DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

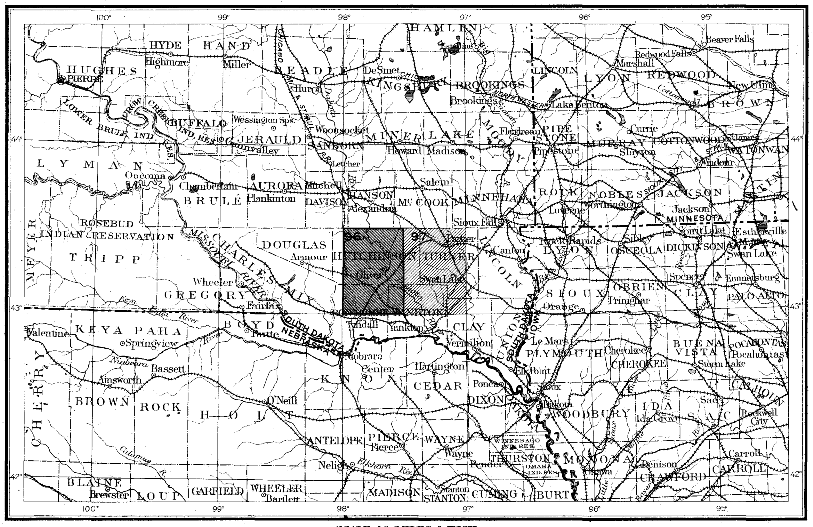
OF THE

UNITED STATES

OLIVET FOLIO

SOUTH DAKOTA

INDEX MAP



SCALE: 40 MILES-1 INCH

AREA OF THE OLIVET FOLIO

AREA OF OTHER PUBLISHED FOLIOS

CONTENTS

LIBRARY EDITION

OLIVET FOLIO
NO. 96

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:

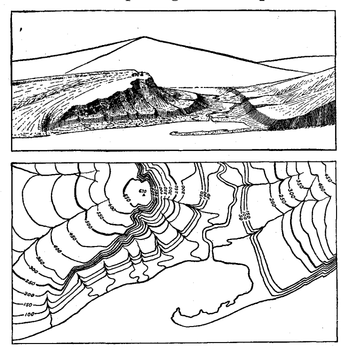


Fig. 1.—Ideal sketch and corresponding contour map.

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		Є	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:

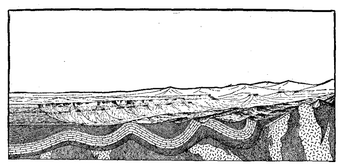


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

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:

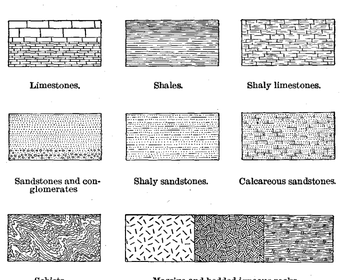


Fig. 3.—Symbols used to represent different kinds of rock.

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 OLIVET QUADRANGLE.

By J. E. Todd.

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 its surface features show 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 low hills 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 that 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 Olivet quadrangle is located between longitude 97° 30′ and 98° west, and between latitude 43° and 43° 30′ north. It embraces portions of Hutchinson, Bonhomme, and Yankton counties, South Dakota, its northern line being also the northern boundary of Hutchinson County, and has an area of about 871 square miles. It lies mostly within the drainage basin of James River, which enters the quadrangle near the center of its northern boundary, and, after an irregular course, leaves the quadrangle in the southeastern portion. A considerable area in the southwestern corner drains directly into Missouri River.

TOPOGRAPHY.

The region is in general flat, and its features are, with few exceptions, those of very subdued glacial topography, the basins being shallow and widely separated, and the swells very low. Rougher areas occur in the morainic regions, which are shown on the Areal Geology sheet. At some points the swells rise into hills from 15 to 25 feet high, which are more fully described under the heading "Moraines." The surface varies in altitude from 1175 to 1625 feet above sea level, the average being about 1400 feet.

By neglecting the channels of the less important streams, it may be said that the lower portion of the plain follows James River as an axis, and is broader near the center of the quadrangle, where it has a width of at least 12 miles and is very little more than 1300 feet above sea. From this plain there is a very gradual rise to the east, the northern half of the eastern border of the quadrangle being more than 1400 feet above sea level. There is a similar gradual rise toward the southwest, to the Choteau Creek Hills, which rise to 1620 feet above sea along the southern half of the western border of the quadrangle. Extending eastward from the Choteau Creek Hills there is a low swell nearly 1500 feet in altitude at the west and declining toward the east. It continues nearly to James Ridge in the southeast corner of the quadrangle, which, just beyond the eastern margin of the quadrangle, rises abruptly to more than 1500 feet.

There are no important elevations wholly within the quadrangle, the Choteau Creek Hills being the most conspicuous. They are largely of morainic origin, though they doubtless owe their location to an elevation on the pre-Glacial surface. They have a nearly north-south axis and an ill-defined outline, the country rising gradually toward them. They present two distinct members in the Olivet quadrangle, a higher central nucleus and an outer rim, separated by a curved valley which contains the headwaters of Emanuel Creek. The rim is best defined at the north end, near Tripp, and declines in prominence and diverges from the main mass toward the south.

James Ridge is a much more distinct but less extensive and less elevated divide than the Choteau Creek Hills. Its axis extends northwest and southeast. The ridge is about a mile wide, and its sides are abrupt, and its greatest altitude is about 1550 feet above sea level, or 180 feet above the surrounding country. Only the northwestern third lies within the quadrangle. Its extreme northern end is separated from the higher and principal mass by a valley which drains to the south on one side and to the east on the other.

The principal valley is that of James River. Its average width is a little more than half a mile, and its average depth a little more than 100 feet. It is bounded by abrupt sides having an average slope of about 35°. The slope of the flood plain is about 25 feet in the distance of about 35 miles traversed in crossing the quadrangle. Its altitude at the northern boundary is about 1200 feet above the sea. This valley is joined by those of the tributaries, which are, however, much narrower, and most of them extend but a few miles back from the main river. The principal tributary valleys are those of Twelvemile Creek (which is divided into two principal branches), Wolf Creek, Lonetree Creek, Dawson Creek, and Prairie Creek. In the extreme southeast corner the valley of Beaver Creek leads outward and joins James River beyond the boundaries of the quadrangle. The valley of Emanuel Creek, in the southwest corner, is broader, and shows abrupt banks for only a few miles north of the southern boundary of the quadrangle.

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 in detail below, under the heading "Pleistocene deposits."

The underlying formations of the region are seldom exposed east of Missouri River, though they outcrop in some of the hills where the drift is thin, and a few of the streams afford natural exposures. The numerous deep wells throughout the region have, however, furnished much information as to the underground structure. There are extensive sheets of clays and sandstones of Cretaceous age lying on an irregular floor of granite and quartzite of Archean and Algonkian age. Under most of the region this floor of "bed rock" 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 is a succession of sandstones and shales of wide extent termed the Dakota formation, which furnishes large volumes of water for thousands of wells. It reaches a thickness of 300 feet or more in portions of the region, but thins out and does not continue over the underground ridge above referred to. It is overlain by several hundred feet of Benton 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 to the north. Where these formations appear at the surface they rise in an anticlinal arch of considerable prominence along the underground ridge of quartzite, but they dip away to the north and west and lie several hundred feet deep in the north-central portion of the State. In the Missouri Valley they rise gradually to the southeast and reach the surface in succession, the Dakota sandstone finally outcropping in the vicinity of Sioux City and southward. The Pierre shale extends in a thick mantle into eastern South Dakota, lying under the drift in the greater portion of the region, except in the vicinity of the higher portions of the anticlinal uplift above 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 east of Missouri River, but they also have undergone widespread erosion and few traces of them now remain in the extreme northern portion of the State. Tertiary deposits also appear to have been laid down over part of the region, as is shown by small remnants still remaining in the Bijou Hills and other higher ridges.

The Olivet quadrangle is covered with glacial drift, with the exception of the alluvial flats along the streams and a few exposures of stratified rocks which appear in the base of the river bluffs. Numerous borings made in sinking artesian wells have furnished many data concerning the underlying strata, which have a nearly horizontal attitude.

ALGONKIAN SYSTEM.

Sioux quartzite.—The oldest rock known in this quadrangle, reached in borings though not outcropping in the quadrangle, belongs to a formation which has been called the Sioux quartzite, from its type locality along Big Sioux River. This formation, which is of Algonkian age, consists for the most part of red or purplish quartzite of intensely compact and durable character. It is extensively exposed a few miles north of the quadrangle, both on Wolf Creek and on James River, and has been struck in borings at perhaps a score of localities within the quadrangle. It seems to underlie the Dakota formation throughout the quadrangle, and is usually termed "bed rock" by well drillers. It is stratified, the layers being frequently 2 or 3 feet thick, but not uncommonly they thin to 2 or 3 inches. While it is usually perfectly consolidated, at some points the grains of sand have been only imperfectly cemented. On Wolf Creek, southwest of Bridgewater, just outside the quadrangle, the quartzite is locally so loosely cemented that it is easily worked with a spade and is used as plastering sand. Associated with this quartzite is a metamorphic clay known as pipestone. This is best known at Pipestone, Minn., but a weathered form of it has been found near Bridgewater and in a boring 2 miles east of Elmspring, where it is reported to have a thickness of 12 feet and to be of a blood-red color. The quartzite has been penetrated to a depth of 145 feet at Milltown, and to a depth of about 85 feet at Elmspring. At Elmspring the rock is reported to be thin bedded, so that the boring was carried on rapidly.

The configuration of the upper surface of the quartzite is represented on the Artesian Water sheet by special contour lines which indicate the height above sea level of the surface of the rock as determined by the deeper wells. In a number of places deep borings have been made without striking the rock. Naturally the localities at which the quartzite has been reached are much more numerous toward the northeastern corner of the quadrangle, where the formation comes nearer the surface. It will be noticed that a ridge of this formation is indicated as extending southwestward from Wolf Creek. This representation is based on the reported striking of the formation southeast of Tripp, together with evidences of uplift of the overlying sandstones so that they are exposed near the mouth of Wolf Creek. The force of the last evidence will appear in a subsequent section. These contour lines are largely conjectural in areas where the borings are not numerous.

