Fresh exposures of this silt rise in numerous steep semicircular cliffs around the sharp bends of the present stream. The James is sluggish and at ordinary stages is from 50 to 100 feet wide and from 2 to 6 feet deep. Its bed is usually muddy, and there are abrupt banks 8 to 10 feet high, so that generally it is difficult to ford.

Moccasin Creek enters the Aberdeen quadrangle along the western edge of the James Valley plain and follows a very irregular hook-shaped course, reaching James River at a point about 10 miles southeast of Aberdeen. The whole course of this stream is upon the James Valley plain; its channel is wide and shallow and the stream very miry.

Snake Creek carries water from two forks rising in ravines along the southwest slope of the highlands in McPherson and northern Edmunds counties, flows southward through the till region to a point near Northville and along the west side of the James River plain to a point near Athol, where the West Branch joins it, and continues in the same general direction to James River 3 miles south of Ashton. West Branch of Snake Creek rises on the north slope of the Bald Mountains in western Faulk County. It enters the Northville quadrangle in T. 118 N., R. 68 W. After flowing eastward a few miles it turns sharply north and 3 miles east of Devoe meets Nixon Creek coming from an opposite direction. Thence it flows southeast for 7 or 8 miles and again turns sharply north, along an old channel to Preachers Run and the old channel from Scatterwood Lake at Wesley. Thence it takes a southeast course to the boundary of the Redfield quadrangle, a short distance south of which it receives Dove Creek, flowing in another north-south channel. West Branch follows the continuation of this channel to the and north as far as a point opposite Athol, where it turns eastward within a few miles joins Snake Creek. The troughs of Snake Creek and West Branch present the usual features of well-worn stream valleys crossing the till or glacial clay. The valleys are not of uniform width nor their sides of uniform height. They pass through lake beds and old shallow channels, as well as through moderately narrow gorges with bluffs of yellow bowlder clay in places 25 or 30 feet in height. These bluffs are especially noticeable in the lower course before the James Valley plain is reached. Near Cortlandt the stream has cut through the drift and 25 feet or more into the underlying shale, and its valley has a little more rugged appearance than elsewhere in its course. After reaching the James Valley plain the trough is shallower and wider, with many sluggish, marshy portions. The prongs of West Branch of Snake Creek present some notable peculiarities, mostly in following the irregular courses of the old channels. They are all intermittent streams.

Turtle Creek flows through St. Lawrence and thence northeastward through Redfield, 3 miles northeast of which it reaches James River. It follows old drainage channels into which it has cut a trough ranging in depth from 20 to 30, and even 50 feet. It receives no tributaries from the southeast, but does receive many intermittent streams, two of which are of considerable size, from the northwest. An interesting modification of drainage in Turtle Creek occurred in the spring of 1897, after an unusually snowy winter. The resulting floods were so high that in sec. 25, Lake Township, Turtle Creek overflowed into an old channel running eastward into Twin Lakes. The flow was so copious that it raised the surface of the lakes several feet.

Wolf Creek is the most important branch of Turtle Creek, which it joins in the northwestern part of Buffalo Township. The stream has two principal tributaries. North Wolf Creek rises in ravines on the southeastern slope of a highland a few miles east of the western boundary of the Redfield quadrangle, and enters the main stream near Burdette post-office, 8 miles above Turtle Creek. The southern tributary, which is somewhat larger than North Wolf Creek, flows along the south line of Florence Township and thence to the main stream at Odessa. The peculiar drainage of Wolf Creek deserves special mention. Its upper watercourses flow from the north, the north-northwest, and the northwest in well-marked valleys to sec. 16, Holden Township (T. 114 N., R. 67 W.), where they join into a single valley leading south toward Odessa. The water, however, does not flow down this valley except in times of flood but turns sharply northward into a narrow ravine cut in another broad old valley and flows to North Wolf Creek, which it joins near the southeast corner of sec. 15, Carlton Township (T. 115 N., R. 67 W.).

Another important tributary of Turtle Creek is Medicine Creek, which rises southwest of Miranda, receives contributions from some springs near the Hand County line, and flows southeastward to the south line of Plato Township, 2 miles north of Helmick post-office. Here it is joined by the northern branch, which has a hook-shaped course west and south of Miranda and then flows southeastward to the main stream. From the junction the stream continues southeastward with two curious splits, by which large islands are surrounded, to the southeast corner of sec. 19, T. 115 N., R. 65 W., whence it takes a direct northerly course to Cottonwood Lake. As explained under "Overflow drainage," Turtle Creek receives the water of Medicine Creek only in early spring or after heavy rains.

Pearl Creek passes across the southern part of the Redfield quadrangle in eastern St. Lawrence and Grand townships. It is intermittent and flows in a trough having low, irregular sides.

Two or three long watercourses which have no names enter James River on the west in the Byron quadrangle. They are generally dry and grassy except in the spring.

The most important of the eastern tributaries of James River in the Aberdeen quadrangle is Mud Creek. This stream rises east of the Aberdeen quadrangle and flows northwestward for a few miles to a point a short distance south of Groton, but has for the most part a nearly straight southwest course across the James River plain and a wide valley similar to an ancient channel of the glacial period, evidently inherited from an older and larger stream. Near the point where it changes its direction it receives a branch from the northeast. Mud Creek has a grassy channel and frequently has extensive reedy water holes. No sand or gravel occur along it except near the confluence of its northeast branch.

Dry Run is a sluggish stream resembling Mud Creek and also lying mostly on the James Valley plain. It heads north and east of Ferney and Verden and flows toward the south and southeast, in greater part parallel to Mud Creek and James River, joining the latter a short distance west of Frankfort. It is an intermittent stream, but, except in the dryest seasons, its lower course has many well-filled water holes. In the northern part of its channel comparatively little water is found.

Timber Creek receives water from the east slope of the James River valley from the vicinity of Verdon to a part about 9 miles south of Doland. The smaller branches flow westward until they join a long north-south channel which lies on the James Valley plain. This channel begins south of Verdon, near the eastern edge of the plain. It broadens northwest of Conde, but does not have continuous well-defined banks north of Turton. The stream joins James River about 6 miles below Frankfort. It differs from most other small creeks in the James River valley because of its larger amount of water and therefore its more vigorous action. Although its upper course is marshy and shows little sand and gravel, its lower course is deeply eroded, rivaling the trough of James River in this respect. Moreover, it has cut through the lake deposits to the underlying till, so that its lower course is very stony. The great number of trees along the stream account for its name.

Foster Creek is a running stream which drains the southeastern part of the Byron quadrangle, including the Byron Lake basin, and flows into James River.

Shue Creek is an intermittent watercourse draining the extreme southeast corner of the Byron quadrangle.

OVERFLOW DRAINAGE.

Parts of the old channels are often reoccupied by drainage in times of flood. Pearl Creek, in the Redfield quadrangle, is connected with a small tributary of Turtle Creek in sec. 31, Gilbert Township, by a shallow, very winding channel that begins 3 or 4 feet above the bottom of the regular channel of Pearl Creek and makes its way across the plain toward Turtle Creek. A channel connects Dove Creek and Medicine Creek north of Bald Mountain, but no clear evidence of recent drainage between the two has been noticed. There has been drainage at no very distant day between Medicine Creek and its northern branch southwest of Rockham, and possibly southwest of Miranda. Ordinarily Cottonwood Lake holds all the water that is collected by Medicine Creek, but occasionally, as in 1897, the lake overflows at its north end through a well-defined channel which skirts the west, north, and northeast sides of Bald Mountain and joins Turtle Creek in sec. 26, Exline Township. Little or no water runs in this outlet except in early spring or after severe rains, and there are but few water holes. The trough of the stream is nowhere very deep. The highest banks, rising 30 or 40 feet, are east and west of Bald Mountain. As already stated, only in times of flood does the water flow from the sharp south bend of North Wolf Creek to the south branch of that creek northwest of Odessa, Holden Township. During floods water flows also from the north branch of Turtle Creek in the northeast corner of York Township northward into the south branch of Wolf Creek, across sec. 2 of that township.

In the Northville quadrangle no definite instances of this sort have been reported, but a flood of 15 feet in West Branch of Snake Creek would cause an overflow south of Devoe into one of the head branches of Dove Creek. Similarly, a flood in Moccasin Creek might cause an overflow down a long, shallow valley which leaves that stream near Rudolph and by another at its sharp bend southwest of Warner. These overflows if of sufficient volume, would reach Snake Creek about 4 miles north of Athol.

In the Aberdeen quadrangle the drainage is sluggish along the east side of the James Valley plain from the vicinity of Groton to Conde, so that local floods may produce flows in various directions at different times. It is probable that a flood in Mud Creek would overflow south of Groton into Dry Run.

In the Byron quadrangle similar changes in drainage may sometimes take place between the different branches of Timber Creek and also between the south branch and Foster Creek. In the autumn of 1897 Foster Creek and James River rose so that their back water raised the surface of Byron Lake several feet, or about 20 feet above the ordinary stage of James River. The natural outlet of Byron Lake is not through Connors Lake but north of the abrupt hill north of that lake. It is said that in 1882 this outlet was 60 feet wide, but it has long been dry, as was also the whole lake basin in 1893. Since that time not only has the lake been replenished by the flood mentioned above, but Foster Creek has been dammed so that in time of flood it contributes considerable water to the lake.

The streams of the region do not afford much reliable water power, for two reasons. Those with considerable fall have little or no perennial flow, and those having perennial flow have very little fall. The most available mill site on James River probably is the one near old Ashton, where the river bed is filled with bowlders and the fall is considerable.

LAKES.

Most of the lakes of this area receive their waters directly from the rainfall and their endurance depends on the extent of their drainage basins, their depths, and the amount of rain. The rainfall of this region varies greatly in different years, but averages a little less than 20 inches annually. After a succession of wet years all the lake beds are full of water, and they are sometimes filled in the spring if there has been much snow during the winter. In the latter part of the summer most of the ponds become dry and the lakes diminish greatly in extent. Within the last twenty-five years some of the lakes have remained through a season with 10 or 15 feet of water, and a few years later have dried up entirely. A few deeper lakes receive small quantities of water from springs on their shores. Many small ponds are now sustained from artesian wells, but few of these deserve mention as lakes.

The only lakes of importance in the Byron quadrangle are Byron and Connors lakes. The former usually covers about 2 square miles, though it varies much in area according to the dryness of the season, for it is very shallow. It receives water not only from the numerous short ravines on the east, but when Foster Creek and James River are high, receives and stores their overflows. In 1897 the current entering the lake from these streams was sufficient to wash out the bridge over the lake outlet. The lake receives considerable water from springs along its shores, seeping from the sands underneath the till.

Connors Lake at its greatest extent covers about 60 acres, but it is frequently dry except in the southwest corner, where there is water from a large spring or pond called Mud Lake. This pond is several rods across and remains open except in the coldest weather. Gravel along its southwest side furnishes water, apparently from an old channel coming from the southeast. This is probably the main source of the water, but the depth of the pond, said to be about 30 feet throughout, and the reported softness of the water have led to the belief that Mud Lake is an outlet from the stratum yielding soft artesian water, which in this region lies at a depth of 200 or 300 feet.

Wall Lake, in the SW. $\frac{1}{4}$ sec. 21, T. 113 N., R. 62 W., is a grassy lake containing usually very little water, but in 1897 it filled to a depth of 10 to 12 feet.

In the Redfield quadrangle the principal lake is Cottonwood Lake, which covers about 2 square miles. It is very shallow and has low shores, except in an angle in the northwest portion and on its south end, where there are wave-cut banks 30 to 40 feet high. It is supplied by Medicine Creek and varies in depth in different years.

Twin Lakes, in T. 115 N., R. 64 W., are connected by a strait, and the west lake is the larger and deeper, being 8 or 10 feet deep at ordinary stages. Much of the southeast lake is usually dry.

Other basins shown as ponds on the map of the Redfield quadrangle are commonly dry. There is a small pond in the southwest corner of sec. 19, T. 117 N., R. 65 W., which covers a few acres and always shows open water. This pond is an exposed portion of a body of water contained in a mass of quicksand that underlies much of the region and is frequently found in wells.

In the Aberdeen quadrangle there are no natural lakes except a marsh on the east side of the James River bottom west of Chedi which shows some open water and which is sometimes spoken of as Lake Chedi. It is, however, simply a marshy depression in the bottom lands and is replenished by the river in times of high floods. It therefore varies greatly in depth and extent from time to time.

In the Northville quadrangle there are three or four notable lakes. The largest are the Scatterwood Lakes, two deep depressions in one of the old stream channels. These lakes were named by the Indians from the trees scattered along their shores. The northern one has an area of less than 1 square mile and lies mostly in Edmunds County. The southern one is about $2\frac{1}{2}$ miles long and covers $1\frac{1}{2}$ square miles, in the northeast corner of Faulk County. Their water comes mostly from melting snows and consequently its volume varies considerably with different years. Rains do not generally affect the water level. In 1897 the water rose so that the lakes ran together. They were then stocked with fish which thrived for several years but were frozen to death in the shallow-water period of 1902. The northern lake is about half open water and there is much less water in the southern lake, though it is said to have shown more open water before 1897 than the other. The banks on the west and east rise like river bluffs, with a height of 30 or 40 feet.

Salt Lake, in the southwest corner of Brown County, lies in a deep, channel-like depression and is about a mile in length. Its bottom is as flat and bare as a floor and in dry weather is partly covered with a frostlike crust of salt. The southern half is covered with a few inches of water. Springs of good fresh water occur at the east end and near its northwest angle.

Lords Lake, about 3 miles northwest of Rudolph, showed open water a few years ago, but is now all grown up with weed and it is doubtful whether it contains surface water. Its basin is a deeper and broader portion of an old stream channel, as represented on the areal geology map. Its bottom lies only about 15 feet below the surrounding level.

About 5 miles west of Northville is a nameless lake with open water covering nearly a quarter of a section and in its vicinity are a few other smaller ponds.

Half a mile east of the southern Scatterwood Lake is a small pond said to be fed by an unfailing spring. Its surface is several feet lower than the level of the Scatterwood Lakes.

SPRINGS.

Permanent springs are rare in this region, though there are a few of importance. The largest one is described in the foregoing section in connection with Connors Lake. All others in these quadrangles appear to receive their waters from the sand underneath the till, or from porous strata higher up. The springs noted in the Byron quadrangle are as follows: In the NW. ¼ sec. 3, T. 117 N., R. 60 W., a copious spring of excellent water from gravel underneath the till; in the SE. ¼ sec. 19, T. 116 N., R. 63 W., a bitter spring, not very copious, on the side of a deep southeast channel; near the southwest corner of T. 117 N., R. 62 W., a bitter spring reported in the side of Dry Creek; in the east side of sec. 2, T. 116 N., R. 63 W., a line of springs at the base of the bluffs on the west side of James River, evidently supplied from sands below the till; in the NW. ¼ sec. 22, also in the southeast corner of the same section, T. 115 N., R. 63 W., meager springs from gravel below till; in the NE. ¼ sec. 8, T. 113 N., R. 61 W., the springs near Connors Lake already mentioned.

There are several notable springs in the Redfield quadrangle. All derive their water from the sands below the till, except one near the northeast corner of sec. 26, T. 116 N., R. 68 W., and another near the northeast corner of sec. 17, T. 115 N., R. 67 W. These are weak and supplied from gravel deposits connected with terraces. There is a spring near the northwest corner of sec. 9, T. 116 N., R. 67 W., and another near the southwest corner of sec. 33, T. 118 N., R. 67 W., where the ice mound occurred in the winter of 1903. This phenomenon imitated in a small way the subterranean ice masses sometimes extensively formed in British America and named sphenocrysts by Canadian geologists. The water from the spring as it oozed up under the frozen crust of earth and sand froze by successive additions of ice at the bottom, lifting the superincumbent mass into a dome-shaped mound. This grew to be 8 feet high and a few rods in diameter and contained clear ice until the following June. A cluster of springs from one source occurs in sec. 2, T. 116 N., R. 68 W., and there is a remarkable cluster of copious springs near the center of sec. 11, T. 112 N., R. 67 W., in short, deep ravines on the south side of Pearl Creek. The temperature of one was found to be 50.7° F. The water is palatable and wholesome for stock and house use, though somewhat injurious to vegetation. It gives an abundant white and yellow efflorescence, evidently due mainly to sulphates of soda and iron.

Another spring or cluster of springs in the northeastern part of sec. 1, T. 116 N., R. 65 W., presents some peculiar features. When the country was first settled this spring issued on a gentle westerly hill slope toward a mud flat or lake basin covering many acres and containing much fine sand. It is stated that the flow was 16 gallons a minute at first, but its owner, hoping to increase the flow, inserted a curb about 18 feet deep, which reduced the flow to about 6 gallons. Then an effort was made to sink tubing, but at a depth of 54 feet this was stopped by a stone. As a last resort a charge of 3½ pounds of dynamite was fired, but instead of opening up the source the spring soon ceased to flow. Boring was carried down to 63 feet, when shale was struck. In April four years later a circular sink hole about 2 rods across and with perpendicular sides appeared on the flat a few rods west of the spring. It was at one time over 15 feet deep and the water stood 3 feet below the top. In August following a similar hole suddenly appeared on the slope several rods to the east. When first seen this hole was several rods across, and its floor, which sloped down from north to south, was 37 feet below the original surface at its south side. In a few days a great mass of surface dirt about its margins disappeared in a seething mass of water and quicksand in which chunks of lignite and bubbles of gas appeared. When visited in August, 1904, the hole was about 70 feet in diameter and partly filled with water from an artesian well near by. The banks were perpendicular and about 5 feet high on the east side and half as much on the west. The water was apparently at least 10 feet deep. Evidently a large body of quicksand underlies the vicinity and may extend northwestward to the pond in quicksand north of Rockham, but how a cavity was made in the sand sufficient to envelop such masses of earth and what influence started the process described remain mysteries. Possibly the explosion of dynamite or the diversion of water to some spring near Turtle Creek a few miles away may have had something to do with it.

In the Aberdeen quadrangle a few weak springs occur in ravines draining the eastern slopes of the James River valley.

In the Northville quadrangle springs are also rare. In the northern portion the shale lies so near the surface and so little sand is found between it and the till that very little water circulates. There is a spring of some importance on the west side of Foot Creek, in the NE. ¼ sec. 9, T. 123 N., R. 64 W., which is supplied from the gravel deposits capping a low terrace. The spring region northeast of Miranda extends into the southwest corner of this quadrangle and in sec. 29, T. 118 N., R. 67 W., there are about 22 springs, mostly in the southwest quarter of the section. There are a few also in sec. 20 and in the W. ½ sec. 19 of the same township. In the latter section the spring water forms a pond of several acres.

The water holes along the intermittent streams have a slow circulation and for this reason the water in the upper ends of the holes is the purest. For this reason also they may be considered as a kind of spring.

DESCRIPTIVE GEOLOGY.

GENERAL STATEMENT.

The surface of eastern South Dakota is in large part covered with a mantle of glacial deposits consisting of gravel, sand, silt, and clay, of varying thickness, which are described in detail below, under the heading "Pleistocene deposits."

The underlying formations of the region are as a rule not exposed east of Missouri River, though they outcrop in some of the hills where the drift is thin, and a few of the streams afford natural exposures. The numerous deep wells throughout the region have, however, furnished much information as to the underground structure. There are extensive sheets of Cretaceous clays and sandstones lying on an irregular floor of supposed Archean granite and quartzite of Algonkian age. Under most of the region these form a floor of "bed rock" which is more than a thousand feet below the surface but rises gradually to the surface toward the east. There is also an underground ridge of Sioux quartzite of considerable prominence, which extends southwestward from outcrops in southwestern Minnesota to the vicinity of Mitchell, S. Dak. No traces of Paleozoic rocks have been found in any of the borings of this region.

The lowest sedimentary formation above the quartzite is usually a succession of sandstones and shales of wide extent termed the Dakota sandstone, which furnishes large volumes of water for thousands of wells. It reaches a thickness of 300 feet or more in portions of the region, but thins out and does not continue over the underground ridge above referred to. It is overlain by several hundred feet of Benton shale, with thin sandstone and limestone layers, and a widely extended sheet of the Niobrara formation, ill defined toward the northwest, consisting largely of chalkstone to the south, and merging into limy clays to the north. Where these formations appear at the surface they rise in an anticlinal arch of considerable prominence along the underground ridge of quartzite, but they dip away to the north and west and lie several hundred feet deep in the north-central portion of the State. In the Missouri Valley they rise gradually to the southeast and reach the surface in succession, the Dakota sandstone finally outcropping in the vicinity of Sioux City and southward. The Pierre shale extends in a thick mantle into eastern South Dakota, lying under the drift in the greater portion of the region, except in the vicinity of the higher portions of the anticlinal uplift above mentioned. It was no doubt once continuous over the entire area, but was extensively removed by erosion prior to the glacial epoch of the Quaternary. Doubtless the Fox Hills sandstone and overlying formations once extended east of Missouri River, but they also have undergone widespread erosion and few traces of them now remain in the extreme northern portion of the State. Tertiary deposits also appear to have been laid down over part of the region, as is shown by small remnants still existing in the Bijou Hills and other higher ridges.

The area treated in this folio is covered with glacial drift, except for small alluvial flats along the streams and a few scattered exposures of Pierre shale. The thick mass of underlying stratified rocks has been penetrated by numerous deep well borings, and by this means many of their relations have been ascertained. The rocks have a nearly horizontal attitude, as shown in figs. ~~2~~ 6 and ~~4,~~ 7 and include representatives of the Cretaceous system lying on a floor of old crystalline rocks at depths of 1000 to 1200 feet.

PRE-CAMBRIAN ROCKS.

The pre-Cambrian crystalline rocks, popularly called "bed rock," underlie the Cretaceous throughout the area treated in this folio. The contour of the surface of these rocks is shown by the red lines on the artesian water maps. These rocks were reached by some of the earlier borings, being reported in wells at Aberdeen and Redfield, in the Motley well, and in four wells near Hitchcock. Many of the deep wells, however, especially the more recent ones, do not reach "bed rock." The pre-Cambrian rocks, so far as known in this region, consist of the Sioux quartzite, granites, and mica schists. They are considered pre-Cambrian because they are similar to rocks that underlie the older Paleozoic sediments in adjoining regions.

The most definite knowledge of the older rocks in this area has been gained from the Budlong well, 5 or 6 miles northeast of Hitchcock, and additional light has been obtained from the Glidden well, less than a mile from Hitchcock, and from the Motley well, 12 miles northeast of the Budlong well. Samples were obtained from the Budlong well at intervals of 10 feet from 800 to 1000 feet in depth. These samples were sandstone to a depth of 960 feet, or 335 feet above the sea, where a rusty sand was penetrated which contained some broken fragments of quartz, possibly indicating weathered "bed rock." For the next 25 feet the drillings consisted mostly of freshly broken quartz, evidently from quartzite. At 995 feet flakes of black mica and a few grains of a white feldspar were mingled with white quartz, These were all freshly broken and are interpreted to indicate a light-colored granite. This rock was penetrated for 3½ feet. Samples from a depth of 1050 feet in the Motley well showed particles of a light-colored granite mingled with fragments of a dark rock apparently composed of chorite, black mica, and particles of kaolin and rounded quartz. Samples from the Glidden well indicated that quartzite was passed through from 1083 to 1142 feet and granite from 1142 to 1150 feet.

At A. A. Kleinsasser's well, in the NE. ¼ sec. 4, T. 113 N., R. 60 W., about 20 miles east of Hitchcock, a gray mica schist was entered at a depth of 940 feet and penetrated for several feet. The character of the rock was definitely determined from a core which was brought up.

At the hospital for the insane at Redfield a core of dark-gray granite was taken from a depth of 1090 feet, the rock having then been penetrated for about 10 feet.

It is claimed that city well No. 4 at Aberdeen passed through quartzite from 1221 to 1267 feet and then 33 feet of granite to the bottom at 1300 feet. Two samples from the lower portion of the well, examined in the United States Geological Survey at Washington, were clearly of a granitic nature. The upper samples contained fragments of quartz, feldspar, and mica, together with rounded grains of quartzite, sand, and shale. A few of the fragments of quartz were sharply crystalline with some feldspar adhering to them, and one or two showed mica also. The sand grains that were mixed with this material were undoubtedly derived from a stratum farther up in the boring by the jar or attrition of the drilling tools. In the sample from the greater depth the rock was somewhat harder but of very similar character. The angular feldspar was unmistakable, and some of it was attached to the quartz fragments. Material of this sort could be derived only from the bed rock itself, unless, as has been suggested, a bowlder from the surface drift had got into the well.

If, as is possible, there is an approximate correspondence between the upper surface of the Dakota sandstone and that of the old crystalline rock surface below, it would appear that near the southeast corner of the Byron quadrangle the top of the "bed rock" probably rises to about the same altitude as in the Budlong well, and thence slopes down very slowly toward the northwest with irregular undulations which may in places have a slope of more than 50 feet to the mile. If this inference is justified, there are traces of a shallow valley in the bed-rock surface running westward from Hitchcock, and of another heading near Doland and extending to the west and southwest past Crandon. However, the irregularities of the "bed rock" floor may reasonably be considered to be greater than those of the upper surface of the Dakota sandstone, for this sandstone probably filled up many of the earlier inequalities of surface. Consequently the contours of the bed rock as shown on the geologic maps are largely conjectural, especially as to details.

The granite in borings may be easily recognized by a microscopic examination of the drillings, but the Sioux quartzite, which is a sandstone firmly cemented with quartz, is not easily distinguished from the harder varieties of Dakota sandstone of a much later age. The latter, however, is more commonly cemented with carbonate of iron or lime, which may be readily detected by effervescence which follows the application of an acid.

It is probable that the Sioux quartzite lies in irregular areas on the granite, especially toward the south. The abrupt drop in the upper surface of the Dakota sandstone in the Byron quadrangle between the 800-foot and 850-foot depth lines, shown on the artesian water map, appears to correspond to a similar feature in the surface of the "bed rock" below, which may be an old escarpment of the Sioux quartzite. This inference is corroborated by a comparison of the records of the Budlong and Motley wells.

CRETACEOUS SYSTEM.

Of the younger sedimentary rocks only the Upper Cretaceous have been certainly found in the area, but it is possible that there are also present rocks equivalent to the Dakota sandstone and overlying shales of the Black Hills region, which are of Lower Cretaceous age. The Jurassic is almost certainly unrepresented, for rocks or fossils of that age have never been found here, and the known area of their distribution is farther west. The Dakota, Benton, Niobrara, and Pierre have all been recognized in drilling, and the Pierre is exposed at several points.

DAKOTA SANDSTONE.

The Dakota sandstone is the chief water-bearing formation of the region, and supplies the more important artesian wells of North Dakota and South Dakota. In this area it nowhere comes nearer the surface than 700 feet. The formation is named from the town of Dakota, Nebr.

Character.—As exhibited in the rim of the Black Hills and along Missouri River near and below Sioux City this formation is generally a brown sandstone, hard and massive below but thinner bedded and interstratified with much shale above. Its grain varies from fine to coarse, and as a rule the rock is only moderately compact. In eastern South Dakota the formation usually lies on the Sioux quartzite, but in the vicinity of Mitchell it abuts against the higher portions of a ridge of this quartzite upon which the Benton shale overlaps. The Dakota sandstone terminates at this overlap along an old shore line, which has considerable irregularity in outline. From this shore line along the quartzite ridge the Dakota slopes to the north, west, and south. It is believed that there was little, if any, erosion of the Dakota before the deposition of the Benton. The dip of the Dakota sandstone is steeper near the quartzite ridge, and gradually diminishes away from it, so that the strata become nearly horizontal. In the quadrangles of this folio the formation is mainly a succession of sheets of sandstone mantling the "bed rock."

Thickness.—The Dakota is variable in thickness and, except from a few borings which have reached its bottom, precise figures are not available. In the Andrew Kleinsasser well, in sec. 4, T. 113 N., R. 60 W., it is 125 feet thick; in the Budlong well it is 185 feet thick, which is less than usual because of the presence of a ridge of the pre-Cambrian rocks below. A similar ridge under Ashton and Redfield is indicated by a thickness near Redfield of only 125 feet. At the Glidden well it is more than 200 feet in thickness, and at Frankfort it was penetrated for more than 200 feet without reaching the bottom. Drillings at Aberdeen show that its thickness is certainly more than 300 feet there and it is doubtless thicker in the northwest corner and toward the west in these quadrangles. The well sections on pages 12–13 exhibit the character and thickness of the formation in detail.

