DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

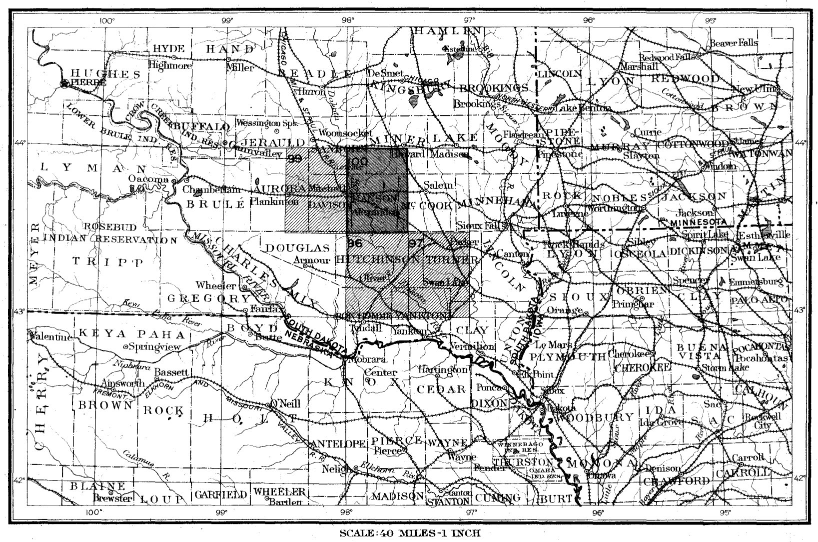
OF THE

UNITED STATES

ALEXANDRIA FOLIO

SOUTH DAKOTA

INDEX MAP



SCALE: 40 MILES-1 INCH

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LIBRARY EDITION

ALEXANDRIA FOLIO
NO. 100

WASHINGTON, D. C.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER

1903

EXPLANATION.

The Geological Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map. The two are being issued together in the form of an atlas, the parts of which are called folios. Each folio consists of a topographic base map and geologic maps of a small area of country, together with explanatory and descriptive texts.

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 which are most important 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 horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map:

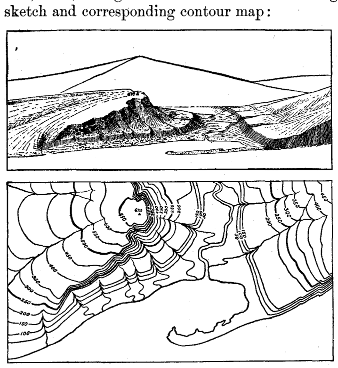


Fig. 1.—Ideal sketch and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply in a precipice. Contrasted with this precipice is the gentle descent of the slope at the left. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates approximately a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, 200 feet, and so on, above sea level. Along the contour at 250 feet lie all points of the surface 250 feet above sea; and similarly with any other contour. In the space between any two contours are found all elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while 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 sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration nearly all the contours are numbered. Where this is not possible, certain contours—say every fifth one—are accentuated and numbered; the heights of others may then be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. The relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The vertical space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise 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.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is used for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Water courses are indicated by blue lines. If the streams flow the year round the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, and artificial details, are printed in black.

Scales.—The area of the United States (excluding Alaska) is about 3,025,000 square miles. On a map with the scale of 1 mile to the inch this would cover 3,025,000 square inches, and to accommodate it the paper dimensions would need to be about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the scale of the map. In this case it is "1 mile to an inch." 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 of "1 mile to an inch" is expressed by $\frac{1}{63,360}$. Both of these methods are used on the maps of the Geological Survey.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents and corresponds nearly to 1 square mile; on the scale $\frac{1}{125,000}$, to about 4 square miles; and on the scale $\frac{1}{250,000}$, to about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three different ways, one being a graduated line representing miles and parts of miles in English inches, another indicating distance in the metric system, and a third giving the fractional scale.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which are bounded by parallels and meridians. The corresponding four-cornered portions of territory are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ contains one square degree, i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-quarter of a square degree; each sheet on a scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, respectively.

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or townships. 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 the names of adjacent sheets, if published, are printed.

Uses of the topographic sheet.—Within the limits of scale the topographic sheet is an accurate and characteristic delineation of the relief, drainage, and culture of the district represented. Viewing the landscape, map in hand, every characteristic feature of sufficient magnitude should be recognizable. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property to be bought or sold; save the engineer preliminary surveys in locating roads, railways, and irrigation ditches; provide educational material for schools and homes; and serve many of the purposes of a map for local reference.

THE GEOLOGIC MAP.

The maps representing areal geology show by colors and conventional signs, on the topographic base map, the distribution of rock formations on the surface of the earth, and the structure-section map shows their underground relations, as far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. The original crust of the earth was probably composed of *igneous rocks*, and all other rocks have been derived from them in one way or another.

Atmospheric agencies gradually break up igneous rocks, forming superficial, or *surficial*, deposits of clay, sand, and gravel. Deposits of this class have been formed on land surfaces since the earliest geologic time. Through the transporting agencies of streams the surficial materials of all ages and origins are carried to the sea, where, along with material derived from the land by the action of the waves on the coast, they form *sedimentary rocks*. These are usually hardened into conglomerate, sandstone, shale, and limestone, but they may remain unconsolidated and still be called "rocks" by the geologist, though popularly known as gravel, sand, and clay.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried, consolidated, and raised again above the surface of the water. In these processes, through the agencies of pressure, movement, and chemical action, they are often greatly altered, and in this condition they are called *metamorphic rocks*.

Igneous rocks.—These are rocks which have cooled and consolidated from a liquid state. As has been explained, sedimentary rocks were deposited on the original igneous rocks. Through the igneous and sedimentary rocks of all ages molten material has from time to time been forced upward to or near the surface, and there consolidated. When the channels or vents into which this molten material is forced do not reach the surface, it may consolidate in cracks or fissures crossing the bedding planes, thus forming dikes, or spread out between the strata in large bodies, called sheets or laccoliths, or form large irregular cross-cutting masses, called stocks. Such rocks are called *intrusive*. Within their rock inclosures they cool slowly, and hence are generally of crystalline texture. When the channels reach the surface the lavas often flow out and build up volcanoes. These lavas cool rapidly in the air, acquiring a glassy or, more often, a partially crystalline condition. They are usually more or less porous. The igneous rocks thus formed upon the surface are called *extrusive*. Explosive action often accompanies volcanic eruptions, causing ejections of dust or ash and larger fragments. These materials when consolidated constitute breccias, agglomerates, and tuffs. The ash when carried into lakes or seas may become stratified, so as to have the structure of sedimentary rocks.

The age of an igneous rock is often difficult or impossible to determine. When it cuts across a sedimentary rock it is younger than that rock, and when a sedimentary rock is deposited over it the igneous rock is the older.

Under the influence of dynamic and chemical forces an igneous rock may be metamorphosed. The alteration may involve only a rearrangement of its minute particles or it may be accompanied by a change in chemical and mineralogic composition. Further, the structure of the rock may be changed by the development of planes of division, so that it splits in one direction more easily than in others. Thus a granite may pass into a gneiss, and from that into a mica-schist.

Sedimentary rocks.—These comprise all rocks which have been deposited under water, whether in sea, lake, or stream. They form a very large part of the dry land.

When the materials of which sedimentary rocks are composed are carried as solid particles by water and deposited as gravel, sand, or mud, the deposit is called a mechanical sediment. These may become hardened into conglomerate, sandstone, or shale. When the material is carried in solution by the water and is deposited without the aid of life, it is called a chemical sediment; if deposited with the aid of life, it is called an organic sediment. The more important rocks formed from chemical and organic deposits are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the above sedimentary deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

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

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks over wide expanses, and as it rises or subsides the shore lines of the ocean are changed: areas of deposition may rise above the water and become land areas, and land areas may sink below the water and become areas of deposition. If North America were gradually to sink a thousand feet the sea would flow over the Atlantic coast and the Mississippi and Ohio valleys from the Gulf of Mexico to the Great Lakes; the Appalachian Mountains would become an archipelago, and the ocean's shore would traverse Wisconsin, Iowa, and Kansas, and extend thence to Texas. More extensive changes than this have repeatedly occurred in the past.

The character of the original sediments may be changed by chemical and dynamic action so as to produce metamorphic rocks. In the metamorphism of a sedimentary rock, just as in the metamorphism of an igneous rock, the substances of which it is composed may enter into new combinations, or new substances may be added. When these processes are complete the sedimentary rock becomes crystalline. Such changes transform sandstone to quartzite, limestone to marble, and modify other rocks according to their composition. A system of parallel division planes is often produced, which may cross the original beds or strata at any angle. Rocks divided by such planes are called slates or schists.

Rocks of any period of the earth's history may be more or less altered, but the younger formations have generally escaped marked metamorphism, and the oldest sediments known, though generally the most altered, in some localities remain essentially unchanged.

Surficial rocks.—These embrace the soils, clays, sands, gravels, and bowlders that cover the surface, whether derived from the breaking up or disintegration of the underlying rocks by atmospheric agencies or from glacial action. Surficial rocks that are due to disintegration are produced chiefly by the action of air, water, frost, animals, and plants. They consist mainly of the least soluble parts of the rocks, which remain after the more soluble parts have been leached out, and hence are known as residual products. Soils and subsoils are the most important. Residual accumulations are often washed or blown into valleys or other depressions, where they lodge and form deposits that grade into the sedimentary class. Surficial rocks that are due to glacial action are formed of the products of disintegration, together with bowlders and fragments of rock rubbed from the surface and ground together. These are spread irregularly over the territory occupied by the ice, and form a mixture of clay, pebbles, and bowlders which is known as till. It may occur as a sheet or be bunched into hills and ridges, forming moraines, drumlins, and other special forms. Much of this mixed material was washed away from the ice, assorted by water, and redeposited as beds or trains of sand and clay, thus forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels in the ice, and forms characteristic ridges and mounds of sand and gravel, known as osars, or eskers, and kames. The material deposited by the ice is called glacial drift; that washed from the ice onto the adjacent land is called modified drift. It is usual also to class as surficial rocks the deposits of the sea and of lakes and rivers that were made at the same time as the ice deposit.

AGES OF ROCKS.

Rocks are further distinguished according to their relative ages, for they were not formed all at one time, but from age to age in the earth's history. Classification by age is independent of origin; igneous, sedimentary, and surficial rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to call the mass throughout its extent a *formation*, and such a formation is the unit of geologic mapping.

Several formations considered together are designated a *system*. The time taken for the deposition of a formation is called an *epoch*, and the time taken for that of a system, or some larger fraction of a system, a *period*. The rocks are mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for its deposition are given the same name, as, for instance, Cambrian system, Cambrian period.

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be discovered by observing their relative positions. This relationship holds except in regions of intense disturbance; sometimes in such regions the disturbance of the beds has been so great that their position is reversed, and it is often difficult to determine the relative ages of the beds from their positions; then *fossils*, or the remains of plants and animals, are guides to show which of two or more formations is the oldest.

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those 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.

When two formations are remote one from the 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 found in the rocks of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

Colors and patterns.—To show the relative ages of strata, the history of the sedimentary rocks is divided into periods. The names of the periods in proper order (from new to old), with the colors and symbol assigned to each, are given in the table in the next column. The names of certain subdivisions and groups of the periods, frequently used in geologic writings, are bracketed against the appropriate period names.

To distinguish the sedimentary formations of any one period from those of another the patterns for the formations of each period are printed in the appropriate period-color, with the exception of the one at the top of the column (Pleistocene) and the one at the bottom (Archean). The sedimentary formations of any one period, excepting the Pleistocene and the Archean, are distinguished from one another by different patterns, made of parallel straight lines. Two tints of the period-color are used: a pale tint is printed evenly over the whole surface representing the period; a dark tint brings out the different patterns representing formations. Each formation is furthermore given

Period.			Symbol.	Color.
Cenozoic	Pleistocene		P	Any colors.
	Neocene	Pliocene, Miocene	N	Buffs.
	Eocene, including Oligocene		E	Olive-browns.
Mesozoic	Cretaceous		K	Olive-greens.
	Juratrias	Jurassic, Triassic	J	Blue-greens.
Paleozoic	Carboniferous, including Permian		C	Blues.
	Devonian		D	Blue-purples.
	Silurian, including Ordovician		S	Red-purples.
	Cambrian		Ꞓ	Pinks.
	Algonkian		A	Orange-browns.
	Archean		Æ	Any colors.

a letter-symbol composed of the period letter combined with small letters standing for the formation name. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

The number and extent of surficial formations, chiefly Pleistocene, render them so important that, to distinguish them from those of other periods and from the igneous rocks, patterns of dots and circles, printed in any colors, are used.

