DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

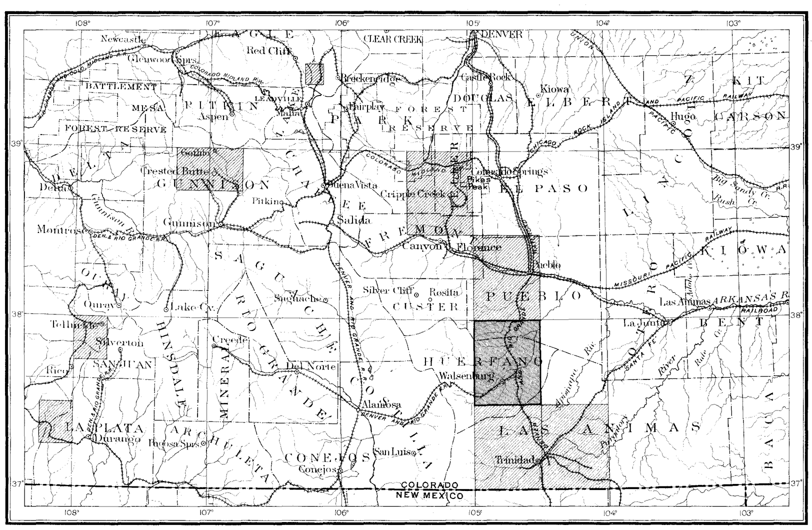
OF THE

UNITED STATES

WALSENBURG FOLIO

COLORADO

INDEX MAP



SCALE: 40 MILES=1 INCH

AREA OF THE WALSENBURG FOLIO

AREA OF OTHER PUBLISHED FOLIOS

LIST OF SHEETS

DESCRIPTION — TOPOGRAPHY — HISTORICAL GEOLOGY — IGNEOUS GEOLOGY — ECONOMIC GEOLOGY

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FOLIO 68 — LIBRARY EDITION — WALSENBURG

WASHINGTON, D. C.

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

1900

EXPLANATION.

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

THE TOPOGRAPHIC MAP.

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

Relief.—All elevations are measured from mean sea-level. The heights of many points are accurately determined, and those which are most important are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea-level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

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

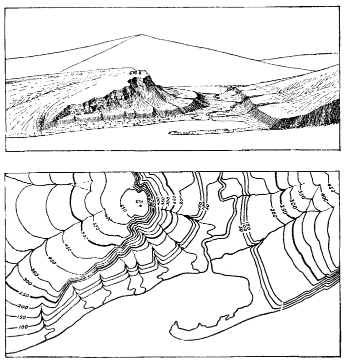

Fig. 1.—Ideal sketch and corresponding contour map.

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

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

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

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

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

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

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

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

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

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

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

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

THE GEOLOGIC MAP.

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

KINDS OF ROCKS.

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

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

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

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

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

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

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

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

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

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

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

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

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

AGES OF ROCKS.

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

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

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

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

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are characteristic types, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present.

When two formations are remote one from the other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first.

Fossil remains found in the rocks of different areas, provinces, and continents, afford the most important means for combining local histories into a general earth history.

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

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

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

Each formation is furthermore given a letter-symbol of the period. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

Historical geology sheet.—This sheet shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any particular colored pattern and its letter-symbol on the map the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

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

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

The geologist is not limited, however, to the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

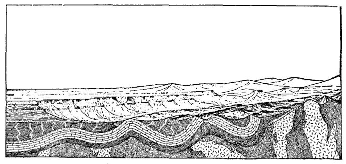

Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

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

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

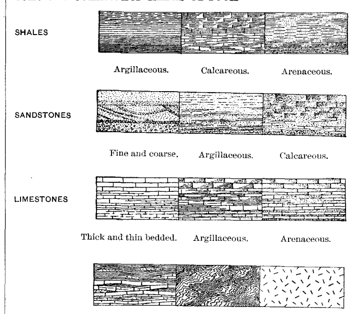

Fig. 3.—Symbols used to represent different kinds of rock.

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

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

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. But these sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets. That they are now bent and folded is regarded as proof that forces exist which have from time to time caused the earth's surface to wrinkle along certain zones.

On the right of the sketch the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

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

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

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

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

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

Columnar-section sheet.—This sheet contains a concise description of the rock formations which occur in the quadrangle. The diagrams and verbal statements form a summary of the facts relating to the character of the rocks, to the thicknesses of the formations, and to the order of accumulation of successive deposits.

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

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

The intervals of time which correspond to events of uplift and degradation and constitute interruptions of deposition of sediments may be indicated graphically or by the word "unconformity," printed in the columnar section.

Each formation shown in the columnar section is accompanied by its name, a description of its character, and its letter-symbol as used in the maps and their legends.

CHARLES D. WALCOTT,
Director.

Revised June, 1897.

DESCRIPTION OF THE WALSENBURG QUADRANGLE.

GEOGRAPHY.

The Walsenburg quadrangle is bounded by meridians 104° 30′ and 105° and parallels 37° 30′ and 38°. It is 34.5 miles long north and south and 27.3 miles wide east and west, and contains 944 square miles. Of the total area, nearly three-fourths lies in Huerfano County and about one-fourth in Pueblo County; a small fraction in the southeast corner lies in Las Animas County.

Topography. The topography is greatly diversified. The central portion is mainly an open, rolling country, traversed by the cultivated valleys of the Huerfano and Cuchara and having an elevation of from 5500 to 6100 feet. The north-central and eastern portions are somewhat higher and the profile of the surface is more often undulating than otherwise. In the northeastern portion the country is traversed by the deep, narrow canyons of the Huerfano and Cuchara, which are bounded by cliffs of varying height, up to 100 feet or more, that terminate abruptly in the general level of the surface. The southwestern portion of the district includes the northern extension of the Park Plateau, a rugged, deeply scored area which has a mean elevation of about 6500 feet and terminates in a line of bluffs facing northeastward. In the west-central portion, near the boundary, there are two small but extremely precipitous mountains about 3 miles apart, the south one known as Black Mountain. The northwestern portion of the district includes the eastern half of the southern extension of the Greenhorn Mountains, which, within the limits of the quadrangle, rise to an elevation of nearly 12,000 feet, though the culminating point, known as Greenhorn Peak, lies west of the boundary. A high mesa several miles wide, but narrowing rapidly to the southward, extends eastward from the base of the mountains.

Drainage. The principal drainage channels are the Huerfano and Cuchara, which flow in a generally northeasterly course to their junction near the northeast corner of the quadrangle. At times these streams are raging torrents, but except during the flood season the irrigating ditches take most of the water. The drainage from the Greenhorn Mountains is of less importance, though it includes several small streams flowing eastward into the Huerfano, Greenhorn, and Saint Charles. In the southern and southwestern portions of the district there are other small streams, rising in the Spanish Peaks and Huerfano Park quadrangles, that drain into the Cuchara.

Vegetation. The slopes of the Greenhorn Mountains are in places well timbered with pine, and dense forests of spruce are found toward the summit. There is also more or less scattered pine timber in the country bordering the deep canyons of the Huerfano and Cuchara. On the Park Plateau and along the eastern border there is a heavy growth of piñon and juniper, and there are patches of quaking aspen on the high mesa at the base of the mountains. The central part of the district is destitute of timber except an occasional fringe of cottonwood and wild plum along the principal streams. The country affords several varieties of plateau and mountain grasses adapted to pasturage, with stretches of meadow land along the bottoms. As a rule, the higher the elevation the stronger the growth of grass and other kinds of vegetation, owing to greater condensation of moisture, which causes deeper snow in winter and more frequent rains in summer.

Climate. The climate varies considerably in different parts of the district according to the elevation. The northwestern mountainous portion is relatively cool and humid, the central portion warm and arid, while the climate of the plateau portion lies between the two extremes. During the summer months local thunder storms of exceptional violence but brief duration are of frequent occurrence. At such times the canyons and dry water courses are suddenly converted into rushing torrents which for the time being are impassable, but which soon subside.

Soil. The bottom land along the streams consists of a rich, dark-colored loam several feet in depth, below which there are deposits of clay and gravel to the "bed rock," which may be from 10 to 50 feet below the surface. Nearly all the low-lying areas afford a loess-like eolian deposit, several feet in depth, of light-colored sandy loam, admirably adapted for cultivation when irrigated.

Agriculture. The agricultural products are such as meet the requirements of the mixed American and Mexican population and of the coal camps. At present tillage is mostly confined to the bottom land. Oats, wheat, corn, potatoes, beans, and garden vegetables are staple crops, and alfalfa is one of the largest and most profitable. Irrigation is usually resorted to wherever water for the purpose is available. It is practicable, however, to cultivate corn without irrigation when the season is favorable, though the yield never equals that obtained by the judicious use of water. On the high mesa at Rye a fair yield of corn, oats, or rye can be obtained without irrigation even in an ordinary season. Sheep raising is a very important industry, for which the grazing facilities of the low country are better adapted than for cattle raising, though in the plateau and mountainous portions the conditions are reversed.

GENERAL GEOLOGY.

In the geology of the Walsenburg quadrangle all the grand divisions of geologic time are represented by rocks, though in some cases not to an important extent. Thus, there are no beds assignable to the earlier periods of the Paleozoic or the earlier epochs of the Cretaceous period, and less than 300 feet of strata have been assigned to the Juratrias period, while the Neocene is represented only by the remnants of a formation doubtfully assigned to its latest epoch. On the other hand, the Archean, later Cretaceous, and Eocene formations are well represented, as are also certain varieties of intrusive eruptive rocks.

UNCLASSIFIED CRYSTALLINE ROCKS.

ARCHEAN PERIOD.

Character of the rocks. The principal mass of the Greenhorn Mountains consists of coarse- and fine-grained granites and gneisses, hornblende-, mica-, and chlorite-schist, and subordinate masses of garnet- and epidote-schist and occasional vein-like bodies of coarse pegmatite. The schistose rocks are more prominent at the southern extremity of the mountains than elsewhere, while the granite and gneissic rocks are more prominent in the main mass toward the culminating point. It does not appear that there is a central core of massive granite flanked by the gneisses and schist, though in places intruded bodies of such granite may have penetrated the mass. The schists are best developed at the southern extremity, but they are also present to some extent at other points, and the core itself is a highly contorted complex of granite, gneiss, and associated small bodies of schist and pegmatite.

Probable Archean age. The absence of uplifted masses of sedimentary strata, in areas where such might have been preserved, suggests that the Greenhorn Mountains occupy the site of one of the earliest land masses of the State, and that the emergence of this mass preceded the deposition of the Algonkian or oldest of the stratified rocks. There is no doubt that this mass was from time to time further uplifted, though more than once depressed, and that the material first exposed has long since been carried away. But the character of the rocks was established during the time preceding the first emergence of the land above the level of the sea, and their origin probably dates back to the Archean period.

SEDIMENTARY ROCKS.

CARBONIFEROUS ? PERIOD.

Badito formation.—The upper half of this formation consists of brick-red sandstone, about 100 feet in thickness, generally massive or thick bedded, but sometimes shaly on the weathered surface. It apparently corresponds to part of the Fountain formation, but to what portion of it is uncertain. **Thickness and extent.** The lower half consists of about the same thickness of very coarse conglomerate of a brownish-red color. The formation outcrops in contact with the Archean around the southern end of the mountains, but the exposures occupy a very limited area. The upper part of the Fountain formation is exposed for a short distance in the canyon of the Cuchara. **Age of the beds.** No organic remains by which the age of these beds could be satisfactorily determined have been found within the limits of the quadrangle. In the Sangre de Cristo Range, to the westward, the stratigraphic section corresponds very nearly with that at the southern extremity of the Greenhorn Mountains except in respect to the thickness of the conglomerate. Below the Cretaceous beds and the Morrison formation there is in each case about the same thickness of capping red sandstone, but the coarse conglomerate and sandstone on which it rests attain in the Sangre de Cristo a thickness of several thousand feet. In that locality the beds have afforded remains of an upper Carboniferous fauna and flora. The evidence of a similar character from the Fountain formation on the eastern slope of the Rocky Mountains is meager and contradictory, and it is still a question whether it should be classed as Permian or Triassic. As the Fountain and Sangre de Cristo formations have not sufficient geologic importance to warrant their separation on the Areal Geology sheet, advantage is taken of this doubt to group them together under the name Badito formation and to refer them to the upper Carboniferous.

JURATRIAS PERIOD.

Morrison formation.—**Thickness and extent.** This formation aggregates about 270 feet in thickness at the southern extremity of the Greenhorn Mountains, where there is a narrow outcrop extending along the foothills a distance of about 5 miles and passing on beyond the west boundary of the quadrangle. It is also exposed along the canyons of the Cuchara and Huerfano for a distance of over 20 miles. About midway between the extremities of the Greenhorn Mountains outcrop the inclination varies from 45° to nearly vertical. **Character of the rocks.** The lower portion consists of about 60 feet of soft, white sandstone having a conglomerate layer at the base. This is followed by hard, shaly beds of pinkish and greenish tints, breaking into fragments with conchoidal fracture. The upper portion consists of variegated shales and clays alternating with bands of hard, fine-grained limestone often containing vermilion-colored cherts. One band of conglomerates a few feet thick contains green pebbles. At one point the basal sandstone overlaps the Badito formation, and rests on the Archean at an angle of 15°. In the canyons of the Huerfano and Cuchara the strata have but slight inclination except where an upward bulge brings an area of the Fountain to the surface. Here the thickness of the Morrison is less than 100 feet, and corresponds to the upper, variegated part of the Greenhorn outcrop, the lower part being entirely wanting. There is still considerable doubt as to the true position of this formation in the time scale, and the assignment to the Juratrias is therefore provisional.

CRETACEOUS PERIOD.

