DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

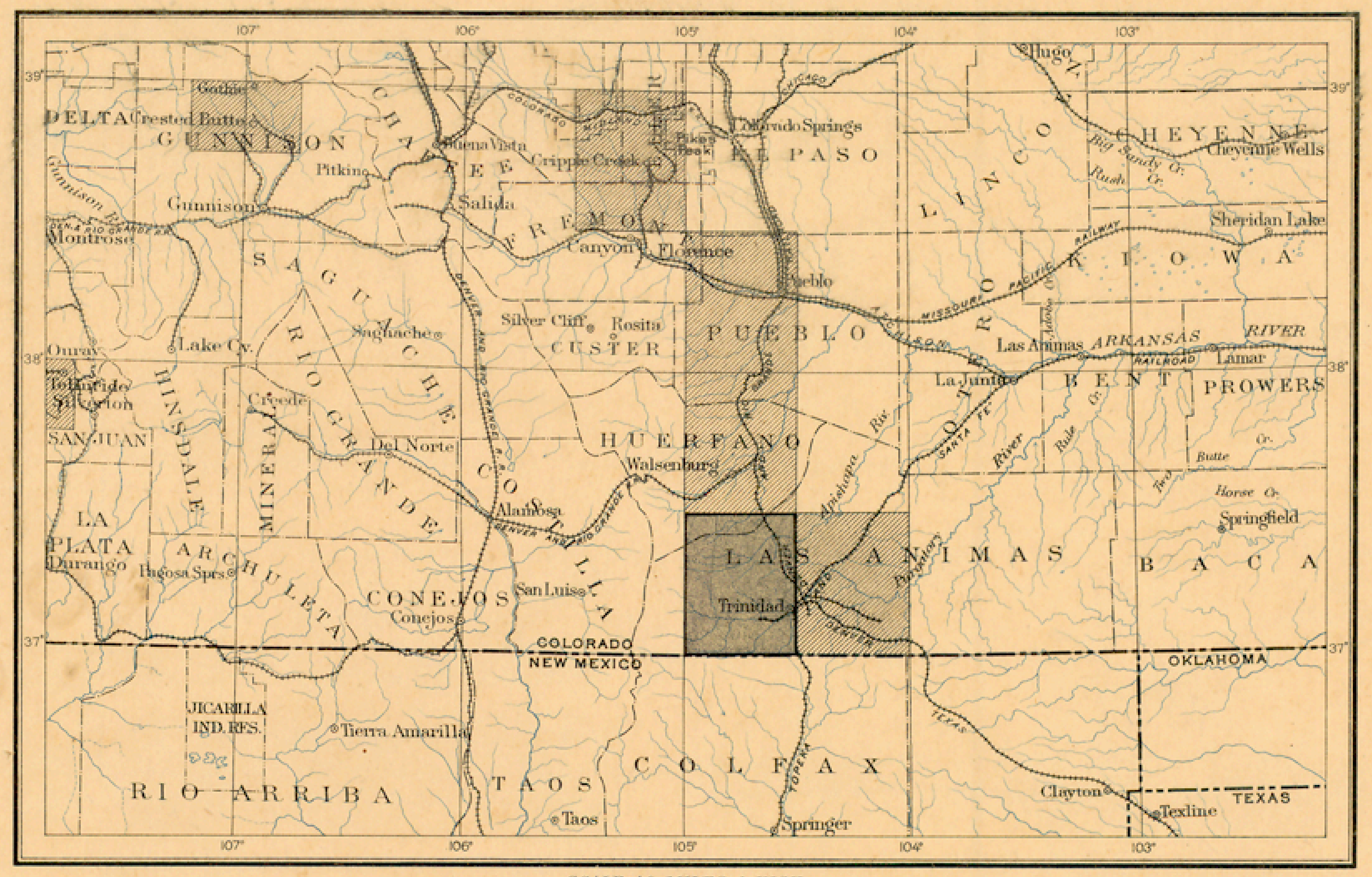
OF THE

UNITED STATES

SPANISH PEAKS FOLIO

COLORADO

INDEX MAP



SCALE: 40 MILES=1 INCH

AREA OF THE SPANISH PEAKS FOLIO

AREA OF OTHER PUBLISHED FOLIOS

LIST OF SHEETS

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

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FOLIO 71 — LIBRARY EDITION — SPANISH PEAKS

WASHINGTON, D. C.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

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

1901

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:

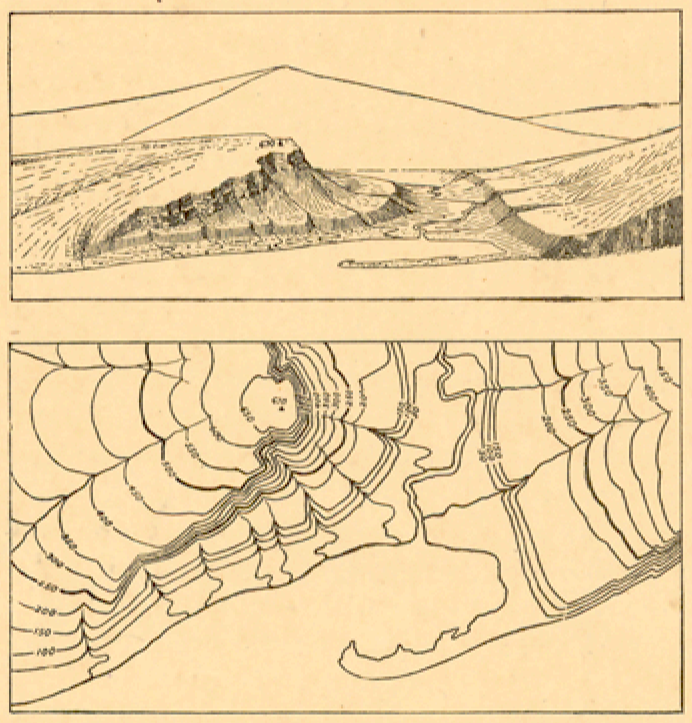


Fig. 1.—Ideal sketch and corresponding contour map.

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

DESCRIPTION OF THE SPANISH PEAKS QUADRANGLE.

GEOGRAPHY.

The Spanish Peaks quadrangle is bounded by meridians 104° 30′ and 105° and parallels 37° and 37° 30′. It is 34.5 miles long north and south, 27.5 miles wide east and west, and contains 950 square miles. It lies mostly in Las Animas County, Colorado, but part of it — about 28 square miles in the northern portion — is situated in Huerfano County, the divide separating the Purgatory and Apishapa drainage from that of the Cuchara being the common boundary. Except in a comparatively small area lying to the northeastward, the surface is hilly and mountainous. The chief topographic feature is the saddle-shaped mountain in the northwestern portion generally known as the Spanish Peaks, though called by the Indians "Wahatoyas," in allusion to the fancied resemblance to a woman's breasts. (See fig. 5, on Special Illustration sheet.) The culminating points are about 3 miles apart, West Peak, which has an elevation of 13,623 feet, being 915 feet higher than East Peak. The mountain rests upon a broad platform that falls gradually toward the east and terminates in a deeply indented, irregular line of steep bluffs that rise abruptly 500 feet above the gently rolling country at their base. The mean elevation of this platform is about 7500 feet, the western portion being about 1000 feet higher than the eastern. It was originally an elevated plain or plateau, of gentle inclination, but has been deeply scored by erosion, and the present surface, rugged in the extreme, is a succession of mesa-like ridges and narrow valleys, the general character being emphasized by many perpendicular walls of rock (dikes) that occasionally rise to a height of 100 feet above the surface and stretch for miles across the country. In the northern two-thirds of the quadrangle the ridges have a rude radial arrangement conforming to the drainage from the peaks. In the southern third the principal ridges trend toward the northeast, conforming to the drainage of the Raton Mountains, which culminate a few miles south of the boundary.

Topographic features.

The Purgatory River is the main drainage channel. It traverses the southern portion of the district from west to east and drains slightly more than one-half the quadrangle. The northern half is drained by a number of small streams, tributaries of the Cuchara and Apishapa, nearly all of which head in the Spanish Peaks. The two drainage systems are separated from each other by a low east-west ridge that extends from the base of East Peak about two-thirds across the district a little north of the center.

Drainage.

The whole of the upland portion of the area is still rather heavily timbered notwithstanding the fact that it has been largely drawn upon for lumber. The eastern margin of the plateau, as well as the slopes bordering the Purgatory Valley, supports a dense growth of piñon and juniper, with scattered pines and scrub oak. The more elevated central, western, and south-border portions of the area afford forests of pine timber, with more or less spruce, fir, and aspen around the base and on the lower slopes of the Spanish Peaks, the summits of the latter being from 1000 to 1500 feet above timber line. There are occasional park-like openings, one of considerable extent in the northern portion, on the Santa Clara, and another in the north-central portion, on the Apishapa. The low-lying portion to the northeast, except the piñon-clad Black Hills Mesa, is practically destitute of timber. There is always a fringe of cottonwood along the running streams. The country affords several varieties of upland and mountain grasses sufficient for pasturage, with stretches of meadow land along the bottoms.

Vegetation.

The climate varies with the elevation. The low-lying northeastern portion is warm and arid, the eastern border of the plateau less so, while the more elevated upland portion is cool and relatively humid, and on the summits of the Spanish Peaks snow is rarely absent for more than two months in the year. The whole of the plateau portion is subject to frequent summer showers, and in the neighborhood of the peaks thunderstorms accompanied by heavy rains are of frequent occurrence.

Climate.

Along the narrow valleys of the Purgatory and Apishapa, cultivation is carried on by means of irrigation. But all the higher valleys and mesas of the central and western portions can generally be cultivated successfully without irrigation, and there is a belt several miles wide around the base of the peaks that is largely under fence, where wheat, oats, rye, maize, timothy, potatoes, and ordinary garden vegetables are sure crops with natural moisture only.

Agriculture.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

In the geology of the Spanish Peaks quadrangle the Archean and Paleozoic eras are not represented by any formations that reach the surface, though the former, if not the latter, may be assumed to underlie the whole of the area. The oldest exposed sedimentary rocks are probably part of the Morrison formation (Juratrias), but they are of very limited extent and are associated with a series of beds, altered by contact metamorphism, the members of which can not be differentiated. In a later paragraph these will be described collectively under the heading "Metamorphosed Cretaceous." Of the unaltered sedimentary beds, part belong to the Mesozoic (Cretaceous) and part to the Cenozoic (Eocene and Neocene).

CRETACEOUS PERIOD.

The older Cretaceous formations of the region — Dakota, Graneros, and Greenhorn — are not represented, but they outcrop extensively in the Elmoro quadrangle to the east and in the quadrangle to the west, and hence doubtless underlie the entire district. Previously there had been a long period of land conditions, which about the middle of the Cretaceous was succeeded by a long-continued, profound subsidence and an invasion by the ocean. The Dakota sandstone was deposited in the brackish-water front of the advancing sea. As the shore line passed onward marine conditions were inaugurated, and with continued subsidence the beds of the marine Cretaceous were successively deposited.

Earlier Cretaceous conditions.

Carlile formation.—The lower marine Cretaceous beds of the region, represented by the Graneros shale, resting upon the Dakota sandstone, the Greenhorn limestone, or middle subdivision of the group, and the Carlile shale, or upper division, have been described as the Benton formation of other localities, and here constitute the Benton group. The first two outcrop eastward beyond the limits of the quadrangle.

The Carlile is the uppermost of the three divisions of the Benton, and the lowest of the unaltered Cretaceous rocks of the quadrangle, in which, however, not more than one-half the full thickness of the Carlile is exposed. It consists of about 200 feet of dark-gray shale, almost black toward the middle, which grades near the top into about 10 feet of sandy shale and rotten yellowish sandstone — *Pugnellus* sandstone — with a layer of purplish bituminous limestone from 1 to 2 feet thick capping the formation. East of the boundary the base is in contact with from 30 to 40 feet of dove-colored limestone strata representing the Greenhorn limestone, or middle division of the Benton group. Concretionary nodules of impure limestone seamed with calcite are usually present in the middle and upper portions of the beds. The capping limestone contains a great many marine fossils, the most numerous being the coiled ammonite *Prionocyclus wyomingensis*. Sharks' teeth are occasionally present. The shale portion of the formation is very soft and easily eroded, though owing to the protection afforded by the harder strata of the succeeding Niobrara the upper part of the beds generally appears as a steep slope. The outcrop is restricted to a small area in the northeast corner of the quadrangle.

Character and extent of the Carlile.

Timpas formation.—The Timpas and Apishapa formations, both of which are characterized by the presence of limestone strata, or of shale containing a considerable proportion of lime, constitute the Niobrara group and are elsewhere mapped undivided as the Niobrara formation. The Niobrara beds are distinguishable by their limy character from all other Cretaceous formations, except the Greenhorn limestone of the Benton group, from which, however, the limestone of the former is readily distinguished by its color and fracture.

The Timpas formation comprises about 200 feet of strata, of which the lower 45 to 50 feet is limestone and the remaining 150 feet calcareo-argillaceous shale interrupted by thin limestone bands, which become prominent toward the top. The limestone at the base is made up of layers, usually less than 12 inches thick, which are separated from one another by very much thinner layers of calcareous shale. The fracture is conchoidal and rudely parallel with the bedding planes, and the grayish-white weathered surfaces break off naturally into thin conchoidal flakes. As the Greenhorn limestone is dove colored and has a cross fracture, the two are easily distinguished. The only fossil at all noticeable is the large oval, concentrically ridged shell, *Inoceramus deformis*, characterized by the excessive bulge of the ventral valve. The limestone itself, however, consists largely of the skeletons of foraminiferal organisms, readily seen in thin, transparent sections under the microscope. The middle and upper portions of the formation consist mainly of bluish or dove-colored shale, with thin bands of limestone at intervals. There are three of these bands from 1 to 3 feet thick in the upper 40 feet of the section, and one of these marks the top of the formation. The resistance of the limestone to erosion renders the basal portion of the Timpas the most conspicuous of the marine Cretaceous beds, and its outcrop is, more often than otherwise, marked by a limestone cliff. The upper contact is usually masked by soil in the limited area in the northeastern part of the district where the exposures occur.

Limestone in the Timpas.

Extent of the Timpas.

Apishapa formation.—The total thickness of the Apishapa approaches 500 feet. The lower portion for about 40 feet consists of dark-gray to blue-gray shales, followed by rotten shales of paper-like lamination about 90 feet thick, which grade through blue sandy shale into calcareo-arenaceous shales. The latter become coarser and flag-like toward the middle of the formation and constitute about one-third of it. The upper 100 feet resembles the basal portion, but includes two, and at times three, thin layers of limestone and usually lens-shaped concretions of similar but more impure material. The middle zone is always more or less bituminous, and fairly constant in character. The remainder of the formation varies considerably except in its general shaly features and the presence of limestone strata near the top. The fossil remains consist of fish scales, which are generally abundant in the shales and sometimes in the coarser flag-like layers. In the sandy shales at the base of the middle zone the tracks of what was probably a small crustacean are characteristic. These tracks appear as a double row of short, straight lines, those on one side inclined toward those on the other. The outcrop of the Apishapa is confined to the northeast corner of the quadrangle, where it occupies an area of about 10 square miles.

Character and extent of the Apishapa.

Pierre shale.—The beds of the Pierre epoch consist of argillaceous shales throughout. The thickness is estimated at from 1300 feet at the southeast extremity of the outcrop to 1500 feet at the northwest extremity, the changing dip and small number of exposures making accurate measurement very difficult, if not impossible. The shales vary much in appearance. The basal and upper zones weather to a yellowish-green color; the middle zone is dark gray to lead-gray, occasionally almost black. The latter zone contains an abundance of lime-iron concretions that break up readily and impart a rusty tint to the surface. They are always arranged parallel with the bedding. The entire formation is soft and easily eroded, and the resulting surface is gently undulating except where the protection afforded by intrusive sheets of lava has tended to form low mesas. The outcrop extends about one-half the length of the quadrangle in the northeastern portion, with two small areas in the vicinity of Trinidad and another somewhat larger area near the southwest corner, the total area approximating 120 square miles.

Character and extent of the Pierre.

Trinidad sandstone.—The Trinidad sandstone represents some part, or possibly the whole, of the Fox Hills group, but on account of its relation to the Laramie and the thickening of the lower zone of the formation northward it is presumably the upper portion only. In the Spanish Peaks quadrangle the total thickness is about 150 feet in the vicinity of Trinidad, and 170 feet toward the north boundary. As elsewhere, the formation consists of a basal zone of thin-bedded, fine-grained, dark-gray sandstone layers, separated from one another by thinner partings of shale; and an upper zone of massive, light-gray sandstone, capped by a few feet of brown sandstone in contact with the overlying Laramie. In the Trinidad section the thin sandstone layers of the lower zone rarely exceed 3 inches in thickness, except near the base, where there is a prominent bed of coarser sandstone from 3 to 5 feet thick. Toward the north boundary the layers are appreciably thicker and the rock is of somewhat coarser texture. The increased development northward is due to the expansion of the lower zone, which is from 70 to 75 feet thick at Trinidad but about 90 feet thick near the north line of the quadrangle. The upper zone is about 80 feet thick throughout. It is characterized by the presence of *Halymenites*, the pitted, cylindrical stems of which are abundant. *Baculites* in an imperfect state of preservation are occasionally found in the lower zone. The outcrop appears as a narrow, irregular line of exposures extending in a southeast-northwest direction across the northeastern part of the district.

Character and extent of the Trinidad.

Laramie formation.—The marine Cretaceous ended with the Trinidad. The conditions of the succeeding Laramie epoch were shallow waters connected with the ocean. Subsidence continued, but to a diminishing extent, and the rates of subsidence and sedimentation varied with respect to each other. Thus, when the former exceeded the latter the water was probably deep enough to admit of the free action of tidal or other currents, and sandy sediments were deposited. When the reverse was the case the currents were obstructed and silt-like sediments were deposited. With continued shallowing extensive swamps and marshes were formed, which supported a dense growth of semi-tropical vegetation and permitted the accumulation of extensive peat-like deposits. This sequence of changes, many times repeated, the deposits meanwhile slowly consolidating, resulted in the alternating sandstone layers and coal-bearing shaly beds of the Laramie formation.