The origin of the Archean rocks is not fully settled. Many of them are certainly igneous. Whether sedimentary rocks are also included is not determined. The Archean rocks, and all metamorphic rocks of unknown origin, of whatever age, are represented on the maps by patterns consisting of short dashes irregularly placed. These are printed in any color, and may be darker or lighter than the background. If the rock is a schist the dashes or hachures may be arranged in wavy parallel lines. If the metamorphic rock is known to be of sedimentary origin the hachure patterns may be combined with the parallel-line patterns of sedimentary formations. If the rock is recognized as having been originally igneous, the hachures may be combined with the igneous pattern.

Known igneous formations are represented by patterns of triangles or rhombs printed in any brilliant color. If the formation is of known age the letter-symbol of the formation is preceded by the capital letter-symbol of the proper period. If the age of the formation is unknown the letter-symbol consists of small letters which suggest the name of the rocks.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology sheet.—This sheet shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any particular colored pattern and its letter-symbol on the map 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 given formation, its name should be sought in the legend and its color and pattern noted, when 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 symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology sheet.—This sheet represents the distribution of useful minerals, the occurrence of artesian water, or other facts of economic interest, showing their relations to the features of topography and to the geologic formations. All the formations which appear on the historical geology sheet are shown on this sheet by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A symbol for mines is introduced at each occurrence, accompanied by the name of the principal mineral mined or of the stone quarried.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface.

In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which exhibits those relations is called a *section*, and the same name 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 the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

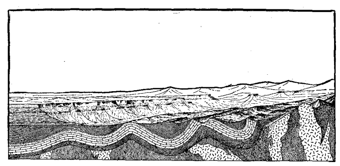


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground by a vertical plane, so as to show the underground relations of the rocks.

The kinds of rock are indicated in the section by appropriate symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:

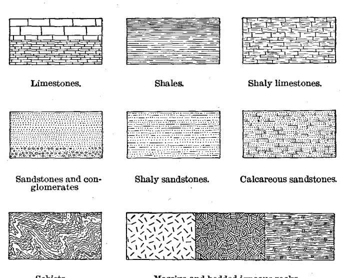


Fig. 3.—Symbols used to represent different kinds of rock.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section.

The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to beds of sandstone that rise to the surface. The upturned edges of these beds form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shales.

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 that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets. That they are now bent and folded is regarded as proof that forces exist which 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 slipped past one another. Such breaks are termed *faults*.

On the right of the sketch the section is composed of schists which are traversed by masses of igneous rock. 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.

In fig. 2 there are three sets of formations, distinguished by their underground relations. The first of these, seen at the left of the section, is the set of sandstones and shales, which lie in a horizontal position. These sedimentary strata are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has swelled upward from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. 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 at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger strata thus rest upon an eroded surface of older strata the relation between the two is an *unconformable* one, and their 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 plicated by pressure and traversed by eruptions of molten rock. But this pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that an interval of considerable duration elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists suffered metamorphism; they were the scene of eruptive activity; and they were deeply eroded. The contact between the second and third sets, marking a time interval between two periods of rock formation, is another unconformity.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections in the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profiles of the surface in the section correspond 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 which appears in the section may be measured by using the scale of the map.

Columnar section sheet.—This sheet contains a concise description of the rock formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thicknesses of the formations, and the order of accumulation of successive deposits.

The rocks are described under the corresponding heading, and their characters are indicated in the columnar diagrams by appropriate symbols. The thicknesses of formations are given in figures which state the least and greatest measurements. The average thickness of each formation is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement: the oldest formation is placed at the bottom of the column, the youngest at the top, and igneous rocks or surficial deposits, when present, are indicated in their proper relations.

The formations are combined into systems which correspond with the periods of geologic history. Thus the ages of the rocks are shown, and also the total thickness of each system.

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

CHARLES D. WALCOTT,
Director.

Revised January, 1902.

DESCRIPTION OF THE ALEXANDRIA QUADRANGLE.

By J. E. Todd and C. M. Hall.

GEOGRAPHY

General relations.—Eastern South Dakota lies on the Great Plains, in the broad, indefinite zone in which these plains merge into the prairies of the Mississippi Valley. It is comprised within the area of glaciation, and most of the surface features present the characteristics of a drift-covered region. The country is mostly level or presents low, rolling slopes rising out of broad expanses of plains. The principal elements of relief are long ranges of hills of moderate elevation due to morainal accumulations left by the ice along lines marking various pauses of glacial advance and retreat. Further diversity of topography has been produced by the excavation of the valleys, especially the valley of the Missouri, which has cut a trench several hundred feet deep, mostly with steeply sloping sides. Between the moraines there are rolling plains of till and very level plains due to the filling up of glacial lakes. The upper James River Valley presents a notable example of this lake-bed topography.

Location.—The Alexandria quadrangle is bounded by parallels 43° 30′ and 44° north latitude and meridians 97° 30′ and 98° west longitude, and covers a quarter of a square degree. It is approximately 35 miles in length and 25$\frac{1}{4}$ miles in breadth, and has an area of about 863 square miles. The quadrangle is in the James River Valley; the greater portion of it is included in Hanson County, and the remainder is in Miner, Sanborn, McCook, and Davison counties, South Dakota.

Topography.—The surface of the quadrangle is a nearly smooth plain sloping gently toward James River, which flows along the western border of the quadrangle on the north and crosses its southwestern quarter. No very abrupt or rough surface, except a few knolls that will be mentioned further on, is found away from the immediate vicinity of the streams. The highest point in the quadrangle is in the northeast corner, where the altitude is 1560 feet above sea level. The lowest point is on James River at the southern boundary of the quadrangle, the altitude there being about 1190 feet.

In the northwestern portion of the quadrangle, embracing the area lying between James River and Rock Creek, is a very even plain having a general altitude of 1310 feet. In this plain the streams have cut narrow, gorge-like channels, and there are several isolated lake basins. Most of these contain water during only a part of the year, but in the southwestern portion of Beaver Township (T. 105 N., R. 58 W.) there are several small lakes which are permanent.

The southwestern part of the quadrangle is somewhat rougher, owing to the presence not only of James River and several important tributary streams but of a number of sharp gravelly and rocky hills and ridges. These form portions of the Gary moraine, which will be discussed in some detail later. Some of the higher points, as along Enemy Creek on the western border and in sec. 29, Hanson Township (T. 103 N., R. 59 W.), rise to 1380 feet above sea level, with moderately steep slopes.

The northeastern and central portions of the quadrangle, while smoother than the southwestern part, are rougher than the plain west of Rock Creek. There is a general slope to the west, which, east of Wolf Creek, amounts to as much as 50 feet to the mile. The surface here, as throughout the quadrangle, presents the usual features of a glacial drift plain. There are numerous basins and shallow ponds, which occasionally hold water the year round. There is a large basin in the northern part of Spring Lake Township (T. 104 N., R. 57 W.) and another on the south line of Benton Township (T. 103 N., R. 56 W.).

The entire quadrangle is within the prairie region, though in the bends of James River and along its steeper bluffs, as well as at a few points along Enemy Creek, there are small groves. These include cottonwood, willow, elm, ash, maple, and a few cedar trees.

Drainage.—The drainage of the quadrangle has been greatly influenced by the former occupation of the region by an ice sheet, as will be more fully explained under the heading "Pleistocene system."

The principal stream is James River, which in this quadrangle flows through a trough about 30 miles in length. This trough is usually about 100 feet in depth, but in some places in the vicinity of the moraines it deepens to 140 feet. It has abrupt sides and an alluvial bottom averaging over half a mile in breadth. The entire quadrangle is drained by James River and its tributaries with the exception of about 2 square miles in the northeast corner, which lies in the basin of Vermilion River.

The principal tributary of James River is Wolf Creek, which flows entirely across the quadrangle from north to south at an average distance of about 5 miles from the eastern margin. It receives numerous short tributaries from the east. It is the only stream in this quadrangle on the east side of James River containing permanent flowing water, a feature which, however, is found for only a few miles of its course above the southern boundary.

The next important stream entering the James on the east is Rock Creek, which is formed by two branches rising west of the head of Wolf Creek, and flows southwest to James River, joining it just above its junction with the Firesteel. Two shorter tributaries, Johnson Creek and Pierre Creek, rise in the northern part of Spring Lake Township (T. 104 N., R. 57 W.) and enter the James between Rock and Wolf creeks. Other shorter and less important watercourses also enter the James from the east.

From the west, James River receives in this quadrangle two streams, the Firesteel, whose course is mostly outside the quadrangle, and Enemy Creek, which flows nearly due east for about 7 miles through the middle of Rosedale Township (T. 102 N., R. 59 W.). Crossing Rome and Worthen townships is Twelvemile Creek, which has permanent water below sec. 20, Worthen Township, at which point there is a large spring.

GENERAL GEOLOGY.

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 under the heading "Pleistocene system."

The underlying formations of eastern South Dakota are seldom exposed east of Missouri River, though they outcrop in some of the hills where the drift is thin, and along a few of the streams. The numerous deep wells throughout the region have, however, afforded much information concerning the underground structure. There are extensive sheets of Cretaceous clays and sandstones lying on an irregular floor of granite and quartzite of Archean and Algonkian age. Under most of the region this floor of old rocks is over a thousand feet below the surface, but it rises gradually to the surface to the northeast. There is also an underground quartzite ridge of considerable prominence which extends southwestward from outcrops in southwestern Minnesota to the vicinity of Mitchell, S. Dak.

The lowest sedimentary formation above the quartzite under the greater part of the quadrangle is a succession of sandstones and shales termed the Dakota formation, which furnishes large volumes of water to thousands of wells. The Dakota formation reaches a thickness of 200 feet or more in portions of the quadrangle, but it thins out and does not continue over the underground ridge above referred to. It is overlain by several hundred feet of Benton shales, with thin sandstone and limestone layers, and a widely extended sheet of Niobrara formation, consisting largely of chalkstone to the south, and merging into limy clays at the north. Where these formations appear at the surface they rise in an anticlinal arch of considerable prominence along the underground ridge of older rocks, 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 referred to. It was no doubt once continuous over the entire area, but was extensively removed by erosion prior to the Glacial epoch. Doubtless the Fox Hills and Laramie formations once extended southeast of Missouri River, but they also have suffered widespread erosion and but 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 in the Bijou Hills and other higher ridges, but none have been found in this quadrangle.

The Alexandria quadrangle is entirely covered with drift deposits except in the vicinity of streams, where, in the lower portions of the bluffs, and sometimes in the bottom of the trough, the older rocks appear. Such exposures, however, are limited to the southern half of the quadrangle. The general attitude of the older rocks is nearly horizontal. Most exposures of indurated rock are of the intensely hard rock known as Sioux quartzite, of Algonkian age, but along James River and west of it there are also numerous exposures of chalkstone, sandstone, and clay of Cretaceous age.

ALGONKIAN SYSTEM.

Granite.—While the Sioux quartzite underlies a large part of this quadrangle, borings in the northern part have shown the presence of a gray granite. Whether this granite is of Algonkian or Archean age is not known. In most of the northern portion of the quadrangle it is believed to lie immediately underneath the Cretaceous, but elsewhere it probably underlies the Sioux quartzite. It has been found in the NE. $\frac{1}{4}$ sec. 17, T. 104 N., R. 57 W., at a depth 510 feet below the surface, and in NW. $\frac{1}{4}$ sec. 19, T. 104 N., N. 57 W., at a depth of 557 feet. It is possible that outlying areas of the Sioux quartzite may be found resting upon the granite and detached from the main area which underlies the south half of the quadrangle. The granite has been struck at only a few points to the south, but not many borings have been carried to great depth in that portion of the quadrangle. A diabase, a dark igneous rock similar to that exposed near Corson, S. Dak., has been struck at a depth of 506 feet in the SW. $\frac{1}{4}$ sec. 25, T. 104 N., R. 59 W. and at 512 feet in the NW. $\frac{1}{4}$ of the same section.

