DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, SECRETARY
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS
OF THE
UNITED STATES

RATON-BRILLIANT-KOEHLER FOLIO

NEW MEXICO-COLORADO

BY

WILLIS T. LEE

WASHINGTON, D. C.
ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY
GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS S. J. KUBEL, CHIEF ENGRAVER
1922

GEOLOGIC ATLAS OF THE UNITED STATES.

UNITS OF SURVEY AND OF PUBLICATION.

The Geological Survey is making a topographic and a geologic atlas of the United States. The topographic atlas will consist of maps called *atlas sheets*, and the geologic atlas will consist of parts called *folios*. Each folio includes topographic and geologic maps of a certain four-sided area, called a *quadrangle*, or of more than one such area, and a text describing its topographic and geologic features. A quadrangle is limited by parallels and meridians, not by political boundary lines, such as those of States, counties, and townships. Each quadrangle is named from a town or a natural feature within it, and at the sides and corners of each map are printed the names of adjacent quadrangles.

SCALES OF THE MAPS.

On a map drawn to the scale of 1 inch to the mile a linear mile on the ground would be represented by a linear inch on the map, and each square mile of the ground would be represented by a square inch of the map. The scale may be expressed also by a fraction, of which the numerator represents a unit of linear measure on the map and the denominator the corresponding number of like units on the ground. Thus, as there are 63,360 inches in a mile, the scale 1 inch to the mile is expressed by the fraction $\frac{1}{63,360}$, or the ratio 1:63,360.

The three scales used on the standard maps of the Geological Survey are 1:62,500, 1:125,000, and 1:250,000, 1 inch on the map corresponding approximately to 1 mile, 2 miles, and 4 miles on the ground. On the scale of 1:62,500 a square inch of map surface represents about 1 square mile of earth surface; on the scale of 1:125,000, about 4 square miles; and on the scale of 1:250,000, about 16 square miles. In general a standard map on the scale of 1:250,000 represents a "square degree"—that is, an area measuring 1 degree of latitude by 1 degree of longitude; one on the scale of 1:125,000 represents one-fourth of a "square degree"; and one on the scale of 1:62,500 represents one-sixteenth of a "square degree." The areas of the corresponding quadrangles are about 4,000, 1,000, and 250 square miles, though they vary with the latitude, a "square degree" in the latitude of Boston, for example, being only 3,525 square miles and one in the latitude of Galveston being 4,150 square miles.

GENERAL FEATURES SHOWN ON THE MAPS.

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

Relief.—All altitudes are measured from mean sea level. The heights of many points have been accurately determined, and those of some are given on the map in figures. It is desirable, however, to show the altitude of all parts of the area mapped, the form of the surface, and the grade of all slopes. This is done by contour lines, printed in brown, each representing a certain height above sea level. A contour on the ground passes through points that have the same altitude. One who follows a contour will go neither uphill nor downhill but on a level. The manner in which contour lines express altitude, form, and slope is shown in figure 1.

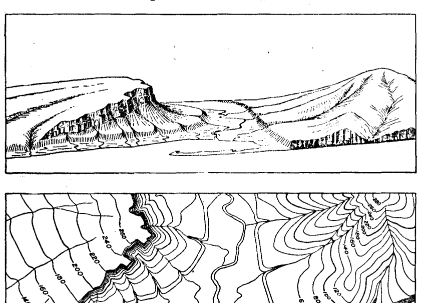


FIGURE 1.—Ideal view and corresponding contour map.

The view represents a river valley between two hills. In the foreground is the sea, with a bay that is partly inclosed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle upward slope; that on the left merges into a steep slope that passes upward to a cliff, or scarp, which contrasts with the gradual slope back from its crest. In the map each of these features is indicated, directly beneath its position in the view, by contour lines. The map does not include the distant part of the view.

As contours are continuous horizontal lines they wind smoothly about smooth surfaces, recede into ravines, and project around spurs or prominences. The relations of contour curves and angles to the form of the land can be seen from the map and sketch. The contour lines show not only the shape of the hills and valleys but their altitude, as well as the steepness or grade of all slopes.

The vertical distance represented by the space between two successive contour lines—the contour interval—is the same, whether the contours lie along a cliff or on a gentle slope; but to reach 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 slopes.

The contour interval is generally uniform throughout a single map. The relief of a flat or gently undulating country can be adequately represented only by the use of a small contour interval; that of a steep or mountainous country can generally be adequately represented on the same scale by the use of a larger interval. The smallest interval commonly used on the atlas sheets of the Geological Survey is 5 feet, which is used for regions like the Mississippi Delta and the Dismal Swamp. An interval of 1 foot has been used on some large-scale maps of very flat areas. On maps of more rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used, and on maps of great mountain masses like those in Colorado the interval may be 250 feet.

In figure 1 the contour interval is 20 feet, and the contour lines therefore represent contours at 20, 40, 60, and 80 feet, and so on, above mean sea level. Along the contour at 200 feet lie all points that are 200 feet above the sea—that is, this contour would be the shore line if the sea were to rise 200 feet; along the contour at 100 feet are all points that are 100 feet above the sea; and so on. In the space between any two contours are all points whose altitudes are above the lower and below the higher contour. Thus the contour at 40 feet falls just below the edge of the terrace, and that at 60 feet lies above the terrace; therefore all points on the terrace are shown to be more than 40 but less than 60 feet above the sea. In this illustration all the contour lines are numbered, but on most of the Geological Survey's maps all the contour lines are not numbered; only certain of them—say every fifth one, which is made slightly heavier—are numbered, for the heights shown by the others may be learned by counting up or down from these. More exact altitudes for many points are given in bulletins published by the Geological Survey.

Drainage.—Watercourses are indicated by blue lines. The line for a perennial stream is unbroken; that for an intermittent stream is dotted; and that for a stream which sinks and reappears is broken. Lakes and other bodies of water and the several types of marshy areas are also represented in blue.

Culture.—Symbols for the works of man, including public-land lines and other boundary lines, as well as all the lettering, are printed in black.

GEOLOGIC FEATURES SHOWN ON THE MAPS.

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

KINDS OF ROCKS.

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

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous.* Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or *magma*, within these channels—that is, below the surface—are called *intrusive.* An intrusive mass that occupies a nearly vertical fissure which has approximately parallel walls is called a *dike;* one that fills a large and irregular conduit is termed a *stock.* Molten material that traverses stratified rocks may be intruded along bedding planes, forming masses called *sills* or *sheets* if they are relatively thin and *laccoliths* if they are large lenticular bodies. Molten material that is inclosed by rock cools slowly, and its component minerals crystallize when they solidify, so that intrusive rocks are generally crystalline. Molten material that is poured out through channels that reach the surface is called *lava,* and lava may build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive.* Lavas generally cool more rapidly than intrusive rocks and contain, especially in their outer parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows are also usually made porous by the expansion of the gases in the magma. Explosions due to these gases may accompany volcanic eruptions, causing the ejection of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

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

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

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

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

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

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

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

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressure, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structural features may have been lost entirely and new ones substituted. A system of parallel planes along which the rock can be split most readily may have been developed. This acquired quality gives rise to *cleavage*, and the cleavage planes may cross the original bedding planes at any angle. Rocks characterized by cleavage are called *slates.* Crystals of mica or other minerals may have grown in a rock in parallel arrangement, causing lamination or foliation and producing what is known as *schistosity.* Rocks characterized by schistosity are called *schists.*

As a rule, the older rocks are most altered and the younger are least altered, but to this rule there are many exceptions, especially in regions of igneous activity and complex structure.

GEOLOGIC FORMATIONS.

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

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

AGE OF THE FORMATIONS.

Geologic time.—The larger divisions of geologic time are called *periods*. Smaller divisions are called *epochs*, and still smaller ones are called *stages*. The age of a rock is expressed by the name of the time division in which it was formed.

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

As sedimentary deposits accumulate successively the younger rest on the older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or their relations to adjacent beds have been changed by faulting, so that it may be difficult to determine their relative ages from their present positions at the surface.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them or were buried in surficial deposits on the land. Such rocks are said to be fossiliferous. A study of these fossils has shown that the forms of life at each period of the earth's history were to a great extent different from the forms at other periods. Only the simpler kinds of marine plants and animals lived 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 forms that 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. If two sedimentary formations are geographically so far apart that it is impossible to determine their relative positions the characteristic fossils found in them may determine which was deposited first. Fossils are also of value in determining the age of formations in the regions of intense disturbance mentioned above. The fossils found in the strata of different areas, provinces, and continents afford the most effective means of combining local histories into a general earth history.

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

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

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

Each symbol consists of two or more letters. The symbol for a formation whose age is known includes the system symbol, which is a capital letter or monogram; the symbols for other formations are composed of small letters.

The names of the geologic time divisions, arranged in order from youngest to oldest, and the color and symbol assigned to each system are given in the subjoined table.

Geologic time divisions and symbols and colors assigned to the rock systems.

Era.	Period or system.	Epoch or series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent; Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene; Miocene; Oligocene; Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		TR	Peacock-blue.
Paleozoic	Carboniferous	Permian; Pennsylvanian; Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		€	Brick-red.
Proterozoic	Algonkian		A	Brownish red.
	Archean		AR	Gray-brown.

DEVELOPMENT AND SIGNIFICANCE OF SURFACE FORMS.

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

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

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

THE GEOLOGIC MAPS AND SHEETS IN THE FOLIO.

Areal-geology map. — The map showing the surface areas occupied by the several formations is called an *areal-geology map*. On the margin is an explanation, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the explanation, where he will find the name and description of the formation. If he desires to find any particular formation he should examine the explanation and find its name, color, and pattern and then trace out the areas on the map corresponding in color and pattern. The explanation shows also parts of the geologic history. The names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and those within each group are placed in the order of age, the youngest at the top.

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

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

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

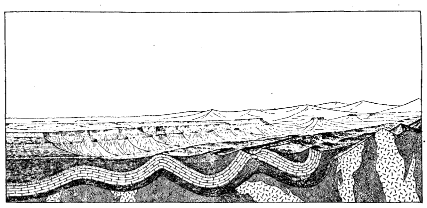


FIGURE 2.—Sketch showing a vertical section below the surface at the front and a view beyond.

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

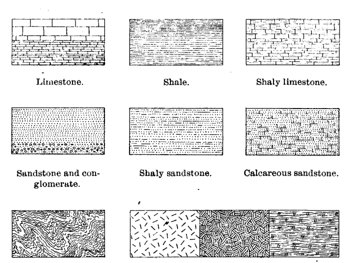


FIGURE 3.—Symbols used in sections to represent different kinds of rock.

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

Where the edges of the beds appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed, and by means of these observations their positions underground are inferred. The direction of the intersection of the surface of a dipping bed with a horizontal plane is called its *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called its *dip*.

In many regions the beds are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the materials that formed the sandstone, shale, and limestone were deposited beneath the sea in nearly flat layers the fact that the beds are now bent and folded shows that forces have from time to time caused the earth's crust to wrinkle along certain zones. In places the beds are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

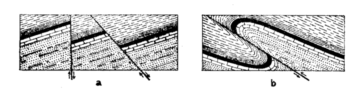


FIGURE 4.—Ideal sections of broken and bent strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted, and the form or arrangement of their masses underground can not be inferred. Hence that part of the section shows only what is probable, not what is known by observation.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of beds of sandstone and shale, which lie in a horizontal position. These beds were laid down under water but are now high above the sea, forming a plateau, and their change of altitude shows that this part of the earth's surface has been uplifted. The beds of this set are *conformable*—that is, they are parallel and show no break in sedimentation.

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

The horizontal beds of the plateau rest upon the upturned, eroded edges of the beds of the middle set, as shown at the left of the section. The beds of the upper set are evidently younger than those of the middle set, which must have been folded and eroded between the time of their deposition and that of the deposition of the upper beds. The upper beds are *unconformable* to the middle beds, and the surface of contact is an *unconformity*.

The lowest set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and intruded by masses of molten rock. The overlying beds of the middle set have not been traversed by these intrusive rocks nor have they been affected by the pressure of the intrusion. It is evident that considerable time elapsed between the formation of the schists and the beginning of the deposition of the beds of the middle set, and during this time the schists were metamorphosed, disturbed by the intrusion of igneous masses, and deeply eroded. The contact between the middle and lowest sets is another unconformity; it marks a period of erosion between two periods of deposition.

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

Columnar section.—Many folios include a *columnar section*, which contains brief descriptions of the sedimentary formations in the quadrangle. It shows the character of the rocks as well as the thickness of the formations and the order of their accumulation, the oldest at the bottom, the youngest at the top. It also indicates intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition.

THE TEXT OF THE FOLIO.

The text of the folio states briefly the relation of the area mapped to the general region in which it is situated; points out the salient natural features of the geography of the area and indicates their significance and their history; considers the cities, towns, roads, railroads, and other human features; describes the geology and the geologic history; and shows the character and the location of the valuable mineral deposits.

GEORGE OTIS SMITH,
Director.

January, 1922.

DESCRIPTION OF THE RATON, BRILLIANT, AND KOEHLER QUADRANGLES.

By Willis T. Lee.

INTRODUCTION.

POSITION AND EXTENT OF THE QUADRANGLES.

The Raton, Brilliant, and Koehler quadrangles lie east of the Rocky Mountains, immediately south of the Elmoro and Spanish Peaks quadrangles (see fig. 1), and constitute the central part of the coal-producing area known as the Raton Mesa region or the Raton section of the Great Plains province. They are chiefly in Colfax County, N. Mex., but include a narrow strip of Las Animas County, Colo.

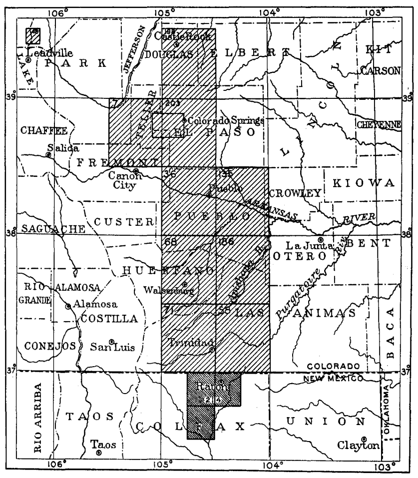


Figure 1.—Index map of south-central Colorado and north-central New Mexico.

The location of the Raton, Brilliant, and Koehler quadrangles (No. 214) is shown by the darker ruling. Published folios describing other quadrangles, indicated by lighter ruling, are the following: 7, Pikes Peak; 36, Pueblo; 48, Tenmile district; 58, Elmoro; 68, Walsenburg; 71, Spanish Peaks; 135, Nepesta; 186, Apishapa; 198, Castle Rock; 203, Colorado Springs.

The Raton and Brilliant quadrangles extend from 36° 45′ to 37° north latitude and from 104° 15′ to 104° 45′ west longitude. The Koehler quadrangle extends from 36° 30′ to 36° 45′ north latitude and from 104° 30′ to 104° 45′ west longitude. The three quadrangles include 717 square miles.

VEGETATION.

The lowlands of the Raton, Brilliant, and Koehler quadrangles sustain a thin growth of grass, many kinds of small flowering plants, several species of cactus (*Opuntia*), sagebrush (*Artemisia tridentata* Nuttall), and other small shrubs. Some parts of the lowlands that can be irrigated from storage reservoirs are cultivated, but most of them are used for grazing. A few cottonwoods and willows grow along the streams. Piñon or nut pine (*Pinus edulis* Engelmann) and juniper (*Juniperus monosperma* (Engelmann) Sargent, commonly known as cedar) grow in the highlands but are found also on some of the lower rocky slopes, their distribution being probably due to the character of the soil rather than to difference in altitude. Piñon and juniper grow mainly in rocky places, especially on sandstone and igneous rock, rarely on the marine shale (Pierre).

Few trees or shrubs grow on the tops of the mesas, which are covered mainly with grass and small flowering plants. Some of the mesas are used for grazing and others for raising crops. The precipitation is sufficient for farming without irrigation. The sides of the mesas are in some places covered with forests of spruce, pine (*Pinus brachyptera* Engelmann), aspen (*Populus aurea* Tidestrom), and other trees, but in most places the spruce and the pine have been cut for lumber. Piñon and juniper are numerous, and scrub oak (probably of several species), locust (*Robinia neomexicana* Gray), and other small trees form thickets. In still other places underbrush and sturdy herbaceous plants grow in dense thickets, which effectively conceal every trace of the underlying rocks. In nearly all places the slopes of the mesas above an altitude of about 7,000 feet are covered with underbrush, whose interlacing roots hold in place fragments of rock that would otherwise be washed away.

In the Brilliant and Koehler quadrangles the slopes of the mesas are not so completely covered with vegetation as their sides. Piñon, juniper, and scrub oak are numerous, and in a few places the pine and the spruce have escaped the lumberman's ax, but they have generally been removed. Little use is made of piñon except for firewood, but juniper and locust are cut for fence posts. Aspen is used for building corrals, for making "corduroy" roads, and for flooring bridges.

SETTLEMENT AND INDUSTRIES.

The main line of the Atchison, Topeka & Santa Fe Railway traverses the Raton and Koehler quadrangles from north to south. A branch from Dillon extends up Dillon Canyon to Gardiner and to Brilliant and another branch up Willow Creek to Van Houten. Another road, known as the St. Louis, Rocky Mountain & Pacific Railway but now a part of the Atchison, Topeka & Santa Fe System, extends from Raton southward to Clifton House, thence eastward beyond the quadrangle to Des Moines, N. Mex., where it connects with the Colorado & Southern, and from Clifton House southwestward through the Koehler quadrangle. A third railway, the Santa Fe, Raton & Eastern, is in operation between Raton, Sugarite, and Yankee and has been constructed from Carisbrook to Cunningham. A branch of the El Paso & Southwestern Railroad, which traverses the Koehler quadrangle, connects the coal-mining town of Dawson with the El Paso & Rock Island Railroad at Tucumcari.

Raton, which had a population of 5,544 in 1920, is the largest town in northern New Mexico. It is the county seat of Colfax County, a division point on the Atchison, Topeka & Santa Fe Railway, and the center of the mining industry in the northern part of the Raton coal field. Coal mining is the principal industry in this region. There are four coal-mining towns in the Raton quadrangle, two in the Brilliant quadrangle, and there is one in the Koehler quadrangle. Yankee, the easternmost mining town, stands picturesquely in the valley of the east fork of Chicorica Creek, almost surrounded by the high mesas. It was the headquarters of the New Mexico-Colorado Coal & Mining Co. until 1918, when the company suspended operations.

Sugarite (shu-gar-eat′), which stands between high mesas on the west fork of Chicorica Creek, had in 1920 a population of 471, consisting mainly of men employed in the Sugarite mine, one of the newer openings of the St. Louis, Rocky Mountain & Pacific Company. The name Sugarite is a corruption of the Spanish word Chicorica (pronounced che-co-re′ka), and the creek and canyon as well as the town are locally called Sugarite instead of Chicorica.

Blossburg, in Dillon Canyon west of Raton, is one of the oldest mining towns in New Mexico; it was established soon after the Atchison, Topeka & Santa Fe Railway reached Raton. In 1890 its population was 1,171, but in 1920 it was only 292. Gardiner, which had 985 inhabitants in 1900, had 373 in 1920. The coke ovens there insure a small permanent population, and the opening of the new Gardiner mine by the St. Louis, Rocky Mountain & Pacific Co. between Gardiner and Blossburg has caused an increase in the population of both towns. This company operates another mine in Dillon Canyon farther upstream, at Brilliant, a town which in 1920 had a population of 606, made up almost exclusively of men employed in mining.

Van Houten, another coal-mining town, one of the largest producers in the Raton coal field, stands near the openings of the Willow mine, on the south fork of Willow Creek, in the southeastern part of the Brilliant quadrangle. Its population in 1920 was 611.

Koehler, a town of 1,090 inhabitants in 1920, stands at the opening of the Koehler coal mine, in the Koehler quadrangle. Maxwell is the center of the irrigation district of this quadrangle.

Several names of places on the maps of these quadrangles indicate little more than temporary accommodations for the caretakers of the railroads. Among these places are Carisbrook, Cunningham, Preston, Clifton House, Otero, Dillon, and Colfax.

The Brilliant and Koehler quadrangles and the west half of the Raton quadrangle form part of the Maxwell land grant, which is owned by a company that has done little to settle and improve the land. The Brilliant quadrangle contains practically no roads except those near the mining towns and few houses outside the mining towns except small shacks that serve as stopping places for cowboys during the summer, while their cattle range in the highlands.

More improvements have been made in the eastern half of the Raton quadrangle, which is subdivided into small tracts on which farm produce is raised in many places where the rainfall is sufficient for growing crops or where storm waters can be stored for irrigation. Much of Johnson Mesa and some of Barilla Mesa is cultivated. Water is stored in several small reservoirs in the lowlands on or near the stream courses and used for watering stock and for irrigating small tracts of land. On the Meloche ranch a considerable tract of land is irrigated from a storage reservoir in Hunter Canyon, east of the Raton quadrangle. There are several small reservoirs on the west fork of Chicorica Creek, one of which supplies the city of Raton with water. Much of the lowland in the Koehler quadrangle is under cultivation. The several lakes shown on the map are storage reservoirs supplied mainly from Vermejo River. They furnish water for irrigating a large area of agricultural land near Maxwell.

GEOGRAPHY OF THE GREAT PLAINS PROVINCE.

The Raton, Brilliant, and Koehler quadrangles are in the southwestern part of the Raton division of the Great Plains province. The surface of the part of this division of the Great Plains that lies in northeastern New Mexico and southern Colorado stands about a mile above sea level. This division, which embraces also the Mesa de Maya, farther northeast, includes many mesas or table-lands which have gently undulating surfaces that rise to altitudes ranging from a few hundred to more than 2,000 feet above the general level of the plain. Between this group of mesas and the mountains proper there are highlands that stand at a general level of 2,000 feet or more above the Great Plains. For nearly 150 miles along the Rocky Mountain front in northern New Mexico and southern Colorado these highlands form a transitional zone between the typical Great Plains and the mountains. The southern part of this transitional zone is known as the Ocate Mesa, but the main part embraces the Trinidad and Raton coal fields of the Raton Mesa region.

Most of the Great Plains province slopes eastward from the region near the foot of the Rocky Mountains at the rate of about 10 feet to the mile, from altitudes ranging from 6,000 to 7,000 feet, but in the part of that province that lies in the Raton Mesa region the altitudes range from 6,000 to more than 10,000 feet. Large parts of the surface of the Great Plains are smooth and gently undulating; others are characterized by low mesas and shallow canyons; and still others by high mesas, rugged hills, and deep canyons. The highland area that includes the Raton and Brilliant quadrangles and that was formerly called the Raton Mountains is probably the most rugged part of the Great Plains province.

The Great Plains are drained by rivers that rise in the Rocky Mountains and flow to the Mississippi. The highlands of the Raton Mesa region lie between two of these rivers, the Arkansas and the Canadian, and are drained northeastward into the Arkansas, mainly through the Purgatoire, which cuts a long, deep canyon into the plains before reaching the main stream; eastward through the Dry Cimarron; and southward into the Canadian, which has cut a conspicuous gorge in the plateau. The Purgatoire receives a small part of the drainage from the Brilliant quadrangle through Long Canyon and from the Raton quadrangle through San Isidro Canyon. The Canadian rises in the highlands of the Raton Mesa region west of the Brilliant quadrangle and receives most of the meager drainage from the Brilliant and Raton quadrangles. Some of the tributaries of this river head in the high mountains to the west and carry larger volumes of water than the trunk stream. Two of these tributaries, Crow Creek and Vermejo River, flow through the Koehler quadrangle.

Though the Great Plains are in general drained by streams that flow eastward the Canadian forms an exception to this rule. From the vicinity of Raton it flows in a southerly direction for nearly 100 miles and drains, through tributaries that flow westward, a considerable area of the plain that lies east of it. The direction of the drainage is controlled in part by the Mesa de Maya dome. (See p. 3.)

GEOLOGY OF THE GREAT PLAINS AND THE ROCKY MOUNTAINS.

The rocks of the Great Plains are chiefly sedimentary. Some of them have been formed from sediments deposited in the water of a sea that invaded the interior of the continent from time to time; others consist of material deposited in fresh-water lakes or on the flood plains of rivers. Some originated as swamp deposits that contained a large proportion

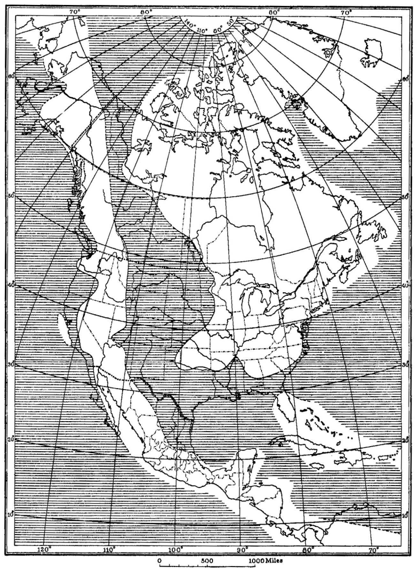


FIGURE 2.—Map of North America showing the parts of the continent that were probably submerged during the early (Benton) part of Upper Cretaceous time.

The shaded part of the map represents the area that is believed to have been covered by the sea in Benton time. (After Charles Schuchert.)

of peat, which later was changed to coal; others consist of coarse sand, arkose, conglomerate, and other material that accumulated above sea level. The stratified rocks lie nearly horizontal beneath the plains but are sharply upturned along the mountains to the west. Some large areas are occupied by rocks of Tertiary age, others by rocks of Cretaceous age, and small tracts by Jurassic, Triassic, and older sedimentary rocks. Beneath these rocks, and not generally exposed at the surface of the Great Plains, lie representatives of some of the Paleozoic systems, and the whole sedimentary series rests on a foundation of granitic rocks of Archean age.

The Rocky Mountains have been formed chiefly by relative uplift, and the mountain mass has undergone extensive erosion, which has exposed broad areas of the Archean rocks. Along the eastern base of the mountains the strata of the plains, which once extended over some or all of the present mountainous area, now are steeply inclined. Their eroded edges form narrow zones of outcrop, and collectively they make up a belt of ridges and valleys that parallels the mountains and that is commonly called the hogback region. This belt of hogbacks and strike valleys separates the ancient and much-disturbed rocks of the mountains from the nearly level strata of the plains.

At a few places along the mountain front in Colorado there are small remnants of red sandstone of Cambrian age, which are overlain by beds of Ordovician limestone and sandstone. There appear to be no Silurian or Devonian beds in this part of the Rocky Mountains, but such beds may lie beneath some parts of the Great Plains and have been overlain by younger beds along the shores of the ancient sea in which they were deposited. Carboniferous and Triassic strata, chiefly red, which differ greatly in thickness from place to place, rest on the older sedimentary rocks where these are exposed and overlap them at most other places along the mountain front. In central and northern Colorado these beds are relatively thin, but in southern Colorado, where they are upturned to a nearly vertical position, they attain a thickness of about 18,000 feet as measured across their eroded edges, and in northern New Mexico they seem to be still thicker.

Marine strata of Jurassic age occur farther north along the mountain front and also farther south, in western Texas, but their marine character in central Colorado and New Mexico has not been demonstrated. At most places along the mountain front a thin but remarkably persistent formation — the Morrison—overlaps all the older strata. On this formation lie, in apparent conformity, sedimentary beds of Cretaceous age. The older beds are steeply inclined, vertical, or even overturned, as are also the Cretaceous beds in some places, but in general the Cretaceous beds are so far from the mountainous area that they are but little disturbed. Where the Cretaceous rocks are upturned along the mountain front the resistant sandstones near the base of the system produce a line of hogback ridges that have smooth dip slopes on the east and rough, precipitous slopes on the west.

The widespread occurrence of sedimentary formations of Cretaceous age in Colorado and New Mexico is probably due to a downwarping of an eroded surface (a peneplain), the downwarping having probably been accompanied by a rise of the sea level that caused the sea to submerge the central part of North America. (See fig. 2.) The mountains that had existed in central Colorado and New Mexico during late Paleozoic and early Mesozoic time had been worn down to low relief before the beginning of the Cretaceous period. During the later part of the Lower Cretaceous epoch this peneplain subsided relative to sea level sufficiently to allow the sea to invade a part of the continent. At the beginning of the Upper Cretaceous epoch the leveling had proceeded so far that

FIGURE 3.—Relief map of central Colorado and north-central New Mexico.

The Raton, Brilliant, and Koehler quadrangles are in the southeastern part of the area, south of Trinidad, in the vicinity of Raton, N. Mex. Their location is shown in fig. 1. Scale: 1 inch=40 miles, approximately. Grand River is now called Colorado River.

the sea completely submerged the interior of the continent, including the area now occupied by the Rocky Mountains of Colorado and New Mexico.[1]

Along the shore of the invading sea and doubtless also in shallow backwater lakes and along streams that flowed into the encroaching sea there was deposited the sand of the basal formation of the Upper Cretaceous series—the Dakota sandstone, or, to be more exact, the several sandstones loosely grouped as Dakota. This sand was afterward covered by clayey and limy muds that accumulated in the Cretaceous sea. Parts of the continent both east and west of the subsiding interior did not sink beneath sea level. The land east of this interior sea seems to have furnished little sediment, but apparently the land west of it was relatively high and may even have been rising as the interior of the continent sank, for the sedimentary rocks of Cretaceous age increase in volume and coarseness westward. From this western land large volumes of rock débris were washed into the sea.

During certain stages of the Upper Cretaceous epoch the shore was built far out into the sea, and broad coastal swamps, in which extensive bodies of peat accumulated, were formed on the newly made land. These accumulations of peat were later covered with marine sediments. This process was repeated several times at one place or another throughout the Upper Cretaceous epoch. For this reason coal-bearing rocks of fresh-water and brackish-water origin are found at several horizons within the Cretaceous system near the border of the western continental land mass, though the rocks of this system in the central and eastern parts of the area occupied by this sea are marine. Not until late in the Upper Cretaceous epoch did the interior basin become filled to such an extent that swamps were formed in eastern Colorado and New Mexico. The material that accumulated in these swamps is now represented in the Raton, Brilliant, and Koehler quadrangles by the coal-bearing rocks of the Vermejo formation and in the Denver Basin by the Laramie formation.

The quiescence under which the Cretaceous beds were formed was followed by a series of movements which were probably a part of a widespread uplift and disturbance that is

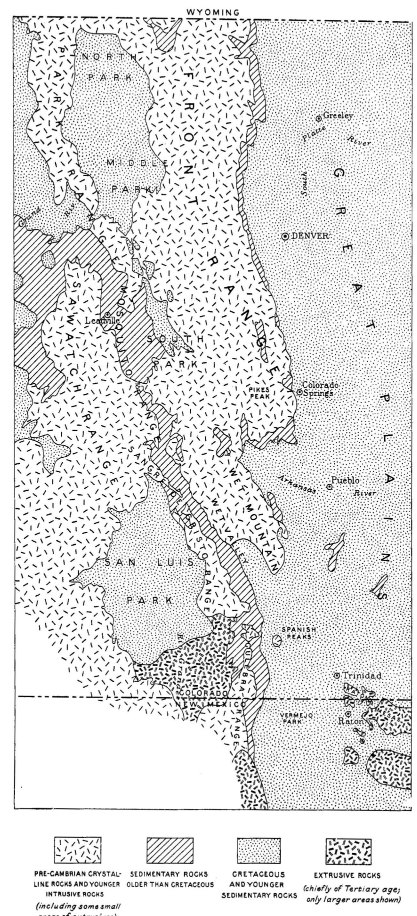


FIGURE 4.—Sketch geologic map of central Colorado and north-central New Mexico, showing the general geology of the area represented in figure 3.

From geologic map of North America by Willis and Stose, published in U. S. Geol. Survey Prof. Paper 71, 1911. Scale: 1 inch=40 miles, approximately.

recognized generally as marking the end of the Cretaceous period. By this uplift the sea was at length expelled from the interior of North America and the Rocky Mountains were formed. The movements were at first probably gentle, but they continued with increasing vigor. The ancient mountains of early Mesozoic time, whose roots had been buried under the Cretaceous sedimentary beds, were again uplifted. The first uplift of the new movement probably did not form notably high mountains, but it was sufficient to raise such Cretaceous beds as may have been deposited over the uplifted area to altitudes that permitted them to be eroded away and to expose also the rocks of pre-Cretaceous age to like erosion. These movements, which involved a differential uplift of several thousand feet, were accompanied by outflows of molten rock, the first of the great lava flows of Tertiary time in western America.

The sedimentary record of the Tertiary period opens with the deposition of conglomeratic, arkosic, and igneous material, washed down from the newly elevated lands. At some places the early sedimentary rocks are prevailingly coarse; at others the coarse material alternates with shale and beds of coal. At

[1] The evidence on which this statement and some of the following statements are based is summarized in the following papers: Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27–58, 1915; Reasons for regarding the Morrison an introductory Cretaceous formation: Geol. Soc. America Bull., vol. 26, pp. 303–314, 1915. Lee, W. T., and Knowlton, F. H., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, 450 pp., 118 pls., 1918.

some places in Colorado and New Mexico younger Tertiary beds were formed, but at most places these beds were removed by erosion, which carried away large masses of the older rocks. Near the end of the Tertiary period the Cretaceous and Tertiary rocks in the Raton Mesa region were eroded to a plain that sloped gently eastward. Over this graded plain (see fig. 5) streams in Quaternary time flowed eastward from the mountains. In some places they deposited beds of sand, gravel, and waterworn boulders, which were later covered with basalt. From time to time thereafter, as the streams continued to cut down the parts of the surface that were not protected by the sheets of lava, molten rock flowed out and occupied the eroded parts. These lowest places, thus protected by the hard rock that was formed from the cooled lava, were in time left in the form of table-lands as the unprotected parts of the plain were still farther worn away by erosion. Thus were formed the lava-capped mesas, some high and some low, that form the Raton Mesa region.

The Rocky Mountain uplift is not simple but compound. Some of the major and many of the minor folds overlap along the eastern mountain front, so that the belt of sharply upturned strata near the mountains does not extend directly from north to south but exhibits a number of salient and reentrant angles, the reentrants pointing northwestward into the mountains and the salients southeastward into the plains. Just north of Arkansas River the south end of the Front Range thus projects into the plains, and just south of the river the end of the Wet Mountain Range marks a similar projection. (See fig. 3.) This succession of reentrants and salients is a result of the general type of structure of the southern Rocky Mountains. To the casual observer the mountain system may seem to consist of ranges that extend from north to south, but on closer inspection it is seen to be made up of a series of ranges that extend from northwest to southeast diagonally across the

extruded mainly from craters. Over the youngest of these craters now stand typical volcanic cones made up of scoriaceous lava, cinders, and ash. The oldest flows originally extended from Raton, N. Mex., eastward into Oklahoma and are now represented by Raton Mesa, Barilla Mesa, Johnson Mesa, Mesa de Maya, and many less conspicuous lava-capped table-lands; the next younger flows are represented by Bartlett Mesa, Horse Mesa, and Horseshoe Mesa; and the youngest flows by Black Mesa, Round Mesa, and scores of similar table-lands south and east of the Raton quadrangle. The youngest volcanoes are represented by inconspicuous cones, such as that in the center of Round Mesa, and by the more imposing cones farther east, of which Mount Capulin is the most conspicuous. The oldest volcanoes are represented by Sierra Grande, which is near Des Moines, N. Mex., and those of intermediate age by a number of cones near Folsom. Two cones of intermediate age are found in the Raton quadrangle, one south of Yankee and the other on Bartlett Mesa.

TOPOGRAPHY.

SHAPE OF THE SURFACE.

GENERAL FEATURES.

The Raton, Brilliant, and Koehler quadrangles are mainly in the highlands of the Raton Mesa region, which constitutes a transitional zone between the Great Plains proper and the Rocky Mountains. All the topographic features in these quadrangles except the tops of the mesas are the products of erosion. The forms thus produced have been influenced by the nature of the rocks, for soft rocks are eroded faster than hard ones. The largest body of soft rock—the Pierre shale—now occupies the lowlands, and the harder rocks form cliffs, escarpments, and mesas. The topographic features fall into three general groups—the mesas, the dissected highlands, and

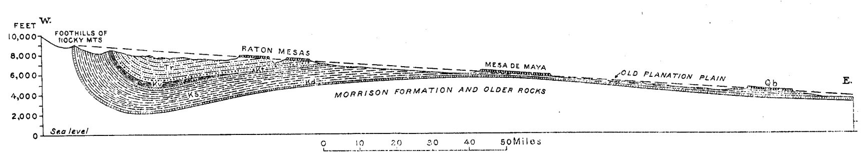


FIGURE 5.—Section from the foothills of the Rocky Mountains eastward along the Colorado-New Mexico line to the Kansas line.

