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Anticlines of
Routt County and
Western Colorado
and Oil Shale

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BULLETIN 23

SOME ANTICLINES OF ROUTT COUNTY, COLORADO

By
R. D. CRAWFORD, K. M. WILLSON
and V. C. PERINI

DENVER COLORADO
EAMES BROS., STATE PRINTERS
1920

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LETTER OF TRANSMITTAL

State Geological Survey,

University of Colorado, June 23, 1920.

Governor Oliver H. Shoup, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 23 of the Colorado Geological Survey.

Very respectfully,

R. D. George,
State Geologist.

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Some Anticlines of Routt County Colorado

INTRODUCTION

BY R. D. CRAWFORD

PURPOSE OF THE REPORT

Oil seeps in Routt County have long been known, and two or three test wells were drilled many years ago. In the summer of 1919 a party of the Colorado Geological Survey studied the local geologic features that might have a bearing on oil formation and accumulation. The result of examination of two structures seemed to be deserving of an early notice which was issued as a one-page statement on "Two Anticlines in Routt County, Colorado," under date of September 30, 1919. The geologic work will be continued in Routt and Moffat counties, but the present report is being published in the hope that it will be of use to operators in 1920.

FIELD AND OFFICE WORK

The field work on which this report is based was done in the summer of 1919 by K. M. Willson, V. C. Perini, J. C. Myers, J. R. Murphy, and the writer. The first three named were in the field nearly three months; the last two were in the field about six weeks. Considerable time was spent by the writer in reconnaissance in the mapped area and in nearby areas; the remainder of the time was employed in detailed work, chiefly in Williams Park. The greater part of the mapping was done by the other members of the party. That part of the Tow Creek anticline north of Yampa River was mapped by Messrs. Willson and Myers. Mr. Willson's report will be found in later pages of this bulletin. That part of the Tow Creek anticline south of Yampa River, the Curtis anticline, and areas near the east border of the region surveyed were mapped by Messrs. Perini, Murphy, and Myers. Mr. Perini's report appears in the last pages of this bulletin.

Part of the drafting in connection with this work was done by R. M. Carr who also made tracings of drawings for the zinc etchings used here.

MAPPING METHODS

In mapping the geology different instruments and methods were used in various parts of the field. In areas for which no base map was available and in which it seemed essential to determine elevations as well as locations on the ground, a traverse plane-table and telescopic alidade were used; locations were made by intersections and by stadia measurements. These instruments and methods were employed in Williams Park, on the Tow Creek anticline, and near the east side of the area mapped.

In Williams Park a base line about 1½ miles long was measured with stadia. From the bases a system of triangulation was carried over the park, while short distances were platted from stadia measurements. The whole was later tied to section corners near the west side of the park on the east line of T. 4 N., R. 88 W.

The two parties that mapped the Tow Creek anticline used a common base line about five miles long, running from the southeast corner of section 1 to the southeast corner of section 36 in T. 6 N., R. 88 W. Distances and bearings along this township line were kindly supplied by United States Surveyor General John B. McGauran of Denver. From this base line a system of triangulation was carried over the Tow Creek anticline and Curtis anticline and tied to the United States Geological Survey triangulation stations on Elk Mountain and Pilot Knob. Short distances were determined by stadia measurements.

For much of the area base maps, traced from township plats in the United States Surveyor General's office in Denver, were used. The geologic mapping was done by making paced traverses and using Brunton compasses. An enlargement of a small part of the United States Geological Survey topographic map of the Hahns Peak quadrangle served as a base map for the northeast part of the area, and a similar map of the Daton Peak quadrangle was used for a small area southwest of Hayden. Nearly all the mapping was done on the scale of two inches to the mile.

POSITION AND TOWNS

Routt County, with an area of about 2,340 square miles, lies in northwestern Colorado immediately west of the Continental Divide. It is reached by the Denver and Salt Lake railroad ("Moffat Road") which enters the county near the southeast corner, runs northward to Steamboat Springs, the county seat, and thence west to Craig, the present terminus, six miles west of the Routt County line. The towns within the county include Yampa, Phippsburg,

Oak Creek, Steamboat Springs, Milner, McGregor, Bear River, Mount Harris, and Hayden on the railroad, besides Hahns Peak and Columbine near the north end of the county.

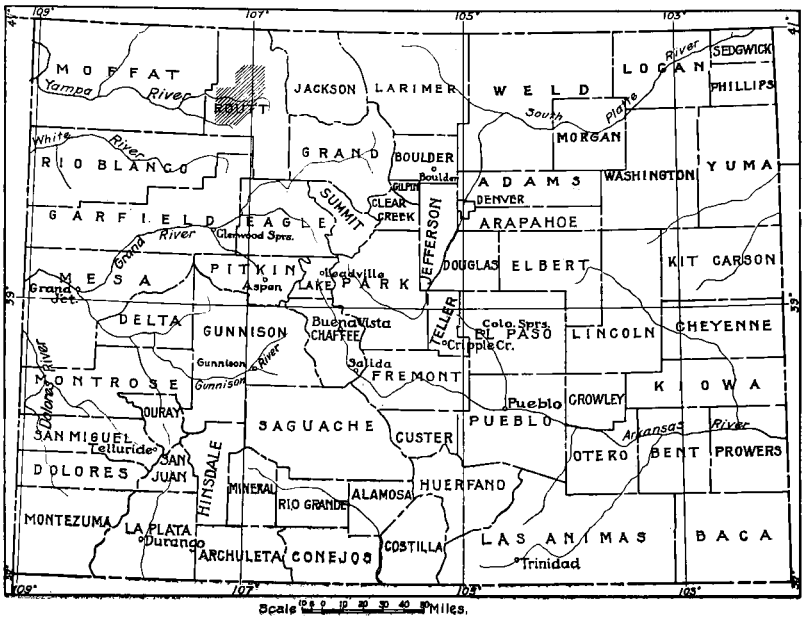

Fig. 1. Index map of Colorado showing area covered by this report

INDUSTRIES

Farming, stock raising, metal mining, and coal mining are the principal industries of the county. In 1919 Routt County, with an output of 1,168,310 tons[1] of coal, held third place among the counties of Colorado in coal production.

GENERAL GEOLOGIC AND PHYSIOGRAPHIC FEATURES

A strip several miles wide along the east border of the county is high on the slope of the Park Range—part of the Continental Divide—whose crest is the east boundary of the county. Here the country rock is composed chiefly of ancient gneisses and granites. By far the greater part of the county is an area of sedimentary rocks. In several localities are basaltic dikes and intrusive sheets and fewer intrusions of acidic rock. Near the south end of the county are a few volcanic necks and craters.

Routt County is drained by Yampa River and its tributaries of which the largest is Elk River. Along these and other streams

[1]See Seventh Annual Report of the State Inspector of Coal Mines for 1919, by James Dalrymple, p. 44.

alluvial flats furnish fertile soil for the heavy crops of hay and oats that are grown on numerous ranches, or farms. Productive soil overlies the Mancos and Lewis shale of the parks and valleys, and much of it is under cultivation.

With the exception of Yampa River[2] and its relationships there is a close connection between the broader topographic and structural features. Where the more resistant beds of the Mesaverde sandstone have been weakened by folding streams have cut gulches or canyons that may reach a depth of several hundred feet; Sage Creek canyon is a good example of an anticlinal valley. Williams Park owes its origin to the folding that led to the easy removal of the Mesaverde formation. Twentymile Park, on the other hand, is a topographic basin that occupies a structural basin, or broad synclinal fold. In places, as mentioned on page 17, there is no close relation between the details of structure and topography. Generally the Mesaverde formation, with its numerous sandstone beds, forms ridges and cliffs. The softer Mancos and Lewis shales are easily eroded, and occupy valleys and parks. The latter are commonly hilly or rolling.

WATER AND FUEL

There is little probability of serious difficulty in obtaining sufficient water for drilling purposes from streams and wells. No part of the area mapped is far removed from good coal seams. Two wells in Williams Park are reported to furnish sufficient gas for drilling operations.

[2]See "The history of Yampa River, Colorado, and its possible bearing on that of Green River," by E. T. Hancock: U. S. Geol. Survey Prof. Paper 90, pp. 183-189, 1915.

SEDIMENTARY ROCKS AND SURFICIAL DEPOSITS

BY R. D. CRAWFORD

Little time was spent by the Survey party in detailed stratigraphic study, and no attempt was made to collect fossils systematically. Aside from the observations on the Mancos shale, what is said in this section is largely summarized from the work of others. The principal formations are of Upper Cretaceous age.

"DAKOTA" FORMATION

The formation that has heretofore been called Dakota by geologists working in northwestern Colorado is exposed about three miles east of Elk Mountain. The same formation outcrops near Hahns Peak, at Steamboat Springs, and near Poose Creek about six miles southwest of Williams Park. The "Dakota" sandstone is not exposed in the mapped area south of Yampa River, but it has evidently been encountered in three wells drilled near the south border of Williams Park by the Twentymile Oil Company.

No detailed examination of this formation was made for the present report, but where seen it seems to have its usual character. It is composed principally of gray to white sandstone and quartzite which, near the top of the formation, alternate with beds of shale; conglomerate is often found at the base. The thickness of the formation probably does not exceed 200 feet in this region.

MANCOS SHALE

In mapping the Yampa coal field Fenneman and Gale[3] included within the Mancos shale all the beds that overlie the "Dakota" sandstone and underlie the Mesaverde formation. The same procedure is followed here. For the present report the top of the Mancos formation is taken at the plane of the first pronounced lithologic change where a shaly sandstone member several feet thick overlies the great mass of shale. This shale-sandstone contact was exposed in a number of places and accurately located, but for the most part it is covered by soil and talus; hence the boundary between the Mancos and Mesaverde formations is generalized on the accompanying maps.

Although the Mancos shale is found over wide areas, continuous exposures from base to top suitable for measurement of

[3]Fenneman, N. M., and Gale, H. S., The Yampa coal fields, Routt County, Colorado: U. S. Geol. Survey Bull. 297, 1906.

the thickness of the formation are absent from the region surveyed. Fenneman and Gale in their report (p. 20) cited above, give the thickness as 2,000 to 2,500± feet. K. M. Willson has determined the Mancos shale north of Yampa River to be about 2,100 feet. Gale[4] gives a general thickness of approximately 5,000 feet for this formation in northwestern Colorado. Lee[5] gives a section of the Mancos shale 5,800± feet in thickness as measured by E. T. Hancock at Axial (Mt. Streeter). Professor R. D. George informs the writer that he found the Mancos shale to be about 4,100 feet thick near the head of Milk Creek in T. 3 N., R. 92 W.