Sioux quartzite.—This formation is composed mostly of an intensely hard quartzite, usually reddish, though sometimes of a purplish tint, and occasionally the strata show a prevalence of dark gray, as on Enemy Creek and to the north in the valley of James River. Some layers show numerous pebbles and others have well-developed ripple marks on their surface, as at Rockport and Bridgewater. Sometimes these ripple marks are found in a fine-grained stone where the thin strata are alternately red and white, and give the general appearance of rough agate. This was noted at Rockport. The quartzite varies much in the thickness of its strata; in many cases the layers have a uniform thickness of a foot or more for 5 or 6 feet; in other cases they are thin and variable. Exposures commonly reveal only the thicker and more durable strata, for the long erosion to which the surface has been subject has left the harder ledges more prominent. Borings, however, have revealed the fact that the rock is sometimes imperfectly consolidated, and southwest of Bridgewater there are extensive pockets in the solid ledges. Here the material can be excavated with pick and shovel and has been found to make an excellent plastering sand.

No successful attempt has been made to correlate the strata in the different exposures so as to make out a definite series. Southeast of Mitchell and near the border of this quadrangle the dip is 3° or 4° SE., which is the steepest dip found. A serious obstacle in ascertaining the dip is offered by the variable thickness of the strata and the frequent occurrence of oblique lamination. The dip, so far as ascertained, is marked on the Areal Geology sheet. No definite flexures have been discovered.

Besides the common arenaceous strata, layers of pipestone have been observed, notably in the boring east of Elm Spring, where this material was reported 12 feet in thickness and of the usual reddish color. Southwest of Bridgewater fragments of pipestone were found apparently but little out of place and weathered so as to resemble chalk.

No fossils have been observed in the quartzite in this quadrangle. Its thickness is unknown. It has been penetrated over 150 feet at Elm Spring, 221 feet at Mitchell, and 500 feet at Sioux Falls.

As already stated, this is the most widely distributed of the older formations exposed at the surface. It is known to extend under the till as far north as Canova, on the east side of the quadrangle, and on the west side as far north as the south line of Sanborn County. Some of the borings made in search of artesian water have revealed the position of this rock in the central and southeastern portion of the quadrangle. As there is no hope of finding artesian water in or below this quartzite, the well driller has named it the "bed rock," and a knowledge of the depth and configuration of its surface is of great economic importance and is shown by contour lines on the Artesian Water sheet. From these contours it will be seen that the upper surface of the so-called "bed rock" is very irregular, presenting prominent knobs with sharp valleys between. Portions of two high underground ridges may be noted extending from southeast to northwest. One of these enters the quadrangle from the east in Pearl Township (T. 104 N., R. 56 W.) and extends into the southwest corner of Canova Township. Its higher points are over 1400 feet above sea level. Another "bed rock" ridge rises near Bridgewater and extends northwest north of Alexandria into the northwestern part of Jasper Township (T. 103 N., R. 58 W.). A branch which extends toward the northeast attains an altitude of nearly 1400 feet in the central part of Edgerton Township (T. 103 N., R. 57 W.). This ridge continues at a lower level to James River near the south line of Sanborn County.

The exposures of the Sioux quartzite are shown on the Areal Geology sheet, and it will be seen that some of them are moderately extensive. The largest is at Rockport, in secs. 5, 6, and 8 of Beulah Township (T. 101 N., R. 58 W.). It covers nearly a square mile. In general these exposures are in the bottom of the valleys of the largest streams. In this quadrangle the most western exposures are at the southeast corner of sec. 5, and in the northeast corner of sec. 19, Rosedale Township (T. 102 N., R. 59 W.). The most northern is a mile northeast of Fulton.

The quartzite found in this quadrangle is a part of an underground ridge that extends with gradually declining summits eastward from the vicinity of Sioux Falls. This ridge, which was buried by marine deposits in Cretaceous time, presents in the Alexandria quadrangle two moderately deep valleys opening toward the northwest, one of which lies wholly within this quadrangle and is underneath Spring Lake Township, while the other, much narrower and with several branches, lies in the western part of Hanson and the eastern part of Mitchell townships. The north slope of the quartzite surface is very abrupt in the northern part of Edgerton and the southern part of Fairview townships, and also in Hanson Township. In some of the exposures the rock is seen to descend 50 feet or more in a few rods. It is therefore impossible to foretell with much confidence the precise depth to bed rock at all points, and the contours on the Artesian Water sheet show only larger features. At many localities the approximation is within 100 feet, although it is accurate to less than half that amount for the greater part of the area. The depths to "bed rock" are shown in fig. 8 (p. 6).

The quartzite ridge already described appears to have been a land surface in this region during all of Paleozoic and much of Mesozoic time. It was subjected to erosion for a very long period; consequently we find in the eastern half of South Dakota no trace of the Cambrian, Silurian, and Devonian rocks which are so extensively developed in other regions.

CRETACEOUS SYSTEM.

The rocks of this system outcropping in the quadrangle belong exclusively to the Colorado group. The underlying Dakota is well known through numerous well records, but it does not outcrop. The sandstones outcropping at several points in the area and mapped as Dakota on the Areal Geology sheet have, since the completion of the map, been determined to be Benton, and hence belong to the Colorado group. Whether certain portions of the Lower Cretaceous, the Fuson shale and Lakota sandstone, are present beneath the Dakota can not be definitely determined. If present they are not discriminated from the Dakota in the well records. It is probable that the Pierre shale, which normally occurs above the Colorado group, does not occur in the quadrangle. If it was originally present it has probably been removed by erosion.

DAKOTA FORMATION.

The Dakota formation supplies water to all of the more important artesian wells in North and South Dakota. Nowhere in this quadrangle does it come nearer the surface than about 200 feet. Judging from wells, it consists of sand and sandstone, from 50 to 100 feet in thickness, interstratified with masses of clay or shale. As exhibited in the rim of the Black Hills, the formation is usually a brown sandstone, hard and massive below, but thinner bedded above, having an average thickness of 100 feet. It varies from fine to coarse grained and usually is only moderately compact. The material obtained in many borings in eastern South Dakota is mostly a fine-grained gray sandstone. The formation abuts against and partly overlaps the ridge of red quartzite along an irregular shore line, the original level of which has been considerably changed by flexure. It is absent in the central and southern portions of the quadrangle.

The shales of the Dakota resemble those of the overlying formations, and like them occasionally contain calcareous concretions which may be mistaken for limestone. Sometimes, also, there are concretions of pyrite large enough to offer a considerable obstacle in drilling. The different layers of sandstone are often harder near the top, and this has given rise to the expression "cap-rock." Frequently the drill has to penetrate several feet of hard rock before the water-bearing strata are reached.

It is the impression among some well borers that this water-bearing rock is not a sandstone, but a porous limestone. While it is possible that the cementing material is sometimes lime, there seems to be no doubt that the strata conducting the water are uniformly sandstone.

In the north-central and western portions of the quadrangle the thickness of the Dakota formation is about 50 feet, but it increases rapidly to the north and west and probably is over 200 feet in the northwest corner. In the northeast corner it is not unlikely that a similar thckness may be found, while in the southwest corner, near the quartzite ridge, its probable maximum is not much over 25 feet. It finally thins out in the central and southern portions of the quadrangle, where it abuts against the quartzite.

The structure section, fig. 1, shows the distribution and character of the formation, as regards both thickness and the number of strata represented along a north-south line across the quadrangle. In studying the section it should be remembered that the data given by well borers, upon which the section is based, are indefinite in many respects. The drill commonly used is a hydraulic machine in which a jet of water is used to bring up the borings, hence the exact character of any particular portion can not be very definitely learned, as the rock brought to the surface is usually finely pulverized and is mixed with the mud of several different strata. Moreover, unfortunately, the driller is usually not disposed to examine the deposit with much care, nor to measure carefully the exact position and thickness of many strata which would be of special interest to a geologist. The driller is interested chiefly in the water-bearing strata, and in only such of these as produce a flow sufficient for his purpose. When asked for a record of a particular well, he is apt to remember only the depths at which water was struck and at which the greatest resistance was encountered. We may safely conclude that the deeper sandstones are often thicker than is represented in the section.

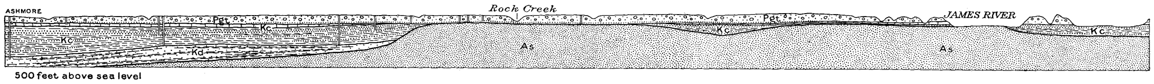


FIG. 1.—Sketch section across the Alexandria quadrangle along the line A-A on the Artesian Water sheet, showing the artesian wells in that vicinity extending to the Dakota water-bearing sandstone. As, Sioux quartzite; Kd, Dakota formation; Kc, Colorado group; Pgt, glacial till.
Horizontal scale: 1 inch=3 miles. Vertical scale: 1 inch=1500 feet.

As shown in the section, the lowest sandstone of the Dakota usually rises as it approaches the quartzite ridge and overlaps it somewhat. This tendency to rise toward the quartzite is probably due partly to original deposition of the sand on a sloping shore of quartzite and partly to subsequent uplift. As a result of this relation of the sand strata to the quartzite, the sandstone beds dip toward the north in the northern half of the quadrangle and toward the southwest in the southwest corner.

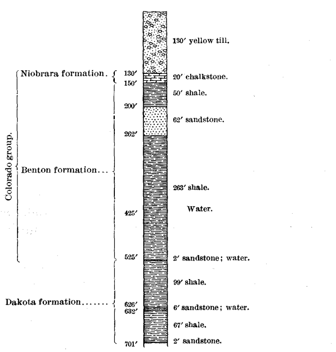


FIG. 2.—Section of well in the northwest corner of the quadrangle, sec. 18, T. 106, R. 59.

The Dakota formation is considered to be a fresh-water deposit, as molluscan fossils are rarely found in it, and those that do occur are of a few distinctly fresh-water species. These have been found mainly near Sioux City and in Nebraska and Kansas. In outcrops near Sioux City and in a well in the vicinity of Hitchcock fossil leaves of deciduous trees have been discovered in the sandstone of this formation, and at some localities farther south they are very abundant. This indicates either that this formation was laid down near the shore or that the waters depositing it were subject to strong currents that carried the leaves far from land before they were decomposed.

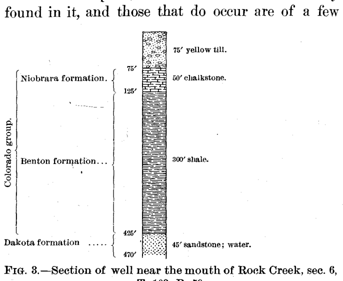


FIG. 3.—Section of well near the mouth of Rock Creek, sec. 6, T. 103, R. 59.

COLORADO GROUP.

This group exhibits two distinct formations. The first or lower is the Benton shale, named from its prominent development near Fort Benton, on the upper Missouri. In the southeast corner of South Dakota it consists of lead-colored or dark-gray shale containing calcareous and ferruginous concretions. Where it is exposed along Missouri River it is estimated to have a thickness of about 200 feet, but it thins to the east. In the vicinity of the Black Hills the thickness is much greater and it is divided into several formations. There it is largely dark-colored shale, but it contains layers of sandstone, sometimes of considerable thickness, and also a persistent layer of shaly limestone abounding in *Inoceramus labiatus*. These features are also prominent in the southeastern South Dakota region.

The second or upper member is the Niobrara chalkstone, named from its prominence near the mouth of Niobrara River. It is usually of a drab color except where it has been weathered; it may then have a snowy whiteness or, more commonly, a light-straw color. It varies considerably in composition, often carrying a large proportion of clay. Owing to its variable composition it is not always clearly distinguished from the Benton shale below. The purer chalk seems to be limited to 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.

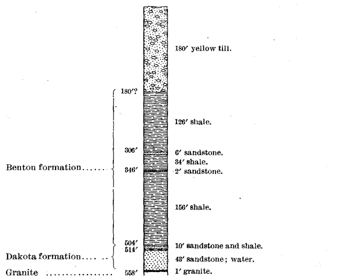


FIG. 4.—Section of Ruth well, 9 miles north of Alexandria, sec. 30, T. 104, R. 57.

Benton formation.—In this quadrangle the Benton formation is somewhat unusual in character, since it includes a relatively larger amount of sandstone than is commonly found in it elsewhere. The general section includes an upper and a lower shale bed with a thick sandstone between. The upper shale bed is occasionally absent, particularly in the northern portion of the quadrangle, and in the lower shale there is a second, thinner sandstone over at least a portion of the quadrangle.

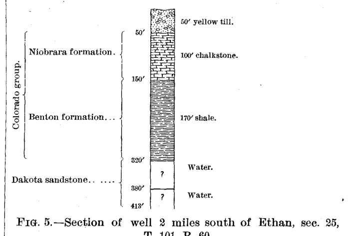


FIG. 5.—Section of well 2 miles south of Ethan, sec. 25, T. 101, R. 60.