Conditions at the beginning of the Laramie.

Owing partly to a certain amount of erosion preceding the deposition of the succeeding Eocene formation, though mostly to the general thinning out of the measures toward the north, the thickness of the Laramie varies considerably. Thus, along the southwestern border of the district and in the Raton Mountains near the southern border, it is not less than 2000 feet, and doubtless exceeds this amount near the crest of the high ridge immediately south of the line; while in the central and northern portions it does not exceed 1700 feet, and is even less than this in the northeastern area near the north boundary, where it is about 1500 feet.

Thickness of the Laramie.

The sections of the Laramie in different parts of the district vary but little in their general features. There is always an alternation of massive or thick-bedded gray sandstone beds with thick shaly beds. The latter predominate toward the base of the group, the former toward the top. The shaly beds of the upper half of the group are shale or clay shale, but in

General features.

the lower half, noticeably in the lower portion of it, they consist of sand shale—that is, thin layers of greenish-gray fine-grained sandstone with partings of shale of the same color. The lower shaly beds are occasionally interrupted by bands of sandstone a few feet in thickness and by beds of clay shale associated with seams of coal, which may occur toward the center of the shale bed or entirely above it and may equal the latter in thickness. Some of the upper sandstone beds are disposed to weather into cavernous forms, and some of the alternating beds associated with them consist of fine-grained, greenish-gray, fissile sandstone instead of shale. But aside from the general features the sections possess little in common. It is only the lower, main sandstone bed and the shaly beds above and below it that are really persistent throughout the district. Beds 10 feet or more in thickness that appear at one point may be absent at another point **Variable features.** only a few miles away; or the roof of a seam of coal may change from sandstone to argillaceous shale in a distance of one-half mile. This variation in the details of the formation extends in a marked degree to the coal beds. The lower workable bed, though not always of workable thickness, can indeed be traced with certainty along the northern half of the outcrop, but above this bed there is less certainty as to the identity of a workable seam, and in respect to the upper seams identification is practically impossible.

The Laramie is the most important formation in the district and the exposures cover about one-half the area of the quadrangle. The **Extent of the Laramie.** greater portion lies in the southern part, though a broad belt parallel with the outcrop extends northward to and beyond the boundary of the quadrangle. Without doubt it underlies the succeeding formations in the northwestern part of the area, since it appears at no great distance beyond the west boundary in a nearly continuous outcrop, and is probably present in the metamorphosed beds bordering the eruptive core of East Spanish Peak.

The group is characterized by a rich semitropical flora, very similar to what is found in the Gulf States to-day, and leaf imprints **Laramie flora.** of certain species of oak, fan palm, fig, poplar, willow, and tulip tree are of common occurrence in the thin-bedded sandstone and lower shaly beds.

Metamorphosed Cretaceous.—The sediments bordering the eruptive cores of the Spanish Peaks have undergone a certain amount **Character of the rocks.** of alteration or contact metamorphism in the vicinity of the eruptive bodies. Around West Peak it is the Eocene beds that are thus altered, but around East Peak it is the Mesozoic sediments that have undergone alteration. All the sediments of Mesozoic age uplifted on the south and west flanks of the East Peak mass consist mostly of slates, quartzites, and partly altered sandstones representing part of the Cretaceous series. The oldest exposed formation occurs on the west flank in contact with and resting upon the eruptive core at an inclination of about 40°. It consists of reddish, indurated marly material, thought to represent a portion of the Morrison formation. The apparent thickness does not exceed 50 feet, though the conditions are such as to render accurate measurement out of the question. In the uppermost beds of the series, a short distance east of the point where a fault plane is shown to cross the head of the South Fork of the Trujillo, a single specimen of fan palm was found in one of the slaty layers, and it is probable, though by no means certain, that part of the Laramie is there represented. On the saddle between the two peaks, however, this group can not be present to an important extent, as a considerable thickness of slate, probably altered Pierre shale, is apparently at once succeeded by slightly altered Eocene yellow clays and sandstones. The Timpas formation is clearly not present in the series, nor is it certain that the Dakota is represented. All of the Cretaceous formations were undoubtedly present originally, and the breaks in the stratigraphic sequence indicate that the uplifting and upturning at this point was accompanied by a great deal of dislocation and disturbance of the sedimentary beds. That this was undoubtedly the case is shown elsewhere in the text. On the south and southeast flanks of East Peak the eruptive mass dragged up portions of the altered beds with it, and the altered rocks thus appear in places on both sides of the fault plane which is represented by the east and south base of the great porphyry core. Even at the northern extremity of the zone of alteration, where the eruptive body is conformable with the bedding of the sedimentaries, the metamorphosed strata appear to have been in part dragged upward during the last stages of eruption. The width of the bordering zone of altered rocks **Extent of the altered rocks.** varies from a few hundred feet at the northern and eastern extremities to fully a mile in places along the western exposures. The aggregate thickness of the strata on the outcrop is about 1800 feet.

EOCENE AND NEOCENE PERIODS.

Mountain growth.—At the close of the coal-bearing Laramie important changes occurred throughout the Rocky Mountains. The **Initial events.** general elevation of the region that then took place was accompanied by pronounced flexing and mountain making, whereby pre-existing lines of uplift were greatly augmented and new ones were initiated. At various points in the mountain provinces broad depressions were formed and became the basins of extensive fresh-water lakes. Along the plains border, subsidiary swells and flexures, accompanied by faulting, induced by the disturbances in the adjacent mountain area, favored the formation of less extensive depressions, which likewise became the basins of fresh-water lakes. It was this period of elevation and mountain growth that witnessed the initial stages of upheaval of the Sangre de Cristo Range, west of the district. At about the same time the pre-existing Greenhorn Mountains, to the north, were also uplifted, the strata of the plains border to the east were arched up, and a synclinal depression that was formed between this arch and the Greenhorn Mountains on the one hand and the Sangre de Cristo Range on the other became the basin of the Huerfano Eocene lake. This lake stretched from the Purgatory Valley in a general northwesterly direction to a point several miles north of the Huerfano River. During early Eocene time the depression continued to deepen and to receive sediments from the neighboring highlands. In some places these sediments consisted wholly of granitic débris, in others of Cretaceous or Carboniferous material, and in consequence the resulting deposits vary greatly in character from place to place.

Poison Canyon formation.—The assignment of this formation to the Eocene is entirely provisional and is based on its structural relation to the Cretaceous, organic remains other than petrified wood being altogether absent. It is possible, however, that it may correspond, wholly or in part, to the Arapahoe, or lower member of the post-Laramie of the Denver Basin, though its angular unconformity with the Cretaceous tends to render this doubtful. The correlation of the formation in the Spanish Peaks quadrangle with that at the type locality in the Huerfano Park quadrangle is based on the stratigraphic succession, the similarity of the sediments, and the fact that the exposures form a nearly continuous outcrop to a point about 4 miles south of the Huerfano River on the eastern border of the lake, where the Poison Canyon beds would naturally reappear from beneath the later Eocene deposits to the west.

The formation as it exists in the district consists of coarse-grained sandstone and conglomerate beds alternating with thinner beds of **Character of the rocks.** yellow clay. The lower beds of sandstone are of a pale-yellow color on the weathered surface, with blended patches of a reddish tint. The thickness of the individual beds varies from 10 to 50 feet. As a rule the rock is massive and entirely without bedding, and the exposed surfaces are rounded and cavernous. They maintain these characters throughout the district. The middle zone is usually conglomeratic and often loosely aggregated, as in the exposures on the Santa Clara and on the saddle between the two peaks. The upper sandstone beds are of a light-gray color, softer and in places finer grained than the lower, and often distinctly bedded. Occasionally, purplish concretions of impure limestone are present and the uppermost bed may appear of a pinkish tint. The beds of yellow clay do not differ materially from top to bottom. Their aggregate thickness is probably about one-third that of the sandstones and conglomerates, though owing to the prominence of the last two the first appear more subordinate than they really are.

The maximum thickness of the Poison Canyon beds is from 1700 to 1800 feet, though, owing to erosion it is only in the vicinity of the **Thickness and extent of the Poison Canyon.** Spanish Peaks that the full thickness is shown. Next to the Laramie it is the most extensive formation in the district and covers an area of about 250 square miles.

Cuchara formation.—The Cuchara beds consist of massive sandstone of yellowish, reddish, and brownish shades of color, with 50 feet **Character of the Cuchara.** or more of red and brown marl, shale, and soft sand at the base and separating it from the Poison Canyon beds below. The sandstone is coarse grained, sometimes conglomeratic, often loosely aggregated, and weathers into rounded and cavernous forms. The composition shows the débris to have been mostly Archean and upper Carboniferous. The maximum thickness is about 500 feet. The exposures within the limits of the district are not extensive and are confined to the neighborhood of the Spanish Peaks. The principal area lies in the northwest corner of the quadrangle and is prolonged southward by a narrow outcrop that extends across the saddle between the peaks and passes the west boundary a few miles south of the West Peak mass.

Thus far, organic remains have not been found in these beds and their age is still a matter of uncertainty. They are conformable with the beds above, and apparently with those below, and stratigraphically considered are probably part of the lower Eocene. Provisionally they are so regarded.

Huerfano formation.—The Huerfano beds of this district consist of a basal zone of red and brownish-red marl, the thickness of **Character of the Huerfano.** which can not be determined with any approach to accuracy owing to the limited amount of exposure, but which is apparently not less than 500 feet. It is succeeded by massive sandstone and conglomerate—the latter very coarse toward the top—having a prevailing brownish-red color, and an estimated maximum thickness of 2500 feet. From the eastern extremity of the West Peak mass the entire formation, at first dipping abruptly westward, rapidly approaches a horizontal position opposite the culminating point of the mountain, where it extends from the base to within 1000 feet of the summit. (See fig. 4 on Special Illustration sheet.) Just west of the boundary of the quadrangle the beds rise in the opposite direction, conformable with the fold of the Sangre de Cristo Range. The Huerfano sediments, pierced by the long and relatively narrow east-west eruptive core, **Extent of the Huerfano.** constitute the principal mass of the mountain. Northward they do not extend beyond its base. Southward the outcrop extends in a southwesterly direction about 4 miles, to where it crosses the west boundary. A few miles west of the district there are extensive exposures of reddish-brown, coarse conglomerate (Sangre de Cristo formation) which attains an enormous thickness and is regarded as of upper Carboniferous age. It was the erosion of this conglomerate that furnished the bulk of the material composing the Huerfano beds of the Spanish Peaks area.

The correlation of the West Peak sediments with the Huerfano formation, from which it is separated by a broad area of erosion, **Correlation.** is based entirely on stratigraphic evidence. Lithologically, only the basal zone is comparable with the typical beds on the Huerfano River, which, however, is accounted for by the difference in the character of the local débris at the time of deposition. In both localities the beds rest upon the Cuchara formation, which outcrops continuously between them, and thus places the fact of their identity almost beyond question.

The Huerfano formation on the Huerfano River has afforded remains of a mammalian fauna rich in species. According to Professor **Mammalian remains.** Osborn, the fauna of the basal zone corresponds mainly with that of the Wind River beds of Wyoming, or the upper portion of the lower Eocene, while the fauna of the principal body of the formation corresponds to that of the Bridger beds of Wyoming, or middle Eocene. The most abundant remains are those of *Tillotherium*, an animal about the size of the modern black bear, but possessing enormous incisor teeth, very much larger and more powerful than those of the beaver. These are associated with remains of carnivores, rodents, and the primitive Bridger horse *Pliolophus*.

Metamorphosed Eocene.—As the Eocene beds rise to the eastward successively lower beds appear in contact with the eruptive core along the slopes of West Peak ridge, and there is a bordering zone, 1000 to 5000 feet or more in width, where the rocks have undergone more or less alteration. Near the eastern extremity of the mass it is the Poison Canyon formation that is thus **Character of the rocks.** altered, the resulting coarse-grained and conglomeratic greenish-gray quartzites being especially prominent. The same formation is also exposed by erosion in the gorges on the north side of the main ridge. On the south, or opposite side, these beds do not appear west of the Trujillo drainage. The alteration of the lower Eocene beds to quartzitic conglomerates with occasional slaty layers is complete wherever they are seen bordering the West Peak mass. The succeeding Huerfano formation is not altered to the same degree—in fact, the change is in the nature of consolidation rather than alteration. On both flanks of the mountain and around its western extremity the coarse, brown conglomerate in the vicinity of the eruptive body is as completely consolidated as the neighboring Sangre de Cristo conglomerate, from which it was derived and which it closely resembles.

Late Eocene and early Neocene events.—At the close of the Bridger (Eocene) epoch the Huerfano lake disappeared, the strata along its west border were steeply upturned, and the swell to the eastward was probably augmented. Whether or not the change was accompanied by eruptions of molten rock is uncertain, though **Igneous activity.** it is clear that the initiation of igneous activity was entirely subsequent to the deposition of the Huerfano sediments, since the latter are either intersected or displaced by the eruptive bodies. It is likewise evident that, within the limits of the district, the principal eruptions occurred between the close of the Bridger and the latter part of the Neocene—that is, in late Eocene and early Neocene times.

Throughout the latter part of the Eocene and nearly to the close of the Neocene the area was subjected to erosion and to intermittent disturbances connected with the eruptions. At a later date, presumably toward the end of the Neocene period, additional flexing occurred, though not of a pronounced character.

Nussbaum formation (late Neocene).—To what extent the movement just referred to may have affected the neighboring ranges is not **Late Neocene movement.** manifest, but the swell on the eastern side of the district was evidently so far uplifted that shallow lakes of limited extent were formed by the breaking up or ponding of the water courses. These small lakes received the torrential drift brought down by the steep gulches heading in the plateau to the westward, and in this way deposits were formed that subsequently consolidated into conglomerate and sandstone, largely through the cementing action of lime carbonate. Since then the greater part of these deposits have been eroded, only a few remnants capping small mesas remaining. The exposures are confined to the northeastern part of the quadrangle, and the deposits nowhere exceed 30 feet in thickness. The assignment of them to the latter part of the Neocene is strictly provisional, and it is possible that they belong to the early portion of the succeeding Pleistocene.

STRUCTURE.

The present structure of the rocks of the quadrangle is attributable to two equally prominent causes: (1) regular mountain growth, and (2) eruptions of lava. The results are clearly distinguishable from each other and may therefore be considered independently.

Structure due to mountain growth.—The district may be said to occupy the southern half of a long synclinal trough which, south of the Spanish Peaks, has a north-south axis, but trends toward the northwest before passing the northern boundary. This trough is the southern continuation of the Huerfano Eocene lake basin, as subsequently greatly modified by the upturning of the beds along its eastern and western borders.

Huerfano trough.

Plains swell.

The slight but recognizable general westerly inclination of the strata resulting from the swell in the plains region east of the district merges rather abruptly into a flexure whose axis is nearly parallel with the eastern Laramie outcrop and in a measure coincides with it. This flexure continues northward to the southern base of the Greenhorn Mountains. The greatest inclination is at Aguilar, where the westerly dip amounts to as much as 18°, but it is less than half this amount near the northern boundary, and to the south decreases rapidly. West of the Laramie outcrop the rocks soon flatten out, and are practically in horizontal position over a large area in the middle of the district, but toward the northwest they again rise in the direction of the mass of the Spanish Peaks.

Sangre de Cristo flexure.

The uplifting of the Sangre de Cristo Range was accompanied by the formation of a great flexure along its eastern base a few miles west of the Spanish Peaks district. The diminishing slopes of this flexure extend a sufficient distance across the boundary to impart a decidedly easterly inclination to the strata along the western border south of the Spanish Peaks, amounting in places to 20°. Thus the inclination of the beds on the western side of the trough is greater than on the eastern, except where they lie within the area affected by the massive eruptions of the peaks.

Faults.

Displacements or faults that are attributable to regular mountain-making movement are not at all common in the southern portion of the area. Toward the northern boundary they are more numerous, but the amount of displacement is usually so small as to pass unnoticed except in mine workings. The north-south fault on the Santa Clara is the only important one observed. The downthrow is to the west, or in the direction of the dip, indicating the near relation of the fault to the flexure already noted. The displacement of the coal measures is from 70 to 80 feet, but there is no apparent displacement of the thick sheet of igneous rock in the immediate vicinity, so that the eruption was evidently a subsequent event.

Sills and dikes.

Structure due to eruptions.—The earlier igneous eruptions gave rise to sheets intruded conformably with the bedding of the sedimentaries, and to dikes, traversing the beds more or less nearly vertically, which in some cases are seen to rise from sills and in others are presumably connected with similar bodies of lava that have not yet been exposed by erosion. The dikes are most numerous in the vicinity of the peaks, which were evidently the chief center of eruption, and from this center they radiate in all directions. Those radiating to the east and west are rather more numerous than those radiating to the north and south. West of the quadrangle this is seen to be due to the greater magnitude of the conformable intrusions there exposed in the upturned marine Cretaceous. East of the eruptive center fewer intrusions are revealed, but the existence of a decided swell in the sedimentaries where the dikes are most numerous strongly suggests their presence in the depths. The radial system of dikes is supplemented by a rudely parallel east-west system, really part of a larger system extending from the Greenhorn Mountains southward to the Cimarron River in New Mexico, a distance of over 100 miles, with an east-west range of as much as 60 miles.

Two dike systems.

Previous to the last upthrust of the eruptive mass the sedimentary rocks of West Peak were riven in an east-west direction and a mass of igneous rock half a mile wide was forced up into the rent. At the same time another portion of the igneous mass was intruded in laccolithic or lens-shaped form beneath the sedimentary strata of East Peak. At a later date the final eruption was initiated by the production of a U-shaped fracture extending, as a prolongation of the rent just mentioned, around the present base of East Peak, and thence westerly to the Wahatoya. The thrusting up of the eruptive mass constituting the basal and main portion of East Peak and of the ridge extending northwesterly from it, which then took place, was accompanied by enormous displacement of the strata along this fracture, amounting to as much as 5000 feet at East Peak, but diminishing rapidly toward the extremities of the U—the sediments included between the arms being upturned somewhat in the form of a spoon-shaped trough, the whole tilted westward. This fault has been removed in most places by the erosion of the beds to the west of the fracture, exposing the underlying laccolithic intrusive. The inclination of the beds at the head of the trough, where they rest on the eruptive mass of the mountain, is about 40°. The beds that originally rested on the ridge extending from it have for the most part been eroded, but the remaining portions are inclined toward the trough, with diminishing dip going northwestward. The effect of the East Peak displacement upon the West Peak mass extended nearly to the present culminating point, but as the upturning resulting from it was compounded with a certain amount of inclination away from the line of the West Peak intrusion the beds on the north flank of the mountain dip toward the northwest, while those on the south flank dip toward the southwest.