Fossils.—The Dakota sandstone contains fossils of various kinds indicative of the earlier part of Upper Cretaceous time, and it is believed to be mainly of fresh-water origin. In this region a few fossils have been obtained from the deep wells. In the Budlong well casts of leaves resembling those of elms and other deciduous trees were found in concretions in the sandstone at a depth of about 810 feet, or a little below the main flow. At the Hill well, in the NW. ¼ sec. 18, T. 115 N., R. 60 W., the water brought up numerous shells, mostly when the casing was at the main flow at 800 feet. Some of the shells were possibly from higher strata, but those believed to have come from the main flow were stated by T. W. Stanton to comprise *Corbula* resembling *C. crassimarginata*, *Natica* sp., and *Cerithium* (?). From this well there were also obtained numerous teleost vertebræ and shark teeth which C. R. Eastman identified as belonging to Lamnidæ, *Otodus* (probably *O. obliquus*), and *Odontaspis*; dermal tubercles and teeth of a small ray; and one ganoid scale, apparently referable to *Lepidosteus*. From the King well, in the SW. ¼ sec. 23, T. 113 N., R. 61 W., numerous spiral shells (*Goniobasis*) were thrown up when the well was cased to 825 feet.

COLORADO GROUP.

BENTON SHALE.

The Colorado group includes two distinct formations, the lower of which is the Benton shale, named from its prominent development near Fort Benton, Mont., on the upper Missouri. In the southeast corner of South Dakota it consists of lead-colored or dark-gray shales containing calcareous and ferruginous concretions. It is estimated to have a thickness of about 300 feet at its exposure to the south along Missouri River, but it thins toward the east. In the vicinity of the Black Hills the thickness is much greater. It is divided into three formations, the Graneros, Greenhorn, and Carlile, named in the order of deposition. The Graneros and Carlile are mostly dark-colored shale, though the former is sandy below and the latter usually has several feet of sandstone near its top. The Greenhorn consists of 20 to 40 feet of chalky, shaly limestone abounding in *Inoceramus labiatus*. These divisions are also prominent in southeastern South Dakota.

The presence of the Benton in this area is indicated mainly by the existence of certain minor water-bearing strata which clearly belong to this formation in adjacent regions. Further evidence is afforded by the fossils sometimes thrown out of wells, notably *Prionocyclus woolgari* from the Hassell & Myers well near Redfield. This fossil is characteristic of the upper portion of the Carlile shale. Fossils which may belong to the Benton formation have been obtained in the Hill well near Doland.

NIOBRARA FORMATION.

The upper formation of the Colorado group is the Niobrara, named from its prominence near the mouth of Niobrara River It is generally of a drab color, but where it has been weathered it presents a snowy whiteness or more commonly a light straw color. It varies considerably in composition, carrying in many places a large proportion of clay. Owing to its variable composition it is not everywhere clearly distinguishable from the Benton shale below. The purer chalk appears to occur in lenses or spheroidal masses grading into the clay. In some exposures chalk may be found at one point and a few rods away its place is taken by a gray clay.

The most characteristic feature of this formation is the chalkstone, but no doubt there are also extensive deposits of limy clay, especially in its northern extension. As the formations both above and below consist mainly of shale, the position of the Niobrara beds is in few places sharply defined in this drift-covered region. It is especially difficult to recognize the formation in boring wells, for much of the chalk that has not been exposed to atmospheric action has a leaden color closely resembling that of the gray shale of the Benton. Well drillers seldom recognize the chalkstone in northern South Dakota, so there is considerable uncertainty as to its position in the records of borings. In many of the well sections the sandstone in the upper part of the Benton is succeeded by dark shale which is overlain by a considerable thickness of lighter-colored shale probably representing the Niobrara formation. In a few places the characteristic fossil *Ostrea congesta* has been found in these beds, which is confirmatory evidence. The thickness of the Niobrara is probably about 100 feet.

MONTANA GROUP.

The Montana group comprises two formations, the lower being the Pierre, so named because it constitutes the Missouri River bluffs at Fort Pierre, and the upper the Fox Hills, which occurs in Fox Ridge north of Big Cheyenne River. Only the Pierre shale is present in this region.

PIERRE SHALE.

General statement.—The Pierre underlies the drift in the region, attaining a thickness of several hundred feet and outcropping at a few points along the streams. Here as elsewhere it is composed mostly of dark lead-colored clayey shale, easily reduced by weathering to a black, waxy clay, but at certain horizons there are harder layers.

At several points a layer of white clay 2 or 3 inches thick appears in the Pierre shale. It resembles strata in the Benton formation which have been supposed to be deposits of volcanic ash decomposed into clay called bentonite. Material of this sort outcrops near the mouth of Turtle Creek a few feet above the stream and at several points on Snake Creek, in secs. 18 and 19, T. 122 N., R. 65 W. These localities are 900 and 940 feet, respectively, above the top of the Dakota sandstone. Similar exposures were found also in the Wessington Hills, which are estimated to be fully 1100 feet above the Dakota sandstone.

Pierre shale outcrops.—The Pierre shale outcrops at numerous points in the Byron quadrangle, where it is mostly a black plastic clay, in banks rising 5 to 20 feet above the streams. One series of exposures extends from a point on Turtle Creek about 1 mile above its mouth to James River and along that stream nearly to the mouth of Dry Run. In one place the clay rises about 18 feet above James River and presents the same black, deeply eroded rough surface as in outcrops of the formation west of Missouri River. One or two exposures in this series are a short distance from the stream. Outcrops are abundant for several miles along the east branch of Timber Creek north of Doland and less numerous along the north branch of Foster Creek. The southernmost exposure noted in this area is an obscure one near the south line of Capitola Township, on the south bank of Foster Creek. The outcrops noted are all natural exposures. In many other places the cutting of streams and the occurrence of landslides may reveal the formation at any time.

The only exposure noted in the Aberdeen quadrangle is near the southwest corner of sec. 35, T. 121 N., R. 60 W., where a few square feet of flaky shale appears in the side of a shallow ravine.

Numerous exposures occur in the Northville quadrangle, mostly in the northern portion, where for many square miles the drift is so thin that the Pierre shale is cut into by nearly every watercourse. It appears mostly along Snake Creek, but is exhibited also along a stream heading southwest of Cortlandt and along shallow watercourses east of Snake Creek in Mercier and New Hope townships. An isolated outcrop is reported in the bottom of Nixon Creek in the northwest corner of sec. 18, T. 119 N., R. 67 W. Cliffs of shale 25 to 30 feet in height appear at some points near Cortlandt. Wherever exposed in the Northville quadrangle the Pierre is a drab, firm, flaky shale popularly called "slate." The same is true of the shale thrown out of excavations in the northwestern part of the Redfield quadrangle. Probably these harder beds are at a higher horizon than the shale at lower altitudes about Ashton and Redfield. This suggestion receives some confirmation from a report that near Conde a soft clay was found underneath "slate." However, the plastic character of the black clay along James River may be due to the former presence of iron pyrites which, by its decomposition, has dissolved the cementing material, leaving the residue plastic, whereas in other localities the absence of pyrites has permitted the formation to retain its original firmness.

Pierre shale surface.—The position of the surface of the Pierre shale has been ascertained in some parts of the area where it does not outcrop, but in others it is very uncertain, especially in the central and northwestern portions of the Redfield quadrangle, and under much of the James Valley plain, where it is overlain and obscured by an unusual depth of Quaternary deposits. The surface of the Pierre in these quadrangles reaches an altitude of about 1400 feet at several points remote from one another. One of these points is near Miller and St. Lawrence, and the formation rises even higher in the hills a few miles farther south. It attains an altitude of nearly 1420 feet near Cortlandt and is somewhat higher west of that place, but slopes gently down toward the east nearly to Aberdeen. It rises to about 1375 feet 4 miles east of Verdon, and this may be taken as the average altitude along the eastern margin of the arc to the vicinity of Dolanda. It is probably about 1350 feet in altitude in the vicinity of Byron Lake. It rises to 1300 feet in an extensive area north of Zell and to nearly 1350 feet around Rockham. It is still higher to the northwest, where it comes at many places within a few feet of the surface. West of Devoe it is found in wells at an altitude of about 1380 feet, and it is reported to outcrop at that altitude in the bed of Nixon Creek about 5 miles above Devoe. These points constitute the principal elevated areas.

On the other hand, there are two or three marked depressions or troughs in the Pierre surface, the principal one being along the James Valley. The greater portion of this subdrift valley is wide like the present valley, but a short distance south of Mellette it appears to be divided by a low ridge of shale which enters from the vicinity of Redfield and Ashton. The summit of this underground ridge east of Ashton is about 1250 feet above sea level. The eastern division of the valley in the Pierre runs southward from the latitude of Mellette between the valleys of Dry Run and Timber Creek. It is estimated to be about 5 miles in width where it enters the Byron quadrangle, but east of Frankfort it appears to be narrower. East of Hitchcock it becomes wider and its sides are not so abrupt. Its course is southward in the main, though it deflects somewhat to the east opposite Frankfort and near Byron Lake. The bottom of this valley in the Pierre lies about 1200 feet above sea level, at least in the southern part of the area. It may be deeper in its wide portion east of Aberdeen. The western portion of the valley near Mellette presumably continues to the south-southwest and corresponds approximately to the course of Turtle Creek. Near Twin Lakes the surface of the Pierre is apparently lower than 1200 feet above sea level. Between Miller and Rockham the Pierre surface is lower and in some places it may not rise over 1200 feet above sea level. This would favor the view that an old valley in the Pierre follows approximately the course of Turtle Creek.

Another deep valley in the Pierre, now filled with till and drift deposits, extends from the James Valley near the north line of Spink County westward past Salt Lake and St. Herbert toward Powell. The bottom of this valley has an altitude of about 1200 feet on the east, but near St. Herbert it lies about 1300 feet above the sea.

QUATERNARY SYSTEM.

PLEISTOCENE DEPOSITS.

The formations thus far described are all sedimentary and, with the exception of the Dakota, are of marine origin. The Pleistocene deposits, however, present a marked contrast, not only in their origin but in their mode of occurrence. They are the products of glacial action and overlie almost all the earlier formations without respect to altitude, forming a blanket over the whole surface with the exception of a few square miles which are covered by alluvium or occupied by outcrops of the older rocks. The deposits include till or bowlder clay, morainic material, and certain stratified or partly stratified clays, loams, sands, and gravels formed along abandoned river channels and lakes. The bowlder clay constitutes a great sheet spreading over nearly the entire area. The morainic material occurs in a series of rough, knobby hills and ridges crossing the quadrangles mostly from north to south. The channel and terrace deposits fill valleys and cover flat areas mainly lying in close proximity to the morainic ridges.

GLACIAL TILL.

General statement.—The till, or bowlder clay, presents features that are found in similar regions elsewhere, as in central Minnesota, Iowa, and Illinois. It is an unstratified mixture of clay, sand, and worn pebbles and bowlders, the bowlders attaining a diameter of several feet. In it are local developments of stratified sand, in part merely pockets, elsewhere portions of channels of considerable length, and still elsewhere sheets that locally separate the bowlder clay into two or more members. The till of this region is much more clayey than that occurring at points farther east, because for a long distance the ice moved over and deeply eroded the dark-colored clays of the Cretaceous. For this reason the erratic bowlders are perhaps less commonly striated and planed.

The till here, as elsewhere, exhibits an upper division, known as yellow clay, and a lower blue clay. The yellow clay is produced by the oxidation or weathering of the blue clay, and the separation between the two is not very sharp. In some sections they may be distinguished, but not in all. The blue clay, moreover, is likely to be confused by well drillers with the underlying Cretaceous clay of similar color, so that in their reports part of this clay may be included with the Pleistocene.

No distinct traces have been found here of a general subdivision of the till into two different members, as occurs in some other localities. It should be noted, however, that even if there is a division there is little likelihood of its being reported by well drillers, for the Pleistocene is in few places the source of water supply, and hence the drillers are less critical in their observations on it than on the underlying rocks. Occasionally fragments of wood have been reported from it, but investigation of such reports has invariably shown that the fragments were clearly isolated pieces and not parts of a general "forest bed."

Character.—The till varies considerably in character at different points in the area, though generally it resembles that of the adjoining regions. Near many of the exposures of Pierre shale it is much blacker than elsewhere and in fact locally it is distinguishable from the Pierre only by the presence of sand mixed with it and by scattered pebbles.

In much of the eastern and southeastern portions of the Byron quadrangle the unweathered till presents similar characters to those just mentioned, but in less degree. On the other hand the upper or thoroughly weathered portion in the same area is of a lighter color than the ordinary weathered or yellow till, having a creamy tint similar to that of the Lake Dakota silt, described below. In the three other quadrangles the till does not differ much from the ordinary till of other regions. In the James Valley and Wolf Creek plains it is largely obscured by other deposits, particularly in the area covered by the loesslike Lake Dakota silt and the wash from the adjacent slopes. In the southern part of the James Valley the till is usually stony. This may be the result of floods that have washed away the finer material.

Subdivisions of till.—From the glacial history of the region, as indicated by the moraines, one might expect to find traces of several distinct sheets of till corresponding to different stages of

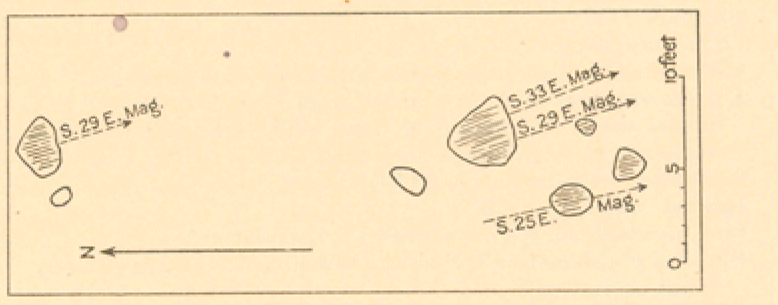


FIGURE 1.—Plan of striated "bowlder pavement," near southwest corner of sec. 9, T. 113 N., R. 60 W., Beadle County.

ice advance. The only clear indications of such subdivisions, however, appear in a comparatively narrow area north of Byron Lake, in Lake Byron and Milford townships, where at several points there are traces of what seems to be a rather extensive "bowlder pavement." In the southwest corner of sec. 9,

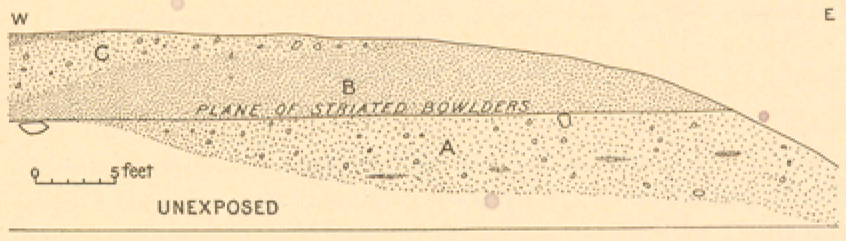


FIGURE 2.—Section of glacial till near southwest corner of sec. 9, T. 113 N., R. 60 W., Beadle County, showing plane of striated bowlders.

A, Yellowish till, darker above, with wet sand pockets. Upper surface is a striated "bowlder pavement." B, Dark gumbo-like till. C, Buff till with few pebbles, darker above.

T. 113 N., R. 60 W. (Milford), and in the northwest and southwest corners of sec. 9, T. 113 N., R. 61 W. (Lake Byron), many bowlders are embedded in the upper surface of a typical brownish till, with their upper surfaces planed and striated with approximately parallel scratches. The directions of the striæ at the locality in Milford Township were S. 20° to 33° E., mostly S. 29° E., magnetic. In Lake Byron Township the

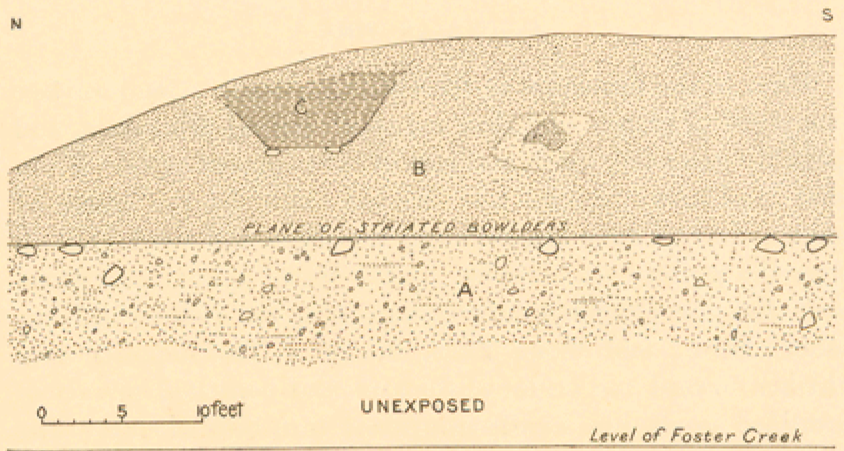


FIGURE 3.—Section of glacial till near northwest corner of sec. 9, T. 113 N., R. 61 W., Beadle County, showing plane of striated bowlders.

A, Yellowish till, with wet sand pockets, traces of stratification, and a few bowlders. Upper surface is a striated "bowlder pavement." B, Dark-brown clayey loam and sand with vertical joints. Contains pockets of loesslike loam and gray till. C, Channel filled with blackish clay.

directions were S. 15° to 34° E., magnetic. These localities are about 6 miles apart, and the pavement has been struck in shallow wells at several places between them. These striated bowlders seem to correspond closely to bowlders that have been noted in the vicinity of alpine glaciers which were undoubtedly the result of glacial action. It seems, therefore, that in this area the ice, during a later stage perhaps corresponding to that of the deposition of the second and third members of the Antelope moraine, overrode and wore down the surface of the till previously deposited. The large number of bowlders at this horizon corresponds with the bowldery surfaces farther west, which appear to be the result of unusual water erosion along the axis of the James River valley.

These bowlder-veneered areas of till, from their relations to ancient channels and the fact that they are generally much more abundant on the surface of the till than below, are believed to have been produced by strong currents, which washed away the clay between the bowlders. Some also were the work of ice blocks carrying bowlders, either floe ice which gathered bowlders from the shore, or ground ice which brought them up from the bottom, as in rivers of Canada at the present time. These ice-borne bowlders were stranded in the shallows of rapids or wide portions of the river.

In the southwestern portion of the Redfield quadrangle there are many facts which may possibly indicate the existence of two till deposits of an earlier stage. Between the Gary and Antelope moraines the till is thicker than elsewhere, and in digging wells there seems to be not only the water-bearing sand at a depth of 70 to 150 feet, but also in many places water at depths of 30 to 50 feet after penetrating blue clay. This may possibly indicate the division between two till sheets, but the facts are indecisive, as local sand lenses and channels are apt to be found in the till at various levels.

MORAINES.

Moraines are more conspicuous in the Redfield and Byron quadrangles than in the remainder of the area, being especially prominent in the ridge southeast of Doland, the Redfield Hills, and Bald Mountain, the last-named rising over 100 feet above the surrounding level. These have already been described under the heading "Relief." Elsewhere the moraines rarely rise more than 10 or 15 feet above the adjoining areas. The moraines of these quadrangles are members of the Gary and Antelope moraines. The former is prominently developed near Gary, in Deuel County, and the latter is named from the Antelope Hills, in the Minnesota Valley. The Gary moraine is represented only in the southwestern and western portions of the Redfield quadrangle. All other moraines represented on the areal geology maps are subordinate members of the Antelope moraine.

Composition.—The material in all the moraines differs little from the till, except that it is generally more stony. This character is easily traced to greater exposure to water action, both while the ice sheet was present and during the later erosion. As the Dakota ice lobe traversed hard rock nowhere south of Manitoba or northern Minnesota on its way to the area under consideration, but only the shaly clays of the Pierre and possibly some soft sandstone of the Fox Hills or Laramie, it follows that the bowlder constituent is small and fairly uniform. Probably over 80 per cent of the material in moraines rising above the average surface is clay and fine sand. The bowlders form a much larger proportion of the surface than of the body of the moraines, because of initial and recent erosion. Much the larger number of bowlders throughout the area considered are of compact, medium-grained granite, mostly light gray, though reddish and darker varieties are not uncommon. Perhaps 10 to 15 per cent of the total number of bowlders are fine-grained sedimentary rocks; many of these are magnesian and show some Devonian or Silurian fossils. Both snow-white and light-yellow sedimentary rocks occur, the former more numerous. About 5 per cent are greenstones of various sorts, diorites, and diabases. Here and there white quartz bowlders of small size may be found, and possibly others, also small, of a very fine grained gray sandstone, showing many casts of plant stems. Such bowlders are numerous west of Missouri River and outside of the first or Altamont moraine. They have been found in the James Valley inside of the Gary moraine, though not surely in this area. They occur in place in the Tertiary. In some places concretions from the Cretaceous have escaped destruction and persist as bowlders. No red quartzite bowlders, such as abound south of the Sioux quartzite ledges in the latitude of Mitchell, are found north of that line in the James Valley.

Gary moraine.—The Gary moraine consists of a belt of bowldery hills 3 or 4 miles north of Miller, so low as to be scarcely noticeable, but farther east it appears more prominently in a range of scattered hills along the north side of the shallow valley which extends across the tributaries of Turtle Creek eastward to the valley of Pearl Creek. This zone of hills continues along the north side of Pearl Creek and to some extent along its south side, turning with the stream toward the southeast in T. 112 N. The scattering morainic knolls in the Pearl Creek valley and to the south may owe their origin to a later stage of advancement of the ice into and perhaps over this valley after its formation. It is possible, however, that these knolls may have been formed at a still earlier stage. The small development of the moraine may be accounted for by supposing that much of the material dropped by the ice sheet during its formation was swept away by a stream running close to its edge. That such a stream formerly occupied the valley is indicated by the extensive gravel deposits. In Howell and Park townships a few scattered peaks rise above the surrounding nearly level surface. One of them is known as Garfield Peak. Their relations are not clearly enough exposed to decide whether they are a part of a reentrant angle of the Gary moraine coming from the west, or whether they are local and unusual deposits of the ice sheet.

Antelope moraine.—The Antelope moraine is unusually irregular and complex in this area, and it has not been practicable to decide fully the relations of its different members. The designations on the areal geology map are somewhat arbitrary, yet it is believed that the general relations have been ascertained.

This unusual complexity probably is due to the following circumstances. As the ice receded from the Gary moraine it doubtless became much thinner, as well as less extensive, so that morainic débris began to accumulate under the thinner portions south of the location of Redfield. This tended to split the broad ice sheet at that time extending across both the James River and Turtle Creek valleys into two subdivisions corresponding to those valleys. The eastern lobe, on lower ground and therefore more vigorous, still reached beyond Cain and Pearl creeks south of Huron, but the western lobe, being on high ground and moving up an incline, was much retarded and shortened. At that time, that is during the formation of the first member of the Antelope moraine, the ice extended beyond Miranda on the west and nearly to Burdette on the southwest.

There is much difficulty in identifying the members of this moraine because the knolls at first glance appear to be scattered uniformly over much of the surface of the western slope of James Valley, particularly in the Northville quadrangle. Consequently it has been found best to represent this diffuse and scattered character by mapping only the more prominent elevations, either knolls or low swells. The ancient channels also give an important clue to the successive stages in the recession of the ice; especially in correlating the different members on the east and west sides of the ice sheet. Attention is also called to the fact that the ice lobe was more active in its western half than in its eastern. Apparently its velocity was greater; it melted faster and more material was deposited, while more also was washed away. Moreover, the recession was probably about three times as fast on the western side as on the eastern.

The first member of the moraine includes a belt of scattering knolls entering the Redfield quadrangle north and south of West Branch of Snake Creek northwest of Miranda, and sweeping in a gentle south and southeast curve to the southeast corner of Wheaton Township, where it joins the corresponding portion formed along the western edge of the eastern or James River valley lobe. It must be supposed that much of the material comprising the hills of the reentrant portion to the north and northeast had already accumulated underneath the ice, and it is not unlikely that the higher hills were at least half formed before the ice receded from them. In other words, it is assumed that the hills north and east of Cottonwood Lake, most of Bald Mountain, and the range of hills connecting with the Redfield Hills were already in existence. This first member includes the prominent hills extending along the east side of the conspicuous valley that runs south-southeastward into the southeast corner of the Redfield quadrangle and joins the hills west of Wolsey. This member enters the east side of the Byron quadrangle in T. 115 N., R. 60 W., in a belt of scattering knolls and ridges that continue to the northwest and north outside (east) of the later members, which combine into a well-defined ridge a little farther west. It leaves the quadrangle north of Doland.

The second member of the Antelope moraine in the northwest corner of the Northville quadrangle lies on the east side of a broad, shallow old stream channel running toward the south. At the north it is clearly defined, but near the south line of Edmunds County it becomes less prominent, probably because of numerous old streams which may have carried away much of the original deposit. It enters the Redfield quadrangle just east of the west branch of Dove Creek, and trends southward and southeastward along a curved course nearly parallel to that of the first member, with which it is connected at a few points. The second member is well developed northwest of Rockham, but farther south it consists of knolls few of which rise over 10 feet higher than the basins between but which occupy a zone 1 to 2 miles wide. Northwest of Cottonwood Lake it curves to the east and northeast and connects with the north end of Bald Mountain. East of that point the second member is scarcely separable from the first and lies on its inner or northern side. Together they swing to the north in the moderately high ridge known as the Redfield Hills. Near Tulare station the moraine appears to be lacking for some distance or to be covered by old stream deposits, but from Tulare southward the second member is a conspicuous feature to and beyond Huron. It is about $1\frac{1}{2}$ miles wide in this region and is distinct in topography. East of the James River valley this member reappears in a line of ridges extending through Union Township and southward past Doland. According to present interpretation it merges into the third member near the southwest corner of Capitola Township, and after crossing Foster Creek forms a high continuous ridge running toward the north. Its further course will be traced in connection with that of the third member.

The third member is less easily traced than the second, especially on the west side of the James River valley, because of its unusual breadth. It appears in the plain just west of the west fork of Snake Creek northwest of Cortlandt, where it is represented by low knolls interspersed with wide shallow basins. Its course, like that of the second member, is due south nearly to the south line of the Northville quadrangle. In T. 119 N. it appears to divide into two parts, one swinging westward to the west side of Preachers Run and West Branch of Snake Creek and extending to the north branch of Dove Creek, which it follows to its southeast bend; and the other passing east of Preachers Run and extending to the southeast bend of Dove Creek, where it unites with the other branch. The member then turns eastward toward Redfield and finally passes into the northern part of the Redfield Hills. In the southern part of these hills west of Crandon this member again separates as an irregular ridge that rises at intervals toward the south, past Hitchcock, on the east side of a prominent old channel. East of the James River valley the third member may be represented by the few osar-like knolls in eastern Iowa Township, but at the northeast corner of Lake Byron Township it rises in a fairly developed ridge which extends to Foster Creek. North of that creek, near the southwest corner of Capitola Township, it joins the second member, and thence northward the two form Doland Ridge, which in places rises from 60 to 75 feet above the adjoining plains. Near Doland and farther north the ridges are low and broken but form a well-marked morainic belt 1 to 2 miles in width. The areas are less continuous near the north line of the Byron quadrangle and trend somewhat to the east. In the Aberdeen quadrangle the second and third members are not distinctly separable, but appear as a belt of scattered knolls, many of them low, running a little east of north till they pass out of the quadrangle in the southeast corner of Hanson Township.

The fourth member of the Antelope moraine occupies a north-south zone of considerable width, passing along the western sides of Brown and Spink counties and ending a short distance north of Zell. This zone includes the rough country east of the Scatterwood Lakes and the still rougher region west and southwest of Northville. The member may reappear in a few scattered knolls in Lodi Township and in a cluster of osar-like knolls in the northeastern part of Cornwall Township (T. 114 N., R. 62 W.). It may be recognized further in a few morainic knolls scattered along the west side of Doland Ridge. Its last representative toward the north is a cluster of knolls just south of the railroad about 4 miles east of Groton, which may be considered meager representatives of the outer portion of this member. The later deposits were lost in the early waters of Lake Dakota.

The knolls scattered on the summits of the divides near the line between Zell and Groveland townships and along the north edge of Exline Township may be considered an intermediate moraine formed between the third and fourth members, or perhaps they may be classed with the fourth. The prominent morainic ridges just northwest of Aberdeen may be regarded as a fifth member of the Antelope moraine, the rest of which was lost in Lake Dakota, as in the case of the preceding member.

ESKERS OR OSARS.