This area is remarkable for the entire absence of rocks of Paleozoic age, which is indicated not only by the borings within the quadrangle but by observations made in the adjoining regions, for the Paleozoic formations that are exposed on the eastern flank of the Rocky Mountains do not appear at any point around the outcropping Algonkian and Archean areas in eastern South Dakota and central Minnesota. Borings as far west as Missouri River have not clearly revealed any formations intervening between the Sioux quartzite (or in some cases the Archean granite) and the Dakota sandstone. Doubtless, therefore, this quadrangle and the surrounding region were dry land throughout the long ages during which the coal fields of the eastern United States and the great limestone beds in the central States were forming. This is further attested by the uneven surface of the quartzite, which, so far as revealed, is deeply trenched, indicating long exposure above sea level.

CRETACEOUS SYSTEM.

Apparently only the Upper Cretaceous is represented in the Olivet region, but it is possible that there are also present the equivalents of the Lakota sandstone and underlying shales of the Black Hills region, which are of Lower Cretaceous age. The Jurassic is almost certainly absent, for its area of deposition was far to the west.

DAKOTA FORMATION.

The Dakota formation consists mainly of fine-grained, soft sandstones in thick sheets, each usually capped by a few feet of harder rock and separated more or less completely by strata of clay or shale, the sandstones greatly predominating in most portions of the area. The formation does not outcrop in the region, but lies from 250 to 800 feet below the surface, the depth increasing gradually to the southwest because of both the dip of the formation and the rise of the land in that direction. It is absent in the northeast corner of the quadrangle where it abuts against the Sioux quartzite along an old shore line which extends from near Mabel post-office southeastward to near Wittenberg post-office, crosses James River a short distance south of Wolf Creek, and thence passes northeast. Along this northern limit it lies at a depth of from 250 to 350 feet. The sandstones shown on the geologic map as Dakota have recently been found to belong within the Benton formation. This determination was made on the evidence of fossils and structure in the adjoining regions, after the map was printed and therefore too late to be modified.

The sections of the Dakota formation given in figs. 1 and 2 are those which show most completely

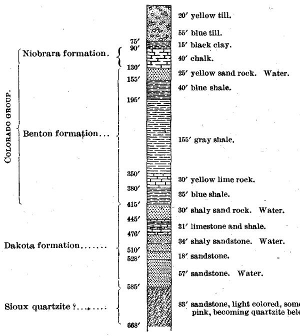


Fig. 1.—Section of town well at Scotland.

the nature of the Dakota formation in this quadrangle. The section at Scotland includes a formation doubtless older than the Dakota, probably part of the Sioux quartzite imperfectly consolidated. The overlying Benton and Niobrara formations are also represented.

COLORADO GROUP.

This group includes two formations which were first separated by F. V. Hayden. The lower is composed mostly of shale and clay with thin sandstone layers and is named Benton, from its great development near Fort Benton, Mont.; the upper is composed largely of chalkstone, and is called

Niobrara. These two subdivisions, though usually differing considerably in lithologic characters, are grouped on the Areal Geology sheet because

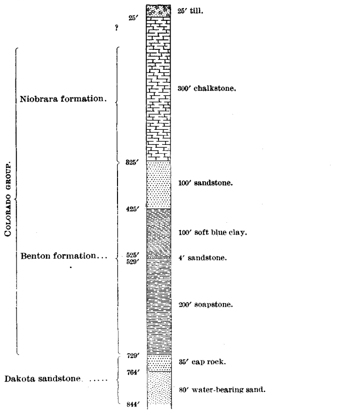


FIG. 2.—Section of well at Tripp. Furnished by Adam Friederich of Parkston. The great thickness of the chalkstone is exceptional and probably 100 feet or more of the upper portion should be represented as till. This would harmonize this section with others.

the line between them is not easily mapped, the chalk in many places grading into clay and shale, and sometimes having a bluish tint resembling that

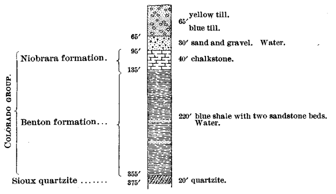


FIG. 3.—Section of well about 7 miles northwest of Milltown, in SW. cor. sec. 14. T. 100 N., R. 60 W.

of the shale. It is very difficult to recognize these subdivisions in the reports furnished by well borers.

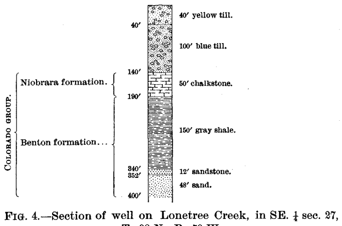


FIG. 4.—Section of well on Lonetree Creek, in SE. ¼ sec. 27, T. 98 N., R. 59 W.

One will report that within a given region he has struck no chalk, only shale and clay; another will distinguish between the chalk and clay, recognizing the difference between the former and the blue shale or "soapstone;" while a third may record the chalk as a fine sand. Practically the distinction which is most obvious to the well borers is that chalk is

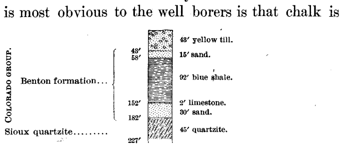


FIG. 5.—Section of well at Wolf Creek.

not plastic when wet, but acts more like fine sand: On the other hand, the shale, or "soapstone," as it is frequently called, becomes plastic and sticky, and is not easily distinguished from the clay, except by its hardness. Typical sections of the Colorado group are shown in figs. 1–5.

The Colorado group is exposed in this quadrangle along James River from Elmspring to Milltown and below the mouth of Wolf Creek, on the north and south forks of Twelvemile Creek, on the next creek to the south, on Wolf Creek about 6 miles above its mouth, on the creek 2½ miles southeast of the village of Wolf Creek, and, still more prominently, in the vicinity of Scotland.

Benton formation.—In this region this formation includes thick deposits of dark shale and plastic clay with at least one widespread stratum of sandstone near its top, which for a time was looked upon as the top of the Dakota and is so represented on the Areal Geology sheet. Above this sandstone there is often a stratum of clayey material which varies much in consistency and thickness. In places it is wet and plastic and in consequence slips down the slopes, so that usually it is not well exposed even when the drift above it has been removed by erosion. A case of this sort was observed in sec. 33, T. 100 N., R. 59 W. In some areas it is locally much hardened, but not in this quadrangle. It is absent in many places and at these localities the chalkstone lies directly on the underlying sandstone bed.

The sandstone bed is generally fine grained, though it sometimes shows considerable coarse material, even pebbles an inch or two in diameter. It is often obliquely laminated and usually friable except where it is consolidated by iron oxide, which is more prevalent in the upper portion. It varies much in thickness; in some places it may be less than 10 feet, and in others over 50, as in the well at Tripp. It seems also in places to be subdivided by shale intercalations and locally to be replaced by shale or shaly sandstone. It frequently contains sharks' teeth, but no other fossils were found in it in this quadrangle. Near Mitchell fossil wood is sometimes found in it, and thin layers of lignite have been reported from apparently this horizon.

In the northwest corner of T. 100 N., R. 59 W., the top of the Benton formation rises 50 or 60 feet above James River, and the sandstone bed forms low cliffs in places along the stream. Below it there is doubtless shale, which, though not distinctly shown, is indicated by the occurrence of springs, and is penetrated by borings in the vicinity. The areas marked Dakota on the geologic map are all exposures of this sandstone of the Benton formation. It appears along Twelvemile Creek, and on the James above Milltown and below the mouth of Wolf Creek, where it seems to be the summit of a low anticline rising to the northeast as if overlapping a ridge of underlying quartzite.

The lower shale of the Benton, which intervenes between the sandstone just described and the top of the Dakota, is also of indefinite thickness. Toward the south and west it seems to attain a thickness of 200 feet or more, while toward the northeast it may be less than 75 feet thick. Its lower limit, the top of the Dakota, is ill defined at some localities in this quadrangle, owing to the incomplete data furnished by well records.

With the limitations defined above, the Colorado group may thicken from 25 feet at the northeast corner to possibly 400 feet in the Choteau Creek Hills.

At Elmspring, in boring a well on the top of the bluff, the following section was obtained:

Section at Elmspring.

		Thickness, feet.	Depth, feet.
	1. Yellow and blue till, with water at 60 feet	83	83
Benton.	2. Sandstone	8	91
Benton.	3. Sand	20	111
Benton.	4. Sandstone and clay, irregularly stratified	20	131
Benton.	5. "Blue clay" shale, with one or two strata of sandstone	116	247
	6. Red quartzite	70	317

All except No. 1 and No. 6 belong to the Benton formation of the Colorado group. The sandstone bed outcrops in the side of the bluff only a few rods from the well. A similar section was obtained in a well 2 miles east. The following section was measured in the river bank:

Section of river bank 1½ miles south of Elmspring.

		Thickness, feet.
	1. Slope, till	50
Benton.	2. Soft brown sandstone, irregularly stratified, some pebbles in upper portion, with springs in lower portion	35
Benton.	3. Slope, mostly clay, to level of James River	20

Section of Milltown well.

		Thickness, feet.	Depth, feet.
	1. Soil	4	4
	2. Sand	54	58
Benton.	3. Blue clay and shale with pyrite streaks	159	217
Benton.	4. Hard rock	3½	220½
Benton.	5. Shale with pyrites	29½	250
Benton.	6. Sand rock, water bearing	7	257
	7. Hard rock, Sioux quartzite	143	400

The Scotland and Tripp well logs, shown in figs. 1 and 2, also give good sections of the Benton formation.

Niobrara formation.—From a study of the formations along Missouri River it is inferred that the Niobrara chalkstone is evenly stratified and compact, with some of its layers forming a hard limestone, but frequently the clayey material is more prominent. The exposures along the river exhibit a thickness of from 150 to 200 feet.

At Scotland and near Milltown the stone has been quarried for building. When first taken out it is easily cut with a knife and shaped to any form desired. When thoroughly seasoned it resists weathering so that buildings formed of it have stood twenty-five or thirty years. When exposed upon a slope it crumbles under the action of frost and becomes a white, earthy mass. The protoxide of iron, which stains it blue or light gray, when exposed to the weather becomes a yellow oxide or a carbonate which is leached out so that near the surface the rock presents a light-yellow or pure white color. It contains the fossils that have been found in it elsewhere in the Missouri Valley, viz, *Ostrea congesta*, different species of *Inoceramus*, some of them rather large but seldom perfect, a large shell which apparently is a species of *Pinna*, and numerous scales and teeth of fishes, both of sharks and common bony fishes. Elsewhere the bones of large reptiles have been found in this formation, but as yet not in this area. The chalk rarely shows noticeable shells of Foraminifera, but the mass of the deposit is found, by microscopic examination, to be composed of coccoliths and other minute organisms found in the chalk elsewhere. At some points the chalk passes laterally into a light-gray clay, and it would seem that chalk and clay might have been formed contemporaneously in different parts of the sea bottom. The difficulty in determining the thickness of the chalk in this region arises from the fact that well borers do not readily distinguish it from the overlying and underlying clays and shales. In no case has its thickness been reported to be greater than 200 feet except at Tripp, where it is said to be nearly 300 feet, but probably this estimate included some of the yellow drift clay at the top. The chalk probably varies in thickness in different localities, though in general it appears to increase toward the southwest, for not so much of it has been removed by erosion in the region lying in that direction.