Briefly, the effect of the eruptions on the previously formed trough was the production in the very bottom of it of a great upward bulge, rent and faulted at the summit, warped by the intrusion of huge masses of igneous rock, and ribbed by a magnificent system of dikes. Structurally considered, the eruptions produced results more striking than those occasioned by mountain growth.

TYPICAL EXPOSURES.

As a knowledge of the distinguishing character of the different formations will be most readily acquired by studying sections that are typical and well exposed, reference to the more easily accessible localities where such sections occur may be of service.

Carlile shale.—This formation appears only in the northeast corner of the quadrangle, on Salado Creek, and even there the base of it is not revealed. But a short distance eastward on the same creek the full section is well shown in the flanking bluffs.

Timpas formation.—The basal limestone of the Timpas is well exposed on Salado Creek not far from the east boundary of the quadrangle, and in places part of the upper shaly zone also, but the contact with the succeeding formation is masked by surface accumulations. No other locality in the district affords Timpas exposures.

Apishapa formation.—The Apishapa beds appear only in exposures of limited extent in the northeast corner of the district, and no locality can be cited where either the upper or the lower division line is shown. The former is exposed near the Black Hills a short distance beyond the east boundary, and the latter at a point a few miles beyond the north boundary, where the lower and middle zones appear in the first line of bluffs on the Rattlesnake Buttes road, the formation lying to the west of the road.

Pierre shale.—The lower zone of the Pierre is well exposed in the broad ravine north of the Black Hills. The middle zone is nowhere fully exposed, but patches of it appear along the Denver and Rio Grande Railroad between Chicosa and Elmoro. The upper zone affords excellent exposures in the immediate vicinity of Trinidad.

Trinidad sandstone.—This formation is fully exposed at Simpsons Rest, near Trinidad, the entire section outcropping about 1000 feet north of the monument. It is also well shown in the bare bluffs north of Powell Arroyo.

Laramie formation.—A very complete section of the Laramie, including the upper and lower workable coal beds, is exposed along the Apishapa between Aguilar and Gulnare post-office. Road Canyon, Canyon de Agua, Powell Arroyo, and Raton Creek also afford fairly good sections.

Poison Canyon formation.—Nearly all the gulches radiating to the south and east from the Spanish Peaks afford good exposures and more or less complete sections, though the rocks are usually more firmly consolidated than the corresponding beds in Poison Canyon. But typical, loosely aggregated conglomerates occur on the saddle between the peaks and in the broken, central portion of Santa Clara Park west of Capp's ranch.

Cuchara formation.—The basal portion, easily distinguished by its brownish-red color, appears on the hilltops west of Bear Creek near the north boundary, and there are numerous exposures in the direction of the peaks. But the most complete are on Wahatoya Creek, along the road extending from the creek to the mines in Monarch Basin near West Peak. The section exposed by the road is fairly good, including the upper and lower contacts.

Huerfano formation.—Along the road just mentioned, near the base of West Peak, the brownish-red clays of the basal zone of the Huerfano formation are well exposed, and at the northern or lower end of the basin the overlying conglomerates appear. The conglomerates of the middle and upper zones can be seen to best advantage on the southwestern slope of West Peak.

Metamorphosed sediments.—The most complete exposure of the altered Cretaceous beds occurs along the ridge running from the Trujillo-Wahatoya divide toward the summit of East Peak. Here the section is practically continuous from the Poison Canyon beds to the reddish-brown stratum supposed to represent part of the Morrison. The best exposures of altered Eocene rocks occur in Monarch Basin, near the end of the wagon road already mentioned. Next to these are others on the head of the most westerly branch of the Trujillo.

Nussbaum formation.—This formation appears conspicuously as escarpments or low cliffs capping a group of mesa-like elevations on the south side of Salado Creek about half a mile east of the line of the Colorado and Southern Railway.

IGNEOUS ROCKS.

OCCURRENCE AND DISTRIBUTION.

The center of eruption.

The igneous rocks of the quadrangle belong mainly to the Spanish Peaks system, of which probably one-half the occurrences only lie within the quadrangle. They consist of stocks, dikes, and sheets, representing a long series of eruptions centering at the Spanish Peaks, the focus of all the earlier ones being situated somewhere in the area now occupied by the West Peak stock, with reference to which the dike system is arranged radially. The intrusion of this stock and of the East Peak mass was subsequent to the dike eruptions, the late basalts excepted. In respect to form, these stock-like masses differ considerably. The West Peak body, which is much the smaller, occupies a broad, nearly vertical fissure in the Eocene beds and presumably the Cretaceous also. It has a length east and west of about 3 miles and in the main portion a thickness of about one-half mile, with two apophyses extending to the northward and a tail-like extension to the eastward. The flanking strata are inclined away from it at various angles, and its eastern portion together with the inclosing sedimentaries was tilted westward by the intrusion of the East Peak body. The latter is nearly 5 miles long in a southeast-northwest direction, and about one-half mile broad near the northwest extremity, increasing to 2 miles at the center of the main portion of the mountain. Along the southeastern, eastern, and northeastern bases the mass emerges at angles of from 60° to 80°, the abutting sandstones curving upward near the contact. To the west and southwest the mass dips more or less conformably beneath the sedimentary beds, the inclination at East Peak amounting to 40°, but diminishing with the thinning of the mass toward the northwest extremity. While it can not be demonstrated that this mass extends beneath the surface to a junction with the West Peak mass, it is extremely probable that such is the case, not only from the structural conditions, but from the fact that toward the east end of the West Peak stock some portions have practically the same mineralogic composition as the summit rock of East Peak.

The stock-like bodies.

The dikes.

The dikes are from 2 to 100 feet or more in thickness, though the majority are from 10 to 50 feet. As a rule they dip slightly one way or the other, but the direction changes from place to place in the same dike. Some are practically vertical and project from the surface as smooth, wall-like masses from 50 feet to occasionally over 100 feet in height. (See figs. 3, 4, 6, and 7, on Special Illustration sheet.) Their course is either straight or curved, though local sinuosities are common. The curvature is toward an axial line passing very nearly through the culminating points of the peaks and at right angles to the orographic axis of the region. East of the eruptive center the dikes are most numerous south of the axial line, while west of the center the reverse is the case, there being a zone of maximum fissuring extending through the peaks, though not coinciding with the axis of eruption. The latter is apparently related to a flat anticlinal swell having its apex between Mavricio Canyon and the Santa Clara, which may be due, though not necessarily, to the presence of sheets of igneous rock in the underlying beds. The dikes range in length from a few hundred yards in the case of the most acid rocks to as much as 10 and 15 miles in the most basic. Intersections are comparatively common, but the point of intersection is often too much obscured to allow of the relative age being determined. As the dikes rise into the higher portion of the Eocene beds they become fewer in number and rarely penetrate the uppermost strata of the Huerfano formation, as may be seen near the summit of West Peak.

Conformable sheets.

The sheets are generally from 5 to 50 feet in thickness, but thinner sheets occur. They are usually, though not always, conformable with the bedding of the inclosing strata. In many cases they are associated, and sometimes directly connected, with dikes of the same kind of rock, and there are instances where a sheet terminates in a dike at one extremity. Except a few occurrences in the immediate vicinity of the peaks, the sheets outcrop in the Cretaceous formations, mostly in the Laramie and the Pierre. Beyond the west boundary of the district the sheets in the upturned Cretaceous are more numerous than in the country east of the peaks, but out of the large number of dikes exposed only two traverse the continuous Dakota hogback just west of the line of sheets. It is therefore apparent that, while exceptions can be noted, the dikes of the Spanish Peaks system are connected with the sheets and presumably occupy the fissures formed in the strata overlying the sheets at the time the latter were injected into the beds.

Second dike system.

A second system of dikes not directly connected with the Spanish Peaks system occurs in the district. This system extends from the Greenhorn Mountains to the Cimarron River in New Mexico. The dikes have a course approaching east and west and are rudely parallel with one another, though taking the system as a whole a tendency toward radial arrangement is apparent, as though the focus of eruption was at some distant point to the westward. In mapping the dikes and sheets of the two systems it was found necessary to generalize only in the case of the group of sheets outcropping on the saddle or divide between the two peaks, where, on account of the small scale of the map, nearly one-half the occurrences had to be omitted. In a few instances, notably in Mavricio Canyon and at the head of the Apishapa near the west boundary, there is some doubt as to the relations having been correctly interpreted; but in nearly all cases the location of the occurrences and the order of eruption as indicated by the intersection may be accepted with considerable confidence.

DESCRIPTION OF THE IGNEOUS ROCKS.

Early monzonite-porphyry.—This term is applied to certain related rocks representing at least four eruptions. They are of various shades of gray, often yellowish-gray owing to decomposition. The texture is nearly always porphyritic, though some varieties show only an occasional large crystal of brown hornblende. Among the feldspar phenocrysts basic plagioclase predominates, but alkali feldspars are usually present in considerable quantities. The dark silicates are represented by augite and brown hornblende, phenocrysts of the former being present invariably. In a large number of the occurrences hornblende is of equal importance with the augite, but in the majority of cases appears merely as an occasional large crystal in the rather fine-grained groundmass. Such large crystals, or more often aggregations of poorly crystallized individuals, increase in number with the amount of the minerals present and are frequently prominent on exposed surfaces. The groundmass is usually granular and the feldspars are generally much kaolinized. In thin sections of the fresher examples augite microliths are abundant, often accompanied by shreds of biotite, and serpentine is present in nearly all cases. Magnetite is usually present as a fine dust, but in only moderate quantity. Where these rocks penetrate the zone of contact metamorphism epidote is a common product of decomposition, and crystals several millimeters in length sometimes appear in the cavities.

Early lamprophyre.—Under this head are included several varieties of rock which vary considerably in mineralogic constitution but possess very much the same habit throughout and represent a distinct series of eruptions. The coarser varieties are distinguishable by their granular appearance and the abundance of needle-like, brown hornblende crystals, or, in the rarer micaceous variety, of large plates of biotite. The fresh rock is of a characteristic iron-gray color, becoming yellowish gray by decomposition, and is easily recognized in the field. In some occurrences the alkali feldspars predominate, though generally the reverse is the case. In the majority of instances hornblende exceeds the other dark silicates in amount, but augite is nearly always present, and as the rock becomes more basic and a porphyritic texture is developed the hornblende is mostly confined to the microlithic forms of the groundmass. A still more basic variety, containing but little hornblende, shows an abundance of biotite, with more or less augite and olivine as phenocrysts, and magnetite in the groundmass. In some cases apatite is exceptionally abundant. Thus the series is one in which alkali feldspars appear in varying proportions throughout, but which ranges from a near approach to the syenites at one extremity, through the hornblende, vogesites, and monzonites, to the camptonite varieties at the other.

Late monzonite-porphyry.—This rock is related to the early monzonite-porphyries, but differs from them considerably in mineralogic composition and belongs to a later epoch of eruption. The color is light gray when not much decomposed, the texture porphyritic, and the abundant white feldspar crystals often appear conspicuously on exposed surfaces. Among the phenocrysts the alkali feldspars, mostly orthoclase, are less abundant than the lime feldspars, though in the groundmass the proportion is uncertain, owing to the very general prevalence of kaolinization. Biotite is generally present to a notable extent, brown hornblende and common augite sparingly, and all are more or less altered to chlorite and epidote. The thin sections usually show a little quartz and magnetite.

Late lamprophyre.—This includes a group of rocks that at one extremity is related to the camptonite section of the early lamprophyres and at the other to the early monzonite-porphyries, but belonging to a later epoch of eruption. The larger number of the occurrences consist of dark-colored fine-grained rocks, rarely of porphyritic texture. As seen in thin sections the mass is made up of lath-shaped feldspars with the intervening spaces occupied by microlithic augites, shreds of biotite, and grains of magnetite. Generally speaking, these minerals are decomposed and the space is occupied by a chloritic product, the texture then simulating the ophitic. As the rock grades into the early monzonite-porphyries this texture disappears. The phenocrysts of the porphyritic variety are mostly altered augite—in some cases altered olivine. While the feldspars are mainly basic plagioclases, it is by no means certain that the alkali feldspars are not present to some extent throughout the series, a question that, owing to decomposition, could not be settled by the sections available for examination. Included with the late lamprophyres is a porphyritic variety, the occurrence of which is restricted mainly to the Santa Clara drainage. This rock probably represents the latest phase in the eruption of the series. Among the prominent feldspar phenocrysts orthoclase is present in subordinate quantities, is less noticeable in the feldspars of the second generation, and can not be identified in the granular material of the groundmass. Augite is the most common dark silicate present.

Augite-diorite.—This is used as a comprehensive term for the rocks of the West Peak stock, which vary considerably in mineral composition, though the bulk of the material may be regarded as belonging to this group. The color is usually gray, weathering to yellowish gray. The texture is granitic to occasionally porphyritic. Orthoclase and quartz are present subordinately. Augite and biotite are the principal dark silicates, with occasionally some hypersthene. At the eastern end of the main body of the stock, much of the material is porphyritic and is closely related, both in appearance and in mineral composition, to the augite-granite-porphyry of the East Peak mass. These bodies of more acid rock were apparently intruded conjointly with the main mass of the stock.

Augite-granite-porphyry.—This rock is represented by several dike occurrences and by the body occupying the summit and western face of East Peak. It is a distinctly porphyritic rock with a coarsely granular, or granitic, groundmass. The color is light gray, mottled with white. The predominant feldspar is orthoclase, and considerable quartz is present, though mostly confined to the groundmass. Augite and biotite occur rather sparingly in all the thin sections examined. This rock grades downward somewhat abruptly into the more acid material of the main mass, and is clearly related on the other hand to the augite-diorite of West Peak.

Granite-felsophyre.—In the Spanish Peaks quadrangle this rock occurs only as conformable sheets and small dikes in the immediate vicinity of the peaks, though in the Huerfano Park area it forms bodies of mountain dimensions. It is a fine-grained granular rock of a grayish-white color. The feldspar microliths appear to be largely orthoclase, and small grains of quartz are scattered through the mass, in which the dark silicates are wholly wanting.

Granite-porphyry.—This rock is represented by the main mass of East Peak and the ridge extending northwesterly from it, as well as by several dike-like bodies in the vicinity, and by a thick lens-shaped body that is sandwiched in between the augite-granite-porphyry and the metamorphosed Cretaceous on the west side of the peak. It is a coarsely crystalline, grayish-white rock, with large phenocrysts of orthoclase and quartz, and some plagioclase. There is an abundance of quartz in the groundmass, which in the finer-grained portions is distinctly micrographic. This rock grades upward into the augite-granite-porphyry, the change from one to the other taking place through a very narrow zone. There is also a noticeable difference between the base and summit of the main mass itself, the material at the base being much richer in quartz than the material near the top. Along the ridge running northwest from East Peak there are two dikes cutting this rock. They are not very well defined and are considerably distorted, the presumption being that the dikes were formed before the mass was forced into its present position.

Basalt.—Of the occurrences referred to this group, all are not typical basalts; indeed, further study may suggest the propriety of transferring several of them to the nearly related sections of the lamprophyres. This is most probable in those rocks containing hornblende or biotite, as at present it is possible to exclude only the normal basalts from the general statement that alkali feldspars in varying proportions range through the Spanish Peaks rocks from one end to the other. However, the majority of the occurrences here included in the basalt group are really normal basalts representing at least two phases in the eruption of the magma. The earlier of these is distinguished by a coarsely crystalline texture and the abundance of augite, both as phenocrysts and as microliths. The later variety has a fine-grained and more or less glassy groundmass and but few augite phenocrysts. Included with the basalts as a matter of convenience is an olivine-augite-haüyne rock with little or no feldspar but with an abundant glassy base. The haüyne is in small pale-blue crystals with the characteristic inclusions and dark borders.

RELATIVE AGE OF THE ROCKS.

Order of eruption.

Observations on more than forty dike intersections demonstrate that the rocks were erupted in the order in which they are described, with the possible exception of the granite-felsophyre, in respect to which it can only be said with certainty that its eruption preceded that of the granite-porphyry. However, in the country northwest of the district, where it is the most abundant of eruptive rocks, no other igneous rock has been found penetrating it. Hence there is good reason to believe that its eruption was subsequent to all the dike rocks except the granite-porphyry and basalt. The occurrence of dikes of the earlier types cutting igneous masses of later age is explained in the paragraph on rock differentiation. The number of groups that enter into the foregoing classification do not by any means indicate the number of eruptions at the common center, which were doubtless more numerous than the varieties into which these groups can be divided. For instance, the intersections show that there were not fewer than four independent eruptions of early monzonite-porphyry, each distinctly more basic in respect to the dark silicates and magnetite than the preceding. Nevertheless, from a petrographic standpoint there are but two varieties into which the group can conveniently be divided. In respect to the other groups it is not so easy to demonstrate that there was more than one eruption of the same variety of rock; but assuming that there was not, as many as fifteen distinct dike eruptions, including the granite-felsophyre, must have taken place from the Spanish Peaks center.

Number of eruptions.

Epoch of eruption.

The earliest of these eruptions must have been subsequent to the close of the Bridger (Eocene), most probably during the progress of the mountain-making disturbances that immediately followed. The eruptions continued intermittently nearly to the present time, with wide though varying intervals between the manifestations.

Theory of the differentiation of igneous rocks.

The relation to one another of the products of the eruptions, as well as the order in which they were erupted, tends to support the current theory of the differentiation of igneous rocks. According to this theory, the related rocks of a region, or those that emanate from one center of eruption, are the complementary products of the gradual differentiation of a more or less deep-seated molten magma, primarily of medium composition—that is, intermediate between the acid and basic extremes of known igneous rocks. It is conceivable that if, at any time during the early stages of the process, disturbances supervened and an eruption took place the product would be either more acid or more basic than the original magma. As differentiation advanced the material erupted at any stage would be more acid or more basic than the material of the previous eruption, according as the nature or intensity of the associated disturbance influenced the character or violence of the igneous manifestation.