Dakota formation.—**Extent and thickness.** The Dakota sandstone outcrops prominently in the northeastern and northwestern portions of the quadrangle. The aggregate area is about 150 square miles. In the canyon of the Huerfano, in the eastern part of the district, the aggregate thickness is about 350 feet, while along the border of the Greenhorn Mountains it is in places nearly 400 feet, though sometimes thinning down so that only the upper layers appear. This is particularly the case where the beds overlap the older formations and rest on the Archean, as they often do along the foothills of the Greenhorn Mountains. The lower two-thirds of the formation consists, as a rule, of yellowish-gray sandstone of a coarse, porous texture, and some of the layers are really fine conglomerate. Cross bedding is rather common. This lower portion is separated from the upper by a bed of gray shale from 8 to 10 feet in thickness, called the fire-clay bed, owing to the highly refractory nature of the material. The upper sandstones, aggregating from 100 to 150 feet in thickness, are light gray when fresh, of fine grain, close texture, and regular bedding. They resist erosion to such an extent that the removal of the softer beds of the marine Cretaceous exposes extensive horizontal floors of the sandstone, the surface barely masked by a thin layer of soil. The effect of stream erosion is the formation of deep, narrow canyons bounded by vertical, inaccessible walls that rise to the general level of the surface. The canyons of the Huerfano, Cuchara, and their tributaries in the northeastern portion of the district are of this character.

Graneros shale.—Resting on the Dakota is a bed of soft shale from 200 to 210 feet thick, the basal formation of the Benton group and the lowest of the marine Cretaceous beds of the country. The top and bottom portions are dark gray; the middle portion is almost black. Large calcareous concretions, arranged parallel with the bedding, are somewhat numerous near the base. These shales outcrop very persistently in the northeastern portion of the quadrangle and along the eastern base of the Greenhorn Mountains, but are not exposed over any considerable area. They are usually very soft and easily eroded, and present steep slopes only where the outcrop is protected by the resistant limestone of the beds overlying them.

Greenhorn formation.—This consists of layers, from 3 to 4 inches thick, of cross-fractured, dove-colored limestone, separated from one another by thin layers or partings of gray shale. The aggregate thickness is about 30 feet. While this formation is of limited thickness, it is one of the prominent horizons of the Cretaceous section and, owing to its relatively greater capacity for resisting erosion, affords a very persistent, though narrow and meandering, outcrop, generally bounded by a low escarpment. The area, however, is less than that of any sedimentary formation in the district except the Nussbaum. The most characteristic and commonly occurring fossil is *Inoceramus labiatus*—a flat, concentrically ringed shell from 3 to 4 inches long and from 2 to 3 inches broad.

Carlile formation.—This is the uppermost of the three subdivisions of the Benton group. It consists of from 170 to 180 feet of dark-gray shale, which, like the Graneros, is of a much darker shade toward the middle. At the top there is a bed of yellowish sandstone 10 to 15 feet thick, capped by a band of bituminous limestone. This varies in thickness from less than 2 feet near the southeastern boundary of the quadrangle, where it is usually of a purplish tint, to 4 feet near the northern boundary, where it is of a yellowish tint. The shaly portion of the formation affords numerous concretions of impure limestone seamed with calcite. The bituminous limestone at the top contains many fragments of fossil shells. Toward the southeastern portion of the area the coiled ammonite *Prionocyclus wyomingensis* is the most conspicuous fossil, but toward the northern portion of the area it is rarely present, though sharks' teeth are of common occurrence. The Carlile shale is soft and is as easily eroded as the Graneros formation. Owing to this fact, it is only where it is protected by the more resistant overlying strata that steep slopes appear. The outcrop is about equal in extent to that of the Graneros, and, like that of the latter, is persistent, though narrow and irregular as compared with the succeeding members of the Cretaceous.

Timpas formation.—This unit is the basal subdivision of the Niobrara, a group that is characterized by the presence of limestone and of shales that are often more or less calcareous in composition. The Timpas formation is from 180 to 200 feet thick, of which the basal portion, from 40 to

45 feet thick, is grayish-white limestone. The remainder consists of shales interrupted at intervals by thin bands of limestone. The basal limestone is in bands from 6 to 10 inches in thickness, separated by very much thinner partings of calcareous shale. The weathered surface of the limestone is much fractured, the flakes that break off being relatively thin and conchoidal, in which respect it differs materially from the Greenhorn limestone. The middle and upper portions of the formation, with the exception of the limestone bands already mentioned, consist of rather hard shales, mostly calcareous, which weather to a dove color, and contain many impure lime concretions arranged in parallel position. The most common and characteristic fossil is a large, concentrically-ridged shell, *Inoceramus deformis*. In the thin, transparent sections of the limestone in which this shell is found, the remains of foraminiferal organisms are very abundant. On account of the resistance which the basal limestone of the Timpas offers to eroding agencies, it commonly forms a conspicuous outcrop, usually marked by an escarpment of varying height—as much as 50 feet when the capping layers of the Carlile are added. The area of the outcrop is about 145 square miles, or but little less than that of the Dakota sandstone. The Timpas is thus one of the important geologic units of the quadrangle.

Basal limestone. *Organic remains.* *Extent of the outcrops.*

Apishapa formation.—This formation, which is the upper division of the Niobrara group, consists of shale and calcareous shale 450 to 500 feet in thickness, with occasional thin bands of limestone near the top. The basal portion, from 30 to 40 feet thick, is mostly made up of gray and bluish-gray shales, followed by from 80 to 90 feet of rotten shale of papery lamination, grading into sand shale at the top. The middle portion consists of sand shale at the top and bottom, with coarse, more or less flaglike, and generally bituminous, muddy-gray shale between. This portion of the formation sometimes forms prominent escarpments. The upper portion, from 80 to 100 feet in thickness, is very similar in character to the lower, but always includes two, and sometimes three, thin beds of grayish-white limestone. The fossil remains are not at all abundant, except fish scales, which are generally present in the shaly layers. In the sandy layers of the middle zone patient search will generally reveal the tracks of what was probably a small crustacean. They appear as a double row of short lines, those of one row inclined toward those of the other. The outcrop of the Apishapa extends continuously from near the southeast corner of the quadrangle to within 5 or 6 miles of the northwest corner, where it turns southward and follows the base of the Greenhorn Mountains to the Huerfano River. The total area is about 78 square miles, or about one-half that of the Timpas.

Character and thickness. *Fossil remains.* *Extent of the outcrop.*

Pierre shale.—This is the lower of the two divisions of the Montana group of the Cretaceous. The beds consist wholly of argillaceous shale, which at the south boundary of the quadrangle has a thickness of about 1500 feet, and toward the northern extremity, on the Huerfano, a thickness of about 2000 feet; though 1750 feet would be nearer the average south of the Cuchara, and 1900 feet in the Huerfano Valley. It must be understood, however, that these figures are but little more than estimates, as accurate measurements are out of the question owing to the small number of exposures and the variation of the dip. In respect to the formation as a whole, the presence of shale throughout the entire section is a distinctive feature. The basal zone consists of gray or yellowish-gray shale. The upper zone is much similar except that the shale is in places very soft. The middle zone material is usually lead-gray or dark-colored, and there are abundant concretions of impure limestone containing iron carbonate and seamed with calcite. These concretions, arranged parallel with the bedding, break up readily into small conchoidal fragments that impart a rusty tint to the soil.

Character and thickness.

The area over which the Pierre is the surface formation is about 200 square miles. It outcrops continuously from the southern border northwesterly to Hayden Butte, and crosses the west boundary, into the Huerfano Park quadrangle, on the south side of the Huerfano River.

Extent of the Pierre outcrop.

Trinidad formation.—This is the upper division of the Montana group, and the uppermost of the marine Cretaceous beds of the district. It probably corresponds to the upper portion of the Fox Hills formation, the basal portion being very much better developed northward on the Arkansas River and in the Denver Basin. The lower portion consists of from 85 to 90 feet of thin-bedded, fine-grained, dark-gray sandstone in layers from 2 to 4 inches thick, separated from one another by thin partings of shale. The upper portion, from 75 to 80 feet in thickness, consists of greenish-gray, heavy-bedded or massive sandstone which is light gray on the weathered surface. This bed of sandstone is characterized by the presence throughout of the fucoid *Halymenites*, easily recognized by the pitted, cylindrical casts of the branching stems. In the lower portion poorly preserved *Baculites* were found in making an excavation near Rouse. The massive sandstone is of close texture and, as it resists erosion more strongly than the beds above and below, generally appears as a prominent escarpment defining very clearly the base of the coal-bearing formation overlying it. The outcrop of the Trinidad is narrow and very irregular. It extends from the Santa Clara in a northwesterly direction to within about 1 mile of the Huerfano River; thence it trends southwesterly nearly to the west boundary of the quadrangle.

Character and thickness of the Trinidad. *Fossil remains.* *Extent of the Trinidad.*

Laramie formation.—The Trinidad sandstone is the last of the marine Cretaceous formations, and with the beginning of the Laramie epoch new conditions were inaugurated. The waters in which the sediments were deposited, while still connected with the ocean, no longer supported marine life. The areas receiving sediments continued to subside, but the rate of subsidence was slower in relation to the rate of sedimentation, though they varied with respect to one another. These variations gave rise to an alternating series of sandy and silt-like deposits. The subsidence was also marked by halting stages, during which extensive peat-like beds were formed from the remains of the semi-tropical vegetation that flourished in the marshy land areas of the period. With further subsidence these areas were buried under fresh sediments, which continued to accumulate until another halting stage permitted the formation of swamps and marshes. These conditions were many times repeated, and the subsequent consolidation of the sediments into sandstone and shale, and the peat into coal, gave rise to the extensive coal-bearing Laramie series.

Early Laramie conditions.

The thickness of the formation near the south boundary is about 1500 feet, but along the northern portion of the outcrop it is only about 1000 feet. This is mostly owing to the general thinning of the series northward, though not entirely, as there was erosion going on in the interval preceding the deposition of the lower Eocene beds. Considered in detail, the sections of the Laramie vary considerably from place to place, though the general features are essentially the same. There is always an alternation of massive or thick-bedded sandstone, with beds of shale, or occasionally sand shale. The sandstone predominates toward the top, the shale toward the base. The sand shales are not so common in the lower portion of the series as in the better-developed areas south of the district. Indeed, aside from the general features of the coal seams, to be presently considered, this is the most noticeable difference. Some of the upper sandstone beds appear rounded and cavernous on the weathered surface, and in this portion of the series the alternating beds are sometimes greenish-gray, fissile, or shaly sandstone instead of shale. There is no persistency to the thinner layers of massive sandstone—they appear and disappear. The lower, shaly portion lying between the Trinidad sandstone and the first massive sandstone bed of the Laramie is, as well as the latter, persistent throughout the district. But in all other respects, even to the occurrence of the coal seams, variation is characteristic.

Thickness. *General features.*

The outcrop of the Laramie extends from the south line of the quadrangle in a northwest direction nearly to the Huerfano River. Thence, curving abruptly southwestward, it passes the west line near Black Mountain. The total area of the outcrop is only about 50 square miles, but the formation no doubt underlies the area occupied by the Eocene beds. The lower portion of the Laramie in the vicinity of Rouse abounds in the remains of semi-tropical vegetation, and a valuable collection of leaf imprints was made in this neighborhood.

Extent of the Laramie outcrop. *Fossil flora.*

EOCENE AND NEOCENE PERIODS.

Mountain growth.—At the close of the Laramie, or not long subsequent thereto, important changes were effected in the configuration of the country by the pronounced mountain growth which then took place. Previous to this time the Sangre de Cristo Range, west of the district, was simply the eastern shore-border of a low-lying land mass that extended west so as to include the area now occupied by the San Juan Mountains. The initial stages in the formation of this range coincide with the post-Laramie movement, though the final stages of the upheaval occurred during a later period of disturbance. At about the same time the Greenhorn Mountains, which had been a land area from very early times, were also uplifted, while the strata of the plains border were arched up and probably more or less faulted, though most of the faulting should, no doubt, be credited to subsequent disturbances. Between this arch and the Greenhorn Mountains on the one hand, and the Sangre de Cristo Range on the other, was formed the depression that was occupied by the Huerfano Eocene lake. This lake stretched from the Purgatory Valley in a generally northwesterly direction to the Huerfano Valley. During the early Eocene this depression or basin steadily subsided, and a great depth of sediments accumulated in it. The character of these sediments varied from place to place according to the composition of the neighboring land surface that furnished the débris. This is especially true of the later Eocene deposits, which were formed during the erosion of Archean, Carboniferous, and early Mesozoic beds; while at the beginning of the Eocene the débris was either Archean or derived from rocks that were made up of Archean material.

Initial events.

Poison Canyon formation.—This formation is made up of alternating beds of coarse sandstone, often conglomeratic, and thinner beds of yellow clay. The lower sandstone beds are of a yellowish tint, blended with pink on the weathered surface. Near the top there are some massive, light-gray, grayish-white, or sometimes pinkish, sandstone layers. The middle portion of the series contains more conglomerate than sandstone, though the separating beds of yellow clay extend from top to bottom. The conglomerate is not firmly cemented, the exposures often suggesting gravel rather than conglomerate. The clay beds constitute about one-fourth the thickness of the formation, though, owing to the prominence of the sandstone and conglomerate, the clay appears more subordinate than it really is. The maximum thickness of the formation is about 2500 feet as developed south of Black Mountain near the west boundary. The area of the outcrop is a little over 100 square miles.

Character of the formation. *Thickness and extent of the outcrop.*

The assignment of the Poison Canyon formation to the Eocene is altogether provisional and is based on its great unconformity with the Cretaceous strata and its relatively small unconformity with beds (Huerfano formation) containing an Eocene fauna. It is possible, however, that it may correspond in part to the Arapahoe beds, or lower member of the post-Laramie series of the Denver Basin.

The only organic remains yet discovered consist of petrified wood, which is in places rather abundant, especially in the conglomerate. The upper portion of the Huerfano formation affords mammalian remains of the age of the Bridger Eocene, and the lower portion, remains of the age of the Wind River Eocene. Hence, if the correlation is correct, the Eocene beds lower than the Huerfano belong to the lower Eocene, and in the absence of any evidence to the contrary they are regarded as of this age.

Age of the formation.

Cuchara formation.—The Cuchara formation consists of a basal portion of reddish or brownish, sometimes white, marl or clay shale, with more or less sandy material, aggregating about 100 feet in thickness. This is followed by from 350 to 400 feet of massive sandstone of yellowish, reddish, and brownish tints, always rather coarse textured, and weathering into rounded and cavernous forms. The composition indicates that the débris was Archean and Carboniferous. The area covered by the outcrop does not amount to more than 12 square miles. South of the Cuchara, near the south boundary, nearly the full thickness of the formation is present, but north of the Cuchara along the west boundary little more than the basal portion appears. Diligent search has failed to reveal the presence of organic remains in these beds, and their age is still a matter of uncertainty. They appear to be conformable with the Poison Canyon formation below, but are overlapped on the eastern shore-border by the succeeding Huerfano formation, or Bridger Eocene of the Huerfano Park quadrangle, and are probably of lower Eocene age, or nearly the equivalent of the Wasatch Eocene of western Colorado and eastern Utah.