As has already been mentioned the melting of the ice on the west side of the James River ice lobe was more rapid and the drainage on that side was more free than on the east side, partly because of the gentler slope. On the east side the melting apparently was slow and the slope so steep that the waters draining from the eastern highlands, instead of cutting channels toward the south, ran toward the ice. In some places the waters ran upon the ice for some distance, and elsewhere underneath it. The latter conditions naturally prevailed at the south, toward the end of the glacier, while to the north the surface flow was more common and several interesting and well-developed lines of osars were formed. The northernmost of these osar groups in this area is a line of ridges about $1\frac{1}{2}$ miles long in secs. 21 and 22, T. 122 N., R. 60 W., rising 20 feet above the surrounding land and sloping down toward the west. Another system about 3 miles long forms a somewhat similar ridge running through the town of Conde. Another east-west system lying just south of Turton has a length of more than a mile. Two small osar-like knolls lie in an east-west direction about 2 miles south-southeast of Conde. All these groups seem to have been formed by streams flowing westward upon and toward the middle of the ice sheet.

There are also one or two lines of ridges running nearly due south in the southeastern portion of the Aberdeen quadrangle. The most conspicuous comprises a series of long, sharp, gravelly ridges extending from sec. 11 in Benton Towship to sec. 23 in Sumner Township, a distance of over 7 miles. In one part the ridge is unbroken for 3 miles. Another system, much less perfectly developed, lies about a mile farther east, including a ridge about half a mile long in sec. 12, Benton Township, and a short ridge in the southeast corner of sec. 13, Sumner Township. The latter coincides in direction with the west end of the Turton ridge. All these ridges consist of gravel and sand irregularly bedded and cross-bedded. A series of knolls in sec. 22, Athol Township, suggested a possibly similar origin, but closer examination failed to reveal any distinct stream deposit, hence they are mapped as a morainic ridge.

ANCIENT CHANNELS AND TERRACES.

Scattered throughout these quadrangles are numerous abandoned channels and terraces, the locations of which are shown on the geologic maps. Most of these channels are clearly separable from the present drainage lines, and are evidently much older. In some of the shallower channels the older deposits can not be clearly distinguished from those of recent origin and all are mapped as old deposits. The ancient channels correspond generally with the present waterways, for the latter are the puny successors of the former, though in some the direction of drainage has been so changed that the course of the water has been actually reversed.

These channels vary from shallow, flat-bottomed depressions, through which streams passed for a comparatively short time, to troughs nearly 100 feet deep that contain an abundance of coarse material, showing that they were long occupied by vigorous streams. In all of them the coarser deposits are as a rule largely covered with finer material. Where the channel deposit has been cut through by the deeper trenching of a later stream, similar differences in the character of the material also occur. In some places the old channel deposit is at a height of 50 to 60 feet above the present streams. Many of the old deposits have been but slightly trenched, however, as the later drainage has passed off in another direction.

These ancient channels were developed during the presence of the ice sheet and served to carry off the water from its front. The arrangement of the channels is the strongest evidence of the former presence of glaciers in the region. The size and direction of some of the channels and the amount of coarse material found in them can be explained in no other way.

The oldest channel in the area treated in this folio doubtless is the one which runs eastward outside or south of the Gary moraine north of Miller and St. Lawrence and which toward the east is now occupied by Pearl Creek. It is less regular than most old channels, because the knolls of the Gary moraine are scattered in the bottom of it as well as on both sides. In general the channels were occupied in succession from the southwest to the northeast throughout the Redfield quadrangle and a part of the Byron quadrangle, but in the east half of the latter the succession was from the southeast and east toward the west.

Many of the larger channels have sandy or gravelly bottoms, though most of them are covered with clay or loam. Some of the localities where the till remains sandy are along Pearl Creek, in the channel running southward from Turtle Creek past Wolsey, in the channel west of Hitchcock, and in a small area southwest of Redfield. A considerable part of the sand appears to have been blown at some time from the bottoms of some of the channels over the eastern banks by the action of westerly winds. Such transported sand is conspicuous, although the bottoms of the channels to the west are now well covered with soil and clay.

The relations of these channels to adjoining moraines and to the recession of the ice sheet is further discussed under the heading "Geologic history." Some of the channels formed during the recession of the ice were partly refilled during the existence of Lake Dakota, and, though some of the resulting deposits were thoroughly washed out afterward, many of them still remain, nearly buried in lacustrine silt.

On the areal geology map the channels are numbered in the order of their occupation so far as possible, but this plan has not been feasible for some channels that were occupied at different times, a few of them with the direction of the stream reversed. The numbers assigned to channels within the limits of Lake Dakota indicate the order of occupation during the recession of the ice sheet, before there was a continuous lake. During the falling and draining of the lake many of the channels were simultaneously occupied by currents or streams.

LAKE DAKOTA SILT.

The deposits of the glacial Lake Dakota occupy an extensive area in the bottom of the James Valley at an altitude of about 1300 feet. The area is about 16 miles wide opposite Redfield and half that breadth east of Hitchcock. Toward the south it resembles a flat area of till, with bowlders and pebbles, but this southern portion consists largely of delta deposits. North of an irregular line passing south of the latitude of Crandon, the surface is remarkably level, though crossed here and there by channels which very commonly trend toward the southeast. The most characteristic feature of this portion is that it is covered on the uplands for a depth of 5 to 35 feet with a fine yellowish or cream-colored silt or loam in which bowlders and pebbles are very rarely found except toward the base. In the deeper channels crossing this silt area bowlders appear at many places on the bottoms and lower slopes, but the shallower channels are covered throughout with the fine lake deposits.

Composition.—The Lake Dakota silt closely resembles the loess that covers wide areas in the southeastern part of South Dakota and in Iowa and Nebraska, and is apparently of the same composition. It consists mainly of very fine quartz sand, of which the grains are mostly clear quartz, though yellowish ones are found. The grains are perfectly rounded and vary in size from less than 0.008 to 0.04 millimeter, the average size being not far from 0.01 millimeter. Like the loess, the silt effervesces slightly with acids and contains calcareous concretions with cracked interiors, very like the "loess kindchen." Some of these concretions are composed largely of sulphate of lime. The silt shows very little trace of stratification except in the lower portion, where, as also in the loess, sand and coarser material are locally imbedded. It has vertical cleavage, like the loess, and is found also at varying levels in much the same way. It differs from the loess in being less coherent and of a lighter shade, with its lower portion usually of gray color, and in having a well-defined upper limit on the sides of the valley. Toward the base of the deposit in some places the silt passes more or less abruptly into fine sand several feet in thickness.

These deposits usually have a massive structure from top to bottom, but in many places they exhibit thin layers of a darker and more clayey nature. In some locations where the conditions of deposition may have been more tranquil than usual there are numerous alternations of clay and loam in somewhat regular series, suggesting that the successive layers might be the result of an annual or seasonal variation of conditions. This character was noted in Lager's brickyard near Aberdeen, where the section is as follows:

Section at Lager's brickyard near Aberdeen.

	Feet.
Black soil	1
Light-gray loam	.6
Yellow massive loam, weathering with rounded corners	1.4
Massive cream-colored loam or silt from three-fourths inch to 5 inches thick, alternating 13 times with dark-gray clay one-sixteenth to three-fourths inch thick	6
Similar to foregoing, but in six beds	1
Banded drab clayey silt	2
Clay blotched below with whitish marly material	2
Blotched bluish and rusty fine clay with some fine grit, apparently lying on blue till	1

The relations of this deposit clearly show it to be of flood origin and indicate that for some time the James River valley was occupied by a lake. In general, the deposit is thicker toward the center of the district covered by it, but in a few places remote from the edge morainic hills or patches of till rise above it. Some of these are shown on the map, but probably not all. Here and there the silt rests almost directly on Cretaceous clays, with only a few inches of drift between.

RECENT DEPOSITS.

ALLUVIUM.

All the streams that traverse this region are subject to sudden floods, caused not only by occasional excessive rainfall but by the rapid melting of abundant snows during certain seasons. The gravels of ancient channels and lake basins are thickly covered with fine silt, which is in part dust deposited from the air. The alluvial plains of James River average about half a mile in width. Some portions of it are dry and are well adapted to cultivation; others are marshy, and all of it is more or less subject to occasional floods. The alluvial deposits are from 10 to 20 feet thick, the upper 3 to 5 feet being usually fine black loam and the lower portion sand or gravel.

GEOLOGIC HISTORY.

ALGONKIAN TIME.

Prior to the formation of the Sioux quartzite a land surface composed of granite and slate occupied central Minnesota, and possibly extended south and east of these quadrangles. From that land area material was derived, both by the action of streams and by wave erosion along the shore, and was laid down over the region now occupied by the Sioux quartzite, a broad area that now extends southwestward from the vicinity of Pipestone, Minn., and Sioux Falls, S. Dak. The deposits were thicker toward the center of the area and consisted mainly of stratified sands, but locally comprised thin beds of clay. The material of the quartzite was laid down in the sea, and at first may have included scores or even hundreds of feet of beds above those which now remain.

After this period of deposition there seems to have been an epoch of slight volcanic and igneous outflow. This is attested by the occurrence of a dike of olivine diabase near Corson and in borings at Yankton and Alexandria, S. Dak., and of quartz porphyry near Hull, Iowa.

Through silicification the sands thus deposited were changed into an intensely hard and vitreous quartzite, and the clay beds were formed into pipestone and more siliceous red slate, as at Palisade. Microscopic examination shows that this silicification was effected by the crystallization of quartz around the separate grains of sand until the intervening spaces were entirely filled.

PALEOZOIC TIME.

In time the region was lifted above the sea, and during some part or all of the long Paleozoic era it was a peninsula. It may at times have been submerged and have received other deposits, but if so, they have been eroded. That it was not far from the ocean, at least during a portion of the time, is attested by the occurrence of Carboniferous rocks under Ponca, Nebr.; and inasmuch as rocks of several of the different systems of the Paleozoic and of the Jurassic and Triassic are present in the Black Hills, it is evident that the shore line during those periods crossed the State between the Black Hills and this region.

CRETACEOUS TIME.

With the beginning of the Cretaceous period the sea began to advance over the land; in other words, this quartzite area began to subside relatively. As the waters gradually advanced waves and currents carried away finer material and left well-washed sands spread as more or less regular sheets extending across the shallow sea from its eastern shore to the Rocky Mountains. From time to time the activity of the erosion diminished; and finer material, or mud, was deposited, or possibly in part sand and mud were laid down contemporaneously in different areas. It is not unlikely also that strong tidal currents sweeping up and down the shallow sea over the area mentioned may have played an important part in distributing so uniformly the sands and clays. Where the currents were vigorous, sands mainly would be laid down; where they were absent or very gentle, clay would accumulate; and not improbably these tidal currents would shift from time to time by the variable warping of the sea bottom and the shore. At any rate, it is known that several nearly continuous sheets of sand extend over this region and are more or less perfectly separated by intervening sheets of shale. The product is the Dakota sandstone.

The fossils found in the Dakota sandstone are some fresh-water shells and leaves of deciduous trees, like the sassafras, the willow, the tulip tree, and the eucalyptus.

Throughout Colorado and Montana time marine conditions prevailed and the region was further submerged until the shore line was probably as far east as central Minnesota and Iowa. During most of this time only clay was deposited in these quadrangles, but calcareous deposits accumulated in the form of chalk during the Niobrara epoch, when the ocean currents brought less mud into the region. The sea then abounded in swimming reptiles, some of gigantic size, whose remains have been found at several points; also sharks and a great variety of other fish, although the remains of these are not abundant.

In the latter part of the Cretaceous period, in the Laramie stage, the sea seems to have receded rapidly toward the north-west, and all eastern Dakota again became dry land.

TERTIARY TIME.

During early Tertiary time, when, according to the prevalent view, large rivers deposited widespread sediments in the region toward the west and southwest, this area received but little material and probably abounded in vegetation and animal life. Apparently the climate was then much warmer and moister.

Later the streams, which had already become located, cut deeper channels and found outlets toward the south, somewhat as at present. At that time the James Valley was occupied by a larger river which received from the west the various streams that now join the Missouri. It had not, however, cut to the depth at which James River lies to-day, though the valley had been so long occupied that its breadth was much greater than that of Missouri River.

QUATERNARY TIME.

Advance of ice.—During the Pleistocene epoch a great ice sheet moved down the James Valley, entering it probably from the north and northeast. It slowly advanced, preceded by waters from the melting ice, which gradually spread a mantle of sand and gravel over much of the preglacial surface. This ice sheet flowed according to the slope of the preglacial surface, moving more rapidly on the lower and more open portions of the valley, and becoming almost stranded on the higher elevations. It certainly reached as far as the outer, or Altamont moraine. Some geologists are confident that it extended down the Missouri Valley and became confluent with a similar sheet flowing down the Minnesota and Des Moines valleys, the combined glaciers extending into Kansas and central Missouri. However that may be, during the formation of the Altamont moraine the ice filled the whole James Valley and extended westward at different points to the present channel of Missouri River near Andes Lake, Bonhomme, and Gayville, so that the Altamont moraine forms an almost continuous ridge or system of stony hills around the edge of the ice sheet of that epoch, except where it was removed or rearranged by escaping waters. (See fig. 4.)

Retreat of ice.—For some unknown cause or combination of causes the ice began to recede, and at a later stage of what is considered part of the Altamont moraine, morainic material was again laid down in the higher part of James Ridge east of Lesterville and near Tripp. After this stage came a period of still more extensive recession, which carried the edge of the ice an indefinite distance to the north. It is not unlikely that it retreated considerably within the line of the Gary moraine.

In the district treated in this folio the first area that became free from ice was the portion outside of the Gary moraine near Miller, on the north slope of the Wessington Hills. During the formation or occupation of the Gary moraine the remainder of the district was covered with an ice sheet similar to that now found in Greenland and in parts of Alaska. This was probably several hundred feet thick in the James River valley.

The drainage from the east side of that valley then found its way southeastward past Willow Lake and De Smet to East Vermilion River. On the west side the drainage from nearly the whole of the lobe of ice which pushed westward up the Red Valley found its way to the James Valley past the edge of the ice, a little north of the location of Miller. The fact that this stream kept close to the edge of the ice brought about two results—first, the moraine was feebly developed because much of the material was washed away; and second, many of the moraine knolls are in the bottom of the channel. The latter fact apparently indicates either that the ice had advanced into the channel after the channel had been formed or that part of the water flowed under the ice.

Beyond the southern border of these quadrangles the water found its way through the upper branches of Sand, Firesteel, and Enemy creeks to James River, at first near Olivet, in Hutchinson County, and later near Mitchell.

Garfield Peak and other hills north of it in Howell Township may be glacial deposits accumulated by superglacial or subglacial streams on the eastern slope of the higher lands to the west. It is also possible that they are imperfect drumlins, irregular in form because of less vigorous action of the ice. It could not be decided whether they are of such origin, or portions of an imperfect and intermediate moraine, or parts of a reentrant angle of the Gary moraine, as shown on the map.

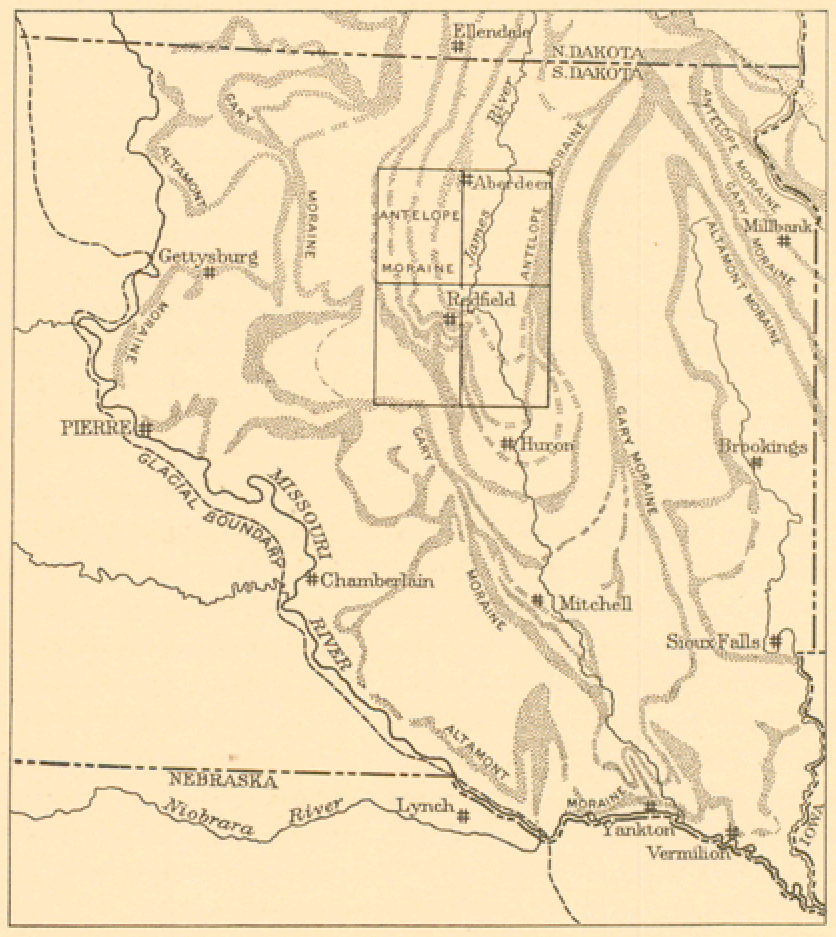


FIGURE 4.—Sketch map showing the southern limit of the Pleistocene ice sheet and the distribution of moraines of the Dakota glacial lobe in South Dakota.

As the ice receded to the Antelope moraine it disappeared most rapidly in the valleys of Turtle and Wolf creeks, and rather slowly around the base of the Wessington Hills, where the two moraines are only a few miles apart. In the James Valley, meanwhile, the ice stream receded from Mitchell and Letcher nearly to Huron. Very likely the recession was to a point some distance within (north of) the first member of the Antelope moraine, and some of the material of the Redfield Hills probably had been accumulated before that time.

The recession was so slow that the drainage from the west side of the ice, because of the uncovering of lower ground, possibly came from the edge as far north as Bowdle. These waters cut two or three more or less distinct channels on the wide flat Wolf Creek plain. The first passed through Holden Township and another through Burdette, but both discharged into Sand Creek. The upper part of that stream in Allen Township was at such altitude, about 1400 feet, that the till plain of Wolf Creek was an undrained, level, mud flat.

Readvance of ice.—The next stage saw an arrest in the retreat of the ice, followed by a readvance, but the ice sheet was thinner and a northward trending ridge 2 to 3 miles east of Ashton and Redfield split its southwestern portion into two lobes. Probably the ridge was originally of considerable prominence, but it was reduced by former ice sheets passing over it and south of the Redfield Hills by numerous creeks. The eastern lobe of the glacier in the advance was more vigorous because it was on lower ground and was moving down a gentle slope. The western lobe, which pushed up the Turtle Creek valley to the southwest, moved less rapidly because it had to force its way up a slope and because its flow was less concentrated. There was, in fact, all along the western side of the lobe more or less westerly motion, which diminished the southerly movement.

First Antelope stage.—At its farthest advance the ice formed the first member of the Antelope moraine. The water from the north still flowed through the channel (marked 3 on the map) which passes west of Miranda and through Burdette. Doubtless it was augmented by copious drainage from the irregular interlobular portion of the moraine south of Redfield and even from superglacial streams between the lobes. Several square miles on the east side of James River in the eastern part of the Byron quadrangle drained east of south, and probably the water from this area flowed down Redstone Creek.

Second Antelope stage.—As the ice receded to the position now occupied by the second member of the Antelope moraine the small streams on the east side of the valley shifted a little farther to the west at several points. Possibly subglacial drainage began in the later part of this stage and portions of glacial ice extending considerably below the present surface became detached and buried in débris during the recession of the ice sheet. The formation of the many basins now occupied by lakes may perhaps be accounted for by the subsequent melting of such blocks of ice.

On the west side of the James Valley the changes were much more marked because the edge of the ice receded eastward for several miles. As the ice lay on an even slope, the water from the uncovered surface farther west and the much greater amount furnished from the ice sheet on the east easily found its way around the edge of the ice toward the south. It flowed in a well-defined, wide, and shallow channel, which entered the Northville quadrangle just east of its northwest corner and followed the western edge of the moraine southward along a portion of the upper portion of Preachers Run east of Ipswich and over a low divide to the valley of Nixon Creek. It thence followed West Branch of Snake Creek southward and probably passed over the low divide between that stream and the headwaters of Dove Creek at two or three points. It soon left Dove Creek by a shallow channel leading outside of the second member of the moraine and flowed into the headwaters of Medicine Creek, which it followed to the sharp bend south of Cottonwood Lake. Here it was joined by an important tributary, supplied from the melting of the great ice block of Cottonwood Lake (which was probably buried at the time the first member was formed) and also from the moraines on the north and northeast.

One unusual phenomenon attended the recession of the ice from the first member of the moraine on the slope east of Miranda. The till was so thin and the pressure of the water in the fine sand under the till so great that numerous springs broke forth and washed out many winding channels both toward the ice and away from it. From these the fine sand came out in large amount.

Third Antelope stage.—As the ice retreated to the position of the third member of the Antelope moraine the main western drainage channel naturally shifted first around the curve north-east and east of Miranda. Four or five different channels were occupied successively during this change. At one time during the interval a long drainage channel was developed from the large basin near St. Herbert, extending southward to West Branch of Snake Creek and across it into Dove Creek, entering the Redfield quadrangle in the northeast corner of T. 117 N., R. 67 W. The basins near St. Herbert appear to have been occupied by buried ice blocks which had become detached and covered up in the deep till that filled the old channel passing that point. Later in this stage a channel was developed from the central part of Fountain Township (T. 123 N., R. 67 W.) and another from the east side of the same township. This eastern channel extended southeastward and southward down Preachers Run to West Branch of Snake Creek, but instead of following the present course of the West Branch valley, which was then blocked with ice, it continued southward to Dove Creek and followed that stream to its sharp southeastern bend. Thence it extended down a wide channel to the lower course of Medicine Creek east of Bald Mountain into Turtle Creek, and thence west of the Redfield Hills past Tulare and down the channel west of Broadland to the vicinity of Huron.

On the east side of the James River valley there was less change, but it is to be inferred that the presence of subglacial streams which had been flowing for some time along the line of Foster Creek together with the narrow form of the ice sheet there, may account for the detachment and burial of an extensive mass of ice from the main glacier. Around this detached mass till and subaqueous clays and gravels accumulated until a level plain was formed. The melting of this vast block of ice formed the Byron Lake basin and the channels leading from it to James River. The depth of the lake basin is supposed to be nearly equal to the earlier thickness of the till in that vicinity. One difficulty in this hypothesis is the existence of the glacial pavement at a higher level to the north, and another is the fact that the alluvial fan or delta of Foster Creek appears to pass across the western half of the lake basin without clearly modifying the sides of the basin. The first-mentioned fact would appear to indicate that the ice was buried during an earlier stage, but that it should remain unmelted during these later stages as required by the second fact seems scarcely credible.

During the recession from the third to the fourth member of the Antelope moraine, a remarkable channel was developed on the west side of the James River valley. It enters the area treated in the folio with the west prong of the main Snake Creek in Cortlandt Township, leaves the present creek at Cortlandt, and passing over a low divide follows a straight course nearly due south for more than 25 miles to West Branch of Snake Creek at Wesley. At first the water may have flowed from that point south-southwestward to Dove Creek, but soon its main course was down the valley of West Branch. Another remarkable feature of this channel is the series of basins now occupied by the Scatterwood Lakes, which doubtless mark the burial place of large ice blocks in the deep till filling the old channel. There are other basins both east and west of these, some of them considerably deeper though of less extent. Four or five more or less perfect cross channels connect this channel and the one next east of it in the eastern portions of Richland and Clear Lake townships. Two or three of them appear to originate east of Snake Creek and to cross the present channel of that stream. These facts presumably indicate that the cross channels were formed by subglacial streams, probably beginning at the east end with "moulins," or glacial cataracts, where the water plunged from the surface of the ice to the bottom. The origin of these cross channels may also be connected with the abrupt descent into the preglacial valley before mentioned, from the preglacial highland just to the north. As the ice moved toward the west-southwest in that locality, there would have been a tendency to form crevasses near the edge of the highland. Moreover, as the ice sheet thinned by ablation the surface may have become concave where it overlapped the preglacial upland, so that superglacial streams may have formed upon it. These streams would have found their way to the crevasses and by them to the bottom of the ice, under which they would flow westward toward the edge of the ice and into the main drainage channel. The cross valleys may have been formed, not contemporaneously, but successively, according to the shifting of the crevasses. This explanation finds additional strength in the fact that a number of these valleys are incomplete—that is, are not on the same level—a fact which suggests that some of the streams may have taken a northerly course after the edge of the ice had been reached. On the other hand, at least two of them are cut completely through from Snake Creek to the main channel under consideration. Some of them may have been subsequently modified by the slipping of till or the burying of ice blocks.

Fourth Antelope stage.—When the ice had fully retreated to the position occupied by the fourth member of the Antelope moraine the principal drainage passed just west of the western margin of the moraine, down a portion of the valley of Snake Creek to the largest one of the cross valleys just mentioned, which it followed to the main Scatterwood Lake channel. Thence the water flowed down this channel to West Branch of Snake Creek, along that stream to its sharp bend, and thence southward to the southeast angle of Dove Creek. From that point it may have at first followed the former course already described west of the Redfield Hills, but later it flowed down the Turtle Creek valley to Redfield and east of the Redfield Hills. Meanwhile west of Hitchcock the recession of the ice from the third member of the moraine uncovered still lower ground and the streams flowing southward found access, at first by former outlet gaps through that member, to the lower channel east of Crandon and thence southeastward by the shallow irregular courses east of Hitchcock. These channels are generally ill defined because of their temporary occupation.

As the ice receded still farther to the northeast, channels were opened one after another around the head of the Redfield Hills. Some of them very likely were at first subglacial. All had sufficient head to scour fairly deep channels and to carry much débris to the plains farther south. In fact, there may have been at that time a shallow lake northwest of this region. In later stages the stream following the channel of Snake Creek crossed the southwestern bend of the present James River and kept a remarkably straight course to the present mouth of Timber Creek. Perhaps the position of the edge of the ice had much to do with the straightness of this course. The thickness of the drift deposits along that line suggests that a preglacial channel may also have been an influential cause.

During the later stages in the formation of the fourth member of the Antelope moraine the drainage followed the edge of the ice southward in the western part of Aberdeen and Warner townships through Lords Lake and reached the level of the glacial Lake Dakota about 4 miles north of the south line of Brown County. From that point it followed the channel just inside the western margin of Lake Dakota to West Branch of Snake Creek and for a time probably flowed on into the northwest corner of Three Rivers Township. Here it turned due south and followed to the southwest corner of the same township, thence in part turning east and flowing to Redfield, finally finding its way through the channel southeast of Redfield now occupied by the railroads. This stream was a rapid one, for the channels were cut deeply and their bottoms and sides were in many places stony.

Meanwhile on the east side of the James River valley the action of the ice was less vigorous, the water less copious, and the deposits less voluminous. During the formation of the second and third members of the Antelope moraine a well-defined channel was cut, at first outside of the moraine and later perhaps under the edge of the ice inside of the moraine to Foster Creek. This channel is particularly noticeable in the Byron quadrangle. In the Aberdeen quadrangle, where the slope was steeper, the channels are not clearly defined, apparently having been occupied for only a short time at any one point. Since the ice left the surface the more recent channels have had a westerly trend down the slopes, and hence the older channels are very inconspicuous. Moreover, as the edge of the ice was much more stationary on this side, the channels are less numerous. For example, when the ice stood at the position of the fourth member of the moraine a channel extended from the vicinity of Conde southward to Foster Creek, being for a portion of the way next to the edge of the ice. This same general course had been occupied during the formation of the third member, with the difference that in the Aberdeen quadrangle much of the water had run upon or under the ice; at that time the eskers or osars described in a previous section were formed. This same channel appears to have been the main drainage outlet until the ice had receded some distance within the fourth member of the moraine so that the waters could find their way into the lower part of Timber Creek.

Fifth Antelope stage.—During the formation of the knolls that have been designated the fifth member of the Antelope moraine, the edge of the ice throughout this region rested in broad sluggish marginal streams and most of the morainic material was swept away or flattened out by the waters. These streams began this work first toward the south in an earlier stage. Channels marked 8, 9, and 10 on the map show the successive courses of the waters as the ice lobe filling the valley gradually dwindled away. Probably two or three of them were occupied at the same time, especially when the wasting of the ice became great. When the melting was slow, as in the winter, probably the channels next the ice were the ones mainly occupied and the opportunity for escape of the waters toward the south was such as to allow the streams to cut down their channels to a considerable depth. On the other hand, during the summer they were probably flooded and had a more or less lacustrine character.

