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GEOLOGY

OF THE

RANGELY OIL DISTRICT

RIO BLANCO COUNTY, COLORADO

WITH A SECTION ON THE WATER SUPPLY

BY

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GEOLOGY OF THE RANGELY OIL DISTRICT, RIO BLANCO COUNTY, COLORADO, WITH A SECTION ON THE WATER SUPPLY.

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INTRODUCTION.

LOCATION OF THE FIELD.

The Rangely oil field is situated in Raven Park, in the extreme northwestern part of Rio Blanco County, Colo. It lies a short dis-

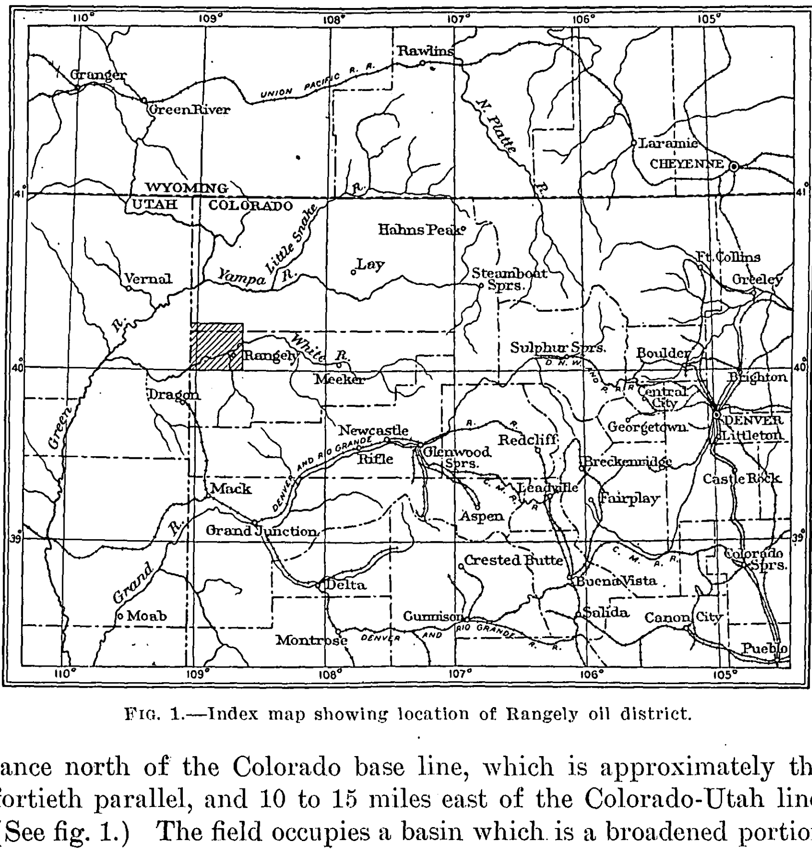

Fig. 1.—Index map showing location of Rangely oil district.

tance north of the Colorado base line, which is approximately the fortieth parallel, and 10 to 15 miles east of the Colorado-Utah line. (See fig. 1.) The field occupies a basin which is a broadened portion of the lower White River valley. It is included within the block of townships 1, 2, and 3 north of the base line in ranges 101, 102, and 103 west of the sixth principal meridian. Rangely post-office, from which the oil field takes its name, is the center of the scattering settlement along the immediate valley of the river, which skirts the southern margin of the basin. The post-office is about 33 miles from Dragon, Utah, the present terminus of the Uintah Railway. The trip from Dragon to Rangely can be readily accomplished in a single day, but must now (summer, 1907) be made by private conveyance, as no regular means of transportation is provided. Stage and principal mail connections from Rangely are by way of Meeker, the county seat of Rio Blanco County, which is 60 miles distant by road up the White River valley. A stage runs from Meeker to Rifle, a station on the Denver and Rio Grande Railroad, about 45 miles farther on. The whole trip from Rangely to the railroad by way of Meeker occupies about two and one-half days of actual travel, not including probable delays incident to the stage connections.

SCOPE OF THE PRESENT REPORT.

Present interest in the Rangely district centers mainly in its prospective development as an oil field. The intelligent study and exploitation of its oil resources must of necessity be based primarily on a knowledge of its geologic structure and rock formations. The field has already been described in the reports of the early geologic exploration of this general territory. The keen observation and admirable descriptions of C. A. White, who as geologist of the Hayden Survey studied this district in the early seventies, have appealed strongly to the popular understanding and have gained ready acceptance as a basis for the interpretation of many later problems of the field.

The present report is intended as a review of the geology of the field in greater detail than was possible in the early exploration and reports. It is also the purpose herein to discuss the conclusions reached in that earlier work and to correct some misinterpretations which are now widespread and probably originated there. The extension of detailed geologic study in Cretaceous and Tertiary strata of the Rocky Mountain and Plateau provinces in the last few years by various field parties of the Geological Survey has made available much additional evidence bearing on the general problems of the geologic history of these regions.

The maps (Pls. I, II, in pocket) are new and more accurate and detailed than any hitherto available. The structure sections (Pl. III, p. 34), though necessarily based largely on theoretical assumptions, are nevertheless carefully worked out from all the evidence available and are thought to be good representations of the relative thicknesses and structure of the stratigraphic formations that underlie this district.

It is hoped that the description and discussion given herein may prove to be of practical value in the economic development of the field. It is beyond the scope of this paper to make any specific predictions as to sites or possible productiveness of wells. The chief purpose, as suggested by the title of the paper, is to present a study and discussion of the geology of the district in which the oil has been found.

FIELD WORK.

The field work which forms the basis of this report occupied a period of about one month in August, 1907. The primary object of the work in this region was an investigation of the coal fields in this part of the State, for the purpose of determining their probable extent and value and of making a classification of the public lands. The topographic and geologic mapping is the work of John Allen Davis, Charles W. Stoops, and the writer.

TOPOGRAPHIC MAP.

The topographic map (Pl. I) which accompanies this report and serves as a base for the geologic mapping is a part of a larger map now (December, 1907) in course of preparation, intended for publication in a report on the coal fields of this general region. The amount and character of the surface relief of the region are represented by contours, or lines of equal elevation, spaced at vertical intervals of 100 feet. These were drawn in the field and to a large extent the sketching was done from the land-survey lines and corners. All the section corners that were found are shown by a symbol on the map, so that some estimate may be made of the relative accuracy of the sketching and locations by noting the corners and lines from which the information was obtained. In addition to the sketching and retracing of section lines, a number of the main roads of the district were traversed with plane table, this work being tied to land-survey corners, with intersections and angles of elevation recorded to prominent points for control.

The recently completed resurveys of the land subdivision lines were found to be in most satisfactory condition, so far as they could be checked by the methods employed during the present work. Most of the corners along the lines traversed were readily found and fairly well marked. It is to be regretted, however, that some of the monuments or corner stakes and markings are not of a more durable character and in a more permanent form. The well-established lines of this new land survey formed an excellent base for the horizontal control of the map here presented. These lines have been plotted according to the standard polyconic projection, with due allowance for convergence and curvature for the scale adopted at the given latitude.

The Colorado base line is approximately the fortieth parallel. The latest survey of this base line is a reestablishment of the older surveyed line, replacing the old corners by the present ones, which are set at 1-mile intervals according to the last and presumably most correct measurements.

Elevations shown on the map are based on and corrected to two lines of railroad surveys and levels, which traverse the Rangely district from east to west, one extending down White River and the other crossing by way of the longitudinal valley at the southern foot of Blue Mountain.[a] In order to record these data the alignments are shown on the map, together with the elevations given at various points along them. With future and more carefully adjusted work it will doubtless be found necessary to apply some minor corrections to the elevations that are given here, but in view of the somewhat incomplete connections with any well-established datum that are now obtainable no attempt has been made to revise the figures of the original survey. The following checks are obtained at the points named, which are independent and situated at either end of the line used:

Elevations at Newcastle, Colo., and Green River, Utah.

	Colorado Midland Railway survey via White River.	Denver and Rio Grande Railroad levels.[a]	Denver, Northwestern and Pacific (Moffat) Railway survey, corrected to Denver.	Evident correction.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Newcastle	5,570	5,552		−18
Green River, Utah, mouth of Ashley Creek, water levels	4,728		[b]4,715	−13

[a] Gannett, Henry, Dictionary of altitudes in United States, 4th ed.: Bull. U. S. Geol. Survey No. 274, 1906.
[b] Approximate.

The sketching of topography throughout the rest of the field is based on elevations determined by aneroid barometers.

GENERAL DESCRIPTION.

LOCALITY NAMES AND SETTLEMENT.

The Rangely Basin was first called Raven Park by C. A. White, who as geologist of the Hayden Survey visited the region in 1875. As a topographic basin it presents a curious contrast to the surrounding broken and more rugged country. The district as an oil field is

[a] Routes were surveyed through the Raven Park district in December, 1886, and January, 1887, also in July, 1887, by the Colorado Midland Railway, to whose courtesy the writer is indebted for the use of the survey notes. Acknowledgment is also due to Mr. F. F. Mallon, of Colorado City, Colo., for his kindness and assistance in looking up these old records.

now more generally known as the Rangely Basin, from the post-office located there. White defines the term "park" in the introduction to his report,[a] and according to that definition his use of the term to describe the White River valley at Rangely is correct. According to popular usage in the Rocky Mountain region, however, the term perhaps implies somewhat of the picturesque quality, a park being an open glade or valley surrounded or partly inclosed by timbered hills. With such a meaning the term would hardly be appropriately applied to the Rangely Basin. This basin is in truth a desolate waste of dry washes and almost barren clay ridges, except only the immediate valley bottoms of White River. There is probably but little change since the time of the Hayden Survey, beyond the establishment of scattering ranches along the river flats. A few wagon trails and wood and coal roads lead out over the ridges or among the well-drillers' camps and these, with an idle derrick or two and well-drillers' cabins, are the only present signs of habitation.

OUTLINE OF THE BASIN.

The Rangely Basin is irregularly oval in outline, its longer diameter extending from northeast to southwest with a total length of about 15 miles. The low valley portion, or Raven Park, has an approximate width of about 5 miles. The valley itself is bordered by an escarpment rim, averaging about 500 feet in height, which presents a steep scarp or cliff facing inward toward the basin center. This innermost escarpment edge is locally known as the "rim rock" and is easily recognized as the upper limit or cap rock of the oil-bearing shale, from which the park has been eroded. Beyond the "rim rock" the ridges dip away in more gradual slopes, rising in successive steps upon cliffs of the higher sandstone strata. Higher steep escarpment bluffs above and beyond the "rim rock" face inward in concentric arrangement rudely parallel to the margin of the park. Sharp rocky canyons intersect the surrounding ridges, draining into the central valley.

DRAINAGE.

White River enters the park through a canyon at its southeast extremity, flows along the southern margin, and leaves again by another canyon. Below the park the river flows continuously in a deepening canyon for the remainder of its course in Colorado. Raven Park thus lies for the most part north of the river valley. Besides the river itself one perennial stream enters the park from the south. This is Douglas Creek, which drains an extensive area south of White River. Its headwaters reach back to the divide between White and Grand rivers along the summit of the Roan or Book Cliffs Plateau. North of

[a] Report on geology of a portion of northwestern Colorado: Tenth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1878, pp. 9.

White River the principal drainage is a wet-weather stream known as Stinking Creek, originally named Unga-too-roosh on the Hayden maps. This, like most of the other drainage channels of the region, is dry most of the summer except immediately after heavy showers, when it runs full with thick muddy water for a few hours only. All these waters are heavily charged with alkaline salts.

SURFACE AND VEGETATION.

The dry, hard soil supports but little vegetation. The clay ridges are sparsely covered with the interminable sage, greasewood, and prickly pear. Along the immediate channels of the dry washes the same shrubs are found in thicker growth. The ground absorbs but little water even after the occasional floods of the summer storms. In heavy showers the water barely wets the top of the ground, running off rapidly and leaving the surface to harden again and crack in the dry air. Lack of water supply, absence of feed for cattle or horses, and the general destitute character of the region as a whole had caused but little value to be attached to the land until the existence of oil was discovered seven or eight years ago.

ROCK FORMATIONS.

GENERAL SUMMARY.

The rocks exposed in the vicinity of the Rangely field represent a large interval in the geologic time scale. On the great axes of uplift that form a part of the Uinta Mountain system north and northwest of Raven Park erosion has exposed the oldest rocks that occur in the region. On the southern flanks of Blue Mountain rocks as low as Carboniferous are brought to view, and from Blue Mountain southward a thickness of more than 7,500 feet of tilted Mesozoic strata is exposed in detail. These beds overlie the incompletely exposed section of Paleozoic rocks and in turn are covered by a similar thickness of Tertiary strata toward the south. The following list of formations and periods is given to outline the groups into which these strata are subdivided for purposes of description:

Summary of formations exposed in the Rangely district as represented on the geologic map (Pl. II, in pocket).

Period.	Formation.	Derivation of the formation names.
Tertiary	Green River Wasatch	King, Powell, and Hayden reports.
	(Unconformity.)	
Cretaceous	Mesaverde formation Mancos shale	Cross, southwestern Colorado reports.
	Dakota sandstone	Meek and Hayden and others.
Jurassic	"Flaming Gorge" "White Cliff"	Powell, Geology of Uinta Mountains.

A discussion of the occurrence of the Rangely oil is directly concerned only with the Cretaceous formations of the preceding table.

For this reason the descriptions here given are largely confined to these formations and include only brief mention of such strata above and below as naturally fall within the field included by the geologic map. It is the intention of the author to present a fuller discussion of the more complete stratigraphic section in a later paper.[a]

PRE-CRETACEOUS ROCKS.

Immediately below the Dakota sandstone is a mass of variegated badland-forming shale and clay, including some harder beds of limestone and sandstone, together with a peculiar dark cherty, siliceous conglomerate almost exactly like that commonly found with the Dakota formation above. The shale or marl is prevailingly of greenish and pinkish shades, with some beds that weather yellow. The lower 100 to 150 feet of this formation is composed of darker-colored beds, fine greenish sandstone and calcareous rock. Limestone layers composed largely of shells are present near the base, although the general character of the beds seems to indicate much limy or marly material throughout. These beds have an approximate thickness of 800 feet, as measured near the base of Blue Mountain. They are well represented in the excellent exposures on the steep northern slopes of the Dakota hogback in that locality, the more resistant sandstones of the Dakota formation capping and preserving from erosion the upper members of these weaker beds. The lower beds almost invariably form valleys, and as they are usually tilted at considerable angles, their outcrop is a relatively narrow strip between inclosing ridges. The lower strata of these variegated beds are of marine origin, as shown by the fossils they contain; the upper part, by analogy with other and better-known sections, is supposed to be composed largely of fresh-water deposits.

The variegated and shaly beds are limited at the base by a second group of sandstones which, like the Dakota, usually forms a steep rocky ridge. This group is more completely composed of sandstone than the Dakota, and is even more conspicuous as a ridge maker. It is usually very white and massive and cross-bedded to an extreme degree.

The variegated beds are of Jurassic age and probably correspond in their upper or supposedly fresh-water part to the Morrison formation east of the Rocky Mountains. They have also been variously named "Flaming Gorge," McElmo, and in part Gunnison in the Uinta Mountain and western Rocky Mountain regions. The relations of these formations are indicated in the correlation table on page 27. The cross-bedded white sandstone is also of Jurassic age, as is shown by fossils obtained from this field. It is with little doubt the equiva-

[a] Coal fields of northwestern Colorado and northeastern Utah: Bull. U. S. Geol. Survey (in preparation).

lent of the "White Cliff" sandstone mapped by Powell on the north side of the Uinta Mountains, and also seems to be with almost equal certainty equivalent to the La Plata sandstone[a] of the southwestern Colorado sections. The following fossils were collected from these formations during the last season, and are considered to prove conclusively the Jurassic age of the beds in which they were found. All are of marine types, being from the basal portion of the variegated beds and from the upper half of the cross-bedded white sandstone.

