DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

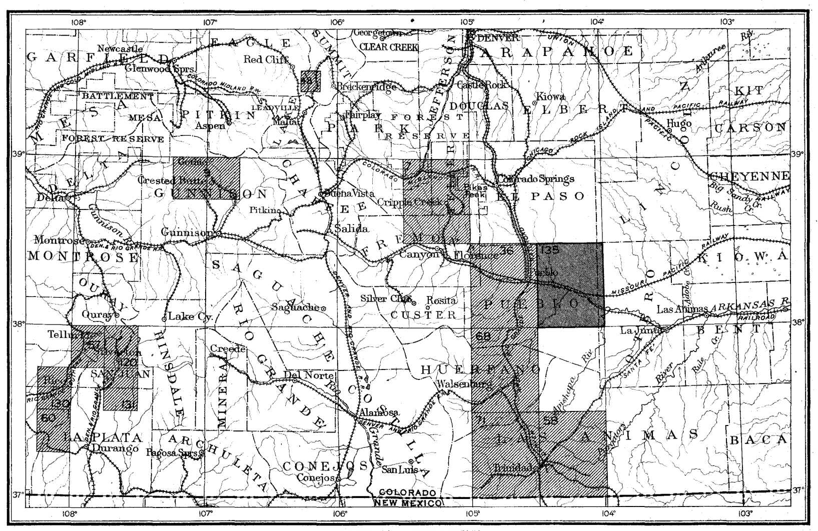
OF THE

UNITED STATES

NEPESTA FOLIO

COLORADO

INDEX MAP



SCALE: 40 MILES-1 INCH

NEPESTA FOLIO

OTHER PUBLISHED FOLIOS

CONTENTS

WASHINGTON, D. C.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

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

1906

GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic map and geologic maps of a small area of country, together with explanatory and descriptive texts.

THE TOPOGRAPHIC MAP.

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

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those which are most important are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the 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 altitudinal interval represented by the space between lines being the same throughout each map. These lines are called *contours*, and the uniform altitudinal space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map (fig. 1).

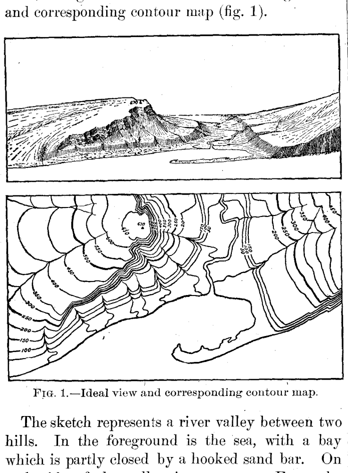


FIG. 1.—Ideal view and corresponding contour map.

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

1. A contour indicates a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours 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 sea; along the contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration all the contours are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contours, and then the accentuating and numbering of certain of them—say every fifth one—suffice, for the heights of others may be ascertained by counting up or down from a numbered contour.

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

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

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

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

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

Scales.—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the *scale* of the map. In this case it is "1 mile to an inch." The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to an inch" is expressed by $\frac{1}{63{,}360}$.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250{,}000}$, the intermediate $\frac{1}{125{,}000}$, and the largest $\frac{1}{62{,}500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62{,}500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale $\frac{1}{125{,}000}$, about 4 square miles; and on the scale $\frac{1}{250{,}000}$, 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 in English inches, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map 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 $\frac{1}{250{,}000}$ contains one square degree—i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125{,}000}$ contains one-fourth of a square degree; each sheet on the scale of $\frac{1}{62{,}500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles.

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

Uses of the topographic map.—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

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 the structure sections show their underground relations, as 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.—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

Sedimentary rocks.—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

The chief agent of 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. In smaller portion the materials are carried in solution, and the deposits are then 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 deposits 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*. Rocks deposited in layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a *residual* layer. Water washes residual material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called *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 a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called *metamorphic*. In the process of metamorphism the substances of which a rock is composed may enter into new combinations, certain substances may be lost, or new substances may be added. There is often a complete gradation from the primary to the metamorphic form within a single rock mass. Such changes transform sandstone into quartzite, limestone into marble, and modify other rocks in various ways.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

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, a rapid alternation of shale and limestone. When the passage from one kind of rocks to another is gradual it is sometimes 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 is constituted of one or more bodies either containing the same kind of igneous rock or having the same mode of occurrence. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics.

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 the rocks were made is divided into several *periods*. Smaller time divisions are called *epochs*, and still smaller ones *stages*. The age of a rock is expressed by naming the time interval in which it was formed, when known.

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*.

(Continued on third page of cover.)

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

Stratified rocks often contain the remains or imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, 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. When 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 found 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 often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes 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 is sometimes 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 of their metamorphism.

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.

Symbols and colors assigned to the rock systems.

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

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. 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 by which formations are labeled 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 recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

Hills and 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; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 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, and these are, in origin, independent of the associated material. 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 afterwards 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. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is called a *peneplain*. If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored 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 given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the 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.—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which exhibits those relations is called a *section*, and the same 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 the 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 of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

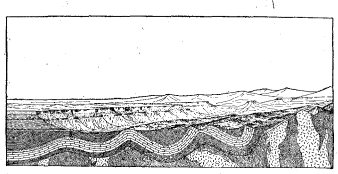


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

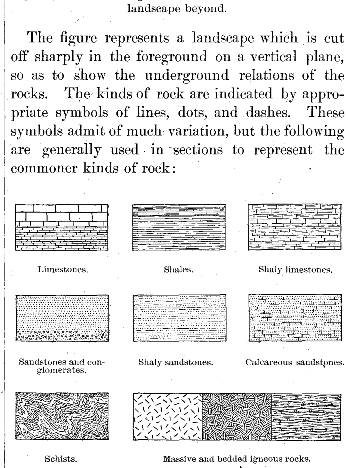


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to 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 that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; that they are now bent and folded is 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 fig. 4.

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be

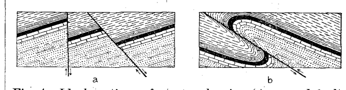


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

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

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

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were plicated by pressure and traversed by eruptions of molten rock. But 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 suffered metamorphism; they were the scene of 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 fig. 2 are ideal, but they illustrate relations which actually occur. 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 which appears in the section may be measured by using the scale of the map.

Columnar section sheet.—This sheet contains a concise description of the sedimentary formations which 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 which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

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

CHARLES D. WALCOTT,

Director.

Revised January, 1904.

DESCRIPTION OF THE NEPESTA QUADRANGLE.

By Cassius A. Fisher.

INTRODUCTION.

POSITION AND AREA.

The Nepesta quadrangle extends in latitude from 38° to 38° 30′ and in longitude from 104° to 104° 30′. Its length is 34.5 miles (55.5 kilometers) and its average width 27.3 miles (43.9 kilometers). The area includes a little more than one-third of Pueblo County and a narrow strip along the western boundary of the north half of Otero County, Colo., and comprises 938 square miles. It is situated on the Great Plains, near their western margin, a few miles east of the Rocky Mountains and nearly opposite the Arkansas embayment.

CLIMATE.

The climate of the quadrangle has a moderate range, corresponding mainly to differences of altitude. The southwestern portion is relatively cool and humid, the central portion warm and more arid, while to the northeast, on the high "Nussbaum plateau," the climate approaches a medium between the two extremes. During the summer the maximum heat and aridity of the district are in the lowlands east of Pueblo, which in the winter are more or less protected from snow. Not infrequently winter storms from the mountains to the west sweep across the district, leaving 1 to 2 inches of snow on the level in the southwestern portion, while to the north and northeast much of the moisture evaporates before reaching the ground. The rainfall occurs in the late spring and early summer months and is usually confined to local thunder storms, which, though of brief duration, are often of exceptional violence, converting for a time the canyons and dry watercourses into impassable torrents. The annual precipitation ranges from 6 to 17 inches. Of this amount about one-fifth is snowfall, generally occurring during the months of December, January, and February. The heaviest seasonal precipitation ever recorded in the district was 9.92 inches. In the southwestern part, where the precipitation is probably greatest, the amount of water which the ground absorbs is relatively small, owing to the short duration of the storms and the rapid run-off.

The prevailing winds are from the northwest, though during the months of greatest rainfall—June, July, and August—southeasterly winds are common. Gales from the northwest are not infrequent and winds attaining a velocity of 64 miles an hour have been experienced at Pueblo, a few miles west of the quadrangle boundary.

VEGETATION.

The greater part of the upland of this quadrangle is practically destitute of timber, but in the extreme southwest corner, on the high bluffs bordering Huerfano River, there is a sparse growth of piñon pine and juniper. Trees are abundant along all the larger and many of the intermittent streams. In addition many varieties of forest and fruit trees are cultivated in the irrigated valleys of the larger streams. The upland areas afford a variety of plateau grasses, cacti, and other low-growing plants, and in the more sandy districts the yucca is common. Small meadows occur here and there in the bottom lands, but most of this area, in its natural state, supports a rank though sparse growth of sagebrush. The elevated plateaus and highlands to the south have a fertile soil well covered by nutritious grasses.

CULTURE.

Culture, here as elsewhere, is determined by geologic and climatic conditions. In the more level portions, where soil is rich and water available, settlements are numerous. The upland grazing districts are practically uninhabited except here and there along the intermittent streams, where water reaches the surface or can be procured by shallow wells. The principal settlements are along Arkansas River Valley and the gravelly mesa adjoining on the south. Here a number of small towns have recently been built, of which the largest is Fowler, situated near the eastern margin of the quadrangle. The immediate valley of the Arkansas is traversed by the Missouri Pacific and the Atchison, Topeka and Santa Fe railways. Along these lines are several small villages, notably Boone and Nepesta, the former near the center of the quadrangle and the latter, from which it derives its name, farther east. Huerfano Valley is sparsely settled by an American and Mexican population.

The roads are numerous and in general good. In the grazing districts they follow natural rather than artificial lines, but in the more thickly populated portions they lie along section lines. The larger rivers are crossed by modern steel-frame bridges on all the main routes of travel.

TOPOGRAPHY.

RELIEF.

Broadly viewed, the surface of this quadrangle is a plateau which rises uniformly from east to west. The range of altitude within the area is moderate, the greatest difference not exceeding 1100 feet, with the extremes 25 miles apart. The lowest point is at the eastern margin of the quadrangle, in the valley of Arkansas River, near the town of Fowler, where the altitude is 4300 feet above sea level. The highest point is in the extreme southwest corner, about 3 miles northwest of the Ben Butler ranch, where an altitude of 5375 feet is reached. The highest portions are near the southwest and northeast corners, and from these areas there is a general slope toward Arkansas River Valley. The maximum difference in elevations for any one area of the quadrangle is in the southwest portion along Huerfano River, where the rise from the river bed to the bluffs on the north, a distance of about 3 miles, is nearly 500 feet.

