

DESCRIPTION OF THE NEPESTA QUADRANGLE.

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INTRODUCTION.

POSITION AND AREA.

The Nepesta quadrangle extends in latitude from 38° to 38° 30' and in longitude from 104° to 104° 30'. Its length is 34.5 miles (55.5 kilometers) and its average width 27.3 miles (43.9 kilometers). The area includes a little more than one-third of Pueblo County and a narrow strip along the western boundary of the north half of Otero County, Colo., and comprises 938 square miles. It is situated on the Great Plains, near their western margin, a few miles east of the Rocky Mountains and nearly opposite the Arkansas embayment.

CLIMATE.

The climate of the quadrangle has a moderate range, corresponding mainly to differences of altitude. The southwestern portion is relatively cool and humid, the central portion warm and more arid, while to the northeast, on the high "Nussbaum plateau," the climate approaches a medium between the two extremes. During the summer the maximum heat and aridity of the district are in the lowlands east of Pueblo, which in the winter are more or less protected from snow. Not infrequently winter storms from the mountains to the west sweep across the district, leaving 1 to 2 inches of snow on the level in the southwestern portion, while to the north and northeast much of the moisture evaporates before reaching the ground. The rainfall occurs in the late spring and early summer months and is usually confined to local thunder storms, which, though of brief duration, are often of exceptional violence, converting for a time the canyons and dry watercourses into impassable torrents. The annual precipitation ranges from 6 to 17 inches. Of this amount about one-fifth is snowfall, generally occurring during the months of December, January, and February. The heaviest seasonal precipitation ever recorded in the district was 9.92 inches. In the southwestern part, where the precipitation is probably greatest, the amount of water which the ground absorbs is relatively small, owing to the short duration of the storms and the rapid run-off.

The prevailing winds are from the northwest, though during the months of greatest rainfall—June, July, and August—southeasterly winds are common. Gales from the northwest are not infrequent and winds attaining a velocity of 64 miles an hour have been experienced at Pueblo, a few miles west of the quadrangle boundary.

VEGETATION.

The greater part of the upland of this quadrangle is practically destitute of timber, but in the extreme southwest corner, on the high bluffs bordering Huerfano River, there is a sparse growth of piñon pine and juniper. Trees are abundant along all the larger and many of the intermittent streams. In addition many varieties of forest and fruit trees are cultivated in the irrigated valleys of the larger streams. The upland areas afford a variety of plateau grasses, cacti, and other low-growing plants, and in the more sandy districts the yucca is common. Small meadows occur here and there in the bottom lands, but most of this area, in its natural state, supports a rank though sparse growth of sagebrush. The elevated plateaus and highlands to the south have a fertile soil well covered by nutritious grasses.

CULTURE.

Culture, here as elsewhere, is determined by geologic and climatic conditions. In the more level portions, where soil is rich and water available, settlements are numerous. The upland grazing districts are practically uninhabited except here and there along the intermittent streams, where water reaches the surface or can be procured by shallow

wells. The principal settlements are along Arkansas River Valley and the gravelly mesa adjoining on the south. Here a number of small towns have recently been built, of which the largest is Fowler, situated near the eastern margin of the quadrangle. The immediate valley of the Arkansas is traversed by the Missouri Pacific and the Atchison, Topeka and Santa Fe railways. Along these lines are several small villages, notably Boone and Nepesta, the former near the center of the quadrangle and the latter, from which it derives its name, farther east. Huerfano Valley is sparsely settled by an American and Mexican population.

The roads are numerous and in general good. In the grazing districts they follow natural rather than artificial lines, but in the more thickly populated portions they lie along section lines. The larger rivers are crossed by modern steel-frame bridges on all the main routes of travel.

TOPOGRAPHY.

RELIEF.

Broadly viewed, the surface of this quadrangle is a plateau which rises uniformly from east to west. The range of altitude within the area is moderate, the greatest difference not exceeding 1100 feet, with the extremes 25 miles apart. The lowest point is at the eastern margin of the quadrangle, in the valley of Arkansas River, near the town of Fowler, where the altitude is 4300 feet above sea level. The highest point is in the extreme southwest corner, about 3 miles northwest of the Ben Butler ranch, where an altitude of 5375 feet is reached. The highest portions are near the southwest and northeast corners, and from these areas there is a general slope toward Arkansas River Valley. The maximum difference in elevations for any one area of the quadrangle is in the southwest portion along Huerfano River, where the rise from the river bed to the bluffs on the north, a distance of about 3 miles, is nearly 500 feet.

The quadrangle is divided by Arkansas and Huerfano rivers and Chico Creek into four unequal parts, which may be conveniently discussed separately. The northeastern part, of the quadrangle is an upland, the southern portion of which resembles a shallow amphitheater opening to the south and southwest, while its northern and northeastern portions have the character of a gently undulating plateau, with a triangular area of typical dunesand topography near the center. This upland (which will be termed the Nussbaum plateau, from the formation which outcrops throughout its greater part) is bounded on the south by the valley of Arkansas River and on the west by Chico Creek. Along the southern boundary the Nussbaum plateau is dissected by the valleys of Haynes and Kramer creeks, between which a narrow neck of highland extends for 6 or 7 miles southeastward, terminating abruptly at a point about 4 miles north of Nepesta and forming one of the most conspicuous topographic features of the quadrangle. Closely adjacent to this ridge on its southern and western borders are several small detached portions of the plateau. Similar outliers occur lower in the valley east of Boone. In the upper parts of the Haynes and Kramer creek valleys the "tepee" horizon of the Pierre shale is exposed, giving rise to numerous cone-like hills. These hills, or "tepee buttes," as they are sometimes called, are a characteristic topographic feature along the north side of Arkansas River across the quadrangle. To the southeast the Nussbaum plateau is terminated by a high, rather deeply serrated line of bluffs overlooking Arkansas Valley. The western part of the plateau slopes gradually toward Chico Creek.

The area west of Chico Creek and north of the Arkansas consists of broad, gently sloping ridges which are roughly parallel and extend in an east-southeasterly direction. At the north, in the vicinity of the Tolle ranch, these ridges terminate

in gradual slopes toward the lower land of Chico Valley; to the south, along the lower courses of the stream, they end abruptly, forming somewhat prominent bluffs.

That portion of the quadrangle lying south of the Arkansas and west of the Huerfano presents some variations of form. The area rises with general uniformity from an altitude of 4500 feet along Arkansas River to the summit (5375 feet) of a high ridge in the southwest corner. This prominent cliff and the corresponding cliff on the opposite side of Huerfano River are capped by hard limestones and inclose a small triangular area of lower land underlain mainly by soft, easily eroded rocks. To the north, in the vicinity of Huerfano Lake, the country is nearly level and is traversed by shallow, intermittent drainage courses. Still farther north a range of flat-topped, detached hills or mesas extends across the area in a line roughly parallel to the course of Arkansas River. These are carved from soft deposits which have been more or less protected from erosion by a capping of gravel. Between this range of hills and Arkansas River Valley is a level terrace which extends from the mouth of Huerfano River to the western margin of the quadrangle and has an average width of 3 miles. The western end of this terrace is crossed diagonally by the narrow valley of St. Charles River.

The area lying east of Huerfano River and comprising the southeastern portion of the quadrangle has a more or less uniform topography. Its salient features are broad, gently undulating hills sloping to the east and surmounted here and there by low, inconspicuous, gravel-capped ridges. To the northwest is a group of high, flat-topped prominences, locally known as the Hooker Hills, which overlook this entire area. To the northeast a narrow fringe of level terrace rises 50 to 75 feet above the level of Arkansas River Valley and extends from the eastern margin of the quadrangle to the mouth of Huerfano River.

DRAINAGE.