In Williams Park the Mancos shale is cut by erosion to within 300 feet of the base as shown by two wells drilled by the Twentymile Oil Company. By using the well logs for the lower part of the formation, calculating the thickness of the upper part from the scaled map distance in the southeastern part of T. 4 N., R. 88 W., where the exposed beds have an average northwestward dip of about 22°, and estimating the thickness of unexposed beds near the crest of the anticline the aggregate thickness is found not to exceed 4,400 feet. Obviously this rough determination is unsatisfactory from the standpoint of prospective drilling, but it is the best that can be done with data at hand. The thickness of the Mancos formation on the west limb of this fold can probably be determined with a fair degree of accuracy when the drill reported to be at work at the time of writing encounters the Mancos sandstone. As mentioned beyond there may be local thickening here. (See page 22.)

The lower part of the Mancos formation is composed mainly of black carbonaceous shale. This is overlain by a sandstone member that was seen by the writer in only three exposures. Near the south border of Williams Park the exposed part of this member is composed of alternating sandstones, shales, and limestones. The beds are dominantly sandstone with some limestone and numerous shale partings. Individual layers range in thickness from less than an inch to five inches. The limestone is fossiliferous and on breaking, gives a distinct though not strong bituminous odor. The sandstone is of medium grain and only moderately porous. The zone as a whole is a fair water carrier as shown by the spring at one outcrop. Both sandstone and limestone weather to brownish gray. From surface indications the thickness of the sandy member was

[4]Gale, H. S. Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 45 and 62, 1910.

[5]Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 53-55, 1916.

estimated at 20 to 40 feet. The log of the first well drilled by the Twentymile Oil Company shows "sand and shale" at depth 1,266 to 1,309 feet with an estimated dip of 29°. These figures give an actual thickness of 38 feet. Near Poose Creek, about 6 miles southwest of Williams Park, the sandy member is 25 feet thick. The well log mentioned gives 450 feet as the distance from the top of the Mancos sandstone to the top of the "Dakota" sandstone. Using the same dip as before, which the writer thinks is a little too high, the thickness of the Mancos sandstone and underlying shale is about 390 feet. On Poose Creek where measurements were taken the sandstone and underlying shale have a thickness of about 425 feet. Owing to difficulty in accurately locating the boundary between the "Dakota" and Mancos formations, on account of mantle rock, the figure given may be in error 10 to 20 feet.

On Poose Creek 30 feet above the sandstone member is a limestone stratum 15 inches thick. Another limestone stratum 12.5 feet thick lies 217 feet above the sandstone. The same limestone strata are found near the south border of Williams Park.

The remainder of the Mancos formation is nearly all shale. For some distance above the limestone the shale is at intervals very calcareous and weathers to thin plates. At least one thin limestone layer an inch or two in thickness and composed principally of Ostrea fossils is found in the shale. Much of the shale higher in the formation is dark and carbonaceous, but near the top, for several hundred feet, it is lighter in color and weathers to a light gray clay. A few hundred feet below the top of the Mancos is a limestone bed at least 18 inches thick. Outcrops of this may be seen near the northwest part of Williams Park.

The Mancos shale was long ago shown by its fossils to be of marine origin. No systematic search for fossils was made for the present report.

MESAVERDE FORMATION

The Mesaverde formation, which conformably overlies the Mancos, is a series of marine and fresh-water deposits having a thickness in this region between 3,000 and 4,000 feet. It contains many beds of soft to fairly hard sandstone of which the most prominent reaches a thickness of more than 100 feet. There are present many beds of sandy shale and fewer beds of carbonaceous shale. Workable seams of good coal are plentiful. No detailed examination of the Mesaverde formation has been made by the writer; but descriptions are given on later pages by Messrs. Perini and Willson.

Fuller descriptions[6] are given by Gale and by Fenneman and Gale in their reports on the coal fields.

LEWIS SHALE

The Lewis shale conformably overlies the Mesaverde formation and has a thickness of probably not more than one-third of the Mesaverde. It is a dark clay shale, but is less carbonaceous than the bulk of the Mancos shale. A few outcrops of limestone beds 3 to 5 inches thick are to be seen. Other workers have found marine fossils in the Lewis formation.[7]

LARAMIE FORMATION

Along the Yampa River in the vicinity of Hayden the Laramie formation, as determined by previous workers, overlies the Lewis shale with apparent conformity. It is composed for the most part of friable sandstone that commonly is cross bedded. The sandstone locally carries bands of concretions several feet in diameter. In a few gullies may be seen outcrops of gray shale. At least one coal seam has been opened in the Laramie near Hayden.

TERTIARY (?) SANDSTONE

South of Williams Park soft, friable cross-bedded sandstone, protected by a basalt flow or sheet, stands in a nearly vertical cliff 300 or 400 feet high. The white to gray rock above the green timber of the lower elevations and below the green timber of the basalt-capped table-land makes a conspicuous landmark visible for many miles. The thickness of the sandstone is not readily determined since sandhills from the disintegration of the sandstone that breaks from the cliff are piled up near the cliff as well as throughout an area about half a mile wide. Small remnants of sandstone in place and near the base of the formation are found farther west.

Inasmuch as the sandstone lies nearly level while the underlying Mancos shale has a pronounced dip in its nearest exposure, it is evident that the unconformity at the contact between shale and overlying sandstone is angular. Since no fossils were collected from these beds their age has not been determined. In appearance the sandstone cliff resembles the cliff of Green River sandstone west of the Grand Hogback, in Garfield and Rio Blanco counties, Colorado. Lithologically and structurally the sandstone south of Williams Park resembles the Laramie sandstone north of Hayden; but the unconformity below the former, representing a

[6]U. S. Geol. Survey Bull. 415, pp. 63-71.
[6]U. S. Geol. Survey Bull. 297, pp. 22-28.
[7]U. S. Geol. Survey Bull. 415, p. 72.

long erosion period, points to an age younger than Laramie for the beds under consideration.

SURFICIAL DEPOSITS

Within the region are numerous areas of variable extent in which unconsolidated talus, gravel, alluvium or soil overlies the bedrock. Locally, particularly near the south side of Williams Park, the unconsolidated mantle rock is deep enough to prevent the working out of details of structure from the surface geology.

FOLDS[8]

BY R. D. CRAWFORD

GENERAL FEATURES

In Routt County and adjacent parts of Moffat County are a number of anticlinal folds whose axes are roughly parallel to the Park Range on the east. The axial trend of other anticlines is toward the west. Fenneman and Gale[9] have shown that these anticlines are minor folds near the border of a general synclinal basin that pitches northwestward with its axis passing through Yampa and Hayden and to the northwest of Hayden many miles. Figure 2 shows the positions of the most important folds.

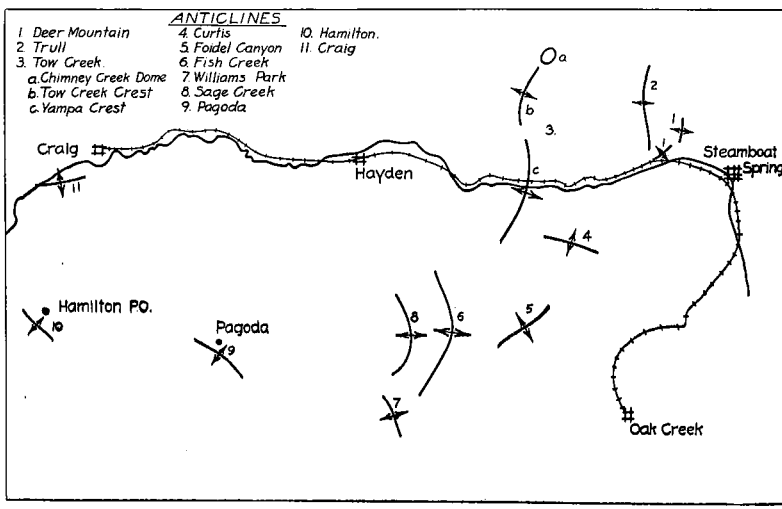

Fig. 2. Index map showing positions of some anticlines of Routt and Moffat counties. Compiled from maps of the United States Geological Survey and the Colorado Geological Survey

Williams Park is a topographic basin that has been eroded down into the Mancos shale in an area where two strong anticlines approach each other or possibly intersect. These anticlines—the Sage Creek on the west and the Fish Creek on the east—diverge

[8]The structural features of the northern and eastern parts of area mapped are discussed in later pages by Messrs. Perini and Willson, who, assisted by J. C. Myers and J. R. Murphy, mapped those parts of the field. Here will be considered chiefly the structures of Williams Park, in the mapping of which the writer was assisted by the four men named. The work within the park was done principally by Mr. Perini and the writer, while the Mesaverde formation north and west of the park was mapped by Messrs. Willson and Myers.

[9]Fenneman, N. M., and Gale, H. S., The Yampa coal field, Routt County, Colorado: U. S. Geol. Survey Bull. 297, p. 12, 1906.

northward. For some distance the intervening synclinal area is likewise deeply eroded and forms part of the park. Toward the south erosion has been retarded by basalt sheets or flows which at one time probably extended a considerable distance northward over the south part of the park site. The Mesaverde beds form the rim of the park on the east, north and west.

While the main topographic features have been controlled by the broader structural conditions there is very little sympathy between the minor details of structure and of topography. In places what appear to be dip slopes are underlain by shale whose bedding planes strike in the direction of the surface slope, and what appear to be escarpments may have no evident relation to the structure of underlying beds. It is not improbable that many minor features of relief are controlled by the vegetation which in turn may depend on the relation between dip of the shale and circulation of the groundwater and consequent seepage.