Differentiation in the Spanish Peaks eruptives.

The sequence of events at the Spanish Peaks center of eruption is substantially in accord with this theory. If the earliest rocks of the series—the early monzonite-porphyry—be regarded as approximating the composition of the original mass, the succeeding late monzonite-porphyry and early lamprophyre are, respectively, more acid and more basic than the mother magma. Subsequently, advancing differentiation gave rise to late lamprophyre and finally basalt, with granite-porphyry and granite-felsophyre as the opposite or complementary extreme. The stock-like bodies of the peaks are themselves an exemplification of the correctness of the theory. These bodies, which doubtless are connected with one another at no great depth, were apparently segregated from the residual mass and forced into their present position in a thick, viscous condition without undergoing any considerable amount of deformation, especially as regards the granite-porphyry, since older dikes that had previously penetrated the mass are still plainly visible, though distorted and poorly defined. From the eastern base of East Peak to the culminating point of West Peak the composition becomes more and more basic, so that while at one extremity the rock is exceedingly rich in quartz and almost wanting in dark silicates, it is rich in ferromagnesian constituents at the other.

The stock-like bodies an exemplification of the theory.

CONTACT METAMORPHISM.

The alteration or metamorphism of the Cretaceous and Eocene beds bordering the eruptive masses of the Spanish Peaks, while not the result of actual contact alone, is directly attributable to causes incident to the eruption of these masses. The whole of the exposed Cretaceous has been altered to such an extent that the units can not be individualized. The greatest amount of alteration of Eocene beds took place in the vicinity of the eruptive body of West Peak, really in the sediments in direct contact with the body, or in the parts adjacent to the fault plane at the east end of the mountain. The transition from the more completely altered rocks to the unaltered, loosely aggregated material of the same horizon is marked by a peripheral zone in which the alteration is in the nature of more perfect consolidation rather than metamorphism. That the alteration is not altogether the result of the contact with the eruptive masses is evident from the fact that the Eocene beds around the eastern and northeastern base of East Peak have suffered no apparent change, while in the vicinity of the eastern, tongue-like extension of the West Peak body and along the fault line still farther east the metamorphism is very pronounced, especially on the north side of the fault.

The evidence of more or less kaolinization in the material immediately adjacent to the fault plane suggests solfataric action as probably one of the factors in the process of alteration. The more deeply buried Mesozoic beds, which from the condition of things must have been more fully exposed to such action, are found to have been metamorphosed even where the overlying Eocene beds were not affected, possibly owing to the impermeable nature of the protecting clay beds of the Poison Canyon formation. The fragmentary bodies of the Mesozoic that were dragged up by the East Peak mass show that beneath the unaltered Eocene on the east side of the mountain there is a bordering zone of completely altered Mesozoic beds.

The changes effected were the transformation of shales, sandstones, and conglomerates into slates, quartzites, and quartzitic conglomerates. Beyond the occasional presence of epidote, crystalline substances directly attributable to metamorphic action are extremely rare in the thin sections examined. The earlier eruptives cutting these rocks in the form of dikes show considerable evidence of alteration, and in them epidote is a common and often abundant secondary product.

ECONOMIC GEOLOGY.

Coal the most important product.

Available mineral substances.—The most important mineral product of the district is coal, the annual tonnage exceeding that from any other district in the State. Sandstone, of which there are several varieties, has been extensively employed for local structures. Other mineral substances that are available but have not yet been utilized, or even experimented with to ascertain their adaptability for certain purposes, are limestone, cement rock, and refractory clay. The existence of petroleum and natural gas in economic quantities is conjectural, though not altogether out of the question, as both these substances have been detected at several points in the vicinity of Trinidad; but bare mention of the fact is sufficient. Producing mines of precious and other metals have not yet been developed, though shipments of valuable ore have been made, and the desultory exploitation work going on may, sooner or later, result in profitable discoveries. Artesian water occurs at two horizons in the quadrangle, and a map has been prepared graphically presenting the artesian problems.

COAL.

Manner of occurrence.—The coal beds of workable thickness are confined to the coal-bearing portion of the Laramie formation, and those from which the present output is **Extent of the coal measures.** derived lie within 150 feet of the base of the measures; but important seams at higher levels may at any time be made available by railway extension. The total area of Laramie outcrop in the Spanish Peaks quadrangle is 495 square miles; but the measures undoubtedly underlie all that portion of the district occupied by Eocene beds. The eastern border of the Laramie terminates in a bold, irregular line of bluffs which, within the limits of the quadrangle, extends from the Purgatory to the north boundary, but south of the river passes into the Elmoro quadrangle. The western border lies several miles beyond the west boundary, except on the South Fork of the Purgatory, where a deep indentation, due to erosion, brings a portion of this border within the limits of the district. The area thus included constitutes an important part of the Colorado portion of the Raton coal field, which extends south to the Cimarron River in New Mexico and north nearly to the Huerfano.

Diamond-drill borings near Sopris, at several points higher up the Purgatory Valley, and in the vicinity of Berwind and Hastings, **Number of coal beds.** demonstrate that the full section of the measures contains not fewer than thirty beds of coal. But the majority of these beds or seams are from 3 to 12 inches thick only, lack continuity, and rarely afford workable bodies of coal. The remainder, or those that exceed a foot in thickness, usually afford workable coal at one or more points in the district, either by thickening of the bed itself or, less frequently, by its coalescence with a neighboring bed. It thus happens that there are numerous areas of workable coal, **Workable areas.** of from 500 to 2000 acres in extent, distributed laterally and vertically throughout the measures and often overlapping one another. Such overlapping areas may occur near together and the workable beds belong to the same group, or they may be situated far apart and belong to independent groups separated by a considerable vertical interval of barren or worthless measures. These groups, the lowest excepted, are not continuous throughout the district. Of the four groups recognized, the upper two practically disappear or pass into barren **Groups of seams.** ground before reaching the north line of the quadrangle. Owing to the thinning out and splitting up of the workable coal, want of continuity becomes a characteristic feature. Not only do the seams vary much in size from place to place, but the number of seams in a group varies; though it is generally the case that at least one seam of a group will afford workable coal 3 feet or more in thickness, which, however, may not contain workable coal in a locality near by.

Berwind-Aguilar group.—This is the lowest of the four groups and at present the most important, since all the mines of the quadrangle **Most important group.** except that at Sopris are in operation on one or the other of the seams. It corresponds to the Engle group of the Elmoro quadrangle and to the Rouse-Walsenburg group of the Walsenburg quadrangle, and includes all seams within 100 feet of the base of the formation. A large number of diamond-drill borings near Sopris show from three to five seams 12 inches thick and upward in this **Number of seams in group.** group, and two shafts from the Sopris mine workings expose the same number. Of seven similar borings made south of the Purgatory River and about 6 miles west of Sopris, one showed only three seams, two showed seven, and four showed five. Borings in Stock Canyon and Canyon de Agua showed from two to five seams 12 inches thick and upward. In nearly all cases there are present several seams a few inches thick. At Aguilar the mine workings and outcrop excavations expose three seams in this group, and the same number are known to be present where the outcrop crosses the Santa Clara near the north boundary. Of the value of this group in the central and western portions of the quadrangle nothing is known, though **The western outcrop.** inferentially the presence of two or more seams along the western border of the measures, one of which shows a workable thickness of coal for a distance of fully 10 miles, suggests continuity over the greater part of the area. In like manner the workings at Blossburg, New Mexico, south of Sopris, suggest continuity between the Purgatory and the southern boundary.

At Sopris the shafts sunk below the present mine workings indicate the existence of a workable area on each of two seams, the **The productive beds.** lower apparently the most extensive, the coal being from 4 to 6 feet thick. In Powell Arroyo, outcrop excavations indicate the presence of an area of considerable extent on what is apparently the same bed; but it thins down northward, and is too small to be workable in Tingley and Chicosa canyons. At the head of Timber Canyon, north of Chicosa Canyon, it again expands to 5 and 6 feet in thickness, and so continues to Road Canyon and beyond, the Berwind workings being on this seam. In Canyon de Agua, however, it affords only "low coal"—that is, less than 4 feet in thickness—and soon ceases to be workable. It is present at Aguilar and at Salado Canyon, though still of small size, but near the north boundary it again expands to 5 feet in the Santa Clara mine. Presumably the seam outcropping near San Francisco on the South Fork of the Purgatory is identical with the Berwind seam, as it is the lowest in the measures. Occasional excavations indicate from 6 to 11 feet of coal continuous for a distance of at least 10 miles. Whether or not the second workable bed at Sopris corresponds to a productive seam elsewhere is uncertain; the Elmoro seam, on which the Starkville workings are located, is most nearly identical with it. The workings of the Forbes mine in Tingley Canyon are on a seam from 5 to 6 feet thick, situated about 60 feet higher in the measures than the Berwind seam. This bed was once continuous from Powell Arroyo to Canyon de Agua, but has been destroyed by an intrusion of igneous rock between Tingley and Chicosa canyons. The workings of the Victor mine at Hastings are on this seam, which is in places 7 feet thick; also the workings at Aguilar, where it is $5\frac{1}{2}$ feet thick; but there is a large area between the two localities where, if the coal was ever of much thickness, it has been destroyed by igneous intrusions. The upper workings at Santa Clara are on a 7-foot seam about 40 feet above the Berwind seam. It is uncertain whether or not it corresponds to the Victor bed at Hastings and Aguilar. The other seams of the group show occasional areas of "low coal," but not to an important extent.

In the southeastern portion of the district the coal is noted for the perfection of the "faces," especially that from the Elmoro seam, **Physical characters.** but to the northward this feature ceases to be characteristic. Thin, bony streaks that adhere strongly to the coal are rarely absent, and the different layers vary much in respect to the amount of impurities and ash percentage. South of the Apishapa the coal usually makes a very dense coke in beehive ovens. From this point north to Santa Clara the coal cakes strongly, but will not afford coke of commercial value by the same process.

Sopris group.—So far as known, this group contains workable coal in the Purgatory Valley only, though there is a possibility that **Extent of the group.** an area near the south line of the Walsenburg quadrangle may really extend a short distance into the Spanish Peaks quadrangle. Along the intervening portions of the outcrop the group is always represented by two or more seams, which are either interlaced with thin bands of shale or have been destroyed by eruptives. Of six borings made in Stock Canyon and Canyon de Agua, only one showed "low coal" in this group, and the area was evidently not sufficient to warrant exploitation. The base of the group lies from 135 to 140 feet above the lowest coal bed of the Engle group, which is usually within a few feet of the top of the Trinidad sandstone. Between the two groups there is a zone of barren ground 30 to 40 feet thick, composed almost wholly of massive sandstone which throughout the district outcrops prominently between this group and the preceding one.

In the neighborhood of Sopris and in the Purgatory Valley there are usually from three to four seams from 12 inches to 7 feet in thickness. **Number of seams.** Sometimes two of these are workable, and occasionally three, though with the exception of the Sopris-mine bed they afford only "low coal" and the areas are of limited extent. The workings of the old Thompson mine, near the mouth of Long Canyon, are on one of the seams of this group, which at a short distance from the outcrop was found to have been transformed into natural coke by an igneous intrusion.

As a rule the seams contain from two to three thin streaks of bone. Some of the coal is clean, soft, and of brilliant luster; some is impure, shows a coarse-granular surface **Physical characters.** of fracture, and is known as "coarse coal" by the miners. But the bulk of it breaks out in large rectangular blocks with smooth faces and is above the average in hardness for coking coal.

Morley-Smiths Canyon group.—This group lies between 700 and 850 feet above the base of the measures. It includes the workable **Extent of the group.** seams at Smiths Canyon and Wet Canyon in the west-central portion, and at Stock Canyon, Canyon de Agua, and on the Apishapa in the east-central portion. There are usually not fewer than three seams present, upward of 12 inches in thickness. In the localities named, one of the beds affords "high coal"—that is, 4 feet in thickness or over—and as the district has not been thoroughly explored other areas of "high coal" may exist in the intervening territory; while of the existence of numerous areas of "low coal" there can be little doubt, as the absence of a second seam about 3 feet thick at the points mentioned is exceptional. Hence, in all the territory back of the outcrop this group is more promising than the one just described.

The seam exploited at Morley is 6 feet thick and, as far as exposed, nearly clean. At Smiths and Zarcillo canyons the workable bed, 5 to 7 feet in thickness, has been shown **Relative value of the group.** by numerous outcrop excavations to contain an area of "high coal" about 3 miles long in its outcrop diameter, with other smaller seams below and above it. There are a few streaks of bony coal in the seam, and in places about one-half inch of clay, but the coal on the whole is rather superior to that obtained from the Berwind-Aguilar and Sopris groups. The Wet Canyon bed apparently corresponds to the upper bed at Smiths Canyon, though this is not certain. It contains about $6\frac{1}{2}$ feet of coal, including an occasional bony streak. The same seam is also exposed to the south on the Purgatory. Between Wet Canyon and Smiths Canyon there are other exposures of workable coal, but of less value. In Burro and Reilly canyons, to the east, only "low coal" has thus far been exposed. In Chicosa Canyon there are four seams exposed. The smallest is 20 inches thick; the other three, separated by intervals of from 40 to 45 feet, each contain from 3 to $4\frac{1}{2}$ feet of coal, though two of them are not workable owing to interbedded bands of shale. In Road and Stock canyons, Canyon de Agua, and on the Apishapa the group affords two workable beds, one of which expands to $6\frac{1}{2}$ feet in thickness in the two last-named localities, where it is known locally as the Rock Island seam. Elsewhere the seams are from $3\frac{1}{2}$ to 4 feet respectively, and are from 55 to 60 feet apart.

All the coal of this group has the joint planes well developed and breaks out readily in large rectangular blocks. Occasionally, however, concentric cleavage is pronounced, **Physical characters.** and the lumps are small and rounded. Such occurrences are associated with evidence of pinching. (See fig. 1.) The kneading effect of such movement evidently affected the structure of the coal and doubtless increased its density. By the majority of consumers this kind of fuel is thought to be of a distinct and superior grade. In places along the Smiths Canyon seam, part of the coal has been crushed and reconsolidated by pressure so that no trace of the original cleavage remains. Thin, bony streaks are generally present in the thick portions of the seams, but not quite to the same extent as in the seams of the lower groups. At Canyon de Agua, however, stony nodules are common in places in the high coal. On the Purgatory drainage the coal is all of the coking kind. Elsewhere it does not coke unless in the vicinity of an igneous intrusion. At present there are no producing mines in operation on this group.

Wootton group.—The Wootton group lies from 1000 to 1100 feet above the base of the measures. In no part of the district does this group contain "high coal" that is not interbedded with shale, and only in a few places does it contain "low coal," or seams from 3 to 4 feet in thickness. It is true that the two or three beds representing it have been but little explored, **Possible resources.** and as most of the outcrop is masked by soil much may remain to be discovered. The localities at present known to afford workable coal are the South Fork of the Purgatory, Wet Canyon, Canyon de Agua, and the Apishapa near Abeyton. North of the Apishapa Valley the group soon thins out, and there is no trace of it on the Santa Clara drainage. There are no mines in operation on any of the seams.

Variable features.—The coal usually rests on a varying thickness of shale or clay shale, which is often more or less refractory owing to the removal of the iron in the layers **Floor and roof.** immediately under the seam. But it frequently happens that sandstone with a mere scale of shale upon it forms the floor. Where a seam is thickest the roof is generally shale, but the sudden thinning or contraction of a seam is often associated with an equally sudden change in the character of the roof material from shale to sandstone. Bony coal is always present, and often what is called "coarse coal," which is simply an impure variety; but the position of **Impurities.** these impurities, as well as the shale or clay partings that may be present, will vary considerably within short distances. If there are bony layers near the top the coal may not part readily from the roof; if near the bottom, it may be "frozen" to the floor and will be hard to "undermine." Natural coke, the result of contact with intrusive bodies, is of common occurrence. It will be encountered wherever a dike intersects a seam or wherever a sheet of igneous rock has been injected horizontally into it.

Structural features.—The eastern border of the measures from Chicosa Canyon northward is affected by the flexure previously mentioned in connection with the structural **Flexures.** geology of the district. The result is that along this border the maximum dip of the seams occurs at or near the outcrop, and the tendency is to flatten out rapidly in a southwesterly direction, or toward the main body of the field. In the vicinity of Stock Canyon and Canyon de Agua the inclination varies from 7° to 9°. On the Apishapa the axis of the flexure passes a short distance east of the Peerless mine and the maximum inclination is about 16°, though this is reduced to 4° one mile up the river, while above the junction of the Trujillo the beds are nearly horizontal. At Salado Canyon the dip varies from 7° to 10°, according to the distance of the outcrop from the eastern border. On the Santa Clara immediately west of the canyon the formation rapidly assumes a horizontal position. Along the western border of the field, on the South Fork of the Purgatory, where the dip is mainly eastward, there is substantially the same inclination at the outcrop and the same tendency to flatten out toward the body of the field.

Wherever sheets of igneous rock have been intruded into the measures the coal seams are often affected by rolling, "troubled" ground, due to movement, causing the pinching **Pinching out of seam.** out of the seam. As a result of such movement the resistant sandstones have been buckled and forced

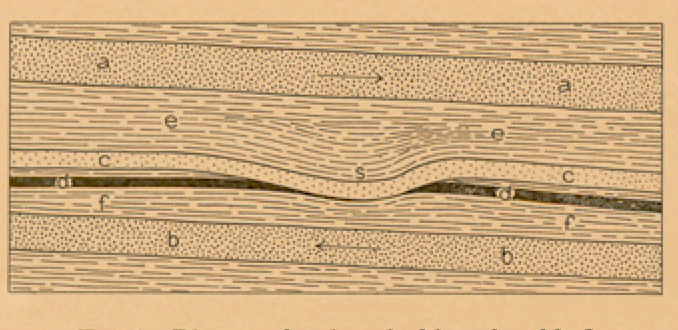


FIG. 1.—Diagram showing pinching of coal bed.

