DESCRIPTION OF THE PUEBLO QUADRANGLE.

INTRODUCTION.

It is assumed by the writer of this text that the facts and deductions recorded in the folio are of interest not only to professional geologists but to those residents of Pueblo and vicinity who care to know the origin of rocks and hills or who desire to make use of the mineral products of the district. Endeavor has therefore been made to avoid technical language, so far as may be, and where avoidance is impracticable, to explain the terms used. The layman is advised to read the "Explanation" printed on the inner pages of the cover, and his attention is invited to the supplementary explanations in the paragraphs immediately following.

Dip and fault defined.

A stratum, layer, bed, or other sedimentary formation having great horizontal extent as compared to its thickness may lie level or may be inclined. If inclined, the amount of its inclination or slope is called its *dip*, and the measure of the dip is the angle between the surface of the formation and a horizontal plane. The direction of its steepest slope is called the direction of dip, and the direction at right angles to this the *strike*. Thus if the dip of a stratum is northeast its strike is northwest. The stratum is also said *to dip* northeast and *to strike* northwest.

When a stratum or other body of rock is broken across and one part has slidden past the other, the dislocation is called a *fault*, and the rock is said to be *faulted*. The amount of dislocation, or the distance separating corresponding parts of the severed mass is called the *displacement* of the fault. In fig. 1 the distance *ab*, separating parts of the faulted stratum 2,2, is the displacement.

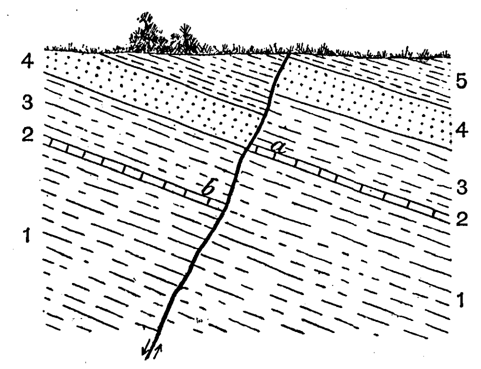

Fig. 1.—Ideal section showing a fault.

The mass of strata at the left has moved down as compared to the mass at the right. The numbers show corresponding strata that were once continuous.

GEOGRAPHY.

The Pueblo quadrangle extends in longitude from 104° 30′ to 105°, and in latitude from 38° to 38° 30′. It is 34.5 miles long, north and south, 27 miles wide, and contains 938 square miles. It includes part of Pueblo County and the southeast corner of Fremont County, Colorado.

Mountains, plains, and foothills.

The great features of the continent to which it is related are the Rocky Mountains and the Great Plains. The surface of the Plains rises gradually from east to west and is more diversified by hills in its western portion, so that the transition from plain to mountain is not abrupt. There is usually a belt of intermediate character, called foothills, and this belt is well developed in the vicinity of the Pueblo quadrangle. At several places the front line of the mountains is broken by embayments into which extend tongues of the plain, and one of these embayments is traversed from west to east by the Arkansas River. The Pueblo district lies near the western edge of the Plains, opposite the Arkansas embayment. It belongs chiefly to the plains province, but includes also two portions of the foothills belt, one along the western part of its north boundary, the other along the southern part of its west boundary.

Relief and drainage.

Broadly viewed, the surface is a plateau, ranging in height from 4700 to 5500 or 6000 feet. It is lowest at the east, near the city of Pueblo, and rises toward the north, south, and west. The streams run below the general level, following narrow valleys or canyons a few scores or a few hundreds of feet in depth, and the plateau is overlooked by the foothills already mentioned as well as by a few outlying hills and mesas. Baculite Mesa, northeast of Pueblo, rises 400 feet from the plain; the so-called "Sand hill," southwest of the city, is about half as high; and there are several unnamed tables in the southern part of the quadrangle.

The drainage system corresponds in its principal lines with the general slopes of the surface. Its main artery is the Arkansas River, which enters the district from the west a few miles north of the middle, runs southeasterly to the center, and thence easterly. The general course of tributaries on the north is southerly, the chief being Fountain Creek, which joins the Arkansas at Pueblo. South of the Arkansas the general course of the drainage is toward the northeast, and the most important stream is the St. Charles River, which joins the Arkansas a few miles east of the boundary of the quadrangle. The Arkansas carries a large body of water at all seasons. Each of the other streams is at certain seasons and at certain places lost, its water being absorbed by the sands of its bed.

Climate and vegetation.

There is a considerable range of climate, corresponding chiefly with differences of altitude. The eastern part shares the heat and aridity of the western belt of the Plains; the foothill tracts at the west are cooler and moister because higher; and the western part has an additional advantage from summer showers generated in neighboring mountains.

Vegetation is of several types, closely related to climate and soil. A forest of yellow pine occupies most uplands above 6500 feet, and there are straggling pine groves on sandy hillsides down to 5300 feet. In the same zone rocky slopes are sometimes covered with aspens; on sandy soils the lower pines are accompanied by thickets of dwarf oak; and moist canyons shelter the hackberry and other hardwood trees of moderate size. Cottonwoods occupy the bottom lands of all permanent and many intermittent streams. Below the yellow pines are junipers and piñon pines, and these extend down to 5000 feet altitude, with stragglers beyond. They grow only on rocky and gravelly soils where the slope is steep, and are chiefly associated with ledges of limestone and sandstone. The remainder of the land, including much the greater part, is prairie, with an open growth of low bushes and grass.

Agriculture.

The moisture necessary for the pine forest is adequate also for cultivated crops, and a few small tracts of favorable soil are farmed without irrigation. The associated climate gives but a short season, and only the hardier cereals and vegetables are grown. There is also a certain amount of natural irrigation of bottom lands, but little agriculture is based on it. Recourse is usually had to artificial irrigation, and for nearly all the land this is essential to successful farming. A large canal—the Bessemer ditch—carries water from the Arkansas River to a broad mesa on the south side and embraces several square miles of arable land, but irrigation is otherwise limited to narrow belts following the river and larger creeks. The cultivated area is but a small fraction of the district, and the remainder is used only for grazing.

GENERAL GEOLOGY.

Order of treatment.

The rocks comprise a number of formations, each with its individual character, and these stand in certain definite relations one to another. They are also related in an intimate way to the forms of the surface. Clearly to understand these relations it is necessary to take account of the ways in which the rocks were made, of the ways in which their original arrangement has been disturbed, and of the ways in which the existing forms of hill and valley have been produced. In the investigation of the district the rocks and hills have been questioned and made to tell the story of their origin, and in this way the long sequence of physical events constituting the geologic history of the district has been gradually worked out. Knowledge of the character and arrangement of the rocks has thus preceded knowledge of their history, but it is thought that the subject can be more clearly presented by reversing this order. The history of the physical changes will first be outlined, and will then be used in explaining the character and arrangement of the rocks and the forms of the surface.

HISTORY OF PHYSICAL CHANGES.

The foundation rocks.

At the earliest date which need be considered here the surface of the district was a plain, more even than the present surface, and the rocks composing its floor were granite, gneiss, mica-schist, and similar formations, known collectively as "crystalline schists." There was, of course, a history of origin for these formations as for all others, but present purposes do not demand its consideration. The individual rock masses of the series were in the form of irregular plates, dipping steeply downward and fitted together so as to form a continuous mass, and the upper edges of the plates formed the continuous surface of the plain. The date at which this plain existed is so remote that its antiquity is not measured or known in years, and if the number of years could be written it would probably be too large to convey a definite impression to the mind.

IDEAL SECTIONS ILLUSTRATING THE GEOLOGIC HISTORY OF THE PUEBLO DISTRICT.

[The line W marks the position of the water surface.]

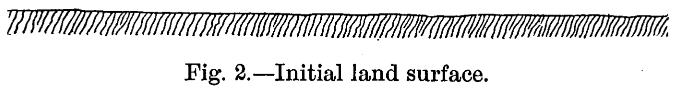

Fig. 2.—Initial land surface.

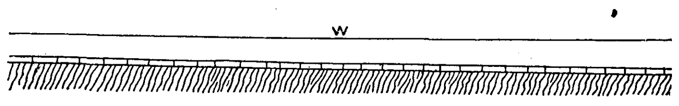

Fig. 3.—After the deposition of the Carboniferous limestone.

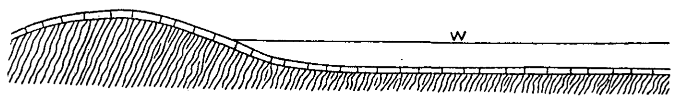

Fig. 4.—After local uplift.

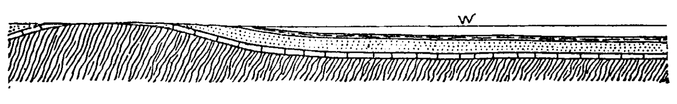

Fig. 5.—After erosion of areas above water and deposition under water of Juratrias sand and shale.

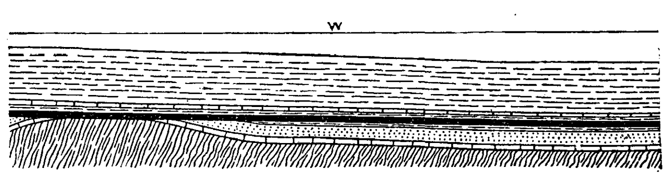

Fig. 6.—After greater submergence and deposition of Cretaceous sandstone, limestone, and shale.

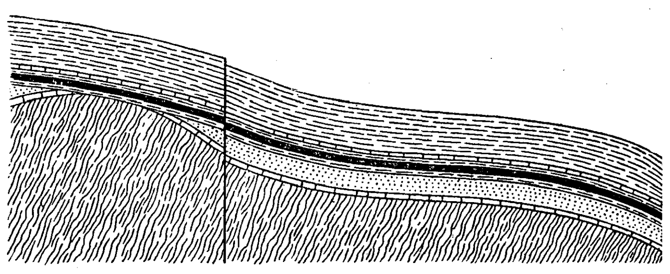

Fig. 7.—After second great uplift and bending.

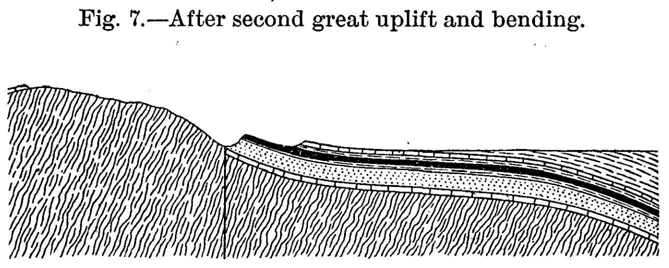

Fig. 8.—After second erosion period (Eocene).

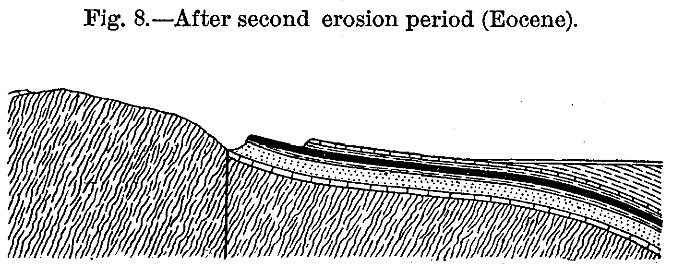

Fig. 9.—After deposition of Neocene sand.

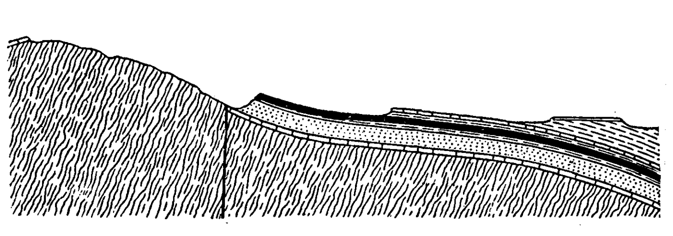

Fig. 10.—After partial erosion of Neocene sand.