Fossils collected from the Jurassic rocks north of Raven Park.[b]

Variegated beds:
- Ostrea sp.
- Ostrea strigilecula White.
- Eumicrotis curta (Hall).
- Tancredia (?) inornata Whitfield.
- Astarte sp.
- Belemnites densus M. and H.

Cross-bedded white sandstone:
- Trigonia quadrangularis H. and M.
- Tancredia sp.

The principal economic interest that has as yet been attached to these beds is due to the occurrence of deposits of ores of uranium and vanadium in the massive cross-bedded sandstone. These deposits have been elsewhere described.[c] A single observed occurrence of a bed of hard black carbonaceous material which is probably an impure coal has been found in Red Wash Creek where its channel cuts the ledges of cross-bedded Jurassic sandstone, the bed outcropping among the upper members of that formation. The coal is 2 to 3 inches thick and only slightly weathered, occurring at water-level in the rather badly disintegrated sandstone. Although very poorly exposed, it is apparently interstratified with the sandstone itself. The analysis of this material has given the following results:[d]

Contains less than 1 per cent of matter soluble in carbon disulphid and does not soften in flame; therefore is not gilsonite or related hydrocarbon. As a coal it has approximately the following composition:

Analysis of coal from Red Wash Creek.

Moisture	10.5
Volatile matter	42.9
Fixed carbon	42.0
Ash	4.6
	100.0

[a] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and Utah: Jour. Geology, vol. 15, 1907, p. 642.

[b] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

[c] Contributions to Economic Geology, 1907: Bull. U. S. Geol. Survey No. 340, 1908, pp. 257–262.

[d] Analysis No. 2262 by E. C. Sullivan, in the chemical laboratory of the United States Geol. Survey.

DAKOTA SANDSTONE.

The Dakota sandstone does not come to the surface in Raven Park, but is well exposed in the foothill ridges at the southern edge of Blue Mountain, a few miles farther north. This formation lies at the base of the oil-bearing shale and has been supposed by many interested in the development of this field to offer highly favorable conditions for the storage of large bodies of oil. It has thus been the objective point for most of the deeper wells drilled in this field.

The remarkable persistence of its lithologic character and its continuity of exposure over such extensive areas have led to the acceptance of the Dakota sandstone as a key rock for the correlation of widely distributed stratigraphic sections of the Mesozoic rocks, both above and below that horizon. Few fossils have been obtained from it in the territory adjacent to the Rangely field, and its recognition there is based on tracing from other fields, on its position immediately below the abundantly fossiliferous lower Mancos (Benton) shale, and on the lithologic constitution of its beds, which correspond to those widely accepted as characteristic of the Dakota.

Although the details of the formation exposed at the southern foot of Blue Mountain can hardly be expected to correspond precisely to those of the formation as it lies underneath the Rangely field, a description of the Blue Mountain section contains the best available estimate of the character and thickness of these beds than can now be had. The following measurements were made of the tilted strata exposed near the headwaters of Willow Creek, one of the principal tributaries of Stinking Creek, in the NW. ¼ SE. ¼ sec. 12, T. 3 N., R. 103 W.

Section of Dakota sandstone at Willow Creek.

	Feet.
1. Sandstone, weathered brown (overlain by dark-gray and black slaty shale, supposed to represent the base of the Mancos [Benton])	10
2. Shale with beds of white clay and a hard siliceous conglomerate; shale very black and slaty near its base	110
3. Sandstone, white, cross-bedded, containing conglomerate layers	40
4. Interval, probably shale, covered by sandstone slide-rock	180
5. Sandstone	3
6. Shale, variegated in colors of pink and green, containing also one or more beds of dense reddish-purple limestone	95
7. Conglomerate, of coarse, perfectly rounded pebbles in a scant sandy matrix; pebbles largely of chert and siliceous material	45
	483

Doctor Stanton has expressed the opinion that Nos. 4 to 7 of the Willow Creek section as indicated above may be found to be older than the Dakota. He says "the variegated shale (No. 6) suggests the Morrison or possibly the Fuson of Darton's Black Hills section." If this opinion is correct the massive conglomerate stratum so naturally included in the base of the Dakota may really be a part of the underlying Jurassic formations and not Dakota at all. This view is given only as a tentative suggestion.

The Dakota outcrop extends westward from the Willow Creek locality continuously, with much uniformity in character and thickness, to and beyond the Colorado-Utah boundary. It there forms a steep, rocky ridge whose summit is composed of the heavy basal stratum of coarse conglomerate, resting immediately upon the variegated clay of the underlying Jurassic. East of the Willow Creek locality the coarse basal conglomerate is found as far as Red Wash Creek, beyond which it is thin or wanting entirely. Near Three Springs, about 15 miles east of Willow Creek, the whole Dakota formation is thin, being apparently represented by an outcrop of two inconspicuous sandstone beds, each not over 10 feet in thickness, separated by an interval of shale.

The only fossils that were found in these beds consist of a few very indistinctly preserved leaves. These were collected in a prospect pit exposing a black carbonaceous shale included between the massive white sandstones near the top of the formation. The pit is situated in the SE. ¼ sec. 5, T. 3 N., R. 101 W., just north of the Yampa River and Vernal wagon trail and near the headwaters of the west fork of Red Wash Gulch. The specimens collected could not be identified, but the locality may serve as a guide in further search for better material.

MANCOS SHALE.

The formation next above the Dakota is the Mancos shale, a thick mass of homogeneous clay shale with a few more sandy layers. It is considered here as a single unit, although it has formerly been subdivided into various formations, largely on paleontologic grounds. The relation of the Mancos shale to the subdivisions of the earlier explorers is indicated in the correlation table on page 27. From this it may be seen that Mancos includes all that has been previously termed Colorado and also a part of that classed as Fox Hills by White, of the Hayden Survey. It thus includes also the Benton, Niobrara, and a part of the Pierre formations, according to a classification of the Cretaceous section based on subdivisions originally adopted for strata of the upper Missouri River and adjoining fields. In brief, the Mancos is intended to include all of the predominatingly shaly strata above the Dakota and below the massive sandstones of the next succeeding or Mesaverde formation.

Raven Park is eroded on the Mancos shale, and it is in this formation that the oil of the Rangely field has been found. The least-altered exposures of these beds known in this area are those found in the bluffs along the north side of White River. Here the shale occurs in slightly weathered condition and presents a more compact, slaty appearance than is usual for this formation. Where fresh and undisturbed the shale is dark and fine grained, and in part at least shows thin lamination with considerable cross jointing. As more commonly exposed in escarpment bluffs or in wash banks of the many intermittent drainage channels, it dries to a lighter-gray color, blending with that of the soil into which it so readily breaks down. By reason of its nonresistant nature this formation commonly gives way to a heavy clay soil cover over low, rounded slopes, and is rarely exposed in a fresh condition.

The basal part of the Mancos shale may be naturally and readily distinguished as a distinct division of the formation, and contains Benton fossils. The Dakota sandstone is almost invariably overlain immediately by 200 feet or more of dense black slaty shale, which usually forms a long, low valley on the dip-slope side of the Dakota ridge. Above these beds is a similar thickness of shaly strata containing a number of more resistant beds of sandstone and limestone, which usually give rise to a distinct line of minor hogbacks similar to those of the Dakota, though of lesser elevation and more largely composed of shaly strata. The sandy layers are in many places of dark color and of moderately fine and even grain, and are as a rule flaggy or somewhat thinly bedded. These beds are commonly fossiliferous, and the calcareous beds also contain abundant shells. Collections obtained from many localities assign these rocks definitely to the upper part of the Benton shale.[a] The following is a list of identified species from the Willow Creek section described above:

Benton fossils from Willow Creek at the southern foot of Blue Mountain.

Ostrea lugubris Conrad.
Inoceramus fragilis H. and M.
Inoceramus dimidius White.
Scaphites warreni M. and H.
Prionocyclus sp.

[a] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

Above the sandstones the remainder of this great shale formation attains a thickness of approximately 5,000 feet, or about 1 mile. It is to all appearances of homogeneous composition throughout, but the records of oil wells driven through it distinguish layers described by some of the drillers as sandy.

The uppermost part of the Mancos shale is perhaps more commonly exhibited at outcrops than any other part of the formation, with the exception of the lowest few hundred feet already described. By reason of the protection offered by the lowest sandstone layers of the next succeeding formation, it occupies in many places nearly the whole face of the escarpment up to heights of 600 or 800 feet. Of these topmost beds the lower portion is normally buried in the débris that slides down from the steep slopes above. The shale here appears to be lighter in color and more sandy than the basal beds already described, but it is uncertain whether this is the result of long exposure to weather and the consequent drying out of its natural moisture, or to variation of constitution in the upper part of the formation.

The soil that forms upon the surface of the Mancos shale is a compact clay, very hard when dry but becoming a deep plastic mud when thoroughly wet. This soil is usually hard and dry during the summer, when its surface becomes deeply cracked and fissured. Rains of short duration, such as frequently occur in the summer season, scarcely penetrate the soil at all, except as they fill these cracks. Surface water runs off rapidly, cutting abrupt vertical-sided channels or miniature canyons even to a depth of 50 feet or more. These gullies rapidly extend and deepen with each succeeding flood, and in places the dissection becomes so intricate as to produce a typical badland. Areas of such topography, which characterizes much of Raven Park, are accessible only with much difficulty, and then only by avoiding the stream courses as far as possible and following the dividing ridges.

The soil is in many places filled or covered with scattered fragments of selenite, which is gypsum in its clear, crystalline form, and larger pieces of this mineral are strewn about upon the surface, as if residual in the soil from the disintegration and removal of the original shale.

The fossils that have been found in the Mancos shale were obtained mainly near the base (see list of Benton fossils, p. 15) and from the upper layers near the base of the next succeeding formation. The fossils from these upper layers are of marine types, which were formerly considered as characteristic of a so-called Fox Hills fauna, and the beds were included by White in his formation of that name. The following is a list of species obtained during the work of the last season from localities in and adjacent to Raven Park:

Fossils from upper part of Mancos shale in White River valley.[a]

Serpula sp.
Ostrea sp.
Syncyclonema rigida H. and M.
Avicula nebrascana E. and S.
Inoceramus sagensis Owen.
Inoceramus cripsi var. barabini Morton.
Mytilus subarcuatus M. and H.
Sphæriola? cordata M. and H.
Cardium speciosum M. and H.
Lucina sp.
Legumen sp.
Leptosolen sp.
Anatina sp.
Goniomya americana M. and H.
Liopistha undata M. and H.
Pholadomya sp.
Spironema? sp.
Odontobasis sp.
Cinulia sp.
Anisomyon sp.
Baculites compressus Say.

The thickness of the Mancos shale is a fundamental consideration in determining the depth to which wells must be sunk in the Rangely field in order to reach the Dakota sandstone. As a large part of the drilling has been carried on with this specific purpose in view the question of that thickness has received much attention from the drillers. When prospecting in the field was first started, White's estimates, given in the Hayden report, were accepted apparently without question. White gave the thickness of the "Colorado" formation as 2,000 feet in the upper White River valley, near Agency Park, but also stated that it was much thinner toward the west, in the vicinity of Raven Park. The first drilling in the Rangely field, however, showed that the figures given in that report were too small. Various attempts were then made to get more accurate information on this subject, but most of them were not very successful. For this reason the thickness of the formation is fully discussed here, and the evidence on which the conclusions are based is given in considerable detail.

The thickness of the Mancos shale may be determined from its upturned edge exposed along the southern foot of Blue Mountain, where these beds form a long, low valley parallel to and south of the Dakota ridge. Several estimates of this thickness have been made in recent years by those interested in drilling through the formation in the Rangely oil field. Most of such estimates have been made just east of the Willow Creek locality at which the detailed section of the Dakota formation (p. 13) was obtained. Chain measurements by Mr. C. F. Carney and others, of Meeker, are said to have shown the breadth of the Mancos Valley at this point to be 4,750 feet. The central portion of the valley is buried in alluvium; consequently the only

[a] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

dip measurements available on which to base an estimate of the true thickness of the shale are those shown in the rocky ridges along the valley margins at the north and south. These dips on the two sides of the valley do not accord, ranging from 33° to about 45° on the north, along the Dakota ridge, and increasing to angles of 75° and near verticality along the southern margin. Considerable uncertainty remains in the estimates of stratigraphic thicknesses based on the data given above, for if the beds are nearly vertical across the major portion of the valley, as they are at its southern margin, their thickness would be from 4,500 to 4,700 feet, but if the lighter dips at the north continue across the valley the thickness of strata represented is only about 3,000 feet. It may be concluded that the true thickness is somewhere between these two limits. The writer is inclined to believe, however, that no measurement obtained in this locality is reliable, and that the apparent regularity of the structure is misleading. As may be seen by reference to the geologic map (Pl. II) accompanying this report, the Dakota hogback bends rather abruptly at the point where Willow Creek emerges from it, about 800 feet east of the center of sec. 12, T. 3 N., R. 103 W. A general view of the topography in this vicinity clearly reveals also a corresponding bend in the structure of all the formations exposed. Thus the longitudinal valley which is eroded along the outcrop of the Mancos shale immediately south of and parallel to Blue Mountain bends abruptly across a zone which extends about due south from the site of the Willow Creek section. At the southern margin of the valley directly opposite the Willow Creek section (NE. ¼ SE. ¼ sec. 13, T. 3 N., R. 103 W.) the strata are irregular and apparently broken and this disturbance continues to the northeast for at least a quarter of a mile, the valley narrowing markedly in that direction. It is in this constricted portion of the valley that most of the measurements of the thickness of the Mancos shale have been made. The disturbance in this area is thought to have been produced by shearing movements within the mass of the shale, rather than by clearly defined faults. The irregular structure is evidently related to the narrowing or partial discontinuity of the Red Wash syncline, which extends eastward, broadening and deepening from this point, as is explained in the section on structure.

There are many places in the valley south of Blue Mountain where it seems fair to assume a uniform dip clear across the valley, but in most of these localities the greater part of each section is concealed beneath the valley wash. Calculations made from measurements at several such points indicate a minimum thickness of about 5,000 feet for the Mancos shale.

An estimate of the thickness of the Mancos shale can doubtless be obtained from well records, if the wells ever reach the Dakota in localities where an estimate of that part of the shale which has been eroded from the well site can also be obtained. The Union well in Raven Park, described on page 42, has been sunk to a depth of 3,655 feet in lightly dipping strata, so that this figure very closely approximates the true thickness of the beds passed through. About 1,200 feet of strata have been eroded from the site on which the well is located, this estimate being based on the same data which were used in constructing the cross section (Pl. III, section C-D) that passes through and includes the Union well. There is some evidence that the bottom of this well is about 300 feet above the Dakota sandstone. The total thickness thus obtained is slightly greater than 5,000 feet when corrected for the light dip of the strata, and this agrees very closely with the estimates made at the more favorable localities along Blue Mountain.

MESAVERDE FORMATION.