Under the conditions described it has been impracticable to work out the details of structure in all parts of the park. The dip and strike symbols on the accompanying maps (Plates I and II in pocket) show the areas in which accurate determinations are possible. In places these determinations were made only after considerable digging with pick and shovel. In the course of the work a great amount of detail was accumulated, and most of this, where dependable, is shown on the maps in order to give all the available evidence for favorable and for unfavorable structural conditions from the standpoint of oil storage. Locally, on escarpment slopes, the platy Mancos shale has very high dip—much higher than at the bottom of nearby gullies. This may be due to the spreading of the shale layers into a fanlike structure as the result of freezing of infiltered water. Most of these abnormally high dips, as well as those where there has been evident creep on the slopes, have been rejected.

WILLIAMS PARK ANTICLINE

This name is here applied to the highest structure in the park—that lying southeast of Willow Creek. The structure might be considered a bulge on an extension of the Sage Creek anticline, but it is separated by at least one synclinal fold from a closed structure several miles north on the anticline named. Whether or not it opens directly into the Fish Creek anticline without intervening synclinal folding has not been determined because of the absence of outcrops from a considerable area.

The thickness of Mancos shale remaining along the axial plane of this fold is less than 300 feet. Erosion has removed the Mancos sandstone from the crest and exposed this member for short distances along both limbs of the fold. The limestone bed that lies a little higher in the formation outcrops on the east limb, but is covered with mantle rock on the west limb. These lowest exposed beds have a dip of 35° to 60° on the east limb and a fairly uniform northward strike throughout the area of limited exposure. The sandstone on the west limb of the fold has a dip of 5° to 10° where it is exposed, and the direction of dip changes greatly and frequently along the short line of outcrop. Several of the determined dips are shown on Plate II. It is evident that there are local wrinkles on the main fold; this is brought out more clearly when the strike of the lower beds is compared with the strike of the shale beds higher in the formation. Although the southernmost determined dip on the west limb indicates a northward pitching anticline, it is obvious that the southward convergence of the strike directions of the higher beds on opposite limbs of the fold tends to close the structure. (See Pl. II.) Further, the presence of gas in the "Dakota" sandstone, as shown by the flow in two wells, points to the possibility of a closed structure. Owing to the scarcity of outcrops the structurally highest point on the anticline has not been located.

FISH CREEK ANTICLINE

A prominent anticline with curving axis can be followed along the east side of Williams Park, thence west of north to a point two miles or more northwest of Grassy Gap. Near the south border of the park the axis of this fold trends southwest. This anticline was mentioned as part of the Tow Creek anticline by Fenneman and Gale,[10] but since it is separated from the main Tow Creek anticline by a deep synclinal fold while the axis near its north end trends in a direction greatly different from that of the Tow Creek anticlinal axis it seems advisable to treat this structure separately. Owing to the fact that Fish Creek runs near its axis for several miles it is here called the Fish Creek anticline.

Like most of the anticlines in this general region this fold shows a higher dip on the east limb than on the west. The dip on the the west limb is 15° or less throughout the length of the fold excepting at the north part where it increases to more than 20°. For the most part the dip of the east limb is between 15° and 50°. The

[10] U. S. Geol. Survey Bull. 297, p. 14.

anticline pitches northward throughout its known length. Toward the south side of Williams Park the axis bends sharply toward the west, and the anticline probably merges with the Williams Park structure previously described. There is, however, an area of about a square mile in which no outcrop appears and which may possibly contain a structural terrace or even a shallow syncline.

SAGE CREEK ANTICLINE

The Sage Creek anticline was mapped by Fenneman and Gale[11] from Williams Park to a point about four miles south of Hayden where it disappears under the Lewis shale. These geologists, who were concerned chiefly with the coal-bearing Mesaverde formation, did not work out the structural details in the Mancos shale in Williams Park. This anticline also is asymmetric with the east limb dipping more steeply than the west. One prominent nose on the west limb in section 15, T. 5 N., R. 88 W., is the only notable minor feature where the Mesaverde beds are exposed.

The Sage Creek anticline, pitching northward, can be easily followed from section 35, T. 6 N., R. 88 W., southward for seven

Fig. 3. Sage Creek anticline looking north from Williams Park

miles or more to Williams Park. In the park the most evident broader structural and topographic features seem to combine to obscure the details of structure, and in a rapid reconnaissance one might easily receive the impression that this anticline passes without interruption into the Williams Park structure previously de-

[11] Op cit., pp. 15, 54.

scribed. It was only by close attention to details and after much digging with pick and shovel that a closure about half a mile north of the Dunkley schoolhouse was proved. Dependable readings of southeastward dips of 3° to 40° were taken. While some of these

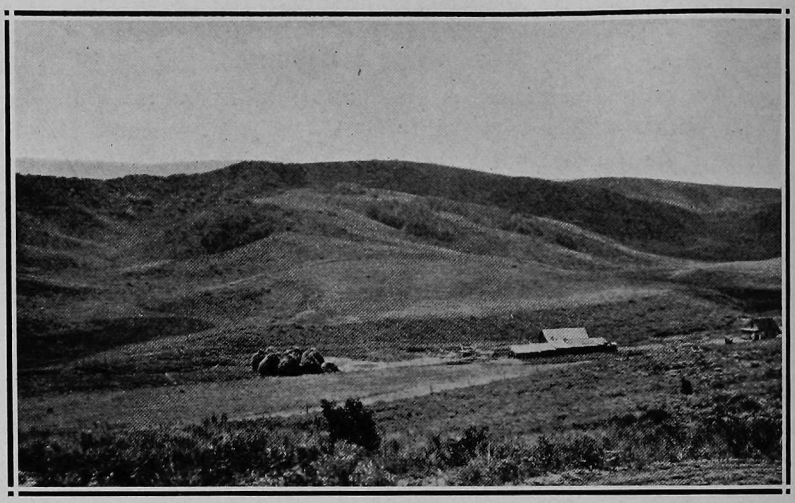

Fig. 4. Sage Creek anticline looking south toward structurally highest part

observations were made where weathering may have increased the dip of the shale near the surface there is no evidence that weathering has affected the strike. It will readily be seen from the convergence of the strike directions on the opposite limbs of the fold that there is a good closure between the schoolhouse and B. A. Long's farm house. (See Pl. II.) It is further evident from the approximate parallelism of strike of the beds on the opposite limbs that the intersection of the axial plans with any bedding plane is nearly horizontal for about a mile.

MINOR FOLDS

One prominent nose in the Mesaverde formation on the west limb of the Sage Creek anticline has been mentioned. South and southwest of Hayden in a few localities the general north to northwestward dip of the Lewis shale is very low and even approaches zero. About three miles south of Hayden a southeastward dip was noted, which indicates a small anticline; but, owing to the scarcity of good outcrops of the Lewis shale and the unreliability of dips taken at the surface, it has not been practicable to work out details of structure in this formation.

OIL AND GAS POSSIBILITIES OF THE STRUCTURES DESCRIBED

The chief factors to be considered in connection with the oil and gas possibilities of the region are: (1) the capacity of the sedimentary rocks for the formation of oil and gas; (2) the presence or absence of suitable reservoirs for the reception and storage of oil and gas; (3) the depth of such possible reservoirs from the surface; (4) the ground-water conditions; and (5) the degree of regional alteration to which the beds have been subjected.

The lower beds of the Mancos shale are highly carbonaceous, and there is no apparent reason to doubt their capacity for the generation of oil and gas. In Wyoming, sandstones in similar shales of approximately the same age have in recent years yielded much petroleum. In the Rangely, Colorado, field, near the Colorado-Utah line, oil has been found in the Mancos formation. Formations below the Mancos in the region under consideration contain a relatively small amount of shale. In the Mesaverde formation overlying the Mancos there are, in addition to the coal seams, many shale beds that carry considerable carbonaceous material.

The "Dakota" sandstone, though in places quartzitic and nearly tight, is usually open enough for the free circulation of ground water. In the Williams Park anticline a considerable flow of gas is reported from two wells that have been drilled into this sandstone since the Survey party was in the field.

About 400 feet above the "Dakota" sandstone is a persistent sandstone member of the Mancos shale. (See p. 12.) This member, which is 25 feet or more in thickness, is composed chiefly of sandstone with intercalated beds of shale and limestone. The sandstone is only moderately porous, but these beds have openings enough for the circulation of ground water as evidenced by at least one spring at the outcrop in the Williams Park anticline. It is believed that the porosity is sufficient for the reception and circulation of oil and gas. The overlying shale furnishes a compact cover that would prevent the escape of petroleum where structural conditions are favorable to accumulation.

Several anticlines of this region are open at one end and have a fairly constant angle of pitch. Owing to the probability of leakage at the open end such anticlines are generally not suited to the accumulation of oil and gas. Only those will be considered here which are closed or which do not furnish conclusive evidence of being open.

Conditions indicating the southward closure of the Williams Park anticline were mentioned on page 18. Even if the change in dip and strike of the beds should not be sufficient to effect a closure, leakage might be prevented by basalt dikes. A dike, or sheet, dipping 20° southward, may be seen a mile or two southwest of the exposed crest of the fold. This rock is in part nearly compact and similar to the basalt that overlies the sandstone of the cliff farther east; it is in part vesicular, with cavities that have a maximum diameter of about two inches. It is obvious that the basalt might form either an impervious cover or a good reservoir, depending on the degree of compactness and the dip of the dike or sheet.

The removal of part of the sandstone member of the Mancos shale and consequent outcropping of the sandy beds afford opportunity for the leakage of any oil that may have found its way to these beds. The chances of finding oil or gas in commercial quantity in the remaining Mancos beds in this anticline are slight. However, the remaining Mancos shale is 200 feet in thickness, or more, and is probably ample to form an impervious cover for the "Dakota" sandstone. The gas already found in this sandstone may have been generated in underlying beds or, possibly, in the overlying Mancos shale.

From the crest of the Sage Creek anticline there has been removed by erosion perhaps 700 or 800 feet of Mancos shale. If the thickness of this formation has not been materially affected by folding it may have been originally about 4,400 feet in all, or about 4,000 feet from the top down to the first prominent sandstone. (See p. 12). The sandstone would accordingly be about 3,200 or 3,300 feet below the present surface. But accurate determination of the thickness of the formation and depth to the sandstone must await the drill. It is not improbable that local thickening has accompanied folding and that the thickness of the shale in the anticline a few miles south may be different from the thickness here. Uniformity of thickness is hardly to be expected in a heavy shale formation between competent sandstone strata in a region of much folding. Hewett and Lupton[12] have found that the shale on opposite limbs of a single anticline may differ several hundred feet in thickness, being thicker on the steeper side.