The floor of crystalline rocks, at the epoch assumed as initial, was part of the dry land, just as now, but that condition has not been continuous from the assumed beginning to the present time. From time to time the level of the ocean has been raised so as to cover the land (or the land has subsided so as to sink beneath the ocean), and there have also been times when the district was covered by the waters of an inland sea.

Silurian, Devonian, and Carboniferous periods.

The first change was a submergence, the plain becoming the bed of an ocean, and on this ocean-bed were spread various sediments brought by currents from neighboring lands. First came a deposit of white sand, and then one of limy ooze. In the course of time the sand was cemented and hardened into sandstone, and the limy ooze became limestone. We do not know how evenly these deposits were spread, but it is probable that the limestone at least covered the entire district, forming a continuous sheet or layer, so that the floor of crystalline rock was wholly concealed. The duration of the submergence corresponds to three periods of the geologic time scale, the Silurian, Devonian, and Carboniferous. Fig. 2 represents in a diagrammatic way the floor of crystalline rocks, as seen in section; fig. 3, the same floor with a covering of sediments.

Juratrias period.

The next event was an unequal uplift of the ocean floor. Parts of it were pushed up from below, so that the even expanse came to be broken in places by heights. At least one of the uplifts was raised above the surface of the ocean (fig. 4), making a new island, or perhaps part of a continent, and in consequence of this exposure was subjected to the dashing of waves, the beating of rain, and the washing of streams, so that the new deposit was locally worn away and even the crystalline rocks were eroded. Another effect of the uprisings which occurred at that time was to partition off a part of the ocean, so that the waters of the Pueblo district became part of an interior sea or salt lake. The sand, gravel, and mud washed by the streams from the surrounding lands accumulated in this sea, forming a new series of deposits. By the waves and currents the material was separated into kinds, so that the deposits in different places were different; and it happened that this district no longer received limy ooze, but clay or mud, and with it sand. Afterward, when the deposits were cemented and hardened, they became strata of shale and sandstone, and they are further distinguished from the older strata on which they rest by having a deep-red color. The general condition of the district at this time is shown in fig. 5. The time represented by the red sediments is the earlier part of the Juratrias period.

There followed a general but not uniform subsidence, so that the land was once more covered by a sea, and this continued during the deposition of other layers of mud and some layers of sand. The sea was completely shut off from the ocean, and became at times a dense brine, like the Dead Sea or Great Salt Lake. When its brine was most concentrated gypsum and perhaps other minerals were separated by evaporation, just as salt is separated by the evaporation of ocean water. There were also disturbances of the bottom by uplift from below, so that part of the new deposit was lifted above the water and again washed away. The hardening of these sediments produced shales of many brilliant colors, with minor layers of sandstone and gypsum. The time of their accumulation was the later part of the Juratrias period.

Dakota epoch.

A change then occurred in the character of the water. The inland sea in which strong brine had gathered became connected with the ocean, so as to be a bay or estuary, and through this connection its waters were rendered as fresh as those of the ocean. At times they were probably even fresher, but on this point the evidence is not clear. In connection with these changes the water first receded from a portion or the whole of the quadrangle, and then advanced so as to completely cover it and extend far beyond. The advance was not at a uniform rate, nor even continuous, but alternated with retreat, so that the coast-line passed and repassed the district several times. The mud and sand washed by the rivers from neighboring lands were sorted by the waves on this shifting coast, the result being that the sand was accumulated at the shore-line and the mud was carried by the currents to deeper water. Each part of the quadrangle, being covered alternately by the shoal water of the coast and the deeper water off shore, received alternating deposits of sand and mud which were afterward compacted into sandstone and shale. The manner in which these sands were deposited is of great practical importance to man, for their long agitation by the waves washed out all the finer particles, so that the resulting sandstone is made up of coarse grains which do not fit closely together and it is therefore porous. Being porous it absorbs water freely and also permits it to flow through, making an underground circulation available for artesian wells.

Other Cretaceous epochs.

After sand with occasional layers of mud had accumulated to a depth of several hundred feet, the Pueblo district sank much lower, so as to be deeply covered by water. Neighboring regions also went down, and the bay was converted into a broad, deep ocean in which mud slowly gathered for a very long period. There was one short interval when sand came instead of mud, and there were two epochs during which limy ooze alternated with clayey mud, but these changes were not accompanied by any local warpings. The floor of the ocean remained smooth and even in the Pueblo district, and the deposits were gathered in flat, uniform layers. Afterward the mud was converted into shale, the limy ooze into limestone, and the sand into sandstone.

These conditions, including the advancing coast-line with its rapid accumulation of sand and the broad, deep ocean with its slow accumulation of mud, belong to the Cretaceous period. The state of the district at the close of that period is shown in fig. 6, where the heavy black line represents the porous sandstone; the shales above are indicated by broken lines, and the principal limestone bed is represented by a notation of blocks.

Eocene and Neocene periods.

The whole quadrangle, together with a much larger territory, was now lifted above the ocean and also warped and deformed. A great lifting of the mountains took place at the same time, and this affected those parts of the district which belong to the belt of foothills. A number of wave-like ridges were also produced, and in some places the strata were broken across and faulted. Fig. 7 illustrates the general character of these changes, but it is misleading in that it implies that the formations remained intact while they were deformed. In fact, the great mountain indicated at the left of that diagram never existed, for the changes of form were slow, and as soon as the sea-bed became land and steep slopes were produced rain and streams began their work of erosion. Uplift and erosion thus went on together, and the actual height of the land at any time represented only the difference between these two modifying factors. Fig. 8 exhibits the same internal structure as fig. 7, but after the removal of large portions of the various formations by erosion. It corresponds in a general way to the actual condition of the district at the present time. The time during which this deformation and erosion took place belongs chiefly to the Eocene period but partly also to the Neocene. The work of erosion is still in progress. Every storm that beats on the surface of the district washes a quantity of mud and sand into the creeks, and the turbid creeks carry it to the Arkansas River. The Arkansas, though already loaded with detritus by the storms in the mountains, receives the tribute of the creeks and sweeps it onward toward the ocean.

This is the process by which the land was eroded during the great uplifting, and it has been nearly continuous from that time to the present. Still there have been local interruptions, and one of these belongs to the history of the district. There was an epoch in the Neocene period when the eastward slope of the plains was less than now, so that the Arkansas and such of its branches as headed in the mountains were too sluggish to carry onward the sands that were given them by the mountain storms. The slackened current washed along the mud but dropped some of the sand, so as to build up its bed. There was thus produced on the plain a formation of sand without the intervention of any body of standing water, either lake or ocean. This deposit was not deep and did not cover the entire surface of the district. It was spread only over the parts which were then lowest and it rested on the worn surfaces of various older formations (fig. 9). It was never hardened into firm rock, but retained the condition of loose sand. When changes of height and changes of slope gave greater speed to the rivers and creeks, so as to renew the erosion of the plain, the soft sands were easily attacked, and little is left of them at the present time. The stream beds, and even the general surface of the country, are worn several hundred feet below their plane, and such remnants of the sands as survive are the caps of mesas. Such a mesa is shown at the right in fig. 10.

Present condition.

As a result of this long and complex history the rocks of the district are broad plates or strata, of great horizontal extent and comparatively small thickness. For the most part they are parallel and lie one upon another like the leaves of a book. They are not flat, but are warped in various ways. They differ in horizontal extent chiefly because the upper and newer have been more widely eroded than the lower and older. The breadth of any particular formation at the surface, or, in other words, the width of its outcrop, depends partly on the extent to which the formation has been removed and partly on the extent to which the next overlying formation has been removed. If a deep well be drilled from any point of the surface the various formations will be penetrated in a definite order, but the only formations reached will be those which have not been eroded from that place, and the depth at which each will be found will also depend on the amount of local erosion.

THE ROCKS.

In this section the various formations are described in the order of their origin, beginning with the oldest. They are classed, according to the periods in which they were formed, as Archean, Silurian, Carboniferous, Juratrias, Cretaceous, Neocene, and Pleistocene. The areas they occupy within the quadrangle are marked on the Historical Geology sheet, and their sequence and relative thicknesses are graphically shown on the Columnar Section sheet.

ARCHEAN.

Schists and granite.

In the southwest part of the quadrangle are two small tracts of crystalline schists to which no formation name has been given. The more abundant kinds of rock are mica-schist and mica-gneiss, colored gray and pink, and a pink variety of granite. The schist and gneiss exhibit schistose structure, the plates of mica lying nearly parallel, so that the mass splits most readily in one direction. The plane of this direction varies in course or "trend" from north to northwest, and is nearly vertical. The granite occurs in large bodies of irregular form, and also in veins penetrating other rocks. The character and relations of the veins show that they were injected in liquid condition after the making of the other rocks, and it is thus known that the granite is of igneous origin. The origin of the other rocks was not determined. The larger of the two tracts occupies the southwest corner of the quadrangle; the smaller lies west of Beulah. Their total area is about 7 square miles. Wherever younger formations are seen to rest on the Archean rocks they are unconformable.

Pre-Silurian topography.

The southwestern tract is an upland, rising 800 to 1500 feet above the adjacent lowland, and is deeply trenched by the canyons of the St. Charles River and its tributaries, so as to have a decidedly rugged and mountainous character. Its higher parts, however, are comparatively smooth, and the distant view from a favorable point shows that they are regularly related to one another. They are remnants of an earlier plain, originally level but now inclined toward the east and northeast. This plain was at one time the upper limit of the Archean mass, and the modern canyons, some of which are nearly 1000 feet deep, have since been carved from that mass by the streams which occupy them. The plain of the uplands is not itself smooth, though in places it is sufficiently level for cultivation. The different rocks have weathered away unequally, and the granite, resisting erosion better than the others, projects above the general plain in rounded knobs. As will be explained in subsequent paragraphs, the plain was originally carved from the Archean mass in the early part of the Juratrias period, and was then nearly horizontal. It was afterward buried beneath the Morrison formation and other deposits having a total thickness of thousands of feet. While still buried it was warped and tilted along with the overlying strata, and it has since been denuded or resurrected by the washing away of its cover.

SILURIAN.

Harding sandstone.—The oldest sedimentary rock of the quadrangle is a white, sugar-like sandstone, 30 feet thick. It appears only in two small tracts west of Beulah, where it rests on the Archean schists. The best exposures are in the walls of the canyon of the north branch of the St. Charles River.

CARBONIFEROUS.

Structure of the older rocks.

Millsap limestone.—Above the Harding sandstone are 200 feet of gray and purple limestones, with some shale, especially in the lower part, and on these are 30 feet of coarse gray and red sandstone. Like the Harding, they occupy two small areas west of Beulah, separated by the St. Charles Canyon. It is evident that strata originally continuous were divided by the erosion of the canyon, and they are, in fact, still united a little west of the boundary of the quadrangle. In the northern area, where they crown a ridge of Archean schists, they are much warped, so as to dip in various directions, but their general slope is toward the south. In the southern area they lie lower, and there are several mesas of limited extent capped by a massive bed of limestone. These mesas are not flat, but have warped surfaces which seem to copy the warping of the limestone.

The Millsap beds are parallel and conformable to the Harding below, but their relation to higher beds does not appear, as none rest on them. At the southeast they adjoin the Fountain formation, from which they are separated by a fault.

JURATRIAS.

Gravels of a Juratrias coast.

Fountain formation.—Two formations represent this period, the Fountain and the Morrison. The Fountain consists chiefly of coarse, deep-red sandstones containing a considerable admixture of clay. The greater number of sand grains are of the mineral feldspar, and the sandstone is consequently of the variety called arkose. In the upper half of the series are many beds of red and chocolate-brown shale; in the lower part are conglomerates. The lowest bed seen is a coarse conglomerate, containing pebbles and bowlders of gneiss, schist, and granite, similar to those of the adjacent Archean. The thickness, as measured 2 miles north of Beulah, is 2100 feet. The top of the series is not there seen, but the missing beds are probably thin.

