DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

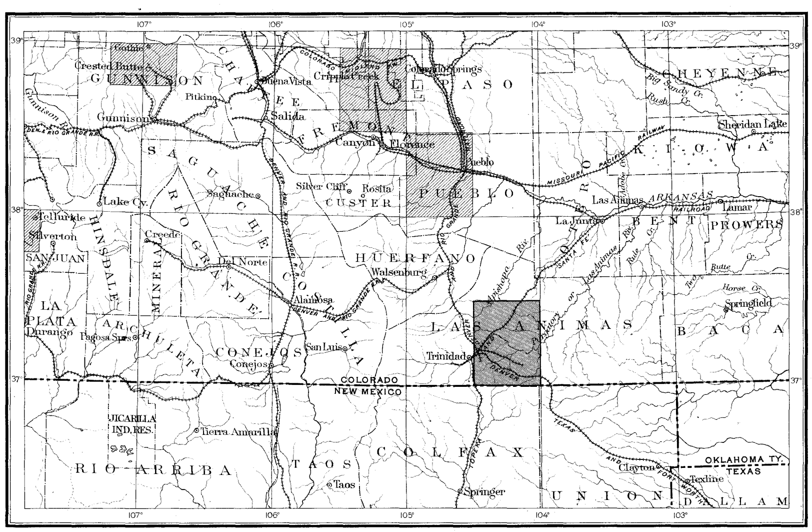
OF THE

UNITED STATES

ELMORO FOLIO

COLORADO

INDEX MAP



SCALE: 40 MILES-1 INCH

AREA OF THE ELMORO FOLIO

AREA OF OTHER PUBLISHED FOLIOS

LIST OF SHEETS

DESCRIPTION — TOPOGRAPHY — HISTORICAL GEOLOGY — ECONOMIC GEOLOGY — STRUCTURE SECTIONS

ARTESIAN WATER — COLUMNAR SECTIONS — SPECIAL ILLUSTRATIONS

FOLIO 58 — LIBRARY EDITION — ELMORO

WASHINGTON, D. C.

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

1899

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:

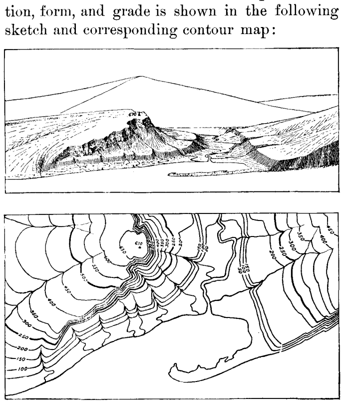

Fig. 1.—Ideal sketch and corresponding contour map.

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:

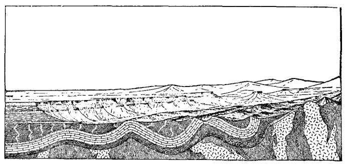

Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

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:

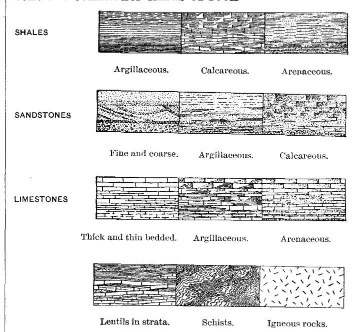

Fig. 3.—Symbols used to represent different kinds of rock.

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 ELMORO QUADRANGLE.

GEOGRAPHY.

The Elmoro quadrangle is bounded by meridians 104° and 104° 30′ and parallels 37° and 37° 30′, being 34.5 miles long (north and south) and 27.5 miles wide and containing 950 square miles. It is situated wholly within the boundaries of Las Animas County, Colorado, and extends nearly to the south line of the State.

The area represented belongs mainly to the rugged border zone where the Great Plains graduate into the foothills of the Rocky Mountains.

Relief.

The central and western portions of the quadrangle have, in general, a broadly undulating surface, of from 5500 to 6000 feet elevation, which toward the north and east breaks off into low, rocky bluffs, and toward the south rises abruptly into the lofty plateau of Raton Mesa. The latter is the chief topographic feature of the quadrangle. (See fig. 2, sheet of illustrations.) It is the most elevated portion of an east-west line of heights stretching along the 37th parallel and known as the Raton Mountains. The plateau itself has a mean elevation of about 9000 feet and is bordered by an escarpment, or perpendicular wall of rock, from 200 to 300 feet high, which renders it inaccessible except in a few places. At a point midway along the southern boundary the escarpment trends abruptly southward into New Mexico, and, circling around the Trinchera Creek embayment, passes back into Colorado a few miles beyond the eastern line of the quadrangle. Beyond the western boundary, though at one point appearing just within the boundary, is a line of bluffs rising to a height of 500 feet above the plain and marking the eastern border of a broad belt of wooded hills which extends westward with gradually increasing elevation to the base of the Culebra Range. A number of low mesas are a notable feature of the central and western part of the quadrangle, and several conical buttes, the necks of old volcanic vents, are conspicuous in the southeastern portion. (See fig. 3, sheet of illustrations.)

Drainage.

The small streams rising on the northern side of the plateau drain northward into Purgatory River, which flows, with a general easterly course, through a shallow valley across the quadrangle to a point near the eastern border, where it plunges into a canyon 300 feet deep. The drainage of the northeastern portion of the quadrangle is eastward, and also into the Purgatory, which, beyond the limits of the quadrangle, bends northward. The northwestern portion drains into the Apishapa.

Vegetation.

The central part of the quadrangle is practically destitute of timber, except a fringe of cottonwoods along the Apishapa, the Purgatory, and small streams heading in the plateau. Along the northern and eastern borders there are narrow belts of scattered piñon and juniper, with a dense growth of the same kind of timber along the base of the Raton Mountains. On the steep slopes of the plateau, pine and spruce trees are scattered through a dense undergrowth of scrub oak, with aspens in places near the base of the escarpment. The entire district up to an elevation of 7500 feet affords a rather scanty growth of exceedingly nutritious grass, well suited for sheep farming, which is one of the chief industries. In the vicinity of the plateau the growth is stronger, owing to greater condensation of moisture, and on the table-land of the summit bunch grass flourishes luxuriantly.

Climate.

The character of the vegetation corresponds to the climate, which varies with the elevation, the mountainous portion being cool and humid and subject to frequent summer rains, while the low-lying portion is warm and arid, with only occasional showers of brief duration, or down-pourings equally brief but of torrential violence. As a consequence of the general aridity of the climate, the land is not susceptible of tillage without irrigation, except in a very few favored places, and at the present time agriculture is restricted to the valleys of the streams that afford sufficient water for irrigation.

Agriculture.

Purgatory River, rising in the Culebra Range, is the main source of supply, and an important acreage of second-bottom land adjacent to that river has been brought under cultivation. This acreage, however, is but a fraction of what might be cultivated by considerate use of the available water in connection with systematic storage of the supply during the flood season, for which purpose the topography and nature of the outcropping formations are, in a great measure, favorable. The chief agricultural products are alfalfa, oats, wheat, barley, corn, and garden vegetables, the character of the crops being determined rather by the demands of the local markets than by the capabilities of the soil.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

The geology of the Elmoro quadrangle is, in most respects, quite simple as compared with corresponding areas in the more mountainous parts of the State. The principal formations succeed one another, in point of age, from east to west; or, as they appear on the sheet, from northeast to southwest. The different strata representing them are frequently exposed, and in most cases the boundaries of the individual groups are not difficult to place approximately, owing to the recurrence, at intervals, of characteristic harder and more resistant layers that stand out in relief. With the exception of a few easily recognized occurrences, the surface rocks form a practically continuous series referable to one period in the geologic time scale. This period, the Cretaceous, was an eventful one in the geologic history of the Rocky Mountains, and the important changes that characterized it gave prominence to the last part of the Mesozoic era and culminated in its close.

Age of the surface rocks.

PRE-CRETACEOUS HISTORY.

Early history.

The Mesozoic history of the district previous to the Cretaceous can be inferred only from occurrences of beds of that age beyond its boundaries. There is strong probability that a series of beds having at the base a stratum of red sandstone, representing the upper part of the Fountain formation, and succeeded by sandstones, marls, and shales of variegated colors, known as the Morrison formation, underlies the whole of the quadrangle; and while these beds do not outcrop, the uppermost layers of the Morrison can not be far below the surface along the bottom of Purgatory Canyon near the eastern border. Relative to the extension of the older formations of the preceding or Paleozoic era beneath the district, the evidence is less conclusive. However, there is good reason for the belief that for a portion of the time, at least, the area was below the level of the ocean, and therefore receiving sediments; though, owing to the limited extent of the land surface from which such sediments could be derived, they could but poorly represent the successive Silurian, Devonian, and Carboniferous periods. In fact, the exposures in the neighboring mountains to the west indicate that it was not until near the end of the Carboniferous, when the Sangre de Cristo conglomerate was formed, that any considerable accumulation of sediments took place; and it is doubtful if the Devonian is represented at all.

Early physical changes.

The facts bearing upon the early physical history of the region indicate that it was subject to changes of level, whereby elevation and subsidence were more than once repeated. These conditions continued into the Mesozoic era. The character of the lower formations of this era in central Colorado suggests deposition in shallow waters, which were fresh or brackish in the beginning, but at last reached that point of saline concentration where lime sulphate, or gypsum, begins to precipitate. These conditions, indicating bodies of water shut off from the ocean, were terminated by an elevation, which was, apparently, long continued and was followed by a great subsidence of the land and the latest invasion by the ocean.

CRETACEOUS PERIOD.

Dakota formation.—The time at which this subsidence began was near the middle of the Cretaceous period, and it was marked by the laying down of the Dakota sandstone, the oldest formation exposed within the limits of the quadrangle. At first the waters were shallow and brackish and the shore line alternately advanced and retreated; but toward the latter part of the epoch the advance became persistent, and at the close true marine conditions prevailed.

Character of the Dakota.

The most complete exposure of the Dakota sandstone is in the canyon of the Purgatory, where the thickness shown approximates 300 feet; but the total is probably about 375 feet, as the base is not revealed. The lower two-thirds of the Dakota consists of sandstones, with fine conglomerates, imperfectly stratified or cross bedded, and the heavy layers which make up this part of the formation are separated from one another by thin bands of finer, shaly material. The upper one-third also consists of sandstone layers parted from one another by thin bands of shale, but the individual beds are not so thick and the shale partings are more numerous. These two portions are separated from each other by a prominent bed of hard shale — fire clay — the position of which, in cliff exposures, is often indicated by a narrow shelf or terrace immediately below it.

The color of the upper sandstone is generally grayish white, the lower somewhat darker, with yellowish and brownish weathered surfaces. The pebbles of the coarser layers are quartzite, quartz, and chert. The finer-grained layers are made up of quartz grains, among which white, kaolin-like specks are included. The lower sandstone is of an open, porous texture, and more loosely aggregated than that lying above the fire-clay stratum. But the texture of any particular layer varies from place to place, and the same is true of the thickness of the individual beds, so that the only constant features are the fine-grained, compact sandstone above and the coarser, porous sandstone below the persistent bed of fire clay separating them.

Extent of the Dakota.