Character and thickness of the Cuchara.

Late Eocene and early Neocene events.—After the Cuchara beds were deposited the basin of the Huerfano continued to receive sediments up to the close of the Bridger (middle Eocene). These later sediments doubtless once extended over part of the southwestern portion of the Walsenburg district, but have since been carried away, together with the greater part of the Cuchara. At the close of the Bridger the Huerfano lake ceased to exist and, coincident with additional upheaval of the Sangre de Cristo, the sediments along the western border of the lake were steeply upturned and the arch or swell to the eastward was considerably augmented. Whether or not this period of disturbance was contemporaneous with the earlier eruptions of igneous rocks has not been determined, though it is evident that the eruptions were subsequent to the laying down of the Eocene sediments, as the numerous dikes that traverse the latter testify. During the latter part of the Eocene and the early part of the Neocene there were eruptions from time to time that were doubtless accompanied by more or less earth movement. Toward the close of the Neocene or possibly early in the Pleistocene period further movement, resulting in appreciable changes of level, gave rise to conditions that admitted of limited areas of sediments being deposited. These are now represented by the Nussbaum formation.

Igneous disturbances and mountain making.

Nussbaum formation.—This formation includes certain small patches of sandstone and conglomerate found capping a few of the low mesas. The cementing material is usually calcite, and the coarser portion closely resembles the more extensive deposits of Wyoming, known as Wyoming conglomerate. The thickness ranges from 10 to 50 feet, depending on the amount of erosion. The deposits are, no doubt, remnants of larger areas that were formed by the backing up or ponding of the water courses, produced by the uplifting of the eastern portion of the district. The assignment of the Nussbaum to the Neocene is entirely provisional, and further investigation may show that it is really early Pleistocene.

STRUCTURE.

The chief structural features of the quadrangle are attributable to two causes: (1) regular mountain making (orogenic) movement, and (2) eruptions of lava. Of the two the former produced the more important results, though, owing to the effects being partly compounded, it is not always possible to determine which force was acting.

Structure due to mountain growth.—The uplifting of the Greenhorn Mountains had its inception far back in geologic time; in fact, one of the early land masses of the region occupied the area now included in this group. The widespread movement at the close of the Laramie resulted in further elevation of the Greenhorn Mountains, the production of a swell

Post-Laramie elevation.

in the adjacent territory to the eastward, and of a trough-like depression in the adjacent territory to the westward, accompanied by upturning of the sedimentary strata along the mountain border. The depression to the westward which became the basin of the Huerfano Eocene lake owes its trough-like form in part to a monoclinal flexure prolonged in the direction of the Greenhorn Mountain axis, and into which the swell east of the district terminates with relative abruptness. This Eocene trough, with a northwest-southeast trend, extended northeastward over the southwestern portion of the district. Subsequent to the Bridger Eocene another movement of pronounced character produced additional upheaval of the Greenhorn Mountains, accompanied by faulting along their base and in the territory immediately east and southeast, and by considerable upturning of the flanking Cretaceous and Eocene beds. To what extent the swell east of the district was augmented by this movement is uncertain; nor is it probable that the uplifting and faulting were due solely to the movements just mentioned, for the angular unconformity between the Poison Canyon beds and those of the uppermost Eocene west of the district shows that between the post-Laramie and post-Bridger movements gradual upheaval took place.

Post-Bridger elevation.

Present structure.

As a result of the disturbances noted, the prevailing inclination of the strata is toward the southwest, except in the vicinity of the Greenhorn Mountains, where they are abruptly upturned, in places into a nearly vertical position, against the protruding Archean mass, and dip away from this mass around its base. But, while the rocks have a prevailing inclination in the direction stated, there is considerable variation in the amount. In the eastern and northeastern portions the dip is generally very slight, and the same is true of the northwestern portion that lies away from the base of the Archean mass — except in the vicinity of a fault and excluding a local roll at Huerfano station. But to the southwest of a line running from Saint Mary southeasterly through Tioga, or in the direction of prolongation of the Greenhorn axis, the dip increases to 6° and 8°, then decreases to almost nothing in the southwestern portion of the quadrangle, except in the extreme corner, where, owing to the influence of the Spanish Peaks eruptions, there is a distinct northerly inclination to the strata. This monocline terminates in the vicinity of the Huerfano against the steep southeasterly dip imparted by the Greenhorn upheaval, which amounts to as much as 15° along the Laramie outcrop facing the Huerfano Valley, and increases rapidly as the Archean mass is approached, the strata immediately flanking it dipping away from the mass at high angles.

Faults and amount of displacement.

East of the base of the Greenhorn Mountains and distributed through a zone lying parallel with its axis there is a system of normal faults having a decided influence upon the structure of the country traversed. These faults do not conform to a common course, are more often curved than straight, and in some instances coalesce with one another at acute angles. The amount of vertical displacement ranges from 50 or more feet to as much as 700 feet in the northwestern portion of the quadrangle, east of Rye, where the Timpas limestone abuts against the lower strata of the Dakota. It is noteworthy that the upthrown area of Dakota sandstone was uplifted without undergoing much change of dip, the formation, except along its western border, resting on the granite in nearly horizontal position.

Unconformities.

Unconformity of the kind termed transgressive — that is, where one formation overlaps another and rests upon a third — is common around the mountain border. Here the Morrison overlaps the Badito, and where it has not been removed by erosion the Dakota overlaps all older sedimentary formations and rests upon the granite.

Structure due to eruptions. — The eruptive bodies of the district take the form of dikes, sheets, laccoliths, and plugs, the first two mentioned being the most numerous. All of these bodies are intrusive. On the summit of the Greenhorn Mountains there is a large area of extrusive lava, but only a small portion of it extends within the quadrangle. Most of the dikes in the southern part of the quadrangle belong to the Spanish Peaks system, though there are a number which do not, but which belong to a system that is common to south-central Colorado and north-central New Mexico. Crossing the western boundary are a few that belong to the Silver Mountain system of the Huerfano Park quadrangle. The small dikes rise but little above the surface of the country; the large ones may protrude as much as 50 feet above the inclosing rock, and as they strongly resist erosion, their course is often marked by a prominent ridge. The majority trend N. 60° to 70° E.; a few trend more or less east and west, and a few north and south, often with more or less irregularity.

Forms of the eruptive bodies.

The sheets are generally conformable with the bedding of the inclosing sedimentary formation. Like the dikes, they resist erosion, and where they outcrop in shaly beds their presence is usually marked by a mesa-like elevation that fades gradually toward the southwest, but presents a steep bluff, capped by the lava sheet, toward the northeast. These occurrences are confined, with one exception, to the south half of the quadrangle.

The laccoliths are represented by two small mountain bodies near the west boundary. They are directly connected by dikes with the similar rock of Silver Mountain to the westward, and are doubtless a lateral intrusion from that center. Previous to erosion they were probably buried under a considerable depth of sediments, and while not in any sense typical, are really modified forms of the laccolith.

The volcanic plugs are few in number and of little structural importance. The most prominent is a projecting pinnacle of lava near the Huerfano River, which, by reason of its conspicuousness and isolated position, has suggested the name Huerfano (Orphan).

Structural effect of the eruptive bodies.

The effect of the numerous eruptive occurrences upon the structure of the country is of considerable geologic importance, more especially from an economic standpoint, as will appear from the description of the chief features of the coal-bearing area. The intrusion of the masses of Black Mountain and the elevation immediately to the north of it emphasized and amplified the upturning of the strata resulting from the upheaval of the Greenhorn Mountains in that vicinity. Thus, while the upturning of the Cretaceous beds below the horizon of the intrusions scarcely extends beyond the southern extremity of the mountains, those that lie above this horizon are upturned so as to form a long flexure extending southward and finally curving sharply around the Black Mountain mass. In this manner the flexing due to orogenic movement and that resulting from the intrusion of the lava blend into each other.

TYPICAL EXPOSURES.

While the several formations outlined on the Areal Geology sheet are not difficult to identify, there are portions of the outcrop where the exposures are more complete and typical than elsewhere.

Archean rocks and Badito and Morrison formations.—In respect to the Archean rocks and the Badito and Morrison formations, there are no localities that are really easy of access under existing conditions. It happens, however, that the most complete outcroppings of all of these are to be found in the vicinity of one another near the southern extremity of the Greenhorn Mountains, where likewise the successive overlapping of the Badito by the Morrison and of the latter by the Dakota is well shown.

Dakota sandstone.—There are good sections of Dakota sandstone in the same locality, but they are less complete than the Huerfano River section east of Huerfano station, or that of the uplifted area north of Rye.

Fire clay.—The bed of refractory shale, or fire clay, characteristic of the formation in south-central Colorado is exposed a short distance east of where the railroad crosses the great fault south of Graneros, but the best outcroppings are along the line of the Huerfano Canyon still farther eastward.

Graneros shale.—The Graneros shale can be seen partly exposed at several points along the railway between Huerfano and Graneros stations, but can be studied to best advantage at a point about 3 miles southwest of Graneros, where the contacts with the underlying Dakota and succeeding Greenhorn are fairly well exposed.

Greenhorn limestone.—The same locality also affords typical exposures of the Greenhorn limestone, which is likewise well shown where Apache Creek crosses the outcrop about 2 miles north of Huerfano station, and along the bed of Salt Creek near the north boundary of the quadrangle.

Carlile formation.—An excellent section of the Carlile is exposed on the north side of the great fault near the Graneros locality just mentioned. The section is typical, although the thickness at that point is less than the average. About 4 miles due east from Graneros there are other bluffs that afford good sections.

Timpas formation.—The basal limestone of the Timpas is one of the most prominent of the Cretaceous horizons, but the upper part of the formation is much less frequently exposed. At Huerfano station the limestone outcrops on each side of the river, and in the bed of the latter, a short distance above, the upper portion is partly exposed, but on the Santa Clara about 2 miles northeast from Rouse Junction and just west of the north-south fault the upper and lower contacts are much better exposed.

Apishapa formation.—The same locality also affords excellent outcroppings of the Apishapa. The middle zone of bituminous calcareo-arenaceous shale is particularly prominent at one point on the east side of the creek. About 4 miles east of the south extremity of the long north-south fault there is a prominent escarpment at the same horizon.

Pierre shale.—The most complete section of the Pierre shale can be seen in the exposures west of Rouse Junction and Tioga, though the upper portion is best shown in the railway cuts between Rouse and Walsenburg and in the cuts on the ridge between Walsenburg and Pictou.

Trinidad formation.—The Trinidad formation outcrops persistently, but the lower half is usually more or less hidden by surface accumulations. The first long gulch south of Rouse affords one of the most complete sections, and there are other good exposures near where the railway crosses Bear Creek south of Walsenburg.

Laramie beds.—Bear Creek Valley also affords a very good section of the Laramie, but less complete than in the first long gulch north of Rouse, or, rather, the right-hand branch of it north of the group of dikes. Here both upper and lower contacts are well shown, as well as the intermediate portion of the formation. The coal beds, however, can be seen to best advantage at Santa Clara and in the Walsenburg district, including Pictou.

Poison Canyon beds.—The Poison Canyon beds are well exposed along the Cuchara, where the alternation of yellow clay and coarse sandstone appears in the exposures on the south side of the valley, and the upper contact with the Cuchara at the point where the road from La Veta north is graded up the bluff on the north side of the river. But the most characteristic exposures are in the vicinity of Black Mountain, especially along the La Veta road a short distance south of the mountain, where the loosely aggregated conglomerate and soft sandstone of the upper half of the formation can be seen to great advantage. Similar, though less extensive, outcroppings of the same beds can be seen just west of Bear Creek along the east-west road between Rouse and the Wahatoya, about 2 miles from the south line of the quadrangle.

Cuchara formation.—The variegated clays at the base of the Cuchara formation are very fully exposed near the wagon road between La Veta and Badito about 4 miles south of Black Mountain. These clays also appear at the base of the mesa near the south boundary of the quadrangle and about 3 miles east of the Wahatoya. The eastern extremity of the same mesa affords the only good exposures of the upper part of the formation within the quadrangle.

Nussbaum conglomerates.—On the small mesa east of Rouse there are very good examples of typical Nussbaum conglomerate and conglomeratic sandstone, especially along the southern rim of the mesa. The western rim of the mesa east of Tioga also affords good exposures.

IGNEOUS ROCKS.

OCCURRENCE AND DISTRIBUTION.

Centers of eruption.

The igneous rocks of the quadrangle belong chiefly to centers of eruption that lie beyond the boundaries of the quadrangle. The earlier eruptions, as well as some of the later ones, belong to the Spanish Peaks center, though it is doubtful if these much preceded in time others that belong to the Silver Mountain and Greenhorn Mountain manifestations. At a later date the Veta Mountain eruption occurred, giving rise to a group of mountain masses west of the district, extending from the Huerfano south to and beyond the Spanish Peaks. With the exception of the Greenhorn Mountain eruption, those cited were confined to the area of the Eocene lake basin. The latest eruption was of much wider range than the others, sheets and dikes extending from the Greenhorn Mountains southward at least as far as the Cimmaron River in New Mexico, if not beyond. This eruption, together with the earlier ones of the Spanish Peaks, so far as they relate to the occurrences in the Walsenburg quadrangle, gave rise to dikes and conformable sheets — that is, sheets intruded conformably with the bedding planes of the sedimentaries. The Silver Mountain eruption gave rise to the dikes and laccoliths near the western boundary of the quadrangle; that of the Greenhorn Mountains to massive overflows, while the Veta Mountain eruption is represented by a single dike-like mass only.

Resulting forms.

The laccoliths.

Black Mountain and the similar body to the north of it are modified forms of the laccolith. They were originally covered, partly or wholly, by sediments, though they are now deeply eroded and the eruptive masses are fully exposed. They differ, however, from the typical laccolith — which is a lens-shaped body of lava injected into the strata from below — in irregularity of form and in the fact that the lava was injected laterally, instead of vertically; at least, this method of injection is very strongly suggested by the dikes of similar rock which directly connect the occurrences with the larger mass of this rock forming the more typically developed laccolith of Silver Mountain to the westward. The connecting dikes presumably occupy the fissures that were formed and filled with lava by the force of the injection, in the beds overlying the channel connecting the main mass with the Black Mountain bodies. The larger of the two bodies has a diameter, at the depth exposed, of nearly 2 miles and a height above the base of about 700 feet. But, as an unknown portion of the mass lies below the lowest exposure, the true dimensions are doubtless considerably greater. The smaller body has a maximum diameter, as exposed, of about $1\frac{1}{2}$ miles and a height of about 400 feet, though, like the mass of Black Mountain proper, an unknown portion is hidden by the shale inclosing the base.