The original relation of the formation to the older rocks was not directly observed, the line of contact being concealed except at a few points where a fault intervenes. The Archean bowlders in the lower conglomerate indicate that when the conglomerate was formed there was a neighboring land area occupied by Archean rocks, and this idea is supported by the great abundance of feldspar in the sandstone, for feldspar is an abundant mineral in all the Archean rocks. It is believed that the resurrected plain appearing in the southwest corner of the quadrangle was shaped during the Fountain epoch, the pebbles, sand, and clay which resulted from the wearing-down of the schistose land mass being deposited in a contiguous sea as the Fountain formation.

The valley behind the hogbacks.

The area occupied by these rocks is a belt from 1 to 2 miles broad, extending 3 miles southwestward from Beulah, where it ends against the Archean upland, and 7 miles northward to the valley of Red Creek, where it passes into the Canyon quadrangle at the west. The strata dip eastward at angles varying from 10 to 20 degrees, and pass under the Dakota sandstone, which there forms the crest and eastern slope of a high ridge or "hogback." Opposing feebler resistance to erosion than do the schists and limestones at the west or the firm sandstones at the east, the Fountain beds have been more extensively removed and their outcrop constitutes a valley. The southern part of this valley is drained by South Creek and North Creek, tributary to the St. Charles River, and the northern part by Red Creek and its branches. Near Beulah the slopes are gentle and there are smooth, soil-covered terraces suited for agriculture; but farther north is a labyrinth of small ridges and canyons whose bare sides afford little foothold even to grasses and give a characteristic redness to the scenery.

Variegated clays and gypsum.

Morrison formation.—The Morrison beds, though broadly exposed in the adjacent quadrangles to the north and northwest, are represented in the Pueblo only by three small areas. One adjoins the northern boundary 3 or 4 miles west of Turkey Creek and is continuous with a much larger tract in the Colorado Springs quadrangle. The beds exposed include only the upper part of the formation. They are chiefly clays or shales of brilliant hues, the lower 200 feet being mostly white and the upper 100 chocolate and green; near the base are several beds of gray and white gypsum; above the middle is a yellowish sandstone, and toward the top are several thin beds of limestone. In the second area, near the northwest corner of the quadrangle, the strata are poorly exposed. The third area, near the southwest corner, is a narrow belt crossing the western slope of Hogback Mountain at a high level, and then turning southeast and following the base of the Archean upland. The part exposed on Hogback Mountain consists chiefly of red shale, but contains a few layers of hard red sandstone. Its total thickness is about 70 feet. The part bordering the Archean area is paler, white and orange predominating, and none of the harder strata were observed. The formation there dips steeply to the northeast, and its apparent thickness changes rapidly from point to point by reason of faulting. At one point it is seen to rise with diminishing dip toward the back of the Archean upland, and on the continuation of that upland in the Walsenburg quadrangle at the south are outlying remnants of the Morrison shale protected by caps of Dakota sandstone. The Morrison shale was the first formation spread over the old land-surface from which the material of the Fountain formation had been eroded. At the end of the Fountain epoch the area of submergence was enlarged so as to include much that had before been land, and the deposits of the Morrison sea accumulated not only on the newly gathered Fountain sediments but on the ancient Archean rocks.

The Morrison overlaps the Fountain.

As the Morrison beds are weaker than all their neighbors, they have yielded readily to erosive attack and their outcrops are marked by valleys; but their extent is so small that these valleys belong only to the minor features of the topography.

CRETACEOUS.

Importance of the Cretaceous.

The outcrops of the formations thus far described occupy about one-fiftieth of the quadrangle; the Cretaceous formations constitute nine-tenths of the entire surface. From an economic point of view the relative importance of the Cretaceous strata is equally pronounced, for they include the limestones, building-stones, fire-clays, and artesian waters of the district. The order of the Cretaceous formations, beginning with the lowest, is: Dakota, Graneros, Greenhorn, Carlile, Niobrara, Pierre. The Dakota consists chiefly of sandstone; all the others chiefly of shale. In the Greenhorn is some limestone, in the Carlile a little sandstone, and in the Niobrara an important body of limestone. The broadest outcrop of the Dakota formation is in the southwest part of the quadrangle, and the Pierre occurs at the northeast. The intermediate members constitute a great belt extending from northwest to southeast, but their individual boundaries are irregular and sinuous, and there are many insular tracts. Some of these islands are *outliers*, or remnants cut off from the main belts by the erosion of intervening parts, and these appear in the landscape as buttes or mesas; others are *inliers*, or limited tracts from which overlying beds have been eroded, and these occur usually in lowlands. The outlier of a formation is completely surrounded by outcrops of the next lower formation; the inlier by outcrops of the next higher formation.

Outliers and inliers.

Dakota sandstone.—Mention has already been made of the Dakota sandstone as a porous rock whose sand was washed clean by waves in the process of formation. It is now necessary to

Variability of the Dakota sandstone.

qualify this statement by describing the formation more in detail. Wherever its full section is exposed to view it is found to consist chiefly of a series of thick sandstone beds separated by comparatively thin shale beds. The sandstone changes rapidly in thickness from point to point, so that no two measurements at different places show close agreement, and when comparison is made between localities as much as 10 miles apart it is usually impossible to recognize the identity of individual beds. At base the formation is sharply limited by a surface of unconformity. Usually it rests on Morrison shales, but in the vicinity of Beulah, and thence northward to Red Creek, it rests on the Fountain sandstone, the Morrison formation having disappeared by erosion before the Dakota was deposited. At top it passes into the Graneros shale without any sharp line of separation, the shaly members of the Dakota becoming gradually more numerous and the sandy members thinner until the latter cease altogether. The highest sandstone is usually a single layer of dense, brittle rock having a vertical fracture. It is in the upper part that shales occur of the peculiar quality necessary for use as fire-clays.

Texture, color, and porosity.

The grains composing the Dakota sandstone are chiefly of quartz, and the rock is thus contrasted with the neighboring Fountain sandstone, in which feldspar predominates. It is further contrasted by its color, which is ordinarily light-gray, pink, or white, weathering at the surface to various shades of yellow, orange, and brown. Some of the lower members are locally so coarse-grained as to merit the name conglomerate. The larger pebbles are of quartzite. There are also white grains of some soft material, which may be a kaolin resulting from the decomposition of feldspar. The fractured surface often has a speckled appearance, flecks of yellowish brown dotting a gray ground. The different beds show considerable difference in porosity, and doubtless the same bed varies from place to place. The highest sandstones are not so porous as to convey artesian water, but the heavier beds of the middle and lower parts of the formation have usually an open texture. The greatest measured thickness, near Beulah, is 650 feet, and nearly the whole of this is sandstone. In the northwestern and southeastern parts of the quadrangle the thickness is from 300 to 350 feet, and the sandstone is more interrupted by beds of shale. Elsewhere the formation has been found to contain leaves of plants in great abundance and variety, and also shells indicative of brackish water. The only fossils discovered in this district were a few leaves and the trails of undetermined animals.

Thickness of the Dakota sandstone.

Extent of the Dakota sandstone.

The formation underlies nearly the whole of the quadrangle. It is exposed at the surface over a large area in the southwest part and in other important areas near the northwest and southeast corners. There are also three small inliers: one on the Arkansas River at Rock Canyon, where the formation is trenched by the river for a few rods; another east of Greenhorn Creek, not far from the junction of its principal branches; the third, east of the eastern branch of Greenhorn Creek, not far from the south boundary of the quadrangle.

Dakota hogbacks.

In relation to the forces of erosion the Dakota is the most resistant formation of the district, with the possible exception of the Archean granite. Where uplift has given it a steep dip it rises above the weaker rocks by which it is surrounded in a bold ridge, ordinarily called a "hogback," and the Dakota hogbacks are among the most important features of the foothill belt along the base of the Rocky Mountains. In this quadrangle a well-characterized hogback forms the eastern wall of the Beulah and Red Creek valleys, and there is another, less characteristic, near the northwest corner.

Graneros shale and concretions.

Graneros shale.—Resting conformably on the Dakota sandstone is the Graneros shale, from 200 to 220 feet thick. Its color includes various shades of bluish gray, being lightest in the lower part and darkest near the middle of the mass. At most localities several thin beds of white clay were seen, but it is not known whether these are continuous for great distances. Some of them include crystals of selenite, and one occurs in immediate contact with a thin limestone layer wholly composed of oyster shells. Oyster beds were observed at several other localities, but they are probably very local features. The most persistent of the contained hard beds is a calcareous sandstone, 1 or 2 inches thick, found about 50 feet below the top of the shale. It contains fossil shells of several kinds. In the southern part of the quadrangle a line of concretions is usually found about 30 feet above the base of the formation. They are from 6 to 12 inches thick, calcareous, and often fossiliferous. The shale passes so gradually into the Greenhorn formation above that the line of separation had to be arbitrarily drawn.

The outcrop is a belt of moderate width, very crooked and irregular, following the margin of the Dakota sandstone. The associated topographic forms include valleys, lowlands, and long slopes descending from terraces of Graneros limestone to basements of Dakota sandstone. The formation is notably infertile, so that its slopes, unless overwashed by débris from other beds, are nearly destitute of vegetation.

Greenhorn limestone and fossils.

Greenhorn limestone.—In the Greenhorn formation limestone beds from 3 to 12 inches in thickness alternate with shale beds 10 to 20 inches thick. The shale factor is thus, in one sense, the more important, but the limestone ledges resist decay so strongly that their fragments usually cover the surface of the outcrop, concealing the shale from view and giving the impression of a thick sheet of limestone. The limestone is pale-blue and of fine texture. Most of the layers are divided by vertical cracks into smooth, flat flakes, from one-fourth inch to 2 inches thick. Some of them have abundant fossil shells, especially a thin form, of oval outline, marked with concentric waves or ridges (*Inoceramus labiatus*). The shale is bluish-gray and darker than the limestone. It contains the same shells in abundance, but so poorly preserved as to escape casual observation. There are also thin layers of white clay. The thickness of the whole series is from 35 to 50 feet. The Illustrations sheet contains a typical view of the limestone and drawings of its characteristic fossil.

The Greenhorn outcrop is a narrow belt, usually but a few hundred feet across, but occasionally expanding to a half mile. Its course is winding and there are many outliers and inliers. Occasionally the limestone caps a hill or forms the crest of a ridge, but usually it constitutes a terrace interrupting the slope from a cliff of Niobrara limestone above to a valley of Graneros shale below. The shattered limestone stores water better than the adjacent shales, thus favoring the growth of trees, and its zone is usually marked by a belt of junipers and piñons.

Carlile shale and sandstone.

Carlile shale.—The Carlile formation is from 180 to 210 feet thick, and consists chiefly of argillaceous shale. The lower 50 feet are medium-gray; then come 25 feet of dark-gray, including bands that are nearly black, and above the color is medium-gray. At 50 or 60 feet below the top of the formation the shale becomes sandy, and within the sandy part are lenses of friable sandstone. Many localities show from 10 to 20 feet of yellow sandstone at the very top, and in the southwest part of the quadrangle there is a bed of sandstone 40 feet below the top. The sandy shale contains also many concretions, which are more or less globular and range in diameter from 1 foot to 5 or 6 feet. Within the larger are cavities in the form of ramifying cracks, and these have been partly or wholly filled by white and wine-colored crystals of calcite.

The outcrops of the shale are irregular in plan and comprise a large number of inliers. The greatest development is at the south and southeast. There are considerable areas in the valleys of Rock and Pecks creeks; exposures follow the banks of the Arkansas River from Goodnight to Beaver; and there are several lines of outcrop between Beaver Creek and Wild Horse Park. The sandstone at top usually unites with the Niobrara limestone resting on it in the formation of a cliff, and the shale below either constitutes a steep slope under this cliff or a valley between two facing cliffs.

Fish-tooth bed in the Niobrara.