PIERRE SHALE.

This formation follows next in succession the Colorado. Along Missouri River it is very thickly developed above the Niobrara, and there is no question that it overlies that formation to some extent in the southwestern part of this quadrangle; but from fact that it is heavily covered with drift, we have very little evidence of its extent. It is not improbable that in the Choteau Creek Hills it may have a thickness of 50 feet or more above the chalkstone. From its outcrops elsewhere it may be said that in its general appearance it resembles closely the Benton, which is a dark-colored shale or clay containing occasional remains of marine animals and a rather large proportion of calcareous material, which is sometimes concentrated in large concretions.

TERTIARY DEPOSITS.

No distinct exposures of the Tertiary deposits have been discovered in the quadrangle, though it is not unlikely that in the Choteau Creek Hills there may be fresh-water deposits similar to those observed in Turkey Ridge and at corresponding levels across Missouri River in Nebraska. It is unlikely that the White River deposits extend so far east, but possibly an outlier of the Loup Fork, and, more likely, some deposits of the Pliocene, may eventually be found in the Choteau Creek region.

A deposit of doubtful age and origin, which may prove to be Pliocene, or possibly very early Pleistocene, has been noted between the chalkstone and the drift. The best exposure of it within the quadrangle is in the side of a ravine in sec. 4, T. 98 N., R. 57 W. It is a cream-colored loam, suggesting a secondary formation from the chalkstone, and yet partaking more of the character of loess. The section at the exposure is as follows:

Section in sec. 4, T. 98 N., R. 57 W.

	Thickness, feet.
1. Slope of pebbly clay, till	50
2. Light cream-colored loam	15
3. Chalky layer	1
4. Slope showing here and there a greenish laminated clay	25
5. Chalk with a convex upper surface. Bottom of ravine	3–5

No. 2 is of uneven thickness, because of the irregularities of the eroded surface of No. 3.

PLEISTOCENE DEPOSITS.

Extent and classification.—The Pleistocene mantle is very prominent in the quadrangle, covering practically the whole surface, as shown on the Areal Geology sheet. These deposits may be enumerated (in chronological order) as follows: (1) Circumglacial sands and gravels; (2) glacial till or bowlder clay, embracing an upper, yellow, and a lower, blue portion; (3) moraines, which include those of two distinct epochs with minor subdivisions; (4) terraces and ancient channels, which may be referred to three or four stages of the glacial occupation of the country; and (5) alluvium.

Circumglacial deposits.—The pre-Glacial surface was probably covered with silt and clays resembling those found in the region west of the Missouri. The surface there, however, is probably being eroded faster now than at that time, for the base-levels controlling drainage channels were relatively much higher then than now. Consequently the valleys were probably much broader and of gentler grade. The hillside wash and alluvium were perhaps more marked than now in the trans-Missouri region, but as the ice sheet, which resembled that of Greenland at the present time, slowly advanced from the north, there was spread before it almost everywhere an apron or fringe of torrential deposits. Heavy sand and gravel bars accumulated along the channels of the principal streams leading from it. A smaller amount of similar deposits was accumulated in all water courses as their upper portions began to be supplied from the melting ice. Hence much of the surface would be covered with a nearly continuous layer of sand and gravel over which the ice advanced, and as the result of the process we to-day find nearly everywhere below the till or blue clay of the region stratum of sand and gravel containing in most cases abundant water. The finer portions of pre-Glacial soil and surficial deposits of that time seem to have been washed away, leaving the sand clean and porous. This deposit of sand, which may be compared to a blanket, lies over the uneven surface of the Cretaceous clays, mantling the upland as well as the lowland. It is generally thinner, probably, upon the higher points, where its accumulation may be due in part to the action of winds. The sands of this deposit contain, like the bowlder clay above, pebbles of granite, greenstone, and limestone. The deposit is rarely exposed, but there are a few places along the base of the bluffs of James River where it appears. The more notable ones are about a mile below Milltown and in a stretch extending for 2 or 3 miles above the mouth of Wolf Creek. It may be recognized at other points by the appearance of springs near the level of the stratum. It appears, usually with less thickness, above the older rocks wherever they are exposed. In these places, however, it is not so frequently the source of springs, because such points are more elevated and because the bowlder clay has crept down and more frequently covered it than where it has been recently exposed by the action of the stream. In some places this deposit may attain a thickness of 100 feet, but commonly it is much thinner. In other localities it is entirely wanting, so that the well borer passes from the bowlder clay into the Cretaceous clay without recognizing the transition. This formation plays an important part in the water supply of the region, and will be further described under that head.

Till or bowlder clay.—The till presents the 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 having a diameter of several feet. In this formation are found 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 Cretaceous clays. For this reason the erratics are perhaps less frequently striated and planed. The bowlders most widely distributed are gray and reddish granites and peculiarly compact and fine-grained limestones of a straw color or clear white. The latter contain *Favosites* and cup corals, with occasional brachiopods, indicating their Paleozoic origin. Next in prominence are bowlders of a fine-grained trap or greenstone. Besides these, in some portions, a large percentage of the erratics, usually of smaller size, consists of fragments derived from a red quartzite ridge a few miles farther north. The distribution of these will be mentioned in connection with the description of the moraines.

The till varies in thickness at different localities from 80 to 250 feet. In general it is thicker on higher elevations, as for example, the Choteau Creek Hills and James Ridge. Near the exposures of the older rocks, which may be supposed to represent points that have resisted pre-Glacial erosion, so that they are relatively more elevated, the till has a thickness of 80 feet, as near Scotland and Elmspring, but over the even surface between Parkston and Olivet it has a depth of from 125 to 150 feet. Between the Choteau Creek Hills and James Ridge the thickness is frequently 300 feet. It is probably not very uniform, as within short distances it varies greatly. The surest evidence that the bottom of the till has been reached is the fact that the water when struck rises promptly and to a considerable height. Well borers recognize this fact more distinctly than any difference of materials, for pebbles and bowlders are found in both the till and the sand below. Not infrequently two neighbors sink wells and one is obliged to go to a depth of 250 or 300 feet before obtaining water, while the other obtains it within 150 or 200 feet. This evidence is not always decisive, though, as has already been said, there are sometimes local developments of sand within the till which afford a copious water supply. However, in many cases the wells have gone farther and demonstrated the fact that in such cases no till is found below the sand.

It has been noted in other regions that the till consists of two or more members belonging to different epochs, and it would seem not improbable that such occurrences may be discovered in this quadrangle, but thus far they have not been found. This is the more remarkable when we consider the number of borings that have extended not only through the till, but to the Dakota formation below. However, since well borers are not discriminating in this matter, more careful observations may eventually reveal the fact that such a division of the till really exists, at least in the vicinity of moraines. In this connection should be mentioned a singular phenomenon occurring about 6 miles east of Wolf Creek. In the extreme northeastern corner of T. 98 N., R. 57 W., and in the sections adjoining, are three or four flowing wells that obtain water at depths of from 55 to 65 feet, while 1½ miles farther west no water is obtained until a depth of about 150 feet is reached, and then it has not sufficient head to flow. This would suggest a separation of the till into two members, with a sand deposit between, which does not extend to the second locality. It may prove to be a separation of the earlier and older deposit of till, which may extend farther east, caused by the recession and readvance of the ice, corresponding to the gravel between the Altamont and the Gary moraines. Another explanation may be equally satisfactory, viz, that at one time there existed in the region of the flowing wells a subglacial channel which deposited a sheet of sand on the till already laid down by the glaciers. This sand deposit would be strictly subglacial, while the till above would be of englacial origin, having been laid down upon the land deposits of the stream during the final melting of the ice sheet. The same hypothesis may explain similar flowing wells both north and south of the area described, and also east of Parkston.

The upper part of the till weathers to a light-buff or yellowish color, which is so prevalent that it is only at unusually recent natural exposures, or in the digging of deep wells, that the blue unweathered till appears. An impression prevails that the blue till differs materially in character from the yellow till, which contains water, often in considerable quantity, and supplies the shallow or surface wells. It is a general rule that if sufficient water is not struck before the blue clay is reached, no more should be expected until that formation is completely penetrated. The blue till is frequently called joint clay, from the fact that it is usually divided into polygonal masses by irregular joints crossing one another. These joints permit slight motion wherever the formation lies upon a slope, so that, though it is less plastic than the Cretaceous clays, in the vicinity of streams it is subject to landslides which cause it to cover the underlying sands.

The surface of the till in this area, as elsewhere outside of the quadrangle, abounds more or less in shallow basins, which in the wet season may be filled with water. In some localities these basins are so deep that year after year they contain several feet of water; but more frequently they dry up in summer, and are capable of tillage. Since rainwater is their only source of supply, even the deepest are likely to become empty after a succession of dry years.

Moraines.—These are local developments of the till in the form of elevated ridges, usually with a rougher surface than elsewhere. In other words, the slopes rise into abrupt ridges or knolls, perhaps to heights of 25 or 30 feet, though the best examples of such topography are not found in this quadrangle. The intervening depressions and basins are also more numerous than they are in the surrounding areas. Moreover, the moraines usually present more bowlders and beds of gravel, and bear other marks of abundant and free-flowing water. They are generally looked upon as marking an area where the edge of the ice sheet remained stationary for a considerable length of time. While the ice gradually brought materials to that point, the process of melting prevented its advance, and the clay and gravel contained in it were dropped along its edge. With this explanation we can easily understand how some areas are much more abundantly supplied with material than others because of difference in velocity and in load of the ice, and its relation to attendant waters. We rarely find the edge of the ice sheet clearly marked for any great distance by morainic deposits. The moraines are usually best developed at higher levels. Where the edge of the ice sheet rested in still water, whether in a lake or a sluggish stream, the material brought by the ice would be widely distributed by the water, and a comparatively level surface would be formed. Again, where the edge of the ice was washed by a stream for some distance, material contributed by the ice would be carried away, instead of being deposited as an accumulation.