The same factors that could produce local thickening might cause a bulge on an anticline and show a closed structure at the sur-

[12]Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyoming: United States Geol. Survey Bull. 656, 1917.

face where none exists at depth. There is, however, no observed indication that the closure of the Sage Creek structure does not hold through the Mancos shale. Of those mentioned in previous pages it should be the first to be tested. Fully to test the structure to and including the "Dakota" sandstone the driller should be prepared to bore 4,000 feet, but it is possible that the Mancos sandstone would be reached within 3,000 feet. Whether or not sandstone lenses or other possible reservoirs exist above the main sandstone member can only be determined by drilling. Jointing, fracturing, or solution might make the limestone or calcareous platy shale sufficiently open to receive oil or gas. Though the highest part of the anticline is limited in width by the syncline on the east, the most promising drilling area extends much farther in a general north-south direction where the axis of the folded sandstone is evidently nearly level for about a mile. A further advantage is found in the wide area of possible drainage which extends far north of Yampa River and includes much of the general synclinal basin mentioned on page 16.

Should the Sage Creek anticline prove to be productive a careful examination of other hitherto untested areas within the region would be advisable. Among these may be mentioned the Fish Creek anticline northeast of the Williams Park anticline and sections 11 and 15, T. 5 N., R. 88 W. Though the writer has not examined in detail the area in the two sections named the dip and strike of the beds, as mapped by other members of the party, are significant.

GROUND WATER

Very little is known about ground-water conditions at depth within the area under consideration. Shallow wells in the Lewis and Mancos shales furnish sufficient water for stock and household use. In all probability any sandstone within the region is sufficiently porous to carry water. Mr. W. A. Dawson, of the Twentymile Oil Company, states that when the first well of his company reached the "Dakota" sandstone water rose in the well 1,000 feet, that is, to within 725 feet of the surface.

DEGREE OF CARBONIZATION OF MESAVERDE COAL

David White[13] has pointed out the close relationship that exists in oil fields between the character of oil and the degree of carbonization of coal in the same or overlying formations. He says:[14]

[13]White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.
———, Late theories regarding the origin of oil; Geol. Soc. Am. Bull., vol. 28, pp. 727-734, 1917.
———, Genetic problems affecting search for new oil regions: Mining and Metallurgy, No. 158, pp. 1-20, 1920.
[14]Geol. Soc. Am. Bull., vol. 28, p. 732.

Noting the gradual elimination of the volatile hydrocarbons—the so-called volatile matter—from the oil shale simultaneously with the devolatilization of the associated coals in the course of the progressive regional alteration of the organic deposits, I have called attention to several other points which seem to indicate a mutual relationship between coal and petroleum in the second or **geochemical stage** of development, and that both react to the same geophysical influence, as follows: (1) That in regions where the coals and other carbonaceous debris in the strata are of the rank of brown lignites, the oils in the same or closely associated geological formations are also of low rank, averaging 20° to 26° Baumé; (2) that where the organic debris (coals, etcetera) has advanced to the sub-bituminous rank, the oils of the same or of nearly contemporaneous underlying formations are of higher rank, averaging 28° to 35°; (3) that when the deposits of organic debris have been regionally transformed (by elimination of volatile matter) until they have reached the bituminous rank, the oils have in general attained a rank of 35° or more, the highest grade of petroleum being found in the areas where the regional alteration of the organic debris has progressed farthest; **except** (4) that in those regions where the organic debris, whether it be represented by beds of coals, by bogheads, or by carbonaceous matter in shales, has passed the point corresponding to a content of 65 per cent of fixed carbon, pure coal basis, the oils which may formerly have been present in the same or in the underlying formations have mostly disappeared; and (5) that wherever the devolatilization of the coals, etcetera—that is, the solid residues in the strata—has progressed so far that they have a fixed carbon content of 70 per cent or more, **oils**, if present, will be "freak" oils, and in pockets or amounts too small to be of commercial importance, though gas pools may persist. I know of no commercial oil pools in the world that are found in or beneath formations in which the regional carbonization of the organic debris has passed 75 per cent fixed carbon, pure coal basis; in fact, I have not yet been able to learn of an oil pool in or beneath a formation in which the fixed carbon percentage of the organic debris exceeds 70, and it is most improbable that oil pools exist under such conditions.

It will at once be seen that these conditions seem to define a law restricting the distribution of productive oil pools, and to afford a basis on which to eliminate many areas of great extent in which fruitless and costly exploration by the drill is now going forward.

In Doctor White's third paper cited, page 5, he states:

More observations and tests are necessary to fix more exactly the stage of regional alteration beyond which commercial oil pools, though formerly present, will not have survived, but it is probable that the limit falls, in general, slightly lower than the point at which coals of the ordinary bituminous type show a fuel ratio of 2.2, or 68 per cent of fixed carbon in the pure coal; it may approach nearer the ratio of 2.0, or 66 per cent fixed carbon. Coals verging toward the sapropolic type, such as are believed by many to approach more closely the typical mother substance of oil, are more fatty and accordingly richer in

hydrogen and lower in fixed carbon (pure coal basis) than the other types, until, in the course of alteration by geologic processes, they approach the above limit, when the volatile matter seems to disappear rapidly. At the semi-bituminous stage (fuel ratio 3.0, fixed carbon 75 per cent), their carbonization is approximately on a parity with typical bituminous coal.

Gale[15] gives analyses of 43 samples of Mesaverde coal from mines and prospects over a wide area extending from Pilot Knob north of Yampa River to Meeker on White River. Of these 43 analyses 39 show fixed carbon between 52 and 62 per cent on a pure coal basis—that is, after eliminating moisture and ash. Only 2 of the 39 contain over 60 per cent fixed carbon. Two others, from Pilot Knob, where the coal has been locally affected by basalt intrusion, show respectively 71.6 and 95.6 per cent fixed carbon. The remaining 2 of the 43 fall considerably below the general lower limit of 52 per cent, having 46.4 and 48.6 per cent fixed carbon, respectively. Gale states that these two analyses were made from weathered samples.

Insofar as the Mesaverde beds are concerned, excepting the areas of local metamorphism, alteration, as shown by coal analyses. has been sufficient, yet not too much for the production of oil, acording to the limits set by White. It is to be expected that the regional alteration of the older Mancos beds would be somewhat more than that of the Mesaverde, yet well within the limits mentioned.

[15]Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 248-249.

TOW CREEK ANTICLINE (NORTHERN PART)[16]

BY K. M. WILLSON

PHYSIOGRAPHY

DRAINAGE

The chief drainages of the area are Yampa River, Elk River, and their tributaries, Deep, Wolf, Trull, Chimney, and Butcherknife creeks. Of these streams, which are named above in order of their importance, all are perennial but upper Wolf Creek. The Yampa and Elk rivers are very large streams which drain a considerable part of the area to the east, which includes a large portion of the west slope of the Park Range. The small tributaries mentioned all have their sources in this area. Deep Creek, of about equal length with Wolf Creek, carries the largest amount of water of any of these small tributaries.

TOPOGRAPHY

The greater part of the area, the surface of which is formed by the Mesaverde formation, consists of rough hilly country with long ridges running northward to the divide between the heads of Tow Creek and Wolf Creek, which flow south, and Deep Creek and Chimney Creek which flow northeastward. This divide is formed by a large dike cutting across in a southeasterly direction from the north crest of Wolf Mountain. Northeast of this divide where the Mancos shales come to the surface, there is a physiographic basin with low rolling hills and valleys, which is inclosed on all sides by mountainous ridges and hills. Along the eastern boundary of this basin the Elk River flows southward to join the Yampa River. The river valleys of this area show youth, maturity, and in places old age. Where the Yampa River cuts the Tow Creek fold it has carved a canyon to keep pace with the upbowing of the beds. The remainder of its course in this area is through an open valley. The same antecedent conditions are true for the canyon cut by the Elk River east of Elk Mountain where the upbowing was accompanied by dislocation. It is characteristic of this district that the tops of the anticlines have been eroded away deeply by the streams, and physiographic valleys now occupy the structural hills. In professional paper 90 of the United States Geological Survey on page 184 Mr. Hancock, speaking of the Yampa River, says:

[16]The report that follows is an abridgment of a thesis submitted by Mr. Willson, in June, 1920, to the Graduate Faculty of the University of Colorado in partial fulfilment of the requirements for the degree M. S.—R. D. C.

Emerging from the foothills of the Park Range it enters a more or less open country and traverses the formations involved in the Axial Basin anticline, and the Juniper unlift with apparent disregard for rock structure.

This statement is very true of the canyon cut by the Yampa River in this district and clearly shows antecedent conditions. The channels of Tow Creek and Chimney Creek are, however, developed along the crest of this anticline and follow what must represent the more or less fractured zone along the top of the fold. Their valleys are clearly subsequent.

There are several prominent peaks in this area, the most noticeable of which are Wolf Mountain, Pilot Knob, Elk Mountain, and Chimney Peak, and many unnamed points between the forks of Tow Creek.

Sand Mountain is a large intrusive body at the northern end of the area which presents a triangular-shaped crest formed by the the union of three sharp ridges. One of these ridges trends southwest in a knifelike ridge of almost the same height as the mountain, to the crest of Wolf Mountain. This ridge forms the divide between Morgan and Deep Creeks. The second ridge is formed by a dike with several interrupted crests which extend southeastward almost to the junction of Elk River and Deep Creek where it ends abruptly in a sharp point four or five hundred feet above the valley floor. The third ridge extends northward toward Hahns Peak and disappears in a high slope after about three miles of prominent points.

Wolf Mountain has two crests, each about 9,000 feet in elevation, and connected by a high ridge of nearly equal height. Running off from the north crest in a southeasterly direction is a high ridge formed by a dike which ends abruptly on the north side of Chimney Creek gap. From the south crest there are three ridges, one of which extends southward formed by the outcropping edges of the Twentymile sandstone, and two which trend southeastward about a mile apart and formed by dikes. Both of the latter ridges end at Wolf Creek, but the first slopes away gradually to the south, and is finally lost in Twentymile Park.