The sheets.

The sheets resemble the laccoliths in some respects — that is, they are intruded conformably with the inclosing sedimentaries, and are often flat lenses of lava much thicker in the central portion than in the peripheral portions. In some cases this is very noticeable, the sheet west of Bradford Lake being a good example. As a rule, lavas that are ultra-basic in composition form thinner sheets of more uniform thickness than less basic lavas. Some of the sheets have an outcrop length of 4 to 5 miles, though the majority are not more than half that length, while a few outcrop for less than a mile. They range in thickness from 12 inches to as much as 50 feet. Parallel occurrences one above the other are common. Ordinarily they are more numerous in the shaly beds of the marine Cretaceous than elsewhere, though a few are found in the shaly beds near the base of the Laramie.

The dikes.

The dikes vary in thickness from 2 to 50 and 60 feet. The great east-west dike near the southern boundary is in places over 100 feet thick. In length of continuously exposed outcrop they vary from one-half mile to as much as 10 and 12 miles. The more prominent ones are marked by high ridges with steep, taluscovered slopes, with the body of the dike as a wall-like crest or apex visible at distances of from 5 to 8 miles. As a rule they do not pursue a straight course, though some vary but little from a straight line. The most common direction is N. 65° to 70° W.; a few trend nearly north and south, others nearly east and west. There is generally a slight inclination from the perpendicular one way or the other, but the dip is not constant even for the same dike. The ultra-basic dikes frequently exhibit a distinct columnar structure normal to the walls. In one instance, that of the great east-west dike near the southern boundary, the body rises from a sheet where the latter terminates. In the same way the dikes of the Silver Mountain system, that extend a short distance within the quadrangle near the west boundary, terminate in the Black Mountain mass. From observations elsewhere it seems probable that most of the dikes of the Spanish Peaks system terminate in sheets or other form of intrusive body. Nevertheless, there are many dike occurrences that may extend to a profound depth. West of the Spanish Peaks the dikes and sheets, with but two exceptions, end in the marine Cretaceous, but west of Silver Mountain there are sheets as low as the Morrison, while south of Rye there is one dike-like body in the Archean.

Volcanic plugs.

The volcanic plugs are few in number and not always distinguishable as such. The mass known as Huerfano Butte, near the Huerfano River, is, however, a typical plug, and the smaller intrusion to the east of it is essentially of the same character. But in places there are outcropping isolated bodies, too small to be shown on the map, that are merely the extremities of apophyses, and do not occupy former channels of eruption.

Overflows.

The lava mass capping the summit of the Greenhorn Mountains is made up of several distinct overflows, the later overlying the earlier in nearly horizontal position. This mass is of considerable extent beyond the boundary of the quadrangle, but is of minor geologic importance within it. The rocks are nearly related to those of the Rosita Hills and may belong to the same series of eruptions, though they are also related to the Silver Mountain intrusive rocks.

DESCRIPTION OF THE IGNEOUS ROCKS.

*Early monzonite-porphyry.**—These rocks belong to the Spanish Peaks system and represent either several independent eruptions or distinct phases of the same eruption. In color they are usually of a grayish shade, changing to yellowish-gray where partly decomposed. The texture is generally porphyritic, though at least one fine grained variety, which is relatively abundant, shows only an occasional large phenocryst of brown hornblende. Among the feldspars, plagioclase phenocrysts predominate, but alkali feldspars are usually well represented. Except in the case of the fine-grained variety mentioned, pale-green augite is invariably present with brown hornblende, the two being about equal in importance. The large hornblendes that occur in the coarse-grained rock are often prominent on exposed surfaces and are generally aggregations of poorly crystallized individuals. The groundmass is usually granular, and the feldspars are more or less kaolinized. Augite microliths are abundant, often accompanied by shreds of biotite, and serpentine is a common product of alteration. Magnetite is present invariably, but as a fine dust, and is never abundant.

Silver Mountain monzonite-porphyry.—This rock belongs to the Silver Mountain center of eruption and is well represented in the Huerfano Park quadrangle to the westward. In many respects it resembles the early monzonite-porphyry of the Spanish Peaks system, and is related mineralogically to the monzonite varieties of the early lamprophyres, though differing from the latter in texture and habit. It is a grayish granular rock, in which aggregations of hornblende crystals in patches of from half an inch to 3 inches across are conspicuous everywhere on the exposed surfaces. The texture is distinctly porphyritic. Phenocrysts of alkali feldspar are common, but basic feldspars predominate. The dark silicates nearly equal the feldspar constituents in some occurrences. They consist of green prismatic hornblende and greenish augite, the former generally predominating over the latter. The groundmass, which is largely feldspathic, is in some cases fine grained and granular, in others coarse grained and holocrystalline. Magnetite is sparingly disseminated as a fine dust and occasionally as crystalline grains. As a rule the rock is comparatively fresh, the most noticeable evidence of decomposition being the separation of ferric oxide around the border of the hornblende.

Andesite.—This is the only extrusive rock the district affords, and its occurrence is confined to the summit of the Greenhorn Mountains. It is a dark-gray, fine-grained rock, varying slightly in appearance in the different flows and in the proportion of the dark silicates present. Feldspar phenocrysts are rarely abundant; in some cases only microlithic forms appear. It is not certain to what extent, if at all, the alkali feldspars are present, but the majority of the microlithic crystals belong to the more acid plagioclases. The most conspicuous phenocrysts are prismatically developed small crystals of green hornblende, usually more or less decomposed, and clouded by separated ferric oxide around the borders. Smaller crystals of pyroxene are also present. The feldsitic groundmass contains an abundance of augite and feldspar microliths, with considerable magnetite dust. Further investigation of this rock may show that it is the effusive equivalent of the Silver Mountain monzonite-porphyry, and more properly a latite, though at present the term andesite seems most appropriate.

Early lamprophyre.—With the exception of the basalts, this rock has a wider geographic range than any here described, its occurrences being distributed over an area 50 miles in length by 35 to 40 miles in width. The more typical varieties are of a characteristic gray color and, notwithstanding that they vary much in mineralogic composition, they possess essentially the same habit, belong to an independent series of eruptions, and are easily recognized in the field. The fine-grained rocks are distinctly granular, the coarse-grained holocrystalline. In a few of the occurrences alkali feldspars largely predominate over the basic ones, but the reverse is usually the case, though the former are always present. Generally speaking, brown hornblende, in long, needle-like crystals, exceeds the other dark silicates in amount, but in some minette-like varieties biotite in large plates is the most conspicuous mineral. Augite is always present, and at times nearly equals the hornblende. The typical rock, whether of coarse or fine texture, is further characterized by lath-shaped feldspars, which, together with the abundance of hornblende needles, at once identifies it in the field. The least typical varieties, however, are not easily recognized except under the microscope. As the composition becomes more basic and the texture more or less porphyritic, the hornblende, while still abundant, is mainly confined to the microlithic forms of the groundmass. Under the same circumstances the augite still appears, both as phenocrysts and as microliths. One highly basic variety contains much biotite with augite and altered olivine as phenocrysts in a groundmass composed of feldspar, augite, and hornblende microliths with grains and dust of magnetite. Occasionally apatite is rather abundant, though on the whole rather rare. The early lamprophyres thus constitute a series, containing alkali feldspars in varying proportions, ranging from a near approach to syenite at one extremity, through the vogesite and monzonite groups, to the camptonite varieties at the other.

Late lamprophyre.—This is one of the groups belonging to the Spanish Peaks system and grades at one extremity into the more basic early lamprophyres. The occurrences generally consist of dark-colored, fine-grained granular rocks, though in the Spanish Peaks quadrangle there is a distinctly porphyritic variety. Microscopically, the typical rock is composed of lath-shaped feldspars with the intervening spaces occupied by augite microliths, shreds of biotite, and grains of magnetite. In the majority of cases these minerals are decomposed and the spaces between the feldspars are occupied by an abundant chloritic product, the texture then simulating the ophitic. In the more acid varieties of the rock this texture disappears. Among the feldspars the basic plagioclases largely predominate, but the alkali feldspars are present to a greater or less extent throughout the group, though the prevalence of kaolinization often renders their identification difficult, if not impossible.

Granite-felsophyre.—This rock is represented by only one occurrence in the Walsenburg quadrangle, but in the country immediately to the westward it is present in masses of mountain dimensions. It is a grayish-white, fine-grained granular rock, more or less indurated on the weathered surface. The feldspars, which are of microlithic dimensions, appear to be largely orthoclase. Small grains of quartz are scattered through the mass, but the dark silicates are entirely wanting.

Basalt.—The majority of the occurrences here grouped with the basalts are simply varieties that differ from one another in the relative proportion of the constituents of the normal rock. There are, nevertheless, a few cases where the material at hand did not suffice to establish satisfactorily the true character, and future study may show that some of these are more nearly related to the late lamprophyres than to normal basalts. One variety is of coarsely crystalline texture, and contains an abundance of augite both as phenocrysts and as microliths, but very little olivine. A second variety contains an abundance of biotite, with less augite and more olivine than the preceding. The latest basalt erupted has a fine-grained and often glassy groundmass in which the olivine phenocrysts largely exceed the augite in amount.

RELATIVE AGE OF THE ROCKS.

Order of eruption.

The relative age of the rocks—that is, the order of their eruption—is indicated by the order in which they are described. It must be explained, however, that, in regard to the monzonite-porphyries and the Greenhorn andesite, the relative age is largely conjectural, especially that of the Silver Mountain and Greenhorn rocks. The dike intersections of the Spanish Peaks quadrangle show that the early monzonite-porphyry was the first rock erupted from that center, and that there were several eruptions of the rock, each more basic than the preceding. The Silver Mountain monzonite-porphyry and the Greenhorn andesite vary considerably in the relative proportion of the basic constituents, but on the whole appear to be more basic than the early monzonite-porphyry, which is also characterized by similar variations. If, as seems probable, the Silver Mountain rock was derived from the same magma as the Spanish Peaks rock, possibly from a different portion of it, the eruption of the former would correspond in time to the latest eruptions of the latter, if not to the eruption of the monzonitic varieties of the early lamprophyres, which it so closely resembles mineralogically. The possibility, as before stated, that the Greenhorn andesite is the extrusive equivalent of the Silver Mountain rock and may be of contemporaneous age, and that it is also closely related to the same varieties of the early lamprophyres, is the only consideration that suggests placing it before the latter in order of eruption. As to the remaining rocks of the quadrangle, the occurrences in the Spanish Peaks region indicate with considerable certainty that their age, with respect to one another and to the earlier eruptions, corresponds to the order in which they are described.

Number of eruptions.

The groups of igneous rocks that are included in the foregoing description are really less numerous than the aggregate of the eruptions that took place at the centers from which they came. The dike intersections show that there were no fewer than four eruptions of early monzonite-porphyry in that region, and three of these are represented by occurrences in the Walsenburg quadrangle. It is noteworthy that the proportion of the dark silicates increased with each succeeding eruption of this rock. The varieties of the early lamprophyres indicate at least two eruptions—the hornblende-augite varieties and the micaceous varieties; but which of them was first erupted is uncertain. The late lamprophyres and basalts, especially the latter, may each be said to represent two eruptions, though the relative age of the varieties in either group has not been determined. Of the remaining groups, each corresponds to but one independent eruption. It is thus certain that the occurrences in the quadrangle represent not fewer than nine distinct eruptions, and very probably as many as twelve.

Period of eruption.

The earliest of these was subsequent to the close of the Huerfano Eocene and was most probably associated with the mountain-making disturbances that followed, as shown by the relation of the occurrences to the upturned Eocene beds. The later eruptions were also associated with similar, though less pronounced, movements.

ECONOMIC GEOLOGY.

Coal the most important product.

Coal is the most valuable of the mineral products of the district, and coal mining is the chief industry, the bulk of the coal mined in Huerfano County being produced in the southwest quarter of this quadrangle. Petroleum has been found, but not in quantities of economic value. Sandstone adapted for structural purposes abounds, while the exposures of limestone are rather extensive. Fire clay of excellent quality underlies the greater part of the area, and over nearly the whole of the northeast quarter of the quadrangle can be rendered accessible. Beds of calcareo-arenaceous shale, much of which is probably adapted for the manufacture of cement clinker, are also available. Deposits of precious or other metals have yet to be discovered, though their existence in the Archean area of the Greenhorn Mountains is not altogether improbable, as they occur elsewhere in the same area.

COAL.

Age of the measures.

General relations.—The coal-bearing area of the quadrangle corresponds to the northeastern portion of the Raton coal field—that is, the portion on the east side of the Huerfano Basin as far north as the coal beds extend, and, indeed, the most northerly portion of the field. The productive measures are of Laramie age, and the present mines are operated on seams that lie near the base of this formation, the lowest seam operated being situated within 10 feet or less of the Trinidad sandstone.

Extent of the outcrop.

The eastern margin of the outcrop is marked by an irregular line of steep bluffs, with the Trinidad usually well exposed near the base. These bluffs extend from about the center of the south boundary in a northwesterly direction to within 3 miles of the Huerfano River at a point due south of Saint Mary. This is the most northerly extremity of the coal outcrop as well as of the line of bluffs. The former, extending thence southwesterly, and finally nearly due south, continues as far west as Black Mountain, though, so far as known, the coal does not reach the western boundary of the quadrangle.

Two groups of seams.

Diamond-drill borings south of Walsenburg, as well as numerous outcrop excavations and the extensive mine workings, indicate the presence of two groups of seams that afford workable bodies of coal. (See detailed sections on the Columnar Section sheet.) These lie well toward the base of the measures, and are separated from each other by a prominent bed of sandstone, from 30 to 60 feet in thickness, situated about 100 feet above the Trinidad sandstone. Both these sandstones are relatively conspicuous, the interval between them being occupied by shale, sand shale, and thin-bedded, fine-grained sandstone.

Workable coal not continuous.