The quadrangle is divided by Arkansas and Huerfano rivers and Chico Creek into four unequal parts, which may be conveniently discussed separately. The northeastern part of the quadrangle is an upland, the southern portion of which resembles a shallow amphitheater opening to the south and southwest, while its northern and northeastern portions have the character of a gently undulating plateau, with a triangular area of typical dune-sand topography near the center. This upland (which will be termed the Nussbaum plateau, from the formation which outcrops throughout its greater part) is bounded on the south by the valley of Arkansas River and on the west by Chico Creek. Along the southern boundary the Nussbaum plateau is dissected by the valleys of Haynes and Kramer creeks, between which a narrow neck of highland extends for 6 or 7 miles southeastward, terminating abruptly at a point about 4 miles north of Nepesta and forming one of the most conspicuous topographic features of the quadrangle. Closely adjacent to this ridge on its southern and western borders are several small detached portions of the plateau. Similar outliers occur lower in the valley east of Boone. In the upper parts of the Haynes and Kramer creek valleys the "tepee" horizon of the Pierre shale is exposed, giving rise to numerous cone-like hills. These hills, or "tepee buttes," as they are sometimes called, are a characteristic topographic feature along the north side of Arkansas River across the quadrangle. To the southeast the Nussbaum plateau is terminated by a high, rather deeply serrated line of bluffs overlooking Arkansas Valley. The western part of the plateau slopes gradually toward Chico Creek.

The area west of Chico Creek and north of the Arkansas consists of broad, gently sloping ridges which are roughly parallel and extend in an east-southeasterly direction. At the north, in the vicinity of the Tolle ranch, these ridges terminate in gradual slopes toward the lower land of Chico Valley; to the south, along the lower courses of the stream, they end abruptly, forming somewhat prominent bluffs.

That portion of the quadrangle lying south of the Arkansas and west of the Huerfano presents some variations of form. The area rises with general uniformity from an altitude of 4500 feet along Arkansas River to the summit (5375 feet) of a high ridge in the southwest corner. This prominent cliff and the corresponding cliff on the opposite side of Huerfano River are capped by hard limestones and inclose a small triangular area of lower land underlain mainly by soft, easily eroded rocks. To the north, in the vicinity of Huerfano Lake, the country is nearly level and is traversed by shallow, intermittent drainage courses. Still farther north a range of flat-topped, detached hills or mesas extends across the area in a line roughly parallel to the course of Arkansas River. These are carved from soft deposits which have been more or less protected from erosion by a capping of gravel. Between this range of hills and Arkansas River Valley is a level terrace which extends from the mouth of Huerfano River to the western margin of the quadrangle and has an average width of 3 miles. The western end of this terrace is crossed diagonally by the narrow valley of St. Charles River.

The area lying east of Huerfano River and comprising the southeastern portion of the quadrangle has a more or less uniform topography. Its salient features are broad, gently undulating hills sloping to the east and surmounted here and there by low, inconspicuous, gravel-capped ridges. To the northwest is a group of high, flat-topped prominences, locally known as the Hooker Hills, which overlook this entire area. To the northeast a narrow fringe of level terrace rises 50 to 75 feet above the level of Arkansas River Valley and extends from the eastern margin of the quadrangle to the mouth of Huerfano River.

DRAINAGE.

The principal drainage channel is Arkansas River, which enters the quadrangle from the west, a little north of the middle, and flows nearly eastward to the center and thence southeastward. Its principal tributaries are Huerfano and St. Charles rivers, entering from the southwest, the former at a point 2 miles east of the southwest corner of the quadrangle and the latter near the center of the western border. Huerfano River flows northeastward and joins the Arkansas near Boone. St. Charles River has a very short course in the quadrangle, crossing the western boundary about 4 miles above its mouth. It has a narrow, flat-bottomed valley bordered by bluffs 30 to 60 feet high. Arkansas River flows below the general level of the region in a meandering course through an open, level-floored valley which averages 1 to $1\frac{1}{2}$ miles in width. This is bordered on the south by a sharp ascent of 50 to 75 feet to a gravelly mesa; to the north long, gradual slopes intervene between the immediate valley and the high bluffs of the Nussbaum plateau. Arkansas River has an average fall of 8 feet to the mile, and its tributaries have steeper grades. The Arkansas carries a large volume of water in all seasons, but the flow in its larger tributaries is of an intermittent character, their stream beds being dry the greater part of the year. Huerfano River is subject to violent and destructive floods during the rainy season, with the result that a large amount of valuable agricultural land has been washed away during the last twenty years. When settlement was first made along the river the average width of the stream bed is reported to have been less than 30 feet; at present it exceeds 200 feet. Apishapa River crosses the southeastern part of the quadrangle. It flows northeastward and joins the Arkansas beyond the boundary, a few miles east of Fowler. The remaining area in the southern half of the quadrangle is drained by Sixmile and Chicosa creeks and smaller tributaries of Apishapa and Arkansas rivers. All these streams flow intermittently for the whole or part of their courses. In the more level portions the surface water, owing to imperfect drainage, tends to collect in lakes or ponds, some of which hold water only during the rainy season, while others, notably Erdman and Hungerford lakes, are ordinarily filled the year round.

The drainage water of the Nussbaum plateau reaches Arkansas River by way of Kramer and Haynes creeks, the former draining the northeastern and the latter the north-central portion of the area. The porous sandstones of the Nussbaum formation absorb water freely and thus prevent a rapid run-off, so that these streams are not subject to violent floods. Haynes Creek has a small flow at all seasons in the vicinity of Langford ranch, but lower in its course the water is lost in the porous sands of the stream bed.

The northwestern portion of the quadrangle is drained by Chico Creek, with Black Squirrel Creek as a tributary from the northeast and Andy Creek from the northwest. Chico and Black Squirrel creeks have a continuous flow in the vicinity of the Skinner and Tabor ranch, but below this the water sinks. The Chico receives considerable flood water from Andy Creek.

DESCRIPTIVE GEOLOGY.

General relations.—The strata forming the surface of the Nepesta quadrangle belong to the Cretaceous, Tertiary, and Quaternary systems. Their distribution is shown on the areal geology sheet, and their thickness, succession, and general characters are illustrated graphically on the columnar section sheet.

Deep-seated formations.—A considerable thickness of sedimentary deposits underlies the formations exposed in the Nepesta quadrangle. These deposits lie in sheets which have a gentle inclination to the east and rest upon a floor of granite and schist. The quadrangle is in the transition zone between the high mountains to the west and the Great Plains region to the east, where the rocks undergo more or less change. There is in consequence some uncertainty in regard to the character and succession of the deep-seated beds.

The Morrison and Fountain formations probably underlie the entire quadrangle, but little is known regarding their thickness and character here, for they have not been penetrated by the deepest borings. The Morrison lies near the surface in Huerfano Valley, in the extreme southwest corner of the quadrangle, being here covered by less than 300 feet of sediments. It is probable also that the quadrangle is underlain by the Millsap limestone and Harding sandstone, for these formations are known to have considerable extent from north to south along the Rocky Mountain Front Range. Concerning the succession of the beds below the Harding sandstone there is much uncertainty. In the Pueblo quadrangle this formation rests unconformably upon the granite and schists, but to the east there may intervene several hundred feet of beds which were laid down as off-shore deposits.

CRETACEOUS SYSTEM.

DAKOTA SANDSTONE.

General relations.—The Dakota sandstone underlies the entire quadrangle. It is exposed over a very small area in the extreme southwest corner. Here the beds, dipping to the east, soon pass beneath the surface in the valley of Huerfano River a short distance above the Ben Butler ranch. The east side of this area is deeply incised by the Huerfano, forming the lower extension of the so-called Huerfano Canyon, a deep and picturesque gorge which continues upstream to the southwest for a distance of 20 miles.

Thickness and character.—The formation has a thickness of about 100 feet. It consists of medium- to coarse-grained sandstone, occurring in beds which are variable in thickness and character. Light-gray and buff colors predominate, weathering to shades of orange and brown. Immediately below the Dakota sandstone is a bed of highly refractory clay about 12 feet thick, underlain by about 200 feet of coarse-grained sandstone merging locally into conglomeratic material. This sandstone and the overlying refractory clay were formerly included in the Dakota formation, but a recent study of these beds by Mr. T. W. Stanton and others has shown that they are of lower Cretaceous age.

It is said that the Dakota sandstone is not water bearing in regions to the west, but in the deep well east of Fowler a good supply of water is obtained from these beds. The same is true of the deep wells at Manzanola and Ordway, still farther east. The Dakota sandstone lies conformably upon the fire clay of the lower Cretaceous, as shown by exposures to the west. Its uppermost limit is not sharply defined, but it merges rapidly into the overlying Graneros shales. The Dakota offers great resistance to erosion and where it outcrops the rock is only partly covered by a thin soil. Owing to the large amount of moisture which it absorbs it furnishes a good rootage for trees, and as a result the exposed areas are generally covered with a relatively dense growth of pine.

Elsewhere the formation contains fossil plants, but only a few fragmentary fossil leaves were found in this district.

BENTON GROUP.

GRANEROS SHALE.

Distribution and character.—The Graneros shale—the lowest formation in the Benton group—outcrops as a narrow belt skirting the margin of the Dakota sandstone in the southwest corner of the quadrangle. It is composed of dark shales, nearly black in the middle, with an occasional layer of sandstone, probably of lenticular character. The most persistent of these layers is a calcareous sandstone about 2 feet thick, occurring in the upper part of the formation. The Graneros shale is generally fossiliferous. There are also near the center several thin layers of light-colored "talc-like" clay, some of which are associated with thin beds of highly fossiliferous limestone containing an abundance of shells. A concretionary horizon usually occurs 30 to 40 feet above the base. These concretions vary from a few inches to a foot in size and are of a calcareous nature. The formation has a total thickness of about 200 feet and merges upward into the Greenhorn limestone.

GREENHORN LIMESTONE.