The uppermost and youngest strata of the Upper Cretaceous section in the Rangely district, as well as in the whole of the Grand River basin, are equivalent in age to the Mesaverde formation as mapped in the Yampa coal field.[a] These beds succeed and overlie the Mancos shale, from which they are distinguished chiefly by their generally more sandy character and the prominence of the massive sandstone ledges. As a whole this formation is composed of massive sandstones, interbedded with sandy shales and many beds of coal and carbonaceous shale. Of these rocks the sandstones are most conspicuous by reason of their greater resistance to erosion than that offered by the softer beds. The formation is thus typically represented by a more or less rugged country, characterized by escarpment ledges and cliffs. The massive sandstones are commonly of medium or rather coarse grained texture, locally showing some cross-bedding, although this is not a distinguishing feature. In many places they weather near the surface to a variety of shades, usually of reddish or yellowish color, which is probably the result of the oxidation of some iron constituents. Where these beds are exposed in mines or in freshly cut rock faces, they are commonly of clear white sand, firmly cemented when fresh, but they crumble and soften readily with exposure to the weather. Much of the cementing material in the sandstone is probably of calcareous or alkaline nature, as calcareous, magnesian, and ferruginous salts are almost invariably found in the waters that leach from these beds. Such salts commonly occur as efflorescent deposits in natural cavities in the massive sandstone, or under projecting ledges where sheltered from the solvent action of rain and snow water.

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[a] Fenneman, N. M., and Gale, H. S., The Yampa coal field, Routt County, Colo.: Bull. U. S. Geol. Survey No. 297, 1906, pp. 22–28.

In general the shales differ from those which constitute the main body of the Mancos, being usually of lighter color as well as more sandy. They show much variation in constitution, ranging from compact clay shale somewhat resembling the typical Mancos rock to sandy shale and from this to thin-bedded and flaggy sandstone. The coal beds constitute one of the most important economic resources of the region. The coals are bituminous and of a good grade, being similar to those of the Danforth Hills field, such as the coals near Meeker. As they are elsewhere[a] described in considerable detail, further discussion of them is omitted here.

As shown on the geologic map forming Pl. II (pocket), the lower part of the Mesaverde is distinguished as a separate member by a distinct pattern, the top boundary representing the base of the principal groups of workable coals. Within a small area such as the Rangely district certain parts of the Mesaverde formation are sufficiently continuous and characteristic to be distinguished and traced throughout the field, although they vary greatly in actual detail within very short distances. Perhaps the most conspicuously constant member of the whole formation as viewed from Raven Park is the irregularly oval escarpment surrounding the valley. This escarpment is composed of the lowest sandstone member of the formation, and is locally known as the "rim rock." The view given in Pl. IV, *A*, illustrates a characteristic portion of this member, and shows the underlying bluff of Mancos shale, capped and preserved by the hard sandstone ledge. The sandstone, or "rim rock" itself, is a bed ranging in general from 20 to 50 feet in thickness. Above this is a mass of characteristic sandy shale, 500 to 600 feet thick. These shales are, in general, easily eroded, leaving the outer edge and in many places a considerable portion of the back slope of the "rim rock" bare. Beyond the gentle back slope of the "rim rock" (as expressed in the contouring on the topographic map) a second characteristic escarpment rises above the first, capped likewise by a group of cliff-forming sandstone beds. Of these the lowest is most commonly of a rusty-brown color, resembling the weathered ledge of the "rim rock" below, and the third and fourth as commonly show a clear white aspect, in marked contrast to the group of darker ledges below. At about the horizon of the third sandstone above the base a thin bed of coal or dark carbonaceous shale is present at many places. This section is significant for purposes of correlation by comparison with the strikingly similar section near the base of the same part of the formation in Agency Park, north of Meeker, and also at many localities along the borders of Axial Basin. Above this

[a] Progress report on investigation of coal fields in northwestern Colorado and northeastern Utah: Bull. U. S. Geol. Survey No. 341, 1908.

second group of sandstones the members become less distinct as individuals, but merge into a prominent series of cliff-forming sandstones, continuing as such up to the horizon of the principal coal group already mentioned. Into these massive sandstones the steep rocky gorges and canyons of many intersecting streams are cut. This lower part of the formation is relatively barren of coal, but is prominent as a ridge maker. Its total thickness ranges from 1,000 to 1,500 feet. The measurements from which the larger estimate is obtained were made in Chase Gulch, northeast of Rangely.

The upper part of the Mesaverde formation is also distinguished as a separate member on the geologic map, the line which marks the lower limit of the principal group of workable coals representing its base. These upper strata resemble very closely the underlying beds, except that the predominance of the massive and resistant sandstone members is not so pronounced and the resulting topography is consequently not so rugged. One of the most readily distinguished horizons in the Mesaverde is the bottom of the principal workable coals. This general horizon has been traced continuously for at least 200 miles along the outcrop and, as already mentioned, is shown by a line on Pl. II. It is marked by a conspicuous white sandstone bed which is commonly one of the most massive members of the whole formation. In a large part of the Danforth Hills this bed is a very prominent white ledge. From its characteristic appearance it has come to be known in the vicinity of Axial post-office as the "white rock." As this member is traced west of that field it disappears and reappears intermittently, so that its position is locally a matter of some conjecture, even in a well-exposed section. Here, as in the Danforth Hills, wherever it can be recognized it furnishes a key rock by which to identify the more valuable coal beds that lie above it.

Above the "white rock" the sandstones and shales alternate in a variable succession, showing almost everywhere some signs of the coal beds that they include. The coals themselves are in many places made conspicuous by the burning which has taken place along their outcrops, baking the inclosing strata to brilliant shades of red and yellow and hardening the clay and shale to a flinty texture. Less commonly the coal beds are found in natural outcrop or show as black streaks along the hillside. By reason of the weaker character of this carbonaceous material it is usually broken down and concealed by the débris of the harder adjacent strata. From the "white rock" to the top of the formation, coals occur at irregular intervals, the principal beds being almost invariably concentrated near the base, or not far above the "white rock."

A number of carefully measured sections of the Mesaverde formation, taken along the Grand Hogback east of the Rangely district, have already been published in a description of the upper White River coal fields.[a] In that region the formation attains a thickness of somewhat over 5,000 feet, or approximately 1 mile. Opportunities for measurement near Raven Park are not so favorable, but the thickness of the Mesaverde here appears to be not more than half that which prevails in the Grand Hogback and Danforth Hills. The principal difficulty in obtaining a satisfactory measurement in the lower White River territory lies in the uncertainty regarding the upper limit of the formation. It is possible that during Mesaverde time a smaller amount of sediment was deposited in the Raven Park region than in the Danforth Hills and farther south. On the other hand, the greater thickness of the formation in the eastern part of the basin is probably to be explained by the assumption that most of the beds originally deposited there still remain, whereas in the western part a large amount had probably been eroded from the upper portion of the formation before the next succeeding strata were laid down. This explanation is more probable, because the section of the Mesaverde formation near Raven Park corresponds in grouping as well as in thicknesses to the lower part of the thicker section farther east. It may be noted from a study of the sections of the Mesaverde near the Grand Hogback and in the Danforth Hills that the principal group of workable coal beds is in the lower part of that formation, immediately overlying a relatively barren zone of 1,000 feet or more. This coal-bearing group is in turn overlain by a considerable thickness of strata containing scattered coal beds or carbonaceous streaks, some of which are of workable thickness. Additional evidence of the removal by erosion of the upper beds in the western part of the field is found in the fact that as these rocks are traced northwestward into Utah they apparently show progressively deeper erosion, without any notable change in the character or grouping of the basal members. The Mesaverde formation may be followed continuously to and beyond Green River, where its outcrop crosses that stream just below the mouth of Ashley Creek in Utah. At this place all of the workable coal group is wanting except one or two coal beds, and these occur at the top of the section, which is roughly estimated as not more than 1,500 feet in thickness.

Not only has a great amount of the Mesaverde formation been eroded from the western part of the White River region, but other and higher Cretaceous formations have probably also been removed from that entire basin, as they are present in adjacent fields to the north and east. In the Yampa coal field the Lewis shale and the Laramie formation overlie the Mesaverde, separating that formation

[a] Coal fields of the Danforth Hills and Grand Hogback in northwestern Colorado; Bull. U. S. Geol. Survey No. 316, 1907, p. 266.

from the succeeding Tertiary sediments, which are similar to those that rest directly upon the Mesaverde in the Rangely field. It is therefore presumed either that beds corresponding to those now found in the Yampa field had been eroded from the Rangely district and vicinity before the deposition of the Tertiary beds began, or that the uppermost Cretaceous beds were never deposited in the Rangely district. In the latter case, the time during which these later beds were being laid down in other regions was marked by dry-land conditions in this district.

The stratigraphic horizon marking the disappearance of beds which are thought to have once been deposited and later eroded before succeeding deposits were laid down represents an interval in the geologic history of the earth probably as important as the time represented by many of the formations that still remain and may be studied at the present day. The causes that brought about first the deposition of certain beds and later the removal of the same material by erosion indicate changes in the earth's crust similar or related to the earth movements that produced the mountain ranges. Although the record of those events, to be interpreted from a study of the strata, may have been wholly or in part obliterated at certain localities, many of the missing clues may be obtained from other places. The horizon of a former land surface that was uplifted and subjected to erosion and subsequently submerged and subjected to renewed sedimentation is known as an erosional unconformity.

The tilted rocks exposed in the ridge north of and approximately parallel to White River between the mouths of Wolf and Red Wash creeks offer what is perhaps the best opportunity for measurements of the Mesaverde formation near the field. An estimate based on a measured line just east of Red Wash Creek (between secs. 13 and 18, 24 and 19, along the township line separating T. 3 N., R. 101 W., and T. 3 N., R. 100 W.) gives a total of only 2,500 feet. The upper limit of the section is defined by an exposure of the varicolored marl characteristic of the overlying Tertiary just east of this line, along the axis of the Red Wash syncline. Some fossils found immediately along the line of this cross section (100 paces southeast of the northeast corner of sec. 36, T. 3 N., R. 101 W., in a conglomerate ledge) also serve to indicate that the top of the formation had been reached and that as complete a section of the Mesaverde as now remains in this part of the field occurs at this place. These fossils consist of internal casts of a species of *Unio* and some indeterminable fragments of leaves. Doctor Stanton considers the *Unio* to be of an age later than the Mesaverde, possibly belonging to Fort Union or related time. He is also of the opinion that it is older than species previously known to have come from the Wasatch formation. No intermediate formation has been recognized in the Rangely field and these rocks are therefore included with the Wasatch formation.

The canyon of White River below Raven Park would seem at first sight to present a most excellent opportunity for obtaining a measurement of the thickness of the Mesaverde formation. Two factors, however, interfere with such a measurement at this locality. The first, which will be described in a subsequent paragraph, is the probable existence of a fault near the mouth of the canyon, and the second is a sharp divergence of dips and strikes along the river banks, caused by irregularity in geologic structure.

As has been explained, the precise determination of the upper limit of the Mesaverde is an especially perplexing problem in and about Raven Park. Near Meeker and along the Grand Hogback between White River and Grand River a bed of coarse bowlder and pebble conglomerate or "pudding stone" with a coarse white-sand matrix marks the boundary between characteristic Mesaverde beds below and the variegated marl and sandstone of the overlying Tertiary. In the Rangely district, however, no such clearly defined stratum was discovered, although some beds of conglomerate not closely resembling the Grand Hogback bed were found. These beds appear to be at or near the top of the Mesaverde formation, but in many places they could not be discovered and the sandstones of the Mesaverde could not be distinguished from those of the overlying beds. Consequently the exact upper limit of the formation could not in all places be determined. In some parts of the Rangely district the variegated colors of the overlying Tertiary beds are less conspicuous, although they are generally recognizable and serve as almost the only distinguishing mark of the transition to Tertiary strata. The occurrence at this horizon of some species of unios and one or more gasteropods, including one which is probably a *Goniobasis*, was not considered determinative, but is thought to indicate the Tertiary age of the beds including them and is considered as a useful clue in the mapping of the Cretaceous-Tertiary boundary at the top of the Mesaverde.

Fossils have been found in all parts of the Mesaverde formation. These indicate that the basal beds are mostly of marine origin, up to and probably including the "white rock." This basal portion of the formation is distinguished as a separate member on the geologic map (Pl. II). Above the "white rock" fresh- and brackish-water invertebrates and plants indicate a change in the body of water in which these beds were formed. The fresh- or brackish-water conditions were not permanent, however, and gave way to true marine conditions when the beds near the top of the formation were deposited. Fresh-water fossils are also found in the lower predominatingly marine beds. The following is a list of the fossils collected from the Mesaverde formation in this field or along the drainage basins of White and Yampa rivers:

Fossils obtained from Mesaverde formation in White River districts.

INVERTEBRATES.[a]

Ostrea subtrigonalis E. and S.
Ostrea glabra var. arcuatilis Meek.
Anomia micronema Meek.
Modiola laticostata (White).
Inoceramus sagensis Owen.
Inoceramus cripsi var. barabini Morton.
Inoceramus erectus Meek.
Unio sp. cf. U. brachyopisthus White.
Unio cf. danæ M. and H.
Corbicula cytheriformis M. and H.
Corbicula occidentalis M. and H.
Cardium speciosum M. and H.
Legumen sp.
Donax? sp.
Mactra formosa M. and H.
Corbula undifera Meek.
Viviparus sp.
Tulotoma thompsoni White.
Campeloma? sp.
Goniobasis? sp.
Baculites compressus Say.

PLANTS.[b]

Halymenites.
Cunninghamites elegans? (Corda) Endl.
Ficus speciossissima Ward.
Ficus squarrosa? Knowlton.
Ficus sp.?
Ficus planicostata Lesq.
Sapindus sp.
Sequoia Reichenbachi (Gein.) Heer.
Dammara cf. D. acicularis Knowlton.
Corylus cf. C. Macquarrii (Forbes) Heer.
Magnolia tenuinervis Lesq.
Zizyphus sp.?
Celastrus sp.
Platanus sp.
Geinitzia sp.

TERTIARY FORMATIONS.

Between the top of the Mesaverde formation and the base of the overlying Tertiary strata an unconformity exists in the Rangely district, as has already been stated. Much difficulty has been experienced in determining precisely the horizon at which this unconformity occurs, as no change in the bedding of the strata has been noted. Definition of the top of the Mesaverde as well as the base of the Tertiary depends on this feature. Both formations contain alternating beds of massive sandstone and sandy shale which are so similar that in many places they can not be distinguished one from another. The chief characteristics of the lower Tertiary beds are the clays or marls of brilliant and variegated colors, which constitute in some places a mass 2,000 feet to possibly 4,000 feet in thickness. The variegated strata are supposed to be of Wasatch age and were so mapped in the Hayden reports. Fossils obtained from the basal part of this formation have been identified as characteristic of the Fort Union formation. The Wasatch is quite distinct as a lithologic unit along the western flank of the Grand Hogback and the Danforth Hills, where

[a] Determined by T. W. Stanton.
[b] Determined by F. H. Knowlton.

it attains a thickness of at least 4,000 feet. In the vicinity of Raven Park, however, these colored clays are much less conspicuous. Below the Cathedral Bluffs red patches are exposed only here and there, and the massive white sandstones very closely resemble those of the Mesaverde formation below.