The productive seams are not of workable size throughout the district, but usually afford areas of "high coal," 4 feet or more in thickness, at several points along the outcrop. These areas are from one-half mile to 2 miles across, the intervening areas containing "low coal," less than 4 feet in thickness, or the seams may be too small to work under existing conditions.

Variation in number of seams.

The variation in thickness is generally the result of expansion or contraction of the seam, though in a few instances two thin seams coalesce and produce "high coal" over an important area. Not only do the seams vary in thickness from place to place, but the number of

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*A related rock of the Spanish Peaks system, termed late monzonite-porphyry, does not occur in the Walsenburg quadrangle.

Overlapping areas of coal.

seams in a group will vary — that is, small seams present in one section may be absent in another section less than a mile distant. Want of continuity is, therefore, a characteristic of the district, as of the Raton field generally. It is noteworthy that when one seam expands or thickens there is nearly always parallel expansion of one or two other seams, as though there had been a local recurrence of the conditions favorable to coal formation. This fact is also characteristic of the field throughout, at least in respect to the lower groups, and it is usually the case that where the lowest seam is workable there are overlapping areas of workable coal in other seams.

The most important group. **Number of seams in group.**

Walsenburg-Pictou group.—This is the lower of the two groups of seams recognized, and corresponds to the Berwind-Aguilar group of the Spanish Peaks quadrangle. In this district it is the source of all the coal produced, and mines are in operation on each of the three workable beds it affords. The seams comprising it lie in the shaly part of the measures between the Trinidad formation and the "parting sandstone." South of Walsenburg, where accurate measurements have been made in a number of places by drill borings, the distance between the two sandstones ranges from 75 to 108 feet. The same borings indicate the presence of from three to four seams, 12 inches thick and upward. In all cases the existence of several thinner seams was demonstrated. Coal over 4 feet in thickness was shown only in the vicinity of the old Rouse mine, where the lowest seam in the group expanded to 6½ and 7 feet. This bed thins down to 18 inches near the southern boundary, but thickens up again just south of the boundary. Northward, as far as Walsenburg, it affords less than 4 feet of coal, usually a little over 3 feet, though at an intermediate point south of Bear Creek for a distance of nearly a mile it has been destroyed by a lava sheet. From 35 to 45 feet above this seam the borings show another seam, which, along the outcrop in the vicinity of Rouse and for several miles north, has been destroyed by lava, but exposures of workable size are found near the south boundary and beyond, and are present in the borings west of the Rouse mine. At the Santa Clara mine this is called the Walsen seam, owing to its relative position and resemblance to the Walsen seam at Walsenburg, though the connection has not been traced and the identity is by no means certain.

The workable coal.

Where the Walsenburg mines are located, on the Cuchara, and at Pictou, north of Walsenburg, the existence of three workable seams has been demonstrated by the mine workings. The lowest seam — known as the Cameron at Walsenburg and as the Maitland at Pictou — is 39 inches thick on the Cuchara. It thickens going north, and in the Pictou mine is 5 feet thick. In the same locality there is a 30-inch seam 14 feet above the Maitland. The Walsen seam at Walsenburg is situated about 35 feet above the Cameron. It includes a lower bench 48 inches thick separated from an upper bench from 36 to 40 inches thick by a 2-inch parting of yellow clay. This seam is called the Lennox in the Pictou workings. There the lower bench is 5 feet thick and is separated by 18 inches of rock from the upper one, which is from 20 to 24 inches thick. The Robinson seam of the Walsenburg mines lies about 60 feet above the Walsen. This seam is about 6½ feet thick in the Robinson mine, though in places it becomes a two-bench bed with a streak of soft carbonaceous matter, or "dirt," near the middle. The same seam appears at Pictou, where it is from 4 to 4½ feet thick. A short distance north of Pictou all three seams contract, the lower one alone affording about 40 inches of coal. Toward the northern extremity of the outcrop it again expands to about 5 feet, in two benches, and continues of this size for about 3 miles along the westerly trending outcrop, but eventually becomes badly streaked with impurities.

Limited extent of group.

The upper group.—This group corresponds to the Sopris group of the Spanish Peaks quadrangle, and in the Walsenburg area is not very well defined. It affords but one workable seam; this is in the southern part of the district, south of Pictou. The borings west of the old Rouse mine show a seam 4 to 4½ feet thick. South of Rouse it is well exposed by surface excavations showing a 5- to 5½-foot seam as far south as the boundary of the quadrangle. The vertical distance between this seam and the Robinson is from 75 to 77 feet near the south boundary, though considerably less than this at Walsenburg, where it is known as Robinson No. 2. At this point it is difficult to separate the two groups, and it is only by tracing the seams from the south that it is possible to distinguish them.

Character of the roof and floor.

General features.—The character of the roof and floor material is by no means constant. The roof is sometimes shale, at others sandstone, thick coal being generally found under a shale roof, and the dipping down of the sandstone usually indicates early thinning of the seam. The floor is generally shale, of the kind called fire clay by the miners, owing to its refractory nature, which results from the removal of the iron in the material immediately underlying the coal. But the shale is often reduced to a mere scale resting upon the sandstone.

Impurities. **General absence of explosive gases.** **Water.**

Sometimes the coal is "frozen" to the floor or to the roof and does not part readily from the adjacent rock, some of which may become mixed with the product. Bony streaks are common, though on the whole of less frequent occurrence than in the southern part of the Raton field. Partings of shale, clay, or sandstone are not rare, and their presence tends to increase the amount of impurities in the coal. The occurrence of natural coke is common, this substance being always found adjacent to the numerous dikes cutting the measures. Certain layers in the seams afford purer coal than others, and the quality varies as these layers expand or contract. Explosive gases are rarely present, but occasionally accumulate in abandoned parts of a mine. An explosion that resulted fatally was due to carelessness in entering old workings that had been abandoned and not ventilated for years. Absence of gas, however, does not insure a district against explosions of dust which may be started by a heavy blast and gather force as the rush of air whirls up more dust from the surfaces exposed in the rooms and roadways. The presence of considerable water in the measures of the district is to some extent a safeguard against dust explosions. The presence of an abundance of water in the measures has, indeed, added considerable to the expense of operating the mines, the working at Rouse having been abandoned mainly from this cause. Here there does not seem to have been a sufficient thickness of shale between the coal and the Trinidad sandstone, so that the water in the latter, when under less than 100 feet head, was capable of forcing up the shale floor and inundating the mine.

The inclination of the outcrop. **Normal faults.** **Overthrusting movement.**

Structural features.— The greatest inclination of the beds, which is southwesterly, occurs generally near the outcrop or a short distance back of it, though the dip does not materially decrease for several miles. West of the old Rouse mine the dip reaches 8°, though it is less than this in the mine workings. Going north along the outcrop, there is in places a slight increase, especially north of Walsenburg and at the northern extremity of the field. Where, as before explained, the dip changes to the southward it increases to 14° and 15°. Normal faults are rather numerous in the southern part of the district. Their course is nearly parallel with the axis of the flexure, and they have no relation to the dikes of the region; in fact, the latter do not fault the measures in the slightest degree. Geologically speaking, these faults are not of great importance, but they entail considerable extra expense in coal-mine operations. The displacement ranges from a few inches up to 25 feet, though in one instance — on the Santa Clara at the boundary line — the amount greatly exceeds this. The location of this fault is shown on the sheet. The thrusting of one portion of the measures over a lower portion, of which there are so many examples in the southern part of the Raton field, has not taken place to any considerable extent. The "dirt" streak in the Robinson seam is probably attributable to movement of this character, and similarly the "kidney" coal of the Pictou mines. The limited number and insignificant size of the intruded lava sheets, as compared with those of the Spanish Peaks quadrangle, are no doubt responsible for the small amount of overthrusting in this area.

Absence of true coking coal. **Increasing dryness of the coal northward.**

Composition of the coal.—The coal from the different mines varies materially in composition, though from one end of the district to the other the coal is of the semi-coking or domestic kind, true coking coal being unknown in this part of the field. Generally speaking the lowest seam affords the best quality of coal. But all the seams yield a product of fair quality and lower in ash percentage than that mined in the southern districts of the field. Their continued and extensive use for steaming shows that they are excellent coals for that purpose. The product from the southern part of the district is, if anything, more disposed to fuse or coke on heating than that from the Walsenburg mines, while Pictou coal cokes less than either of the other products. At the northern extremity of the field the coal scarcely cokes at all and approaches the Canyon type in composition, though not in purity. This increasing dryness of the coal — that is, the disappearance of the coking property — is really progressive from the Raton Mountains northward. The accompanying table of analyses, reproduced from Mineral Resources of the United States, 1892, shows — noticeably in the increasing percentage of water in the coals of the northern part of the district — this gradual change in composition, though not so strikingly as would a list representing the entire Raton field.

Position of eruptive bodies an important factor.

Changes produced by eruptions.—In localities in the Rocky Mountains where Laramie coal has not been deeply buried under later accumulations of sediments or where eruptions of lava have not taken place, it still remains in the condition of lignite, contains a high percentage of water, and does not possess in the slightest degree the property of coking. Earth movement, resulting in folding and contorting of the strata, has likewise been instrumental in promoting the alteration of lignite. But depth of sediments and earth movement combined have rarely sufficed to transform Laramie lignite into true coking coal, though observation elsewhere indicates that these causes are competent to transform such lignite into coal of the kind found in the Walsenburg quadrangle. But it does not appear that the eastern border of the Raton coal field was ever deeply buried, or the earth movement sufficiently pronounced to produce this change, which must in the main be attributed to the effect of the injection of lava into the measures, more particularly into the underlying formations. The changes that in other fields have evidently resulted from this cause are seen to be connected with the intrusion of bodies of lava beneath the measures, and scarcely at all with their intrusions into overlying beds, unless such bodies are of large size or are near. The action of ascending steam generated by the injection of lava into strata invariably containing water seems most probably the promoting cause. In the southern part of the district, where the coal cokes most strongly, the intrusive sheets, or sills, are rather extensive, but they are limited to the section of country south of Walsenburg. From this point north the coking property soon disappears, and to the effect of the dikes alone must be attributed the alteration of the coal that has advanced beyond the lignite stage.

Formation of natural coke.

Wherever a bed of coal is crossed by a dike or has been invaded by a body of lava forming a sheet the substance called natural coke is always present. The amount of coal thus changed will depend on the thickness of the dike and the magnitude of the sheet. The dikes in the old Rouse mine were from 30 to 40 feet thick and the coking extended about the same distance on each side. The Walsen seam at the same place shows natural coke mingled with lava at every outcrop excavation, the main body of the lava being toward the floor and the coke largely toward the roof. The coke is always finely porous and of prismatic structure, the size of the individual prisms depending on the coking property of the coal. Thus, in the southern part of the field the prisms are relatively large, owing to the coal being of the coking variety. At Rouse, where the coal is but semi-coking, the prisms are smaller, while at Pictou, where the coal scarcely cokes at all, the prisms are about one-half the size of those at Rouse. This also goes to show that, whatever the effect of the later eruptions, it was mainly the earlier ones that exercised the greatest influence in promoting alteration. The smaller bodies of lava that have been brought into contact with the coal are invariably badly decomposed, the feldspars are kaolinized, calcite is formed, and the iron of the dark silicates is removed. Presumably these changes result from the action of carbon dioxide, hydrocarbons, and steam at the high temperature at which the contact occurred.

Total area of productive measures.

Area of workable coal.—The total area of the measures outcropping within the quadrangle is approximately 50 square miles, of which 32 square miles are embraced in the outcrop of the coal-bearing portion, though above the horizon of the upper group the seams are all too thin to be workable under existing conditions. There is little question, however, that the area that will eventually be rendered accessible will greatly exceed 32 square miles, as it is practicable by means of deep shafts to reach much of the coal which it is safe to assume passes uninterrupted under nearly the entire area of the Eocene beds. It is thus probable that the total area of workable coal within the quadrangle approximates 160 square miles.

Method of mining.

Coal mining.—The important producing mines are located on the Santa Clara and at Walsenburg and Pictou. The mines have a capacity of from 150 to 1000 tons daily, though the output varies greatly with the season and is highest during the fall and winter months. All the mines are worked on the "room-and-pillar" system — that is, from the main slope, which usually takes the full dip, cross entries are turned off at regular intervals, and from these the rooms are turned every 50 feet and carried forward a distance of about 300 feet, pillars being left on the side to be subsequently removed. The distance between the cross-entries depends on whether the dip will admit of rooms being turned both ways or only to the "rise." Accordingly the entries may approximate 300 feet or 600 feet apart, as the circumstances may require. They are usually run with a slight down grade in favor of the loads, or toward the main slope, and follow in consequence a very irregular course, owing to the frequent variations in dip. All underground haulage away from the main slopes is done by mules. Steel pit cars are very generally used. They hold from 2500 to 3000 pounds, are brought to the surface by steam power, and the coal, separated by screens into "lump," "nut," and "slack," is loaded on railway cars standing on track scales, the increase of weight as each pit car is dumped being credited to the miner whose numbered tag accompanies it. The miners are usually paid on the basis of the lump coal produced, the present mining price being 70 cents per ton of 2000 pounds. This plan is advantageous to the skilful miner and insures the maximum production of the most valuable size of coal.

SANDSTONE.

There are no fewer than five formations that afford different varieties of sandstone within the quadrangle. They vary much in color, texture, and adaptability, and are not all of them suitable for the better grades of structural work.

Morrison sandstone.

The white sandstone near the base of the Morrison formation is too soft and friable to have any value as a building stone except at a few points, accessible with difficulty, along the eastern base of the Greenhorn Mountains, where the steeply upturned beds are well exposed.

Dakota sandstone.

The sandstone of the Dakota formation is one of the most valuable rocks for structural purposes that the district affords. The best quality of stone is found in the upper 100 to 150 feet of the formation, or that which lies above the bed of fire clay. This is also the most accessible portion. The rock is of a light-gray color when fresh, of fine grain and regular bedding, and possessed of great firmness and resisting power. While it has been largely used as a building stone in other parts of the country, it has not been quarried to any extent in this district, where it is easily accessible and where the quantity available is practically unlimited.

Trinidad or Halymenites-bearing sandstone.