Character and thickness.—The Greenhorn formation consists of alternating layers of light-gray to dove-colored limestone and a slightly darker-gray sandy shale. The limestone beds vary from 2 to 10 inches in thickness and contain an abundance of fossil shells, the most common being *Inoceramus labiatus*. The limestone is traversed by vertical cracks, which, with the bedding planes, separate it into flat plates. These plates lodge on the slopes in sufficient abundance to obscure the intervening shale in many places. The shale occurs in layers 1 to 2 feet thick and is also very fossiliferous. Thin layers of white clay are also sometimes found. The formation has an aggregate thickness of about 50 feet. It lies conformably upon the Graneros shale and merges upward rapidly into the Carlile shale.

Distribution.—The Greenhorn outcrops in a narrow band bordering the underlying Graneros and Dakota in the extreme southwest corner of the quadrangle. The characteristic topographic expression of the formation is a low, winding escarpment interrupting the gradual slopes of the softer Carlile and Graneros shales. The broken limestone of the formation holds considerable moisture, thus favoring the growth of trees, and its surface is generally covered with piñon. This forested strip separating the talus slopes of the Graneros and Carlile shales affords a means by which the position of the Greenhorn limestone may be easily recognized.

CARLILE SHALE.

Character and thickness.—The Carlile formation is composed of shales, shading from light gray to black, with an occasional layer of lenticular sandstone and concretions. The sandstone lenses are usually confined to more sandy portions of the shale occurring above the middle. Associated with these sandy shales are the concretions, which generally have rounded outlines and vary in size from a few inches to 6 feet. The larger are septaria, being traversed by numerous large shrinkage cracks filled with white or wine-colored calcite in crystals of varying dimensions. At the top of the formation is a layer of light-brown sandstone, 4 feet thick, which is used to some extent as a building material. In thickness this formation varies from 210 to 225 feet.

Distribution.—The areal extent of the Carlile in this quadrangle is greater than that of the Greenhorn and less than that of the Graneros. It occurs as a narrow meandering zone between the low escarpment of the underlying Greenhorn limestone and the bold cliffs of the Timpas. Its steep slopes are largely due to the protection afforded by the resistant massive limestones of the Timpas formation. The soft shales of the upper part of the Carlile sometimes give way under the heavy load of the overlying limestone, causing small landslides.

NIOBRARA GROUP.

TIMPAS FORMATION.

Thickness and character.—The Timpas formation has a thickness of 200 feet. The basal member is a dark-colored sandy limestone, about 2 feet thick, very fossiliferous and containing shells and many shark's teeth, also numerous dark-colored pebbles. Above this is a series of massive gray limestones 40 to 50 feet thick, which is in turn overlain by lead-colored shale containing a few thin bands of limestone. At the top of the formation there are one or two distinct layers of impure limestone. The massive limestone is in strata which range from 6 inches to 1 foot in thickness, intercalated with thin layers of a light-gray calcareous shale. Exposed surfaces of the limestone are usually badly broken and fractured; the cracks run parallel to the bedding and the detached plates are thin and conchoidal. *Inoceramus deformis* is the most common fossil, though not especially abundant, and to the surface of this marine shell *Ostrea congesta* is often found attached. A closer examination of the limestone generally reveals the presence in great abundance of minute organisms, collectively known as foraminifera. In the lower portion of this formation nodules of iron oxide abound. They are of a dark-brown color, spherical or cylindrical in shape, with a diameter rarely exceeding three-quarters of an inch. The surfaces of the less weathered specimens are found on close examination to be covered with angular projecting crystals. These iron particles are probably the oxidized product of marcasite nodules. As the limestone decomposes these resistant nodules are freed from their matrix and lie loose on the surface. The main part of the Timpas formation is a paper-like shale, of medium- to dull-gray color. It contains an abundance of minute crystals of gypsum, of the selenite variety. Fish scales of considerable size occur throughout the formation.

Distribution.—The outcrop of the Timpas is a relatively broad band extending diagonally across the southwest corner of the quadrangle. Its eastern boundary is marked by a low ridge of hills capped with a thin layer of weathered yellow limestone; the middle shaly portion forms an undulating plain; and the massive basal limestones give rise to bold cliffs overhanging the softer Carlile shales.

APISHAPA FORMATION.

Character and thickness.—The Apishapa formation—the upper division of the Niobrara group—is composed mainly of dark- to light-gray sandy shales, interrupted at intervals by dull-gray to cream-colored calcareous shales and impure limestone. The most persistent of these calcareous beds are found at the top of the formation, where a series of alternating layers of yellow limestone and light bluish-gray shale reaches a thickness of 10 to 20 feet. The formation has a total thickness of 425 to 450 feet. The lowest 50 feet is composed of a dark, fissile shale, followed by about 100 feet of a somewhat decayed papery shale of slightly darker shade. The shale of the central portion of the formation is generally arenaceous, and in places, owing to its increased hardness, has resisted erosion sufficiently to form low escarpments. None of these, however, occur within the limits of this quadrangle. This sandy shale contains tracks of small crustaceans, and fish scales abound in it as elsewhere in the formation. The upper portion of the Apishapa, comprising about 100 feet of sediment, is a dark bluish-gray, fissile shale containing two and in some places three horizons of cream-colored limestone, the uppermost marking the top of the formation. There is also near the top a horizon of limestone lenses varying in size from 1 to 20 feet and arranged parallel to the bedding plane. These lenses are ramified by cracks filled with pale-blue crystals of barite. Along the south side of Chicosa Creek, north of Hungerford Lake, these limestone lenses have protected the underlying softer shale from erosion in such a manner as to give rise to low rounded mounds or hills, forming a conspicuous feature of the topography.

Distribution.—The outcrop of the Apishapa is a broad band extending from east to west across the southern part of the quadrangle and comprising about one-fourth of its entire area. It has a simple boundary on the north, but a more complex one on the south. The shale mass, constituting the greater part of this formation, appears in the landscape as a gently undulating plain, interrupted here and there by a low prominence capped by a remnant of Nussbaum sandstone. The upper limestone is seen within the limits of this quadrangle only on Sixmile Creek at the northern boundary of the formation and on the Rocky Ford Highland canal 2 miles south of Fowler.

PIERRE SHALE.

Thickness and character.—The Pierre is the highest formation of the Cretaceous period which occurs within the quadrangle. It has a thickness of about 2300 feet. The lowest portion, 400 to 500 feet thick, is composed of a black, shaly series, somewhat yellow at the base, which has been called the "barren zone" on account of the absence of fossil remains. Above this zone are about 500 feet of dark-gray shale characterized by bands of concretions composed chiefly of iron and lime carbonate. These concretions are a dark bluish gray when newly exposed, but weather to rust color. They vary in size from a few inches to 2 feet, and where they outcrop broken, angular fragments are strewn over the surface in great abundance. Above this is a deposit 100 to 200 feet thick of a somewhat lighter gray shale which contains many specimens of the marine shell known as baculite. This shell varies from one-half to 1 inch in diameter and is 4 to 5 inches long. Next above is a shaly series known as the "tepee zone," a name suggested by the tepee-shaped hills which it exhibits. This zone has a total thickness of 500 feet or less. It is composed mainly of light-gray shales containing bands of concretions and large bodies of gray limestone known as "tepee cores." The concretions are composed of calcium carbonate, oval in shape and ranging in size from a few inches to 6 feet. They are very fossiliferous. The tepee cores vary in diameter from 10 to 30 feet, are irregular in shape, and have a vertical extension of at least 50 feet. While they are generally roughly cylindrical, one case was noted where the core apparently tapered downward like an inverted cone, and in other localities there is evidence that some are of lenticular shape. These tepee buttes have been studied jointly by Messrs. G. K. Gilbert and E. P. Gulliver and their description of the tepee rock is here given:

> The tepee rock is essentially a calcium carbonate, the ratio of calcium carbonate to magnesium carbonate being 18 to 1 in the single sample analyzed. That sample contained also 12 per cent of argillaceous material. For comparative purposes analyses were also made of the inclosing shale and of one of the ordinary concretions of the shale, the determinations showing that the tepee rock does not differ materially in composition from the concretions and that the argillaceous material is practically identical with the shale. This permits us to regard the argillaceous material as included shale, and therefore an impurity rather than an essential constituent of the tepee rock.
>
> The rock is of coarse texture, breaks with rough fracture, and its general color is a light, warm gray. It is full of fossil shells, and the microscope shows that they are embedded in a matrix which is composed of fragments of shell, waterworn grains of calcite, foraminifera, and clay. Cross sections of *Lucina* shells show that the original shell structure remains, although the lime of the shell has been recrystallized into calcite. Inside of the shell wall there is a band of radiating crystals of calcite, showing well-marked spherulitic structure. The calcareous ooze which must have at first occupied the central cavity of the shell has recrystallized into very pure calcite, leaving the clay impurites at one side of the shell. This central calcite crystal is the same individual which has replaced the lime of the shell, for the two parts extinguish together, the cleavage cracks extend from the center through the outside, and when the spherulitic band is faulted the clear calcite is continuous through the cracks. Experiments showed the spherulitic layer to be slightly less soluble in dilute hydrochloric acid than the clearer calcite.

An analysis of a typical sample of tepee rock, made by Dr. W. F. Hillebrand (Gilbert, G. K., Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897), is as follows:

Analysis of limestone in "tepee core."

Silica (SiO_2)	7.46
Titanium dioxide (TiO_2) Alumina (Al_2O_3)	1.78
Iron sesquioxide (Fe_2O_3)	.94
Lime (CaO)	46.98
Magnesia (MgO)	2.36
Potash (K_2O) Soda (Na_2O)	.37
Phosphoric oxide (P_2O_5)	Undetermined.
Carbon dioxide (CO_2)	39.25
Water lost at 100° C.	.16
Water lost above 100° C. Organic material	.70
	100.00

The limestone constituting these "tepee cores" bears a marine fauna. *Lucina occidentalis* is the most abundant molluscan species, forming a leading constituent of the rock. *Inoceramus* is rather common and cephalopods occur in considerable variety. Foraminiferal forms are frequently seen under the microscope. The occurrence of fossil wood has also been reported from some of the cores. The following is a list of the molluscan species determined by Mr. T. W. Stanton, from specimens collected by Mr. Gilbert:

Ostrea inornata M. and H.
Inoceramus crispii var. barabini Morton.
Inoceramus vanuxemi M. and H.
Inoceramus sagensis Owen.
Lucina occidentalis var. ventricosa M. and H.
Thetis circularis M. and H.
Anchura (Drepanochilus) americana E. and S.
Nautilus dekayi Morton.
Baculites ovatus Say.
Baculites compressus Say.
Scaphites nodosus Owen (?).
Scaphites nodosus var. quadrangularis M. and H.
Scaphites nodosus var. brevis Meek.
Ptychoceras crassum Whitfield.
Heteroceras (Exiteloceras) cheyennense M. and H.
Heteroceras (Didymoceras) nebrascense M. and H.
Heteroceras (Didymoceras) cochleatum M. and H.
Heteroceras sp. undet.
Helicoceras sp. undet.

