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# DESCRIPTION OF THE ELMORO QUADRANGLE.

## GEOGRAPHY.

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

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

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

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

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

The character of the vegetation corresponds to the climate, which varies with the elevation, the mountainous portion being cool and humid and subject to frequent summer rains, while the low-lying portion is warm and arid, with only occasional showers of brief duration, or down-pourings equally brief but of torrential violence. As a consequence of the general aridity of the climate, the land is not susceptible of tillage without irrigation, except in a very few favored places, and at the present time agriculture is restricted to the valleys of the streams that afford sufficient water for irrigation. Purgatory River, rising in the Culebra Range, is the main source of supply, and an important acreage of second-bottom land adjacent to that river has been brought under cultivation. This acreage, however, is but a fraction of what

might be cultivated by considerate use of the available water in connection with systematic storage of the supply during the flood season, for which purpose the topography and nature of the outcropping formations are, in a great measure, favorable. The chief agricultural products are alfalfa, oats, wheat, barley, corn, and garden vegetables, the character of the crops being determined rather by the demands of the local markets than by the capabilities of the soil.

## GENERAL GEOLOGY. SEDIMENTARY ROCKS.

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

## PRE-CRETACEOUS HISTORY.

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

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

## CRETACEOUS PERIOD.

**Dakota formation.**—The time at which this subsidence began was near the middle of the Cretaceous period, and it was marked by the laying down of the Dakota sandstone, the oldest formation exposed within the limits of the quadrangle. At first the waters were shallow and brackish and the shore line alternately advanced and retreated;

but toward the latter part of the epoch the advance became persistent, and at the close true marine conditions prevailed.

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

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

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

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

The Graneros formation, which marks the beginning of the marine conditions following the subsidence that terminated the Dakota epoch, consists of dark-gray clay shale, from 200 to 210 feet in thickness, darker near the center than elsewhere, resting on the Dakota sandstone and graduating rather abruptly into it. Large limestone concretions are not uncommon in the upper half, but are not a distinguishing feature, as similar concretions are met with in the other shale formations of the district. At a distance of about 30 feet above the base there is a layer, from 1 to 2 feet thick, of hard, concretionary limestone, weathering an orange tint, which is noticeable and characteristic. Owing to the soft, loose nature of the shale, it offers but slight resistance to erosion, and its rapid removal has exposed broad, smooth surfaces of the Dakota base-ment. The outcrop extends nearly the entire length of the quadrangle along the eastern border,

and doubtless underlies the entire quadrangle west of it. There is also a small area outcropping in Apishapa Valley near the northern border. The profile of the exposures usually is undulating; steep slopes are rare. The protection afforded by the layer of concretionary limestone toward the base has greatly aided in preserving the lower portion of the formation, which in places occupies a comparatively large extent of country.

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

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

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

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

Character and extent of the Greenhorn.

Character and extent of the Carlile.

Character of the Dakota.

Age of the surface rocks.

Early history.

Extent of the Dakota.

Surface forms within the Dakota area.

Benton group.

Niobrara group.

Character and extent of the Timpas.

Character and extent of the Graneros.

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hoof-shaped marine shell, *Inoceramus deformatis*. When examined microscopically in thin, transparent slices, the mass is found to be made up largely of the skeletons of minute organisms, Foraminifera.

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

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

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

*Pierre formation.*—The beds referred to the Pierre epoch attain a thickness of from 1250 to 1800 feet in the southern half of the quadrangle, though this amount may be exceeded in the northern half. They consist of shale throughout. The basal portion is soft, clay shale, weathering to a pale greenish-yellow tint. Above this appear bands of darker color, in places almost black, and the material flakes up into paper-like scales. Still higher there are dark-gray and lead-gray shales, containing in abundance concretions of impure ferruginous limestone seamed with carbonates of lime and iron and crumbling readily on exposure. These concretions are arranged parallel with the bedding of the shale, at certain levels situated at varying distances from one another. The nodules may be as much as 3 feet in diameter at one level, but less than a foot at the next level above or below, the size being nearly uniform at a given level. The upper portion resembles the lower in character and general appearance, except that it contains flat calcareous concretions, about 6 inches thick and several yards in diameter, lying conformable with the bedding. It can hardly be said that the characters enumerated are constant throughout the district, as the exposures are few and of limited extent. However, the presence of the concretions, generally of a rusty color, near the middle of the formation can be depended upon as characteristic.