Niobrara formation.—The Niobrara formation consists chiefly of shale and has a thickness of 600 or 700 feet, but is parted from shales above and below by limestones. Considering its elements in detail, the lowest stratum is a peculiar bed, from 1 foot to 2 feet thick, intermediate in character between limestone and sandstone. Its original color is dark-gray, but its weathered surface is yellowish-brown. It contains many teeth of sharks and other fishes, a few fossil shells, and numerous dark pebbles a half inch in diameter. The presence of the pebbles is noteworthy, as all the rocks for hundreds of feet above and below are composed of fine material. The bed is remarkably persistent, having been found through a broad territory.

Niobrara limestones and shells.

The next element is a limestone about 50 feet thick, consisting of strata ordinarily 1 or 2 feet thick, separated by shale layers 1 or 2 inches thick. Where its interior is exposed by quarrying the limestone is seen to have a pale-blue or gray color, but the natural surface is nearly white and somewhat chalky in texture. It breaks under the action of the weather into rough flakes whose longer dimensions are horizontal, and this character serves to distinguish it readily from the Greenhorn limestone, which is split into plates by vertical cracks. It contains fossil remains of various kinds, the most common and characteristic being a rotund bivalve shell (*Inoceramus deformis;* see Illustrations sheet) from 5 to 10 inches across. The shell itself is not often seen complete, but molds of its interior are commonly found and attract attention from their resemblance to the hoof of a horse. At top the limestone passes gradually into calcareous shale, which is more than 100 feet thick and often contains beds of limestone. Thin limestone layers occurring near its top are white or cream-colored, and contain fossil shells, especially a small oyster attached to fragments of a larger shell (See Illustrations sheet). Above this is the body of the formation, a medium-gray shale, which often splits under the action of the weather into paper-like layers. The surfaces of these layers are roughened by minute white crystals of selenite, and the same mineral often occurs in thin veins crossing the rocks in various directions. Fish-scales from a half-inch to an inch in diameter are so abundant that a few minutes' search will usually discover them in the unweathered rock. At the top of the formation are 10 to 20 feet of calcareous shales, including one or two layers of impure limestone.

Shales with fish-scales in the Niobrara.

The calcareous shales are characterized by a somewhat regular variation of texture and hardness, the amount of calcareous material becoming alternately greater and less. These alternating phases resist the weather unequally, so that where the rock is exposed in a cliff its face is barred across by obscure ribs. The space from rib to rib is usually 18 to 24 inches.

The outcrop of the Niobrara is broader than that of any other formation of the quadrangle. It occupies nearly one-half of the entire area. Its belt runs from northwest to southeast, having a simple boundary on the east and a very irregular one on the west. There are also at the west many outliers, usually containing only the basal limestone.

Limestone mesas.

The shale mass appears in the landscape only as a plain of gentle slope. The upper limestone caps a series of small ridges running from Pueblo west-northwest up the valley of Dry Creek. The lower calcareous shales are usually masked in the general plain, but are occasionally betrayed in cliffs. The lower limestone forms the back or top of many mesas and inclined tables, and usually ends in a cliff overlooking exposures of the Carlile shale.

Zones of the Pierre shales.

Pierre formation.—Above the Niobrara is a still greater formation composed almost entirely of shale. A thickness of 2200 feet appears in the district, but the top is not seen. Different parts of this shale mass exhibit diverse characters, but the gradation from one to another is so complete that it was not found practicable to divide the formation into distinct parts. Still, there is advantage in recognizing a series of zones, even though their boundaries and precise thickness can not be indicated. The Barren zone, so-called on account of the rarity of its fossil remains, lies at the bottom of the series and is 400 to 500 feet thick. It is of bluish-gray color, and its lower part resembles the Niobrara shale in the tendency to divide into papery layers, rough from the crystallization of selenite. The Rusty zone, 600 feet thick, is also bluish-gray in color but is comparatively free from gypsum. It contains many concretions composed of lime carbonate and iron carbonate, and these are of oval form, measuring, usually, from 1 foot to 2 feet across. Their material is originally dark-gray, but under the action of the weather turns a rusty brown, and the soil derived from the formation is usually so strewn with their angular fragments as to appear reddish-brown. The Baculite zone, 100 to 200 feet thick, is pale-gray, and is so called from the abundance of a fossil shell of that name. The shell has the form of a flattened cylinder, tapering slightly toward one end, and is usually a half-inch to an inch in diameter and 4 or 5 inches long. The Tepee zone, 1000 feet thick, includes the upper part of the formation as exhibited in this quadrangle. It is pale-gray, and contains numerous oval concretions ranging from 1 foot to 4 or 5 feet in diameter. In these concretions are many fossil shells, including several large forms which are also conspicuous by reason of the pearly luster of their white or gray walls. There are also large masses of rough gray limestone, called *tepee cores*, and these, though not abundant, constitute a peculiar and striking feature. They are from 10 to 30 feet in horizontal diameter and extend vertically through the shale to unknown distances, probably 50 or 100 feet. In general form they are cylindric, but their surfaces are in detail quite irregular. They also contain numerous fossil shells, especially a small bivalve (Lucina).

Tepee cores in the Pierre shale.

Areas of Pierre shales.

The principal Pierre area is triangular, occupying the northeast corner of the quadrangle, and there is a single outlying tract extending southeast from near Bessemer Junction. The total area is not far from 120 square miles, and exceeds that of any other formation excepting the Niobrara. The surface is in general a plain of gentle inclination, but about the Baculite Mesa and in some other localities there are steep slopes. These are furrowed by numerous gullies, so as to have the character of bad lands. Where the tepee cores occur their positions are marked by steep-sided conical buttes 20 to 50 feet high. The limestone of the core constitutes the apex of the butte, and its fragments sheathe the sides. The resemblance of these buttes to the conical lodges or tepees of northern Indians suggested their name. Figures of Pierre fossils and a sketch of a tepee butte may be found in the Illustrations sheet.

NEOCENE.

Gravel and sand of the higher mesas.

Nussbaum formation.—The beds composing this formation are chiefly of sand, and have an extreme thickness of 100 feet. At a few points the sand is overlain by a fine silt. At various levels it contains pebbles, and near the bottom the pebbles are usually so numerous as to constitute gravel. All these beds are *alluvial*, having been spread where they lie by the flowing water of streams. They have never been submerged under a sea or lake, and as a rule the particles do not cohere, but lie loose, just as when first deposited. The lowest part, including a thickness of 2 or 3 feet, is in a number of places bound together by calcareous or ferruginous cement, so as to constitute a rock of some firmness; and as this part was originally gravel the resulting rock is a conglomerate.

The Nussbaum is not conformable with any underlying formation, but rests on eroded surfaces of the Pierre, Niobrara, and other Cretaceous strata. The greater part of it has been eroded, so that the existing beds are merely remnants. Usually they cap buttes and mesas and lie at a considerable height above the surrounding country (fig. 11). The tops of the mesas slope in various easterly directions, conforming in a general way to the modern drainage, and there can be little question that these slopes show the direction of the streams by which the formation was made.

Baculite Mesa and Blue Hill.

The largest and thickest body is on Baculite Mesa. A second body occupies the mesa north of Blue Hill, and there are others between that and Turkey Creek. A group of small remnants occurs on the upland between the headwaters of Pecks and Rush creeks, and several are found on the St. Charles and Greenhorn a few miles above their junction.

PLEISTOCENE.

Other alluvial deposits are found at lower levels in all the principal valleys. Usually they constitute terraces overlooking the streams, and these are often in series, one above another (fig. 11). The lowest of all is the deposit in which the stream now flows and which it modifies from year to year in time of flood. Each terrace was, in fact, once the flood-plain or bottom land of the stream, and their arrangement in steps is a record of the gradual deepening of the valley by erosion. Their order of position is also their order of age, but in an inverse way, as the lowest is the latest. They thus belong to several epochs which might perhaps be distinguished, but in mapping only two colors or patterns have been used, the one indicating the modern alluvium and the other all the earlier deposits.

Origin of stream terraces.

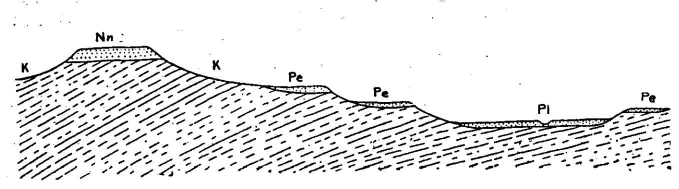

Fig. 11.—Ideal section showing the arrangement of alluvial deposits.

K, eroded surface of Cretaceous shale; Nn, remnant of Nussbaum beds, capping high mesas; Pe, remnants of earlier Pleistocene beds, capping terraces; Pl, later Pleistocene beds, making flood-plain.

The material as originally deposited includes gravel at bottom with sand and silt above, but the finer beds have been washed away from all the narrower terraces, leaving only gravel; and in the modern alluvium, along the streams, the gravel is often wholly concealed by the overlying sand. As all the material has been brought to its present position by the streams, and as different streams head in regions occupied by different rocks, the composition of the deposits varies from valley to valley. This is specially noticeable when the pebbles are compared. For example: the gravel in the bed of Fountain Creek, as well as in the bordering terraces, consists chiefly of gray quartzite and pink granite, while the gravel of the Arkansas and its terraces includes a wide range of rocks, among which andesites are conspicuous.

Ancient and modern bottom lands.

The Pleistocene deposits, like the Neocene, rest unconformably on all the Cretaceous formations.

FORMATION NAMES, ETC.

In describing the geology of the district the various formations must frequently be mentioned, and it is important that each have a name. For this purpose it matters little what particular name is used; but as soon as attention is extended to other districts questions of consistency arise. All formations of the Pueblo quadrangle occur also elsewhere, and so far as their indentity can be established the same names should be used. Much care has therefore been taken in the selection of the names employed in this folio; but as their use is not in all cases free from doubt, and as some of the names are new, it seems proper to place on record certain qualifications and explanations.

Selection of names for formations.

The reference of the schists and granites to the Archean period is provisional only. The rocks are broadly exposed in the adjacent district at the west, and when they shall have been there studied it is possible that some other classification will be found better.

The names Harding, Millsap, Fountain, and Morrison are all derived from the Pikes Peak folio, where they were introduced and defined by Dr. Whitman Cross. The Pikes Peak quadrangle lies northwest of the Pueblo, touching it at one corner, and the continuity of the various formations has not yet been established by direct tracing. The sandstone here named Harding contains no fossils and is connected with the Harding sandstone of the Pikes Peak quadrangle only through similarity of physical character and relation.

Harding, Millsap, Fountain, Morrison.

In a bed near the middle of the overlying limestone were found a few fossil shells of *Spirifera rockymontana*, a Carboniferous species found also in the Millsap limestone of the Pikes Peak quadrangle, but nothing was found to mark the presence of the Fremont limestone (Silurian), which in the Pikes Peak district separates the Harding and Millsap formations. The application of the name Millsap to the whole limestone series of the Pueblo district is a somewhat arbitrary procedure and is subject to correction when more facts are available.

There is yet another doubt as to the name Millsap. The fact has recently been brought to the attention of Dr. Cross and myself that Mr. W. F. Cummins applied the same name to a formation in Texas in 1891, but ignored it and apparently abandoned it in 1893. Should the name be retained for the Texas formation the rule of priority will require the substitution of another name for the formation occurring in the Pikes Peak–Pueblo region.

In each district the Fountain formation lacks fossils, and the determination of its period depends wholly on physical characters. These are inconclusive, and the time relations of the formation are in doubt. By Cross it has been provisionally placed in the Carboniferous; by the writer, in the Juratrias.

When the geology of this region was first studied by Dr. F. V. Hayden, in 1868, the beds lying between the Dakota and Niobrara formations were called the "Fort Benton formation." They comprise a series of shales about 450 feet thick, interrupted near the middle by a number of limestone layers. The limestone strata have so important an influence on the topography and afford so much aid in the study of artesian problems that it seemed best, in connection with the present work, to give them a special name, and this led to the separate designation of the shale beds above and below them. The name Graneros, applied to the lower shale, was suggested by Mr. R. C. Hills, and is derived from a village and creek a short distance south of the district. The name Greenhorn, applied to the limestone, is derived from Greenhorn Creek and Greenhorn station. The name Carlile, applied to the upper shale, is derived from Carlile Spring and Carlile station on the Arkansas River. At the localities to which the names refer the several formations are well exposed for study.

