SYRACUSE–LAKIN FOLIO
NO. 212

DEPARTMENT OF THE INTERIOR
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GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS
OF THE
UNITED STATES

SYRACUSE–LAKIN FOLIO
KANSAS

BY

N. H. DARTON

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GEOLOGIC ATLAS OF THE UNITED STATES.

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

THE TOPOGRAPHIC MAP.

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

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

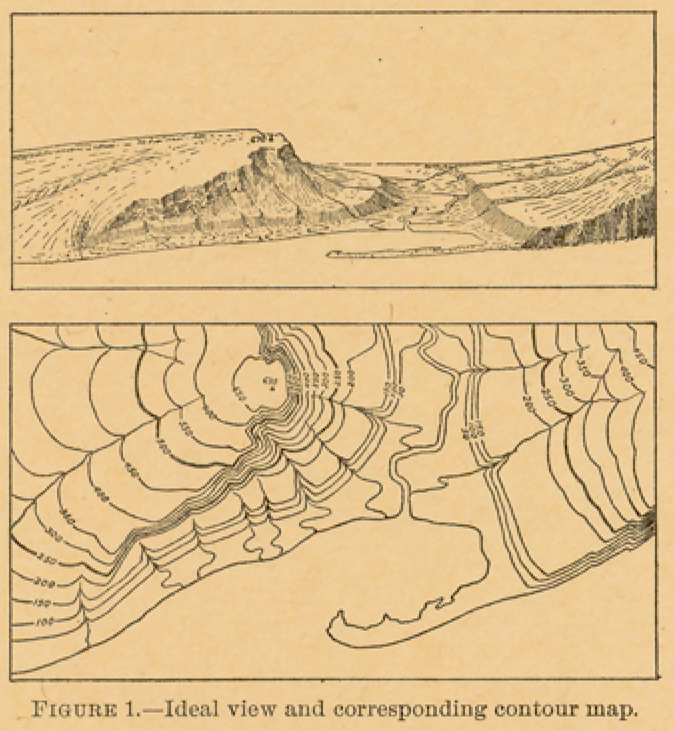

FIGURE 1.—Ideal view and corresponding contour map.

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

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

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

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

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

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

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

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

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

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

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

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

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

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

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

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

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

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

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

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

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

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

FORMATIONS.

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

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

AGES OF ROCKS.

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

DESCRIPTION OF THE SYRACUSE AND LAKIN QUADRANGLES.

By N. H. Darton.

INTRODUCTION.

POSITION AND EXTENT OF THE QUADRANGLES.

The Syracuse and Lakin quadrangles include the half of a square degree that lies between parallels 37° 30′ and 38° north latitude and meridians 101° and 102° west longitude. They measure 34½ miles from north to south and about 55 miles from east to west, and their area is 1,887.6 square miles. As shown in figure 1, they comprise the greater part of Stanton and Grant counties, the southern halves of Hamilton and Kearny counties, and small parts of Finney and Haskell counties, in southwestern Kansas. The area is traversed by Arkansas River, which drains most of it, but its southern part is drained by Cimarron River, a branch of the Arkansas. (See fig. 1.) The quadrangles lie entirely in the Great Plains province, a general account of which will be given as an introduction to the detailed description of the quadrangles.

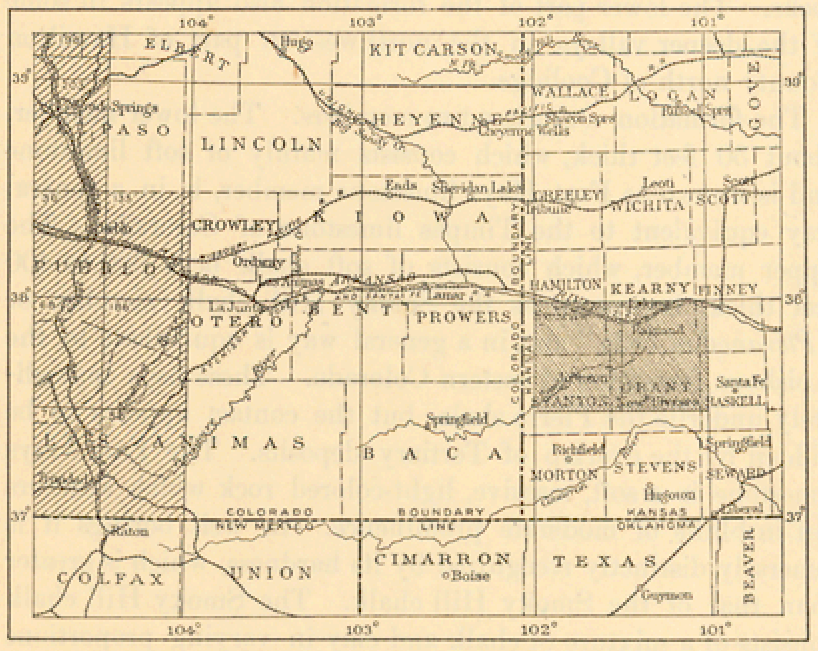

FIGURE 1.—Index map of southwestern Kansas and parts of adjacent States.

The location of the Syracuse and Lakin quadrangles (212) is shown by the darker ruling. Published folios describing other quadrangles, indicated by lighter ruling, are the following: Nos. 36, Pueblo; 58, Elmoro; 68, Walsenburg; 71, Spanish Peaks; 135, Nepesta; 186, Apishapa; 198, Castle Rock; 203, Colorado Springs.

SETTLEMENT.

The Syracuse and Lakin quadrangles are thinly populated. North of Arkansas River there are many ranches, and at intervals along the Atchison, Topeka & Santa Fe Railway, which extends up the valley, there are small settlements. The largest of these is Syracuse, which according to the census of 1910, then had a population of 1,126. Kendall, Lakin, and Hartland have populations of about 400, and Deerfield a population of about 150. In the region farther away from the river there are widely scattered ranches, many of them abandoned. New Ulysses and Johnson are small towns in the southern part of the area. The extensive sand hills south of the river present a formidable obstacle to travel, but roads have been built across them at intervals. The principal industry in the region is raising cattle, usually a profitable business; only a small area of land is under continuous cultivation. There is some irrigation, at places along the river, especially below Lakin, and forage and sugar beets are the principal products.

CLIMATE.

General features.—The climate of western Kansas is typical of that of the central Great Plains. The summers are warm, the winters are moderately cold, and the precipitation, although variable, averages less than 17 inches a year. In most years the snowfall is moderate, and snow does not remain long on the ground. The maximum winter temperatures seldom continue for more than a few days, the cold spells alternating with periods of moderately low temperature. As the air is dry in summer the heat is seldom oppressive, and most of the nights are cool.

Temperature.—The mean annual temperature at Lakin is 54.2 and at New Ulysses it is 54.6. In investigating the underflow of Arkansas River from Hartland to Garden City in the summer of 1914 Slichter determined the temperature of water in many of the test wells. In the wells from 25 to 40 feet deep the temperatures mostly ranged from 56° to 58°, or 2° to 4° higher than the mean air temperature of the region. The averages were: Wells 20 to 30 feet deep, 55½°; 30 to 40 feet, 55°; 40 to 70 feet, 53½°. The average date of the last killing frost in spring is May 1, and of the first killing frost in autumn October 12.

Precipitation.—The precipitation in southwestern Kansas is similar to that in a wide area in the central Great Plains. The chart (fig. 2) shows the variation in annual rainfall for

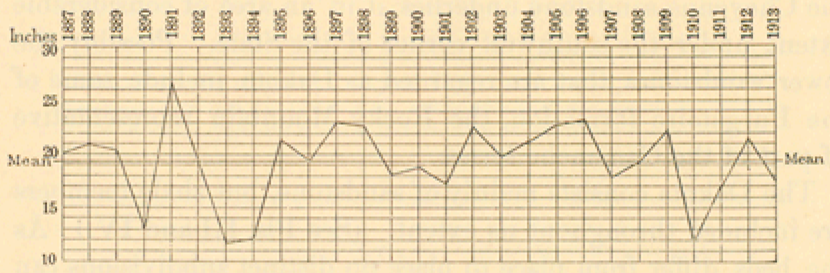

FIGURE 2.—Curve showing variations in annual precipitation in western Kansas, 1887 to 1913.

Mean rainfall, 19.27 inches, shown by straight line. Compiled from U. S. Weather Bureau reports.

western Kansas from 1887 to 1913. As the average annual rainfall in the Syracuse and Lakin quadrangles is between 15 and 16 inches the region is classed as semiarid. However, most of the rain (75 to 82 per cent) falls in the crop-growing season, from March 1 to September 30, so that in this respect it is favorable for agriculture. Most of the snow falls between November and April, and, as the amount is generally moderate and the storms are widely separated, the ground is rarely covered by much snow for a long time. The average total snowfall for the year is 18 inches, but it varies greatly from year to year. The records of precipitation at New Ulysses and Lakin for 25 years show yearly totals ranging from 8.42 to 24.75 inches, but there is no evidence that the average rainfall is greater now than in earlier years.

AGRICULTURE.

During half a century many attempts have been made to raise crops on the high plains of western Kansas and adjoining regions, but as the rainfall has been insufficient the general results have been unsatisfactory. In nearly every decade there are several seasons of rainfall sufficient to afford good crops, even when the soil is not well cultivated, but in the long run the farmer who has depended exclusively on ordinary agriculture has failed. Many abandoned homes and other evidences of occupancy are found, and some of them represent several successive attempts at settlement.

Most of the land is smooth, the soil is generally fertile, the temperatures are favorable, and if the ground is suitably cultivated and drought-resisting plants are raised the High Plains may yield some return to agriculture.

In the valleys where irrigation is practicable from surface water or from water pumped from shallow wells its results are satisfactory, but on the highlands the water lies too deep for pumping for profitable irrigation, even where the volume is sufficient and surface waters can not be impounded. Ordinarily it is not considered economically practicable to lift water more than 50 feet for irrigation, but, though this limit may apply to field crops, water sufficient to irrigate a garden plot or a small acreage of special crops may be pumped economically from a greater depth.

PHYSIOGRAPHY AND GEOLOGY OF THE GENERAL REGION.

PHYSIOGRAPHY OF THE GREAT PLAINS PROVINCE.

General features.—The Great Plains province is that part of the continental slope which extends from the foot of the Rocky Mountains eastward to the Mississippi Valley (Central Lowland), where it merges into the prairies on the north and into the low plains that adjoin the Gulf coast and the Mississippi embayment on the south—the western part of the Gulf Coastal Plain. The plains present wide areas of tabular surfaces (see Pls. I and II) that are traversed by the broad, shallow valleys of large rivers, most of which rise in the Rocky Mountains, and that are cut more or less deeply by the narrower valleys of tributaries of those rivers. Smooth surfaces and eastward-sloping plains are the characteristic features of the province, but in some parts of it there are buttes, escarpments, and areas of badlands. Sand hills surmount the plains in some localities, notably in northwestern Nebraska, where they occupy an area of several thousand square miles. (See Pl. VI.) The province is developed on a great thickness of soft rocks, sands, clays, and loams, in general spread in thin but extensive beds that slope gently eastward with the slope of the plains. These deposits lie on relatively smooth surfaces of the older rocks. During earlier epochs the surface was even smoother than as present. Owing to the great breadth of the plains and their relatively gentle declivity, general erosion has progressed slowly notwithstanding the softness of the formations; and as at times of freshet many of the rivers bring out of the mountains a larger load of sediment than they can carry to the Mississippi, they are now locally building up their valleys rather than deepening them.

Altitudes and slopes.—The Great Plains province as a whole slopes eastward at a gradient of about 10 feet to the mile from the foot of the Rocky Mountains to an altitude of about 1,000 feet in the Mississippi Valley. The altitudes and the rates of slope differ considerably in different areas, particularly in areas to the north, along the middle course of Missouri River, where the general altitude has been greatly reduced. The Great Plains attain an altitude of 6,200 feet at the foot of the Rocky Mountains west of Denver and farther north, along the foot of the Laramie Mountains. A high altitude is also attained in Pine Ridge, a great escarpment that extends from a point near the north end of the Laramie Mountains eastward through Wyoming, across the northwest corner of Nebraska, and for many miles into southern South Dakota. Pine Ridge marks the northern margin of the High Plains division of the Great Plains province and the cliffs and steep slopes on its northern front descend a thousand feet into the drainage basin of Cheyenne River, one of the larger branches of the Missouri. From this basin northward there is a succession of other basins, between which there are relatively low intervening divides, none of which attain the altitude of the plains south of Pine Ridge. This high plain extends across western Nebraska, Kansas, Oklahoma, and eastern Colorado and becomes the Llano Estacado or Staked Plain of Texas and New Mexico.

Drainage.—The Great Plains are drained by many rivers, most of which rise in the Rocky Mountains and empty into the Mississippi. Missouri River is the principal stream in their northern part, and the Cheyenne, Niobrara, and Platte are its larger tributaries. Arkansas, Canadian, and Red rivers and their branches drain the southern part of the area, and the Pecos, a tributary of the Rio Grande, flows along the western and southern sides of the Llano Estacado. The rivers cross the Great Plains in wide, shallow valleys that are bordered from place to place by low bluffs, and except at time of flood the streams shrink to narrow channels that are separated by sand bars.

GEOLOGY OF CENTRAL AND WESTERN KANSAS.

GENERAL FEATURES.

The geology of Kansas is in many features similar to that of Colorado and Nebraska, but several of the formations show considerable differences in their structural relations and in their stratigraphic components, owing to a gradual change of conditions of sedimentation or erosion toward the south and east. The eastern part of the State is crossed by the outcrop zone of a broad belt of limestones, shales, and sandstones of the Carboniferous system, from Mississippian to Permian in age, which dip gently to the west or slightly north of west under the younger formations. The younger formations comprise representatives of the Upper Cretaceous series from the Pierre shale to the Dakota sandstone, which lie directly on strata of Permian age, except where they are separated by upper formations of the Comanche series of the Lower Cretaceous and in part possibly the Morrison formation. In general they dip gently to the northwest, and owing to this dip, together with the rise of land to the west, the mass of strata thickens to the northwest. West of the ninety-eighth meridian nearly all the higher lands are covered by Tertiary and Pleistocene deposits to a thickness of 150 to 250 feet.

The following list sets forth the order, age, and principal characteristics of the formations:

Geologic formations in central and western Kansas.

Age.	Name.	Character of rocks.
Recent	Sand hills	Sand, mainly in dunes formed by action of wind.
	Alluvium	Sand, loam, and gravel in valleys; talus on slopes.
Pleistocene	Loess	Fine coherent sandy loam, of pale brownish-buff color.
	McPherson formation ("*Equus* beds").	Sands and sandy clays.
Pliocene and late Miocene.	Ogalalla formation, comprising "Tertiary grit," "mortar beds," etc.	Calcareous grit, sandy clay, and sand.
Upper Cretaceous	Pierre shale (Montana group.)	Dark-gray shale or clay.
	Niobrara formation (Colorado group)	Chalk, soft limestone, and shale.
	Carlile shale (Colorado group)	Dark shale with concretions.
	Greenhorn limestone (Colorado group)	Slabby limestone.
	Graneros shale (Colorado group)	Dark shale.
	Dakota sandstone	Sandstone and shale.
Lower Cretaceous (Comanche).	Kiowa shale and Cheyenne sandstone.	Do.
Lower Cretaceous (?).	Morrison (?) formation.	
Permian	Cimarron group ("Red Beds").	Red sandstone, shale, and gypsum.
	Sumner group.	Shale, limestone, and thick salt beds.

CARBONIFEROUS SYSTEM.

Sumner group.—Limestones and shales of Carboniferous age come to the surface in a wide belt across central-eastern Kansas. There are many formations, the uppermost of which, constituting the Sumner group, of Permian age, are the Wellington shale and the Marion formation. The Marion consists of light-colored limestone, shale, and marl and contains thick deposits of salt and gypsum. It is 300 to 400 feet thick, and in an extensive area in central Kansas a large proportion of it is made up of beds of salt. The Wellington shale, which consists mainly of light-colored shale, is about 200 feet thick in the northern and possibly 445 feet thick in the southern part of Sumner County. It passes beneath the Dakota sandstone north of Reno County and apparently merges on the south into the lower portion of the Cimarron group ("Red Beds").

Cimarron group ("*Red Beds*").—In the southern part of Kansas, from Sedgwick and Sumner counties westward, the Dakota sandstone and the Comanche series are underlain by red shale and sandstone, which thicken greatly to the west. They constitute the surface rock in Harper County and in the greater part of Kingman, Barber, Comanche, and Clark counties, as well as in Oklahoma and southeastern Colorado, but pass unconformably under younger formations to the north and west. They constitute the Cimarron group. The rocks are mainly soft fine-grained sandstone and shale, both of dark-red color, and contain thick beds of gypsum. The total thickness in western Kansas is not known but is probably at least 1,000 feet. According to G. I. Adams[1] these red rocks merge laterally into the Wellington shale in Sedgwick and Sumner counties. How far they extend to the northwest under the Dakota sandstone is not known, well borings not having given decisive evidence in this regard much beyond Arkansas River.

CRETACEOUS SYSTEM.

Morrison (*?*) *formation.*—The oldest rocks tentatively assigned to the Cretaceous system in southwestern Kansas possibly represent the eastern edge of the Morrison formation, of Cretaceous (?) (possibly Jurassic) age, and materials reputed from wells in the Syracuse and Lakin quadrangles have some of the characteristics of that formation.

Comanche series.—The upper formations of this series of marine Lower Cretaceous rocks underlie the Dakota sandstone in a portion of central-southwestern Kansas and outcrop under the edge of the Tertiary deposits in Clark, Comanche, Kiowa, and Barber counties. Another small area underlies the Dakota sandstone in the northwest corner of McPherson County. The lower formation, the Cheyenne sandstone, 40 to 60 feet thick, is composed mainly of coarse sandstone, mostly of light color and of relatively soft texture. It is not unlike the Dakota sandstone in appearance and weathers with somewhat similar aspect, but usually it is of lighter color. The Cheyenne sandstone is absent in McPherson County, where the Kiowa shale lies on the Wellington shale. The middle and lower beds are black and bluish-black to gray shale, with a thin hard stratum of sandy and calcareous matter at the bottom. The upper formation is the Kiowa shale, which is from 125 to 150 feet thick. Its upper beds are yellowish-gray shale and contain thin layers of yellowish to pinkish fossiliferous limestone. It is not known how far north the rocks of the Comanche series extend under southwestern Kansas, for well records do not reveal their identity. They may constitute the lower part of the beds reported as Dakota sandstone under an area of considerable extent and may include the eastern representatives of the Purgatoire formation of Colorado which is of late Comanche (Washita) age.

[1] Adams, G. I., The Carboniferous and Permian age of the Red Beds of eastern Oklahoma, from stratigraphic evidence: Am. Jour. Sci., 4th ser., vol. 12, pp. 383-386, 1901.

Dakota sandstone.—The Dakota sandstone, the oldest formation of the Upper Cretaceous series, underlies the western half of Kansas and outcrops in a zone 12 to 20 miles wide, which extends from Washington County south and southwest to Arkansas River in Rice and Barton counties, and thence up Arkansas River and Sawlog Creek to Ford County, where it passes under Tertiary deposits. It appears again in the valleys of Bear Creek and Cimarron River and some of its branches near the Colorado State line and on Arkansas River near Hartland. To the north and west, in northwestern Kansas, it passes beneath the shales of Benton and Niobrara age, the Pierre shale, and sands and gravels of Tertiary age and probably lies more than 2,000 feet below the surface in the northwest corner of the State. In north-central Kansas it lies on the dark shale and salt beds of the Wellington formation; in southern and southwestern Kansas it rests on the red sandstone and shale of the Cimarron group. In places the Kiowa shale and Cheyenne sandstone intervene, and probably the Cheyenne sandstone underlies it in an area of considerable extent under the southwest corner of the State. Possibly the lower sandstones that are regarded as Dakota include some of the Purgatoire formation, the Rocky Mountain representative of part of the Comanche series.

The Dakota consists mainly of sandstone, but shale members are included throughout its extent. (See Pls. III and IV.) As the beds differ from place to place no distinct subdivisions can be established. The characteristic Dakota sandstone is of considerable thickness, and beds of different kinds of clays are intercalated in it. The relations of the shale to the sandstone are exceedingly variable, but in the eastern part of the State well borings show first a thick body of sandstone, next a mass of shales locally 100 feet thick, then a second sandstone 50 or 60 feet thick, and at the base an alternation of sandstone and shale, amounting in all to 300 feet or more.

The sandstone is generally gray or buff, but in places it is a strong red, and some local beds are white. The material is quartz of varying degrees of fineness. The cementing material is partly calcareous and differs considerably in amount, parts of the stone being hard and resistant and other parts soft and crumbling. The rock is nearly everywhere very porous and forms a good reservoir for the storage of underground water. Some outcrops of sandstone at the head of Medicine Lodge River, in the southeast corner of Kiowa County, are doubtfully referred to the Dakota, although they lie directly upon upper members of the Comanche series.

In central Kansas the formation includes an upper member that is composed of 25 to 50 feet of shale capped by a foot or more of sandstone and in places is separated from the main body of sandstone by a deposit of lignite locally 2 feet thick. The upper part of the shale contains much gypsum in loose crystals and veins and the lower beds contain salt, which gives rise to saline lakes and springs at numerous localities.

Rocks of Benton age.—In northwestern and west-central Kansas three formations of Benton age overlie the Dakota sandstone in conformable succession. The rocks are shale (generally dark), limestone, and sandstone. The thickness of the formations is probably somewhat variable but aggregates about 400 feet. The outcrop extends in a wide belt diagonally across the State from Republic County into Ford and Finney counties, where it passes under the Ogalalla formation. It reappears again along both sides of the Arkansas Valley in Kearny and Hamilton counties, but the Tertiary deposits (Ogalalla formation) cover its southern edge in the southwest corner of the State.