The principal drainage channel is Arkansas River, which enters the quadrangle from the west, a little north of the middle, and flows nearly eastward to the center and thence southeastward. Its principal tributaries are Huerfano and St. Charles rivers, entering from the southwest, the former at a point 2 miles east of the southwest corner of the quadrangle and the latter near the center of the western border. Huerfano River flows northeastward and joins the Arkansas near Boone. St. Charles River has a very short course in the quadrangle, crossing the western boundary about 4 miles above its mouth. It has a narrow, flat-bottomed valley bordered by bluffs 30 to 60 feet high. Arkansas River flows below the general level of the region in a meandering course through an open, level-floored valley which averages 1 to 1½ miles in width. This is bordered on the south by a sharp ascent of 50 to 75 feet to a gravelly mesa; to the north long, gradual slopes intervene between the immediate valley and the high bluffs of the Nussbaum plateau. Arkansas River has an average fall of 8 feet to the mile, and its tributaries have steeper grades. The Arkansas carries a large volume of water in all seasons, but the flow in its larger tributaries is of an intermittent character, their stream beds being dry the greater part of the year. Huerfano River is subject to violent and destructive floods during the rainy season, with the result that a large amount of valuable agricultural land has been washed away during the last twenty years. When settlement was first made along the river the average width of the stream bed is reported to have been less than 30 feet; at present it exceeds 200 feet. Apishapa River crosses the southeastern part of the quadrangle. It flows northeastward and joins the Arkansas

beyond the boundary, a few miles east of Fowler. The remaining area in the southern half of the quadrangle is drained by Sixmile and Chicosa creeks and smaller tributaries of Apishapa and Arkansas rivers. All these streams flow intermittently for the whole or part of their courses. In the more level portions the surface water, owing to imperfect drainage, tends to collect in lakes or ponds, some of which hold water only during the rainy season, while others, notably Erdman and Hungerford lakes, are ordinarily filled the year round.

The drainage water of the Nussbaum plateau reaches Arkansas River by way of Kramer and Haynes creeks, the former draining the northeastern and the latter the north-central portion of the area. The porous sandstones of the Nussbaum formation absorb water freely and thus prevent a rapid run-off, so that these streams are not subject to violent floods. Haynes Creek has a small flow at all seasons in the vicinity of Langford ranch, but lower in its course the water is lost in the porous sands of the stream bed.

The northwestern portion of the quadrangle is drained by Chico Creek, with Black Squirrel Creek as a tributary from the northeast and Andy Creek from the northwest. Chico and Black Squirrel creeks have a continuous flow in the vicinity of the Skinner and Tabor ranch, but below this the water sinks. The Chico receives considerable flood water from Andy Creek.

DESCRIPTIVE GEOLOGY.

General relations.—The strata forming the surface of the Nepesta quadrangle belong to the Cretaceous, Tertiary, and Quaternary systems. Their distribution is shown on the areal geology sheet, and their thickness, succession, and general characters are illustrated graphically on the columnar section sheet.

Deep-seated formations.—A considerable thickness of sedimentary deposits underlies the formations exposed in the Nepesta quadrangle. These deposits lie in sheets which have a gentle inclination to the east and rest upon a floor of granite and schist. The quadrangle is in the transition zone between the high mountains to the west and the Great Plains region to the east, where the rocks undergo more or less change. There is in consequence some uncertainty in regard to the character and succession of the deep-seated beds.

The Morrison and Fountain formations probably underlie the entire quadrangle, but little is known regarding their thickness and character here, for they have not been penetrated by the deepest borings. The Morrison lies near the surface in Huerfano Valley, in the extreme southwest corner of the quadrangle, being here covered by less than 300 feet of sediments. It is probable also that the quadrangle is underlain by the Millsap limestone and Harding sandstone, for these formations are known to have considerable extent from north to south along the Rocky Mountain Front Range. Concerning the succession of the beds below the Harding sandstone there is much uncertainty. In the Pueblo quadrangle this formation rests unconformably upon the granite and schists, but to the east there may intervene several hundred feet of beds which were laid down as off-shore deposits.

CRETACEOUS SYSTEM.

DAKOTA SANDSTONE.

General relations.—The Dakota sandstone underlies the entire quadrangle. It is exposed over a very small area in the extreme southwest corner. Here the beds, dipping to the east, soon pass beneath the surface in the valley of Huerfano River a short distance above the Ben Butler ranch. The east side of this area is deeply incised by the Huerfano, forming the lower extension of the so-called Huerfano Canyon, a deep and picturesque gorge

which continues upstream to the southwest for a distance of 20 miles.

Thickness and character.—The formation has a thickness of about 100 feet. It consists of medium- to coarse-grained sandstone, occurring in beds which are variable in thickness and character. Light-gray and buff colors predominate, weathering to shades of orange and brown. Immediately below the Dakota sandstone is a bed of highly refractory clay about 12 feet thick, underlain by about 200 feet of coarse-grained sandstone merging locally into conglomeratic material. This sandstone and the overlying refractory clay were formerly included in the Dakota formation, but a recent study of these beds by Mr. T. W. Stanton and others has shown that they are of lower Cretaceous age.

It is said that the Dakota sandstone is not water bearing in regions to the west, but in the deep well east of Fowler a good supply of water is obtained from these beds. The same is true of the deep wells at Manzanola and Ordway, still farther east. The Dakota sandstone lies conformably upon the fire clay of the lower Cretaceous, as shown by exposures to the west. Its uppermost limit is not sharply defined, but it merges rapidly into the overlying Graneros shales. The Dakota offers great resistance to erosion and where it outcrops the rock is only partly covered by a thin soil. Owing to the large amount of moisture which it absorbs it furnishes a good rootage for trees, and as a result the exposed areas are generally covered with a relatively dense growth of pine.

Elsewhere the formation contains fossil plants, but only a few fragmentary fossil leaves were found in this district.

BENTON GROUP.

GRANEROS SHALE.

Distribution and character.—The Graneros shale—the lowest formation in the Benton group—outcrops as a narrow belt skirting the margin of the Dakota sandstone in the southwest corner of the quadrangle. It is composed of dark shales, nearly black in the middle, with an occasional layer of sandstone, probably of lenticular character. The most persistent of these layers is a calcareous sandstone about 2 feet thick, occurring in the upper part of the formation. The Graneros shale is generally fossiliferous. There are also near the center several thin layers of light-colored "tale-like" clay, some of which are associated with thin beds of highly fossiliferous limestone containing an abundance of shells. A concretionary horizon usually occurs 30 to 40 feet above the base. These concretions vary from a few inches to a foot in size and are of a calcareous nature. The formation has a total thickness of about 200 feet and merges upward into the Greenhorn limestone.

GREENHORN LIMESTONE.

Character and thickness.—The Greenhorn formation consists of alternating layers of light-gray to dove-colored limestone and a slightly darker-gray sandy shale. The limestone beds vary from 2 to 10 inches in thickness and contain an abundance of fossil shells, the most common being *Inoceramus labiatus*. The limestone is traversed by vertical cracks, which, with the bedding planes, separate it into flat plates. These plates lodge on the slopes in sufficient abundance to obscure the intervening shale in many places. The shale occurs in layers 1 to 2 feet thick and is also very fossiliferous. Thin layers of white clay are also sometimes found. The formation has an aggregate thickness of about 50 feet. It lies conformably upon the Graneros shale and merges upward rapidly into the Carlile shale.

Distribution.—The Greenhorn outcrops in a narrow band bordering the underlying Graneros and Dakota in the extreme southwest corner of the quadrangle. The characteristic topographic expression of the formation is a low, winding escarpment interrupting the gradual slopes of the softer Carlile and Graneros shales. The broken limestone of the formation holds considerable moisture, thus favoring the growth of trees, and its surface is generally covered with piñon. This forested strip separating the talus slopes of the Graneros and Carlile shales affords a means by which the position of the Greenhorn limestone may be easily recognized.

CARLILE SHALE.

Character and thickness.—The Carlile formation is composed of shales, shading from light gray to black, with an occasional layer of lenticular sandstone and concretions. The sandstone lenses are usually confined to more sandy portions of the shale occurring above the middle. Associated with these sandy shales are the concretions, which generally have rounded outlines and vary in size from a few inches to 6 feet. The larger are septaria, being traversed by numerous large shrinkage cracks filled with white or wine-colored calcite in crystals of varying dimensions. At the top of the formation is a layer of light-brown sandstone, 4 feet thick, which is used to some extent as a building material. In thickness this formation varies from 210 to 225 feet.