Glacial Lake Dakota.—Later, when the ice had receded southward to the limits of the area treated in this folio and possibly beyond the limits of South Dakota, the melting of the ice was so rapid that a high flood stage was reached and sustained for some time. The somewhat spoonlike or concave surface of the till of the whole valley due to the recession of the ice above the last member of the Antelope moraine and to the constriction in the valley of James River near the south line of Spink County caused the water level to rise to the north, flooding a wide area to an altitude which is now a little more than 1300 feet above the sea. To this condition is ascribed Lake Dakota, with its deposit of cream-colored silt. In the earlier stages of the flood the various channels were probably violently eroded, especially toward the south, but when the flood reached its height a lacustrine stage was established in which sediment was deposited throughout the valley, much as along the Missouri River in the great flood of 1881. The channels received the sediment no less than the upland. Some channels remain to-day so nearly filled that they are only slight winding depressions on the level plain. Others, from their greater size or from their relation to the drainage of the lake, were washed out by the subsiding waters, so that their bowlder-covered bottoms and sides apparently are much as they were before the flood, except that they are deeper in proportion as their banks have been raised by the accumulation of the silt. The basin of Lake Dakota reaches as far north as the fourth member of the moraine near Amherst and Oakes, N. Dak. Hence it may be supposed that the edge of the ice during its formation was at least that far north.

At that time drainage was open from the headwaters of James River; and doubtless the fine sandy detritus, so different from the dark Cretaceous clays which form the main mass of the till and underlie this region generally, was derived from the Laramie loams and sands on the highlands northwest of Ellendale and west of Jamestown, N. Dak.

As the rate of melting of the ice diminished and the outlet of the lake was lowered by erosion the lake finally disappeared, though the deeper prelacustrine channels continued for some time as watercourses, many of them with currents of considerable strength which cleared out most of the silt which had clogged them.

Final retreat of ice.—Finally the ice sheet receded until its waters no longer had influence on this area. The streams by that time had become fixed in their present courses and, though probably somewhat larger than at present, had little effect on the surface of the country except to deepen channels which were permanently occupied by water. It is believed that James River had cut nearly to its present depth before the ice disappeared from South Dakota.

Postglacial history.—The principal geologic event since the disappearance of the ice sheet has been the deposition of the thin mantle constituting the soil. This has accumulated by the formation of alluvium along the principal streams, by wash from the hillsides, and by the settling of dust from the atmosphere. To these soil-making agencies may be added the burrowing of animals, by which the soil is loosened and deepened, and the deposition and intermingling of vegetable remains. The watercourses have deepened their channels somewhat, especially James River, which has cut a narrow trench in the alluvium.

ECONOMIC GEOLOGY.

There are no workable deposits of metalliferous minerals in these quadrangles. Nodules of iron pyrites occur in the clays, but the mineral has no value unless found in very large quantities, and such should not be expected in this region. A few nonmetallic deposits, such as clay, sand, and gravels, occur in considerable quantities; others, such as lignite, salt, and gas, have been somewhat exploited.

LIGNITE.

It has been stated that deposits of lignite occur in this area, but the lignite is found only in fragments and not in minable beds. These fragments are present in both the glacial till and gravel and some of them are remarkably clean and bright and burn readily with a flame.

In the drilling of wells pieces of lignite are sometimes encountered in the till or underlying gravel and give the idea that a layer of coal of considerable thickness has been penetrated. A case of this kind was reported in 1903 in sec. 19, T. 121 N., R. 64 W. Numerous holes were drilled in that section and the one north of it with a jet drill, and the lignite fragments appeared in such number as to give the impression that a layer of coal about 8 feet thick underlay several acres in that vicinity. An effort was made to sink a shaft to the deposit but it was abandoned at a depth of 60 feet on account of water. The top of the bed was estimated to be about 72 feet below the surface. From an examination of the material thrown out of the shaft and a comparison of the reports from different persons concerned in the work it seems clear that the top of the lignite was not below the glacial drift and that very probably the whole of the coal was in the drift itself rather than in the underlying shale.

There was a similar experience in sec. 19, T. 122 N., R. 64 W., and lignite was reported in the SE. ¼ sec. 7, T. 123 N., R. 64 W., about 35 feet below the surface. This was above the level of ground water and a shaft was sunk to it without difficulty. What had been thought by the driller to be a layer of coal 3 or 4 feet thick was found to be in reality a comparatively small block of coal which had worked downward before the drill for 2 or 3 feet. Similar deposits of lignite in some places in blocks weighing nearly a ton and in others an accumulation of several pieces close to each other, have been reported from localities outside of this area. The region is underlain by the Pierre shale, which was deposited in the sea; the materials of coal and lignite accumulate in swamps where there is luxuriant vegetation. It is, therefore, highly improbable that any lignite deposits of value were formed in this region. The probable explanation of all the facts thus far reported is that the lignite fragments have been brought hither by preglacial streams or by the glaciers from the lignite beds of the Laramie formation, which are so prominent in North Dakota and in South Dakota west of Missouri River. It is suggested that the accumulation of lignite northwest of Mansfield was probably connected with the ancient preglacial channel traced past St. Herbert as a former extension of Grand River, a stream which passes through the lignite region west of the Missouri.

CLAY.

Although the till is composed largely of clay, it is so mixed with gravel and calcareous matter that it has not been found useful for economic purposes, even in the manufacture of brick. Some of the alluvium near James River and the gumbo in the lake basins may prove to be of local value in brick making. The Pierre shale, which is exposed at several points, might be utilized for tiles or brick, especially if mixed with the loam that in some places is found not far away.

The cream-colored loam deposited in glacial Lake Dakota furnishes an inexhaustible supply of good material for making a handsome and durable brick. This loam was tested at Redfield several years ago, The bricks if burned moderately were of light-red color and soft, but if burned hard they took on a pleasing shade of light greenish gray. If overburned, the shade became dark, although the interior of the brick was still light colored. Valuable bricks have been made from this formation at Aberdeen for several years, and doubtless similar results could be obtained throughout the area of old Lake Dakota. The main difficulty is the absence of convenient fuel.

SAND AND GRAVEL.

Sand and gravel suitable for plastering and other ordinary purposes are present at many points, especially along the ancient channels and terraces and in the morainic knolls, also on the shores of Byron Lake. Many of the localities where sand and gravel pits have been opened are marked upon the areal geology maps. One of the most notable, though it is not marked, is at Twin Lakes, where a large quantity is easily accessible not far from the Chicago, Milwaukee and St. Paul Railway. Similar material occurs near Scatterwood Lakes, and the osars near Ferney, Conde, and Turton all furnish gravel and sand. The watercourses on the east slope of the James Valley, especially in the Aberdeen quadrangle east of Conde and Verdon, abound in gravel deposits. Near Aberdeen the old delta of Foot Creek furnishes large quantities of gravel and sand. Where the railroad crosses a broad old channel in the southwest corner of Fountain Township there is an important gravel pit, and similar pits could be opened at many points along these ancient channels. The quality of the gravel and sand is depreciated in some places by the abundance of shale pebbles.

SALT.

Salt is not found in workable quantities anywhere in this region, but it appears as "alkali" in certain areas. Its source is originally from the Pierre shale or from the till, which is largely composed of that formation. Some wells contain salty water supplied from sands in the till or under the till, or from the Pierre shale, especially in places where the circulation is slow. Draws and ravines, particularly those in shale, usually show scattered salt patches; there are also basins, some of considerable extent, in which large areas are covered with an incrustation of salt. Salt Lake is one of these basins, and there is another of similar character in the section east of Lords Lake. There appears to have been considerable deposition of salt in shallow lagoons along the west side of old Lake Dakota, for in a strip a mile or two wide running northward from Northville shallow wells usually contain waters too saline for ordinary uses.

GAS.

Gas has been reported in wells at many widely distributed localities in this area. The largest volume was struck at Ashton in 1881, at a depth of 66 feet, just below the till, where it had evidently accumulated by leakage from below. Another supply, struck at 89 feet, had a pressure of 46 pounds and was piped and used for heating and lighting a hotel and a large store through the winter of 1885-86. Similar supplies were found at a depth of 75 feet on a farm 2½ miles south and at a depth of 160 feet 2 miles southeast of Ashton. Gas was reported at a depth of 66 feet about 7 miles southeast of Ashton, but it proved not to be inflammable. In several wells 3 to 5 miles north of Ashton gas was struck at depths of 180 to 200 feet. In sinking the deep artesian wells at Ashton additional supplies of gas were found at a depth of 650 feet.

Several years ago gas was obtained at a depth of 320 feet in sec. 29, T. 121 N., R. 66 W., and was for a short time utilized for cooking. In 1905 gas was found in drilling a well in the NE. ¼ sec. 32, T. 122 N., R. 65 W. The depth was uncertain, for the gas was not observed until the drill had been put down to 540 feet and then drawn back to about 280 feet. The gas flowed vigorously for several hours, but further drilling did not develop additional supplies. Gas in notable quantities was found in sinking artesian wells in the SE. ¼ sec. 33, T. 122 N., R. 67 W., in the SW. ¼ sec. 25, T. 122 N., R. 68 W., and in a few other localities near by, but the depths from which it came were not determined.

It would appear from these occurrences that gas exists in thin lenses of sand in the Pierre shale, usually in association with salt water but not in amounts likely to prove valuable. Only one locality—Ashton—was reported as having shown gas below that horizon. The fact that it has been found higher up at a few other localities may be explained by the leaking of the gas upward to the bottom of the till.

It is possible that gas may be found in the Benton shale and in some of the lignite strata which have been found in the Dakota sandstone. It is probable, however, that there is no basis for expecting any considerable supply in the area under consideration. It is very doubtful whether any supply would be found by going below the Dakota sandstone, for in the greater part of the area that formation is known to be underlain by crystalline rocks which never contain gas or oil.

WATER RESOURCES.

Water is the most important natural resource of these quadrangles. It may be divided into surface and underground waters. The former include lakes, springs, and streams, which are described under the heading "Drainage;" the latter are derived from wells of various kinds.

UNDERGROUND WATERS.

SHALLOW WELLS.

Shallow wells are those supplied by water which has recently fallen on the surface and which can be reached without perforating an impervious layer. The most common source of supply for these wells is the water that lies near the surface and seeps through the upper portion of the till, or through silt and sand, toward a watercourse, wherever there are accumulations of coarse material that form conduits for it. It is to such subterranean streams that the water holes already mentioned owe their permanent supply. In many parts of this area the Cretaceous shales are so near the surface that but little water accumulates in the surface gravels and sands, and the wells yield but a meager supply. This condition prevails in an extensive area east of the moraine running north of Byron Lake. Along the James River valley shallow wells usually yield satisfactory water supplies both from the silt and from sand under the till. In many places, especially near old watercourses, practically inexhaustible supplies are found. Locally, however, the water is so contaminated with mineral salts from the till or from Cretaceous rocks below, that it is not suitable for domestic purposes. In the silt-covered area many wells from 20 to 30 feet deep afford excellent water, and in the bottoms of channels they are less than 10 feet in depth. The supply in these wells is generally not large unless they lie at a low level in some large basin or are connected with some important old channel. In the latter case it is usually inexhaustible.

The waters of the shallow wells vary greatly in composition. In many wells deriving their supply from the lower portion of the loam in Lake Dakota or from the thicker strata of sand and gravel, especially near the ancient channels or underneath the till, the water is very good. If, however, the water-bearing stratum is close to the underlying till or to the black shale of the Pierre below, the water may be highly charged with various soluble salts—in some wells sulphate of lime, in others sulphate of magnesia, sulphate of iron, sulphate of soda, and carbonate of soda—even to the extent of being not only unpalatable but injurious to health. Some waters are so strong as to injure stock.

TUBULAR OR DEEP PUMPED WELLS.

Under this head will be included the deeper wells in which a "tubular" or force pump is usually necessary to raise the water. Most of them are 100 feet or more in depth and the water in some rises nearly to the surface. The first water found in many of these wells is in the sand below the till, but this sand is not

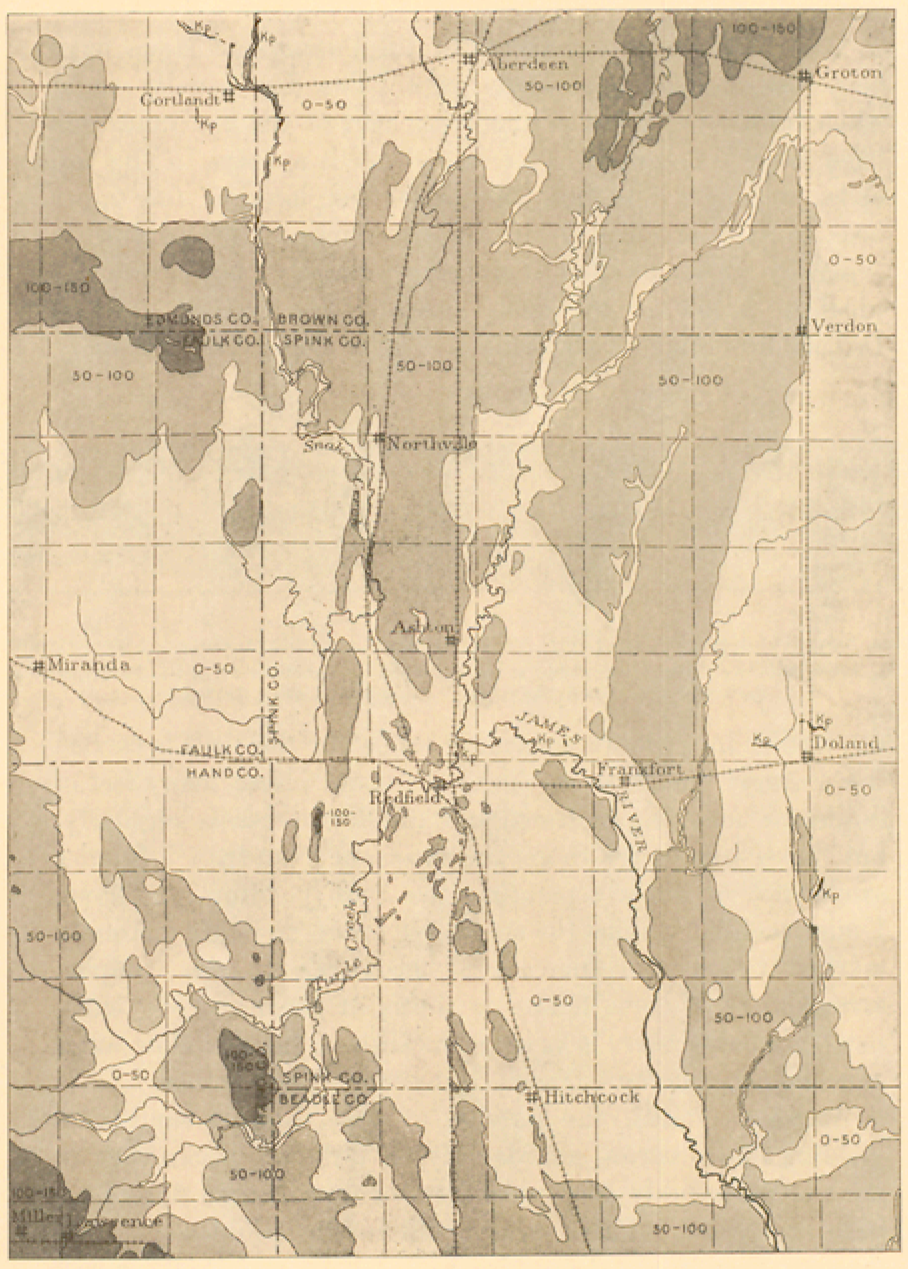


FIGURE 5.—Map of Northville, Aberdeen, Redfield, and Byron quadrangles showing approximate depth to base of the glacial till. Water can frequently be had from sands at the base of the till, and generally rises many feet in wells.

Small black areas, marked Kp, are outcrops of bed rock, Pierre shale. Depth to base of till is indicated by figures on shaded areas.

a common source of supply, especially to the south, at a distance from the broad deep preglacial channels. The reason for this is that in that area sand is less generally present between the till and the underlying Cretaceous shale and in some localities lies so high that the water has drained out of it. In some places at low levels the sand is so fine that it is very difficult to separate it from the water; in others, the water is so contaminated with soluble salts from the underlying shales that it is of no value. Another reason why the water from this horizon is not utilized, particularly in the Byron quadrangle, is because much more desirable water is found a little deeper in sandy beds in the Pierre shale. The sketch map, figure 5, shows approximately the depth to the base of the till in these quadrangles.

There are at least two water horizons in the Pierre shale. One in the southeastern part of the area lies at an altitude of about 1100 feet above the sea, except southeast of Hitchcock, where it rises to 1175 feet. It has been traced nearly to Mellette. The water is soft and has a slight salty taste which appears to become stronger farther north. This water stratum seems to be irregular, in many places being too thin to afford a useful supply. In a zone 4 to 6 miles wide, running northward and including Scatterwood, Salt, and Lords lakes, fine sand causes much trouble in the drilling of tubular wells. This sand may be partly due to a deep deposit of drift, but the depth of 200 to 300 feet to water sometimes reported suggests a local thickening of the upper sand stratum in the Pierre. This horizon has been found at a depth of about 125 feet at two or three points near Ashton, probably at 225 feet in the SE. ¼ sec. 11, T. 117 N., R. 67 W., at 156 feet in the NW. ¼ sec. 19, T. 116 N., R. 64 W., at 300 feet near Devoe; and at 320 feet in sec. 20, T. 121 N., R. 66 W. Its greater depth toward the west may be the reason why it has not been more frequently noticed there.

In the southeast corner of the Byron quadrangle, another and similar horizon lies about 100 feet lower, with sufficient head to raise the water nearly 1260 feet above the sea. This stratum will afford flowing wells near Byron Lake and in the vicinity of the James River valley.

The waters from most tubular wells are soft but have a salty taste, which in some wells is so strong that the water is not suitable for drinking purposes. The flows from the Benton horizons are soft and slightly saline, those from the upper bed more so than those from the lower.

ARTESIAN WELLS.

In drilling wells a water-bearing stratum in which the water is under pressure is frequently spoken of as a "flow," and the well is classed as artesian even if the pressure is not sufficient to raise the water to the surface. Artesian wells are numerous throughout these quadrangles and derive their supply mainly from the Dakota sandstone. (See figs. 6 and 7.) Some wells of minor importance draw water from the Benton and a very few from the Pierre and the glacial drift.

FLOWS FROM THE DRIFT.

Flowing wells supplied from the drift, though numerous in some portions of the James River valley, are very scarce in the area treated in this folio—in fact, only two have been reported. One, in the SE. ¼ sec. 2, T. 117 N., R. 60 W., Byron quadrangle, is only 20 feet deep and though barely overflowing it furnishes a copious supply. In sec. 9, T. 116 N., R. 67 W., in the Redfield quadrangle, a weak flow was found in the bottom of the valley at a depth of about 25 feet.

The pressure exhibited in the springs near Miranda strongly suggests that at lower levels in that region flows might be obtained from shallow wells in the sand underneath the till, or in the till itself.

FLOWS FROM THE PIERRE.

Water-bearing beds in the Pierre shale have already been mentioned under the heading "Tubular wells." One well on the east side of Byron Lake is reported as flowing from this source, and no doubt other flowing wells could be obtained from it in the basin of Byron Lake and along the valley of James River in the southern half of the Byron quadrangle. Several flowing wells reported from the Northville quadrangle appear to be exceptional. Two of them are in the SE. ¼ sec. 17, T. 121 N., R. 64 W., where good water in sufficient quantities for a stock farm is obtained from a depth of 300 feet. The water is hard, like that from most of the pumped wells in the vicinity, and has a temperature of 52° F. A considerable flow was struck at a depth of 129 feet in the SE. ¼ sec. 24, T. 118 N., R. 68 W., but it was cased off and a deep flowing well made. Another light flow was found in the southwest corner of sec. 4, T. 118 N., R. 67 W.

FLOWS FROM THE BENTON.

There are at least two horizons in the Benton formation which supply flowing wells of considerable importance. (See figs. 6 and 7.) These flows are weak and in consequence are often overlooked under present methods of drilling. Nevertheless, they have high pressures which indicate their durability, and here and there they may be copious enough for stock wells. Their water is soft, so that they are desirable for supplementing the stronger hard-water wells. Moreover, the stronger flows are now greatly taxed and they may eventually become so diminished that the higher flows will be valuable. The upper flow is believed to be afforded by the sandstone near top of the

Benton which appears along Firesteel and Enemy creeks a little below the Niobrara chalkstone in Davidson county. The variable volume of the flow in different localities corresponds to the variable thickness of this upper sandstone member of the Benton in its outcrops. This flow has been conspicuous in an area 2 or 3 miles wide and 20 miles long, extending from the center of Doland Township to the corner of Antelope Township, in the Byron quadrangle. Some wells, such as the Krantz well, 450 feet deep, and the Morris well, 500 feet deep, are supplied wholly from this source. The former flows 7 gallons a minute. The water is soft and although slightly salty, is not unpalatable. The temperature is 56½° F., and that of the water from the Morris well is 60°, whereas the water from the next lower flow is several degrees warmer. Some evidences of this horizon appear as far northwest as the vicinity of Mellette and Northville. On the James River plain the top of the Benton formation usually lies at a depth of 450 to 500 feet. At the Budlong well it is 360 feet above the main flow, at Ashton and Doland 395 feet, and a few miles northeast of Ashton 421 feet. Toward the southeast it is believed to lie about 300 feet below the surface, or 420 feet above the main flow.

SE. ¼ sec. 31, T. 122 N., R. 61 W. That this water horizon should often be disregarded or overlooked in the hydraulic method of drilling is easily explained by the small volume of water it yields and the great depth at which it lies.

FLOWS FROM THE DAKOTA.

General statement.—The main supply of artesian water in this region is undoubtedly derived from the porous sandstone beds of the Dakota. (See figs. 6 and 7.) This formation is also the source of artesian water not only under much of eastern South Dakota but in a wide area in adjoining States. Its productiveness is due to five factors—(1) Its great extent, underlying most of the Great Plains from the Rocky Mountains eastward to about the ninety-fifth meridian; (2) its porosity; (3) its highly elevated western border, located in the moist region of the mountains and crossed by numerous mountain streams; (4) its extensive sealing along part of its eastern margin by the overlapping clays of the Benton, or, where these clays are absent, by the till sheet of the glacial epoch; and (5) the cutting of wide valleys, especially in South Dakota, by preglacial streams, so as to bring the land surface

they seemed to fall into two fairly distinct groups, a fact which may indicate that two sandstones are the main sources of supply in that portion of the James Valley. These water-bearing sandstones vary much in thickness and prominence in different localities. The upper one is usually from 2 to 6 feet thick and the lower from 2 to 18 feet and they are from 30 to 50 feet apart. The practice is to stop drilling in the upper stratum if sufficient water is obtained; if not, to go on to the second. The first flow is preferred because it is softer, cooler, and more palatable. A third flow has been reached in many wells, especially where a large supply of water or high pressure to be used for mechanical power was desired. Such are the Ashton mill well, the Glidden well, and most of the large wells that were sunk several years ago for irrigation and power purposes. The city wells have usually gone to the third stratum. The first and second strata are as a rule separated by shale of considerable thickness, but the shale is less prominent between the second and third. In the Aberdeen city well No. 4 a fourth thick stratum of sand was penetrated, which at a depth of 1200 feet yielded a large volume of water under a pressure of 240 pounds to the square inch. This deep stratum probably

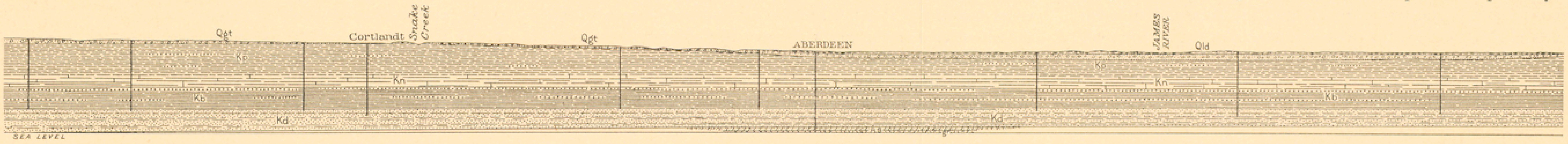


FIGURE 6.—Section across the Northville and Aberdeen quadrangles along the lines A-A and B-B on the areal geology maps, showing the artesian wells extending to the Dakota water-bearing sandstone.

Qgt, Glacial till; Qld, glacial lake deposits; Kp, Pierre shale; Kn, Niobrara formation; Kb, Benton shale; Kd, Dakota sandstone; As, Sioux quartzite; gr, granite.

Horizontal scale, 1 inch = 3⅓ miles. Vertical scale, 1 inch = 1750 feet.

At another horizon in the Benton formation is obtained the water popularly known as the "mud flow" because of the difficulty of separating the water from the very fine sand or mud mingled with it. It seems likely that this difficulty arises partly because the stratum is so thin that it is hard to prevent the adjoining shale from working with the water through the perforations in the pipe. This flow corresponds to what is sometimes called the "trickling" flow farther south. The water is soft and of excellent quality but is usually cased off because of its small volume. It appears to have high pressure and some day it may be more utilized. It lies at a depth of about 600 feet—that is about 700 feet above the sea, or 150 to 200 feet above the main flow in the Dakota sandstone. Traces of this flow are almost universal over this area, although only a few wells draw from it. In McFarland's well, in the NE. ¼ sec. 14, T. 112 N., R. 63 W., it is the main supply, the water being soft and very clear, with a pressure of 10 pounds and a temperature of 59.5° F., and flowing 9 gallons a minute from a 1¼-inch pipe.

Another well in the NW. ¼ sec. 15, T. 123 N., R. 64 W., has a depth of 800 feet and a good flow with temperature of 60° F. About 3 or 4 miles west of Mansfield this flow is struck at 800 feet; 3 or 4 miles northwest of Miranda it was found at depth of 850 feet; and at Mina or Cortlandt it is 875 feet below the surface. In the vicinity of Ashton, where there seems to be a low anticline running north and south, it is less deep, being struck at a depth of 750 feet about 3 miles northeast of Ashton and at 650 feet in Ashton. At Redfield it lies

below the pressure height or "head" generated by the elevated western border of the formation. From this sandstone also is derived a copious pumping supply over wide areas where the pressure is not sufficient to produce flowing wells. The Dakota sandstone underlies the whole area treated in this folio, and rests on quartzite or granite, the "bed rock" of well drillers. (See figs. 6 and 7.)

The artesian water maps show depths to the top of the Dakota sandstone, but in many areas the first strong flow lies somewhat deeper. In general the formation lies nearly horizontal but in the Byron quadrangle and the northeastern part of the Redfield quadrangle it is somewhat less regular in structure than elsewhere in the area. Its top is about 550 feet above the sea at the southeast corner of the Byron quadrangle, and declines to about 475 feet in the northwest corner, or to a depth of 810 feet below the surface. At Aberdeen it lies at an altitude of 370 feet, or slightly more than 900 feet below the surface.

The thickness and character of the Dakota sandstone have been described on a previous page. The flow usually comes when from 5 to 25 feet of the upper part of the first sandstone have been penetrated. In a few places it appears in the top beds; in others it is from 50 to 100 feet lower if the upper beds contain much clay or are very compact. The flow is generally so strong that it appears promptly, but where the pressure is low or the rock especially fine grained the first Dakota flow may be so feeble that it is overlooked. Usually

extends widely underneath the western and northern parts of the area treated in this folio and corresponds to the deepest waters at Pierre, Chamberlain, and Ellendale, outside of the area.

Volume of flow.—The largest flows are usually from the deepest wells. The amount of flow from a well depends on several conditions—the porosity of the rock yielding the water, the thickness of this rock, and the pressure. Most wells in these quadrangles have a diameter of 1¼ inches and the flow from them is from 10 to 80 gallons a minute; the average flow for the whole area is probably about 25 gallons. Many ¾-inch wells furnish from 5 to 15 gallons a minute. Two-inch wells, which are usually sunk to a deeper sandstone, flow from 80 to 150 gallons a minute, with an average of about 100 gallons. Three-inch wells, which are comparatively few, yield from 200 to 300 gallons a minute. A few of the largest wells are reported to have originally flowed as follows:

The pressure in other large wells is given in the table below. Some of the large wells have been allowed to run freely and the flow from most of them has greatly diminished; in some wells it has ceased entirely. There may be several reasons for diminution in flow, but they fall into three categories—(1) the development of leakage, (2) clogging, (3) too great a draft on the supply.