The basal member of the Benton consists of 100 feet or more of gray and black shale, indistinguishable from similar deposits in other formations of the Cretaceous. Above the basal shale there is a sandstone which for some time has been considered the top of the Dakota and is so represented on the Areal Geology sheet. It appears at several places in prominent exposures. The most northern exposure is in sec. 22, T. 104 N., R. 60 W., in the bottom of the trough of James River, just beyond the western border of the quadrangle. The sandstone also occurs on Enemy and Twelvemile creeks, and it has been found in numerous borings throughout the quadrangle. It varies in thickness from 20 to 50 feet or more. It is a rusty-brown sandstone, usually hard and dark colored on the surface, but softer below. It varies much in character, in some places being coarse and containing small pebbles, and at others being extremely fine grained. In strata 3 or 4 feet in thickness it frequently shows oblique lamination. This sandstone, in the northern portion of the quadrangle, is found immediately beneath the chalk of the Niobrara, but toward the south an upper, clayey member occurs between them and attains a thickness of 50 feet or more. This clay appears in several wells, but its only outcrops are in secs. 25 and 26, T. 103 N., R. 60 W., where it occurs near the railroad on opposite sides of a ravine leading into James River. The clay readily absorbs water and becomes so plastic as to creep on the hillsides. The records of a number of wells in the northeastern part of Hanson County also show that several feet of clay occur between the chalkstone and the upper Benton sandstone.

Fossils characteristic of the Benton have been reported from wells on the east side of James River, near the south line of Hanson County, more than 100 feet below the surface.

Niobrara formation.—As already stated, chalkstone is the most characteristic feature of this formation, but it no doubt contains considerable deposits of clay. This formation is especially difficult to recognize in wells where the chalk has not been exposed to atmospheric action. In such cases the chalk has a lead color and closely resembles the gray clays of the Benton.

The chalkstone is exposed at many points along James River and its western tributaries, as will be seen from the geologic map. It often forms cliffs 15 to 20 feet above the adjacent streams, but as it is quickly disintegrated when moist and exposed to freezing, it more frequently appears as a steep slope with whitish soil and stunted vegetation. Over most of the quadrangle the chalkstone has been greatly thinned by erosion, and it does not outcrop in the central and northeastern portions.

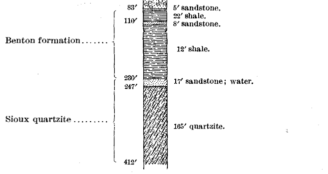


FIG. 6.—Section of well at Elm Spring, sec. 33, T. 101, R. 58.

The formation rises on the slopes of the underground quartzite ridge. Over its crest the upper members were removed by erosion before the ridge was covered by glacial deposits.

The chalkstone frequently contains fish teeth and scales, mostly of bony fishes, although sharks' teeth are also found. Occasionally perfect specimens of bony fishes have been found. The most common fossil is the small oyster, about an inch in length, called *Ostrea congesta*. These are frequently clustered on the fragments of large bivalve shells, either of *Pinna* or *Inoceramus*. Even where there are good exposures the latter are rarely found except in small fragments.

Well sections showing the character and relations of the Cretaceous formations in different portions of the quadrangle are given in figs. 2 to 6.

PLEISTOCENE SYSTEM.

The formations so far described are all sedimentary and, with the possible exception of the Dakota, are of marine origin. The Pleistocene deposits, however, present a marked contrast, not only in their origin but in their occurrence. They are the products of glacial action and overlie almost all 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 partially stratified clays, sands, and gravels formed along abandoned river channels and terraces. The bowlder clay forms a great sheet spreading over nearly the entire quadrangle. The morainic material occurs in a series of rough, knobby hills and ridges crossing the southwest corner of the quadrangle from northwest to southeast, with smaller areas in the southeast and northwest corners of the quadrangle. The channel and terrace deposits fill valleys and cover flat areas mainly lying in close proximity to the morainic ridges.

Till or bowlder clay.—The till 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 latter sometimes attaining a diameter of several feet. In it are local developments of stratified sand, sometimes merely pockets, sometimes portions of channels of considerable length, and sometimes sheets that locally separate the bowlder clay into two or more members. The till of this region is much more clayey than 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 erratics are perhaps less frequently 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 the sections they may sometimes be distinguished, but not always. The blue clay, moreover, is apt to be confused by well drillers with the underlying Cretaceous clay of similar color, so that in their reports part of this clay may in some cases be included with the Pleistocene formation.

No distinct traces have been found of a subdivision of the till into two different members, as occurs in some other localities. It should be noted, however, that even if there should be a division there is little likelihood of its being reported by well drillers, since the Pleistocene is not frequently the source of water supply and hence the drillers are less critical in their observations on it than on the underlying rocks. Occasional fragments of wood have been reported from it, but in every case inquired into they were clearly isolated pieces and not parts of a general "forest-bed."

The till of the entire quadrangle lies within what is known as the second or Gary moraine, which is described below. Both the moraine and the drift were formed by the Wisconsin ice sheet. In the northwestern portion of the quadrangle there is an area of very level land, where the drift seems to have been deposited under lacustrine conditions. The glacier descending the James River Valley evidently eroded more deeply in the soft deposits than in the hard quartzite which lay athwart its course in the southern half of the quadrangle. As a result, the débris left by the melting ice sheet fell into a shallow lake. While the surface material in this portion of the quadrangle does not differ greatly in composition and general character from that farther east and south, it presents a much more even surface, and there are numerous extensive depressions below the general level. These facts support the hypothesis that a shallow lake existed in this region.

The surface of the till throughout this quadrangle presents the usual features of a drift-covered plain. In the northwestern portion, as just noted, there is a wide area containing minor lakes and depressions and representing probably a temporary lake. In the southwest, as well as in the extreme northeast and northwest, there are morainic areas. The remaining surface has the usual rolling contour characteristic of drift plains, and is more or less covered with silt, probably in part laid down by the waters escaping from the ice and in part deposited by the winds since the retreat of the ice, or formed from hillside wash.

The till is less than 50 feet in thickness over considerable portions of the southeast-central part of the quadrangle, in the southwest quarter, and also in a narrow area south of Canova. It thickens rapidly to the east to nearly 200 feet, and more gradually to the north to about 150 feet, a thickness which it maintains across the whole northern end of the quadrangle. In Hanson Township and extending some distance to the southeast there is also an area of thick till.

Striæ.—None of the exposures of older rocks in this quadrangle exhibit glacial striæ except the quartzite, and this exhibits them best where the surface has not been long exposed to weathering. The chalkstone and sandstone present no striæ, because they are too soft to preserve them.

The following table shows the direction of the striæ so far as noted:

divisible into three quite distinct members. The first or oldest is a northwest-southeast belt of rough land about 2 miles wide south of Ethan; the second includes three detached areas of rougher and higher ground lying between Enemy Creek and Twelvemile Creek, as is shown on the map; and the third, beginning with the high ridge south of Mitchell, extends southeast and east across James River to the high point northwest of Bard, where it seems to have formed in a notch in the edge of the ice sheet. It also includes the higher knolls which lie within 2 or 3 miles of the James River, along its east bank, the last being at Elm Spring. These areas are not all of equal prominence. Some are very rough and others are simply low, broad swells with occasional basins. These three members were formed in the order given as the southwestern margin of the ice lobe receded,

Glacial striæ on quartzite in the Alexandria quadrangle.

[Corrected for magnetic variation.]

Rockport:	
Schoolhouse at west side of valley	S. 22°, 49°, 51°, 57° E.
Farther east	N. 78° W., S. 78° E., S. 51°, 59°, 65° E.
Northeast of Fulton, sec. 8, T. 103 N., R. 58 W.	S. 2°, 10°, 20°, 22° E.
East of Fulton, sec. 15, T. 103 N., R. 58 W.	S. 17°, 27° E.
Pierre Creek:	
Five miles northeast of Alexandria	S. 14°, 17° E.
Three miles northeast of Alexandria	S. 8°, 21° E.
Southeast of Alexandria	S. 4° W., S. 28° E.
Wolf Creek:	
Sec. 24, T. 103 N., R. 57 W.	S. 8°, 12°, 17°, 22°, 29°, 32°, 37°, 42°, 49°, 57° E.
Southwest of Bridgewater	S. 12° W., S. 12°, 15°, 17°, 19°, 21°, 22°, 27°, 29°, 39° E.

In most cases the rock shows an irregular surface, with the corners of the blocks rounded and the striæ only in small patches. This may be partly the result of weathering, but probably it was due largely to the feebleness of the glacial action. Southwest of Bridgewater, however, in the bottom of Wolf Creek, the quartzite is nearly as level as a floor over several square rods, and is marked by deep striæ. Near the stream there is a steep hummock 8 feet high.

In numerous cases where striæ have not been cut in the surface of the quartzite the direction of the movement of the ice is recorded by series of crescentic cracks. These series vary in width from an inch to 18 inches, and sometimes have a length of 2 or 3 feet. The cracks curve like crescents, lie nearly parallel to one another, and at regular intervals. In the smaller series the cracks are about half an inch apart, but in the larger the interval between them is frequently 2 or 3 inches. The convexity of these cracks is toward the north, or in the direction from which the ice moved. In the larger series these cracks extend into the quartzite sometimes to a depth of an inch or more, and their dip is almost perpendicular, inclining a little toward the concave side. The breadth of the series in each case seems to have depended upon the size of the pebble or bowlder which was pushed over the surface of the underlying rock by the ice.

Moraines.—The moraines in this quadrangle are characterized mostly by a subdued type of topography. During their formation the ice was comparatively thin and the débris consisted largely of clay. At a few points the morainic hills present steep, high ridges, but none of these are more than a mile in length. A ridge of this character enters the quadrangle immediately south of Enemy Creek, and a conspicuous example is seen in the high point in secs. 28 and 29, Hanson Township (T. 103 N., R. 59 W.). These ridges rise from 60 to 80 feet above the adjoining surface, but more commonly the knolls are low, not often more than 10 to 20 feet in height, and nowhere arranged in a very crowded form. One of the best examples of the low ridges is seen south and southeast of Ethan. In morainic areas covering a few square miles along the east side of James River, especially northeast of Rockport, the surface is rough and there are numerous small, deep basins among the hills.

The morainic areas are mainly comprised in three groups. The most extensive is in the southwestern part of the quadrangle, and, with its intervening channels and plains of till, covers the entire region southwest of James River and includes a series of prominent knolls along the eastern bank of that stream. A second area occupies several square miles in the northeastern portion of the quadrangle and is very faintly marked. A third area occurs in the northern part of Spring Lake Township (T. 104 N., R. 57 W.), in the northwest corner of the quadrangle.

The southwestern morainic area is naturally

and are doubtless representatives of the Gary moraine, which derives its name from its development near Gary, S. Dak.

The area in the northeastern portion of the quadrangle is more marked by its elevation above the drainage channel just east than by any very conspicuous difference in its surface features. It is believed to have been formed about the same time as the third member in the southwestern area. The portion extending faintly into Spring Lake Township, however, is apparently a thin local accumulation deposited during the recession of the ice sheet, considerably later than the other members. It seems to have resulted from the damming of one of the drainage channels which flowed from the ice sheet and the burial of a large ice mass in the northern part of Spring Lake Township. As a result, the débris which otherwise would have been carried away accumulated in a ridge extending southwestward. A few knolls farther west seem to be properly correlated with this morainal accumulation.

The area in the northwest corner apparently belongs to the Gary, but to a later stage than the areas in the southwest corner.

Ancient channels and terraces.—Scattered throughout the quadrangle are numerous abandoned channels and terraces, the locations of which are shown on the geologic map. Usually, though not always, these 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. In such cases the latter have been included under this head. The former channels correspond generally with the present waterways, for the latter are the puny successors of the former, though in some cases 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 the channels were long occupied by vigorous streams. In both cases the coarser deposits are usually 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 cases the old channel deposit is at a height of 80 to 100 feet above the present streams. In many cases, however, the old deposits have been slightly trenched, as the later drainage has passed off in another direction.

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

The order in which these channels were occupied is shown on the Areal Geology sheet, where they are numbered, but it should be remembered that it is impossible to represent the order with minute accuracy. This is the case along the present course of James River, where the southern portion of the channel, which is outside of the third member of the moraine, was probably occupied considerably earlier than the portion farther north, which was inside of this member of the moraine.