Distribution.—The areal extent of the Carlile in this quadrangle is greater than that of the Greenhorn and less than that of the Graneros. It occurs as a narrow meandering zone between the low escarpment of the underlying Greenhorn limestone and the bold cliffs of the Timpas. Its steep slopes are largely due to the protection afforded by the resistant massive limestones of the Timpas formation. The soft shales of the upper part of the Carlile sometimes give way under the heavy load of the overlying limestone, causing small landslides.

NIORARA GROUP. TIMPAS FORMATION.

Thickness and character.—The Timpas formation has a thickness of 200 feet. The basal member is a dark-colored sandy limestone, about 2 feet thick, very fossiliferous and containing shells and many shark's teeth, also numerous dark-colored pebbles. Above this is a series of massive gray limestones 40 to 50 feet thick, which is in turn overlain by lead-colored shale containing a few thin bands of limestone. At the top of the formation there are one or two distinct layers of impure limestone. The massive limestone is in strata which range from 6 inches to 1 foot in thickness, intercalated with thin layers of a light-gray calcareous shale. Exposed surfaces of the limestone are usually badly broken and fractured; the cracks run parallel to the bedding and the detached plates are thin and conchoidal. *Inoceramus deformis* is the most common fossil, though not especially abundant, and to the surface of this marine shell *Ostrea congesta* is often found attached. A closer examination of the limestone generally reveals the presence in great abundance of minute organisms, collectively known as foraminifera. In the lower portion of this formation nodules of iron oxide abound. They are of a dark-brown color, spherical or cylindrical in shape, with a diameter rarely exceeding three-quarters of an inch. The surfaces of the less weathered specimens are found on close examination to be covered with angular projecting crystals. These iron particles are probably the oxidized product of marcasite nodules. As the limestone decomposes these resistant nodules are freed from their matrix and lie loose on the surface. The main part of the Timpas formation is a paper-like shale, of medium- to dull-gray color. It contains an abundance of minute crystals of gypsum, of the selenite variety. Fish scales of considerable size occur throughout the formation.

Distribution.—The outcrop of the Timpas is a relatively broad band extending diagonally across the southwest corner of the quadrangle. Its eastern boundary is marked by a low ridge of hills capped with a thin layer of weathered yellow limestone; the middle shaly portion forms an undulating plain; and the massive basal limestones give rise to bold cliffs overhanging the softer Carlile shales.

APISHAPA FORMATION.

Character and thickness.—The Apishapa formation—the upper division of the Niobrara group—is composed mainly of dark- to light-gray sandy shales, interrupted at intervals by dull-gray to cream-colored calcareous shales and impure limestone. The most persistent of these calcareous beds are found at the top of the formation, where a series of alternating layers of yellow limestone and light bluish-gray shale reaches a thickness of 10 to 20 feet. The formation has a total thickness of 425 to 450 feet. The lowest 50 feet is composed of a dark, fissile shale, followed by about

100 feet of a somewhat decayed papery shale of slightly darker shade. The shale of the central portion of the formation is generally arenaceous, and in places, owing to its increased hardness, has resisted erosion sufficiently to form low escarpments. None of these, however, occur within the limits of this quadrangle. This sandy shale contains tracks of small crustaceans, and fish scales abound in it as elsewhere in the formation. The upper portion of the Apishapa, comprising about 100 feet of sediment, is a dark bluish-gray, fissile shale containing two and in some places three horizons of cream-colored limestone, the uppermost marking the top of the formation. There is also near the top a horizon of limestone lenses varying in size from 1 to 20 feet and arranged parallel to the bedding plane. These lenses are ramified by cracks filled with pale-blue crystals of barite. Along the south side of Chicosa Creek, north of Hungerford Lake, these limestone lenses have protected the underlying softer shale from erosion in such a manner as to give rise to low rounded mounds or hills, forming a conspicuous feature of the topography.

Distribution.—The outcrop of the Apishapa is a broad band extending from east to west across the southern part of the quadrangle and comprising about one-fourth of its entire area. It has a simple boundary on the north, but a more complex one on the south. The shale mass, constituting the greater part of this formation, appears in the landscape as a gently undulating plain, interrupted here and there by a low prominence capped by a remnant of Nussbaum sandstone. The upper limestone is seen within the limits of this quadrangle only on Sixmile Creek at the northern boundary of the formation and on the Rocky Ford Highland canal 2 miles south of Fowler.

PIERRE SHALE.

Thickness and character.—The Pierre is the highest formation of the Cretaceous period which occurs within the quadrangle. It has a thickness of about 2300 feet. The lowest portion, 400 to 500 feet thick, is composed of a black, shaly series, somewhat yellow at the base, which has been called the "barren zone" on account of the absence of fossil remains. Above this zone are about 500 feet of dark-gray shale characterized by bands of concretions composed chiefly of iron and lime carbonate. These concretions are a dark bluish gray when newly exposed, but weather to rust color. They vary in size from a few inches to 2 feet, and where they outcrop broken, angular fragments are strewn over the surface in great abundance. Above this is a deposit 100 to 200 feet thick of a somewhat lighter gray shale which contains many specimens of the marine shell known as baculite. This shell varies from one-half to 1 inch in diameter and is 4 to 5 inches long. Next above is a shaly series known as the "tepee zone," a name suggested by the tepee-shaped hills which it exhibits. This zone has a total thickness of 500 feet or less. It is composed mainly of light-gray shales containing bands of concretions and large bodies of gray limestone known as "tepee cores." The concretions are composed of calcium carbonate, oval in shape and ranging in size from a few inches to 6 feet. They are very fossiliferous. The tepee cores vary in diameter from 10 to 30 feet, are irregular in shape, and have a vertical extension of at least 50 feet. While they are generally roughly cylindrical, one case was noted where the core apparently tapered downward like an inverted cone, and in other localities there is evidence that some are of lenticular shape. These tepee buttes have been studied jointly by Messrs. G. K. Gilbert and E. P. Gulliver and their description of the tepee rock is here given:

The tepee rock is essentially a calcium carbonate, the ratio of calcium carbonate to magnesium carbonate being 18 to 1 in the single sample analyzed. That sample contained also 12 per cent of argillaceous material. For comparative purposes analyses were also made of the inclosing shale and of one of the ordinary concretions of the shale, the determinations showing that the tepee rock does not differ materially in composition from the concretions and that the argillaceous material is practically identical with the shale. This permits us to regard the argillaceous material as included shale, and therefore an impurity rather than an essential constituent of the tepee rock.

The rock is of coarse texture, breaks with rough frac-

ture, and its general color is a light, warm gray. It is full of fossil shells, and the microscope shows that they are embedded in a matrix which is composed of fragments of shell, waterworn grains of calcite, foraminifera, and clay. Cross sections of *Lucina* shells show that the original shell structure remains, although the lime of the shell has been recrystallized into calcite. Inside of the shell wall there is a band of radiating crystals of calcite, showing well-marked spherulitic structure. The calcareous ooze which must have at first occupied the central cavity of the shell has recrystallized into very pure calcite, leaving the clay impurities at one side of the shell. This central calcite crystal is the same individual which has replaced the lime of the shell, for the two parts extinguish together, the cleavage cracks extend from the center through the outside, and when the spherulitic band is faulted the clear calcite is continuous through the cracks. Experiments showed the spherulitic layer to be slightly less soluble in dilute hydrochloric acid than the clearer calcite.

An analysis of a typical sample of tepee rock, made by Dr. W. F. Hillebrand (Gilbert, G. K., Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897), is as follows:

Analysis of limestone in "tepee core."