The upper half of the Trinidad formation affords a sandstone of medium grain and hardness that is of an even greenish-gray tint away from the weathered surface when quarried. The only objection to it is that in places the evenness of the texture is impaired by the presence of *Halymenites*. Otherwise its homogeneity and accessibility render it a valuable building stone, and one that has been found well adapted for structural work. There are a number of suitable locations between Santa Clara and Pictou where this stone could be quarried to advantage.

Laramie sandstone.

The entire Laramie formation affords beds of sandstone adapted for building purposes. The rock is of light-gray color and even texture, though the different layers show considerable variation both in tint and in texture. As a rule it is more porous than the Trinidad sandstone, and less resistant. The best layers are situated toward the top of the formation. The quantity is practically unlimited, as it is coextensive with the outcrop of the formation.

Eocene sandstone.

The Poison Canyon and Cuchara sandstones are generally too soft and friable or too porous and coarse textured to be of much structural value; but certain of the Cuchara beds afford sandstone of medium grain and of such degree of firmness that, on account of the desirable pale-pink and greenish-gray tints, they are well adapted for building purposes. The shade of color differs in the different beds, but is constant in the same bed. These sandstones are all thick bedded and are disposed to weather into cavernous forms. Their occurrence is restricted to the southwest corner of the quadrangle.

LIMESTONE.

Morrison limestone.

The Morrison formation contains thin bands of limestone that, in sections of the country where there are no other occurrences of the rock, is often used for the manufacture of lime.

Greenhorn limestone.

The Greenhorn limestone affords a narrow, irregular outcrop extending from the southeastern corner of the quadrangle to the northern border and along the base of the Greenhorn Mountains. It is a hard, dove-colored limestone occurring in layers less than 6 inches thick, separated from one another by partings of shaly material. This rock is also available for burning into lime.

Timpas limestone.

The Timpas limestone, however, is better adapted for this purpose and for fluxing, exists in unlimited quantities, and is easily accessible. The best exposures lie close to the railroad in the north-central portion of the quadrangle. The rock forms the base of the formation, and on account of its resisting power usually appears as an escarpment. The limestone occurs in layers from 6 to 12 inches thick, separated from one another by shaly partings. In the Pueblo quadrangle, to the north, this limestone is extensively quarried for the use of the smelting establishments.

FIRE CLAY.

Dakota fire clay.

The so-called fire clay that occurs frequently as the floor of a coal seam, while refractory to a certain extent, owing to the removal of the iron oxide by the reducing action of carbonaceous matter, has little or no value for the manufacture of refractory ware. The great source of superior fire clay is the Dakota formation, from which the material is obtained that is now so extensively used in the manufacture of bricks, tile, muffles, and crucibles. The adaptability of material for this purpose depends as much on its physical properties as on its chemical composition, and the only sure test is subjection to a high temperature.

Practical demonstration of its quality.

A sample of Dakota fire clay taken from a natural exposure near the east boundary of the quadrangle was submitted to the Standard Fire Brick Company of Pueblo, and subjected to this test by exposing the sample for thirty-six hours to the full heat of the kilns. Upon removal the clay was found to be of a dead-white color, with scarcely a trace of iron oxide, and absolutely no indication of softening even on the thin edges of the fragments.

Extent of the bed.

The position of the bed is about 100 feet, in places considerably more, below the top of the Dakota sandstone, and it is often exposed naturally in the canyons that have been eroded in the formation. The bed itself is from 8 to 10 feet thick. The material is of a light-gray to greenish-gray color, shaly in appearance, and breaking rather easily into fragments of conchoidal fracture. It is not of the same composition throughout, and there are local impregnations of iron oxide that seriously impair the quality. The bed undoubtedly underlies all the territory mapped as Dakota. In the canyons it can be developed by tunnels from the outcrop; elsewhere by shafts from 100 to 150 feet deep. Except along the mountain border and for a short distance along the great fault south of Graneros, the bed is practically in horizontal position and the material can be mined by the methods employed in operating a flat seam of coal.

OTHER MINERALS OF ECONOMIC VALUE.

Cement rock.

The middle portion of the Apishapa formation is largely made up of calcareo-arenaceous shaly layers that may be regarded as a promising source of cheap material for the manufacture of cement clinker. One of the most accessible localities lies on the Santa Clara east of a point on the Denver and Rio Grande Railroad midway between Cuchara and Rouse junctions. Another locality is the low bluff about 6 miles east of Rouse Junction, where the rock forms a prominent escarpment.

Petroleum.

The existence of petroleum in quantities of economic value is among the possibilities. About 2 miles north of the Huerfano River, near the west boundary of the quadrangle, there are two small dikes of dark-colored basalt. At the point where they cut through the bituminous material of the Apishapa formation the cavities in the dike rock afford sufficient crude petroleum to soil the hand when the rock is freshly broken. The supposition is that the oil has resulted from the action of the lava at a high temperature on the adjacent bituminous matter, and that at other points where the same formations are cut by larger and more numerous bodies of eruptive rock the same process may have operated on a more extensive scale.

ARTESIAN WATER.

What constitutes artesian water.

Water which under ordinary conditions exists at a greater or less depth below the earth's surface, but which is potentially capable of rising to a higher level, called its plane of head, is termed artesian. Such water is usually contained in a porous stratum that is overlain by impermeable beds, and has its source at a higher and more or less distant point of inflow.

Conditions that favor an artesian flow.

The structural forms usually involved in the establishment of artesian conditions are: (1) A basin-shaped or trough-shaped depression having an inflow on all sides. This form occurs in the arid regions of the West, and is illustrated in cross section by fig. 1.

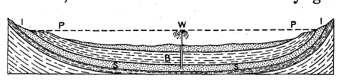


FIG. 1.—Ideal section of a basin-shaped depression.

SS, water-bearing stratum. B, impermeable bed. W, well. II, inflow. PP, plane of head.

(2) An asymmetric synclinal depression or laterally inclined trough having the inflow on one side

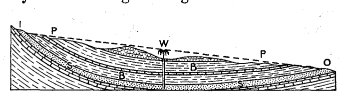


FIG. 2.—Ideal section of a depression having inflow on one side and outflow on the opposite side.

SS, water-bearing stratum. BB, impermeable bed. I, inflow. O, outflow. W, well. PP, plane of head.

and the outflow on the opposite side, as shown in fig. 2, which is an ideal cross section of such a depression. Gently dipping monoclinal strata would produce a modification of this form. (3) A synclinal flexure in which the passage of the water toward the outflow side is partly or entirely obstructed by either faults or dikes in such a way that the edge of the water-bearing bed is brought in direct contact with an impermeable formation, as shown in the ideal section, fig. 3. This obstruction might also be caused by the change of the porous stratum toward the center of the basin into an impermeable bed.

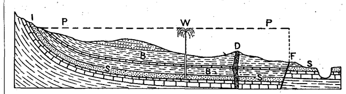


FIG. 3.—Ideal section showing artesian conditions where the outflow is obstructed by faulting.

SS, water-bearing stratum. BB, impermeable bed. D, dike. F, fault. W, well. I, inflow. PP, plane of head.

Artesian structure of the quadrangle.

The geologic structure of the quadrangle, so far as it affects the artesian conditions, is partly a combination of the conditions illustrated by figs. 2 and 3—that is, a laterally inclined trough more or less dislocated by faults toward the outflow side. As regards the northern portion of the area, the inflow takes place along the upturned outcrop of the strata at the base of the Greenhorn Mountains; as regards the southern portion, the inflow is along the similarly upturned outcrop at the base of the Sangre de Cristo Range to the westward.

The water-bearing Dakota.

There are two formations that are potentially capable of furnishing artesian water—the Dakota and the Poison Canyon. The Dakota sandstone is the chief water-bearing formation of southeastern Colorado, and a number of flowing wells derive their supply from this source. While the upper portion of the Dakota will afford a little water, the lower portion is the main reservoir—that is, the 200 or 250 feet of open, porous sandstone and fine conglomerate which lies below the bed of fire clay. This sandstone underlies the greater part of the area, but is too deep to be available in the southwestern part, west of the outcrop of the Trinidad formation.

The artesian contours.

The contours on the Artesian Water sheet indicate the approximate depth in feet to the base of the fire-clay bed, or top of the principal water-bearing zone, to a depth of 3000 feet. These contours are based on the ascertained thickness of the several overlying formations, and to a depth of 1500 feet may be accepted with considerable confidence. Beyond this depth the increasing thickness of the Pierre formation northward, and the difficulty of accurately measuring it, introduce an element of uncertainty that renders the higher contours subject to an error of from 200 to 300 feet.

Lower Eocene water.

The Poison Canyon beds, owing to their limited extent, are much less important than the Dakota as a source of artesian water; yet the area they occupy is sufficiently large to warrant their consideration in this connection. The structural conditions are similar to those affecting the Dakota, except that while dikes are present faults are absent. But the obstructive influence of the former is largely neutralized by the fact that where they occur they tend mostly to obstruct the flow from the westward, whereas there is also a flow from the direction of the Spanish Peaks, or from the southward. The thickness of the formation and the open, porous texture of the sandstones and their alternation with impermeable beds of clay afford ideal conditions for artesian water, each alternation in depth constituting an additional source of supply. Thus, the deeper the well the more water it may be expected to yield.

Pumping wells.

In regard to the location of pumping wells, the area that will furnish them is practically coextensive with the accessible portions of the two formations.

Areas that will afford flowing wells uncertain.

In regard to the area that will probably afford flowing wells, it would be useless and misleading to indicate the extent of territory covered by the plane of head. Even if the resistance to the passage of water through the interstices of the rock were uniform, which is not the case, or if other causes affecting the flow were absent, the sinking of a few wells would materially lower this plane and reduce the area lying below it. Accordingly, the map does not indicate the full extent of the territory in which flowing wells may be obtained, but merely the most favorable areas, or localities where trial borings to the requisite depth are most likely to prove successful.

Precautions to be observed in boring.

To obtain the strongest available supply, a bore hole should penetrate to the base of the Dakota formation; and to insure the preservation of the bore through the soft, shaly beds above, it should be cased down to the sandstone as soon as the latter is reached. Many wells are lost through neglect to observe this precaution. (See artesian-water section on the Columnar Section sheet.)

Time required to put down a well.

With an ordinary drill of the size used in oil-well boring, and two shifts of men, a well can be put down through 1000 feet of the Pierre shale to its base in less than three weeks, provided no serious difficulties are encountered, such as the drill becoming fastened in the bore. The next 1100 feet through the Niobrara and Benton formations may require five weeks' additional time, as the limestones of the Timpas and Greenhorn and the hard shales of the middle portion of the Apishapa are not so easy to penetrate. The 350 to 400 feet of Dakota sandstone will require from two to three weeks, owing to the hardness of the rock, the increasing depth, and the time required to remove the cuttings from the bottom. Accordingly, it will take about three months' time to put down a bore to the base of the Dakota at a depth of 2500 feet and case it to the top of the formation.

Cost of well boring.

The cost of such work in Huerfano County, exclusive of the iron casing and the rental of the machinery, but including fuel and supplies, will amount to about $20 per day. Boring in the Poison Canyon formation will cost the same per day, but the time required will be longer in proportion. However, it is not likely that wells of a greater depth than 1500 feet will be required in the Poison Canyon formation within the limits of this quadrangle.

R. C. HILLS,
Geologist.

August, 1900.

Analyses of coals from the Walsenburg quadrangle.

Name of mine and seam.	Carbon.		Hydrogen.		Oxygen.	Nitrogen.	Sulphur.	Moisture.	Ash.	Volatile combustibles.	Specific gravity.
	Fixed.	Combined.	Disposable.	With oxygen.							
1. Rouse—Cameron	53.43	20.87	4.08	1.14	9.10	1.00	0.77	2.36	7.25	36.96	1.329
2. Rouse—Cameron	51.12	22.82	3.76	1.24	9.94	0.99	0.56	2.12	7.45	39.31	1.316
3. Rouse—Cameron	52.04	21.73	3.69	1.16	10.00	0.75	0.72	2.06	7.75	38.15	1.318
4. Rouse—Cameron	52.77	20.79	4.21	1.01	8.12	1.35	1.48	3.50	6.77	36.96	1.326
5. Rouse—Cameron	52.52	20.42	3.99	1.13	9.06	0.80	0.69	3.39	8.00	36.09	1.325
6. Rouse—Cameron	50.78	17.39	3.24	1.58	12.60	0.80	0.72	2.48	10.45	36.29	1.330
8. Walsenburg—Cameron	54.05	19.15	3.86	1.41	11.33	1.36	0.67	2.62	5.55	37.78	1.302
9. Walsenburg—Walsen	49.91	22.25	3.61	1.20	9.55	1.31	0.60	2.97	8.60	38.52	1.312
10. Pictou—Lennox	51.05	21.25	3.84	1.54	12.31	1.29	0.60	3.27	5.05	40.63	1.342
11. Pictou—Maitland	54.53	17.02	3.50	1.48	11.87	1.26	0.74	4.01	5.75	35.71	1.320
12. Huerfano—Upper Bench	49.70	18.25	3.15	1.51	11.99	0.83	0.64	6.74	7.20	36.36	1.352
13. Huerfano—Lower Bench	48.52	19.24	2.97	1.47	11.82	0.92	0.55	6.54	7.97	36.97	1.348

1. Hard, compact coal, 120 feet from surface, but above water level.
2. Average of clean coal above water level.
3. Average of clean coal, 175 feet from surface, but above water level.
4. Average of clean coal, 6th west entry, below water level.
5. Average of clean coal, whole of No. 2 entry, above water level.
6. Average of large lot in bin, Denver.

(7. Excluded; taken near present Pictou mine, but too near the crop to be characteristic.)

8. Clean coal below water level.
9. Clean coal with calcite in fractures.
10. Large, clean piece below water level.
11. Large, clean piece below water level.
12. Clean coal above water level.
13. Clean coal above water level.

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

TOPOGRAPHIC SHEET

COLORADO
WALSENBURG QUADRANGLE

LEGEND

RELIEF
(printed in brown)

Figures
(showing heights above mean sea level instrumentally determined)

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

Depression contours

DRAINAGE
(printed in blue)

Streams

Intermittent streams

Lakes and ponds

Intermittent lakes

CULTURE
(printed in black)

Roads and buildings

Railroads

County boundary lines

Triangulation stations

Henry Gannett, Chief Topographer.
E. M. Douglas, Topographer in charge.
Triangulation by A. H. Thompson.
Topography by R. O. Gordon and W. J. Lloyd.
Surveyed in 1894.