The basal formation is dark bituminous shale, which is only 25 to 30 feet thick in central Kansas but thickens toward the west, attaining a thickness of 200 feet or more near the Colorado line. The shale is dark, moderately hard, breaks into thin flakes on weathering, and is regarded as the basal formation of Benton age and as representing the Graneros shale of eastern Colorado and adjoining States. This formation is overlain by a series of beds of limestone and shale in places 65 feet thick, which represents the Greenhorn limestone of eastern Colorado. The basal member of this formation is a massive bluish-gray limestone about 15 feet thick, which, although hard and flinty, weathers easily and is locally known as the Lincoln marble. Next above is the "flagstone," as it is sometimes called, a member consisting of several layers of limestone separated by thin beds of shale, having in all a thickness of about 10 feet. The limestone is white or light cream-colored, fine grained, and hard, and has been used extensively for flagstones at many places in central Kansas.

It is overlain by the "*Inoceramus* beds," as they are called locally, which consist of limy shale, including several thin beds of limestone separated by thin beds of shale. The limestone is filled with very numerous impressions of *Inoceramus labiatus* (see Pl. V, B), a fossil which occurs also in other members of the Greenhorn limestone. The top member of the Greenhorn limestone is a hard bed about 9 inches thick in north-central Kansas and is known as the "Fence-post limestone," because it readily splits into masses suitable in size and shape for fence posts and flagstones.

The uppermost formation of Benton age in Kansas consists almost entirely of shale, which represents the Carlile shale of eastern Colorado. In places this upper formation is 250 feet thick. Two members are recognized locally; the upper one (called Blue Hills shales by the Kansas University Geological Survey) consists of loose dark bluish-gray shale, which contains in its upper portion numerous lens-shaped concretions 4 to 5 feet in diameter, a feature that is characteristic of this horizon throughout central Kansas as well as in adjoining States. These concretions are dark and consist largely of calcium carbonate. Some of them have cone-in-cone structure; some are hollow geodes lined with crystals of calcite; others are traversed by cracks filled with calcite or other minerals. Many of these contain fossils of typical late Benton forms, including *Scaphites, Prionotropis woolgari*, and *Inoceramus*. The lower 150 feet of the Carlile formation, which is called *Ostrea* shales by the Kansas University Geological Survey, consists of soft dark blue-gray shale which contains in some places thin beds of limestone.

Niobrara formation.—The Niobrara formation underlies a wide region in Kansas west of the ninety-eighth meridian and north of Arkansas River. Its eastern margin lies in slopes that rise above the rolling surface of the formations of Benton age and trend southwestward across the State from Jewell County to the northeast corner of Finney County. It is thickly overlain by Tertiary deposits to the west, but some of the larger valleys, notably that of Smoky Hill River, are cut so deep that they afford extensive exposures of the Niobrara rocks. The lower part of the formation also appears in some of the deeper valleys in the northwestern part of Hamilton County north of Coolidge.

The formation comprises two members. The lower member, about 50 feet thick, which consists mainly of soft limestone and is known as Fort Hays limestone member, is in a general way equivalent to the Timpas limestone of Colorado. The upper member, which consists of soft chalk beds 300 to 400 feet thick, is known as the Smoky Hill chalk member or "*Pteranodon* beds," and in a general way is equivalent to the Apishapa formation of eastern Colorado. These beds immediately underlie the Pierre shale, but the contact appears to be hidden by the overlap of Tertiary deposits. The Fort Hays limestone is a soft, massive, light-colored rock which weathers out in bluffs of moderate prominence. In well borings it is generally distinctly recognized by its hardness, which is greater than that of the Smoky Hill chalk. The Smoky Hill chalk consists of a mixture of chalk and clay in varying proportions and is in part thin bedded; some portions of it are pure chalk. In its unweathered condition the Smoky Hill chalk appears as a massive light bluish-gray clay, but on weathering it usually becomes yellow or buff, and in some places light red—tints which are due to the oxidation of the iron contained. In well borings the material is a pale-blue chalky clay, not very sticky when wet. Some nearly pure chalk occurs in places, notably in the vicinity of Norton, in the valley of Prairie Dog Creek, where it has been quarried. The chalk beds, however, are best exposed in the valley of Smoky Hill River, where they form many prominent buttes and castellated cliffs. A small exposure has been observed northwest of Horace, near the State line. Crystals of gypsum are not uncommon in the weathered beds, and a large amount of pyrite weathers out in nodules in many localities. The principal molluscan fossils of the Niobrara formation are *Ostrea congesta* (see Pl. V, A) and *Inoceramus deformis*, and remains of many animals of various kinds have also been found.

The Niobrara formation has been penetrated by numerous wells, which throw light on its position and thickness underground. At Horace, in Greeley County, the deep boring found the top of the formation a short distance below the surface and apparently about 650 feet thick, although some of the top beds may have been removed by erosion.

Pierre shale.—In the northwest corner of Kansas the Niobrara formation is overlain by the Pierre shale, which is exposed at intervals in the valleys of Republican and Arikaree rivers and their branches in Cheyenne County, notably in the banks of Hackberry Creek, 15 miles south of St. Francis; on Beaver Creek, in Rawlins County; and on Prairie Dog Creek, in Norton County. The shale is of dark grayish-blue color but weathers to a clay of rusty yellowish-brown tint. Lens-shaped concretions of different sizes occur in some of the beds and carry distinctive Pierre fossils.

TERTIARY SYSTEM.

The rocks of the White River group, of Oligocene age, appear to be absent in western Kansas, for the southern edge is not far south of Akron in Colorado. Probably they extended farther to the southeast in earlier times and have been removed by erosion. Possibly some outliers still remain, however. Adams[2] has called attention to some soft sandstones uncon-

[2] Adams, G. I., Am. Geologist, vol. 29, pp. 301-303, 1902.

formably underlying the Ogalalla beds on Cimarron River in Seward County, which he suggests may be of the White River group.

Ogalalla formation.—Most of western Kansas and southeastern Colorado is covered by a thick sheet of sand and gravel which represents the southern extension of the Ogalalla formation. It is from 100 to 350 feet thick and constitutes the surface of all of the uplands and parts of the valley slopes, and extends to the bottoms of the valleys in places. It upper surface is generally very level. (See Pls. I and II.) It lies on an irregularly eroded surface of the Cretaceous formations, from Pierre shale to Dakota sandstone, and in some of the valleys is overlain by Quaternary deposits. The materials of the Ogalalla formation are uniform in general character, but there is much local difference in the thickness, succession, and texture of the beds. The sands are in irregular bodies, thickening and thinning from place to place, and they contain varying proportions of gravel on the one hand and grade into silt and clay on the other. The coarser deposits are interspersed irregularly among beds of clay, and locally the clay or loam deposits become thick and prominent. The surface of the formation is clay or silt in some places and loose sands in others, but ordinarily the surface sand is blown away unless well protected by sod. Calcium carbonate occurs in considerable amount in most of the formation, especially in the coarser deposits, which it cements into the loose conglomerate known as "mortar beds." This rock outcrops in the slopes of many of the depressions, generally as ledges or low cliffs, for much of the rock is moderately hard and much more resistant to erosion than the unconsolidated sand and gravel. The calcium carbonate appears in this rock as a white cement between grains of the sand and gravel, and in places it occurs in nearly pure condition as irregular bodies or beds of no great thickness. This calcareous grit or "mortar beds" outcrops extensively along the sides of the valleys and draws throughout western Kansas as well as in adjoining States north and west.

The origin of the "mortar beds" is closely connected with the semiarid climatic conditions. The water that falls as rain as it soaks into the ground takes up more or less carbon dioxide from vegetation and other sources at the surface. This water acts on particles of calcium carbonate disseminated in the deposits and carries them down into the coarse deposits of the Ogalalla formation. Here the water accumulates, and as the circulation is very sluggish on account of the little rainfall, much of the calcium carbonate is eventually precipitated about the sand and gravel, cementing it to rock.

Owing to its removal by erosion and to the unevenness of its base, the southeastern margin of the Ogalalla formation in Kansas is irregular and indefinite, extending eastward on the divides and retreating far westward up the valleys of Smoky Hill and Solomon rivers. From Hartland to Dodge the base of the formation descends below the bottom of Arkansas River and probably occupies an old depression which continues eastward through Kiowa and Pratt counties and the western part of Reno County.

In the divide south of Arkansas River the Ogalalla formation extends westward as the surface of the High Plains to a point beyond longitude 103° and is found at intervals farther west on some of the higher summits. Near the south line of Colorado it is overlain, according to W. T. Lee,[1] by lava flows of the Mesa de Maya and other areas.

The formation extends northward across the southwestern part of Nebraska, but in the vicinity of North Platte River it is thin, and farther north and northeast it apparently thins out entirely and gives place to the Arikaree formation, which has similar topographic relations on the northern plains. Its distinctness from that formation, however, was clearly ascertained both along the southern side of North Platte Valley in west Nebraska and in exposures in northeastern Colorado, where the Arikaree beds are well characterized and are unconformably overlain by the Ogalalla beds. Moreover, the Arikaree formation contains numerous bones of Miocene age at many localities in Nebraska, Wyoming, and South Dakota, but the bones that occur in abundance at some places in the Ogalalla formation are of Pliocene age. Possibly some of the sand and loam deposits covering the plains of western Kansas are younger than Ogalalla and represent the McPherson formation ("*Equus* beds") and other deposits of early Quaternary age.

Osborn and Matthew[2] in their review of mammal horizons ot North America regard the Ogalalla deposits in southwestern Nebraska and northwestern Kansas as comprising two zones, the *Procamelus* zone, of upper Miocene age, and the *Peraceras* zone, of uppermost Miocene or earliest Pliocene age.

On the other hand, apparently typical "mortar beds" in Meade County, similar to those farther north, have yielded many remains of horses, llamas, elephants, and other animals, which are classed as early Pleistocene, probably representing the McPherson formation or "*Equus* beds" of central Kansas. Other fossils of this fauna have been found in Smoky Hill Valley and near Goodland, but the containing deposits may prove to be younger than the Ogalalla. Some portions of such younger deposits cemented by calcium carbonate might be expected to resemble the Ogalalla closely.

[1]Jour. Geography, vol. 2, p. 78, 1903.
[2]U. S. Geol. Survey Bull. 361, pp. 79–81, 1909.

QUATERNARY SYSTEM.

The Quaternary system is represented in central Kansas by the McPherson formation ("*Equus* beds") and loess, of Pleistocene age, and by Recent alluvium and sand hills. The Recent deposits are also present in western Kansas. It is possible that some of the surficial sand and loam there represent the McPherson formation.

TOPOGRAPHY.

Plateaus.—The most marked topographic features of the Syracuse and Lakin quadrangles are the wide, high plain, which constitutes most of the area, the flat-bottomed valley of Arkansas River cut in this plain, and the broad belt of sand hills that extends along the south side of the river and up the slopes to the south. This high plain is part of the smooth general upland of the Great Plains. (See Pls. I and II.) In the region south of Syracuse it presents some marked irregularities, which are due to erosion by the two forks of Bear Creek. Its most striking feature in this area is a ridge between the sand hills and the valley of North Fork of Bear Creek, which rises from 100 to 150 feet above the general slopes farther south. This ridge begins 10 miles south of Hartland and extends westward into Colorado, where it merges into the general High Plains. It is broad and smooth in the region south of Kendall and Syracuse but on the sides is deeply cut by long draws. In R. 42 W. it narrows, and the summit finally consists of a succession of rounded knobs, one of which, in sec. 7, T. 25 S., R. 42 W., is about 3,690 feet above sea level and is the highest point in the two quadrangles. On the north this ridge slopes with moderate steepness to the sand-hill belt; on the south steep slopes descend along the valley of North Fork of Bear Creek to its mouth and then to Bear Creek, which finally flows around its eastern end. South of the ridge is a broad area of slightly lower, rolling plains that rises gradually to the west and is trenched by the shallow valley of Bear Creek. This plain extends eastward past New Ulysses, where it is trenched by the wide but moderately deep valley of North Fork of Cimarron River and its branches. It slopes gradually to the north into the valley of the Arkansas, but a wide belt of sand hills covers much of the slope.

On the north side of Arkansas River there are steep slopes to the high plain, which is about 250 feet above the bottom of the valley. Its surface is smooth, notably so in the broad area northwest of Hartland, and it slopes gently eastward. Near Lakin the rise to the highland diminishes in steepness and the highland itself recedes considerably from the river.

River valley.—The valley of Arkansas River, which extends across the northern portions of the Syracuse and Lakin quadrangles, presents the usual characteristics of a river valley of the Great Plains. It consists of a flat-bottom trench with sloping sides; on the north there are slopes to the High Plains, and on the south there is a broad zone of sand hills. The river meanders through the valley in long curves and for part of its course has low banks on one side or the other. In places the stream reaches the foot of the slope which rises to the adjoining highlands and cuts a bank of greater or less prominence, as in the bend 4 miles west of Hartland. The width of the river flat is about 2 miles near Syracuse and Kendall, but it narrows to 1½ miles and finally to 1 mile from Kendall to Hartland, probably because of the encroachment of sand hills from the south. Below Hartland it widens greatly and its width is 5 miles or more near Lakin and Deerfield, where the slopes on the north trend away to the northeast and the sand hills on the south do not extend so near to the river as in the region west of Hartland. The bottom lands adjoining the river are nearly flat, but there is in most places a slight slope toward the stream and in places low terraces. The higher lands in the valley are known as "second bottoms," which is the land mostly cultivated. Freshets flood the lower bottom lands or "first bottoms," and at times the water reaches the foot of the adjoining slopes on the north and the sand hills on the south. The river leaves the area in the northeast corner of the Lakin quadrangle at an altitude of about 2,860 feet above sea level, which is the lowest point in the area. The fall to this point from the north margin of the Syracuse quadrangle northwest of Syracuse is about 390 feet, and as the distance is 50 miles the rate of declivity is very nearly 8 feet to the mile.

Sand hills.—The sand hills that extend in a broad belt along the southern side of the Arkansas Valley in the Syracuse and Lakin quadrangles have a width of 3 to 4½ miles from a point opposite Syracuse to Kendall, but southeast of Hartland they broaden greatly and they are 18 miles wide in the western part of Finney County. The margins of the sandy belt are usually somewhat indefinite, for in greater part the hills rise gradually from the river flats and on the south they merge into an irregular thin mantle of blown sand extending far up the slopes of the High Plains. The southern limit generally is farther south than is shown on the areal-geology sheet, for at many places the margin is indefinite. The material consists of sand brought by the river and blown to the south and southeast by the strong winds. It is heaped up in irregular slopes and dunes that are separated by irregular basins and winding valleys. (See Pl. VI.) These valleys in some places expose the floor on which the sand lies, but in other places the bottoms of the basins are covered with a deposit of silt from dried-up ponds. The highest hills rise 60 to 80 feet above their base and a large part of the surface consists of loose sand, which is not tillable and is difficult for transportation by wagon. In many places there are "blow-outs" or "craters," where the sand has been blown out of a circular or semicircular pit on the summit or in the side of the dune. Considerable sand moves when the winds are high, and thus many details of configuration are altered; more or less new sand is also blown from the bed or freshet plain of the river to add to the deposits. Bunch grass grows in most places on the sand hills, so that the region affords good pasturage. Water is usually available from shallow wells and ponds. Much of the rain falling on the sand hills sinks vertically, but the water spreads laterally when it reaches the valley floor. Bear Creek empties into the sand hills, and in times of great freshets, which occur at long intervals, its water flows into irregular valleys among the hills where in a few days it disappears partly by underground leakage and partly by evaporation. There was a flood of this sort in 1884 and another in 1895, when the water, flowing at a mile or two an hour and 1 to 2 feet deep, overflowed an area 1 to 2 miles wide in T. 27 S., R. 38 W. There are traditions that some of the freshet waters have passed entirely through the sand hills and thence by Clear Lake into Arkansas River, and there is a well-defined channel across sec. 13, in which a small stream flowed at one time. Clear Lake is a nearly circular pond, about 300 feet in diameter, in a notable depression in the valley floor, and its water surface is about 8 feet below the level of the Arkansas at a point half a mile northwest and 3 feet below at a point due north. It is said that the pond is very deep and is fed by underflow from Bear Creek, but soundings made by Slichter in August, 1914, found only 16 feet of water, and measurements in test holes in the vicinity showed that the underflow came from the west and was in no way connected with the Bear Creek drainage.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

GENERAL CHARACTER OF THE ROCKS.

The strata that outcrop in the Syracuse and Lakin quadrangles are only about 200 feet thick. They are sandstones,

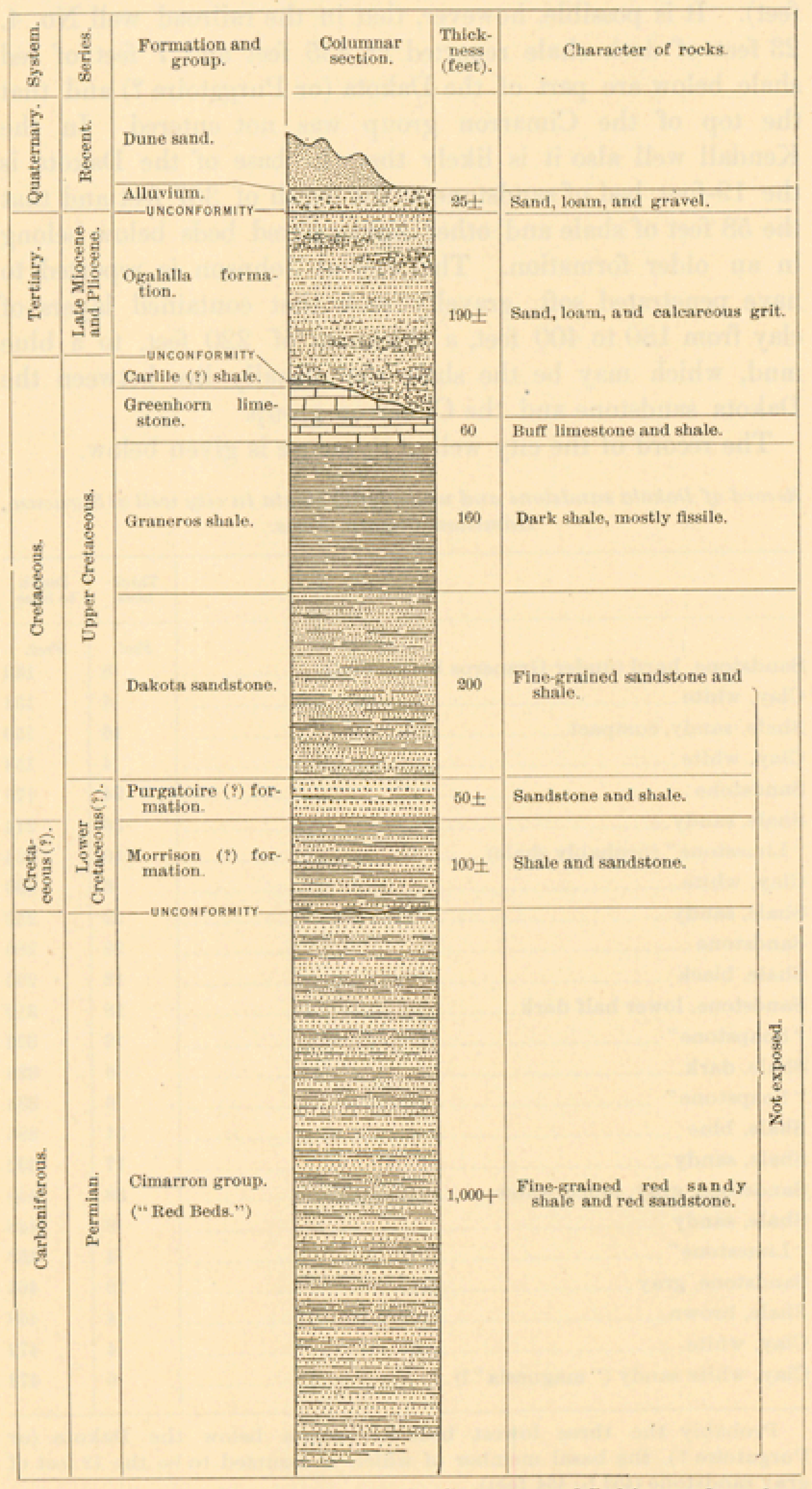

FIGURE 3.—Generalized section for the Syracuse and Lakin quadrangles.
Scale: 1 inch=200 feet.

shales, and limestones of Cretaceous age, and gravels and sands of late Tertiary and Quaternary age. Cretaceous rocks underlie the entire area and below them there is a thousand feet or more of Carboniferous rocks consisting of red sandstone and red shale, probably underlain by limestones. There are no igneous rocks. The formations exposed are shown in the columnar section (fig. 3), which indicates the thickness, character, and relations of the beds.

CRETACEOUS SYSTEM.

UPPER CRETACEOUS SERIES.

The sandstones and limestones of Cretaceous age that outcrop to a small extent in the slopes of the valleys of Arkansas River and Bear Creek comprise three formations—Dakota sandstone, Graneros shale, and Greenhorn limestone. The Carlile and Niobrara formations, which lie above the Greenhorn, appear to be absent, but doubtless they formerly extended across the region and have been removed by erosion. Possibly some of the Carlile shale remains in the ridge south of Arkansas River and east of New Ulysses, but its edge is overlapped by the Ogalalla formation.

DAKOTA SANDSTONE.