In this quadrangle are portions of two systems of moraines, with probably representatives of three or four subdivisions of each. This is shown not so much by the facts presented in this quadrangle as by the relations of the morainal deposits to those in adjacent areas. The quadrangle lies wholly within the area occupied by the ice sheet during the advance known as the Wisconsin stage, so named because the deposits of that stage are best represented and were first distinctively studied in that State. This was one of the more recent of the principal advances of the ice sheet, and, unlike earlier advances, marked its different stages by the formation of conspicuous moraines. These, however, are not so well marked in this quadrangle as in Wisconsin or in the northern part of South Dakota.

The oldest, or first-formed, moraine, is called the Altamont, from its development near the town of that name in South Dakota. The earliest member of this moraine is found in the higher portions of the Choteau Creek Hills, in the extreme western portion of Ts. 95, 96, and 97 N., Rs. 60 and 61 W. This member was formed first, or was the first bare ground uncovered upon the recession of the ice from this quadrangle. Portions of a second member of this moraine are recognized in a conspicuous ridge west of Tripp, forming the rim of the Choteau Creek Hills, and lying east of Emanuel Valley, and in the higher and older portion of James Ridge as it is found developed from sec. 36, T. 96 N., R. 57 W. southeastward.

An early development of the second or Gary moraine, so called from the town of that name in Deuel County, S. Dak., is represented by a broken, irregular ridge around the north end of James Ridge, by the hills north of Lesterville, by the elevations in secs. 33 and 34, T. 96 N., R. 58 W., by the stony hill in the northern limits of Scotland, and by scattered elevations west of Olivet. A later member of the Gary moraine is recognized in the system of low ridges forming a strip 2 or 3 miles in width extending across the nearly level plain, from the northwest corner of T. 100 N., R. 60 W., to James River above Olivet. The outline of the strip is not sharply defined, there being a very gradual transition from the undulation of the surrounding plain to the rougher portions which mark a distinctively morainic area. There are also slight ridges northeast of James River, lying along the river bluffs from near Milltown to Wolf Creek, and another ridge, which enter the quadrangle at Elmspring. As determined in the Alexandria quadrangle, the ridges northeast of James River are part of a third morainal belt, and the one at Elmspring is the end of a fourth belt. A discussion of the formation of these ridges and the correlation of the different phenomena attending it are given under the heading "Geologic history."

The hills forming the earlier members of the Gary moraine near Lesterville and at James Ridge rise 25 or 30 feet above the intervening valleys, and some of the basins in them contain permanent lakes. In the later member the ridges are rarely more than 10 or 15 feet in height, and are much more remote from one another. They may be from a half to three-fourths of a mile apart.

Old terrace and channel deposits.—From the description already given, and from a consideration of the ice sheet, it is evident that at different stages in its occupation of the region there must have been lines of drainage different from those occupied by the present streams. The channels occupied by the present streams, especially by James River, could not have been utilized freely until the ice had entirely withdrawn. It follows also that each stage in the ice sheet would have its peculiar avenues of drainage, so that we may recognize, according to the minuteness with which we investigate the deposits, many or few of the different systems. A general discussion only will be attempted. The channels herein referred to are represented on the Areal Geology sheet and the chronological order of their occupation is indicated by numbers associated with the letter symbols.

During the formation of the Choteau Creek Hills the whole quadrangle was covered by the ice sheet, and the only drainage was west and south from the head of the Choteau Creek Hills into some of the open branches of Choteau Creek. As the ice melted away and uncovered areas farther east, a stage was reached when the drainage was quite free down the valley of Emanuel Creek. At the same time, probably, the lower end of James Ridge was beginning to be uncovered, so that the water from that region drained southeastward by the lower part of Beaver Creek. As the melting of the ice became more rapid and limited still more the extent of the ice sheet, a stage was reached when the ice edge lay against the outer rim of James Ridge and along the northern sides of the hills near Lesterville, and extended thence northwest and north to the vicinity of Scotland. At that time the drainage channel just west of Lesterville probably carried away from the ice large quantities of water, and not unlikely a channel farther west drained a large, shallow, and comparatively temporary lake covering the region northwest of Scotland. The outlines of this channel have not been distinctly observed, and it is probable that the water which accumulated along the western side of the ice lobe very soon found its way southeastward beneath the ice, down the present channel of James River. At the same time water was escaping in considerable volume to the south, along the west side of James Ridge, and also to the southeast, between the ridge and the edge of the ice. Beaver Creek Valley was wholly uncovered, and probably was full of water.

The course of the drainage during the formation of the later portion of the moraine is plainly defined. It is especially marked along the lower course of Lonetree Creek, and can be traced up the creek to the southern bend of Dry Creek. Shallow deposits of gravel and sand abound in this channel and cover the terraces that rise from 60 to 80 feet above the valley of Lonetree Creek and from 80 to 100 feet above James River. The broad area occupying the upper valley of Dry Creek exhibits the peculiar topography of a shallow lake bed partially filled, and contains only clay and silt, with few or no erratics, and has more alkali than is found elsewhere in the region. A less distinct channel close along the outer margin of the moraine and between the morainal ridges in the northwest corner of the quadrangle possibly existed. Farther northwestward it is evident that at one time the drainage from the west side of the ice lobe which occupied James River Valley discharged, for the most part, down such a marginal channel, for it is well marked east of Plankinton and northward up the valley of Firesteel Creek.

Another stage of the streams was reached when the ice withdrew from the second portion of the Gary moraine sufficiently to permit the water to escape down the course of James River from Milltown to Wolf Creek. This occurred before the excavation of the present trough of the river. A well-developed gravelly terrace extends, at a height of 90 feet above James River, down the lower course of Twelvemile Creek, on the spur west of Milltown, across the lower valley of Dry Creek, and thence eastward until it coincides with the present course of the river. The lower portion of this channel runs eastward from Dry Creek to James River Valley, in the southern part of sec. 11, T. 99 N., R. 59 W., where it forms a very interesting feature of the channel, merging at both ends into much deeper valleys.

Later stages of the drainage need no detailed description, since they are comparatively unimportant. On the retreat of the ice from the area north of James River, Wolf Creek became a prominent water course, and a well-defined terrace was formed 120 feet above the present stream. Deposits were also spread over the shallow depressions to the west, draining in part into Wolf Creek and in part into James River. As the ice receded farther up James River Valley, the water gradually eroded the deep trough which is now occupied by that river.

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 due to floods and in part to the deposition of dust 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 in thickness, the upper 3 to 5 feet being usually fine black loam, the lower portion sand.

GEOLOGIC HISTORY.

As the area exhibits no rocks older than the 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 schists occupied central Minnesota, and possibly extended to the north and to the 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 occupied at present by the Sioux quartzite. The deposit was mainly in the form of stratified sands, although occasionally thin beds of clay accumulated. Possibly the deposits were laid down more thickly toward the center of the area, in the vicinity of the underground ridge of quartzite which now extends, as a broad peninsula, in a southwest direction, from the vicinity of Pipestone, Minn., and Sioux Falls, S. Dak. After such deposition there seems to have been an epoch of slight disturbance and igneous intrusion. This is indicated by a dike of olivine-diabase near Corson, S. Dak., and in borings at Yankton and Alexandria, S. Dak., and by a dike of quartz-porphyry near Hull, Iowa. Through silicification the sandstone was changed into an intensely hard and vitreous quartzite, and the clay beds were transformed into pipestone and the more siliceous into red slate, as at Palisade. Microscopic examination shows that the silicification was effected by the crystallization of quartz around the separate grains of sand until the intervening spaces have been entirely filled. The material of the quartzite was 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 period 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.; and since rocks of several of the different ages of the Paleozoic and of the Jurassic and Triassic are found in the Black Hills, it is evident that the shore line during those ages repeatedly crossed the State some distance to the west.

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

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

During Colorado and still later Cretaceous times marine conditions prevailed and the region was further submerged until the shore line was probably as far east as central Minnesota and Iowa. During most of this time only clay was deposited in this quadrangle, but calcareous deposits accumulated in the form of chalk during the Niobrara epoch, when the ocean currents brought less mud into the region.

During these epochs the sea abounded in swimming reptiles, some of gigantic size, whose remains have been found at several points; also sharks and a great variety of other fish, although the remains of these are not abundant at most points.

After the Cretaceous period the sea seems to have receded rapidly toward the northwest, and all eastern Dakota again became dry land.

During the early Tertiary, when, according to the prevalent view, large rivers deposited widespread sediments in the region to the west and southwest, this area received but little material and probably abounded in vegetation and animal life which exhibited features not markedly different from those of the present age. Probably the climate was then much warmer and moister.

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

During the Pleistocene period the great ice sheet moved down James River Valley, entering it probably from the north and northeast. It slowly advanced, preceded by waters from the melting ice, which gradually spread a mantle of sand and gravel over nearly the whole pre-Glacial surface. This ice sheet flowed according to the slope of the pre-Glacial surface, moving more rapidly on the lower and more open portions of the valley, and becoming almost stranded on the higher elevations. It certainly extended as far as the outer, or Altamont, moraine. Some geologists are confident that it extended down the Missouri Valley and became confluent with the similar sheet flowing down the Minnesota and Des Moines valleys, both sheets extending into Kansas and central Missouri. However that may be, during the formation of the Altamont moraine the ice filled the whole James River Valley and extended westward at different points to the present channel of Missouri River, near Andes Lake, Bonhomme, and Gayville, so that the Altamont moraine forms an almost continuous ridge or system of stony hills around the edge of the ice sheet of that epoch, except where it was removed or rearranged by escaping waters. Morainal deposits of this stage are found in this quadrangle in only the higher portion of the Choteau Creek Hills.

For some unknown cause or combination of influences the ice began to recede, and at a later stage of what is considered part of the Altamont moraine, morainic material was again laid down in this quadrangle in the higher part of James Ridge and near Tripp. At that time the water was discharged copiously down Emanuel Creek, but other lines of drainage in the quadrangle were covered by the ice sheet.