The remainder of the Pierre shale, as found in this quadrangle, consists of a series of lighter gray sandy shales containing concretionary bands, with an aggregate thickness of about 600 feet.

Distribution.—The Pierre shale occupies a broad band, narrowing to the east, extending from northwest to southeast across the quadrangle along the general course of Arkansas River. On the south its outline is relatively simple, with one outlying portion at the western margin of the quadrangle, near the head of a large branch of Sixmile Creek; but on the north the boundary is very irregular, being determined by the overlapping of the Nussbaum formation. The shale yields readily to erosion and the slopes of the larger areas are traversed by numerous ravines.

TERTIARY SYSTEM.

NUSSBAUM FORMATION.

Distribution.—The Nussbaum formation has the greatest surface extent of any deposit within the limits of the quadrangle, occupying the greater part of the northern half. Its main portion extends from Chico Creek eastward to the boundary of the quadrangle, and several large detached areas are found west of Chico Creek. It is the highland formation south of Vineland and Avondale and it caps the Hooker Hills on the opposite side of Huerfano River. The district lying to the south and east of Arkansas and Huerfano rivers contains many small isolated areas of Nussbaum, especially in the region of Erdman Lake, along Chicosa Creek and its tributaries, between Hungerford Lake and the southern margin of the quadrangle, and along Apishapa River. There is also a remnant of the formation on the south side of the Huerfano about 4 miles south of Undercliff.

Thickness and character.—The formation rarely exceeds 60 feet in thickness. It consists of gravel, sands, and silt, with very little clay. The sand and gravels at the base are often bound together by a calcareous cement, forming sandstone and conglomerate of considerable firmness. The formation lies unconformably upon the underlying Cretaceous rock and is of river origin, as is indicated by the coarseness of the material and the general direction of the slope of the mesas.

QUATERNARY SYSTEM.

TERRACE DEPOSITS.

Age and distribution.—The terrace deposits of this quadrangle represent two epochs of Quaternary time. In most places the boundaries of the earlier and later deposits can be easily delineated and in mapping distinct patterns have been used. The materials composing these two terraces are much the same and the basis of their classification is largely topographic. The earlier terrace caps a number of small flat-topped hills bordering the south side of Arkansas River Valley between St. Charles and Huerfano rivers. A few smaller areas are also found in the vicinity of Erdman Lake. The later terrace occupies a strip from 2 to 3 miles wide on the south side of Arkansas River, extending across the entire quadrangle and forming its most fertile agricultural district. There are also less extensive terraces along the Huerfano from the vicinity of Undercliff to its mouth. On the north side of the Arkansas, from Boone to the eastern margin of the quadrangle, terrace remnants cap some of the more prominent ridges; and a few small areas occur on the east side of Chico Creek, in the vicinity of the Skinner and Tabor and the Tolle ranches.

Character and thickness.—The chief components of the terrace deposits are gravel and sand in varying proportions, the whole having an aggregate thickness of about 30 feet, but in places the earlier terrace is somewhat thicker. At the base the material is locally cemented by lime, forming conglomeratic sandstone, a notable feature of the earlier terraces. The gravels of the later terraces are smoothly spread and slope gently toward the river, terminating abruptly in low cliffs. While the materials composing the earlier and later terrace deposits are much the same, the former exhibits a slightly wider range of rocks. The deposits along Huerfano River, Chico Creek, and on the north side of Arkansas River rarely exceed 15 feet in thickness, but in composition they show no material difference from those of the larger terraces.

ALLUVIAL DEPOSITS.

Distribution and character.—The alluvial deposits of this area are confined mainly to Arkansas River and its principal tributary, the Huerfano. A relatively narrow strip occurs along the St. Charles and at the mouths of Chico and Chicosa creeks. The alluvium of Arkansas River has a fairly uniform width of 1 to 1½ miles, continuing across the entire area. Through this flat the river pursues a meandering course, generally adhering to the south bank. The deposit consists of a light-colored, fine-grained sand with varying proportions of clay and decayed vegetable matter. Its total thickness is 20 to 25 feet. The alluvium of Huerfano River extends from the Ben Butler ranch to its junction with the Arkansas. It rarely exceeds one-half mile in width. Along St. Charles River the alluvial flat is very narrow. It continues from the western margin of the quadrangle to its mouth, a distance of 4 or 5 miles.

DUNE SANDS.

Distribution.—Extensive accumulations of dune sands derived from the sandy Tertiary beds to the north cover an area reaching from the northern margin of the quadrangle to a point about 5 miles northeast of Boone. Other smaller areas are found along the eastern margin, on the highlands between Haynes and Chico creeks, and on the gravelly terrace southeast of Boone.

Character and age.—The sands are of recent origin and in many places are still loose and travel before the winds. Throughout the southern half of the large sand-hill district north of Boone the entire surface is a system of hills and hollows with practically no drainage by streams. The dunes are 30 to 40 feet high and they lie with their greater diameters from northwest to southeast, which is the direction of the prevailing winds. Farther north the sand has been blown about by the wind to some extent, but not formed into distinct dunes, and this area has a well-defined drainage. West of Langford ranch and along the eastern margin of the quadrangle the sand hills are low and inconspicuous, rising only a few feet above the level of the plains. In the area southeast of Boone the sands are derived from the terrace deposits.

STRUCTURE.

The general structure of the Cretaceous rocks of the Nepesta quadrangle is indicated in fig. 1, which

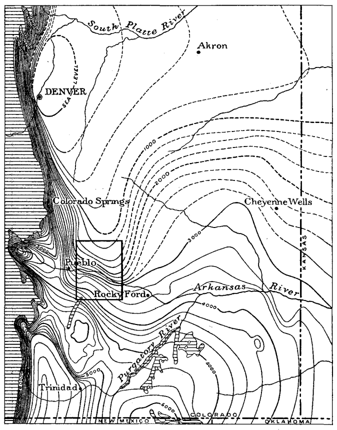


FIG. 1.—Diagram showing structure of Dakota sandstone in eastern Colorado.

Contours show elevation above sea level of the top of the Dakota sandstone at intervals of 250 feet vertically. Ruled pattern represents area where Dakota sandstone is absent. The location of the Nepesta quadrangle is indicated by the heavy rectangle.

shows the configuration of the Dakota sandstone in the surrounding portions of the Great Plains. Over all except the southwestern portion of the area the beds have a slight northeastward inclination, as illustrated in the structure section on the artesian water sheet. A broad dome with a general southeast-northwest trend crosses the Apishapa and Walsenburg quadrangles, which lie to the south and southwest respectively. Extending from this dome in a northerly direction, a low anticline crosses the extreme southwest corner of the Nepesta quadrangle, giving rise in that region to a perceptible increase in the dips. There is also a low, flat arch, with a corresponding trough on the west passing through East Pueblo, which enters the Nepesta quadrangle about 1½ miles south of St. Charles River, but extends only a short distance inside the limits. In the southwest corner of the quadrangle the Cretaceous strata exhibit many waves and small faults. These could not be traced, owing to superficial covering, but they probably prevail throughout the general region. Deformation by the intrusion of igneous rocks has not occurred within the quadrangle, so far as could be ascertained.

HISTORICAL GEOLOGY.

SEDIMENTARY RECORD.

The rocks occupying the surface in the western part of the central Great Plains are of sedimentary origin. They consist of sandstone, shale, limestone, sand, gravel, and loam, and present considerable variety in composition and appearance. They were originally sand, gravel, and calcareous mud, derived from the erosion of ancient land surfaces or chemical precipitates from sea waters.

These rocks afford a record of physical changes which have taken place from near the beginning of Cambrian time to the present, but owing to the lack of knowledge of the relations of some of the deeply buried rocks only a general outline of the sequence of events can be offered. One significant feature is that some of the conditions were widespread, for there is remarkable uniformity in the resulting products. There were undoubtedly many marine submergences and several periods of emergence in which the surface was sculptured by running waters, especially in the later epochs.

Cretaceous seas.—In the Nepesta quadrangle the geologic record begins with sediments characteristic of shallow seas along a coastal plain which alternately rose and sank, but the general movement of which was one of subsidence. These coastal deposits, of which the Dakota sandstone is the oldest representative outcropping in the quadrangle, consist mainly of coarse, pebbly sandstone laid down by strong currents in beds 25 to 30 feet thick. At the close of the Dakota deposition marine conditions were established over wide areas and continued until near the end of the Cretaceous period. During the middle of Benton time there was a change in conditions, resulting in the deposition of the Greenhorn limestone. The close of this epoch is marked by a layer of light-brown sandstone. The shales of the Benton group were followed by a series of limestones and shales, the latter predominating, now known as the Niobrara group. A marked episode at the beginning of Niobrara time was that which resulted in the deposition of the massive limestones which now constitute the base of the Timpas formation. At the close of this epoch several thin layers of limestone were deposited, and these were followed by over 2000 feet of Pierre shale laid down under uniform conditions.

The retreat of the Cretaceous seas marks the Fox Hills epoch. During this time extensive sheets of sand were deposited on the underlying clays, forming a basis for the accumulation, in shallow water and swamps, of the sediments of the succeeding Laramie epoch. Whether or not these two last-named formations were deposited over the area occupied by the Nepesta quadrangle is not definitely known, but it is probable that they were and that attenuated representatives still exist between the Pierre and Nussbaum formations in the northern part of the quadrangle. To the west, in the vicinity of Florence, the Laramie reaches a considerable thickness and to the northeast and southwest Fox Hills, Laramie, and later deposits occur in thick masses.

Early Tertiary conditions.—At the close of the Cretaceous period the Nepesta quadrangle was raised above the water, and an epoch of great mountain growth ensued. The disturbances, however, which accompanied this epoch elsewhere were here manifested only by a general uplift, except in the southwest corner of the area, where local folding of the strata took place. During the early part of the Tertiary period this quadrangle was being gradually uplifted and rapidly eroded, so that large portions of the various formations were removed. This uplift and erosion were accompanied by local interruptions, one of which, occurring in late Tertiary time, has had an important bearing on the history of the district. At this time river deposits accumulated on the plains opposite the Arkansas embayment, owing to elevation to the east, which decreased the gradient of the Arkansas and its more important tributaries and rendered these streams incapable of disposing of their sediments. As a result an extensive but relatively thin deposit of sand and gravel, known as the Nussbaum formation, accumulated on the eroded surfaces of the older formations over the greater part of the quadrangle. Subsequent erosion, stimulated by change of level and increase of slope, has removed much of the deposit in the southern half of this area.