Overlying the Wasatch or lowest Tertiary formation is a second mass of shale and sandstone without the variegated colors. These rocks have been named Green River group in the earlier geologic work. They are characteristically exposed in escarpments of considerable elevation, among the best examples being those of the Book Cliffs and Cathedral Bluffs, south of Raven Park. These steep scarps stand at elevations of 1,500 to 2,000 feet above the neighboring valleys, and are almost everywhere characterized by the chalky-white appearance of the weathered cliffs as seen at a distance. The Green River formation usually lies nearly horizontal or with a very light dip, and in most places it forms a high mesa or plateau surface, occupying the undisturbed interiors of the great structural basins.

In detail the Green River formation is composed of sandstones and thin-bedded slaty shales, with layers of limestone and calcareous shale. Many beds of oolitic or pisolitic limestone occur, and at some localities they form the major part of the harder beds which the formation contains. In many places the thin-bedded shale is of dark or brownish color when freshly exposed, in marked contrast to the almost universal whitish aspect of nearly all these beds on their weathered edges. The characteristic occurrence of most of these Tertiary beds in areas of slight structural disturbance and their consequent horizontal position are discussed in the section on structure (p. 34).

MODIFICATION OF FORMER CRETACEOUS CLASSIFICATIONS IN THE PRESENT PAPER.

All the names of Cretaceous formations used in the reports of the Hayden, King, and Powell surveys, with the single exception of Dakota sandstone, have been superseded by other names in the foregoing descriptions. The relations of this recently adopted nomenclature to the old classifications and also the relations of those formations to each other are indicated in the accompanying table of correlations. The classification of the Cretaceous strata above the Dakota as Laramie, Lewis, Mesaverde, and Mancos here replaces altogether the older grouping of Laramie, Fox Hills, and Colorado as used by the King and Hayden surveys for this general region. Although the term Laramie is retained in the present classification as the name of the uppermost of the formations of Cretaceous age as they are now recognized, this term is no longer accepted as it was formerly applied by any of the early investigators in this

Table of correlations to explain the relations of the various groupings adopted for western Colorado strata.

[The horizontal arrangement is intended to indicate actual equivalency of the strata. The heavy lines indicate the various conclusions as to the age of the strata thus designated.]

	Hayden, about 1870.	King, Fortieth Parallel Survey, 1875.	Powell, Geology of Uinta Mountains, 1876.	White, Hayden Survey, 1878; Ninth Ann. Rept. U. S. Geol. Survey, 1889.	Cross, San Juan folios, U. S. Geol. Survey, 1899.	Fenneman and Gale, Yampa coal field report, Bull. U. S. Geol. Survey No. 297, 1907.	Present report.	
Tertiary.	Green River.	Uinta. Green River.	Green River.	Green River.			Green River.	Tertiary.
	Wasatch.	Uinta. Vermilion Creek. (a)		Wasatch.			Wasatch.	
	All coal-bearing formations mapped as Lignitic.		Various formations mapped as Bitter Creek.	Neither unconformity nor hiatus recognized.			Fort Union? (a)	
					Laramie.	Laramie.	Laramie.	Cretaceous.
					Lewis.	Lewis.	Lewis.	
		Laramie.	(b) Point of Rocks.	Laramie.[c]	Mesaverde.	Mesaverde.	Mesaverde.	
Cretaceous.	Fox Hills. Pierre.	Fox Hills.	Salt Wells.	Fox Hills.				
	Niobrara. Benton.	Colorado.	Sulphur Creek.	Colorado.	Mancos.	Mancos.	Mancos.	
	Dakota.	Dakota.	Henrys Fork.	Dakota.	Dakota.	Dakota.	Dakota.	
Jura-Trias.	Jurassic.		Flaming Gorge.	Jurassic.	Gunnison. McElmo.		"Flaming Gorge."	Jurassic.
	Triassic.		White Cliff.	Triassic.	Gunnison. La Plata.		"White Cliff."	

[a] Unconformity. [b] Local unconformity. [c] White regarded this Laramie as transitional between the Cretaceous and Tertiary.

particular field—a point that is discussed in detail farther on (see pp. 27–32). This more recently adopted nomenclature has already been introduced into the literature of northwestern Colorado geology.[a] Still more recent stratigraphic studies have confirmed the tentative conclusions of the Yampa coal report, relating to the necessity for a revised nomenclature, and also the expediency of the names there adopted for the northwestern Colorado region.

Although the classifications and conclusions of the early geologic writers on this field have gained wide recognition and become very firmly established in a popular as well as more technical way, there is ample justification and indeed urgent necessity for abandoning entirely this older terminology and revising the basis of its stratigraphic grouping. This revision, as adopted here, is intended to accomplish three specific aims. These are, first, to do away with the uncertainty that prevails with regard to the precise definitions and limits assigned to certain terms by the various authors in the older work, the differing significance attached to the geologic term Colorado being the principal instance; second, to establish a stratigraphic and lithologic basis of separation of the formations instead of the previously adopted paleontologic basis, which depended on distinctions that are always difficult and locally impossible to recognize; third, to call attention to and correct an old and now widespread misinterpretation of the age of the beds formerly called "Laramie" in this field—a group of strata that should never have been included in the formations to which that name was applied, even according to the original somewhat uncertain definition of the term. These points are considered in more detail as follows:

First. The use of the same geologic formation name with varying significance is found in the application made of the term Colorado by the King and Hayden surveys. This disagreement is indicated in the correlation table (p. 27). In the reports of the Fortieth Parallel Survey the term Colorado is defined so as to include a considerably wider stratigraphic range than as it was later used by White in his work with the Hayden Survey. The reasons for this confusion are largely paleontologic, as stated by White in his report.[b] He says:

> While adopting the name "Colorado group" of Mr. King, I, for paleontological reasons chiefly, so restrict its application as to include only what I understand to be equivalent with Nos. 2 and 3 of Meek and Hayden's original section, leaving the equivalent of No. 4 to be included with the strata of the Fox Hills group, instead of with the Colorado group, as Mr. King has done.

The restriction of the Colorado was not successfully applied in the mapping of the Rangely district, where this subdivision could not be

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[a] The Yampa coal field, Routt County, Colo.: Bull. U. S. Geol. Survey No. 297, 1907.
[b] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 20–21, 30.

traced on a lithologic basis. White's usage of the term has, however, been generally and consistently followed in other fields for thirty years and it is still of great value as a correlation term. As Stanton states, the group is a natural division from a lithologic as well as a paleontologic standpoint east of the Rocky Mountains, where the calcareous Niobrara separates the two dark shales, Benton below and Pierre above.

Second. The necessity for the use of stratigraphic and lithologic distinctions as the primary basis in geologic mapping is well brought out by the difficulties that have been encountered in Raven Park and adjoining districts. White himself admits [a] that "all the groups of strata that are referred to the Cretaceous period in this report are, within this district, not only strictly conformable with each other as regards their stratification, but I have never been able to fix upon a plane of demarkation between any of them with entire precision." White's grouping of the strata was made on a purely paleontologic basis, a policy which he considered imperatively necessary [b] for the purpose of establishing at once wide-range correlations over extensive areas. Thus the division planes which he adopted depended entirely on scattering and to a large extent inadequate fossil evidence and not on recognizable changes in the rock strata themselves. His planes of demarkation were thus impossible of precise definition and could never or very rarely be identified exactly in the field. The geologic boundaries he has shown on his maps are therefore scarcely more than mere estimates or are purely arbitrary lines which had to be assumed in the absence of the criteria necessary to establish any actual subdivision. Even if sufficient fossil evidence were everywhere at hand to make such a division it is extremely doubtful if it would serve the most useful purposes, as no one without paleontologic training could appreciate its value when drawn.

Although it now appears to be more practical to map geologic formations in any particular field largely on the basis of lithologic distinctions—that is, changes in the character of the rock strata themselves—no one will question the necessity of paleontologic evidence in determining the position of these rocks in the geologic time scale and their correlation across the larger areas or in discontinuous fields. The errors introduced by some of the older surveys as a result of attempted correlation on the basis of lithologic similarity of rock formations occurring in discontinuous areas have been as many and as serious as those resulting from the use of paleontologic criteria. The argument of the present work is that the more practical method of subdivision should be applied to any specific stratigraphic section. For any one field or basin marked changes in the

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[a] Op. cit., p. 29. [b] Op. cit., p. 30, line 30.

constitution of the rock strata themselves furnish as important evidence of changes in geography and in conditions of sedimentation during past geologic time as do the fragmentary records of animal life that now happen to be preserved.

A part of the confusion in the early geologic mapping based on paleontologic distinctions was probably due to the failure at that time to understand the significance of the so-called Fox Hills fauna. It is likely that the use of the term Fox Hills to define any particular formation representing a specific time interval in the Cretaceous history of the Rocky Mountain region will now be abandoned. This conclusion has been reached by Stanton and others after an extensive study of western Cretaceous stratigraphy, and so far as known to the author is not now disputed by anyone familiar with these problems. As stated by Stanton,[a] "Faunas similar to that of the Fox Hills sandstone have a great vertical range and are likely to be found at any horizon within the Montana group where a littoral or shallow-water facies is developed. The use of the term Fox Hills as a formation or horizon name outside of the original area in South Dakota is therefore of doubtful propriety, as experience has shown."

In most of the fields west of the Rocky Mountains or the Great Plains the term Pierre has also led to some confusion. Sections in central and northern Montana that have been described have defined as the Pierre formation (later named Bearpaw, although still assigned to Pierre age) a shale body overlying the Judith River, Claggett, and Eagle formations. The latter three formations are now considered to be in greater part the equivalents of the Mesaverde formation of northwestern Colorado and southern Wyoming sections. In the Colorado and Wyoming fields, however, Pierre has been used to denote beds which normally underlie the Mesaverde formation. The shales above and below the Mesaverde are of similar lithologic composition, resembling the Pierre shale of the Great Plains region, and also contain fossils that are commonly found in the Pierre of the Great Plains. Pierre is certainly a valid and useful term in the large area where the Niobrara is typically developed and Mesaverde and similar formations do not exist, but probably has no place in a section which also includes either the Mesaverde or the Judith River.

Third: With regard to the previous misinterpretation of the term Laramie so far as it relates to the Raven Park district the solution is clear. None of the rocks in this field to which the name Laramie has hitherto been applied are properly so classed. The Laramie formation in the sense in which the name was originally adopted is almost certainly not represented at all by any of the strata exposed in the immediate vicinity of Raven Park. Either this formation was never

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[a] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: Bull. U. S. Geol. Survey No. 257, 1905, p. 66.

deposited in this field or if it was deposited it was completely eroded at a later time, before the overlying Tertiary beds were laid down.

The name Laramie was adopted by agreement between King and Hayden to apply to the Cretaceous strata then thought to lie at the top of that system, conformably above the marine deposits. It was assumed at that time that marine conditions existed throughout a large part of the interior province during most of Cretaceous time, and that these conditions terminated with a succession of crustal movements that uplifted the Rocky and Uinta mountain ranges. Portions of this sea were supposed to have been cut off in interior basins at the time of that upheaval, so that their waters gradually became less and less salty, until the fresh-water conditions which marked Tertiary time were fully established. It was clearly the intention of the early investigators to denote the beds laid down during this transitional stage by a formation name, for which purpose Laramie was agreed upon. In terms of later geologic nomenclature, therefore, Laramie was probably meant to include all the brackish-water deposits which succeeded the Montana, or latest marine sediments then recognized in the Cretaceous system. This formation was less certainly defined by an upper limit, but was in all probability intended to include all strata up to whatever beds should be considered as belonging to the fresh-water or Tertiary basins established after the mountain-building movements already mentioned were completed.

Early investigators did not at first recognize that temporary transitions to brackish and fresh water deposition occurred at various periods during marine Cretaceous time. Such conditions apparently prevailed for a while in certain interior basins at the same time that the normal marine deposits were being laid down in adjoining regions. These periods which preceded the close of the Cretaceous were, however, of short duration and were apparently terminated by incursions of the sea and reestablishment of salt-water conditions. The Judith River beds of Montana and the Mesaverde formation of Colorado are examples of deposits laid down during such periods. Both contain a fauna and flora resembling those of the Laramie and were formerly supposed to be Laramie. Both are now known, however, to represent stages of fresh-water deposition somewhat similar to those which prevailed during Laramie time, but occurring long before the close of the Cretaceous. It is perfectly clear that such beds can not be included under any interpretation which can be reasonably given to the original definition and agreement as to the use of the term Laramie.

The fact that Mesaverde time was succeeded by a considerable period of true marine deposition was entirely unrecognized at the time of the earlier surveys. Evidence of this return of salt-water conditions is found in the existence of a normal succession of marine strata overlying the Mesaverde formation in the Yampa River valley, north of the fields structurally included with those of the White River districts. The Yampa basin contains a great body of dark clay shale with lenticular interbedded sandstones and calcareous layers, overlain by a second large body of sandstones, sandy shales, and coal beds. Of these deposits the lower or shale group (Lewis shale) is of marine origin and the overlying beds indicate a second transitory stage, reintroducing brackish and fresh-water conditions. The later beds are thought to represent, at least in part, the Laramie, so far as the best interpretation of that term is at present understood.

STRUCTURE.

GENERAL FEATURES.

The geologic structure of the region here discussed can best be described by means of graphic sections. Several of these have been constructed to represent the features exhibited in the Rangely district and are reproduced in Pl. III. The locations of the lines along which these cross sections are drawn are shown on the geologic map (Pl. II, pocket) by letters corresponding with those on the sections.

The whole field constitutes only a portion of the huge structural basin that lies south of the Uinta Mountains. The term basin is variously used, but in its structural geologic sense it refers to the attitude of the rock strata and is intended to signify a syncline or relatively depressed portion of the earth's crust, commonly retaining beds of the younger geologic formations, while the corresponding beds are very likely to have been worn away over the uplifted portions that surround and form the rim of the basin. A basin in this sense should not be confused with a topographic basin, which is also commonly understood as a relative depression, but referring to the earth's surface only without any implication as to the attitude of the underlying strata—for instance, a valley or drainage basin. Raven Park is an excellent example of a topographic basin, but is structurally quite the reverse of a basin, being formed of strata relatively uplifted at the center or axis, and not depressed.

The Raven Park district lies on the northern margin of the Uinta Basin, where the younger beds that occupy the major basin are upturned and eroded along the uplifted axes of the Uinta Mountain system. The Uinta Basin as a whole lies south of the Uinta Range in Utah and Colorado. It is limited on the east by the various axes of uplift which form the western foothills of the Rocky Mountain system. It extends westward to the Wasatch Mountains in Utah and southward to the uplifted areas of the Uncompahgre Plateau and the San Rafael Swell. In the major structural basin, as well as in the subordinate synclines included within it, the axes or deepest portions of the folds lie in the main parallel to the major axes of the uplifts that border them. Thus within the influence of the Rocky Mountain system all the folds exhibit marked parallelism in a northwest-southeast direction. The axes of the Uinta system trend more nearly east and west, and an extension of the Uinta uplift eastward as a comparatively simple anticline through Axial Basin bends southeastward and merges into the corresponding uplifts and folds of the White River Plateau, which are clearly a part of the Rocky Mountain system. This connecting anticline is comparatively inconspicuous as regards its magnitude of uplift, but it connects the two great mountain systems and separates two huge basins of the younger Cretaceous and Tertiary rocks which lie north and south of it. The basin to the north is described in part as the Washakie Basin in Wyoming, a portion of the greater structural feature known as the Green River Basin, and terminates southeastward in the valley of upper Yampa River in Colorado.