Movement of the heavy sandstone bed aa in the direction indicated would cause the thinner and less rigid sandstone cc lying between the soft shale beds ee and ff to buckle down and pinch out the coal bed dd at the point s.

either upward or downward, as the case may be, through the less resistant shale and coal. A sudden change in the character of the roof or floor material from shale to sandstone is a reliable indication that the workings are approaching a "pinch," if nothing worse. While displacements of this nature have been encountered in nearly every mine Normal faults. in the district, they are less numerous than normal faults, or such as cause vertical displacement along a plane of shearing movement. Such faults, usually amounting to a few feet only, are of small geologic importance, but in coal-mine operations they entail considerable additional expense in the matter of grading the roadways through ground affected by them.

Composition of the coal.—The appended table of analyses is intended to illustrate the general composition of the coal. The difference in character between the coking coal of the True coking coals. southern portion of the district and the semi-coking variety of the northern portion is indicated by the difference in composition shown by the analyses. Aside from the percentage of ash, which is on the average less in the product from the northern part of the field, the coking coal of the southern part is lower in moisture and oxygen and higher in total carbon. The moisture rarely exceeds 2 per cent, the oxygen is usually below 7 per cent, while the carbon generally exceeds 75 per cent. On the other hand, the semi-coking or domestic coals of the northern Domestic coals. area rarely contain less than 2 per cent of moisture, or 7 per cent of oxygen, and usually contain less than 75 per cent of total carbon. This difference in composition between the bituminous or coking coals and the semi-bituminous, semi-coking, or domestic coals is in no wise peculiar to the Raton coal field; and it may be stated as a general proposition that, other things being equal, the greater the divergence in respect to the coking behavior of two coals the greater the divergence in composition in respect to the constituents noted. As compared with the products of other Colorado fields, the Raton field coals are rather low in nitrogen, the constituent that is depended upon to form ammonia in by-product coke ovens. The richness of the gaseous products in carbon renders the coking variety a very desirable coal for the manufacture of illuminating gas.

Changes produced by eruptions.—In the Western Cretaceous coal fields the alteration of lignite into the more bituminous varieties can be traced to two causes: (1) subsequent accumulation of sediments, and (2) eruptions of igneous material. In the absence of these causes Laramie coal usually remains in the condition of lignite, contains a high percentage of moisture, and is altogether wanting in the property of coking. Earth movement has also performed an important part in promoting alteration, for even where the measures have been deeply buried under thousands of feet of later formations it is apparent that the coal in the upturned portion is more decidedly bituminous than that elsewhere. But the combined effects of depth of sediments and earth movement have rarely sufficed to change completely Cretaceous lignite into true coking coal. The latter variety is usually associated with eruptive bodies of greater or less magnitude, the degree of alteration being roughly proportional to their size. But the position of an eruptive mass is also important. Thus, lavas that have been Position of eruptive bodies an important factor. poured out over the surface appear to have exercised very little influence, while a comparatively thin sheet of molten magma injected into the measures may have sufficed to produce coking coal in any seam that is not more than 100 feet above it; though unless within 20 to 30 feet it will have produced but little change in a seam lying beneath it. This is very generally the case in the coal fields of the Rocky Mountains, and there is one remarkable instance of it in this district. In the southern half of the quadrangle, where the alteration has been complete from the base to the summit of the measures, an instance of this kind could not very well occur; but north of Road Canyon, where with one exception the seams of the upper groups do not afford coking coal, there is enough evidence to show that the numerous sheets of eruptive rock in the upper part of the Pierre shales are responsible for the presence of coking coal only in the lower or Berwind-Aguilar group. The exception noted is in Stock Canyon. Here for a distance of about one-half mile there is an outcrop of coking coal in one of the beds of the Morley-Smiths Canyon group. This outcrop is associated with a thin sheet of igneous rock situated about 50 feet below it. At the southern extremity the sheet rises above the seam, which then ceases to contain coking coal, while at the northern extremity the sheet passes suddenly to a lower horizon, and again the seam ceases to contain coking coal.

The passage of a dike through the measures has invariably produced natural coke wherever a seam of coal is intersected. If the Formation of natural coke. dike is but a few feet thick the coal will not be affected to a serious extent, but where the dike is 50 feet thick or more the coal will be found transformed into coke for a distance of at least 40 feet away from it. But a sheet of igneous rock that has been injected into and along a seam of coal is an occurrence most to be dreaded, since it may mean the early abandonment of any mine in which it is encountered. One mine in the district was dismantled and abandoned a few years ago solely for this reason. The extent to which some of the most important stretches of the outcrop have suffered from these injections along one or more of the coal seams is considerable. On the north side of the Purgatory above Trinidad there is a continuous outcrop of natural coke over a mile in length. This outcrop corresponds to another one on the

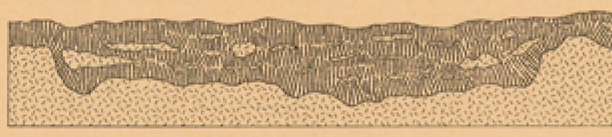


FIG. 2.—Section of a natural exposure of coke and an intrusive sheet on the north side of the Purgatory River opposite Sopris.

The structure of the coke is approximately normal to the surface of the intrusive.

south side of the river at Sopris, and is apparently connected with the same sheet that was encountered in the Thompson mine opposite the mouth of Long Canyon. At Chicosa and Road canyons there is a less extensive occurrence of powdery coke. Where the sheet that formed it is seen to terminate at the mouth of Stock Canyon the coal for some distance beyond has been transformed into anthracite. North of Canyon de Agua there is a similar sheet, which in places, notably at Graphite Canyon, has destroyed one of the beds of coal. The lower group of seams has suffered more than the upper ones from the destructive effects of igneous intrusions, though in Stock Canyon and on the upper Purgatory the Smiths Canyon group has been more or less affected by these intrusions. It is doubtless to this cause that the excellent coking quality of Smiths Canyon coal is largely due.

Area of workable coal.—The total area of measures outcropping within the quadrangle is approximately 495 square miles, of which 290 square miles constitutes the outcrop of Total area of outcropping productive measures. the coal-bearing portion and 205 square miles the outcrop that does not contain coal of economic value. It should be stated, however, that the area of productive measures outlined on the Economic Geology sheet does not include all the accessible coal of the district. The coal-bearing formation extends under the later sedimentary beds, and as the coal most readily won becomes exhausted it will be quite practicable by means of deep shafts, such as those of South Wales, to mine out much of the coal contained in the measure underlying the Poison Canyon sandstone. However, the dike occurrences of the northwestern part of the quadrangle tend to limit the ground that can ever be profitably mined to an area of about 600 square miles.

The greater part of the productive measures contains coking coal, though owing to the fact that the process of alteration was more effective toward the base of the formation, the semi-coking or domestic coal of the upper portion considerably overlaps the coking-coal area. Thus, the coking coal of the Berwind-Aguilar group Area of coking coal. is continuous throughout the southern and central portions of the district up to a line about midway between Hastings and Aguilar, where the change from one kind of coal to the other takes place within a very short distance. In respect to the Sopris group, the northern boundary of the coking-coal area does not extend beyond Chicosa Canyon; while in respect to the two upper groups the coking coal is confined to the Purgatory drainage. The area of the lower group that may be regarded as containing coking coal within the boundaries of the productive coal-measure outcrop is approximately 260 square miles, which includes also the whole of the same kind of coal contained in the middle and upper groups and part of the domestic coal area of these groups. The remainder of the productive outcrop, amounting to 30 square miles, contains domestic coal only, or coal that is Area of domestic coal. adapted to the requirements of the domestic trade and steaming, but is not suitable for the manufacture of coke. In this connection it is well to recall the fact that the productive outcrop is less than one-half the area that can be rendered productive by contemporary methods, and, as before stated, the total area is about 600 square miles.

DEPENDENT INDUSTRIES.

The region tributary to Trinidad produces the greater part of the coke supplied to the metallurgic establishments of Colorado, New Mexico, and Arizona, and of the total output about two-thirds may be credited to the mines and coking plants of the Spansh Peaks quadrangle.

Coal mining.—The principal mines are located at Sopris, Starkville, Forbes, Berwind, Hastings, Aguilar, and Santa Clara. The capacity of the respective mines ranges from 500 to 1500 tons daily. The output varies with the season, though to a less extent than in districts where the coal is entirely of the domestic kind. Most of the mines are worked by the ordinary Method of mining. "room-and-pillar" system; though occasionally, where the coal is low and the conditions are favorable, the "long-wall" system has been found advantageous. Most of the underground haulage between the rooms and the engine roads is done by mules. In the neighborhood of Trinidad the inclination of the beds is comparatively slight and it is practicable for mules to haul the loaded pit cars along the "dip" as well as the empty cars to the "rise;" but in the northern part of the district, where the inclination at the outcrop is often considerable, the rooms are turned off from the cross entries in only one direction—that is, to the "rise." Up to the present time the mines have not been troubled by explosive gases and open lights are in Absence of explosive gases. use in all of them. The product of the coking-coal mines may be loaded and shipped as "run-of-mine" or the "slack" may be screened from the "lump" and sent to the coke ovens, according to requirements. At the mines producing domestic coal the slack is subjected to additional screening for the purpose of separating the "nut."

Coke making.—Much of the "slack," or smaller sizes of coal, made into coke is first washed in order to remove a certain amount of the associated slate and bony material. The washing is done either by jigging, as at Sopris, or on bumping tables, as at Hastings. The washed coal, with or without further reduction in size, is charged into ovens of the beehive type, leveled off, the the oven door bricked up, and the charge allowed to coke for either forty-eight or seventy-two hours, according to the weight of the charge. This depends on the day of the week, the ovens charged on Friday and Saturday, having to burn over Sunday, receive seventy-two-hour charges which range from 4½ tons for an oven having a floor 10 feet in diameter to 6½ tons for one having a 13-foot floor. The corresponding forty-eight-hour charges range from 3½ to 5½ tons. In the case of unwashed slack, the respective charges are of about the same weight. The air required to produce a certain amount of combustion, and thus develop the heat requisite for coking the charge, is admitted either through small openings left in the brickwork of the door or through numerous perforations connected with an annular space around the dome. When the coking is finished the charge is quenched with water and withdrawn, the heat remaining in the brickwork being sufficient to ignite the succeeding charge. It has lately been found advantageous to conduct the products of combustion through flues beneath the oven floor and thus hasten the completion of the coking process. The coke made from ordinary slack usually contains 18 per cent and upward of ash, and the presence of flakes of bone and slate increases the tendency to break up readily in handling. The coke made from washed coal contains about 15 per cent of ash, is homogeneous in texture, and does not break up to the same extent as the ordinary product. In both cases the coke is dense, of silvery luster, and thickly glazed with dissociated, graphitic carbon. Repeated exhaustion under water to one-half-inch barometric pressure shows the ordinary coke to contain from 30 to 31 per cent of cell space, though in the coke made from washed and more finely crushed coal the percentage is somewhat higher.

SANDSTONE.

Trinidad sandstone.—This rock, which forms the upper half of the Trinidad formation, is a medium-grained grayish or greenish-gray sandstone, about 75 to 80 feet thick, outcropping prominently from Trinidad northward immediately beneath the coal-bearing beds of the Laramie, and extending up to within a few feet of the lowest coal seam. The homogeneity of this rock in color and texture and its accessibility render it the most important stone for structural purposes in the district, though where the branching *Halymenites* are most abundant the evenness of the texture is to some extent impaired. Trinidad sandstone has been largely used as a building stone in the city of Trinidad, where many substantial structures testify to its excellent qualities. There are no regular quarries of the stone, it being the custom to procure it from the nearest of the many accessible outcrops in the vicinity of the city.

Laramie sandstone.—The entire section of the Laramie affords beds of sandstone suitable for structural purposes. The texture and gray color are more variable than in the Trinidad sandstone, and as a rule the Laramie is more porous. Nevertheless, it has been largely used for foundations, and for retaining walls of coke ovens at Starkville and Sopris. The exposures of this rock are practically coextensive with the Laramie formation, and the accessible supply is unlimited.

Eocene sandstone.—The Eocene sandstones of the Poison Canyon and Cuchara formations are, as a rule, too soft, porous, or conglomeratic to be of service in structural work. But there are several beds in the Cuchara formation that locally afford sandstone of medium grain and hardness and are of a desirable color, such as pale pink or greenish gray. The tint varies in different beds, though constant in the same bed. These sandstones occur only in the vicinity of the Spanish Peaks and in the northwest corner of the district.

LIMESTONE.

Timpas limestone.—This limestone is exposed in the northeast corner of the quadrangle in a bed about 40 feet thick made up of layers from 6 to 12 inches thick, separated from one another by shaly partings. The limestone layers are well suited for burning into lime, and the northern extension of the same bed furnishes the limestone used as flux by the smelting establishments at Pueblo.

Cement limestone.—The cement works at Trinidad, when in operation, depended upon the concretions in the Pierre shale as the chief source of cement rock. Such a source could hardly be expected to meet the demands of a steady output, at least to an economic extent. Prospectively, the Apishapa formation may be regarded as the most promising source of cheap raw material for the manufacture of cement. The central portion of this formation abounds in calcareo-arenaceous, coarse shaly layers that locally may furnish rock suitable for the production of cement clinker. The Apishapa formation outcrops in the northeast corner of the district, extends northward through the Walsenburg quadrangle, and southeastward into the Elmoro quadrangle.

METALLIFEROUS DEPOSITS.

With the exception of the iron-ore concretions toward the base of the Laramie, there are no known deposits of this ore within the boundaries of the district. Nor are the conditions such as to warrant a belief in the probable existence of deposits of economic value. The same is true of copper ores for copper alone. Moreover, where it is possible for deposits of these metals to occur the formations are so fully exposed that ores in paying quantity could not very well escape detection. The precious metals — more especially gold — unless associated with base metals or contained in the matrix of well-defined veins, are not so easily detected, and it frequently happens that the most unpromising-looking rock of a district is really the most valuable.

Auriferous gravels.

The occurrence of ores containing precious and other metals is confined to West Spanish Peak. Nearly all the gulches draining into the Wahatoya and Apishapa contain more or less placer gold, and close to the base of the mountain the gravel near the "bed rock" generally yields "colors," or small specks of gold, on panning. But, so far as known, it is doubtful if any of the gravel can be profitably washed. Beyond the fact that this gold must have been derived from auriferous material occurring somewhere within the boundaries of the West Peak mass, its source has not been definitely ascertained.

Argentiferous ores.

Most of the lodes discovered contain silver, usually associated with galena, gray copper, chalcopyrite, sphalerite, and siderite. The matrix is generally quartz, though calcite is of common occurrence and barite is sometimes present. While ore-bearing veinlets have been found in the eruptive mass of the mountain, the most promising deposits are confined to the surrounding zone of metamorphosed sediments, where there are small vertical veins containing comparatively rich ore cutting the formation. Ore shipments made from Monarch Basin, on the Wahatoya side of the mountain, are reported to have yielded over $100 per ton in silver and lead. Judging from its appearance, the ore is rich enough to ship when once extracted, but the smallness of the veins and pay streaks does not encourage the working of the deposits under existing conditions.

ARTESIAN WATER.

What constitutes artesian-water conditions.

Water that exists beneath the surface of the earth and which, owing to the greater elevation of its source or point of inflow, is capable of rising to a higher level, though not necessarily to the surface, is termed artesian water. Such water is usually contained in a coarse-textured porous rock that is overlain by a rock of fine texture through which the water can not percolate, or through which it can pass only with great difficulty. The height to which it is capable of rising — termed its plane of head — is a plane, conforming to the curvature of the earth, that connects the source with the more or less distant point of outflow. Theoretically considered, if the water-bearing bed should coincide with this plane and the resistance to the passage of water be uniform throughout, the head, or hydrostatic pressure, would be zero and artesian conditions would not exist. If, however, the structure should be such that portions of the bed would lie below the plane of head, the water would then be artesian and capable, when tapped by boring, of rising to this plane, or if the surface were also below the plane of head, of affording a flowing well. But the actual conditions rarely approximate the theoretic. The resistance is never uniform throughout, while the presence of dikes or faults between a well and the point of inflow may seriously obstruct the circulation of the water or cut it off entirely. It is only where artesian conditions are emphasized, and not threatened by obstructing causes, that the result of boring operations can be predicted with any degree of certainty.

Dakota water.

In the Spanish Peaks quadrangle the formations that contain artesian water are the Dakota sandstone and the lower Eocene sandstones, chiefly the Poison Canyon formation; though it is worthy of remark that the Laramie will also afford water to a limited extent. The Dakota sandstone does not outcrop anywhere within the boundaries of the district, but its position in depth is known from its outcroppings east and west. It consists of 350 to 400 feet of sandstone — the upper 100 to 150 feet being separated from the lower 200 to 250 feet by a layer of refractory material called fire clay. The water-bearing portion of the formation lies below this layer. The sandstone is porous, coarse-textured, and well adapted for the storage of artesian water. Along its eastern outcrop a strong spring of water usually appears at each gulch crossing, and it is the source of the flowing wells at Pueblo, La Junta, and other points. Throughout the Spanish Peaks district the Dakota lies at too great a depth to be available for ordinary purposes and only a small area in the vicinity of Trinidad can be depended upon to furnish flowing wells. The artesian contours, shown in the northeastern corner of the Artesian Water sheet simply indicate the approximate depth to the water-bearing zone. It is not to be expected that the area covered by these contours will afford flowing wells, except in a small tract in the Purgatory Valley, indicated on the map. In the Apishapa Valley, however, the water will rise close to the surface.

On the western border of the quadrangle the depth of the Dakota is uncertain, owing to the variation in thickness of the intruded bodies of lava that outcrop in the Pierre west of the boundary and probably extend eastward some distance beneath the surface. For this reason that portion of the area is not contoured.

Lower Eocene water.