Shows the eroded edges of the Cretaceous and Tertiary rocks covered by early Quaternary lavas, which have since been partly eroded into lava-capped mesas Kd, Dakota sandstone; Ks, Cretaceous shale; Kt, Trinidad sandstone; Kv, Vermejo formation; Tr, Raton formation resting unconformably on the Cretaceous; Qb, basalt.

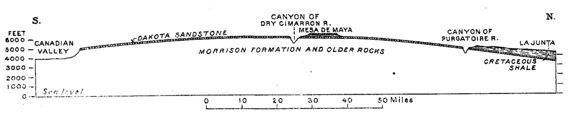


FIGURE 6.—Section across the Mesa de Maya dome from Canadian Valley on the south to La Junta, Colo., on the north.

Shows the doming of the Cretaceous rocks. Mesa de Maya is capped by Tertiary lava.

trend of the main mountain system. (See fig. 3.) This fact becomes still more evident when the distribution of the stratified rocks is considered. The strata preserved as remnants in the troughs of the folds indicate the trend of the axes of the ranges. (See fig. 4.) The Rocky Mountains probably did not rise equally in all places. The scarcity of Tertiary beds to the south and their relative abundance to the north suggest that the southern ranges are older than the northern ranges and that the rock waste from the older mountains was transported mainly in a northeasterly direction.

The general evenness of the strata of the plains is interrupted here and there by broad undulations, some of which are associated with the mountain folds. A broad, shallow synclinal trough lies east of Culebra Range, essentially parallel with it. In this trough are preserved the coal-bearing rocks of the Raton Mesa region. Those of the Raton, Brilliant, and Koehler quadrangles slope gently westward toward the center of this trough. Farther east these and the older strata are arched into a broad dome, whose crest lies in the vicinity of Mesa de Maya, near the boundary between Colorado and New Mexico. At many places on the eastern and southern slopes of this dome the younger rocks have been removed down to the Dakota sandstone, and the underlying red beds of Triassic age are exposed in the canyons. (See figs. 5 and 6.) The older Cretaceous strata in western Kansas and Oklahoma, east of this broad, gently arching dome, descend beneath the surface and toward the north pass beneath the broad depression occupied by the marine Cretaceous beds of the Arkansas Valley. Toward the west they form the synclinal trough occupied by the coal-bearing rocks. The southern surface slope of the dome is developed chiefly on Dakota sandstone, the younger rocks of Cretaceous age having been eroded away.

From the central parts of this great dome large quantities of molten rock were extruded. The older lavas were extruded from fissures and from volcanic vents now filled by dikes, plugs, and necks of igneous rock. The younger lavas were

the lowlands. The mesas and plains are the most conspicuous topographic features in the Raton quadrangle, the intermediate highlands occupy most of the Brilliant quadrangle, and both highlands and lowlands are represented in the Koehler quadrangle.

MESAS.

General features.—The highest mesas are remnants of a once continuous plain that sloped a little south of east away from the mountains. From Raton Mesa, which lies in Colorado north of the Raton quadrangle and which has a maximum altitude of 9,586 feet, this ancient plain descended to a height of about 8,000 feet within the Raton quadrangle and to still lower altitudes farther east and south. There is a second group of mesas, the remnants of a later plain of erosion, which lies 200 to 400 feet below the top of those of the highest group. These lower mesas have been discriminated from the higher mesas only in the Raton quadrangle, but beyond the limits of this quadrangle there are mesas that differ in altitude and that probably represent two or more plains of degradation. Part of a third group of mesas, which rise but little above the general level of the lowlands, is found in the southern half of the Raton quadrangle, but many others may be seen in the area farther south and east, where also there are mesas that stand at altitudes between those of the second and third groups. All these mesas owe their existence to protecting sheets of the hard igneous rock which cover them and which originated as flows of lava. This lava was poured out upon the surface from vents now marked by volcanic cones that rise above the general surface of the table-lands. The lava spread out in relatively thin sheets and on cooling solidified into very resistant rock, which has protected the underlying, relatively soft sedimentary rocks from erosion. In places where they were not thus protected the softer rocks were worn down, but the protected surfaces were only slightly affected by erosion and now form the mesas.

Barilla Mesa.—A part of the highest plain is preserved in the northeastern part of the Raton quadrangle on Barilla Mesa and on a small outlier northeast of Bartlett Mesa. Barilla Mesa has an irregular outline, due to the erosion of its cap rock during the long time that has elapsed since the lava was poured out. The greater part of the original lava flow has been eroded away, the areas around the mesa have been degraded, and broad valleys have been cut into the softer underlying rocks. These valleys occupy the broad reentrants, which extend well in toward the center of the mesa and which are separated by long, flat-topped lobes.

The surface of the mesa is relatively flat but is rough and shows evidence of exposure for a long time, during which the softer scoriaceous material which doubtless covered the surface at one time has been removed, so that the harder, less scoriaceous parts now occupy the surface. In some places there are low hills, which seem to mark places from which the molten rock flowed. One such hill north of Yankee that stands at an altitude of 8,728 feet rises about 250 feet above the general level of the mesa. It is roughly conical in form and consists of rock which is more scoriaceous than that surrounding it. Another conical hill near the eastern end of the mesa is nearly as high.

In some places there are surface depressions which contain standing water except in the dryest times. They are not products of erosion, and very little of the surrounding surface drains into them. Some of them may be formed by the union of two or more flows of lava about a space unoccupied by lava, but probably most of them are due to the collapse of the lava crust after the still liquid lava had flowed out from beneath it.

The rim of the mesa consists of an almost continuous escarpment, 50 to 200 feet or more in height. Its precipitous faces are formed of hard basaltic rock that cleaves so as to form vertical columns, which finally fall away. In some places where the cap rock consists of two or more flows of lava the rim is terraced, each flow forming a separate bench terminated by a cliff. (See Pl. IV.)

Bartlett Mesa.—Bartlett Mesa, a table-land in the northern part of the Raton quadrangle, west of Barilla Mesa, stands about 2,000 feet above the general level of the plain. Its relatively smooth surface, which is terminated on all sides by an escarpment, represents the second plain of degradation, which stood 200 to 400 feet below the highest plain. (See Pl. V.) The surface of Bartlett Mesa, which represents the younger plain, is more regular than that of Barilla Mesa, which represents the older plain, even though the rock at the surface of the younger plain is more scoriaceous and therefore more easily eroded. Apparently the lava that forms this cap spread from a single vent. There is only one elevation on this mesa that marks clearly the location of a volcanic vent. This elevation stands near the north rim of the mesa and rises about 250 feet above its general level. It is conical in form and has a shallow saucer-shaped depression in its top. From this crater cone the surface slopes away in all directions.

Bartlett Mesa is younger than Barilla and has been much less affected by erosion; hence its outline is more regular and its surface is more even. It contains several sinks or wet-weather lakes similar to those on Barilla Mesa, and these are most numerous where the individual lava flows seem to be thickest. At many places on the rim the cap rock consists of basalt of a single flow and is more conspicuously columnar than in places where the rim rock consists of more than one flow. In these places also the cliffs at the rim of the mesa are more precipitous than elsewhere.

Horse Mesa.—Horse Mesa is a shelf at the southwestern extremity of Barilla Mesa. Its surface is 100 to 350 feet lower than that of the contiguous parts of the higher mesa, and the line of separation between the two mesas is marked by scarps. (See Pl. V.) Horse Mesa has the same altitude as Bartlett Mesa and probably formed a part of it before Sugarite Canyon, which separates them, was excavated.

Horseshoe Mesa.—Horseshoe Mesa is a shelf at the eastern extremity of Barilla Mesa similar to the one formed by Horse Mesa at the southwestern extremity and stands at practically the same altitude. In its relative smoothness its surface contrasts sharply with that of the higher mesa. (See Pl. VI.) The line of separation between the two mesas is marked by scarps, and a line of weakness is indicated at their junction by erosional reentrants on both sides of the mesa. The surface of Horseshoe Mesa slopes gradually away from the older mesa, on which stands a broad, low cone that probably covers the vent from which the lava of Horseshoe Mesa was extruded. This lava seems to have flowed down over the rim of the older mesa to the plain, a part of whose surface has been preserved by the lava. (See fig. 7.)

Johnson Mesa.—Johnson Mesa, in the eastern part of the Raton quadrangle (see Pl. II), rises about 2,000 feet above the general level of the plain. Like the mesas farther north, it owes its formation to a covering of hard igneous rock, but it differs in several ways from the other mesas. Some parts of it, especially those near the western end, represent the highest plain of degradation and correspond in altitude to Barilla Mesa. Others, such as the part north of Towndrow Peak, lie at the level of the second plain and correspond in altitude and in character to Horseshoe Mesa, with which it was once probably continuous, as shown in figure 7. The shape of the surface varies considerably from place to place. The southwestern part is rough, probably in some places owing to the long erosion of an old sheet of lava and in other places owing to the presence of younger lavas poured out upon the older one. The surface of the northern part of the area of the mesa that is included in the Raton quadrangle is about 500 feet lower than the west end of the mesa and is relatively smooth, like the surfaces of the other lava sheets that lie at this altitude.

There are several minor hills on Johnson Mesa, which may mark the volcanic vents from which the basalt was extruded. One of these hills, in the center of the mesa west of Towndrow Peak, has an altitude of 8,406 feet and is composed of dark-red scoriaceous basalt like that which elsewhere in northern New Mexico is found near volcanic craters. Another conical hill, which may mark the older opening, as it is composed of hard and less scoriaceous rock, stands south of Towndrow Peak. A well-defined volcanic cone of recent origin rises several hundred feet above the general level of the mesa a short distance east of the Raton quadrangle. This cone is composed of scoriaceous basalt, cinders, and ash and has a well-defined depression in its side, which marks the opening through which the lava was poured out.

The most conspicuous elevation on this mesa is Towndrow Peak, a conical mass of igneous rock of different origin from the basalt, which rises about 500 feet above the general level. (See Pl. VII and fig. 8.) Two miles west of Towndrow Peak stands a broad, low hill that is oval in form and that has a relatively smooth surface. It consists principally of sand, gravel, and large waterworn boulders. A small area at the top is occupied by a thin sheet of basalt.

Some depressions in the surface of Johnson Mesa are occupied by "wet-weather lakes," but these are not so numerous as the similar depressions on the other mesas in the Raton quadrangle. The largest one lies south of Towndrow Peak (shown in the foreground in Pl. VII) and is nearly filled with sand, clay, and volcanic ash. Where it has been penetrated by wells this material attains a thickness of at least 37 feet.

The rim of the mesa is a precipitous and almost continuous escarpment. In some places the weathered edges of the columnar basalt sheets, 100 to 400 feet or more in thickness, form a single cliff. In others the escarpment is made up of terraces or shelves, each shelf representing a single flow of lava. Here and there the older basalt seems to have been deeply eroded before the later flows were poured out upon it. These later flows occupy erosional depressions, and in places they seem to have flowed down the valleys in the channels of the streams. Cross sections of these old lava-filled valleys are exposed in the southern rim of Johnson Mesa (see Pl. VIII), where a flow about 300 feet wide and 150 feet deep occupies an old valley and is separated from the lava in which the valley was eroded by blocks of basalt, the largest of which are 5 feet or more in diameter. The molten lava of this flow seems to have cooled from all sides alike, producing columns which radiate outward from the middle of the flow.

Hunter Mesa.—Hunter Mesa forms a long tongue extending southeastward from the main part of Johnson Mesa. It has a maximum altitude of 8,316 feet above sea level, and from this highest point it slopes steeply toward the southeast and less steeply toward the north. The surface in its northern part is about 250 feet lower than the adjacent parts of Johnson Mesa. In this respect it holds the same relation to Johnson Mesa that Horse Mesa holds to Barilla Mesa—that is, the lava of its cap rock is younger than that of Johnson Mesa and was poured out upon a surface from which the older lavas and 200 to 300 feet of the underlying sedimentary rocks had been eroded away. The lava sheets have a maximum thickness of 400 feet or more and are terminated on the west by nearly vertical cliffs. The east face is not so precipitous.

Meloche Mesa.—Meloche Mesa was probably once the southward extension of Hunter Mesa, although their igneous cap rocks are not now connected. Meloche Mesa attains its maximum altitude at its southern point, from which it slopes evenly northward. At this southernmost point the igneous rock that occupied the surface extends downward as a stocklike mass in the exposed face of the mesa, forming a cliff about 800 feet high. The smooth surface formed on the sheets of the igneous rock that cap the mesa is interrupted to the north by a small area that has a roughly uneven surface of craggy scoriaceous lava of recent origin. A low hill at the north end of the mesa is composed of this craggy material and probably marks the volcanic opening through which the lava was extruded. From this hill the surface descends by a steep but even slope, formed on the surface of a lava flow, to a lower lava-covered mesa that lies east of the Raton quadrangle.

Yankee "Volcano."—In the valley north of Johnson Mesa there are remnants of a low shelf, which have been preserved by their caps of hard basalt. The surface on which this lava was poured out stands about 7,400 feet above sea level, or 1,000 feet lower than that on which the lavas of Johnson Mesa were poured out. The basalt sheet on the principal remnant of this shelf is surmounted by a conical hill composed of scoriaceous cinders and flow lava. There is a well-defined depression in its western side, where the crater rim was broken away. (See fig. 8.) The surface of the flow west of the crater is smooth. This flow once extended for a considerable distance down the valley, and remnants of it now appear on two isolated mesas southwest of the cone.

The simple structure of the mesas in the northern part of the Raton quadrangle presents a marked contrast to the complex structure of Johnson Mesa. The surface on which the igneous rocks of the western part of the mesa rest forms a part of the highest plain of degradation in this region, and the lavas that were poured out upon it were probably once continuous with those that cap Barilla Mesa. The second plain of degradation, whose level is represented by the tops of Bartlett, Horse, and Horseshoe mesas, embraced parts of the area now occupied by Johnson Mesa. Probably about the time that the lavas of Bartlett, Horse, and Horseshoe mesas were poured out volcanic openings were made also on Johnson Mesa. Some of the lava from these openings flowed northward across the site of Rathbun Canyon and connected with the lava of Horseshoe Mesa. Other flows covered the older sheets and filled valleys that had been eroded in them. On top of these younger lavas were deposited beds of sand, gravel, and waterworn boulders, remnants of which are now found in the region east of Manco Burro Pass and west of Towndrow Peak.

Erosion later cut away some of the igneous rock and degraded the areas occupied by the softer sedimentary rocks. Into one of the depressions formed by erosion was poured the lava of Hunter and Meloche mesas. Probably at about the same time the similar lava of Towndrow Peak was extruded. As degradation of the softer rocks proceeded, this lava-filled depression, as well as the broader mesas, was left undisturbed because of the protection afforded by the hard igneous rock. When the valley of the east branch of Sugarite Creek had reached a depth of about 1,000 feet below the top of Johnson Mesa there was a fourth period of volcanic eruption, at which time Yankee "Volcano" was formed, and from it was extruded the basalt that flowed down the valley. Probably about the same time the vent north of Meloche Mesa was opened, and also the vents of Black and Round mesas, the lava sheets of which, however, may be somewhat younger.

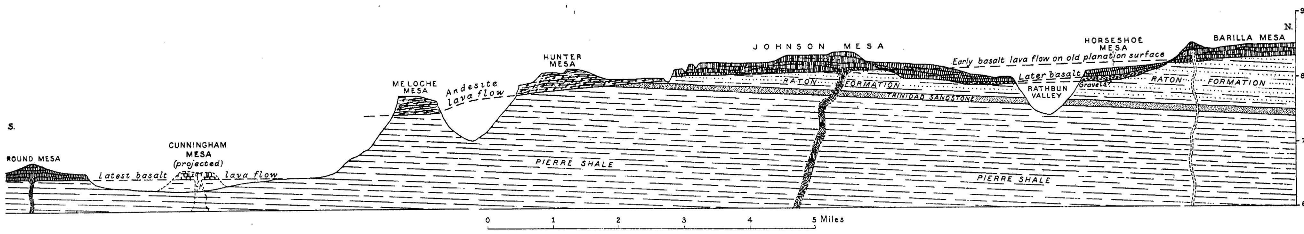


FIGURE 7.—Section from Round Mesa to Barilla Mesa in the Raton quadrangle, showing the relations of the different lava flows.

The early basalt lava flow, which formerly extended from Barilla Mesa to Johnson Mesa, was cut through by a valley that has been in part filled with later basalt, and this in turn has since been cut through by Rathbun Creek. The eruption of this lava was followed by flows of andesitic lava, which caps Hunter and Meloche mesas, and by flows of the latest basalt, which caps Round and Cunningham mesas.

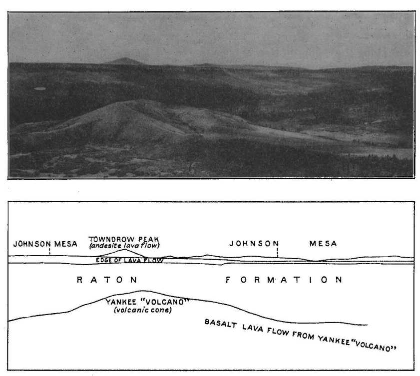


FIGURE 8.—Lava-capped Johnson Mesa and Towndrow volcanic peak in the distance; Yankee "Volcano" and later basalt flow in the foreground.

Black Mesa.—Several isolated mesas rise 300 to 500 feet above the general level of the plain in the south-central part of the Raton quadrangle. The largest of the group is Black Mesa, so called because of its dark basaltic rock. This rock probably once extended over the group of mesas as a continuous sheet, but most of it has since been eroded away. The tops of Black Mesa and of the mesas farther east, near Cunningham Butte, are flat because those parts of this sheet are undisturbed. The steep slopes surrounding these mesas are covered with large blocks of basalt that have fallen from the cap rock. The small mesa east of Black Mesa differs from the others in being rounded rather than flat-topped. The basalt, which once covered it in a solid sheet, is now broken into blocks that cover the whole surface of this mesa as the similar blocks cover the sloping sides of the others.

In the midst of this group of basalt-covered mesas stands a hill of very different shape, called Cunningham Butte. The principal mass is subcircular in outline, like that of Towndrow Peak, and consists of the same kind of rock. It has a prominent northwest elongation caused by a dike of the same rock, from which the softer shale on both sides has been eroded away.

Round Mesa. — Another basalt-covered mesa known as Round Mesa stands partly in the Raton quadrangle and partly in the region to the south. It is 200 to 300 feet above the general level of the plain, but unlike some of the other lava-capped mesas its surface rises from the bordering rim by a slight but constant incline toward the center, where a low cone of scoriaceous and ropy lava marks the location of a vent from which the lava was extruded. (See fig. 9.)

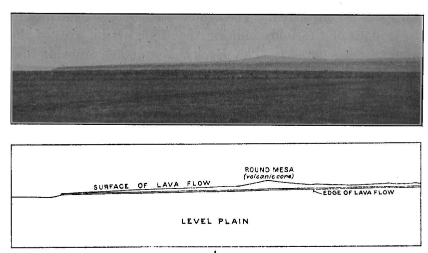


FIGURE 9.—Lava-capped Round Mesa and associated volcanic cone.

DISSECTED HIGHLANDS.

The Raton Mesa region consists mainly of a dissected plateau whose surface ranges in altitude from that of the lowland plains to that of the highest mesas, or from about 6,500 to 9,000 feet or more above sea level. This plateau has been developed upon rocks that are more resistant than the soft rocks of the lowland plains but less resistant than the igneous rocks which cap the mesas. At one time the surface of this plateau was continuous with that represented by the tops of the highest mesas. (See fig. 5.) The erosion which reduced the plains to their present form did not reduce the plateau so much in the same time because its surface is formed of harder rocks.

In the mesa region of the northern part of the Raton quadrangle, where the ancient surface has been protected by sheets of igneous rock, the slopes are steep and relatively regular in outline, but in the Brilliant quadrangle and in the northwestern part of the Koehler quadrangle, where erosion has not been influenced by these sheets, the streams have dissected the plateau into an intricate network of ridges and sharp, V-shaped valleys. (See fig. 10.)

The rocks of the highlands consist of alternating beds of hard and soft strata. At the base of these beds is the soft, easily eroded shale that occupies the lowlands. Above this shale lies a resistant sandstone, which is overlain in some places by shale and coal and in others by conglomerate. Where the sandstone and conglomerate crop out together they generally form a single bench. (See Pl. III.) Upon the conglomerate lies a bed of soft rock, mainly shale, about 100 feet thick, which erodes easily and forms smooth slopes. Still higher

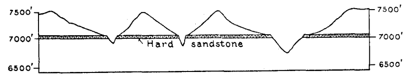


FIGURE 10.—Profile typical of the dissected plateau in the Brilliant quadrangle

Shows canyons separated by sharp-crested ridges of sandstone and shale with a medial bench where horizontal layers of hard sandstone crop out. The sandstone is the Trinidad, and below it is Pierre shale.

there are several beds of massive sandstone separated by thin layers of shale, the whole ranging in thickness from 300 to 600 feet. The sandstones are hard and resist erosion so well that they generally form cliffs where they crop out, making a nearly continuous escarpment that is one of the most prominent features of the Raton Mesa region. (See Pls. I and III.) Most of the rocks above these cliff-forming sandstones are soft and form relatively smooth slopes. A typical profile in the dissected highlands is shown in figure 11.

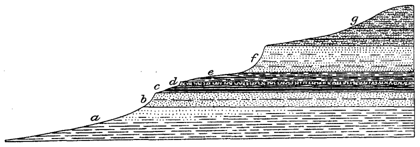


FIGURE 11.—Diagrammatic profile illustrating the principal elements of the topographic features of the dissected highlands of the Raton Mesa region.

a, Smooth, gentle slope of Pierre shale. *b*, Prominent cliff formed by the edge of the Trinidad sandstone. *c*, Slope formed of the Vermejo formation. *d*, Small cliff formed by the edge of the basal conglomerate of the Raton formation. *e*, Smooth, gentle slope of shale of the Raton formation. *f*, Almost continuous high cliff formed by the edge of the massive sandstones of the Raton formation. *g*, Relatively smooth, gentle slope on the upper coal-bearing sandstones and shales of the Raton formation.

The shale that lies between the two series of prominent bench-forming layers is relatively thin and from a distance is inconspicuous. The cliff-forming layers—*b* and *f* in figure 11—form a bold, persistent escarpment in most places along the eastern margin of the Raton Mesa region. (See Pl. I.) The escarpment is cut through by numerous streams, so that the valleys and canyons form deep reentrants separated by promontories which overlook the plains like bold headlands overlooking the sea. The shelf-making sandstones crop out high up in most of these promontories, but in the reentrants they gradually approach the level of the streams. The valleys in the reentrants become narrower upstream until, where they cross the line of contact of one of the hard sandstones, they are reduced to narrow box canyons. These canyons widen to some extent in the softer strata, but in most places upstream from the line of outcrop of the most resistant sandstone (the Trinidad) the streams occupy box canyons or narrow V-shaped valleys.

The middle group of land forms that have resulted from the dissection of the highlands occupies a large part of the Raton and Brilliant quadrangles and the northwestern part of the Koehler quadrangle. The highlands of the Brilliant and Koehler quadrangles are cut into an intricate pattern of steep ridges and branching valley canyons. Those in the northern part of the Raton quadrangle are not cut into so intricate a pattern because of the protection afforded by the hard rocks that cap the mesas. The middle group in the Raton quadrangle is represented by the slopes of the mesas, which, though precipitous, are comparatively regular in shape and conform in outline to the rim of the mesas.

All the main ridges in the Brilliant quadrangle—those lying between the main lines of drainage—rise to nearly the same altitude. The altitude of the highest points is a little more than 8,000 feet above sea level and that of the crests averages a little less. These crests seem to be the least degraded parts of the ancient plain of degradation that occupied this region. The maximum altitudes of the highlands correspond closely with the altitudes of the second plain of degradation already described, which has been preserved in part by the lava flows of Bartlett, Horse, and Horseshoe mesas. As these plains slope eastward, away from the mountains, the original peneplain probably lay somewhat above the highest points of the ridges (see fig. 5), for even the least degraded parts, which are composed of poorly consolidated sandstone, must have been worn down faster than the basalt-covered mesas. Since the time of this planation some areas, such as the southern part of the Raton quadrangle, have been cut down nearly 2,000 feet; other areas, such as the greater part of the Brilliant quadrangle, have been deeply dissected; and still others, such as the central part of the Raton Mesa region west of the Brilliant quadrangle, are only slightly dissected and lie at altitudes of 8,000 feet or more above sea level. Thus the Brilliant quadrangle constitutes a part of the deeply dissected transitional zone between the uniformly degraded areas of the typical Great Plains and the slightly dissected highlands in the central part of the Raton Mesa region.

The main streams of the Raton and Brilliant quadrangles have excavated depressions in this plateau which are canyon-like in its central portions and valley-like near its borders. These valley-like canyons may be described as valley canyons, though they are locally called canyons, irrespective of their form, which varies with the rock structure. (See figs. 10 and 12.) Their upper or canyon-like parts are cut in relatively

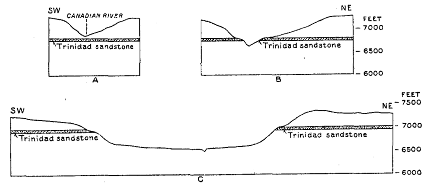


FIGURE 12.—Profiles across the valley of Canadian River, showing the effect of the rocks exposed.

A, Profile at a locality 1 mile above the point where the Trinidad sandstone is exposed in the bed of the river. B, Profile at a locality just below the point where the river crosses the Trinidad sandstone. C, Profile at a locality 8 miles below the point where the river crosses the Trinidad sandstone.

hard rocks—the coal-bearing sandstone and shale of the Raton formation—and assume the modified V shape illustrated in the profile of figure 10. Below the crossing of the lowest hard stratum—the Trinidad sandstone—the canyons widen to valleys, the floor of which consists of soft Pierre shale (see figs. 11 and 12) and finally merge into the open plain. Erosion influenced by the rock structure has produced in this region land forms that simulate those of a rugged coast facing the sea. If these quadrangles were submerged until the Trinidad sandstone lay near sea level they would exhibit the intricate shore line, bays, drowned valleys, bold headlands, and other characteristic features of a sunken coast.

LOWLANDS.

General features.—The degraded areas that surround the mesas are represented by the relatively level lowlands in the southern part of the Raton quadrangle and the greater part of the Koehler quadrangle. These lowlands form parts of the Great Plains and owe their existence mainly to the presence of soft, easily eroded shale. They were formed by the coalescence of several valleys. Vermejo River, Canadian River, and Crow, Willow, Dillon, Raton, Chicorica, Uña de Gato, and other creeks all occupy well-defined valleys in the highlands; but in the southern part of the Raton quadrangle and in the Koehler quadrangle these valleys join laterally to form the lowland plain. Layers of hard rock within the soft shale and accumulations of rock from the highlands, chiefly fragmental basalt, have protected the shale from erosion and thus caused the development of minor features of the relief. Degradation is now progressing rapidly; the plain is trenched by steep-walled gorges or arroyos, which increase in number and in size toward the highlands.

Elevations due to layers of hard rock.—Many of the minor land forms in the lowland area have been developed through differences in the hardness of the rocks, soft rocks being eroded faster than hard ones. In the southwestern part of the Raton quadrangle, east of Clifton House, there is an irregular ridge which is crossed by the St. Louis, Rocky Mountain & Pacific Railway. This ridge is capped by a thin layer of limestone that has retarded erosion, but the soft shale east of the ridge, which is stratigraphically below the limestone, has been worn down 100 to 200 feet. Less conspicuous unevennesses in the plain, due to hard layers of rock, are seen at many other places in these quadrangles, especially near the principal lines of drainage.

Elevations due to surface accumulations of hard detrital rock.—At several places in the Raton quadrangle the surface material of the lowlands consists of detritus made up of pebbles and angular fragments of hard rock. The conspicuous ridge in sec. 6, T. 30 N., R. 25 E., on the southern slope of Johnson Mesa, is capped by fragmental rock, which apparently marks the course of an ancient stream that drained a part of the southern slope of this mesa. Another similar bed of detritus caps the ridge south of Linwood Canyon, a mile east of Raton. The detritus on this ridge was evidently washed from Bartlett Mesa by Linwood Creek when this creek flowed where the ridge now stands. Since that time this creek has lowered its bed about 150 feet. Some of these beds of detritus occur many miles from the mesas, but most of them lie near the foot of the slopes. Much of the surface between Black Mesa and Johnson Mesa is covered with them. In the southern part of the Raton quadrangle and in the Koehler quadrangle the pebbles in the surface débris are waterworn and were doubtless deposited by the larger streams. In some places these gravel beds are several feet thick and protect the underlying shale from erosion. Small gravel-capped hills stand southeast of Raton near the creek which flows through the town, and gravel formerly deposited by Canadian River now covers a knoll, 6,294 feet in altitude, that stands a mile east of that river, near the southern margin of the quadrangle. Similar gravel-capped hills occur at many places in the Koehler quadrangle, the most conspicuous of which are Cedar Hills, in the extreme southwestern corner of the quadrangle. East of Canadian River, except in the vicinity of the streams, the shale is covered with several feet of cemented gravel and angular fragments of rock.

Valleys and arroyos.—The valleys in the lowland region are not so distinct from the plain as to make it necessary to describe them separately. They head in broad-mouthed reentrants in the highlands and form what are here called valley canyons. The short temporary stream courses, however, are clearly marked. In the Southwest these stream courses, which are generally known as arroyos, reach their maximum development in semiarid regions, where much of the rain falls in short, violent showers, commonly called "cloudbursts." The term arroyo is often used in the sense of ravine or gulch and is sometimes applied to small valleys and canyons, but in this folio it is used to designate the narrow, steep-walled water-courses that trench the plain and that range in depth from a few feet to 20 feet or more. They are canyon-like in form but differ from canyons and gorges in that they are small and are cut in soft rock.

Many parts of the gently sloping plain are trenched with these arroyos. They range in length from a few hundred feet to several miles. Their walls are almost vertical and they form effectual barriers to grazing stock and to ordinary travelers. They have been formed wherever flood waters gather into streams of sufficient force to cut through the soil but are most numerous near the highlands, from which small torrents carry fragments of hard rock at velocities so high that they have great power of abrasion.

DRAINAGE.

General features. — The average annual precipitation at Raton is a little less than 13 inches, but the precipitation on the highlands is considerably greater. The northeastern part of the Raton quadrangle drains northward through San Isidro Canyon to the Purgatoire, and the northwestern part of the Brilliant quadrangle drains northward through Long Canyon to the Purgatoire, and thence by way of the Arkansas and the Mississippi to the Gulf of Mexico. The main lines of drainage, however, are tributary to Canadian River, which flows southward to central New Mexico and thence southeastward to the Mississippi and the Gulf. Although Vermejo River and Crow, Willow, Dillon, Raton, Chicorico, and Uña de Gato creeks occupy separate canyons in the highlands, these canyons were all branches of Canadian Canyon before the ridges that separated them were eroded away.

During most of the year a little water derived from springs in the sandy rocks may be found in the larger canyons, especially in the uplands, but little of it reaches the plain. At times even the surface flow of Canadian River ceases where it emerges from its canyon, although water may always be found below the surface in the gravel of the stream bed. Farther upstream, however, there is a small permanent flow, and many of the tributary streams are perennial, but even the stream courses that are usually dry sometimes contain raging floods of muddy, débris-laden storm water that sweep great quantities of rock waste out upon the plain.

Springs.—Aside from the seepage springs that supply the streams in the dissected highlands there are many springs under the rims of the mesas. They range in volume of flow from small seeps to streams of considerable size. The flow from several of these springs along the southern rim of Bartlett Mesa has been considered sufficient to supply water for the city of Raton, and at one time pipes were laid to carry the water to the city, but the project was not completed. Most of the springs in the Raton quadrangle are used for watering stock, but some of those east of the quadrangle have volumes of flow so great that their water is used for irrigation.

The position of the springs that lie under the rims of the mesas is due to the nature of the rocks. Some of the igneous rock of the mesas is columnar and some of it is porous. The rainwater that falls on the mesas finds its way downward through the sheets of lava to beds of poorly consolidated sand and gravel. These beds rest on relatively impervious shale in the Raton formation, which prevents most of the water from sinking through it. The sand and gravel hold the water for a time, releasing it so gradually that many of the springs are only slightly affected by differences in rainfall from season to season.

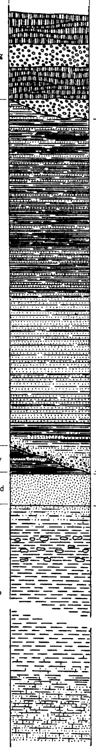
DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

SEDIMENTARY ROCKS.

GENERAL FEATURES.

The sedimentary rocks exposed in the Raton, Brilliant, and Koehler quadrangles belong to the Cretaceous, Tertiary, and Quaternary systems. Rocks of some of the older systems underlie these quadrangles and crop out in areas surrounding them. Those of Cretaceous age occupy the surface over about two-thirds of the Raton, most of the Koehler, and small areas in the southeastern part of the Brilliant quadrangles. Those of Tertiary age occupy the greater part of the Brilliant, the northern third of the Raton, and the northwestern part of the Koehler quadrangle. They are confined to the highlands and lie unconformably on the Cretaceous beds. The Quaternary beds consist of the high-level gravels, of unconsolidated material that caps some of the low buttes and ridges, and of fine loesslike material that is spread out generally over the plain. A columnar section showing the character of the consolidated rocks of these quadrangles and of their relations by age is given in figure 13.



System.	Series.	Formation.	Symbol.	Columnar section	Thickness (feet).	Character of rocks.	Character of topography and economic features.
Quaternary.		Basalt.	Qb		200±	Lava flows of mesas and intrusive sills, stocks, and dikes, with interbedded and underlying sand, gravel, and waterworn boulders.	Flat-topped table-lands. Fertile soil. Springs at outcrop of gravel.
		High-level gravels.	Qhg				
		UNCONFORMITY					
Tertiary.	Eocene.	Raton formation.	Tr		1,150	Sandstone, brown to buff shale, and coal in alternating layers. Sandstone generally conglomeratic at base; ledge-making sandstone in lower middle part.	Steep slopes and sharp ridges, covered with forest in some places. Contains many beds of bituminous coal, some of which can be coked.
		UNCONFORMITY					
Cretaceous.	Upper Cretaceous.	Montana group. Vermejo formation.	Kv		0–200	Dark shale, carbonaceous in places, light-colored friable sandstone, and coal. Many fossil plants. Rail Canyon sandstone in middle part occurs in Koehler quadrangle.	Steep slopes between Trinidad sandstone below and conglomerate above. Contains several beds of high-grade bituminous coking coal.
		Montana group. Trinidad sandstone.	Ktd		100	Massive feldspathic light-gray sandstone.	Cliffs and precipitous escarpments. Furnishes building stone.
		Montana group. Pierre shale.	Kp		3,000±	Drab to black fossiliferous shale containing concretions of limestone. Grades downward into sandy calcareous beds of Niobrara age (Apishapa shale).	Rolling plains. Rich soil. Furnishes brick clay.
		Colorado group. Apishapa shale.					

FIGURE 13.—Generalized section for Raton, Brilliant, and Koehler quadrangles.
Scale: 1 inch=300 feet.

The numerous local sections from which this general section was compiled and the lists of fossils by which the relative ages of the several formations have been determined are given in a report on the Raton Mesa region published as Professional Paper 101 of the United States Geological Survey.

CRETACEOUS SYSTEM.

The part of the Cretaceous system exposed in the area here considered includes the upper part of the Colorado group of the Upper Cretaceous series, which is exposed in the southeastern part of the Raton and the eastern part of the Koehler quadrangle, and the Pierre shale, the Trinidad sandstone, and the Vermejo formation of the Montana group. These rocks are more than 3,300 feet thick and include nearly 3,000 feet of marine shale, 100 feet of massive sandstone, and a maximum of 200 feet of coal-bearing sandstone and shale. Nearly 3,000 feet of marine shale was penetrated in a well drilled east of Raton, in which rocks of Montana age were not distinguished from those of Colorado age, and the bottom of the shale was not reached.

If younger Cretaceous rocks or rocks of Laramie age were ever deposited in this area they were eroded away prior to the deposition of the overlying rocks, of Tertiary age. The lower part of the Upper Cretaceous series, including beds of Niobrara, Benton, and Dakota age; the Morrison formation, perhaps of Lower Cretaceous age; and the "Red Beds," of Triassic and Carboniferous age, underlie these quadrangles.