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

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

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

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

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

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

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

While the general features of the formation may be regarded as constant for the quadrangle, the

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

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

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

#### NEOGENE PERIOD.

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

#### STRUCTURE OF THE CRETACEOUS ROCKS.

The structure of the rocks does not call for extended consideration. Over the greater part of the central and western portions of the quadrangle the beds have a very slight southwestward inclination, which is most pronounced in the southwest corner of the quadrangle. Toward the north-west, and on the Apishapa, the beds are to some extent affected by local rolls, and in places there is a decided southerly inclination. About 6 miles west of the east boundary there is a decided monoclinical flexure, having a north-south axis, which traverses the district from the north line to and beyond the upper end of Purgatory Canyon, but disappears before reaching the south line of the quadrangle. The position north of Van Bremer

Arroyo is indicated by the general line of the eastern Timpas outcrop. The inclination of the beds near the axis is about 7° westward, but they flatten out rapidly toward the central part of the quadrangle. On the east side of the axis the strata are nearly horizontal. This flexure excepted, there is a remarkable absence of displacements of any kind. This is especially noticeable in the coal-mine workings, where normal faults worthy of note are practically unknown, the only disturbed ground being that which is more or less deformed in the immediate vicinity of intruded bodies of lava.

#### TYPICAL EXPOSURES.

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

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

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

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

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

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

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

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

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

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

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

#### IGNEOUS ROCKS.

*Age of eruption.*—The eruptive rocks are assignable to two epochs of eruption, (1) an earlier one related to the late Eocene eruptions of the Spanish Peaks region, and (2) a later one related to the Neocene eruptions of southern Colorado and north-

ern New Mexico. There is also a probability that the district did not entirely escape the effects of more recent volcanic activity (Pleistocene) represented by cinder cones situated on the north and south flanks of the eastern extension of the Raton Mountains. One of these appears in the Trinchera Creek embayment, east of the creek and immediately south of the margin, though none occurs in the quadrangle itself. The late Eocene rocks consist of early lamprophyres and later lamprophyres, both of minor importance. The Neocene rocks were nearly all erupted during the early part of that period, and are deeply scored by erosion. They consist entirely of intrusive and extrusive basalt.

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

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

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

The extrusive rocks greatly overshadow the others in geologic importance. They are all confined to the southwestern part of the district, where a succession of outflows rests, with apparent unconformity, on the Laramie, and forms the capping rock of Raton Mesa. (See fig. 2, sheet of

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

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

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

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

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

## ECONOMIC GEOLOGY.

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

### COAL.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The mines most extensively operated are situated at Engle and Gray Creek; though the present workings of the Starkville mine, the mouth of which is situated in the Spanish Peaks quadrangle, extend a distance of

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

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

#### SANDSTONE.

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

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

From base to summit the Laramie includes thick beds of sandstone available for structural purposes. The color is light gray and the tint even. The grain and texture vary slightly in different beds, the average stone being somewhat coarser and more porous than Trinidad sandstone. It has been used to some extent for

the retaining walls of coke ovens, for foundations, and for railway culverts. Lately it has been crushed to suitable size and used for ballasting the Atchison, Topeka and Santa Fe track. The supply is practically unlimited.

#### LIMESTONE.

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

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

#### FIRE CLAY.

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

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

#### OTHER MINERALS OF ECONOMIC VALUE.

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

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

Petroleum has been reported as of occasional appearance along the base of Raton Mesa, by trustworthy residents, and it must be admitted that the conditions closely resemble those at Florence, Colorado, in every

important particular. This part of the quadrangle is certainly worthy of consideration as a possible oil field.