The Colorado portion of the Uinta Basin has been termed the Grand River Basin, and is in a minor way naturally distinct from the larger extension of the Uinta Basin into Utah, being separated by a series of anticlinal or domal uplifts of which the Raven Park fold is one. This series of uplifts has an approximately north-south axis. It is, however, composed of three or more distinct structural domes, to be presently described in detail, whose axes of greater elongation are approximately parallel to each other but oblique to their north-south alignment as a group. The longer axis of the Raven Park anticline lies apparently in extension of the major axis of the whole Grand River Basin. The similar and more pronounced fold of the southern Blue Mountain region lies north of the Raven Park anticline. A less pronounced fold south of the Raven Park anticline will be described as the Douglas Creek uplift. South of the Douglas Creek uplift and beyond the area here considered in detail the Uinta Basin as a whole terminates against the flexures bordering the Uncompahgre Plateau south of Grand River, just as it does against the Uinta axes on the north.

RAVEN PARK ANTICLINE.

The structure of Raven Park is essentially that of a simple anticline or dome of the underlying strata, the valley itself having been eroded from the crest of the uplifted portion. The strata are inclined outward, dipping in all directions from the center or axis of the uplift. The dome is roughly oval in form, the axis or longer diameter lying in an almost due northwest-southeast direction. At either end of the axis the fold flattens and is lost to view, merging into the flexures of adjoining areas. Toward the northwest the two flanks of the flexure unite, the strata becoming approximately horizontal, with a number of minor irregularities, and the fold disappears entirely at a point near the Colorado-Utah State line. Beyond that point all trace of subordinate folds is lost, the strata showing a uniform southward dip away from the higher uplifts to the north and extending in this way westward to the Green River Valley. Southeast of Raven Park the fold apparently terminates in the flat-lying Tertiary beds of the high escarpment known as the Cathedral Bluffs. These strata fill most of the interior of the Grand River Basin. The portions that now remain are, as a rule, horizontal or only very gently flexed or tilted, and constitute most of the high plateau surfaces that characterize that general region.

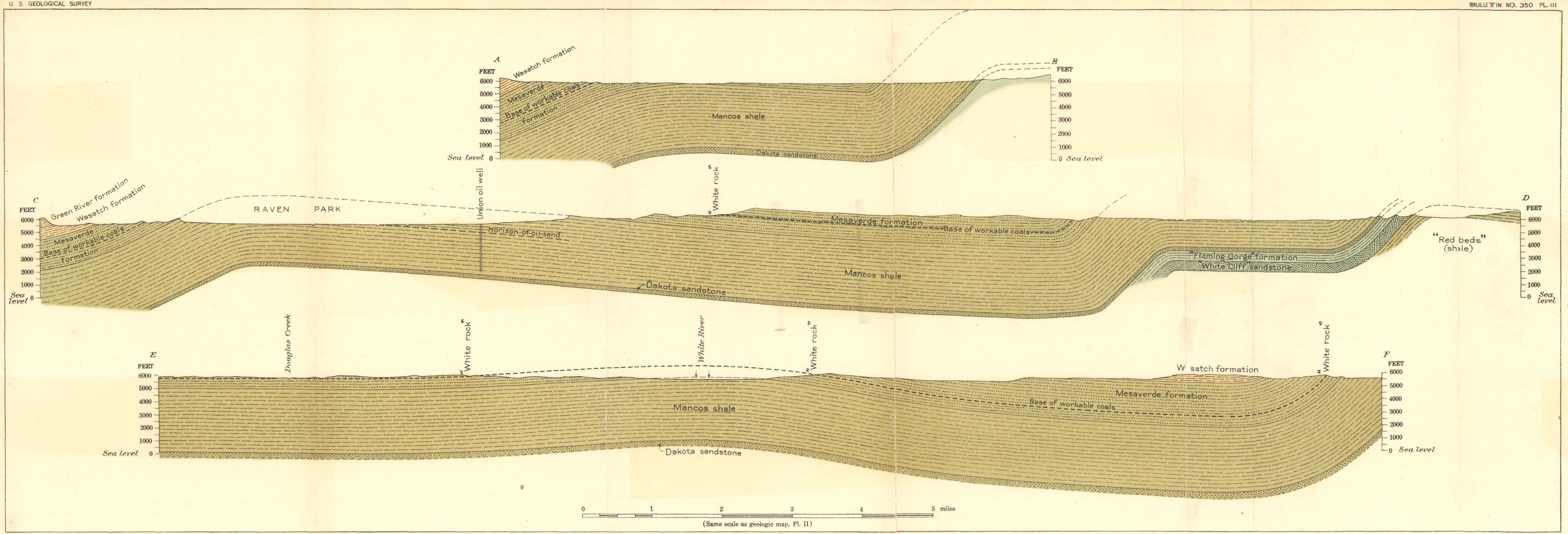
The Raven Park anticline is not a symmetrical fold. Toward the northeast the strata dip away at light angles, averaging from 4° to 6°, but the dips to the south and southwest are much steeper—from 15° to about 35°—the flexure itself being very abrupt, as is characteristic of most of the folds in the western Cretaceous foothill strata. These steeper dips are found along Raven Ridge and the south side of White River.

As stated, the Raven Park anticline lies midway between similar flexures on the north and the south. All these folds exhibit striking features of similarity and apparent relationship. The most prominent of these features are the character and position of the flexures themselves, and the correspondence in direction of their longer axes. It is of interest to note the gradation of the intensity of uplift that produced the various folds. In the Midland fold to the north the upheaval was sufficient to bring to surface level rocks as old as Carboniferous, but even this uplift is of much less magnitude than similar and greater folds immediately north of it. The Raven Park fold exposes the Mancos shale at its center. The Douglas Creek flexure is broader and of less intensity than that of Raven Park, so that its upper portion is now largely capped by the Mesaverde strata still younger than those found in Raven Park.

MIDLAND UPLIFT.

The Midland uplift was named and described by White[a] in a report of the Hayden Survey. The name is intended to include the anticlinal flexure that forms the southern margin of Blue Mountain (Yampa Plateau of the earlier work), a portion of which was then designated as the Midland Ridge. The southern part of this region of uplift is included in the area of the geologic map and sections that accompany this report (Pls. II and III). It is in many respects the

[a] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, p. 45.



ANDREW B. GRAHAM CO., PHOTO-LITHOGRAPHERS, WASHINGTON, D. C.

STRUCTURE SECTIONS ALONG LINES A-B, C-D, AND E-F ON GEOLOGIC MAP, PL. II most striking feature of the region and is of especial interest in connection with a study of the Raven Park uplift because of its similarity in form and parallelism of structure and the greater magnitude of the stratigraphic displacement which it represents. By reason of the greater intensity of its uplift, and also of later erosion along its axis, it brings to view a considerable section of the older strata which underlie Raven Park but are not there exposed.

Like the Raven Park anticline, the Midland uplift exposes at its center beds of weaker texture than those which compose the flanking ridges, and thus a portion of the axis or crest of the uplift is eroded to a valley of comparatively low relief. This valley is in form a great amphitheater about 15 miles in length, inclosed by an almost continuous wall of brilliantly colored strata. This escarpment is a striking feature of the landscape and can be seen from a great expanse of territory to the south as far as and beyond White River valley. It is in form a precipitous wall 1,000 to 1,500 feet in height, composed of brilliantly colored clay or shale capped by ledges of massive white sandstone. The underlying shale and sandstone present a banded appearance, a feature traceable with remarkable uniformity through the entire length of the central or axial basin. The upper beds in the escarpment are of vivid red; the lower part is mainly of a dull greenish-gray color divided by a narrower band of red similar to the brighter-colored strata above. At places the overlying red seems to encroach irregularly upon the gray beds below, but on close inspection it may be seen that this appearance is due to wash and slide and to the stain derived from the overlying material.

The view given in Pl. IV, *B*, is taken from the summit of the cross-bedded white sandstone ridge at the south side of Blue Mountain, and shows the structure and topography of that part of the field. The structure, as explained above, is that of the southern margin of the Midland uplift, with southward-dipping strata of the Jurassic white sandstone in the foreground and the Dakota and Benton ridges to the right and in the distance. The valleys represent the weaker beds that have been eroded. The escarpment in the background to the left is that of the "red beds" in the Midland Ridge.

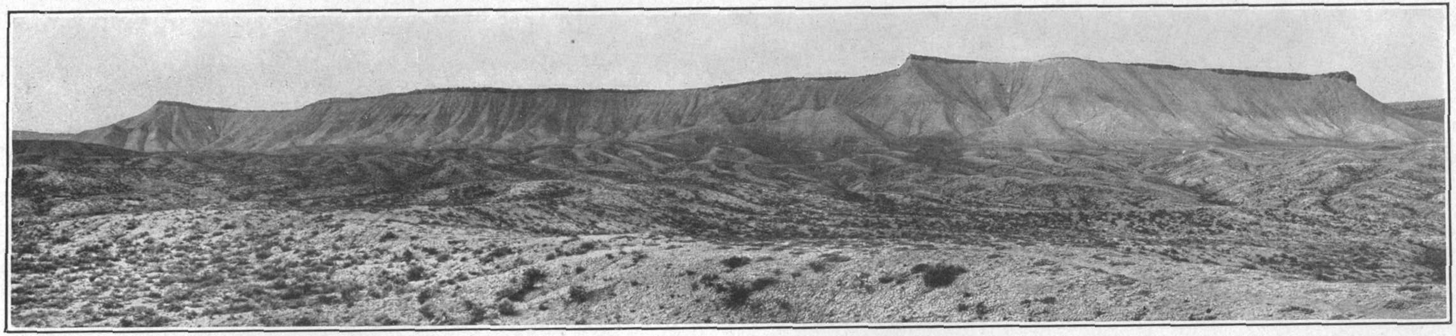
Like the Raven Park uplift this fold is not symmetrical but dips more abruptly on the south than it does in other directions. It is also limited on the north by a still higher upthrust of similar and related structure. The Midland fold pitches down and terminates abruptly toward the west within a mile or two of the Colorado-Utah State line. Throughout the greater part of its extent its principal axis of flexure lies in an approximately due east-west course, parallel to the larger uplifts of the Uinta system on the north. The Midland fold extends toward the east, its axis bending southward in the upper valley of Wolf Creek, and crosses White River at the mouth of that creek. In this portion of its course the axis conforms to the trend of the Raven Park anticline, as it does also with the prevailing structures of all the flexures southwest of this region. Southeast of White River the Midland fold flattens and is lost to view in the lightly dipping strata of the high plateaus of Tertiary strata composing the interior of the Grand River Basin to the south.

RED WASH SYNCLINE.

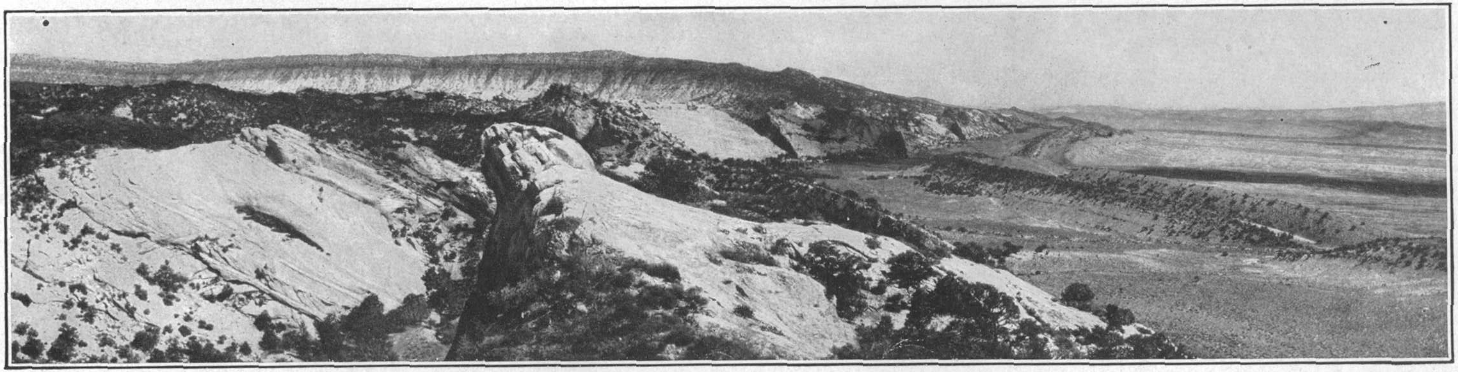
The Raven Park anticline is separated from the Midland uplift by a syncline or depression of the rock strata. This axis of depression enters the Raven Park district from the east, passing approximately along the channel of White River in the vicinity of Angora post-office. From this point it follows a course somewhat north of west, crossing the valley of Red Wash along the eastern margin of the territory represented on the map. It there produces a broad area of low, rolling country, where lightly dipping sandstone ledges of the Mesaverde formation form the principal outcrops along ridges and gulch sides. The varicolored marls of the overlying Tertiary beds remain along this axis in White River valley and extend westward as far as the twelfth auxiliary guide meridian. The axis of the syncline rises to the west and this fold consequently narrows in that direction. This axis may be readily traced westward as far as Willow Creek as a clearly defined flexure of the strata. Beyond that place, with a slight confusion of dips and strikes, as has been explained (pp. 33–34), the strata assume a lighter dip and the syncline is much less marked. It may be traced, however, as a gentle flexure almost as far west as the State line, where it is lost in the same coalescence of subordinate structures into which the Raven Park anticline disappears.

DOUGLAS CREEK UPLIFT.

The Raven Park anticline is terminated on the south by a narrow and rather abrupt syncline separating the uplift from another low anticlinal structure in the valley of Douglas Creek, farther south. This is a broad, low arch of far greater areal extent than the Raven Park fold, but of less intensity of uplift, so that the strata exposed at the crest on the eroded surface and in the valley bottoms are mainly those of the Mesaverde formation. It occupies chiefly the drainage basin of Douglas Creek, a broken, somewhat roughly mountainous district surrounded by the higher escarpment ridges and plateaus of the Tertiary strata. This broad basin of anticlinal structure extends westward approximately to the State line in the vicinity of Dragon, Utah, and is terminated on the south by the high summits of the divide on the Roan or Book Cliffs Plateau. It is limited on the east by the high, precipitous wall of the Cathedral Bluffs. The areal



A. THE "RIM ROCK" IN RAVEN PARK.



B. SOUTHERN MARGIN OF BLUE MOUNTAIN.

extent of this fold is estimated as at least 250 square miles. A large part of this district is coal bearing, and it may eventually prove to be an important coal field.

This uplift lies intermediate between the Raven Park anticline on the north and the uplifted area south of Grand River which forms the northern margin of the Uncompahgre Plateau. It thus completes a north-south series of dome structures which constitute a natural separation of the Grand River Basin of Colorado from the Utah portion of the Uinta Basin, a feature that has already been referred to.

The dips on the flanks of this broad, low fold are very gentle, but there are many irregularities, and the main fold is not, therefore, so well defined nor so readily discerned as the simpler uplifts to the north. The prevailing dips over the larger part of the district are approximately equivalent to the grades of the streams. The oldest strata are exposed on the West Fork of Douglas Creek about 3 miles above the N Bar ranch. Here a small topographic basin is eroded in a shale that clearly belongs near the base of the Mesaverde, but the writer is not certain whether it actually occurs below the lowest sandstone corresponding to the "rim rock" of Raven Park or is just above that bed. By analogy with the Rangely field, the anticlinal structure of this little basin may be considered indicative of a field favorable to prospecting for oil. According to the best information obtained by the writer, however, no indications of oil have been found at the surface and no drilling has been done to determine its presence in strata below the surface.