ECONOMIC GEOLOGY.

SOILS.

Character and distribution.—The soils of the Nepesta quadrangle include several different varieties, some of which are exceptionally fertile. Over a great portion of the area they are closely related to the underlying rocks, of which they are in part residual products. The exceptions are along the larger valleys, where the soils have formed from alluvial deposits.

The bottom land immediately bordering the streams consists of a rich, dark loam overlying a deposit of light-colored sandy clay containing alternating layers of gravel. Below this, resting on the bed rock, is a layer of coarse gravel of variable thickness which affords a local water supply. Bordering this bottom land in some places, especially along Arkansas and Huerfano rivers, is a loess-like sandy loam several feet deep, which is well adapted to agriculture when watered. The most productive soil of the quadrangle is on the terraces bordering the Arkansas and its more important tributaries. It is of a sandy character, but contains a sufficient amount of clay to make it coherent when moistened. It varies from 1 to 6 feet in thickness, the maximum being reached at the outer portion of the mesa, adjacent to the base of the older terrace. Along its inner border is a strip of gravelly soil, varying in width from one-eighth to one-fourth of a mile, which is too stony for agricultural purposes. These terraces also contain small areas of very sandy soil, especially where the intermittent streams of the adjoining highland traverse them. In some localities the material is sufficiently incoherent to be moved about by the wind, forming low hills of dune sand.

The soil of the Nussbaum upland is prevailingly sandy, but sufficiently rich to support a strong growth of various kinds of plateau grasses with a small amount of moisture. In the sand-hill area the soil is very loose and unfit for cultivation, though it supports a vigorous growth of nutritious grasses.

The soil resulting from the disintegration of the Pierre shale, which is essentially a clay formation, is stiff and "gumbo"-like, highly acid on account of decomposing pyrites, and generally not well adapted to cultivation. There are, however, a few open valleys, notably those along Andy Creek and some of the larger tributaries of Chico Creek, in which there are overplaced soils of marked fertility. Similar deposits, but of limited extent, border Haynes and Kramer creeks.

The Niobrara beds, which occupy the uplands south of Arkansas River, have soils of clayey character, containing sufficient limy material mixed with the sand to give fertility. However, over a great part of this region there is no water available for irrigation and hence farming is not pursued. A notable exception to this is the district under the Huerfano Valley ditch, where considerable farming is done by irrigation from flood waters.

The Carlile outcrop within the quadrangle is very limited in extent and usually consists of steep, barren slopes. There is, however, a small tract of productive valley land along Huerfano River just below the Ben Butler ranch. The Graneros shales furnish a narrow strip of tillable land along the Huerfano.

The Dakota sandstone, covering about 2 square miles in the extreme southwest corner of the quadrangle, is only partly covered by a scanty soil.

Agriculture.—The general aridity of the climate renders tillage without irrigation impracticable, except in a few low-lying areas adjacent to the principal streams. Agriculture at present is restricted to the valley land and the adjoining gravelly mesas. The cultivated portions comprise about one-eighth of the total area, the remainder being utilized for pasturage of cattle, an important industry of the region to which the upland areas are well adapted. Among the chief products are oats, corn, wheat, sugar beets, potatoes, Mexican beans, and a variety of garden vegetables, most of which are marketed at Pueblo. The largest and most profitable crops are alfalfa and melons. The alfalfa is consumed in the region, while the melons, especially the cantaloupes, owing to their superior quality, find a ready sale in the best markets of the United States. Fruit raising is a growing industry and many large, well-kept orchards are to be found in the irrigated districts. Cherries, plums, and other small fruits have a hardy growth and abundant yield, but the apple crop is as yet usually a failure owing to an insect which attacks the fruit in its advanced stages. The seasons are ordinarily of sufficient length to insure the maturing of all cultivated crops.

WATER RESOURCES.

The underground waters of the Nepesta quadrangle are of two general classes, ground and artesian. The former is the chief source of supply for domestic purposes throughout the area, but as it usually contains much "alkali" there is great need of artesian water.

GROUND WATER.

The ground waters of the area are confined chiefly to the alluvial sands and gravels bordering the Arkansas and its larger tributaries. Some of the intermittent streams of the upland region, such as Chicosa, Haynes, and Kramer creeks, carry a small underflow, which is often sufficient to supply domestic wells. The gravelly terraces contain considerable water derived by seepage from irrigation ditches. As the conditions governing these sources of ground-water supply are for the most part variable, the amount of water is by no means constant. When the annual precipitation is low there is a perceptible decrease in the underflow of the intermittent streams. During the late summer and fall months, when the irrigation canals carry the minimum amount of water, there is also less water in wells adjacent to these ditches, owing to a lowering of the water plane. The seepage from the ditches is constantly leaching out the soluble salts contained in the clays of the terrace gravel and the shales upon which they lie, as is proved by the character of the water in the marginal springs issuing from these terraces. This leaching process has been more effective in some places than in others, and the water in certain wells has improved in quality as irrigation progressed, while in others it has apparently become more highly mineralized.

Wells drawing their supply from the underflow of the Arkansas River Valley are more or less affected in quality and quantity by the amount of water in the river. During flood times there is a lateral underflow from the stream to the alluvial flats, and, as the river water at such times contains an abundance of "alkali" washed from the adjoining highlands, the well water of the valley soon becomes highly charged with objectionable salts.

The Nussbaum formation, which covers the surface over much of the area north of Arkansas River, contains the only good ground water found in the quadrangle. Along the western and southern boundaries of the Nussbaum plateau, from the Skinner and Tabor ranch to the vicinity of Fowler, there are numerous springs at the base of the Nussbaum formation. These have a small flow of comparatively pure water. The gathering ground of these springs is the Nussbaum plateau, which extends far to the north. On this plateau several trial wells have been sunk, but, with a few exceptions, little water was obtained.

The water supply for the town of Fowler is furnished by a number of these small springs on the north side of the river. The water is first collected by porous tiling laid along the sides of the smaller ravines which head in the plateau. This tiling delivers the water into pipes leading to a storage reservoir situated in the Nussbaum bluffs. From here the water is piped to Fowler, a distance of about 2 miles. The springs in the bluffs near Nepesta, Boone, and Nyburg could be similarly utilized. The following analysis of the Fowler water was made in the laboratory of the Atchison, Topeka and Santa Fe Railway:

Analysis of spring water at Fowler, Colo.

	Grains per gallon.	Parts per million.
Organic material	1.983	34
Silica	.991	17
Calcium carbonate	2.500	43
Magnesium carbonate	1.470	24
Sodium carbonate	8.260	141
Sodium chloride	3.750	64
Sodium sulphate	9.190	157
	28.144	480

ARTESIAN WATER.

Source.—In the Nepesta quadrangle, as elsewhere throughout the central Great Plains region, the Dakota sandstone is the principal artesian-water bearer. It is present throughout the entire area included in this quadrangle. From the extreme southwest corner, where it disappears underground, the sandstone descends uniformly toward the east. The only known irregularities in this inclined plane are a low anticlinal fold entering the quadrangle from the northwest at a point due west of Huerfano Lake, and a small arch from the south, crossing the boundary about 4 miles east of the Ben Butler ranch. These folds do not extend far inside the Nepesta quadrangle, as will be seen by reference to fig. 1, which shows the configuration of the Dakota sandstone. The gathering grounds of the artesian water lie to the west and southwest, where this sandstone is extensively exposed in the form of hogback ridges and broad anticlinal folds. Throughout these areas of outcrops the water is received by imbibition from rain and streams, and descends within the porous sandstones, to which it is confined by the impervious shales of the marine Cretaceous. In the lowlands bordering Arkansas River to the east the water in the Dakota sandstone is under sufficient pressure to bring it to the surface when the formation is reached by well borings. The overlying formations have fairly uniform thicknesses, and as these thicknesses are known, it is possible to predict, with a considerable degree of certainty, the depth below the surface at which the Dakota is to be found. The water-bearing beds in this formation occur at various distances from its top in different localities. In the western part of the area the highest bed furnishing artesian water is encountered about 100 feet below the top of the formation, while to the east the uppermost member produces not only the strongest flow but often the best quality of water. The depth below the surface of the top of the Dakota sandstone is shown by the contours on the artesian water sheet. For instance, the 1000-foot artesian contour is drawn through all points where the top of the sandstone is 1000 feet below the surface. While these estimates are subject to some error, it is believed that they are sufficiently accurate to be of practical service. The facts set forth by these contours indicate that the Dakota sandstone lies at only a moderate depth below the surface in the southern half of the quadrangle, but that the depth increases to the northeast.

Head.—As above stated, the artesian water underlying the Nepesta quadrangle enters the Dakota formation on the high slopes to the west. These slopes, which may be regarded as the head of the artesian water, rise to altitudes ranging from 4000 to 5500 feet. Throughout the lower lands to the east the height to which water will rise in wells reaching the Dakota sandstone decreases toward the zone where the water is free to escape at the surface, which is in the vicinity of Lamar, Colo. If the physical conditions governing the storage and transmission of this water were uniform the rate of decrease from head to leak could be easily calculated, but as these conditions are variable a certain amount of local variation in the decrease of head must be expected. Along Arkansas Valley, from Pueblo to Rocky Ford, several wells have been sunk to the Dakota and artesian flows obtained. The pressure of these wells affords a means of estimating the total amount of decrease in head from one side to the other of the Nepesta quadrangle. By equally distributing this loss of head along lines connecting wells of known head at Fowler, Manzanola, and Rocky Ford with the lowest points of inflow of the Dakota outcrop to the west, the head for points intermediate has been computed. Through all points of equal head contours or head lines have been drawn, which are intended to illustrate the decrease in head from west to east. The contour interval is 100 feet. These lines of head afford a means of ascertaining the pressure of wells within the area of flow and the height to which water will rise in wells that do not flow. The depth below the surface at which water would stand in a well at any point outside the area of flow is equivalent to the difference in altitude of the head and the surface of the ground for the locality in question. The head lines also serve as a basis for the determination of the area where artesian flows might be expected. The territory of flowing wells within the Nepesta quadrangle is not large. It is confined to Arkansas River Valley and its principal tributaries from the south. Along the Huerfano it is limited to a very narrow strip, but in the vicinity of Chicosa Creek and Apishapa River it occupies broad bands which increase in width to the southern margin of the quadrangle.