Scale $\frac{1}{125000}$

Contour interval 50 feet.
Datum is mean sea level.

Edition of June 1900.

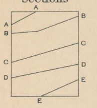
U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

HISTORICAL GEOLOGY SHEET

COLORADO
WALSENBURG QUADRANGLE

LEGEND
(continued)

Sections



Henry Gannett, Chief Topographer.
E. M. Douglas, Topographer in charge.
Triangulation by A. H. Thompson.
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Surveyed in 1894.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.

Datum is mean sea level.

Edition of Sept. 1900.

Geology by R. C. Hills.
Surveyed 1895-1896.

LEGEND

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

NEOCENE

Nn — Nussbaum formation *(sandstone and conglomerate)*

EOCENE ?

Ech — Cuchara formation *(cavernous variegated sandstone, brown clay and sand at base)*

Epc — Poison Canyon formation *(conglomerate and sandstone with beds of yellow clay)*

CRETACEOUS

Kl — Laramie formation *(sandstone and shale containing seams of coal)*

Ktd — Trinidad formation *(massive and shaly sandstone)*

Kp — Pierre shale *(shale of various shades of gray with concretions)*

Subdivisions of the Niobrara formation

Ka — Apishapa formation *(coarsely laminated shale often bituminous; paper shale at base)*

Kt — Timpas formation *(calcareous shale with thin-bedded limestone)*

Kcr — Carlile shale *(gray shale capped by soft sandstone)*

Kgn — Greenhorn limestone *(thin-bedded limestone with shale partings)*

Kgs — Graneros shale *(gray and dark-colored shale with concretions)*

Kd — Dakota sandstone *(fine-grained massive sandstone, fireclay, coarse sandstone, and conglomerate)*

JURATRIAS

Jm — Morrison formation *(variegated shale and clay, limestone, and sandstone)*

CARBONIFEROUS ?

Cb — Badito formation *(fine-grained red sandstone and coarse conglomerate)*

IGNEOUS ROCKS
(Areas of Igneous rocks are shown by patterns of triangles and rhombs.)

EOCENE and NEOCENE

an — Andesite *(lava flow)*

llp, bs, gf — Late lamprophyre, basalt, and granite-felsophyre *(dikes and sheets)*

smp, elp, emp — Silver Mt. monzonite-porphyry, early lamprophyre, and early monzonite-porphyry *(stocks, dikes, and sheets)*

UNCLASSIFIED CRYSTALLINE ROCKS
(Areas of Archean rocks and metamorphic rocks of unknown origin are shown by patterns of short dashes.)

ARCHEAN

ARs — Granite and schist

Faults

Legend is continued on the left margin.

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

ECONOMIC GEOLOGY SHEET

COLORADO
WALSENBURG QUADRANGLE

Henry Gannett, Chief Topographer.
E. M. Douglas, Topographer in charge.
Triangulation by A.H. Thompson.
Topography by R.O. Gordon and W. J. Lloyd.
Surveyed in 1894.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.

Datum is mean sea level.

Edition of Sept. 1900.

Geology by R.C. Hills.
Surveyed 1895–1896.

LEGEND (continued)

Sections

⚒ Coal mines

Known productive formations

Kl — Coal (*Laramie formation contains semi-bituminous coal in its lower portion*)

Fire clay (*workable bed in the upper portion of the Dakota sandstone*)

LEGEND

SEDIMENTARY ROCKS

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

NEOCENE

- Nn — Nussbaum formation (*sandstone and conglomerate*)

EOCENE ?

- Ech — Cuchara formation (*cavernous variegated sandstone, brown clay and sand at base*)
- Epc — Poison Canyon formation (*conglomerate and sandstone with beds of yellow clay*)

CRETACEOUS

- Kl — Laramie formation (*sandstone and shale containing seams of coal*)
- Ktd — Trinidad formation (*massive and shaly sandstone*)
- Kp — Pierre shale (*shale of various shades of gray with concretions*)
- *Subdivisions of the Niobrara formation*:
  - Ka — Apishapa formation (*coarsely laminated shale often bituminous; paper shale at base*)
  - Kt — Timpas formation (*calcareous shale with thin-bedded limestone*)
- Kcr — Carlile shale (*gray shale capped by soft sandstone*)
- Kgn — Greenhorn limestone (*thin-bedded limestone with shale partings*)
- Kgs — Graneros shale (*gray and dark-colored shale with concretions*)
- Kd — Dakota sandstone (*fine-grained massive sandstone, fireclay, coarse sandstone, and conglomerate*)

JURATRIAS

- Jm — Morrison formation (*variegated shale and clay, limestone, and sandstone*)

CARBONIFEROUS ?

- Cb — Badito formation (*fine-grained red sandstone and coarse conglomerate*)

IGNEOUS ROCKS

(Areas of Igneous rocks are shown by patterns of triangles and rhombs.)

EOCENE and NEOCENE

- an — Andesite (*lava flow*)
- llp, bs, gf — Late lamprophyre, basalt, and granite-felsophyre (*dikes and sheets*)
- smp, elp, emp — Silver Mt. monzonite-porphyry, early lamprophyre, and early monzonite-porphyry (*stocks, dikes, and sheets*)

UNCLASSIFIED CRYSTALLINE ROCKS

(Areas of Archean rocks and metamorphic rocks of unknown origin are shown by patterns of short dashes.)

ARCHEAN

- ARs — Granite and schist

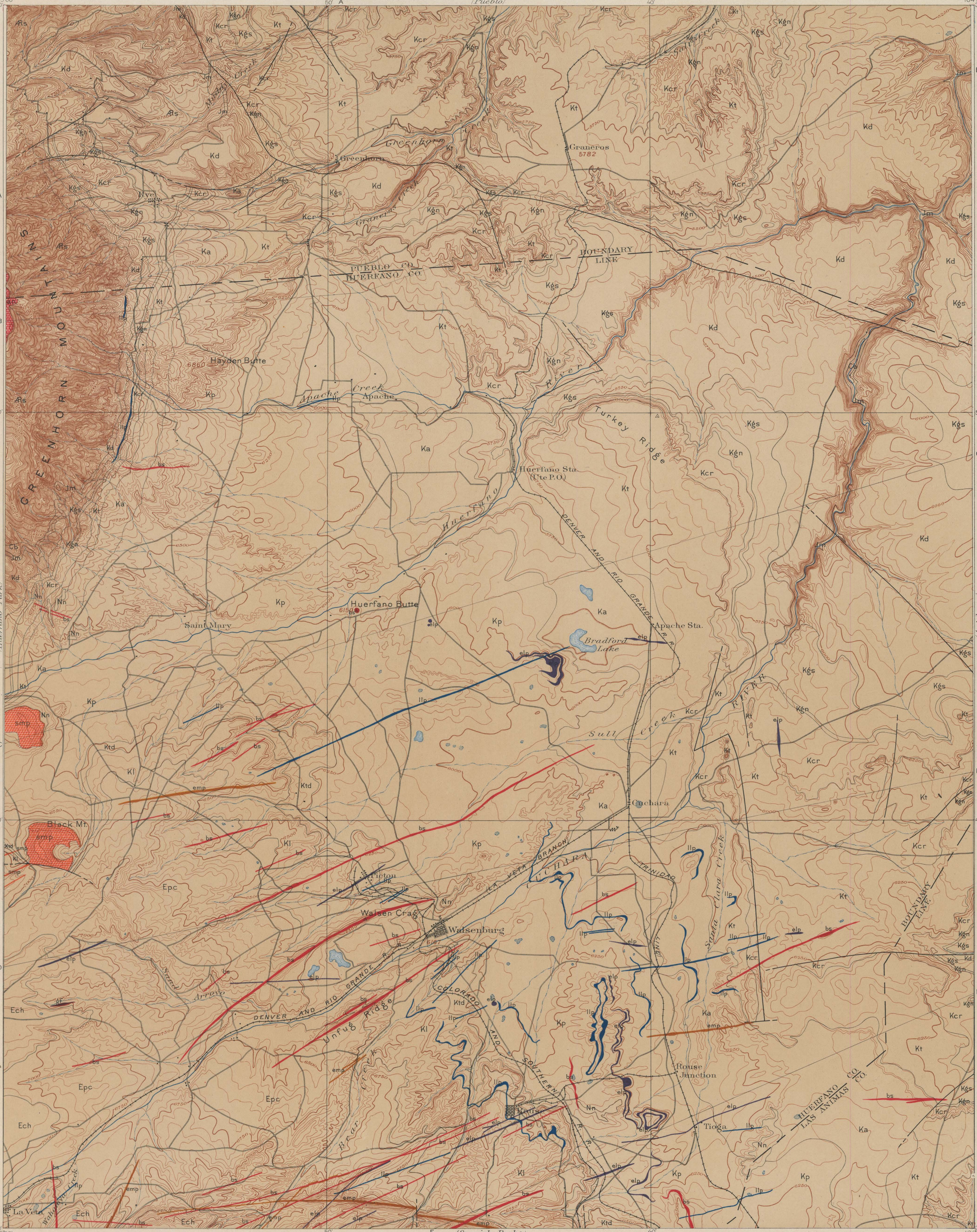
Faults

Legend is continued on the left margin.

IGNEOUS GEOLOGY SHEET

(Pueblo)

(Huerfano Park)



(Apishapa)

LEGEND

EOCENE and NEOCENE

- bs — Basalt (dikes and sheets)
- gf — Granite-felsophyre (dike)
- llp — Late lamprophyre (dikes and sheets)
- elp — Early lamprophyre (dikes and sheets)
- an — Andesite (lava flow)
- smp — Silver Mt. monzonite-porphyry (stocks and dikes)
- emp — Early monzonite-porphyry (dikes)

Sedimentary and Archean rocks (formations are differentiated on the Historical Geology sheet)

(Spanish Peaks)

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.

Datum is mean sea level.

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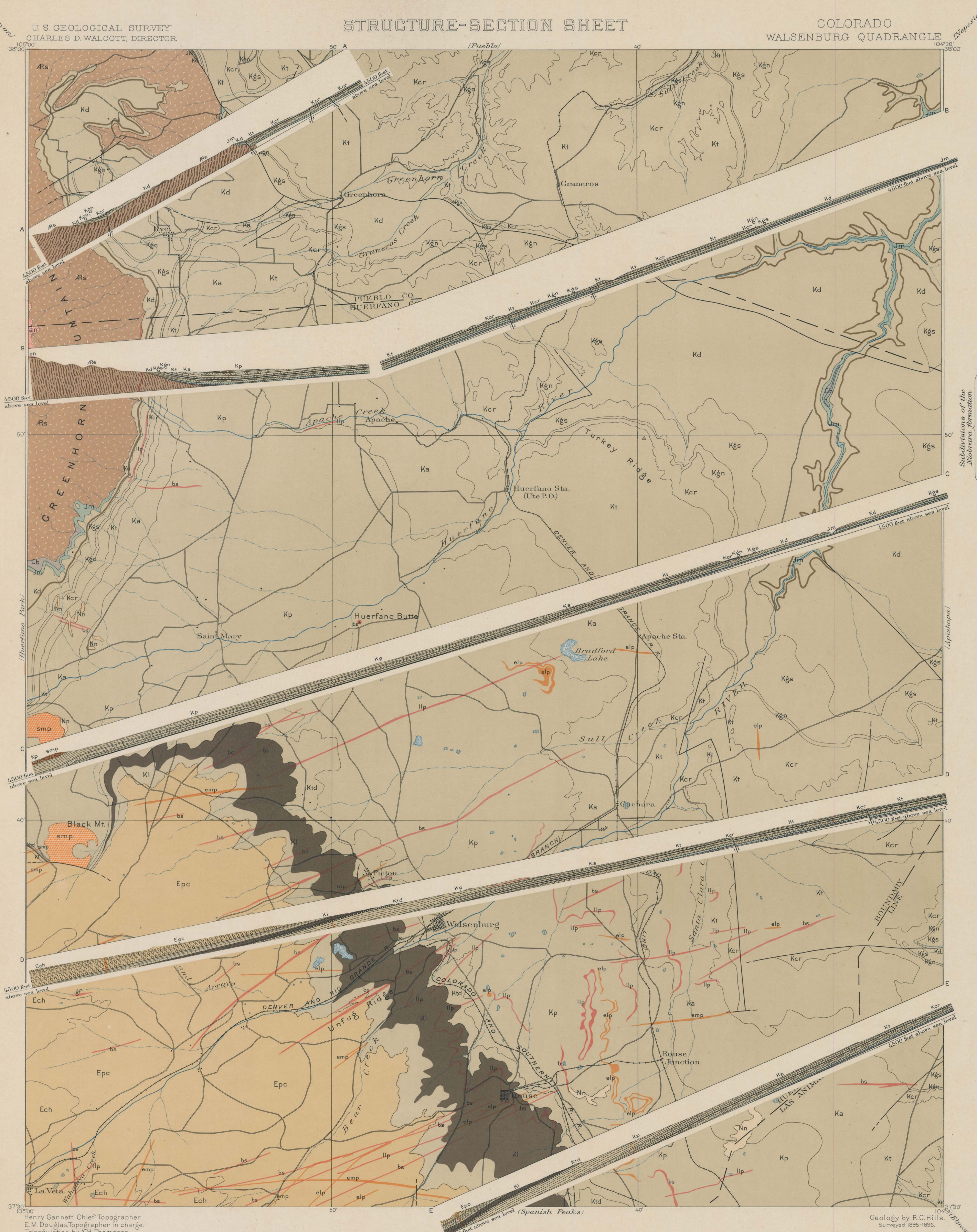
(Elmoro)

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

STRUCTURE-SECTION SHEET

COLORADO
WALSENBURG QUADRANGLE



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Scale $\frac{1}{125000}$

Miles

Kilometers

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LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

NEOCENE

Nn — Nussbaum formation (sandstone and conglomerate)

EOCENE?