It is perhaps important to note that the whole region south of the fortieth parallel was erroneously mapped and described in the reports of the Hayden Survey as occupied by the Wasatch formation.[a] For this reason the distribution of the rock formations in this region has not been correctly represented in other publications, nor has its probable economic value as a coal field been appreciated.

UPLIFTS IN ADJOINING REGIONS.

Domes or anticlines similar to the Raven Park uplift occur in many places in the Cretaceous and Tertiary strata west of the Rocky Mountains. Agency Park, the valley in which Meeker is situated, is eroded on a dome that closely resembles the Raven Park fold and exposes the same formation at its crest, although it is of somewhat greater extent. A number of similar, though less conspicuous, folds occur in the Danforth Hills north of Agency Park.

[a] Endlich, S. F., Report on geology of White River district: Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 63–131.

An anticline similar to the Raven Park fold, but less pronounced in size and intensity of folding, crosses White River between Raven and Agency parks, at White River post-office. This fold is of some interest as a prospective oil and gas field and is described on page 48.

The Rock Springs uplift in southern Wyoming is a well-known feature, similar in form although of considerably greater extent than either the Raven Park or Agency Park uplift. The Mancos shale is exposed at the center of the Rock Springs uplift, as in the other folds, surrounded by ridges of the coal-bearing Mesaverde formation.

DISTRIBUTION OF STRATA DEPENDENT ON INTENSITY OF DEFORMATION.

The occurrence and distribution of the Tertiary formations in this general region is largely dependent on lack of disturbance in the areas they occupy. They are found in the interior portions of the major structural basins, and in their horizontal or slightly inclined position they constitute the high plateaus which characterize those areas. In normal or horizontal position these beds are little affected by the disintegrating action of surface waters and the elements, except where subjected to the actual corrasion of the streams, and in such places they are chiefly cut away by the attrition of the material mechanically transported over them. The streams cut vertical or steep-walled gashes whose sides retreat but slowly into the neighboring uplands. The recent geologic age of these rocks and their consequent position near the top of the stratigraphic column usually account for their entire disappearance over areas that have been uplifted even to a moderate degree. Their softness and lack of coherence has caused them to be removed from the more abrupt portions of the folds, and their outcrops in folds or tilted positions are usually occupied by low valleys.

Both the Wasatch and Green River formations were involved in the folding that produced the uplifts that have been described. This is shown in certain favorable localities where beds of the younger groups are tilted in the same flexures with the older beds.

FAULTS.

So far as has been observed, faults are not of common occurrence in the Rangely district. A possible fault is marked by an offset in the line of hogbacks developed on the "rim rock" at the upper end of the canyon of White River below Raven Park, near which an oil spring was discovered, as described below. Although this particular locality was not examined with sufficient care to enable the writer to reach a satisfactory conclusion, the very evident offset of the lower hogback ridges is thought to indicate very probably a minor displacement. Several faults in the Douglas Creek valley showed vertical displacements up to 200 feet or more, but these are south of the area included in the accompanying map. Extensive faults are described along the major axes of uplift in the Uinta Mountains, but these are chiefly north of this area and probably have no effect on the accumulation of oil in this field.

DEVELOPMENT OF THE OIL FIELD.

DISCOVERY OF THE OIL.

Attention was first directed to Raven Park as an oil field by the discovery of an oil seep in a spring at the lower end of the park. This spring is said to have been situated on the north bank of the river, near the location of the new land-survey corner between secs. 5, 6, 7, and 8, T. 1 N., R. 102 W. At the present time the position of this spring seems not very well known, and inquiry as to its location was met with the reply that it is probably trampled down by cattle and its flow obscured in the mire. After the report of this discovery a number of companies were organized among the local residents of Meeker and vicinity to prospect and develop the new field. The whole field is now covered by unpatented locations of the so-called "oil placer claims," the various holdings being still divided under the names of the companies by which they were originally taken up. The total area thus controlled is approximately 45,000 acres, or about 70 square miles.

LOCATION OF CLAIMS.

The original claims were staked and surveyed from the accepted corners of the old land surveys. Since their location, however, a resurvey of the whole territory has been authorized by Congress,[a] and the completed plats are now in the General Land Office in Washington and in the surveyor-general's office in Denver. It is the general understanding that lands filed on previous to the completion of the resurvey are subject to patent as filed, even though their outlines do not conform to the lines or corners of the new survey, unless it shall be mutually agreed by all parties concerned to shift the boundaries to correspond to the reestablished survey lines.

DESCRIPTION OF WELLS.

The first well drilled in the field was known as the Pool well, and was put down in the summers of 1901 and 1902. This well is situated in the SE. ¼ NW. ¼ sec. 33, T. 2 N., R. 102 W. (new survey). In this project three of the Meeker companies combined interests in equal shares with the avowed intention, from the beginning of the work, of sinking through the shale to reach the Dakota sandstone.

[a] Act approved May 28, 1904.

All work in the early developments was planned in accordance with the erroneous estimates of the thickness of the rocks now called Mancos shale, as given in the Hayden reports. The Pool well was drilled to a depth of 2,130 feet, although an oil-bearing sand with a flow said to have been a barrel or so a day was struck at a depth of 750 feet. The hole became crooked, and for this reason it was finally abandoned and lost.

Three wells were sunk by the Requina Company, of Meeker. The first, known as Requina No. 0, was drilled in 1902 in the SE. ¼ SW. ¼ sec. 21, T. 2 N., R. 102 W. (new survey). Oil struck at a depth of 480 feet is reported to have yielded a flow of several barrels a day, as tested by the bailer. The well was continued to a depth of 600 feet, when it also became crooked and was abandoned. The following notes were obtained from memoranda kept by Maj. L. W. Boutwell, who was present at the time the work was done:

Nov. 13, 1902: Shut down at Requina No. 0 on account of broken injector pump.

Nov. 24, 1902: Pump repaired and started bailing well.

Nov. 25, 1902: Completed bailing of well. Total result was six water tanks filled, holding 5 barrels each, a total of about 30 barrels. This would indicate an average of about 3 barrels per day.

The oil obtained was poured out on the ground and burned.

The Requina No. 1 was drilled a few feet distant from well No. 0, which had just been abandoned, striking the same oil-bearing sand at the same depth. This work was done in 1902 and 1903. Drilling was continued to a depth of 1,680 feet, when a bailer and 1,000 feet of sand line were lost in the hole, and this well was also abandoned. When this well was visited on August 19, 1907, a test of its capacity was in progress, a pump, engine, and small derrick having been temporarily installed for this purpose. The oil obtained was being burned under the steam boiler. A sample of this oil obtained directly from the well and representing the fresh product has been analyzed by Dr. David T. Day, of the United States Geological Survey, and the results are given on page 50.

The Requina No. 2 was sunk in the valley close to the channel of Stinking Creek, about 4 miles north of White River, in the NW. ¼ NW. ¼ sec. 20, T. 2 N., R. 102 W. (new survey). Work was done on this well at intervals from 1903 to 1906. At the time of visit (August, 1907), a derrick and a couple of driller's cabins were still standing. Reports state that water was struck at a depth of 80 feet in coarse, gravelly material, which is said to have been the base of the valley wash, or "adobe" overlying "bed rock." This water is almost certainly the underflow of Stinking Creek; no water has ever been struck in any of the wells within the Mancos shale. It is reported that some gas was found at a depth of about 400 feet, but that no oil was obtained from this well. The drilling was continued to a depth of 2,560 feet, but was finally abandoned because of the accidental parting of the casing and the loss of several hundred feet of it in the hole.

All the Requina wells were drilled with the intention of continuing through the Mancos shale to the Dakota sandstone. Each hole was lost or abandoned through accident.

Two wells were sunk by the Meeker Company, also of Meeker. Both of the wells of this company were drilled to the first oil horizon and discontinued at or near that depth. The well known as Meeker No. 1 is situated in the NW. ¼ NW. ¼ sec. 28, T. 2 N., R. 102 W. (new survey), about one-fourth mile southwest of the Requina wells Nos. 0 and 1. This well is said to have struck oil at a depth of 736 feet, and the hole was drilled to a total depth of 771 feet. At present the site is marked by a metal tank partly filled with oil. This well is said to have shown a flow similar to or slightly less than that of the near-by Requina wells.

The Meeker No. 2 was sunk in 1903, almost exactly 1 mile due east of the Meeker No. 1, in the NW. ¼ NW. ¼ sec. 27, T. 2 N., R. 102 W. (new survey). The well is said to have struck what were thought to be the same oil-bearing sands as those found in the wells already described at a depth of 1,002 feet, when work was discontinued. No oil was obtained from this hole.

The second attempt, by combined interest, to prospect the so-called "deep sands" (meaning thereby the supposed oil pool in the Dakota sandstone) was made in 1903 by drilling the well known as the Union. The site selected was on the northeast side of Raven Park, slightly over half a mile from the "rim rock," in the middle of the west side of sec. 16, T. 2 N., R. 102 W., near the quarter-section corner of the new survey. The adoption of this site was based on an application of the anticlinal theory, as explained on page 34. On the assumption that oil would be found on the flanks of the anticline and that gas would occupy the summit, the site was selected near the margin of the basin, a location giving nearly the maximum thickness of the shale body available from the valley to be passed through before the Dakota sandstone could be reached. This well, known as the first Union, was commenced in 1903 and the hole drilled to a depth of 1,300 feet. Oil was found at a depth of 584 feet, but was cased off and the drilling continued. The hole was finally abandoned owing to the loss of a string of tools due to collapsing casing.

The second Union well was put down on approximately the same site as the first, striking the first oil sand at the same depth as before. This well was also commenced in 1903 and continued at intervals until April 15, 1907, when the rig took fire while still at work and the whole surface equipment was lost. The depth of the hole is

3,655 feet, and the well is said to be still in good condition. It is cased to a depth of 2,974 feet with a string of casing made up of 1,228 feet 8½-inch, 1,332 feet 6⅝-inch, and 414 feet 5-inch.[a] The following is a record of the strata passed through; it is said to be somewhat incomplete on account of the destruction of a part of the data at the time of the burning of the rig:

Record of second Union well, Raven Park.

[Sybert and Joe Trachta, drillers.]

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, dark, at bottom of which small oil-bearing was struck	584	584
Shale, dark	816	1,400
Shale, light colored	200	1,600
Shale, dark, much of it of purple color	839	2,439
Shale, very light colored, drillings being nearly white	41	2,480
Sand, shaly	5	2,485
Shale, dark, with fine lines of white, very rotten	194	2,679
Sand, flinty, alternating with rotten shale	58	2,737
Shale, dark	343	3,080
Shale, black, a little sandy	170	3,250
Shale, hard, black, alternating with light-colored shale	405	3,655

From the manner in which the drill was worn it is supposed to have penetrated hard sandstone at the bottom of the well. This bed is locally supposed to be that of the Benton horizon already described (p. 15), and is reported to have contained fossils, none of which, however, were saved.

In the summer and fall of 1907 several new wells were drilled and some of the older wells were systematically pumped as a test of capacity, under the supervision of Mr. J. H. Hunt, of Haywards, Cal. Of the older wells the only ones available for the test were the Meeker No. 1 and the Requina No. 1. At present writing (December, 1907) it is understood that this work is still progressing and that systematic prospecting of the field will be pushed. It is also reported that five new wells have been drilled, of which four are claimed to have struck oil. Mr. Hunt gives the following statement with regard to his work in the field:

Altogether my experiments and tests show that oil is found in all the wells except two, at depths from 400 to 700 feet below the surface. The wells cover a distance of about 3 miles from north to south and 1½ miles from east to west. The oil is of a uniform character and in all wells rises to the same level, approximately 360 feet below the surface. By continued pumping the production increases. The formation in which the oil is found is sand and shale mixed, varying in thickness from a few feet to 45 feet. By shooting with nitroglycerine the flow is apparently increased, although we have not yet experimented sufficiently to determine the size shot which is most effective. The production of both the wells shot was increased, but the formation is so hard that neither well was caved in, indicating that they will stand a still heavier shot without damage.

[a] Information received from Mr. Henry J. Hay, of Meeker.

OCCURRENCE OF THE OIL.

ATTEMPTED APPLICATION OF THE ANTICLINAL THEORY IN THE RANGELY FIELD.

The scientific study of an oil or gas field from the standpoint of the geologist is the only means worth consideration by which the probable presence or absence of these substances in depth may be predicted in advance of actual drilling. In such a study lies the only hope of eliminating any of the large number of failures and the consequent loss of capital so often involved in random drilling in the search for productive sites. However, no geologist or mining engineer can yet recognize with certainty the essential criteria that determine productive pools, nor can he say even in a well-known field what new locations will prove productive. At best such statements can be no more than mere probabilities. In a new field conditions are still more uncertain, and specific knowledge of the occurrence of oil can be obtained in no other way than by actual drilling. An intelligent study of the geologic structure and the formations is the only means of arriving at even a partial understanding of the occurrence of the oil or gas.

The interests that have controlled the prospecting in the Rangely oil field have been for the most part local, distributed among the older residents of the country, who were personally acquainted with the field and with the work that was being done. All of the preliminary drilling seems to have been directed by an intelligent effort to apply the structural or anticlinal theory of the accumulation of oil and gas, which has appeared to explain so successfully some of the oil pools found in the fields of West Virginia and adjacent States.[a]

C. A. White, in the Hayden report, described this valley as eroded from the crest of an anticline or dome and suggested it as a field favorable to the location of artesian wells, should they ever be desired—a prediction which he also stated was based wholly on its geologic structure. With the discovery of oil, the prediction of artesian conditions suggested flowing oil wells. The anticlinal structure of the field suggested, further, the application of the anticlinal theory in this region. Several wells have now been drilled to considerable depth in search of the Dakota "sands." This formation has been thought to fulfill the assumed requirements as a principal storage reservoir for the oil. The theories on which these assumptions are based are briefly reviewed in the following paragraph. In the application of these theories the estimates of the Hayden report for the thickness of the Mancos shale (then termed Colorado and

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[a] White, I. C., The Mannington oil field [West Virginia] and the history of its development: Bull. Geol. Soc. America, vol. 3, 1892, pp. 193–216. The geology of petroleum and natural gas: Rept. West Virginia Geol. Survey, vol. 1, 1899, pp. 155–195.

lower part of the Fox Hills) were at first accepted. The figures and sections of that report indicated that the Dakota would be found at no great depth in the valley lands. The wells that have been drilled as yet have failed to reach the base of the shale and it is now clear that the first estimates of its thickness were far too small.

It is undoubtedly true that in many or most oil fields some well-defined relationship exists between the structure—that is, anticlines and synclines in the strata—and the distribution of the oil pools. It is probable also that this relationship is not so simple as exponents of the anticlinal theory from time to time have been led to believe.

After the discovery of the oil spring, attention was attracted to Raven Park as an oil field by the suggestion of its quaquaversal[a] structure, which has been commonly referred to locally as a "perfect anticline." It was at once inferred that in this area were to be found the ideal conditions for the accumulation of a large body of oil, according to the postulates of the anticlinal theory. The conditions assumed by the anticlinal theory as controlling the accumulation of oil and gas are briefly as follows:

(*a*) Porosity of a reservoir rock, which is commonly a stratum of sandstone or sandy rock, capable of containing the oil supply in the interstices between the sand grains. This is generally known as an oil sand and is in many places of sandy composition, although it may be a fractured shale, or even limestone, sufficiently porous to allow the accumulation of oil.

(*b*) An impervious cover or cap rock to serve as a seal and prevent the escape of the oil and gas in an upward direction.