The Poison Canyon formation, which consists of beds of coarse, porous sandstone alternating with beds of clay, is quite capable of affording artesian water under favorable structural conditions, but in this quadrangle the inflow occurs in gulches heading in the Spanish Peaks, and as the dikes in the vicinity of the peaks are numerous they will doubtless seriously obstruct the free circulation of the water in the area affected by them. Bordering this area the beds are still slightly upturned and are in a position to receive much of the water draining from the peaks. There is thus a considerable portion of the Poison Canyon formation that will afford pumping wells. As there is no formation overlying the Eocene, contours are not necessary to indicate the depth at which water will be obtained. In nearly all cases it will be found below the first bed of clay passed through, and as each succeeding bed of sandstone will augment the amount of water the requirements will determine the depth of the bore.

R. C. HILLS,
Geologist.

April, 1900.

Analyses of coals.

Group and seam.	Carbon.		Hydrogen.		Oxygen.	Nitrogen.	Sulphur.	Moisture.	Ash.	Volatile combustibles.	Net calories.*	Specific gravity.
	Fixed.	Combined.	Disposable.	With oxygen.								
Berwind-Aguilar:												
Forbes mine, middle seam	57.87	16.08	3.39	1.19	9.51	1.28	0.42	1.21	9.05	31.82	69.16	1.320
Berwind mine, lower seam	54.81	24.41	4.53	0.91	7.30	1.46	0.59	1.24	4.75	39.20	76.92	1.274
Berwind mine, lower seam	50.66	21.50	4.41	0.79	6.30	1.31	0.63	2.05	12.35	34.94	70.88	1.320
Berwind mine, lower seam	54.55	......	......	......	......	......	......	1.63	8.00	35.82	......	......
Canyon de Agua Victor mine, middle seam	54.34	20.94	4.23	0.90	7.21	1.34	0.69	1.95	8.40	35.31	72.82	1.315
Aguilar Peerless mine, middle seam	57.51	18.31	3.99	1.21	9.67	1.32	0.77	1.89	5.33	35.00	72.40	1.298
Aguilar Peerless mine, middle seam	54.18	22.18	4.37	1.00	8.01	1.16	0.64	2.36	6.10	37.36	74.04	1.309
Santa Clara mine, middle seam	51.45	22.74	3.98	1.08	8.64	0.84	0.64	1.68	8.95	37.92	71.12	1.316
Santa Clara mine, lower seam	49.98	17.38	4.60	1.07	8.58	1.21	0.40	1.08	15.70	33.24	67.48	1.360
Sopris:												
Sopris mine, clean coal	58.40	20.45	4.87	0.59	4.68	0.99	0.60	0.52	8.90	32.18	77.83	1.318
Sopris mine, average sample	57.80	16.74	4.05	0.89	7.11	0.92	0.59	0.40	11.50	30.30	71.77	1.314
Morley-Smiths Canyon:												
Morley seam	59.19	17.55	4.21	0.77	6.21	1.06	0.61	1.63	8.77	30.41	74.02	1.358
Smiths Canyon	58.61	......	......	......	......	......	......	0.69	12.18	28.52	......	......
Wet Canyon	50.38	......	......	......	......	......	......	5.59	11.33	32.70	......	1.382
Stock Canyon	50.39	24.57	4.55	1.03	10.14	1.29	0.67	1.44	5.82	42.35	73.47	1.288
Primrose	56.10	......	......	......	......	......	......	2.75	9.08	32.07	......	......
Canyon de Agua	48.83	21.01	3.62	1.36	10.84	1.25	0.47	1.49	11.13	38.53	66.42	1.282

* The "net calories" represents the heat due to perfect combustion of the carbon and disposable hydrogen, less that absorbed by the total amount of water given off by the coal.

Analyses of coal ash.

Source.	Silica.	Ferric oxide.	Alumina.	Lime.	Magnesia.	Soda.	Potash.	Sulphuric acid.	Phosphoric acid.	Total.
Morley	68.60	6.42	19.94	1.30	Tr.	1.46	1.32	0.34	Included with iron.	99.38
Sopris*	60.18	9.12	25.14	1.72	Tr.	2.12	0.78	0.76	0.659	100.479
Starkville	65.02	7.56	24.73	0.16	0.30	2.22	0.52	0.35	0.095	100.955
Aguilar	58.40	7.32	27.80	3.52	Tr.	0.80	0.62	1.76	0.120	100.34
Santa Clara, middle seam, lower group	65.65	5.30	21.63	3.06	......	2.59	0.88	1.04	0.32	100.47

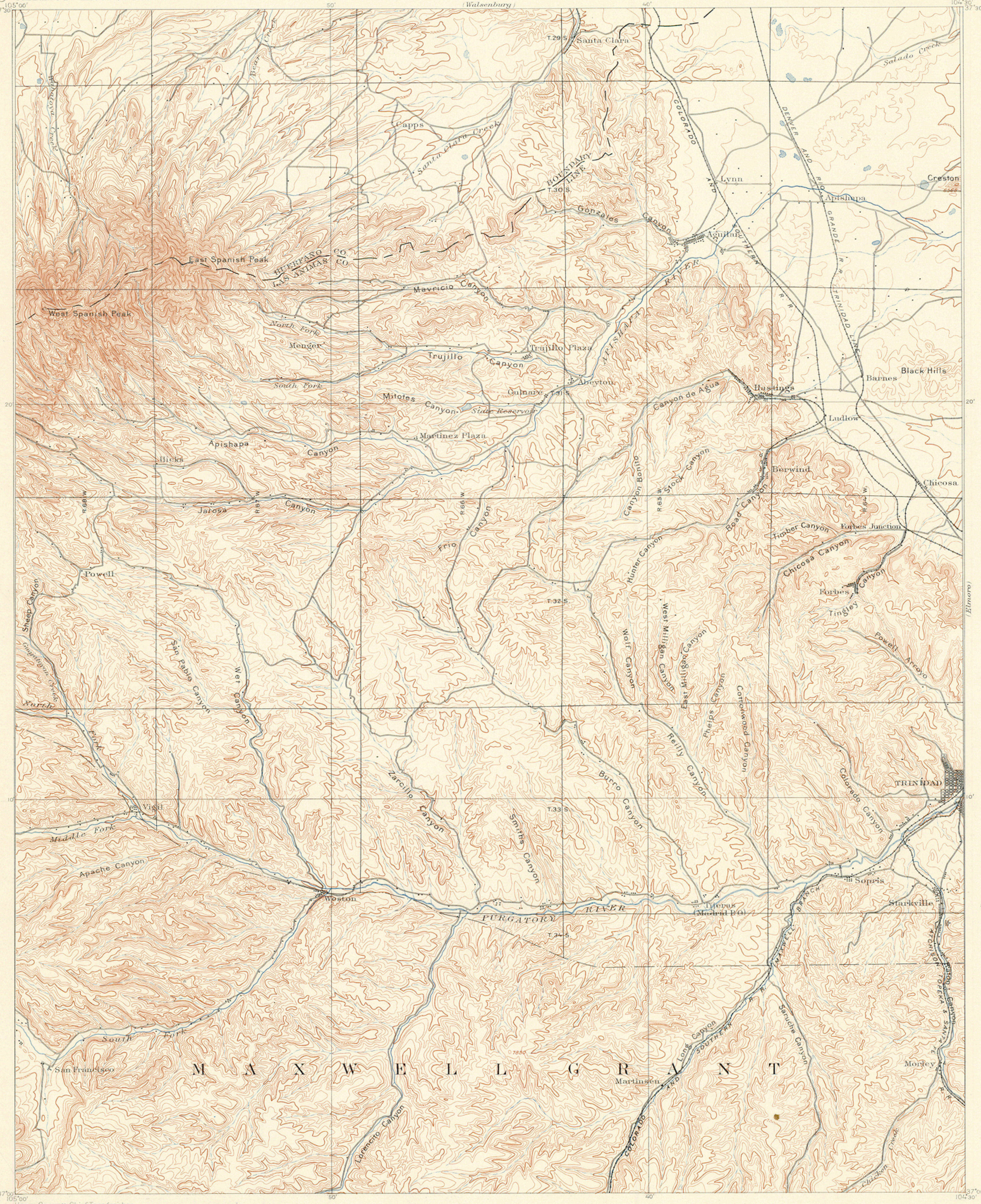
* A combined sample from 100 railway cars of coke, made from washed Sopris coal, afforded 14.43 per cent ash having the composition above given.

NOTE.—All the above analyses were made in the laboratory of the Colorado Fuel and Iron Company at Denver.

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

TOPOGRAPHIC SHEET

COLORADO
SPANISH PEAKS QUADRANGLE



LEGEND

RELIEF
(printed in brown)

Figures
(showing heights above mean sea level instrumentally determined)

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

DRAINAGE
(printed in blue)

Streams

Intermittent streams

Ponds and reservoirs

Intermittent lakes

CULTURE
(printed in black)

Roads and buildings

Trails

Railroads

Bridges

County boundary lines

Land grant boundary lines

U.S. township lines

Located township and section corners

T.32 S.
R.66 W.
Township and range numbers

Triangulation stations

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.

Scale 1:125000
Miles
Kilometers

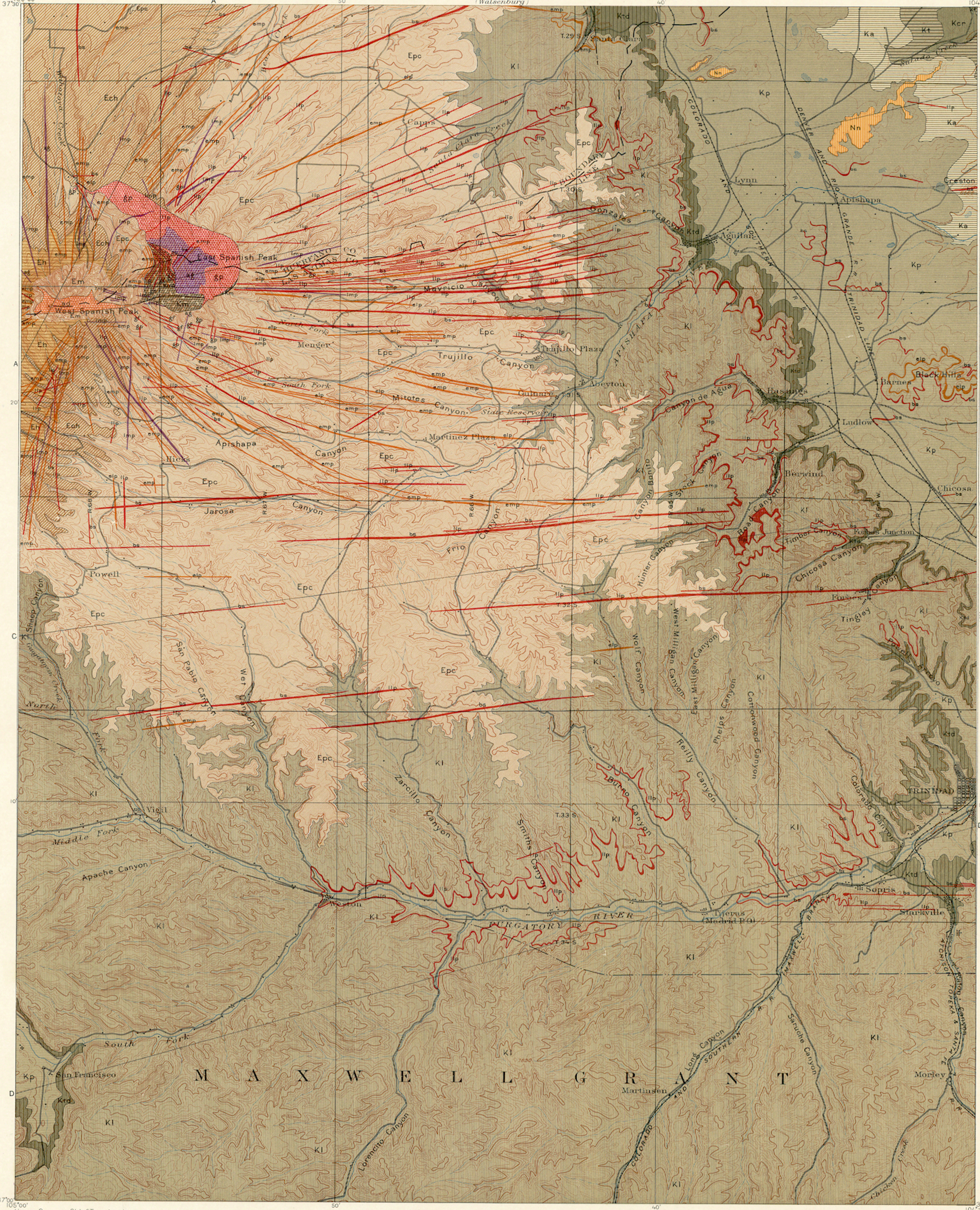
Contour interval 100 feet.
Datum is mean sea level.

Edition of Nov. 1900.

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

HISTORICAL GEOLOGY SHEET

COLORADO
SPANISH PEAKS QUADRANGLE



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Scale 1/125000

Contour interval 100 feet.
Datum is mean sea level.
Edition of Feb 1901.

Geology by R.C. Hills.
Surveyed 1894-1895.

LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines. Metamorphism is indicated by short dashes combined with the parallel lines.)

NEOCENE

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

EOCENE

- Eh — Huerfano formation *(coarse, brown or reddish sandstone and conglomerate; red or brown clay at base)*

EOCENE?

- Ech — Cuchara formation *(cavernous variegated sandstone, brown clay and sand at base)*
- Epc — Poison Canyon formation *(conglomerate and sandstone with beds of yellow clay)*
- Em — Metamorphosed Eocene *(quartzite and quartzitic conglomerate grading into unaltered rocks)*

CRETACEOUS

- Kl — Laramie formation *(sandstone and shale with beds of coking and domestic coal)*
- Ktd — Trinidad sandstone *(massive and shaly sandstone)*
- Kp — Pierre shale *(shale of various shades of gray with concretions)*
- *Subdivisions of the Niobrara formation:*
  - Ka — Apishapa formation *(coarsely laminated shale often bituminous; paper shale at base)*
  - Kt — Timpas formation *(calcareous shale with thin-bedded gray limestone)*
- Kcr — Carlile shale *(gray shale capped by soft sandstone)*
- Km — Metamorphosed Cretaceous *(slate, quartzite, and partly altered sandstone)*

IGNEOUS ROCKS

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

EOCENE and NEOCENE

- gp, bs, gf, llp — Basalt, granite-porphyry, granite-felsophyre, and late lamprophyre *(stock, dikes, and sheets)*
- ag, lmp — Augite-granite-porphyry and late monzonite-porphyry *(stock and dikes)*
- ad, emp, elp — Augite-diorite, early lamprophyre, and early monzonite-porphyry *(stock, dikes, and sheets)*

Dikes and sheets are shown in detail on the Igneous Geology sheet.

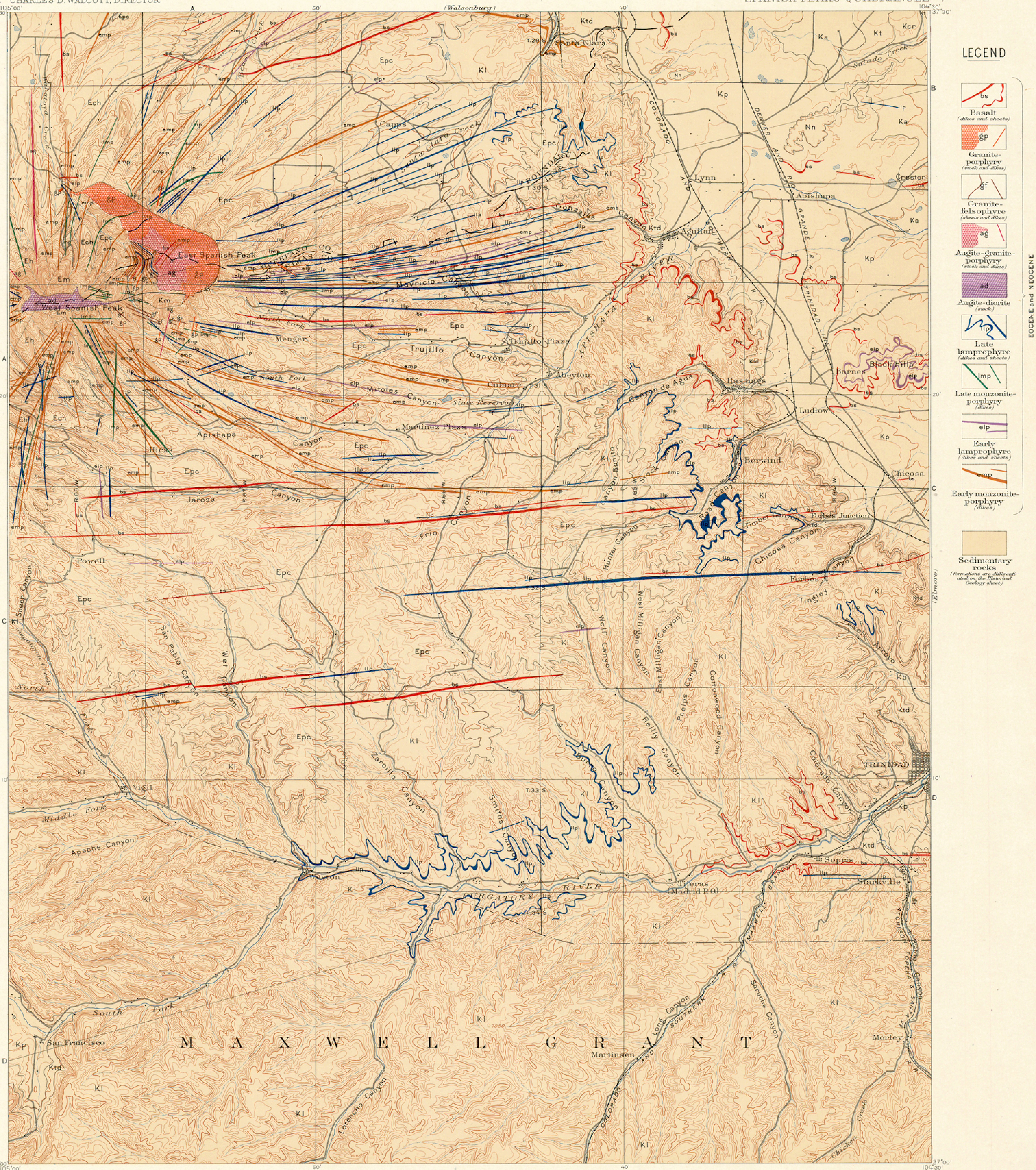
Faults

Sections

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

IGNEOUS GEOLOGY SHEET

COLORADO
SPANISH PEAKS QUADRANGLE



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Edition of Feb. 1901

Geology by R. C. Hills.
Surveyed 1894-1895.