The first channel occupied by glacial waters is that in the extreme southwest corner of the quadrangle, just outside the area of the first member of the southwestern moraine. This is a portion of a channel which drained the water from all the western side of the ice lobe that occupied the James River Valley. The channel which next furnished an outlet for glacial water is now occupied by the northern branch of Twelvemile Creek, and corresponds in time with the second member of the moraine. The channel which crosses the extreme northeast corner of the quadrangle was probably contemporaneous with this. The channel next developed is that followed by the present Enemy Creek. At first this channel overflowed to the southeast, but as the ice receded it followed more closely the west side of the trough of James River. At about the same time the ice uncovered the lower portions of the eastern tributaries of James River and the channel now occupied by Wolf Creek, which for a time drained the whole eastern edge of the ice sheet. The rapid melting of the ice caused these streams to be greatly swollen and to deposit much sand and gravel. As the eastern side of the ice receded to lower ground, new drainage lines were developed along its margin. At one time the eastern branch of Rock Creek had its outlet southward through Spring Lake Township into Pierre Creek, but some blocking of the course, possibly by a detached mass of ice, or by the upward bulging of the till because of the unequal transfer of pressure, caused the water to flow westward along its present lines into Rock Creek, running possibly for a short time along the line of Johnson Creek. A further recession developed another line of drainage across Beaver and Plano townships; still later there was another channel across Diana and Union townships.

Alluvium.—All of the streams that traverse the 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 these ancient channels and lake basins, already referred to, are thickly covered with fine silt, which is in part dust deposited from the air. The alluvial plain of James River is about half a mile wide. Some portions of it are dry and are well adapted to cultivation; other parts are marshy, and all are 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.

GEOLOGIC HISTORY.

As the area exhibits no rocks older than later Algonkian, the earliest phases of the history of the region of which this quadrangle is a part may be stated very briefly. At some stage preceding the formation of the Sioux quartzite a land surface composed of granite and slate occupied central Minnesota, and possibly extended north and east of this quadrangle. From that land area material was derived, both by the action of streams and by wave erosion along the shore, which was laid down over the region now occupied by the Sioux quartzite. The deposits consisted mainly of stratified sands, but occasionally comprised thin beds of clay. The deposits were thicker toward the center of the broad area that now extends southwestward from the vicinity of Pipestone, Minn., and Sioux Falls, S. Dak. 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, S. Dak., and in borings at Yankton and Alexandria, S. Dak., and of quartz-porphyry near Hull, Iowa.

Through silicification the sandstone thus deposited was changed into an intensely hard and vitreous quartzite, while the clay beds were formed into pipestone and more siliceous red slate, as at Palisade. Microscopic examination shows that this silicification was caused by the crystallization of quartz around the separate grains of sand until the intervening spaces were entirely filled. The material of the quartzite was thus laid down in the sea, and at first may have included scores or even hundreds of feet of material above that which is now found. In time the region was lifted above the sea, and during some part or all of the long era of the Paleozoic 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.

At the beginning of Jurassic time the land began to subside and the sea gradually advanced in central South Dakota, but apparently in this region a land surface continued until much of Cretaceous time had passed, for the first deposits appear to have been sediments of Dakota time. These were mainly sands deposited on beaches and in estuaries, but in intervals of quieter and deeper waters clays also were laid down. The sands, which were doubtless carried to and fro by vigorous tidal currents, were probably derived in part from the disintegration of the quartzite along the adjacent shore. The clay may be traced with considerable confidence to the soil and fine material that were washed from the land as the waters continued to advance toward the east.

At the end of the Dakota epoch the ocean waters overspread the region as far as southeastern Minnesota, and the deposition of the Benton shale began. There were some short periods of shallow waters with strong currents which deposited local layers of sand, but clays were the predominant sediments. In Niobrara time the waters were deep and clear in the greater part of the area and large deposits of carbonate of lime accumulated, now represented by the chalkstone. At this time there was abundant life in the waters, including fishes, huge reptiles, and mollusks. Deep waters with clay deposition continued during Pierre time, and probably several hundred feet of Pierre sediments extended across southeastern South Dakota. In the latter part of the Cretaceous there were at first shallow ocean waters of Fox Hills time and then brackish and fresh waters in which the Laramie sandstones were laid down, but as these formations are absent in the region lying to the southeast there is no evidence as to the conditions existing in southeastern South Dakota during this epoch. Presumably the region was then a land surface, which probably continued during Tertiary time, when some of the streams of the late Tertiary spread local deposits of sands in portions of the region. If, however, these sands covered any part of this quadrangle they have been removed by erosion. During the later part of Tertiary time there was doubtless a large stream flowing southward somewhere near the present position of James River.

Such was the condition that existed until the Ice Age began, when the climate became moister and colder. During the earlier stages of the Ice Age, before and during the Kansan stage, the ice had not passed over the divide between James River and Red River, and hence the streams, though swollen by rains, did not receive water from the ice. If the ice reached the boundary of this State it did so probably in Minnehaha County, coming over from the Minnesota Valley, and Big Sioux and Vermilion rivers carried off the products of melting.

During the Wisconsin stage the ice finally crossed the divide, entered the James River Valley, and steadily progressed down that valley until it had filled it to a depth in the center of 1000 to 2000 feet. At that time the ice extended westward as far as Kimball, southwest of Lake Andes, southward to Yankton, and eastward to Lake Madison. During this stage the region was being ground down and the chalkstone carried away to be mingled with the débris of the ice sheet.

This condition continued probably for hundreds of years, but in due time, for some reason, the strength of the ice current was checked, and it gradually melted back until this quadrangle and the adjacent region became uncovered.

The ice paused in the retreat, and, after forming a slight moraine south of Huron and another near the north line of the State, it then receded so far that it no longer influenced this area. The streams by this 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 that were permanently occupied by water. It is believed that James River had cut nearly to its present depth before the ice disappeared from the State.

The principal geologic event since the disappearance of the ice sheet has been the deposition of the thin mantle constituting the soil. This has gone on by the formation of alluvium along the principal streams, by the wash from 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 of vegetable remains.

ECONOMIC GEOLOGY.

There are no deposits of mineral ores or of coal in this quadrangle. The few samples which are sometimes submitted as "mineral" are invariably iron pyrites, which has no value unless found in very large quantities. Fragments of coal are sometimes found in the drift, but these have been brought by the ice or by streams from the northern part of the James River Valley, in which are found beds of lignite.

BUILDING STONE.

Much of the stone locally used for foundations and other rough building is derived from the drift. It consists of granite, limestone, and greenstone bowlders, which are extremely durable and, when carefully selected, give very neat effects.

Quartzite.—The red quartzite commonly known as "Sioux Falls granite" or "jasper" is a most durable rock, and although very hard the natural jointing of the rock and its brittleness make it possible to quarry and shape it with comparative ease. It is composed almost exclusively of quartz. Several varieties are distinguished by different shades of color, varying from light pink to dark gray, with intermediate shades of purple. It varies from extreme hardness, the most common phase, to grades of soft sandstone. The bedding and jointing of the rock in certain localities render it most suitable for paving stone. Layers of sufficient size for large building stone are usually found with little difficulty. At almost any of the localities marked upon the map, valuable quarries might be developed if the demand for the stone were sufficient. As it is, systematic quarrying has not been carried on except southwest of Spencer, in the valley of Wolf Creek.

Polished samples of this rock were exhibited at the World's Columbian Exposition, and the report "Mineral Resources of the United States" for 1893 contains the following statement regarding it:

> This stone shows occasional small knots which will not take polish, but these do not seriously interfere with its beauty. The stone, although beautiful enough for ornamental work, is at present quarried for paving purposes, the blocks being used in Chicago, where they have given satisfaction. The stone splits easily into paving blocks, and it is claimed that it can be worked for this purpose more cheaply than granite. The crushing strength gave about 22,000 pounds to the square inch. The quarrying of this stone has been going on for about ten years, and it is becoming fairly well known to the country at large as well as to such of the western cities as have had practical experience with it.

The quartzite is a favorite stone for important buildings. The medium-colored varieties are used for the main walls, while the darker and lighter ones are used for trimmings. It is practically indestructible.

Sandstone.—The brown sandstone of the upper Benton has been little used in this quadrangle, but doubtless durable blocks might be obtained without much difficulty along Enemy Creek, in sec. 18, Rosedale Township (T. 102 N., R. 59 W.); also along James River above Elm Spring. Some layers are very hard, while others are soft. They are irregular in form and not suitable for fine work. The stone varies in color from yellow to dark brown.

Chalkstone.—There are no ledges of limestone in the region, but chalkstone has been locally used for the walls of buildings, especially in early years, and several put up at that time show its pleasing appearance and afford evidence of its durability. The stone, when carefully chosen and seasoned, seems to be easily worked. It may be cut with a common saw, but hardens by exposure and withstands the effects of weather well. The main drawbacks are the difficulty of finding blocks of sufficient size and the danger of injury in quarrying. The rock varies in color from a dull white to a cream yellow. When left moist, as upon the ordinary surface of a hillside, it is broken and disintegrated by frost, so that but few blocks of any size appear after a few seasons, but on an abrupt slope or in a cliff where drainage is good it stands for years. Quarries have been opened at a few points, as shown on the Areal Geology sheet.

CLAY.

Deposits of clay of economic value are rare. Brick has been made from the Benton shale or clay exposed near the railroad southeast of Mitchell and near the western border of this quadrangle. The localities are shown upon the geologic map. The clay is not very well suited to this use, however, because of small lime nodules scattered through it. These have to be sifted out or thoroughly ground.

It is possible that diligent search may discover in some of the old channels or in the flood plains of the recent streams accumulations of silt of sufficient depth for brickmaking, but nothing of this sort has yet been found. The common glacial till might be suitable for this purpose if it were not so charged with pebbles and coarser material, much of which is calcareous.

SAND AND GRAVEL.

Sand and gravel are abundant in the channels occupied by Glacial streams. So far as can be judged from appearances, these deposits are suitable for use. Pits have been opened in the vicinity of nearly all the principal towns. Sand may also be obtained from the softer strata of the Benton sandstone. This sand, however, is too fine for many uses. In the exposure of quartzite southwest of Bridgewater a place is found where the strata have not been consolidated, and sand may here be excavated with pick and shovel. This pit furnishes an excellent quality of clean, uniform plastering sand.

WATER.

Water is of the utmost importance in this region, and probably the most valuable result of geologic investigation is the information obtained regarding its distribution, variety, and accessibility. Water may be classified into surface waters, including springs, streams, and lakes, and subterranean waters, including both pump and artesian wells.

SURFACE WATERS.

Streams.—Running water is found throughout the year only along James River and a few miles of the lower course of Enemy Creek. James River is a sluggish stream, several yards in width and from 3 to 10 feet deep. Because of its steep banks and soft bottom it can rarely be crossed except by bridges. The water is more or less hard and has the qualities common to surface streams.

Enemy Creek shows running water from its mouth to the west boundary of the quadrangle, but in the latter part of summer the stream in its narrower portions is not more than a yard in width and 3 or 4 inches deep. The amount of water conveyed by the stream, however, can not be judged from its size, as a large portion of the water carried by this and the other streams of the quadrangle flows underneath the surface through the surrounding gravel. Along most of its course there are deep ponds, nearly a rod in width and 3 or 4 feet deep, which extend up the valley some distance beyond the head of running water. The water in the water-holes is kept pure by its passage through the gravel; in fact, the ponds have the general characteristics of springs. It is probable that much of the water in this stream is derived from the upper stratum of the Dakota or the Benton sandstone, which also supplies the soft-water pump wells of the region.

Similar statements may be made of Twelvemile Creek. The upper portions of the streams generally carry much water in the spring and after a rain, when they are subject to flood. Water holes are found along the streams at distances which increase more and more as the source is approached. As the season advances, the holes dry up one after another, the larger ones being most persistent. They usually show connection with a subterranean movement of the water, and if kept free from contamination afford good water. The exceptions to this statement are shallow pools which are separated from the subterranean flow by an impervious layer of sand.

Springs.—The water-holes just mentioned are really springs, but there are better examples. The springs of the region are supplied from at least three different horizons, and, as in other regions, the springs are near the larger streams.

The source of springs in this area is commonly in the Pleistocene deposits. The water comes from layers of sand and gravel, above, within, or underneath the bowlder clay, more commonly from the coarse material deposited in old channels or upon terraces. Frequently where a recent stream has cut across an older channel a springy slope appears. Such springs are often copious and constant and usually may be recognized by their high altitude. They are sometimes 50 feet above the present streams. Most of the springs are of this class.