After this came a period of still more extensive recession, which carried the edge of the ice an indefinite distance to the north. It is not unlikely that it retreated considerably within the line of the Gary moraine. As has already been suggested, it is probable that along the eastern side of the quadrangle it may have retired from the head of Turkey Ridge into the eastern part of T. 98 N., R. 57 W. and in the western portion farther east than the drainage channel from Dry Creek to Lonetree Creek; but there is little evidence on this point. Then came a stage during which the edge of the ice was stationary or advanced slightly until it rested against James Ridge west of Lesterville and near Scotland. About this time a shallow, fluctuating lake was formed by the waters which ran down the western side of the ice lobe and accumulated in the region northwest of Scotland, submerging the site of that place also. At times the lake apparently overflowed through the channels west of Lesterville into the valley of Beaver Creek. At other times temporary outlets may have been formed underneath the ice along the present course of James River. To the presence of this lake is probably due the level surface of the country in the region mentioned and the apparent absence of morainic accumulations along that portion of the edge of the ice during the earlier stage of the Gary moraine. The latter fact is difficult to explain, although from a study of this quadrangle alone the explanation seems clear; since, however, the morainic accumulations of corresponding age are from 150 to 220 feet higher along the eastern edge of the ice lobe near Freeman and between Marion and Parker, the solution is not so apparent. There is apparently no adequate reason for so heavy a deposit along the eastern edge of the ice lobe at such an elevation, while along the western edge there is a broad sheet of nearly level till. It would seem that this lake, although so transient that it appears to have left no beaches, was able to render the englacial till so plastic that it was very smoothly spread. Moreover, it not improbably caused a bay to form on the western side of the ice sheet, producing a distinct offsetting of the moraine toward the east, as shown on the geologic map. Possibly also it may have started a transverse current which rendered the action upon the eastern edge of the lobe less vigorous during the later stages of the moraine. During the formation of the later portions of the Gary moraine and in stages shortly subsequent, the drainage changed rapidly from one system of channels to another, as is indicated on the Areal Geology sheet, and as has been explained more fully under "Old terrace and channel deposits."

Eventually the ice again receded, vacating the whole area. Its last occupation of any portion of the quadrangle was possibly east of Elmspring, and its final disappearance was evidently attended by unusual floods, even for that time, during which abundant sands were laid down, forming a pitted plain, which is associated with the western branch of Wolf Creek along the western line of T. 100 N., R. 57 W. The lake beds that abound not only in the morainic areas but here and there over the whole surface are due to the unevenness of the deposition of the material included in the ice. Some of the depressions may be due to temporary torrents plunging from the ice, others to blocks of ice—detached portions of glaciers—which became buried in the accumulating till or sand beds. The sandy region just mentioned is especially marked by such depressions, but unlike similar basins elsewhere in the till, these depressions rarely hold water. It would seem that the sand was so deep and the clayey material so scarce that wherever water accumulated in them it was very promptly absorbed.

Since the retirement of the ice the basins in the till have gradually been filling from the accumulation of dust and the wash from the adjacent surface. In some cases erosion has opened them so that they are drained, but in most cases they have been filled to a depth of several feet. An interesting indication of the climate that has prevailed in this region at some time since the ice finally receded is the fact that basins of similar nature and age found elsewhere are occupied by tamarack swamps in which peat has accumulated, in some cases to a depth of several inches, and in some of these basins trunks of tamarack 8 inches in diameter have been found. The more notable cases of this sort are in northern Douglas County.

ECONOMIC GEOLOGY.

No mineral ores or beds of coal or lignite are found in this quadrangle. The rusty sandstones along James River around Milltown may contain local thin beds of lignite, but as they have not yet been discovered either upon the surface or in the frequent borings, it is improbable that any lignite beds of value occur in this area.

BUILDING STONE.

The most abundant stone in the quadrangle is that brought by the glaciers of the Pleistocene. It is in the form of bowlders, which are scattered over most of the country but are much more abundant in the morainic areas. They consist mainly of granite, limestone, and red quartzite. They are not easily prepared for ordinary building purposes, because of their hardness and toughness, and thus far their use has been principally confined to the laying of foundations.

SANDSTONE.

Between Milltown and Elmspring the Benton formation contains a bed of moderately durable brown sandstone of irregular grain which so far has been adapted only to the building of rough walls, although by careful selection material of better quality might be obtained. The color varies from shades of rusty yellow to black, due to the iron which it contains. Locally it has been used for building purposes and the quarries are indicated on the Areal Geology sheet. Blocks of this stone are found several miles to the south, in the drift along James River.

CHALKSTONE.

This rock occurs along the South Fork of Twelvemile Creek and also along Pony Creek, 2 or 3 miles from Milltown. The quarries are shown on the Areal Geology sheet. More extensive exposures are found near Scotland, where some years ago the rock was used in the erection of buildings of considerable size which exhibit the durable character of the stone when well seasoned. The blocks, however, need to be carefully selected, else weathering will cause them to crumble. The slopes where the rock is naturally exposed show little besides white earth with small chips of stone. When moist, if exposed to the frost, it seems to disintegrate very rapidly. Because of the difficulty of selecting durable pieces, and of its association with strata unsuited for cutting into proper shape, it has of late years been little used. When fresh it can easily be sawed or cut with a knife. Eventually, it seems not impossible that quarries of considerable importance may be opened near Scotland and at other points where the formation is exposed, for, doubtless deeper within the earth the blocks are much less broken than toward the surface, and at a number of points quarries of considerable extent could easily be opened.

LIME.

The chalkstone and limestone bowlders of the drift were used in the early settlement of the country for the manufacture of lime, but with indifferent success. The limestone bowlders are largely magnesian.

CLAY.

Although the till is composed largely of clay, it is so mixed with gravel, and especially with calcareous matter, that it has nowhere been successfully used for economic purposes, not even in the manufacture of brick. Cretaceous clay is so little exposed that there has been no attempt to utilize it. Considering the good quality of the lower part of the Colorado group near Mitchell, as has been shown experimentally, it would seem probable that there are similar valuable deposits near the junction of Pony Creek with Twelvemile Creek, in sec. 33, T. 100 N., R. 59 W. No trial has been made of material from this place, nor has it been clearly exposed, but, from the slipping of surface deposits on the slopes in that vicinity it may be inferred that the clay is of good quality.

SAND AND GRAVEL.

Plastering sand and gravel suitable for ordinary purposes are found at many points, especially along the ancient channels and terraces, and in some of the knolls in the morainic areas.

WATER RESOURCES.

Under this head is included an account of the most important natural resource of this quadrangle, water, which is readily divided into surface water and underground water. Under the former are included lakes, springs, and streams, and under the latter the sources which furnish shallow wells, artesian wells, and tubular wells.

SURFACE WATERS.

Lakes.—Lakes receive their waters directly from the rainfall, and endure according to the extent of the drainage basins, the depth of the reservoirs, and the sufficiency or lack of precipitation. The rainfall of the region varies greatly in different seasons, but it averages about 25 inches a year. The lake beds over the whole district are filled with water after a succession of wet years, and usually in the spring, if there has been much snow during the winter, but in the latter part of summer most of the ponds become dry. Some of the more prominent are marked upon the map as lakes. Within the last twenty-five years some of these lakes have remained throughout a summer with 10 or 15 feet of water, while a few years later they would be dry enough for tillage.

Springs.—Permanent springs are rare, but a few occur along James River and its principal tributaries. They receive their waters from the various formations which are discussed more fully under the head of underground waters. Certain springs, which perhaps are not often recognized as such, derive their waters from the rainfall that seeps through the upper part of the drift into the water courses. Since their water is contained in isolated basins or water holes occurring in stream beds, many may not recognize the fact that the water is supplied, to some extent, from beneath the surface, but this is doubtless the fact. The purity of the water of these springs is due to its constant movement as is more fully explained under the heading "Underground waters." Other springs derive their water from the gravel and clay deposits capping the ancient terraces or lining the old drainage courses of the Glacial epoch. As an example of this class may be mentioned a spring in the southwest corner of sec. 34, T. 100 N., R. 59 W., which is supplied from the gravel deposits in an old channel of James River about 100 feet above the present stream. Another spring, less copious, appears in sec. 3, where the same channel meets the deeper valley of Dry Creek. Still another, from these same deposits, appears in or near sec. 15, T. 99 N., R. 59 W. It is probable that careful examination would reveal others of similar origin. Still other springs derive their waters from the sands below the bowlder clay. These fail to bring water to the surface except in areas where underlain by clays, probably of the Cretaceous system, although this may not always be easily demonstrable. Springs of this character have been noted at the base of the bluffs along the right bank of James River at a number of points between the mouths of Dry Creek and Wolf Creek. It is probable that a further search would discover many more.

A fourth class of springs seems to be supplied from the sandstone of the Benton formation. Springs of this kind have been noted a mile or two south of Elmspring, where the water escapes from the base of the sandstone as it rests upon the shaly clay below. Other springs believed to be supplied from the same stratum are found near Olivet. They are two in number, the smaller appearing 10 or 20 rods southeast of the bridge crossing James River east of Olivet, the other about a quarter of a mile farther south, within a few rods of the edge of the bottom adjoining the river. Both of these springs, or ponds, as they may be called, are of circular form and are surrounded by bullrushes. The water rises nearly to the level of the bottom land, which is 10 feet higher than the ordinary stage of James River, near by. Since they are more than a half mile from the base of the bluffs on the east, and since the water is higher than that found at ordinary stages in James River within 2 or 3 miles upstream, it seems evident that the supply is derived from an underlying stratum of the Benton, and that we have here natural artesian wells. The larger one has a diameter of about 150 feet in the open area, exclusive of that occupied by bullrushes. It is probable that similar leaks from the artesian stratum feed James River below the surface of the water. Some of the small marshes that are found on the flood plain may derive their water from this source, although probably most of them are supplied from the sand sheet below the till.

Streams.—James River is the only stream that can be depended upon to contain water throughout the year. Although the lower portions of Wolf Creek, Twelvemile Creek, and Lonetree Creek are rarely entirely dry, in the latter part of summer the water seldom flows continually more than a mile or two above their mouths.

UNDERGROUND WATERS.

Water from the till.—The most accessible underground water is that which flows near the surface of the ground, seeping through the yellowish upper portion of the till toward a water course wherever there are shallow accumulations of sand to form conduits for it. It flows slowly through the lower portion of these sand accumulations and appears at intervals in water holes along the upper portion of the more prominent streams. In these it rarely comes forth in sufficient volume to attract attention. Where the slope of the surface is toward an undrained basin, the water of the yellow till flows out and forms an open lake, so that the general water level sinks, a condition which often exists. It may then be drawn upon by shallow wells, and for a number of years may prove to be entirely adequate for the demand of neighboring farms, but in time of drouth it is gradually exhausted. Where the surface slopes toward a water course the water accumulates in larger quantity, but it also flows away more quickly. Shallow wells, therefore, along the ancient water courses which were occupied by streams of considerable size during the presence of glaciers in the region, afford some of the most copious water supplies in the quadrangle. In the early settlement of the region these shallow wells were the main dependence of the farmers. In 1881 and a few years subsequent, water in them was abundant; but after a series of dry years it became exhausted, and farmers were forced to go deeper for their supply.