Ech — Cuchara formation (cavernous variegated sandstone, brown clay and sand at base)

Epc — Poison Canyon formation (conglomerate and sandstone with beds of yellow clay)

CRETACEOUS

Kl — Laramie formation (sandstone and shale containing seams of coal)

Ktd — Trinidad formation (massive and shaly sandstone)

Kp — Pierre shale (shale of various shades of gray with concretions)

Subdivisions of the Niobrara formation:

Ka — Apishapa formation (coarsely laminated shale often bituminous; paper shale at base)

Kt — Timpas formation (calcareous shale with thin-bedded limestone)

Kcr — Carlile shale (gray shale capped by soft sandstone)

Kgn — Greenhorn limestone (thin-bedded limestone with shale partings)

Kgs — Graneros shale (gray and dark-colored shale with concretions)

Kd — Dakota sandstone (fine-grained massive sandstone, fireclay, coarse sandstone, and conglomerate)

JURATRIAS

Jm — Morrison formation (variegated shale and clay, limestone, and sandstone)

CARBONIFEROUS?

Cb — Badito formation (fine-grained red sandstone and coarse conglomerate)

IGNEOUS ROCKS

SHEET SYMBOL / SECTION SYMBOL

EOCENE and NEOCENE

an — Andesite (lava flow)

llp, bs, gf — Late lamprophyre, basalt, and granite-felsophyre (dikes and sheets)

smp, elp, emp — Silver Mt. monzonite-porphyry, early lamprophyre, and early monzonite-porphyry (stocks, dikes, and sheets)

UNCLASSIFIED CRYSTALLINE ROCKS

SHEET SYMBOL / SECTION SYMBOL

ARCHEAN

Ꞧs — Granite and schist

Faults

Known productive formations

Kl — Coal (Laramie formation contains semi-bituminous coal in its lower portion)

Fire clay (workable bed in the upper portion of the Dakota sandstone)

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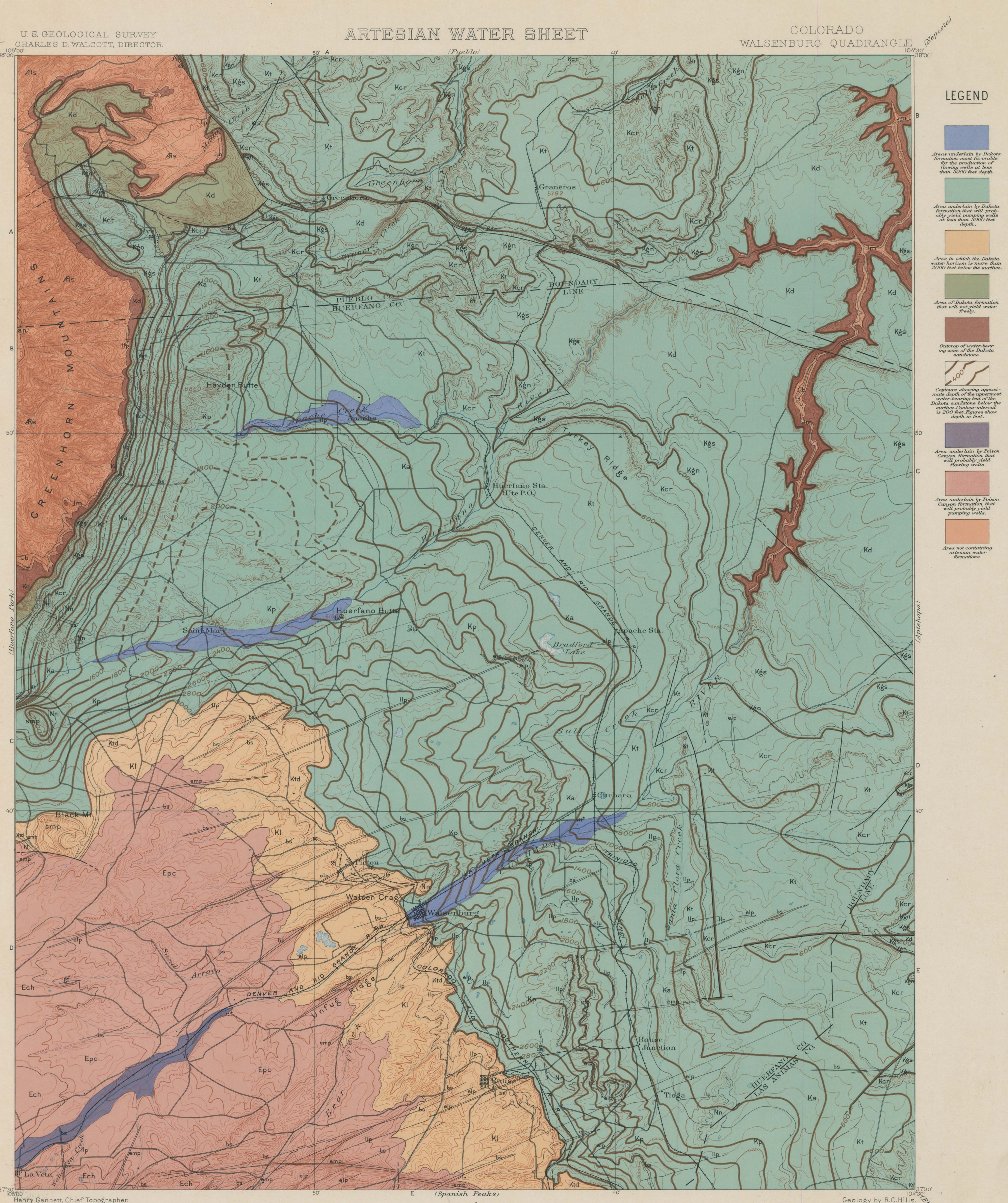
ARTESIAN WATER SHEET

COLORADO
WALSENBURG QUADRANGLE



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Scale $\frac{1}{125000}$

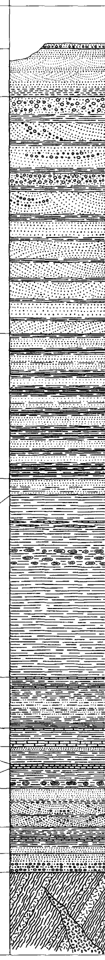
Contour interval 50 feet.
Datum is mean sea level.
Edition of Nov. 1900.

Geology by R. C. Hills.
Surveyed 1895-1896.

COLUMNAR-SECTION SHEET

GENERALIZED SECTION OF THE ROCKS OF THE WALSENBURG QUADRANGLE.

SCALE: 1 INCH = 1000 FEET.



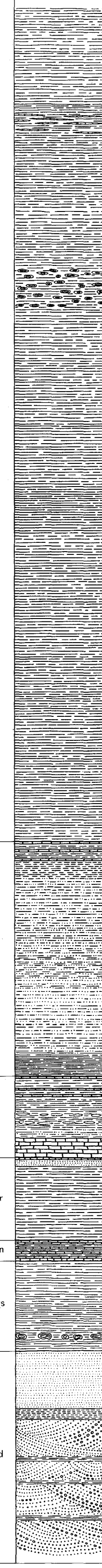
Period.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.
NEOCENE	Nussbaum formation.	Nn		30-50	Sandstone and conglomerate capping low mesas.
EOCENE ?	Cuchara formation.	Ech		450-500	Thick-bedded cavernous sandstone of white, yellowish, and pale-pink tints. Brownish-red clay at base.
	Poison Canyon formation.	Epc		2000-2500	Thick beds of loosely cemented sandstone and conglomerate alternating with beds of greenish-yellow clay. Contains petrified wood. Coarse porous sandstone weathering pale-yellow dappled with pink. Surface cavernous.
CRETACEOUS	Laramie formation.	Kl		1000-1500	Alternating beds of gray sandstone and shale. Contains workable seams of coal.
	Trinidad formation.	Ktd		160-165	Massive sandstone with fucoids (*Halymenites*), becoming shaly below and containing baculites.
	Pierre shale.	Kp		1750-1900	Yellowish and greenish-gray shale. Lead-gray shale with lime-iron concretions arranged parallel with the bedding. Chiefly gray and dark-gray shale. Light-gray shale locally dark-gray and nearly black.
	Apishapa formation.	Ka		450-500	Thin bands of limestone near the top. Bituminous sand shale near the middle. Paper shale at the base.
	Timpas formation.	Kt		180-200	Calcareous shale with thick bed of limestone at the base.
	Carlile shale.	Kcr		170-180	Gray shale capped by yellow sandstone.
	Greenhorn limestone.	Kgn		30-40	Thin-bedded limestone with shale partings.
	Graneros shale.	Kgs		200-210	Gray and dark shale with concretions.
	Dakota sandstone.	Kd		350-400	Fine-grained sandstone and bed of fire clay. Coarse porous sandstone and conglomerate.
JURA-TRIAS	Morrison formation.	Jm		270	Variegated shale and clay, hard, fine-grained limestone in the middle, and white sandstone at the base.
CARB. ?	Badito formation.	Cb		200	Brick-red sandstone above, reddish, coarse conglomerate below.
ARCHEAN	Granite and schist.	Æs			Schists containing hornblende, mica, chlorite, garnet, and epidote; with coarse granite and pegmatite.

TABLE OF FORMATION NAMES.

Period.	Names and Symbols used in this Folio.		Names used by Various Authors.	G. K. Gilbert: Seventeenth Annual Report U. S. Geological Survey, 1896.	Whitman Cross: Pikes Peak Folio, U. S. Geological Survey, 1894.
Neocene	Nussbaum formation.	Nn	Nussbaum.	Upland sands.	
Eocene ?	Cuchara formation.	Ech			
	Poison Canyon formation.	Epc			
Cretaceous	Laramie formation.	Kl	Laramie.		
	Trinidad formation.	Ktd	Fox Hills.		Montana formation.
	Pierre shale.	Kp	Pierre.	Pierre shale.	
	Apishapa formation.	Ka	Niobrara.	Apishapa formation.	Colorado formation.
	Timpas formation.	Kt		Timpas formation.	
	Carlile shale.	Kcr	Benton.	Carlile shale.	
	Greenhorn limestone.	Kgn		Greenhorn limestone.	
	Graneros shale.	Kgs		Graneros shale.	
	Dakota sandstone.	Kd	Dakota.	Dakota sandstone.	Dakota sandstone.
Jura-Trias	Morrison formation.	Jm	Morrison.	Morrison formation.	Morrison formation.
Carboniferous ?	Badito formation.	Cb	Fountain.	Fountain formation (Juratrias).	Fountain formation (Carb.).
			Sangre de Cristo.		
Archean	Archean.	Æs	Archean.	Archean.	Archean.

SECTION OF ROCKS FROM THE PIERRE SHALE TO THE WATER-BEARING DAKOTA SANDSTONE.

SCALE: 1 INCH = 200 FEET.

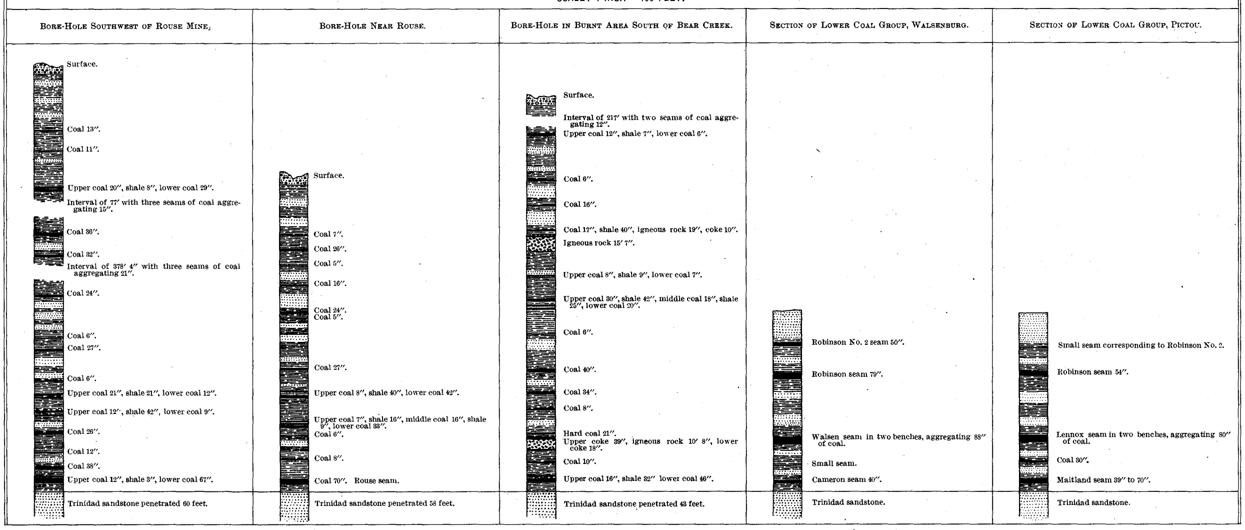


Formation Name.	Symbol.	Columnar Section.	Artesian Contours.	Character of Rocks.
Pierre shale.	Kp		3000	Yellowish and greenish-gray shale.
			2800	Dark-gray shale with lenses of impure limestone.
			2600	
			2400	Lead-gray shale with lime-iron concretions containing calcite in seams and arranged parallel with the bedding.
			2200	
			2000	Chiefly gray and dark gray shale.
			1800	
			1600	
			1400	Light-gray shale locally dark gray and in places nearly black.
Apishapa formation.	Ka		1200	Thin bands of limestone at intervals near the top.
			1000	Fine-grained, yellowish-brown sandy shale grading into coarsely laminated, usually bituminous, sand shale in the middle portion, becoming more finely laminated downward.
			800	Papery shale at base.
Timpas formation.	Kt			Thin bands of limestone at varying intervals in gypsiferous shale. Shale, weathering dove color, with flat concretions.
			600	Foraminiferal limestone with large fossil shells (*Inoceramus deformis*).
Carlile shale.	Kcr			Thin band of bituminous limestone and bed of yellowish sandstone. Gray and dark-gray shale.
			400	
Greenhorn limestone.	Kgn			Thin-bedded limestone with shale bands. Contains fossil shells (*Inoceramus labiatus*.)
Graneros shale.	Kgs			Dark-gray shale, almost black in middle portion.
			200	Contains large concretions near the base arranged parallel with bedding.
Dakota sandstone.	Kd			Fine-grained light-gray sandstone resting on a band of shale or fire clay.
			0	TOP OF WATER-BEARING ZONE.
				Coarse-grained porous sandstone, often conglomeratic, with bands of shale at wide intervals.

R. C. HILLS.
Geologist.

DETAILED SECTIONS OF LOWER PORTION OF LARAMIE FORMATION, SHOWING POSITION OF COAL BEDS.

SCALE: 1 INCH = 100 FEET.



R. C. HILLS,
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The Director, U. S. Geological Survey,

Washington, D. C.