COLORADO GROUP.

Strata belonging to the Colorado group have been found in the Elmoro quadrangle, which joins the Raton quadrangle on the north. There the beds of the upper part of this group are of Niobrara age and consist of the Timpas limestone and the overlying Apishapa shale. These formations extend southward beneath the Raton and Brilliant quadrangles, and similar rocks crop out farther east and south. Certain fossils indicate that the upper part of the Apishapa shale crops out in the southeastern part of the Raton quadrangle and in the eastern part of the Koehler quadrangle, but in those areas no line of separation between the Apishapa and the overlying Pierre shale can be mapped.

MONTANA GROUP.

PIERRE SHALE.

The Pierre consists mainly of soft, easily eroded, dark shale of marine origin, which has been worn down in the lowlands of the Raton, Brilliant, and Koehler quadrangles and in the broad reentrants that head in the highlands. It is a thick formation, with thin beds of yellowish shaly limestone near its base and irregularly cylindrical concretions of limestone at many horizons, especially in its upper part, and with sandy beds near the top, which constitute a transitional zone between the typical shale and the overlying massive sandstone. This shale is 1,200 to 1,300 feet thick in the Elmoro quadrangle, in southern Colorado, and is still thicker farther north. Of the 3,000 feet of shale indicated by the well put down near Raton probably 2,000 feet or more belong to the Pierre. In Hunter Canyon the top of this shale crops out at altitudes of about 8,000 feet above sea level. South of Meloche Mesa the highest known stratum of Colorado (Niobrara) age occurs at an altitude of about 6,650 feet. To this indicated thickness of 1,350 feet must be added a correction for dip, which, on the assumption that the dip is uniform and that there are no displacements by faulting, amounts to 750 feet, these assumptions making a thickness for the Pierre at this locality of 2,100 feet.

A shaly limestone in the lower part of the Pierre shale about 3 miles southwest of Black Mesa contains a variety of fossil shells of marine invertebrates, including several chambered shells—Ammonites, Baculites, and Scaphites—and bones and teeth of fishes. Few fossils were found near the middle of the Pierre formation, but many have been obtained from its upper part. These are all marine invertebrates, which, according to T. W. Stanton, have a wide stratigraphic range, none of them being restricted to definite zones.

TRINIDAD SANDSTONE.

Name and character.—Next above the Pierre shale lies a body of massive gray sandstone which ranges in thickness from less than 50 feet to a little more than 100 feet. This sandstone is somewhat feldspathic but consists principally of grains of quartz. Although poorly cemented it does not weather readily and it generally crops out in precipitous cliffs. At most places in the Raton, Brilliant, and Koehler quadrangles its thickness varies little from 100 feet. At some places it contains near the middle a shaly zone, which is locally carbonaceous.

The name Trinidad, from Trinidad, Colo., was given to this sandstone in the Elmoro folio by R. C. Hills.[1] He defined the formation as consisting of a light-gray sandstone 70 to 80 feet thick, which he called Upper Trinidad, and a series of thin layers of sandstone and shale about 75 feet thick, which he called Lower Trinidad. The term was later redefined[2] to apply only to the upper sandstone, the so-called Upper Trinidad of Hills, his so-called Lower Trinidad being referred to the Pierre shale. The term Trinidad sandstone is applied in this folio to the massive portion above the sandy transitional zone that forms the upper part of the Pierre shale.

Within these quadrangles the Trinidad sandstone constitutes a well-defined sedimentary unit, but farther south it merges into coal-bearing rocks which overlie a cliff-making sandstone. This lower sandstone (see fig. 14), which seems to be the equivalent of some part of the transitional zone of the Raton region, has locally been called the Trinidad on the erroneous assumption that it is the same as the Trinidad sandstone near Raton.

FIGURE 14.—Sketch section illustrating the relation of the Trinidad sandstone to the coal beds in the Vermejo formation above and to the Pierre shale below.

a, Coal (Raton bed) at base of Vermejo formation. *b* and *e*, Cliff-making Trinidad sandstone. *c*, Transition zone between Pierre shale below and Trinidad sandstone above. *d*, Coal in Trinidad sandstone. Vertical scale: 1 inch=400 feet, approximately.

Distribution and surface form.—The Trinidad sandstone crops out in the escarpment overlooking the lowlands and underlies the north third of the Raton quadrangle, the greater part of the Brilliant quadrangle, and the northwestern part of the Koehler quadrangle. It usually forms cliffs that rise abruptly above less precipitous slopes of Pierre shale. Along the border of the highlands it forms a distinct bench (Pl. III).

Fossils and age relations.—The Trinidad sandstone contains numerous impressions of a fossil fucoid (*Halymenites major* Lesquereux), which are so abundant that the formation was once called the "fucoidal sandstone." It also contains marine invertebrates and impressions of the leaves of land plants, although few have been collected within these quadrangles. The association of these marine and land forms indicates that this sandstone is a sea-margin formation.

The Trinidad sandstone has been traced continuously throughout the Raton Mesa region, and the greater part of the evidence bearing on its age, which is in doubt, was obtained from the northern part of this region. It overlies Pierre shale, as does the Fox Hills sandstone, and R. C. Hills describes it as representing some part of the Fox Hills formation.[3] Richardson[4] collected from it several invertebrate fossils in the Trinidad field, and Lee[5] has added a few from the Raton field.

Of the seventeen invertebrates found in the Trinidad sandstone T. W. Stanton states that some have a wide range in time but that others have been found only in the upper part of the Pierre and in the Fox Hills. Of eight forms specifically identified, six range downward into the Pierre, leaving only two, one of which is doubtfully identified, that occur only in the Trinidad sandstone. The fossil plants from the rocks overlying this sandstone indicate Montana age. The six fossils of the Trinidad sandstone are not distinguished from those of the overlying formation. The stratigraphic position of this sandstone, which lies beneath a formation of recognized Montana age, indicates that it is not youngest Montana.

VERMEJO FORMATION.

Name and character.—Next above the Trinidad sandstone and lying conformably on it is a body of coal-bearing shale and sandstone called the Vermejo formation, which has a maximum thickness of about 75 feet in the Brilliant and Raton quadrangles but which thickens locally in the Koehler quad-

[1] U. S. Geol. Survey Geol. Atlas, Elmoro folio (No. 58), p. 2, 1899.
[2] Lee, W. T., and Knowlton, F. H., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, p. 48, 1917.
[3] Hills, R. C., U. S. Geol. Survey Geol. Atlas, Elmoro folio (No. 58), 1899; Walsenburg folio (No. 68), 1900; Spanish Peaks folio (No. 71), 1900.
[4] Richardson, G. B., The Trinidad coal field, Colo.: U. S. Geol. Survey Bull. 381, pp. 379-446, 1910.
[5] Lee, W. T., and Knowlton, F. H., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, 1917.

rangle to a maximum of about 200 feet. As the formation is variable in thickness within short distances the average thickness, 50 to 75 feet, is indicated on the map. It thins to the east, owing to the removal by erosion of the higher beds, and does not outcrop in the eastern part of the Raton quadrangle, where it was entirely eroded away before the younger sedimentary beds were formed. It thickens to the south and west to a maximum of nearly 400 feet in the western part of the Raton Mesa region, but in all places the highest beds of the Vermejo have been eroded away and the original thickness is nowhere exposed. The name is derived from Vermejo Park, N. Mex., about 50 miles west of Raton, where the formation has a maximum thickness of about 375 feet.

The Vermejo formation consists of sediments that are mainly of fresh-water origin. Sandstone occurs in it in layers which in regularity of thickness are intermediate between those of marine origin below and those of stream deposition above. In general appearance the sandstone resembles the Trinidad sandstone, except that most of it is more friable. On weathering it disintegrates rapidly and crumbles to beds of sand.

In most places the Vermejo consists principally of shale, much of it carbonaceous. It ranges in color from blue through many shades of buff and tan to coal-black. Beds of high-grade coking bituminous coal occur at many horizons within the formation. These range from thin seams to beds 15 feet thick and from slightly carbonaceous shale through mixtures of shaly and coaly matter in different proportions to coal that is free from shale. The coal beds are persistent over wide areas and are relatively uniform in character. The coal usually rests on shale, which in many places contains fossil rootlets. At some places silicified stumps and trunks of trees have been found in the coal. The coal beds are usually covered with shale containing great numbers of fossil plants in the form of impressions of leaves and crushed branches and trunks of trees. These plants indicate proximity to uplands, but the uniformity in the character of the sediments throughout the Raton Mesa region and the absence from them in all places of material coarser than sand show that these lands were not high. The Vermejo was probably formed on broad coastal plains so far from the source of the material that the sediments show little difference in character throughout the Raton Mesa region, an area about 90 miles long and 50 miles wide.[1]

An exception to this rule is found in the Dawson district, which includes the northwestern part of the Koehler quadrangle, where the Vermejo is more complex in structure than elsewhere. In this district it consists of a lower coal-bearing portion, which contains the coal locally called the Dawson bed; a median sandstone, here named the Rail Canyon sandstone member, from a locality near Dawson; and an upper coal-bearing portion, whose lowest coal ranges from 2 to 4 feet in thickness. The Rail Canyon sandstone is in so many places made up of clay pellets that it may be regarded as a mud-ball conglomerate. In some places it rests on the Dawson coal, but in others it is separated from this coal by many feet of shale. This relation is evidently due to local erosion of the lower portion of the Vermejo before the material of the Rail Canyon sandstone was deposited. This sandstone occurs in Saltpeter Mountain below the higher coal and is recognizable as far north as the east wall of Five Dollar Canyon, where it occurs between two coal beds and is less than 2 feet thick. It was not found farther north.

Distribution and surface form.—The Vermejo formation underlies the highlands and crops out above the Trinidad sandstone in most places along the escarpment in the southeastern part of the Brilliant quadrangle. In some places south of Van Houten and near Red River Peak it has not been found; nor has it been found in the Raton quadrangle east of Bartlett Mesa. It is essentially continuous to the north, west, and south of these quadrangles and underlies the highlands generally throughout the greater part of the Raton Mesa region. As the formation is easily eroded it crops out chiefly in gentle slopes (see fig. 11), many of which are inconspicuous because they lie in the steep escarpment amid more imposing topographic forms. In the two quadrangles here described the Vermejo is at many places so thin that it appears as a shaly zone in the cliff formed by the underlying Trinidad sandstone and the overlying conglomerate. (See Pl. IX.)

Fossils and age.—Post-Vermejo erosion left so little of the Vermejo formation in the Raton, Brilliant, and Koehler quadrangles that they do not form good collecting ground for Vermejo fossils, but large collections of such fossils have been made from other parts of the Raton Mesa region. Aside from fossil seaweeds and a single shell reported from a bed above the lowest coal bed in the southern part of the Raton Mesa region the fossils thus far found in the Vermejo formation in the Raton Mesa region are land plants. A full list of the Vermejo flora has already been published.[2] According to F. H. Knowlton, these plants, which represent 108 species, belong to the Montana flora. Eighteen of them occur also in the Vermejo formation of the Canon City field, Colo., but the Vermejo formation near Canon City differs from that of the Raton Mesa region in being much thicker and in having in the middle of it a layer of sandstone of marine origin, which contains fossil invertebrates that tend to correlate it with the Fox Hills sandstone. This sandstone occurs in the Colorado Springs quadrangle,[3] about 40 miles northeast of Canon City. The Montana age of the Vermejo plants and their relation to the invertebrates in the coal measures of the Canon City field furnish grounds for the belief that the Vermejo was deposited contemporaneously with the Fox Hills sandstone of the Colorado Springs quadrangle.

The Vermejo formation constitutes the lower part of the rocks formerly called the Laramie of the Raton Mesa region. They were so designated because of their supposed equivalency in age to the Laramie of the Denver Basin. This designation was abandoned when it became known that the coal-bearing rocks are separated by a well-marked unconformity into two formations, neither of which contain the fossil plants characteristic of the Laramie formation of the Denver Basin. The lower formation is of Montana age and is therefore older than Laramie; the other is of Tertiary age and is therefore younger than Laramie. If beds of Laramie age were ever deposited in the Raton Mesa region they were eroded away before the Tertiary sediments were laid down. The Vermejo flora includes fossil plants that indicate its correlation with formations in many places west of the Rocky Mountains which, on the evidence of fossil plants as well as other evidence, are considered middle Upper Cretaceous.

Something of the climate of Vermejo time and of the surface conditions in the Raton Mesa region during this epoch is known from the fossil plants. Some of the ferns belong to swamp-loving types, others to types that thrive on drier ground. Fan-palms and other marsh plants are numerous, but the hardwoods are most abundant. However, these differ materially from the hardwoods that now grow in New Mexico. There were few oaks or other trees that might thrive in a cool climate. The near relatives of the Vermejo plants are found now in such warm, moist regions as parts of Australia, southern Africa, and the subtropical parts of North America.

The fossil plants indicate rather clearly that the sediments of the Vermejo formation were laid down in a warm, swampy region close to sea level. In the sluggish streams and bayous floated many water plants, and at the edge of the water grew large-leafed cannas. In the swamps grew fan-palms, cypress-like trees, many varieties of figs, and an occasional breadfruit tree. Laurels, ivies, and grapevines also were abundant. Details of this flora have been published elsewhere.[4]

TERTIARY SYSTEM.

EOCENE SERIES.

RATON FORMATION.

Name and subdivisions.—Next above the Vermejo formation lie coal-bearing rocks of fresh-water origin, which have a maximum thickness in these quadrangles of about 1,150 feet, although they are somewhat thicker in the area west of these quadrangles. They lie unconformably on the Vermejo formation where it is present, and in some places they overlap it onto the Trinidad sandstone. In the southwestern part of the Raton Mesa region this overlap brings the Tertiary beds in contact with the Pierre shale. The name Raton formation has been adopted for the coal-bearing rocks above the unconformity. These rocks constitute the principal part of what was called Laramie in this region before the beds above the Vermejo were shown to be of Tertiary age. The formation varies considerably from place to place, but four well-marked zones are recognizable throughout the Raton and Brilliant quadrangles and three of these zones can be traced throughout the Raton Mesa region. In order from oldest to youngest they include the basal conglomerate, a series of coal-bearing rocks here called the lower coal group but known locally as the "Sugarite zone," a series of ledge-making sandstones locally called the barren series because of the absence of commercially valuable coal, and a series of coal-bearing shale and sandstone called the upper coal group.

Basal conglomerate.—The conglomerate at the base of the Raton formation is a pebbly sandstone of variable character. At the outcrop along the escarpment in the Koehler quadrangle and the southeastern part of the Brilliant quadrangle, where it is 10 to 40 feet or more in thickness, it is made up largely of siliceous pebbles and forms a conspicuous ledge. (See Pls. IX–XI.) In the vicinity of Raton it is in some places only 2 or 3 feet thick and consists of sand through which a few small pebbles are scattered. East of Raton it is variable in thickness and character, and in some places it is entirely absent. Near Linwood Canyon it increases in thickness locally to 25 or 30 feet and contains pockets of small pebbles. In Sugarite Canyon it is wholly absent, but in many places in the eastern part of the Raton quadrangle it may be recognized as a hard quartzose layer 1 to 10 feet thick above the Trinidad where that sandstone forms a cliff. In the Koehler quadrangle it forms a conspicuous ledge near Koehler, but it becomes less prominent toward the south. In the bluffs of Saltpeter Canyon the bed is only slightly pebbly.

This conglomerate has been traced toward the northwest through the Trinidad coal field, where it is in some places 50 feet or more in thickness, and along the western margin of the Raton Mesa region, where it is made up largely of pebbles and attains a thickness ranging from 200 to 300 feet. It becomes coarser toward the south, and at its southwestern extremity, in the vicinity of Ute Park, N. Mex., it contains rounded pebbles or boulders, the largest 6 inches or more in diameter.

This basal member of the Raton formation generally consists of a matrix of firmly cemented sand, almost a quartzite in some places, in which are embedded pebbles of many kinds of rock, pebbles of chert and quartzite being the most numerous. The pebbles are irregularly distributed, some in roughly lenticular masses, some in small "pockets," and some scattered generally throughout the mass. Besides the chert and quartzite there are pebbles of gray quartzose sandstone similar to the Dakota; pebbles of conglomeratic sandstone like the conglomerate of the Purgatoire formation; pebbles of petrified wood, which may have come from the Vermejo formation or from the Dakota sandstone; pebbles of red sandstone from the red beds of Carboniferous or Triassic age, which crop out in the mountains west of the Raton Mesa region; pebbles of cherty limestone containing crinoid stems and horn corals, such as are found in the limestones of Pennsylvanian age which occur below the red beds; pebbles of quartz, jasper, and fine-grained igneous or dike rocks; pebbles of coarsely crystalline rock like the granites of the mountain core; pebbles of feldspar, most of them kaolinized but others showing characteristic crystal faces; and in a few places rounded or waterworn pebbles of coal, which probably came from the coal beds of the Vermejo formation.

In the Brilliant, Raton, and Koehler quadrangles the conglomerate is coarsest and thickest where the Vermejo formation is thinnest, as in Crow Canyon (see Pls. IX and X), or where that formation is entirely absent, as south of Van Houten (see Pl. XI) and in Linwood Canyon, east of Raton. The base of the Raton formation rests on Trinidad sandstone north of Barilla Mesa, and in the southwestern part of the Raton Mesa region the conglomerate overlaps the Vermejo formation and the Trinidad sandstone and rests on Pierre shale. These localities are in line from southwest to northeast and may mark the course of one of the streams which helped to erode the Vermejo formation. As its valley was the lowest part of the degraded area it was the first to be filled when deposition was renewed and received the coarsest material.

In many places the lower surface of the conglomerate is covered with cylindrical, wormlike bodies an inch or more long and about an eighth of an inch thick. These bodies are most numerous and best preserved where the conglomerate rests on coal or on carbonaceous shale. They look like fillings of worm burrows, but their nature is not definitely known.

In some places the base of the conglomerate is very uneven and extends downward into irregular cracks or openings the nature of which is not well understood. These cracks were observed at several places in the Brilliant quadrangle, but they are best seen in the Willow mine, where measurements and sketches of some of them were made. (See fig. 15.)

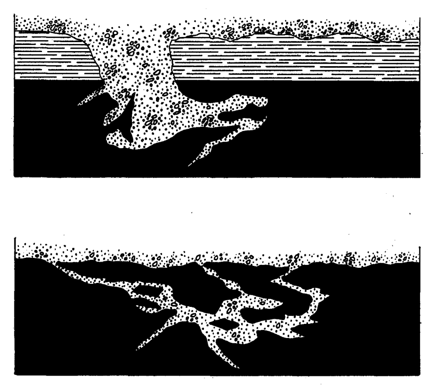


FIGURE 15.—Sketches showing the relation of the basal conglomerate of the Raton formation to the underlying shale and coal of the Vermejo formation in the mine face of the Willow mine, near Van Houten.
The conglomerate seems to fill irregular crevices in the upper surface of the coal and associated shale of the Vermejo formation.

Lower coal group.—Next above the conglomerate is a series of beds of coal-bearing shale and sandstone about 100 feet thick, locally called the "Sugarite zone." This series is best developed in the Raton quadrangle, where it contains the Sugarite coal bed, on which a mine has been opened in Sugarite Canyon. In the Brilliant quadrangle also the group consists of coal-

[1] Lee, W. T., and Knowlton, F. H., op. cit., p. 54. Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27–58, 1917.
[2] U. S. Geol. Survey Prof. Paper 101, pp. 227–238, 1917.
[3] Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (No. 203), 1916.
[4] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, pp. 226–235, 1917.

bearing shale, but the coal beds are thin and differ in number from place to place. In Canadian Canyon six thin beds of coal occur in a measured thickness of 60 feet of strata. This so-called "Sugarite zone" can be recognized for a considerable distance north of the area here described, where it extends into the Trinidad coal field of Colorado, but little attempt has been made to differentiate it except in the Raton quadrangle. It has not been recognized in the western and southern parts of the Raton Mesa region and seems there to merge into coarse sediments.

Barren series.—Above the lower coal group is a series of sandstones separated by thin layers of shale. These sandstones weather to a yellowish-brown color and are locally called the "barren series" because they contain no thick beds of coal. The series ranges in thickness from about 300 feet in the eastern part of the Raton quadrangle to about 600 feet in the western part of the Brilliant quadrangle. The sandstones are massive and resistant, so that they form cliffs along the outcrop. (See fig. 11, p. 5.) It is chiefly these sandstones that make the escarpment facing the plains so precipitous.

Upper coal group.—Above the barren series lies the highest member of the Raton formation, known locally as the "upper coal group." In it occur several thick beds of coal, which in some places are mined. This group of beds crops out in the sides of the high ridges throughout the greater part of the Brilliant quadrangle and underlies the highest mesas of the Raton quadrangle. It consists of shale, friable sandstone, and coal in alternating layers. The coal beds of this group are less persistent than those of the Vermejo formation, and the coal is more shaly. In most places the beds are more easily eroded than the underlying beds, so that they crop out in gentle slopes (see fig. 11), and much of the group has been eroded away during the dissection of the highlands. The coal, although bituminous, is much softer than the bituminous coal of the Vermejo formation and weathers readily, so that in few places can a correct judgment of the character of a coal bed be formed from an exposure of it seen at the outcrop.

Many sections of this formation have been measured at its outcrop, and in several places it has been penetrated by the diamond drill. Some of these sections and drill records are given in the plate showing drill records, at the end of the text.

Fossils and age.—Invertebrate fossils have been found in the Raton formation at only one place in the Raton Mesa region—on the ridge south of Dillon Canyon, near the eastern line of the Brilliant quadrangle, where a few poorly preserved fresh-water shells were found. But the Tertiary age of the formation has been determined chiefly from the evidence afforded by the fossil plants, which are in many places abundant and are especially well preserved in the upper coal group. The Raton formation in these quadrangles has furnished a considerable number of plants, and in other parts of the Raton Mesa region has furnished large collections. The plants have been found at many levels from the bottom to the top of the formation, but they are most abundant near the coal beds. A full list of the Raton flora has been published elsewhere.[1] It contains 148 species, only 4 of which are found in the underlying Vermejo formation. It is noteworthy also that this flora contains few species found in the Laramie formation of the Denver Basin, with which the coal-bearing rocks of the Raton formation formerly were correlated. On the other hand, it corresponds closely with the flora from the beds which lie unconformably on the Laramie, just as the Raton formation lies unconformably on the Vermejo. It also corresponds with the flora from the older Eocene beds in Wyoming, western Colorado, western New Mexico, and on the Gulf Coast, notably the Wilcox group.

Although the rocks containing this assemblage of plants rest directly on those of the Vermejo formation, the Raton and Vermejo floras are distinct. They are similar in many ways, for swamp vegetation grew here in both epochs, but close inspection shows notable differences. The marine algae of the Vermejo flora are not represented in the Raton flora, nor the cone-bearing trees. There were fewer ferns but vastly more palms in Raton time than in Vermejo time. Magnolias grew in great numbers, and laurel, cinnamon, sumac, buckthorn, and many other shrubs, as well as herbs, were common, but the hardwood trees formed the most conspicuous group in the Raton flora. On the whole, the Raton plants were probably direct descendants of those of Vermejo time. The differences arose from development during the time between the Vermejo and the Raton epoch.

During the Raton epoch the Raton Mesa region was a low, swampy surface to which the streams from the newly formed highlands to the west brought sand and silt. In the swamps accumulated the vegetable matter which on being covered by the stream-borne débris formed coal. In the shallow, open waters grew water lilies of modern type, and in the marshes reedlike grass, fan palms, and ferns. About the smaller marshes may have been seen cinnamon and breadfruit trees, and in the larger marshes many magnolias, figs, sweet gums, and sycamores and climbing vines. On the higher ground there were numerous hardwood trees, such as oaks, walnuts, beeches, chestnuts, and poplars.

[1] U. S. Geol. Survey Prof. Paper 101, pp. 235-286, 1917.

In the eastern part of the Raton field the Raton formation is overlain by the lavas that cap the mesas and by the poorly consolidated sand and gravel that in some places lies beneath these lavas. The coal-bearing rocks west of the mesas are overlain by beds of coarse material, which may be equivalent to the Poison Canyon formation. Since the publication of the geologic folios covering the Trinidad coal field, in southern Colorado, the Raton and Poison Canyon formations have generally been regarded as unconformable with each other.[2] The Poison Canyon formation, mainly because of its lithologic character and its stratigraphic relations, was correlated with the Denver formation of the Denver Basin. G. B. Richardson found in it fossil plants that are identical with species in the Denver formation, and later the same species of plants were found in the Raton formation. This evidence shows that the Raton, the Poison Canyon, and the Denver formations are of approximately the same age.

It seemed difficult to reconcile the stratigraphic and paleontologic evidence until the work was done for this folio, when, in the highlands west of Raton, it was found that in many places the beds above the upper group of coals are arkosic and conglomeratic and closely resemble those of the Poison Canyon formation. No line of demarkation corresponding to the unconformity that was supposed to exist in the Trinidad field between the Poison Canyon and older rocks was found, and it seems probable that there is little difference in age between them and that the differences in physical character are due to local variations in sedimentation. Similar relations in the vicinity of Castle Rock, Colo., have been described by Richardson,[3] who shows that the Dawson arkose and the Denver formation constitute essentially one formation, although they differ in physical character.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

HIGH-LEVEL GRAVELS.

Occurrence and kind.—At two places beds of gravel occur on the basalt that caps Johnson Mesa, in the Raton quadrangle. Other beds of gravel underlie the lava sheets of the high mesas. The gravel is in some places unconsolidated and in others poorly cemented, so that it is rarely well exposed. Its occurrence in most places under the lavas, however, is shown by the pebbles that are generally distributed over the sides of the mesas just below the rim. The gravel of the highest mesas includes pebbles of quartz, quartzite, argillite, limestone, chert (some of which contain crinoid stems), a variety of fine-grained igneous rock like that which occurs in dikes and intrusive sheets in the foothills to the west, several kinds of granitic rock (especially the red granite that is abundant in the Culebra Range), gneiss, schist, and quartz monzonite porphyry like that which occurs in great intrusive masses in the foothills of the southwestern part of the Raton Mesa region.

The gravels that have come from underneath the highest lavas are observed to advantage in the slopes of Barilla Mesa. On the trail up the western slope, about a mile south of the State line, beds of these pebbles, some of them 6 inches or more in diameter, were observed from the base of the lava downward for 100 feet or more, but they were not seen in place, and the true thickness of the gravel beds was not determined. On the opposite side of the narrow neck of the mesa beds of yellow sand and gravel that seemed to be undisturbed were observed along the wagon road and down to a point 50 feet below the base of the lava. On the other hand, about $1\frac{1}{2}$ miles farther south, in the point of Barilla Mesa north of the Yankee mines, no pebbles were found and the coal-bearing sandstone extends upward practically to the base of the lava. However, gravels are abundant in other parts of Barilla Mesa, as, for example, in the long spur west of Rathbun Canyon.

Beds of gravel occur in some places under the younger lavas of Bartlett, Horse, and Horseshoe mesas, but these beds seem to be not so widely distributed as the older gravel beds, and they also differ from the older ones in containing pebbles of basalt similar to that of the older flows. The basalt of some of these flows contains pebbles of siliceous rock, which the molten basaltic lava had picked up, the combination forming a conglomeratic basalt. This conglomerate, on erosion, furnished the pebbles that lie beneath the younger flow. A bed of consolidated gravel of this kind, 15 feet thick, lies unconformably on the Raton formation at the south end of Horseshoe Mesa. Upon this consolidated layer lies a greater thickness of poorly consolidated and poorly exposed sand and gravel.

On Johnson Mesa gravel beds occur both above and below the sheets of basalt. Those above the basalt are well exposed, but no place was found where their full thickness could be measured. The hill west of Towndrow Peak rises 150 feet or more above the general level of the mesa, and the slopes are covered with pebbles and rounded boulders, mainly of quartz and light-colored igneous rock, a quartz monzonite porphyry. Many of these boulders are a foot or more in diameter. At several places where small undisturbed parts of the beds are exposed the irregular bedding of the sand and gravel is suggestive of stream action. A similar deposit east of Manco Burro Pass rests on the lava sheet but overlaps it to the west onto the underlying sedimentary rocks. This deposit is about 50 feet thick and consists of sand and coarse gravel composed of quartz and quartz monzonite porphyry, such as the gravel that is found on the hill west of Towndrow Peak. But associated with these materials are rounded pebbles of basalt.

[2] U. S. Geol. Survey Geol. Atlas, Elmoro folio (No. 58), 1899; Walsenburg folio (No. 68), 1900; Spanish Peaks folio (No. 71), 1901.

[3] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), p. 8, 1915.

A bed of cemented gravel 70 feet thick occurs under the lava of Johnson Mesa at the head of San Isidro Creek. Between the head of this creek and Manco Burro Pass this gravel bed is only 10 feet thick. It is well exposed and contains various kinds of pebbles, including many of basalt.

In Hunter Canyon, south of Johnson Mesa, a similar deposit of gravel separates the lava of Johnson Mesa from the underlying coal-bearing rocks, and at the west end of that mesa a bed of cemented gravel a little more than 45 feet thick occupies the same position. The pebbles in that place consist of the several kinds of rocks found in the beds already described, including basalt. The presence of these pebbles of basalt raises a query as to the relations of the older lava of Johnson Mesa to the lava that caps Barilla Mesa, for these pebbles were obviously derived from older lava flows. In places where these basalt pebbles occur under the younger lavas, such as those of Horseshoe Mesa, they may readily have been derived from the cap rock of Barilla Mesa. But, as already stated, the cap rock at the west end of Johnson Mesa stands at the same altitude as that of Barilla Mesa and is presumably of the same age. Yet these basalt pebbles prove that this flow is not the oldest one in the region.

Origin and age.—The gravel was probably deposited by streams on the old plains of degradation (see figs. 7 and 20), and their presence in some places but not in others suggests that they occupy depressions eroded in these plains. The beds are not exposed continuously enough to indicate the course of the ancient streams, but the abundant pebbles of igneous rock, which were probably brought from the southwestern part of the Raton Mesa region, indicates that the larger streams flowed in general northeastward, the direction in which they seem to have flowed in earlier Tertiary time, as shown by the distribution of the basal conglomerate of the Raton formation.

The plain of degradation represented by Barilla Mesa is the highest one in the Raton quadrangle and is the oldest well-marked plain in the Raton Mesa region. After it had been formed on the sedimentary rocks its depressions were filled with gravel brought down from the mountains, and these deposits were in turn covered with basalt. Renewed erosion cut away parts of the older basalt flow and degraded the general surface of the region to the level of the lower plain. This younger plain of degradation seems to have been more irregular than the older one, for the gravel beds are not found in all places and where they do occur they range in thickness from a few feet to 165 feet or more. This maximum thickness of the younger gravels occurs in Horseshoe Mesa, where their base at the southern point of the mesa is about 400 feet lower than the older gravels, which are exposed under the rim of Barilla Mesa where this mesa joins Horseshoe Mesa. (See fig. 7, p. 4.)

In his description of the Trinidad region, in Colorado, Hills[4] says that the volcanic eruptions which resulted in the outflow of the mesa lavas occurred at the close of the Eocene and extended into the succeeding epoch. This statement implies that the plain of degradation on which the lavas rest was formed before the end of Eocene time. Later Darton[5] stated that certain gravels found under the lavas of Mesa de Maya belong to the Ogalalla formation, which, he says, "contains numerous bones of Pliocene age at many localities in Kansas and in adjoining regions." This correlation does not rest on a secure basis, and the pebbles of basalt suggest later age. It seems probable that the plain on which they rest is a part of the peneplain which in late Tertiary time had been completed over the Great Plains province and on which the sands and gravels of early Quaternary age were spread out.

This correlation harmonizes the data gathered in the Raton Mesa region with those obtained in other parts of the Great Plains. It is obvious from the structure (see fig. 5) that after the early Tertiary deposits were laid down there was renewed uplift of the mountains and warping of the surface east of them. The irregularities of the surface thus produced were later planed off; large areas were stripped of the Cretaceous beds and of such Tertiary beds as may have covered them. The long time required for this erosion renders it improbable that this plain was completed at the end of Eocene time, but if it is a part of the Great Plains peneplain, which was not

[4] Hills, R. C., U. S. Geol. Survey Geol. Atlas, Elmoro folio (No. 58), 1899.

[5] Darton, N. H., Preliminary report on the geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, pp. 178-179, also pl. 35, 1905.

completed until the end of the Tertiary period and on which the deposits of Quaternary age were spread out, there was ample time for this work.

The evidence on which the lava flows are referred to early Quaternary is chiefly physiographic and is given below under the heading "Geologic history" (p. 13), but certain bones found in the well of Mr. A. Halles on this mesa appear to confirm the conclusion that they are of Quaternary age. Mr. Halles informed the writer that in sinking this well he dug through 30 feet of loose "volcanic ash" and into material which he described as "soil." In this material he found fragments of bone, the largest of which was cylindrical, "18 inches long and 6 or 8 inches in diameter." The size and shape suggest the limb bone of a Pleistocene mastodon.

Other unconsolidated deposits fill depressions in the surface of the lavas on the high mesas. A large depression south of Towndrow Peak was once occupied by a lake and still holds water during wet weather. It is filled with clay and sand to a depth of at least 37 feet. A well at this place penetrated 30 feet of soft clay and entered an underlying bed of sand for 7 feet.

RECENT SERIES.

On the sides of the mesas and in the lowland areas there are many deposits of unconsolidated detritus of recent origin, consisting of fragmental lava from the cap rock of the mesas, débris from landslides, stream gravels, alluvium, surface wash, wind deposits, and other materials.

Talus.—The slopes of the lava-capped mesas are generally covered with angular fragments of the lava, which in some places constitute masses of talus formed by the fall of parts of the basalt when the softer rock below was eroded away. Further erosion causes these masses of talus to scatter as they slowly work their way down the slopes, and much of the material is washed far out onto the plain. In some places, as on the west slope of Horse Mesa north of Lake Alice, the talus is so abundant that it completely obscures the underlying rocks for a considerable distance from the base of the cliff. In several places on the south slope of Hunter Mesa and on the slopes of Meloche Mesa there are large masses of igneous rocks, most of which were derived from the top of the mesa, though some of them may be sills or small stocks.

The slopes that surround Black Mesa, Round Mesa, and the smaller mesas between these two are covered with blocks of lava derived from the cap rocks. The covering of the first small mesa east of Black Mesa consists entirely of these blocks, the original lava sheet having been wholly broken down.

Landslides.—Landslides were observed at many places in the Raton and Brilliant quadrangles, but few of them are conspicuous enough to deserve individual mention. One slide on the southeast slope of Horseshoe Mesa has displaced a considerable mass of the sedimentary rock and left exposed a conspicuous cliff, which is shown at the left in Plate VI. Another landslide in the west fork of Schomburg Canyon, in the Brilliant quadrangle, has left exposed the cliff shown in Plates IX and X.

Incipient landslides may be seen at many places, especially along the outcrop of the Vermejo formation in the southeastern part of the Brilliant quadrangle, where the soft shale of the Vermejo formation is crushed by the weight of great blocks broken from the massive conglomerate that rests upon it. In some places these blocks have so crushed and displaced the beds of shale and coal of the underlying Vermejo that the true character of the beds can not be determined from surface exposures. This conglomerate does not weather as readily as the neighboring rocks, and some of the canyon sides are covered with boulders derived from it.

Stream gravel.—In a few places beds of waterworn gravel cap low buttes and terraces in the canyons and on the lowlands. A small group of these gravel beds lies southeast of Raton. One of these beds, in the southern part of the Raton quadrangle, stands at an altitude of 6,294 feet, about 100 feet above the present bed of the river which doubtless deposited the gravel. Several of the low hills in the Koehler quadrangle are capped with beds of waterworn gravel, and considerable areas in the Cedar Hills and an area east of Canadian River are capped with cemented beds of coarse gravel and angular fragments of rock.

Alluvium and wind deposits.—In relatively recent time sheets of alluvium have been spread out by the streams along their courses through the lowlands and in the broad mouths of the canyons, but at present most of the streams occupy deep trenches cut in these sheets. These trenches expose the alluvium to thicknesses of 20 feet or more. At many places in these quadrangles there is little distinction between surface wash and alluvium. There seems to be a complete gradation from the silty deposits that are typical of flood-plain deposition to the mixtures of soil and rubble deposited by the floods which follow the short, violent showers or "cloudbursts."