The next lower water is derived from the sand and gravel at the base of the drift. These are reached by penetrating the till by borings, usually an inch or two in diameter, to a depth of from 100 to 250 feet, or even 300 feet, below the surface. This depth would be a serious disadvantage were it not in a measure compensated by a rise of the water, which in many wells in this deposit stands from 5 to 25 feet below the surface and in some cases produces flowing wells. There are in the quadrangle wells of this class which have been flowing for more than twenty years. The approximate depths to the bottom of the drift in the Olivet quadrangle are shown in fig. 6.

The area in which flowing waters are obtainable from this source is shown on the Artesian Water sheet. Probably other areas may be found, especially at moderate altitudes remote from important streams. In some cases in deep depressions the land surface is low enough to afford a flow which would not have sufficient head to rise to the surface on the adjoining higher slopes. In some localities, as in a portion of the Choteau Creek Hills, there is no water-bearing sand at the base of the drift.

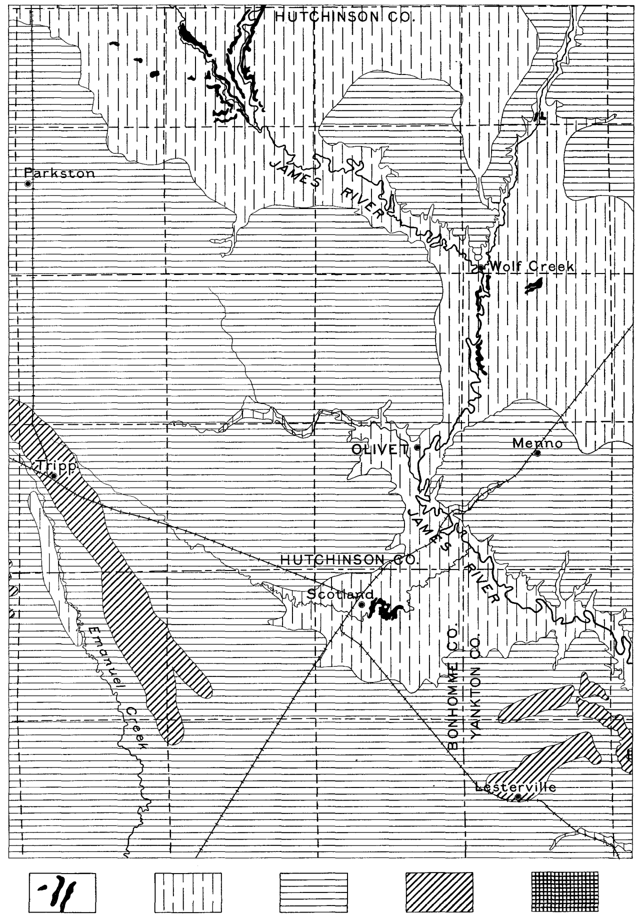


FIG. 6.—Sketch map of Olivet quadrangle showing approximate depths to the bottom of the drift. Water can usually be obtained from sands and gravel at the base of the drift and generally rises many feet in wells.

As already stated under the heading "General geology," deposits of sand and gravel are not infrequently locally developed in the till itself. These usually furnish copious supplies of water, so that it is not necessary entirely to penetrate the till. On the other hand, sands below the till may be absent, and in such cases no water is likely to be reached short of the main artesian supply. The deep wells supplied from sources in the till are commonly known as tubular wells. Hence, we may conveniently speak of water within the Pleistocene sands as the "tubular well supply."

It seems evident that the original source of this supply is the local rainfall, the same as that of shallow wells, but it is a more constant supply, because the water enters more gradually. It is more continuous and does not waste in evaporation, as does the former. It should not, however, be considered inexhaustible, for if a tubular well is drawn upon too freely the supply may gradually fail, the failure being first apparent in an elevated region.

The way in which the water enters the sands within and below the till is not well understood. In general, the till seems to be so perfectly impervious that, especially at lower levels, it prevents the escape of the waters below; yet we have already called attention to the joints in the clay, which in certain places and at certain times, especially in the more abrupt slopes of the surface and after drought, are probably opened sufficiently to permit some water to enter. It is not improbable that the bottom of the ancient channels may at some points cut through the till to the lower Pleistocene sands in such a way as to add materially to this supply. It is not unlikely that some of the flowing wells from the Pleistocene east of Parkston are supplied by leakage from sandstones in the older formations.

Water from the older strata.—The Niobrara chalkstone is porous and water-bearing at some localities; in fact springs are occasionally found flowing from it, as at Scotland. Its water appears not to have much head wherever it lies immediately beneath the drift, and it must be regarded as part of the tubular well supply. In some areas, mainly outside of this quadrangle, tubular wells apparently obtain their water from a sandstone layer underneath the chalkstone. Moreover, there exists in some places, although not certainly in this quadrangle, a stratum of sandstone in the chalk formation which affords water copiously.

Main artesian supply.—It is universally agreed, by those who have studied the subject, that the main artesian supply is from the sandstone and sand beds of the Dakota formation (see fig. 7), though smaller flows are obtained from sandstones in the Benton formation. The Dakota sandstone owes its capacity as a water storer to (1) its great extent, underlying, as it does, most of the Great Plains from the Rocky Mountains eastward to about the ninety-fifth meridian; (2) its highly elevated western border, which is located in the moist region of the mountains and is crossed by numerous mountain streams; (3) its being largely sealed at its eastern margin by the overlapping of shales (clays) of the Colorado formation, and, where that is not the case, by the glacial till sheet; and (4) the denudation of wide areas by older streams, especially in North and South Dakota, so as to bring the land surface below the level of the pressure height produced by the elevated source of the water at the western border of the formation.

Wells supplied from the Dakota and overlying sandstones may be either pumping or flowing wells. In the former the water does not rise to the surface, but must be pumped. In flowing wells the water runs out at the surface or rises above it, as in a fountain. Some writers would confine the use of the word *artesian* to the latter class of wells, in which the water rises to or above the surface. Others would extend it to all wells deriving their supply from a like deep source, under pressure, whether or not the pressure were sufficient to raise the water quite to the surface. The area of probably flowing wells within this quadrangle is shown on the Artesian Water sheet. The distinction between areas that will yield pumping wells and those that will yield flowing wells depends upon several factors, which are discussed under the heading "Artesian pressure." From a comparison of the sections of different wells it appears that the sheets of sandstone are more or less subdivided by intercalated sheets of clay, the permeable sandy deposits extending out as wing-like sheets. Thus there are at least three well-marked flows in the quadrangle. The first, or uppermost, probably corresponds to the stratum exposed above Milltown, which of course can not hold water under pressure sufficient to produce flowing wells in the vicinity of its exposure. The second is that which supplies most of the wells northeast of Tripp. The third is probably that reached in the deep well at Tripp. Presumably others occur still deeper in the southeastern portion of the quadrangle.

From a study of the sections of the wells it is evident that the successive flows rise somewhat toward the north in the direction of the exposures of quartzite, but the higher water-bearing strata are found to overlap very considerably those below. In other words, the lowest sandstone of the Dakota does not extend so far northeast, by several miles, as the higher sandstones in the Benton formation.

The number of flows and the distance between them become important questions to those sinking wells near the margin of the area, for if the water in the uppermost water-bearing stratum is not under pressure enough to bring it to the surface, the drilling must be continued until a stratum with sufficient head is reached. The depths to the water-bearing beds shown on the Artesian Water sheet do not always agree with the depths given by the well records. These discrepancies can be assigned largely to the fact that different horizons are tapped by different wells, but they may be produced by other factors, viz: (1) the altitude of the surface; (2) the pressures in the underlying water-bearing strata, which in general decrease in the direction of freest leakage, and which increase

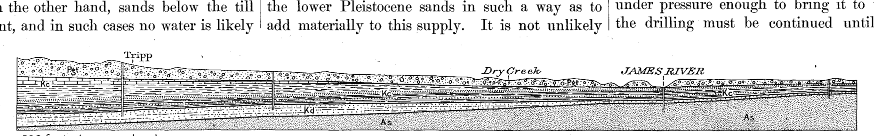


FIG. 7.—Sketch section across the Olivet quadrangle along the line A–A on the Artesian Water sheet, showing the artesian wells in that vicinity extending to the Dakota water-bearing sandstone. As, Sioux quartzite; Kd, Dakota formation; Kc, Colorado group; Pgt, glacial till.
Horizontal scale: 1 inch=3 miles. Vertical scale: 1 inch=1500 feet.

with the depth of the strata below the surface; (3) the dip of the strata, which is not great, but in this quadrangle is usually toward the south; (4) the number of underlying water-bearing strata, which is usually three or four; and (5) the vertical distance between successive water-bearing strata. According to reports on wells in the vicinity of the lower James River Valley the more important strata are from 75 to 100 feet apart. This appears from the following data: Flowing water was reached in a well in the NW. ¼ of sec. 34, T. 97 N., R. 57 W. at 300, 400, and 475 feet; in the Excelsior Mill well at Yankton flows at 300, 375, and 450 feet; in a well in sec. 20, T. 94 N., R. 54 W. at 230 and 300 feet; and in a well in the southern part of T. 95 N., R. 54 W. at 250 and 500 feet, with a faint flow between. The cement company west of Yankton reports flows at 375, 390, 405, 433, and 450 feet, indicating either a subdivision of the usual flows or a confusion of the facts. Most wells show fewer than three flows.

ARTESIAN PRESSURE.

Variation of pressure.—From a superficial study of artesian wells may be obtained the idea that the water, especially that in any one artesian basin, has everywhere the same head, or would rise to the same plane. Such, however, is not the case with the wells of North and South Dakota. In general the pressure declines toward the margin of the water-bearing strata. This is readily explained, as already noted, in the shallow basins, by supposing that the water is moving as a slow current toward leaks along the margin of the formation, where it joins the older rocks or where fissures may connect it with the bottom of streams. In general each flow shows this same decline in pressure toward the northeast.

Moreover, from what has been said about the relation of the Dakota formation to the Sioux quartzite and the Colorado clays, it can easily be understood why the lower flows have the higher pressures, for their leakage is much less. On the Artesian Water sheet are contours representing the "artesian head," which may be regarded as a hydraulic gradient. From the nature of the case it is impossible to represent on the map the pressure for each water-bearing stratum, and therefore the data from the more important wells have been used. In other words, the contour lines represent the pressure in the more available and accessible stratum. It is not unlikely that the sinking of wells to greater depths, or to deeper and additional flows, may increase the pressure considerably. It will be observed that the contours have a distinct curve toward the south and east. This may be ascribed, especially in the case of the 1400-foot contour, to leakage from the water-bearing strata along James River.