Subterranean leakage is especially common in old wells, mainly through perforation of the casing caused by rusting, so that water escapes into higher porous strata. In new wells it

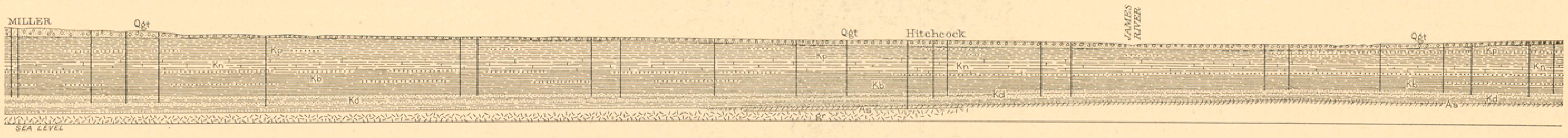


FIGURE 7.—Section across the Redfield and Byron quadrangles, along the lines C-C and D-D on the areal geology maps, showing the artesian wells extending to the Dakota water-bearing sandstone.

Qgt, Glacial till; Kp, Pierre shale; Kn, Niobrara formation; Kb, Benton shale; Kd, Dakota sandstone; As, Sioux quartzite; gr, granite.

Horizontal scale, 1 inch = 3⅓ miles. Vertical scale, 1 inch = 1750 feet.

at a depth of 750 feet. At Miller a thin layer of sandstone at a depth of 947 feet probably corresponds to the source of this flow. In a well in the SW. ¼ sec. 9, T. 113 N., R. 60 W., a small flow from sandstone in the Benton is reported at 665 feet, but the main flow is from the Dakota sandstone at 810 feet. In the Doland well a Benton flow was reported at 500 feet, and similar flows were found at the same depth in a well in sec. 28, T. 117 N., R. 60 W., 3 miles northeast of Doland, and in sec. 1, T. 115 N., R. 61 W. Other Benton flows reported are as follows: At 600 feet in the NW. ¼ sec. 28, T. 115 N., R. 62 W.; at 680 feet in the NE. ¼ sec. 11, T. 114 N., R. 60 W; at 830 feet 2 miles east of Rockham; at 750 feet in a well 2 miles southwest of Randolph; at 930 feet in the NE. ¼ sec. 24, T. 120 N., R. 68 W.; at 800 feet in two wells in the northwest corner of T. 120 N., R. 65 W.; at 675 feet at Northville; at 750 and 820 feet in an 886-foot well 2 miles northwest of Northville; at 600 feet 4 miles south-southwest of Werner; at 750 feet in the SW. ¼ sec. 19, T. 121 N., R. 62 W.; at 750 and 850 feet in the SE. ¼ sec. 24, T. 121 N., R. 62 W.; at 850 feet in the SW. ¼ sec. 20, T. 121 N., R. 61 W.; at 820 feet 2 miles east-southeast of Ferney; at 500 feet in the SE. ¼ sec. 22, T. 119 N., R. 63 W.; at 400 feet in the Baker well, in the NE. ¼ sec. 32, T. 119 N., R. 63 W.; at 800 feet in the Day well, in the SE. ¼ sec. 21, T. 119 N., R. 64 W.; and at 820 feet in the

the farther into the water-bearing sandstone the drill is carried the stronger the flow becomes. In some places many feet of sandstone may be penetrated and the flow increases regularly, but more commonly there are sheets of "hardpan" (harder sandstone) or shale separating the beds yielding the flows. Under such conditions the successive lower flows are distinctly marked by sudden increase of pressure. In the complex arrangement of these lenses or sheets of shale and of "hardpan," probably there is at many localities a maze of slow water currents and counter-currents, lying one above another.

As above stated, the number of water-bearing sandstones yielding flows varies considerably in different places, but in most of the notably deep wells three or four distinct flows have been recognized. Three were noted in the Glidden well and three or four in the Frankfort well, but in the Budlong well there are only two because the lower ones are cut off by an underground ridge of crystalline rock. As the "bed rock," or the lower limit of the water-bearing sandstones, declines toward the west and north from this ridge, the Dakota sandstone is more level and uniform, and probably the water-bearing strata are more uniform in those directions.

From a comparison of the pressure of representative wells in the Aberdeen quadrangle it was noticed that if reasonable allowance was made for the time the wells had been flowing,

may be caused by imperfect construction, such as bursting the casing, or imperfect connections, so that the water may rise outside of the casing from a stronger lower flow to a higher stratum. Such a leak may wash a channel of considerable size unless it is clogged by caving.

Diameter and flow of some large wells in Aberdeen-Redfield district.

	Diameter.	Flow per minute.
	Inches.	*Gallons.*
Ashton (mill well)	8	2000
Everett	4½	1000
Hassell & Myers, near Redfield	6	1900
Redfield, first	6½–4½	1260
Bonilla, sec. 29	4½	1435
Northville	9–6	1900
Beard, near Aberdeen	6–5	1060

Probably the most common cause of decline of flow is the choking of the well in some way, especially by fine, tightly packed sand gradually filling the water-receiving cavity. Most wells have perforated casing in their lower portion, corresponding to the thickness of the water-bearing stratum, so that the water is delivered to the well from the whole thickness of that stratum. Accordingly when sand accumulates in this perforated casing it diminishes the surface of inflow. Under such conditions relief may be sometimes obtained by letting down an iron rod by means of a wire and stirring up the sand so that it can be brought out by the flow.

Clogging of the well may also occur when the lower end of the pipe is fixed in the cap rock and the flows comes from a cavity in the water-bearing rock just below. In time the cavity may become filled with clay and the flow thus become checked or stopped. By this method of construction, also, stone or masses of clay may be washed into the end of the casing in such a way as to check or shut off the stream of water. This method has been so generally unsatisfactory that it is now rarely used.

Another way in which wells cased with perforated pipe may be clogged is by the entanglement of pebbles in the openings of the pipe, and diminution of flow may result from the washing of fine particles of sand or clay into the pores of the water-bearing rock adjacent to the casing. In some localities relief from these two conditions of clogging has been obtained either by quickening the flow so as to wash the particles out or, more effectively, by placing a powerful pump on the mouth of the well and reversing the flow of the water strongly, so as to force back the clogging material. Sometimes the flow can be quickened by the attachment of a siphon so as to lower the outlet.

Ordinarily a well may be nearly or quite closed without injury, but sudden opening is dangerous if the sand is easily started. When sand is running it is dangerous to close the well completely except perhaps by gradual stages occupying several days.

The exhaustion of supply by allowing large wells to run freely is clearly apparent at most localities, and the multiplication of wells must also deplete the supply.

Variation in flow.—The flow of wells varies somewhat with the pressure of the air—that is, according as the barometer is high or low—but this variation is noticeable only in the weaker wells, in which the flow diminishes or ceases when the barometric pressure is high. Sometimes changes in pressure also cause variation in the amount of sand in the water. This may be due to the fact that the more vigorous flow caused by diminished atmospheric pressure loosens the sand from the bottom of the well. In general it has been found that when sand is rising its flow may be stopped by checking the velocity of the stream at the valve. These fluctuations are frequently associated with the direction of the wind and the approach of a storm.

In some wells the flow gradually increases for a time after the well is first opened; this may be due either to the sand washing out, so that the resulting larger cavity gives an increased surface from which water is delivered to the well, or to the sudden breaking of an impervious stratum that separates the first flow from a deeper and stronger one.

Artesian pressure.—The "closed pressure" of artesian wells is much more variable than would be expected and there are problems connected with the variation which have not yet been satisfactorily solved. In general in eastern South Dakota the pressure declines to the southeast, toward the outcrop zone of the water-bearing strata. This is due to the fact that the water is moving toward outlets in the Dakota sandstone outcrops along Missouri and Big Sioux rivers. All the flows show this decline of pressure toward the southeast. Owing to the varying thickness of the water-bearing rock and to the irregular and incomplete separation of the strata by local impervious beds, so that there is perhaps communication between some of the different flows, the real course of the waters may be very crooked and complex, and consequently adjacent wells may exhibit great differences of pressure. The lower flows have the highest pressures because their leakage is much less free.

The blue contours on the artesian water maps show the altitude of head as indicated by the artesian pressure. As they have a downward slope to the southeast, they define a "hydraulic gradient." They are based on the strongest pressures noted of the upper flows from the Dakota sandstone. The hydraulic gradient in this area is not great because the pressures do not vary much after reasonable allowance has been made for leaks and clogging as already discussed. There is some discrepancy between the contours showing the "head" and the recorded pressures of wells in which the flow is from a lower sandstone where the pressure is higher. Moreover, these contours are drawn to represent present conditions rather than early ones. The original and present pressures in a number of wells in this area are given in the table in the next column.

Variations in pressure from place to place are indicated by the following facts: At Hitchcock the first town well is reported to have had a pressure of 150 pounds and the Glidden well, less than a mile away, of only 50 pounds. In the first well at Ashton the pressure was 60 pounds but in the mill well it is 150 pounds. This may be explained by the fact that in the mill well the lower flow is completely separated from the upper. The Budlong well has a pressure of 125 pounds; the Everett well, a mile and a half away and no deeper, showed 150 pounds. The two township wells near Bonilla though much alike in size and depth, had pressures of 50 pounds and 150 pounds.

Decline of pressure.—Decrease of flow attends diminution of pressure in any particular well, but great flow may attend slight

pressure and vice versa, for pressure is only one factor of the flow of a well.

Marked decline of pressure is the experience of many artesian wells, as shown in the table. For example, the Ashton mill well showed a pressure in 1895 of 150 pounds and in 1903 of 87 pounds, or perhaps, if surface leaks were stopped, 90 pounds. The first Redfield well showed 177 pounds in 1886, but in 1903 it had diminished to 75 or perhaps 100 pounds. The second well showed 87 pounds in 1903 and the same in 1904. The third well, sunk in 1903, showed 110 pounds at first and 106 pounds the following year. The asylum well at Redfield, drilled in 1901, had at that time a pressure of 125 pounds, and in 1904 a pressure of 75 pounds. At Aberdeen the first well opened is believed to have had a pressure of 180 pounds, but when other wells were opened in the vicinity the pressure fell considerably. The relation between different wells is shown by the fact that when the Aberdeen city well was opened the railroad well lost 15 pounds in pressure. But indications of permanent decline are also afforded by the railroad well. In 1901 the closed pressure of this well was 75 pounds; in 1903 it was about 65 pounds; and in 1905 it did not rise above 55 pounds.

The pressure of the second town well at Ipswich was 105 pounds in 1903; in 1905 it was 75 pounds. In Von Wald's well, in the NW. ¼ sec. 8, T. 122 N., R. 61 W., southwest of Groton, the pressure was at first 90 pounds; about a week later it was 95 pounds, and two years later 105 pounds; then, after the well flowed for a few months, it dropped to 90 pounds. The first increase of pressure may have been due to the enlarging of the receiving basin at the bottom of the well, so as to admit a stronger flow. A still more striking illustration is given by well No. 3 at Redfield. At first this well was allowed to run freely for two or three weeks with a 2½-inch opening. When it was closed for five minutes a pressure of 65 pounds was indicated. Then the flow was shut off except through a small outlet cock and after a few days when the flow was entirely shut off the pressure rose to 102 pounds, and in three days more to 108 pounds.

Pressures in representative wells in Aberdeen-Redfield district.

Location (Township N.; Range W.).	Depth (feet).	Pressure (pounds to the square inch).	
		Original.	Present (1903–1905).
NE. ¼ sec. 32, T. 118, R. 64	960		137½
NW. ¼ sec. 22, T. 116, R. 64	964		110
Redfield (recent)	920	(1903) 110	106
Redfield (old)	750–1030	(1886) 177	75+
Redfield, 1 mile northwest of	956	(1901) 125	75
Redfield, west of	967	87	87
SW. ¼ sec. 10, T. 115, R. 64	935		93
NW. ¼ sec. 9, T. 115, R. 64	930		102½
SE. ¼ sec. 28, T. 114, R. 66	956		132½
SE. ¼ sec. 2, T. 114, R. 66	1050		165
NE. ¼ sec. 11, T. 114, R. 66	1000±		109
SE. ¼ sec. 14, T. 114, R. 66	945		125
NE. ¼ sec. 26, T. 114, R. 65	940		42
NE. ¼ sec. 5, T. 113, R. 67	1070		53
SE. ¼ sec. 25, T. 113, R. 67	1100–1129	128	
NE. ¼ sec. 17, T. 113, R. 65	949		110
SW. ¼ sec. 14, T. 113, R. 65	955(?)		101
NW. ¼ sec. 15, T. 113, R. 64	1066	(1897) 53	
NE. ¼ sec. 29, T. 113, R. 64	1118	(1896) 175	
Miller	1105	(1886) 120	53
St. Lawrence	1070	40	
NE. ¼ sec. 2, T. 112, R. 66	892		135
NE. ¼ sec. 17, T. 112, R. 64	900		84
NW. ¼ sec. 4, T. 112, R. 64	875±	150	
Aberdeen (second or third flow; old)		(1882) 155	55
Aberdeen (fourth flow; recent)	1200+	(1904) 240	240
Aberdeen		(1890) 138	
NW. ¼ sec. 34, T. 123, R. 63	900±		103
NE. ¼ sec. 9, T. 123, R. 62	890+		57
NE. ¼ sec. 11, T. 123, R. 62	875		135
Chedi, T. 123, R. 61	1022		150
NE. ¼ sec. 33, T. 123, R. 61	850		73
SW. ¼ sec. 7, T. 123, R. 60	904	(1891) 80	
Groton	951?	(1889) 135	
NE. ¼ sec. 8, T. 122, R. 62	910	130	
NW. ¼ sec. 1, T. 122, R. 62	920		104
SE. ¼ sec. 21, T. 122, R. 62	900–950		102
NW. ¼ sec. 8, T. 122, R. 61	910	90	90
NE. ¼ sec. 4, T. 122, R. 61	930		117
SW. ¼ sec. 11, T. 122, R. 61	900–953		42
SE. ¼ sec. 2, T. 122, R. 60	1025		88
NW. ¼ sec. 11, T. 122, R. 60	983		96
SE. ¼ sec. 35, T. 122, R. 64	905		80
Warner, T. 121, R. 64	956		80
NE. ¼ sec. 2, T. 121, R. 63	940		136
NE. ¼ sec. 10, T. 121, R. 63	900+		134
NW. ¼ sec. 7, T. 121, R. 62	900+		140
NE. ¼ sec. 19, T. 121, R. 62	900+		137
NW. ¼ sec. 8, T. 121, R. 61	875±		82
SW. ¼ sec. 33, T. 121, R. 61	900		75
SW. ¼ sec. 9, T. 121, R. 61	930		82
SW. ¼ sec. 13, T. 121, R. 61	897		91
SE. ¼ sec. 15, T. 121, R. 61	912		76
SE. ¼ sec. 17, T. 121, R. 60	935		140
SE. ¼ sec. 2, T. 121, R. 60	1064		56
East central part sec. 25, T. 121, R. 60	1032		120
SW. ¼ sec. 5, T. 120, R. 60	950		100

Pressures in representative wells in Aberdeen-Redfield district—Continued.

Location (Township N.; Range W.).	Depth (feet).	Pressure (pounds to the square inch).	
		Original.	Present (1903–1905).
NW. ¼ sec. 28, T. 120, R. 60	1000		60
Conde	940–1025	(1890) 130	
SE. ¼ sec. 4, T. 120, R. 61	889		120
SW. ¼ sec. 15, T. 120, R. 61	880		100
SE. ¼ sec. 31, T. 120, R. 62	940		135
SW. ¼ sec. 14, T. 120, R. 63	920		68
SW. ¼ sec. 20, T. 120, R. 63	941		126
NW. ¼ sec. 33, T. 120, R. 63	960		107
NW. ¼ sec. 34, T. 120, R. 63	970		126
SW. ¼ sec. 28, T. 120, R. 63	900+		45
Mellette		165	
NW. ¼ sec. 7, T. 119, R. 63	880		136
SE. ¼ sec. 3, T. 119, R. 62	870		137
SE. ¼ sec. 7, T. 119, R. 62	875+		133
NW. ¼ sec. 18, T. 119, R. 62	925		107
NW. ¼ sec. 10, T. 119, R. 63	955		135
NE. ¼ sec. 16, T. 119, R. 63	930		135
SW. ¼ sec. 19, T. 119, R. 63	930	(1891) 153	
SW. ¼ sec. 20, T. 119, R. 63	930+		132
SE. ¼ sec. 22, T. 119, R. 63	958	(1890) 141	
SE. ¼ sec. 30, T. 119, R. 63	924		130
SE. ¼ sec. 28, T. 119, R. 63	925		133
SE. ¼ sec. 23, T. 119, R. 64	993	(1891) 135	
Cortlandt	919	(1903) 105	40
NE. ¼ sec. 1, T. 123, R. 66	(?)		100
NE. ¼ sec. 31, T. 122, R. 66	1050		93
SE. ¼ sec. 32, T. 122, R. 66	1060		66
SE. ¼ sec. 33, T. 122, R. 66	1030		95
SW. ¼ sec. 22, T. 122, R. 66	1000		40
NE. ¼ sec. 32, T. 122, R. 65	1020		91
NE. ¼ sec. 2, T. 122, R. 66	1070		72
Center sec. 19, T. 122, R. 64	931		132
SE. ¼ sec. 8, T. 121, R. 67	1050		93
NW. ¼ sec. 32, T. 121, R. 67	1125	115	89
NE. ¼ sec. 32, T. 121, R. 66	967		76
NW. ¼ sec. 6, T. 120, R. 66	1066		53
NE. ¼ sec. 13, T. 120, R. 65	920		84
NE. ¼ sec. 3, T. 119, R. 67	1000		44
SW. ¼ sec. 1, T. 119, R. 67	980		70
SE. ¼ sec. 25, T. 119, R. 67	1040		101
NW. ¼ sec. 17, T. 119, R. 66	984		131
Northville	1053	(1893?) 156	93
SW. ¼ sec. 9, T. 119, R. 64	(?)		114
Ashton	1003	(1895) 150	87
Center sec. 10, T. 114, R. 63	890		116
NW. ¼ sec. 8, T. 117, R. 63	899		120
SE. ¼ sec. 27, T. 117, R. 61	900		124
Doland (?)		(1889) 122	110
NW. ¼ sec. 3, T. 116, R. 62	968	140	123
SW. ¼ sec. 31, T. 115, R. 62	(?)		137
NW. ¼ sec. 28, T. 115, R. 62	891–936		130
NW. ¼ sec. 7, T. 115, R. 61	840	87	
NW. ¼ sec. 27, T. 115, R. 61	450		7½
Hitchcock	953	(1885) 154	
NW. ¼ sec. 11, T. 113, R. 64	(?)		118
SW. ¼ sec. 23, T. 113, R. 63	912		105
NW. ¼ sec. 23, T. 113, R. 63	988		125
NE. ¼ sec. 10, T. 113, R. 61	725		60
NW. ¼ sec. 2, T. 112, R. 63	788		65
SW. ¼ sec. 2, T. 112, R. 63	880		87
NE. ¼ sec. 14, T. 112, R. 63	600		10
NE. ¼ sec. 11, T. 114, R. 60	835		75
SE. ¼ sec. 32, T. 114, R. 63 (Glidden)	1035	50	
SW. ¼ sec. 18, T. 114, R. 62	820		125
NE. ¼ sec. 30, T. 114, R. 62 (Everett)	840	150	
SW. ¼ sec. 5, T. 114, R. 62	835		117
NW. ¼ sec. 19, T. 114, R. 61	800		109
SE. ¼ sec. 18, T. 114, R. 60	860		85

The table given above shows changes in pressure of wells so far as recorded. These changes have considerably affected the location of the pressure contour shown in blue on the artesian water maps. For instance, the 1600-foot contour, based on the present pressures in the first Dakota flow, shows a marked bend to the north up James River, whereas a line based on the former pressures would run straight across the valley. This local decline of pressure appears most marked in the vicinity of the older and larger wells, or where wells have been unusually multiplied.

Decline of pressure may be due to various accidents, such as the rusting of pipes and the consequent increase of leakage below the surface. Sometimes it is only apparent owing to an overestimate of the original amount or to the interference of neighboring wells, so that the real closed pressure may not now be obtained unless all the wells are closed at the same time.

The most important cause of decline however, is local exhaustion of the water supply. This is shown by the following facts:

1. A large well will decrease more rapidly in flow and pressure than a small one. In certain city wells where water is used freely in the day time and not at night the pressure is perceptibly greater in the morning than in the evening and it is greatly lowered temporarily when a very large amount of water is used for a fire.

2. The decline will be most rapid at first, and after a few years, with diminished velocity of flow due to lower pressure, an equilibrium of pressure may be reached. Such a point will be first reached by a small well.

3. The larger the well the more rapid and far-reaching will be its influence on surrounding wells.

4. The less numerous and the farther apart these wells are the less rapid will be the decline of pressure and the larger will be their ultimate discharge.

Well notes.—The numerous wells in and about Aberdeen have furnished large volumes of water, mostly for domestic use, and have afforded power for mills and other machinery. In the first or railroad well the main flow was in sandstone extending from 940 to 955 feet. This was overlain by alternating limestones, sandstones, and shales from 895 to 940 feet, with a small flow at 925 feet. The great mass of shale from 100 to 895 feet was parted by limestone extending from 515 to 530 feet. In city well No. 1 a 330-gallon flow was found at 904 to 918 feet and a small flow at the top of the Dakota at 879 feet. The second city well, which was far south of the other, passed through 6 feet of hard cap rock from 940 to 946 feet, and then penetrated 46 feet into sandstone yielding an 825-gallon flow from a 4-inch casing. In the third city well the Dakota sandstone was entered at 890 feet and although hard at the top afforded flows at 901 and 926 feet. The main flow is from a sandstone extending from 1016 to 1066 feet, the bottom of the well. Shale was found from 941 to 966 feet and from 984 to 1018 feet. A fourth city well, sunk in 1893, is reported to have penetrated quartzite from 1211 to 1257 feet and granite from 1257 to 1290 feet. It did not develop a satisfactory water supply below the horizons at which water had been found in the former wells. The log is given in figure 8.

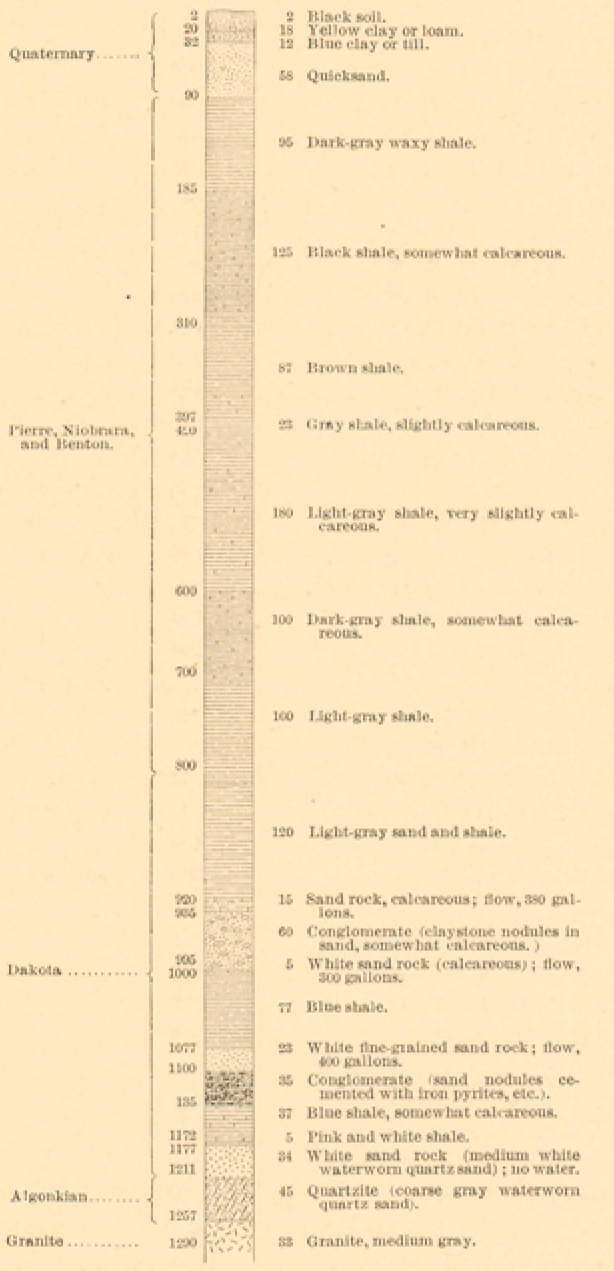


FIGURE 8.—Log of Aberdeen city well No. 4.

In 1904 a boring was made at Loyd street and Twelfth avenue and at a depth of 1200 feet obtained a 500-gallon flow with the unprecedented pressure of 240 pounds and a temperature of 71°. The failure to obtain this lower flow at high pressure in well No. 4 is difficult to understand.

In the Beard well, 2 miles east-southeast of Aberdeen city well No. 4, the Dakota sandstone was encountered at a depth of 940 feet, extending for 20 feet and yielding a light flow. Below this were 37 feet of shale and, under 3 feet of cap rock, 50 feet of sandstone which yielded a 1060-gallon flow to a 5-inch casing, probably corresponding to the second flow at Aberdeen.

At Groton the first town well had a large flow from sandstone at 925 to 960 feet. In the second well the sandstone was penetrated from 889 to 922 feet. At the Adams well, in sec. 8, T. 123 N., R. 60 W., the first flow was obtained at 906 feet, and a 100-gallon flow was found in sandstone extending from 917 to 977 feet.

There are several deep wells in the vicinity of Redfield. The first city well is 4½ inches in diameter and has a flow of 1260 gallons from sandstone extending from 941 to 964 feet. The small flow at 750 feet was in a 1-foot layer of sandstone in the Benton. In the new well in the southern part of town the main flow comes from a depth of 920 to 930 feet. At the asylum, about one-half mile farther northwest, a strong flow was found at about the same level as in the city well, but on drilling deeper a dark medium-grained granite was struck at 1080 feet and penetrated for 10 feet.

In the Hassell & Myers well, 1 mile north of Redfield, a good flow was found at 860 feet and another at 950 feet. This well was deepened to 1030 feet. East of Redfield good flows have been obtained at depths of 858 and 895 feet.

The record of the Northville mill well is given in figure 9.

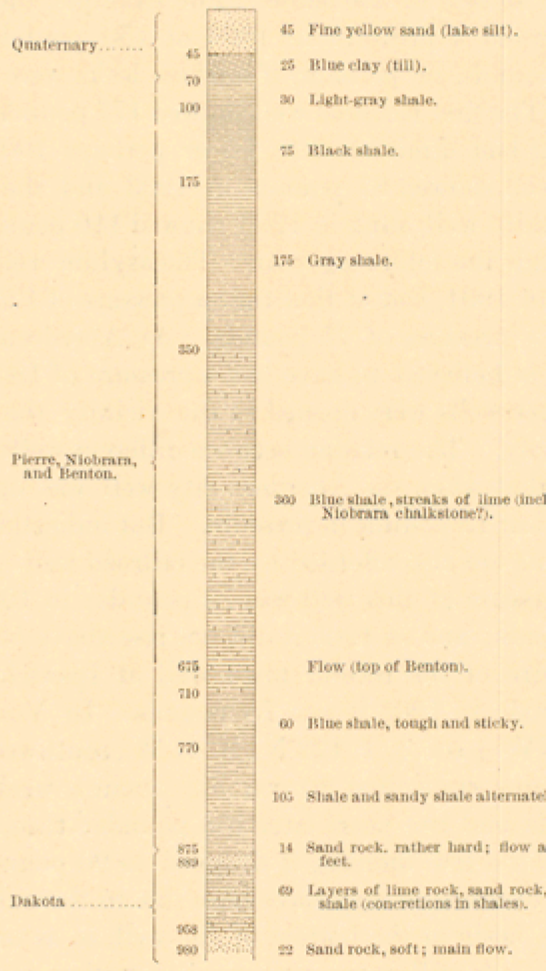


FIGURE 9.—Log of Northville mill well.

The main flow is from the sand rock at 958 to 980 feet. Weak flows were reported in the overlying beds at 675 and 875 feet, and a strong flow of gas at a depth of 135 feet. The 675-foot flow probably is from the Upper Benton and the 875-foot flow from the top of the Dakota. In the Hunter well, 2¼ miles east-southeast of the mill well, the first and main flow was obtained at a depth of 904 feet.