It is also impossible to distinguish clearly between water-laid and wind-laid deposits. The surface of the lowlands in these quadrangles, like that in the Great Plains generally, is at many places covered by fine material that resembles loess

and that has sometimes been called "mountain loess." The deposits of this material in these quadrangles are at some places obviously alluvium, but at others they doubtless consist of wind-blown dust. The surface in this region is not well protected by vegetation, and strong winds frequently shift great quantities of fine material as dust, which as it settles mingles with other deposits to form the veneer of loose material that covers most of the lowlands. However, there are no very thick deposits of wind-blown material in these quadrangles, and probably the same dust is lifted again and again and shifted from place to place with only minor geologic results.

IGNEOUS ROCKS.

By J. B. Mertie, Jr.

GENERAL FEATURES.

The igneous rocks of the Raton, Brilliant, and Koehler quadrangles are of considerable interest for three reasons—first, because of their connection with the geologic history of this region; second, because of the observed relations between the manner of their intrusion and extrusion and the tectonics of the region; and third, because of possible variations in the chemical and mineral composition of the different lavas, due to magmatic differentiation. An adequate exposition of the igneous geology should be more than a mere description and comparison of the igneous rocks in these quadrangles; it should include references to features of the igneous rocks of adjacent areas, though only the rocks of these quadrangles need be described in detail.

If classified according to their mode of origin the igneous rocks may be divided into two general types—the intrusive and the extrusive. These two types, however, are by no means sharply defined, for some of the intrusive bodies are dikes, which fill fissures that served as conduits for the lava in its passage from its underlying reservoirs to the overlying sheets. In some of these dikes the two types grade into each other, but other dikes, and probably also the sills, were not formed of extrusive lava but are abnormal products of igneous intrusion, their character being due in part to physical differences in manner of intrusion and solidification and in part to original differences in the composition of the lavas.

The extrusive lavas in the area under discussion may be subdivided into groups according to their ages, but the intrusive rocks can not be thus subdivided, and they are therefore classified according to differences in manner of intrusion and solidification. A further subdivision of the dikes and sills that show markedly the effects of the differences is made according to their chemical and mineral composition.

ERUPTIVE ROCKS.

BASIS OF SUBDIVISION.

The lavas in these quadrangles are found on the mesas, but some of the younger lavas in areas farther east are found on the floors of the valleys. Nearly all the oldest lavas are on the highest mesas, and nearly all the younger ones are on the lower mesas. After the first flows were poured out parts of the surface were eroded, and these parts were in turn covered with younger lavas. In this way three general periods of volcanism are indicated in the Raton and Brilliant quadrangles. A fourth period, represented by the youngest lavas of the region, is indicated in the area east of these quadrangles. During each of the three periods there were many flows of lava, but the intervals between the flows were short in all except the third period. Certain obvious differences in the character of the lavas also justify their subdivision into groups corresponding with the four periods of eruption. One minor interval of erosion during the third period has been recognized, and the petrographic differences between certain lavas of this period indicate that there may be other intervals that are not yet recognized.

FIRST PERIOD OF ERUPTION.

EXTENT AND CHARACTER OF FLOWS.

The oldest lavas are found on Barilla Mesa and at the west end of Johnson Mesa. The flows range in thickness from 100 to 500 feet and consist of a number of sheets. The variation in total thickness is due in part to erosion, but the minimum thickness occurs where the flows are fewest. If the variation in thickness were due to uneven original distribution of the lava the number of flows would doubtless be nearly the same in all places, for the lavas were highly fluid and probably spread rapidly over the country.

The flows are separated by scoriaceous material, which represents the rapidly cooled surfaces of the ancient lavas. On the north side of Barilla Mesa five separate sheets of lava have been distinguished, and in the west face of Raton Mesa, north of these quadrangles, there are at least eleven sheets. The flows seem to have occurred in rapid succession—as rapid, perhaps, as those of Vesuvius.

These older lavas were extruded chiefly through fissures. Many dikes formed in this way are found in the area surrounding the mesas. Their trend is in general east and west, differing at only a few places more than 20° from the normal trend. At some places, however, the lava seems to have been erupted through volcanic vents rather than through fissures, for low volcanic cones occur on both Barilla and Johnson mesas.

PETROGRAPHY.

The most striking feature of the lavas poured out during the first period of eruption is their marked similarity in chemical and mineral composition and in texture. Examination of a large number of specimens of the different flows indicates that there is a common type to which these lavas conform in all except a few details, so that a composite description of them will represent the mean of the specimens examined.

The hand specimens are ash-gray to dark-gray, compact to vesicular rocks, and some of them contain phenocrysts that appear as numerous red specks scattered through the rock, the largest 2 millimeters in diameter. These phenocrysts are iddingsite, which was derived from olivine. The groundmass is generally aphanitic.

Under the microscope these rocks are invariably porphyritic, and the phenocrysts are considerably less abundant than the groundmass. The altered phenocrysts of olivine are of a reddish-brown semitranslucent material and contain numerous inclusions of magnetite. The reddish-brown mineral grades into pleochroic varieties, which are believed to be iddingsite. The euhedral and equant outline of the original olivine crystals is well preserved, showing that the iddingsite is a true pseudomorph after olivine. The alteration of the olivine is usually complete, but sufficient of the core of some of the crystals is preserved to show its original character.

The groundmass is holocrystalline and has a fine-grained doleritic fabric. The essential minerals are plagioclase, pyroxene, altered olivine, and magnetite. The plagioclase is the variety labradorite and occurs as subhedral prismatic crystals, none more than 0.5 millimeter in greatest diameter. The pyroxene is augite and occurs in short, chunky greenish-yellow nonpleochroic prisms, the largest 0.1 millimeter in diameter. The magnetite is in the form of euhedral equant crystals, the largest 0.5 millimeter in diameter. Apatite in pale-green needles having a maximum length of 0.6 millimeter is the only accessory mineral. In a few of the vesicular varieties some of the gas cavities are filled with calcite.

All these rocks are true olivine basalts. Volumetric mineral analyses of nine specimens of the lavas of the first period were made by the Rosiwal method. The percentage of apatite, which in none of the analyses exceeds 1 per cent, was distributed among the percentages of other minerals, and these were recalculated to 100 per cent. The maximum, minimum, and average mineral composition, as determined by this method, is shown below.

Percentage of principal minerals in lavas of first period of eruption.

	Maximum.	Minimum.	Average.
Labradorite	57	33	46
Augite	52	24	29
Magnetite	13	2	8
Altered olivine	23	9	17

The average of these nine mineral analyses is thought to be fairly representative of the lavas as a whole. A chemical analysis of one specimen of these lavas is given on page 11.

SECOND PERIOD OF ERUPTION.

EXTENT AND CHARACTER OF FLOWS.

The lavas of the second period are found on Bartlett, Horse, and Horseshoe mesas and on the northern part of Johnson Mesa. When they were poured out the older lavas had been eroded away in part, and the younger flows, which seem to have been slightly less viscous than the older ones, were spread out evenly over wide areas, covering, perhaps, more ground than had been covered by the older sheets. Owing to erosion the younger sheets lie at lower elevations than the older ones and in some places abut against the rocks that underlie the older lavas. (See fig. 7, p. 4, and Pl. V.) During this period there were fewer separate flows than in the former period. There were still fissure eruptions, but several volcanic cones like the one on Bartlett Mesa were formed.

PETROGRAPHY.

The lavas of the second period of eruption, like those of the first period, are very much alike in appearance, composition, and habit. Like those of the first period, they range in color from light gray to dark gray and include both compact and vesicular varieties. They are universally porphyritic, but in the hand specimens the only phenocrysts commonly visible are crystals of altered olivine. The groundmass is aphanitic.

The microscope shows phenocrysts of augite, olivine, and, rarely, of biotite. The phenocrysts of olivine, which are rather well formed, attain a maximum diameter of 2.0 millimeters and contain inclusions of magnetite. The alteration to iddingsite is general in these rocks, but it has not progressed so far as in the older lavas. The center of the olivine is almost invariably unaltered or is altered only along cracks that penetrate the crystals. Augite occurs in yellowish-green phenocrysts, the largest of which have a diameter of 1.0 millimeter. The crystals of augite, like those of olivine, contain inclusions of magnetite, but the inclusions are not so numerous.

The groundmass is holocrystalline and consists essentially of labradorite (in laths up to 0.4 millimeter in length), augite, olivine, and magnetite, and accessory apatite. Calcite fills some of the vesicular cavities.

The lavas of the second period of eruption, like those of the first period, are olivine basalts. The following tables show the average mineral composition, and maximum and minimum variation from the mean, as computed by the Rosiwal method from seven typical lavas of this period. Three of these specimens were obtained from the lavas in the area east of the Raton quadrangle.

Percentage of principal minerals in lavas of second period of eruption.

	Maximum.	Minimum.	Average.
Labradorite	57	36	46
Augite	38	26	33
Magnetite	17	5	9
Altered olivine	20	8	12

The average of the seven volumetric analyses represents the average mineral composition of the lavas of the second period of eruption. A chemical analysis of one specimen of these lavas is given on page 11.

THIRD PERIOD OF ERUPTION.

EXTENT AND GENERAL CHARACTER OF THE LAVAS.

The lavas of the third period occur on Hunter Mesa, Meloche Mesa, Yankee "Volcano," Round Mesa and Black Buttes (including Black Mesa and Cunningham Butte), Towndrow Peak, Johnson Mesa, and other mesas east and south of the Raton quadrangle. The flows were not so large as the older ones, and the lava issued from many widely separated vents, although some was extruded from fissures. Unlike the older lavas, those of the third period occur at different altitudes; some are on low mesas, as those of Black Buttes; others are on high mesas, as those of Towndrow Peak, on Johnson Mesa. Many of the differences in altitude, but not all, may be due to erosion between flows. Some of the openings from which the lavas were extruded were on the high mesas, so that certain high-altitude lavas may be of the same age as those on the lowlands. Also there are several different kinds of lava in this group, as described below. The group will doubtless be subdivided when a wider knowledge of the igneous rocks of this region is obtained. Until that time the lavas may for convenience be grouped together thus loosely, and the flows may be described separately.

DETAILS OF THE SEVERAL FLOWS.

Hunter Mesa.—There are at least three kinds of lava on Hunter Mesa and probably a greater number of flows. In the saddle that separates Hunter Mesa from Johnson Mesa there are two kinds of lava, a haüynite basalt and an ordinary olivine basalt, but the relative ages of these two flows have not been ascertained. Haüynite basalt has also been observed on the east side of Hunter Mesa, in Hunter Canyon, so that it has a considerable lateral extent. Lava of both these types probably flowed southward from Johnson Mesa. Just above these lavas lies a mass of augite andesite, which forms the upper and major part of Hunter Mesa. The low hill at the north end of Hunter Mesa is the northern limit of the augite andesite. The basaltic rocks, then, marked the beginning of the volcanism which formed Hunter Mesa, and the flows of augite andesite occurred later. There is no means of estimating the time that elapsed between the extrusion of the basaltic rock at the base of Hunter Mesa and that of the augite andesite which forms the top of the mesa, and it is even possible that the two flows may have been synchronous.

The haüynite basalt in the saddle at the north end of Hunter Mesa is a very dark gray porphyritic vesicular rock, containing phenocrysts of pyroxene and olivine as much as 2.0 millimeters in diameter. The groundmass makes up most of the rock and is aphanitic.

The phenocrysts are augite, olivine, and haüynite. The augite occurs in greenish-yellow crystals, which carry inclusions of magnetite. The olivine is fresh and colorless in part, but along the edges and cracks much of it is altered to iddingsite. It also contains inclusions of magnetite. The haüynite, which was not observed in crystals larger than 0.5 millimeter in diameter, has two distinct sets of planes of cleavage, which stand at right angles to each other. Magnetite, apatite, augite, olivine, and red serpentinous material appear as inclusions, generally in the centers of the crystals. The crystals of haüynite have remarkably clear edges, but at some distance from the edges of each crystal there is a circular opaque zone which may extend to the center.

The groundmass is composed of labradorite, augite, magnetite, apatite, and nepheline. The nepheline forms a faintly birefringent interstitial cement.

A volumetric mineral analysis under the microscope gave augite, 61 per cent; magnetite, 13 per cent; olivine, 10 per cent; labradorite, 8 per cent; haüynite, 5 per cent; and nepheline, 3 per cent. The most striking feature of this rock is the scarcity of plagioclase.

The haüynite basalt on the east side of Hunter Mesa, in Hunter Canyon, is probably a part of the same flow, for it has the same general appearance under the microscope as the haüynite basalt just described. Nepheline was not observed in this specimen, and the percentage of plagioclase was small.

The olivine basalt, which is associated with the haüynite basalt at the north end of Hunter Mesa, is a very fine grained basaltic rock of normal type. The olivine, which forms the only phenocrysts, is altered along the edges and cracks to a yellowish nonpleochroic serpentinous product.

The augite andesite, which forms the upper part of Hunter Mesa, is a pinkish-gray, somewhat pumiceous, aphanitic rock. Under the microscope it is seen to have a hypocrystalline porphyritic habit. It contains phenocrysts of basaltic hornblende, the largest of them 2.0 millimeters in size.

The basaltic hornblende occurs as subhedral prisms, pleochroic from green to brown, and contains many inclusions of magnetite. Black alteration rims are common.

The groundmass consists of feldspar, augite, magnetite, olivine, and glass. The plagioclase is andesine in subhedral laths. A little orthoclase, not unlike the andesine in habit, is also present. The olivine is somewhat altered. Analcite occurs as a cavity filling.

A volumetric mineral analysis under the microscope showed andesine, 45 per cent; augite, 35 per cent; magnetite, 6 per cent; glass, 6 per cent; basaltic hornblende, 4 per cent; analcite, 3 per cent; and olivine, 1 per cent. The rock has been named an augite andesite because of the andesitic character of the plagioclase feldspar.

Meloche Mesa. — Meloche Mesa is somewhat lower than Hunter Mesa and is connected with it by a narrow ridge. The rock which forms Meloche Mesa is about the same as that which forms the upper part of Hunter Mesa, and the two extrusions of lava may have been roughly contemporaneous.

The highest point on Meloche Mesa is at its south end, whence the lavas are supposed to have come. At this point the igneous rock, which is exposed in a steep cliff, extends from the surface downward as a stock or volcanic neck. Certain bedded volcanic material, which underlies the lava at the southeast side of Meloche Mesa, rests on an eroded surface about 700 feet lower than the south end of Johnson Mesa. This relation gives an idea of the difference in age between this lava and that on Johnson Mesa, which belongs in the oldest group.

The lava of Meloche Mesa is chiefly andesitic. Several specimens collected from different parts of the mesa show a slight difference in mineral composition. A chemical analysis has been made of one specimen of this lava. (See p. 11.)

A typical specimen of this lava is a light-gray vesicular rock, with black phenocrysts of basaltic hornblende. The groundmass is aphanitic. The microscope shows that it is a dominantly crystalline rock carrying few phenocrysts. The phenocrysts are exclusively pseudomorphs after basaltic hornblende. Most of the hornblende crystals have been entirely altered to a black, opaque substance, which appears red on thin edges. The centers of a few of the crystals show two minerals, one yellow and the other colorless. The yellow mineral may be included augite, but the colorless one is probably of secondary origin. This alteration is thought to be of magmatic origin.

The groundmass consists of feldspar, augite, altered olivine, magnetite, apatite, and glass. The feldspar consists largely of prisms of andesine, but a little orthoclase forms an interstitial cement. The augite occurs as very small greenish-yellow prismatic crystals, the largest not exceeding 0.07 millimeter in size. The glass is colorless to yellow. Some analcite fills cavities.

A volumetric mineral analysis, under the microscope, shows feldspar, 45 per cent; augite, 35 per cent; altered olivine, 7 per cent; glass, 5 per cent; magnetite, 4 per cent; hornblende, 2 per cent; analcite, 2 per cent.

Other specimens of the lava of Meloche Mesa show certain variations. Some are holocrystalline. In two specimens hornblende was entirely lacking; in another it was more plentiful than the pyroxene. In this specimen the hornblende was quite unaltered and showed a strong pleochroism from brown in one direction to greenish and almost colorless in another. The feldspar is of variable character also. The plagioclase usually has nearly the composition of andesine, but the interstitial feldspar is more often oligoclase than orthoclase.

At the north end of Meloche Mesa there is also an olivine basalt, which is a fresh-looking rock that contains phenocrysts of olivine and augite. Its relation to the andesitic rocks is not known.

Mesa east of Meloche Mesa.—At the north end of Meloche Mesa stands a low, craggy hill, which represents an orifice from which issued the lava that forms the low mesa east of Meloche Mesa. This mesa, which lies mainly east of the Raton quadrangle, is about 500 feet lower than Meloche Mesa, and this vertical distance is believed to represent the erosion which took place in the interval between the formation of the two lava caps.

The lava of this mesa, like that of Meloche Mesa and the upper part of Hunter Mesa, is mainly an augite andesite. The rock is very light gray, in most places dense but in some places vesicular. It is holocrystalline and nonporphyritic and has a fine-grained hypidiomorphic granular fabric. The component minerals are andesine, orthoclase, augite, magnetite, and apatite. The andesine and subordinate orthoclase fill the interstices between augite and magnetite.

A volumetric mineral analysis of this lava shows feldspar, 60 per cent; augite, 30 per cent; magnetite, 9 per cent; and apatite, 1 per cent. A chemical analysis of the rock is given on page 11.

A specimen of haüynite basalt, almost identical with that collected from the base of Hunter Mesa, has also been taken from the mesa east of Meloche Mesa. The relation of this rock to the andesitic lava is not known.

Sierra Grande.—Sierra Grande, a prominent volcanic mountain surrounded by many lava flows which have issued from it, stands about 20 miles southeast of the southeast corner of the Raton quadrangle. It is referred to here because several specimens collected from this volcanic mass have been identified as pyroxene andesites, a rock type common in the third period of eruption. This mountain has had a long and complex igneous history, and it has probably been a center of volcanic activity at many times since the beginning of volcanic action in this region. Its andesitic lavas may have been poured out during the third period of eruption, but the almost complete destruction of its crater by erosion and the deep trenching of its sides harmonize better with the idea that its lavas belong to an earlier period of eruption.

Towndrow Peak.—Towndrow Peak, on Johnson Mesa (see Pl. VII), consists of lava which broke through the basaltic cap of the mesa and spread out to its present position. The high angle of slope of this peak is good evidence of the extreme viscosity of the lava. The glassy character of the lava is further proof of its great viscosity. The absence of scoriaceous material indicates a lack of explosive violence, the lava probably having been squeezed quietly out upon the mesa from a central vent.

This lava, which is designated a hornblende dacite, differs considerably from any of the rocks so far described, but it is almost identical with that which forms Cunningham Butte. The lava of Cunningham Butte is known to be older than the basalt of Black Mesa, and the lava of Towndrow Peak is unquestionably younger than that which caps Johnson Mesa. There is no means of ascertaining, at least within the Raton quadrangle, the relative age of the lava of Towndrow Peak as compared with the lavas of Hunter or Meloche mesas.

The lava from Towndrow Peak is pure white when fresh but weathers reddish. It is compact and megascopically porphyritic, the phenocrysts being feldspar and hornblende. The groundmass is dense and aphanitic.

Under the microscope the lava is seen to have a vitrophyric habit. The feldspar is andesine and ranges in size from a maximum of 3.0 millimeters down to tiny crystals in the glassy matrix. Zonal growths are common, but the variation in composition indicated by the different extinctions in these zones is small. A few inclusions of magnetite were noted. The crystals of hornblende, which are of the basaltic variety, attain a maximum size of 5.0 millimeters and grade into much smaller crystals set in the glass. The subhedral prisms are pleochroic, in tones of green and brown. There are numerous inclusions of magnetite, and magnetite also occurs in the glassy base. The glass is colorless to dusty brown.

By volume the proportion of minerals in this rock is glass, 67 per cent; feldspar, 21 per cent; basaltic hornblende, 10 per cent; magnetite, 2 per cent.

The chemical analysis of a rock from Red Mountain, farther east on Johnson Mesa, which is identical with the rock from Towndrow Peak, when calculated into normative minerals, shows the presence of nearly 22 per cent of quartz and almost 18 per cent of orthoclase. There is no trace of these minerals in the rock mode. This amount of normative quartz shows that the rock is dacitic and not andesitic, as the microscopic examination would suggest.

Yankee "Volcano."—The base of the lava that forms Yankee "Volcano" is about 1,000 feet lower than Johnson Mesa, and this difference in elevation represents the amount of erosion that took place from the time of the extrusion of the lava of Johnson Mesa and the outpouring of the Yankee flow. From this relation it appears that this lava is probably younger than the lava of either Hunter or Meloche mesas. At least two different flows, and probably more, have issued from Yankee "Volcano," for two widely different rock types have been recognized among the lavas.

One of the specimens from Yankee "Volcano" is a quartz-bearing olivine basalt. It is a dark-gray, somewhat vesicular rock that has a general aphanitic appearance. Under the microscope it appears as a somewhat glassy, porphyritic rock. Olivine, augite, and quartz constitute the phenocrysts. The quartz occurs as corroded grains that show numerous internal cracks. At the outer edge of the crystals there is a resorption rim, composed of a zone of augite needles, radially arranged with respect to the center of the quartz.

The groundmass is composed of plagioclase, augite, olivine, magnetite, and glass. The plagioclase is scarce, and forms an interstitial cement, the individual crystals not exceeding 0.05 millimeter in size. The augite and olivine of the groundmass have the same general characters as those of the phenocrysts. The glass is colorless to yellow.

The volumetric analysis of minerals in this rock shows augite, 55 to 65 per cent; glass, 5 to 15 per cent; magnetite, 11 per cent; feldspar, 9 per cent; olivine, 8 per cent; and quartz, 0.5 per cent.

The other specimen from Yankee "Volcano" is a nepheline basalt. It is a dark-gray compact rock, of holocrystalline porphyritic fabric. The phenocrysts, which are olivine and augite, have the same habit as those in the specimen described above. The groundmass, however, is lacking in feldspar, being composed of augite, nepheline, and magnetite. The nepheline is anhedral and fills the interstices between the other rock-forming minerals.

The mode of this rock, as determined by the Rosiwal method, is augite, 61 per cent; nepheline, 11 per cent; magnetite, 8 per cent; olivine, 10 per cent; and glass, 10 per cent.

Black Mesa and Round Mesa. — Although the lava caps of Black Mesa and Round Mesa are lower than Yankee "Volcano," the lavas are probably of about the same age, the difference in altitude of 650 feet being due to the ancient slope of the surface. There are two kinds of rock on these mesas. Black Mesa and its neighbors are covered with basalt and Cunningham Butte with dacitic rock. Fragments of the dacitic rock are included in the basalt, from which it follows that the basalt is younger than the dacite and presumably younger than the flow at Towndrow Peak, which consists of closely related rock.

This basaltic lava forms a dense dark-gray porphyritic rock, with an aphanitic groundmass. The phenocrysts consist of olivine, augite, and labradorite. The crystals of olivine attain a maximum size of 3.0 millimeters and have the habit usually developed and previously described. The olivine is very little serpentinized. The crystals of augite do not exceed 0.7 millimeter in size and are developed in chunky prisms. Labradorite that shows magmatic resorption occurs in crystals as much as 1.5 millimeters in length.

The groundmass consists of labradorite, augite, magnetite, and glass in a fine-grained basaltic fabric. The glass is colorless to yellowish-brown.

A mineral analysis of a specimen from Black Mesa shows the rock to contain augite, 60 per cent; labradorite, 13 per cent; olivine, 11 per cent; magnetite, 11 per cent; and glass, 5 per cent. The rock is a normal type of olivine basalt.

Cunningham Butte.—Although Cunningham Butte, stands in the midst of the Black Buttes, the group of buttes that surrounds Black Mesa, it consists of rock different from that of its neighbors. It is an elongated plug, connected at both ends with a dike which runs northwest and southeast. The top of the butte is probably a remnant of a surface flow.

In the hand specimens, this rock is similar to that from Towndrow Peak. It is light in color, almost white when fresh, and alters reddish. It is noticeably porphyritic, and the phenocrysts are mainly hornblende and subordinately plagioclase.

Under the microscope much glass is apparent. The hornblende is a green variety and has no pleochroic tones in brown like those of the rock from Towndrow Peak. It occurs in euhedral prisms. The plagioclase, which is developed largely in the groundmass, has nearly the composition of andesine and here and there shows rims of oligoclase. It has the form of subhedral, poorly terminated laths. Analcite in six-sided forms that show a marked tendency toward a rounded outline is also present. This mineral appears to be primary but may have been formed shortly after the solidification of the rock. Iron oxides in euhedral and subhedral grains are accessory.

Although no quartz has been observed in this rock, its general resemblance to the dacite of Towndrow Peak is so marked that quartz probably constitutes some of the rock glass. The term dacite, rather than andesite, is therefore applied.

Green Mountain flows.—About 3 miles east of Round Mesa, at the southeast corner of the Raton quadrangle, there is some siliceous igneous rock which forms the northern extremity of a series of lava flows that came from Green Mountain, to the southeast.

Some of the lava from this vicinity shows distinct flow lines (see Pl. XII) and has much red glass distributed in irregular patches along a general trend parallel to the flow lines, which gives it a banded appearance.

Owing to the large quantity of glass in the mode of these rocks their petrographic family can not be determined without a chemical analysis. They resemble so much the other dacitic rocks, however, that they too are probably dacites.

The lava 5 miles east of Round Mesa is a light-colored rock, similar in general appearance to that of Cunningham Butte and Towndrow Peak. It is a porphyritic rock that contains phenocrysts mainly of plagioclase. The composition of the plagioclase, as in the specimens from Towndrow Peak and Cunningham Butte, is andesine. The groundmass is composed of plagioclase, hornblende, a very little magnetite, and about 50 per cent of rock glass. The hornblende, which is a basaltic variety, has a small extinction angle and occurs as slender prisms. Most of the glass is clear and colorless and has an index of refraction noticeably lower than Canada balsam. In this glass there are irregular patches of cloudy glass, which possibly represent incipient devitrification. Alteration to calcite has taken place along cracks that permeate the glass in an irregular pattern.

FOURTH PERIOD OF ERUPTION.

Within the general volcanic field east of the Raton quadrangle the flows of a fourth period of eruption lie on the valley floors. These flows came from volcanoes of the central type. Most of the craters are well preserved, and their cones are but little incised by erosion. It is apparent that this latest manifestation of volcanism is very recent. The last flows probably occurred less than a thousand years ago.

There are no lavas of this latest period of eruption within the Raton, Brilliant, and Koehler quadrangles, but a short distance to the east many volcanic cones were formed during this period. The largest and probably the most perfectly preserved of these cones is Mount Capulin, about 5 miles southwest of Folsom, N. Mex. The lava from this volcanic cone is a vesicular and glassy olivine basalt, but other types of lava are known from these latest volcanoes.

COMPARISON OF LAVAS OF THE FOUR GROUPS.

MINERALOGIC DIFFERENCES.

The different kinds of igneous rocks attributed to the three eruptive periods in the Raton and Brilliant quadrangles have already been described. The lavas of the first two periods are basalts that closely resemble one another. The percentage of feldspar is about the same in both. In the lavas of the second period there appears to be a slight increase in the amount of pyroxene and a correspondingly slight decrease in the amount of olivine, but these differences are too small to have any significance. The chief difference between the two types is textural, for the lavas of the second period contain, in addition to phenocrysts of olivine, phenocrysts of pyroxene and, in a few specimens, of biotite. Moreover, in the flows of the second period the olivine, both of the phenocrysts and groundmass, is less altered.

The lavas of the third period show great variation as compared with one another, and they also differ greatly from the lavas of the first and second periods. Thus there have been recognized among the lavas of the third eruptive period pyroxene andesite, olivine basalt, haüynite basalt, hornblende dacite, quartz-bearing olivine basalt, and nepheline basalt. The olivine-bearing rocks of this period show still less alteration of the olivine than the lavas of the second period of eruption. In comparing the olivine basalt of the third period of eruption, such as that at Black Buttes and Round Mesa, with the olivine basalt of the second period, it should be noted that olivine, augite, and plagioclase all occur as phenocrysts in the lavas of the third period, whereas only olivine and augite with occasionally biotite were observed as phenocrysts in the lavas of the second period. It therefore appears that among the olivine basalts of this region there is a progressive development of phenocrysts from the lavas of the oldest to those of the youngest flows, olivine developing first, olivine and augite next, and olivine, augite, and plagioclase last. There is no chemical basis for this relation, because the oldest basalts were the richest in plagioclase and the youngest the poorest. It is therefore not likely that these phenocrysts represent an excess over a ternary eutectic ratio. More probably they originated deep within the earth, and they point to a longer period of cooling prior to the extrusion of the lavas of the latest flows.

Another point of difference between the basalts of the three eruptive periods is the progressive fineness of grain and the development of glass in the mode during the volcanic eruptions in this region. The lavas of the earliest flows have a doleritic habit, those of the second period are somewhat finer in grain, those of the third period contain some glass, and those of the fourth period, as developed east of the Raton quadrangle, are highly glassy. The latest basaltic lavas seem to have been not much less fluid than the older lavas of similar composition, for the lava that issued from Mount Capulin, east of the Raton quadrangle, and that represents the fourth period of eruption, flowed for miles down the valley of Cimarron River. The later sheets of lava were thinner than the earlier and consequently cooled more quickly, and this fact may account for the differences in the granularity and crystallinity of the two kinds of rock.

Another progressive change from the oldest to the youngest basaltic lavas is an increase in the relative amounts of augite and plagioclase. The lava of the flows of the first and second periods, as shown by the volumetric analyses already given, contains more plagioclase than augite, whereas in that of the flows of the third and fourth periods the reverse is true, the augite predominating over the plagioclase. This difference may be due in part to differences in the chemical composition of the lava, but it is more probably due to the greater power of spontaneous crystallization inherent in augite than in plagioclase, which enabled the augite to crystallize sooner than the plagioclase in the quickly cooling late flows. Hence the glassy material of the later flows probably in large part represents plagioclase.

CHEMICAL DIFFERENCES.

To show the variations in the chemical composition of the lava of the flows seven specimens that were selected as types of the rock of the various flows were analyzed in the laboratory of the United States Geological Survey. The results of the analyses and the theoretical mineralogic composition (norms) of the rocks analyzed are given below.

Analyses and norms of lavas from the Raton Mesa region, N. Mex.

Analyses.

	L512	L515	L541	L542	M15	B15	L571 (a)
SiO_2	51.68	49.73	54.08	53.52	67.98	40.72	53.27
Al_2O_3	15.05	15.46	21.87	17.88	15.53	15.03	15.43
Fe_2O_3	5.22	3.32	5.22	4.21	2.68	5.52	2.43
FeO	5.64	8.14	.88	3.51	.18	6 86	6.50
MgO	5.63	7.20	2.69	3.90	1.47	8.29	6.16
CaO	8.30	9.63	5.53	7.36	3.39	13.95	8.18
Na_2O	3.75	3.30	5.46	5.19	4.53	4.01	3.51
K_2O	1.39	.87	2.88	2.39	3.00	2.34	1.71
H_2O-	.72	.16	.16	.15	.11	.12	None.
H_2O+	.62	.32	.00	.00	1.05	.32	.62
TiO_2	1.54	1.59	.98	1.14	.34	.99	1.30
CO_2	None.	None.	None.	None.	None.	None.	None.
P_2O_5	.45	.42	.91	1.26	.33	1.75	.50
S	------	------	None.	None.	None.	------	------
MnO	.12	.13	.09	.11	.04	.18	.12
	100.11	100.27	100.75	100.62	100.63	100.08	99.73

Norms.

	L512	L515	L541	L542	M15	B15	L571 (a)
Quartz	1.56	------	------	------	21.90	------	1.14
Orthoclase	8.34	5.00	17.24	14.46	17.79	------	10.01
Albite	31.96	27.77	45.59	42.97	38.25	------	29.34
Anorthite	20.02	25.02	21.68	18.07	13.07	16.12	21.41
Corundum	------	------	1.73	------	------	------	------
Leucite	------	------	------	------	------	10.46	------
Nepheline	------	------	.28	.57	------	18.46	------
Diopside	14.71	16.01	------	6.72	1.51	31.36	12.61
Hypersthene	10.84	9.50	------	------	3.00	------	17.34
Olivine	------	7.62	4.76	5.44	------	9.03	------
Hematite	------	------	5.22	------	2.68	------	------
Magnetite	7.66	4.87	------	6.03	------	7.89	3.48
Ilmenite	2.89	3.04	1.82	2 13	.46	1.82	2 43
Apatite	1.01	1.01	2.02	3.02	.67	4.03	1.34

L512. Olivine basalt. First eruptive period. East rim of Barilla Mesa, near Yankee, N. Mex. Symbol, II (III).5.3.4. Andose.

L515. Olivine basalt. Second eruptive period. South rim of Barilla Mesa, at the mouth of Chicorica Creek, Colfax County, N. Mex. Symbol, ¹III.5.3¹4(5). Camptonose.

L541. Augite andesite. Third eruptive period. Meloche Mesa, Colfax County, N. Mex. Synbol, (I) II.5.¹3.4. Andose.

L542. Augite andesite. Third eruptive period. Mesa east of Meloche Mesa, Colfax County, N. Mex. Symbol, ¹II 5.2.(3).4. Akerose.

M15. Hornblende dacite. Third eruptive period. Red Mountain, Colfax County, N. Mex. Symbol, I.¹4.2.4. Lassenose.

B15. Nepheline basalt. Third eruptive period. Flow at Yankee, N. Mex. Symbol, III.(7)8.(2) 3.4. Unnamed.

L571 (a). Olivine basalt. Fourth eruptive period. Mount Capulin, Union County, N. Mex. Symbol, II (III).5.3.4. Andose.

Specimens L512, L515, B15, and L571 (a) were analyzed by George Steiger, and specimens L541, L542, and M15 by J. G Fairchild.

Under the microscope specimens obtained from Towndrow Peak and Red Mountain appear to be identical, but as that from Red Mountain is less weathered it was selected for analysis, though the locality at which it was collected is some distance east of the Raton quadrangle.

Specimens L512 and L515, which represent the flows of the first and second periods of eruption, fall respectively into the families andose and camptonose, but each is transitional toward the other, a fact that confirms the conclusion reached by microscopic examination—that there is little difference between the lavas of the first and second periods of eruption. Specimen L571 (a) also is an andose, grading toward a camptonose, and shows that the lavas of Mount Capulin, the most recent flows, are nearly identical with those of the first two periods of eruption. The close similarity of the lavas of the oldest and youngest flows is also strikingly seen in the similarity of the norms.

Specimens L541 and L542 are respectively andose and akerose, but L541 approaches piedmontose. Specimen L542 differs from L541 mainly in containing a somewhat higher proportion of lime as compared with the alkalies. Though falling in different classes and rangs in the quantitative system of classification, they are nevertheless much alike. Both were determined microscopically as augite andesites.

Specimens M15 and B15 are the two types that show the greatest divergence from the other rocks. Specimen M15 is a rather siliceous rock and is classed as a lassenose, a family that includes many of the granites and rhyolites. This rock contains about 67 per cent of glass, and neither quartz nor orthoclase appear to have entered into the mode, but the chemical analysis shows clearly the silicic character of the rock.

Specimen B15 falls into an unnamed division of the quantitative system—III.8.3.4. Actually, however, this specimen is transitional in both order and rang, as indicated by the symbol III.(7)8.(2)3.4, and is not truly representative of the division to which it is assigned. Hence no name for it is proposed.

The subrangs of six of these norms have the symbol 4, and the seventh is transitional from 5 toward 4. The norms of two other lavas from the area east of the Raton quadrangle, one from Sierra Grande and one from the San Rafael flow, likewise belong in subrang 4. This fact shows the regional predominance of soda over potash, and as the percentage of silica is relatively low, nepheline, haüynite, and analcite have been formed in some of the lavas. The albitic character of the plagioclase feldspars in the intrusive vogesites of the region also indicates the sodic nature of the rocks. In one of the lavas, B15, a very low content of silica has resulted in the formation of normative leucite, though only nepheline was recognized in thin section.

GENETIC DIFFERENCES.

Harker[1] has distinguished two types of volcanic eruptions, one from fissures and the other from central vents, which he correlates respectively with plateau-building and mountain-building movements. Although the Raton Mesa region is essentially a plateau the volcanic eruptions there were not exclusively of the fissure type. In the passage from the oldest to the youngest period of volcanism in the region there seems to have been a progressive increase in eruptions of the central type and a corresponding decrease in those of the fissure type. Even the lava sheets of the oldest eruptions, however, probably did not come entirely from fissures that were opened for long distances, for low volcanic hills with gently sloping sides have been noted on Johnson and Bartlett mesas, and the outpouring of lava of an old eruption is supposed to have been concentrated at these places. The central type of eruption was increasingly developed during the third eruptive period, as illustrated by the volcanic hills at Towndrow Peak, at Yankee "Volcano," at Round Mesa, and at a number of other places south and east of the Raton quadrangle, where volcanic eruptions occurred during this period. The fourth or last period of eruption culminated in the maximum development of the central type of eruption, accompanied by much explosive volcanic action, and most of the later cones therefore consist of tuffaceous and scoriaceous material that stands at a high angle of slope. The lavas of the last volcanic period are also more vesicular than those of the preceding periods, a fact indicating a greater development of magmatic gases. The large amount of gas in these latest lavas may have made the latest eruptions the most explosive.