The Dakota sandstone undoubtedly underlies the entire quadrangle, but the surface exposures are chiefly confined to the eastern part, there being but one occurrence, and that of limited extent, along the north line of the quadrangle. Owing to the hardness of the rock, the resistance it has offered to the action of eroding agencies, and the non-resistant, soft, shaly character of the succeeding formation, the exposed areas usually appear as slightly inclined, smooth floors of sandstone protected by a light cover of soil. It is only where the superior cutting power of running water has manifested itself that there is any noteworthy departure from this form. The effect of stream erosion has been to produce deep, narrow canyons bounded by high, inaccessible walls, the edges of which generally terminate sharply in the profile of the surface. The gorges of the Purgatory and the Trinchera are of this character. They range from 200 to 300 feet or more in depth, about one-third being represented by the bounding walls.

Surface forms within the Dakota area.

Benton group.

Graneros formation. — The Graneros, Greenhorn, and Carlile formations, which it has been thought advisable to differentiate, constitute a group which corresponds to the Benton formation elsewhere and which may be called the Benton group. They are separated partly on account of their geographic extent, partly as a guide in boring for water, and partly because their individuality and their frequent, almost continuous exposure render it easy to recognize and trace them.

Character and extent of the Graneros.

The Graneros formation, which marks the beginning of the marine conditions following the subsidence that terminated the Dakota epoch, consists of dark-gray clay shale, from 200 to 210 feet in thickness, darker near the center than elsewhere, resting on the Dakota sandstone and graduating rather abruptly into it. Large limestone concretions are not uncommon in the upper half, but are not a distinguishing feature, as similar concretions are met with in the other shale formations of the district. At a distance of about 30 feet above the base there is a layer, from 1 to 2 feet thick, of hard, concretionary limestone, weathering an orange tint, which is noticeable and characteristic. Owing to the soft, loose nature of the shale, it offers but slight resistance to erosion, and its rapid removal has exposed broad, smooth surfaces of the Dakota basement. The outcrop extends nearly the entire length of the quadrangle along the eastern border, and doubtless underlies the entire quadrangle west of it. There is also a small area outcropping in Apishapa Valley near the northern border. The profile of the exposures usually is undulating; steep slopes are rare. The protection afforded by the layer of concretionary limestone toward the base has greatly aided in preserving the lower portion of the formation, which in places occupies a comparatively large extent of country.

Character and extent of the Greenhorn.

Greenhorn formation.—This formation is made up of layers of dove-colored limestone, usually less than 12 inches thick, separated from one another by somewhat thicker layers of shaly material. It graduates into the Graneros shale below and the Carlile shale above. Fossil shells are abundant in the limestone layers, especially the flat, oval, concentrically ridged *Inoceramus labiatus*. The coiled ammonite, Prionocyclus, is sometimes present. The thickness varies from place to place, owing to the thickening or thinning of the shaly layers. At the same time the gradation into the Graneros and Carlile formations is more abrupt in some places than in others, thus rendering it doubtful at times where to draw the line. The maximum thickness occurs in the northeastern part of the quadrangle, where it is often 50 feet. In the southeastern part the exposed sections are not so complete and it is thought that in some places the thickness may not exceed 30 feet. The outcrop is usually very narrow, though widening out occasionally to over a mile. In a few instances it is found capping low, piñon-clad mesas, but it generally appears as a narrow terrace of irregular outline, fringed with piñon and juniper trees. It outcrops along the entire eastern border of the quadrangle and on the Apishapa.

Character and extent of the Carlile.

Carlile formation.—This formation consists of about 180 feet of dark-gray shale, the middle portion the darkest, overlain by from 10 to 15 feet of soft, shaly, yellowish-gray sandstone, into which it graduates through a varying thickness of more distinctively shaly material. A thin band of purplish, bituminous limestone containing large numbers of coiled ammonites is persistently present capping the formation. Concretionary nodules several feet in diameter and seamed with lime spar are rather common, especially in the upper half of the beds. The Carlile shale is soft and easily eroded and the meandering outcrop is generally much narrower than that of the similar Graneros formation. This is partly due to the protection afforded by the hard limestone of the succeeding Niobrara group. Owing to this protection the exposures usually appear as steep, barren slopes descending from a limestone escarpment and flattening out rapidly toward the contact with the Greenhorn below. Like the formations that precede it, its geographic range leaves no doubt of its extending continuously beneath the quadrangle west of the meandering eastern outcrop.

Niobrara group.

Timpas formation.—The Niobrara group, which corresponds to the Niobrara formation elsewhere, is represented by sediments of which the prevalence of limestone, calcareous shale, or other rocks containing a notable proportion of lime is the most characteristic feature. The group is separable into two portions: the lower, or Timpas formation, and the upper, or Apishapa formation. The division line between the two is not always strongly marked, though the individual characters are easily recognized, and they are not more difficult of separation than is the Niobrara group itself from the succeeding Pierre.

Character and extent of the Timpas.

The Timpas formation consists of a basal limestone, about 50 feet thick, followed by from 150 to 200 feet of calcareous shale interrupted at intervals by thin limestone layers from 12 to 18 inches thick. The basal limestone is made up of layers, a foot or more in thickness, separated by shale partings. The color is grayish white, often creamy white on weathering. It has an easy conchoidal fracture rudely parallel with the bedding, and the exposed surface is generally thus fractured. Small faceted nodules of iron oxide are often found near the bottom. They result from the oxidation of the iron sulphide, marcasite. Fossils are not numerous, but a short search will usually reveal the presence of casts of a large, concentrically ridged, hoof-shaped marine shell, *Inoceramus deformis*. When examined microscopically in thin, transparent slices, the mass is found to be made up largely of the skeletons of minute organisms, Foraminifera.

The overlying shale beds are alternately light colored and of a bluish tint. They graduate at intervals into thin bands of grayish-white limestone, which sooner or later disappear. Toward the top these bands are more persistent and form at least two well-defined, hard limestone beds, from 12 to 18 inches thick and within a few feet of each other. The upper one marks the summit of the formation.

The capacity of the Timpas limestone to resist erosion renders it the most conspicuous of marine Cretaceous beds. It caps a nearly continuous line of bluffs extending irregularly from one end of the quadrangle to the other along the eastern margin, and a similar line of bluffs along the western half of the northern border. North of the Purgatory and on the Apishapa the face of the bluff fronting eastward usually terminates in a limestone cliff.

Character of the Apishapa.

Apishapa formation.—The Apishapa beds have a total thickness of from 450 to 500 feet. The lower 50 to 75 feet consists of argillaceous shale of a bluish tint, cleavable into paper-like layers, and sometimes containing stony concretions which lie with their greatest diameter parallel with the bedding. The middle portion of the formation, which constitutes the bulk of it, is composed of coarse, calcareo-arenaceous shale of a yellowish-gray color and more or less bituminous throughout. The upper half of this middle zone affords the coarsest material. Where the Apishapa crosses the outcrop this portion is made up of hard, resistant layers that break out in flags of several square feet of surface. The upper 50 feet of the Apishapa contains two or more thin bands of grayish-white limestone, the uppermost marking the summit of the formation. Fish scales are abundant from top to bottom. In the bituminous zone tracks of an undetermined animal, probably a small crustacean, are frequently met with and may be regarded as characteristic. The tracks appear as a double row of very short, parallel markings, those of one row being inclined toward those of the other. Imperfect casts of Inoceramus are occasionally present in the limestone layers. The middle portion of the formation is most frequently exposed, owing doubtless to its superior resisting power; but the exposures are nowhere extensive, though the area it occupies exceeds that of any other in the district.

General characters of the Pierre.

Pierre formation.—The beds referred to the Pierre epoch attain a thickness of from 1250 to 1300 feet in the southern half of the quadrangle, though this amount may be exceeded in the northern half. They consist of shale throughout. The basal portion is soft, clay shale, weathering to a pale greenish-yellow tint. Above this appear bands of darker color, in places almost black, and the material flakes up into paper-like scales. Still higher there are dark-gray and lead-gray shales, containing in abundance concretions of impure ferruginous limestone seamed with carbonates of lime and iron and crumbling readily on exposure. These concretions are arranged parallel with the bedding of the shale, at certain levels situated at varying distances from one another. The nodules may be as much as 3 feet in diameter at one level, but less than a foot at the next level above or below, the size being nearly uniform at a given level. The upper portion resembles the lower in character and general appearance, except that it contains flat calcareous concretions, about 6 inches thick and several yards in diameter, lying conformable with the bedding. It can hardly be said that the characters enumerated are constant throughout the district, as the exposures are few and of limited extent. However, the presence of the concretions, generally of a rusty color, near the middle of the formation can be depended upon as characteristic.

Extent of the Pierre.

The area occupied by the Pierre beds forms a broad belt of irregular outline crossing the southwestern portion of the quadrangle, and very much wider at the northwestern than at the southeastern extremity. The formation yields readily to erosion, more so indeed than the Apishapa, and the exposures that present steep slopes are generally such as are protected by the overlying beds or by intrusions of lava.

Fox Hills group.

Trinidad formation.—It is uncertain what part of the Fox Hills group elsewhere observed is represented in this section of the district, though it is thought to be the upper. In view of this uncertainty the section near Trinidad can not be regarded as typical of the formation generally, but merely of the beds occurring within the limits of the quadrangle, for which reason the name Trinidad has been applied to it.

The marine conditions that had prevailed since the Dakota continued into the Fox Hills epoch, though a change was foreshadowed in the fact that while previous marine deposits were shale and limestone those of the Fox Hills were chiefly arenaceous.

Lower Trinidad.

The total thickness of the Trinidad is about 150 feet. The lower portion, which grades abruptly into the Pierre, consists of thin layers of fine-grained dark-gray sandstone, with shale partings, aggregating 75 feet in thickness, sometimes less. The sandstone layers are from 1 to 3 inches thick, with local occurrences of thicker and more prominent, lighter-colored layers toward the base. The shale partings are generally subordinate to the layers of sandstone. Imperfectly preserved baculites have been found in this part of the formation in localities northwest of the quadrangle, but none in the quadrangle itself.

Upper Trinidad.

The upper portion consists of from 70 to 80 feet of light-gray sandstone, sometimes with a pale greenish tint, usually massive or very heavy bedded, but with prominently developed joint planes. A layer of brown sandstone, the color emphasized by weathering, caps the formation. Remains of a certain kind of seaweed, Halymenites, are abundant and characteristic, but other forms of organic remains seem to be wanting. The formation outcrops as a narrow, irregular line of exposures extending across the southwestern part of the quadrangle in a southeast-northwest direction, the upper sandstone usually appearing as a prominent escarpment. With the close of the Trinidad epoch the ocean finally receded, and has not since invaded the territory in which the district is situated.

Conditions of sedimentation in Laramie time.

Laramie formation.—The water bodies that succeeded the marine Cretaceous were shallow, but were connected with the ocean and varied in depth according as the rate of subsidence exceeded that of sedimentation, or the reverse. Throughout the Laramie these conditions were constantly changing from one extreme to the other. For a time the water would be sufficiently deep and the currents sufficiently strong to admit of the deposition of sand only; then the water would become shallower, and silt-like material be deposited. Finally, broad areas of swamp or marsh land would be formed, capable of supporting a luxuriant semi-tropical vegetation and favoring the accumulation of extensive peat-like deposits. Subsequent changes, slow but long continued, consolidated these deposits, respectively, into sandstone, shale, and coal. Thus, the operation being many times repeated, the alternating sandstones and coal-bearing shaly beds of the Laramie were built up until they attained an aggregate thickness of 2500 feet.

Characteristics of the Laramie beds.