Graneros, Greenhorn, Carlile.

In later publications by the survey under Dr. Hayden's direction, the Niobrara and Fort Benton were united under the name "Colorado Group," and this usage has been largely followed. In the atlas of Colorado published by the Hayden Survey the color representing the Colorado group is erroneously made to include a large tract now known to be occupied by the Pierre shale.

Colorado group.

The name Nussbaum is here used for the first time, being derived from Nussbaum Spring, which flows from the Nussbaum sands near the south end of Baculite Mesa.

Nussbaum.

The diversities of usage here mentioned, as well as other discrepancies to be found in the literature of the region, are arranged in tabular form at the bottom of the sheet of columnar sections.

STRUCTURE OF THE ROCKS.

The strata of sediment formed on the bottoms of lakes and oceans are nearly level. Steep dips of strata result from uplift or other disturbance by underground forces. The process by which level strata are transformed into dipping strata is called *deformation*. The resulting forms include *arches* and *domes*, which are convex upward, and *troughs* and *basins*, which are concave upward. Associated with these are faults.

Deformation defined. Arches and troughs.

As already stated, the strata of the district were deformed at three epochs: first, after the making of the Millsap limestone; second, after the Morrison shale was formed; third, after the Pierre shale had accumulated. The older formations were affected by two or three of these disturbances; the Cretaceous formations—Dakota to Pierre—only by the last. Thus the oldest are most deformed, but as the area of their exposure within the quadrangle is small little is known of their structure. The Cretaceous formations are so widely exposed to view that their structure is comparatively well determined.

THE DEFORMATION SHEET.

The dips, arches, and troughs given to the Cretaceous strata by deformation are exhibited graphically in the Structure Section sheet and the Deformation sheet. The uppermost section on the Structure Section sheet shows the structure of the formations along the line A A. If a single rock bed be traced from side to side it will be seen to exhibit several flexures and to be dislocated at two points by faults. Take, for example, the Dakota sandstone (Kd), which lies at the surface near Red Creek and also to the left of White Butte. Between these points it passes beneath the surface, being flexed down into a trough, and various other formations lie above it. To the right, also, it passes down beneath other formations, and although somewhat flexed in detail, descends so rapidly that at the margin of the quadrangle it is nearer to sea-level than to the surface of the land. It is, in fact, about 3000 feet underground. The other sections exhibit similar facts along their respective lines. In the Deformation sheet a different mode of representation is employed. Let us imagine that all the rocks lying above the Dakota sandstone are dug away, so as to lay bare the surface of that formation. Let us suppose, further, the Dakota sandstone to be restored in those small portions of the quadrangle from which erosion has removed it. There will result from this denudation and reconstruction an uneven surface exhibiting the shapes given to the Dakota sandstone by the processes of deformation. The work thus imagined is altogether too stupendous to be actually accomplished, but our knowledge of the thickness and extent of the overlying formations and of other geologic facts makes it possible to determine with considerable accuracy many details of the form which would result. To represent this form a model has been constructed on the same scale as that of the map. A photograph was made of the model, and the engraving constituting the Deformation sheet was prepared from that photograph. The arches and domes of the deformed surface there appear as ridges and mounds, the troughs as valleys, and the faults as cliffs.

Sections of the Structure Section sheet.

Deformation sheet; a photograph from a model.

When one looks at the photograph of such a model it is important that the light illuminating the photograph come from the same side as the light which illuminated the model when the picture was made. If these relations are reversed the hills may appear as hollows and the hollows as hills. The general effect is also more easily obtained at a distance of a few yards than if the sheet is held in the hand. In the making of this photograph the illumination was from the right, as shown by the shadow of the object placed on the model, and the picture should therefore be so held as to be illuminated from the right.

STRUCTURE OF THE CRETACEOUS ROCKS.

In the central part of the quadrangle and extending thence toward the northwest is a neutral tract where the deformation is only of moderate amount. At the north and northwest, at the southwest, and at the southeast are uplifts which encroach on the quadrangle but lie principally beyond its boundaries. Westward, in the vicinity of the Arkansas River, the strata descend toward a large basin in which lie the oil-bearing rocks of the Florence region. Eastward and northeastward they descend more rapidly toward a still greater basin.

Uplifts and basins beyond the quadrangle.

The northern and northwestern uplifts.—The Front Range of the Rocky Mountains, lying to the north-northwest of the district, is itself a great uplift, and much of its margin is fringed by a series of smaller uplifts which appear as arches in the strata of the Plains region. Two of these arches enter the Pueblo quadrangle, pitching down toward the south and losing themselves in the neutral tract. The more westerly is approximately bounded by Beaver Creek and Pierce Gulch; the more easterly is traversed by Turkey Creek and is impressed on the landscape as a high ridge of Dakota sandstone. From the latter project two minor arches, one running southward to Pumpkin Hollow, and the other including Wild Horse Park and a cedar-covered ridge to the east and south of it.

Beaver, Turkey, Pumpkin, and Wild Horse arches.

The Beaver arch has gentle slopes, the dips to the southwest and southeast ranging from 1 foot in 40 to 1 in 15. Near its west margin it is crossed by a fault. The Turkey arch is 1000 feet high. It has gentle dips to the east and steeper ones to the southwest, the latter averaging 1 foot in 5. The Pumpkin arch resembles the Turkey in form but is only one-third as high. The Wild Horse arch is almost independent of the Turkey, joining it at a single point. It has the form of an inverted canoe, 2½ miles wide, 6 or 7 miles long, and 500 feet high. Section AA of the Structure Section sheet crosses three of these arches.

The southwestern uplifts.—The southwest corner of the quadrangle is occupied by the northern part of a high arch, the St. Charles, which runs east as a spur from the great uplift of Greenhorn Mountain. The top of the arch is comparatively flat, dipping eastward at 1 foot in 10, but its northeastern side is steep and in places vertical. The strata are not only turned sharply down along its edge, but are faulted in a complex way, so that the outcrop does not show their full thickness. At the south end of Hogback Mountain this zone of steep slope branches, one part continuing west and the other turning sharply to the north and curving around the east end of the Beulah arch, which adjoins the St. Charles. The form of the Beulah arch is revealed only in part, as the Cretaceous formations do not occur west of the Dakota hogback. It is a spur of the Wet Mountain uplift and merges with a broader spur, the Red arch, which lies just north and is outlined by the Dakota hogback. The height of the steep northeast face of the St. Charles arch is 1800 feet. The east face of the Beulah arch rises 1400 feet in the first mile, and probably continues with gentler dips. The general dip of the Red arch is about 1 foot in 10, and its height within the district is 1800 feet.

St. Charles arch bounded by a fault.

Beulah and Red arches.

The curved bases of the St. Charles and Beulah arches are followed by a narrow trough, the Three-R trough, which separates them from a low dome somewhat triangular in form. The general depth of the trough is about 400 feet.

From the St. Charles, Beulah, and Red arches there is a general descent east-northeast to the neutral tract, the prevailing dip being 1 foot in 30. Its continuity is broken by a series of parallel faults which cross it at right angles. These are clearly shown on the Deformation sheet and do not require individual mention. In some the eastern side was uplifted; in others it was dropped. The greatest dislocation is but little more than 200 feet, and in some faults it is barely 100 feet. They are minor features as compared to the great fault about the St. Charles arch, but have important influence on the configuration of the surface, as will be explained later. Several of them are represented in sections CC and DD of the Structure Section sheet.

The general northeastward descent from the Red arch is also traversed by a flexure running nearly at right angles to the fault system. This flexure resembles a fault in that it forms the boundary between two great bodies of strata which are at different levels. The strata of the southeastern body are flexed downward so as to remain continuous with those of the northwestern body. This is the Rush flexure, and the amount of its displacement ranges from 200 to 600 feet.

Rush flexure.

The southeastern uplift.—The Walsenburg and Apishapa quadrangles, lying south and southeast of the Pueblo, include a broad dome of strata; and a spur from this dome, the Carlos arch, enters the Pueblo quadrangle near its southeast corner. Its general height is 400 feet, and it is unsymmetric, being steepest on the west side. In common with the general rock slope on which it rests, it rises toward the south. Six miles south of San Carlos it is sharply interrupted or indented by a lozenge-shaped basin, a definitely limited block of strata, about 1½ miles across, having gone down instead of up.

Carlos arch.

Arch and basins of the neutral tract.—In a general way the rocks rise gradually from the center of the district toward the north and southwest, so that the middle part might be called a broad, shallow trough. Athwart this trough rises a low arch, the Rock Canyon arch. It is about 10 miles long, north and south, and from 3 to 4 miles broad. Its crest line is uniformly about 350 feet above its base, but, sharing the general curvature of the central trough, is higher near the ends than in the middle. The character of the arch is well shown at Rock Canyon, where the Arkansas River cuts across it, but both ends are obscured by surficial deposits, and it is an open question whether the arch

Rock Canyon arch.

stands altogether by itself or is somewhat connected with the Wild Horse arch at the north and the Carlos at the south. It appears in sections BB and DD of the Structure Section sheet, and its southern part is expressed in the topography of the district as the "Sand hill" west of Pueblo.

West of the Rock Canyon arch is a shallow and ill-defined hollow, 6 or 8 miles long, north and south, and two-thirds as broad.

Pueblo arch.

The northeastern depression.—From the eastern limits of the Wild Horse, Rock Canyon, and Carlos arches there is a general descent of the rocks toward the east and northeast, the average dip being 1 foot in 25. The slope is interrupted by a long, flat arch, 100 to 150 feet high, which passes through the eastern part of the city of Pueblo and runs thence to the north and southwest; and the companion of this arch is a shallow trough just west of it.

Many small faults.

Minor faults and flexures.—Wherever the Cretaceous strata are quite free from soil and other surficial material, they show many waves and small faults. These can not be traced out and mapped, because they are largely covered from view, but it is believed that they abound everywhere in the district, modifying the greater flexures as ripples modify the broad swells of the ocean.

ORIGIN OF THE TOPOGRAPHY.

Topography produced by stream erosion.

The hills and valleys, mesas and canyons, and all the details of topographic form that diversify the district have been wrought by the eroding action of flowing streams and beating rain. Had there been no erosion the deformed surface of the highest Cretaceous formation would exhibit a system of smooth arches, domes, troughs, and basins, with here and there a fault-cliff; but that formation was long ago all washed away, and with it disappeared the simple structural shapes. Along with that formation portions of all the lower beds were carried away, and the loss was greatest where the structural arches would otherwise be highest. The general lowering of the surface has amounted to thousands of feet, and during its progress the details of topographic form have been carved out. They have, in fact, been remodeled many times, the pattern being gradually modified as the conditions of the work were varied, and the existing forms are only one phase of a changing scene.

Topographic details related to drainage system and rock structure.

The chief conditions affecting the sculpture of the land are the positions of streams, the slopes of stream beds, and the rock structure, or the extent and arrangement of resistant and yielding rocks. Where the water is gathered in streams it carves deeper than on the interstream areas, and the divides are comparatively high because they escape the strongest action of the water. The down-cutting of the streams is limited by the fact that they are also the carriers of all the waste from the land; if their channels become too flat their current slackens and the waste is not carried off. In this and similar ways the slopes of all the stream beds are automatically adjusted in a harmonious system, so that the wasting of the whole district is nearly uniform, and its entire surface is gradually reduced. The chief variations from uniformity are occasioned by differences in rocks, some of which resist erosion better than others. Nine-tenths of all that has been eroded from the district since the deformation of the Cretaceous system of strata was shale, one of the most yielding of rocks, but in this mass of shale were embedded sandstones and limestones, which are comparatively resistant. As the shale was slowly pared away, the harder beds were from time to time laid bare, appearing first from under the tops of high arches. Wherever so exposed the hard rock retarded erosion and was soon left as a hill projecting above the plain of shale. After a time the hard bed was eaten through at the top of the arch, and a valley was eroded from the core of shale, the worn edge of the hard bed becoming the crest of a circling ridge. Then the valley grew broader and the ridge was moved farther back; but though changing its position it persisted as a topographic feature, marking the outcrop of the resistant rock. The accompanying diagrams (figs. 12–14) illustrate three stages in the erosion of an arch.