There is a group of large wells between Mellette and Ashton. The record of the Day well, which is representative, is given in figure 10. This is a 4½-inch well with a 1300-gallon flow from a

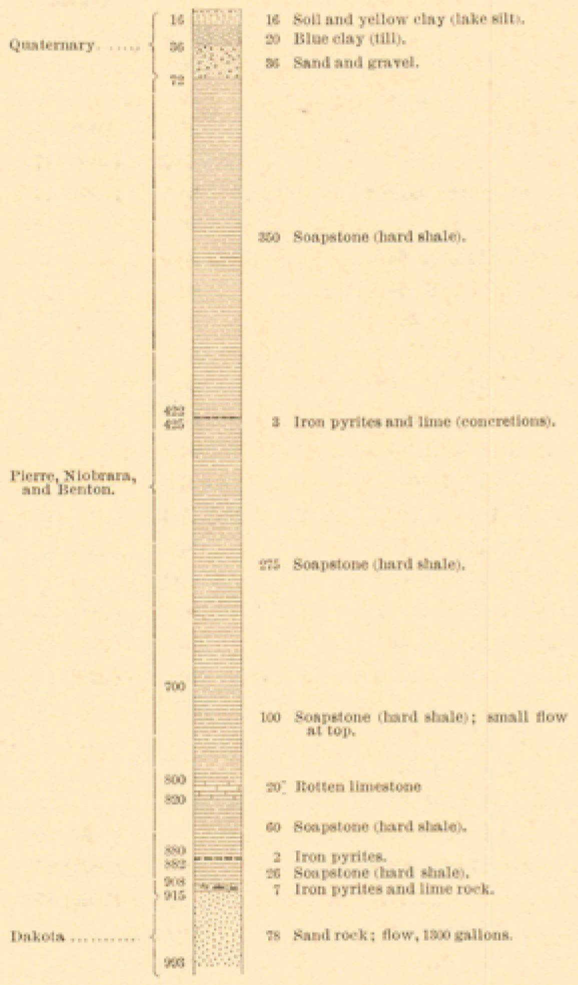


FIGURE 10.—Log of Day well, southeast corner sec. 23, T. 119 N., R. 64 W.

sandstone extending from 915 to 993 feet, overlain by 7 feet of hard cap rock. The Bird well is a 3-inch boring 1½ miles east of the Day well. It is 915 feet deep; from 902 feet to the bottom it passed through sandstone which yielded a flow of 670 gallons a minute. The sandstone was overlain by 2 feet of conglomerate, above which was an 8-foot layer of limy rock of considerable hardness. The Baker well, in sec. 32 of the same township, reached a 7-foot bed of cap rock at 864 feet and penetrated 49 feet of sandstone to a depth of 920 feet. The flow was 1000 gallons from a 3-inch casing and began at 871 feet. The first Brunn well, in sec. 22, T. 119 N., R. 63 W., reached sandstone at 925 feet, under a 2-foot cap rock, and was bored to a depth of 958 feet. It is a 3½-inch well and yields a 60-gallon flow. Small flows were reported at 500 and 880 feet in the shale. The 4½-inch well at the mill at Mellette had a log similar to those above described, with sandstone from 877 to 920 feet that yielded a small flow at 884 feet and a 1215-gallon flow at 910 feet. A 10-foot bed of sandy limestone was reported from 811 to 821 feet and conglomerate from 841 to 844 feet. The railroad well at Ashton has a 4½-inch casing and yields a 100-gallon flow from the sandstone at 900 to 915 feet. The "yellow limestone" reported from 830 to 860 feet may be a compact sandstone. A sandy shale at 650 to 660 feet yielded a small flow, and another small flow was found at 795 feet. Apparently in this well the Dakota begins with the sandy shale at 796 feet, and this changes to a water-bearing sandstone in wells a short distance farther north. The well at the mill in Ashton is 1003 feet deep and yields a larger flow than the railroad well.

The record of the first Frankfort well is given in figure 11.

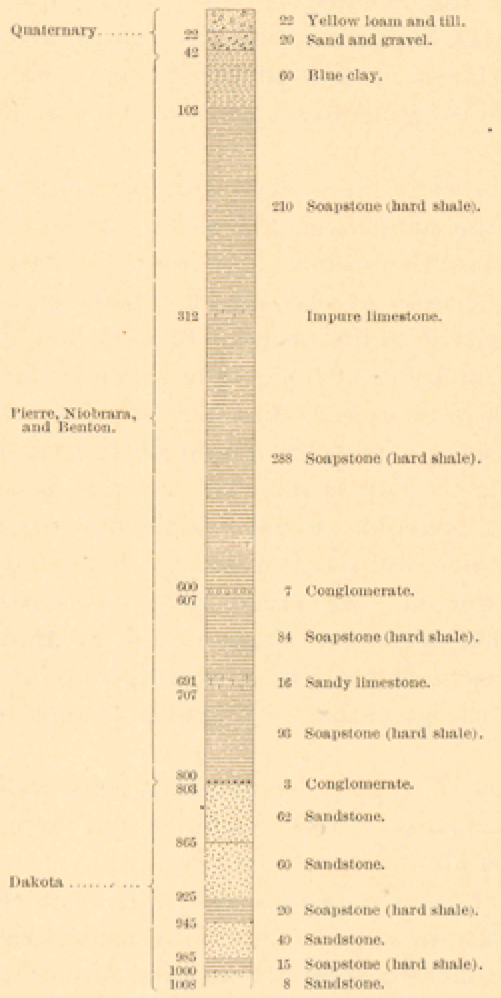


FIGURE 11.—Log of Frankfort well No. 1, NE. ¼ sec. 7, T. 116 N., R. 62 W.

This well yields a large flow from thick sandstone beds occurring at intervals from 803 feet to the bottom, at 1000 feet. The Doland town well is 4½ inches in diameter and obtains a 370-gallon flow in sandstone extending from 880 to 895 feet. A small flow in a Benton sandstone bed was recorded at a depth of 550 feet.

A group of deep wells about Hitchcock presents considerable variation in records and results. The Hitchcock well penetrated sandstone from 920 feet to the bottom at 953 feet. The first 4 feet of this sandstone was hard cap rock and this was succeeded by several feet of shaly sandstone before the strong flow began at a depth of 950 feet. The Glidden well, half a mile northwest of Hitchcock, had the record given in figure 12.

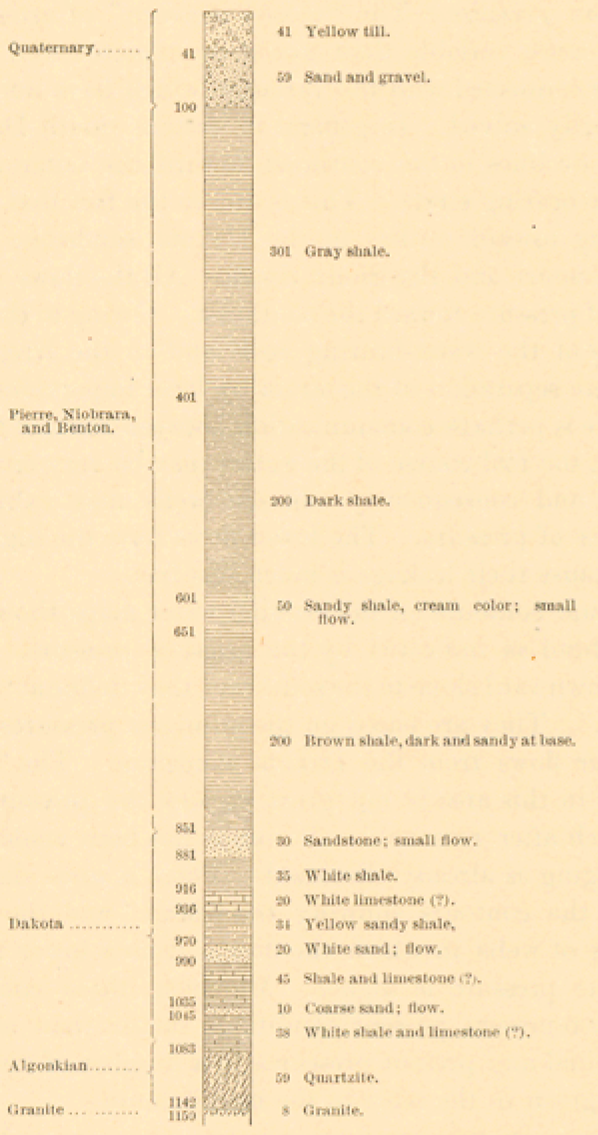


FIGURE 12.—Log of Glidden well, SE. ¼ sec. 32, T. 114 N., R. 63 W.

It entered the Dakota sandstone at a depth of 851 feet and although the bed was 30 feet thick only a small flow was obtained. A strong flow was found at 970 to 990 feet and another at 1035 to 1045 feet which amounted to 650 gallons a minute from a 4½-inch casing. In the Everett or Cavanaugh well, in the NE. ¼ sec. 30, T. 114 N., R. 62 W., the Dakota sandstone began at a depth of 777 feet and yielded flows at 782 and 876 feet amounting to 1200 gallons. A small flow from an upper Benton bed was found at 468 feet. The Budlong well, in the SW. ¼ sec. 18, T. 114 N., R. 62 W., had the log given in figure 13. It afforded a 75-gallon flow from a 4½-inch casing at

790 feet and a 100-gallon flow at 810 to 815 feet; this flow was much less than expected. A 10-gallon flow in a sandstone bed of the Benton was found at 408 feet.

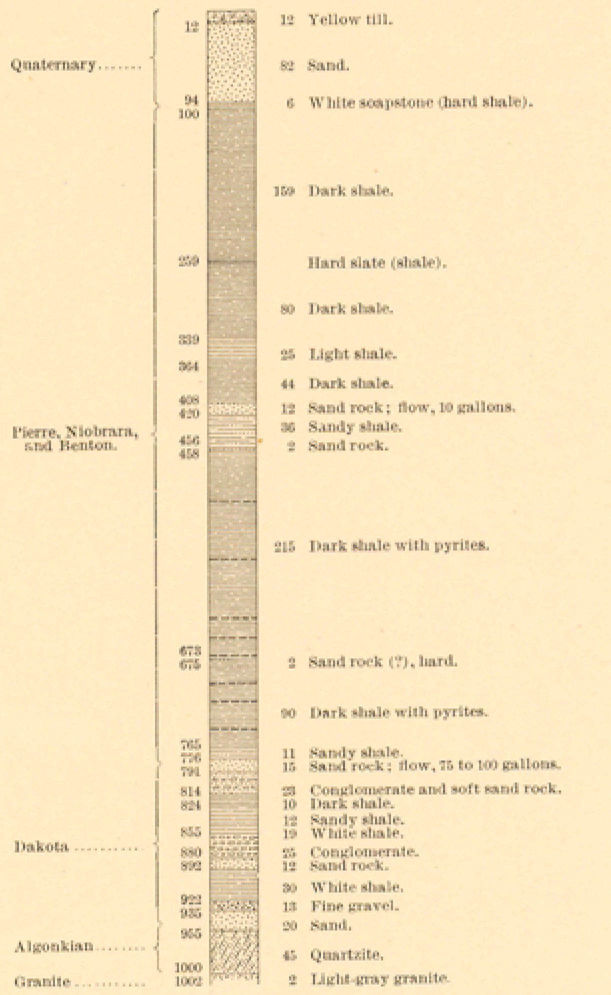


FIGURE 13.—Log of Budlong well, SW. ¼ sec. 18, T. 114 N., R. 62 W.

The record of the second city well at Miller is given in figure 14. The record of the first well differs somewhat in showing

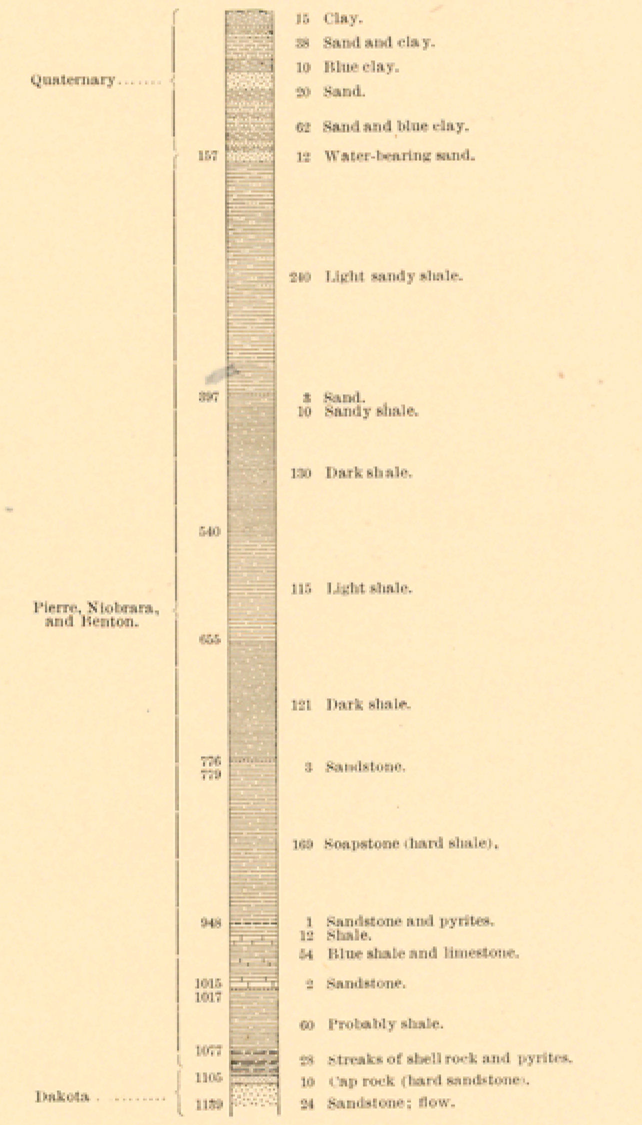


FIGURE 14.—Log of Miller well, city well No. 2.

hard sandstone and pyrites from 930 to 975 feet and then 130 feet of shale, under which, below 3 feet of cap rock, was 40 feet of sandstone yielding a 480-gallon flow. This well clogged up and the second well obtained a similar flow. In both the casing rests on the cap rock at a depth of 1105 feet.

QUALITY OF WATER.

The water from the Dakota sandstone is usually soft in the upper flows but increases in hardness in the lower flows. In some wells the uppermost flow yields moderately soft water at first but the hardness increases as draft is made on the supply. The water from the deepest flow at Aberdeen in the Twelfth avenue well was very hard, in strong contrast with that of the higher flows. According to an analysis by F. A. Norton, it contains 570 parts per million of hardness calculated as $CaCO_3$ and 500 parts of this, or nearly all, is present as permanent hardness. The total salts compare closely in amount with those of the Aberdeen city well No. 4, 1290 feet deep, sunk in 1893; but as the flows in that well were not kept separate the composition shown in the table is, except as to hardness, that of a first flow water. The analyses in the following table show the composition of waters from representative wells. The uniformity in total solids is a notable feature.

Analyses of artesian water in Aberdeen-Redfield district.

[Parts per million.]

Constituents.	1.	2.	3.	4.
Silica (SiO_2)	30	9.8	37	11
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	10	9.4	15	8.8
Calcium (Ca)	178	35	288	34
Magnesium (Mg)	26	23	81	19
Sodium and potassium (Na+K)	440	635	304	635
Lithium (Li)	Trace.	Trace.	Trace.	Trace.
Carbonate radicle (CO_3)	38	117	337	126
Sulphate radicle (SO_4)	1,285	1,118	589	1,061
Chlorine (Cl)	72	144	388	159
Total solids by evaporation	2,078	2,090	2,036	2,054
Constituents.	**5.**	**6.**	**7.**	**8.**
Silica (SiO_2)	10	8.8	9.2	------
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	7	16	------	3.8
Calcium (Ca)	9.2	267	135	8.4
Magnesium (Mg)	15	88	54	3.4
Sodium and potassium (Na+K)	716	261	456	671
Lithium (Li)	Trace.	Trace.	Trace.	------
Carbonate radicle (CO_3)	166	92	127	166
Sulphate radicle (SO_4)	1,020	1,257	1,159	748
Chlorine (Cl)	210	97	91	310
Total solids by evaporation	2,153	2,089	2,039	1,910

1. Twelfth avenue, Aberdeen. 2. City well No. 4, Aberdeen. 3. Northville. 4. Redfield. 5. Doland. 6. Hitchcock. 7. Miller. 8. City well, Mellette.

Analysis 1 by F. A. Norton, assistant chemist, South Dakota Agr. Coll., 1904; 2 to 7 by J. H. Shepard, Bull. South Dakota Agr. Coll. No. 41, 1895; 8 by G. N. Prentiss, chief chemist, Chicago, Milwaukee and St. Paul Railway Co.

SOILS.

The soils of these quadrangles have not been studied in detail and only the more prominent features are noted here. They may be divided into stony soils, sandy soils, clayey soils or "gumbo," and loam.

Stony soils.—Stony soils are present only in small areas, mainly on the rougher surfaces of the moraines and along the edges of terraces bordering the principal streams. The morainic areas usually carry bowlders on the surface, most of which are removed in preparing the land for cultivation.

Bowlders and pebbles are thickly strewn along the terraces and in some places form thick bowlder beds which offer a serious hindrance to cultivation. The slopes of many of the steeper bluffs along the streams are covered with bowlders that have either slipped down from the stratum capping the terrace or have stranded in time of flood. In some places the bowldery strata have offered such resistance to erosion, which took place in part at least before the close of the glacial epoch, that they have been cut away from the adjacent upland so as to form ridges, some of which suggest osars. An example of this sort may be found on the east side of James River for 1 or 2 miles on each side of the Beadle-Spink county line.

There are some nearly level bowldery areas a few square miles in extent on the plain southeast of Crandon, and smaller scattered areas occur a few miles northwest and west of La Delle. Some rougher areas lie along James River and the deeper ancient channels at many points in the Byron quadrangle.

Extensive bowlder areas constitute the surface of much of the eastern part of T. 113 N., R. 62 W. (Pleasant View Township), on the bottoms and sides of old shallow channels and particularly in low ridges, some of which are thickly covered with bowlders. In places the bowlders have been gathered into numerous heaps which reach the size of haystacks. Most of the higher portions of the osars have gravelly surfaces. There are also extensive gravelly surfaces on the old delta of Foot Creek southwest of Aberdeen.

Sandy soils.—Sandy soils are of comparatively meager extent in the Byron quadrangle, being confined to the broad channels west and north of Hitchcock and to very small areas east of James River in the northeastern part of Cornwall Township. In the Redfield quadrangle sandy areas are to be found near Cottonwood Lake and Twin Lakes, in portions of the Pearl Creek valley, and particularly on the plain northwest of Tulare. In the Aberdeen quadrangle a few small sandy areas lie along the east side of the region occupied by glacial Lake Dakota, and more extensive low dunes occur about 4 miles south of Aberdeen in secs. 1 and 2, T. 122 N., R. 64 W. Similar sandy areas lie near Athol. In the Northville quadrangle there are small sandy areas in the vicinity of the Scatterwood Lakes and in the channel farther south.

In all these localities the sand is at present so largely mixed with organic matter as to form a fertile soil, and but little of it is affected by the wind.

Clayey soils.—The most common clayey soil in this region is in the main a dense, fine, drab-colored clay, usually of a dark tint though in some places light. It is soft and very sticky when wet, and intensely hard and seamed with cracks when dry. It almost completely prevents the sinking of rain water into the ground and the rising of moisture from the subsoil in time of drought. While it is damp grasses may flourish on it, but they wither when the dry season comes. As a rule it consists mostly of clay, but has more or less fine sand mingled with it. Such soils are found in the bottoms of lake basins, along some of the alluvial flats near the principal streams, in the ancient channels where the drainage is poor, and in some depressions in the surface of the silt deposits of the glacial Lake Dakota. In exposures of the Pierre shale there are also some rather small areas of a nearly pure black clay, which has the appearance and character of the extensive gumbo deposits west of Missouri River. The term "gumbo" is popularly applied to all distinctly clayey soils.

Loamy soils.—Loamy soil occupies the wide area shown as lacustrine silt on the areal geology maps. It is of great fertility and has the further good quality of an even surface. It possesses a medium degree of porosity, which affords good natural underdrainage in wet seasons and a ready rise of ground water toward the surface in times of drought. This advantage is diminished on some of the higher lands by the occurrence of a thin hardpan or clayey layer a little below the surface, but this feature is not general, and is lacking in the vicinity of the broad channels that traverse the area. There are also, in some of the basins where water stands, patches of clayey soils which are commonly called gumbo. The soils on the till and morainic areas that are not stony are usually made up of yellow loam with a few small pebbles intermixed.

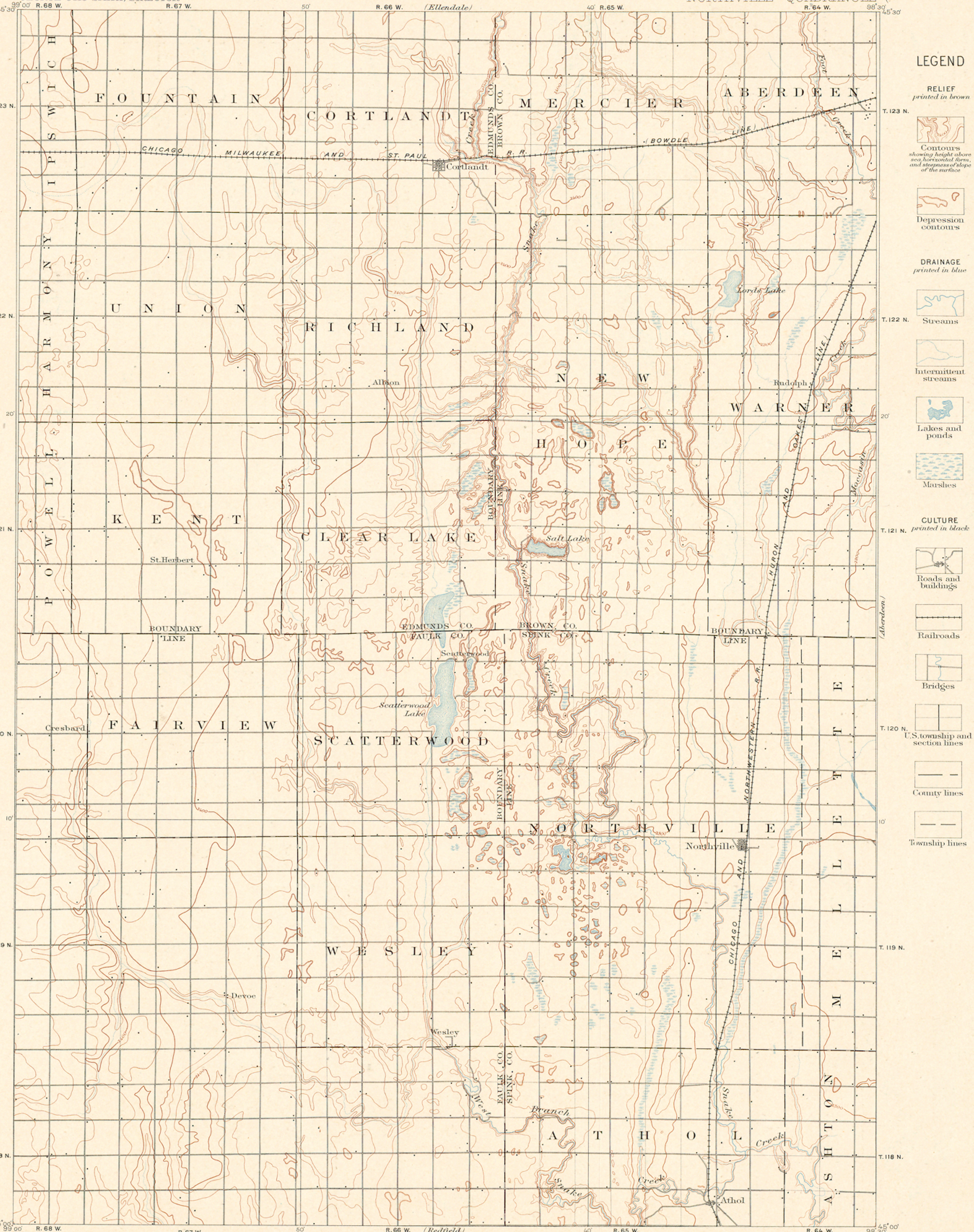
"Alkali."—In morainic strips, to a less degree on the till, and still less commonly on the loamy plain, the various soluble salts derived from the Quaternary deposits collect in depressions of the surface. When moisture is abundant they are invisible, and do not seriously interfere with the growth of vegetation—in fact, they even render it more rank in places, this effect being particularly noticeable on cereals. During the dry season, however, the salts appear on the ground in great abundance in the form of white, efflorescent incrustations which kill vegetation or prevent its growth altogether. Many such barren or poisoned spots, however, are so small that ordinary cultivation is sufficient to mingle the salts with the surrounding soil so that they produce no injurious results. In some areas where the soluble salts are so abundant that this treatment is not effective drainage will aid greatly, and if this is not practicable the incrustations may be scraped off from time to time and either dumped into a well or pit or stored as fertilizer for looser or more sandy soils.

March, 1906.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

SOUTH DAKOTA
NORTHVILLE QUADRANGLE (Columbia)



Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Topographer in charge.
Control by Geo. T. Hawkins.
Topography by D.C. Harrison and H.S. Wallace.
Surveyed in 1893-94-95.

APPROXIMATE MEAN DECLINATION 1906.

Scale 1/125000

Contour interval 20 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

Edition of Mar. 1899, reprinted Dec. 1908.

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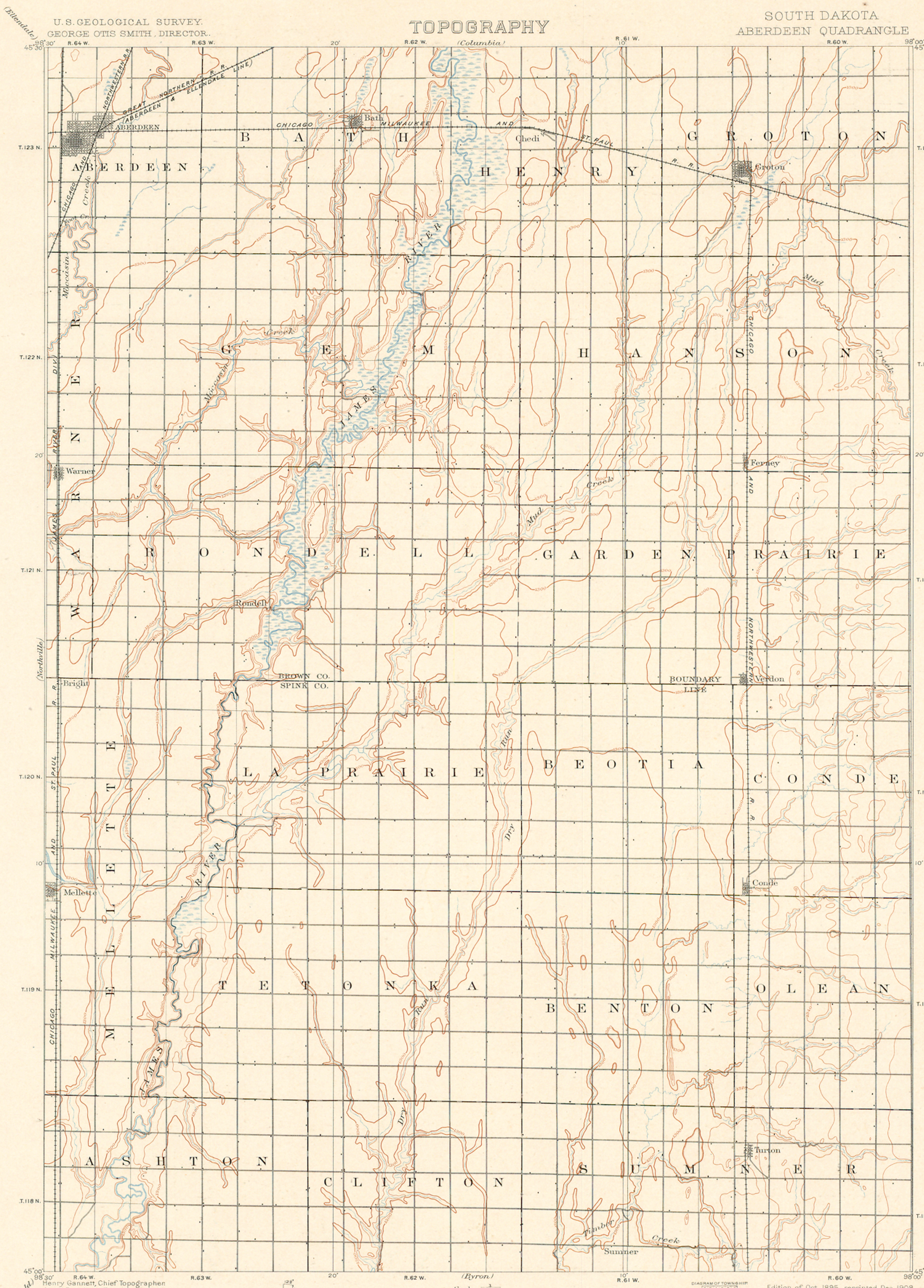
TOPOGRAPHY

SOUTH DAKOTA
ABERDEEN QUADRANGLE



LEGEND

RELIEF
printed in brown

Contours
showing height above sea, horizontal form, and steepness of slope of the surface

Depression contours

DRAINAGE
printed in blue

Streams

Intermittent streams

Lakes and ponds

Marshes

CULTURE
printed in black

Roads and buildings

Railroads

Bridges

U.S. township and section lines

County lines

Township lines

Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Topographer in charge.
Control by Geo. T. Hawkins.
Topography by D. C. Harrison.
Surveyed in 1893.