Silica (SiO ₂).....	7.46
Titanium dioxide (TiO ₂).....	1.78
Alumina (Al ₂ O ₃).....	.94
Iron sesquioxide (Fe ₂ O ₃).....	46.93
Lime (CaO).....	2.36
Magnesia (MgO).....	.37
Potash (K ₂ O).....	.87
Soda (Na ₂ O).....	Undetermined.
Phosphoric oxide (P ₂ O ₅).....	39.25
Carbon dioxide (CO ₂).....	.16
Water lost at 100° C.....	.70
Water lost above 100° C.....	
Organic material.....	
	100.00

The limestone constituting these "tepee cores" bears a marine fauna. *Lucina occidentalis* is the most abundant molluscan species, forming a leading constituent of the rock. *Inoceramus* is rather common and cephalopods occur in considerable variety. Foraminiferal forms are frequently seen under the microscope. The occurrence of fossil wood has also been reported from some of the cores. The following is a list of the molluscan species determined by Mr. T. W. Stanton, from specimens collected by Mr. Gilbert:

Ostrea inornata M. and H.
Inoceramus crispus var. *barabini* Morton.
Inoceramus vanuxemi M. and H.
Inoceramus sagensis Owen.
Lucina occidentalis var. *ventricosa* M. and H.
Thetis circularis M. and H.
Anchura (*Drepanochilus*) *americana* E. and S.
Nautilus dekayi Morton.
Baculites ovatus Say.
Baculites compressus Say.
Scaphites nodosus Owen (?).
Scaphites nodosus var. *quadrangularis* M. and H.
Scaphites nodosus var. *brevis* Meek.
Ptychoceras crassum Whitfield.
Heteroceras (*Exiteloceras*) *cheyennense* M. and H.
Heteroceras (*Didymoceras*) *nebrascense* M. and H.
Heteroceras (*Didymoceras*) *cochleatum* M. and H.
Heteroceras sp. undet.
Helicoceras sp. undet.

The remainder of the Pierre shale, as found in this quadrangle, consists of a series of lighter gray sandy shales containing concretionary bands, with an aggregate thickness of about 600 feet.

Distribution.—The Pierre shale occupies a broad band, narrowing to the east, extending from northwest to southeast across the quadrangle along the general course of Arkansas River. On the south its outline is relatively simple, with one outlying portion at the western margin of the quadrangle, near the head of a large branch of Sixmile Creek; but on the north the boundary is very irregular, being determined by the overlapping of the Nussbaum formation. The shale yields readily to erosion and the slopes of the larger areas are traversed by numerous ravines.

TERTIARY SYSTEM.

NUSSBAUM FORMATION.

Distribution.—The Nussbaum formation has the greatest surface extent of any deposit within the limits of the quadrangle, occupying the greater part of the northern half. Its main portion extends from Chico Creek eastward to the boundary of the quadrangle, and several large detached areas are found west of Chico Creek. It is the highland formation south of Vineland and Avondale and it caps the Hooker Hills on the opposite side of Huerfano River. The district lying to the south and east of Arkansas and Huerfano rivers

contains many small isolated areas of Nussbaum, especially in the region of Erdman Lake, along Chicosa Creek and its tributaries, between Hungerford Lake and the southern margin of the quadrangle, and along Apishapa River. There is also a remnant of the formation on the south side of the Huerfano about 4 miles south of Undercliff.

Thickness and character.—The formation rarely exceeds 60 feet in thickness. It consists of gravel, sands, and silt, with very little clay. The sand and gravels at the base are often bound together by a calcareous cement, forming sandstone and conglomerate of considerable firmness. The formation lies unconformably upon the underlying Cretaceous rock and is of river origin, as is indicated by the coarseness of the material and the general direction of the slope of the mesas.

QUATERNARY SYSTEM.

TERRACE DEPOSITS.

Age and distribution.—The terrace deposits of this quadrangle represent two epochs of Quaternary time. In most places the boundaries of the earlier and later deposits can be easily delineated and in mapping distinct patterns have been used. The materials composing these two terraces are much the same and the basis of their classification is largely topographic. The earlier terrace caps a number of small flat-topped hills bordering the south side of Arkansas River Valley between St. Charles and Huerfano rivers. A few smaller areas are also found in the vicinity of Erdman Lake. The later terrace occupies a strip from 2 to 3 miles wide on the south side of Arkansas River, extending across the entire quadrangle and forming its most fertile agricultural district. There are also less extensive terraces along the Huerfano from the vicinity of Undercliff to its mouth. On the north side of the Arkansas, from Boone to the eastern margin of the quadrangle, terrace remnants cap some of the more prominent ridges; and a few small areas occur on the east side of Chico Creek, in the vicinity of the Skinner and Tabor and the Tolle ranches.

Character and thickness.—The chief components of the terrace deposits are gravel and sand in varying proportions, the whole having an aggregate thickness of about 30 feet, but in places the earlier terrace is somewhat thicker. At the base the material is locally cemented by lime, forming conglomeratic sandstone, a notable feature of the earlier terraces. The gravels of the later terraces are smoothly spread and slope gently toward the river, terminating abruptly in low cliffs. While the materials composing the earlier and later terrace deposits are much the same, the former exhibits a slightly wider range of rocks. The deposits along Huerfano River, Chico Creek, and on the north side of Arkansas River rarely exceed 15 feet in thickness, but in composition they show no material difference from those of the larger terraces.

ALLUVIAL DEPOSITS.

Distribution and character.—The alluvial deposits of this area are confined mainly to Arkansas River and its principal tributary, the Huerfano. A relatively narrow strip occurs along the St. Charles and at the mouths of Chico and Chicosa creeks. The alluvium of Arkansas River has a fairly uniform width of 1 to 1½ miles, continuing across the entire area. Through this flat the river pursues a meandering course, generally adhering to the south bank. The deposit consists of a light-colored, fine-grained sand with varying proportions of clay and decayed vegetable matter. Its total thickness is 20 to 25 feet. The alluvium of Huerfano River extends from the Ben Butler ranch to its junction with the Arkansas. It rarely exceeds one-half mile in width. Along St. Charles River the alluvial flat is very narrow. It continues from the western margin of the quadrangle to its mouth, a distance of 4 or 5 miles.

DUNE SANDS.

Distribution.—Extensive accumulations of dune sands derived from the sandy Tertiary beds to the north cover an area reaching from the northern margin of the quadrangle to a point about 5 miles northeast of Boone. Other smaller areas are found along the eastern margin, on the highlands between Haynes and Chico creeks, and on the gravelly terrace southeast of Boone.

Nepesta.

Character and age.—The sands are of recent origin and in many places are still loose and travel before the winds. Throughout the southern half of the large sand-hill district north of Boone the entire surface is a system of hills and hollows with practically no drainage by streams. The dunes are 30 to 40 feet high and they lie with their greater diameters from northwest to southeast, which is the direction of the prevailing winds. Farther north the sand has been blown about by the wind to some extent, but not formed into distinct dunes, and this area has a well-defined drainage. West of Langford ranch and along the eastern margin of the quadrangle the sand hills are low and inconspicuous, rising only a few feet above the level of the plains. In the area southeast of Boone the sands are derived from the terrace deposits.

STRUCTURE.