Distribution and relations.—The Dakota sandstone outcrops at intervals on the southern slope of the ridge that crosses the southern part of Hamilton County and also on Bear Creek 12 to 15 miles southwest of Johnson. A small exposure also appears in the south bank of Arkansas River 2 miles southwest of Hartland. Doubtless the formation is not far beneath the surface at many other places in the valleys and it has been entered by numerous wells. At Syracuse it lies 122 to 193 feet below the valley floor, at Johnson 180 feet, at Kendall 153 feet, and at Lakin 156 feet. It is probably at no great depth in the greater portion of Grant and Stanton counties under the covering of the Ogalalla formation and alluvium. In the ridges on both sides of Arkansas Valley it is overlain by Graneros shale and Greenhorn limestone. As shown by records of several deep borings it lies on red beds (Cimarron group), with some intervening shale and sandstone, which may possibly be older than Dakota and represent the Purgatoire and Morrison formations of eastern Colorado.

Thickness and well sections.—The thickness of the exposed beds of Dakota sandstone is about 80 feet in the outcrops south of Syracuse, but there are 150 feet or more of lower beds possibly including the Purgatoire formation, which do not reach the surface. The total thickness of the sandstones is indicated by records of several wells. In the railroad well No. 4 at Syracuse the thickness is apparently 265 feet (170 to 435 feet), in the city well it is 342 feet (122 to 464 feet), and at Kendall it may be as much as 440 feet (53 to 493 feet). It is possible, however, that in the railroad well No. 4, 23 feet of dark shale reported at 435 feet and 7 feet of red shale below are part of the Dakota (or Purgatoire ?) and that the top of the Cimarron group was not entered. In the Kendall well also it is likely that the base of the Dakota is the 19-foot bed of sandstone at the depth of 367 feet and that the 58 feet of shale and other light-colored beds below belong in an older formation. The well at Johnson is reported to have penetrated soft, gravelly rock that contained layers of clay from 180 to 400 feet, a thickness of 220 feet, to a blue mud, which may be the shale that usually lies between the Dakota sandstone and the Cimarron group.

The record of the city well at Syracuse is given below.

Record of Dakota sandstone and underlying strata in city well at Syracuse, Hamilton County, Kans.

	Thickness.	Depth to base.
	Feet.	*Feet.*
Sandstone, hard (under Graneros black shale)	8	130
Clay, white	4	134
Shale, sandy, compact	16	150
Clay, white	4	154
Sandstone	24	178
Shale, sandy	36	214
"Limestone" (probably shale)	10	224
Clay, white	6	230
Shale, sandy	22	252
Sandstone	28	280
Shale, black	12	292
Sandstone, lower half dark	18	310
"Soapstone"	12	322
Shale, dark	6	328
"Soapstone"	6	334
Shale, blue	51	385
Shale, sandy	17	402
Sandstone, gray, much water	38	440
Shale, sandy	8	448
"Limestone"	4	452
Sandstone, gray	12	464
Shale, brown	4	468
Clay, white	4	472
Clay, white sandy ("magnesia" ?)	6	478

Probably the three lowest beds are strata below the Dakota (or Purgatoire ?), the basal member of which is assumed to be the 12 feet of gray sandstone (452 to 464 feet).

In this well the Dakota (or Purgatoire ?) sandstone apparently began at a depth of 122 feet under 100 feet of black shale and continued to or nearly to the bottom at 478 feet.

In another well at Syracuse shale is reported to a depth of 185 feet, followed by 8 feet of joint clay, beneath which the Dakota sandstone is penetrated for 91 feet (193 to 284 feet), probably without its base being reached.

The strata are reported as follows:

Partial record of Dakota sandstone in well at Syracuse, Kans.

	Thickness.	Depth to base.
	Feet.	*Feet.*
Sandstone, soft water	4	197
Shale with thin limestone layer at 225 feet	43	240
Clay, white	10	250
Sandstone, soft water	29	279
Shale	5	284

In well No. 2 of the railroad company there are reported white sandstone 235 to 237 feet and 252 to 255 feet, gray shale 255 to 262 feet, brown sandstone 262 to 265 feet, white sand 283 to 286 feet, and gray shale 286 to 291 feet.

Railroad well No. 4 is 465 feet deep. This well is some distance from the others and enters the Dakota sandstone at 170 feet under 9 feet of sandy shale, which may possibly be Dakota also. It is overlain by 31 feet of soft white clay, which underlies the usual black shale and which is not reported in other wells. The strata penetrated are reported as follows:

Record of Dakota sandstone in railroad well No. 4, Syracuse, Kans.

	Thickness.	Depth to base.
	Feet.	*Feet.*
Sandstone, gray, water bearing	12	182
Clay, white	38	220
Sand and shale	3	223
"Limestone"	1	224
Clay, white	31	255
Sandstone, gray, much water	12	267
Clay, white	13	280
Sand, dark	26	306
Shale	94	400
Sandstone, much water at base	35	435
Shale, sandy, dark	23	458

Below the sandy shale, which may be older than the Dakota, is 7 feet of red variegated shale, presumably of the Cimarron group.

The 537-foot boring at Kendall passed through the Dakota sandstone and some underlying shale of unknown age, and from 496 to 537 feet is in the Cimarron group. The following record is given:

Record of Dakota and associated strata in boring at Kendall, Kans.

	Thickness.	Depth to base.
	Feet.	*Feet.*
Soil, gravel, and sand	53	53
Sandstone (top of Dakota)	56	109
Lignite	2	111
Clay	3	114
Sandstone, gray, soft water	38	152
Clay, very hard	2	154
Sandstone, gray	13	167
Shale, very hard in center	48	215
Sandstone, gray, soft water	53	268
Shale	23	291
Sandstone	6	297
Shale	35	332
Sandstone, black	2	334
Shale	14	348
Sandstone, gray, soft water	19	367
Shale, gray	58	425
Sand, brown	5	430
Clay, brown below	23	453
Clay, sandy	23	476
Sandstone, light gray	17	493
Fire clay	3	496
Clay, red	34	530
Hard layer	3	533
Shale, red	4	537

It is possible that the base of the Dakota sandstone is at a depth of 367 feet at the bottom of the 19-foot bed of water-bearing gray sandstone. The underlying shale and sandstone (367 to 496 feet) would then represent Comanche sediments (Purgatoire formation of eastern Colorado) or the Morrison formation.

In a 535-foot well in the SE. ¼ sec. 9, T. 25 S., R. 41 W., 7 miles southwest of Syracuse, the Dakota sandstone is entered at a depth of 250 feet under 40 feet of "hard sandy shale" and apparently continues to 532 feet; it may also comprise the 3 feet of black shale at the bottom of the boring. The following strata are recorded:

Record of Dakota sandstone in well in SE. ¼ sec. 9, T. 25 S., R. 41 W., near Syracuse, Kans.

	Thickness.	Depth to base.
	Feet.	*Feet.*
Sandstone	20	270
Clay, white	35	305
"Limestone"	13	318
Shale, hard, sandy	12	330
Clay, white	40	370
Shale, variegated	20	390
Rock and clay	26	416
Sandstone, gray	14	430
Shale, hard, sandy	20	450
Sandstone, gray	15	465
Clay, brown and white	35	500
Sandstone and clay, alternating thin beds	20	520
Sandstone, light gray	12	532
Shale, black (age ?)	3	535

A 362-foot well in the NW. ¼ sec. 33, T. 25 S., R. 41 N., enters Dakota sandstone under black shale at a depth of 140 feet and penetrates the following beds:

Partial record of Dakota sandstone in well in NW. ¼ sec. 33, T. 25 S., R. 41 W., near Syracuse, Kans

	Thickness.	Depth to base.
	Feet.	*Feet.*
Sandstone, gray	40	180
Clay, white	30	210
Shale, hard, sandy	50	260
"Limestone" (?)	22	282
Shale, hard, sandy	23	305
Sandstone, gray	53	358
Clay, white	4	362

A 232-foot well in the NE. ¼ sec. 27, T. 25 S., R. 41 W., enters Dakota sandstone at 170 feet under 34 feet of hard sandy shale and penetrates the following beds:

Partial record of Dakota sandstone in well in NE. ¼ sec. 27, T. 25 S., R. 41 W., near Syracuse, Kans.

	Thickness.	Depth to base.
	Feet.	*Feet.*
Sandstone	15	185
Clay, white	15	200
Limestone	10	210
Sandstone	20	230
Clay, white	2	232

In the well at Santa Fe, a few miles east of the southeast corner of the Lakin quadrangle, the Dakota sandstone appears to extend from the base of 13 feet of limestone (Greenhorn?) at 357 feet to the Cimarron group at 620 feet, a thickness of 263 feet.

In a boring in the northwestern part of Garden City, 6 miles east of the northeast corner of Lakin quadrangle, the Dakota appears to have been entered at 461 feet, but its thickness can only be surmised from meager data as from 250 to 300 feet.

A boring 1,160 feet deep in the northwestern part of Morton County, about 9 miles due south of the southwest corner of the Syracuse quadrangle, enters Dakota sandstone at 118 feet under sand, gravel, and clay, and penetrates the following beds which are regarded as Dakota sandstone: Yellow shale, 17 feet; blue sandstone, 35 feet; blue shale, 80 feet; and white sandstone, 125 feet; total, 257 feet. The underlying rocks are of the Cimarron group.

Character in outcrops.—Most of the Dakota sandstone is a brown, massive to thin-bedded, fine-grained rock. It is in bodies mostly from 5 to 25 feet thick, separated by light-colored shale or clay, which in places is reddish, purplish, or yellow. (See Pls. III and IV.) On Bear Creek southwest of Johnson, in a bank 20 feet high, the following beds dip gently eastward:

Section of Dakota sandstone on Bear Creek 10 miles southwest of Johnson, Kans.

	Feet.
Sandstone, thin bedded, soft	5
Sandstone, thin bedded, hard	8
Clay, gray, sandy, with thin bed of sandstone cemented by iron oxide	3
Sandstone, hard, massive, compact	4

A mile farther upstream 8 feet of the sandstone appears and is capped by grit and conglomerate of the Ogalalla formation. Half a mile farther southwest is an exposure (see Pl. IV) showing the following beds:

Section of Dakota sandstone in NW. ¼ sec. 14, T. 29 S., R. 43 W., 12 miles southwest of Johnson, Kans.

	Feet.
Sandstone, soft	3
Sandstone, hard, brown to buff, massive	4
Clay, light gray, sandy, with thin beds of brown sandstone	6.
Sandstone, hard, massive	4½
Clay, gray, shaly, with 6-inch ironstone layer near base	12

The beds are considerably eroded and their irregular surface slopes southwest under the grit of the Ogalalla formation. In the southwest quarter of the same section, however, there is another prominent exposure with the following components:

Section of Dakota sandstone in SW. ¼ sec. 14, T. 29 S., R. 43 W., 12 miles southwest of Johnson, Kans.

	Feet.
Sandstone, thin bedded	6
Sandstone, massive	10
Shale, dark	3
Clay, thin sandstone, and ironstone	8
Sandstone and shale, thin bedded	4
Sandstone, gray, in part massive	8

The 10-foot massive sandstone in this section is the same as the 4⅔-foot bed in the preceding section.

The Dakota sandstone outcrops at intervals in draws and along the lower slopes on the southern or Bear Creek side of the ridge from sec. 27, T. 26 S., R. 40 W., to sec. 12, T. 26 S., R. 42 W., and doubtless it is under the wash at many other points in this slope. The southeastern exposure in this belt is in a draw in the SW. ¼ sec. 27, T. 26 S., R. 40 W., where the rock has been quarried to some extent. A thickness of 8 feet of beds is exposed, mainly thin-bedded, fine-grained, light-colored sandstone. Its irregularly eroded surface is overlain by Ogalalla grit and slopes down to the south.

The exposures in the large draw 15 miles south of Syracuse are near the main road to Johnson. They begin a mile north of bench mark 3,365 and extend to bench mark 3,362 in an almost continuous outcrop. They consist of scattered ledges of buff to brownish sandstone, mostly thin bedded, that contains intercalated gray and buff shale and clay, which in places has a purplish tint. About 80 feet of these beds which are exposed lie nearly level but are capped by grit of the Ogalalla formation on an irregular plane, which slopes to the south. The sandstone outcrops at intervals west of this draw, and it has been quarried to some extent in the NW. ¼ sec. 17 and in sec. 27, T. 26 S., R. 41 W. In these quarries the sandstone is of the usual character, a buff, moderately fine grained, moderately hard rock, in beds which differ in thickness. In the northeastern part of sec. 7, T. 26 S., R. 41 W., the thin-bedded buff sandstone which is exposed in the bottom of a draw is overlain by 30 feet of dark Graneros shale. The last exposure to the northwest is in a draw in the eastern side of sec. 12, T. 26 S., R. 42 W.

The Dakota sandstone outcrops in low ledges along the south bank of Arkansas River 2 miles southwest of Hartland. These ledges extend for a hundred yards and consist of a hard bed of gray to buff sandstone underlain by softer material. The beds appear to lie nearly horizontal, but probably they are brought to the surface by a low anticline.

Fossils.—The only fossils found in the Dakota sandstone are a few fragments of plant stems in sec. 24, T. 26 S., R. 41 W., 15 miles south of Syracuse, which F. H. Knowlton regards as probably *Equisetum*. From this vicinity St. John[1] reports leaves of *Salix*.

GRANEROS SHALE.

Distribution.—The Graneros shale underlies a large part of the Syracuse and Lakin quadrangles, but it is soft, in places deeply eroded, and for the most part so much covered by Tertiary and Quaternary deposits that it rarely crops out. It underlies the high ridge that extends across the southern part of Hamilton County, where a few of the deeper draws afford exposures of most of its beds. It is covered by alluvium and dune sand in the valley of the Arkansas in the vicinity of Syracuse, and farther east past Lakin, except in an interval from a point near Kendall nearly to Hartland. The most extensive exposures are a mile east of Sutton Siding, where it outcrops in the north bank of the river, in railroad cuts, and in the slopes north of the railroad. The river valley cuts entirely through it near Kendall and Hartland, as indicated by records of wells near Kendall and an outcrop of Dakota sandstone west of Hartland. Its southern limit is not located. In the Lakin quadrangle it probably underlies part of the sand-hill belt and some of the highlands to the southeast; in the Syracuse quadrangle it probably extends southward across the greater part of Stanton County. Wells in Syracuse are reported to enter it from 20 to 30 feet below the surface and to reach its base at depths of 122 to 193 feet.

Character.—The Graneros shale is a soft dark-gray shale, mostly fissile. It contains thin beds of gray sandstone and a thin layer of fossil oysters near the top. In the extensive exposure in the river bank and railroad cut half a mile east of Sutton Siding 40 feet of the shale is visible and is capped by slabby beds of the Greenhorn limestone. Two 4-inch layers of fossil oysters, determined by T. W. Stanton as *Ostrea congesta*, lie 20 feet below the contact. This outcrop extends for several miles east and west along the slopes just north of the railroad, but in most places the beds are concealed by wash. The shale is dark gray and mostly in thin splintery layers, easily separable. Some layers are composed of thin slabby sandstone. A small outcrop of the top beds appears in a ditch 1½ miles west of Kendall.

The Graneros shale that outcrops in the draws near the southern slope of the ridge in T. 25 S., R. 42 W., is dark shale that carries thin sandstone and limy layers, and the exposures are small and considerably obscured by talus. One of the clearest exposures is in a draw near the center of the north half of sec. 36 in this township. Here 30 feet of the shale is exposed and is capped by grit and conglomerate of the Ogalalla formation. Fossils collected in this vicinity and in draws 20 miles southeast of Syracuse were determined by T. W. Stanton as *Inoceramus fragilis* and *Metoicoceras swallowi?*

Thickness.—The thickness of the Graneros shale is somewhat difficult to determine from the outcrops, for none of the exposures exhibit all the beds. In the slopes north of Irene the thickness appears to be about 150 feet and in the slopes west of Hartland about 80 feet.

In one of the wells at Syracuse the shale that extends from 28 to 161 feet is probably Graneros and comprises all of the formation except possibly a few feet at the top that may have been removed by erosion; the 30 feet of white clay reported from 130 to 161 feet is a peculiar feature; and the dark-brown sandy shale from 161 to 170 feet may be a transition member to the Dakota sandstone. In an earlier well Graneros shale is reported from 21 to 193 feet; the lower 8 feet is given as "joint clay"; and a 1-foot bed of limestone is mentioned at 51 feet. A well in the northern part of the town, which began near the top of the formation, passed through shale to a depth of 153 feet. A well in the SE. ¼ sec. 9, T. 25 S., R. 41 W., passed through strata reported as black shale from 30 to 210 and from 210 to 250 feet through hard sandy shale underlain by Dakota sandstone. These beds 220 feet in thickness included the greater part of the Greenhorn limestone and all of the Graneros shale. Black shale that extends from 22 to 140 feet and overlies Dakota sandstone in a well in the NW. ¼ sec. 33, T. 25 S., R. 41 W., is probably mostly if not all Graneros. The beds reported as black shale, 118 feet in thickness, which are underlain by 34 feet of hard sandy shale that overlies Dakota sandstone in a well in the NE. ¼ sec. 27, T. 25 S., R. 41 W., probably include some Greenhorn beds. A well in the northeast corner of sec. 32, T. 27 S., R. 42 W., passed through clay from 20 to 150 feet, and then penetrated soft sandstone. A boring at Garden City penetrated 150 feet of Graneros shale that underlies a very thick body of quicksand at a depth of 311 feet and extends to the supposed top of the Dakota sandstone.

In the well at Santa Fe, not far east of the southeast corner of the Lakin quadrangle, 13 feet of hard blue limestone which lies on the water-bearing sandstone at 337 feet appears to be Greenhorn limestone, and, if this is the fact, the Graneros shale is locally absent. This limestone is overlain by 160 feet of blue shale. A similar feature is reported in the well in the northwest corner of T. 28 S., R. 33 W., where 20 feet of "hard blue rock" that lies on Dakota sandstone at 325 feet may also be Greenhorn.

GREENHORN LIMESTONE.

Distribution.—The northern portions of the Syracuse and Lakin quadrangles are underlain by Greenhorn limestone, but the formation is mostly so covered by the Ogalalla formation and wash that outcrops are not extensive. In Hamilton County the formation extends southward across the high ridge south of the river, but its southern margin is mostly concealed by later deposits. It is deeply trenched by the river valley, which is excavated into the underlying Graneros shale in most of the area. Its southern limits in Kearny and Finney counties are not located, owing to the cover of dune sand and the Ogalalla formation, and it is not definitely known to extend south of the river in those counties. Its distribution beneath the surface in the vicinity of Lakin is also unknown, owing to the cover of the Ogalalla formation which is overlapped by the alluvium. There are extensive outcrops about Kendall and for some distance westward and eastward nearly to Hartland. The quarries a short distance northwest of Syracuse furnish excellent exposures, and there are scattered outcrops in draws along the slope of the ridge south and southwest of Syracuse.

Character.—The Greenhorn limestone consists of beds of hard, slabby limestone separated by shale—features which characterize it in the region to the west. The limestone beds are mainly from 4 to 12 inches thick and the intercalated beds of shale range from 3 to 10 inches in thickness for the most part. The shale is black when fresh, but it usually includes some limy layers which weather buff. The limestone varies considerably in character, for some beds contain much sand or clay, and it weathers to a light buff. Many layers contain impressions of *Inoceramus labiatus*, the characteristic fossil of the formation. (See Pl. V, B.) The limestone is exposed in contact with Graneros shale in places, notably in the railroad cut half a mile east of Sutton Siding, where the usual abrupt change from shale to limestone is exhibited. The formation is capped by conglomerate of the Ogalalla formation, which lies on an irregular erosion surface.

Thickness.—Where the Greenhorn limestone is exposed its thickness ranges from a few inches to 40 feet, but in no place is a complete section revealed, so that the total thickness is unknown. Probably it is about 60 feet.

Fossils.—The limestone contains many impressions of the characteristic *Inoceramus labiatus* mentioned above, a fossil which is especially abundant in the layers of shale that separate the limestone beds. (See Pl. V, B.) T. W. Stanton has examined microscopically some of the limestone from the quarry near Syracuse and found that it contains somewhat abundant Foraminifera of the genus *Globigerina*, which is common in most Cretaceous chalks and chalky limestones and is widespread in the present oceans. Exposures in a canyon in sec. 11, T. 25 S., R. 41 W., 8 miles southwest of Syracuse, yielded remains of *Inoceramus labiatus* and *Globigerina*.

CARLILE (?) SHALE.

No outcrops were found of the Carlile shale, which is next above the Greenhorn limestone in regular succession, but possibly a thin body of this shale underlies part of the high tableland north of Kendall and Hartland, and comes in above the Greenhorn limestone as the base of the Ogalalla formation rises to the north.

TERTIARY SYSTEM.

OGALALLA FORMATION.

Distribution and outcrop.—Most of the highlands of the Syracuse and Lakin quadrangles is occupied by the thick sheet of sand and gravel of late Tertiary age which constitutes the surface of the Great Plains in the western Kansas region. (See Pls. I and II.) This formation, the Ogalalla, extends across Haskell, Grant, and Stanton counties, and although its surface has been considerably eroded in places its base is not cut through, except by Bear Creek, west of Johnson. It caps the high ridge that extends across the southern part of Hamilton County, but where it is cut through by some of the draws the underlying Dakota sandstone, Graneros shale, and Greenhorn limestone are exposed. It constitutes the high plain north of the river at Syracuse, Kendall, Hartland, and Lakin, and though the river trenches it widely from Syracuse to Hartland its base near Hartland descends to and probably below the edge of the alluvium that fills the valley—a condition which continues for many miles eastward. The formation is well exposed at but few places, for most of the area is covered with sod or the surface is mantled by soil and wash. The materials which are mostly sand and sandy loam are not at all distinctive in appearance and do not give rise to prominent exposures. Many of the draws, even the large ones, have sloping sides covered with sod or talus. In places, however, there are cut banks, notably along Bear Creek west of Johnson, on the ridge that extends across the southern part of Hamilton County, and in some of the draws in the edge of the table-land on the north side of the valley from Syracuse to Lakin.