TRUE NORTH — MAGNETIC NORTH 12½°
APPROXIMATE MEAN DECLINATION 1906.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Edition of Oct. 1895, reprinted Dec. 1908.

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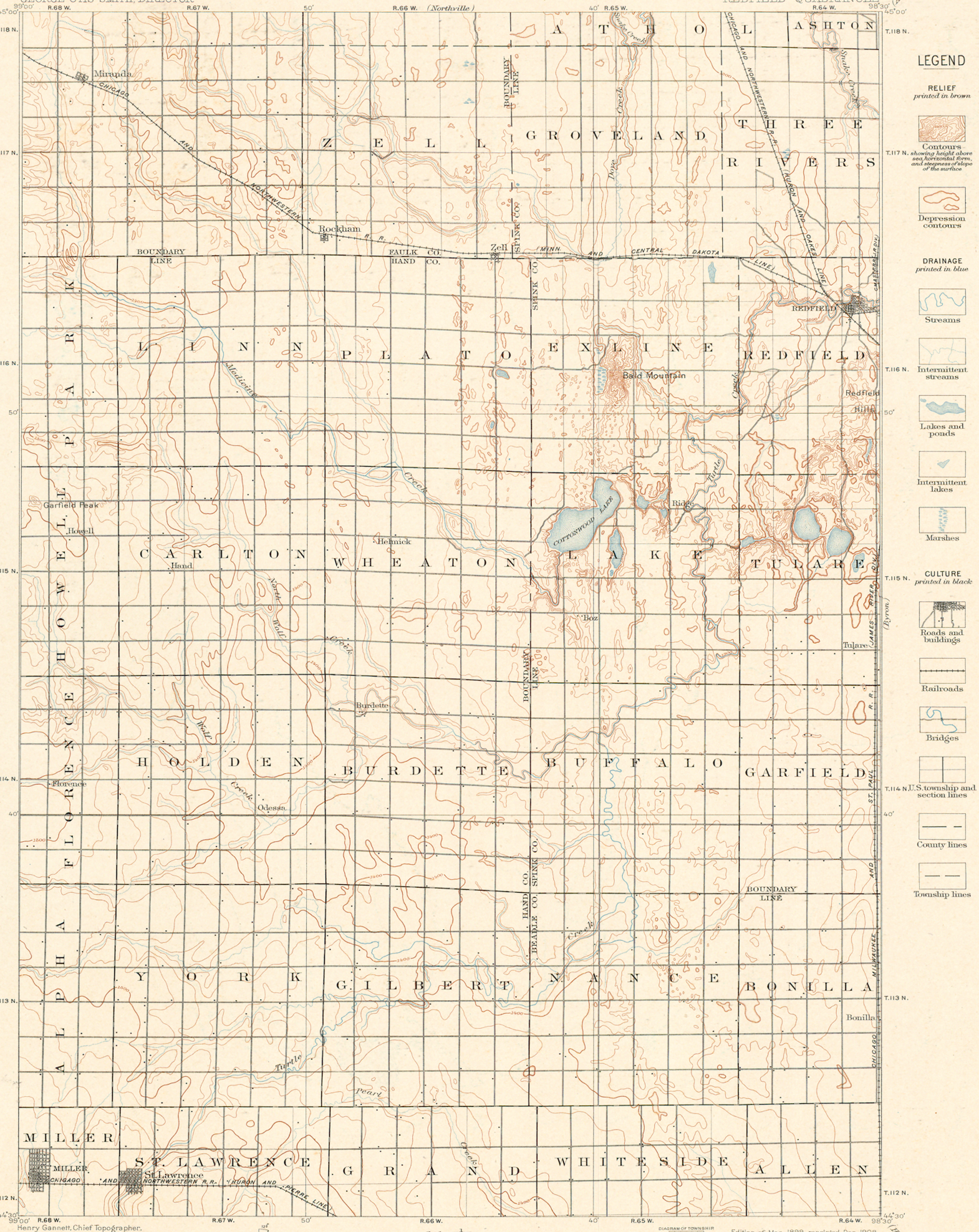
TOPOGRAPHY

SOUTH DAKOTA
REDFIELD QUADRANGLE



Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Topographer in charge.
Control by Geo. T. Hawkins.
Topography by H.S. Wallace and D.C. Harrison.
Surveyed in 1893 and 1895.

APPROXIMATE MEAN DECLINATION 1906.

Scale 1/125000

Contour interval 20 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

Edition of Mar. 1899, reprinted Dec. 1908.

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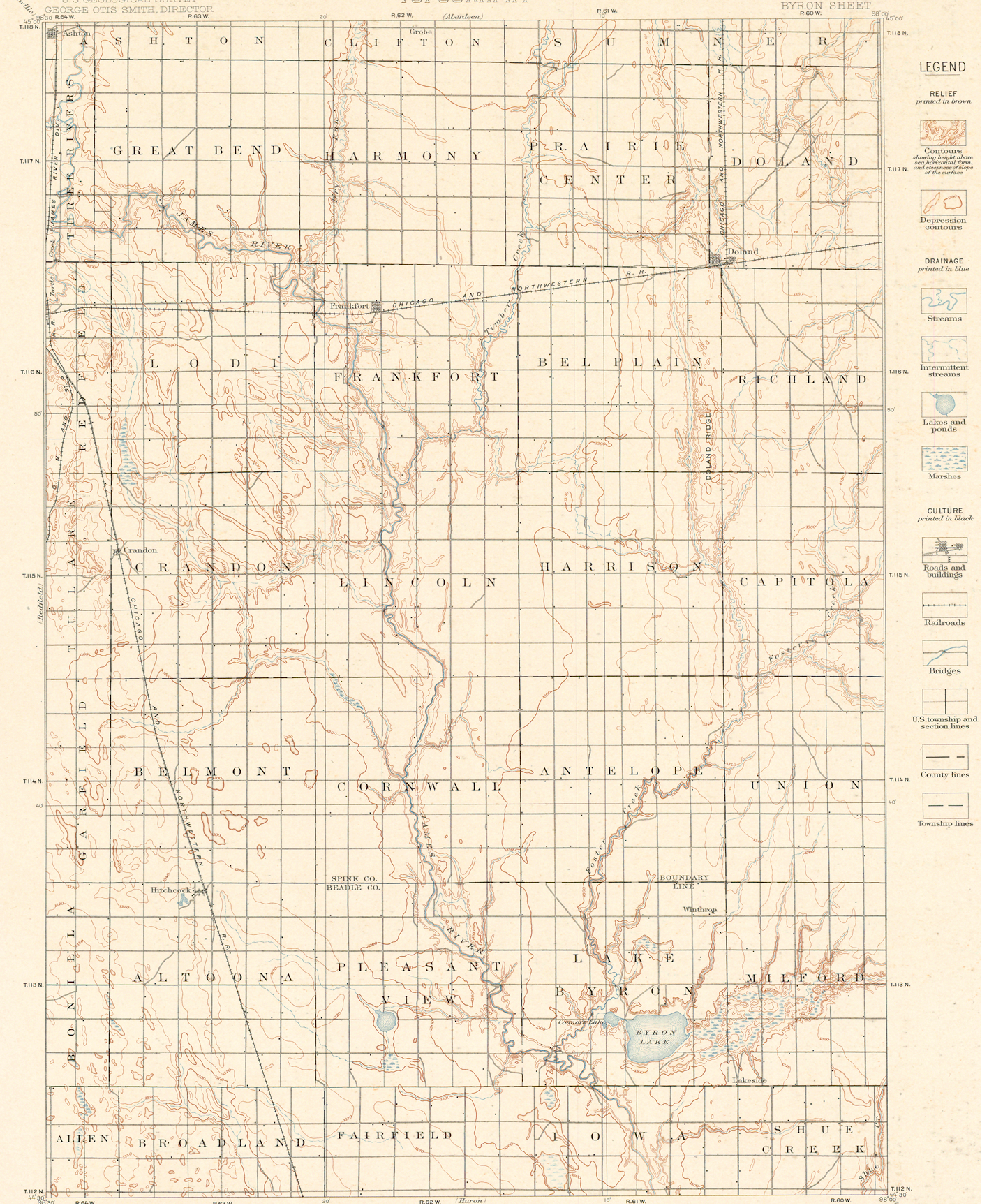
TOPOGRAPHY

SOUTH DAKOTA
BYRON SHEET



Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Topographer in charge.
Control by Geo. T. Hawkins.
Topography by D.C. Harrison.
Surveyed in 1893.

APPROXIMATE MEAN DECLINATION 1906.

Scale $\frac{1}{125000}$

Contour interval 20 feet.
Datum is mean sea level.

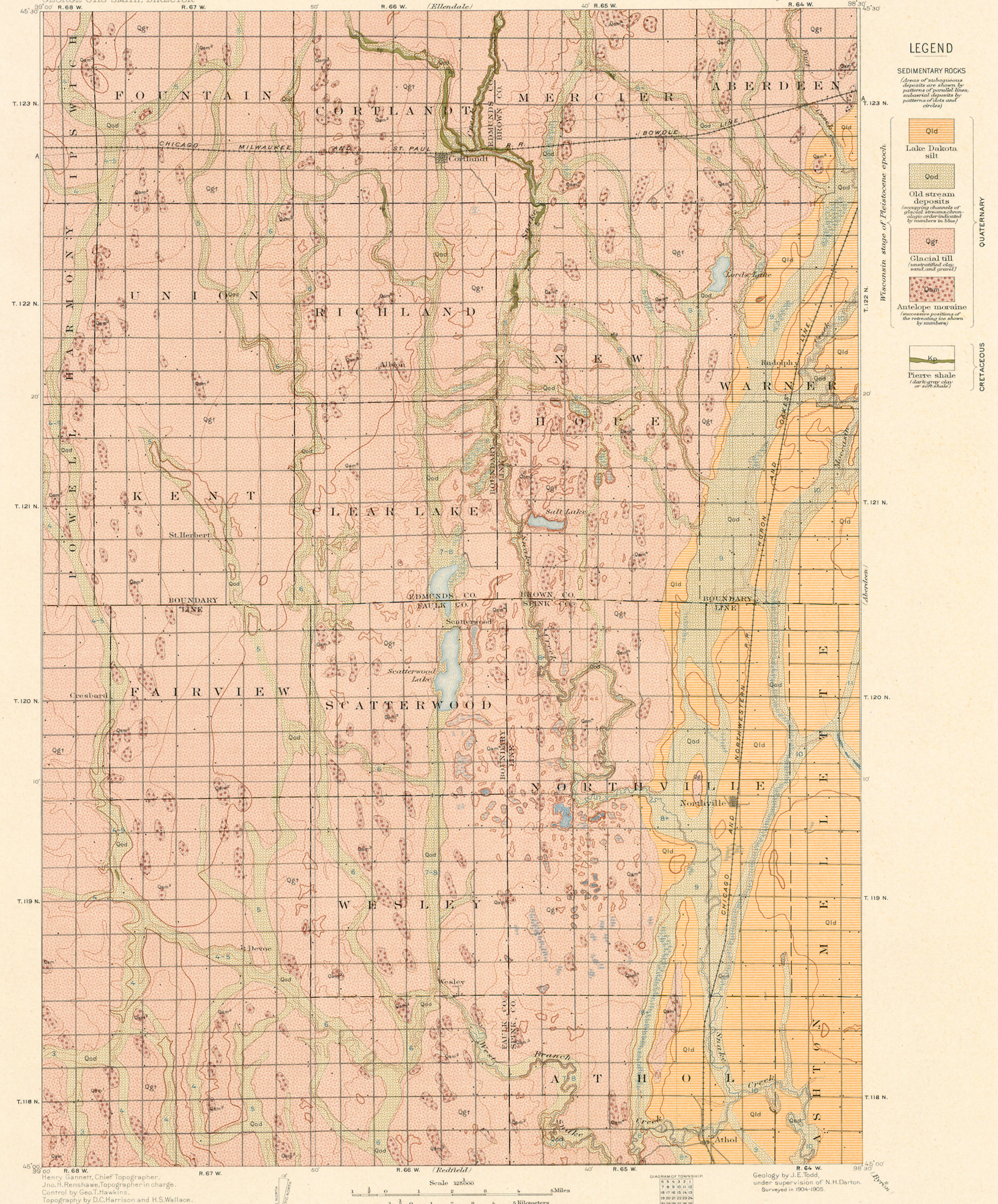
DIAGRAM OF TOWNSHIP

Edition of Dec. 1895, reprinted Dec. 1908

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR.

AREAL GEOLOGY

SOUTH DAKOTA
NORTHVILLE QUADRANGLE



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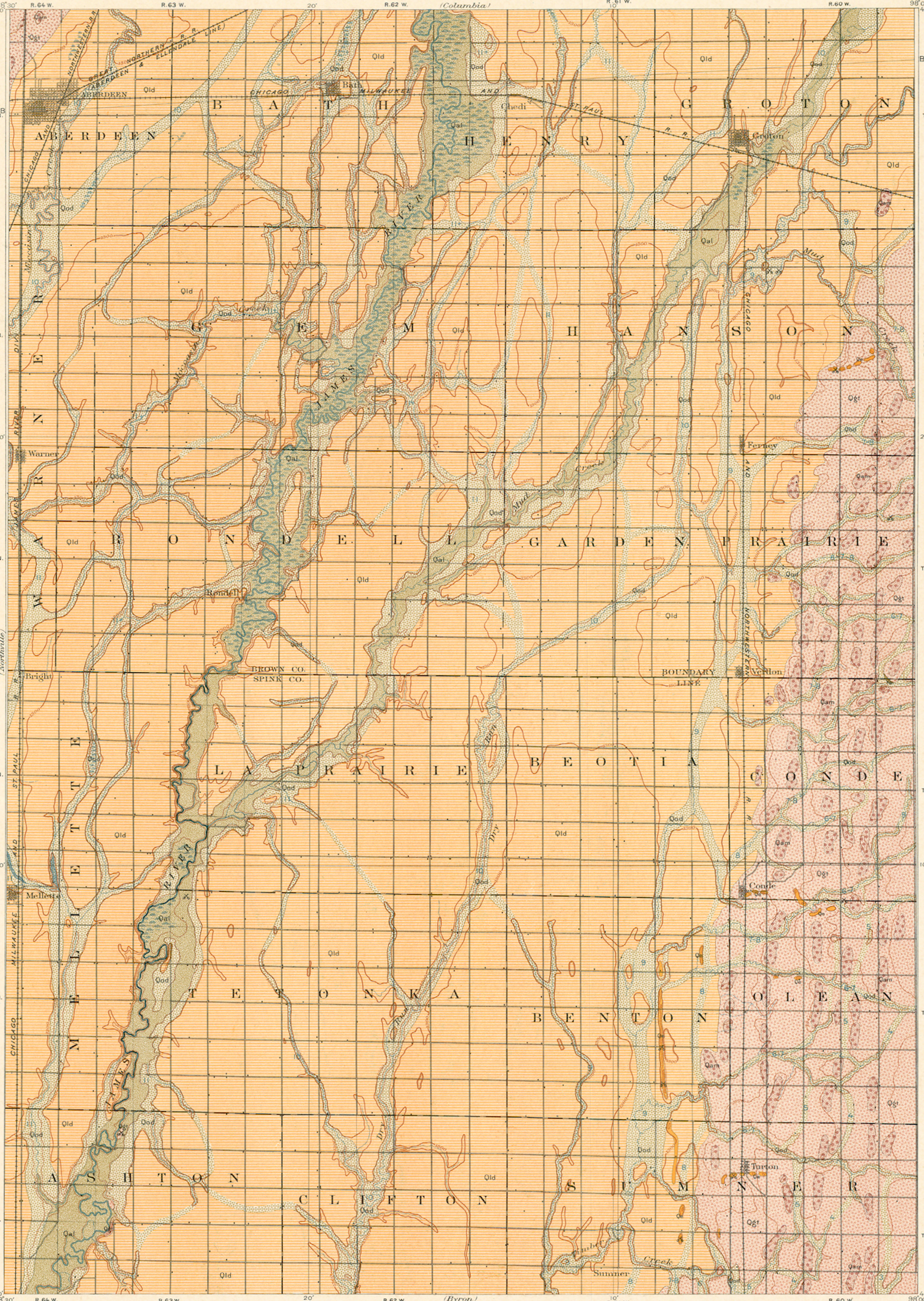
Geology by J. E. Todd,
under supervision of N. H. Darton.
Surveyed in 1904-1905.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

SOUTH DAKOTA
ABERDEEN QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles)

QUATERNARY

Recent

- Qal — Alluvium (only the larger areas shown)

Wisconsin stage of Pleistocene epoch

- Qld — Lake Dakota silt
- Qod — Old stream deposits (occupying channels of glacial streams; chronologic order indicated by numbers in blue)
- Qgt — Glacial till (unstratified clay, sand, and gravel)
- Qam — Antelope moraine
- Qe — Eskers

CRETACEOUS

- Kp — Pierre shale (dark-gray clay or soft shale)

Sand and gravel pits

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APPROXIMATE MEAN DECLINATION 1908.

Scale 1/125000

0 1 2 3 4 5 Miles

0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Nov. 1908.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
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31	32	33	34	35	36

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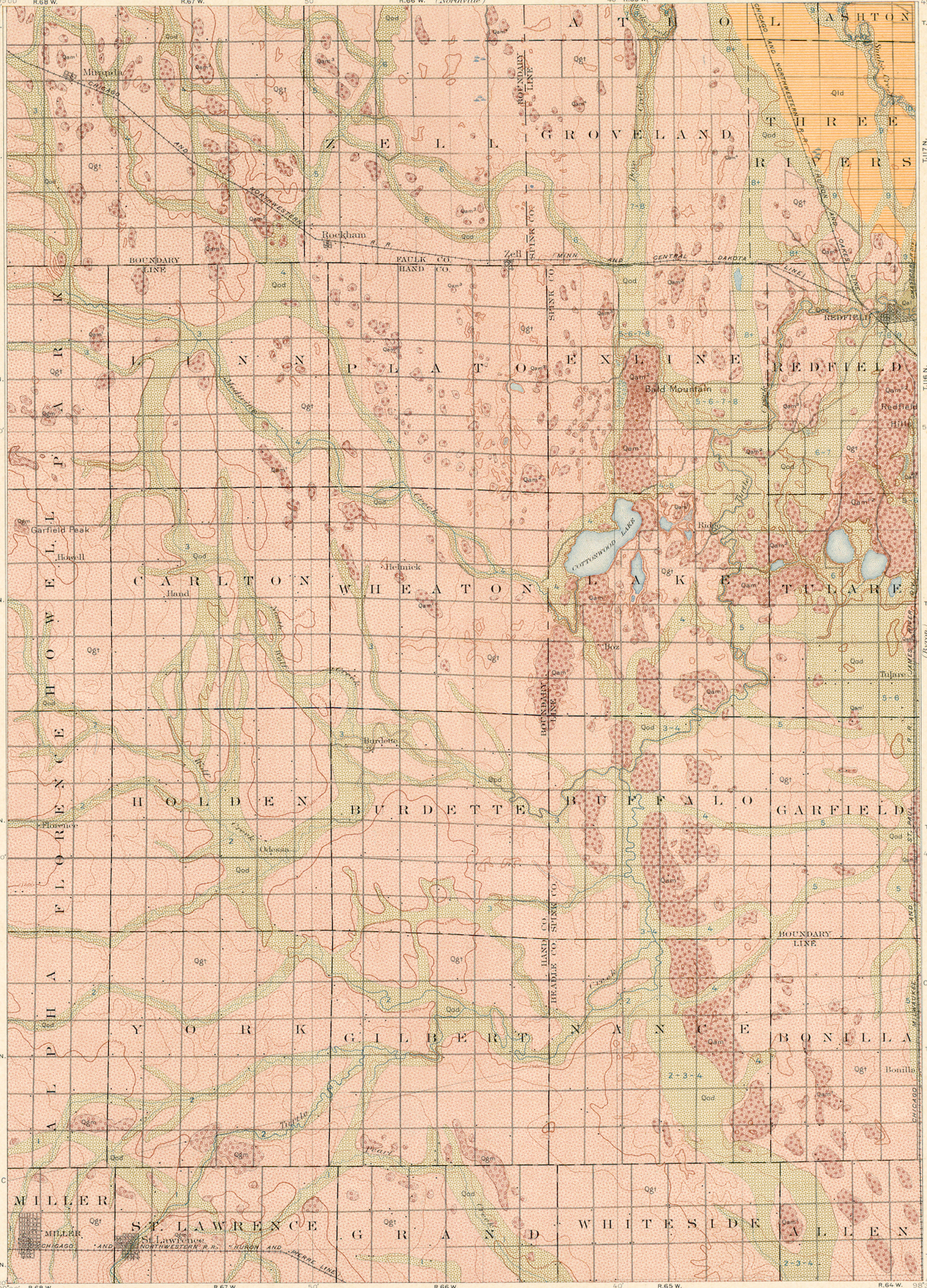
AREAL GEOLOGY

SOUTH DAKOTA
REDFIELD QUADRANGLE



LEGEND

SEDIMENTARY ROCKS
(Areas of subaqueous deposits are shown by patterns of parallel lines; subaerial deposits by patterns of dots and circles)

QUATERNARY

Recent
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- Qld — Lake Dakota silt
- Qod — Old stream deposits (occupying channels of glacial streams; chronologic order indicated by numbers in blue)
- Qgt — Glacial till (unstratified clay, sand, and gravel)
- Qam — Antelope moraine (successive positions of the retreating ice shown by numbers)
- Qgm — Gary moraine

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Surveyed in 1893 and 1895.

APPROXIMATE MEAN DECLINATION 1906.

Scale $\frac{1}{125000}$
5 Miles
5 Kilometers
Contour interval 20 feet.
Datum is mean sea level.

Edition of Nov. 1908.

DIAGRAM OF TOWNSHIP

Geology by J. E. Todd,
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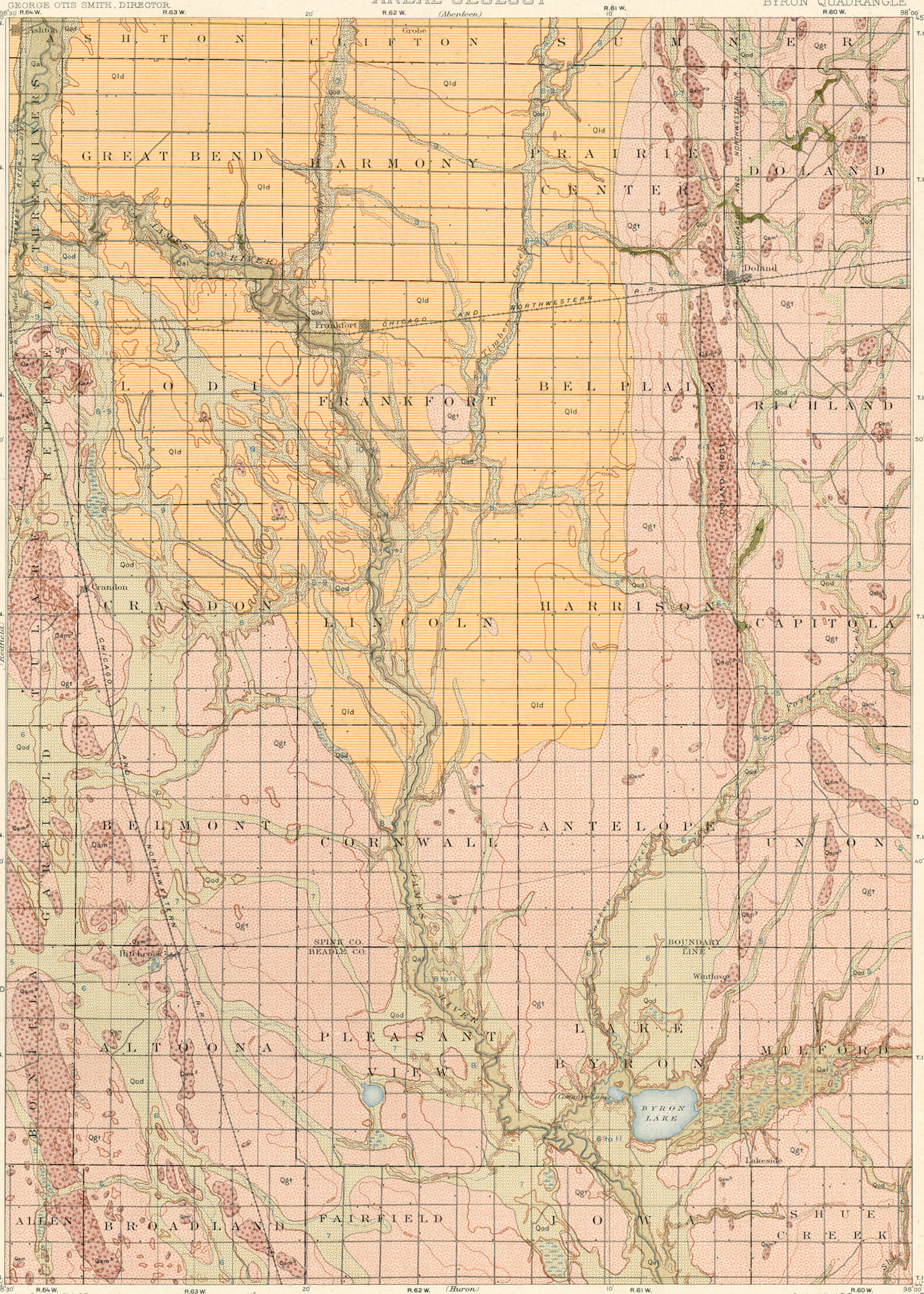
AREAL GEOLOGY



LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles)

QUATERNARY

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- Qam — Antelope moraine *(successive positions of the retreating ice shown by numbers)*

CRETACEOUS

- Kp — Pierre shale *(dark-gray clay or soft shale)*

↘ *Glacial striæ on bowlder pavement in till*

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Scale $\frac{1}{125000}$

Miles

Kilometers

Contour interval 20 feet.
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6	5	4	3	2	1
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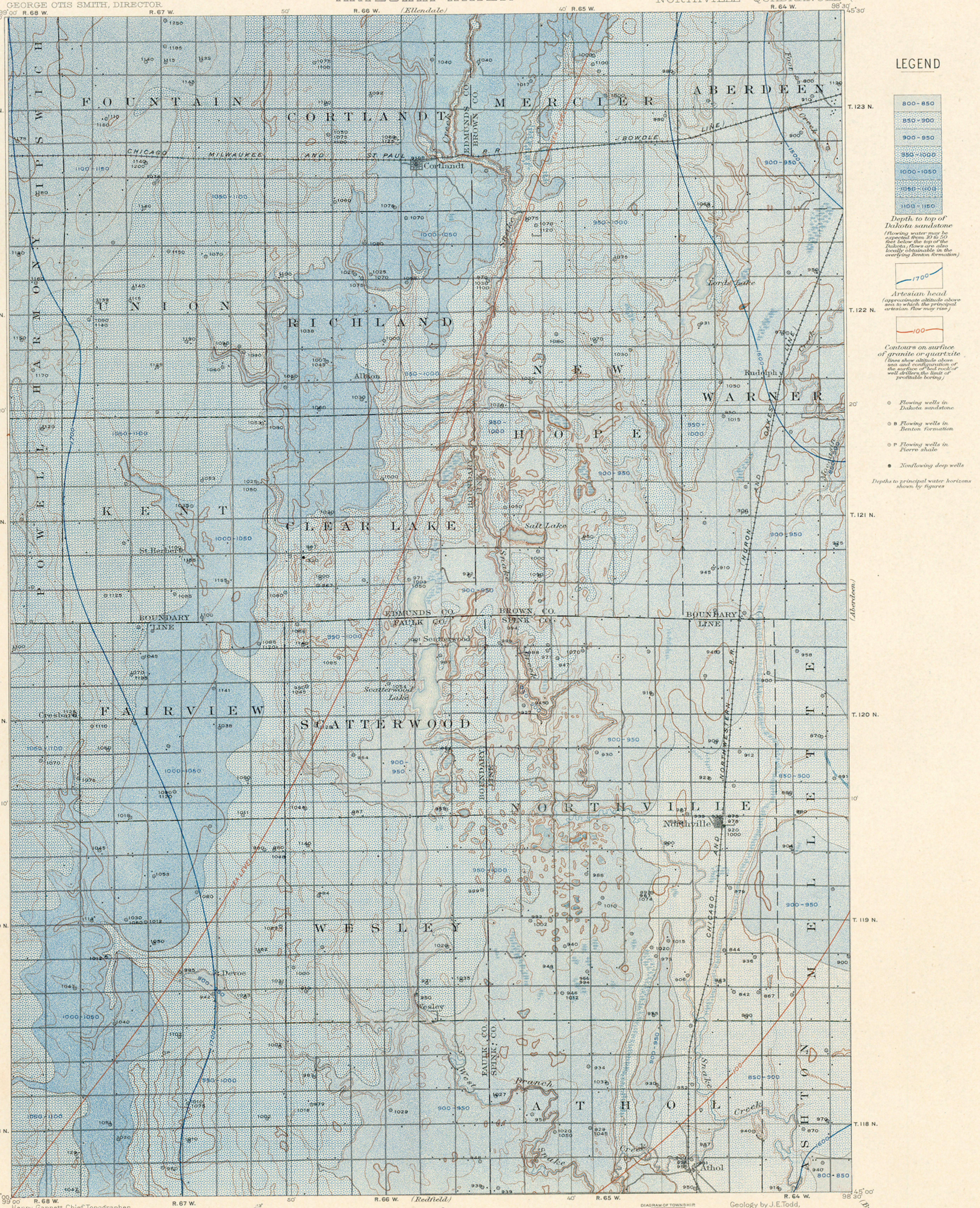
ARTESIAN WATER

SOUTH DAKOTA
NORTHVILLE QUADRANGLE



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Surveyed in 1893-94-95.