(*c*) Geologic structure or folds in the rock, favoring the accumulation of the oil and gas in certain localities by draining these substances from more extensive areas of adjoining beds less favorably situated for their retention.

(*d*) Saturation of the rocks by ground water, on which the oil will move by reason of its lighter specific gravity, and therefore be forced into the upper parts of the folds—that is, toward the crests of the anticlines.

Oil and gas are commonly found together. According to this theory the gas may be expected above the oil. It is most frequently found in the crests of the anticlines. Small folds or irregularities in the rock structure may hold some of the gas farther down the flanks of the anticlines, or even in parts of the synclines; or, as another condition, less permeable portions of the reservoir stratum may also imprison both the oil and gas below the summit of the fold.

This theory is based on the assumption of the presence of water in the oil sand. Experience has shown, however, that although partial

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[a] "Dip of strata in all directions away from a center."—White, C. A., Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, footnote, p. 42.

saturation is the condition most generally encountered, yet at a great many places, in both the eastern and the western oil fields, no water is present. These conditions present many modifications of the original theory. Thus the oil may be found almost anywhere with reference to the geologic structure, its position in many localities apparently depending largely on the presence or absence of ground water. The places of accumulation in dry rock are thought to be at or near the bottom of the synclines, or the lowest point of the porous medium, or at any point where the slope of the rock is not sufficient to overcome the friction that retards the movement of the oil. In porous rocks only partly filled with water the oil probably accumulates at and just above the ground-water level, or above the level of saturation. This level may be fairly constant in one basin or structural feature, but probably varies greatly in different basins or in different sands in the same basin. As most of these considerations depend on the position of the ground water and its relation to the oil, they do not seem to apply to a discussion of the oil as it is found in the Rangely field.

In the first attempted application of the anticlinal theory to the Rangely field, it was pointed out that the Mancos shale (then known as the Colorado and Fox Hills) would furnish the required impervious cap rock. The Dakota sandstone, locally referred to as the Dakota "sands," was assumed to form the requisite porous stratum for the storage of the oil. Attention was called to the fact that White had already predicted that the Dakota would be a source of artesian water, and this water was therefore expected to provide the degree of saturation required to cause the oil to rise into the anticline and to afford a hydrostatic pressure which it was supposed would also produce flowing wells. The spring containing oil at the lower end of the park was thought to be a seepage from this reservoir along a somewhat indefinite fault. (See p. 38.) The first wells drilled in the field were therefore put down with a view to penetrating the overlying shale as far as the Dakota sandstone. The numerous failures from one cause and another to accomplish this aim have been described.

GEOLOGIC RELATIONS IN THE RANGELY FIELD.

The wells that have been drilled in the Rangely field have discovered one or more oil-bearing sands in the body of the Mancos shale. But one oil sand has been found in any one well, and there seems to be a rather indefinite belief or assumption on the part of the local operators that this lies everywhere at one and the same horizon. If the reports of the depths of the oil sand are correct, this assumption does not seem to be warrantable. Any single horizon at the depths recorded in the various wells would not accord with the recognized general structure of the field.

Records kept by the drillers and observations at the outcrops of the Mancos shale show the existence of beds of more or less sandy composition at various horizons within the formation. The well records obtainable are incomplete and not very specific in their description. There seems to be considerable uncertainty, even among those who are most familiar with the work as it was done or who have actually done the drilling, as to the precise nature of the beds in which the oil was found. In a personal communication Mr. Henry J. Hay, of Meeker, states:

> As to the thickness of the oil sand I can not say exactly. Sybert, who drilled the Union to the first sand, thought not over 2 feet, and perhaps less; but Trachta thinks it is greater. No other sand beds were found except in the Union well.

The following note was received from Mr. Joseph Trachta, who has had charge of most of the drilling in the field:

> In regard to the layer where they strike the upper strata of oil I wish to say that it is not a sand layer. It is a hard gritty shale. It is much grittier than the other shale. It looks very much the same all the way through, only a little darker. The gritty shale I speak of is about 100 feet thick and you strike oil through that 100 feet somewhere. The same gritty shale will not decompose to clay as quickly as the other for the reason that it is harder, but is not like the sand we struck at the bottom of the Union well, for that was sand.

The quotations given above are at present the only available descriptions of the nature of the beds that contain the oil as they have been encountered in the wells.

The oil-bearing sands of the Rangely field are probably more in the nature of lenses forming completely inclosed and isolated reservoirs than of "pools" in the sense implied by the anticlinal theory. This conclusion is based mainly on a study of the general characteristics of the strata observed at their outcrops, for the small amount of well drilling that has been done in the field has not supplied sufficient data from which to determine this feature. The lenticular character of almost all the individual beds observed along the outcrops of the Mancos and associated formations is strong presumptive evidence of their similar discontinuity in depth. Like all the minor members of the Cretaceous strata in general, particular beds are found to thicken and thin from place to place along their outcrops or even to disappear entirely, some of them very abruptly, although the features which characterize these particular beds recur at many places at what appears to be the same horizon, over widely extended areas. This irregularity of bedding is more marked in the smaller or thinner strata than in the more prominent members.

Sandy beds, or even strata of fairly massive sandstone, are known to occur along the outcrop of the Mancos shale at some localities outside of Raven Park. An example may be noted in Agency Park, where such sandy beds form a minor hogback in the valley of Mancos shale. Similar beds are present in the upper valley of Coal Creek east of "The Transfer," in eastern Rio Blanco County.[a] So far as known there are no beds in the Raven Park district as prominent as these just cited. From the descriptions of the well drillers, however, it is assumed that some minor beds of this character do occur. In all of this discussion it is recognized that the zones of oil accumulation commonly referred to as sands may not be true sands, but merely porous strata of any constitution in which the oil can gather. The variability and discontinuity of the rocks described are not, however, confined to any one particular feature, such as their sandy composition, as has frequently been observed in the field, but seem to be shown no less by all other physical characteristics and therefore probably apply with equal certainty to the feature of porosity.

The oil-bearing sands that have been struck have been entirely free from water and apparently from the influence of any hydrostatic pressure. The body of the shale itself appears to be wholly barren of water, to which it seems to offer an impervious barrier. If the oil bodies of the Rangely field are in truth contained in isolated or completely inclosed reservoirs they can hardly be expected to exhibit artesian conditions to any marked degree. If, however, a tilted reservoir is tapped somewhere below the upper surface of its contained oil this fluid would of course seek its level in the opened well, or might even be forced higher by a pressure of gas confined in the reservoir above the oil. In any case, it seems clear that whatever artesian conditions may exist in the Dakota sandstone or below that stratum, they are confined beneath the main body of the impervious Mancos shale and do not affect the distribution of the upper oil bodies.

The presence of oil in the Dakota sandstone appears to be a problem of purely speculative nature which can be proved only by the drill. No evidence of oil has ever been found in the outcrop of the Dakota beds in the neighborhood of the Rangely field. The inference of its presence in those beds is therefore based entirely on the supposition that their constitution offers a reservoir particularly well adapted to oil accumulation. This is entirely within the bounds of possibility, as is also the existence of artesian conditions in view of the structure and exposure of the Dakota strata in the apparently favorable catchment area at the south side of Blue

[a] Illustrated in the cross section published with the geologic map of that district in Bull. U. S. Geol. Survey No. 315, 1907, Pl. III.

Mountain. Oil is reported as occurring in the Dakota sandstone at Turkey Creek and near Golden City, in the Denver Basin.[a]

THE WHITE RIVER FIELD.

In connection with a discussion of the occurrence of oil in the Rangely field, it is interesting to note that some indications of a similar field have been noted on Blacks Gulch, 40 miles east of Rangely in the White River valley. Blacks Gulch opens into White River from the north 20 miles below Meeker. It is near the crest of a minor anticlinal fold, the longer axis of which crosses White River in a north-south direction near the mouth of Piceance Creek at White River post-office. This fold is a low dome of the rocks, exposing the Wasatch strata at the surface, surrounded by escarpments of the Green River formation on all sides. The dips are all light, being about 3° toward the east, increasing to 10° or so south of the river and to about 5° toward the west. Gas is said to have been found by Tom Scarritt, a cowboy, by the accidental igniting of a small flow from a lighted match. A small derrick was set up and a hole drilled to a depth of 400 feet and abandoned. According to reports, a second well was sunk about half a mile farther up the gulch. Here at a depth of 538 feet gas was struck under such pressure that the derrick was destroyed and the driller seriously injured. The gas burned with a blue flame and under much pressure for six months, when it stopped abruptly. The fact that the tools have been left in the hole leads to the supposition that it became suddenly blocked. Gas is also said to be issuing along this same anticline south of the river, at the locality known as Alkali Flats. So far as known no oil has yet been obtained in this field. It resembles the Rangely field only in its geologic structure, the strata being of much later age and overlying by many thousands of feet the oil-bearing beds of the Rangely district.

COMPARISON WITH OTHER KNOWN FIELDS.

Oil has been found at approximately the same geologic horizon as in the Rangely district in a number of fields of this same general region, notably in other parts of Colorado and in Wyoming. Among these may be cited the Florence and Boulder fields,[b] and some flows or seeps in the eastern part of Routt County, Colo. In Wyoming a basin similar to the Raven Park basin in structure and topography has been prospected east of Rock Springs, on the Union Pacific Railroad. It is understood that the work at that locality was undertaken

[a] Lakes, Arthur, Oil in Colorado: Mines and Minerals, vol. 22, 1902, p. 257.

[b] Fenneman, N. M., The Boulder (Colorado) oil field: Bull. U. S. Geol. Survey No. 213, 1903, pp. 322–332; Bull. No. 225, 1904, pp. 383–391; The Florence (Colorado) oil field: Bull. No. 260, 1905, pp. 436–440.

wholly from the suggestion of the anticlinal structure of the field. Although several holes were sunk to a considerable depth in the Mancos shale, it is said that neither oil, gas, nor water was found in that formation. Occurrences of oil in Uinta County, Wyo., some of which are at a horizon analogous to that of the Rangely oil, are described by Veatch and Schultz.[a]

It has been suggested by some of those interested in the Rangely field that conditions here may be held to be more comparable with those of the California fields than with those of the oil fields of the eastern United States. It is believed, however, that this view is not well founded. The California fields are of great complexity of structure, the oil occurring in almost every conceivable structural situation—along faults, in synclines, or in anticlines—and it is thought that no clear understanding has yet been reached of the conditions controlling the accumulation of oil in certain beds there. No direct relationship can be traced to the situation in the Rangely field.

It has also been suggested, and probably with more reason, that the Rangely field may be compared to the Kansas-Oklahoma oil and gas fields.[b] In those districts the oil, though occurring in a much older formation geologically, is said to be found in sandstones interbedded with shale, in lenticular bodies or completely inclosed reservoirs. The geologic structure of those fields is, however, much more simple than that of the Rangely field, being that of a fairly uniform monocline, with a northwesterly to westerly dip of about 20 to 25 feet per mile.

QUALITY OF THE OIL.

PHYSICAL PROPERTIES.

The color of the Rangely oil is clear light red, with strong green fluorescence, closely resembling that of many of the Pennsylvania oils, although perhaps slightly darker than the average. Its odor is like that of kerosene, much resembling that of a refined oil. It is apparently free from sulphur. The specific gravity of the crude oil from Requina well No. 1 is 0.8092, or 44° Baumé. It would therefore be described as a very light, thin oil.

[a] Veatch, A. C., Coal and oil in Uinta County, Wyo.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 331–353; Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: Prof. Paper U. S. Geol. Survey No. 56, 1907. Schultz, A. R., The Labarge oil field, central Uinta County, Wyo.: Bull. U. S. Geol. Survey No. 340, 1908.

[b] Adams, G. I., and others, Economic geology of the Iola quadrangle, Kansas: Bull. U. S. Geol. Survey No. 238, 1904. Schrader, F. C., and Haworth, E., Economic geology of the Independence quadrangle, Kansas: Bull. U. S. Geol. Survey No. 296, 1906.

CHEMICAL PROPERTIES.

An analysis of the Rangely oil, reported as made by the Standard Oil Company, and already used in the published notes and descriptions of the Rangely field, is as follows:

Analysis of Rangely oil.

[By Standard Oil Company.]

	Per cent.
Crude oil, gravity, 43.6° Baumé; burns at 60°.	
Light naphtha, gravity, 70.3° Baumé	7
Heavy naphtha, gravity, 61.1° Baumé	12
Illuminating oil, gravity, 45.1° Baumé; flashes at 90°; burns at 116°	60
Paraffin, gravity, 32.8° Baumé	20
Coke and waste	1

The oil is free from sulphur compounds.

A sample of the oil collected fresh from the pump that was running at the Requina No. 1 well on August 19, 1907, was distilled by Dr. David T. Day, of the United States Geological Survey, giving the following results:

Analysis of Rangely oil from Requina No. 1 well.

[By David T. Day.]

	Per cent.
Initial boiling point, 48° C.	
Gasoline and naphtha (below 150° C.), specific gravity 0.68	25
Illuminating oil (150° C. to 300° C.), specific gravity 0.751	45
Residue (above 300° C.)	27
Loss	3

The oil contains no water. The residue contains much paraffin wax, and there is no asphalt in the sample.

WATER SUPPLY OF THE RAVEN PARK DISTRICT.

GENERAL.

The question of water supply is important to all interests in Raven Park and vicinity, whether engaged in agriculture, stock raising, or the development of natural resources. The annual rainfall is small, and the climate may be described as semiarid. West of the Rocky Mountains the aridity of this plateau province becomes more and more pronounced away from the higher mountain masses, and Raven Park may be said to lie on the border land between the badlands, or more typically desert regions farther west, and the productive basins and valleys of the mountain foothills. A great extent of pasture lands of much value to stockmen is available here only as a winter range when the snow lies on the ground, being wholly destitute of water during the summer season. This is especially true of the territory south of Raven Park and west of Douglas Creek, locally known as the "park country" and designated on some of the maps Rabbit Hills.

AVAILABLE SUPPLIES.

Near the Rangely district only White River and two of its principal tributaries, Douglas Creek and Spring Creek, retain water in their channels throughout the year. In drier seasons both these creeks are said to dry up in the summer, although they have flowed continuously for the last two seasons. The water supply of the Raven Park settlement, both for domestic use and for irrigating the land, is taken from White River, which flows with a good volume and a moderately swift current throughout the year. The stream has a normal width through Raven Park of 2 to 4 chains, or an average of about 200 feet. It pursues a meandering course through the bottom lands, but has a number of slight rapids or riffles over bowlder and gravel bottoms. Its average rate of fall across the park is about 12 feet per mile in a straight course down the valley, and about the same in the canyon above the park. Recent gagings of White River by the United States Geological Survey are quoted in the following tables:[a]

Discharge measurements of White River.

At Meeker, Rio Blanco County, Colo.						At Ignacio, Uinta county, Utah.[b]					
Date.	Width of river.	Area of cross section.	Mean velocity.	Gage height.	Discharge.	Date.	Width of river.	Area of cross section.	Mean velocity.	Gage height.	Discharge.
1906.	*Feet.*	*Sq.ft.*	*Ft. per sec.*	*Feet.*	*Sec.-feet.*	1906.	*Feet.*	*Sq.ft.*	*Ft. per sec.*	*Feet.*	*Sec.-feet.*
						Apr. 17	72	184	3.19	3.60	587
						Apr. 18	73	198	3.43	3.78	679
Apr. 23	79	267	3.67	4.60	980						
May 4	79	240	3.11	4.39	747						
						May 13	80	506	4.56	6.60	2,308
May 17	78	326	6.42	5.50	2,097						
May 22	78	380	8.57	6.15	3,256						
May 31	78	343	6.94	5.65	2,383						
June 8	78	336	6.69	5.55	2,249						
June 23	78	310	6.41	5.47	1,988						
						June 24	89	631	3.10	6.20	1,955
July 3	78	267	3.76	4.60	1,014						
						July 19	72	285	3.27	4.28	931
July 24	78	187	3.48	4.05	651						
Aug. 10	78	167	2.11	3.85	356						
Aug. 20	78	172	2.15	3.90	369						

[a] Discharge measurements at regular stations; estimated monthly run-off based on daily readings of gage height for stations named.