The formation presents much the same characteristics throughout, the chief points of difference being those that bear on the economic questions, to be considered later. However, the upper and lower portions, while they grade almost imperceptibly into each other, are in some respects dissimilar. In the basal portion, the lower 200 feet shows the predominance of shaly sandstone—that is, beds made up of thin layers of fine-grained greenish-gray sandstone separated from one another by thinner partings of shale. These beds are interrupted at intervals by bands of light-gray sandstone of coarser texture and by bands of shale containing seams of coal. Dark-brown concretionary nodules, from 2 to 3 feet in diameter, are also present. They consist of impure limestone seamed with iron carbonate. In ascending order, the shaly sandstone beds become thinner, or give place to argillaceous shale, and coarse-grained, thick-bedded sandstone finally predominates, varied at intervals toward the top by beds of fine-grained, greenish-gray, fissile sandstone, which is often micaceous. With the predominance of sandstone, there is a marked decrease in the number and thickness of the beds of coal, and while thin seams occasionally appear well toward the summit of the formation, the workable beds are confined to the lower half.

Variable features of the Laramie beds.

While the general features of the formation may be regarded as constant for the quadrangle, the details, when closely examined, show that within certain limits the variations observed elsewhere are not absent here. For instance, only the more prominent beds of sandstone and shale are persistent for any considerable distance, and two carefully measured sections less than a mile apart will exhibit little in common except the general features. This remark applies also to the coal seams, though not quite to the same extent. It is the groups rather than the individual beds that possess continuity.

The great body of the formation is confined to the southwestern portion of the quadrangle, though an intimation that another large body exists to the westward is furnished by a small exposure on the western boundary. The thickness ranges from 800 feet at the eastern extremity of the main body to 2500 feet at Fishers Peak, the difference being chiefly due to erosion preceding the eruption of the lava now capping Raton Mesa. Fossils characteristic of the group are of common occurrence in the thin-bedded sandstones. They consist of leaf imprints of semi-tropical vegetation, such as Platanus, fig, tulip tree, poplar, willow, oak, fan palm, and many others.

Land conditions at the close of Laramie time.

Late Eocene eruptions.

Events succeeding the Laramie.—The record of the Cretaceous period in this region ends with the Laramie. The long-continued subsidence during which the marine Cretaceous strata were deposited extended into the Laramie, but it became intermittent and was marked by many halting stages. At the close of the Laramie epoch general elevation took place, though the disturbances that accompanied it elsewhere were scarcely manifested here. But land conditions henceforth prevailed, and, so far as the quadrangle was concerned, sedimentation, except in the nature of drift deposits, had ceased. Throughout the succeeding Eocene period it included part of the shore border of a large fresh-water lake which was steadily deepening and accumulating sediments. This episode ended with the disappearance of the lake during a time of disturbance and upturning of strata, the district itself being to some extent affected. The disturbance was accompanied by eruptions of basic lava, sheets of which were injected into the marine Cretaceous beds; and other similar eruptions followed at intervals, probably extending into the succeeding period.

NEOCENE PERIOD.

Character and extent of the Nussbaum.

Nussbaum formation.—Of the early part of the Neocene the quadrangle affords no record, except that it was a time of general and rapid erosion and included stages of eruptive activity. But toward the close of the Neocene certain gravelly deposits were formed, remnants of which have been preserved. The Nussbaum formation consists of from 10 to 50 feet of gravelly beds, of which the basal 5 to 10 feet is cemented by lime carbonate into coarse conglomerate. It is found capping low mesas at different elevations, and resting unconformably upon the eroded surface of the marine Cretaceous. The beds are clearly torrential deposits, and the relation of many of the occurrences to the main drainage of the Purgatory suggests that they represent the flood level of that stream at the time of deposition. In the vicinity of Trinidad and Elmoro there is a difference of several hundred feet in the elevations of deposits of this character. The reference of the formation to the last part of the Neocene is provisional. The basal conglomerate closely resembles the Bishop Mountain conglomerate of Wyoming, described by Powell, which is also regarded as Neocene, though no fossils have been found in it.

STRUCTURE OF THE CRETACEOUS ROCKS.

The structure of the rocks does not call for extended consideration. Over the greater part of the central and western portions of the quadrangle the beds have a very slight southwestward inclination, which is most pronounced in the southwest corner of the quadrangle. Toward the northwest, and on the Apishapa, the beds are to some extent affected by local rolls, and in places there is a decided southerly inclination. About 6 miles west of the east boundary there is a decided monoclinal flexure, having a north-south axis, which traverses the district from the north line to and beyond the upper end of Purgatory Canyon, but disappears before reaching the south line of the quadrangle. The position north of Van Bremer Arroyo is indicated by the general line of the eastern Timpas outcrop. The inclination of the beds near the axis is about 7° westward, but they flatten out rapidly toward the central part of the quadrangle. On the east side of the axis the strata are nearly horizontal. This flexure excepted, there is a remarkable absence of displacements of any kind. This is especially noticeable in the coal-mine workings, where normal faults worthy of note are practically unknown, the only disturbed ground being that which is more or less deformed in the immediate vicinity of intruded bodies of lava.

TYPICAL EXPOSURES.

It rarely happens that a complete section of a formation is exposed to view at any one point, or that the division lines between the less resistant beds can be observed except at long intervals. For this reason mention will be made of a few accessible localities where characteristic exposures can be studied to the best advantage.

Dakota sandstone.—The canyons of the Purgatory and Trinchera present the best sections of this formation, though the bed of the stream is not deep enough by probably 50 feet to reveal the base of the group. But the basal portion differs but little from that above.

Graneros shale.—The complete section, including the upper and lower contacts, can be seen on both sides of the river at the head of Purgatory Canyon; also on the Apishapa near the north line of the quadrangle.

Greenhorn limestone.—There are many exposures of this formation north of Van Bremer Arroyo and on the Apishapa that afford good sections, but none better than the locality already mentioned at the head of Purgatory Canyon.

Carlile shale.—Complete sections, including the upper and lower contacts, can be seen about 4 miles north of Van Bremer Arroyo, also on the Apishapa near where it leaves the quadrangle. It can likewise be seen to advantage, between the two contacts, in the hills southeast from Trinchera.

Timpas formation.—The basal limestone usually outcrops wherever the formation is present, the lower contact being frequently exposed to view. The upper portion as well as the upper contact can be seen at the base of a hill just south of the railway track near Adair. All the upper bands of limestone are there exposed.

Apishapa formation.—The best exposure of the lower portion of the Apishapa is at the locality last mentioned. The upper portion and its relation to the Pierre can be best studied near the junction of the roads northwest from Barela. At one point the Barela-Trinidad road crosses the contact between the two formations, and the upper half of the Apishapa with its limestone bands is very fully exposed.

Pierre shale.—The basal portion of the Pierre outcrops at the locality just cited, and the overlying beds appear close to the road as one travels westward. The middle-zone exposures are most numerous in the country around Beshoar and in the vicinity of the dikes due north from Elmoro, where the concretions are abundant. The upper portion is well exposed in the vicinity of Trinidad, and the upper contact appears in several places close to the town.

Trinidad formation.—A complete section is afforded in the vicinity of Trinidad, the most accessible being at Simpsons Rest, or at a point just north of it, where the top of the sandstone has not been eroded.

Laramie group.—The valley of Raton Creek affords the best section of the Laramie, there being fully 1500 feet of it exposed between Starkville and the summit at Raton Pass. The remaining 1000 feet underlying Raton Mesa is pretty thoroughly masked by surface accumulations, and an idea of its true character must be sought for in the hills west of Raton Creek and outside of the quadrangle.

Nussbaum formation.—A very fine section of the beds of this formation is revealed by the long side cut where the Trinidad-Engle wagon road climbs the hill midway between the two places.

IGNEOUS ROCKS.

Age of eruption.—The eruptive rocks are assignable to two epochs of eruption, (1) an earlier one related to the late Eocene eruptions of the Spanish Peaks region, and (2) a later one related to the Neocene eruptions of southern Colorado and northern New Mexico. There is also a probability that the district did not entirely escape the effects of more recent volcanic activity (Pleistocene) represented by cinder cones situated on the north and south flanks of the eastern extension of the Raton Mountains. One of these appears in the Trinchera Creek embayment, east of the creek and immediately south of the margin, though none occurs in the quadrangle itself. The late Eocene rocks consist of early lamprophyres and later lamprophyres, both of minor importance. The Neocene rocks were nearly all erupted during the early part of that period, and are deeply scored by erosion. They consist entirely of intrusive and extrusive basalt.

Occurrence and distribution.—The intrusive rocks, including those of Eocene age, occur as dikes, sheets, stocks, and irregular bodies. The majority outcrop at different horizons in the marine Cretaceous, but a few appear in the Laramie area. The dikes cut the strata nearly perpendicularly to the bedding. They diverge more or less from an east-west course, most of them trending a few degrees north of east, only two being known that trend south of east. The thickness varies greatly. The big dike north of the Apishapa, and also the one south of Van Bremer Arroyo, are from 20 to 50 feet thick, and in places may exceed 100 feet, as the true thickness is usually masked by talus. Both are double dikes—that is, after one dike was formed the fissure opened a second time and was again filled with lava. The smallest dike in the quadrangle, the one near the northern boundary, is only about 1 foot thick. The sheets are not as numerous as the dikes. They are generally, though not always, intruded conformably with the bedding of the sedimentary rocks. The most prominent, typical examples of the mode of occurrence are to be seen in the Black Hills, near the western margin, and on Trinchera Creek near the southern margin. They have a thickness, in places, of about 20 feet. A smaller sheet outcrops in Ferris Canyon south of Trinidad. It is apparently an offshoot from the dike in the same locality. A similar sheet appears in the mine workings, at a lower level, in connection with the same dike, and extends a distance of about 300 feet along the bed of coal. Another occurrence, which is probably part of a sheet, appears a short distance east of San Francisco Creek.

Dikes. **Sheets or sills.**

The volcanic plugs are the cores of basaltic material that choked up and consolidated in the lava conduits of extinct volcanoes. They are a noticeable feature of the southern portion of the quadrangle. The cores, being harder and more resistant than the inclosing shale, stand out above the general level of the surface from 50 to 200 feet, and are, in consequence, easily recognized. Fig. 3 on the sheet of illustrations is a reproduction of a photograph of the volcanic plug near Adair. Seven of these plugs are situated within the quadrangle, all of them in the southern third of it. Several others appear just beyond the limits, near the southeast corner. They vary in size from 50 to 150 feet in diameter. The basal portion is invariably surrounded and masked by an accumulation of talus from the breaking off of the peripheral portions of the protruding column, so that the full diameter is seldom revealed.

Extinct volcanoes.

In the southwest corner of the quadrangle there is an unconformable mass of gray basalt too irregular in mode of occurrence to be assigned to any recognized form. Its upper surface has been exposed by erosion and its southern side deeply scored by the same action; but the base is not shown, and whether the vertical or horizontal diameter is the greater is uncertain. The earlier dikes of the region are not always of regular vein-like form where they cut through the soft beds of the Cretaceous. Occasionally one appears as a row of protrusions of considerable prominence. One of these occurs in the north-central portion of the quadrangle. It consists of four prominent bodies of lava, apparently connected with one another along a line of fissuring by a thin filling of the same material. (See fig. 4, sheet of illustrations.)

Irregular bodies of igneous rock.