[1] Harker, Alfred, The natural history of igneous rocks, 1909.

INTRUSIVE ROCKS.

GENERAL FEATURES.

The intrusive rocks in the Raton and Brilliant quadrangles occur in dikes and sills, which invade the rocks of all the sedimentary formations. No larger intrusive bodies are known in these two quadrangles, although such bodies are found in neighboring areas to the north, west, and south. The intrusive rocks of these quadrangles are of two clearly defined types—(1) the basaltic rocks, such as compose the lava sheets already described, and (2) a series of sodic vogesites, which are petrographically distinct from the basalts and which represent the products of extreme magmatic differentiation. There are likewise two well-defined types of rock bodies—(1) dikes and plugs that represent openings through which the lava was carried upward to the surface and (2) dikes and sills that did not reach the surface and therefore had no connection with the flows. The two petrographic types coincide in a general way with the two types of bodies—that is, the basaltic rocks of the dikes that supplied the lava for the flows have about the same composition as the rocks of the overlying sheets and are different from the sodic vogesites of the sills and dikes that are not connected with surface flows. There are other basaltic rocks, however, which occur in both sills and dikes that are not believed to have been directly connected with flows.

BASALTIC INTRUSIVE ROCKS.

OCCURRENCE AND DISTRIBUTION.

In these two quadrangles there are many dikes, plugs, and sills of basaltic rock, of which two general types may be distinguished. The first of these types consists of the larger dikes and plugs, which were connected with the lava flows. Dikes of this kind are relatively scarce, because there were apparently not many fissures through which the lavas of the first and second periods of eruption reached the surface. One of the finest examples of this type is a large dike north of Johnson Mesa, east of the Raton quadrangle, along the Colorado and New Mexico State line. This dike is connected with the east end of Barilla Mesa. Plugs are even less commonly exposed, because, although many of the later flows came to the surface through openings now represented by plugs only a few plugs have been exposed by erosion.

Basaltic rocks of the second type form the small dikes and sills that have been intruded into the sedimentary rocks of this area. These rocks are generally found in or near the coal beds in the Cretaceous and Tertiary strata. Sills of this kind are found in the Van Houten mine in Willow Creek, on the ridge south of Cottonwood Creek, in Coal Creek, and around Red River Peak. Dikes of this kind have been noted in Little Crow Canyon, in Coal Creek, at a place 3 miles northwest of Koehler, at another place 6 miles southeast of Raton, and elsewhere.

PETROGRAPHY.

These basaltic rocks have much the same composition and habit as those of the basaltic flows. The hand specimens consist of dark-gray rocks, generally greenish. As a rule they are holocrystalline and porphyritic, though the phenocrysts are not in all specimens visible to the naked eye. Olivine, pyroxene, and plagioclase are the common phenocrysts, but in many of the more altered specimens the olivine and pyroxene are completely altered to secondary products. The olivine in all the dikes and sills, however, has been altered universally to a green serpentinous mineral, whereas the olivine of the flows has been altered just as universally to the red iddingsite already described.

The groundmass of these rocks is about the same as that of the other basaltic rocks and usually consists of labradorite, pyroxene, and magnetite, with accessory apatite. The groundmass in a sill south of Johnson Mesa included considerable haüynite in the characteristic four and six sided grains with brown, cloudy centers. This sill may have been connected with the flows that form the lower part of Hunter Mesa, already described.

By the substitution of basaltic hornblende for olivine there is a transition between the olivine basalts above described through hornblende basalts to the hornblende-pyroxene vogesites. The hornblende basalts differ from the olivine basalts in the usual absence of olivine and in their intersertal nonporphyritic habit. They differ also from the vogesites in that plagioclase forms a considerable part of the rock mode, and this plagioclase is labradorite and not a sodic variety, such as is found in the vogesites of this area.

A notable feature of these dike rocks, as well as of the vogesitic rocks, is their tendency toward extensive alteration, which produces their greenish color. Many of these rocks are completely altered to a mixture of chloritic and serpentinous products and calcite, and most of them show partial alteration of dark minerals to light chloritic minerals. As the dikes and sills occur along zones of original weakness and have well-marked contacts with the country rock they invaded, these contacts afforded ample channels for the migration of underground waters, which formed solutions that probably caused the alteration noted.

SODIC VOGESITES.

OCCURRENCE AND DISTRIBUTION.

The sodic vogesites occur in the same general form as the basaltic rocks of the second type—that is, they constitute sills and dikes in and near the coal measures. Sills of these rocks have been observed in Coal Creek, in Dillon Canyon, on the north side of Canadian River, at the graphite mine in Cottonwood Canyon, and at several places on the sides of Red River Peak. A dike of this kind was also noted in Chicorica Creek.

PETROGRAPHY.

The sodic vogesites are dark-gray to dark greenish-gray compact rocks, some of them rather coarse grained and others almost aphanitic. Almost without exception they are nonporphyritic. Their fabric is in some places almost ophitic or diabasic. More commonly, perhaps, it is granular, and here and there it is intersertal.

The most common essential rock-forming minerals are hornblende, pyroxene, plagioclase, and magnetite. The dark minerals predominate greatly over the plagioclase. The hornblende is commonly more or less altered, but its original character is usually evident. In every specimen examined except one the hornblende is basaltic and showed pleochroism only in tones of yellow and brown. The exceptional specimen showed pleochroism in tones of brown and green. The hornblende is generally in the form of poorly terminated prisms, but some of it is anhedral. The pyroxene is most commonly augite in small chunky prisms, but diopsidic augite also occurs. Like the hornblende, the pyroxene is generally partly altered. Here and there a little biotite is developed in anhedral areas, but as a rule it is much chloritized. The most interesting feature of these rocks is the plagioclase. In five out of eight specimens examined, it was either albite or oligoclase-albite; in two it was either andesine or labradorite; and in the other it was indeterminate. The plagioclase is commonly much sericitized. Apatite in long needles, with the characteristic basal parting, is unusually abundant. Olivine was observed in only one of the rocks, whose plagioclase was andesine or labradorite.

In addition to calcite and the chloritic and sericitic material developed in these rocks some quartz and zeolites are developed as secondary products. One specimen contained spherulitic aggregates resembling prehnite; another contained a zeolite having an index of refraction about the same as that of thompsonite and a birefringence comparable to that of natrolite. In the dike in Chicorica Creek analcite occurs in the groundmass, but whether it is primary or secondary is uncertain.

These rocks, then, are chiefly hornblende-augite sodic vogesites. They seem to be very closely allied to the hornblende-augite vogesites in the Apishapa quadrangle,[1] which lies north of the Raton and Brilliant quadrangles in Colorado.

STRUCTURE.

GENERAL FEATURES.

The sedimentary rocks that crop out in the Raton, Brilliant, and Koehler quadrangles fall into two general classes—those of marine origin and those of nonmarine origin. The older formations, such as the Pierre shale, were deposited in nearly or quite horizontal beds below sea level. Others, such as the Trinidad sandstone, were deposited close to sea level, and still others, such as the Vermejo formation, were deposited on low-lying coastal plains or in coastal swamps. The younger sedimentary beds are of nonmarine origin and were deposited on a slightly inclined plain to which streams brought sediments from the mountains on the west, depositing their loads here and there as they swung laterally over the aggrading plain. These younger beds (the Raton formation) are more varied in character and more complicated in structure than the older ones. They consist of coarse channel deposits, fine-grained flood-plain accumulations, and swamp deposits, interfingering and merging in a complex manner one into the other. Many of the beds are lenticular, and at some places there are unconformities.

The sediments that were deposited on the floor of the sea and on the old coastal plains have since been warped from their nearly horizontal position and raised to maximum altitudes of nearly 8,000 feet above sea level, but the movements were so broad and so regular that they produced no conspicuous structural features in the Raton, Brilliant, and Koehler quadrangles. The major structural features in these quadrangles result from broad flexures, which embrace not only the whole Raton Mesa region but extend far beyond it. Also, they are associated with two or more great orogenic or mountain-forming movements, which affected the whole southern Rocky Mountain region. These movements may be termed the post-Vermejo uplift and the post-Raton uplift.

POST-VERMEJO UPLIFT.

Effect of the uplift.—Some time between the end of the Vermejo epoch and the beginning of the Raton epoch, the beds in this region which had been formed below sea level and on coastal plains were uplifted and exposed to erosion. The same uplift reelevated the mountains west of the Raton Mesa region, whose roots had been covered by marine strata, and raised them so high that such sedimentary beds as may have covered them were in some places removed, so that rocks in the core of the newly elevated range furnished material to the next succeeding formation.

[1] Cross, Whitman, Dike rocks of the Apishapa quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 90, pp. 24-26, 1914.

The erosion that followed this uplift removed from these quadrangles the greater part of the Vermejo formation and all of the later beds that may have been formed there prior to the uplift. Nowhere in the Raton Mesa region can a measure of this erosion be obtained, for at no place is the Vermejo formation completely exposed. It has a maximum measured thickness of nearly 400 feet, and where it has been entirely removed this figure gives the best actual measure of post-Vermejo erosion obtainable in this region. A thickness of more than 1,200 feet of the Vermejo formation remains in the Canon City field, but there also the upper part has been eroded away. It has been shown[1] that the marine Cretaceous formations probably once extended over the mountainous area west of the Raton Mesa region and that they were removed by the post-Vermejo erosion, which would indicate that this erosion must have amounted to several thousand feet. This erosion resulted in the unconformity between the Vermejo and Raton formations in the Koehler and Brilliant quadrangles and in the western part of the Raton quadrangle and in that between the Trinidad sandstone and the Raton formation in the eastern part of the Raton quadrangle, where the Vermejo was entirely removed. The character of this unconformity is shown by the several detailed sections given in the plate of sections.

Age of the uplift.—The post-Vermejo unconformity has been recognized throughout the Raton Mesa region. The youngest beds below it are of Montana (Upper Cretaceous) age and the oldest beds above it are Tertiary. It has been correlated with the post-Cretaceous unconformity of the Gulf region and with the post-Laramie unconformity of the Denver Basin. It is probably a part of the general post-Cretaceous unconformity that has been recognized in many places throughout the Southern Rocky Mountain province.

POST-RATON UPLIFT.

The largest structural features in the Raton, Brilliant, and Koehler quadrangles were formed by an orogenic disturbance that affected the Southern Rocky Mountain province some time during the Tertiary period after the Raton formation had been laid down. The mountains were again lifted, upturning the sedimentary formations, including the Raton, along the foothills. Probably at the same time also were formed the syncline east of the foothills in the Raton Mesa region and the Mesa de Maya dome (figs. 5 and 6, p. 3), which lifted the beds at its center several thousand feet. The Dakota sandstone, which had been covered by about 3,000 feet of marine sedimentary strata, now lies near the center of the dome at altitudes of more than 6,000 feet above sea level. Within the area considered in this folio the younger marine beds (Pierre shale and Trinidad sandstone) outcrop at altitudes ranging from 6,000 to 8,000 feet. Some of this uplift may have taken place at the time of the post-Vermejo movement and some may be the result of minor movements at other times, but the relation of the dome and syncline to the Tertiary planation surface indicates that the uplift took place before the peneplain was completed. In other words the planation was accomplished in middle and late Tertiary time.

The Raton and Brilliant quadrangles lie between the center of the Mesa de Maya dome and the syncline. The strata have a gentle northwesterly dip, ranging from about 150 feet to the mile in the eastern part of the Raton quadrangle to only a few feet in the Brilliant and Koehler quadrangles. The bending of the strata was so regular that it produced few faults, and these few have small displacement. Slight secondary warping of the beds also occurred. In some parts of the Raton Mesa region outside of these quadrangles larger secondary structural features were produced, such as the Morley dome, in the center of which, 4 miles north of the Raton quadrangle, the beds are locally arched several hundred feet.

The most conspicuous effect of this uplift was the production of surface features by renewed erosion. The top of the Mesa de Maya dome was planed off to form the peneplain represented by the tops of the mesas, the uneven surface of which appears at the unconformity between the Raton formation and the gravel beds which underlie the lavas of the high mesas.

The effect of the post-Raton movement on the volcanic activity of the region is not known, but the grouping of the numerous extinct volcanoes and lava flows near the center of the Mesa de Maya dome indicates some relation between the doming and the volcanic activity and suggests that this activity may have originated with the doming movement and that some of the early lava flows may have been removed by erosion. Numerous dikes and sills of intruded igneous rock are found in these quadrangles, some of which differ in composition from the mesa lavas and may be older. There are two distinct types of intruded igneous rock in the area between Willow and Canadian canyons—basalt and lamprophyre. These rocks occur in dikes, which cut the strata, and in numerous sills, which separate or cut diagonally across them, presenting in cross section an intricate pattern of interlacing lines.

[1] Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27-58, 1915.

The small faults produced in these quadrangles are of the normal type. In some places the faulting seems to have been followed by a slight thrust, perhaps a recoil, so that the beds of the hanging wall bend downward as shown in figure 16.

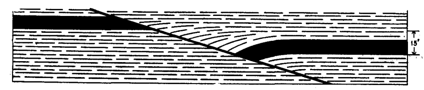


FIGURE 16.—Sketch of normal fault in Willow mine, south of Van Houten.
The coal bed, which has been dropped about 15 feet, is bent downward on the downthrown side of the fault, as if it had been subjected to compression and slight upthrusting after the original faulting.

Similar faults were noted in the mine at Brilliant and in the Willow mine, but most of the faults observed in the mines are ordinary normal faults with displacement of only a few feet.

GEOLOGIC HISTORY.

PRE-PALEOZOIC TIME.

The oldest rocks of the Raton Mesa region, in which the Raton, Brilliant, and Koehler quadrangles are situated, are the crystalline pre-Cambrian rocks that form the core of the mountains to the west. These rocks doubtless extend eastward underneath the surface and form the base on which the oldest sediments of the Great Plains were deposited. Some of the finer grained crystalline rocks may represent ancient sediments, but the coarse-grained granite represents molten magma that cooled below the surface of the earth and was exposed only when the mountains were formed and the surficial rocks removed by erosion.

PALEOZOIC EVENTS.

During a great part of the Paleozoic era large areas of North America were covered by the waters of epicontinental seas, which shifted in position from time to time and in which sediments were deposited. The Raton Mesa region, however, may have remained above sea level in early Paleozoic time or marine sediments may have accumulated there. The second alternative is the more probable, for small remnants of sedimentary beds formed in Cambrian and Ordovician seas are found along the mountain front north of this region and larger remnants are found south of it. In central New Mexico also there are remnants of sedimentary formations of Devonian and early Carboniferous (Mississippian) age, and the Mississippian beds extend northward into Colorado. In early Pennsylvanian time large parts of the southern Rocky Mountain region stood above sea level, and nonmarine deposits accumulated at many places in the region. These deposits contain thin beds of coal, with which are found plants representing an early Pennsylvanian (Pottsville) flora. These deposits were later covered by the sea, in which thick limestones were formed. In the mountains west of the Raton Mesa region layers of limestone alternate with coarser material, which was evidently laid down near the shore.

Later in Pennsylvanian time the beds of limestone and associated rocks were raised above sea level and to some extent eroded, so that in places pebbles of fossiliferous limestone are found in the basal conglomerate of later sedimentary beds. These beds (the Manzano group) were formerly classed as Pennsylvanian, but more recent investigation has shown that they are Permian. They form a part of the "Red Beds" of the southern Rocky Mountain region. Some of them were deposited in the sea and contain marine invertebrates; others, consisting of coarse sand and conglomerate, may represent accumulations on the uplands. The history of the "Red Beds" is long and complicated and has not yet been fully worked out. The detritus from the highlands, which probably occupied about the same place as the present Rocky Mountains, was carried to the lowlands by streams and deposited there, in part as alluvial wash. A part of it was carried beyond these lowlands to shallow shifting bodies of water, some of which may have been saline lakes, though others were arms of the sea. The waters of these bodies evaporated, leaving layers of salt and gypsum, in some places interbedded with shale and in others with limestone containing shells of marine or brackish-water mollusks. The "Red Beds" continued to accumulate through the Permian epoch and into Triassic time.

MESOZOIC EVENTS.

Triassic and Jurassic periods.—Although it is uncertain what part of the "Red Beds" may be Permian, it is certain that some of the fine-grained sedimentary rocks of the upper part of the "Red Beds" accumulated during the Triassic period in waters that were fresh enough in some places to be inhabited by fresh-water clams (unios) and the crocodile-like animals called belodonts. Triassic sedimentation was interrupted by a movement that domed the strata in some places in northeastern New Mexico and may also have lifted the mountains to some extent, for renewed erosion planed off the tops of the domes. The truncated edges of the older strata were later covered with beds of sand, which hardened into the Exeter sandstone. This formation may be of Jurassic age, but no fossils have been found in it. It is well exposed in the walls of the canyons east and south of the Raton Mesa region. There are reasons for believing that the Exeter sandstone of eastern New Mexico was formed at about the same time as the Wingate sandstone of western New Mexico and the La Plata sandstone of southwestern Colorado. At about the same time beds of gypsum and limestone accumulated at some places in northeastern New Mexico and eastern Colorado. Some of these beds have been referred at one time or another to the Triassic and some to the Morrison formation. In northwestern New Mexico and southwestern Colorado, west of the mountains, beds of gypsum and limestone occur in the Jurassic rocks above the Wingate sandstone. Certain beds east of the mountains have the same lithologic character and occur at so nearly the same place in the stratigraphic column that they also may be Jurassic.

Cretaceous period.—Probably in early Cretaceous time the streams of the Rocky Mountain region spread out sediments of many colors and of wide range in composition, from limy mud to sand and even to conglomerate. These beds consolidated to make the Morrison formation, which underlies the Raton, Brilliant, and Koehler quadrangles and crops out on all sides of them. This formation has been found at many localities, from central New Mexico to Montana and from Utah to eastern Colorado. In some places it contains fresh-water shells and the remains of land animals. In many places it contains the bones of gigantic dinosaurs, some of which lived in the swamps and the streams and on the shores of the shallow temporary lakes. The mountains that furnished the coarse sediments of late Paleozoic and early Mesozoic time had been so much worn down by Morrison time that the Morrison formation was deposited over most if not all of the area they formerly occupied.

The stream deposition of Morrison time was probably accompanied by the slow subsidence of a large area in the interior of North America, including the southern Rocky Mountain region. This movement culminated later in the occupation of the interior of the continent by the sea. Later in Cretaceous time the Morrison sediments, which are of varied constitution and color, were covered with sediments that have a uniform constitution and color over a wide area. The lower part of this new material is light colored and consists of relatively pure quartz sand and fine conglomerate. The deposition of this material was followed by that of dark mud, which formed shale, some of it limy. These deposits make up the Purgatoire formation. They show a great change in physical conditions in the region and probably denote a long break in the sequence of deposition between the Purgatoire and the underlying Morrison formations. The change in the character of the deposits marks the advance of the sea over an area which had formerly been occupied by marshy lowlands that lay but little above sea level. The subsidence of the land, which was possibly accompanied by a rise of sea level, had progressed far enough at the close of the Morrison epoch to allow sea water, supposedly from the Gulf of Mexico, to invade the interior of the continent as far at least as the present mountain front. The truncated edges of the Purgatoire formation there upturned indicate that it may once have extended considerably farther. Similar sediments west of the mountains may be of the same age, also the Lakota and Fuson formations of more northerly localities.

The Purgatoire formation was covered in turn by the sand that formed the Dakota sandstone, the name being restricted to the equivalents of the beds so called in southern Colorado. This sandstone is lithologically similar to the basal sandstone of the Purgatoire, and until recently the Purgatoire was regarded as the lower part of the Dakota. The two sandstones may not be essentially different in age and may be regarded as belonging in a single group of strata.

At the beginning of the Upper Cretaceous epoch the Rocky Mountain region had been planed down nearly to sea level. The area considered in this folio was included in the subsiding area, and the sand of the Dakota seems to have been distributed somewhat uniformly over the site of the southern Rocky Mountains. Continued subsidence, possibly intermittent and accompanied perhaps by a rise of sea level, resulted in the formation of the broad interior basin of Upper Cretaceous time. In the waters of this basin were deposited the sand, mud, and limy ooze which hardened into the marine formations of the Upper Cretaceous series, and on its shores accumulated the beds of peat which were later transformed into the Upper Cretaceous coals. The rate of sedimentation in this basin was comparable with the rate of subsidence, and probably at no time was the sea very deep. In many places it was so shallow that sediments were distributed somewhat uniformly over large areas, probably by waves and currents. At times during the Upper Cretaceous epoch parts of the basin were filled with sediments to the limit of marine deposition, and broad coastal plains, which extended from the western shore well out toward the center of the basin, were formed. On these low-lying flats grew the vegetation that formed peat in the broad swamps.

The coal beds and other features that indicate nearness to land during early Upper Cretaceous time occur in the western part of the basin from central New Mexico northward. The Raton Mesa region was covered by an open sea until after the middle of Montana time, when the basin had become nearly filled with sediment, derived mainly from the west. The coarser sediments delivered to the sea were deposited near shore and hardened into the Trinidad sandstone. The finer sediments doubtless accumulated farther off shore, but these have since been eroded away. Along the line of outcrop in the Raton coal field the filling progressed from southwest to northeast. While the sand that formed the Trinidad sandstone was accumulating near Cimarron, southwest of the Koehler quadrangle, the mud that formed the upper part of the Pierre shale was accumulating near Raton, and while the vegetable matter that formed coal was accumulating near Cimarron the sand that formed the Trinidad sandstone was accumulating near Raton. (See fig. 14, p. 6.)

When the sands of Trinidad time had filled the sea in this region to the limit of marine deposition, coastal swamps were formed in which accumulated the vegetable matter that became the Vermejo coal beds. The later events of Cretaceous time in this region are not known, for the evidence of them has been destroyed by erosion. Farther north, however, near Canon City, the fresh-water sedimentation of Vermejo time, interrupted now and then by temporary incursions of the sea, continued until a thickness of 1,000 feet or more of strata had accumulated. Still farther north, in the Denver Basin, the sediments of a formation generally regarded as still younger—the Laramie—were deposited.

POST-CRETACEOUS UPLIFT AND EROSION.

Cretaceous sedimentation was terminated in the southern Rocky Mountain province by a general withdrawal of the sea from the continent. This withdrawal may have been due wholly or in part to a lowering of the sea level, possibly because of some readjustment in the interior of the earth that increased the capacity of the ocean basins, or it may have been due to a rise of the land. The withdrawal of the water was accompanied by a differential movement that lifted the mountain region above the level of the surrounding country. The erosion that followed this uplift gave rise to the post-Laramie unconformity of the Denver region, the post-Vermejo unconformity of the Raton Mesa region, and the post-Cretaceous unconformity of the Gulf Coast. These unconformities are probably local manifestations of a general post-Cretaceous erosion that affected the whole southern Rocky Mountain province.

The diastrophic movement that resuscitated the mountains, whose roots had been buried beneath the Cretaceous strata, changed the Rocky Mountain region from an area of general downwarping to one of general upwarping. It included many local orogenic movements and volcanic eruptions, which seem to have been produced by the same causes that effected the world-wide changes in the distribution of land and sea that have been regarded as marking the end of the Mesozoic and the beginning of the Cenozoic era.

Although the first post-Cretaceous uplift in the southern Rocky Mountain province was significant in that it ended a long period of relative quiescence and began a period of great mountain-making movements and intense volcanic activity, the actual magnitude of the uplift probably was not so great as that of some uplifts which followed. The differential uplift, however, must have amounted to several thousand feet, for the Cretaceous beds that had covered the mountains were eroded from them, in some places exposing the pre-Cretaceous rocks to erosion. All beds that may have been formed in the Raton Mesa region later than those of the Vermejo were removed. The Vermejo also was removed entirely from the eastern part of this region and reduced to a maximum thickness of little more than 400 feet in the western part.

CENOZOIC EVENTS.

TERTIARY PERIOD.

In the Raton Mesa region the post-Cretaceous uplift and erosion were followed by the deposition of the stream and swamp deposits that constitute the Raton formation. This deposition may have been caused in part by local subsidence, possibly in the syncline (fig. 5, p. 3) that had already begun to form. But this subsidence was not enough to allow the sea to return, for no marine beds have been found in the Tertiary formations of this region. At first the streams deposited sand and gravel, which were derived from the highlands on the west, but later they deposited finer sediments, and on their broad flood plains grew the subtropical plants which supplied the vegetable matter that formed the coal beds of the Raton formation.

Tertiary beds that are younger than Raton were possibly formed in this region and later eroded away. Remnants of these beds are found in the northern part of the region, where they form the Poison Canyon, Cuchara, and Huerfano formations. The oldest of these formations were cut by intrusive igneous rocks of the Spanish Peaks eruption, during which were formed great stocks and dikes of granite porphyry, monzonite porphyry, lamprophyre, augite diorite, and perhaps also basalt.[1] Probably at about the same time quartz monzonite porphyry in the form of sills and dikes was injected into the Raton and older sedimentary formations in the southwestern part of the Raton Mesa region. As no rocks younger than Raton occur in this part of the region this intrusion can only be assigned to post-Raton time, but the similarity of these rocks to the intrusive rocks of the Spanish Peaks renders it probable that they were produced by the same volcanic disturbance and were formed not before the end of the Eocene and possibly during the orogenic disturbances that brought the Eocene to a close. The broad domes and synclinal flexures east of the mountains (see fig. 5, p. 3), which involve the youngest consolidated sediments of the region, may also have been formed chiefly through these disturbances. The newly elevated lands were attacked by erosion, which seems to have continued in this region nearly to the close of the Tertiary period. By that time a peneplain had been produced which extended across the beveled edges of the upturned sedimentary rocks. This peneplain may have been coextensive with the Great Plains. A peneplain in northern Colorado formed at essentially the same time has been called the Rocky Mountain peneplain.

QUATERNARY PERIOD.

On the plain just described thin beds of gravel were spread out and over them were poured great floods of lava, remnants of which form the hard basalt caps of the mesas that extend from Raton eastward to Oklahoma and Texas. At the same time large dikes and sheets of igneous rock were in many places formed in the sedimentary rocks. Little direct evidence of the Quaternary age of these gravels and lava flows has been found; they are placed in the Quaternary chiefly because of their physiographic relations.

The opinion formerly prevailed that the mesa lavas of this region are middle Tertiary in age, but there was little real basis for this opinion, and much evidence has been gathered which indicates that the Quaternary period was longer than was formerly supposed. The length of time required for the general degradation of the plains that surround the mesas is of the same order of magnitude as that required for carving out certain mesas in northern Montana which are covered with Pleistocene till and which rise a thousand feet or more above the floor of the neighboring valleys. It is also comparable to the length of Quaternary time as indicated in western Colorado by Pleistocene glacial deposits on divides up to 2,000 feet above the bottoms of canyons tributary to the Grand Canyon of the Colorado.

The beginning of the Quaternary period may have been marked in the Rocky Mountain region by a notable orogenic movement, and one of the results of this movement may have been the outpouring at many places of basaltic lavas. This suggestion finds support in the fact that after the first great flow of lava in the Raton Mesa region the same kind of basaltic lava was extruded in this region again and again down to a time so recent that the youngest cinder cones and flows show little alteration by erosion. The alternation of these periods of eruption with the periods of degradation has resulted in the steplike character of the lava-covered mesas. (See fig. 7, p. 4.)

ECONOMIC GEOLOGY.

The mineral resources of the Raton, Brilliant, and Koehler quadrangles consist of coal, graphite, clay, and building stone. There are slight indications of the occurrence of oil and gas, but these substances have not been found in paying quantities. Other natural resources are the surface and underground waters and the soils.

The field work on which this folio is based extended over several years. In 1908 and again in 1910 work was done near Raton, chiefly for the purpose of classifying coal lands. This work was followed by stratigraphic work that embraced the entire Raton Mesa region and later a still broader area in the southern Rocky Mountain province, the results of which were published in Professional Paper 101 and in other scientific papers cited in this folio. The topographic map of the Raton quadrangle was made in 1911 and 1912, and the maps of the other two quadrangles later. In the meantime the geologic work was progressing, so that much of the data for the folio was transferred to the maps as soon as they were completed. Additional observations were made from time to time as late as 1919. Thus the mined-out areas as shown on the maps should not be interpreted as representing exactly the conditions in the years given on the maps. Some of the mines have been in active operation for years, and the worked-out areas have been gradually enlarged.

Caution should also be exercised in interpreting exact locations with reference to land lines. Only a few of the corners

[1] U. S. Geol. Survey Geol. Atlas, Spanish Peaks folio (No. 71), pp. 3-4, 1901.

fixed by land surveys were located in the field by the map makers. The land lines are fixed on the maps with reference to the corners they found. Thus, though a land line appears straight, yet if it passed through all fixed corners on its course it would not be straight. The land lines shown may therefore lead to error if they are used in making exact locations.

COAL.

OCCURRENCE.

Coal is the most valuable natural resource in these quadrangles, and the only one that has been much developed. It occurs in two formations—a lower one, of Cretaceous age, called the Vermejo formation, and an upper one, of Tertiary age, called the Raton formation. For convenience of reference the lower and best developed coals are described by districts, and the localities are referred to by numbers, which appear on the maps and on the graphic coal sections. The numerous coals are described by groups and beds, and the localities are indicated by numbers.

COAL BEDS OF THE VERMEJO FORMATION.

DISTRIBUTION.

The coal of the Vermejo formation underlies the greater part of the Brilliant quadrangle, the northwestern part of the Koehler quadrangle, and a small area in the northwestern part of the Raton quadrangle. The coal-bearing rocks were removed by recent erosion from a small area in the southeastern corner of the Brilliant quadrangle, from the southern and eastern parts of the Raton quadrangle, and from the greater part of the Koehler quadrangle. The Vermejo formation was also removed by post-Cretaceous erosion from small areas south of Van Houten and near Red River Peak, where the Raton formation now rests unconformably on the Trinidad sandstone. The Vermejo may possibly have been eroded also from areas now wholly covered by the younger rocks in the Brilliant quadrangle, though no such areas are now known. (See fig. 17.)

Koehler district.—The Koehler coal district lies between Saltpeter Creek, in the Koehler quadrangle, and Crow Creek, in the Brilliant quadrangle. In the center of the district, where the main part of the Koehler mine is situated, there is only one bed of coal in the Vermejo formation and it occurs near its base. In the southern part of the district there are two coal beds in this formation. The coal beds south of Curtis Canyon had not been carefully prospected when the writer visited the area. A thick bed of coal occurs in Saltpeter Mountain at locality 1, and a still thicker bed farther north, in Five Dollar Canyon. From Curtis Canyon northward, however, the outcrop has been surveyed, and the coal, which has been opened at short intervals, shows the features illustrated in sections 2–39 in the plate of coal sections. In the northern part of the district the main bed forks. Two beds also occur in Crow Canyon, at localities 38 to 42, but farther east in this canyon only one bed of coal was found, at localities 43–48, and this bed does not extend to Falls Canyon (locality 49).

The variations in the coal bed from place to place and its relation to the neighboring rocks are indicated in the sections, which are arranged in order from south to north along the outcrop and designated by numerals which correspond to the locality numbers on the map. Many of the sections of the coal beds here given are taken from the records of the engineers who surveyed the outcrop and opened the prospects. All the sections were constructed from measurements made in fresh prospect openings, and only such sections of the coal beds are presented as will give a general idea of their structure and their relation to neighboring beds.

The coal beds in the Vermejo formation vary greatly in thickness and character from place to place, because of irregularity of original deposition, which is indicated by variations in the number and position of the partings of shale and impure coal, and because of differences in the erosion of the beds. At localities where the basal conglomerate of the Raton formation appears in the section the coal was partly eroded away before the pebble bed was formed. Thus, at locality 29 more than half of the coal bed was removed.

The Koehler mine is one of the largest producers of coking bituminous coal in the Raton coal field. The character of the bed within the mine differs but slightly from that shown by the sections measured at the surface, and therefore no mine sections are given. The quality of the coal is indicated by four analyses in the accompanying table. The floor of the mine is shale, but the hard Trinidad sandstone lies only a few feet below it. The coal is overlain in some places by shale and in others by the basal conglomerate of the Raton formation.

Willow district.—The Willow coal district lies between Crow Creek and Canadian Canyon, in the Brilliant quadrangle. The coal of the Vermejo formation in this district has until recently been called the Raton coal bed but is now known locally as the Willow bed, a name derived from the mine which opens on Willow Creek at Van Houten. This coal is but little disturbed in the southwestern part of the district, where the main part of the Willow mine is situated, but south of Willow Creek, east of the mine, it was removed by erosion in whole or in part before the deposition of the Raton formation. There is also a large area between North Willow Creek and Canadian Canyon from which the coal was removed by the post-Cretaceous erosion. Little coal is to be expected east of a line connecting localities 48 and 51. Most of the coal in this district north of Willow Creek that escaped this erosion was later destroyed by intrusions of igneous rock. So intense was the metamorphic action that accompanied this intrusion that the coal in Cottonwood Canyon was changed to graphite.

Two beds of coal in the Vermejo formation, which are separated by a maximum measured interval of 24 feet, are exposed in the southwest wall of Crow Canyon. (See section 38 in plate of coal sections.) The upper bed is the thicker one. The lower bed may be an offshoot or "split" from the upper one or it may be a local lens, for it is not recognizable as a separate bed either in Ox Canyon, to the south, or in the north wall of Crow Canyon east of Antlers Canyon. It has a maximum thickness of 2 feet 8 inches. (See section 41 on plate of coal sections.) As its relation to the higher bed is not definitely known the sections representing it have been platted in their correct relative positions in the illustration but set off from the sections representative of the higher bed. Where the outcrop crosses Crow Creek this lower bed is shaly and shows signs of thinning out toward the west. Two drill holes in Crow Canyon, 2,000 feet and 1 mile respectively west of the outcrop, reveal the presence of only one bed of coal, presumably the upper bed.

In the north wall of Crow Canyon the two beds persist as far east as locality 40, but at locality 41 only the lower bed is present, the upper one having been eroded away. However, both beds were found farther north in West Antler Canyon, at locality 42, but only one bed, presumably the upper one, was found at localities east of this canyon. This upper bed is continuous south of Schomburg Canyon as far as the southern border of the quadrangle, but it thins out farther south. It was not found in Falls Canyon (locality 49) nor in the highlands farther east, between this canyon and Van Houten. (See section 50, fig. 17.) In this part of the quadrangle the Vermejo formation is absent and the Raton formation lies unconformably on the Trinidad sandstone.

Farther north, at locality 51, the Willow coal bed reappears between the Trinidad sandstone and the basal conglomerate of the Raton formation. From this locality westward and northward along the outcrop to locality 62 the Willow coal bed ranges in thickness from 6 feet to nearly 15 feet. In the area between these localities the post-Vermejo erosion removed most of the Vermejo rocks that overlie the coal and in some places cut away the upper part of the coal bed but nowhere removed it entirely. The variation in thickness of the coal is due in part to this erosion. North of Van Houten the coal has been destroyed in some places by the intrusion of igneous rock, and although there is much coal in North Willow Canyon no undisturbed body of it is known to be of value under the existing conditions of mining.

The Willow mine is in the southern part of the Brilliant quadrangle, partly north and partly south of Willow Creek. The main openings are in the sides of the canyon, and from them the entries are driven on the bed back into the hills on both sides. This mine became productive in 1902 and has been in operation since that time.

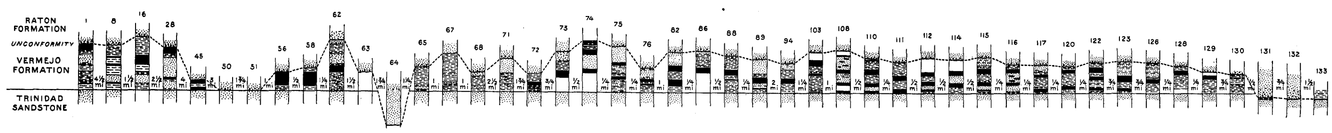


FIGURE 17.—Sections across the Raton, Brilliant, and Koehler quadrangles showing the unconformity at the base of the Raton formation.
Sections are arranged from southwest at the left to northeast at the right and numbers indicate the localities on the economic-geology maps where the sections were measured.