No distinct cases can be mentioned of springs deriving their waters from layers of sand within the till, but there are many which derive their waters from underneath the till.

A few springs may possibly derive their waters from the Niobrara formation. It is known that in adjacent territory water is found following crevices in the chalkstone and underlying shale. There are only a few points where impervious layers of clay between the chalkstone and the sandstone appear at the surface, and hence the water is not apt to be brought out in the form of a spring. It should be remarked that the chalkstone does not readily absorb and distribute water unless it has been weathered. A few springs derive their waters from the upper Benton sandstone. These are the most copious in the region.

Lakes.—The map sufficiently indicates the lakes; none are large or very prominent except those in the southwestern part of Miner County.

SUBTERRANEAN WATERS.

In the discussion of surface waters reference was made to the close connection between water-holes along watercourses and the motion of waters near the surface in the upper part of the till. Mention has been made also of the connection between springs and the water in the drift, as well as the waters in the Niobrara chalk and the upper Benton sandstone. Thus far surface waters only have been treated. Those obtained from below the surface by artificial means will now be discussed. These may be studied under the headings shallow wells, tubular wells, and artesian wells.

SHALLOW WELLS.

By shallow wells is meant those supplied from waters that have recently fallen on the surface and that can be obtained without penetrating an impervious layer. Wells of this class can easily obtain water close to any of the present watercourses, whether these contain standing water on the surface or not, and also in the vicinity of basins, especially after a wet season. Such wells may obtain water at depths ranging from 10 to 50 feet, but do not afford a copious or permanent supply except when located near the bottom of a large depression or near a channel draining a considerable area. The reason for this is obvious, since the water comes from precipitation only and the region is subject to continuous droughts. Only those wells of this class that are so situated as to draw from a large catchment basin can be depended upon for a permanent supply. In digging such wells, if no water is reached before the blue bowlder clay is struck, none will be found until the clay is passed through.

TUBULAR WELLS.

Under this head will be included simply the deeper wells in which a tubular or force pump is usually necessary. Frequently the water rises nearly to the surface, and occasionally it flows. These wells are from 100 to 300 feet deep. In this region the deep tubular wells usually derive their waters from the upper sandstone of the Benton formation, but a few obtain water from the sands underneath the till, or sometimes from the chalk just below. Others possibly procure water from the lower part of the Niobrara formation, although the last is uncertain. The depths to the base of the drift are shown in fig. 7.

A very important and valuable supply of water is derived from the first sandstone below the chalk, which has been erroneously called the first sandstone of the Dakota, and is so shown on the Areal Geology sheet. Throughout the whole quadrangle this water is soft. It is not pure, but carries considerable quantities of soluble alkali, which, however, does not give it a disagreeable taste. Unlike the waters from lower levels, it does not rust iron and tin, and it may be used for washing without the use of any alkali to break it. It is the favorite supply of tubular wells, and many draw from this source who have a copious supply of artesian water.

Certain of the wells deriving their supply from near the base of the drift are characterized by a high pressure. Areas where such flowing wells have been obtained are shown on the Artesian Water sheet. The head sufficient to cause this high pressure must be sought without the drift, for there are no local elevations sufficient to account for it. Neither can there be found sufficient head in the upper sandstone of the Benton formation, for that is exposed not very far west of the area, and the water in it has but feeble pressure. It is therefore concluded that the pressure comes from a lower water-bearing stratum, outcropping beneath the drift, and the absence of the Niobrara chalk and upper Benton sandstone may be accounted for by their removal by glacial action. This seems to be borne out by a study of adjacent well sections and the thickness of the drift over the area. The flows in the eastern and larger area of such water supply shown on the Artesian Water sheet are with some certainty referred to that source. These flows seem clearly due to the rapid rise of the water-bearing stratum toward the east and north. In this area there is such an increase in pressure and such continuity in the water in tubular wells adjacent as to establish this conclusion. The deeper wells in the Plano Township area derive their water from the lower Benton sandstone.

ARTESIAN WELLS.

The ease with which flowing wells have been obtained from the Pleistocene in this region has prevented the sinking of many deeper wells into the Benton and Dakota formations in the artesian area, but as the former supply is gradually failing, a rapid increase in the number of deeper wells may be expected.

Main artesian supply.—The deeper wells derive their waters directly from either the Benton or the Dakota sandstone. The lower horizons of the Dakota sandstone in particular afford an abundant supply under good pressure. Below this is the "bed rock" of well drillers, the limit of profitable boring, and the depths to its surface are indicated in fig. 8.

The location and depth to flow or flows of the wells so far drilled are given on the Artesian Water sheet. There are several of the deeper-seated water horizons, but most of the wells are supplied from the "first" and "second" flows, as they are popularly called, while the stronger and larger wells are supplied from the "third" and "fourth" flows. It is improbable that these water-bearing horizons preserve their continuity throughout the artesian basin, and these terms are relative only. The sandstones are in widely extended sheets, with intervening deposits of shale or clay, and doubtless they vary greatly in continuity, porosity, and relative position; hence a sandstone that affords a flow in one locality may thin out and yield no flow in another locality. Moreover, any estimate which comes from a comparison of simple depth may be misleading, because of the very gradual slope of the surface, which, although it appears to be a level plain, in fact often slopes 20 feet or more to the mile.

The extent, thickness, and variable character of the sandstone strata of the Benton and Dakota have been described. One of these strata may constitute a single water-bearing horizon; or two, if connected either by porous beds or by breaks in the intervening shale, may be considered as forming a single horizon, although, if the water is in motion, its flow may be irregular in volume and its pressure and rate of movement may vary greatly from place to place. Whether the supply in different wells or from different depths in the same well is from the same sandstone or not will be most clearly determined by the pressure. In other words, the pressure should be the same from the same sandstone bed in the same locality. In some cases the evidence of pressure is not trustworthy, for some wells, which have imperfect casing or connections, allow the water to escape beneath the surface, so that it does not show its full force at the mouth of the well. From the different pressures in different wells and of waters from different depths in the same well it is evident that there are, as before stated, several water-bearing beds in the Dakota formation underlying portions of this quadrangle.

From a comparison of depths, pressures, and amount of flow it may be inferred, not only that the water-bearing beds are mainly in sheet form, but that these sheets rise as they approach elevated portions of the underlying quartzite ridge and overlap, and yet each sandstone probably ends at a certain horizon, which originally corresponded to that of the seashore at the time the sand was deposited; hence the lower beds do not extend so far as the upper, and are more closely sealed along their eastern margin. It is not impossible that, by the interpretation of carefully taken pressures at wells, evidence may be found showing that different water-bearing sandstones communicate imperfectly with one another along the upper surface of the quartzite.

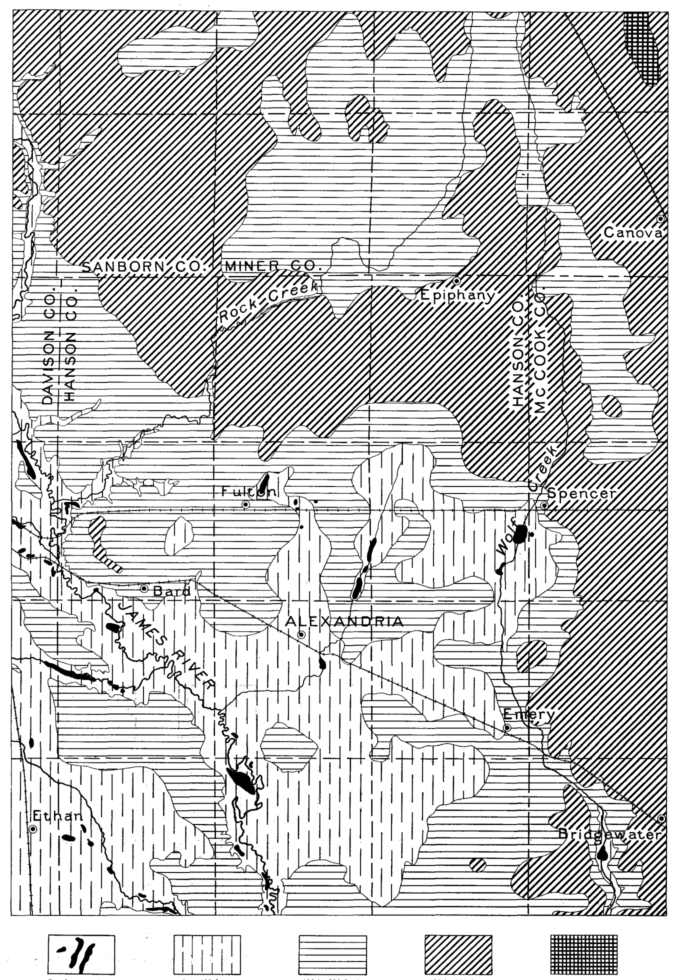


FIG. 7.—Sketch map of Alexandria quadrangle showing approximate depths to the bottom of the drift. Water can usually be obtained from sands and gravel at the base of the drift, and generally rises many feet in wells.

As already stated, a large number of the wells of the region are supplied from a water horizon above the Benton formation. The head of this water is probably sustained from the highlands lying northeastward. Its waters are usually hard. The first water horizon of the Benton probably furnishes soft water, the same as farther west, except where it has been contaminated from the Pleistocene waters above. To the second Benton water-bearing bed are referred most of the wells of moderate depth in Plano Township. It would include also the wells in the north-central part from 250 to 350 feet deep, while the deeper and stronger wells are probably supplied from the third water-bearing bed, the first bed of the Dakota sandstone. It is uncertain whether the fourth horizon extends under the northern portion of this quadrangle. The wells in the southwest corner are probably supplied from the first and second water-bearing sandstones of the Dakota, which are there very thin. The depths to the top of the Dakota sandstone are shown on the Artesian Water sheet.

The second flow evidently furnishes soft water southward to the vicinity of Epiphany. As in the Mitchell quadrangle farther west, this horizon furnishes soft water toward the north and hard water toward the south; and following the same analogy, it is expected that the third sandstone would furnish soft water still farther north. This peculiar presence of soft and hard water in the same bed is somewhat more difficult of explanation. Doubtless it is accounted for by the water partaking of the character of the deposits through which it passes in its flow toward the south and east. If the difference is due to the composition of the soluble materials in the beds carrying the water, it is possible that under certain conditions there was a greater amount of lime and iron salts deposited locally in the beds, while more soluble compounds accumulated in other portions of the area of deposition.

Amount of flow.—Artesian wells vary much in respect to relative copiousness of supply. Those of smaller diameter afford a much smaller supply proportionately than larger ones because of the greater friction in the smaller pipe. It may be thought that the cause of variation in the copiousness of the supply is difference of pressure, but that is not the case. For example, some wells in the vicinity of Letcher, in the Mitchell quadrangle, deriving water from the second water-bearing sandstone, afford only a flow from a 2-inch pipe, and yet the pressures run up to 50 or even 70 pounds, while others in the vicinity, deriving their supply from the third water-bearing sandstone, afford several hundred barrels a day with less than half the pressure. The primary cause, therefore, of the amount of the discharge must be found in the porosity of the water-bearing stratum and the perfection with which the well is kept in communication with it. From this it may be understood why wells from the same bed differ greatly in the freedom of their discharge. The amount of flow is dependent not only on the factors already mentioned, but also on the amount of surface of the water-bearing rock in the cavity communicating with the bottom of the well; hence a well that strikes the thin portion of the water-bearing bed can not obtain so great a flow as one penetrating a thicker portion, other things being equal.

Quality of water.—Allusion has already been made to the softness of the water in the upper Benton sandstone and in the lower sandstones toward the north. In all these cases the water has a pleasant taste, and many persons think it is quite pure, but on evaporation it leaves a deposit of some white mineral, probably carbonate of soda. It may be used with soap as easily as rain water. It does not rust iron and does not show the iron deposit about the well that is common to other artesian waters.

The waters from the second and third water-bearing sandstones toward the south, and the fourth and fifth horizons throughout the quadrangle, are hard, often intensely so. They deposit a coating of rust on all objects with which they come in contact; moreover, they rapidly corrode the iron pipes used in the wells. This latter difficulty is obviated somewhat by the use of galvanized pipe, but even that in time yields at the joints, where the zinc is removed. It is the common impression that ordinary iron pipes are destroyed in less than ten years.