Thickness.—The thickness of the Ogalalla formation differs greatly from place to place. As the formation generally slopes downward into the larger valleys, which were outlined before the formation was deposited, it appears to be thicker than it really is. Well records give the most reliable figures. The State well on the plateau 5 miles north of Kendall apparently penetrates the formation for 192 feet, the depth at which the underlying shale is entered. In the State well 6 miles north of New Ulysses the beds regarded as Ogalalla are 212 feet thick and are underlain by shale. The well at Johnson penetrates 180 feet of loam and soft sand, all presumably Ogalalla, before it reaches the Dakota sandstone. In the well at Santa Fe, in the Garden quadrangle, a few miles east of the east margin of the Lakin quadrangle, the Ogalalla beds are 226 feet thick; in another well half a mile south of Santa Fe they are 286 feet thick; and in a well 6 miles southwest of Santa Fe they are 180 feet thick.

Character.—The principal material of the Ogalalla formation is sand, which differs in texture from place to place and in different beds. In most places there are at several horizons, especially toward and at the base, deposits or streaks of small gravel mixed with the sand in greater or less amount, and much of this coarser material is cemented into a loose conglomerate or coarse sandstone. Throughout the formation irregular bodies of calcium carbonate have been deposited about the sand grains and make a soft "grit," as it is termed. This material ranges in texture from coarse conglomerate to a fine-grained mixture of calcium carbonate and silt, often called "magnesia." Some of the limy layers contain a large proportion of calcium carbonate, one notable example of which is a thin bed of nearly pure limestone which caps the high summits in the northwestern part of T. 25 S., R. 42 W., and outcrops in the draws in the southern part of T. 26 S., Rs. 39 and 40 W., and in the northern part of T. 27 S., R. 39 W.

In a draw a mile east of Kendall the ledges of Greenhorn limestone are capped by a conglomerate that consists of fragments of the limestone in a matrix of calcium carbonate. A loose calcareous conglomerate appears in a small quarry on the north side of North Fork of Cimarron River 3 miles southeast of New Ulysses. It is about 75 feet above the stream.

[1] St. John, O. H., Notes on geology of southwestern Kansas: Kansas Board Agr. Fifth Bienn. Rept., p. 145, 1887.

Some of the most extensive exposures of the formation occur along the slopes north of Bear Creek and its north branch near the line between Hamilton and Stanton counties. One of these exposures in the northern part of T. 27 S., R. 39 W., shows 15 feet of beds, at the top of which is a layer of friable sand and below this are layers of fine sand, which contain streaks of gravel and limy nodules and layers of coarse calcareous grit, in part compact. The gravel consists partly of feldspathic rocks from the Rocky Mountains. In the northeast corner of this township the gray grit and conglomerate overlie a pink loam. In the northwestern part of the same township the formation includes a conspicuous bed of limestone which is 3 feet thick in places. This limestone lies on brown gravelly loam, and in sec. 6, where it is exposed, it is overlain by 30 feet of coarse conglomerate and grit, and these beds are overlain by 30 feet or more of brown loam. In the township to the northwest this limestone lies on the surface of Dakota sandstone. In sec. 9, T. 27 S., R. 39 W., the limestone lies on sand and is overlain by coarse gray grit and conglomerate and loam. The pebbles in the grit are derived from the rocks of the Rocky Mountains.

The formation is exposed at intervals in bluffs along Bear Creek west of Johnson. The ledges of Dakota sandstone in the southwest corner of the Syracuse quadrangle are capped by 8 to 15 feet of characteristic light-colored conglomerate and grit. Along the southern margin of sec. 33, T. 28 S., R. 42 W., there is a 25-foot bluff of dirty brown loam of distinct pinkish tint which constitutes the north bank of Bear Creek. This loam and the brown sand into which it merges extend along the creek in banks 10 to 25 feet high in T. 28 S., R. 41 W., northwest of Johnson. In one bluff along the creek 2½ miles northwest of Johnson there is 12 feet of pale-pinkish loam at the base overlain by fine gray loam, some of which becomes dark in part of the exposure. A bank 4 miles due north of Johnson consists of compact pinkish loam with limy nodules, overlain by coarse pale-brown loam.

Some of the gravel and sand reported in wells in Tps. 27 and 28 S., Rs. 41 to 43 W., is probably Ogalalla, but their identity is difficult to establish from the well records that are available. The same difficulty is encountered in the broad low area northeast of Johnson.

The record[1] of the State well in the NW. ¼ NW. ¼ sec. 36, T. 29 S., R. 37 W., in Grant County, shows the succession of the strata that constitute the Ogalalla formation.

Record of Ogalalla formation in State well 6 miles southeast of New Ulysses, Kans.

	Thickness.	Depth to base.
	Feet.	*Feet.*
Top soil	2	2
Clay and "gypsum[a]"	6	8
Ashy	8	16
Sand, red, hard	5	21
"Gypsum," very hard	14	35
Sand, red	35	70
Clay and "gypsum," very hard	9	79
Sand, red, hard	12	91
Sand, gray, soft	2	93
Sand, red, hard below	16	109
Clay, sandy, hard	11	120
Clay	4	124
Joint clay, water bearing	20	144
Clay, red, hard, dry	4	148
Sand, red, water bearing	5	153
Clay, red, hard, dry	1	154
"Gypsum," hard, dry	3	157
Sand, water bearing	8	165
Joint clay, water bearing	5	170
Sand, coarse, water bearing	2½	172½
Clay, red, dry	12½	185
Sand, water bearing	14	199
Joint clay, water bearing	3	202
Sand, water bearing	10	212

[a]The so-called gypsum is probably a mixture of sand or clay and calcium carbonate.

Under the water-bearing sand at 212 feet are 8 feet of dry "rock" and 11 feet of blue shale, doubtless Graneros shale. The "red" material is probably pinkish sand, which appears in many places in the Ogalalla sediment.

The record[2] of the State well 5 miles due north of Kendall or half a mile north of the north margin of the Syracuse quadrangle illustrates the succession of Ogalalla beds on the High Plains in that region.

Record of Ogalalla formation in State well 5 miles north of Kendall, Kans.

	Thickness.	Depth to base.
	Feet.	*Feet.*
Soil	8	8
"Gypsum"	6	14
Sand and gravel	57	71
Rock, solid	28	99
Sand and gravel	6	105
"Gypsum," red	5	110
Clay, sandy	20	130
Gravel and boulders	12	142
Sand, yellow, fine	13	155
Gravel	9	164
Clay	6	170
Sand and gravel, water	10	180
Gravel, water	7	187
Sand, fine	5	192

[1]Kansas Board of Irrigation Survey and Experiment Rept. 1895–96, pp. 20–21, 1897.
[2]Idem, p. 17.

The so-called gypsum probably is a fine-grained mixture of clay or sand and calcium carbonate. Below the fine sand is compact yellow shale, probably Carlile, which is penetrated 4 feet.

In the boring at Santa Fe the Ogalalla beds reported comprise 46 feet of loam and limy earth, 94 feet of limy grit with hard layers, much sand and pebbly streaks, 86 feet of alternations of buff, clayey, and sandy layers, with 10½ feet of water-bearing sand at base.

Correlation and age.—The Ogalalla formation is believed to be a stratigraphic unit and to be continuous from the type locality near Ogalalla station in western Nebraska. Hay supposed that the deposits comprised two formations, the "Plains marl" at the top and "mortar beds" below, but later studies by Haworth, Adams, and others have shown that these apparent divisions are local features and that generally fine-grained sediments alternate with the coarser "mortar beds" at different horizons. It is possible that the 300 feet or more of beds that constitute the Ogalalla formation comprise deposits elsewhere separable, even including locally in their upper part a representative of the McPherson formation ("*Equus* beds"). Apparently, however, no separation is practicable in this region. Originally the entire formation was known as "Loup Fork beds," but this term also included the Arikaree formation, which is older than the Ogalalla formation and apparently does not extend into Kansas.

Although no fossils have been obtained in or near the Syracuse and Lakin quadrangles, many bones have been found in the Ogalalla area elsewhere in Nebraska and northern Kansas. The bones range in age from very late Miocene to early Pleistocene, indicating a longer range in time than would appear to have been required for the continuous deposition of the Ogalalla formation. Most of the material of this formation appears to have been laid down rapidly by streams, although the fine-grained strata required considerable time for their accumulation. It is believed that the bones of Pleistocene age found in some places are in local deposits of later age that overlie the true Ogalalla, which appears more likely to have been laid down in Pliocene and late Miocene time. In the valleys and also in places on the uplands the Ogalalla formation grades up into fine sands and silts, which appear to have been carried and deposited by the wind at various times from Tertiary to very recent. In part these are the Plains marl of Hay, and fossils found in them are Recent.

QUATERNARY SYSTEM.

ALLUVIUM.

Distribution.—The alluvial flat along Arkansas River is underlain by sand and gravel, in greater part from 30 to 50 feet thick. At Syracuse and Kendall this flat is about 2 miles wide, but east of Hartland it gradually widens, and at Deerfield it is 6 miles wide. At many places north of the river the northern limit of the alluvial deposits is well defined by the rise of the valley slope, but south of the river the alluvium is overlain by dune sand, which completely hides its southern margin. There is considerable alluvium in the valleys of Bear Creek and North Fork of Cimarron River and in some of the larger draws, but it merges into the wash of the adjoining slopes. The mantle of wash is widespread on much of the area, and it has been working down the slopes for a long time. In places its thickness is 15 to 20 feet, but owing to its irregularity and its lack of distinctive features it can not be represented on a map.

Thickness.—The thickness of the alluvium differs in different places. In a well at Syracuse the underlying Graneros shale is reached at a depth of 21 feet, whereas at Kendall 53 feet of soil, gravel, and sand are reported. The river bank 2 miles east of Hartland, where it is 25 feet high, is all alluvium and the base of the deposit is not there visible.

Character.—The alluvium consists mainly of sand and silt that have been deposited by the streams. Streaks of gravel occur irregularly. The deposit is not exposed in cross section, but wells in the river flat show its character. The railroad cut a mile east of Hartland is in gravel, and a thick body of this material was formerly quarried for railroad ballast 4 miles east of Syracuse.

DUNE SAND.

Dune or wind-blown sand occupies a belt along the south side of Arkansas River, which has a breadth of 5 miles near Syracuse and gradually widens eastward to 18 miles in the western parts of Finney and Haskell counties. The general appearance of similar dunes is shown in Plate VI. Considerable sand of similar origin also extends southward from the sand-hill belt, especially on the northern slope of the ridge southwest and south of Syracuse and Kendall. Locally also the sand of the Ogalalla formation has been blown about by the wind, but no marked dunes had been formed except in a small area north of Johnson. The sand in the dunes south of the Arkansas is probably in places 100 feet thick.

STRUCTURE.

The strata under the central Great Plains are nearly horizontal but have low dips in different directions. In the Syracuse and Lakin quadrangles the Cretaceous beds slope very gently eastward in general (see Pl. III) but have some broad, low undulations. At Syracuse the top of the Dakota sandstone is about 3,062 feet above sea level; at Kendall, 3,070 feet; the outcrop southwest of Hartland is 3,040 feet; and east of Hartland the sandstone slopes gently eastward to about 2,370 feet in wells at Garden City. South of Syracuse, however, the sandstone rises steeply and reaches an altitude of 3,420 feet in the southeastern portion of T. 25 S., R. 42 W. At Johnson, at a depth of 180 feet, the altitude is about 3,150 feet, and in the outcrops on Bear Creek in the southwest corner of the Syracuse quadrangle, it is 3,525 feet. Here the easterly dip is plainly perceptible. These altitudes indicate a general rise to the west and a local irregular doming on an axis that extends northeastward across the center of the northern half of the Syracuse quadrangle and that probably continues with diminishing height to Lakin. The principal facts bearing on this subject are given in the following table, and although some of the well records are not altogether satisfactory as to depth and identity of material, the data afford a very satisfactory basis on which to represent the structure by contour lines drawn at the top of the Dakota sandstone, as shown in figure 4. Wells and outcrops of overlying formations have also been used somewhat in locating the contour lines.

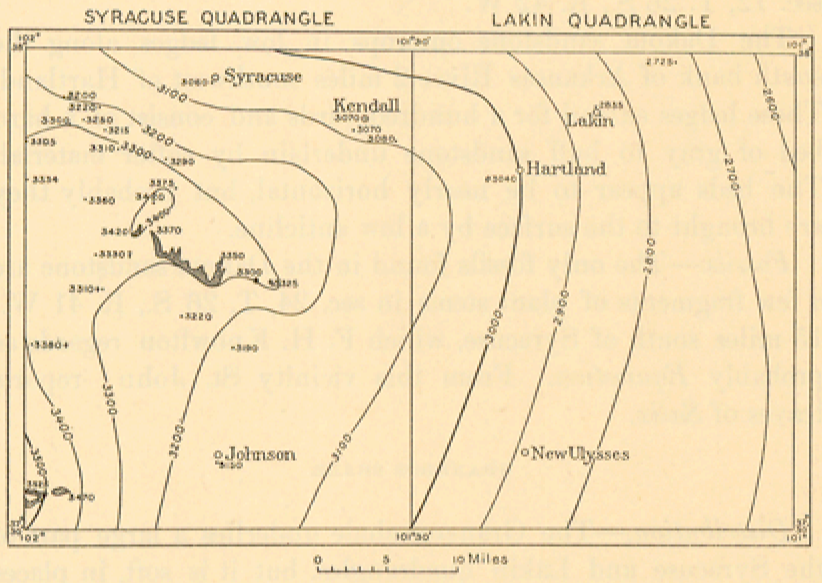

FIGURE 4.—Map showing altitude and structure of the Dakota sandstone in the Syracuse and Lakin quadrangles.
Outcrop of Dakota sandstone (at or near surface) indicated by ruled pattern. Figures show altitude of bedrock in wells and at surface. Contour interval, 100 feet; datum, mean sea level.

Position of top of Dakota sandstone in Syracuse-Lakin area.

Location.	Altitude of surface.[a]	Depth to top of sandstone	Altitude of top of sandstone.[a]
Syracuse:	*Feet.*	*Feet.*	*Feet.*
Railroad, well No. 4	3,230	170	3,060
Rogers well	3,235	168	3,067
City well	3,225	122	3,103
Well near depot	3,230	153	3,077
SW. ¼ SW. ¼ sec. 34, T. 24 S., R. 42 W	3,498	248	3,250
NE. ¼ sec. 27, T. 25 S., R. 41 W	3,545	170	3,375
SE. ¼ sec. 9, T. 25 S., R. 41 W	3,540	250	3,290
NW. ¼ sec. 33, T. 25 S., R. 41 W	3,560	140	3,420
Northeast corner sec. 32, T. 27 S., R. 42 W	3,485	150	3,335
Center sec. 12, T. 25 S., R. 42 W	3,520	180	[b]3,340
Center sec. 34, T. 25 S., R. 42 W	3,420	60	3,360
SE. ¼ sec. 18, T. 27 S., R. 40 W	3,255	65	3,190
SE. ¼ sec. 13, T. 25 S., R. 40 W	3,312	92	3,220
SW. ¼ sec. 3, T. 27 S., R. 41 W	3,331	111	[c]3,220
SE. ¼ SE. ¼ sec. 20, T. 25 S., R. 42 W	3,400	200	3,200
NE. ¼ sec. 2, T. 25 S., R. 42 W	3,475	260	3,215
NW. ¼ NW. ¼ sec. 4, T. 25 S., R. 42 W	3,330	180	3,150
Johnson	3,555	255	3,300
SW. ¼ sec. 13, T. 25 S., R. 43 W	3,540	206	[d]3,334
NW. ¼ NW. ¼ sec. 12, T. 25 S., R. 43 W	3,595	290	3,305
Kendall	3,123	53	3,070
D 6 ranch, 1½ miles southeast of Kendall	3,115	35	3,080
Lombard ranch, 1½ miles southwest of Kendall	3,153	83	3,070
Lakin	2,991	156	2,835
Deerfield, 1 mile northwest of	2,985	260	2,725
Olive, southeast of, northeast corner T. 28 S., R. 33 W	3,000	325	2,675
Garden City	2,829	311	2,370

[a]Mostly approximate.
[b]Contains 18 inches of coal.
[c]Sandstone 25 feet thick, at depths of 111 to 136 feet.
[d]Contains 30 feet of sandstone.

The wells in T. 25 S., Rs. 42 and 43 W., do not throw much light on the position of the Dakota sandstone because of indefinite records. The Hutchinson well (360 feet) and the Griggs well (385 feet) report only about 75 feet of sandstone. It is probable, however, from the structure and outcrops of overlying beds near by that they penetrate the Dakota sandstone for double that distance, but perhaps the top beds are shaly and were not recognized. In a well in the SE. ¼ sec. 2, T. 25 S., R. 41 W., the sandstone was probably entered at a depth of 200 feet, according to outcrops of Greenhorn limestone near by, but no record was obtainable.

Some of the structural features are further illustrated by the sections in figures 5 and 6.

The dome southwest of Syracuse lifts the sandstone 360 feet higher than it is in the wells at Syracuse and 270 feet higher than in the well at Johnson. The slope on the northeast side is to the north-northeast at the rate of about 30 feet to the mile, or an angle of considerable less than one-half degree. This northerly dip is well exposed in outcrops of Greenhorn limestone, in sec. 11, T. 25 S., R. 41 W., where, however, it is at least 5° locally, and the southerly dip is plainly perceptible in the ledges of Dakota sandstone in the quarry in sec. 23, T. 26 S., R. 41 W. In the strata exposed along the northern side of the Arkansas Valley from Syracuse to Hartland there is a slight but perceptible rise along the eastern extension of the anticlinal axis, probably culminating west of Hartland, where the Dakota sandstone comes to the surface.

As shown in figure 5, the top of the Dakota sandstone descends only 10 feet from wells at Syracuse to Kendall and only 30 feet from Kendall 9 miles southeast to the outcrop 1½ miles southwest of Hartland—a rate of 3⅓ feet to the mile.

In the eastern part of the region there is a general eastward slope. The descent of the sandstone is 660 feet from the Hartland outcrop to wells in Garden City, 7 miles east of the northeast corner of the Lakin quadrangle, where apparently the Dakota is reached at a depth of 461 feet or an altitude of 2,370 feet. As the distance is 30 miles, the rate is 22 feet to the mile. The direction is northeast and probably the maximum slope is in that direction.

At Lakin, which is 9 miles from the Hartland outcrop, the top of the Dakota sandstone is apparently 152 to 155 feet below the surface, or at an altitude of 2,835 feet. This altitude indicates a relatively uniform rate of slope, as shown in figure 4. Probably all the beds east of Hartland descend on this slope, so that the Greenhorn limestone passes beneath the valley floor and the Ogalalla formation constitutes the valley slopes, a condition which continues eastward to Dodge.

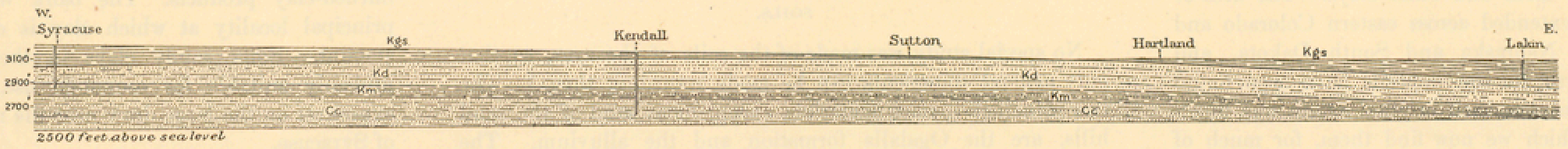

FIGURE 5.—Section along Arkansas Valley from Syracuse to Lakin, Kans., by way of Sutton, showing a low anticline west of Hartland.
Kgs, Graneros shale; Kd, Dakota sandstone, possibly including Purgatoire; Km, Morrison formation; Cc, Cimarron group.
Horizontal scale: 1 inch=3 miles.

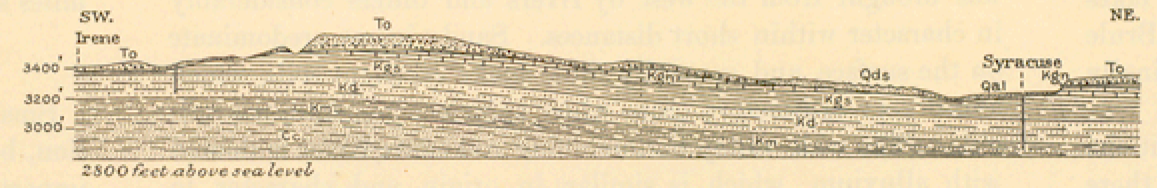

FIGURE 6.—Structure section from Irene to Syracuse, Kans.
Qds, Dune sand; Qal, alluvium; To, Ogalalla formation; Kgs, Greenhorn limestone; Kgs, Graneros shale; Kd, Dakota sandstone, possibly including Purgatoire; Km, Morrison formation; Cc, Cimarron group.
Horizontal scale: 1 inch=3 miles.

GEOLOGIC HISTORY.

GENERAL FEATURES.

The geologic history of western Kansas has been the same as that of a wide area of the central Great Plains. Evidence of some of the conditions and of their results appears in the Syracuse and Lakin quadrangles, but much of the history has to be read from geologic facts observed in other parts of the province. Rocks of nearly all the geologic periods are exhibited in the uplifts along the Rocky Mountains, but the extensions of the older formations under the Great Plains are so deeply buried that their characters and relations are not apparent. Moreover, portions of geologic time are not here represented by sediments, and it is not known whether this lack of beds representing them is due to nondeposition or to the removal of the beds by erosion. For this reason and because of the uncertainty of the significance of many geologic features only a general outline of the sequence of events can be given. It is evident that the conditions were uniform over wide areas and that the Great Plains province has been a plain at different times in the past. The province was undoubtedly submerged by the sea many times and it emerged many times and was sculptured by running waters, especially in the later epochs.