The extrusive rocks greatly overshadow the others in geologic importance. They are all confined to the southwestern part of the district, where a succession of outflows rests, with apparent unconformity, on the Laramie, and forms the capping rock of Raton Mesa. (See fig. 2, sheet of illustrations.) The occurrences are simply outliers of a broad eruptive area, deeply indented by erosion, lying to the south and east, which at the time of eruption was much more extensive than it is at present. The western or principal mass has a length of 8 miles, a maximum width of 4 miles, and covers an area of 20 square miles. It has been entirely detached by erosion from a similar area to the south and from the main lava field to the east. The portion of the latter that enters the quadrangle has a length of 5 miles, is less than 1 mile wide at its narrowest part, and has an area of 7 square miles. This mass continues eastward south of the boundary, but eventually curves northward and appears in the Mesa de Maya quadrangle. Around the peripheral portion the aggregate thickness of the flows is from 250 to 300 feet, increasing to 500 feet toward the central part of the western mass. As many as eight distinct beds of lava, probably representing nearly the same number of independent eruptions, can be distinguished in the cliff exposures of Fishers Peak, with several other beds that can not be made out with certainty on account of talus accumulations. The respective beds are 30 or more feet in thickness, but vary greatly from place to place. They are grayish or dark colored, occasionally reddish brown, though when seen from a distance the weathered surface of the cliffs is usually of a dark-brown tint.

Extrusive rocks.

Early lamprophyre.—This rock is common in the Walsenburg quadrangle, but in the Elmoro the occurrences are confined to the Black Hills—a high mesa north of the Chicosa, which owes its form to the presence of thick sheets of this rock. Two of these sheets, about 100 feet apart, appear in the basal exposures at the eastern extremity of the mesa. The thickness varies from 6 to 20 feet, there being a noticeable thinning of the upper sheet toward the west, while the lower sheet soon thins out and disappears in the same direction. They are not strictly conformable with the bedding of the shale, and at times jump from one level to another. Thin sheets of brown, decomposed basalt are present in the same exposures. The early lamprophyre of the region includes a group of rocks of the same habit, and apparently derived from the same magma, in which the proportion of alkali feldspars to lime feldspars may incline one way or the other. It is a grayish rock of medium grain and even, crystalline texture. Brown, lath-shaped hornblende crystals are generally abundant; augite is often present in considerable amount, and more rarely plates of biotite.

Late lamprophyre.—This is a very common rock in the Spanish Peaks quadrangle, but is represented here by only one occurrence, previously mentioned as an irregular dike-like intrusion in the north-central part of the quadrangle. It is a greenish-gray, fine-grained rock, containing crystals of augite embedded in a groundmass which consists of feldspars and interstitial augite and chlorite with some biotite.

Intrusive basalt.—The intrusive basalts vary much in color and appearance. As a rule, the dike rocks and thicker sheets have undergone little alteration, but the thin sheets are invariably decomposed, as are those that occur in contact with coal or carbonaceous shale. The fresh, unaltered rock is rarely grayish, more often nearly black; but various shades of green, resulting from the alteration of the dark silicates to serpentine and chlorite, are common. Relatively large crystals (phenocrysts) of augite and olivine are embedded in a groundmass of microscopic crystals of lime-soda feldspar, augite, and magnetite. Sometimes augite predominates over the other constituents of the groundmass. Biotite is occasionally present, and serpentine, chlorite, and calcite are common secondary products.

Extrusive basalt.—The extrusive basalts are grayish or dark colored, occasionally reddish brown. All are at times vesicular. Notwithstanding that the rocks of the individual flows differ from one another in outward appearance, they are much alike in texture and mineral constitution. The groundmass is usually a fine-grained aggregation of minute crystals of lime-soda feldspar, augite, and magnetite, and rarely some glass. Of the porphyritic crystals (phenocrysts), olivine largely predominates over augite. Chlorite, serpentine, and biotite appear as products of the alteration of olivine and augite, and calcite is often abundant in the cavities.

ECONOMIC GEOLOGY.

The chief mineral resources of the quadrangle, stated in the order of their importance, are coal, sandstone, and limestone. Other substances whose adaptability for the purposes for which they could be utilized remains to be determined, or whose existence in an economic sense is largely conjectural, are fire clay, cement limestone, iron ore, natural gas, and petroleum. A large amount of exploratory work has been done on basalt dikes in expectation of discovering valuable ores, and a little copper-bearing rock has been found in the eastern part of the quadrangle. But it may be well to remark in this connection that the prospects of finding precious or other metals in sufficient quantity to have economic value are not encouraging.

COAL.

The productive measures are restricted to the lower half of the Laramie group, and the coal beds that have been worked up to the present time lie within 150 feet or less of the base of the formation. The total area of the Laramie in the Elmoro quadrangle is about 89 square miles, part of which, however, is practically barren. It is the northern portion of an area of nearly twice the size which extends eastward as a branch of the main Raton coal field.

Observations at various points, supplemented by borings, indicate the existence of not fewer than 30 seams of coal of 3 inches in thickness and upwards. The extremely thin seams of one locality rarely afford workable coal in another, but there are certain groups of seams in each of which at least one individual will afford a workable body of coal continuous for a distance which bears some relation to its thickness. At the same time a seam workable at one point may not be of workable size at another point. This is due in some cases to simple thickening or thinning, and in others to divergence or the reverse—that is, a mere shale parting near the middle of a bed will thicken rapidly until in a few hundred feet it becomes a bed of shale 6 feet thick or more, permanently dividing the coal bed into two distinct and possibly unworkable seams. In this manner the seams will vary much in size from place to place and the number of seams in a group will vary.

Variability of the coal beds.

Engle group.—This group includes all seams within about 100 feet of the base of the Laramie. In the vicinity of the Engle and Gray Creek mines, exploratory work has demonstrated the existence of from four to six seams in this group, of which one is always of workable size and sometimes two are workable; though it is only at intervals that what is termed "high coal"—that is, coal of 4 feet in thickness or over—is present. In the Gray Creek mine the "high coal" is at one point as much as 14 feet thick, inclusive of shale bands and impure bony layers. Elsewhere in this mine there is from 6 to 7 feet of coal in two "benches" separated from each other by about 1 foot of shale. The Engle mine affords the largest area of "high coal" in the district. It is at present from 6 to 7 feet thick (though in portions of the mine now exhausted the clean coal was as much as 11 feet thick), and extends into the workings of the Starkville mine, part of which lies beyond the western boundary of the quadrangle. The seam worked is formed by the coalescing and thickening of the two upper seams of the group, shown beneath the parting sandstone on the Columnar Section sheet. The coal is remarkable for the perfection of the "faces," or joints, which causes it to break easily into large slabs.

Workable coal seams in the Engle group.

Sopris group.—This group is represented by two workable seams about 75 feet apart, the lower one being from 135 to 140 feet above the base of the measures. A band of massive sandstone of variable thickness separates this group from the preceding. Sometimes both seams afford "low coal," more often only one, and occasionally both are of less than workable size. "High coal" has not been developed along the outcrop of these seams in this quadrangle. The coal is of the same character as that of the Engle group, but the joints are not so well defined and in consequence the coal will not break out as readily in mining. No attempt has yet been made to work these seams in the Elmoro quadrangle, though in the adjoining quadrangle to the westward the Sopris mine has been in operation eleven years on the upper one.

Workable coal seams in the Sopris group.

Morley group.—The number of seams in this group is uncertain owing to the limited amount of exploratory work that has been done on the more promising portions of the outcrop. Excavations at a number of points in the vicinity of Morley, on Raton Creek, show a clean seam 6 feet thick extending into the Elmoro quadrangle. This seam is about 750 feet above the base of the measures. Other excavations along the western slope of Raton Mesa show bodies of "high coal" in the same group, but not, apparently, on the Morley seam. It includes thin bands of shale, which may or may not be a constant feature. No attempt has yet been made to work the seams of this group, notwithstanding that the coal is of excellent quality. Nor have they been explored anywhere along the northern outcrop, though promising natural exposures appear at several points. At present the chief objection is the elevation at which they outcrop.

Workable coal in the Morley group.

Wootton group.—This group occurs at an elevation of about 1000 feet above the base of the measures. Like the Morley group, it has not been sufficiently explored to determine the number of seams, though two are known. Excavations made a short distance above Wootton's station on the old Santa Fe trail, and on the line of the Atchison, Topeka and Santa Fe Railway, show one seam to have a thickness of about 5 feet. The excavations are too shallow to enable one to judge of the quality of the coal, though outside of shale partings it is, apparently, fairly good.

Character of coal.—Elmoro coal possesses the property of coking in a high degree, and exhibits the fracture and luster peculiar to coal, of this character. The seams are not of the same character from top to bottom, the different varieties lying in bands of varying thickness. The larger bands are moderately hard, of coarse cleavage and average composition. Others afford very pure coal of cross cleavage; others again, a tough, coarse-grained coal, more impure than either of the preceding. On the whole, the coal is harder and tougher than coking coal generally, and in consequence is well adapted for transportation. There are usually two or more bands, about an inch thick, of hard, fine-grained, dull-black, bony material that adheres strongly to the coal and is mined with it. There is also an occasional shale parting, and more rarely a thin band of shale. It sometimes happens that dikes, which do not appear on the surface, cut through the coal and send sheets of lava into the measures or along one of the seams. Such occurrences are present in the two largest mines of the quadrangle. The coal in proximity is transformed into hard, dense natural coke which has no market value.

Structure of the coal seams. **Impurities in the coal.**

Composition and uses.—The appended analyses are intended to show the average composition of the coal. The percentages of nitrogen and sulphur are very low, as is also the so-called fixed carbon, while the combined carbon and earthy matter, or ash, are relatively high. The specific gravity is likewise somewhat high for coal of this character. When coked in retorts it does not yield more than the average volume of gas, but the latter possesses great illuminating power, owing to its richness in carbon; hence it is much used for the manufacture of illuminating gas. As compared with coals from other fields to the north its calorific intensity is exceptionally high, and, notwithstanding the rather large amount of ash, it is extensively employed for smithing purposes.

Analyses of the coal.

Changes produced by eruptions.—In its original, unaltered condition Laramie coal is of the kind called lignite, and in northern Colorado and Wyoming this is the character of much of the coal produced. In the Rocky Mountain region the change from lignite to more condensed varieties took place wherever subsequent great accumulation of sediments caused the measures to remain for a long period of time deeply buried, or where the lignites suffered disturbance during folding of the rocks. But these conditions alone rarely sufficed to produce a true coking coal. The same change, often in a more pronounced form, has resulted from the injection of bodies of lava into the measures, the amount of alteration being related partly to the magnitude of the intruded mass and above all to the position the body occupied with reference to the measures. Thus, a mass of lava intruded at a given distance below a bed of coal will have been much more effective in promoting alteration than a similar mass intruded at a corresponding distance above it.

There is no evidence that the measures of the Elmoro quadrangle were ever deeply buried, and they have suffered but little disturbance, so that the effects of past eruptions must **Cause of alterations of the coal.** be considered responsible for the bituminous character and coking property of the coal. Taking the Raton field as a whole, the intrusive eruptive rocks produced the alteration. Nor is the coking property more pronounced in the vicinity of the Raton Mesa overflows than in the body of the field to the west, though this does not mean that the eruption failed to influence the character of the coal, since there are fewer intrusive occurrences than in the body of the field, and the passage of vast quantities of lava up through the measures probably exerted a compensating effect.

The change that takes place in the transformation of lignite into coking coal is not well understood. But in a general way it may be said that there is a decrease in porosity without increase in weight; indeed, if anything, the specific gravity decreases, while the capacity to absorb moisture is reduced to at least one-tenth of what it was originally. At the same time there is a decided decrease in the amount and increase in the density of the tarry matter.