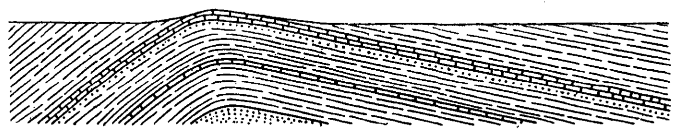

Fig. 12.—Ideal section of an arch of strata, including a thick limestone and a thinner limestone, both embedded in shale.

At a certain stage of erosion the thicker limestone projects above the plain at the crest of the arch.

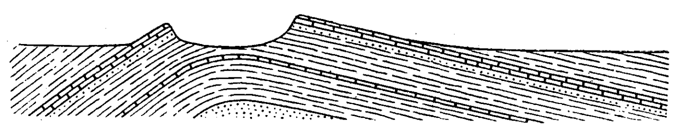

Fig. 13.—The same at a later stage of erosion.

The crest of the arch is occupied by a valley in shale. The cut edges of the thicker limestone crown parallel ridges enclosing the valley.

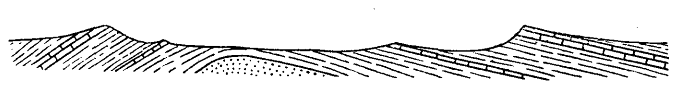

Fig. 14.—The same at a still later stage of erosion.

The valley is broadened by the wearing back of the limestone ridges, and a second pair of ridges mark the outcrops of the thinner limestone.

THE ARCHEAN UPLAND.

Uplands of the resistant granites of the St. Charles arch.

The upland in the southwestern corner of the quadrangle stands higher than any other. As already stated, it is part of a mosaic pavement of various hard rocks which had been first ground off to a level, then buried by Juratrias shales and other strata, and finally uplifted in the St. Charles arch and denuded. Its sloping plain is uneven because the granites of its tessellated pattern are more resistant than the schists, and it is divided into parts because it lies in the track of the St. Charles River and its tributaries. Here, as elsewhere, the streams have carved out the canyons in which they run; and they have carved deeply because the steep slopes of their beds give great power to their waters in time of flood.

THE DAKOTA HOGBACKS.

Hogbacks of the resistant Dakota sandstone.

The most resistant formation of the local sedimentary series is the Dakota sandstone. Below it are more than 2000 feet of shale and weak sandstone; above is a still greater depth of shale, containing only one strong bed of notable thickness. Wherever the Dakota is laid bare on the flank of an arch or other uplift it is carved into bold relief by the deep erosion of the enclosing shales, and the ridge to which it gives rise is called a hogback. The outer slope of the ridge (the slope away from the arch) is composed chiefly of the upper layers of sandstone, which dip with the inclination of the surface. The inner slope, which is steeper, exposes the edges of various formations, the Dakota sandstone appearing at the top and the Morrison and Fountain beds below.

Characteristics of the hogbacks.

The hogback shows its typical character in the southeastern part of the quadrangle, where it curves about the Beulah and Red arches. Its height above the adjacent lowlands is more than 1000 feet, the westward slope being very steep and the eastward more moderate. It is crossed by two streams, Red Creek and the north fork of St. Charles River, which divide it to the base. It ends where the Beulah arch joins the St. Charles, because the sandstone, after its outcrop turns eastward along the latter arch, is so much broken by faults as to have lost much of its resistant character.

Wind-gaps.

In the crest of the hogback between Red Creek and Beulah are three notches, marking the places of streams that once crossed the ridge but have been diverted. They were probably small creeks rising west of the Pueblo quadrangle and flowing eastward, and being small they could not deepen their channels so rapidly as Red Creek and the St. Charles. They fell a prey to the branches of the larger streams, which enlarged their valleys in the yielding beds of the Fountain formation and finally drew off the headwaters of the smaller streams. These old channels, stranded high on the sandstone ridge, are identical in origin with the so-called wind-gaps of the Appalachian region. The northernmost, near Red Creek, and the southernmost, opposite Wells Canyon, are each more than 300 feet deep and nearly half a mile broad; the middle one is smaller. The course of the northern stream is indicated at a few points by remnants of Neocene gravel perched on the mesa between Rush and Pecks creeks, and it thus appears that the stream did not coincide in position with any of the modern waterways. It is noteworthy that these gravels include fragments of granite as well as Dakota sandstone, thus showing that the creek which brought them rose west of the hogback and in the Archean area beyond the valley now carved from the Fountain beds. The diversion of these streams because they were too weak to keep pace with their neighbors in carving channels through the resistant sandstone is part of a general process of rearrangement by which the minor elements of drainage are turned away from resistant rocks. The arrangement of small waterways is continually adjusted to the arrangement of resistant rocks, which changes as the face of the land is worn down.

Adjustment of drainage to structure.

Sandstone of the Turkey arch.

At the north the hogback is flexed by two arches, the Beaver and the Turkey. In the Turkey arch it makes an abrupt turn, doubling on itself, and the parts on opposite sides coalesce at top instead of being separated by a valley. The hogback form is thus locally lost, and in its stead is a great hill shaped like the toe of a slipper and cased on three sides by dipping sandstone. The fourth side breaks off in a cliff overlooking a valley in the Morrison shale, but this lies north of the quadrangle boundary. The sandstone hill is furrowed by many gorges and trenched near its eastern base by the canyon of Turkey Creek.

LIMESTONE MESAS AND TERRACES.

Geologic stairway of limestone and shale.

Above the Dakota sandstone are three limestone beds whose resistance to erosion has diversified the topography. These are the Greenhorn limestone, the heavy limestone at the base of the Niobrara formation, and the thin limestone at the top of the same formation. The first two are closely associated, being separated by only 200 feet of shale, but the third is independent. In going outward from any outcrop of Dakota sandstone, one usually crosses a valley marking the position of the Graneros shale, ascends a low cliff capped by the Greenhorn limestone, crosses a narrow terrace of the same limestone, ascends a second slope marking the outcrop of Carlile shale, climbs a higher cliff whose face is composed of the sandstone beds at top of the Carlile and the limestone beds at base of the Niobrara, and then stands upon a plain constituted by various beds of the Niobrara formation. This topographic stairway is illustrated by the diagram, fig. 15, and is one of the most characteristic features of the district.

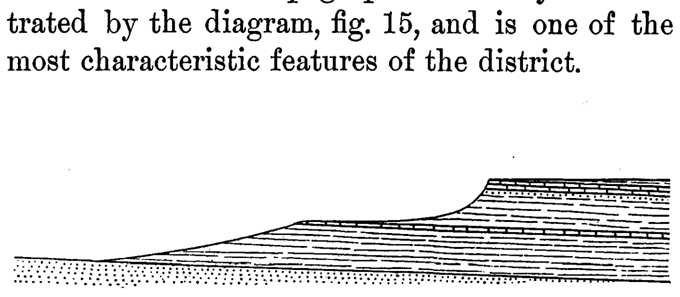

Fig. 15.—Typical profile of the cliff capped by the Niobrara limestone and the terrace capped by the Greenhorn limestone.

Mesas of Niobrara limestone.

Where the rock dips gently backward from the head of the stairway the plain at top usually begins with a long slope composed of the upper limestone, and the edge of the limestone is then the crest of a ridge analogous to the Dakota hogback. This general character obtains in the southern part of the district, but the upland is crossed by so many lines of drainage that its limestone cap is cut into a multitude of insular buttes or mesas, and the ridge character is greatly masked. In the region of parallel faults erosion has been further influenced by the dislocations, with the result that the limestone mesas lie at different heights and are even more numerous. On the Historical Geology sheet it will be observed that the pattern representing the Niobrara limestone and indicated by the letters Kn is there broken up into many small patches which coincide with the tops of hills, as indicated by the contours.

Coves in the Carlile shale.

On the east side of Rush Creek, where the rocks are flexed downward to the northwest, the Niobrara limestone, by resisting erosion, has preserved a hill-slope with the general profile of the flexure; but there are many places where the limestone has been eaten through by the streams, and cliff-bounded coves have there been opened in the Carlile shale below. As one ascends the creek valley one finds these coves successively larger, and at last merged together.

Topography of the Rock Canyon and other arches.

In the "Sand hill" south of Rock Canyon are many similar valleys eroded from the Carlile shale and surrounded by cliffs of limestone. The canyon of the Arkansas from Beaver to the Goodnight ranch is everywhere bounded by cliffs of the Niobrara limestone, but is in general not deep enough to reach the Greenhorn ledge. In crossing the Rock Canyon arch the river cuts down to the Dakota sandstone, and the Niobrara cliff recedes on each side so as to open a sort of amphitheater. The steep slopes of this opening are greatly diversified by spurs and canyons, but among these can be traced the Greenhorn terrace, forming an interrupted arch on either side.

Limestone mesas of the Beaver.

On the gentle slopes of the Beaver arch the Niobrara limestone occupies a belt from 1 to 2 miles wide, and is dissected by a plexus of streams. Pierce Gulch divides it on the east and the canyon of Beaver Creek on the west, and a dozen waterways leading from the axis outward to these main channels cut the limestone table into an archipelago of mesa buttes.

The Pumpkin arch is outlined by low ridges of the Niobrara and Greenhorn limestones, somewhat as represented in fig. 14, and the westward ridge, holding the same character, follows the base of Turkey arch also.

Wild Horse Park.

The Wild Horse arch is represented in the landscape by a hill, sometimes called the Cedar Ridge. The stage of erosion is here approximately that shown by fig. 12, the arching hard rock being the lower Niobrara limestone; but in part of the arch the stage of fig. 13 has been reached, for four of the small streams draining the ridge have cut through the limestone and opened coves in the Carlile shale. Three of the coves coalesce, making Wild Horse Park, a beautiful valley 2 miles long, whose circle of limestone cliffs is broken only by the narrow gateways through which the eroding streams escape.

The "Sand hill."

South of the Arkansas Canyon the Rock Canyon arch exhibits the same transitional stage of erosion. The resistant Niobrara bed has delayed the wearing down of the land so that the miscalled "Sand hill" rises above the plain, a dome sheathed by limestone, but the draining streams have here and there worn through the limestone, as already mentioned.

The upper limestone of the Niobrara, though thin and too weak to make a serviceable building stone, is yet so much stronger than the shales enclosing it that its outcrop usually caps a ridge or hill 30 to 50 feet high. A line of these hills faces Fountain Creek opposite Pueblo, and another line, starting at the Arkansas River in the western suburb of the city, follows the valley of Dry Creek northward to the vicinity of Blue Hill. These lines have many irregularities occasioned by small faults and flexures.

TEPEE BUTTES.

Structure of the Tepee Buttes.

The cylindrical masses of limestone standing vertically in the Pierre shale not only project from the general plain but preserve conical hills of shale. At the top of each hill the limestone core is exposed to the weather and is slowly broken up by frost. The fragments, falling to the slope below, lodge on it and form a stony or gravelly mantle by which its erosion is retarded. Though only 25 to 60 feet high, the hills are conspicuous by reason of their symmetry. They occur only in the northeast part of the quadrangle, abounding on the southern part of Baculite Mesa and on the plain east of Pinyon. The form of the tepee butte and the appearance of a cluster of them are shown by a view in the Illustrations sheet.

GRAVEL MESAS AND TERRACES.

Mesas protected by sand and gravel.