The general structure of the Cretaceous rocks of the Nepesta quadrangle is indicated in fig. 1, which

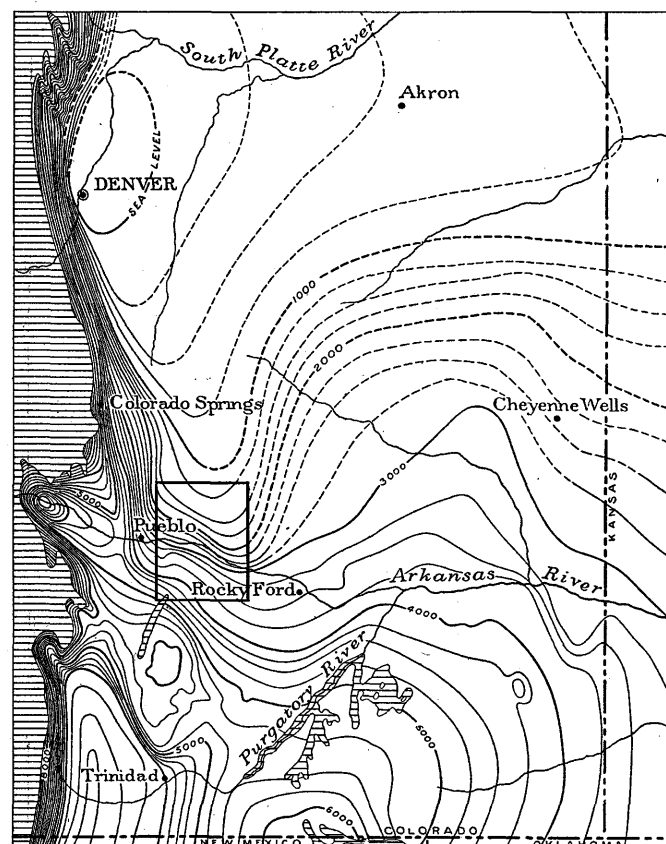


FIG. 1.—Diagram showing structure of Dakota sandstone in eastern Colorado.

Contours show elevation above sea level of the top of the Dakota sandstone at intervals of 200 feet vertically. Ruled pattern represents area where Dakota sandstone is absent. The location of the Nepesta quadrangle is indicated by the heavy rectangle.

shows the configuration of the Dakota sandstone in the surrounding portions of the Great Plains. Over all except the southwestern portion of the area the beds have a slight northeastward inclination, as illustrated in the structure section on the artesian water sheet. A broad dome with a general southeast-northwest trend crosses the Apishapa and Walsenburg quadrangles, which lie to the south and southwest respectively. Extending from this dome in a northerly direction, a low anticline crosses the extreme southwest corner of the Nepesta quadrangle, giving rise in that region to a perceptible increase in the dips. There is also a low, flat arch, with a corresponding trough on the west passing through East Pueblo, which enters the Nepesta quadrangle about 1½ miles south of St. Charles River, but extends only a short distance inside the limits. In the southwest corner of the quadrangle the Cretaceous strata exhibit many waves and small faults. These could not be traced, owing to superficial covering, but they probably prevail throughout the general region. Deformation by the intrusion of igneous rocks has not occurred within the quadrangle, so far as could be ascertained.

HISTORICAL GEOLOGY.

SEDIMENTARY RECORD.

The rocks occupying the surface in the western part of the central Great Plains are of sedimentary origin. They consist of sandstone, shale, limestone, sand, gravel, and loam, and present considerable variety in composition and appearance. They were originally sand, gravel, and calcareous mud, derived from the erosion of ancient land surfaces or chemical precipitates from sea waters.

These rocks afford a record of physical changes which have taken place from near the beginning of Cambrian time to the present, but owing to the lack of knowledge of the relations of some of the deeply buried rocks only a general outline of

the sequence of events can be offered. One significant feature is that some of the conditions were widespread, for there is remarkable uniformity in the resulting products. There were undoubtedly many marine submergences and several periods of emergence in which the surface was sculptured by running waters, especially in the later epochs.

Cretaceous seas.—In the Nepesta quadrangle the geologic record begins with sediments characteristic of shallow seas along a coastal plain which alternately rose and sank, but the general movement of which was one of subsidence. These coastal deposits, of which the Dakota sandstone is the oldest representative outcropping in the quadrangle, consist mainly of coarse, pebbly sandstone laid down by strong currents in beds 25 to 30 feet thick. At the close of the Dakota deposition marine conditions were established over wide areas and continued until near the end of the Cretaceous period. During the middle of Benton time there was a change in conditions, resulting in the deposition of the Greenhorn limestone. The close of this epoch is marked by a layer of light-brown sandstone. The shales of the Benton group were followed by a series of limestones and shales, the latter predominating, now known as the Niobrara group. A marked episode at the beginning of Niobrara time was that which resulted in the deposition of the massive limestones which now constitute the base of the Timpas formation. At the close of this epoch several thin layers of limestone were deposited, and these were followed by over 2000 feet of Pierre shale laid down under uniform conditions.

The retreat of the Cretaceous seas marks the Fox Hills epoch. During this time extensive sheets of sand were deposited on the underlying clays, forming a basis for the accumulation, in shallow water and swamps, of the sediments of the succeeding Laramie epoch. Whether or not these two last-named formations were deposited over the area occupied by the Nepesta quadrangle is not definitely known, but it is probable that they were and that attenuated representatives still exist between the Pierre and Nussbaum formations in the northern part of the quadrangle. To the west, in the vicinity of Florence, the Laramie reaches a considerable thickness and to the northeast and southwest Fox Hills, Laramie, and later deposits occur in thick masses.

Early Tertiary conditions.—At the close of the Cretaceous period the Nepesta quadrangle was raised above the water, and an epoch of great mountain growth ensued. The disturbances, however, which accompanied this epoch elsewhere were here manifested only by a general uplift, except in the southwest corner of the area, where local folding of the strata took place. During the early part of the Tertiary period this quadrangle was being gradually uplifted and rapidly eroded, so that large portions of the various formations were removed. This uplift and erosion were accompanied by local interruptions, one of which, occurring in late Tertiary time, has had an important bearing on the history of the district. At this time river deposits accumulated on the plains opposite the Arkansas embayment, owing to elevation to the east, which decreased the gradient of the Arkansas and its more important tributaries and rendered these streams incapable of disposing of their sediments. As a result an extensive but relatively thin deposit of sand and gravel, known as the Nussbaum formation, accumulated on the eroded surfaces of the older formations over the greater part of the quadrangle. Subsequent erosion, stimulated by change of level and increase of slope, has removed much of the deposit in the southern half of this area.

ECONOMIC GEOLOGY.

SOILS.

Character and distribution.—The soils of the Nepesta quadrangle include several different varieties, some of which are exceptionally fertile. Over a great portion of the area they are closely related to the underlying rocks, of which they are in part residual products. The exceptions are along the larger valleys, where the soils have formed from alluvial deposits.

The bottom land immediately bordering the streams consists of a rich, dark loam overlying a

deposit of light-colored sandy clay containing alternating layers of gravel. Below this, resting on the bed rock, is a layer of coarse gravel of variable thickness which affords a local water supply. Bordering this bottom land in some places, especially along Arkansas and Huerfano rivers, is a loess-like sandy loam several feet deep, which is well adapted to agriculture when watered. The most productive soil of the quadrangle is on the terraces bordering the Arkansas and its more important tributaries. It is of a sandy character, but contains a sufficient amount of clay to make it coherent when moistened. It varies from 1 to 6 feet in thickness, the maximum being reached at the outer portion of the mesa, adjacent to the base of the older terrace. Along its inner border is a strip of gravelly soil, varying in width from one-eighth to one-fourth of a mile, which is too stony for agricultural purposes. These terraces also contain small areas of very sandy soil, especially where the intermittent streams of the adjoining highland traverse them. In some localities the material is sufficiently incoherent to be moved about by the wind, forming low hills of dune sand.

The soil of the Nussbaum upland is prevailingly sandy, but sufficiently rich to support a strong growth of various kinds of plateau grasses with a small amount of moisture. In the sand-hill area the soil is very loose and unfit for cultivation, though it supports a vigorous growth of nutritious grasses.

The soil resulting from the disintegration of the Pierre shale, which is essentially a clay formation, is stiff and "gumbo"-like, highly acid on account of decomposing pyrites, and generally not well adapted to cultivation. There are, however, a few open valleys, notably those along Andy Creek and some of the larger tributaries of Chico Creek, in which there are overplaced soils of marked fertility. Similar deposits, but of limited extent, border Haynes and Kramer creeks.

The Niobrara beds, which occupy the uplands south of Arkansas River, have soils of clayey character, containing sufficient limy material mixed with the sand to give fertility. However, over a great part of this region there is no water available for irrigation and hence farming is not pursued. A notable exception to this is the district under the Huerfano Valley ditch, where considerable farming is done by irrigation from flood waters.