Pilot Knob is a very prominent point 9,200 feet in elevation on the ridge about midway between Sand Mountain and Wolf Mountain. Its western end is sharp, and on it is a secondary triangulation station of the United States Geological Survey. It can be seen from all parts of the surrounding country. Elk Mountain is a somewhat circular body having a very steep slope on the east rising about 3,500 feet above the valley to a ridgelike crest which extends for nearly half a mile in a north and south direction and

which slopes westward at an angle of about 30°. This mountain is probably an igneous stock, and its character causes it to stand out abruptly in an area of soft shale. It can be seen for long distances north and south, but is hidden to the west by the higher ridges of Mesaverde sandstone. It can be seen almost as far east as Steamboat Springs.

The other really prominent high point is Chimney Peak. It is not known locally by any name so far as the writer was able to find out, and this has been given it here because Chimney Creek derives the greater part of its water from drainages on the north and west slopes. It is formed by a dike having several sharp points in a line extending southward, the highest of which was very useful in our triangulation work on account of its prominence from all directions. It is located about four miles west of Elk Mountain and about four miles southeast of Wolf Mountain.

Between the forks of Tow Creek are many sharp-pointed hills, but they do not form landmarks that may be seen from any considerable distance because they are surrounded by the higher ridges of Mesaverde sandstone. West of Chimney Peak there is a group of three having an average elevation of 8,000 feet. Their east slope drains into the east branch of Tow Creek and their west slope drains into the west branch of the same creek. South of these hills are two or three lesser ones, one of which is seen quite prominently from the Tow Creek valley. These hills are all of igneous rock, and represent erosion remnants of an intrusive body. These points and the country immediately adjacent to them are heavily wooded and present a decidedly mountainous aspect.

VEGETATION

Much of this area is good farming land, especially along the Yampa and Elk River valleys, and Deep Creek. In these valleys the principal crop is timothy and alfalfa hay, while in the rough country large truck gardens and small fields of oats, rye and wheat are raised. Throughout the hilly parts of the area scrub oak is abundant with frequent groves of aspen and pines, and occasional spruces. Some cottonwoods and willows and small brush grow along the main stream channels. No use is made of the scrub oak, and large tracts are cleared for agricultural purposes by burning. The pines furnish logs for buildings, for timbering mines, and some is used for firewood. Few of the evergreens in this area are of sufficient size to be used for lumber. Sagebrush grows along the valley slopes and the area covered by the Mesaverde sandstone, and with the scrub oak forms a part of the food for the herds of cattle

and horses which range through the country. The basin which drains into Elk River is covered with a sparse growth of spear grass, except where it has been cultivated.

SOILS

In this district the soils vary according to the character of the rocks from which they are derived. The sandstones as a rule produce sandy clay; the shales weather out to a fine dark gray silt of a somewhat sandy character; and the igneous rocks produce a dark, rich soil of fine to coarse texture. All are productive.

CLIMATE

The winds of this district are varied but during the summer months blow mostly from the north down the parallel ridges and valleys. Their work is very noticeable in the soft sandstones where pinnacles, balanced rocks, and various similar forms have been produced. On the north slopes some polishing and, in a few places grooving of rock surfaces were seen in the district of igneous rocks. Rapid changes in temperature and frost action are evident by the slide-rock and talus on most of the high points. On the whole the climate is semiarid. Precipitation is about the same as at Denver, coming at irregular intervals with long periods of drought. The winters are long and severe, and the summers are short and generally dry with heavy showers. The following table was made from data obtained from the summaries of the United States Weather Bureau showing the maximum, minimum, and mean monthly, and annual temperatures, and the precipitation for the year 1918, at Steamboat Springs.

Weather record at Steamboat Springs

	Temperature in degrees Fahrenheit						Precipitation in inches
	1918			1919			
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	1918
January	43	—24	15.2	43	—24	11.9	5.00
February	45	—36	17.3	53	—16	19.4	2.70
March	61	—13	28.8	60	—20	27.4	2.12
April	61	—15	36.8	74	12	41.0	1.86
May	76	21	48.0	79	20	48.6	.46
June	94	19	59.3	89	19	55.6	.79
July	88	27	60.1	92	30	63.4	3.07
August	89	25	57.6	92	28	60.0	1.02
September	87	20	52.8	90	14	55.2	2.70
October	81	10	45.3	76	—16	34.6	2.81
November	65	—12	26.0	—	—	...	1.31
December	44	—26	15.6	42	—32	6.9	1.16
Annual	94	—36	38.6	92	—32	...	25.00

GROUND WATERS

The work of the ground waters must be considerable as there are about ten large perennial springs in the area, and a great many boggy places and intermittent springs. Some of these seem to be connected with the oil-bearing sandstones as they contain oily matter in small quantities. Others are of the finest, clear, cold and tasteless water. The solvent action of these waters is not noticeable in the formation of sinks or caves, but good water wells are easily obtained in the areas where the Mesaverde sandstones are near the surface. In the shale areas the water contains much saline matter in solution which makes it undrinkable. The largest of these is the one which comes up near the center of the body of Tow Creek intrusive. This makes a fair-sized stream which flows into the east fork of Tow Creek.

STRATIGRAPHY

The stratigraphy of the region has to deal with sedimentary and igneous rocks. The sediments consist of sandstone and shale, and the igneous rocks, which are all intrusive, are both acidic and basic in character. The rocks in this district range in age from the pre-Carboniferous gneisses and granites which form the basal complex to later Tertiary in the form of dikes, sheets, and laccolithic, and stocklike bodies, and to Quaternary alluvium. The sedimentary strata were laid down when this part of the continent was largely submerged. The submergence likely ranged from deep-water to shallow-water and swampy conditions, as well as from salt-water or marine to brackish-water and fresh-water stages. These strata were deposited in an approximately horizontal position but subsequent movements of the earth's crust have folded and even broken the originally continuous strata. Their position in the stratigraphic section indicates their relative geologic ages. Their exact equivalents are known but partly. Some are transitional while between others there are small unconformities due to erosion or non-deposition.

These sediments are for the most part of Cretaceous age. There is a thin layer of "Red Beds" lying on the basal complex of which little information was obtained. There are thin beds of alluvium in the river valleys. The rocks adjacent to the eastern boundary of the area are gneisses and granites of pre-Carboniferous or probably pre-Cambrian age which form the masses of the Park Range and the basal complex of this area.

Since the chief interest is limited to that part of the stratigraphic column which may be oil bearing, namely, the Cretaceous, only a brief summary of the older rocks is given here. The following summarized description of the Cretaceous strata is given in tabular form for convenience of reference and comparison.

Summarized description of the strata

Geologic Age	Formation name	Description	Topographic Forms	Thickness Feet
Cretaceous	Lewis	Composed largely of dark gray to black, calcareous, marine, clay shale containing lenticular beds of limestone.	Slopes, valleys and rolling plains.	1200-1800
	Mesaverde	Includes a succession of alternating sandstone, shale and clay, and coal seams. Three very prominent ledges of massive sandstone. The shale and clay form valleys and slopes covered with debris and waste. The coal seams are generally hidden by debris.	Steep, rough ridges with narrow valleys between the sandstone ledges.	3000-3700
	Mancos	A thick mass of dark shale containing lenticular beds of sandstone and several hard calcareous layers near the base.	Slopes, valleys and rolling plains.	2000-2500
	Dakota	Two heavy sandstones with a thin layer of interbedded black shale.	Hogbacks.	160±
Undetermined	"Red Beds"	Red sandy clay and shale with a thick, massive red sandstone bed near the middle.	Slopes and valleys.	?
	Basal complex	Gneisses and granitic rocks.	Mountainous masses.	...

PRE-CRETACEOUS ROCKS

Basal complex.—The igneous and metamorphic rocks like those of similar areas in the Rocky Mountains form a vast complex of schist, gneiss, granite, and quartzite, each with various phases of development. A fairly detailed description of these beds is given on pages 200-202 of the first report of the Colorado Geological Survey of 1908, which, according to the present limited information applies also to this region.

"Red Beds."—These rocks consist of red sandstone and shale lying on gneisses and granitic rocks. These red beds can be traced to the Hahns Peak district where, in the report cited above, they were referred to as Carboniferous to Jurassic. They consist of sandy red shale with a thick cross-bedded sandstone near the middle of the group. No outcrop was found which would serve as a place for the determination of their thickness.

CRETACEOUS ROCKS

These rocks consist of four important formations; the ages are matters which as yet have not been settled completely, but lithologic similarities and other characters are so similar to related districts that this is not at present important.

"Dakota" formation.—The oldest of these formations is the "Dakota," the basal part of which is a conglomerate layer about ten feet thick composed of fragments from the older beds of the mountain district. This layer lies unconformably on the "Red Beds." Above this is a layer of dark sandy shale a few inches thick which is overlain by a hard, massive, sandstone white to brown in color, and from 30 to 40 feet thick, which in places has been changed to a quartzite. Lying on this is a bed about 70 feet thick which is composed of thin beds of sandstone and interbedded sandy shale. Above this is a forty-foot bed of hard massive sandstone much jointed and cross-bedded.

This is directly overlain by the dark Mancos shales. A maximum thickness for the "Dakota" in the section measured on Elk River near the mouth of Salt Creek is thus 160 feet. Due to the dislocation and probable compression at this point, this figure may be somewhat low. The lower sandstones are generally somewhat prominent as ridge makers and form the highest part of the hogbacks in which the whole formation is exposed, owing to the highly tilted condition of the strata along the mountain border. No fossils were obtained from this formation and none have been reported from the Hahns Peak district or in nearby fields, and its assignment to Dakota Cretaceous is based on its stratigraphic position and lithologic similarity to "Dakota" east of the range.

Mancos formation.—Above the Dakota is the Mancos shale, a thick mass of dark clay shale with a calcareous sandstone member about 460 feet above the base, and containing some very calcareous shales in the 600 feet above the sandstone. The layers above the calcareous shales are very dark colored. The formation is considered as a single unit, but has been subdivided in other places on

paleontological grounds. As taken here it includes the dark shales of the Benton and the limy layers of the Niobrara of other fields. The term Mancos is here applied to all the dark-colored shaly strata conformably overlying the Dakota and apparently conformably underlying the soft, yellow, thin-bedded sandstone at the base of the Mesaverde formation. A very exact determination of the thickness of this formation is impossible in this area because nowhere is a section of constant dip and definitely exposed contacts to be found. Measurements taken give it a total thickness of 2,127 feet. These measurements were made from the exposures on the Chimney Creek dome and from exposures along Elk River in section 4, T. 7 N., R. 85 W. Some fossils were found in the Mancos and the following is a list of those identified by Professor Junius Henderson from the collection:

Inoceramus dimidus
Inoceramus sp.
Inoceramus sp.
Inoceramus probably fragilis
Inoceramus fragilis
Scaphites warreni

Fish scales were identified by Professor T. D. A. Cockerell, as follows:

Hypsodon sp.
Ichthyodectes sp.