Chemical properties.—The quality of the artesian water probably varies considerably within the boundaries of the area, as is suggested by a comparison of the analyses of the two deep wells at Pueblo, less than 2 miles apart:

Analysis of water from Fariss artesian well, Pueblo, Colo.

	Grains per gallon.	Parts per million.
Sodium chloride	2.42	41
Sodium sulphate	41.92	718
Calcium sulphate	3.43	59
Calcium carbonate	6.28	108
Magnesium carbonate	6.16	105
Ferrous carbonate	.91	16
Silica	.91	16
	62.03	1063

Analysis of water from well of Colorado Coal and Iron Company, Pueblo, Colo.

	Grains per gallon.	Parts per million.
Sodium chloride	1.82	31.0
Sodium sulphate	41.43	709.0
Potassium chloride	1.83	31.0
Calcium sulphate	16.94	290.0
Calcium carbonate	2.64	45.0
Magnesium carbonate	11.65	199.0
Ferrous carbonate	1.17	20.0
Silica	.55	9.4
	78.03	1334.4

A comparison of the various analyses of the Dakota waters along Arkansas River from Pueblo to Lamar, Colo., shows that their mineral contents include sulphates, carbonates, and chlorides, the sulphates being the most abundant. Sodium, calcium, magnesium, and potassium are the principal metals, their relative quantities being in the order named, while the kind and amount of salts, including sodium sulphate, magnesium sulphate, calcium carbonate, sodium carbonate, and sodium chloride, vary considerably in different wells.

Record of deep borings.—In the deep well on Andy Creek, which penetrates the Dakota 50 feet, the water rose 1000 feet. It is reported to be of good quality, but no analysis has been made. The material penetrated by this well is shown in the following record (fig. 2):

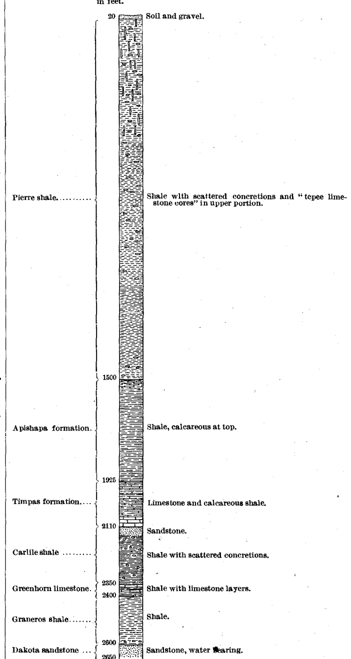


FIG. 2.—Section of deep well near mouth of Andy Creek.

This boring begins in the Pierre shale, 1500 feet above the base, passes through the basal Timpas limestone at 2000–2100 feet, and penetrates 450 feet of Benton shale before reaching the Dakota. If the boring had been continued farther into the Dakota it is probable that the water would have risen much higher in the well.

The deep boring near Boone is a dry hole, owing to the fact that the well was discontinued as soon as the Dakota sandstone was reached. The record of the well follows.

At this place the boring begins near the middle of the Pierre shale and passes through the Niobrara series from 1100 to 1750 feet, below which 460 feet of Benton are penetrated, containing the characteristic "talc" layer near the base.

Record of deep boring near Boone, Colo.

Formation.	Character.	Thickness.
		Feet.
	Soil	0–20
Pierre	Shale with concretion	20–1100
Apishapa	Shale, calcareous at top	1100–1525
Timpas	Shale with limestone in upper and lower parts	1525–1750
Carlile	Shale	1750–1950
Greenhorn	Limestone intercalated with shale	1950–2000
Graneros	Shale	2000–2200
Dakota	Sandstone.	

An artesian well a short distance east of Fowler, on the Atchison, Topeka and Santa Fe Railway, has a flow of soft water from the upper sandstone of the Dakota. The following beds were penetrated:

Record of artesian well near Fowler, Colo.

	Feet.
Surface materials	0–40
Shale	40–825
Limestone	825–1270
First Dakota sandstone	1270–1372

The boring begins near the base of the Pierre shale and passes through the Apishapa and Timpas formations, the characteristic limestones of the latter being penetrated at 825 to 875 feet. Below this are 395 feet of Benton beds overlying the Dakota sandstone.

IRRIGATION.

The annual rainfall of the quadrangle is so small that all successful farming must depend on irrigation. The principal source of water supply is Arkansas River, but the demands on this stream throughout its course are so great that the amount to which this area is entitled is inadequate to supply the present needs, and recourse is had to flood water along some of the principal tributaries and small intermittent streams. About 37,000 acres of irrigated land are supplied with water from five large canals—the Bessemer, Rocky Ford Highland, Fowler, Excelsior, and Huerfano Valley ditches. All except the last named obtain water from Arkansas River. In addition to the above there is a considerable acreage of lowland watered by private ditches. The Bessemer ditch furnishes water for a district comprising about 20,000 acres in the vicinity of Vineland and Avondale. The waters are diverted from the Arkansas about 10 miles west of Pueblo through a substantially built stone headgate. The main ditch is 30 feet wide on top and 8 feet at the bottom and has a carrying capacity of 400 cubic feet of water per second.

The region about Fowler is included under the Rocky Ford Highland and Fowler ditches. The former begins near the mouth of the Huerfano and supplies water for about 25,000 acres, most of which is outside of the quadrangle. It is stated that the ditch is entitled to 464 cubic feet of water per second. The Fowler ditch is relatively small, with a water right of only 116 second-feet. Its waters are diverted from the Arkansas above Nepesta.

The Excelsior ditch is taken out of the Arkansas nearly opposite the mouth of the St. Charles and extends about 7 miles down the river. This is one of the oldest canals on the river, but carries a relatively small amount of water. Bob Creek and Otero ditches have their head-gates within the quadrangle, but supply no water to it. The Huerfano Valley ditch is dependent on Huerfano River for its water supply, and as the flow of this stream is intermittent it is necessary to store the water.

In the southeastern part of the quadrangle there are several natural storage reservoirs, of which the most important are Hungerford and Erdman lakes. At present the latter is being converted into a reservoir where a part of the flood waters of Chicosa Creek are to be stored. There are also a few small lakes near Langford ranch, on the head of Haynes Creek, but here the general conditions for water storage are not so favorable.

At Carpenter Spring there is a tract of land supplied with water from a number of small springs situated along the side of the valley. Other areas are similarly irrigated on the north side of Chico

Creek, from the Skinner and Tabor ranch to the northern margin of the quadrangle.

MINERAL RESOURCES.

SANDSTONE.

Dakota sandstone.—There are two formations in the quadrangle which afford sandstone suitable for building purposes. That of the Dakota formation is the more valuable for general structural use. The best quality of this rock occurs in the upper 100 to 150 feet of the formation. It is of a light-gray color, fine grain, and uniform texture, and possesses remarkable firmness and durability. It has been used only to a limited extent in this district, the principal building material being sun-dried brick, a product which in this semiarid climate is very durable.

Carlile sandstone.—A thin layer of sandstone near the top of the Carlile formation has been used to some extent as a building stone. In the vicinity of Pueblo, a short distance to the west of this quadrangle, a stratum of this deposit is quarried for flagging. The rock shades from yellow to light brown in color, is of uniform texture, and moderately soft. It occurs immediately beneath the massive limestone of the Timpas formation. In many places it is somewhat inaccessible, and, as it is limited in amount, it can not be regarded as an especially valuable economic resource.

LIMESTONE.

The chief source of limestone within the quadrangle is the Timpas formation, though a small amount is used from the Greenhorn and Apishapa beds. The Timpas limestone occurs near the base of the formation. It is in layers 6 to 12 inches thick, constituting a series of beds 50 feet in thickness. The rock is dull gray, but weathers to cream color. It is compact, hard, and much of it satisfactory for constructional purposes. Its principal uses are for burning to lime and fluxing. In the vicinity of Pueblo this rock is extensively quarried to supply the smelters. The following analysis of the limestone was made at the Pueblo Smelting Company's laboratory (Geologic Atlas U. S., folio 36, 1897):

Analysis of Timpas limestone.

Silica (SiO_2)	6.4
Alumina (Al_2O_3)	1.3
Iron sesquioxide (Fe_2O_3)	2.1
Lime (CaO)	50.4
Magnesia (MgO)	Trace.
Carbon dioxide (CO_2)	39.5
	99.7

FIRE CLAY.

A fire clay occurring about 150 feet below the top of the Dakota sandstone is said to be of good quality. Numerous samples of the material have been burned with satisfactory results. This clay is not exposed in the Nepesta quadrangle, but could be reached by shafts from 100 to 150 feet deep anywhere within the Dakota outcrop. The clay varies somewhat in composition, but the following analysis may be regarded as representative. It was made in the chemical laboratory of the United States Geological Survey by Mr. George Steiger (Geologic Atlas U. S., folio 36, 1897):

Analysis of fire clay below Dakota sandstone.

Silica (SiO_2)	76.56
Titanium dioxide (TiO_2)	.60
Alumina (Al_2O_3)	8.30
Iron sesquioxide (Fe_2O_3)	.38
Lime (CaO)	.12
Magnesia (MgO)	.24
Potash (K_2O)	Trace.
Soda (Na_2O)	Trace.
Phosphoric oxide (P_2O_5)	.06
Water lost at 100°C	1.26
Water lost above 100°C	4.40
Organic material	8.31
	100.23

PORTLAND CEMENT.

Various attempts have been made in this general region to utilize certain rocks in the manufacture of Portland cement, but generally without success. Argillaceous limestone concretions occurring at various horizons throughout the Pierre shale have been tested with this object in view. A series of limy shales found just above the massive limestones of the Timpas formation have also been suggested as suitable material for this purpose, if proper limestone can be found to complete the mixture. The following analysis of the Timpas shales was made in the laboratory of the United States Geological Survey by Mr. George Steiger (Geologic Atlas U. S., folio 36, 1897):

Analysis of Timpas shales.

Silica (SiO_2)	45.89
Titanium dioxide (TiO_2)	.52
Alumina (Al_2O_3)	13.24
Iron sesquioxide (Fe_2O_3)	3.88
Lime (CaO)	12.09
Magnesia (MgO)	2.12
Potash (K_2O)	2.31
Soda (Na_2O)	.47
Phosphoric oxide (P_2O_5)	.17
Carbon dioxide (CO_2)	10.38
Water lost at 100°C	1.38
Water lost above 100°C	4.16
Organic material	3.47
	100.08

IRON ORES.