APPROXIMATE MEAN DECLINATION 1906.

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U.S. GEOLOGICAL SURVEY
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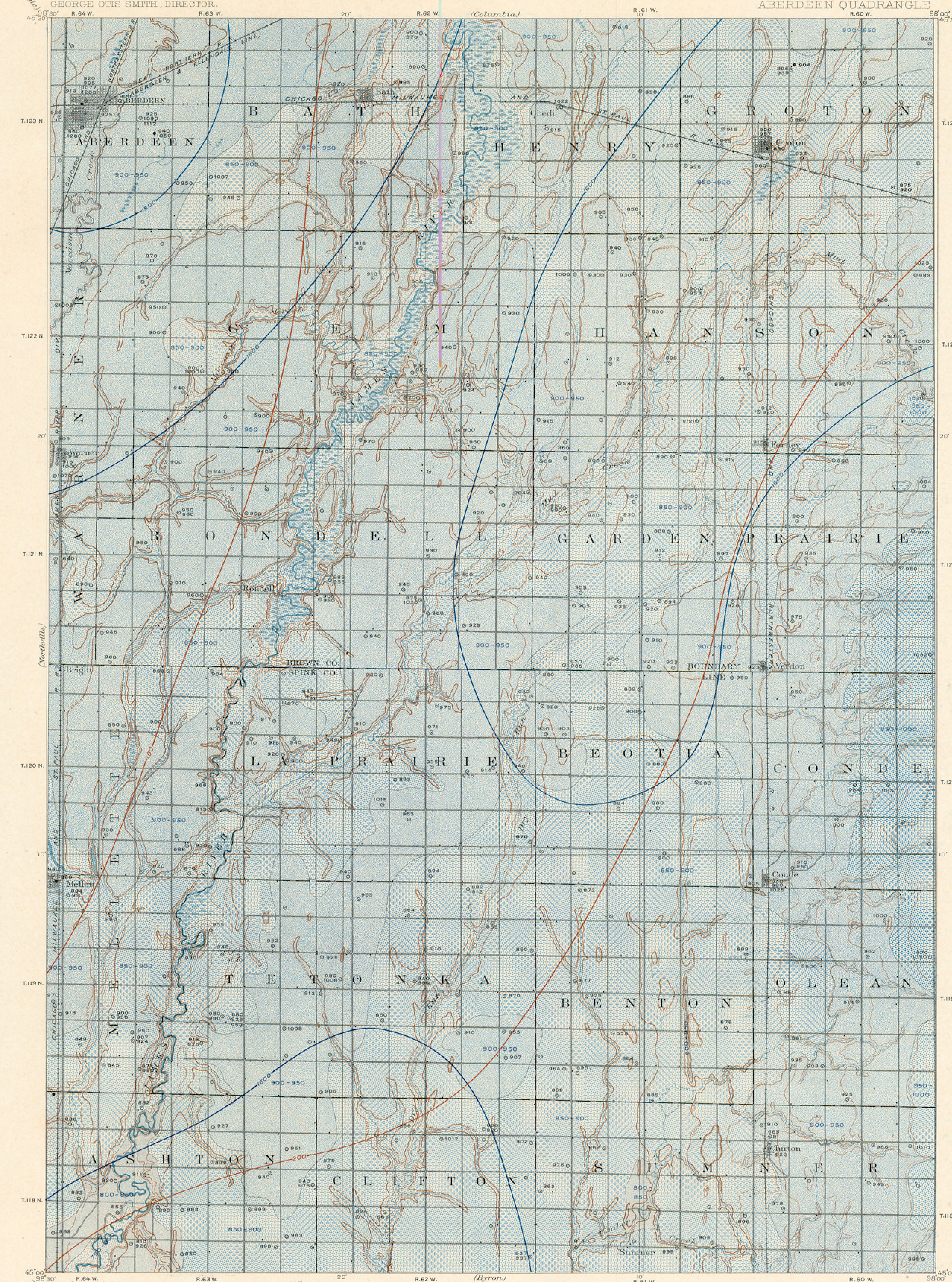
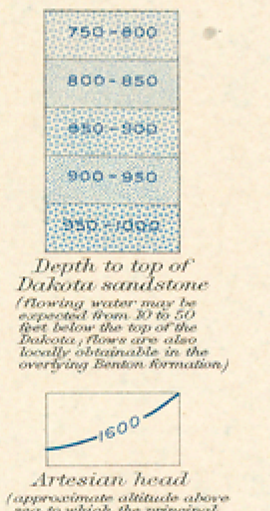
ARTESIAN WATER

SOUTH DAKOTA
ABERDEEN QUADRANGLE



LEGEND



Depth to top of Dakota sandstone
(Flowing water may be expected from 30 to 50 feet below the top of the Dakota; flows are also locally obtainable in the overlying Benton formation)

Artesian head
(approximate altitude above sea to which the principal artesian flow may rise)

Contours on surface of granite or quartzite
(lines show altitude above sea and configuration of the surface of "bed rock" of well drillers, the limit of profitable boring)

Flowing wells in Dakota sandstone

B Flowing wells in Benton formation

Nonflowing deep wells

Depths to principal water horizons shown by figures

Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Topographer in charge.
Control by Geo. T. Hawkins.
Topography by D. C. Harrison.
Surveyed in 1893.

APPROXIMATE MEAN DECLINATION 1906.

Scale $\frac{1}{125000}$

Contour interval 20 feet.
Datum is mean sea level.
Edition of Nov. 1908.

DIAGRAM OF TOWNSHIP.

Geology by J. E. Todd,
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Surveyed in 1905.

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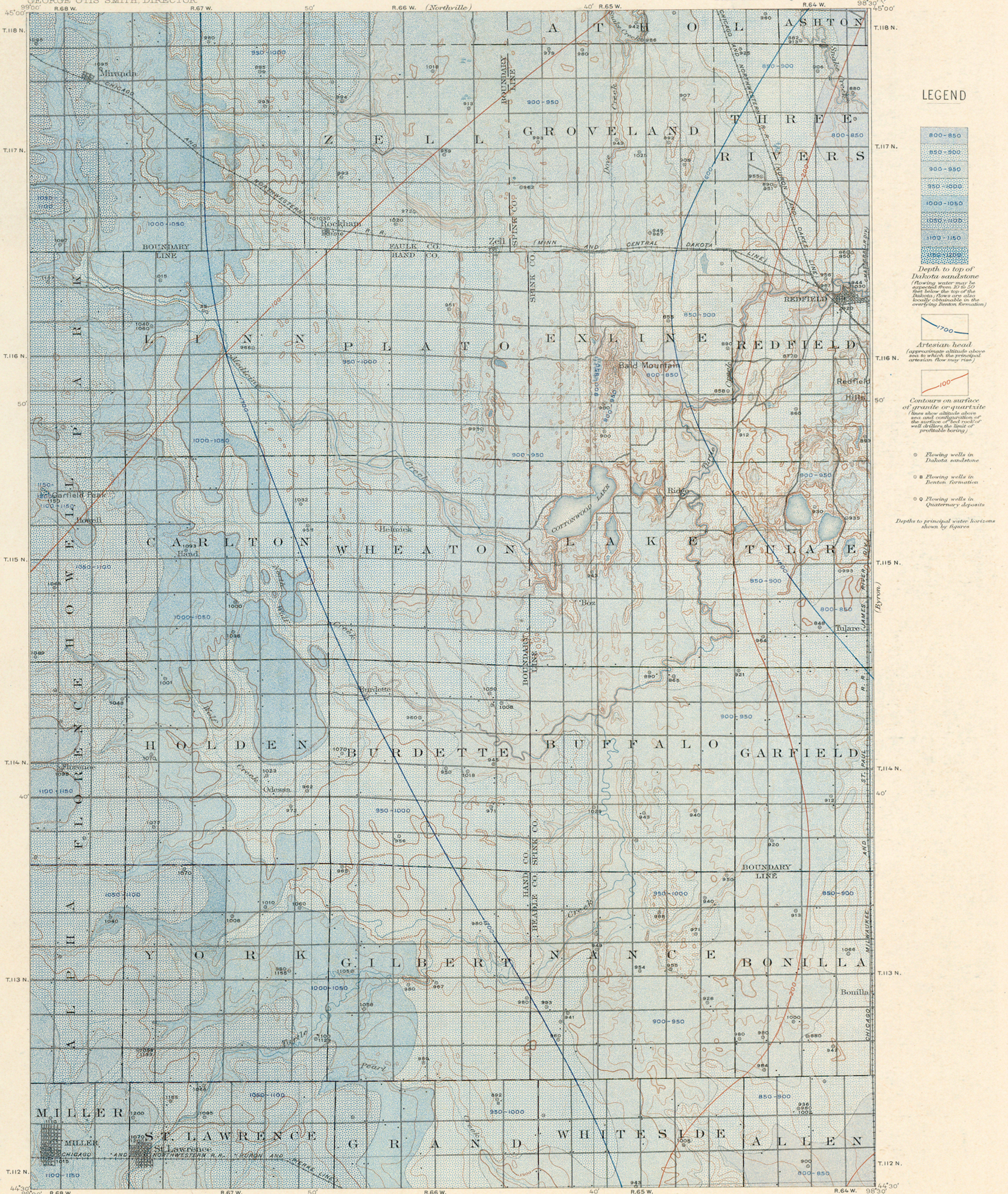
ARTESIAN WATER

SOUTH DAKOTA
REDFIELD QUADRANGLE



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Control by Geo. T. Hawkins.
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Surveyed in 1893 and 1895.

TRUE NORTH
MAGNETIC NORTH
12°
APPROXIMATE MEAN DECLINATION 1906.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

Edition of Nov. 1908.

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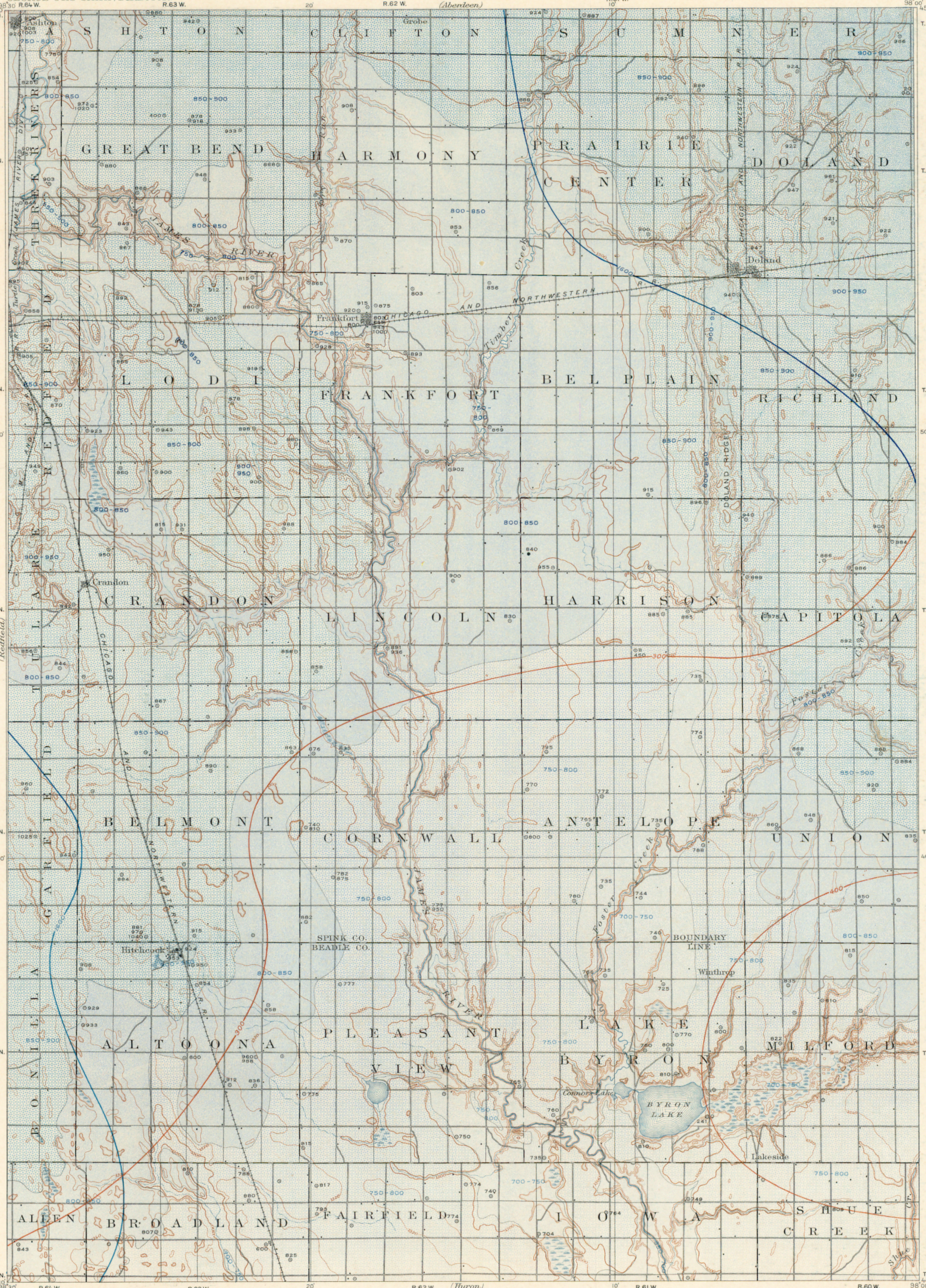
ARTESIAN WATER

SOUTH DAKOTA
BYRON QUADRANGLE



LEGEND

650 - 700
700 - 750
750 - 800
800 - 850
850 - 900
900 - 950

Depth to top of Dakota sandstone
(Flowing water may be expected from 10 to 50 feet below the top of the Dakota; flows are also locally obtainable in the overlying Benton formation)

Artesian head
(approximate altitude above sea to which the principal artesian flow may rise)

Contours on surface of granite or quartzite
(lines show altitude above sea and configuration of the surface of bed rock of well drillers, the limit of profitable boring)

Flowing wells in Dakota sandstone

Flowing wells in Benton formation

Flowing wells in Quaternary deposits

Nonflowing deep wells

Depths to principal water horizons shown by figures

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Surveyed in 1904.

and still smaller ones *stages*. The age of a rock is expressed by the name of the time interval in which it was formed.

The sedimentary formations deposited during a period are grouped together into a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

Inasmuch as sedimentary deposits accumulate successively the younger rest on those that are older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or superposed by faulting, so that it may be difficult to determine their relative ages from their present positions; under such conditions fossils, if present, may indicate which of two or more formations is the oldest.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. Where two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

Symbols, colors, and patterns.—Each formation is shown on the map by a distinctive combination of color and pattern and is labeled by a special letter symbol.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin. The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system.

The symbols consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters.

The names of the systems and of series that have been given distinctive names, in order from youngest to oldest, with the color and symbol assigned to each system, are given in the subjoined table.

Symbols and colors assigned to the rock systems.

	System.	Series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent, Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene, Miocene, Oligocene, Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		Ꞧ	Peacock-blue.
Paleozoic	Carboniferous	Permian, Pennsylvanian, Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Є	Brick-red.
	Algonkian		A	Brownish red.
	Archean		Æ	Gray-brown.

SURFACE FORMS.

Hills, valleys, and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; waves cut sea cliffs and, in cooperation with currents, build up sand spits and bars. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterward partly eroded away. The shaping of a marine or lacustrine plain is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. Lakes or large rivers may determine local base-levels for certain regions. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the fairly even surface thus produced is called a *peneplain*. If the tract is afterward uplifted, the elevated peneplain becomes a record of the former close relation of the tract to base-level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—The map showing the areas occupied by the various formations is called an *areal geology map*. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any particular formation, its name should be sought in the legend and its color and pattern noted; then the areas on the map corresponding in color and pattern may be traced out. The legend is also a partial statement of the geologic history. In it the names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic geology map*. The formations that appear on the areal geology map are usually shown on this map by fainter color patterns and the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral mined or stone quarried. If there are important mining industries or artesian basins in the area special maps to show these additional economic features are included in the folio.

Structure-section sheet.—In cliffs, canyons, shafts, and other natural and artificial cuttings the relations of different beds to one another may be seen. Any cutting that exhibits those relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface and can draw sections representing the structure to a considerable depth. Such a section is illustrated in figure 2.

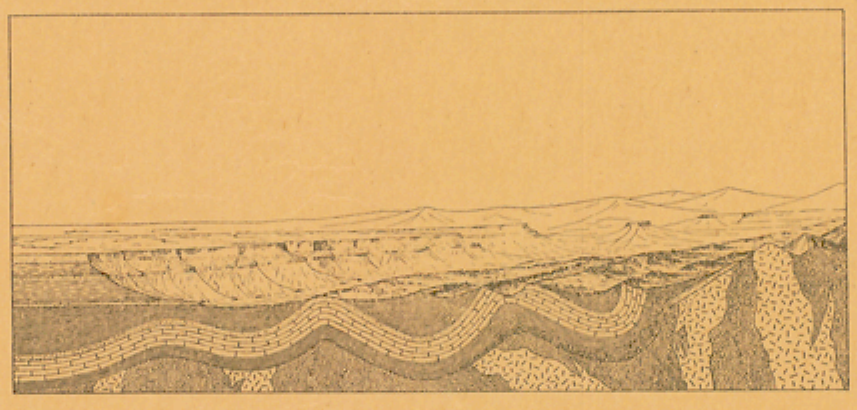

FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.

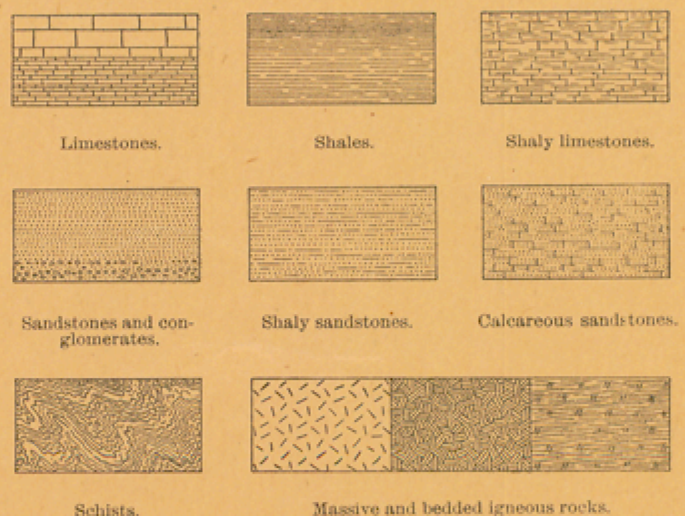

FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to the outcrops of a bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction of the intersection of a bed with a horizontal plane is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

In many regions the strata are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets, the fact that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

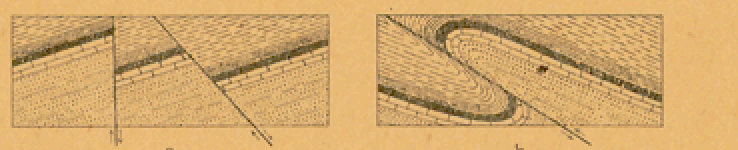

FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of sandstones and shales, which lie in a horizontal position. These strata were laid down under water but are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been uplifted. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata that have been folded into arches and troughs. These strata were once continuous, but the crests of the arches have been removed by erosion. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set shown at the left of the section. The overlying deposits are, from their position, evidently younger than the underlying deposits, and the bending and eroding of the older beds must have occurred between their deposition and the accumulation of the younger beds. The younger rocks are *unconformable* to the older, and the surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists were metamorphosed, they were disturbed by eruptive activity, and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

The section and landscape in figure 2 are ideal, but they illustrate actual relations. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the section corresponds to the actual slopes of the ground along the section line, and the depth from the surface of any mineral-producing or water-bearing stratum that appears in the section may be measured by using the scale of the map.

Columnar section.—The geologic maps are usually accompanied by a *columnar section*, which contains a concise description of the sedimentary formations that occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures that state the least and greatest measurements, and the average thickness of each formation is shown in the column, which is drawn to scale. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest at the bottom, the youngest at the top.

The intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

GEORGE OTIS SMITH,
Director.

May, 1909.

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34	Buckhannon	West Virginia	25
35	Gadsden	Alabama	25
36	Pueblo	Colorado	25
37	Downieville	California	25
38	Butte Special	Montana	25
39	Truckee	California	25
40	Wartburg	Tennessee	25
41	Sonora	California	25
42	Nueces	Texas	25
43	Bidwell Bar	California	25
44	Tazewell	Virginia-West Virginia	25
45	Boise	Idaho	25
46	Richmond	Kentucky	25
47	London	Kentucky	25
48	Tenmile District Special	Colorado	25
49	Roseburg	Oregon	25
50	Holyoke	Massachusetts-Connecticut	25
51	Big Trees	California	25
52	Absaroka	Wyoming	25
53	Standingstone	Tennessee	25
54	Tacoma	Washington	25
55	Fort Benton	Montana	25
56	Little Belt Mountains	Montana	25
57	Telluride	Colorado	25
58	Elmoro	Colorado	25
59	Bristol	Virginia-Tennessee	25
60	La Plata	Colorado	25
61	Monterey	Virginia-West Virginia	25
62	Menominee Special	Michigan	25
63	Mother Lode District	California	50
64	Uvalde	Texas	25
65	Tintic Special	Utah	25
66	Colfax	California	25
67	Danville	Illinois-Indiana	25
68	Walsenburg	Colorado	25
69	Huntington	West Virginia-Ohio	25
70	Washington	D. C.-Va.-Md.	50
71	Spanish Peaks	Colorado	25
72	Charleston	West Virginia	25
73	Coos Bay	Oregon	25
74	Coalgate	Indian Territory	25
75	Maynardville	Tennessee	25
76	Austin	Texas	25
77	Raleigh	West Virginia	25
78	Rome	Georgia-Alabama	25
79	Atoka	Indian Territory	25
80	Norfolk	Virginia-North Carolina	25
81	Chicago	Illinois-Indiana	50
82	Masontown-Uniontown	Pennsylvania	25
83	New York City	New York-New Jersey	50
84	Ditney	Indiana	25
85	Oelrichs	South Dakota-Nebraska	25
86	Ellensburg	Washington	25
87	Camp Clarke	Nebraska	25
88	Scotts Bluff	Nebraska	25
89	Port Orford	Oregon	25
90	Cranberry	North Carolina-Tennessee	25
91	Hartville	Wyoming	25
92	Gaines	Pennsylvania-New York	25
93	Elkland-Tioga	Pennsylvania	25
94	Brownsville-Connellsville	Pennsylvania	25
95	Columbia	Tennessee	25
96	Olivet	South Dakota	25
97	Parker	South Dakota	25
98	Tishomingo	Indian Territory	25
99	Mitchell	South Dakota	25
100	Alexandria	South Dakota	25
101	San Luis	California	25
102	Indiana	Pennsylvania	25
103	Nampa	Idaho-Oregon	25
104	Silver City	Idaho	25
105	Patoka	Indiana-Illinois	25
106	Mount Stuart	Washington	25
107	Newcastle	Wyoming-South-Dakota	25
108	Edgemont	South Dakota-Nebraska	25
109	Cottonwood Falls	Kansas	25
110	Latrobe	Pennsylvania	25
111	Globe	Arizona	25
112	Bisbee	Arizona	25
113	Huron	South Dakota	25
114	De Smet	South Dakota	25
115	Kittanning	Pennsylvania	25
116	Asheville	North Carolina-Tennessee	25
117	Casselton-Fargo	North Dakota-Minnesota	25
118	Greeneville	Tennessee-North Carolina	25
119	Fayetteville	Arkansas-Missouri	25
120	Silverton	Colorado	25
121	Waynesburg	Pennsylvania	25
122	Tahlequah	Indian Territory-Arkansas	25
123	Elders Ridge	Pennsylvania	25
124	Mount Mitchell	North Carolina-Tennessee	25
125	Rural Valley	Pennsylvania	25
126	Bradshaw Mountains	Arizona	25
127	Sundance	Wyoming-South Dakota	25
128	Aladdin	Wyo.-S. Dak.-Mont.	25
129	Clifton	Arizona	25
130	Rico	Colorado	25
131	Needle Mountains	Colorado	25
132	Muscogee	Indian Territory	25
133	Ebensburg	Pennsylvania	25
134	Beaver	Pennsylvania	25
135	Nepesta	Colorado	25
136	St. Marys	Maryland-Virginia	25
137	Dover	Del.-Md.-N. J.	25
138	Redding	California	25
139	Snoqualmie	Washington	25
140	Milwaukee Special	Wisconsin	25
141	Bald Mountain-Dayton	Wyoming	25
142	Cloud Peak-Fort McKinney	Wyoming	25
143	Nantahala	North Carolina-Tennessee	25
144	Amity	Pennsylvania	25
145	Lancaster-Mineral Point	Wisconsin-Iowa-Illinois	25
146	Rogersville	Pennsylvania	25
147	Pisgah	N. Carolina-S. Carolina	25
148	Joplin District	Missouri-Kansas	50
149	Penobscot Bay	Maine	25
150	Devils Tower	Wyoming	25
151	Roan Mountain	Tennessee-North Carolina	25
152	Patuxent	Md.-D. C.	25
153	Ouray	Colorado	25
154	Winslow	Arkansas-Indian Territory	25
155	Ann Arbor	Michigan	25
156	Elk Point	S. Dak.-Nebr.-Iowa	25
157	Passaic	New Jersey-New York	25
158	Rockland	Maine	25
159	Independence	Kansas	25
160	Accident-Grantsville	Md.-Pa.-W. Va.	25
161	Franklin Furnace	New Jersey	25
162	Philadelphia	Pa.-N. J.-Del.	50
163	Santa Cruz	California	25
164	Belle Fourche	South Dakota	25
165	Aberdeen-Redfield	South Dakota	25

* Order by number.
† Payment must be made by money order or in cash.
‡ These folios are out of stock.

Circulars showing the location of the area covered by any of the above folios, as well as information concerning topographic maps and other publications of the Geological Survey, may be had on application to the Director, United States Geological Survey, Washington, D. C.