On page 207 of the Colorado Geological Survey, First Report of 1908, the following fossils are recorded from the Mancos:

Baculites gracilis
Inoceramus dimidus
Ostrea congesta
Prionocyclus wyomingensis
Scaphites warreni

The sandstone which lies about 460 feet above the top of the Dakota formation was examined in cross section on Poose Creek about half a mile from its junction with the Williams Fork River, and also along the Elk River east of Elk Mountain. In both cases it was found to be a porous sandstone with numerous thin shale partings. The measurement on Poose Creek gave its thickness as 25 feet. The exact determination of its thickness as exposed in the north end of the Trull anticline was not possible on account of the intense folding which had taken place there, but further south near Trull it was found to be about 35 feet thick. From these

measurements it seems safe to assume that it would provide an ample reservoir for the storage of commercial quantities of oil.

Mesaverde formation.—The thick series of sandstones and shales overlying the Mancos shales and overlain by the conformable Lewis shales are called the Mesaverde. On page 23 of Bulletin 297 of the United States Geological Survey the following is reported concerning the correlation of the Mesaverde. "In the Yampa field the formation is apparently analogous to that of the type locality both in character of its constituent members, in its position between two great clay shale groups, and in the fossils that it contains." It corresponds approximately to what is called Pierre-Fox Hills on the east side of the range. It consists of thick-bedded and thin-bedded sandstones with interbedded shale and coal seams. This formation has been described in detail in the bulletin mentioned above and also in the United States Geological Survey Bulletin 415, pages 63-71. The formation may be divided into two, three, or more groups but is here considered in three groups—an upper, middle, and lower.

The lower contact with the top of the Mancos is marked by a soft yellowish to white sandstone showing discontinuous and irregular bedding, and in some places cross bedding. This contact is not often plainly marked, as it occurs on the lower part of the slope between the heavy basal sandstones and the shale flats. It is nearly always covered with debris and wash from above, and generally overgrown with brush. In mapping the boundaries the exact contact was therefore found only at intervals, and it is to be considered as generalized.

The upper boundary was taken as the top part of the highest sandstone in the upper group. This sandstone does not outcrop continuously but is covered with waste and wash from the slope above it. When found it is a soft, iron-stained layer, seven or eight feet thick, lying on a bed of interstratified white calcareous sandstone and dark shale, and is overlain by light brown clay shale of the Lewis formation.

For purposes of mapping the structural contours, the ledges of sandstones making prominent scarps were taken as horizons. Three such ledges were used in the work on this area, they are the Twentymile and Trout Creek, described in Bulletin 297 of the United States Geological Survey on pages 26-27, and a heavy brown sandstone forming the top of the ridges of both sides of Tow Creek and lying 890 feet above the base of the formation. The last will be referred to as the Tow Creek sandstone member; it has a total

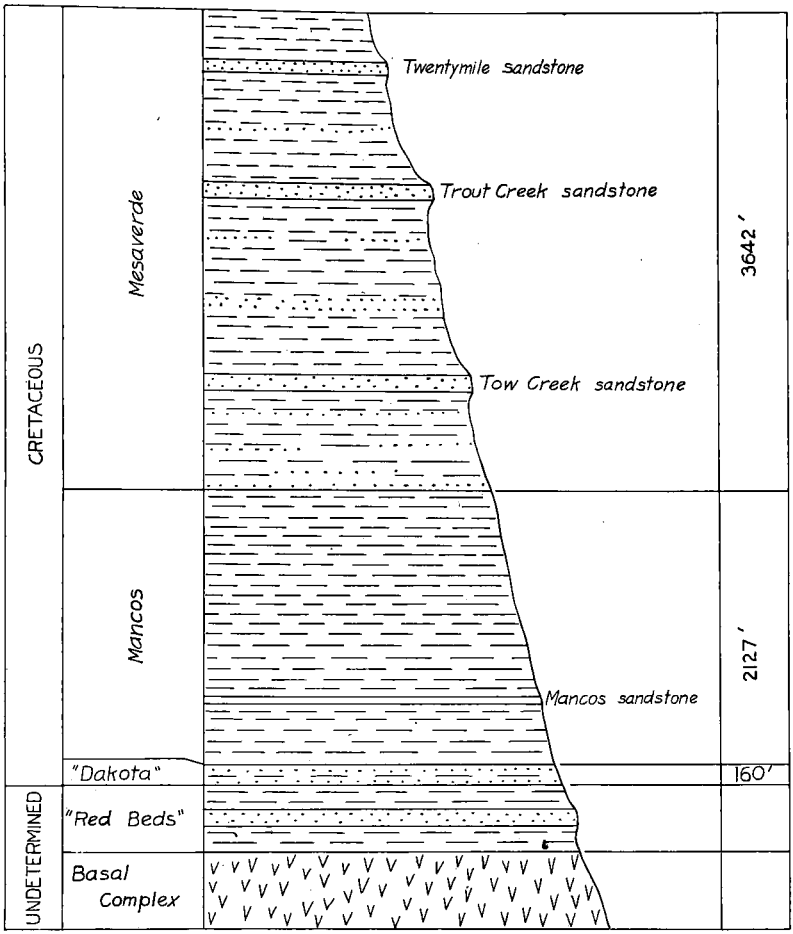

Fig. 5. Vertical section of sedimentary rocks of the Tow Creek anticline

thickness of 100 to 112 feet, and though massive throughout it has two or three more or less prominent divisions, due to erosion of streaks of softer material.

Descriptions of the Mesaverde formation given in the bulletin referred to above apply very well to this area, and as it is eroded too deeply to allow oil accumulation in this area it was not studied in detail beyond the location of horizons within the formation. The following shows the position and character of the strata used in mapping this structure, as obtained from the cross section measured along the Yampa River. (1) The Twentymile is a massive white sandstone, averaging 75 feet thick and occupying a stratigraphic position 2,307 feet above the Tow Creek sandstone. (2) The Trout

Creek is a similar layer of equal thickness which occupies a position 1,470 feet above the Tow Creek member. (3) The Tow Creek is a massive brown sandstone averaging 100 feet thick. The figures given above are from the top of the Tow Creek to the top of the bed mentioned. The total thickness of the Mesaverde as calculated from the measurements made along the north side of the Yampa River where it cuts this fold, is 3,642 feet.

IGNEOUS ROCKS

The main part of this paper is not to consider the petrography of the area, and what is reported here is of a limited nature. Specimens and slides were made and examined only from the main bodies of igneous rocks. No specimens were taken and no slides examined from Pilot Knob or Sand Mountain, but a description of them is given on pages 32-33 of Bulletin 297, United States Geological Survey. The rocks of related districts are described on pages 45-55, Bulletin 5, pt. 1, Colorado Geological Survey, and also in the First Report (1908) of the Colorado Geological Survey on pages 211-219. The igneous rocks of this district are all intrusive in character, and consist of two general types. The laccolithic and stocklike bodies are of acidic porphyry, with attendant phases, and the dikes and sheets are of basalt. There are two varieties of basalt; one contains quartz and the other does not.

RHYOLITE PORPHYRY

The rocks of acidic type were studied in less detail than the basalts. They occur in the laccolithic body in the Tow Creek crest and on Elk Mountain; on page 32 of Bulletin 297 of the United States Geological Survey they are reported to be present on Sand Mountain. The Tow Creek intrusive, the only body strictly within the area, when seen from a distance was so light colored and apparently stratified, that it was thought to be sandstone. It was found that this apparently bedded part of the intrusion near the north central part of the body changes quite rapidly into a finer-grained and structureless rock toward the borders of the intrusion.

The hand specimen of the most acidic part shows frequent quartz phenocrysts about one-fourth of an inch in maximum diameter, numerous colorless feldspar phenocrysts of about equal size, and many small but quite perfect hexagonal crystals of biotite embedded in a fine, light groundmass. The quartz phenocrysts can be distinguished by their lack of cleavage which is very noticeable in the feldspars. The rock presented a chalky appearance

except where it was stained by alteration of the iron-bearing minerals.

Under the microscope quartz is not very abundant and is found to consist mainly of large corroded phenocrysts containing numerous bays which contain portions of the groundmass. Orthoclase and andesine feldspars are present in much more abundance than the quartz and generally in somewhat larger phenocrysts. The latter is the more common feldspar and it often shows albite and Carlsbad twins. Biotite is very sparingly present and very occasional small subhedrons of hornblende can be seen. The groundmass which makes up approximately half of the rock is microgranular, and appears to be composed largely of feldspar which is much kaolinized, with some quartz. The phenocrysts of both feldspar and quartz contain many inclusions of glass, apatite, and some titanite. Many small cavities are distributed through the rock.

This rock is here designated a rhyolite porphyry though it is almost coarse enough to be a granite porphyry, and might be so named without being far wrong. It grades into felsitic phases where there are only a few small phenocrysts and the amount of femic minerals is considerably more.

OLIVINE BASALT

The quartzless variety of basalt is the most basic of these igneous rocks. It is found in the dikes extending from the south crest of Wolf Mountain into the Tow Creek laccolithic body. It is a very dark, compact rock with frequent small phenocrysts of olivine.

The microscope shows this rock to be composed principally of Olivine and feldspar in nearly equal amounts with some pyroxene and iron ore. The olivine is less altered than in the finer-grained quartz-bearing variety, and is present as subhedral and anhedral grains of various sizes up to 1 mm. The feldspar is present in medium-sized lathlike microlites oriented in every direction. It was found by measuring the extinction angles to consist principally of labradorite. The feldspar has suffered more or less alteration in some places and a cloudy appearance is presented by the resulting products. The pyroxene is chiefly augite in subhedral grains of small size. The iron ores consist chiefly of magnetite or ilmenite in numerous small irregular grains widely distributed through the rock. Biotite is present in occasional small anhedral flakes.