The pressure in only a few of the wells of this area has been noted. Many of the wells are small and intended simply for farm supply, so that the pressure has not been an important consideration. The following pressures were taken soon after the different wells were finished, but some of them have since declined nearly to zero: Parkston, 20 pounds; Tripp, 10 pounds; and Scotland, perhaps 4 or 5 pounds. A number of wells southeast of Parkston are reported to have a pressure of 40 pounds. At present the wells at Tripp and Scotland do not flow.

Variations of pressure in adjacent wells.—Instances are not infrequent, although not notable in this quadrangle, where wells at nearly the same point have widely different pressure. In some cases it is evident that the wells are supplied from different sources, or flows; and this may be true, even when the water is from the same depth. As before stated, the water-bearing strata branch; and they do not always have the same level. More frequently, however, the variations presented by wells of this class are explained by subterranean leakage, while the pressure from the stronger flow is expending itself outside of the pipe upon a stratum of less pressure.

Variations of pressure in the same well at different depths.—This need not be dwelt upon, for it has been explained already that lower strata are more perfectly sealed on their eastward margin, and therefore display higher pressure.

Variations of pressure in the same well due to draughts on neighboring wells.—The extent of the influence of the escape of water from the well may reasonably be supposed to be directly proportional to the amount of water discharged. It may be conceived that the flow of the well produces a depression in the pressure surface, or "head," so to speak, proportional to the amount of water discharged, somewhat as in the case of an opening in the bottom of a reservoir. If the flow is rapid, the depression may be great, so that if the well be closed its pressure at first will be perhaps several pounds below the original pressure; but as the water flows in, the pressure will gradually return to its former state. If, therefore, two wells are near each other, it should not be expected that the closed pressure of one will approach very closely the original pressure if the other be left open.

Effect of varying barometer on pressure.—As the pressure is taken with a gage which is affected by the pressure of the air, it follows that when the barometer is high the pressure of the fluid within will be correspondingly diminished. This influence is of course slight, and will be overlooked unless the pressure in the well is very weak, in which case, however, an increase in the pressure of the air may sometimes be sufficient to stop the flow; and, conversely, a low barometer may increase the flow.

Periodic variations in pressure.—In a number of the weaker wells there has been not only a decline in pressure, but from time to time an increase as well. This increase has in some cases been related to the season, the spring being sometimes marked by a stronger flow. This, again, varies according to years; and it is believed to be most satisfactorily explained by supposing that the water is obtained from the melting of snows or from streams subject to floods.

Effect of leakage on pressure.—This has been observed in wells near Missouri River; when the river is high the pressure in the wells increases. It is easily explained by supposing that there are points of leakage beneath the surface of the river, and that the increase of hydrostatic pressure from the stream checks the leakage to such an extent that it increases the pressure in adjacent wells. Although this has not been noted in this quadrangle, it is not improbable that examples of this kind occur near James River. This variation is of course slight, and would be unnoticed except in very weak wells.

AMOUNT OF FLOW.

The flow depends not only on pressure but on the freedom with which the water is delivered to the bottom of the well from the porous stratum. The coarser the deposit the less the friction. Most of the wells in this area are small, varying in diameter from 1 inch to 3 inches. None of them is reported to have a larger flow than 150 gallons a minute, which was obtained from a 2-inch well in sec. 7, T. 99 N., R. 60 W. A 6-inch well at Tripp for a time delivered 700 gallons a minute, and a flow of 66 gallons a minute was obtained from a well in the northwest corner of sec. 20, T. 98 N., R. 60 W. The others supply from 30 to 50 gallons a minute. These all receive their supply from the Dakota formation.

Of the wells from the Pleistocene, the largest flow reported is from a 2-inch well in the northeast corner of sec. 1, T. 98 N., R. 60 W., 20 gallons a minute being the reported volume. Usually the flow is much less.

PROBABILITIES OF OBTAINING ADDITIONAL FLOWS.

The water-bearing strata, which seem to be at least three in number, vary much in pressure. The well at Tripp probably draws from the third flow; the wells farther northeast from the second; while the higher water-bearing strata of the Dakota, or first flow, do not afford flowing wells in this region. It is probable that the wells northeast of Tripp may be sunk to a deeper flow, which very likely extends underneath, but it is doubtful whether it extends much farther northeast, for it seems to be cut out, so to speak, by the rising slope of the quartzite. Moreover, if the quartzite continues in a ridge toward the southwest, as is represented on the Artesian Water sheet, it is somewhat doubtful whether even the third flow extends much east of Tripp. The possibility of deeper flows in the southeastern corner of the quadrangle seems strong.

CONSTRUCTION OF WELLS.

Although the practical application of the following suggestions belongs to the well borer, and may be discussed more effectively from the standpoint of the engineer, yet some of them are closely related to the geology, and for that reason they are presented here:

(1) Since the pressure in the upper flows is less than in the lower flows, by scores of pounds to the inch, it is very important that communication between the lower and the higher flows should be entirely cut off. Otherwise the full pressure from the lower stratum will not be observed at the mouth of the well, but will be partially expended by leaking into the higher strata. The well borer, in his desire to keep his pipe loose, is often tempted to leave the bore too large, and this should be guarded against.

(2) It is very desirable that the larger pipe lining the bore should be firmly fixed in the hard stratum above the water-bearing rock, for if the pipe is left loose and the opening in the rock is not completely stopped, water is likely to escape around the pipe, and will eventually, if not checked, destroy the well. In most localities this can be done because such a compact stone is found just above the porous sands which conduct the water.

(3) A well should be sunk as rapidly as is consistent with good work, especially after water has been reached. Otherwise, the great pressure of the water may caused it to erode an irregular opening.

RETENTION OF RAINFALL.

From the discussion of the underground waters it is evident that both shallow wells and tubular wells are replenished by the percolation of rainfall. Hence, it is advisable, where practicable, to build dams across shallow water courses in such a way to produce ponds, the water of which will gradually sink into the ground and reach the wells referred to. The advantages of this are obvious in the reenforcement of the underground water supply. The water from artesian wells may similarly be retained, the gentle slope of the country and the shallowness of the water courses being favorable to the creation of artificial bodies of water. The only disadvantage is the occupation of otherwise valuable ground; but this would certainly be more than compensated by the increased value of adjacent lands, due to irrigation.

SOILS AND VEGETATION.

The soil of this quadrangle may be said to be generally very uniform, and to have the characteristics that are common to the soil of all drift regions. It is a black loam, fertile and easily tilled. The subsoil is sufficiently clayey to keep the moisture from leaving the surface, and yet loamy enough to prevent caking under ordinary treatment. In some areas particularly along the larger streams and some of the terraces at higher levels, the soil is decidedly sandy, notably on the general upland level occupying considerable portions of T. 100 N., R. 58 W., around the head of and between the channel leading into James River near Milltown, and on Wolf Creek near its mouth. Here the sand seems to be so deep as in places to produce barren ground. In the lake basins which are scattered over the surface, especially in the larger ones, the soil is very clayey, and is apparently gathered by washing. In the larger basins this clay is so abundant and so pure that it interferes with tillage. There is an area east of Parkston, around the upper portion of Dry Creek, which has been described as an old lake bed, of which this statement is particularly true.

Alkali soils.—The soil in drift regions is likely to show accumulations of alkali, which sometimes interferes with the growth of vegetation. This, however, depends upon the amount of moisture. When the moisture is abundant the alkali seems rather to be a fertilizer. The composition of alkali varies greatly, but it is largely carbonate and sulphate of soda. Gravelly soils are found at a few points along the higher terraces and in the moraines, where bowlders also are troublesome.

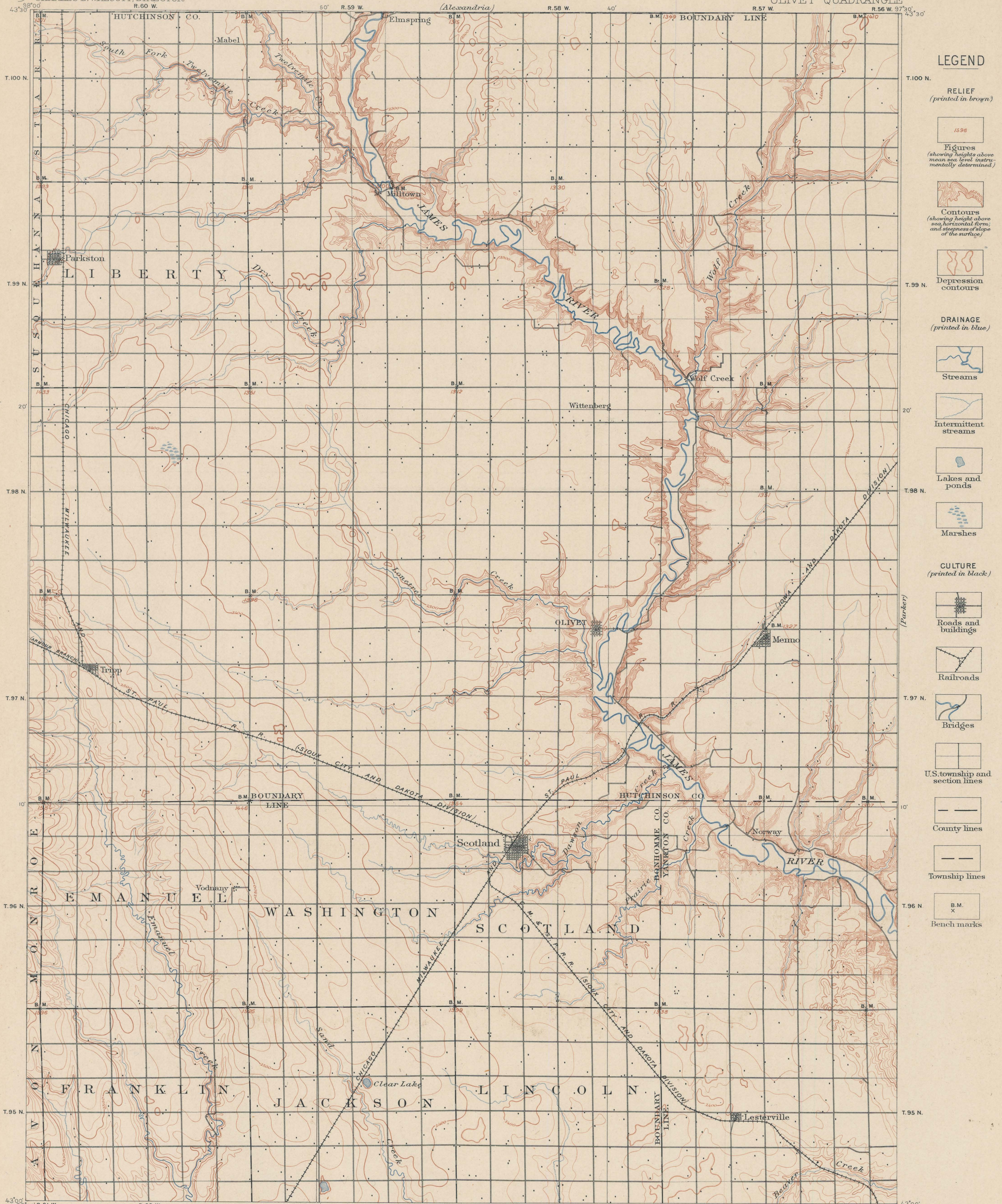
Vegetation.—The prevalent native grasses are those known as buffalo grasses (*Bulbilis* and *Bouteloua*), having the common character of being very short and thick set, and forming a mat upon the ground, the alkali grass, which abounds in the more clayey spots, and the "blue-joint" (*Andropogon*), of two or three species, which during wet years is generally abundant. Along the streams ordinary marsh grass (*Spartina*) abounds. There are no trees except along James River and the lower courses of its larger tributaries. At several points, more particularly on shaded and springy banks, considerable groves of elm, ash, cottonwood, and willow were found by the early settlers of the country. They have largely been removed, but with a little care may easily be replaced by new groves consisting of trees of these or other species. Trees do not flourish on the upland level except with special care. The principal hindrance to their growth is the long, dry season of the latter part of the summer, which is likely to be attended by extremely dry and hot southeast winds. The groves in this region have shown luxuriant growth for a few years, during a period of moisture, then the gradual dying out of the larger trees during a succeeding period of aridity, generally extending over several years. Despite this drawback, over much of the elevated country on James River, and more particularly near some of the lakes and moraines, there are trees of moderate size which have been grown within the last twenty years.