Faults and displacements.—The conspicuous absence of faults of any considerable amount of displacement has already received attention in connection with the general structure of the quadrangle. The mere passage of a dike through the measures does not, as a rule, cause a vertical displacement of the strata, and mine workings can be extended through them without change of grade. Faults of limited amount are met with near the western boundary, but less frequently than in other quadrangles in the same field. The most serious displacements are those that accompany lateral **Rolling ground.** injections of lava. Such occurrences are invariably associated with rolling, "troubled" ground, through which it is always difficult and expensive to continue the workings. Even displacements of this kind are not common, and, on the whole, the quadrangle is remarkably free from these sources of annoyance and expense to the operator.

Area of the coal field.—The total area of the Laramie is about 89 square miles, of which an area of 27 square miles lies beneath the Raton Mesa lava cap. Up to the present time exploration has failed to demonstrate the existence of workable seams in any portion of the area lying east of a line running south from the village of San Miguel. The absence of workable coal in this part of the field is evidently related to the thinning out of the formation eastward, only a limited amount of the thinning being attributable to erosion preceding the eruption. Exclusive of the barren eastern portion of the measures, there remains an area of 64 square miles, of which 16 square miles is capped by lava. What proportion should be excluded on account of the coal being destroyed by the upward passage of lava through the strata, or the more serious lateral injection of it, can hardly be conjectured. It is only possible to bear in mind that the coal of a considerable area of the lower zone, far removed from the outcrop and from observation, may have been destroyed. Aside from this probability the reserve areas on the respective groups will be about as follows: Engle group, 63 square miles; Sopris group, 59 square miles; Morley group, 40 square miles; Wootton group, 32 square miles. What portion of these areas will be rendered available will depend largely on future requirements. At present 5-foot coal can be worked successfully at a distance of 3 miles from the outcrop, and eventually 3-foot coal will probably be worked to the same limit. But when the depth of shaft mining elsewhere is considered there appears no reason why any part of the coal-bearing formation should be regarded as inaccessible.

Dependent industries.—Elmoro district in conjunction with the region around Trinidad, collectively known as Trinidad district, is the chief producer of coke for the metallurgic establishments of Colorado, New Mexico, and Arizona, and the mining of coal and the manufacture of coke are the principal industries.

The mines most extensively operated are situated at Engle and Gray Creek; though the present workings of the Starkville mine, **Coal mines.** the mouth of which is situated in the Spanish Peaks quadrangle, extend a distance of over 2 miles into the Elmoro quadrangle south of Engle, the two mines being almost connected with each other. Two other mines, known as the Bloom and the Butler, lie between the Engle and Starkville openings respectively. They are operated merely to supply part of the local demand. Mining is conducted on the ordinary room-and-pillar system—that is, from a main **Mining methods.** entry and parallel air course cross entries, with parallel back entries for ventilation, are driven at intervals of about 600 feet, and from these, rooms are turned off to the right and the left at intervals of from 40 to 50 feet. The rooms are then driven forward until they encounter those coming from the opposite direction. About one-half the coal is thus extracted, the other half being left as a supporting pillar on the side. The greater part of what remains is extracted subsequently and all except the necessary roadways allowed to fall in. Tail-rope haulage is usually employed in transporting the "trips" to and from the workings. On arriving at the tipple the coal is dumped over screens and passes at once to the railway cars as "lump" and "slack," the former being largely used for locomotive purposes and the latter for the manufacture of coke. Occasionally the coal as it comes from the mine is loaded without screening. Each of the large mines has a capacity of from 1000 to 1200 tons daily.

In the manufacture of coke, ovens of the beehive pattern are employed. The slack coal, in charges of from 4 to 5 tons per 12-foot standard oven, is "leveled off," bricked **Coke making.** up, and allowed to burn for either forty-eight or seventy-two hours, according to the size of the charge. The latter is subsequently quenched with water and withdrawn, the heat remaining in the oven being sufficient to ignite the next charge. The resulting coke possesses great hardness and density and a silvery luster, properties which are due to the large amount of dissociated carbon deposited while burning. Coke made from ordinary slack coal contains from 80 to 82 **Character of the coke.** per cent of carbon, from 17 to 18 per cent of ash, with small quantities of volatile substances, moisture, and sulphur. Repeated exhaustion under water to one-half inch barometric pressure shows a cell space of from 30 to 31 per cent only. While this extreme density is not desirable in ordinary metallurgic work, it is preferred for certain kinds of foundry work, such as the manufacture of car wheels.

SANDSTONE.

The Dakota sandstone forms extensive exposures near the eastern border, but up to the present time little use has been made of it **Dakota sandstone.** owing to the greater availability of the other sandstone, in most respects equally desirable. Except in the canyons of the Purgatory, Trinchera, and their tributaries, only the upper portion of the formation is accessible. The rock is light gray, almost white away from the weathered surface, of medium hardness, and has a fine-grained, even texture. The lower portion of the formation is somewhat darker colored and of a coarser, more porous texture, in places conglomeratic. Dakota sandstone is well adapted to structural purposes, and the supply is practically inexhaustible.

The Trinidad sandstone represents the upper half of the Trinidad formation. It outcrops almost continuously beneath the Laramie in **Trinidad or Halymenites-bearing sandstone.** the vicinity of Trinidad, usually appearing as an irregular line of cliff-like, deeply indented exposures. It is also more or less conspicuous eastward along the base of Raton Mesa. The rock is of medium hardness, fine grained, greenish gray in color, and of even texture. The only objection to it as a building stone is the presence of Halymenites, which slightly impairs its homogeneity. This sandstone is extensively employed for structural purposes in the city of Trinidad, where it has been used in the erection of many fine buildings. The retaining walls of the coke ovens at Elmoro are built of this stone. As yet there are no regular quarries in operation, the practice being to obtain the rock from the nearest accessible point.

From base to summit the Laramie includes thick beds of sandstone available for structural purposes. The color is light gray and the tint **Laramie sandstone.** even. The grain and texture vary slightly in different beds, the average stone being somewhat coarser and more porous than Trinidad sandstone. It has been used to some extent for the retaining walls of coke ovens, for foundations, and for railway culverts. Lately it has been crushed to suitable size and used for ballasting the Atchison, Topeka and Santa Fe track. The supply is practically unlimited.

LIMESTONE.

The Timpas limestone is a bed of grayish-white limestone from 40 to 50 feet thick. The outcrop is a prominent feature of the eastern portion of the quadrangle, where it appears **Timpas limestone.** as an irregular line of rocky bluffs extending north and south the entire length of the quadrangle. Near the northern border the outcrop is in places equally prominent and is practically continuous across the district from east to west. The Atchison, Topeka and Santa Fe and the Colorado and Southern railroads cross accessible portions of the bed. Elsewhere this limestone is much used as a flux in smelting lead and iron ores, but at present there is no demand for it here.

The Greenhorn limestone forms a narrow, irregular outcrop in the eastern and northern portions of the quadrangle. It occurs in layers usually less than a foot thick, separated **Greenhorn limestone.** by thinner layers of shaly material. The limestone is dove colored and is harder and apparently more impure than the Timpas limestone, and, on account of the abundance of the latter, can have very little value for fluxing purposes.

FIRE CLAY.

There is usually present beneath the workable beds of coal a layer of soft shale, of varying thickness, from which the iron has been removed by the reducing action of carbonaceous matter and the formation of the soluble ferrous oxide. The removal of the iron tends to render the shale refractory, for which reason it is often **Laramie fire clay.** termed fire clay. But the absence of iron is not the only requisite, and as the other bases vary considerably, such deposits are rarely of economic value. These coal-measure clays, while probably not suited for the manufacture of the better grades of refractory ware, may be found of more or less value in connection with local requirements.

The shale employed in Colorado for the manufacture of bricks, crucibles, muffles, and other highly refractory articles is obtained from the upper part of the Dakota group. This shale separates the upper and lower sandstones and is invariably present about 100 feet below the top of the formation. It is exposed in Purgatory and Trinchera canyons, near the eastern border of the quadrangle. The outcrop is usually covered by talus, but its position is often marked **Dakota fire clay.** by a terrace or narrow ledge immediately below it, or by cavernous recesses parallel with the bedding. The comparative refractory value of the Dakota fire clay on the Purgatory has not been determined; such determination is necessary before any statement can be made as to the real importance of the occurrence, it being known that the composition varies widely from place to place in other localities.

OTHER MINERALS OF ECONOMIC VALUE.

An attempt that was not a financial success was made to manufacture Portland cement from the impure limestone concretions of the **Cement limestone.** Pierre shales. It is questionable, from the nature of their occurrence, if these concretions could be made a cheap source of raw material for this purpose. On the other hand, the calcareo-arenaceous shales of the Apishapa formation may be regarded as more than a possible source of an unlimited supply of material for the manufacture of cement clinker. These shales vary in composition and texture at different levels and in different localities, and bodies containing almost any desired lime-silica-alumina combination may not be difficult to find.

Thin bands of impure limonite and concretions containing iron carbonate are sometimes present in the shaly portions of the Laramie. **Iron ore.** But aside from the fact that important deposits of iron ore have not been discovered, the conditions under which such deposits occur are entirely wanting.

Petroleum has been reported as of occasional appearance along the base of Raton Mesa, by trustworthy residents, and it must be **Petroleum.** admitted that the conditions closely resemble those at Florence, Colorado, in every important particular. This part of the quadrangle is certainly worthy of consideration as a possible oil field.

ARTESIAN WATER.

The Dakota formation is the chief water-bearing bed of the country, and is the source of artesian water at Pueblo, La Junta, and elsewhere. Lying as it does beneath the impervious Benton shales, it constitutes a rock reservoir which, owing to the open, porous texture of the sandstone, affords considerable space for water, and is thus a source of supply nearly coextensive with the quadrangle. While it is only at a few points in the eastern part of the district that erosion has cut deep enough into the formation to reach this source, there are at all of these points strong springs of pure, clear water, and it is to be expected that wherever the lower zone of the Dakota is penetrated by boring, a supply of artesian water will be found. This zone extends from the base of the formation to the uppermost band of **Position and thickness of the water-bearing zone.** shale (fire clay) which occurs under the fine-grained sandstone and 100 feet or more from the top. Hence, a bore must penetrate the sandstone from 100 to 150 feet before a supply of water will be obtained. The approximate thickness of the zone is from 200 to 250 feet. The depth of the uppermost water-bearing bed at any point is indicated by the contours on the artesian-water sheet. These contours are based on the ascertained thickness of the respective overlying formations, which are **To what extent the contours are reliable.** fairly uniform throughout the district, with the exception of the Greenhorn and Timpas, which thicken materially toward the south. In the eastern and northern portions of the quadrangle, and up to a depth of 1200 feet, these contours may be accepted with considerable confidence; but uncertainty increases with the increasing thickness of the Pierre shale to the southwest, and the 2000-foot contour may be as much as 200 feet in error.

It is doubtful if the conditions are anywhere such as to insure a strong artesian flow, **Flowing wells.** but there is good reason for the belief that a limited area in Purgatory Valley will afford flowing wells.

Fig. 1.—Ideal section illustrating the general artesian conditions along the plains border.

Kl, Laramie; Km, Montana; Kc, Colorado; Kd, Dakota sandstone, water-bearing zone; P P, Plane of head; I, Point of inflow; O, Point of outflow.