QUARTZ BASALT

The variety of basalt containing quartz is found in Chimney Peak and in sheets around the Chimney Creek dome. It is a heavy rock of bluish-gray color containing numerous imperfect crystals of bright green olivine about 3 mm. in diameter, and less numerous grains of quartz of about the same size embedded in a dark bluish-gray groundmass.

Under the microscope this rock shows olivine, pyroxene, feldspar, iron ores, and quartz.

Olivine is the most abundant mineral present. It is present in the larger grains as phenocrysts of small size and also as fine crystals in the groundmass. These grains have the typical cracks along some of which iron ore has developed. In some instances the olivine seems to have altered to fine grains of iron ore and the original outline of the olivine retained. All gradations between the fresh grains and the iron ore replacements are present. A reddish, pleochroic aggregate of irregular outline occurs in small amounts. This may be iddingsite, an alteration product of olivine. The pyroxene is chiefly augite in small euhedral and subhedral grains. The feldspar is present in lathlike microlites, probably of labradorite or anorthite, but this is a little doubtful on account of the small size and imperfect definition of the twinning. In the uneven groundmass, considerable iron ore, chiefly magnetite and ilmenite, is present in small irregular grains. One of the noticeable features of this rock is the fairly frequent number of corroded grains of quartz. They average about 3 mm. in diameter and have very irregular outlines with numerous bays. A fringe of mineral surrounds each grain. This fringe is composed of a fibrous aggregate, probably serpentine, produced from the partial absorption of these grains, and the surrounding minerals. These grains are probably not true phenocrysts as they appear to have been picked up by the magma before it cooled. Occasional rods and specks are found as inclusions in the grains. These may be rutile or some similar mineral.

AGE

The age of these rocks is post-Mesaverde and probably Tertiary, since they came approximately into their present position subsequent to the deposition and solidification of the Mesaverde formation, and accompanying or subsequent to the folding. There seem to have been two periods of igneous activity. The earlier rocks were acidic in type, for the heavy olivine basalt which extends

from the south crest of Wolf Mountain cuts the acidic porphyry in the Tow Creek crest. The dikes and sheets may be of the same age, as their close resemblance in composition suggests. Nowhere was a dike found cutting a sheet. The rocks of this area so closely resemble those in the Hahns Peak and Rabbit Ears district that it seems quite probable that they are of nearly the same age, and came from the same general reservoir.

METAMORPHISM

The metamorphism of this area is chiefly confined to very narrow contact zones of intruded igneous rocks in the form of dikes, sheets, and laccolithic bodies.

In the case of dikes very little effect could be noticed. Nowhere was there a well exposed contact of sedimentary beds and dike rocks, but examination a very few feet away from the contact shows nothing beyond a slight hardening, and not always that. The beds into which the dikes were intruded have not been perceptibly tilted, or otherwise changed by the intruded rock. It seems probable that they were fissure fillings in part, with some absorption and minor fracturing.

The sheets intruded into the Mancos shale and showing in nearly circular outcrop in three successive beds around the Chimney Creek dome have caused very little metamorphism. On the upper and under sides the effects seem to be about equal. The effects extend from a foot to 10 feet with a fairly constant average of 18 inches. The shale at the contact has for an inch or two been baked to a material resembling porcellanite, and the succeeding layers vary in hardness from that rock to ordinary shale in about a foot and a half. The effect is most noticeable on the innermost and outermost sheets. The middle sheet is thinner and less continuous than the others, and has caused less metamorphism. The contact metamorphism as seen along the borders of the Tow Creek laccolithic mass is very slight. Though the mass is largely acidic porphyry and must have been intruded at a higher temperature than that of the dikes and sheets, its effect is apparently no more pronounced. No good exposure of this contact with shale was found, but a sandstone at the south end and near the forks of Tow Creek showed only a slight hardening of the rock. None of the intrusions seems to have been accompanied by any appreciable amount of water and this likely accounts for the very slight effects thus produced.

STRUCTURE

GENERAL

The structure in this district is an asymmetrical anticline having three crests located along an axis of northward trend which bends northeast at its northern extremity and slightly southeast at its southern extremity. This axis plunges to the south and hence the northern crest is the highest. These three crests are separated from each other by synclines crossing the anticline almost at right angles to the axis. The fold produced lies approximately parallel with the mountain uplift with the steep side facing toward it. The general trend of the axis of this fold is roughly parallel with the major folds in bordering districts, such as the Trull anticline, and the Sage Creek anticline. The west limb of this anticline has a rather constant dip of about 12° westward and the east limb a steep dip of from 40° to 50° eastward in the Yampa River valley and lessening considerably to the north. (See Pl. III., in pocket.)

YAMPA CREST

The southern and lowest crest occupies the area along Tow Creek below its forks and along the Yampa River in sections 7, 8, and 17, T. 6 N., R. 86 W. The anticline has been tested by two wells, neither of which gave favorable results. The logs are not reliable and there is no certainty of the depth attained. The well along the Moffat Highway in section 7, T. 6 N., R. 87 W., is a dry hole, and from reports concerning its depth went down a consid-

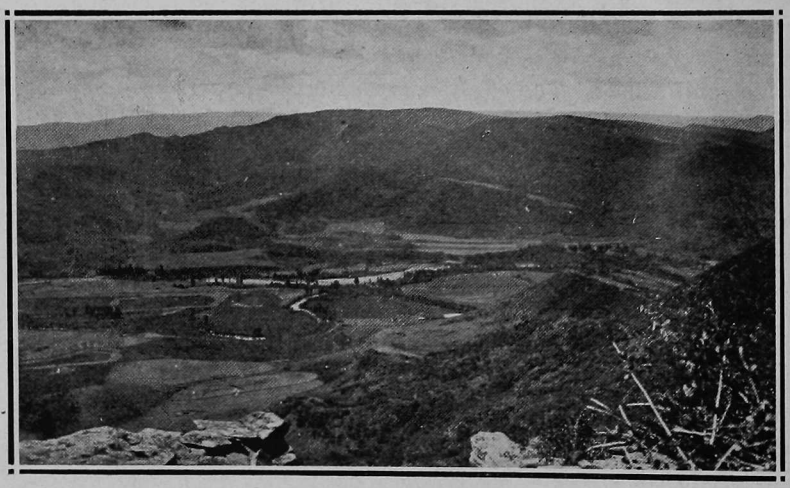

Fig. 6. Yampa crest of the Tow Creek anticline from the Tow Creek sandstone ledge

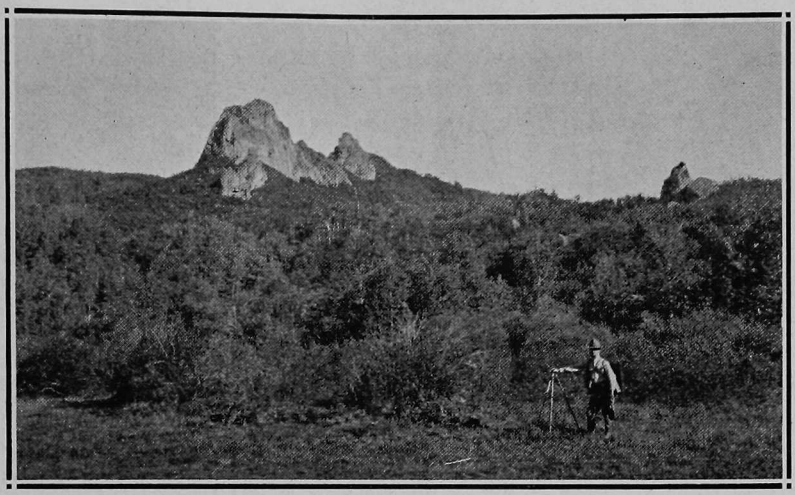

Fig. 7. Dike in the Tow Creek anticline

erable distance into the Mancos shale without obtaining any oil. The other well located in section 32, T. 7 N., R. 87 W., is on the east side of Tow Creek about a quarter of a mile below the forks. It flows a small amount of water steadily. This well begins near the base of the Mesaverde and probably went some distance into the Mancos. This well is seemingly fairly well located to test the structure, but perhaps is a little too far to the east and may have gone principally into the Mesaverde beds, which have a very strong dip to the east at this place. This seems to be indicated by the fact that artesian water was obtained. A more favorable and decided test would be about a half mile farther south and on the west side of Tow Creek. The possibility that the intrusion resembling a laccolith, to the north of the well, but separated from it by a syncline, has caused leakage in this dome, cannot be overlooked. Its nearness suggests that it may have fractured or replaced a part of the possible oil reservoir south of the syncline and thus rendered this crest unproductive. From the contact slopes of the intrusion it seems quite probable that downward it breaks into and fractures the possible reservoir rocks of this district.

In case future developments should secure good quantities of oil in the Chimney Creek crest a more extended exploration of this dome might be warranted. Plentiful fuel from the coal mines of MacGregor and Mount Harris could be easily obtained, and the Yampa River and Tow Creek would furnish a plentiful supply of water for drilling needs.