THE SEDIMENTARY RECORD.

It has been shown that the rocks which appear at the surface in the Syracuse and Lakin quadrangles comprise limestone, shale, sandstone, gravel, sand, and clay. The limestone was principally a chemical precipitate from salt water, the shale was fine mud or clay, and the sandstone was sand, all materials derived from the waste of older rocks. These sedimentary rocks afford a record of physical geography extending from Upper Cretaceous time to the present; the "Red Beds" (Cimarron group), limestones, and sandstones which underlie the region extend back to Carboniferous and probably to earlier Paleozoic time. The conditions under which these strata were deposited are indicated to some extent by their composition, appearance, and relations. Sandstones ripple-marked by waters or by wind or cross-bedded by currents and shale cracked by drying on mud flats show deposition in shallow water; pure limestones generally indicate open seas and scarcity of land-derived sediment. The fossils that the strata contain belong to species resembling those that now inhabit waters that are fresh, brackish, or salt, warm or cold, muddy or clear, and therefore indicate the conditions prevailing at the time and place at which they were entombed. The character of the adjacent land is shown by the kind of sediments derived from its waste. The quartz sand and the pebbles in coarse sandstones and conglomerates, such as are found in the Dakota and Ogalalla formations, had their origin in crystalline rocks and have been repeatedly redistributed by streams and concentrated by currents and by wave action on beaches. Red shale and sandstone, such as make up the Cimarron group, are as a rule the result of the revival of erosion on a land surface that has been long exposed to rock decay and oxidation and hence have been covered with a deep residual soil. Limestone, on the other hand, if deposited near the shore, indicates that the land was low and that its streams were too sluggish to carry off coarse sediments, the sea receiving mainly substances in solution.

PALEOZOIC CONDITIONS.

The uplifts along the Rocky Mountain Front Range and the drill records in eastern Nebraska and Kansas reveal early Paleozoic sandstones and limestones which lie on a floor of granite and other pre-Cambrian crystalline rocks. Doubtless these rocks underlie western Kansas also, but nothing is known of their relations. The sand of the sandstone was deposited along beaches and in shallow waters and the material of the limestones was deposited in seas that extended across a large part of the continent, periods of deposition alternating with periods of uplift in which the sediments were more or less deeply and extensively removed by erosion. The general absence of Devonian and Silurian rocks in the central Rocky Mountain province is believed to indicate that there was an extensive land area during those periods, or that, if those rocks were deposited, they were removed by widespread erosion in early Carboniferous time. Early Carboniferous rocks (Mississippian) underlie western Kansas, and as they are mostly limestone of marine origin they indicate an extension of the sea across that region. In later Carboniferous time (Pennsylvanian and Permian) widespread emergence of this land produced shallow basins and low plains on which there were wide mud flats over a large part of the Rocky Mountain province. In this region the great mass of red clay and sand that forms the Cimarron group was laid down. These beds, which probably were largely deposited during a period when the climate was prevailingly arid, accumulated to a thickness of 1,000 feet or more. The materials of the coarser beds were carried by streams, but the finer beds were laid down in shallow local basins or bayous and on wide mud flats, as is indicated by the numerous mud cracks, ripple marks, and impressions of various kinds on many of the layers. The nearly general red tint of the deposits was doubtless their original color, for it is present not only throughout the lateral extent of the formation but also, in most beds, through its entire thickness, as is shown by deep borings. This red tint is therefore not due to later or surface oxidation.

At different times, which were not synchronous throughout the region, the accumulation of sand and clay was interrupted by the chemical precipitation of comparatively pure gypsum in beds that range in thickness from a few inches to nearly 70 feet and that, as a rule, are free from sand and clay. It is apparent that this gypsum is the product of evaporation in lakes, and its purity indicates that the waters in which the beds were formed were quiet.

EARLY MESOZOIC CONDITIONS.

Triassic development.—Red sandstones representing part of Triassic time occupy an extensive area in the Rocky Mountain province and extend eastward for some distance in South Dakota, Colorado, New Mexico, and Texas. They are absent in western Kansas and adjoining regions north and south, and this may indicate either nondeposition in this area or the removal of deposits by late Triassic uplift and planation. It seems probable, however, that during a large part of Triassic time the region was a land surface of low relief in which general planation progressed slowly. This condition resulted from widespread uplift without local structural deformation.

Jurassic and Cretaceous seas.—Marine sediments of later Jurassic age are present in most parts of the Rocky Mountain province as far south as central New Mexico and as far east as the Black Hills, but they thin out eastward and are absent in the western Kansas region. It is likely that the sea in which these sediments were deposited occupied a larger area than that in which the deposits now remain, but its limits can only be conjectured. If it covered western Kansas and adjoining regions north and south its sediments were removed by erosion resulting from uplift near the end of Jurassic time or in the early part of Cretaceous time.

During the Cretaceous period a great series of beds of sand and clay was deposited in formations that are generally uniform over wide areas. In the central and northern areas the earlier deposits were evidently laid down in streams or shallow estuaries along a coastal plain, but to the south marine conditions prevailed during much of earlier Cretaceous time. In a wide area in and near the Rocky Mountain province the first deposits of the Cretaceous, or possibly the last of the Jurassic, now constitute the Morrison formation, a mantle of massive sandy shale, which extends from Montana to New Mexico. The deposits were mixtures of clay and fine sand, which were laid down in a series of basins or troughs that were occupied by sluggish streams and shallow bodies of fresh water bordered by wide mud flats. The deposits at most places include thin, irregular bodies of coarser sand laid down by streams or currents, and at intervals thin beds of impure calcium carbonate. Huge dinosaurs were then numerous, and their remains are found in abundance in the formation. Probably at this time the earliest deposits of the Comanche series were accumulating in the regions to the south, but there is no evidence as to the relations of the marine and fresh-water deposits.

Morrison time was succeeded by coastal-plain conditions, and in some areas by transient marine submergence. At this time thick mantles of sand were deposited and also some widespread sheets of clay of the later formations of the Comanche series, although the character of the deposits differs somewhat from place to place and there is local channeling of the surface of the soft Morrison deposits. The erosion of these deposits appears to have been remarkably slight—no more than would be expected from currents of sufficient strength to transport the coarse materials. It is therefore believed that no long interval of uplift and erosion followed Morrison deposition, for had there been such an interval the soft clays would have been widely removed. The coarse deposits of the Cheyenne, Purgatoire, and Dakota sandstones were derived from sources that are not clearly indicated and were spread by currents over a wide area. The coarse-grained lower member, which is generally 50 to 60 feet thick, gives place to a medial member of clay, mostly of purplish color, in places not unlike the Morrison beds. The Cheyenne and Purgatoire formations contain fossils of late Comanche (Washita) age, which are found also in the Purgatoire sandstone along the Rocky Mountain front in southern Colorado. The Lower Cretaceous formations are overlain by the Dakota sandstone, of the Upper Cretaceous series, a fresh-water deposit that was laid down on beaches and by currents during an uplift in which the sea receded far to the south.

After these great sheets of sandy sediment had been formed there was a rapid change in the conditions of sedimentation to those under which clay was deposited, beginning with the widespread Graneros shale. The deposition of this shale marks the beginning of the period of very extensive later Cretaceous submergence, in which marine conditions prevailed over a large area and for a long time, or until several thousand feet of clay was deposited, during the Benton, Niobrara, and Pierre epochs. In places some of the first sediments laid down were a thin transition series of alternating sand and clay, but there is wonderful uniformity in the character of the great mantle of Graneros shale, which in places reaches a thickness of more than 1,000 feet. The next episode was marked by the deposition of the thin but very distinctive Greenhorn limestone in an area at least 1,000 miles long and 600 miles wide. This limestone, with its peculiar features and associations, extends from the Black Hills to New Mexico and far eastward into Iowa. It was everywhere succeeded by the clay now represented by the Carlile shale, with its sandstones and distinctive concretions, which is even more widespread than the Greenhorn limestone. Its deposition was followed by that of several hundred feet of impure chalk and limy shale, which now constitutes the Niobrara formation, and this in turn was followed by the accumulation of the thick mass of clay that constitutes the Pierre shale, which was deposited under very uniform conditions over a vast area. On the retreat of the sea in late Cretaceous time a widespread mantle of sand was laid on the Pierre clays. This sand is the Fox Hills sandstone. On the further retreat of the sea extensive land surfaces were exposed, diversified by streams, lakes, and estuaries of brackish or fresh water, which received the sands, clays, and marsh deposits at the end of the Cretaceous and the beginning of the Tertiary period. Marine conditions recurred locally in late Cretaceous time, as is shown by the appearance of a characteristic marine fauna in the shales that overlie the earliest coal measures.

TERTIARY DEPOSITION.

ORIGIN OF THE GREAT PLAINS.

There was extensive uplift in the Rocky Mountain province in early Tertiary time, and the products of the resulting erosion were spread over wide areas in the valleys and the adjoining plains. Some of the earlier Tertiary deposits probably covered part or all of Kansas and have since been removed by erosion. In Oligocene time, after the outlines of the great mountain chains had been developed, there was a long period in which streams of moderate gradient flowed across the semiarid central Great Plains region. These streams, which frequently shifted their channels and overflowed extensive areas, laid down the widespread mantle of the Oligocene White River deposits. The first of these deposits were the sands of the Chadron formation, which show clearly the location of the old channels by beds of coarse sandstone and the areas of slack water and overflow by beds of fuller's earth and other clays. The area of deposition of this series extended across eastern Colorado and Wyoming and western Nebraska and South Dakota, and probably also farther north, for the deposits have been found in western Canada. Doubtless their original extent was much wider than the area in which we now find them, for much of the formation has been removed by erosion. The White River epoch was continued by the deposition of the Brule clay under conditions in which the currents were less strong and lakes and slack-water overflows were more extensive. The Brule clay has about the same area as the Chadron and originally was much more extensive than it is now.

At the beginning of Miocene time the general conditions had not changed materially, but doubtless for a while there was an extensive land surface in the central Great Plains area. In the stream channels that traversed this surface the Gering formation was laid down. One of these channels extended across western Nebraska for several miles just south of North Platte River. The next deposit was a widespread sheet of sands, derived from the mountains to the west. This sheet was probably spread over the entire central Great Plains region by streams and to some extent by winds. The streams of this time shifted their courses across the plains and spread the débris from the mountains in a sheet which in some parts of the area attained a thickness of 1,000 feet—a flat alluvial fan of surprisingly wide extent. This material forms the Arikaree formation, which buried some of the lower ranges of the uplift, as is shown by the high altitudes to which it extends on the slopes along the front of the Rocky Mountains in Colorado and Wyoming. It has been so widely eroded since its deposition that its original extent is unknown, but it doubtless covered most of the central Great Plains, far to the east. Its deposition was followed by uplift and erosion which removed the Arikaree and parts of the underlying formations from the southern and the eastern part of the region and left the thickest mass of the deposit in western Nebraska and eastern Wyoming. Probably, however, it never was thick nor widespread in the southern part of the region, where erosion predominated while deposition was in progress in the northern part. Next came the epoch in which the streams began to deposit the thin mantles of sands of the Ogalalla and other late Pliocene formations, especially in southern Colorado, in southern Nebraska, in Kansas, and in regions farther south. These deposits appear to have been at this time laid down mainly in the southern region above described, erosion probably predominating in the region farther north.

These alternations of later Tertiary deposition and erosion, first in the north and then in the south, were undoubtedly determined by differential uplift, the uplifted region undergoing erosion and the depressed or stationary region receiving deposits from streams whose slope was not sufficient to carry off their loads. This condition was accentuated by the semiarid climate of the plains, where then, as now, the mountain torrents and the resulting vigorous erosion furnished large quantities of débris, which the streams, being of low declivity and constantly diminishing volume as they crossed the plains, were unable to carry to the sea. Even if such a region is traversed by valleys cut during a time of uplift or of increased rainfall, the valleys are soon filled by sediments when the cutting ceases; and during freshets, and to a less extent during the dry periods of the year, they shift their courses so as to spread a wide mantle of deposits over the entire area in which the drainage is sluggish.

PLEISTOCENE DEVELOPMENT.

During the early part of the Pleistocene epoch there was uplift and there were floods caused by increased precipitation, which resulted in widespread denudation of the preceding deposits, so that the later deposits were entirely removed in the eastern part of the area, where there were glacial floods, and were widely and deeply trenched in the western part. To the west there extended to the foot of the mountains a great high plain of remarkable smoothness, mantled in its northern part mostly by the Arikaree formation and in the southern part by the Ogalalla and possibly some later deposits, the product of later Tertiary deposition. As the Black Hills dome rose somewhat higher than the general uplift it was deeply eroded, so that the High Plains, whatever may have been their extent in that region, were largely removed, and their northern edge was left, as at present, in the great escarpment of Pine Ridge, facing toward the Black Hills uplift. Farther south, across Nebraska, Colorado, Kansas, and Texas, the High Plains still presented wide areas of tabular surface, though the streams of Pleistocene time cut into them deeply and removed them widely. Numerous changes in stream courses took place in Pleistocene time, and some of the valleys still present relations that clearly illustrate their history.

ECONOMIC GEOLOGY.

With the exception of underground water the mineral resources of the Syracuse and Lakin quadrangles are not of great value. They include soils, building stone, limestone materials for concrete, clay, volcanic ash, and ocher, and possibly oil and gas.

SOILS.

No special study was made of the soils of the area, so that only general statements can be made regarding them.[1] The two principal surface materials, except loose sand of the sand hills, are the Ogalalla formation and the alluvium. The Ogalalla formation consists largely of sand and loam but in places contains more or less calcium carbonate. The material was brought from the west by rivers and differs considerably in character within short distances. Sandy loams predominate on the surface, and generally these make excellent soils, which afford very satisfactory crops when sufficient moisture is available. The wide valley bottom along Arkansas River is floored with alluvium, which is similar in origin and character to the Ogalalla deposits. There is great local variation in the proportions of coarse and fine material, but many areas are thickly covered with loam of great fertility.

The exposed areas of Dakota sandstone, Graneros shale, and Greenhorn limestone have distinctive soils, but the areas are small and are partly covered by sandy wash carried down from higher slopes.

BUILDING STONE.

The Greenhorn limestone and the Dakota sandstone have been quarried in the Syracuse and Lakin quadrangles to a moderate extent for building stone for local use. An extensive quarry a mile northwest of Syracuse is the principal producer. This quarry contains ledges of hard buff limestone, most of them 6 to 8 inches thick, which is easily worked and serves well for rough work. Another quarry in the northwestern part of Kendall has furnished supplies of similar stone, and a smaller quarry in Greenhorn beds 7 miles south by west of Syracuse has been worked at intervals.

The Dakota sandstone has been obtained for several years from small quarries, one in the SW. ¼ sec. 27, T. 26 S., R. 40 W., and others in the NW. ¼ sec. 27 and the center of sec. 26, T. 26 S., R. 41 W. The rock is light buff in color, though rather irregular in tint, and the beds range in thickness from a few inches to a foot. It is suitable only for foundations and rough walls.

LIMESTONE.

Much of the Greenhorn limestone contains from 90 to 95 per cent of calcium carbonate, and the purer stone could be burned for lime. It has been so burned in a small way for local use. Its availability for making cement is mentioned below. Small deposits of excellent limestone cap the knolls 15 miles southwest of Syracuse and outcrop in ledges in the southern part of T. 26 S., Rs. 39 and 40 W., and in the northwest corner of T. 27 S., R. 39 W.

MATERIALS FOR CONCRETE.

Limestone and shale for making cement are available from beds that extend along the northern side of the Arkansas Valley from Syracuse nearly to Hartland. Sand and gravel for making concrete occur in large quantities in alluvial deposits along the river and at many places in the Ogalalla formation. A large part of the Greenhorn limestone is suitable for Portland cement if it is mixed with shale. The mixture is ground, burned in suitable kilns, and the product reground. Some of the limestone contains sufficient clay to be suitable for cement without additional shale. Beds of shale are intercalated between the beds of limestone, and there are high banks of excellent shale near Sutton Siding, west of Hartland. Sufficient limestone is available from Syracuse to Hartland to maintain large cement plants, for even where exposures are small or absent the Greenhorn beds are continuous all along the outcrop zone shown on the geologic map. A large quantity of the rock also underlies the ridge south of Syracuse. The following analyses of limestones of the region were made by W. C. Wheeler, of the United States Geological Survey:

Approximate analyses of limestones in Syracuse region, Kans.

	Quarry at Syracuse.	Ledges southwest of Syracuse.	Ledges southeast of Syracuse.	Quarry northwest of Kendall.	Knoll 18 miles southwest of Syracuse (Ogalalla).
Calcium carbonate	93.3	93.3	76.4	93.3	93.3
Magnesium carbonate	.8	.8	.7	.8	.8
Insoluble	3.2	2.7	18.6	2.7	3.2
Not determined	2.7	3.2	4.3	3.2	2.7
	100.0	100.0	100.0	100.0	100.0

CLAY.

Parts of the alluvium consist of sandy clay that is suitable for making brick and that has been used to a small extent for that purpose. The Graneros shale consists of clay which could be burned for brick of different kinds and other burned-clay products. The bank west of Hartland is the principal locality at which clay is easily available in large amount. Some sandy clays in the Dakota formation are probably suitable for economic use, notably those in the exposures on the large draw near the main road 15 miles south of Syracuse.

A deposit of clay that might be useful as fire clay is included in the Dakota formation in the south bank of Bear Creek, 12 miles southwest of Johnson. (See Pl. IV.)

VOLCANIC ASH.

Small deposits of voicanic ash occur in the Ogalalla formation, but the only one observed that appears to have economic importance is in the east side of sec. 23, T. 20 S., R. 41 W., south of Syracuse. This material is mined extensively in Nebraska and some other States for polishing and cleansing powders.

OCHER.

A small deposit of impure red ocher is included in the Dakota formation in sec. 25, T. 26 S., R. 41 W., south of Syracuse. It may be of value as a pigment, if the amount is sufficient to warrant development.

PROSPECTS FOR OIL OR GAS.

The Syracuse and Lakin quadrangles are underlain by 1,000 feet or more of red shale and sandstone, which are probably barren of all useful products, but below these red rocks are limestones and shales of the same age as those which yield gas and oil in eastern Kansas and elsewhere. Several borings have gone deep into the red beds, but apparently the underlying rocks have not been reached. Their depth is probably 1,500 feet or more in most of the area, and they are at least 1,000 feet thick. Although there are no indications that these rocks contain oil or gas in this region, it may be desirable to test them at some time. The low dome along the west-central portion of the Syracuse quadrangle shown in figure 4 would be an advantageous place for the test.

In 1918 a hole was bored 725 feet deep in the southwest corner of sec. 9, about 1 mile west of Hartland, but apparently without encouraging results. It was not deep enough to test all the strata.

WATER RESOURCES.

SURFACE WATER.

Arkansas River does not carry a large volume of water at ordinary stages, but in spring and early in summer it is subject to great floods. The other streams of the area are Bear Creek and North Fork of Cimarron River, which have only transient flows, although at times of heavy rainfall they also are in flood. The many small streamways of the region carry water only during rain, although in some of them as well as in Bear Creek and Cimarron River water remains in holes far into summer. There are no permanent springs.

Arkansas River.—Arkansas River rises in the high ridges of the Rocky Mountains of central Colorado, and many of its streams head in the Sangre de Cristo, Saguache, and Culebra ranges. These mountains have summits 14,000 feet high and large areas of perpetual snow. The river crosses the Front Range in a deep canyon, well known as the Royal Gorge, traverses the foothills in a deep valley, and enters the Great Plains between Canon City and Pueblo. In the mountains it descends from an altitude of more than 10,000 to about 5,300

[1] Many facts regarding soils are given in "Reconnaissance soil survey of western Kansas," by G. N. Coffey and T. D. Rice, U. S. Dept. Agr. Bur. Soils Twelfth Rept., for 1910, pp. 1345-1442, pl. 34 in atlas, 1912.

feet in a distance of about 100 miles. East of Pueblo it flows in a wide, shallow valley across eastern Colorado and southwestern and south-central Kansas. In the mountains the river receives many tributaries, most of them vigorous streams fed by both snow and rain, the precipitation amounting to about 30 inches a year. In the Great Plains, where the climate is arid, the affluents are few and are of small, irregular volume, and there are many dry washes. The river itself is usually shrunken, but it has floods of great volume though of short duration, mainly late in spring, caused by the rapid melting of the snow, and at intervals early in summer, caused by heavy rainfall. In places it is dry much of the year.

Measurements of the flow of Arkansas River were made near Syracuse[1] in 1903, 1904, and 1905.

The river at this point has a wide range in fluctuation, being practically dry at times and at other times having a flow of nearly 30,000 second-feet. The total flows for the three years above mentioned were 406,000, 602,000, and 942,000 acre-feet, with mean discharge of 562, 831, and 1,423 second-feet.

A summary of analyses of composite samples of water from Arkansas River near Deerfield, Kans., during 1906 and 1907 is presented in the following table. The averages represent a highly mineralized sulphate water unfit for use in boilers, very hard, and concentrated enough to have a distinct mineral taste. The water ranges widely in concentration and composition, because of the intermittent addition of strong sulphate and chloride waters from tributaries above Deerfield. Its content of suspended matter is often very high.

Chemical composition of the water of Arkansas River near Deerfield, Kans.[a]

[Detailed analyses published in U. S. Geol. Survey Water-Supply Paper 273, p. 283, 1911.]