In the Raton quadrangle the Vermejo beds were removed by post-Cretaceous erosion from most of the area east of Raton, where the Raton formation now rests unconformably on the Trinidad sandstone. How much of Bartlett Mesa is underlain by them is uncertain, but their presence north of this mesa as far east as San Francisco Canyon indicates that they may underlie most of this mesa.

The coal of the Vermejo formation was opened first near Raton and was called the Raton coal bed. Later development has proved that there are two beds of economic value and in some places two other thin beds, which, however, have not received separate names. (See sections 107–116 in plate of coal sections and in fig. 17.)

DISTRICTS.

The Vermejo coal of the Raton coal field has been mined in five districts—the Dawson district, which lies chiefly west of the Koehler quadrangle, with a mining center at Dawson, N. Mex.; the Koehler district, which lies in the northern part of the Koehler quadrangle and the southern part of the Brilliant quadrangle, with a mining center at Koehler; the Willow district, in the Brilliant quadrangle, with a mining center at Van Houten; the Blossburg district, which lies on both sides of Dillon Canyon, partly in the Raton quadrangle and partly in the Brilliant quadrangle; and the Raton district, which is wholly in the Raton quadrangle.

Dawson district.—The underground workings of the mines at Dawson extend eastward into the Koehler quadrangle and may eventually be extended as far as Saltpeter Creek, which is regarded as the line of separation between the Dawson and the Koehler districts. There are no mine openings and few prospects in the part of the Dawson district that lies in the Koehler quadrangle.

The coal mined at Dawson is the lowest and thickest of several beds in the Vermejo formation, but it becomes thinner and more shaly toward the east and is represented in Saltpeter Mountain by a coal bed only a few inches thick. One of the higher coal beds of the Vermejo, perhaps a 3-foot bed about 38 feet above the one mined at Dawson, becomes thicker eastward and contains 5 feet 6 inches of coal in Saltpeter Mountain. It is not certain which of these coal beds is to be correlated with the bed mined in the Koehler district, but the position of the Koehler coal at the bottom of the Vermejo suggests that it corresponds to the lower bed in the Dawson district.

The roof of the mine differs from place to place, ranging from shale or bony coal to the massive conglomeratic sandstone that constitutes the base of the Raton formation. This sandstone rests on the coal at some places where the shale of the Vermejo formation, which normally overlies the coal, was removed during the post-Vermejo erosion. At places where the shale was not thus removed it remains between the coal bed and the conglomerate. This roof shale has a reported maximum thickness of 20 feet.

In parts of the mine where the conglomeratic sandstone rests on the coal its lower surface is covered with a network of cylindrical bodies that are supposed to be the casts of worm borings. In these parts also, notably in the eastern part of the mine south of Willow Creek, numerous irregular masses of conglomeratic sandstone occur within the coal and are connected with the overlying conglomerate. Some of these masses extend partly through the coal bed, others extend completely through it. At some places these masses lie along a fault plane; at others they are irregular in form and contain angular blocks of coal, which are embedded in the sand and gravel. The origin of these bodies is not known.

The Willow mine yields a high-grade coking bituminous coal. It is vitreous to dull in luster and has a seamy or banded texture, which is caused by the alternation of thin layers of vitreous coal with seams of dull coal or mineral charcoal. It differs greatly in purity from place to place, being bony or shaly in some places and relatively free from bone and other bedded impurities in other places. Some of the shale parts readily from the coal, but much of the bone is not separable by ordinary methods of mining.

The chemical composition of the coal from the Willow mine is indicated by the analyses in the accompanying table.

The Willow coal bed is the same as the Koehler bed, but in the southern part of the Willow district the bed is thinner and more irregular than it is near Koehler. This difference is doubtless due in part to original differences in the thickness of the bed, but in some places the thinning is due to erosion after the bed was formed. Some of the irregularities were produced by local disturbances of the rocks, which formed several small faults and caused the intrusion of the igneous rock of several dikes. The coal is coked on both sides of the dikes but seems to be unaffected a few feet from them. The variation in the thickness of the coal bed, as indicated by measurements made in the southern part of the Willow district, is shown in sections 52–61 in the plate of coal sections.

In the southwestern part of the mine the coal is in some places bony, but farther east it is thicker and less bony, though it becomes thinner toward the southeast owing to the removal by erosion of its upper part, and mining on it was stopped at places where its thickness decreased to 2 feet 6 inches.

Between the forks of Willow Canyon (see section 56 in plate of coal sections) the coal bed is 13 feet thick and is overlain by the basal conglomerate of the Raton formation. Farther west, however, this bed is divided into two benches by a layer of shale, and the lower bench is said to pinch out. Northeast of Spring Gulch the entries were driven in on the lower bench, but the upper bench occurs there and will possibly be mined in the future.

Near the northern extremity of the part of the mine east of Spring Gulch the coal bed has been disturbed by rock movements and by the intrusion of igneous rock near the horizon of the coal. The bed is warped and faulted and at several places the coal has been coked. West of the main entry there is a normal fault that has a downthrow of 15 feet to the northwest. This fault is peculiar in that the beds of the hanging wall are bent downward instead of upward, as would naturally be expected in a normal fault. (See fig. 16, p. 12.) The condition of the coal bed north of the mine workings has been tested in two places by the drill. One hole was put down in the canyon east of Spring Gulch, about 1,150 feet upstream from the point where the stream crosses the outcrop of the coal. About 2,000 feet farther up the canyon another drill hole was put down, but it showed that the coal here had been destroyed by intrusive igneous rock. The occurrence of more than 8 feet of coke here, however, indicates that a thick body of coal occurs north of the Willow mine, and places may yet be found where it has not been destroyed.

In the easternmost part of the mine north of Willow Creek the coal bed is thick (see coal section 59) and the coal is relatively free from impurity, but at many places it has been destroyed by igneous intrusion. The coal is so good, however, that such parts of the beds as have not been affected by the intrusion are still mined on a small scale. The analyses of five samples of coal collected in the Willow mine, included in the table of analyses given herewith, indicate the character of the coal.

The floor of the coal bed is a sandy black shale, which is at most places carbonaceous and hard. In the easternmost part of the mine, south of Willow Creek, the floor is ridgy or "billowy," the crests of the billows rising 2 feet or more above the troughs. Farther west in the mine the floor shale, where it has been penetrated to the underlying Trinidad sandstone, is about 5 feet thick. Northeast of Spring Gulch it is more than 17 feet thick and contains beds of sandstone and a 1-foot bed of coal. The top of the Trinidad sandstone was apparently uneven, and the depressions in it were filled with clay and sand prior to the formation of the coal.

Area north of North Willow Canyon.—Much of the land north of North Willow Canyon, some of it south of Canadian River and some north of it, may not contain coal of economic value. The coal of the Vermejo formation is not found in a considerable area near Red River Peak but is found in the area farther northwest, although it has there been destroyed at many places by igneous intrusions. It occurs undisturbed and in full thickness, however, at some places, as in Coal Canyon (locality 69), where it is more than 7 feet thick. In this area, however, no body of undisturbed coal large enough to warrant mining on it has yet been found. The bed thins to 1 foot 6 inches at locality 70, on Canadian River, and drill record B, from a locality farther southwest, near the head of Coal Canyon (see fig. 18) indicates that conditions unfavorable to mining extend westward several miles from the outcrop.

In some places in this district igneous rock was forced into the Vermejo coal and transformed it to graphite. Prospects have been opened on this graphite in Cottonwood Canyon, and there is an abandoned mine at locality 66, where graphite was mined years ago.

Blossburg district. — The Blossburg district lies between Canadian River, in the Brilliant quadrangle, and the divide in the Raton quadrangle west of Raton. Most of the coal in the north wall of Canadian Canyon has been destroyed by igneous intrusions, but that farther north is undisturbed. The stratigraphic relations of the coal beds in the Blossburg district and the relation of the "beds" or "benches" of the Vermejo coal to one another are shown graphically in sections 77–113 in the plate of coal sections. The relations back from the outcrop are probably similar, but they are complicated by the lack of continuity of some of the coal beds, due either to their lenticular form or to the removal of the higher beds in some places by the post-Vermejo erosion. It is not easy to recognize the line of separation between the Vermejo and Raton formations in the drill records thus far available, and it is now quite impossible to correlate the coal beds shown in the platted records of holes drilled in the Blossburg district. (See drill records A to M, fig. 18.)

Coal has been mined in this district for many years, but most of the old mines have been abandoned. The New Gardiner mine, which has an opening at locality 106, was in active operation in 1919, and a new mine opening had been started at a place a little south of locality 97. The nature of the coal beds is indicated by the sections platted in the plate of coal sections, most of which were measured in prospect openings along the outcrop. The bed on which the New Gardiner mine was opened is the third coal bed above the base of the Vermejo formation, but in the opposite wall of Dillon Canyon west of this mine there is only one bed (see section 92 in plate of coal sections), although farther south there are two or more beds of Vermejo coal. In the mines now abandoned coal was possibly taken from both these beds where the rocks separating them were so thin that they may have been regarded as only a parting within a single bed.

The quality of the coal in this district is indicated by an analysis given in the accompanying table.

Raton district.—The Raton district is not now commercially important. There are several abandoned coal mines in the district, but no mines are now in operation there. The occurrence and character of the Vermejo coal beds in this district are indicated by sections 114–129 in the plate of coal sections and in figure 17.

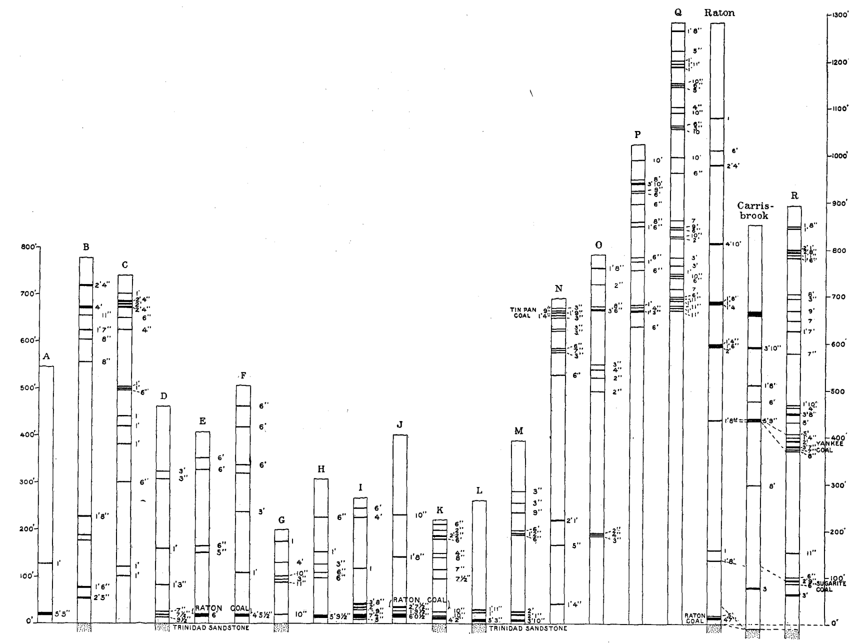


Figure 18.—Sections compiled from diamond-drill records and sections measured at the surface with Locke level showing position and thickness of coal beds (represented by black bands) in the Vermejo and Raton formations.
Sections were measured at places indicated by corresponding letters on the economic-geology maps.

COAL BEDS OF THE RATON FORMATION.

There are two well-defined groups of coal beds in the Raton formation in these quadrangles, a minor group in the lower part of it and a major group in the upper part. These groups are separated by non coal-bearing rocks, consisting chiefly of massive sandstone.

LOWER COAL GROUP.

Sugarite coal bed.—Several beds of coal occur in the lower coal group of the Raton formation, but only one, the Sugarite bed, is known to be valuable under present conditions. A thin bed crops out at several places in the Brilliant quadrangle at a horizon which indicates that it is probably the Sugarite coal, and beds at or near this horizon were penetrated at many places by the drill.

The Sugarite coal has been found in the Raton quadrangle wherever the Raton formation crops out, but it has been systematically prospected in only a small area near the town of Sugarite. It occurs in the western part of the quadrangle, but it is not thick enough there to be of much value. It has not been mined west of the old Wagon mine, locality 134, northeast of Raton. East of this locality the bed has been opened at many places, and its variations in thickness are shown graphically in the plate of coal sections (localities 134–169). This coal attains its maximum known thickness near the town of Sugarite. Drill prospects and openings at the outcrop indicate that it thins both east and west of this town. The center of the swamp in which the vegetable matter that formed the coal accumulated was apparently near the present site of Sugarite.

The only mine in operation on the Sugarite coal bed in 1919 was the Sugarite mine, which was opened in 1912 at Sugarite. The bed here thickens locally so much that it contains a valuable body of bright, black noncoking bituminous coal of vitreous luster. Large quantities of resin occur in it in irregular streaks and lumps. The floor of the mine is soft shale that heaves badly in some places, especially when it is wet.

The quality of this coal is indicated by two analyses of samples collected in the Sugarite mine and one from the old Wagon mine, which was opened at locality 134 and which operated from 1902 until 1912. The Sugarite coal has been mined for local use also at localities 157, 166, and 167.

UPPER COAL GROUP OF RATON QUADRANGLE.

Little is known of the coal beds of the upper coal group in Bartlett Mesa, and the beds east of this mesa may therefore be described before those of the larger area farther west and south. The stratigraphic position of the several beds of coal is indicated by the drill records in figure 18.

Yankee coal bed.—The lowest thick coal bed of the upper group in the eastern part of the Raton quadrangle is known as the Yankee bed. It has been mined to some extent, but in 1919 no mines were in operation on this bed. The farthest point west at which the Yankee bed was recognized is locality 170, northwest of Carisbrook. East of Sugarite Canyon it seems to be continuous throughout the northeastern part of the Raton quadrangle. In the east wall of Sugarite Canyon it was observed in prospect openings at localities 171 and 172. At localities 173–179 there are old mines, now abandoned. At one time this coal was also opened at the Block coal mine, at locality 181, and at the Old Sperry mine, at locality 182. Its identity south of this locality is somewhat doubtful, but it is recognized east of Barilla Mesa at localities 183 and 184. The two prospects in Bear Canyon, at localities 185 and 186, are probably also on the Yankee coal bed.

The Yankee bed crops out in the northwestern part of Johnson Mesa at several places above the cliffs of the barren series, but it has been opened at only a few places, probably because it is too thin to be of much value. It crops out on the west and south slopes of Johnson Mesa, but no satisfactory measurements of its thickness were made there. A line drawn from a point 1 mile east of Potato Mountain to Manco Burro Pass would mark approximately the southeastern limit of the Yankee bed in this mesa.

The Yankee coal has been mined west of the town of Yankee, where a mine was operated from 1906 to 1914. The openings of this mine are at localities 175–179. The coal is variable in thickness and character and the shale floor gave much trouble by creeping laterally and closing the entries. The bed contains a black bituminous noncoking coal of vitreous luster that contains much resin. Its quality is indicated by an analysis of a sample collected within the mine before mining was suspended.

Beds above the Yankee coal.—Several beds of coal were observed above the Yankee bed north of Raton (see sections marked Raton and Carisbrook and drill record R, fig. 18), and thick beds have been found high in the sides of the mesas at many places farther east, but the beds have not been systematically prospected and can not now be definitely correlated with one another. These upper coal beds vary in character from place to place, and some of them contain many partings of shale, which detract greatly from their economic value. The variation in the thickness of the beds is best shown by platted sections. (See fig. 19.) Surface indications of relatively thick beds of coal were found at several places in upper Sugarite Canyon, but no undisturbed bed was seen in this canyon. Near the southern end of Horse Mesa, however, both the Yankee bed and a higher bed of impure coal, 5 feet 8 inches thick, have been opened.

A bed of coal thick enough to be of economic value occurs 65 feet above the Yankee coal and has been opened near locality 175, where it contains one bench of coal 2 feet 10 inches thick and two thin benches, each less than a foot thick. The bed is known locally as the Metcalf bed.

The highest coal bed of the upper coal group, known locally as the Kellogg bed, has been opened at locality 187. At a point 470 feet from the mouth of this opening a sample of the coal was collected for analysis.

About 2 miles farther northeast, at locality 188, there are two beds of coal 64 feet apart. An opening known as the Reynolds mine, though a mine was never operated there, was made on the lower bed. A sample of the coal was collected in this opening for analysis. A thick bed of coal, possibly the same bed, occurs farther southeast, at localities 189 and 190.

Many years ago coal was mined for local use west of Manco Burro Pass, where the coal bed is reported to be 3 feet 4 inches thick. The same bed east of this pass is 5 feet thick.

Three beds of coal occur above the Yankee bed in Rathbun Canyon, near locality 184. The highest and thickest one is platted in section 191, in figure 19. The record of a drill hole

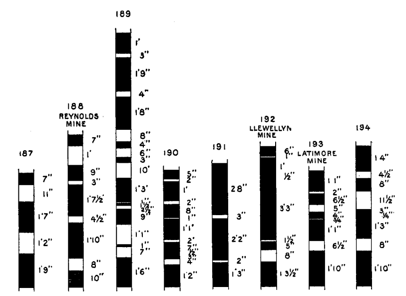


FIGURE 19.—Sections of coal beds younger than the Yankee coal, measured chiefly in prospect openings.

Black bands represent coal. Numbers above columns indicate localities marked on the economic-geology map where sections were measured.

on the eastern slope of Barilla Mesa near the head of Rathbun Canyon also indicated a good thickness for this bed. The coal beds between this one and the Yankee coal are thinner. The lower bed contains 3 feet of coal in two benches, and the higher bed contains 2 feet 11 inches of coal in two benches. Reports of coal beds opened at different times in Bear Canyon indicate that these upper beds are rather thick where they crop out in this canyon, but no definite measurements were made.

Some of the higher coal beds of the upper group underlie the western part of Johnson Mesa. The thickest bed has been opened at locality 192, in the Llewellyn mine. (See section 192, fig. 19.) The quality of the coal in this mine is indicated by the analysis of a sample collected 500 feet from the opening. Another abandoned opening, known as the Turner mine, is a quarter of a mile northwest of the Llewellyn mine. The coal in this mine is reported to be 4 feet 6 inches thick.

Locality 193 is the site of the old Latimore mine. A coal bed 2 feet thick is reported to occur 52 feet above this coal. A quarter of a mile farther south there is an abandoned opening called the Hobbs mine, in which the coal bed is reported to be 6 feet thick. No details of it were obtained. Three beds are also reported to occur above the one worked at the Hobbs mine. The first bed contains 3 feet 1 inch of coal, the second 2 feet 10 inches of coal, and the third 4 feet of coal. Locality 194 is the site of the old Honeyfield mine. (See section 194, fig. 19.) A bed containing 2 feet 6 inches of coal is reported to occur 94 feet above this coal. These higher beds of coal crop out farther south, but they probably do not underlie any great part of Johnson Mesa. Within 1 to 2 miles from the outcrop the northwestward dip of the strata should bring them to the gravel beds on which the mesa lavas were outpoured, as illustrated in figure 20.

UPPER COAL GROUP OF BRILLIANT AND KOEHLER QUADRANGLES.

General features.—The series of stratified rocks that contain the upper group of coal beds of Raton age is about 500 feet thick. Coal beds occur at many horizons within this 500 feet of strata, and many of the beds are commercially valuable, but only two have been prospected systematically over a wide area.

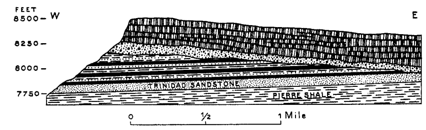


FIGURE 20.—Section at west end of Johnson Mesa, at locality 415 on map.

Shows the relation of the basalt lava sheet and associated gravels to the beds of coal in the underlying Raton formation.

The lower bed is called the Tin Pan coal, from Tin Pan Canyon, in the northeastern part of the Brilliant quadrangle; the higher bed is called the Potato Canyon coal, from Potato Canyon, in the central part of this quadrangle. These two beds have been surveyed at their outcrops and have been opened at short intervals. The mining engineers kept records of the measurements they made of the coal in these openings, and from these records many of the coal sections have been platted. Several other beds of coal are locally thick enough to be of economic value, but relatively little is known of them. The upper coals crop out in the highlands in the northern part of the Koehler quadrangle. They underlie the greater part of the Brilliant quadrangle and the high mesas of the Raton quadrangle.

Tin Pan coal.—The Tin Pan coal probably underlies the highlands in the southern half of the Brilliant quadrangle, but the southernmost prospects on it are in the south wall of Potato Canyon. The bed contains much bright, clean coal, but it includes many partings of shale. It may consist of several lenses of coal, each separated from the others by thin layers of shale, or it may be made up of several wedgelike offshoots from a central thick bed. This central mass may have lain east of the outcrop, where it was eroded away, or it may still exist under the surface to the west. It is quite impossible at present to correlate the several benches, and the details of the bed are best presented graphically, as they are in sections 195–217 in the plate of coal sections. Sections 212–217, however, may represent not the Tin Pan bed but some higher bed.

The Tin Pan coal underlies the highlands between Rombo and Dutchman canyons, but little is known of it there. It crops out in Dutchman Canyon, where it has been opened at localities 218–220, and in the south wall of Dillon Canyon, at localities 221–227.

This coal is mined in Tin Pan Canyon and in Dillon Canyon, near the town of Brilliant. Before the mine was opened the coal was prospected along its outcrop, and the results are shown in sections 228–244 in the plate of coal sections. Prospect openings made later farther east and in the west wall of Coal Canyon show that the bed extends as far as Coal Creek with little change in thickness or character. It has not been systematically prospected still farther east. Prospect drillings west of the mine show that the coal becomes shaly toward the west and that the bed assumes more nearly the character which it exhibits in Rombo Canyon.

The Brilliant mine, in Dillon Canyon, and the Tin Pan mine, in Tin Pan Canyon, work the main bench of coal shown in sections 228–244 in the plate of coal sections. Throughout most of the developed area the bed consists of this thick bench of coal, above and below which lie thinner benches, but in the area north of Dillon Canyon the presence of bony coal and a thick bed of sandy shale in the middle of the bed made mining expensive and caused the abandonment of this part of the mine. The roof of the mine consists in some places of the bench of coal above the lower bench and in others of the shale parting between these two benches.

The coal is softer than the older or Vermejo coals, is lustrous and bituminous, and yields poorer coke. The thickness of the bed as observed in the mine is shown in sections 228–244 in the plate of coal sections. The quality of this coal is shown by the analysis given in the accompanying table. North of Dillon Canyon the main bench is thinner and a higher bench is thicker than the corresponding benches south of the canyon. Farther east, however, the lower bench is thick enough for profitable mining, and new mines were

Analyses of samples of coal from the Raton, Brilliant, and Koehler quadrangles, N. Mex.

[Made at the Pittsburgh laboratory of the Bureau of Mines.]

Coal of Cretaceous age from Vermejo formation.

Name of mine.	No. on map.[a]	Laboratory number.	Air-drying loss.	Form of analysis.	Proximate.				Ultimate.					Heating value (British thermal units).
					Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	
Koehler mine	27	14796	1.0	A	2.3	35.9	49.9	11.85	0.63	5.17	71.27	1.34	9.74	12,920
				C		36.7	51.2	12.13	.65	5.03	72.98	1.37	7.84	13,230
				D		41.8	58.2		.74	5.72	83.05	1.56	8.93	15,060
Do	26	33018	.9	A	2.5	36.7	49.3	11.48	.70	5.22	71.59	1.35	9.66	12,820
				C		37.6	50.6	11.77	.72	5.07	73.41	1.38	7.65	13,140
				D		42.7	57.3		.82	5.75	83.20	1.56	8.67	14,900
Do	32	17781	.4	A	2.0	35.7	49.2	13.10	.78	5.27	70.71	1.32	8.85	12,670
				C		36.4	50.2	13.36	.80	5.12	72.13	1.35	7.24	12,920
				D		42.1	57.9		.92	5.91	83.25	1.56	8.36	14,910
Do	24	33017	.9	A	2.3	36.8	50.0	10.90	.71	5.19	72.28	1.34	9.58	12,990
				C		37.7	51.1	11.16	.73	5.05	74.01	1.37	7.68	13,300
				D		42.4	57.6		.82	5.68	83.31	1.54	8.65	14,970
Willow mine (upper part of bed)	60	6417	1.4	A	2.4	33.7	54.4	9.47	.66	5.21	72.84	1.10	10.72	13,150
				C		34.5	55.8	9.70	.68	5.06	74.65	1.13	8.78	13,470
				D		38.2	61.8		.75	5.60	82.67	1.25	9.73	14,920
Willow mine (lower part of bed)	60	6418	1.5	A	2.5	34.7	54.0	8.82	.76	5.50	73.65	1.20	10.07	13,330
				C		35.5	55.4	9.05	.78	5.35	75.54	1.23	8.05	13,670
				D		39.1	60.9		.86	5.88	83.06	1.35	8.85	15,030
Willow mine (entire bed)	54	6980	1.5	A	2.8	33.3	51.5	12.37	1.19	5.26	71.59	1.24	8.35	12,720
				C		34.2	53.1	12.73	1.22	5.08	73.68	1.28	6.01	13,088
				D		39.2	60.8		1.40	5.82	84.48	1.47	6.88	15,000
Do	54	32592	.8	A	2.3	36.2	50.5	11.00	.83	5.33	72.45	1.37	9.02	12,910
				C		37.0	51.7	11.27	.85	5.19	74.20	1.40	7.09	13,220
				D		41.8	58.2		.96	5.85	83.62	1.58	7.99	14,900
Do	60	32593	.8	A	2.6	35.1	50.4	11.86	.56	5.27	71.41	1.34	9.56	12,700
				C		36.0	51.8	12.18	.58	5.11	73.35	1.38	7.40	13,040
				D		41.0	59.0		.66	5.82	83.52	1.57	8.43	14,850
New Gardiner mine	107	14795	.9	A	2.4	36.7	45.7	15.23	.64	5.13	67.91	1.30	9.79	12,260
				C		37.6	46.8	15.60	.66	4.99	69.54	1.33	7.88	12,550
				D		44.5	55.5		.78	5.91	82.39	1.58	9.34	14,870
Coal of Tertiary age from Raton formation.														
Wagon mine; (Sugarite bed)	134	6286	.5	A	2.1	36.1	50.2	11.60	.64	4.94	69.96	1.33	11.53	12,970
				C		36.8	51.3	11.85	.65	4.80	71.48	1.36	9.86	13,250
				D		41.8	58.2		.74	5.45	81.09	1.54	11.18	15,030
Sugarite mine No. 1	137	14791	2.1	A	3.9	38.1	49.1	8.93	.56	5.71	72.37	1.58	10.85	13,070
				C		39.6	51.1	9.29	.58	5.49	75.25	1.64	7.75	13,590
				D		43.7	56.3		.64	6.05	82.96	1.81	8.54	14,990
Sugarite mine No. 2	149	14792	1.0	A	2.9	39.7	48.7	8.70	.51	5.62	73.52	1.57	10.08	13,280
				C		40.9	50.1	8.96	.53	5.46	75.73	1.62	7.70	13,680
				D		44.9	55.1		.58	6.00	83.18	1.78	8.46	15,030
Brilliant mine	229	17708	.9	A	2.6	36.0	45.3	16.08	.56	5.35	67.63	1.56	8.82	12,150
				C		37.0	46.5	16.51	.57	5.19	69.43	1.60	6.70	12,470
				D		44.3	55.7		.68	6.22	83.16	1.92	8.02	14,940
Yankee mine No. 3 (Yankee bed)	178	6248	2.4	A	5.0	36.8	46.2	12.00	.56	5.15	66.01	1.28	15.00	12,060
				C		38.7	48.7	12.63	.59	4.88	69.50	1.35	11.10	12,700
				D		44.3	55.7		.68	5.58	79.54	1.55	12.70	14,540
Yankee mine (Kellogg bed)	187	17746	1.6	A	5.7	37.4	44.6	12.28	1.09	5.47	66.31	1.40	13.45	11,980
				C		39.6	47.4	13.02	1.16	5.13	70.33	1.48	8.88	12,700
				D		45.6	54.4		1.33	5.90	80.86	1.70	10.21	14,600
Reynolds mine (abandoned)	188	6244	3.4	A	5.6	33.8	49.3	11.29	.63	4.97	64.93	1.21	16.97	11,920
				C		35.8	52.2	11.96	.67	4.60	68.81	1.28	12.68	12,630
				D		40.7	59.3		.76	5.22	78.16	1.45	14.41	14,350
Llewellyn mine	192	6255	3.5	A	9.0	34.9	48.9	7.18	.54	5.34	67.48	1.22	18.24	12,260
				C		38.4	53.7	7.89	.59	4.77	74.19	1.34	11.22	13,480
				D		41.6	58.4		.64	5.18	80.55	1.45	12.18	14,640

[a] Some of the numbers given in this column indicate only approximately the localities from which the samples were collected. The localities in the Koehler and Willow mines are distributed over considerable areas. The sample from the New Gardiner mine was taken from a point near the middle of the area represented by the mine workings. That from the Brilliant mine was taken from the middle of the mine south of Tin Pan Canyon. The other localities are indicated with sufficient accuracy by the numbers given.

Analysis A represents the composition of the sample as it comes from the mine.

Analysis C represents the composition of the coal after all moisture has been eliminated. It is obtained from A by recalculation.

Analysis D represents the composition of the coal after all moisture and ash have been theoretically removed. It is obtained from the others by recalculation. This form of analysis is supposed to represent the true coal substance.

opened on it north of locality 244 about in 1919. Prospects farther east and in Coal Canyon, at localities 245–248, indicate that this thickening of the coal is local.

Coal beds near the Tin Pan coal.—Although the Tin Pan coal bed is the lowest of the large beds of coal in the upper coal group there are several thin beds beneath it. (See sections N and O, fig. 18.) A bed 90 feet below the Tin Pan coal is about 4 feet thick in the spur south of locality 242 and has been mined there for local use. A bed about 200 feet above the Tin Pan coal between Dillon and Coal canyons has also been opened in a number of prospects and found to contain coal of considerable commercial value.

Potato Canyon and Savage Canyon coals.—In Potato Canyon a thick bed of coal lies 115 feet above the Tin Pan bed. It has been surveyed at the outcrop and opened at short intervals from this canyon northward to Rombo Canyon, and a bed supposed to be the Potato Canyon coal has been opened and examined in detail in Tin Pan, Coal, and Savage canyons, with the results shown in sections 249–300 in the plate of coal sections. Like the Tin Pan coal this bed differs in thickness and character from place to place, consisting of several benches of clean, bright coal separated by thin layers of shale, as indicated in the graphic sections.

Coal beds near the Potato Canyon coal.—Coal crops out at many places in the western part of the Brilliant quadrangle and the northwestern part of the Koehler quadrangle, but little is known of the extent of the beds or of their correlation with other beds. Coal beds were observed in the southwestern part of the Brilliant quadrangle at localities 301–310, and the measured sections at these localities are shown in figure 21.

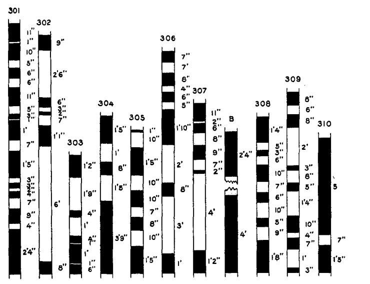


Figure 21.—Sections of coal beds in the Raton and Vermejo formations in the southwestern part of the Brilliant quadrangle.
Black bands represent coal. Numbers above columns indicate localities marked on economic-geology map where sections were measured.

A coal bed crops out at several places in Canadian Canyon, in the western part of the quadrangle, but it is too thin to be of much value, although a little coal was once mined for local use about a mile from the western boundary of the quadrangle.

QUALITY AND QUANTITY OF COAL.

All the coal in the Raton field is bituminous, and much of it is of coking quality. With some apparent exceptions the coal of Cretaceous age is highest in rank and makes the best coke. The Tertiary coals, with few exceptions, have lower heating value than the Cretaceous coals, burn more freely, and either form weak coke or are noncoking. The samples collected for analysis were all obtained from working faces in mines in the same manner, and each represents a complete cross section of the bed or such part of the bed as was sampled.

The Vermejo or Cretaceous coal has been most extensively mined and is represented in the table by 10 analyses. These analyses show an average of 14,990 British thermal units for the pure or ash-free and moisture-free coal. The next younger or Sugarite coal has been mined at only one place. Theoretically it should be of lower rank, for it is younger than the Vermejo coals, yet the analysis of the three mine samples shows an average for the ash-free and moisture-free coal of 15,013 British thermal units. It may be that the large amount of resin in this coal increases its heating capacity. The coals of the upper coal group of the Raton formation are all more brittle than the older coals and have lower fuel value. The five samples represented in the table, which were collected from mines in the upper coal beds, show an average of 14,624 British thermal units for the ash-free and moisture-free coal. Thus, except for the Sugarite coal, which seems to be abnormal, there is a notable difference in character between the coal of the youngest beds and that of the oldest. This difference is shown in the "pure" coal analyses by an average difference of 389 British thermal units.

Although there is a large quantity of coal in these quadrangles, the continuity of the coal beds of the Vermejo formation is so broken and the character of the younger beds so irregular that an estimate of the quantity is likely to be misleading. The quantity of coal in the Vermejo formation is rendered uncertain in two ways—(1) the intrusions of igneous rock have destroyed it in many places and the areal extent of the intrusions is not known, and (2) some of the coal was eroded away in post-Cretaceous time, and the barren areas are of unknown extent. The quantity of coal in the Raton formation is rendered uncertain by the variation in the character of the beds. A coal bed thick enough in one locality to be mined with profit may break up laterally into several benches separated by shale or it may become so thin as to be practically valueless.

GRAPHITE.

Little has been done with the graphite in the Canadian district. A mine was opened on it in 1889 in Cottonwood Canyon, at locality 66, by the Standard Graphite Co. of New York. Some of the material was shipped for experimental purposes, but no further use has been made of it.

A sample for analysis was collected at a place 160 feet from the mouth of the old mine, where the graphite is about 3 feet thick. In order to obtain a representative sample the weathered material was cleared from the exposed face of the bed. The sample represents the entire thickness of the graphite at this place, and the analysis therefore shows a greater percentage of impurity than would be found in pieces selected from the best material. The sample was analyzed as coal in the laboratory of the United States Geological Survey (now the laboratory of the Bureau of Mines) at Pittsburgh. The results are as follows:

Analysis of graphite from the Raton coal field, N. Mex.

[F. M. Stanton, chemist in charge. Laboratory No. 6521. Air-drying loss, 0.40.]

	Sample as received.	Sample air-dried.	Sample free from moisture	Sample free from moisture and ash.
Moisture	1.31	0.91		
Volatile matter	6.07	6.09	6.15	7.39
Fixed carbon	76.11	76.42	77.12	92.61
Ash	16.51	16.58	16.73	
Sulphur	.17	.17	.17	.20

CLAY.

Shale and clay for brick can be obtained in many parts of the Raton, Brilliant, and Koehler quadrangles. The shale in the Raton and Vermejo formations occurs as thin sandy layers but has never been much utilized. The Pierre formation consists chiefly of dark clay shale, which has been used near Raton (see Pl. II) in making brick for the local market. This shale occupies the lowlands of the three quadrangles.

BUILDING STONE.

The Trinidad sandstone has furnished building stone for local use, but the demand for it is hardly sufficient to warrant its quarrying for shipment. It has been used somewhat extensively in Raton and in neighboring mining towns. It has an attractive appearance because of its even texture and light color, but its tendency to weather irregularly and scale off lessens its usefulness. Some of the massive sandstones of the Raton formation seem to be suitable for building stone, but little use has been made of them. Some of this stone would probably be more durable than the Trinidad sandstone, but its uneven rusty-brown color makes it less attractive.

The rock of the basaltic flows, sills, and dikes makes durable building material, although it is somewhat difficult to work. Similar rock quarried elsewhere is crushed for ballast, but little use has been made of it in these quadrangles, except locally, where volcanic cinders have been used in making footpaths and drives.

The lighter-colored igneous rocks, especially the pink and blue mottled varieties that occur in the extreme southeastern part of the Raton quadrangle, seem to be suitable for use as ornamental stone. (See Pl. XII.) They polish well, and the colors are pleasing to the eye. The hornblende andesites of Cunningham Butte and of Towndrow Peak probably would also make excellent building stone. They are lasting and much more easily worked than the tougher basalts.

INDICATIONS OF OIL AND GAS.