In the above diagram the broken line P P represents the plane of head—an inclined plane between the point of inflow, I, and the point of outflow, O. Theoretically, if **Conditions governing the flow of wells.** the resistance to the passage of water through the Dakota sandstone, Kd, is uniform throughout, and the inflow is equal to the capacity of the rock for transmission, the water when tapped at any point will rise to this plane, and wherever the latter lies above the surface a bore hole to the water zone will afford a flowing well. In reality the texture of the sandstone varies more or less, so that the resistance is not uniform. Moreover, the inflow may not equal the capacity of the rock for transmission, while faults and eruptive bodies will operate to lessen this capacity or to obstruct the flow. If the obstruction is between the bore and the point of outflow the water may be capable of rising above the plane of head; if the reverse is the case it may fall considerably below that plane. Accordingly, it is not to be expected that the available head will coincide with the theoretic head, and to be on the safe side one should regard it as much less.

Under the conditions that exist in Purgatory Valley, the point I in the diagram is situated at the great Dakota sandstone reef of Stonewall Park, which at an elevation of about 8000 feet is crossed by the several branches of Purgatory River. The point O is situated at the outcrop of the water-bearing zone along the eastern border of the quadrangle, with an **Artesian conditions in this quadrangle.** elevation of about 5000 feet. The plane of head, P P, will be about 450 feet higher than the city of Trinidad and 300 feet higher than Hoehne. For one of the reasons above given, it is not at all certain that the water will rise to this plane, or that flowing wells will be had not far below that elevation; and considering the fact that the head will decrease with the number of wells bored, the area that will yield flowing wells must be considerably less than that covered by the theoretic head. But any attempt to represent this area on the map would be out of the question, as the boundaries are necessarily arbitrary. Accordingly, the area colored blue on the sheet is merely intended to indicate the territory most likely to yield flowing wells.

Pumping wells.

There is little doubt that the water-bearing zone will yield pumping wells over the greater part of the quadrangle. The north-south flexure which crosses the Purgatory just above the canyon separates the territory on the east that may be expected to yield but sparingly from the territory on the west that may be expected to yield a more abundant supply. From the line of this flexure the water-bearing zone dips gradually in a southwestern direction toward the bottom of the trough, which is situated several miles beyond the western boundary; and as the land surface rises gradually in the same direction, the depth of the zone increases, as shown by the contours on the sheet. But the supply of water must also increase as the heart of the reservoir is approached. It is not to be supposed that the water will have to be pumped from the depth the bore must penetrate to reach the zone, since in nearly all cases it will rise in the well to a height that will admit of pumping by wind power.

It may be well to add that the life of a well passing through such soft, shaly beds will be very short unless the bore is cased with iron pipe down to the top of the Dakota sandstone.

RICHARD CHARLES HILLS,
Geologist.

July, 1898.

Analyses of coals from the Elmoro district.

Locality.	Carbon.		Hydrogen.		Oxygen.	Nitrogen.	Sulphur.	Moisture.	Ash.	Volatile hydrocarbons.	Specific gravity.	Character of sample.
	Fixed.	Combined.	Disposable.	With oxygen.								
Engle mine	54.65	18.33	3 68	0.87	6.70	0.85	0.61	0.70	13.35	31.30	1.366	Sample of slack coal taken from cars.
Engle mine	57.07	17.56	3.67	0.99	7.89	0.47	0.55	0.75	11.05	31.13	1.287	Clean lump coal.
Starkville mine	57.39	16.19	3.65	1.18	9.41	0.31	0.63	0.44	10.80	31.37	1.303	Clean lump coal.
Morley seam	59.19	17.55	4.21	0.77	6.21	1.06	0.61	1.63	8.77	30.41	1.358	Clean lump coal.
Sprouls opening*	52.50	20.25	4.06	1.31	10.46	1.72	0.50	2.90	6.30	38.30	1.250	Clean lump coal.
Bloom mine	57.03	......	......	......	......	......	0.70	0.45	10.71	31.11	1.333	Clean lump coal.
Butler mine	56.59	......	......	......	......	......	0.65	0.45	11.51	30.80	1.329	Clean lump coal.

* This opening is a little south of the southern boundary of the quadrangle.

Analyses of coal ashes from the Elmoro district.

	Silica.	Alumina.	Ferric oxide.	Lime.	Magnesia.	Soda.	Potash.	Sulphuric acid.	Phosphoric acid.	Total
Starkville mine	65.02	24.73	7.56	0.16	0.30	2.22	0.52	0.32	.095	100.92
Engle mine	68.42	17.33	11.50	0.66	0.21	1.49	0.71	0.37	.080	100.77
Morley seam	68.60	19.94	6.42	1.30	Tr.	1.46	1.32	0.34	*	99.38

* Not determined.

NOTE.—The above analyses were made by the writer in the Denver laboratory of the Colorado Fuel and Iron Company.

TABLE OF FORMATION NAMES.

<table>
<tr><th>PERIOD.</th><th colspan="2">NAMES AND SYMBOLS USED IN THIS FOLIO.</th><th colspan="2">NAMES USED BY VARIOUS AUTHORS.</th><th>G. K. GILBERT: SEVENTEENTH ANNUAL REPORT U. S. GEOLOGICAL SURVEY, 1896.</th><th>F. V. HAYDEN: GEOLOGICAL ATLAS OF COLORADO, 1881.</th></tr>
<tr><td>NEOCENE ?</td><td>Nussbaum formation.</td><td>Nn</td><td colspan="2">Nussbaum.</td><td>Upland sands.</td><td></td></tr>
<tr><td rowspan="10">CRETACEOUS</td><td>Laramie formation.</td><td>Kl</td><td colspan="2">Laramie.</td><td></td><td>Laramie (post-Cretaceous).</td></tr>
<tr><td>Trinidad formation.</td><td>Ktd</td><td>Fox Hills.</td><td rowspan="2">Montana.</td><td></td><td rowspan="2">Fox Hills (including Pierre).</td></tr>
<tr><td>Pierre shale.</td><td>Kp</td><td>Pierre.</td><td>Pierre shale.</td></tr>
<tr><td>Apishapa formation.</td><td>Ka</td><td rowspan="2">Niobrara.</td><td rowspan="5">Colorado.</td><td>Apishapa formation.</td><td rowspan="5">Colorado (comprising Benton and Niobrara).</td></tr>
<tr><td>Timpas formation.</td><td>Kt</td><td>Timpas formation.</td></tr>
<tr><td>Carlile shale.</td><td>Kcr</td><td rowspan="3">Benton.</td><td>Carlile shale.</td></tr>
<tr><td>Greenhorn limestone.</td><td>Kgn</td><td>Greenhorn limestone.</td></tr>
<tr><td>Graneros shale.</td><td>Kgs</td><td>Graneros shale.</td></tr>
<tr><td>Dakota sandstone.</td><td>Kd</td><td colspan="2">Dakota.</td><td>Dakota sandstone.</td><td>Dakota.</td></tr>
</table>

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

TOPOGRAPHIC SHEET

COLORADO
(LAS ANIMAS CO.)
ELMORO QUADRANGLE

CONVENTIONAL SIGNS

CULTURE
(printed in black)

- Roads and buildings
- Private and secondary roads
- Trails
- Railroads
- Street railroads
- Tunnels
- Bridges
- Ferries
- Fords
- Dams
- Locks
- U.S. township and section lines
- Located township and section corners
- Township and section corners not found
- Triangulation stations
- Bench marks
- Mines and quarries
- Prospects
- Shafts
- Mine tunnels *(showing direction)*
- Mine tunnels *(direction unknown)*

CONVENTIONAL SIGNS

RELIEF
(printed in brown)

- 5463 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
- Levees
- Cliffs
- Mine dumps

DRAINAGE
(printed in blue)

- Streams
- Falls and rapids
- Intermittent streams
- Canals and ditches
- Lakes and ponds
- Intermittent lakes
- Glaciers
- Springs
- Salt marshes
- Fresh marshes
- Tidal flats

The above signs are in current use on the topographic maps. Variations from this usage appear in some maps of earlier dates.

Henry Gannett, Chief Topographer.
E.M. Douglas, Topographer in charge.
Triangulation by A.H. Thompson.
Topography by W.H. Herron and W.J. Lloyd.
Surveyed in 1895.

Herron | Lloyd | Herron

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 April 1899.

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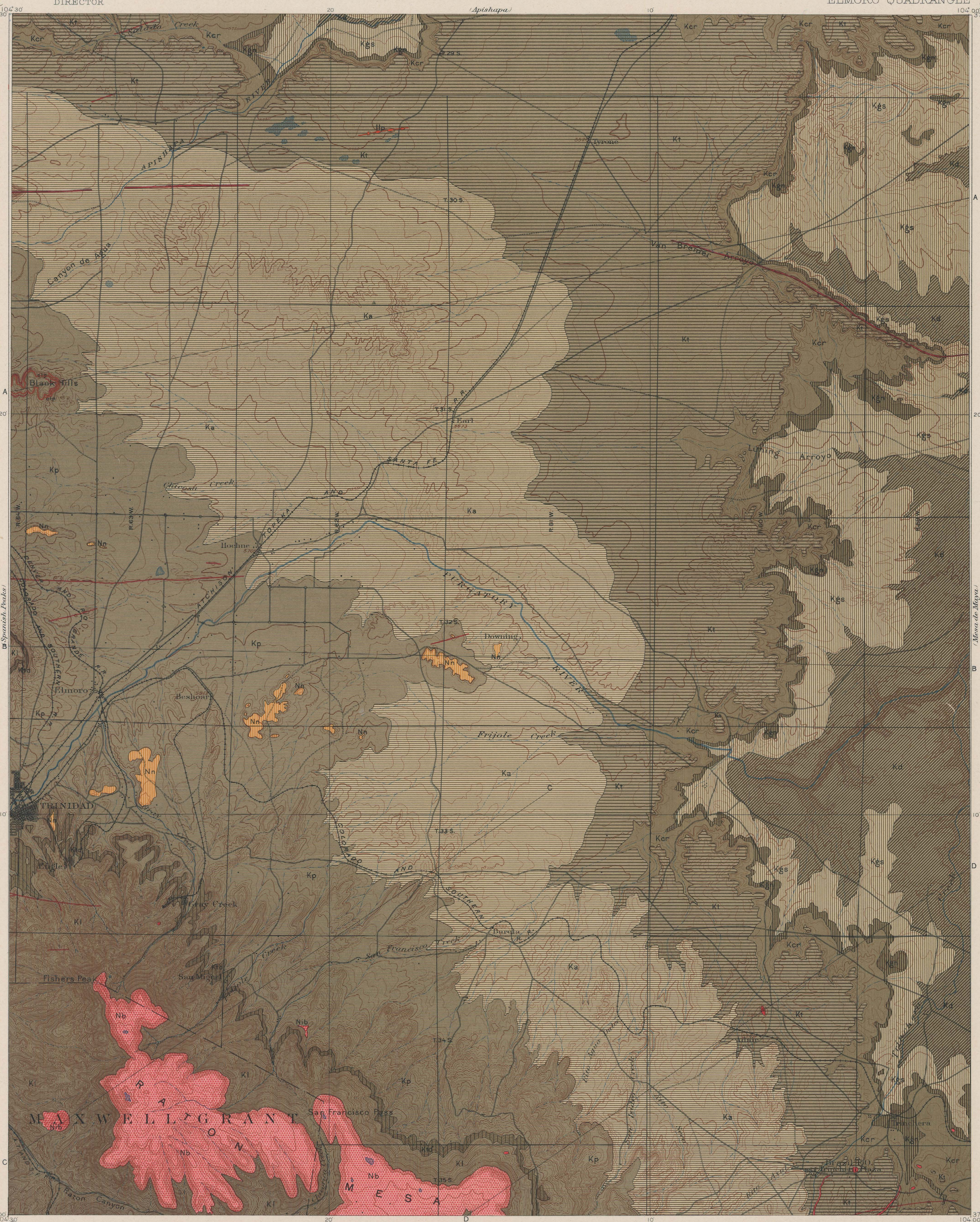
HISTORICAL GEOLOGY SHEET

COLORADO
(LAS ANIMAS CO.)
ELMORO QUADRANGLE



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Scale $\frac{1}{125000}$

Contour interval 50 feet.
Datum is mean sea level.
Edition of July 1899.