	Maximum (parts per million).	Minimum (parts per million).	Average.	
			Parts per million.	Percentage of anhydrous residue.
Silica (SiO_2)	68	16	29	1.9
Iron (Fe)	10	.04	1.9	.2
Calcium (Ca)	256	97	186	12.3
Magnesium (Mg)	88	12	62	4.1
Sodium and potassium (Na+K)	301	29	215	14.2
Carbonate radicle (CO_3)	.0	.0	.0	7.6
Bicarbonate radicle (HCO_3)	296	144	231	....
Sulphate radicle (SO_4)	1,201	65	826	54.7
Nitrate radicle (NO_3)	10	.5	3.2	.2
Chlorine (Cl)	104	39	72	4.8
Total dissolved solids	2,179	410	1,571	....
Turbidity	26,200	12	3,359	....
Suspended matter	18,477	21	2,551	....
Coefficient of fineness	2.42	.53	1.09	....

[a] Analyses by F. W. Bushong and A. J. Weith, University of Kansas.

UNDERGROUND WATER.

General conditions.—In nearly all parts of the Syracuse and Lakin quadrangles satisfactory supplies of water are obtainable from wells of moderate depth, but in some places the volume is not great. The alluvial deposits near the river yield water to shallow wells in large quantities at most places, and the Ogalalla formation in the wide table-lands or High Plains generally affords water to wells from 20 to 200 feet deep. The Dakota sandstone underlies the entire region and contains a large volume of water, which is utilized in numerous wells, notably at Syracuse, Johnson, Lakin, and Kendall, and in the region southwest of Syracuse. This formation yields artesian flows from Coolidge westward up the Arkansas Valley, but the head falls gradually and finally passes beneath the valley bottom a short distance east of Coolidge. Hence there is apparently no likelihood of finding artesian flows within the area.

Wells in the Cimarron group.—The Watkins well, in the northwestern part of Morton County, about 9 miles south of the southwest corner of the Syracuse quadrangle, affords valuable information concerning the strata which underlie that general region. Its record shows clay, gravel, and sand to a depth of 118 feet, presumably in the Ogalalla formation. Next comes 17 feet of yellow shale, 35 feet of blue sandstone, 80 feet of blue shale, and 125 feet of white sandstone, doubtless all Dakota, which extend to a depth of 375 feet. From this depth to the bottom of the boring at 1,160 feet the rocks are mostly red and brown shale and sandstone, including a 130-foot member of cream-colored sandstone near the top and 40 feet of limestone from 765 to 805 feet. Considerable water is obtained in the strata at 135 to 170, 720 to 725, and 805 to 975 feet; the two lower sources are in red beds and the water rises to a level less than 80 feet below the surface.

A 1,000-foot boring was sunk many years ago south of Syracuse. It obtained no additional water supply below that found in the Dakota sandstone. Doubtless it penetrated far into the Cimarron group.

Wells in Dakota sandstone.—Water is obtained from the Dakota sandstone at Syracuse in several wells that enter the formation at depths from 122 to 191 feet under alluvium and Graneros shale. The water is much better in quality than that obtained from shallow wells in the alluvium and the wells are safer from surface contamination.

The city well, the record of which is given on page 4, is 478 feet deep and furnishes 7,000 gallons an hour without material drawdown. Most of the water is in a massive sandstone from 402 to 445 feet and it rises to a level 100 feet or less below the surface. A 6-inch well just north of the railroad station enters shale at 16 feet and at 153 feet enters Dakota sandstone which continues to the bottom of the boring at 210 feet. It is stated that the water rises to a level within 35 feet of the surface. The well has been tested to 75 gallons a minute, but it is believed to be capable of yielding more. Another well, reported to be 284 feet deep, penetrates sandstones at 193 to 197 and at 250 to 279 feet, both of which yield satisfactory supplies of soft water. At the Rogers place in Syracuse a well 208 feet deep penetrates about 40 feet into sandstone. Well No. 4 of the Atchison, Topeka & Santa Fe Railway Co. is 465 feet deep and yields 65 gallons of water a minute. The water rises to a level less than 75 feet below the surface. According to the record (see p. 4) the well enters a 12-foot bed of water-bearing sandstone under shale at 170 feet; other sandstones that carry larger volumes of water are penetrated at 255 to 267 and at 400 to 435 feet. The basal portion of the lowest sandstone yields the greater part of the supply utilized. (For analysis, see p. 10.) In well No. 2 of the railway company, some distance away, sandstone is reported at 235 to 237, 252 to 255, 262 to 265, and 283 to 286 feet.

The four deep wells sunk by C. W. Beeler in T. 25 S., R. 41 W., on the high ridge southwest of Syracuse obtain abundant supplies from the Dakota sandstone. Their records are given on page 4. One well 535 feet deep in the SE. ¼ sec. 9 enters the Dakota sandstone at 250 feet and the water rises to a level less than 90 feet below the surface. The principal sandstone beds are from 250 to 270, 416 to 430, 450 to 465, and 500 to 532 feet deep, but which of them yield water is not reported. The water level in the 232-foot well in the NE. ¼ sec. 27 is less than 50 feet below the surface. It penetrates sandstones at 170 to 185 and at 210 to 230 feet, and some water is found in sandy layers in shale between 136 and 170 feet. The 362-foot well in the NW. ¼ sec. 33 enters the Dakota sandstone at 140 feet, in a bed 40 feet thick, and penetrates another body of sandstone at 305 to 358 feet, from which water rises to about 50 feet below the surface. The fourth well, in the SW. ¼ sec. 2, is 240 feet deep, and the water rises to about 70 feet below the surface.

The well of Samuel Yaggi, in the NE. ¼ SE. ¼ sec. 16, T. 25 S., R. 42 W., is 385 feet deep and obtains a fair supply of water, which rises to about 125 feet below the surface and comes mainly from white sandstone that is penetrated at 379 to 385 feet. Many other beds of sandstone are penetrated. The well on A. Hutchinson's ranch in the SW. ¼ sec. 8, 2½ miles west by south of Yaggi's and at about the same altitude, is 360 feet deep and has a good supply of fine water that rises to about 100 feet below the surface.

It is reported that wells 300 and 400 feet deep at the Unruh ranch in sec. 26, T. 25 S., R. 42 W., 1½ miles south of Yaggi's, were unsuccessful.

There is a fairly satisfactory well 354 feet deep at Sanders ranch in the SW. ¼ sec. 12, T. 25 S., R. 43 W. A 306-foot well in the northeast corner of sec. 2, T. 25 S., R. 42 W., has water within 146 feet of the surface. The well ends between the second and third sandstone strata and is not very satisfactory. The Overton well, near the center of sec. 12, T. 25 S., R. 42 W., is in sandstone between 180 and 370 feet, and is a fairly good well. The water rises to about 190 feet below the surface.

Most of the wells in the southwest quarter of the Syracuse quadrangle are 120 to 200 feet deep and obtain their supply from the upper part of the Dakota sandstone, but some of them find water in the overlying sand and gravel of the Ogalalla formation. Very few records are available to throw light on the identity of the water-bearing beds. The deepest boring is one 500 feet deep on the Rea ranch in the SW. ¼ sec. 1, T. 28 S., R. 43 W. In this well two water-bearing beds that are separated by shale were found between 300 and 500 feet. A large volume of soft water was obtained. A 300-foot well on another Rea ranch in the NE. ¼ sec. 32, T. 27 S., R. 42 W., had the following record:

Record of well in the NE. ¼ sec. 32, T. 27 S., R. 42 W.

	Feet.
Soil	0- 20
Clay (Graneros in part)	20-150
Sandstone, soft	150-160
Sand, with water	160-260
Sandstone, porous	260-290
Shale	290-300

There was a large volume of soft water in coarse sand from 160 to 260 feet, which is reported to be capable of yielding 1,500 gallons or more a minute.

A well was sunk in Johnson late in 1889 to a depth of 420 feet. According to the driller it penetrated 180 feet of loam and nearly dry, fine sand of the Ogalalla formation. Below this material from 180 to 400 feet was a formation that was reported as "gravel with three clay layers containing a large volume of water which rises to within 180 feet of the surface." Probably these beds comprise the base of the Ogalalla formation and about 200 feet of Dakota sandstone. Below the water-bearing deposits from 400 to 420 feet was "blue mud, like putty," probably the shale which underlies the Dakota sandstone at most places.

At Kendall a well 537 feet deep yields 70 gallons a minute. The record of this well is given on page 4. It reached Dakota sandstone at 53 feet under the valley fill. Water-bearing sandstones were found at 114 to 152, 215 to 268, and 348 to 367 feet. Brown sand was penetrated from 425 to 430 feet and light-gray sandstone from 476 to 493 feet, but they were not reported to contain water. The boring ended in the Cimarron group.

At the Lombard ranch on the river flat, 1½ miles southwest of Kendall, a 110-foot well obtains a large volume of soft water that rises to within 5 feet below the surface. The water comes from Dakota sandstone, which is reported to have been entered at a depth of 83 feet.

At D 6 ranch, just north of the railroad, about 2 miles southeast of Kendall, a 127-foot well has a good volume of soft water that rises to about 40 feet below the surface. It is in Dakota sandstone, which is reported at a depth of 35 feet.

A well at Lakin, drilled by the Atchison, Topeka & Santa Fe Railway Co. in 1901, has the following record:

Record of railroad well at Lakin, Kans.

	Feet.
Loam and sand	0- 40
Clay, blue	40- 55
Sand, blue, with water	55- 84
Clay, yellow and blue	84-156
Sand and gravel with water	156-194

Water level, 30 feet below surface; yield, 55 gallons per minute.

Another well near by, 197 feet deep, has closely similar features.

Records of other wells at Lakin.

No. 2.

	Feet.
Surface material and sand	0 - 30
Clay	30 - 55
Sand, blue	55 - 84
Clay, blue	84 -153½
Clay, yellow	153½-156
Sand, gravel, and water	156 -174
Conglomerate	174 -189
(?)	189 -191

No. 3.

	Feet.
Surface material and sand	0 - 30
Clay	30 - 55
Sand, blue	55 - 84
Clay, blue	84 -152
Water, sand, and gravel (Dakota)	152 -176½
Conglomerate (in part?)	176½-197

A well near the northwest corner of T. 28 S., R. 33 W., in the Garden quadrangle is reported to pass through the following beds:

Record of well near northwest corner of T. 28 S., R. 33 W.

	Feet.
Soil	0- 3
Grit (Ogalalla)	3- 45
Clay, blue (Graneros)	45-305
Rock, hard, blue (Dakota?)	305-325
Sandstone (Dakota)	325-330

The sandstone contains much water, which rises to within about 210 feet of the surface.

Wells in Ogalalla formation.—Most of the ranches on the High Plains obtain a supply of water for domestic use from wells in the sand and gravel of the Ogalalla formation. The water is contained chiefly in the lower part of the formation and generally the volume is good, but there are places where fine-grained deposits extend down to the shale and no water is obtainable. Some of the wells in the Ogalalla formation also penetrate into underlying Dakota sandstone, which yields increased supply. In a large area about New Ulysses and to the north and west the wells are less than 100 feet deep, and along Bear Creek and far into Stanton County the water is less than 50 feet from the surface. At Johnson the formation carries but little water, but the underlying Dakota sandstone yields a satisfactory volume.

Several wells have been sunk by the State to test the underground-water resources in western Kansas. One of these, 5 miles north of Kendall and half a mile north of the northern margin of the quadrangle, shows the water conditions on the High Plains in that region. The well is 196 feet deep and obtains an abundant supply of water, mostly from the lower beds of the Ogalalla formation, from 170 to 187 feet. The yield, when pumped from a depth of 170 feet, is estimated at 33 gallons a minute. The State well in Grant County is in the NW. ¼ NW. ¼ sec. 36, T. 29 S., R. 25 W. It was sunk in 1895 to a depth of 231 feet and obtains an abundant supply of water from basal Ogalalla beds at 148 to 212 feet. The water rises within about 123 feet of the surface. The records of these wells are given under the discussion of the Ogalalla formation (p. 6).

[1] For detailed description see U. S. Geol. Survey Water-Supply Papers 99, pp. 269-271, 1904; 131, p. 134, 1905; and 173, pp. 28-30, 1906.

Wells in the alluvium.—The lower part of the coarse sand and gravel in the lowland along the river is saturated with water at most places, and is the source of supply for many houses and ranches in the valley and also to some extent for irrigation. The thickness of the valley deposits differs considerably from place to place and at some places the materials are finer grained than at others and contain less water. The thickness at Syracuse is only about 20 to 30 feet; at Kendall, 53 feet; and at Lakin, 30 to 40 feet. The water is mainly derived from local rainfall and is moving toward the river and also down the valley at a low rate of flow. Most of the wells are from 25 to 50 feet deep, and there is considerable difference in depth to water and in volume of water obtained from place to place within short distances. In general the water rises to within from 10 to 20 feet of the surface, according to the height of the land above the river and the local volume of water. Most of it is hard.

The sand and gravel adjoining and under Arkansas River carry a large volume of water which is known as the underflow. The conditions under which the water accumulates, its quantity, direction, and rate of flow were investigated in detail by Charles S. Slichter[1] in the summer of 1904. A series of test wells, mostly 14 to 36 feet deep, were sunk at intervals across the valley at Deerfield, Sherlock, and near Garden City, and observations were made in the "Narrows," near Hartland.

It has been popularly supposed that the underflow in the valley deposits along Arkansas River comes from Colorado or even from the Rocky Mountains, but Slichter's investigation showed that its source is mostly local. A small part of the water sinks from the river or spreads laterally from it, but the greater part is derived from rainfall on the near-by flats and sand hills, together with small additions from run-off on the side slopes and tributary valleys. Slichter's principal conclusions are as follows:[2]

1. The underflow of Arkansas River moves at an average rate of 8 feet per 24 hours in the general direction of the valley.
2. The water plane slopes to the east at the rate of 7.5 feet per mile, and toward the river at the rate of 2 to 3 feet per mile.
3. The moving ground water extends several miles north from the river valley. No north or south limit was found.
4. The rate of movement is very uniform.
5. The underflow has its origin in the rainfall on the sand hills south of the river and on the bottom lands and plains north of the river.
6. The sand hills constitute an essential part of the catchment area.
7. The influence of the floods in the river upon the ground-water level does not extend one-half mile north or south of the channel.
8. A heavy rain contributes more water to the underflow than a flood.
9. On the sandy bottom lands 60 per cent of an ordinary rain reaches the water plane as a permanent contribution.
10. The amount of dissolved solids in the underflow grows less with the depth and with the distance from the river channel.

No indication of a decrease in the underflow at Garden was noted in the five years from 1899 to 1904. The city well at Garden showed the same specific capacity in 1904 that it had in 1899.

In one place Slichter found that the soft water from the sand hills was crowding the hard water of the river underflow toward the north side of the valley. He found that the slope of the water plane toward the river is reversed when there is a heavy flood in the stream without any local rainfall. Under this condition the water table near the river rises and there is lateral flow into the sands of the bottom lands for a short distance. A heavy local rain, however, rapidly raises the water level under the valley.

As is shown by the contour lines in figure 7, the ground-water slope does not follow the river channel.

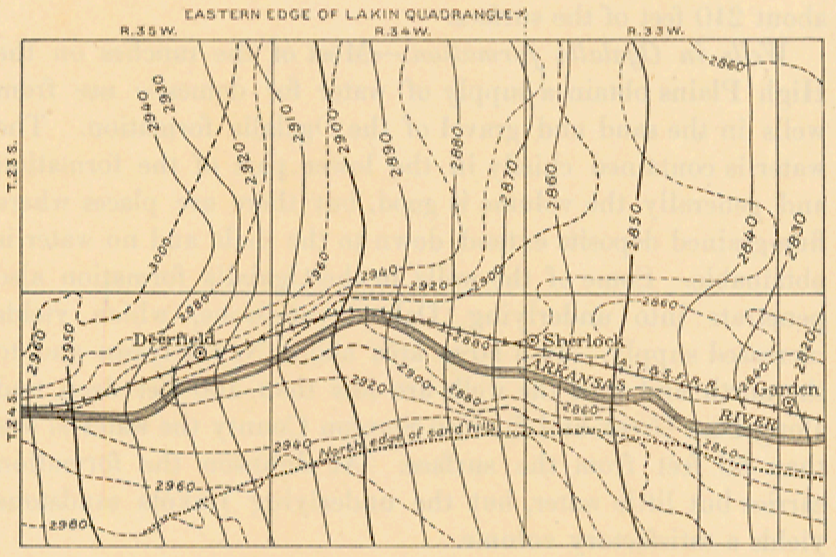

Figure 7.—Map showing slope of ground-water plane between Deerfield and Garden, Kans., east of the Lakin quadrangle; determined by C. S. Slichter in the summer of 1904.

An investigation was made at Clear Lake to ascertain if its supply of water was replenished by a large underflow from Bear Creek, as is supposed by some people in the region. Test holes were sunk near the pond, and it was found that at this place the underflow was moving nearly eastward down the valley without any notable influx from the south. The pond, therefore, would not furnish any large volume of water for irrigation.

The measurement of the underflow at the "Narrows," 1½ miles above Hartland, gave some interesting results bearing on the total volume of underflow passing along the valley bottom, which at this place is greatly narrowed by rocky bluffs 2,250 feet apart. Test holes found bedrock under the valley fill at a depth of about 40 feet below the river. The cross section of fill is about 75,000 square feet, and if the sand holds one-third of its volume of water and the average velocity is 10 feet a day the total flow is 250,000 cubic feet a day or 2.9 cubic feet a second. However, the average velocity probably is less than 10 feet a day, for determinations near the center of the valley gave 9.6 feet at a depth of 16 feet, and 3.4 feet a day at a depth of 25 feet. In the Narrows the gradient of the water plane is 8.5 feet to the mile, but just above the Narrows the rate is 11.4 feet.

[1] U. S. Geol. Survey Water-Supply Paper 153, 1906.
[2] Idem, p. 5.

Slichter[3] made some experiments at Deerfield to determine the rate of evaporation of ground water from different depths and under varying meteorologic conditions. In part of July and August, 1904, when the evaporation of open water ranged from about 2 to 3 inches a week, the rate was about half as much as this where the water level was 1 foot below the surface, one-fourth to one-sixth as much where it was 2 feet below the surface, and about one-twentieth as much where it was 3 feet below the surface.

Wells in the dune sands.—A plentiful supply of water is obtainable by shallow wells in many places in the sand dunes south of Arkansas River. In some places this water occurs in the basal portion of the sand that lies on the valley floor of the alluvium, and in other places it is at greater or less depth in the alluvium. Very few permanent wells have been sunk in the sand area and apparently no tests have been made to show the quantity of water available.

Quality of well waters.—The following analyses of water from wells in the area have been compiled from various sources:[4]

tration of the water by evaporation, for in the bottom lands the water plane is close to the surface. The shallow water also is more subject to dilution by rain and by overflow from the river.

Classifying average analyses of water from wells less than 40 feet deep, north of the river by general location, gives the following results:

Quality of ground water in wells north of Arkansas River.

[Parts per million.]

Location.	Number of samples.	Chloride radicle (Cl).	Alkalinity as $CaCO_3$.	Total hardness as $CaCO_3$.	Total dissolved solids.
First bottom	38	69	182	428	938
Second bottom	7	40	183	476	894
Upland	3	18	199	768	350

Water for irrigation.—The large volume of water that saturates the sands in most parts of the valley of Arkansas River nearly to the surface is pumped for irrigation of areas of considerable extent. Several large pumping plants have been installed in the broad flats south of Lakin.

Slichter[5] has estimated that in a properly constructed well in coarse material each square foot of percolating surface of the well strainers can be relied on to yield fully one-fourth of a gallon of water a minute under 1-foot head.

Pumping tests were made by Slichter in two wells near Lakin. One well in the NE. ¼ sec. 10, T. 25 S., R. 36 W., consisting of a pit and 7 feeder tubes, was 42 feet deep. The water level was 8 feet below the surface. The yield was about 540 gallons a minute, and the drawdown was 6⅓ feet. With gasoline at 21 cents a gallon and a lift of 17 feet the fuel cost of pumping was $1.37 an acre-foot.

Analyses of water from wells in Syracuse and Lakin quadrangles, Kans.

[Parts per million; analyses by Atchison, Topeka & Santa Fe Railway Co.]

Date of collection.	Locality.	Source.	Depth of water-bearing stratum.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chloride radicle (Cl).	Volatile and organic matter.	Total dissolved solids.
			Feet.										
June 22, 1900	Kendall	Artesian well	215–368			34		136	166	79	15	36	464
Do	do	do.[a]	349–367			34	7.4	104	106	138	15	26	430
Sept. 5, 1902	do	do.[a]		29	8.9	24	11	114	96	168	12		
May 30, 1902	do	do.[a]	500			34	8.4	114	121	143	12	55	488
May 22, 1900	do	Well in fine sand	152			221	35	60	63	432	46	70	928
	do	Well No. 1 of Atchison, Topeka & Santa Fe Railway Co.	115			198	9.3	60	52	491	45	68	923
Nov. 12, 1898	Syracuse	Well of H. R. Taylor	154			31	11	69	96	91	14	27	344
Nov. 7, 1898	do	Well of C. T. Rose	186			33	12	102	113	134	17	24	418
Dec. 7, 1898	do	Tank of Atchison, Topeka & Santa Fe Railway Co. (well water).	28			343	80	110	203	962	61	116	1,876
July 28, 1899	do	Well	157			120	53	106	79	391	68	123	847
Oct. 25, 1899	do	do	170			63	3.9	203	174	254	42	135	876
Apr. 16, 1902	do	Artesian well	250			18	4.4	153	138	143	12	24	493
1910	do	Well No. 4 of Atchison, Topeka & Santa Fe Railway Co.	465			([b])	([b])	441	189	679	85		1,308
Dec. 7, 1898	1½ miles south of Syracuse.	Well of J. H. Bolt	1,120			63	13	34	89	113	17	48	377
Do	6½ miles south of Syracuse.	Well of E. Osteton	15			80	29	21	132	92	32	48	433
Do	1 mile south of Syracuse.	Well of I. Overton	28			161	24	109	254	291	7.3	216	1,061
May 12, 1900	Lakin	Artesian well	160			50	8.4	38	101	45	20	60	322
May 30, 1902	do	Three wells	184, 192, 195			53	14	20	102	25	5.2	22	141
1901	do	Well of Atchison, Topeka & Santa Fe Railway Co.	160			([c])	([c])	36	([e])	44	19	58	313
Dec. 2, 1907	Deerfield	([d])	198	31	.14	82	38	90	[e]123	199	42		[e]591

[a] Same well at different depth.
[b] $CaCO_3+MgCO_3$=99 parts per million.
[c] $CaCO_3+MgCO_3$=152 parts per million.
[d] Well No. 1, U. S. Reclamation Service; A. J. Weith, analyst, University of Kansas.
[e] Nitrate (NO_3)=4 parts per million.