#### ARTESIAN WATER.

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

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

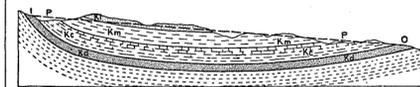


Fig. 1.—Ideal section illustrating the general artesian conditions along the plains border. Kl, Laramie; Km, Montana; Kc, Colorado; Kd, Dakota sandstone, water-bearing zone; P P, Plane of head; I, Point of inflow; O, Point of outflow.

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

Under the conditions that exist in Purgatory Valley, the point I in the diagram is situated at the great Dakota sandstone reef of Stonewall Park, which at an elevation of about 8000 feet is crossed by the several branches of Purgatory River. The point O is situated at the outcrop of the water-bearing zone along the eastern border of the quadrangle, with an elevation of about 5000 feet. The plane of head, P P, will be about 450 feet higher than the city of Trinidad and 300 feet higher than Hoehne. For one of the reasons above given, it is not at all certain that the water will rise to this plane, or that flowing wells will be had not far below that elevation; and considering the fact

that the head will decrease with the number of wells bored, the area that will yield flowing wells must be considerably less than that covered by the theoretic head. But any attempt to represent this area on the map would be out of the question, as the boundaries are necessarily arbitrary. Accordingly, the area colored blue on the sheet is merely intended to indicate the territory most likely to yield flowing wells.

There is little doubt that the water-bearing

zone will yield pumping wells over the greater part of the quadrangle. The north-south flexure which crosses the Purgatory just above the canyon separates the territory on the east that may be expected to yield but sparingly from the territory on the west that may be expected to yield a more abundant supply. From the line of this flexure the water-bearing zone dips gradually in a southwestern direction toward the bottom of the trough, which is situated

several miles beyond the western boundary; and as the land surface rises gradually in the same direction, the depth of the zone increases, as shown by the contours on the sheet. But the supply of water must also increase as the heart of the reservoir is approached. It is not to be supposed that the water will have to be pumped from the depth the bore must penetrate to reach the zone, since in nearly all cases it will rise in the well to a height that will admit of pumping by wind power.

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

RICHARD CHARLES HILLS,  
*Geologist.*

July, 1898.

*Analyses of coals from the Elmore district.*

Locality.	Carbon.		Hydrogen.		Oxygen.	Nitrogen.	Sulphur.	Moisture.	Ash.	Volatiles by distillation.	Specific gravity.	Character of sample.
	Fixed.	Com-bined.	Dispos-able.	With oxy-gen.								
Engle mine.....	54.65	18.33	3.68	0.87	6.70	0.85	0.61	0.70	13.35	31.30	1.366	Sample of slack coal taken from cars.
Engle mine.....	57.07	17.56	3.67	0.99	7.89	0.47	0.55	0.75	11.05	31.13	1.287	Clean lump coal.
Starkville mine.....	57.39	16.19	3.65	1.18	9.41	0.31	0.63	0.44	10.80	31.37	1.303	Clean lump coal.
Morley seam.....	59.19	17.55	4.21	0.77	6.21	1.06	0.61	1.63	8.77	30.41	1.358	Clean lump coal.
Sprouls opening*.....	52.50	20.25	4.06	1.31	10.46	1.73	0.50	2.90	6.30	38.30	1.250	Clean lump coal.
Bloom mine.....	57.08						0.70	0.45	10.71	31.11	1.333	Clean lump coal.
Butler mine.....	56.59						0.65	0.45	11.51	30.80	1.329	Clean lump coal.

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

*Analyses of coal ashes from the Elmore district.*

	Silica.	Alumina.	Ferric oxide.	Lime.	Magnesia.	Soda.	Potash.	Sulphuric acid.	Phosphoric acid.	Total.
Starkville mine.....	65.02	24.73	7.56	0.16	0.30	2.22	0.53	0.32	.095	100.92
Engle mine.....	68.42	17.33	11.50	0.66	0.21	1.49	0.71	0.37	.080	100.77
Morley seam.....	68.60	19.94	6.42	1.30	Tr.	1.46	1.32	0.34	*	99.38

\* Not determined.

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

TABLE OF FORMATION NAMES.

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