The Carlile outcrop within the quadrangle is very limited in extent and usually consists of steep, barren slopes. There is, however, a small tract of productive valley land along Huerfano River just below the Ben Butler ranch. The Graneros shales furnish a narrow strip of tillable land along the Huerfano.

The Dakota sandstone, covering about 2 square miles in the extreme southwest corner of the quadrangle, is only partly covered by a scanty soil.

Agriculture.—The general aridity of the climate renders tillage without irrigation impracticable, except in a few low-lying areas adjacent to the principal streams. Agriculture at present is restricted to the valley land and the adjoining gravelly mesas. The cultivated portions comprise about one-eighth of the total area, the remainder being utilized for pasturage of cattle, an important industry of the region to which the upland areas are well adapted. Among the chief products are oats, corn, wheat, sugar beets, potatoes, Mexican beans, and a variety of garden vegetables, most of which are marketed at Pueblo. The largest and most profitable crops are alfalfa and melons. The alfalfa is consumed in the region, while the melons, especially the cantaloupes, owing to their superior quality, find a ready sale in the best markets of the United States. Fruit raising is a growing industry and many large, well-kept orchards are to be found in the irrigated districts. Cherries, plums, and other small fruits have a hardy growth and abundant yield, but the apple crop is as yet usually a failure owing to an insect which attacks the fruit in its advanced stages. The seasons are ordinarily of sufficient length to insure the maturing of all cultivated crops.

WATER RESOURCES.

The underground waters of the Nepesta quadrangle are of two general classes, ground and artesian. The former is the chief source of supply for

domestic purposes throughout the area, but as it usually contains much "alkali" there is great need of artesian water.

GROUND WATER.

The ground waters of the area are confined chiefly to the alluvial sands and gravels bordering the Arkansas and its larger tributaries. Some of the intermittent streams of the upland region, such as Chicosa, Haynes, and Kramer creeks, carry a small underflow, which is often sufficient to supply domestic wells. The gravelly terraces contain considerable water derived by seepage from irrigation ditches. As the conditions governing these sources of ground-water supply are for the most part variable, the amount of water is by no means constant. When the annual precipitation is low there is a perceptible decrease in the underflow of the intermittent streams. During the late summer and fall months, when the irrigation canals carry the minimum amount of water, there is also less water in wells adjacent to these ditches, owing to a lowering of the water plane. The seepage from the ditches is constantly leaching out the soluble salts contained in the clays of the terrace gravel and the shales upon which they lie, as is proved by the character of the water in the marginal springs issuing from these terraces. This leaching process has been more effective in some places than in others, and the water in certain wells has improved in quality as irrigation progressed, while in others it has apparently become more highly mineralized.

Wells drawing their supply from the underflow of the Arkansas River Valley are more or less affected in quality and quantity by the amount of water in the river. During flood times there is a lateral underflow from the stream to the alluvial flats, and, as the river water at such times contains an abundance of "alkali" washed from the adjoining highlands, the well water of the valley soon becomes highly charged with objectionable salts.

The Nussbaum formation, which covers the surface over much of the area north of Arkansas River, contains the only good ground water found in the quadrangle. Along the western and southern boundaries of the Nussbaum plateau, from the Skinner and Tabor ranch to the vicinity of Fowler, there are numerous springs at the base of the Nussbaum formation. These have a small flow of comparatively pure water. The gathering ground of these springs is the Nussbaum plateau, which extends far to the north. On this plateau several trial wells have been sunk, but, with a few exceptions, little water was obtained.

The water supply for the town of Fowler is furnished by a number of these small springs on the north side of the river. The water is first collected by porous tiling laid along the sides of the smaller ravines which head in the plateau. This tiling delivers the water into pipes leading to a storage reservoir situated in the Nussbaum bluffs. From here the water is piped to Fowler, a distance of about 2 miles. The springs in the bluffs near Nepesta, Boone, and Nyburg could be similarly utilized. The following analysis of the Fowler water was made in the laboratory of the Atchison, Topeka and Santa Fe Railway:

Analysis of spring water at Fowler, Colo.

	Grains per gallon.	Parts per million.
Organic material.....	1.983	34
Silica.....	.991	17
Calcium carbonate.....	2.503	43
Magnesium carbonate.....	1.470	24
Sodium carbonate.....	8.260	141
Sodium chloride.....	3.750	64
Sodium sulphate.....	9.190	157
	28.144	480

ARTESIAN WATER.

Source.—In the Nepesta quadrangle, as elsewhere throughout the central Great Plains region, the Dakota sandstone is the principal artesian-water bearer. It is present throughout the entire area included in this quadrangle. From the extreme southwest corner, where it disappears underground, the sandstone descends uniformly toward the east. The only known irregularities in this inclined plane are a low anticlinal fold entering the quadrangle from the northwest at a point due west of Huerfano Lake, and a small arch from the south,

crossing the boundary about 4 miles east of the Ben Butler ranch. These folds do not extend far inside the Nepesta quadrangle, as will be seen by reference to fig. 1, which shows the configuration of the Dakota sandstone. The gathering grounds of the artesian water lie to the west and southwest, where this sandstone is extensively exposed in the form of hogback ridges and broad anticlinal folds. Throughout these areas of outcrops the water is received by imbibition from rain and streams, and descends within the porous sandstones, to which it is confined by the impervious shales of the marine Cretaceous. In the lowlands bordering Arkansas River to the east the water in the Dakota sandstone is under sufficient pressure to bring it to the surface when the formation is reached by well borings. The overlying formations have fairly uniform thicknesses, and as these thicknesses are known, it is possible to predict, with a considerable degree of certainty, the depth below the surface at which the Dakota is to be found. The water-bearing beds in this formation occur at various distances from its top in different localities. In the western part of the area the highest bed furnishing artesian water is encountered about 100 feet below the top of the formation, while to the east the uppermost member produces not only the strongest flow but often the best quality of water. The depth below the surface of the top of the Dakota sandstone is shown by the contours on the artesian water sheet. For instance, the 1000-foot artesian contour is drawn through all points where the top of the sandstone is 1000 feet below the surface. While these estimates are subject to some error, it is believed that they are sufficiently accurate to be of practical service. The facts set forth by these contours indicate that the Dakota sandstone lies at only a moderate depth below the surface in the southern half of the quadrangle, but that the depth increases to the northeast.

Head.—As above stated, the artesian water underlying the Nepesta quadrangle enters the Dakota formation on the high slopes to the west. These slopes, which may be regarded as the head of the artesian water, rise to altitudes ranging from 4000 to 5500 feet. Throughout the lower lands to the east the height to which water will rise in wells reaching the Dakota sandstone decreases toward the zone where the water is free to escape at the surface, which is in the vicinity of Lamar, Colo. If the physical conditions governing the storage and transmission of this water were uniform the rate of decrease from head to leak could be easily calculated, but as these conditions are variable a certain amount of local variation in the decrease of head must be expected. Along Arkansas Valley, from Pueblo to Rocky Ford, several wells have been sunk to the Dakota and artesian flows obtained. The pressure of these wells affords a means of estimating the total amount of decrease in head from one side to the other of the Nepesta quadrangle. By equally distributing this loss of head along lines connecting wells of known head at Fowler, Manzanola, and Rocky Ford with the lowest points of inflow of the Dakota outcrop to the west, the head for points intermediate has been computed. Through all points of equal head contours or head lines have been drawn, which are intended to illustrate the decrease in head from west to east. The contour interval is 100 feet. These lines of head afford a means of ascertaining the pressure of wells within the area of flow and the height to which water will rise in wells that do not flow. The depth below the surface at which water would stand in a well at any point outside the area of flow is equivalent to the difference in altitude of the head and the surface of the ground for the locality in question. The head lines also serve as a basis for the determination of the area where artesian flows might be expected. The territory of flowing wells within the Nepesta quadrangle is not large. It is confined to Arkansas River Valley and its principal tributaries from the south. Along the Huerfano it is limited to a very narrow strip, but in the vicinity of Chicosa Creek and Apishapa River it occupies broad bands which increase in width to the southern margin of the quadrangle.