The "Rusty zone" of the Pierre, shale lying above the so-called "Barren zone," contains many bands of calcium-carbonate and iron-carbonate concretions varying in size from 6 inches to a foot. The horizon is well exposed on the gradual slopes between Arkansas River Valley and the base of the high Nussbaum plateau to the north. At one time the iron-carbonate concretions were collected by local miners and hauled to Pueblo, where they were used in combination with other ores in the manufacture of steel. The ore is said to be of good quality for a carbonate, but the manner of its occurrence prevents extensive operation.

PETROLEUM AND GAS.

Considerable prospecting for oil has been done during the last year in the Pierre shale area north of Arkansas River. Two deep wells were sunk by the Skinner & Tabor Cattle Company on their ranch northeast of Pueblo. The deeper of these wells, located near the mouth of Andy Creek, was sunk to a depth of 2600 feet, passing through the Pierre and Benton shales into the Dakota without obtaining oil. The other, which is about 10 miles northeast of Pueblo, penetrated the Pierre and Benton formations to a depth of 1900 feet and was equally unsuccessful in finding oil. At a depth of 800 feet, about 400 feet above the base of the Pierre shale, gas was discovered, but not in paying quantities. In 1903 a deep boring was made in search of oil on Haynes Creek 2 miles north of Boone. Here the Dakota was reached at a depth of 2200 feet and the project was abandoned. It is very doubtful if either petroleum or gas occurs in paying quantities within the limits of this quadrangle.

GRAVEL.

The later Quaternary gravels along the south side of Arkansas River have been used extensively as railroad ballast during the last decade. The gravel about 2 miles west of Fowler, on the Atchison, Topeka and Santa Fe Railway, is especially well suited for this purpose. The material is composed of medium-sized pebbles of quartz, quartzite, and various kinds of igneous rock. Its chief value as a ballast material is due to the uniform size and subangular shape of the pebbles and the small percentage of sand associated with them.

BARITE.

In the upper part of the Apishapa formation is a zone of large limestone lenses. Within these lenses occur cavities in the form of ramifying cracks, which have been partly or wholly filled by pale-blue barite crystals. Outcrops of these limestone lenses were observed in two localities only, in the vicinity of Hooker Hills and on the east side of Chicosa Creek about 3 miles west of Fowler. In the latter locality barite crystals have been collected to some extent, but are not of economic importance.

FUEL.

There are no coal-bearing formations within the limits of the quadrangle. The chief supply of firewood is found in the extreme southwest corner, in the exposed area of the basal Timpas, Greenhorn, and Dakota formations, where there is a sparse growth of piñon.

April, 1905.

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

TOPOGRAPHY

COLORADO
NEPESTA QUADRANGLE

A. H. Thompson, Geographer.
Willard D. Johnson, Topographer in charge.
Topography and triangulation by J. W. Hays.
Surveyed in 1889.
Partially revised by Frank Tweedy in 1894
and Fred Mc. Laughlin in 1903.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

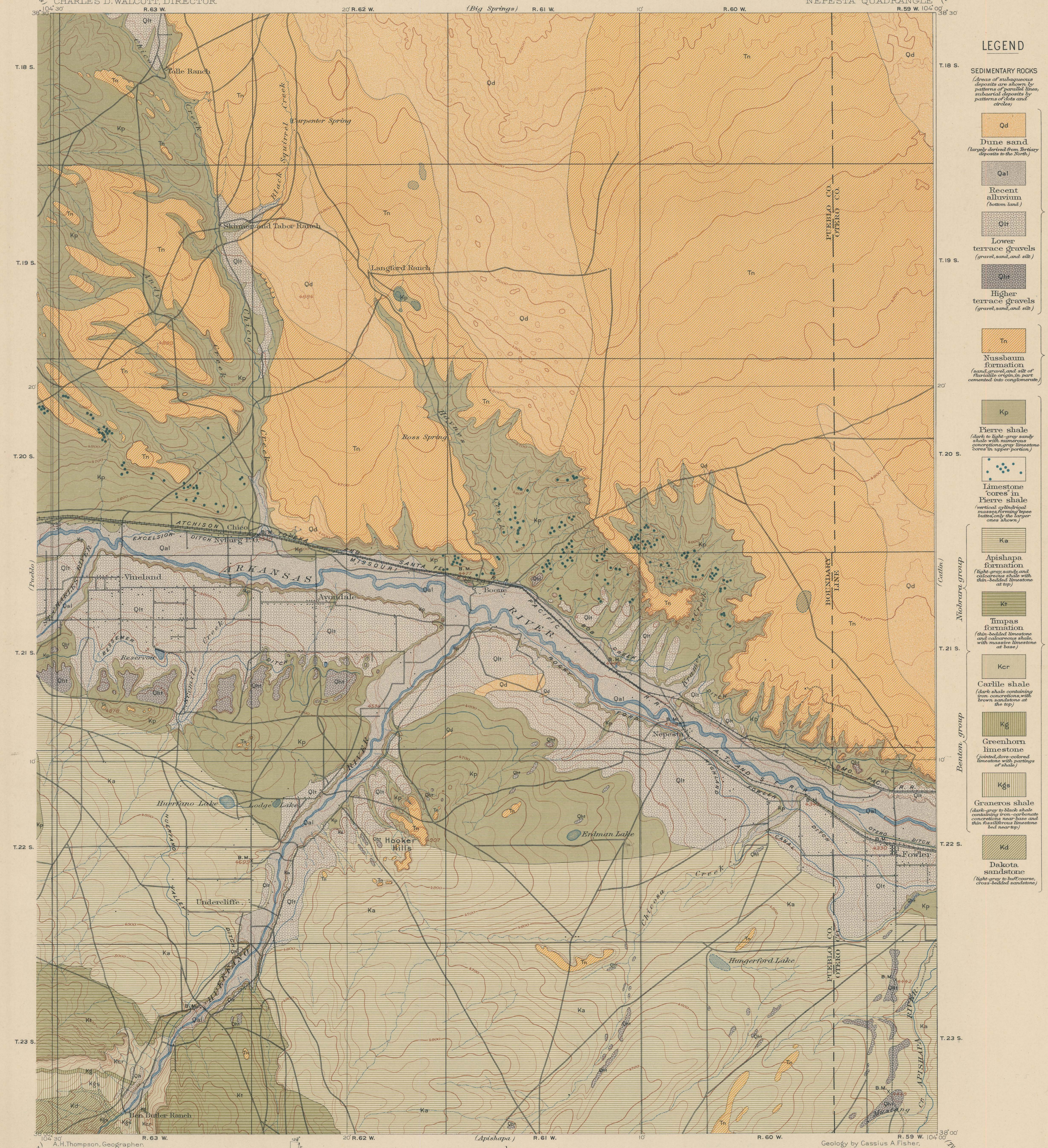
Contour interval 25 feet.
Datum is mean sea level.
Projection based on U.S.C. and G. Survey data of 1900.
Projection of Pueblo and Apishapa sheets based on earlier data.

Edition of Nov. 1904, reprinted Jan. 1906.

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

AREAL GEOLOGY

COLORADO
NEPESTA QUADRANGLE



A. H. Thompson, Geographer.
Willard D. Johnson, Topographer in charge.
Topography and triangulation by J. W. Hays.
Surveyed in 1889.
Partially revised by Frank Tweedy in 1894
and Fred Mc Laughlin in 1903.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 25 feet.

Datum is mean sea level.
Projection based on U.S.C. and G. Survey data of 1900.
Projection of Pueblo and Apishapa sheets based on earlier data.

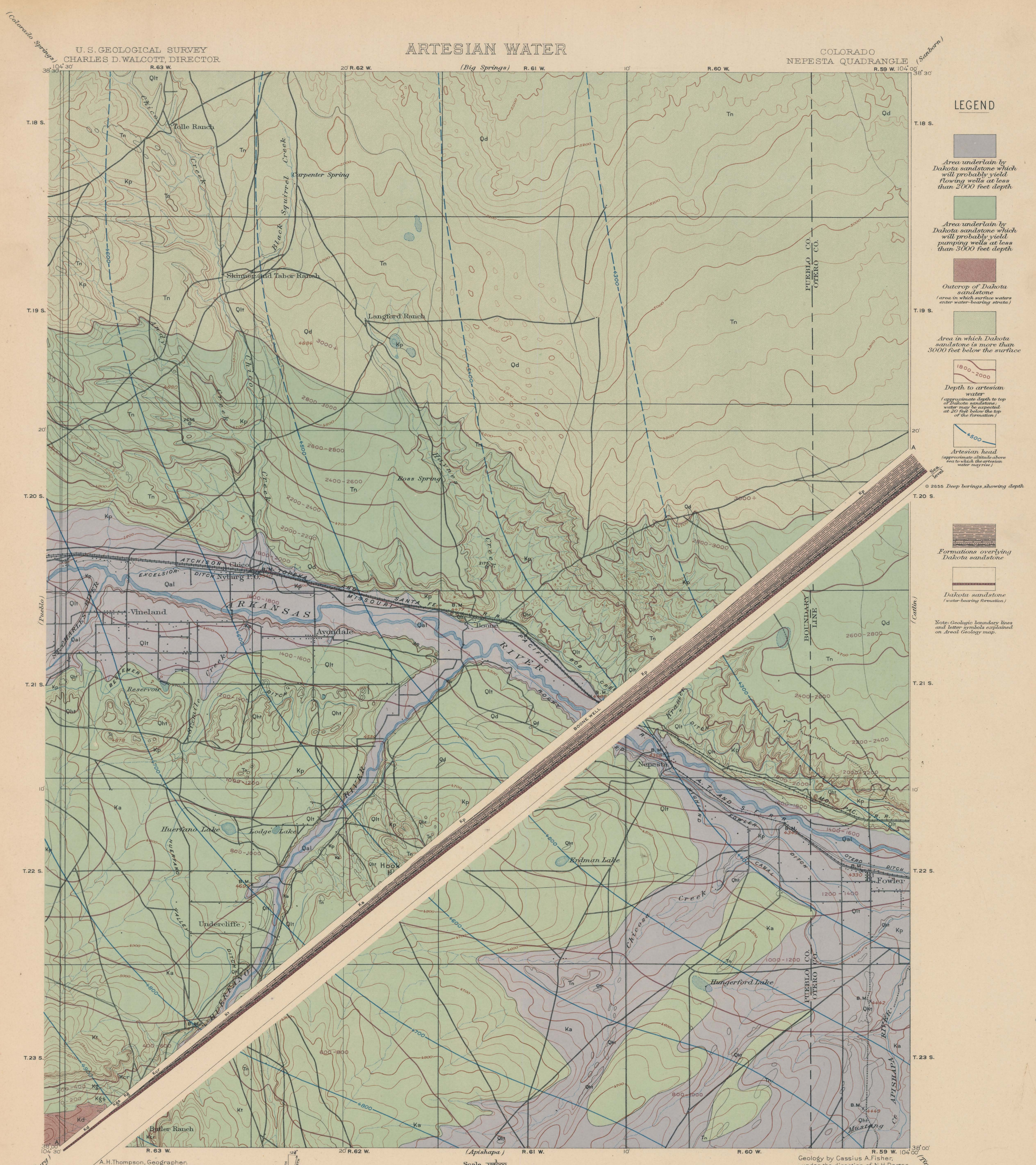
Edition of Jan. 1906.