Considerable attention was given by Slichter[1] to the composition of the ground water in the Arkansas Valley from Deerfield to Garden City, and the following figures are based on the results of a large number of field assays in his report:

Average mineral composition of ground water in the Arkansas River valley.

[Parts per million.]

Depth of wells.	Number of samples.	Chloride radicle (Cl).	Alkalinity as $CaCO_3$.	Total hardness as $CaCO_3$.	Total dissolved solids.
Less than 10 feet	11	103	208	385	758
10 to 20 feet	18	78	186	401	967
20 to 30 feet	14	50	163	410	910
30 to 40 feet	10	46	176	380	928
40 to 70 feet	6	25	121	167	350
More than 70 feet	4	11	163	284	247
Sand-hill wells	9	12	164	182	269

These figures show a marked decrease of total solids in the waters from wells of greater depth than 40 feet, and it is well known all along the valley that wells 60 to 100 feet deep, reaching "second" or "third" waters, as they are termed, yield very much softer water than the shallow wells. The sand-hill waters are in general exceptionally soft. The increase in mineral content near the surface is believed to be due partly to concen-

[3] Idem, pp. 43–44.
[4] Parker, H. N., Quality of the water supplies of Kansas: U. S. Geol. Survey Water-Supply Paper 273, pp. 103–105, 116–118, 1911.

The other well, in the SE. ¼ sec. 4, T. 25 S., R. 36 W., 3 miles southwest of Lakin, also had a pit and feeder tubes that reached a depth of 42 feet. The water level was 11½ feet below the surface and the drawdown was 4⅙ feet. The yield was about 215 gallons a minute. With gasoline at 22 cents a gallon and a lift of 15.8 feet, the fuel cost of pumping was $2.78 an acre-foot. The fuel cost for pumping in other wells ranged from $1.09 to $2 an acre-foot, except in one plant using coal, where it was only 85 cents.

The largest pumping plant in operation in 1911 was that of the United States Sugar & Land Co. This company had a 400-horsepower plant at Deerfield and about 20 miles of electric transmission line connecting 14 pumping units. The typical pumping unit consisted of 5 wells pumped by a single centrifugal pump and had a capacity of about 1,800 gallons a minute. The wells were about 50 feet deep and 16 inches in diameter, they had perforated casings and extended chiefly through sand and gravel. About 4,200 acres were under irrigation with water supplied by this plant. The water level was reported to average about 12 feet below the surface and the drawdown to be about 12 feet. No considerable depletion of the total supply had been noted.

Several other pumping plants, which were operated in the valley, had capacities that ranged from 1 to several second-feet.

April, 1917.

[5] Op. cit., p. 6.

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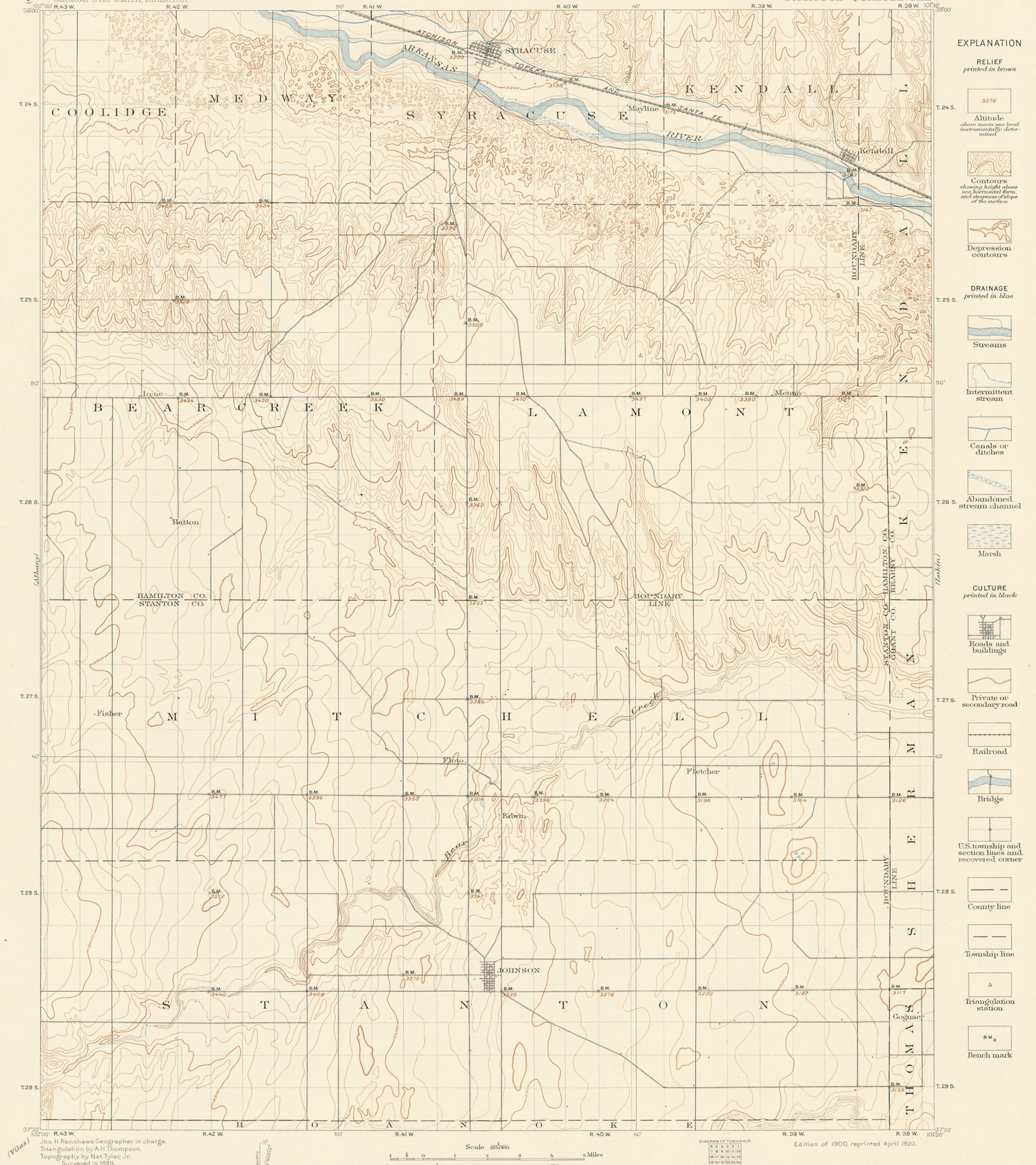
TOPOGRAPHY

KANSAS
SYRACUSE QUADRANGLE



Jno. H. Renshawe Geographer in charge.
Triangulation by A.H. Thompson.
Topography by Nat. Tyler, Jr.
Surveyed in 1898.

APPROXIMATE MEAN DECLINATION 1919

Scale 1/125000
Contour interval 20 feet.
Datum is mean sea level.

Edition of 1900, reprinted April 1920.

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KANSAS
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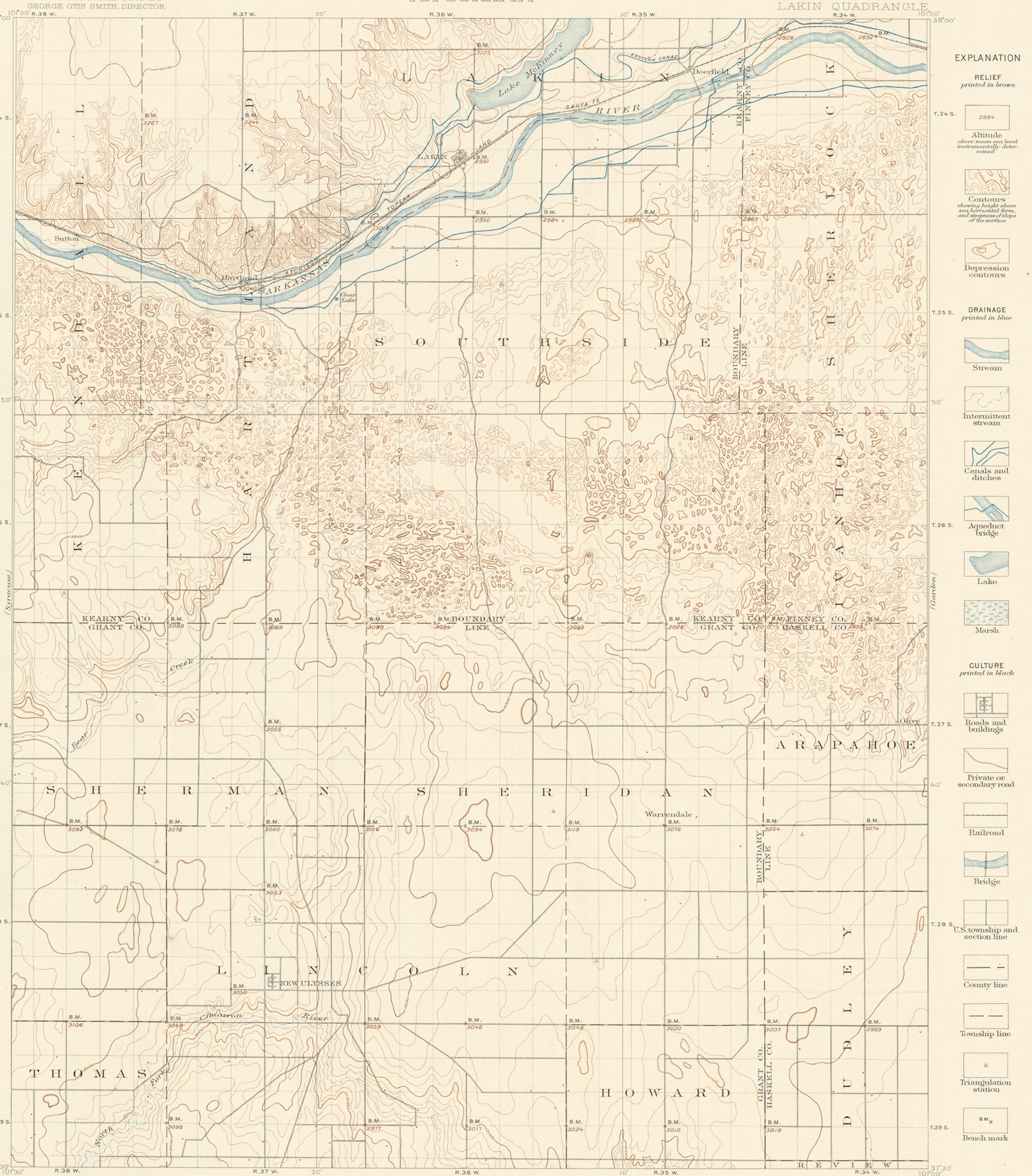

Jno. H. Renshawe, Geographer in charge.
Triangulation by A.H. Thompson.
Topography by W.H. Herron and Nat. Tyler Jr.
Surveyed in 1892 and 1898.

APPROXIMATE MEAN DECLINATION 1919

Scale 1/125000

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DIAGRAM OF TOWNSHIP

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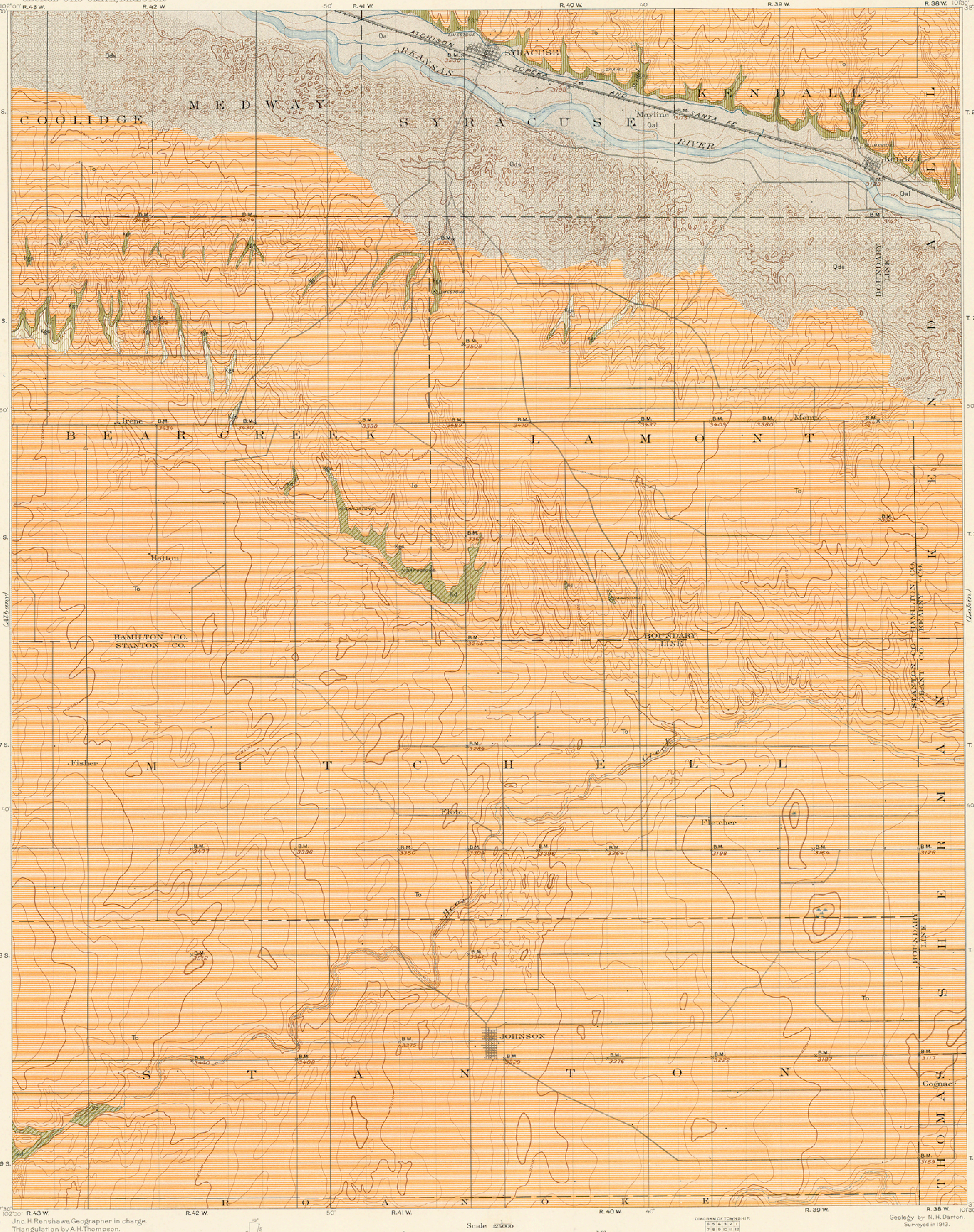
AREAL GEOLOGY

KANSAS
SYRACUSE QUADRANGLE



EXPLANATION

SEDIMENTARY ROCKS

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

QUATERNARY — *Recent*

Qds — Dune sand *(derived from river alluvium by prevailing northwest winds)*

Qal — Alluvium *(sand, loam, and gravel in river bottom)*

TERTIARY — *Pliocene and late Miocene*

To — Ogallala formation *(sand, loam, and calcareous grit covering the uplands)*

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous*

Kgn — Greenhorn limestone *(thin-bedded limestone and interbedded shale)*

Kgs — Graneros shale *(dark shale)*

Kd — Dakota sandstone *(hard massive gray to buff sandstone)*

Quarries
Gravel pit

Economic note: *Sand and gravel for concrete and other uses occur in Ogallala formation, alluvium, and dune sand; impure limestone in Greenhorn limestone. Dakota sandstone is available for rough building stone. Wells and depth to underground water shown on underground-water sheet.*

Jno. H. Renshawe, Geographer in charge.
Triangulation by A. H. Thompson.
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APPROXIMATE MEAN DECLINATION 1919.

Scale $\frac{1}{125000}$

Contour interval 20 feet.
Datum is mean sea level.
Edition of Feb. 1920.

DIAGRAM OF TOWNSHIP

Geology by N. H. Darton.
Surveyed in 1913.

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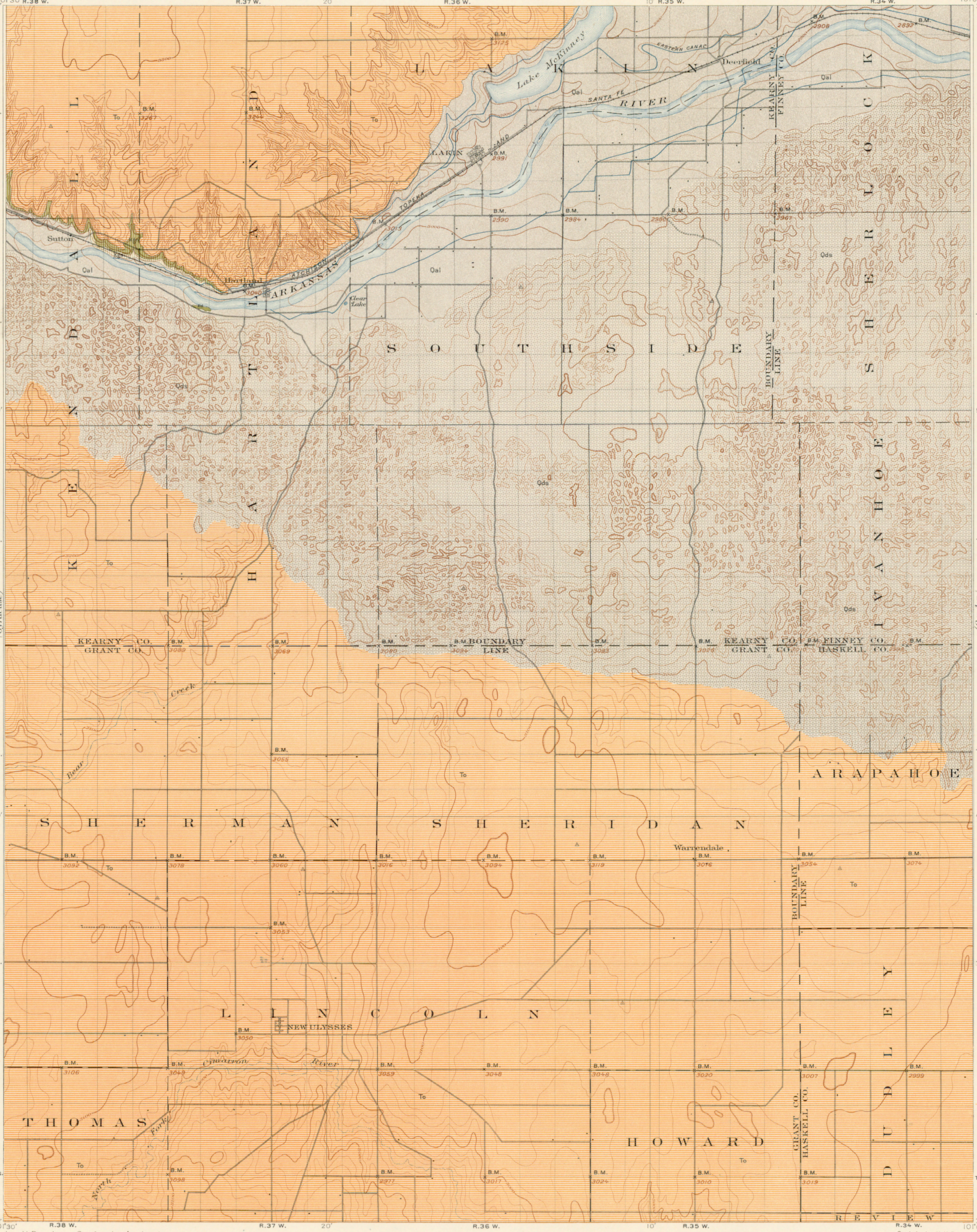
AREAL GEOLOGY

KANSAS
LAKIN QUADRANGLE



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Contour interval 20 feet.
Datum is mean sea level.

Edition of Feb. 1920

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Geology by N. H. Darton.
Surveyed in 1913.