Loose gravel and coarse sand, by absorbing storm water as it falls, retard its flow and interfere with its erosive action. Gravel also resists the force of rills by the weight of its pebbles. Thus the gravel and sand beds of the Nussbaum and later formations, though to be counted as weak beds in relation to creeks and rivers, are resistant when occupying interstream areas. In such situations they are more resistant than the various shales of the Cretaceous, and they often protect bodies of shale from erosion. The Baculite Mesa is a large mass of Pierre shale protected from erosion by a capping of Nussbaum sand and gravel. Of the same character are "The Mesa," in Pueblo, and the flat hills southeast of Bessemer Junction, except that the protective gravels are of later date.

Since the Nussbaum epoch the general level of the land has been reduced by erosion several hundred feet, so that all surviving deposits of that date are the caps of hills. The alluvial deposits of the earlier Pleistocene were made during the same wasting, and their remnants were stranded at various heights above the modern streams, where they protect hills and terraces of shale.

ECONOMIC GEOLOGY.

The Economic and Artesian sheets.

The mineral resources of the district which have already received some development are clay, limestone for flux and quicklime, building stone, artesian water, iron ore, and gypsum. Most of these will have greater development in the future, and there are possibilities of fire-clay and hydraulic cement. Each material is definitely associated with one or more of the geologic formations, so that the areas in which it occurs can be pointed out with the aid of the map of formations, the Historical Geology sheet; but in certain cases more specific information can be given, and to this end two special sheets have been added: The Economic Geology sheet shows the distribution of building stone, limestone, fire-clay, and gypsum. The Artesian Water sheet gives the principal facts about underground water.

SANDSTONE.

Sandstones occur in the Carlile, Dakota, Fountain, and Harding formations. Those of the Dakota and Carlile are available for building stone. The Fountain sandstones may include useful beds, but so far as examined contain too much clay to be either strong or durable. The quality of the Harding sandstone was not determined. It has but a small area within the quadrangle and was not seen to be well situated for quarrying.

Sandstone of the Carlile formation.—This rock is of fine grain and rather close texture. The cementing material is probably calcite, but there is always enough clay present to make the rock soft and weak. The color is light-yellow and permanent. Some strata are found 1 to 2 feet thick, but the chief product of the quarries is thinner. The total thickness of workable layers of this sandstone rarely exceeds 5 feet. It is found at and near the top of the Carlile formation, and being covered by the heavy limestone of the Niobrara comes to the surface in the cliff that usually marks the edge of that limestone. It is only in places where most of the limestone has been removed by natural erosion that the quarryman can afford to strip off the remainder in order to obtain the sandstone. Such a locality is found in the "Sand hill" south of Rock Canyon, and there are others of less extent in many parts of the district. On the Economic Geology sheet no attempt has been made to show either these places of special availability or variations of quality, but the whole line of outcrop is marked. It is a sinuous line winding through the southern and western parts of the sheet.

Quarry rock of the "Sand hill."

Dakota sandstone.—Most of the sandstones of the Dakota formation are in thick strata, ranging from 2 to 20 feet. In grain and texture they vary from fine to coarse and from open to close. Their colors—white, yellow, orange, and speckled-brown—are probably permanent. They contain little clay, and the cementing material is usually calcite. Their strength has not been practically tested, but their resistant quality, in virtue of which they project above the plain in hogbacks, betokens architectural durability. Their quantity is inexhaustible; with a net thickness of 200 to 500 feet, they cover 85 square miles within the quadrangle.

Dakota sandstone as building material.

With its broad exposure, its great thickness, and its variety of color and texture, there can be little question that the Dakota sandstone has a much greater value for building purposes than the Carlile. The Carlile was first used because most accessible, but the ultimate source of supply is the Dakota, and only the Dakota can furnish a product for shipment.

LIMESTONE.

Workable beds of limestone are found in three formations, the Niobrara, the Greenhorn, and the Millsap. The upper limestone of the Niobrara formation is hardly worthy of mention in this connection, although its convenient occurrence in the suburbs of Pueblo has led to its occasional employment where neither strength, hardness, nor durability is essential.

Lower limestone of the Niobrara formation.—This rock is fine-grained, of a pale-gray color, and on the whole is remarkably uniform. It is a typical lime carbonate, with only a trace of magnesia and less than 10 per cent of argillaceous impurity. Its exact composition is shown in the table of analyses. For most purposes its only deleterious constituent is marcasite, or iron sulphide, which forms small nodules in certain layers. Its mode of occurrence is exceptionally convenient for quarrying. Beds from 1 foot to 3 feet in thickness are naturally separated by thin partings of shale, and the whole mass, 35 to 50 feet deep, usually lies in the face of a hill, so that gravity can be used in the handling. It is extensively employed as a flux in the reduction of silver and iron ores, and it is equally qualified for the making of quicklime. Although readily obtainable in blocks of convenient dimensions, it is not serviceable for building purposes because its brittleness leads to cracking and spalling from changes of temperature.

Flux and lime rock of the Niobrara.

The area in which it occurs at the surface, or so near the surface as to be readily accessible, is very large, and constitutes a complicated series of belts in the northwestern, central, and southern parts of the quadrangle. On the accompanying Economic Geology sheet a special color is assigned to the representation of these belts.

Limestone of the Greenhorn formation.—This limestone is also widely distributed, its outcrop forming a terrace on the slope under the Niobrara cliff. Its strata are thinner than those of the Niobrara limestone, and are separated by shale beds of such thickness as to render quarrying expensive. Being less accessible, it has remained practically untested, and its qualities can not be described further than to say that its brittleness and tendency to vertical cleavage disqualify it for building purposes.

Greenhorn limestone.

Limestone of the Millsap formation.—This limestone also is untested, except that a moderate amount has been burned for lime. It differs from both the others in its variability, color and texture showing considerable range. So far as may be judged from its behavior under the influence of the weather, it contains beds which would be available for construction. It occurs only in two small areas near Beulah.

Millsap limestone.

MARBLE.

Just west of the boundary of the Pueblo quadrangle is a quarry of marble. It was not visited during the survey of the district because it had not then been opened; but from information since obtained the marble is supposed to occur in the Millsap formation, and it is therefore possible that similar discoveries may be made within the quadrangle in the vicinity of Beulah. The single specimen seen is white and of rather coarse grain.

GYPSUM.

Near the northwestern corner of the quadrangle are two small areas of the Morrison formation. These are parts of a much larger area occurring in the Colorado Springs quadrangle, adjacent at the north, so that they belong rather to that quadrangle than to the Pueblo. The formation contains an important series of gypsum beds, and a few of those beds were observed in the more easterly of the Pueblo areas. They are overlooked from the south by a high cliff of Dakota sandstone, and are accessible only from the Colorado Springs side. The gypsum is massive and is mottled with gray and white.

Gypsum in the Morrison formation.

A granular or earthy gypsum, used in Pueblo for the manufacture of plaster, is said to have been obtained from an alluvial flat near Greenhorn station. I am unable to describe its mode of occurrence, as the locality was overlooked during the progress of the survey. Gypsum also occurs in the form of selenite crystals in many of the Cretaceous shales, especially the Niobrara and the lower part of the Pierre, where the shales have been much broken in the process of deformation. This gypsum is concentrated in veins, but no veins were seen of such thickness as to constitute deposits of practical importance.

Alluvial gypsum.

SHALE AND CLAY.

These argillaceous materials occupy fully one-half of the surface of the quadrangle, and they afford much variety of composition and quality. Shales occur in the Millsap, Fountain, Dakota, and Greenhorn formations, and they constitute the chief part of the Morrison, Graneros, Carlile, Niobrara, and Pierre. Clays occur in the various alluvial formations, sparingly in the Nussbaum and earlier Pleistocene, abundantly in the fresh-formed deposits along the streams that traverse the shale districts.

The clays have been used in Pueblo for the manufacture of bricks and tiles, and trials have been made of the availability of the various clays and shales for the manufacture of pottery.

Plastic clays.

The beds of shale are so extensive and they afford such variety of texture that it may fairly be expected that they will eventually constitute the basis of important industries. For this reason analyses were made of specimens representing various types, and these are here published (See table of analyses, p. 7) as a matter of record, although it is at present impossible to point out their full economic bearing.

Economic importance of shales.

Hydraulic cement; Portland cement. — The hydraulic cements, or cements having the property of setting under water, are partly derived from the burning of certain argillaceous limestones and partly from the burning of mixtures of limestone with clay or slag. The successful prosecution of the industry requires much technical knowledge, and in each locality depends on experimentation with the particular materials available; but some preliminary indications may be based on the composition of the materials as determined by chemical analyses, and it appears quite possible that the necessary combinations may be found in this district.

Materials for Portland cement.

The concretions in the upper part of the Pierre formation are essentially of argillaceous limestone, and closely resemble in composition certain concretions from which hydraulic cement has been made in England without the admixture of other material. They occur in considerable abundance about the flanks of Baculite Mesa and thence northward to the limit of the quadrangle. In the same region occur the tepee cores, which also consist of argillaceous limestone and might be available for the manufacture of cement if mixed with a small amount of the enclosing shale.

Concretions for cement.

In the Niobrara formation, just above the limestone bed quarried for flux, is a series of beds of varying texture containing unequal mixtures of limy and argillaceous material, and it is quite possible that trial may discover in this series individual beds which have the necessary composition. Analysis No. 4 gives the composition of one of the more argillaceous of these beds, and a comparison with analysis No. 1, representing the underlying limestone, shows that a mixture in the ratio of about 1 to 4 would have approximately the composition of some Portland cement before burning.

Limestones and shales.

FIRE-CLAY.

Clays and shales which resist great heat without fusing are said to be refractory and are called fire-clays. They differ in composition from ordinary clays, having large amounts of silica and alumina and relatively little iron, lime, magnesia, potash, and soda. In the Pueblo and adjacent quadrangles they have been found only in the Dakota sandstone. The upper part of that formation contains a variable number of shale beds interstratified with the sandstone beds, and some of these are in certain places refractory. The writer collected shale samples from the outcrop of the formation in the Pueblo, Apishapa, Canyon, and Colorado Springs quadrangles, and six of these were shown by proper tests to have the refractory property in greater or less degree. Prospecting will doubtless discover a number of deposits equal to the best of these samples, and may discover still higher grades.

Dakota shales available as fire-clay.

The most satisfactory and valuable test of fire-clay is the fire test. Samples properly prepared are heated in a furnace by the side of standard compounds and the results are compared. On the Seger scale of refractoriness, eleven grades, numbered from 26 to 36, cover the range of fire-clays, the best being No. 36. This test was applied to the six samples mentioned above by Prof. H. O. Hofman, of the Massachusetts Institute of Technology, and their several grades were found to be 29, $30\frac{1}{2}$, 31, $33\frac{1}{2}$, $34\frac{1}{2}$, $34\frac{1}{2}$. Two of the samples were obtained from the Pueblo district, and these are further reported in the table of analyses, Nos. 9 and 11. It is judged from the analysis that No. 10 of that table is also a fire-clay, but the sample in hand was too small for the application of the fire test. To give the above figures a more intelligible meaning, I quote also Professor Hofman's rating of two well-known Colorado fire-clays: a sample from Carbondale gave $33\frac{1}{2}$ on the Seger scale, and one from Golden $31\frac{1}{2}$.

Behavior of samples under fire test.

The areas occupied by the upper part of the Dakota formation, or the areas to which the fire-clays are restricted, are shown on the Economic Geology sheet. The largest is in the southwest quarter; others at the northwest and southeast connect with still larger tracts outside the quadrangle; a small tract surrounds Rock Canyon; and two small tracts lie in the valley of Greenhorn Creek and its eastern branch.

Extent of outcrop.

The refractory shales are all below the highest sandstone layer. They differ so widely in color that no general description can be given. The one represented by analysis No. 10 is nearly black and full of fossil twigs converted to coal. No. 9 is dark blue-gray; No. 11, light-gray. One of the samples ranking highest by fire test is nearly white, and gritty from the presence of much sand.

Colors and textures.

IRON ORE.