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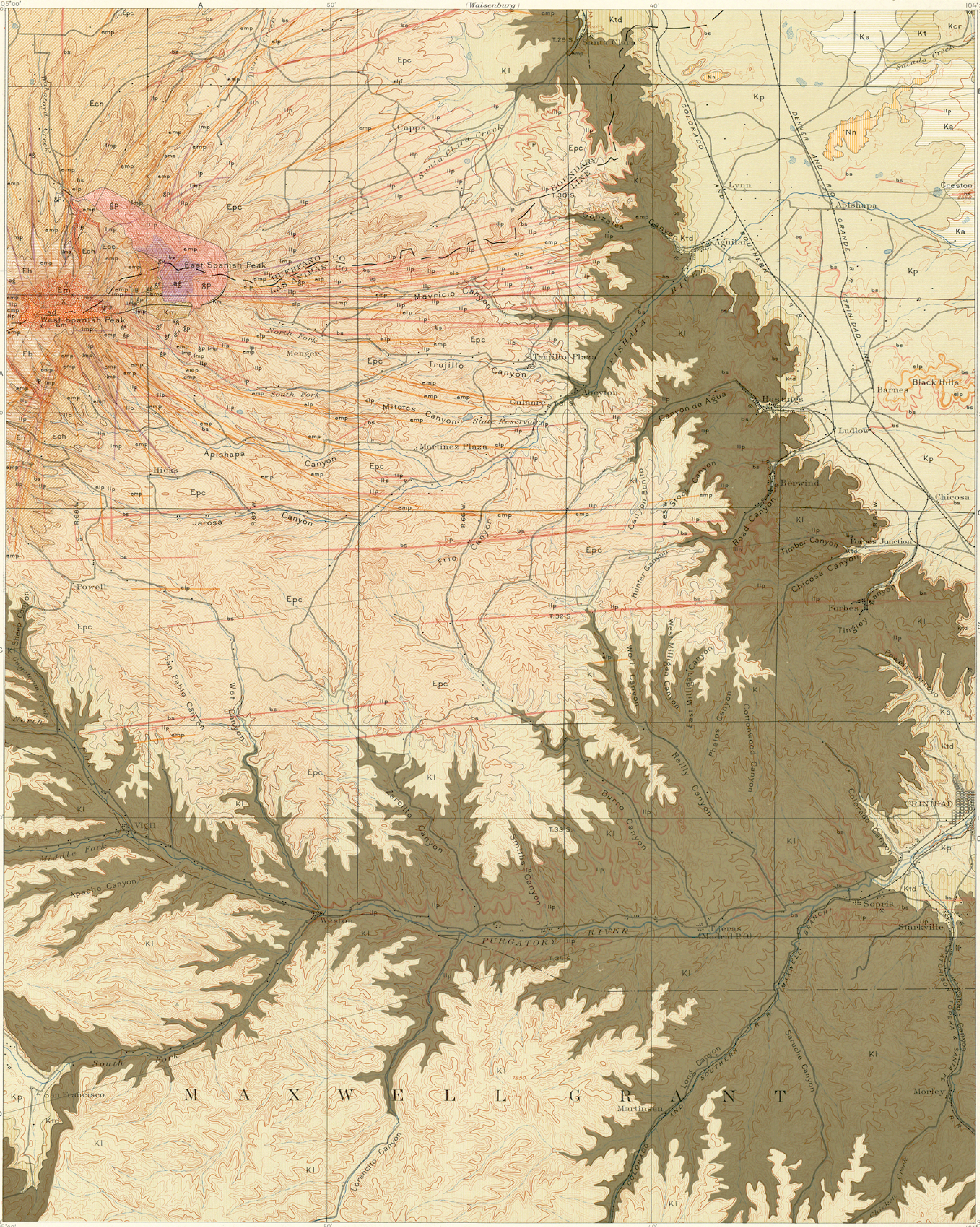
ECONOMIC GEOLOGY SHEET

COLORADO
SPANISH PEAKS QUADRANGLE



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Surveyed in 1895.

Lloyd
Herron
Lloyd

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

Datum is mean sea level.

Edition of Feb. 1901.

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LEGEND

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Subdivisions of the Niobrara formation:

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

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

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

Km — Metamorphosed Cretaceous *(slate, quartzite, and partly altered sandstone)*

IGNEOUS ROCKS

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

EOCENE and NEOCENE

gp, bs, gf, llp — Basalt, granite-porphyry, granite-felsophyre, and late lamprophyre *(stock, dikes, and sheets)*

ag, lmp — Augite-granite-porphyry and late monzonite-porphyry *(stock and dikes)*

emp, elp, ad — Augite-diorite, early lamprophyre, and early monzonite-porphyry *(stock, dikes, and sheets)*

Dikes and sheets are shown in detail on the Igneous Geology sheet.

Faults

Sections

⚒ Coal mines
X Silver prospects

Known productive formations

Metalliferous deposits *(area containing metalliferous deposits, chiefly silver and lead)*

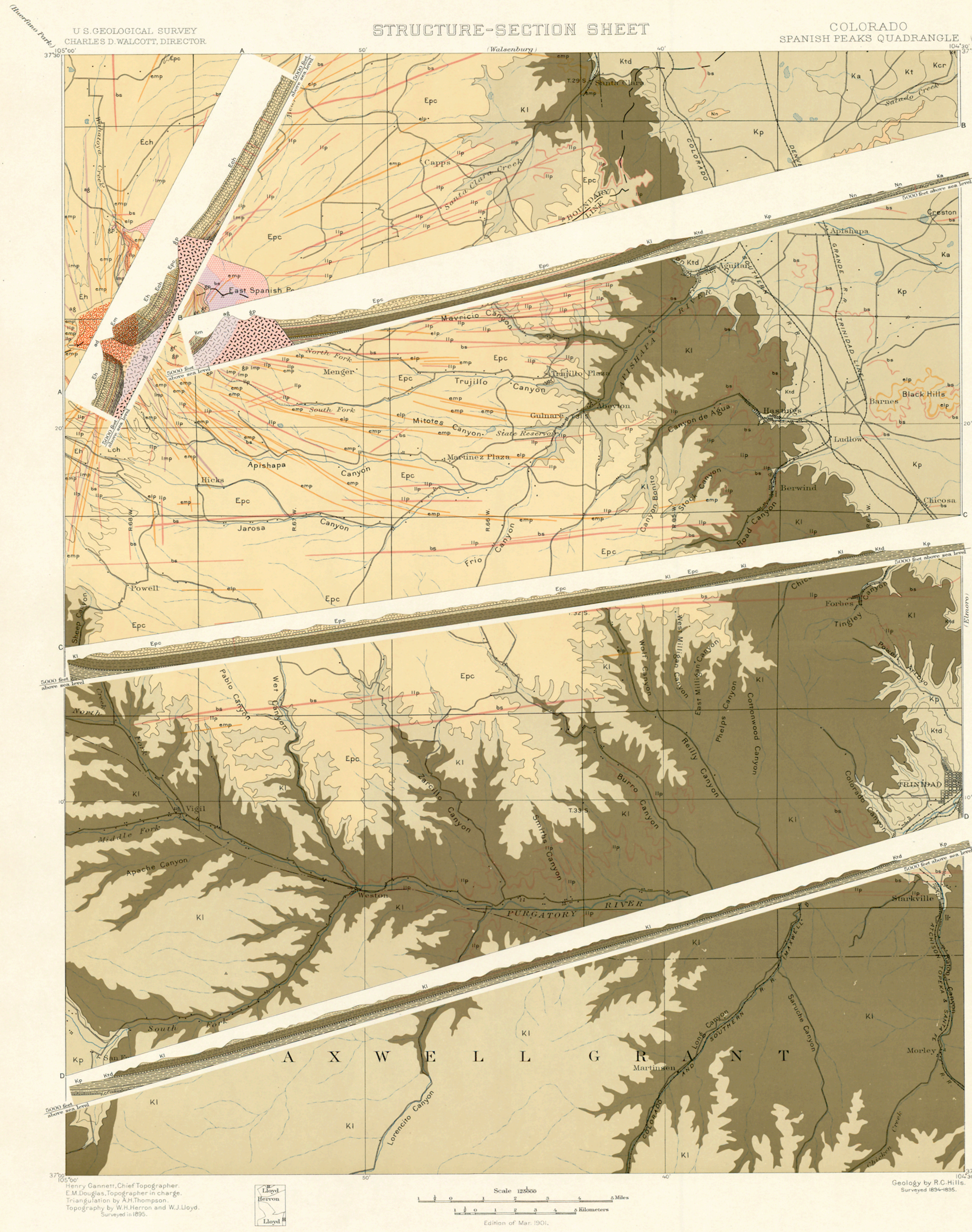
Slightly auriferous gravels

Coal *(Laramie formation contains coal beds in its lower portion. Coking coal occurs to the south of the Apishapa River, domestic coal to the north.)*

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

STRUCTURE-SECTION SHEET

COLORADO
SPANISH PEAKS QUADRANGLE



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.

Scale 1:125000
Miles
Kilometers

Edition of Mar. 1901.

Geology by R.C. Hills.
Surveyed 1894-1895.

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

NEOCENE
- Nn — Nussbaum formation (sandstone and conglomerate)

EOCENE
- Eh — Huerfano formation (coarse, brown or reddish sandstone and conglomerate, red or brown clay at base)

EOCENE?
- Ech — Cuchara formation (cavernous variegated sandstone, brown clay and sand at base)
- Epc — Poison Canyon formation (conglomerate and sandstone with beds of yellow clay)
- Em — Metamorphosed Eocene (quartzite and quartzitic conglomerate grading into unaltered rocks)

CRETACEOUS
- Kl — Laramie formation (sandstone and shale with beds of coking and domestic coal)
- Ktd — Trinidad sandstone (massive and shaly sandstone)
- Kp — Pierre shale (shale of various shades of gray, with concretions)
- Subdivisions of the Niobrara formation (Elmoro):
  - Ka — Apishapa formation (coarsely laminated shale often bituminous; paper shale at base)
  - Kt — Timpas formation (calcareous shale with thin-bedded gray limestone)
- Kcr — Carlile shale (gray shale capped by soft sandstone)
- Km — Metamorphosed Cretaceous (slate, quartzite, and partly altered sandstone)

IGNEOUS ROCKS

SHEET SYMBOL / SECTION SYMBOL

EOCENE and NEOCENE
- bs, gp, lp — Basalt, granite-porphyry, granite-felsophyre, and late lamprophyre (stock, dikes, and sheets)
- ag, lmp — Augite-granite-porphyry and late monzonite-porphyry (stock and dikes)
- ad, elp, emp — Augite-diorite, early lamprophyre, and early monzonite-porphyry (stock, dikes, and sheets)

Dikes and sheets are shown in detail on the Igneous Geology sheet.

Faults

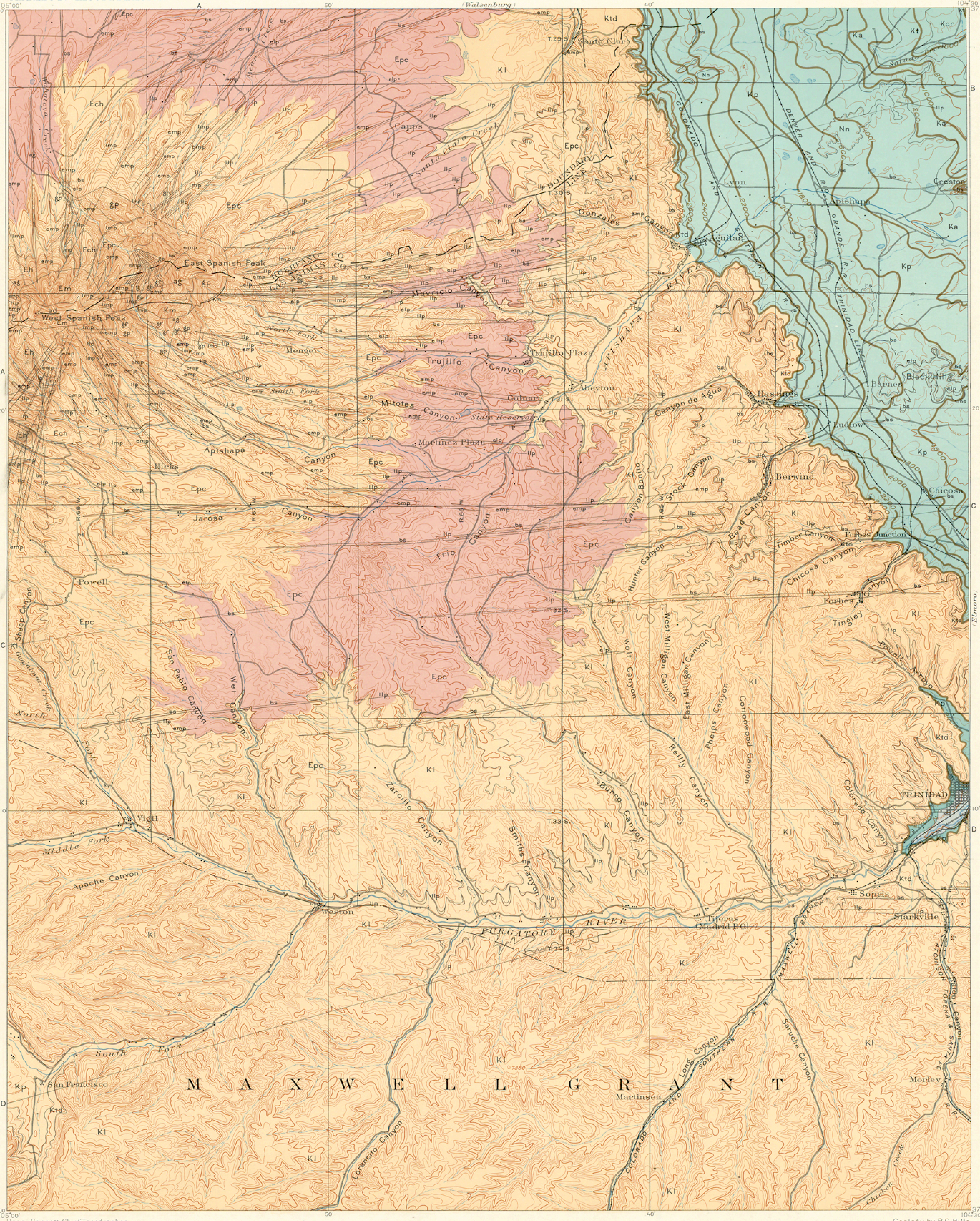
Known productive formations

- *Metalliferous deposits* (area containing metalliferous deposits, chiefly silver and lead)
- *Slightly auriferous gravels*
- *Coal* (Laramie formation contains coal beds in its lower portion. Coking coal occurs to the south of the Apishapa River; domestic coal to the north)

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

ARTESIAN WATER SHEET

COLORADO
SPANISH PEAKS QUADRANGLE



LEGEND

Area underlain by Dakota formation that will probably yield flowing wells.

Area underlain by Dakota formation that will probably yield pumping wells at depths indicated by the heavy contours.

1400

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

Area underlain by Poison Canyon formation that will probably yield pumping wells.

Area in which artesian water can probably not be profitably obtained.

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.

Lloyd
Herron
Lloyd

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

Datum is mean sea level.

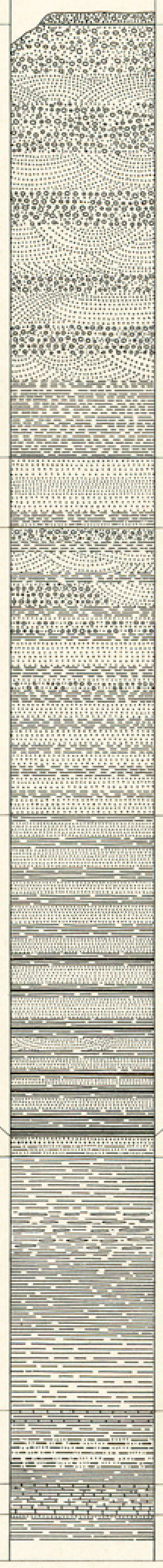
Edition of Mar. 1901.

Geology by R. C. Hills.
Surveyed 1894-1895.

COLUMNAR SECTION SHEET

GENERALIZED SECTION OF THE ROCKS OF THE SPANISH PEAKS QUADRANGLE.

SCALE: 1 INCH = 1000 FEET.



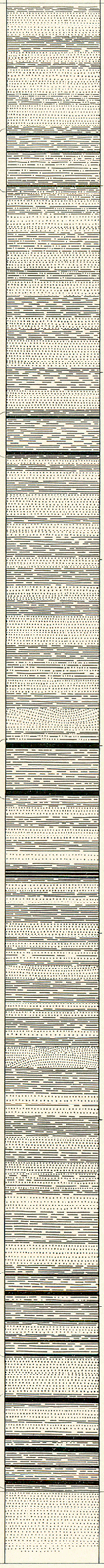
Period.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.
NEOCENE	Nussbaum formation.	Nn		30	Sandstone and conglomerate capping low mesas.
EOCENE	Huerfano formation.	Eh		2800–3000	Heavy-bedded, coarse sandstone, frequently cross bedded, and conglomerate of brown or reddish-brown color. Reddish-brown clays and marls.
EOCENE?	Cuchara formation.	Ech		450–500	Thick-bedded sandstone of white, yellowish-white, and pale-pink tints with cavernous surface. Brownish-red clay and soft sandy layers at base.
	Poison Canyon formation.	Epc		1800–2000	Thick beds of loosely aggregated sandstone and conglomerate alternating with bands of greenish-yellow clay. Contains petrified wood. Coarse, porous sandstone weathering pale yellow dappled with pink. Surface cavernous.
CRETACEOUS	Laramie formation.	Kl		1500–2200	Alternating beds of gray sandstone and shale. Contains workable beds of coking and domestic coal in lower portion.
	Trinidad sandstone.	Ktd		150–170	Massive sandstone with remains of fucoids (*Halymenites*). Shaly sandstone with baculites at the base.
	Pierre shale.	Kp		1300–1700	Yellowish- and greenish-gray shale. Lead-gray shale with lime-iron concretions parallel to the bedding. Chiefly gray or dark-gray shale. Light-gray shale, locally dark gray or greenish gray.
	Apishapa formation.	Ka		450–500	Bituminous sandy shale with thin bands of limestone near top and papery shale near base.
	Timpas formation.	Kt		190	Calcareous shale and thin limestones, with thick bed at base.
	Carlile shale.	Kcr		170	Gray shale capped by sandstone.