Geology by R. C. Hills.
Surveyed in 1896.

LEGEND

SEDIMENTARY ROCKS

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

NEOCENE?

Nn — Nussbaum formation *(sand and gravel in part cemented into conglomerate)*

CRETACEOUS

Kl — Laramie formation *(gray sandstone and shale containing coal beds)*

Ktd — Trinidad formation *(gray sandstone with shaly beds in the lower portion; probably represents the upper part of the Fox Hills series)*

Kp — Pierre shale *(argillaceous shale with calcareous concretions)*

Niobrara formation

Ka — Apishapa formation *(chiefly calcareous arenaceous shale, somewhat bituminous)*

Kt — Timpas formation *(calcareous shale and pale-gray limestone)*

Kcr — Carlile shale *(argillaceous shale with large septarian concretions in the upper beds)*

Kgn — Greenhorn limestone *(alternating beds of dove-colored limestone and shale)*

Kgs — Graneros shale *(argillaceous shale with large concretions)*

Kd — Dakota sandstone *(gray sandstone with thin shale partings and a bed of fire clay)*

IGNEOUS ROCKS

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

NEOCENE

Nb — Extrusive basalt *(lava flows)*

Nib — Intrusive basalt *(plugs, sheets, dikes, and irregular bodies)*

EOCENE?

Earlier intrusives - *(dikes and sheets of early lamprophyre, elp, and later lamprophyre, llp)*

Sections

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ECONOMIC GEOLOGY SHEET

COLORADO
(LAS ANIMAS CO.)
ELMORO QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

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

NEOCENE ?

- Nn — Nussbaum formation *(sand and gravel in part cemented into conglomerate)*

CRETACEOUS

- Kl — Laramie formation *(gray sandstone and shale containing coal beds)*
- Ktd — Trinidad formation *(gray sandstone with shaly beds in the lower portion; probably represents the upper part of the Fox Hills series)*
- Kp — Pierre shale *(argillaceous shale with calcareous concretions)*
- *Niobrara formation:*
  - Ka — Apishapa formation *(chiefly calcareous arenaceous shale, somewhat bituminous)*
  - Kt — Timpas formation *(calcareous shale and pale-gray limestone)*
- Kcr — Carlile shale *(argillaceous shale with large septarian concretions in the upper beds)*
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IGNEOUS ROCKS

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

NEOCENE

- Nb — Extrusive basalt *(lava flows)*
- Nib — Intrusive basalt *(plugs, sheets, dikes, and irregular bodies)*

EOCENE ?

- Earlier intrusives - *(dikes and sheets of early lamprophyre,* elp, *and later lamprophyre,* llp*)*

Sections

⚒ Coal mines

Known productive formations

- Kl — *Coal (in the Laramie formation; extensively mined for making coke)*
- *Fire clay (in the Dakota sandstone)*

Henry Gannett, Chief Topographer.
E.M. Douglas, Topographer in charge.
Triangulation by A.H. Thompson.
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Surveyed in 1895.

Scale $\frac{1}{125000}$

Contour interval 50 feet.
Datum is mean sea level.

Edition of July 1899.

Geology by R.C. Hills.
Surveyed in 1896.

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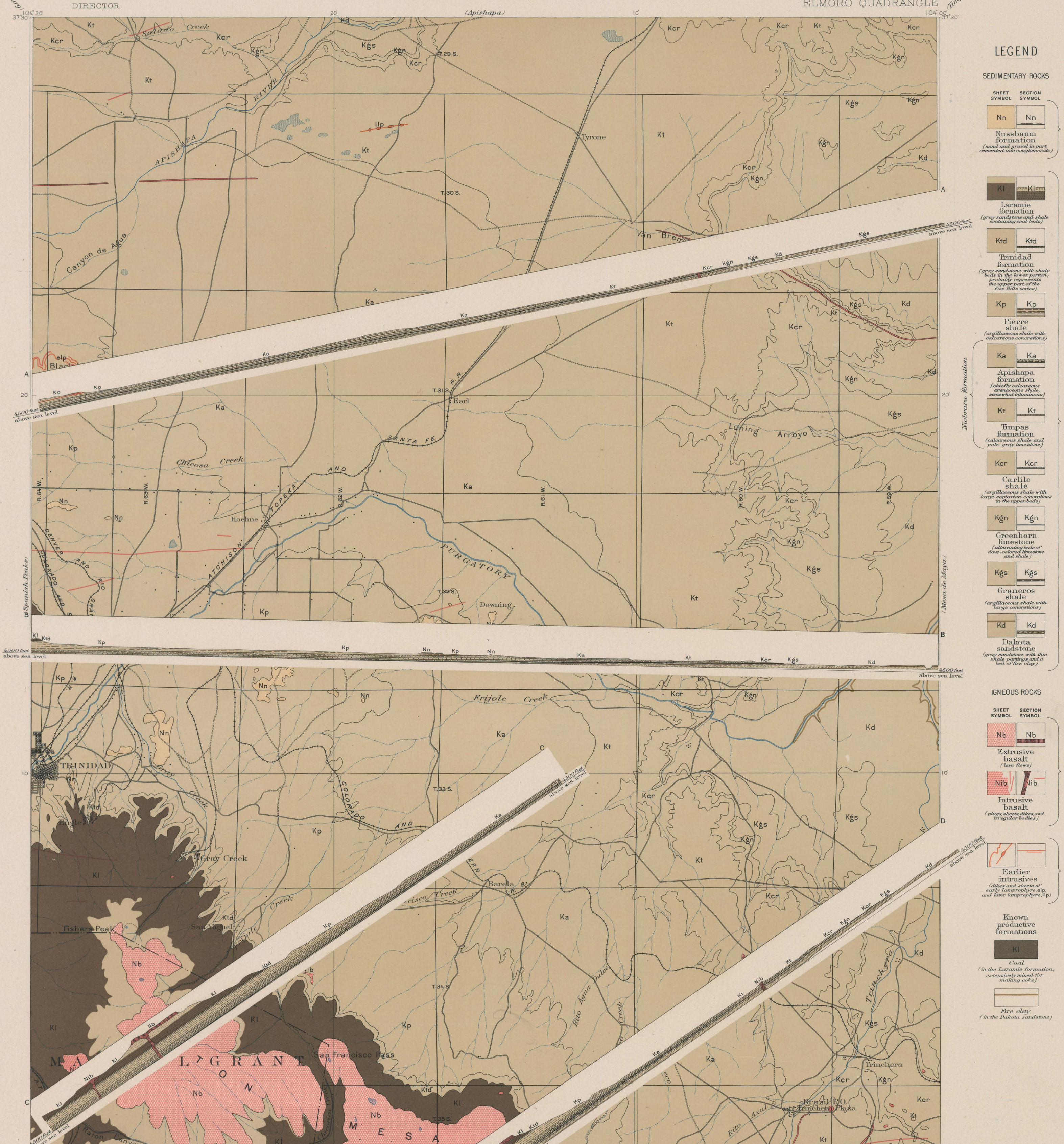
STRUCTURE-SECTION SHEET

COLORADO
(LAS ANIMAS CO.)
ELMORO QUADRANGLE



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Surveyed in 1895.

Geology by R.C. Hills.
Surveyed in 1896.

Scale 1/125000

5 Miles

5 Kilometers

Edition of Aug. 1899.

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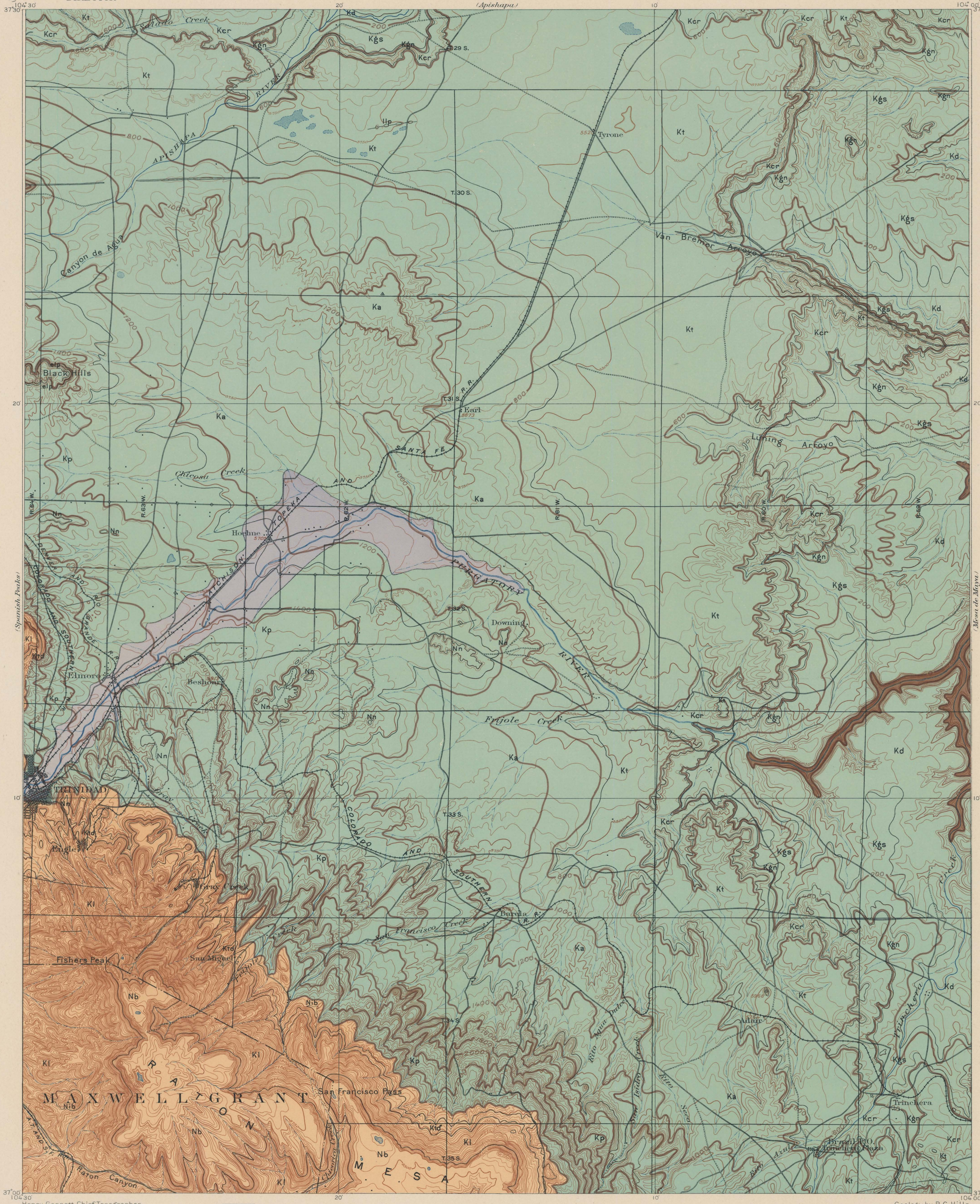
ARTESIAN WATER SHEET

COLORADO
(LAS ANIMAS CO.)
ELMORO QUADRANGLE



LEGEND

Area of artesian water which will probably yield flowing wells at less than 2400 feet depth

Area of artesian water which will probably yield pumping wells at less than 2400 feet depth

Area in which the water-bearing zone is more than 2400 feet below the surface

Outcrop of the water-bearing zone of the Dakota sandstone

Contours showing approximate depth below the surface of the highest water-bearing bed of the Dakota sandstone. Contour interval is 200 feet. Figures show depth in feet.