Varying pressure.—In general the pressure increases with the depth in different sandstones. This is true mainly because there is less chance for leakage along their eastern margin, but possibly also because of the higher altitude of the lower beds along their western margin in the Black Hills and Rocky Mountains, where the water enters. While the above rule holds in a great majority of cases, there are marked exceptions.

It seems probable, from certain facts noticed in wells in the southern part of the quadrangle, that the lowest water-bearing bed has not the pressure of some higher up. This may be connected with the fact that several deep wells have been sunk in Douglas County, which perhaps have locally diminished the water from this stratum more than from those higher up.

Cause of apparent decline of pressure.—It is a fact now generally admitted that not only does the flow of wells decrease but their first pressure declines. This becomes evident without direct measurement, first by a shortening of the distance to which the water is thrown from a horizontal pipe, and later by the fact that a stream which at first filled a pipe gradually fails to do so. In some cases a test with the gage shows that this is merely a decline in amount of flow, without material decline in pressure, but in many cases the pressure is also found to be markedly diminished. For example, at Mitchell the water at first rose 13 feet above the surface, and it now barely reaches the surface. At Mount Vernon, where a pressure of 30 pounds was first reported, only 12 pounds is now obtained. At Plankinton the city well, which once had 55 pounds from the third sandstone, now gives only 45. The well at Letcher, which at first was reported to have 90 pounds, now shows little over 40. It seems probable, however, that in this case, as in the Plankinton well, the highest pressure first reported came from a lower stratum which, because of imperfect packing, now communicates with one above, of lower pressure.

These facts suggest the partial exhaustion of the artesian supply, but it is claimed—and the claim is partially substantiated by facts—that new wells frequently have a pressure equal to that of the early wells supplied from the same water-bearing bed. Since the closed pressures, however, are less frequently taken than formerly, and from the nature of the case liberal margins are sometimes made for leakage, it is difficult to prove this.

In many cases diminution of flow results from the clogging of the well. As the wells are usually finished by resting the pipe on a firm stratum at the bottom of the well and perforating a portion corresponding to the thickness of the water-bearing stratum above, it will readily be seen that the surface open for the delivery of water to the well extends through the whole thickness of that stratum. As the water continues to flow, sand will gradually accumulate on the inside of the pipe and gradually diminish the surface supplying water to the well. Something of the same sort may less frequently occur even when the pipe is fastened in the cap rock above the water rock and a cavity is made in the water rock. As time passes, sand gradually works in from the side and possibly portions of the cap rock are undermined and drop down, so that even in such cases the freedom of the flow of the water is considerably checked.

Theoretically, the closed pressure should be the same whether the well is flowing freely or not, so long as the head of the water is the same. If the well becomes clogged, as suggested above, the only difference in the pressure should be that when a gage is attached it takes longer to reach the maximum point. As this rise may be very gradual, some errors of reading are likely to result because the observers have not waited long enough.

Another cause of decline of flow is leakage. This may take place either by imperfect closing of the pipe or it may occur below the surface of the ground. As is well known, pipes deteriorate materially under the influence of most artesian waters, and it becomes almost impossible to close the joints perfectly. Where any considerable extent of piping, as in the case of the distributing pipes of a city, is included in the circuit, one can never be sure that all leaks are stopped. Doubtless the apparently diminished pressure in many older wells is due to leakage.

The diminished pressure in a particular well may sometimes be apparent only and may result from the opening of another well not far away. In such case no real closed pressure can be obtained unless both wells are closed at the same time. The distance to which this influence may extend will of course be greater where the water-bearing stratum is of coarser texture, and the usual supply of the water is therefore freer. For example, at Letcher there are two wells not far apart which are of the same depth. The pressure of either taken alone is about 40 pounds, while about a mile away another well supplied from the same water-bearing bed showed a pressure of 55 pounds, and 2 miles away one showed 65 pounds. The diminished pressures reported from Mitchell, Mount Vernon, and Plankinton are probably due to this cause. Moreover, in cases where water has been drawn freely from several wells there is no doubt a local depression of head which it would take considerable time to restore, possibly several days with all the wells closed. Such a local depression of head might occur and yet no permanent diminution of supply exist.

Notwithstanding all the considerations offered thus far, it seems not unlikely that the rapid multiplication of the wells may have really reduced the pressure a few pounds over the whole region. It is therefore important that facts should be collected and sifted to ascertain whether this is the case, and if so the amount of diminution.

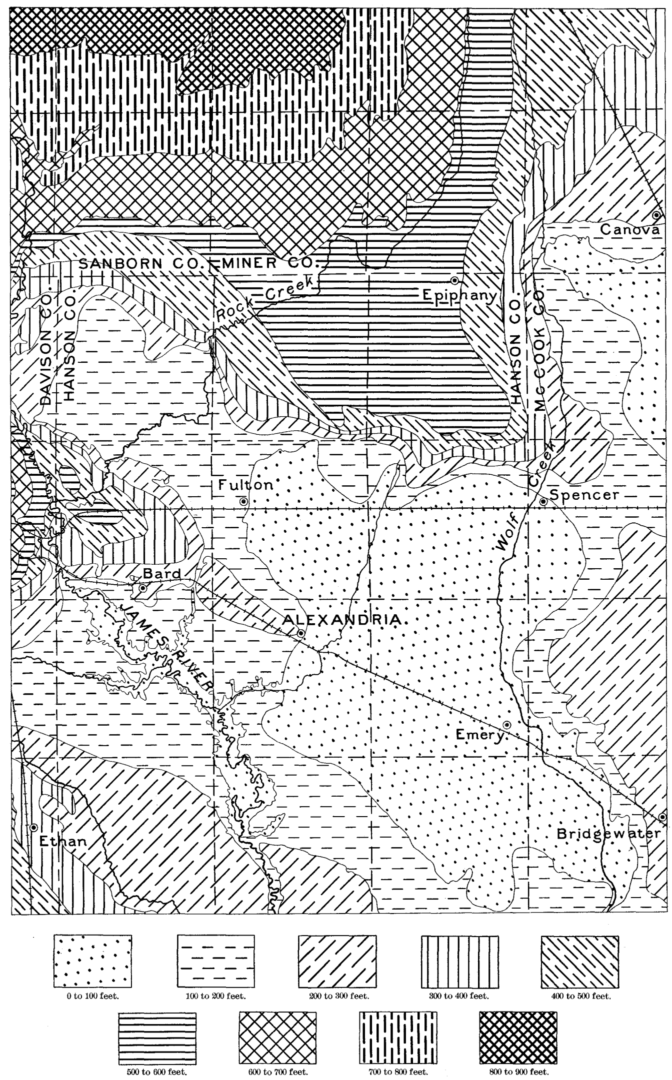


FIG. 8.—Sketch map of Alexandria quadrangle showing approximate depths to the Sioux quartzite, "bed rock" of well drillers, which is the lower limit of water-bearing strata.

In view of such a possibility of overtaxing the supply, it would seem desirable to limit in some way the number of large wells allowed to flow freely. A single thousand-gallon-a-minute well would be sufficient to supply 144 wells, one to each quarter section in a township, each furnishing 285 barrels a day, or 7 gallons a minute, which would be an abundant supply for any ordinary farm. As it is, some large wells have been drilled with the intention of irrigating, and sufficient rainfall during recent years has rendered them worse than useless, for considerable areas have been reduced to unproductive marshes by their overflow.

SOILS.

No careful analysis of the soils of the region has been made and only some of the more obvious characteristics can be noted here. The soils may be broadly divided into three classes—stony, sandy, and clayey.

Stony soils are represented only in limited areas, found mainly on the more abrupt slopes of the morainic areas. There, as elsewhere in till-covered areas, large bowlders are found, mainly on the surface. Along the streams, especially on the abrupt edges of the higher terraces, and sometimes capping them for several rods back, bowlders, especially of smaller size, usually abound. They are portions of a horizontal stratum originally laid down in the bottom of an ancient channel. This coarse material seldom extends very far back from the edge or very far up and down the stream. It represents bowlder bars that accumulated at particular points.

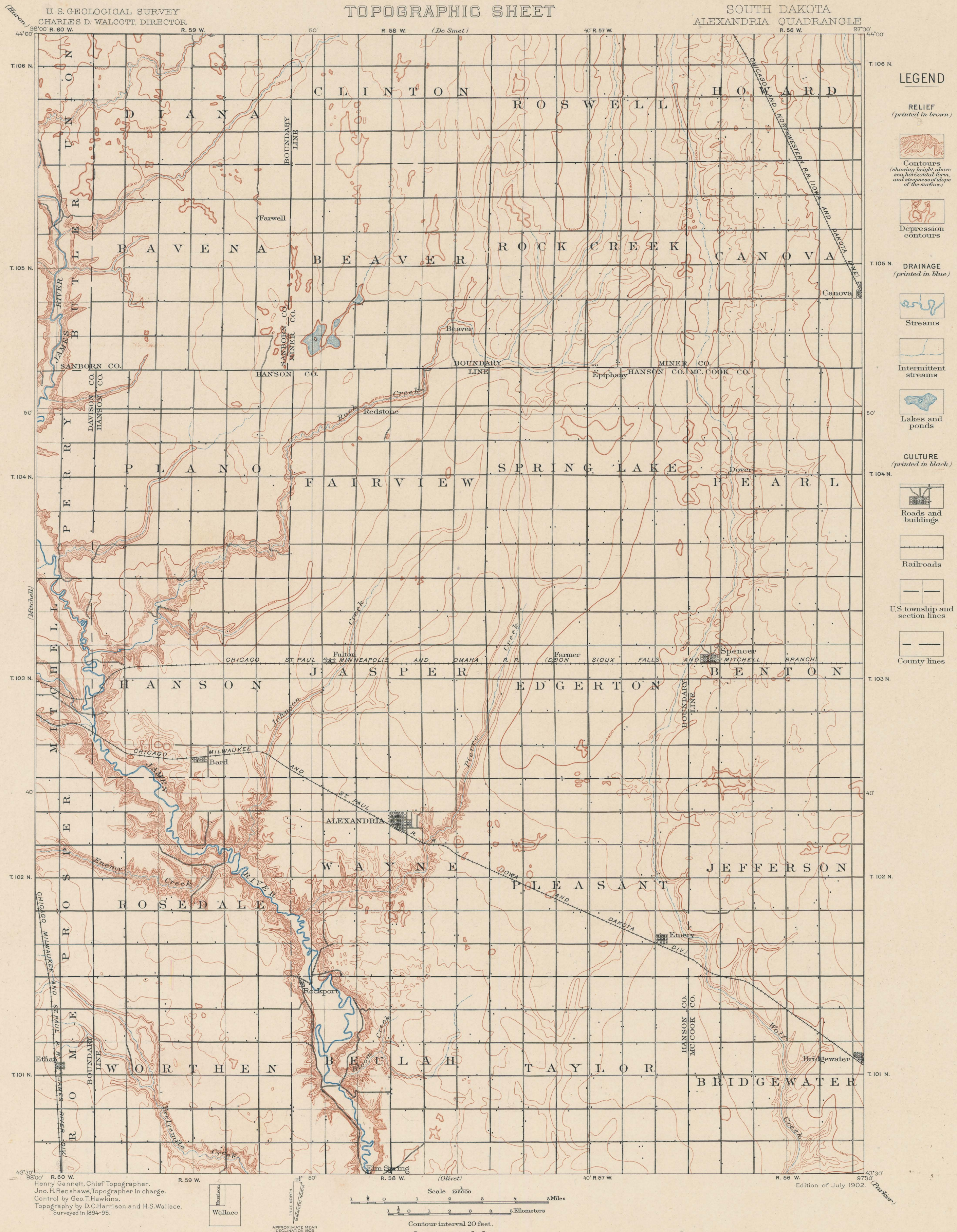
On some of the terraces this coarse material underlies the surface at so shallow a depth that it becomes a serious injury to the soil, because it produces too rapid underdrainage.

Sandy and loamy soils are found in the northwest corner of the quadrangle, in the region between James River and Rock Creek.

Though the soil of this quadrangle resembles that in other drift-covered regions there are some peculiarities that need further explanation. In the morainic areas the soil varies considerably within short distances. The basins are usually covered with a clayey soil, which is more pronouncedly clayey toward the center, being loamy near the margin. The loams of these areas are not only stony, as already described, but contain a great quantity of sand and gravel. The differences are not sufficient to require special treatment. Ordinary tillage so mingles the different soils that they are mutually beneficial.