[b] 18 miles northwest of Dragon, Utah.

Estimated monthly discharge of White River.

At Meeker.		At Ignacio.	
Date.	Total in acre-feet.	Date.	Total in acre-feet.
1906.		1906.	
April	37,400	April	47,800
May	129,000	May	123,000
June	151,000	June	133,000
July	51,400	July	58,400
August	22,800	August	38,600
September	20,500	September	42,100
October	18,000	October	34,400

White River has its principal headwaters in the wooded "Flat-tops" of the White River Plateau, 70 or 80 miles east of the Rangely field. In its upper course, or above Agency Park, this stream is normally a clear, fresh mountain stream. There are some scattering settlements and irrigation along the narrow bottoms in this upper valley, but the volume and swift current of the river at that part of its course seem ample security against appreciable deterioration in the quality of its water. In Agency Park the stream enters on the areas of younger and less consolidated Cretaceous strata, and from this point down the water rapidly loses the freshness and clarity of its upper course. Many ditches divert water for irrigation and return it to the stream more or less charged with alkaline salts from the meadow soils and in practically all cases considerably polluted by cattle and surface refuse. In Agency Park, as also lower on its course during wet seasons, the tributaries empty heavily charged alkaline waters into the main stream, most of that material being leached from the soils of the younger Cretaceous and Tertiary strata.

Below Powell Park the territory drained by the lateral tributaries of the main stream is composed on the north of badland drains of the "Crooked Wash," or Coyote Basin, and the valleys of Wolf Creek and Red Wash, with numerous other smaller drains. From the south side the extensive drainage basins of Piceance and Yellow creeks and other smaller streams from the Roan or Book Cliffs Plateau pour their alkaline waters into the main stream. In times of flood, as in the spring and early summer, and at frequent intervals in the summer months during the brief and violent storms which are characteristic of the region, all of this lower tributary drainage empties a great volume of thick, muddy water into the main channel, making the river water much of the time heavy with mud and clay and surface refuse. At times of such turbidity the river water has a foul odor, suggestive of putrefying flesh, which is, however, thought to come from the clay that is suspended in the moving water. Along its lower course, in the vicinity of Raven Park, White River seldom runs clear for long at a time. The constantly recurring storms at one locality or another in its upper valley keep its water in a condition which is by nature distasteful to man and beast. The question of its effect on the animal system is open to much conjecture, and with increasing population of the district may become a vital issue.

OBJECTIONABLE FEATURES OF THE WHITE RIVER WATER.

The normally distasteful condition of the river water during most seasons of the year is evidently a source of growing complaint among the settlers. Whether rightfully or not, to its effects have been attributed various maladies among those more or less in ill health who are compelled to depend on its use. Its most apparent objections are its turbidity and to a less extent perhaps the odor which seems to accompany this condition when extreme. This turbidity is of course due largely to mechanically suspended sediment that settles out readily when the water is allowed to stand undisturbed. In view of this fact it is a prevalent custom among the residents to dip the water first into a settling barrel at the river bank, whence the supply is carried from time to time to the houses in pails. The suspended matter is so fine and sticky that its removal by filtration would be difficult.

An objection hardly less evident than its muddy condition to those who give the subject any consideration is the constant presence of dead and putrefying animals in the tributary channels and also along the main stream. In a country so largely given to cattle raising it is inevitable that many dead animals must constantly lie scattered about the country. It is perhaps an unfortunate instinct that leads the sick and injured animals to these watering places, where their dead bodies very often pollute the supply for all the rest of the herd, if not also for human use. Flood seasons or heavy storms sweep the refuse from such decay into the main stream. It is said that in winter great numbers of cattle break through the ice and are drowned. Their bodies then lodge in the stream until the breaking up of the ice in spring, when they are passed on down the stream with the high waters. The effect of such decaying matter on the water as a whole, though very unpleasant to consider, is perhaps not yet proved to be essentially harmful, in view of the extreme dilution of the objectionable matter with the total volume of water. The organisms of decay of both organic and vegetable matter, though often offensive to the senses, are not necessarily the vitally dangerous elements of a polluted drinking water. The most dangerous elements to human life are certain specific germs of disease, such as those of cholera and typhoid, which propagate and spread only from sources that contain those germs in advance. So long as these diseases are absent from the drainage basin of White River it seems fair to assume that their germs are not contained in the river water.

A further source of objection may be found in the fact that the river water itself may also exert a harmful influence upon the human system by reason of its chemically dissolved constituents. These are clearly present to a rather marked degree, so that the water is described as "hard." The hardness of a water is due to the presence of alkaline carbonates such as those of calcium, sodium, and magnesium, or to the alkaline sulphates, chlorides, and nitrates. The carbonates produce what is known as temporary hardness, because it may be remedied by boiling. Water containing the constituents of the second group is permanently hard—that is, it remains so even after it has been boiled. The hardness of the White River water is of the permanent kind.

None of these dissolved constituents are of the nature of actively poisonous substances, but the effect of the water on persons unaccustomed to it or to other similarly hard waters is pretty clear evidence of a certain amount of activity. Chemical analyses of the inorganic constituents may be relied on to define very clearly the nature of these dissolved mineral substances, and a fair estimate of its probable effect on the human system from this cause only may be thereby obtained.

With this purpose in view a sample of White River water was collected by the writer from the main stream just above the Rangely bridge on August 26, 1907. The water at that time was in a somewhat turbid condition, and though the river was not so low nor the water so clear as it had been at times during the month, its condition was not at all an extreme of flood or muddiness, and the sample is considered to represent a very fair average. This water has been analyzed in the laboratory of the United States Geological Survey at Washington, with the following results:

Analysis of White River water collected at the iron bridge, Rangely, Colo., August 26, 1907.

[By R. B. Dole.]

	Parts per million.
Total suspended solids	5,000
Total dissolved solids at 180° C	400

SUSPENDED MATTER.

	Per cent.
Insoluble in HCl (sand, clay, silica, etc.)	71
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	11
Calcium (Ca)	.13
Magnesium (Mg)	.05
Sulphate radicle (SO_4)	Trace.
Organic and volatile matter	16
Undetermined	1.82
	100

DISSOLVED CONSTITUENTS.

	Parts per million.
Silica (SiO_2)	20
Iron (Fe)	1.5
Calcium (Ca)	66
Magnesium (Mg)	24
Sodium and potassium (NaK)	35
Carbonate radicle (NO_3)	5.5
Bicarbonate radicle (HCO_3)	194
Sulphate radicle (SO_4)	146
Chlorine (Cl)	9.3
	501.30

There is apparently no poisonous mineral matter in the water in sufficient quantity to do any harm. The suspended matter is very high and is of such fine, sticky, or "gumbo" character that its removal by filtration without coagulant would be difficult. The sulphates are rather high and calcium-sulphate scale would doubtless result from the use of the water in boilers. If carefully filtered the water would be sufficiently good for domestic use, but in its raw state it is absolutely unacceptable.

USE OF ICE.

It has been an established custom among some of the older residents of Raven Park and vicinity to preserve ice from the river in winter for their summer supply of drinking water. This custom has several important advantages and is to be heartily indorsed. The ice is obtained when the surface of the river is covered and for the most part securely sealed. Refuse and objectionable matter are in the main frozen also, and decay is arrested, so that very little of such matter can gain access to the flowing water, or if it does it lies essentially inert. The water at this time is derived largely from melted snow and ice collected from a frozen ground surface and so is unusually free from the alkaline salts which enter so largely into its composition in the summer. The process of freezing itself excludes a large proportion of the chemically dissolved constituents. It is well known that the ice formed on the salt water of the ocean includes but a small percentage of the normally contained salt.

SPRINGS.

Aside from White River itself there is but little water to be had over a rather extensive area, especially in the lower valley lands bordering the river basin. A few springs are known among the sandstone ridges bordering Raven Park, and a number of them are indicated on the topographic map (Pl. I). Some of these are of good though usually hard water. The following list gives the location of those that are best known or that were found in the present survey:

Springs and water holes in Raven Park district away from White River.

Name.	Location.	Remarks.
Nate Spring	In Nate Spring Gulch, sec. 34, T. 3 N., R. 102 W	
Iron Spring	SE. ¼ sec. 35, T. 3 N., R. 103 W	Not very good.
Flat Rock Spring	SW. ¼ sec. 26, T. 3 N., R. 103 W	Good water, but small flow.
Iron Spring	In Chase Gulch, NW. ¼ sec. 20, T. 2 N., R. 101 W	
Three Springs	At old Mobley post-office, sec. 34, T. 4 N., R. 100 W	Good water.
Box Elder Spring	Sec. 8, T. 3 N., R. 100 W	
Skull Creek	At Jones's ranch, sec. 1, T. 3 N., R. 101 W	Do.
Red Wash Creek	Sec. 2, T. 3 N., R. 102 W	
Willow Creek	Sec. 12, T. 3 N., R. 103 W	Camping site and stream; good water.
Small stream	Sec. 35, T. 4 N., R. 104 W	Good water.
Cliff Creek	K ranch, sec. 23, T. 4 N., R. 104 W	

Beyond the southern and southeastern margins of the district here described, springs and headwaters of streams containing excellent water are found in the wooded slopes close up under the Cathedral Bluffs. The upper courses of the various forks of Douglas Creek are fresh and clear at a distance of 30 miles or more above Raven Park.

To the north, along the southern foot of Blue Mountain, as indicated on the map (Pl. I), there are numerous supplies of good fresh water, though usually in springs or streams of small volume. These have long furnished the excellent camping sites that lie along the old Uinta trail, which follows the valley from the Yampa and White River territory into Utah, forming a part of the route through this country to Salt Lake City. These waters are derived from the various sandstone strata in the older formations that flank the high plateau. They can be readily traced to the points where they issue from these strata in the form of springs, but in their lower courses they dry up soon after reaching the open prairie and valley lands.

Above Jones's ranch on Skull Creek, in the NE. ¼ sec. 1, T. 3 N., R. 101 W., a good flow of water issues from the upper beds of the Carboniferous sandstone, which underlies the brilliantly banded strata of the Midland Ridge escarpment. These waters are rather strongly charged with iron and sulphur, but were found very agreeable to the taste by comparison with the muddy water of the river below.

Box Elder is a camping site situated on the main wagon trail in the middle of the north side of sec. 8, T. 3 N., R. 100 W., about 2 miles southeast of Jones's ranch. A spring of good water is said to issue from the hogback ledges about half a mile above this place.

At Three Springs, which is east of the area shown on the map, on a minor fork of Wolf Creek, in sec. 24, T. 4 N., R. 100 W., the water issues from the "White Cliff" sandstone (Jurassic) capping the brilliantly banded strata of the Midland Ridge escarpment. This is a well-known locality to the old settlers and travelers of the region. A ranch, formerly the post-office Mobley (now discontinued), is situated by one of the springs. The springs lie north of the main east-west route of travel, being about $2\frac{1}{2}$ miles from the Yampa River-Utah trail. The approach from Wolf Creek valley is over a somewhat rough and rocky wagon trail, which also continues northward and is one of the routes of access to the summit of Blue Mountain. The water is clear and cool and flows with very good volume from several of the seeps that issue along the hillside within a distance of perhaps half a mile.

A group of springs is also found in the NE. $\frac{1}{4}$ sec. 2, T. 3 N., R. 102 W., in the west or main fork of Red Wash, at the point where that stream crosses the same Jurassic sandstone ("White Cliff") from which the water is derived at Three Springs. The lowest spring of this group is one of considerable size and flow and is strongly charged with iron. From these springs water flows down the channel of Red Wash for only a short distance, soon sinking and drying up, except in wet weather.

The springs next west of Red Wash are those that form the headwaters of Willow Creek, in the SE. $\frac{1}{4}$ sec. 12, T. 3 N., R. 103 W. Here also the water issues from the "White Cliff" (Jurassic) sandstone, as at Three Springs and on Red Wash. It gathers in two small branches in the valley north of the Dakota hogback, uniting into a single stream of some little volume as it crosses the wagon road, but sinking soon after it passes out into the valley below.

West of Willow Creek the next spring water found along the Uinta trail is a small stream issuing from behind the Dakota hogback 2 miles south of the K ranch and near the Colorado-Utah State line, in the SE. $\frac{1}{4}$ sec. 35, T. 4 N., R. 104 W. Here also the water is derived from the Jurassic sandstone already referred to. This stream is very feeble in dry weather, often becoming of very small flow during the day and regaining a somewhat stronger volume at night. It runs but a short distance out into the valley, however, before it sinks and its channel is normally dry.

At the K ranch one of the main branches of Cliff Creek contains sufficient water to irrigate a small field. The water is ponded in a small reservoir near the house and probably would flow for a considerable distance down the main creek channel were it not diverted. A more northerly fork of Cliff Creek lying near the escarpment named on the older maps as Section Ridge is said also to contain water.

RAIN WATER.

So far as is known to the writer no attempt has ever been made to save the rain water or snow water for domestic use. This is, however, accomplished in a natural way and is occasionally found to serve a very useful purpose. The back slopes of the cuesta or dip-slope ridges surrounding Raven Park are in many places capped by bare ledges of heavy-bedded massive white sandstone. Irregularities in these nearly horizontal beds retain the rain water of the summer showers, which frequently form innumerable pools, some very large and deep, in firmly inclosed rock basins. One of these pools situated in the ledges near the road from Rangely to the K ranch is used as a camp or watering stop by travelers if they are so fortunate as to be acquainted with its location.

ARTESIAN WELLS.

Of the wells that have been driven in the Rangely field none have encountered water in the Mancos shale, and as yet none have penetrated far enough to reach the Dakota sandstone, which is so commonly known to be a water-bearing formation under favorable conditions in other localities. It is reported that water was struck at a depth of 80 feet in the Requina oil well No. 2, which is situated close to the channel of Stinking Creek, and probably encountered an underflow of that stream. The drillers' reports state that this water was found "at the base of the adobe, in a bed of gravel overlying the shale bed rock." It is therefore assumed that the body of the Mancos shale is without water.

The possibility of obtaining artesian flow in Raven Park was suggested by White in the Hayden reports, but it now seems clear that he far underestimated the depth of the Dakota sandstone in that field. The structural conditions on which he based his estimate are apparently favorable, and such artesian flow might be available if the depth of the water-bearing stratum were not so great. Furthermore, the beds which are now seen to be the best water carriers at the springs along the foot of Blue Mountain and which occupy the most favorable positions as catchment areas on the flanks of that mountain are stratigraphically much lower than the Dakota sandstone and it would probably be impracticable to reach them by drilling from any point within the park. Although the chances that these sandstones below the Dakota may contain an artesian water supply are considered excellent, it is not at all certain that a similar flow would be found also in the Dakota beds. On the other hand, in spite of the meager catchment exposure of that formation and its apparent barrenness of springs along its outcrop it may possibly accumulate a sufficient volume of underground water to establish an artesian flow if reached by boring in the lower park lands.

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