Henry Gannett, Chief Topographer.
E.M. Douglas, Topographer in charge.
Triangulation by A.H. Thompson.
Topography by W.H. Herron and W.J. Lloyd.
Surveyed in 1895.

Herron | Lloyd | Herron

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 Nov. 1899.

Geology by R.C. Hills.
Surveyed in 1896.

U.S. GEOLOGICAL SURVEY
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COLUMNAR-SECTION SHEET

COLORADO
(LAS ANIMAS CO.)
ELMORO QUADRANGLE

GENERALIZED SECTION OF THE ROCKS OF THE ELMORO QUADRANGLE.

SCALE: 1000 FEET = 1 INCH.

Period.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.
NEOCENE	Nussbaum formation.	Nn		10–50	Sand and gravel, cemented into conglomerate at the base.
	Extrusive basalt.	Nb	Nn	500	Gray to brown basalt, often vesicular. Separate flows are 30 feet or more thick.
CRETACEOUS	Laramie formation.	Kl		800–2500	Heavy-bedded gray sandstone, alternating with thick bands of shaly sandstone and shale containing workable coal beds.
	Trinidad formation	Ktd		155	Massive sandstone with fucoids, thin bedded at the base.
	Pierre shale.	Kp		1200–1300	Gray and dark-colored shale, containing ferruginous limestone concretions seamed with carbonates of lime and iron.
	Apishapa formation.	Ka		450–500	Thin bed of limestone. Calcareous, arenaceous shale, somewhat bituminous.
	Timpas formation.	Kt		200–250	Gray calcareous shale. Thin limestone beds at top and base.
	Carlile shale.	Kcr		180–200	Massive sandstone and dark shale.
	Greenhorn limestone.	Kgn		30–50	Thin-bedded limestone and shale.
	Graneros shale.	Kgs		200–210	Gray and dark shale, containing concretions.
	Dakota sandstone.	Kd		300+	Gray sandstone with gray, greenish, and dark-colored shales.

SECTIONS OF LOWER PORTION OF LARAMIE FORMATION FROM DIAMOND-DRILL BORINGS BETWEEN ENGLE AND GRAY CREEK.

SCALE: 50 FEET = 1 INCH.

Bore No. 1.

Height above base in feet.	Thickness: Coal in inches.	Thickness: Rock in feet.	Character of Rocks.
406			
		127	Sandstone and shale
279	2		
		81	Shale and sandstone.
197	14		Bony coal.
		42	Sandstone and shale.
	3		
		25	Shale with some sandstone.
127	5	1	Shale.
	10		
		35	Massive sandstone.
90	13	1	Shale.
	7		
		42	Thin-bedded sandstone and shale.
46	29	3	Shale.
	10	4	Shale.
35	48		
		6	Shale.
	14		
		12	Sandstone and shale.
	5		
		10	Shale.
0	11	4	Shale.
	Trinidad formation. Penetrated to a depth of 60 feet 8 inches.		

Bore No. 2.

Height above base in feet.	Thickness: Coal in inches.	Thickness: Rock in feet.	Character of Rocks.
			Sandstone with shale partings.
413	3		
		20	Sandstone and shale.
		38	Sandstone.
355	2		
		72	Sandstone with a little shale.
		62	Alternating beds of shale and sandstone.
218	34		
		75	Sandstone and sandy shale.
141	38		
		38	Massive sandstone with some shale.
99	42		
		45	Thin-bedded sandstone and shale.
	46		
48	12	2	Shale.
		14	Shale and sandstone.
30	40		
		27	Shale and sandstone.
0	23	2	Shale.
	Trinidad formation. Penetrated to a depth of 24 feet 10 inches.		

GENERALIZED SECTION OF THE LARAMIE FORMATION IN THE TRINIDAD DISTRICT.

SCALE: 200 FEET = 1 INCH.

Formation Name.	Name of Coal Beds.	Columnar Section.	Height above base in feet.	Character of Rocks.
Extrusive basalt (Nb)			3000	Eruptive flows of gray, drab, brown, and dark-brown basalt, often vesicular.
			2500	
Laramie formation (Kl)				Heavy-bedded gray sandstone, alternating with thin-bedded, greenish-gray, micaceous sandstone and beds of shale. Massive sandstone predominates.
	Raton Pass group (small seams, not workable).		1500	
	Wootton seam, 5 feet (not yet worked).		1000	Heavy-bedded gray sandstone, alternating with bands of shaly sandstone and shale, the latter containing the workable beds of coking coal.
	Morley seam, 6 feet (not yet worked).		750	
	Sopris group.		220	Shale and shaly sandstone, with a predominance of thin-bedded sandstone and shale partings for 250 feet above the base of the formation.
			140	
			100	
	Engle group.		0	
Trinidad formation (Ktd)				Massive sandstone, containing Halymenites. Thin-bedded, fine-grained sandstone with shale partings.
Pierre shale (Kp)				Argillaceous shale with ferruginous limestone concretions.

RICHARD CHARLES HILLS,
Geologist.

SPECIAL ILLUSTRATIONS

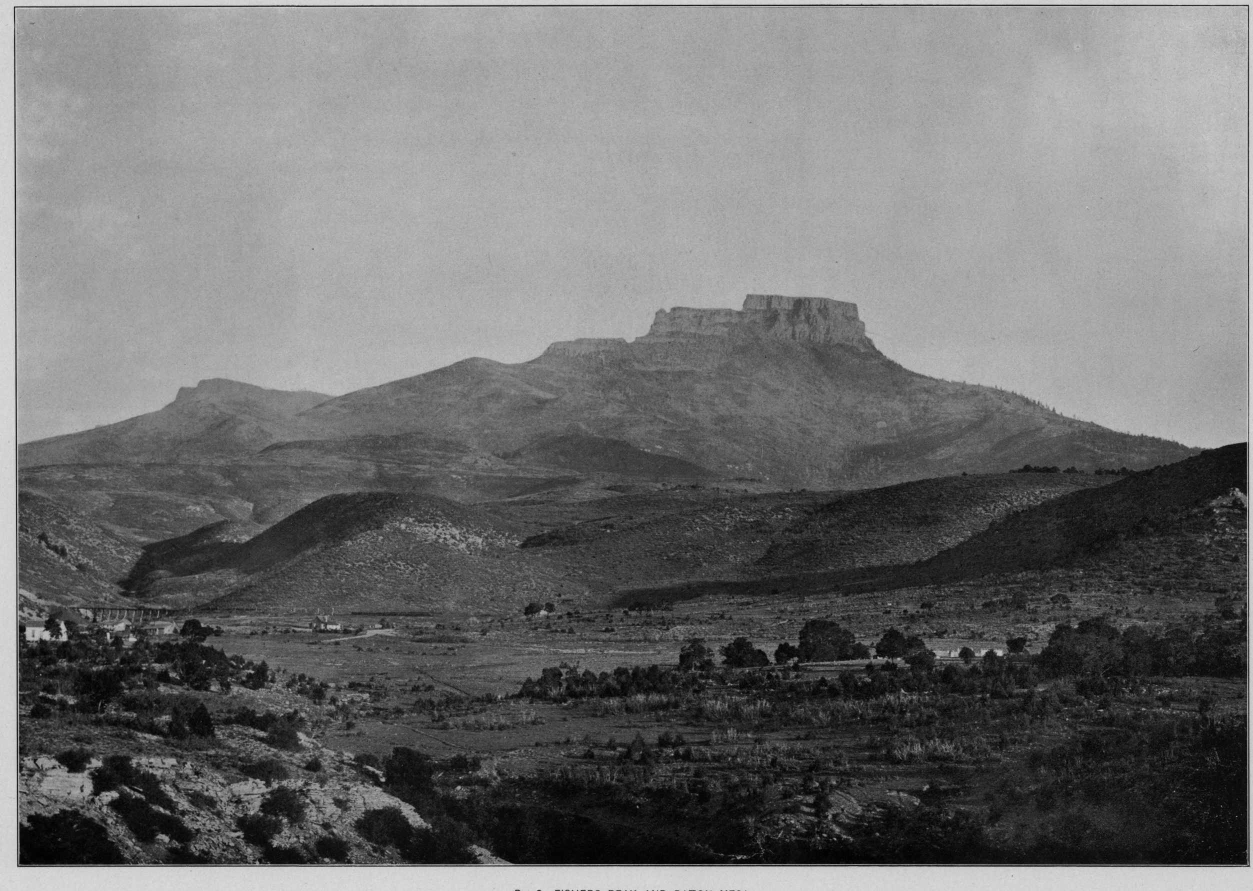

FIG. 2.—FISHERS PEAK AND RATON MESA.

This view is taken from near the Engle mine. It shows the flat-topped character of the mesa, which rises 3,000 feet above, and the vertical cliffs of basalt forming its summit. The slopes of the mountain are composed of the coal-bearing Laramie, a hard stratum of which has produced the terrace in the middleground. The rock exposed in the foreground is the Trinidad formation.

FIG. 3.—CONICAL BUTTES OF IGNEOUS ROCK.

This represents one of the most typical of the volcanic plugs of the district. It consists of a cylindrical mass of basalt occupying the vent of an extinct volcano, and is surrounded by an accumulation of basalt talus. The butte is situated one mile north of Adair station, on the Colorado and Southern Railroad.

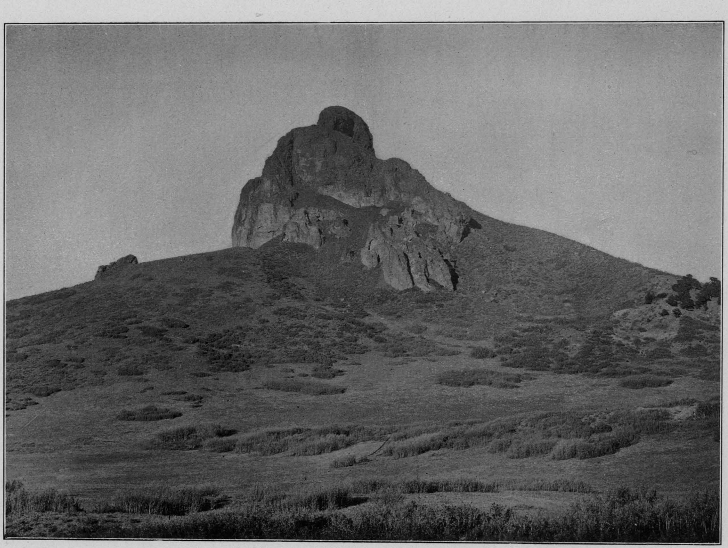

FIG. 4.—IGNEOUS BUTTES OF IRREGULAR FORM.

This is one of a row of plug-like bodies of lamprophyre which are connected with one another by dike-like bodies of the same material. They occur in the northern part of the quadrangle.