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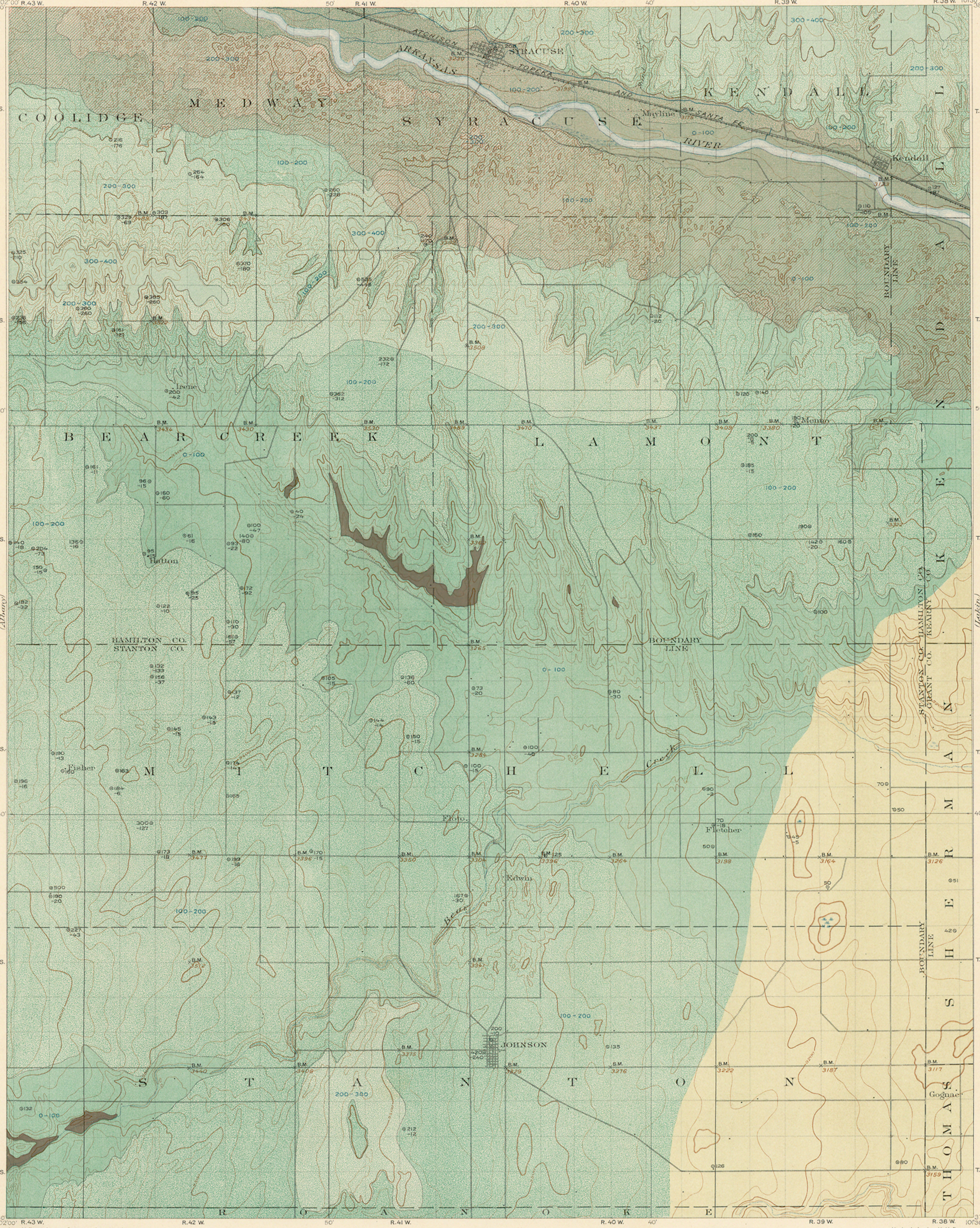
UNDERGROUND WATER

KANSAS
SYRACUSE QUADRANGLE



EXPLANATION

Water in alluvium (in large volume in most places at depths of 5 to 40 feet; water in Dakota sandstone at greater depths)

Water in dune sand (in moderate volume at most places at depths less than 100 feet)

Water in Ogallala formation (water locally abundant at 15 to 100 feet depth; water may also be obtained from underlying Dakota sandstone at greater depth)

0-100
100-200
200-300
300-400

Depths to Dakota sandstone (water occurs in considerable volume in Dakota sandstone, especially in beds 50 to 150 feet below its top; on the higher land in the eastern part of the quadrangle water may be obtained in many places at depths of 30 to 140 feet from beds in the Ogallala formation)

Outcrop of Dakota sandstone (in part thinly covered by wash or soil; carries some water in lower beds)

150 / −15 **Artesian wells** (only representative wells are shown; depth indicated in feet; depth to water surface in wells indicated by figures with minus sign)

Jno. H. Renshawe Geographer in charge.
Triangulation by A. H. Thompson.
Topography by Nat. Tyler Jr.
Surveyed in 1898.

APPROXIMATE MEAN DECLINATION 1919.

Scale $\frac{1}{125000}$

Contour interval 20 feet.
Datum is mean sea level.
Edition of Dec. 1920.

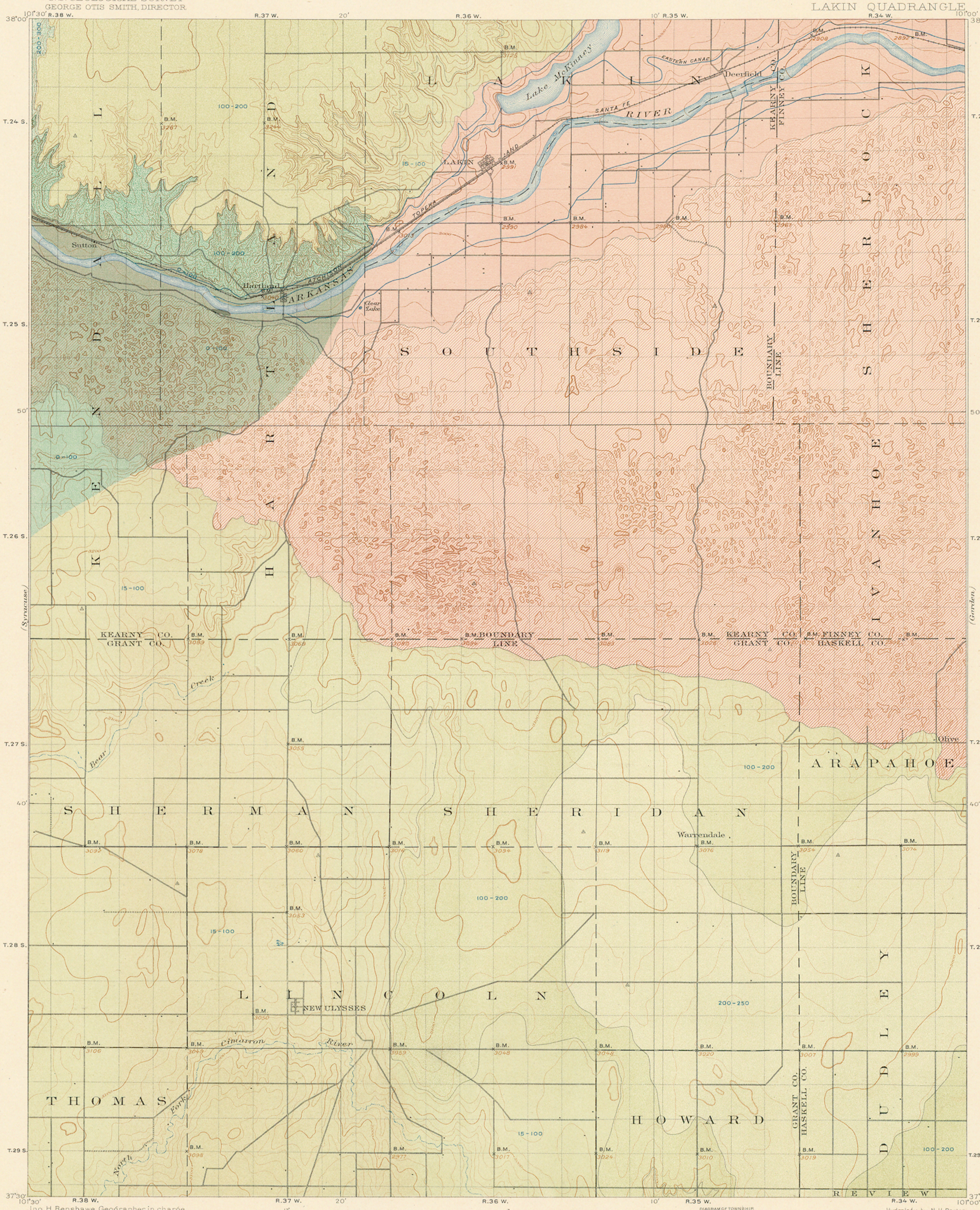
DIAGRAM OF TOWNSHIP

Hydrology by N. H. Darton.
Surveyed in 1913.

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

UNDERGROUND WATER

KANSAS
LAKIN QUADRANGLE



EXPLANATION

Water in alluvium
(in large volume in most places at depths of 5 to 100 feet;water in Dakota sandstone at greater depths)

Water in dune sand
(in moderate volume in lower part of sand and underlying alluvium at depths of 15 to 100 feet)

15-100
100-200
200-250

Depth to water in Ogallala formation
(water locally abundant and of good quality; water may also be had from underlying Dakota sandstone at greater depth)

0-100
100-200
200-300

Depths to Dakota sandstone
(water occurs in considerable volume in Dakota sandstone, especially in beds 50 to 150 feet below its top)

Outcrop of Dakota sandstone
(in part thinly covered by wash or soil; carries some water in lower beds)

Jno. H. Renshawe, Geographer in charge.
Triangulation by A.H. Thompson.
Topography by W.H. Herron and Nat. Tyler Jr.
Surveyed in 1892 and 1898.

TRUE NORTH
MAGNETIC NORTH
12°
APPROXIMATE MEAN DECLINATION 1919.

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 Dec. 1920.

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

Hydrology by N.H. Darton.
Surveyed in 1913.

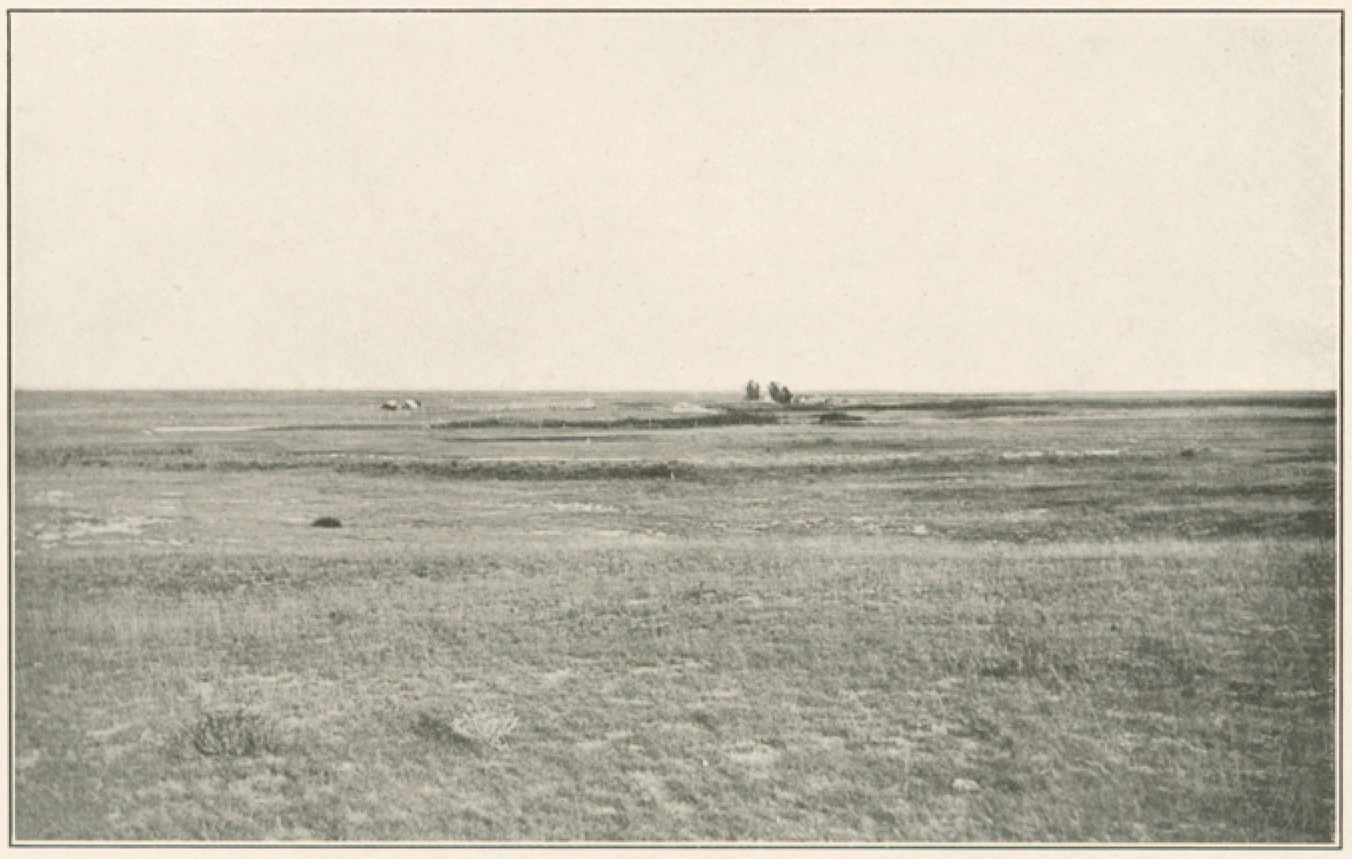


PLATE I.—TYPICAL VIEW ON THE HIGH PLAINS OF WESTERN KANSAS, SHOWING LEVEL SURFACE UNDERLAIN BY THE OGALALLA FORMATION.

PLATE II.—TYPICAL SURFACE OF THE COUNTRY UNDERLAIN BY THE OGALALLA FORMATION ON THE HIGH PLAINS OF WESTERN KANSAS.

Buffalo wallow, shallow circular depression in the level surface, in foreground.

PLATE III.—DAKOTA SANDSTONE ON BEAR CREEK 11 MILES SOUTHWEST OF JOHNSON, KANS.

View looking south. Shows heavy top ledge and underlying thinner beds dipping gently eastward beneath the level of the creek.

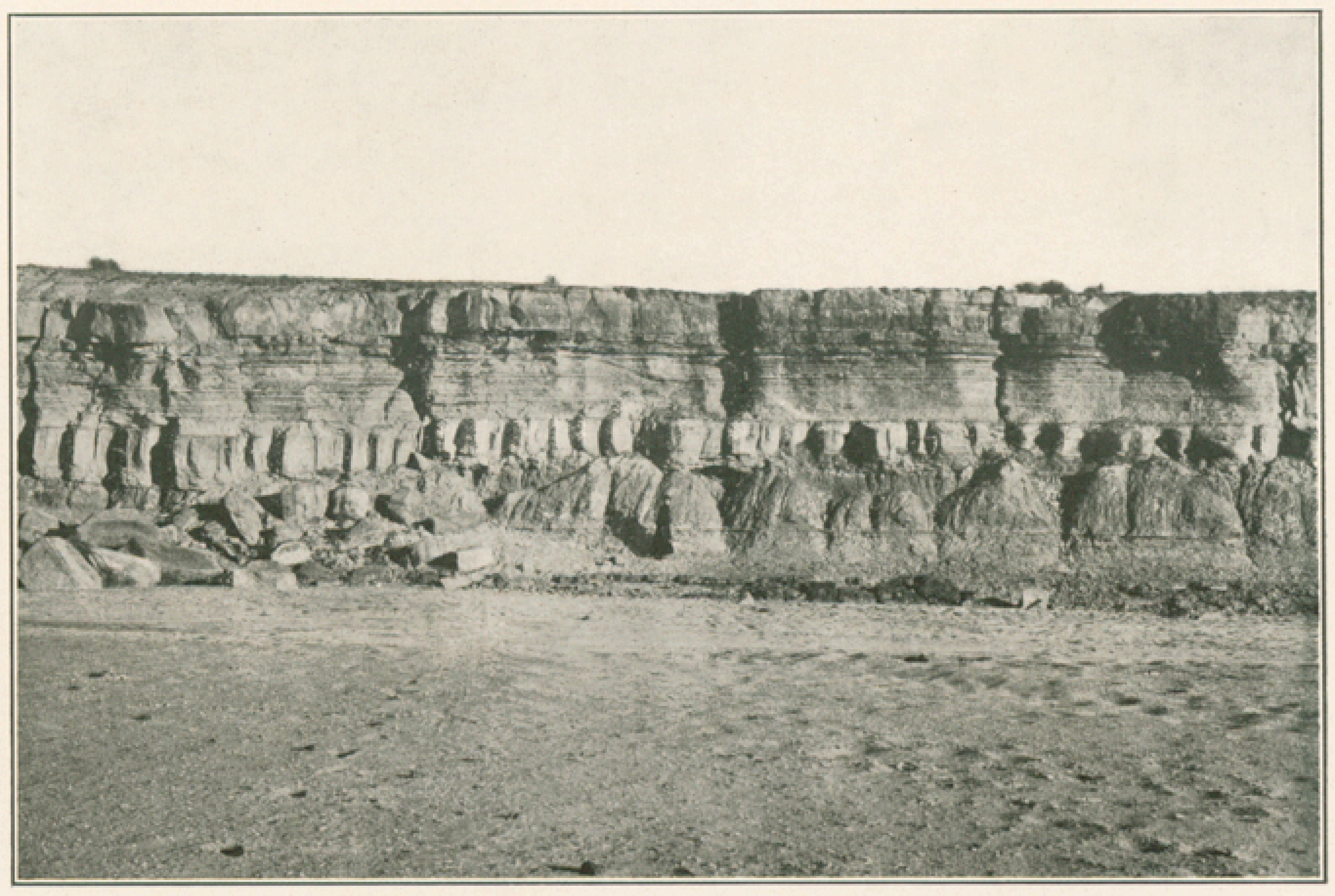


PLATE IV.—DAKOTA SANDSTONE ON SOUTH BANK OF BEAR CREEK 12 MILES SOUTHWEST OF JOHNSON, KANS.

View looking south. Shows upper sandstone divided by layers of shaly sandstone into two massive beds, the lower one strongly jointed. The sandstone is underlain by clay.

A B

PLATE V.—MARINE FOSSILS CHARACTERISTIC OF ROCKS OF CRETACEOUS AGE.

A, Ostrea congesta, a small oyster of the Niobrara formation.
B, Inoceramus labiatus, a bivalve shell of the Greenhorn formation.

PLATE VI.—SAND HILLS IN WESTERN CHEYENNE COUNTY, NEBR.

View on the leeward side, looking west. These hills are similar in appearance to those in the Lakin quadrangle and still smaller ones *stages*. The age of a rock is expressed by the name of the time interval in which it was formed.

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

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

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

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

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

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

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

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

Symbols and colors assigned to the rock systems.

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

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

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

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

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

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

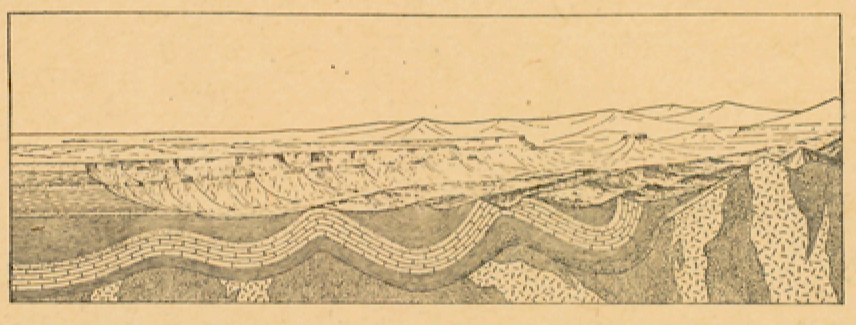


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

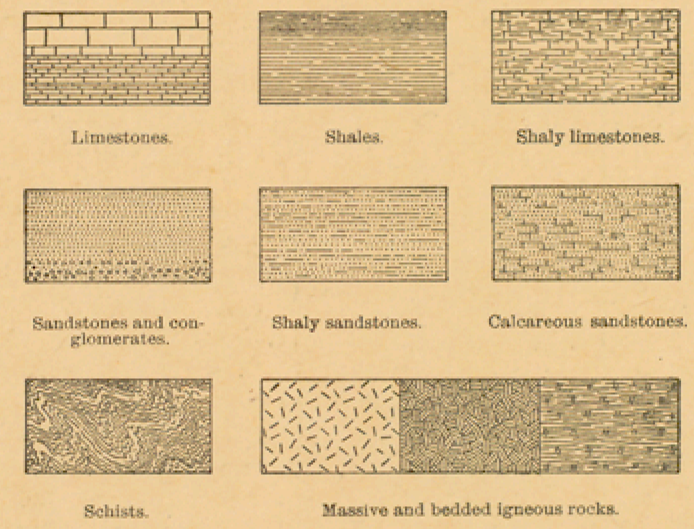


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

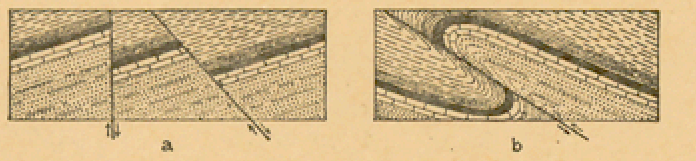


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

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

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

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

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

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

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

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

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

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

GEORGE OTIS SMITH,
Director.

May, 1909.

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‡ These folios are out of stock.
● The texts and economic-geology maps of the Placerville, Sacramento, and Jackson folios, which are out of stock, have been reprinted and published as a single folio (Folio reprint Nos. 3, 5, and 11), the price of which is $1.

‖ Octavo editions of these folios may be had at same price.
¶ Octavo editions only of these folios are in stock.
§ These folios are also published in octavo form at 50 cents each, except No. 193, which is 75 cents.

The stock of folios from Nos. 1 to 184 and No. 186 was damaged by a fire in the Geological Survey building, but those folios that were only slightly damaged and are usable will be sold at 5 cents each. They are priced accordingly in the list above. Circulars showing the location of the area covered by any of the above folios, as well as information concerning topographic maps and other publications of the Geological Survey, may be had on application to the Director, United States Geological Survey, Washington, D. C.