Natural gas and petroleum occur in the Raton, Brilliant, and Koehler quadrangles but have not yet been found in paying quantities. East of Van Houten, near the point of the mesa in the fork of Willow Creek, gas escapes from a natural vent in sufficient volume to be ignited. Gas has been flowing steadily for many years from a well drilled north of Barilla Mesa, a few miles beyond the northern border of the Raton quadrangle. A well in the Koehler quadrangle, near Maxwell, furnishes a small quantity of gas for domestic use.

Indications of oil have been reported from many places in the mesa region, and a small flow was encountered in the coal mine at Dawson, N. Mex. Several wells have been drilled in search of oil, but no productive pools have yet been found. A well put down about 2 miles east of Raton is reported to be 2,700 feet deep, but it did not reach the bottom of the shale. Oil has been found in cavities of the basalt in a dike $2\frac{1}{2}$ miles south of Black Mesa. A well was sunk at the side of this dike to a depth reported to be about 1,000 feet. Oil has also been found in a basalt dike near Trinchera, Colo., a few miles northeast of the Raton quadrangle. Oil is more abundant at this place than in the dike south of Black Mesa, and more is known about it. As its occurrence in both places is probably due to the same causes, a knowledge of the conditions near Trinchera may throw some light on the conditions generally in the Raton, Brilliant, and Koehler quadrangles.

The rock of the dike at Trinchera is somewhat scoriaceous, and in some places the cavities are full of petroleum. The oil is very fluid and flows in small streams from the rock when it is broken, but until the rock is broken it does not escape. A piece of the fresh rock from this dike was treated in a Soxhlet extraction apparatus with ether for three days, and afterward allowed to stand in benzole for a month, until no more oil was extracted. The piece was then broken open, and the cavities which had not been fractured were found full of oil that was unaffected by the benzole. An examination of a thin section of the rock showed that the cavities are lined with calcite. Some of the rock that had been treated with benzole was boiled in hydrochloric acid, by which treatment considerably more of the oil was extracted. The oil is therefore evidently sealed within the cavities by calcite, and when this is dissolved it escapes.

On the assumption that the oil was derived in some way from an underlying oil-bearing stratum a well was drilled near the dike. It was started near the top of beds of Niobrara age and passed through beds of Benton age into the Dakota sandstone. Oil was found near the bottom of the Benton, but not in sufficient quantity to warrant further development.

GROUND WATER.

Water issues as springs from the gravel that underlies the sheets of lava that cap the high mesas. The water is free from objectionable mineral matter, and the flow is great enough to make these springs valuable sources of domestic supply, but few of them have thus far been utilized. Springs occur at many places in areas occupied by the Raton formation, especially in seepage areas at the outcrops of layers of sandstone, so that small streams usually flow near the heads of the canyons.

The water that issues at a few places from the Pierre shale is strongly charged with sulphate and other substances that are equally objectionable in drinking water. Moderately good water sufficient for domestic use is found in the coarse superficial deposits that overlie the Pierre shale in many parts of the lowlands, and there is a small underflow at some places in the gravel beds near the courses of streams.

The Dakota and Purgatoire sandstones, which underlie the Raton, Brilliant, and Koehler quadrangles, are the most useful water-bearing strata in the Rocky Mountain region, but no well in these quadrangles has yet reached them. The well east of Raton, said to be 2,700 feet deep, was started about 300 feet below the top of the Pierre shale, so that this shale and the beds of Colorado age must together be 3,000 feet or more thick. Hydrostatic pressure would probably force the water from these sandstones well up toward the surface, but flowing water would probably not be obtained.

SOILS.

The soil of the mesas, which has been derived from the basalt, is a dark rich loam, admirably suited to farming. The precipitation on the mesas is sufficient for agriculture, but the altitude is so great that crops which are easily destroyed by frost can not be raised. The soil of the lowlands is of two general varieties—a dark adobe soil derived by decomposition from the Pierre shale and a lighter colored soil derived from silt washed down from the highlands. The lowlands are used for farming wherever water can be impounded for irrigation and in some places for dry farming. A considerable area in the southern part of the Koehler quadrangle is irrigated from reservoirs that conserve flood waters, chiefly those of Vermejo River, but the greater part of the surface in these quadrangles is used for grazing.

May, 1922.

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

TOPOGRAPHY

NEW MEXICO - COLORADO
BRILLIANT QUADRANGLE

R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E.P. Davis, C.C. Holder, and C.A. Ecklund.
Control by R.B. Robertson and C.C. Holder.
Surveyed in 1912-1913.

APPROXIMATE MEAN DECLINATION 1921.

Scale $\frac{1}{62500}$

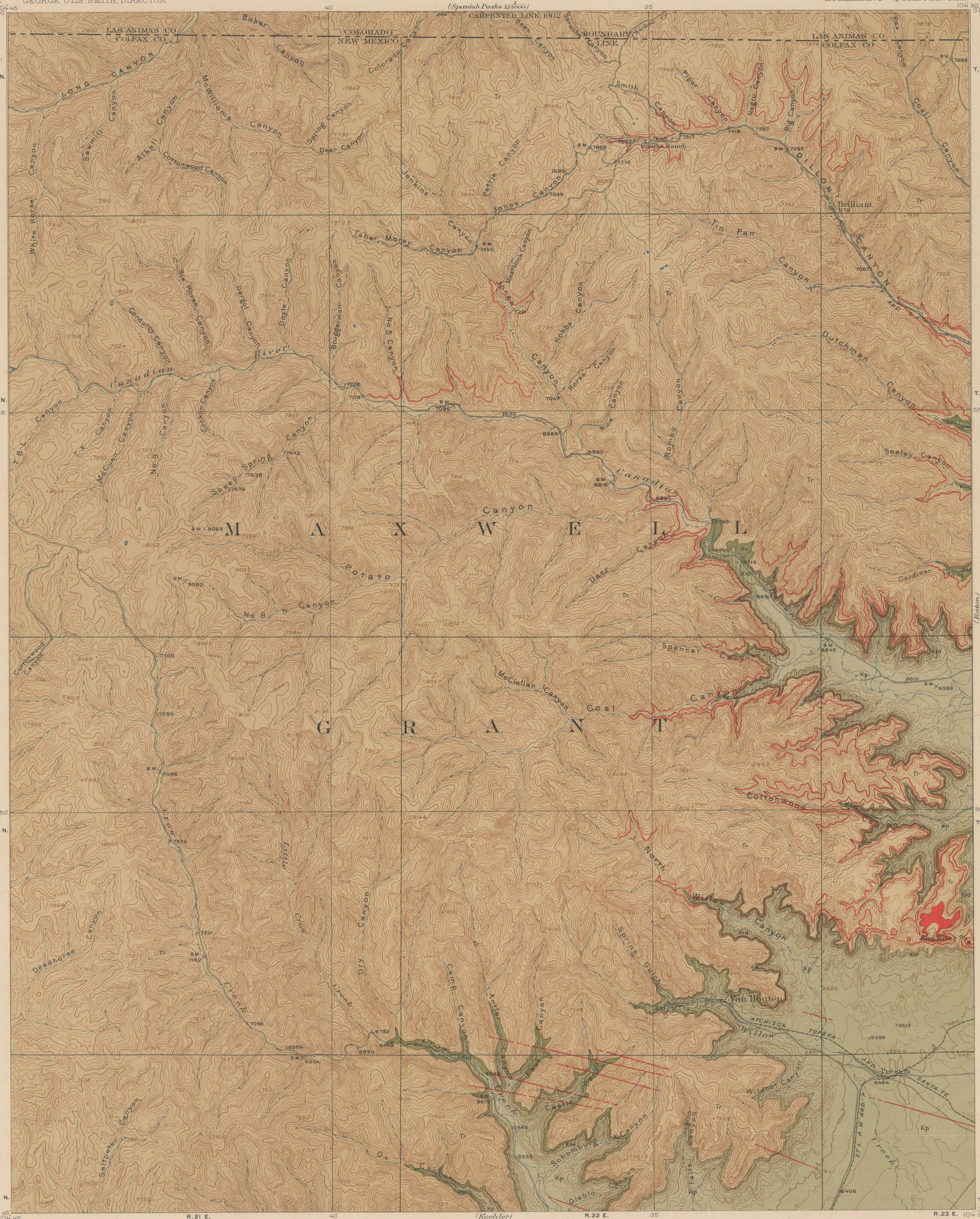
Contour interval 50 feet.
Datum is mean sea level.

Edition of Oct. 1915, reprinted 1921.

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

AREAL GEOLOGY

NEW MEXICO - COLORADO
BRILLIANT QUADRANGLE



EXPLANATION

SEDIMENTARY ROCKS

(Areas of sedimentary deposits are shown by patterns of parallel lines)

TERTIARY — *Eocene*

Tr — Raton formation *(sandstone, brown to buff shale, and coal beds; conglomerate at base)*

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous* — *Montana group*

Kv — Vermejo formation *(dark shale, light-colored friable sandstone, and coal beds)*

Ktd — Trinidad sandstone *(massive, light-gray, feldspathic sandstone)*

Kp — Pierre shale *(drab to black fossiliferous shale; containing limestone concretions in upper part)*

IGNEOUS ROCKS

QUATERNARY

Dikes and sheets, chiefly basalt; some andesite and lamprophyre

R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E.P. Davis, C.C. Holder, and C.A. Ecklund.
Control by R.B. Robertson and C.C. Holder.
Surveyed in 1912-1913.

TRUE NORTH / MAGNETIC NORTH 13½°
APPROXIMATE MEAN DECLINATION, 1920.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

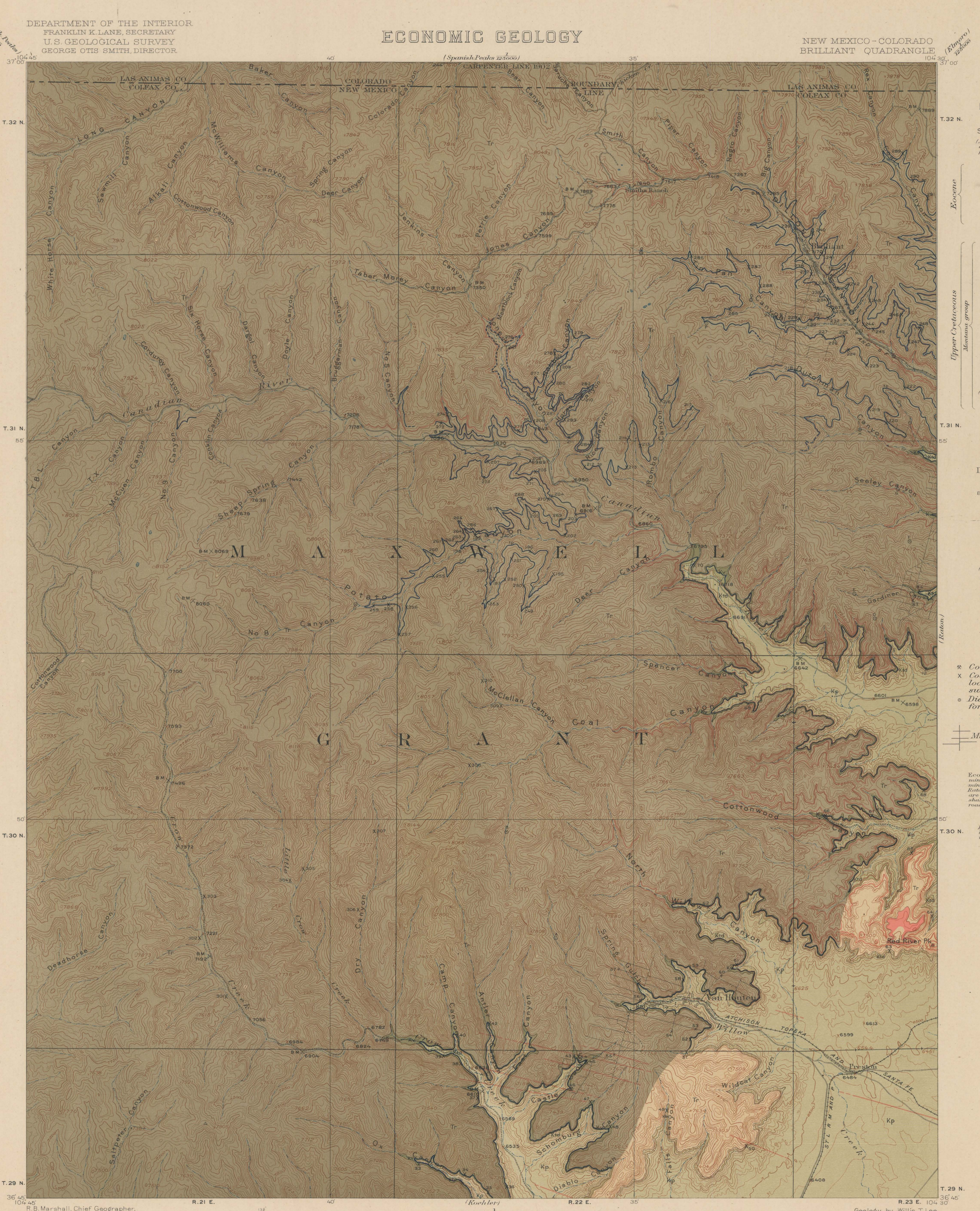
Contour interval 50 feet.
Datum is mean sea level.
Edition of Sept. 1921.

Geology by Willis T. Lee.
Surveyed in 1913.

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

ECONOMIC GEOLOGY

NEW MEXICO - COLORADO
BRILLIANT QUADRANGLE



R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E.P. Davis, C.C. Holder, and C.A. Ecklund.
Control by R.B. Robertson and C.C. Holder.
Surveyed in 1912-1913.

APPROXIMATE MEAN DECLINATION, 1920.

Scale 1/62500

Contour interval 50 feet.
Datum is mean sea level.
Edition of Sept. 1921.

Geology by Willis T. Lee.
Surveyed in 1913.

EXPLANATION

SEDIMENTARY ROCKS

(Areas of sedimentary deposits are shown by patterns of parallel lines)

TERTIARY — *Eocene*

Tr — Raton formation *(sandstone, brown to buff shale, and coal beds; conglomerate at base)*

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous* — *Montana group*

Kv — Vermejo formation *(dark shale, light-colored friable sandstone, and coal beds)*

Ktd — Trinidad sandstone *(massive, light-gray, feldspathic sandstone)*

Kp — Pierre shale *(drab to black fossiliferous shale; containing limestone concretions in upper part)*

IGNEOUS ROCKS

QUATERNARY

Dikes and sheets, chiefly basalt; some andesite and lamprophyre

ECONOMIC DATA

Coal bed outcrops (chiefly in Vermejo formation; Tinpan, tp, Potato Canyon, pc, Savage Canyon, sc, and other coal beds in Raton formation. Coal changed to coke or graphite where in contact with igneous rocks)

Area underlain by coal beds

⚒ *Coal mine entries*

x *Coal prospects and location of measured surface sections*

⊙ *Diamond drill tests for coal*

Numbers and letters refer to sections and descriptions in text.

Mine workings in 1913

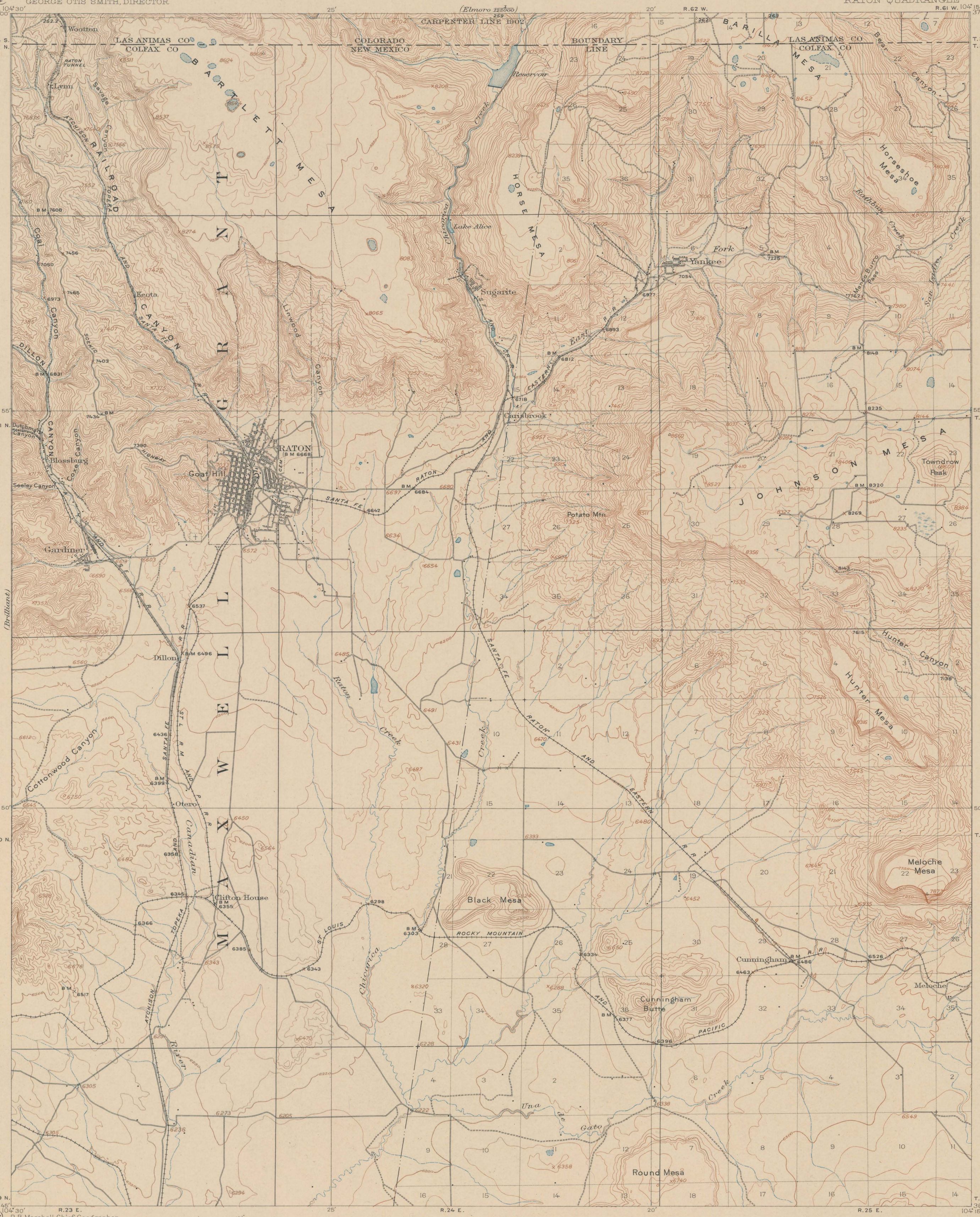
Economic note: *Bituminous coal is extensively mined in the Vermejo and Raton formations; brick clays are obtained from the Pierre shale; basalt is suitable for road metal.*

Land lines on map are based on found corners indicated thus (+)

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

TOPOGRAPHY

NEW MEXICO–COLORADO
RATON QUADRANGLE



R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E.P. Davis and S.E. Taylor.
Control by R.B. Robertson and C.P. Gross.
Surveyed in 1911-1912.

TRUE NORTH
MAGNETIC NORTH
$13\frac{1}{2}°$
APPROXIMATE MEAN DECLINATION 1920.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.

Datum is mean sea level.

Edition of May 1914, reprinted 1921.

EXPLANATION

RELIEF
printed in brown

Altitude above mean sea level instrumentally determined

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

Depression contour

DRAINAGE
printed in blue

Streams

Intermittent streams

Lake, pond, or reservoir

Intermittent lakes

Marsh

Spring

CULTURE
printed in black

Roads and buildings

Schoolhouse

Church and cemetery

Private or secondary roads

Trail

Railroads

Tunnels

Bridge

Coke ovens

U.S. township and section lines and located corner

State line

City, village, or borough line

Land grant line

Triangulation station

Bench mark giving precise altitude

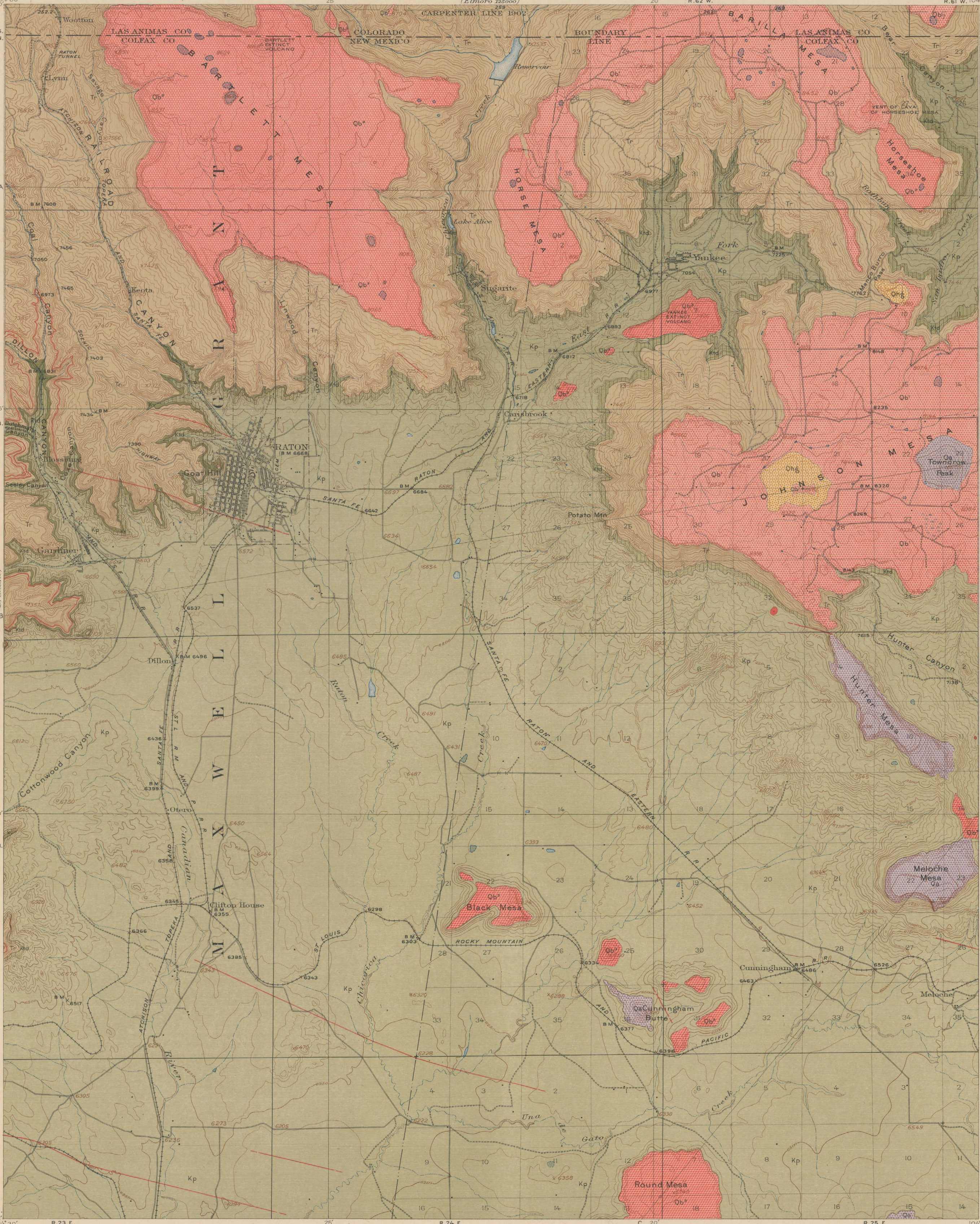
Temporary bench mark

Boundary monument

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

AREAL GEOLOGY

NEW MEXICO-COLORADO
RATON QUADRANGLE



EXPLANATION

SEDIMENTARY ROCKS

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

QUATERNARY

Qhg — High-level gravels *(sand, gravel, and boulders)*

TERTIARY — Eocene

Tr — Raton formation *(sandstone, brown to buff shale, and coal beds; conglomerate at base)*

UNCONFORMITY

CRETACEOUS — Upper Cretaceous — Montana group

Kv — Vermejo formation *(dark shale, light-colored friable sandstone, and coal beds)*

Ktd — Trinidad sandstone *(massive, light-gray, feldspathic sandstone)*

Kp — Pierre shale *(drab to black fossiliferous shale; containing limestone concretions in upper part; in southeast parts of Raton and Koehler quadrangles includes representatives of Niobrara limestone and Benton shale, of underlying Colorado group, not readily separable from Pierre shale)*

IGNEOUS ROCKS

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

QUATERNARY

Qa — Andesite flows and stocks *(probably intermediate in age between second and youngest basalt flows)*

Qb¹, Qb², Qb³ — Basalt lava flows *(Qb¹ oldest and highest flow; Qb² second or intermediate flow; Qb³ youngest and lowest flow; some lava of second flow is mapped with oldest flow on Johnson mesa north of Towndrow Peak)*

Dikes and sheets, chiefly basalt; some andesite and lamprophyre

R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E.P. Davis and S.E. Taylor.
Control by R.B. Robertson and C.P. Gross.
Surveyed in 1911-1912.

APPROXIMATE MEAN DECLINATION, 1920.

Scale 1/62500

Miles — Kilometers

Contour interval 50 feet.
Datum is mean sea level.

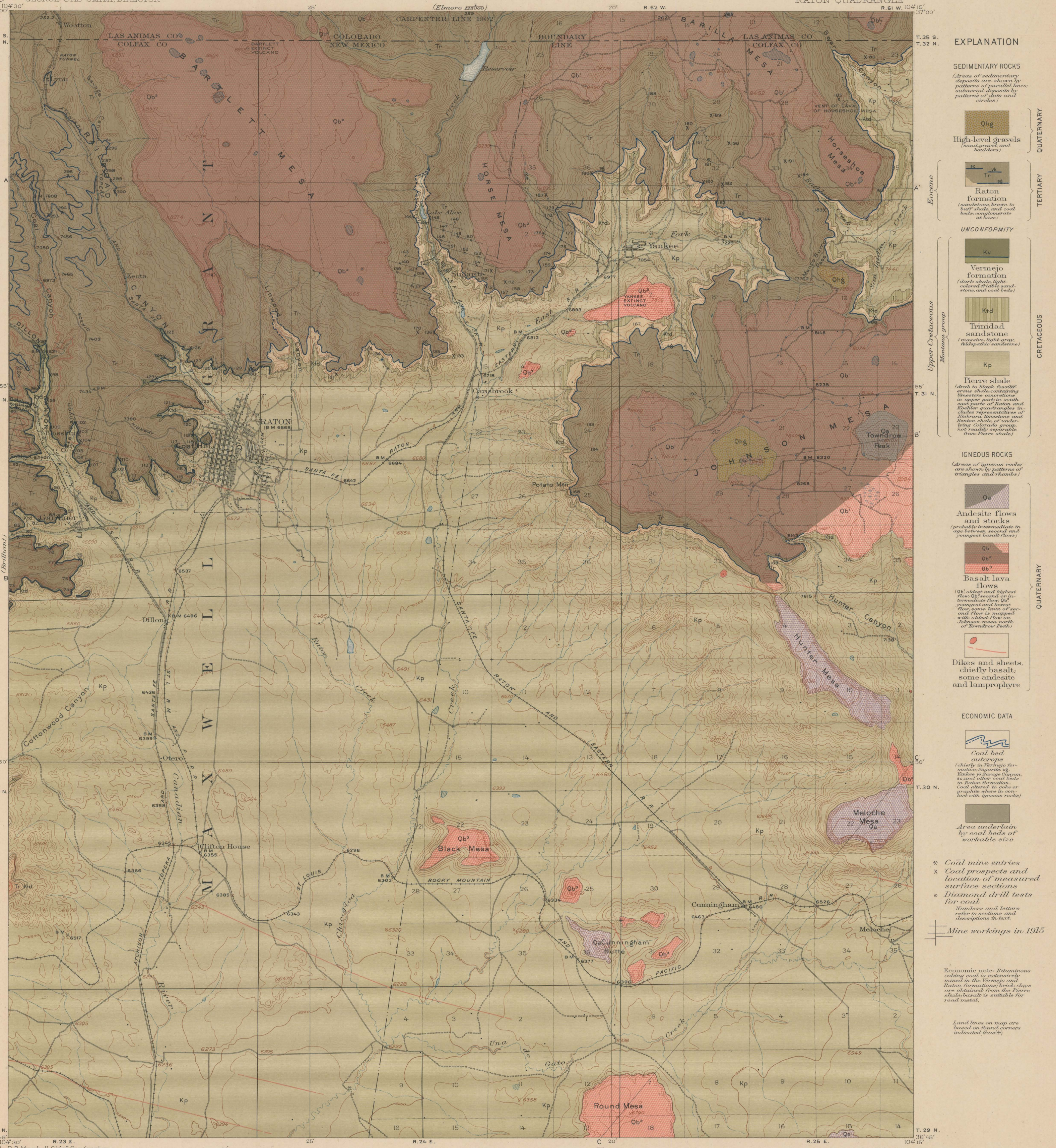
Edition of Sept. 1921.

Geology by Willis T. Lee.
Surveyed in 1913.

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

ECONOMIC GEOLOGY

NEW MEXICO–COLORADO
RATON QUADRANGLE



R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E.P. Davis and S.E. Taylor.
Control by R.B. Robertson and C.P. Gross.
Surveyed in 1911-1912.

APPROXIMATE MEAN DECLINATION, 1910.

Scale $\frac{1}{62500}$

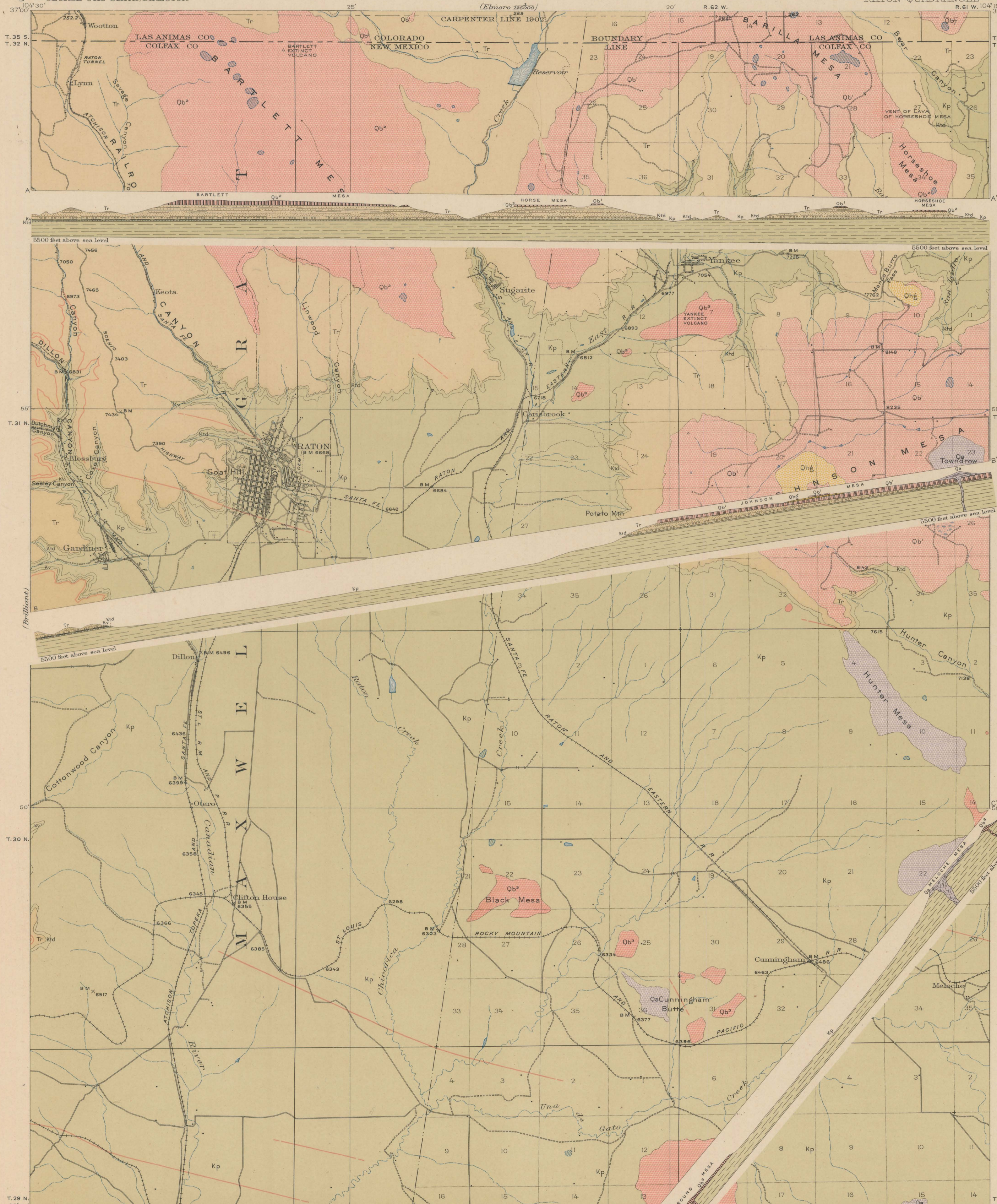
Contour interval 50 feet.
Datum is mean sea level.
Edition of Sept. 1921.

Geology by Willis T. Lee.
Surveyed in 1913.

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

STRUCTURE SECTIONS

NEW MEXICO-COLORADO
RATON QUADRANGLE



EXPLANATION

SEDIMENTARY ROCKS

SHEET SYMBOL — SECTION SYMBOL

QUATERNARY

Qhg — High-level gravels (*sand, gravel, and boulders*)

TERTIARY — *Eocene*

Tr — Raton formation (*sandstone, brown to buff shale, and coal beds; conglomerate at base*)

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous* — *Montana group*

Kv — Vermejo formation (*dark shale, light-colored friable sandstone, and coal beds*)

Ktd — Trinidad sandstone (*massive, light-gray, feldspathic sandstone*)

Kp — Pierre shale (*drab to black fossiliferous shale; containing limestone concretions in upper part; in southeast parts of Raton and Koehler quadrangles includes representatives of Niobrara limestone and Benton shale, of underlying Colorado group, not readily separable from Pierre shale*)

IGNEOUS ROCKS

QUATERNARY

Qa — Andesite flows and stocks (*probably intermediate in age between second and youngest basalt flows*)

Qb¹, Qb², Qb³ — Basalt lava flows (Qb¹ *oldest and highest flow;* Qb² *second or intermediate flow;* Qb³ *youngest and lowest flow; some lava of second flow is mapped with oldest flow on Johnson mesa north of Towndrow Peak*)

Dikes and sheets, chiefly basalt; some andesite and lamprophyre

(Koehler)
R.B.Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E.P. Davis and S.E.Taylor.
Control by R.B.Robertson and C.P.Gross.
Surveyed in 1911-1912.