Chemical properties.—The quality of the artesian water probably varies considerably within the boundaries of the area, as is suggested by a

comparison of the analyses of the two deep wells at Pueblo, less than 2 miles apart:

Analysis of water from Fariss artesian well, Pueblo, Colo.

	Grains per gallon.	Parts per million.
Sodium chloride.....	2.42	41
Sodium sulphate.....	41.92	718
Calcium sulphate.....	3.43	59
Calcium carbonate.....	6.28	108
Magnesium carbonate.....	6.16	105
Ferrous carbonate.....	.91	16
Silica.....	.91	16
	62.03	1063

Analysis of water from well of Colorado Coal and Iron Company, Pueblo, Colo.

	Grains per gallon.	Parts per million.
Sodium chloride.....	1.82	31.0
Sodium sulphate.....	41.43	709.0
Potassium chloride.....	1.83	31.0
Calcium sulphate.....	16.94	290.0
Calcium carbonate.....	2.64	45.0
Magnesium carbonate.....	11.65	199.0
Ferrous carbonate.....	1.17	20.0
Silica.....	.55	9.4
	78.03	1334.4

A comparison of the various analyses of the Dakota waters along Arkansas River from Pueblo to Lamar, Colo., shows that their mineral contents include sulphates, carbonates, and chlorides, the sulphates being the most abundant. Sodium, calcium, magnesium, and potassium are the principal metals, their relative quantities being in the order named, while the kind and amount of salts, including sodium sulphate, magnesium sulphate, calcium carbonate, sodium carbonate, and sodium chloride, vary considerably in different wells.

Record of deep borings.—In the deep well on Andy Creek, which penetrates the Dakota 50 feet, the water rose 1000 feet. It is reported to be of good quality, but no analysis has been made. The material penetrated by this well is shown in the following record (fig. 2):

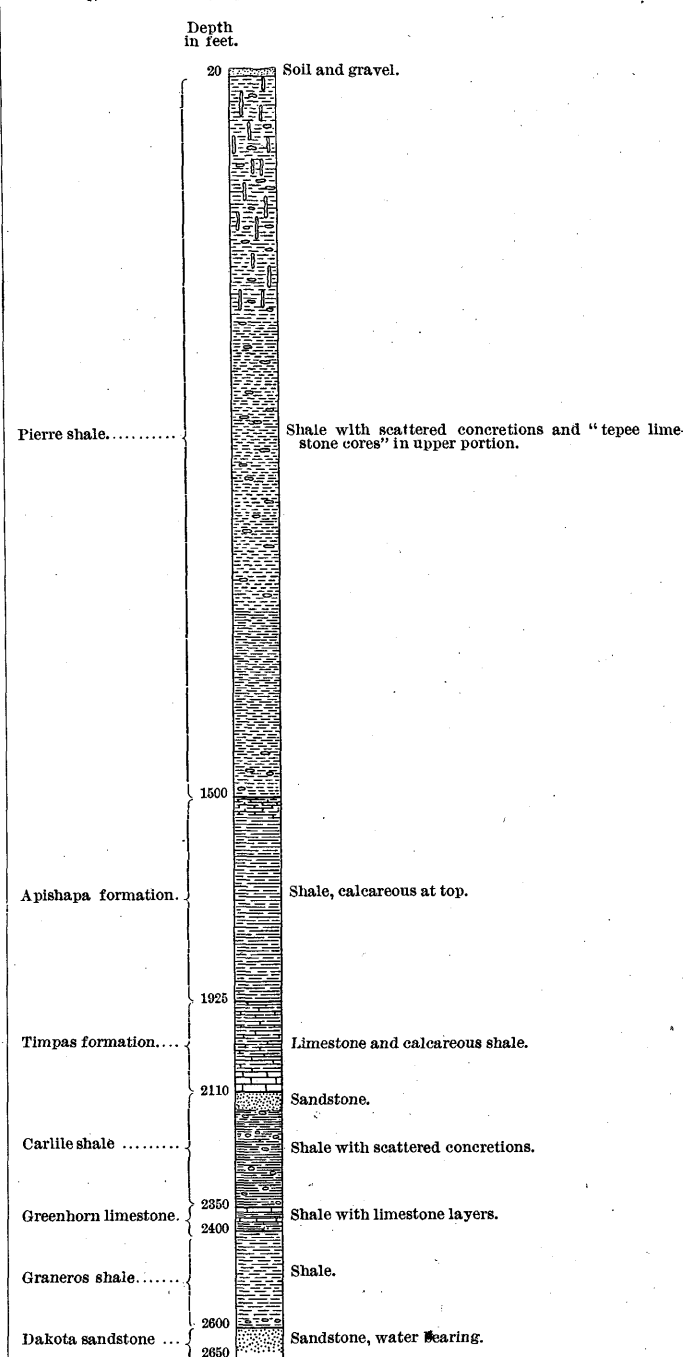


FIG. 2.—Section of deep well near mouth of Andy Creek.

This boring begins in the Pierre shale, 1500 feet above the base, passes through the basal Timpas limestone at 2000–2100 feet, and penetrates 450 feet of Benton before reaching the Dakota. If the boring had been continued farther into the Dakota it is probable that the water would have risen much higher in the well.

The deep boring near Boone is a dry hole, owing to the fact that the well was discontinued as soon as the Dakota sandstone was reached. The record of the well follows.

At this place the boring begins near the middle of the Pierre shale and passes through the Niobrara series from 1100 to 1750 feet, below which

460 feet of Benton are penetrated, containing the characteristic "talc" layer near the base.

Record of deep boring near Boone, Colo.

Formation.	Character.	Thickness.
	Soil.....	Feet. 0-20
Pierre.....	Shale with concretions.....	20-1100
Apishapa.....	Shale, calcareous at top.....	1100-1525
Timpas.....	Shale with limestone in upper and lower parts.....	1525-1750
Carlile.....	Shale.....	1750-1950
Greenhorn.....	Limestone intercalated with shale.....	1950-2000
Graneros.....	Shale.....	2000-2200
Dakota.....	Sandstone.....	

An artesian well a short distance east of Fowler, on the Atchison, Topeka and Santa Fe Railway, has a flow of soft water from the upper sandstone of the Dakota. The following beds were penetrated:

Record of artesian well near Fowler, Colo.

	Feet.
Surface materials.....	0-40
Shale.....	40-825
Limestone.....	825-1270
First Dakota sandstone.....	1270-1372

The boring begins near the base of the Pierre shale and passes through the Apishapa and Timpas formations, the characteristic limestones of the latter being penetrated at 825 to 875 feet. Below this are 395 feet of Benton beds overlying the Dakota sandstone.

IRRIGATION.

The annual rainfall of the quadrangle is so small that all successful farming must depend on irrigation. The principal source of water supply is Arkansas River, but the demands on this stream throughout its course are so great that the amount to which this area is entitled is inadequate to supply the present needs, and recourse is had to flood water along some of the principal tributaries and small intermittent streams. About 37,000 acres of irrigated land are supplied with water from five large canals—the Bessemer, Rocky Ford Highland, Fowler, Excelsior, and Huerfano Valley ditches. All except the last named obtain water from Arkansas River. In addition to the above there is a considerable acreage of lowland watered by private ditches. The Bessemer ditch furnishes water for a district comprising about 20,000 acres in the vicinity of Vineland and Avondale. The waters are diverted from the Arkansas about 10 miles west of Pueblo through a substantially built stone headgate. The main ditch is 30 feet wide on top and 8 feet at the bottom and has a carrying capacity of 400 cubic feet of water per second.

The region about Fowler is included under the Rocky Ford Highland and Fowler ditches. The former begins near the mouth of the Huerfano and supplies water for about 25,000 acres, most of which is outside of the quadrangle. It is stated that the ditch is entitled to 464 cubic feet of water per second. The Fowler ditch is relatively small, with a water right of only 116 second-feet. Its waters are diverted from the Arkansas above Nepesta.