TABLE OF FORMATION NAMES.

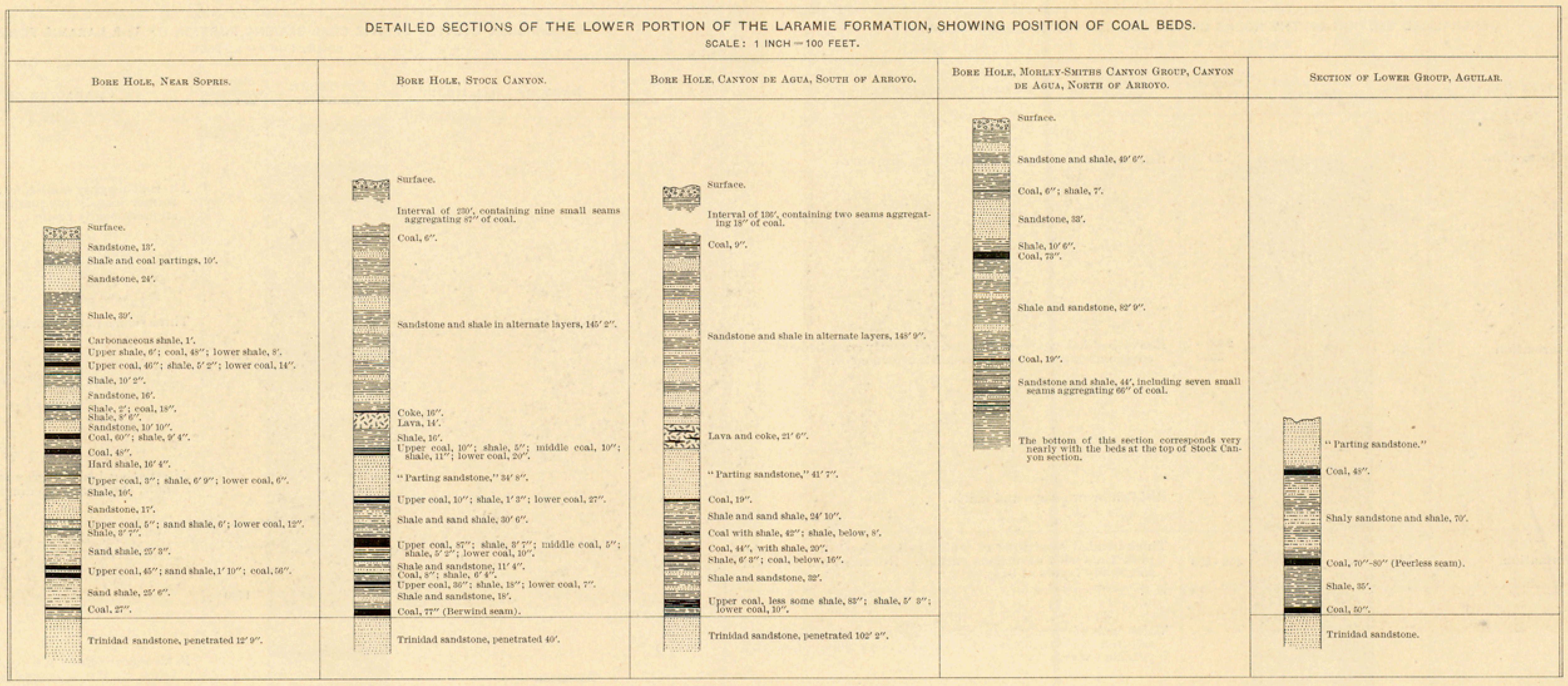
Period.	Names and Symbols used in this Folio.		Names used by Various Authors.		G. K. Gilbert: Seventeenth Annual Report U. S. Geological Survey, 1896.	F. V. Hayden: Geological Atlas of Colorado, 1881.
NEOCENE	Nussbaum formation.	Nn	Nussbaum.		Upland sands.	
EOCENE	Huerfano formation.	Eh				
EOCENE?	Cuchara formation.	Ech				
	Poison Canyon formation.	Epc				
CRETACEOUS	Laramie formation.	Kl	Laramie.			Laramie (post-Cretaceous).
	Trinidad formation.	Ktd	Fox Hills.	Montana.		Fox Hills (including Fort Pierre).
	Pierre shale.	Kp	Pierre.		Pierre shale.	
	Apishapa formation.	Ka	Niobrara.	Colorado.	Apishapa formation.	Colorado (comprising Fort Benton and Niobrara).
	Timpas formation.	Kt			Timpas formation.	
	Carlile shale.	Kcr	Benton.		Carlile shale.	

GENERALIZED SECTION OF THE COAL-BEARING PORTION OF THE LARAMIE FORMATION.

SCALE: 1 INCH = 100 FEET.



Formation Name.	Name of Coal Group.	Columnar Section.	Height above base in Feet.	Character of Rocks.
LARAMIE FORMATION (Kl)				Alternating gray sandstone and soft shale, the former largely predominating. The sandstone is locally fissile.
	Raton Pass.			These seams not of workable size.
			1400	
				Alternating beds of gray sandstone and soft shale, the former predominating.
			1200	
	Wootton.			Both seams afford low coal in Raton Mountains, on the Apishapa near Abeyton, and on the upper Canyon de Agua.
			1000	Alternating beds of gray sandstone and shale, the former slightly predominating.
			800	
	Morley-Smiths Canyon.			Seam at Morley and in Wet Canyon 6 to 7 feet thick; in Stock Canyon 38 inches of coking coal; in Smiths Canyon, Canyon de Agua, and on the Apishapa 5 to 7 feet thick.
				Seams in the Purgatory Valley above Tijeras; good coal in benches separated by shale bands.
			600	
				Alternating beds of gray sandstone, shale, and shaly sandstone, the shaly beds predominating. Many very thin seams of coal but none workable. Fossil leaves sometimes abundant.
			400	
				Valley mine seam.
				Sopris seam.
	Sopris.		200	
				Thompson seam.
				Massive sandstone, "Parting sandstone."
				Road Canyon, Aguilar, and Starkville upper seam.
	Berwind-Aguilar.			Hastings, Forbes, and Starkville seam.
				Peerless seam, Aguilar.
			0	Berwind seam, Road Canyon.
TRINIDAD FORMATION (Ktd)				Massive sandstone containing fucoids (*Halymenites*).



R. C. HILLS,
Geologist.

FIG. 3.—EAST SPANISH PEAK, FROM THE NORTHWEST.

The great dike, which runs north from the West Peak, is shown in the middle ground. The ridge on the left is granite-porphyry.

FIG. 4.—WEST SPANISH PEAK, FROM THE NORTHWEST.

Flat-lying Eocene rocks outcrop on the middle slopes of the mountain. One large dike and several smaller ones are seen in the foreground.

FIG. 5.—GENERAL VIEW OF THE SPANISH PEAKS, FROM THE NORTHWEST.

West Spanish Peak on the right of the picture; East Spanish Peak on the left; flat-topped bluff of Cuchara sandstone on the extreme left. View is taken from the north end of the great dike ridge, seen in the middle of the picture.

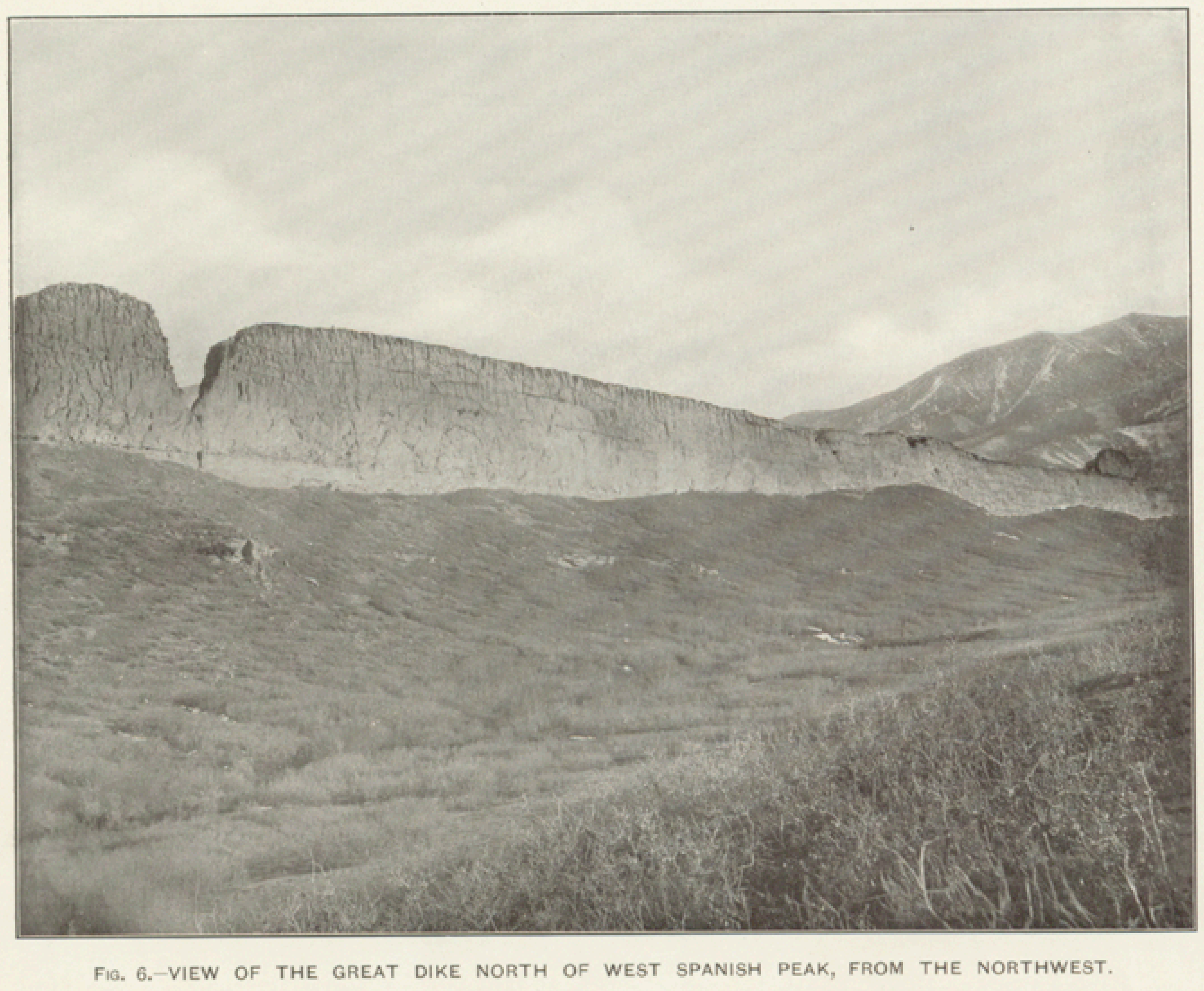


FIG. 6.—VIEW OF THE GREAT DIKE NORTH OF WEST SPANISH PEAK, FROM THE NORTHWEST.

Horizontal lines on the dike are casts of the bedding planes of the inclosing Cuchara sandstone. Base of the West Peak is on the right.

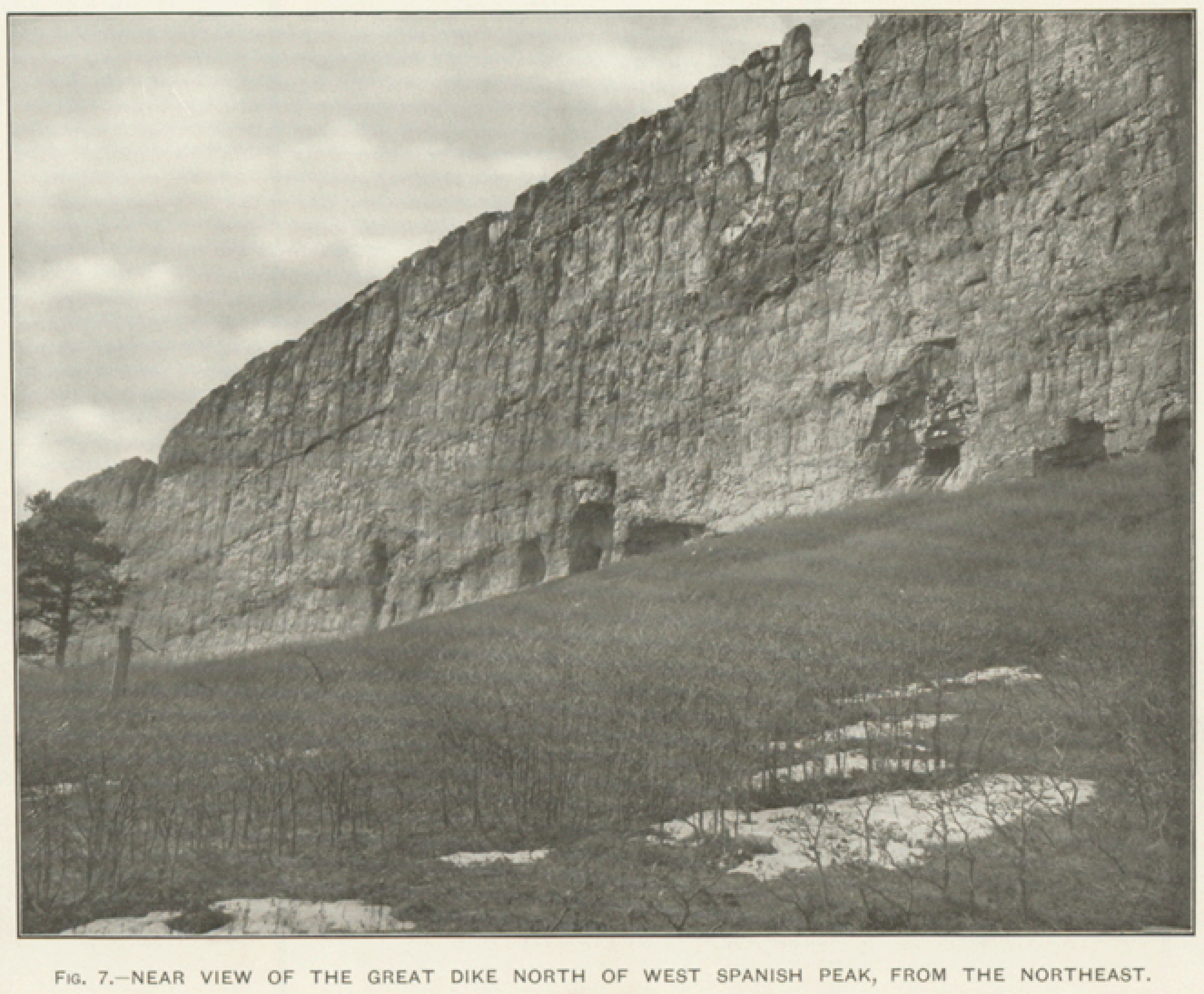


FIG. 7.—NEAR VIEW OF THE GREAT DIKE NORTH OF WEST SPANISH PEAK, FROM THE NORTHEAST.

At this point it forms a continuous wall, 100 feet in height.

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	€	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:

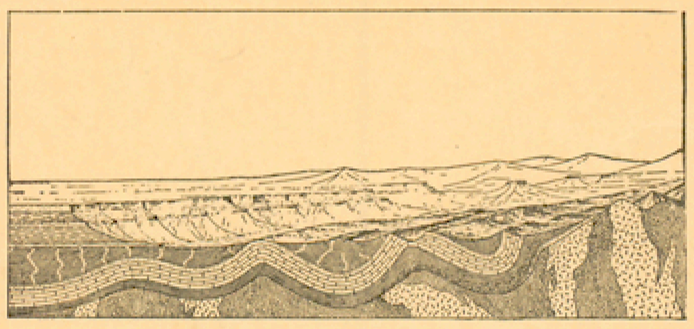


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

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:

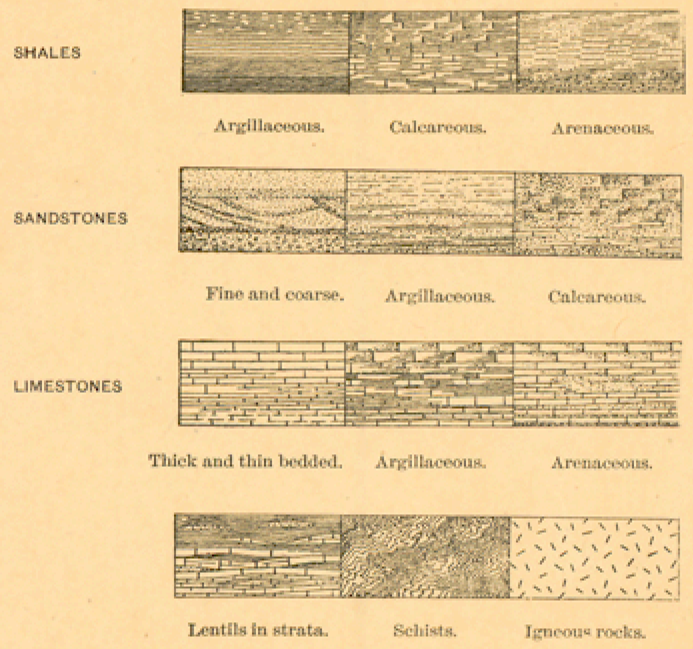


Fig. 3.—Symbols used to represent different kinds of rock.

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.

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