A very different condition is found on the till-covered surface outside the moraine, especially where the land is unusually level. On the ordinary loamy surface of the till patches of clay are spread irregularly. These differ much in size and in depth. In wet weather these areas are very soft and miry, and in dry weather they are very hard and frequently seamed with mud cracks. They are usually covered with what is commonly called alkali grass, which in the latter part of the summer is dead, while the blue joint and other grasses on the loamy surfaces about them are still green. Sometimes the alkali in these spots is so abundant that they become barren. Frequently they are depressed below the level of the ground about them. This may be due partly to the wind blowing away the loose material from the bare ground and partly to the buffalo in previous times licking the alkali and wallowing in the mud. It is possible that this peculiar feature is due to bowlders or masses of Cretaceous clay that were brought by the ice and deposited without mingling with the other ingredients of the till. Another and more probable explanation is that alkaline water gathers in depressions on the surface and dissolves out the silica, or fine quartz sand, in the till, leaving only the clay. These spots, though producing a marked impression on the vegetation of the natural surface, are not found to seriously interfere with cultivation. The alkali, if not too concentrated, is probably a help rather than a hindrance. Where it is collected in a large basin, so as to be persistent at one point in spite of cultivation, drainage or the addition of arenaceous material are the only remedies applicable.

July, 1903.


U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR
TOPOGRAPHIC SHEET
SOUTH DAKOTA
ALEXANDRIA 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
CULTURE
(printed in black)
Roads and buildings
Railroads
U.S. township and section lines
County lines
CLINTON
ROSWELL
HOWARD
DIANA
RAVENA
BEAVER
ROCK CREEK
CANOVA
PLANO
FAIRVIEW
SPRING LAKE
PEARL
HANSON
JASPER
EDGERTON
BENTON
WAYNE
PLEASANT
JEFFERSON
ROSEDALE
WORTHEN
BEULAH
TAYLOR
BRIDGEWATER
ALEXANDRIA
Farwell
Canova
Beaver
Epiphany
Redstone
Dover
Fulton
Farmer
Spencer
Bard
Emery
Rockport
Ethan
Bridgewater
Elm Spring
JAMES RIVER
Rock Creek
Enemy Creek
Wolf Creek
Pierre Creek
CHICAGO ST. PAUL MINNEAPOLIS AND OMAHA R.R. (SOO SIOUX FALLS AND MITCHELL BRANCH)
CHICAGO MILWAUKEE AND ST. PAUL R.R. IOWA AND DAKOTA DIV.
CHICAGO AND NORTHWESTERN R.R. (IOWA AND DAKOTA LINE)
SANBORN CO.
HANSON CO.
MINER CO.
MC COOK CO.
DAVISON CO.
BOUNDARY LINE
(Huron)
(De Smet)
(Mitchell)
(Olivet)
(Parker)
T. 106 N.
T. 105 N.
T. 104 N.
T. 103 N.
T. 102 N.
T. 101 N.
R. 60 W.
R. 59 W.
R. 58 W.
R. 57 W.
R. 56 W.
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 1894-95.
Wallace
APPROXIMATE MEAN DECLINATION 1902
Scale 1/125000
Contour interval 20 feet.
Datum is mean sea level.
Edition of July 1902.

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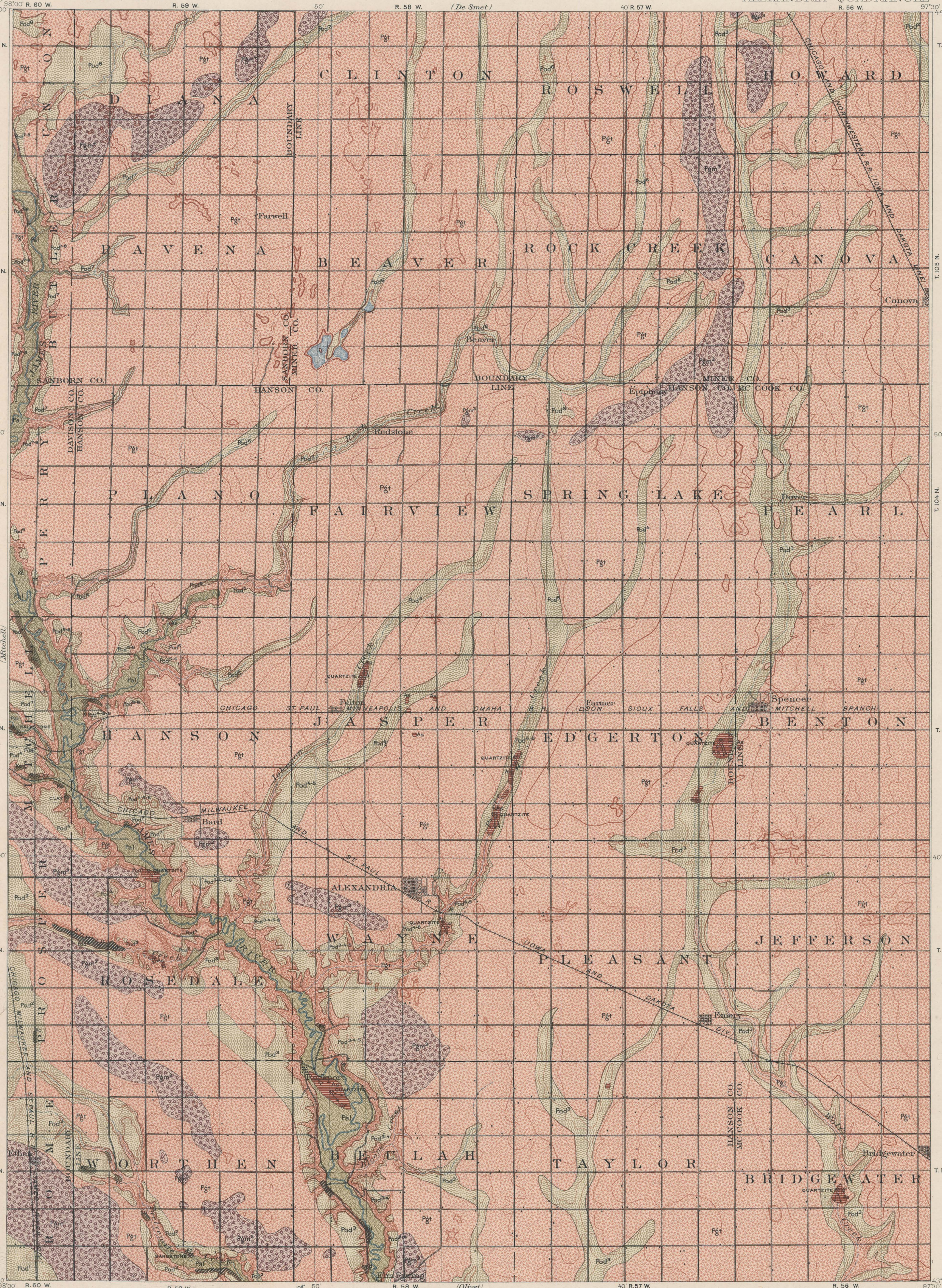
AREAL GEOLOGY SHEET

SOUTH DAKOTA
ALEXANDRIA QUADRANGLE



LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles.)

PLEISTOCENE

Wisconsin Stage of Glacial Epoch

- **Pal** Alluvium *(only the larger deposits represented)*
- **Pod** Old stream deposits *(occupying channels of glacial streams, chronologic order indicated by numbers)*
- **Pgm** Gary moraine *(successive positions of the retreating ice in this quadrangle shown by numbers)*
- **Pgt** Glacial till *(unstratified clay, sand, and gravel)*

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines.)

CRETACEOUS

Benton and Niobrara formations

- **Kc** Colorado group *(shale, clay, and soft limestone or chalkstone)*
- **Kd** Dakota * formation ? *(sandstone and shale)*

ALGONKIAN

- **As** Sioux quartzite *(very compact purplish quartzite)*

7° Dip and strike of stratified rocks
Glacial striae
Quarries and clay pits

Approximate positions of dividing lines between old stream deposits of different ages are shown by dotted boundaries.

* *Since this map was printed it has been recognized that the sandstone here called Dakota is probably a member of the Benton formation, 250 to 300 feet above the Dakota.*
March, 1903.

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 1894-95.

Harrison
Wallace

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902

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 Sept. 1902.

Geology by J.E. Todd and C.M. Hall.
Surveyed in 1899.

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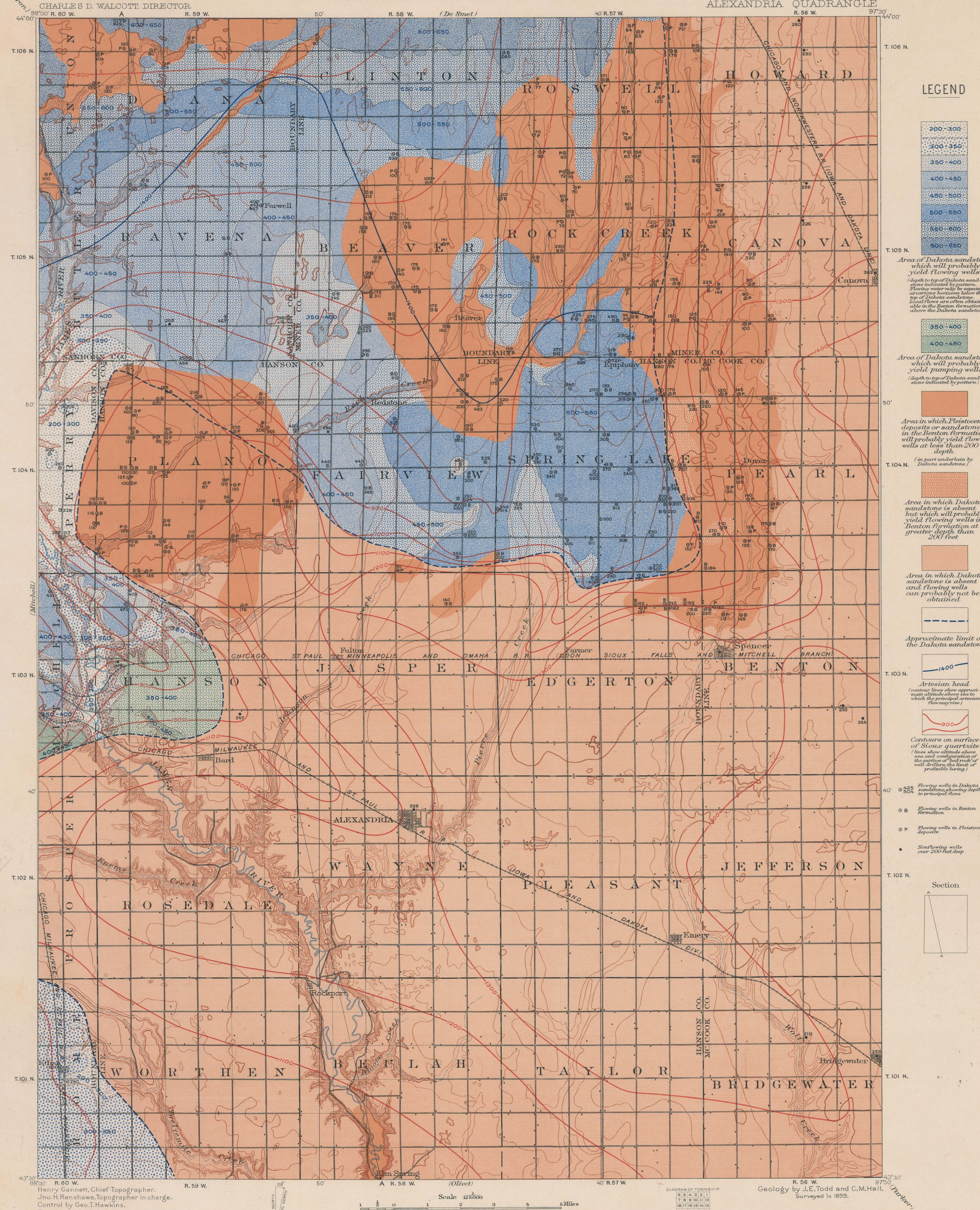
ARTESIAN WATER SHEET

SOUTH DAKOTA
ALEXANDRIA QUADRANGLE



Henry Gannett, Chief Topographer.
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Surveyed in 1894-95.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

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 Oct. 1903.

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

Geology by J. E. Todd and C. M. Hall.
Surveyed in 1899.

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35	Gadsden	Alabama	25
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