May, 1903.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

TOPOGRAPHIC SHEET

SOUTH DAKOTA
OLIVET QUADRANGLE



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Surveyed in 1896.

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 May 1902.

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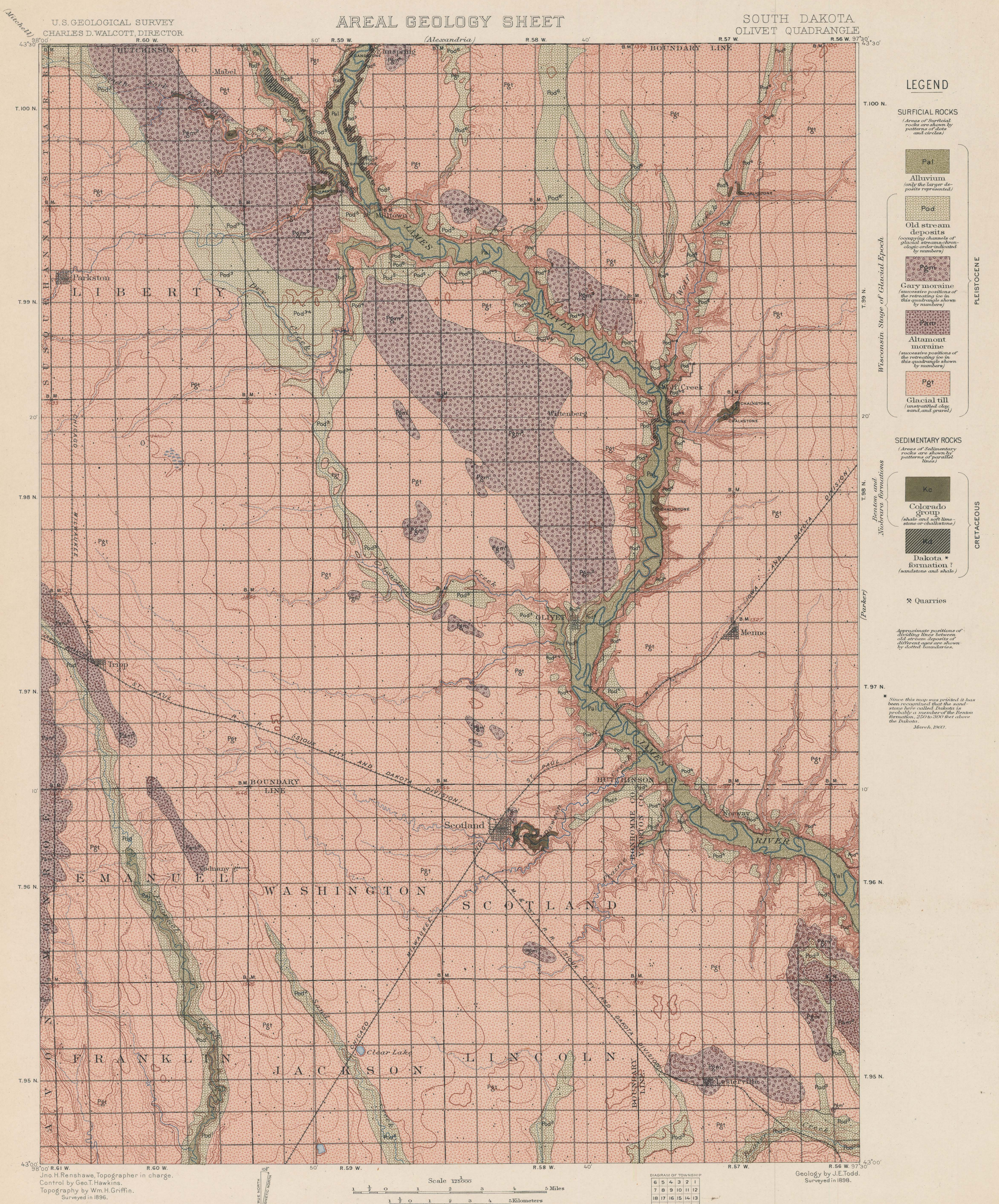
SOUTH DAKOTA
OLIVET QUADRANGLE



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Scale $\frac{1}{125000}$

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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.
Surveyed in 1898.

U.S. GEOLOGICAL SURVEY
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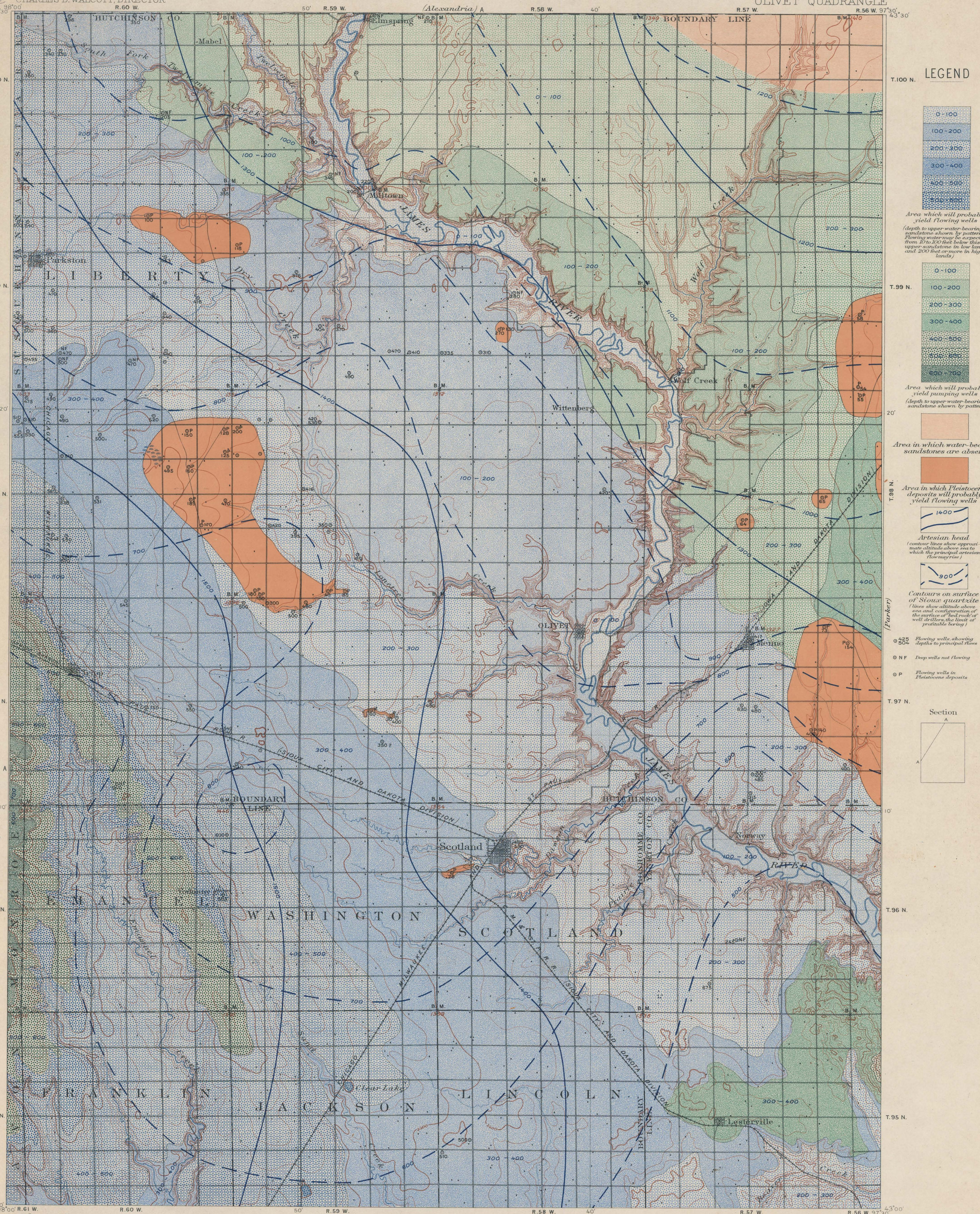
ARTESIAN WATER SHEET

SOUTH DAKOTA
OLIVET QUADRANGLE



Jno. H. Renshawe, Topographer in charge.
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Surveyed in 1896.

Scale $\frac{1}{125000}$

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