TRUE NORTH — MAGNETIC NORTH — 13½°
APPROXIMATE MEAN DECLINATION, 1920.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

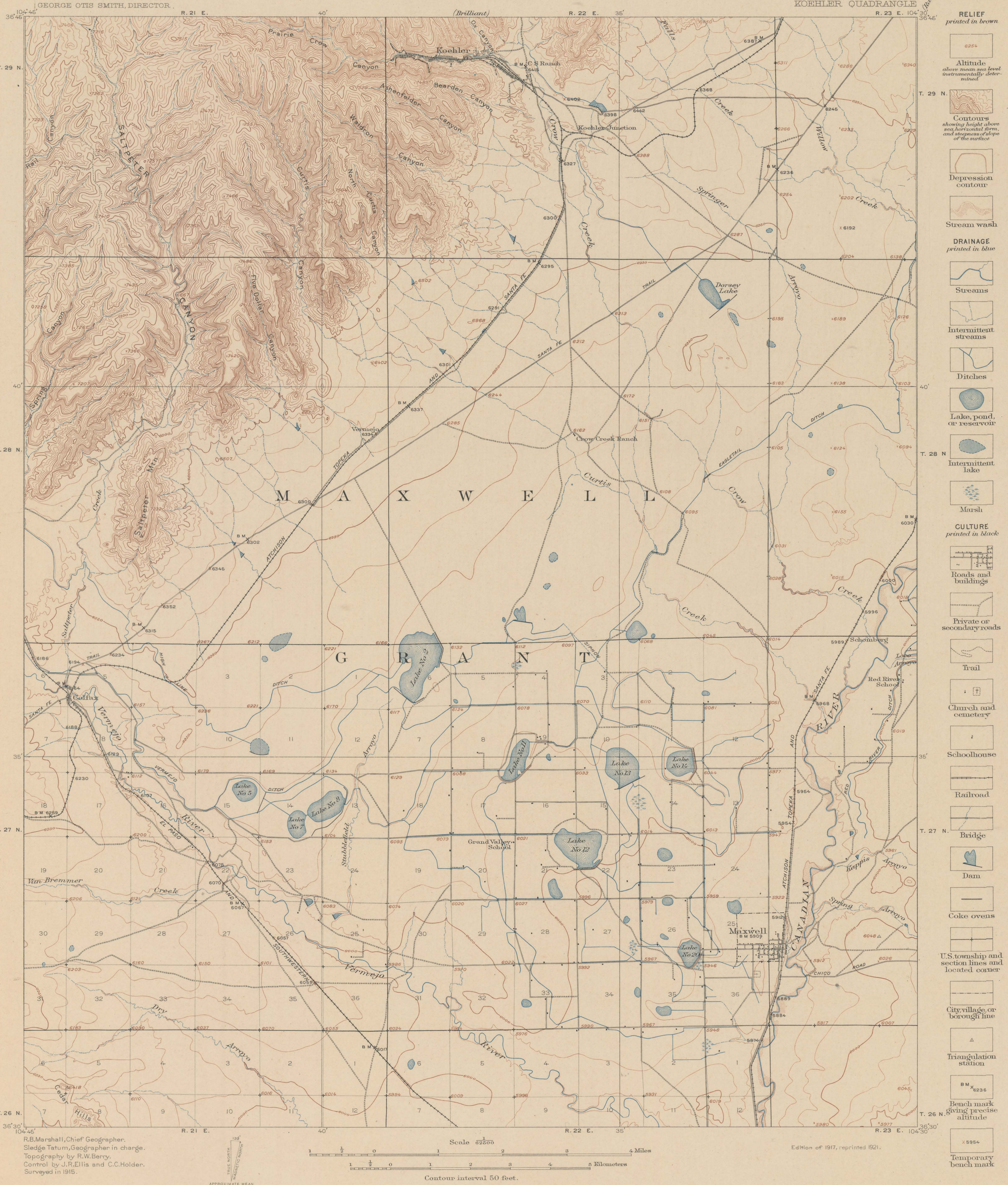
Edition of Oct. 1921.

Geology by Willis T. Lee.
Surveyed in 1913.

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

TOPOGRAPHY

NEW MEXICO
(COLFAX COUNTY)
KOEHLER QUADRANGLE



R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by R.W. Berry.
Control by J.R. Ellis and C.C. Holder.
Surveyed in 1915.

APPROXIMATE MEAN DECLINATION 1921

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

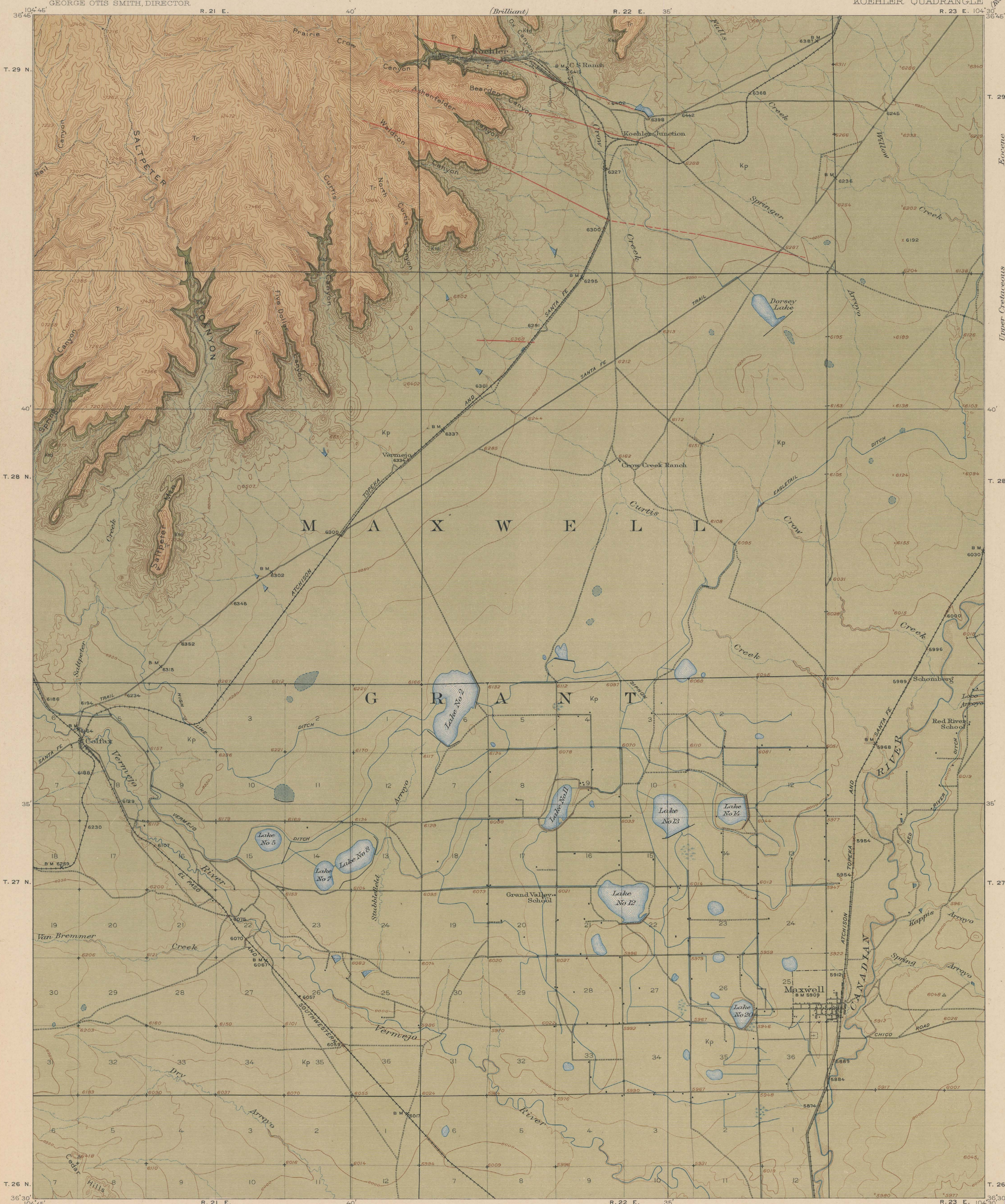
Contour interval 50 feet.
Datum is mean sea level.

Edition of 1917, reprinted 1921.

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

AREAL GEOLOGY

NEW MEXICO
(COLFAX COUNTY)
KOEHLER QUADRANGLE (Raton)



EXPLANATION

SEDIMENTARY ROCKS

(Areas of sedimentary deposits are shown by patterns of parallel lines)

TERTIARY — Eocene

Tr — **Raton formation** (sandstone, brown to buff shale, and coal beds; conglomerate at base)

UNCONFORMITY

CRETACEOUS — Upper Cretaceous — Montana group

Kv — **Vermejo formation** (dark shale, light-colored friable sandstone, and coal beds)

Ktd — **Trinidad sandstone** (massive, light-gray, feldspathic sandstone)

Kp — **Pierre shale** (drab to black fossiliferous shale; containing limestone concretions in upper part; in southeast parts of Raton and Koehler quadrangles includes representatives of Niobrara limestone and Benton shale, of underlying Colorado group, not readily separable from Pierre shale)

IGNEOUS ROCKS

QUATERNARY

Dikes and sheets, chiefly basalt; some andesite and lamprophyre (pattern indicates dike rock that replaces coal bed in mine)

R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by R.W. Berry.
Control by J.R. Ellis and C.C. Holder.
Surveyed in 1915.

TRUE NORTH — MAGNETIC NORTH 13½°
APPROXIMATE MEAN DECLINATION, 1920.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.
Datum is mean sea level.

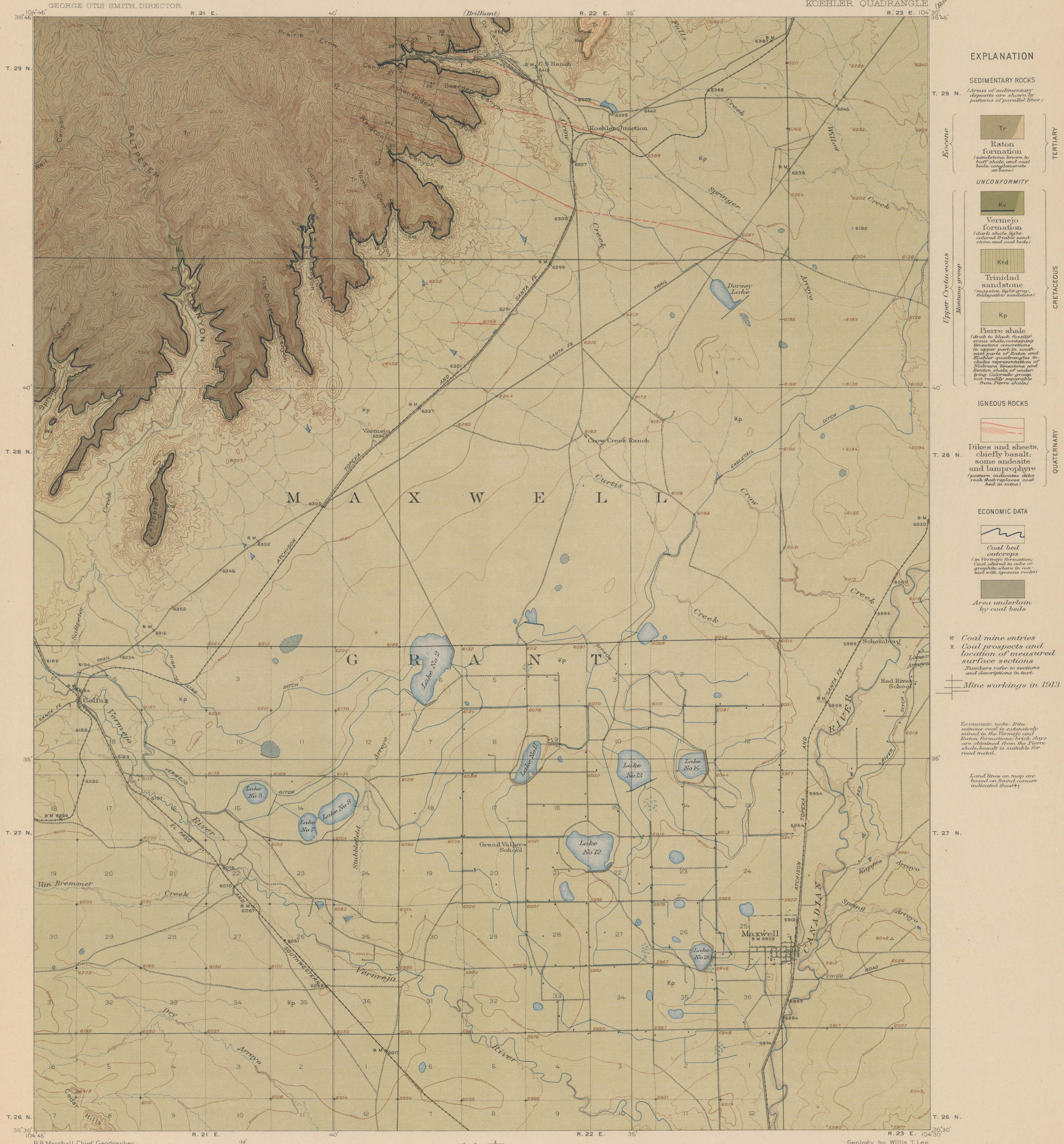
Edition of Sept. 1921.

Geology by Willis T. Lee.
Surveyed in 1913.

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

ECONOMIC GEOLOGY

NEW MEXICO
(COLFAX COUNTY)
KOEHLER QUADRANGLE



R.B.Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by R.W.Barry.
Control by J.R.Ellis and C.C.Holder.
Surveyed in 1915.

APPROXIMATE MEAN DECLINATION, 1915.

Scale $\frac{1}{62500}$

Contour interval 50 feet.
Datum is mean sea level.

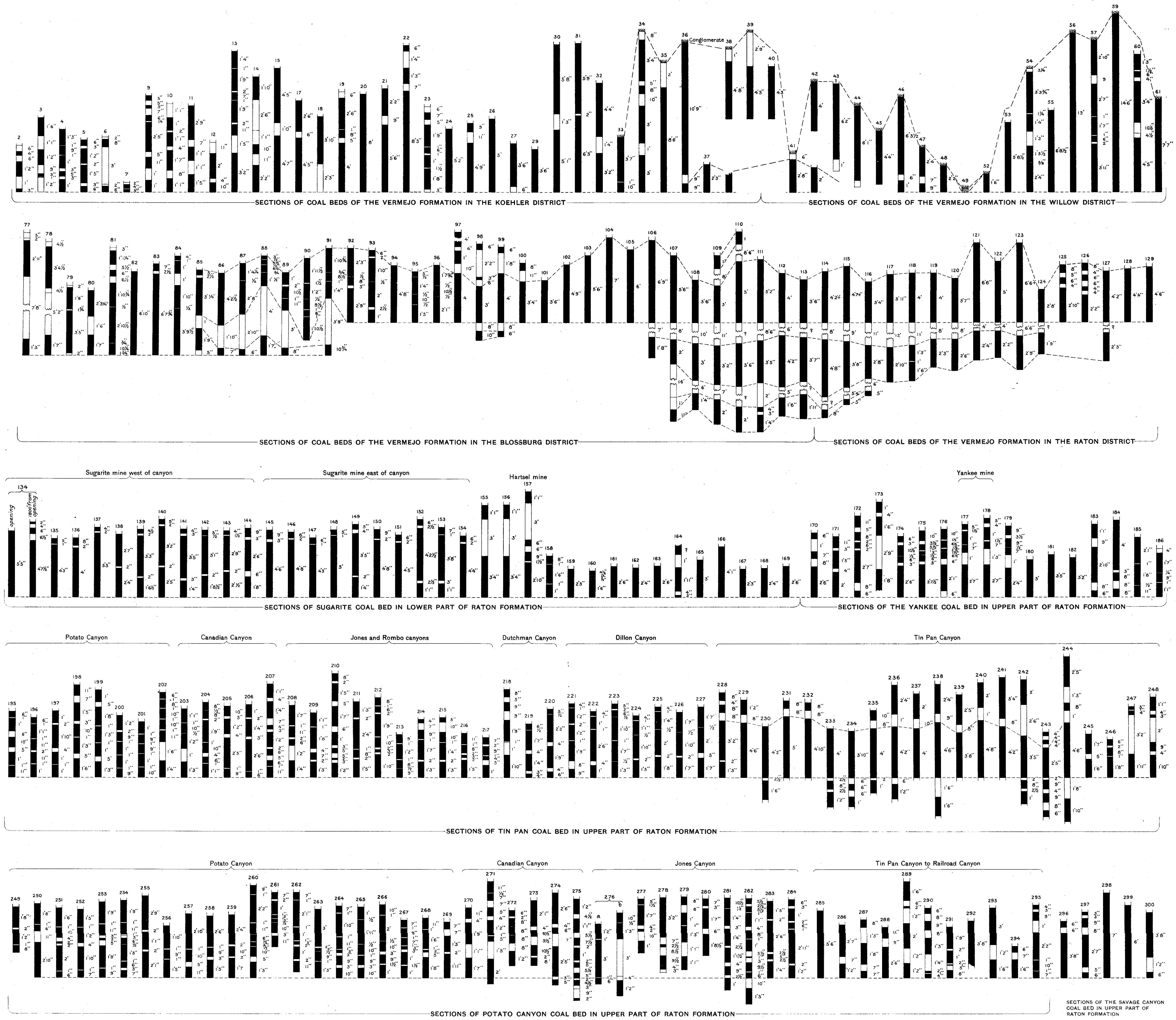
Edition of Sept. 1921.

Geology by Willis T. Lee.
Surveyed in 1913.

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

COAL SECTIONS

NEW MEXICO-COLORADO
RATON-BRILLIANT-KOEHLER QUADRANGLES



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

ILLUSTRATIONS

NEW MEXICO
RATON, BRILLIANT, AND KOEHLER QUADRANGLES

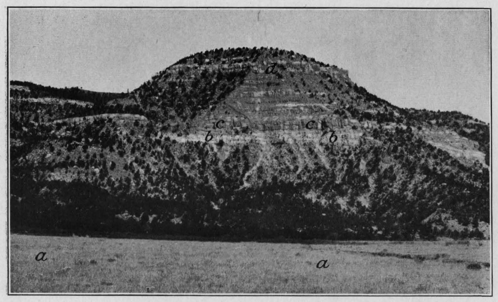


PLATE I.—AN EASTWARD-FACING PROMONTORY NEAR VAN HOUTEN, RISING 1,000 FEET ABOVE THE LOWLAND PLAIN.

Foreground (*a*) and lower slope composed of soft Pierre shale. Trinidad sandstone (*b*) and basal conglomerate of Raton formation (*c*) together form base of cliff (Vermejo formation absent). Hard sandstones (*d*) of middle part of Raton formation near top of cliff.

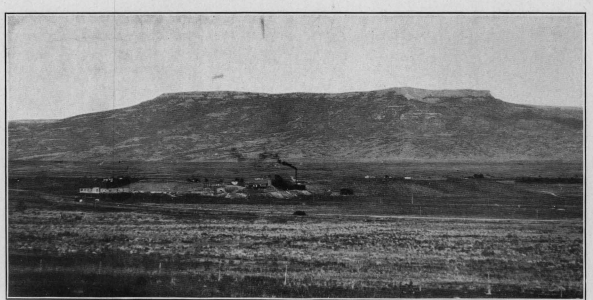


PLATE II.—JOHNSON MESA, AS SEEN FROM RATON.

Shows lowlands of the plain, high flat-topped table-lands of the mesa region, and smooth brush-covered slopes of the mesas. The plain and the lower part of the mesa slope are formed on Pierre shale, and the precipitous mesa rim is the edge of the basalt sheet that caps the mesa. Under this rim the sandstones of the Raton formation crop out conspicuously at only one place, the formation being covered with brush and slide rock in most places.

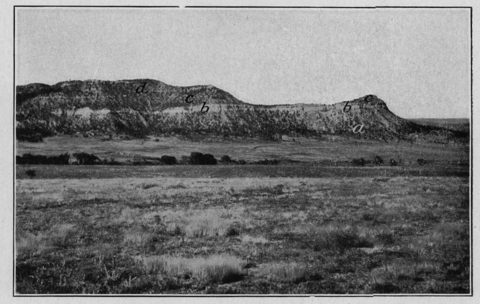


PLATE III.—NORTH WALL OF CANADIAN CANYON, SOUTH OF GARDINER.

A characteristic canyon wall ending in a promontory that overlooks the plain. The cottonwoods in the middle ground grow only near the stream. Pinon and juniper grow on the dry hillsides. *a*, Pierre shale; *b*, Trinidad sandstone; *c*, Vermejo formation; *d*, lower part of Raton formation.

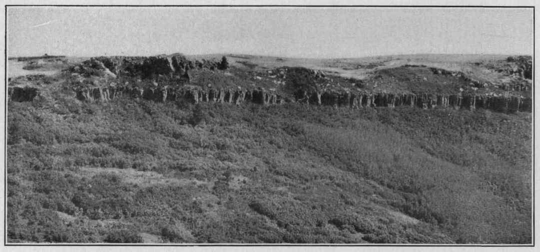


PLATE IV.—PART OF SOUTH RIM OF BARILLA MESA NORTH OF YANKEE.

Shows the uneven surface characteristic of the highest mesas; two sheets of lava, the lower one regularly columnar, the upper one less so; and the dense growth of scrub oak and aspen that covers the slopes of the mesa.

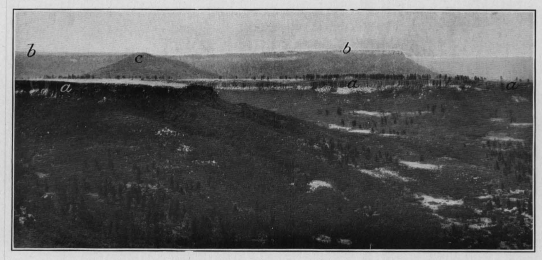


PLATE V.—EAST RIM OF BARTLETT MESA, LOOKING NORTHWARD TOWARD AN OLDER AND HIGHER MESA.

Shows the basalt cap of Bartlett Mesa (*a*); the remnant (*b*) of an older mesa, which lies at and beyond the northern border of the Raton quadrangle; and an outlier (*c*) of the higher distant mesa. In the foreground is the slope of Sugarite Canyon, covered with scrub oak and scattered pines and spruces.

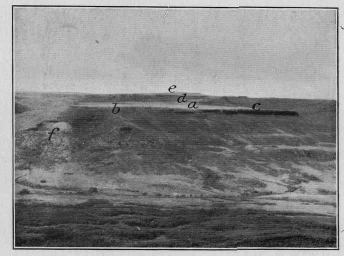


PLATE VI.—HORSESHOE AND BARILLA MESAS AS SEEN FROM JOHNSON MESA.

a, Smooth surface of Horseshoe Mesa; *b*, *c*, edge of the sheet of basalt (thin at *b*, thick at *c*) which caps the mesa; *d*, narrow neck connecting Horseshoe Mesa with the higher Barilla Mesa; *e*, volcanic cone on Barilla Mesa from which the lava capping Horseshoe Mesa was probably extruded; *f*, recent landslide on steep slope of mesa.

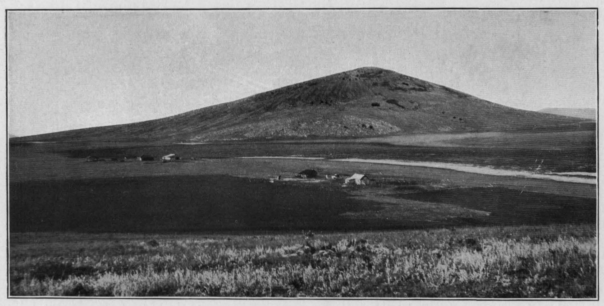


PLATE VII.—TOWNDROW PEAK ON JOHNSON MESA, FROM THE SOUTH

The peak consists of younger andesitic lava which overlies the basalt sheet that forms the flat surface of the mesa in the foreground.

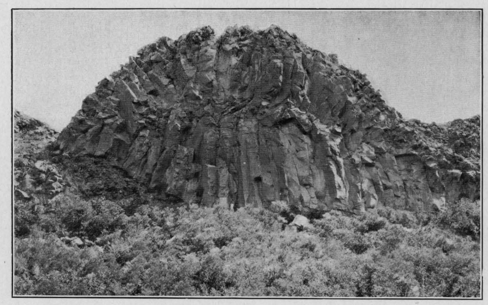


PLATE VIII.—PART OF SOUTH RIM OF JOHNSON MESA.

Shows the columnar structure of the basalt exposed in the cross section of a lava stream that flowed down an old valley, one side of which appears at the left. The trees in the foreground are 20 to 30 feet high.

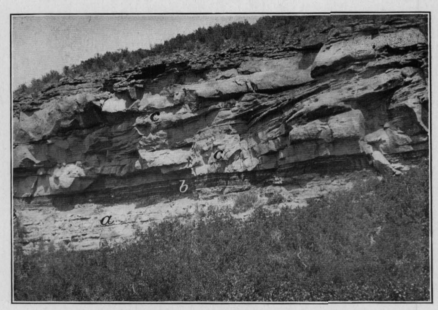


PLATE IX.—NORTH WALL OF SCHOMBURG CANYON.

Trinidad sandstone (*a*) overlain by shale and Willow coal bed (*b*), 8 feet thick, of the Vermejo formation, on which rests unconformably the basal conglomerate (*c*) of the Raton formation.

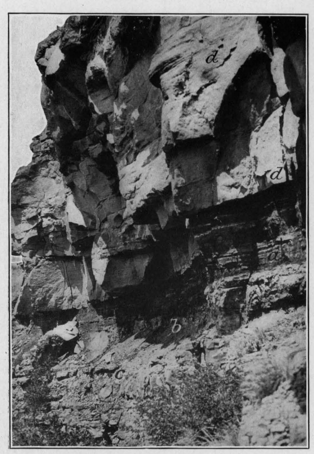


PLATE X.—RELATION OF THE WILLOW COAL BED TO OTHER BEDS WHERE THE VERMEJO FORMATION IS THIN.

The coal bed (*a*), here about 5 feet thick, is separated by a few feet of shale (*b*) from the underlying Trinidad sandstone (*c*). The basal conglomerate (*d*) of the Raton formation rests with uneven base directly on the coal.

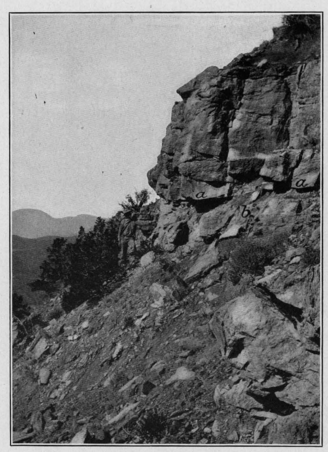


PLATE XI.—CLIFF SOUTH OF VAN HOUTEN, SHOWING RELATION OF RATON FORMATION TO TRINIDAD SANDSTONE WHERE VERMEJO FORMATION IS ABSENT.

The basal conglomerate (*a*) of the Raton formation rests on the Trinidad sandstone (*b*).

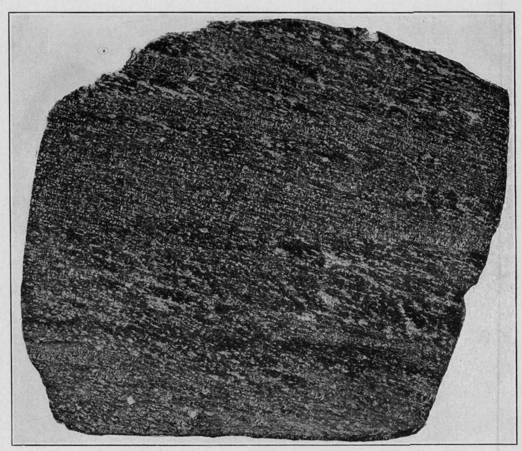


PLATE XII.—POLISHED SURFACE OF PINK AND BLUE RHYOLITE.

PUBLISHED GEOLOGIC FOLIOS

No.*	Name of folio.	State.	Price.†
			Cents.
1	Livingston	Montana	Out of stock.
2	Ringgold	Georgia-Tennessee	do.
●3	Placerville	California	100
4	Kingston	Tennessee	Out of stock.
●5	Sacramento	California	100
6	Chattanooga	Tennessee	Out of stock.
7	Pikes Peak	Colorado	do.
8	Sewanee	Tennessee	do.
9	Anthracite-Crested Butte	Colorado	do.
10	Harpers Ferry	Va.-Md.-W. Va	do.
●11	Jackson	California	100
12	Estillville	Ky.-Va.-Tenn	Out of stock.
13	Fredericksburg	Virginia-Maryland	do.
14	Staunton	Virginia-West Virginia	do.
15	Lassen Peak	California	do.
16	Knoxville	Tennessee-North Carolina	do.
17	Marysville	California	do.
18	Smartsville	California	do.
19	Stevenson	Ala.-Ga.-Tenn	do.
20	Cleveland	Tennessee	do.
21	Pikeville	Tennessee	do.
22	McMinnville	Tennessee	do.
23	Nomini	Maryland-Virginia	do.
24	Three Forks	Montana	do.
25	Loudon	Tennessee	do.
26	Pocahontas	Virginia-West Virginia	do.
27	Morristown	Tennessee	do.
28	Piedmont	West Virginia-Maryland	do.
29	Nevada City Special	California	do.
30	Yellowstone National Park	Wyoming	do.
31	Pyramid Peak	California	do.
32	Franklin	West Virginia-Virginia	do.
33	Briceville	Tennessee	do.
34	Buckhannon	West Virginia	do.
35	Gadsden	Alabama	do.
36	Pueblo	Colorado	do.
37	Downieville	California	do.
38	Butte Special	Montana	do.
39	Truckee	California	do.
40	Wartburg	Tennessee	do.
41	Sonora	California	do.
42	Nueces	Texas	do.
43	Bidwell Bar	California	do.
44	Tazewell	Virginia-West Virginia	do.
45	Boise	Idaho	do.
46	Richmond	Kentucky	do.
47	London	Kentucky	do.
48	Tenmile District Special	Colorado	do.
49	Roseburg	Oregon	do.
50	Holyoke	Massachusetts-Connecticut	do.
51	Big Trees	California	do.
52	Absaroka	Wyoming	do.
53	Standingstone	Tennessee	do.
54	Tacoma	Washington	do.
55	Fort Benton	Montana	do.
56	Little Belt Mountains	Montana	do.
57	Telluride	Colorado	do.
58	Elmoro	Colorado	do.
59	Bristol	Virginia-Tennessee	do.
60	La Plata	Colorado	do.
61	Monterey	Virginia-West Virginia	do.
62	Menominee Special	Michigan	do.
63	Mother Lode District	California	do.
64	Uvalde	Texas	do.
65	Tintic Special	Utah	do.
66	Colfax	California	do.
67	Danville	Illinois-Indiana	do.
68	Walsenburg	Colorado	do.
69	Huntington	West Virginia-Ohio	do.
70	Washington	D. C.-Va.-Md	do.
71	Spanish Peaks	Colorado	do.
72	Charleston	West Virginia	do.
73	Coos Bay	Oregon	do.
74	Coalgate	Oklahoma (Ind. T.)	do.
75	Maynardville	Tennessee	do.
76	Austin	Texas	do.
77	Raleigh	West Virginia	do.
78	Rome	Georgia-Alabama	do.
79	Atoka	Oklahoma (Ind. T.)	do.
80	Norfolk	Virginia-North Carolina	do.
81	Chicago	Illinois-Indiana	do.
82	Masontown-Uniontown	Pennsylvania	do.
83	New York City	New York-New Jersey	do.
84	Ditney	Indiana	5
85	Oelrichs	South Dakota-Nebraska	5
86	Ellensburg	Washington	5
87	Camp Clarke	Nebraska	5
88	Scotts Bluff	Nebraska	5
89	Port Orford	Oregon	Out of stock.
90	Cranberry	North Carolina-Tennessee	do.
91	Hartville	Wyoming	5
92	Gaines	Pennsylvania-New York	Out of stock.
93	Elkland-Tioga	Pennsylvania	5
94	Brownsville-Connellsville	Pennsylvania	Out of stock.
95	Columbia	Tennessee	5
96	Olivet	South Dakota	5
97	Parker	South Dakota	5
98	Tishomingo	Oklahoma (Ind. T.)	Out of stock.
99	Mitchell	South Dakota	5
100	Alexandria	South Dakota	5
101	San Luis	California	Out of stock.
102	Indiana	Pennsylvania	do.
103	Nampa	Idaho-Oregon	do.
104	Silver City	Idaho	5
105	Patoka	Indiana-Illinois	5
106	Mount Stuart	Washington	Out of stock.
107	Newcastle	Wyoming-South Dakota	do.

No.*	Name of folio.	State.	Price.†
			Cents.
108	Edgemont	South Dakota-Nebraska	5
109	Cottonwood Falls	Kansas	5
110	Latrobe	Pennsylvania	Out of stock.
111	Globe	Arizona	do.
112	Bisbee (reprint)	Arizona	25
113	Huron	South Dakota	5
114	De Smet	South Dakota	5
115	Kittanning	Pennsylvania	Out of stock.
116	Asheville	North Carolina-Tennessee	do.
117	Casselton-Fargo	North Dakota-Minnesota	5
118	Greeneville	Tennessee-North Carolina	5
119	Fayetteville	Arkansas-Missouri	Out of stock.
120	Silverton	Colorado	do.
121	Waynesburg	Pennsylvania	do.
122	Tahlequah	Oklahoma (Ind. T.)	do.
123	Elders Ridge	Pennsylvania	do.
124	Mount Mitchell	North Carolina-Tennessee	do.
125	Rural Valley	Pennsylvania	do.
126	Bradshaw Mountains	Arizona	do.
127	Sundance	Wyoming-South Dakota	do.
128	Aladdin	Wyo.-S. Dak.-Mont	do.
129	Clifton	Arizona	do.
130	Rico	Colorado	do.
131	Needle Mountains	Colorado	do.
132	Muscogee	Oklahoma (Ind. T.)	do.
133	Ebensburg	Pennsylvania	do.
134	Beaver	Pennsylvania	do.
135	Nepesta	Colorado	do.
136	St. Marys	Maryland-Virginia	do.
137	Dover	Del.-Md.-N. J	do.
138	Redding	California	do.
139	Snoqualmie	Washington	do.
140	Milwaukee Special	Wisconsin	do.
141	Bald Mountain-Dayton	Wyoming	do.
142	Cloud Peak-Fort McKinney	Wyoming	do.
143	Nantahala	North Carolina-Tennessee	do.
144	Amity	Pennsylvania	do.
145	Lancaster-Mineral Point	Wisconsin-Iowa-Illinois	do.
146	Rogersville	Pennsylvania	do.
147	Pisgah	N. Carolina-S. Carolina	do.
148	Joplin District (reprint)	Missouri-Kansas	50
149	Penobscot Bay	Maine	Out of stock.
150	Devils Tower	Wyoming	do.
151	Roan Mountain	Tennessee-North Carolina	do.
152	Patuxent	Md.-D. C	do.
153	Ouray	Colorado	do.
154	Winslow	Ark.-Okla. (Ind. T.)	do.
155	Ann Arbor (reprint)	Michigan	25
156	Elk Point	S. Dak.-Nebr.-Iowa	5
157	Passaic	New Jersey-New York	Out of stock.
158	Rockland	Maine	do.
159	Independence	Kansas	do.
160	Accident-Grantsville	Md.-Pa.-W. Va	do.
161	Franklin Furnace	New Jersey	do.
162	Philadelphia	Pa.-N. J.-Del	do.
163	Santa Cruz	California	do.
‡164	Belle Fourche	South Dakota	5
‡165	Aberdeen-Redfield	South Dakota	5
166	El Paso	Texas	Out of stock.
167	Trenton	New Jersey-Pennsylvania	do.
‡168	Jamestown-Tower	North Dakota	5
169	Watkins Glen-Catatonk	New York	Out of stock.
170	Mercersburg-Chambersburg	Pennsylvania	do.
‡171	Engineer Mountain	Colorado	5
‡172	Warren	Pennsylvania-New York	5
173	Laramie-Sherman	Wyoming	Out of stock.
174	Johnstown	Pennsylvania	do.
175	Birmingham	Alabama	do.
176	Sewickley	Pennsylvania	do.
177	Burgettstown-Carnegie	Pennsylvania	do.
178	Foxburg-Clarion	Pennsylvania	do.
179	Pawpaw-Hancock	Md.-W. Va.-Pa	do.
‡180	Claysville	Pennsylvania	5
‡181	Bismarck	North Dakota	5
‡182	Choptank	Maryland	5
183	Llano-Burnet	Texas	Out of stock.
184	Kenova	Ky.-W. Va.-Ohio	do.
‖185	Murphysboro-Herrin	Illinois	25
‖186	Apishapa	Colorado	5
‖187	Ellijay	Ga.-N. C.-Tenn	25
‖188	Tallula-Springfield	Illinois	25
189	Barnesboro-Patton	Pennsylvania	25
‖190	Niagara	New York	50
‖191	Raritan	New Jersey	25
192	Eastport	Maine	25
‖193	San Francisco	California	75
194	Van Horn	Texas	25
195	Belleville-Breese	Illinois	25
196	Phillipsburg	Montana	25
‖197	Columbus	Ohio	25
198	Castle Rock	Colorado	25
199	Silver City	New Mexico	25
200	Galena-Elizabeth	Illinois-Iowa	25
‖201	Minneapolis-St. Paul	Minnesota	25
202	Eureka Springs-Harrison	Arkansas-Missouri	25
203	Colorado Springs	Colorado	25
204	Tolchester	Maryland	25
‖205	Detroit	Michigan	50
206	Leavenworth-Smithville	Missouri-Kansas	25
207	Deming	New Mexico	25
208	Colchester-Macomb	Illinois	25
209	Newell	South Dakota	25
210	Herman-Morris	Minnesota	25
211	Elkton-Wilmington	Md.-Del.-N. J.-Pa	25
212	Syracuse-Lakin	Kansas	25
213	New Athens-Okawville	Illinois	25
214	Raton-Brilliant-Koehler	New Mexico-Colorado	50

* Order by number.

† Payment must be made by money order or in cash.

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

‡ Octavo editions of these folios may be had at same price.

‖ These folios are also published in octavo form at 50 cents each, except No. 193, which is 75 cents.

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