The Excelsior ditch is taken out of the Arkansas nearly opposite the mouth of the St. Charles and extends about 7 miles down the river. This is one of the oldest canals on the river, but carries a relatively small amount of water. Bob Creek and Otero ditches have their head-gates within the quadrangle, but supply no water to it. The Huerfano Valley ditch is dependent on Huerfano River for its water supply, and as the flow of this stream is intermittent it is necessary to store the water.

In the southeastern part of the quadrangle there are several natural storage reservoirs, of which the most important are Hungerford and Erdman lakes. At present the latter is being converted into a reservoir where a part of the flood waters of Chicosa Creek are to be stored. There are also a few small lakes near Langford ranch, on the head of Haynes Creek, but here the general conditions for water storage are not so favorable.

At Carpenter Spring there is a tract of land supplied with water from a number of small springs situated along the side of the valley. Other areas are similarly irrigated on the north side of Chico

Creek, from the Skinner and Tabor ranch to the northern margin of the quadrangle.

MINERAL RESOURCES.

SANDSTONE.

Dakota sandstone.—There are two formations in the quadrangle which afford sandstone suitable for building purposes. That of the Dakota formation is the more valuable for general structural use. The best quality of this rock occurs in the upper 100 to 150 feet of the formation. It is of a light-gray color, fine grain, and uniform texture, and possesses remarkable firmness and durability. It has been used only to a limited extent in this district, the principal building material being sun-dried brick, a product which in this semiarid climate is very durable.

Carlile sandstone.—A thin layer of sandstone near the top of the Carlile formation has been used to some extent as a building stone. In the vicinity of Pueblo, a short distance to the west of this quadrangle, a stratum of this deposit is quarried for flagging. The rock shades from yellow to light brown in color, is of uniform texture, and moderately soft. It occurs immediately beneath the massive limestone of the Timpas formation. In many places it is somewhat inaccessible, and, as it is limited in amount, it can not be regarded as an especially valuable economic resource.

LIMESTONE.

The chief source of limestone within the quadrangle is the Timpas formation, though a small amount is used from the Greenhorn and Apishapa beds. The Timpas limestone occurs near the base of the formation. It is in layers 6 to 12 inches thick, constituting a series of beds 50 feet in thickness. The rock is dull gray, but weathers to cream color. It is compact, hard, and much of it satisfactory for constructional purposes. Its principal uses are for burning to lime and fluxing. In the vicinity of Pueblo this rock is extensively quarried to supply the smelters. The following analysis of the limestone was made at the Pueblo Smelting Company's laboratory (Geologic Atlas U. S., folio 36, 1897):

Nepesta.

Analysis of Timpas limestone.

Silica (SiO ₂).....	6.4
Alumina (Al ₂ O ₃).....	1.3
Iron sesquioxide (Fe ₂ O ₃).....	2.1
Lime (CaO).....	50.4
Magnesia (MgO).....	Trace.
Carbon dioxide (CO ₂).....	39.5
	99.7

FIRE CLAY.

A fire clay occurring about 150 feet below the top of the Dakota sandstone is said to be of good quality. Numerous samples of the material have been burned with satisfactory results. This clay is not exposed in the Nepesta quadrangle, but could be reached by shafts from 100 to 150 feet deep anywhere within the Dakota outcrop. The clay varies somewhat in composition, but the following analysis may be regarded as representative. It was made in the chemical laboratory of the United States Geological Survey by Mr. George Steiger (Geologic Atlas U. S., folio 36, 1897):

Analysis of fire clay below Dakota sandstone.

Silica (SiO ₂).....	76.56
Titanium dioxide (TiO ₂).....	.60
Alumina (Al ₂ O ₃).....	8.30
Iron sesquioxide (Fe ₂ O ₃).....	.38
Lime (CaO).....	.12
Magnesia (MgO).....	.24
Potash (K ₂ O).....	Trace.
Soda (Na ₂ O).....	Trace.
Phosphoric oxide (P ₂ O ₅).....	.06
Water lost at 100°C.....	1.26
Water lost above 100°C.....	4.40
Organic material.....	8.31
	100.23

PORTLAND CEMENT.

Various attempts have been made in this general region to utilize certain rocks in the manufacture of Portland cement, but generally without success. Argillaceous limestone concretions occurring at various horizons throughout the Pierre shale have been tested with this object in view. A series of limy shales found just above the massive limestones of the Timpas formation have also been suggested as suitable material for this purpose, if proper limestone can be found to complete the

mixture. The following analysis of the Timpas shales was made in the laboratory of the United States Geological Survey by Mr. George Steiger (Geologic Atlas U. S., folio 36, 1897):

Analysis of Timpas shales.

Silica (SiO ₂).....	45.89
Titanium dioxide (TiO ₂).....	.52
Alumina (Al ₂ O ₃).....	13.24
Iron sesquioxide (Fe ₂ O ₃).....	3.88
Lime (CaO).....	12.09
Magnesia (MgO).....	2.12
Potash (K ₂ O).....	2.31
Soda (Na ₂ O).....	.47
Phosphoric oxide (P ₂ O ₅).....	.17
Carbon dioxide (CO ₂).....	10.38
Water lost at 100°C.....	1.38
Water lost above 100°C.....	4.16
Organic material.....	3.47
	100.08

IRON ORES.

The "Rusty zone" of the Pierre, shale lying above the so-called "Barren zone," contains many bands of calcium-carbonate and iron-carbonate concretions varying in size from 6 inches to a foot. The horizon is well exposed on the gradual slopes between Arkansas River Valley and the base of the high Nussbaum plateau to the north. At one time the iron-carbonate concretions were collected by local miners and hauled to Pueblo, where they were used in combination with other ores in the manufacture of steel. The ore is said to be of good quality for a carbonate, but the manner of its occurrence prevents extensive operation.

PETROLEUM AND GAS.

Considerable prospecting for oil has been done during the last year in the Pierre shale area north of Arkansas River. Two deep wells were sunk by the Skinner & Tabor Cattle Company on their ranch northeast of Pueblo. The deeper of these wells, located near the mouth of Andy Creek, was sunk to a depth of 2600 feet, passing through the Pierre and Benton shales into the Dakota without obtaining oil. The other, which is about 10 miles northeast of Pueblo, penetrated the Pierre and Benton formations to a depth of 1900 feet and was equally unsuccessful in finding

oil. At a depth of 800 feet, about 400 feet above the base of the Pierre shale, gas was discovered, but not in paying quantities. In 1903 a deep boring was made in search of oil on Haynes Creek 2 miles north of Boone. Here the Dakota was reached at a depth of 2200 feet and the project was abandoned. It is very doubtful if either petroleum or gas occurs in paying quantities within the limits of this quadrangle.

GRAVEL.

The later Quaternary gravels along the south side of Arkansas River have been used extensively as railroad ballast during the last decade. The gravel about 2 miles west of Fowler, on the Atchison, Topeka and Santa Fe Railway, is especially well suited for this purpose. The material is composed of medium-sized pebbles of quartz, quartzite, and various kinds of igneous rock. Its chief value as a ballast material is due to the uniform size and subangular shape of the pebbles and the small percentage of sand associated with them.

BARITE.

In the upper part of the Apishapa formation is a zone of large limestone lenses. Within these lenses occur cavities in the form of ramifying cracks, which have been partly or wholly filled by pale-blue barite crystals. Outcrops of these limestone lenses were observed in two localities only, in the vicinity of Hooker Hills and on the east side of Chicosa Creek about 3 miles west of Fowler. In the latter locality barite crystals have been collected to some extent, but are not of economic importance.

FUEL.

There are no coal-bearing formations within the limits of the quadrangle. The chief supply of firewood is found in the extreme southwest corner, in the exposed area of the basal Timpas, Greenhorn, and Dakota formations, where there is a sparse growth of piñon.

April, 1905.