In the Rusty zone of the Pierre shale are many concretions carrying iron. They consist of lime carbonate and iron carbonate with some clay. Where exposed to the air the iron carbonate is slowly converted to limonite, the color changing from gray to reddish-brown. The zone is best exposed on the slope between Baculite Mesa and the Arkansas River, and its belt of outcrop runs thence north-northwest past Overton and Steele Hollow. The concretions were at one time used in combination with other ores in the manufacture of steel.

Clay-iron concretions.

PETROLEUM, ROCK GAS, COAL, PRECIOUS METALS.

None of these substances are to be counted among the mineral resources of the district, but they should nevertheless be mentioned, as there have been false impressions in regard to them.

The only rocks of the district that are even slightly bituminous are certain parts of the Graneros and Carlile shales. If petroleum or gas were naturally distilled from these it would tend to accumulate in the Greenhorn and Niobrara limestones. As the limestones have been repeatedly penetrated by the drill without the discovery of more than a trace of gas, there is no reason to expect that a valuable accumulation will be discovered. The petroleum obtained in the Florence oil field, a few miles west of the district, comes from sandy layers in the upper part of the Pierre shale, but the Pueblo district includes only the lower part of that formation.

Absence of oil and gas.

In the calcareous shales below the middle of the Niobrara formation fossil logs consisting of coal are occasionally found, but there are no coal beds. Some layers of the Dakota sandstone contain many shreds of vegetal matter in the condition of coal, and so do some of the interbedded shales. It is within the range of possibility that the formation contains local seams of coal, but the occurrence of workable coal beds is not probable. The formation yielding coal in the adjacent Canyon quadrangle does not extend to the Pueblo.

Coal.

Metalliferous veins often occur on faults, and they are sometimes associated with metamorphic schists. There is therefore warrant for prospecting among the schists and along the faults in the southwest part of the district, and frequent openings show that intelligent search has already been made in that area. The writer is not acquainted with the history of that

Metalliferous veins.

search, but the general abandonment of claims seems to show that it was unsuccessful.

ARTESIAN WATER.

The Dakota sandstone an artesian reservoir.

Rock reservoirs are usually not open chambers, but beds of sand or porous sandstone, and the water occupies the small spaces between the grains. The only important water-bearing beds in the district are the sandstones of the Dakota formation.

Definition of artesian water.

Water confined in the rocks so as to press on the cover of its reservoir is said to be artesian. When tapped by boring, it rises in the bore-hole, making an artesian well. The highest level to which it will rise is called its head. If the head is above the surface of the ground the well is said to flow; otherwise it is called a pumping well.

The question of depth.—The Dakota formation is altogether wanting from certain small areas; in other, larger areas it lies at the surface, and thence it dips down below the surface. Through the greater part of the quadrangle it is not visible, but is buried under other rocks, chiefly shales. Owing to the deformation of the rocks and the resulting unequal erosion, its depth below the surface differs from place to place, ranging from nothing to more than 3000 feet.

Depth of the water-bearing strata.

If a person starts to sink a well where the upper stratum of the Dakota formation lies at the surface, he has to go down only 100 to 200 feet to reach one of the artesian beds. If he starts his well where the surface rock is the top of the Greenhorn limestone he must penetrate the Greenhorn limestone, 50 feet, and the Graneros shale, 200 feet, in addition to the 100 feet or more of Dakota beds. If he starts on the Niobrara limestone he must go still deeper, penetrating in addition the Niobrara limestone and the Carlile shale, and the depth of his well will be 600 or 700 feet. The thicknesses of the various formations penetrated in making artesian wells are graphically shown on the Columnar Section sheet by the "Artesian Section," in which the scale of feet has its zero at the horizon of the highest water-bearing bed. If one can determine what member of the rock system forms the surface of the ground at any spot, one can read in this section the depth to water. The relations of surface rock to water depth are also illustrated by sections of the Structure Section sheet, and they are still further illustrated by the accompanying ideal section (fig. 16), where

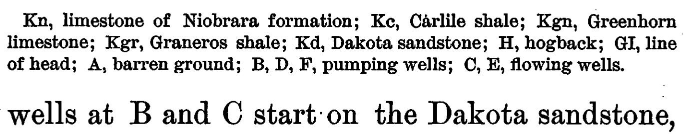

Fig. 16.—Ideal profile and section illustrating artesian conditions.

Kn, limestone of Niobrara formation; Kc, Carlile shale; Kgn, Greenhorn limestone; Kgr, Graneros shale; Kd, Dakota sandstone; H, hogback; GI, line of head; A, barren ground; B, D, F, pumping wells; C, E, flowing wells.

wells at B and C start on the Dakota sandstone, at E on the Greenhorn limestone, at D on the Niobrara limestone, and at F in Niobrara shales. A boring at A, starting in rocks which underlie the Dakota sandstone, would not find the water.

More than one water horizon.

It happens that the formations above the Dakota are remarkably uniform in thickness from place to place, so that a thorough knowledge of the rock formations makes it possible to predict with tolerable accuracy the depth at which the first Dakota stratum will be encountered. The Dakota formation itself is much more variable, not only in thickness but in the order and number of its water-bearing beds. The thickness varies from 650 feet at the southwest to 300 feet at the northeast. The water-bearing beds occur at different distances from the top in different localities, the depth of the first or highest being in places less than 100 feet, and elsewhere more than 150 feet. The number of such beds probably ranges from one to three or four, but this has not been tested by the drill, as the borer usually stops at the first good stream.

The Artesian Water sheet.

Assuming the first artesian water to lie 150 feet below the top of the formation, the writer has estimated its depth below the surface of the ground for the whole artesian area, and by the aid of these estimates has drawn the contours of the Artesian Water sheet. Each contour is a line drawn through points where the estimated depth of water below the surface of the ground is the same; for example, the water is estimated to lie 800 feet below the surface at all points of the district corresponding to the 800-foot artesian contour. To make practical use of the map the enquirer should locate on it the point as to which he wishes information, and note the numbers of the artesian contours between which it falls. The estimated depth in feet is between the numbers attached to the two contours.

While the estimates are everywhere subject to some error, especially from the variability of the Dakota formation, it is believed that they will in general come within 100 to 200 feet of the fact, and thus prove practically serviceable. Their greatest uncertainty is on Boggs Flat, where for several miles there are no good rock exposures, and on a similar flat 10 or 12 miles farther north; and to indicate this uncertainty the contours are there drawn as broken instead of full lines.

The known variability of the Dakota formation suggests that in some localities there may be no rock bed so porous as to be freely traversed by water; but as no boring known to penetrate the sandstone in the Pueblo and adjoining districts has heretofore failed to find a supply of water, great weight need not be given to the possibility of barren tracts.

Places where water is near the surface.

The more general facts of distribution shown by the contours are that the depth of artesian water is moderate in the southern, central, and western parts of the territory, and great in the northeastern corner of the quadrangle. Within the artesian area the crests of arches are in general more favorable for wells than the troughs, because erosion has there left less rock to be penetrated. Over much of the Rock Canyon arch the water horizon is within 600 feet of the surface, and the crests of the St. Charles, Wild Horse, Pumpkin, and Beaver arches afford equally favorable sites.

Variation of artesian head from place to place.

The question of head.—The question whether the artesian water when found will rise to the top of the well and flow out is often as important as the question of depth, and unfortunately can not be answered in an equally satisfactory way. If the water-bearing rock were merely a reservoir in which the water lay motionless the head would be the same at all points; that is, the water would in all wells reach the same level, and flowing territory would be separated from pumping territory by a horizontal line contouring the hillsides. But the water is really flowing at a slow rate through the rock, and its head varies from point to point. The mode and rate of variation depend on the source of supply, the direction of flow, the resistance to flowage through small pores, and various other factors. On these various points there is little information, and all prediction as to head is correspondingly uncertain. Moreover, the head is usually not the same for different water-bearing beds, and it is reduced in each locality by every draft on the supply through a flowing or pumping well.

Area of artesian flow.

The line on the map separating the supposed flowing from the supposed pumping territory was drawn with much less confidence than the contours of depth. These two territories are distinguished by colors. A third color shows the territory occupied by the Dakota sandstone but not believed to carry water under notable pressure; this is part of the gathering ground where rain water is absorbed by the rock. A fourth color shows territory in which the sandstone does not occur. For practical purposes these may be classed together as barren ground.

In fig. 16 the broken line, GI, represents the plane of head, a plane sloping away from the Dakota hogback, H. Where this line passes above the profile of the land, as in crossing the valleys at C and E, flowing wells may be obtained; where it passes below the surface, as in the regions B, D, F, only pumping wells are possible. In selecting a site for boring, the water-seeker should bear in mind that the local level of head, or its height above the ocean, is independent of the shape of the ground. The chance of a flowing well is always better in a valley than on a neighboring hill or mesa.

GROVE KARL GILBERT,
Geologist.

June, 1897.

COMPOSITION OF ROCKS AS SHOWN BY CHEMICAL ANALYSIS.

	1. Limestone; lower part of Niobrara formation.	2. Shale; 30 feet above base of Graneros formation.	3. Shale; 70 feet below top of Carlile formation.	4. Shale; 150 feet above base of Niobrara formation.	5. Shale; Rusty zone of Pierre formation.	6. Shale; Tepee zone of Pierre formation.	7. Earthy limestone; Tepee core; Pierre formation.	8. Earthy limestone; concretion; Pierre formation.	9. Fire-clay; Dakota formation; Davis ranch.	10. Fire-clay; Dakota formation; head of Rock Creek Canyon.	11. Fire-clay; Dakota formation; near head of Pierce Gulch.
Silica (SiO_2)	6.4	63.60	60.60	45.89	51.69	60.80	7.46	12.47	63.52	76.56	86.79
Titanium dioxide (TiO_2)	....	.66	.35	.52	.66	.47	1.78 (Ti O₂ + Al₂ O₃)	3.30 (Ti O₂ + Al₂ O₃)	.68	.60	8.29 (Ti O₂ + Al₂ O₃)
Alumina (Al_2O_3)	1.3	16.74	16.42	13.24	16.50	15.63			24.72	8.30	
Iron sesquioxide (Fe_2O_3)	2.1	4.63	4.95	3.88	7.90	4.62	.94	1.37	.43	.38	.75
Lime (CaO)	50.4	.68	1.61	12.09	4.41	1.63	46.98	42.26	.30	.12	.34
Magnesia (MgO)	trace	1.19	1.43	2.12	2.10	2.73	2.36	2.61	.13	.24	.13
Potash (K_2O)	....	2.92	2.98	2.31	2.68	2.55	.37 (K₂ O + Na₂ O)	.59 (K₂ O + Na₂ O)	trace (K₂ O + Na₂ O)	trace (K₂ O + Na₂ O)	.25
Soda (Na_2O)	....	.29	.92	.47	2.07	1.45					....
Phosphoric oxide (P_2O_5)	....	.16	.31	.17	.22	.10	undet.	undet.	trace	.06	.05
Carbon dioxide (CO_2)	39.5	....	....	10.38	3.19	....	39.25	35.57	....	....	....
Water lost at 100° C.	....	2.88	3.91	1.38	3.02	3.19	.16	.52	1.58	1.26	3.78 (water lost at and above 100° C. + organic material)
Water lost above 100° C.	....	5.99	5.72	4.16	6.00	4.16	.70 (water above 100° C. + organic material)	1.31 (water above 100° C. + organic material)	8.41	4.40	
Organic material	....	.46	.84	3.47	.53	2.87			.40	8.31	
Total	99.7	100.20	100.04	100.08	100.97	100.20	100.00	100.00	100.17	100.23	100.38
Fire test									31		29

NOTE.—Analysis No. 1 was made by the chemist of the Pueblo Smelting Company from a carload sample obtained from Harp's quarry. The other analyses were made in the chemical labratory of the United States Geological Survey, Nos. 2, 3, 4, 5, 6, 9, 10, and 11 by Mr. George Steiger, Nos. 7 and 8 by Dr. W. F. Hillebrand.