Geology by Cassius A. Fisher,
under the direction of N. H. Darton.
Surveyed in 1903.

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

ARTESIAN WATER

COLORADO
NEPESTA QUADRANGLE



A. H. Thompson, Geographer.
Willard D. Johnson, Topographer in charge.
Topography and triangulation by J. W. Hays.
Surveyed in 1889.
Partially revised by Frank Tweedy in 1894 and Fred Mc Laughlin in 1903.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 25 feet.

Datum is mean sea level.

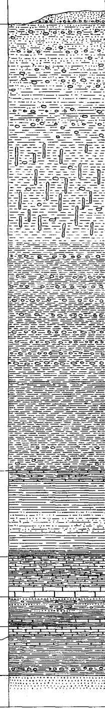
Projection based on U. S. C. and G. Survey data of 1900.
Projection of Pueblo and Apishapa sheets based on earlier data.

Edition of Jan. 1906.

Geology by Cassius A. Fisher,
under the direction of N. H. Darton.
Surveyed in 1903.

COLUMNAR SECTION

GENERALIZED SECTION FOR THE NEPESTA QUADRANGLE.
SCALE: 1 INCH = 500 FEET.

System.	Formation Name.	Symbol.	Thickness in Feet.	Columnar Section.	Depth to Dakota Sandstone.	Character of Rocks.	Character of Topography and Soil.
Tertiary	Nussbaum formation.	Tn	20–60			Sand and gravel, often cemented into conglomerate.	Mesas.
Cretaceous (Upper Series)	Pierre shale.	Kp	2300		3200 3000 2800 2600 2400 2200 2000 1800 1600 1400 1200	Light-gray sandy shale containing layers of iron-carbonate concretions. Upper members very sandy. Fine-grained gray shale containing vertical cylindrical limestone "cores" and large iron-carbonate concretions. Fine-grained dark-colored shale characterized by numerous layers of iron- and lime-carbonate concretions which are dark bluish gray but weather to rust color. Dark-gray to black shale, yellow at base. Iron-carbonate concretions in lower members.	Numerous small conical hills, "tepee buttes." Long, gradual slopes traversed by ravines which in the higher portions are moderately shallow but throughout the lowlands are often deeply trenched. Stiff "gumbo"-like soil, highly acidic, due to decomposed pyrites. Not well adapted to cultivation.
	Niobrara group: Apishapa formation.	Ka	425–450		1000 800	Shale containing thin bands and large lenses of impure limestone near the top. Sandy shale. Paper shale.	Gently undulating plains with wide, open valleys. Soil sandy and fertile.
	Niobrara group: Timpas formation.	Kt	200–225		600 400	Thin bands of impure limestone at the top; calcareous shale near the middle; massive gray limestone at the base.	Level plains. Rocky slopes and high cliffs.
	Benton group: Carlile shale.	Kcr	150			Dark shale capped by light-brown to yellowish sandstone; concretions in upper part and limestone layers near base.	Bare shaly slopes.
	Benton group: Greenhorn limestone.	Kg	50		200	Alternating layers of dove-colored, jointed limestone and thin shale.	Low shelving ridges.
	Benton group: Graneros shale.	Kgs	200		0	Dark-gray shale containing concretions near base and limestone above.	Gradual slopes and valleys. Soil thin, except where covered with alluvium.
	Dakota sandstone.	Kd	100+			Brown sandstone.	Rocky slopes. Deep, narrow canyons.

CASSIUS A. FISHER,
Geologist.

PUBLISHED GEOLOGIC FOLIOS

No.*	Name of folio.	State.	Price.†
			Cents.
1	Livingston	Montana	25
‡2	Ringgold	Georgia-Tennessee	25
3	Placerville	California	25
‡4	Kingston	Tennessee	25
5	Sacramento	California	25
‡6	Chattanooga	Tennessee	25
‡7	Pikes Peak	Colorado	25
8	Sewanee	Tennessee	25
‡9	Anthracite-Crested Butte	Colorado	50
‡10	Harpers Ferry	Va.-Md.-W.Va.	25
11	Jackson	California	25
12	Estillville	Ky.-Va.-Tenn.	25
13	Fredericksburg	Virginia-Maryland	25
14	Staunton	Virginia-West Virginia	25
15	Lassen Peak	California	25
16	Knoxville	Tennessee-North Carolina	25
17	Marysville	California	25
18	Smartsville	California	25
19	Stevenson	Ala.-Ga.-Tenn.	25
20	Cleveland	Tennessee	25
21	Pikeville	Tennessee	25
22	McMinnville	Tennessee	25
23	Nomini	Maryland-Virginia	25
24	Three Forks	Montana	25
25	Loudon	Tennessee	25
26	Pocahontas	Virginia-West Virginia	25
27	Morristown	Tennessee	25
28	Piedmont	West Virginia-Maryland	25
29	Nevada City Special	California	50
30	Yellowstone National Park	Wyoming	50
31	Pyramid Peak	California	25
32	Franklin	West Virginia-Virginia	25
33	Briceville	Tennessee	25
34	Buckhannon	West Virginia	25
35	Gadsden	Alabama	25
36	Pueblo	Colorado	25
37	Downieville	California	25
38	Butte Special	Montana	25
39	Truckee	California	25
40	Wartburg	Tennessee	25
41	Sonora	California	25
42	Nueces	Texas	25
43	Bidwell Bar	California	25
44	Tazewell	Virginia-West Virginia	25
45	Boise	Idaho	25
46	Richmond	Kentucky	25
47	London	Kentucky	25
48	Tenmile District Special	Colorado	25
49	Roseburg	Oregon	25
50	Holyoke	Massachusetts-Connecticut	25
51	Big Trees	California	25
52	Absaroka	Wyoming	25
53	Standingstone	Tennessee	25
54	Tacoma	Washington	25
55	Fort Benton	Montana	25
56	Little Belt Mountains	Montana	25
57	Telluride	Colorado	25
58	Elmoro	Colorado	25
59	Bristol	Virginia-Tennessee	25
60	La Plata	Colorado	25
61	Monterey	Virginia-West Virginia	25
62	Menominee Special	Michigan	25
63	Mother Lode District	California	50
64	Uvalde	Texas	25
65	Tintic Special	Utah	25
66	Colfax	California	25
67	Danville	Illinois-Indiana	25
68	Walsenburg	Colorado	25

No.*	Name of folio.	State.	Price.†
			Cents.
69	Huntington	West Virginia-Ohio	25
70	Washington	D. C.-Va.-Md.	50
71	Spanish Peaks	Colorado	25
72	Charleston	West Virginia	25
73	Coos Bay	Oregon	25
74	Coalgate	Indian Territory	25
75	Maynardville	Tennessee	25
76	Austin	Texas	25
77	Raleigh	West Virginia	25
78	Rome	Georgia-Alabama	25
79	Atoka	Indian Territory	25
80	Norfolk	Virginia-North Carolina	25
81	Chicago	Illinois-Indiana	50
82	Masontown-Uniontown	Pennsylvania	25
83	New York City	New York-New Jersey	50
84	Ditney	Indiana	25
85	Oelrichs	South Dakota-Nebraska	25
86	Ellensburg	Washington	25
87	Camp Clarke	Nebraska	25
88	Scotts Bluff	Nebraska	25
89	Port Orford	Oregon	25
90	Cranberry	North Carolina-Tennessee	25
91	Hartville	Wyoming	25
92	Gaines	Pennsylvania-New York	25
93	Elkland-Tioga	Pennsylvania	25
94	Brownsville-Connellsville	Pennsylvania	25
95	Columbia	Tennessee	25
96	Olivet	South Dakota	25
97	Parker	South Dakota	25
98	Tishomingo	Indian Territory	25
99	Mitchell	South Dakota	25
100	Alexandria	South Dakota	25
101	San Luis	California	25
102	Indiana	Pennsylvania	25
103	Nampa	Idaho-Oregon	25
104	Silver City	Idaho	25
105	Patoka	Indiana-Illinois	25
106	Mount Stuart	Washington	25
107	Newcastle	Wyoming-South-Dakota	25
108	Edgemont	South Dakota-Nebraska	25
109	Cottonwood Falls	Kansas	25
110	Latrobe	Pennsylvania	25
111	Globe	Arizona	25
112	Bisbee	Arizona	25
113	Huron	South Dakota	25
114	De Smet	South Dakota	25
115	Kittanning	Pennsylvania	25
116	Asheville	North Carolina-Tennessee	25
117	Casselton-Fargo	North Dakota-Minnesota	25
118	Greeneville	Tennessee-North Carolina	25
119	Fayetteville	Arkansas-Missouri	25
120	Silverton	Colorado	25
121	Waynesburg	Pennsylvania	25
122	Tahlequah	Indian Territory-Arkansas	25
123	Elders Ridge	Pennsylvania	25
124	Mount Mitchell	North Carolina-Tennessee	25
125	Rural Valley	Pennsylvania	25
126	Bradshaw Mountains	Arizona	25
127	Sundance	Wyoming-South Dakota	25
128	Aladdin	Wyo.-S. Dak.-Mont.	25
129	Clifton	Arizona	25
130	Rico	Colorado	25
131	Needle Mountains	Colorado	25
132	Muscogee	Indian Territory	25
133	Ebensburg	Pennsylvania	25
134	Beaver	Pennsylvania	25
135	Nepesta	Colorado	25

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

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