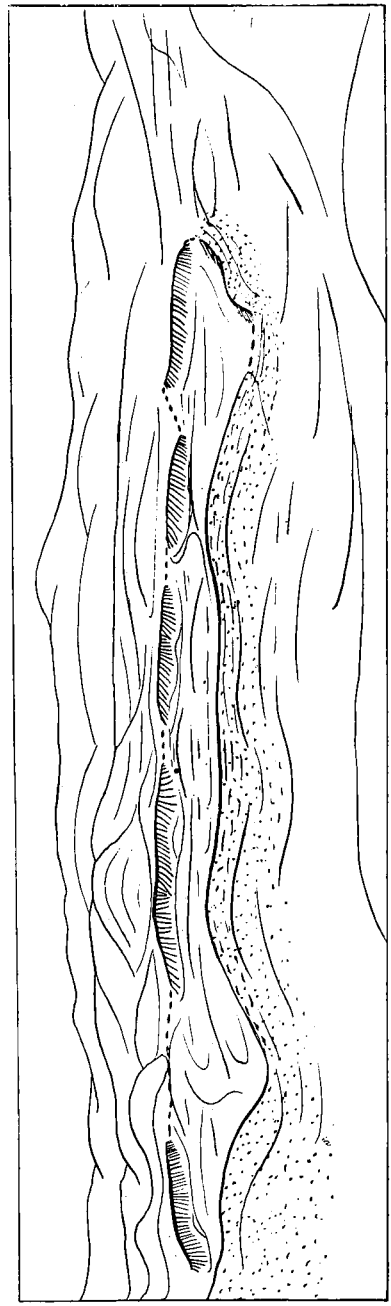

Fig. 8. Chimney Creek dome looking north; sketched from a photograph

CHIMNEY CREEK DOME

The northern crest is a quaquaversal structure in Mancos shale on Chimney Creek with its center in section 4, T. 7. N., R. 86 W. This structure is nearly a perfect dome as shown by the almost circular outcrop of calcareous layers and the rather equal dip of about 25° in every direction. These dips flatten out in every direction quite rapidly. The results of operation of forces necessary to produce such a fold can be seen in other parts of the area, but it is possible that an intrusion of igneous rock, laccolithic in type, may underlie this fold. (See fig. 9.) It may also have been formed by a combination of these forces. The possibilities of igneous intrusion beneath this crest are strengthened by the presence of three dikes or sheets which show in irregular and interrupted outcrop around the dome. These sheetlike bodies do not follow the bedding planes of the shale exactly, but are intruded at practically the same angle and cut across the bedding only for short distances. The rock of these intrusions is basalt and is about the same in all, and very much like that of the dike in Chimney Peak. The nearest body is a dike about three miles to the northwest. That these sheetlike bodies around the dome carry corroded grains of quartz seems to indicate that they have picked up this material not far away, and it is quite possible that they are really dikes and the included quartz was taken up in passing through the sandstones. That dikes would be intruded in a circular form at such nearly equal distances from the center of the fold seems rather improbable unless connected to a laccolithic body underlying the dome. Assuming this to be the case, oil may still be found in the dome, as their metamorphic effect on the shale is very slight. If the oil had accumulated previous to intrusion there would likely be some seeps around the intrusions. No such seeps were found nor was there anything along the contact to indicate that oily matter had been passed through. In case the accumulation is taking place at present the dikes would not materially injure the chances of obtaining oil from this structure, but it might restrict the district in which it could be obtained to that part of the dome lying outside of the area inclosed by them. The metamorphism of the possible oil reservoirs is probably not much greater than that seen in the shales.

The possibility suggested above that the crest is underlain by a laccolithic body deserves much consideration, but nothing more than hypothetical conjectures can be advanced until data obtained

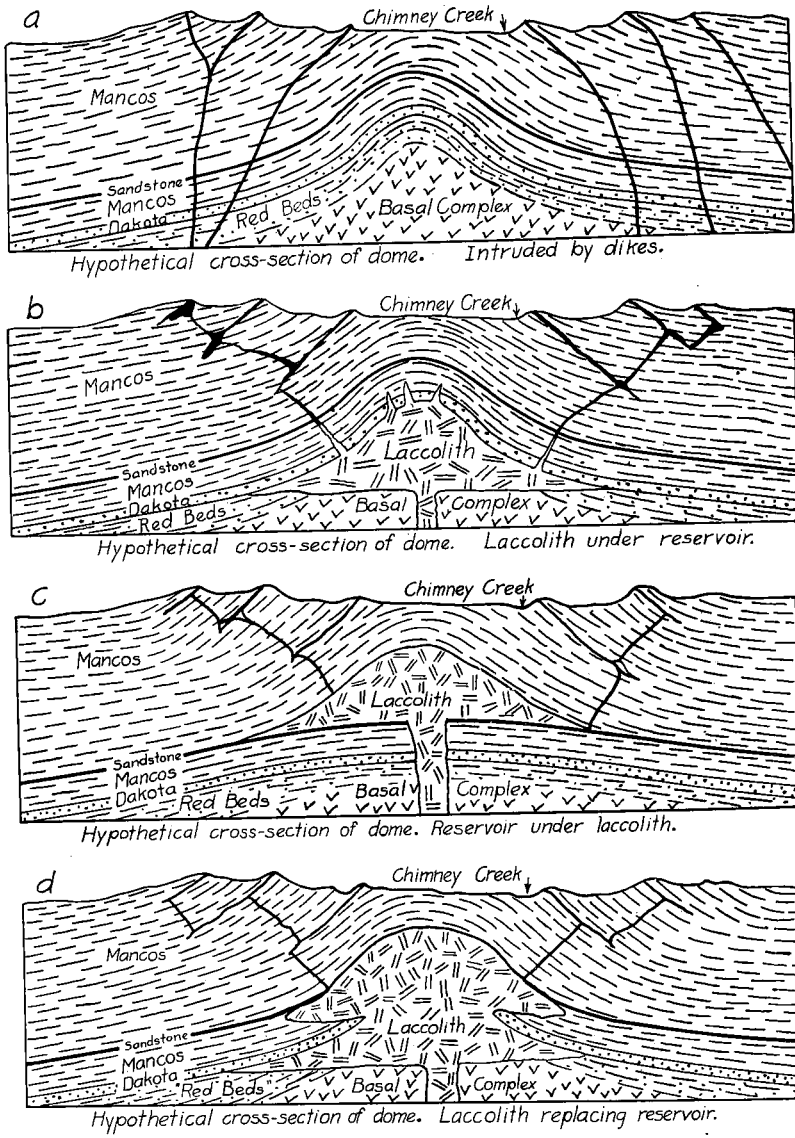

Fig. 9. Possible relationships of rocks in the Chimney Creek dome

from drill holes are available. If a laccolith or thick sill has caused or accentuated the arching and doming of this structure it would still be possible for oil to accumulate under certain conditions as follows:

(a) If an oil reservoir lies above the laccolithic body and it is not materially changed by the intrusion, the possibilities of obtaining any oil which may have accumulated are not affected by the presence of the intrusion. (See fig. 9b.)

(b) If a reservoir lies underneath the laccolith and has not been too much altered it probably has sufficient arching for the accumulation of a commercial quantity of oil. (See. fig. 9c.)

(c) If the possible reservoir has been displaced or broken up by the igneous intrusion it would probably be necessary to go beyond the borders of such disturbed area to find an oil reservoir. (See fig. 9d.)

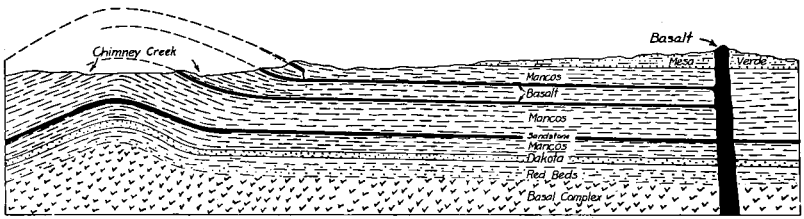

Fig. 10. Possible relationships of sedimentary and igneous rocks in the Chimney Creek dome

Evidence of channels which would allow the movement of magma upwards is seen in the thickened bodies at four or five places in the line of these intrusions. That these channels seem to diverge upwards from a point near the center of the dome may indicate that arching movement took place subsequent to their opening. That these thickened places probably represent channels which probably connect the sheetlike intrusions seems likely. If such is the case they would not materially affect the foregoing discussion as they may or may not indicate a laccolithic intrusion. The size of one such body appearing in a hill on the south side of Chimney Creek at the southwest side of the dome is such as to give evidence of outlet sufficient to almost, if not quite, prevent the formation of a laccolith.

So far as the present knowledge permits, based on data obtained at the surface, these intrusions may be regarded as sheets (fig. 10) with occasional thickenings, or possible channel connections. As to the possibility of there being other sheets below the known bodies very little can be said. If there are others it is likely that they are quite similar to those exposed and would thus have a small effect on any oil which may have accumulated or may be accumulating. Regarding these bodies as sheets, they were probably

intruded either at a time previous to the folding which, followed by erosion, has caused them to be exposed, or perhaps subsequent to folding and previous to erosion. The metamorphic effects of these intrusions is described elsewhere.

Drilling needs.—Water sufficient for drilling needs could probably be obtained from Chimney Creek with little trouble. In case the water there was found to be insufficient it could be easily obtained by pumping from Deep Creek. Coal for fuel can very likely be obtained in good quality and quantity from mines and prospects, within four or five miles.

TOW CREEK CREST

The middle crest of this anticline, of which the structure contours are shown on the map, is filled with an igneous intrusion which resembles a laccolith. No deeply eroded channel has been cut by which such a hypothesis can be substantiated but certain evidence is available. The shape of the igneous body as presented on the surface is roughly elliptical with its long direction lying north and south. On all sides the Mesaverde sandstones dip away at angles varying from 10 to 45 degrees. The borders of the igneous intrusion are of a finer-textured rock than that composing the central parts. This central part which grades insensibly into the finer-grained rock of the fairly wide border is porphyritic, and is described elsewhere. On the igneous rock near the central part of the southern half is a small patch of basal Mesaverde sandstone, the lower part of which contains a layer of bituminous sandstone very similar to that from which oil seeps to the east along the creek. Near the border at the south end of the igneous rock is another small patch of Mesaverde sandstone similar to the one above and also to those connected with the oil seeps. The significance of these patches of sandstone seems to be that the Mesaverde formation once covered at least the greater part of the intrusion. That a considerable cover was present on the intrusion is indicated by the porphyritic texture of the central part of the mass. Provided the intrusion was stocklike in character the rock would likely be porphyritic in character to within a very short distance of the contact. The particular position of this intrusion with the adjacent folding is suggestive of the fact that the strata were affected by some such force as would be exerted by an intrusion of laccolithic shape.

From impressions gained in the field and substantiated in making the structural contour map, the normal results of folding, with-

out intrusion, would have produced a fairly broad syncline, of low dip northward away from the Yampa crest. Instead, this syncline dips sharply away from the north end of the Yampa crest, and flattens out abruptly for a short distance. From the contact on the south end of the intrusion the sediments dip southward to the flat part of this syncline. The syncline thus produced instead of being broad is narrow, and instead of making a smooth downward curve, is irregular. The shape of this syncline between the Yampa and Tow Creek crests is not strictly characteristic of the forces which seem to have operated in the formation of the other parts of the anticline, but seems to indicate a force acting at an angle upwards, such as would be exerted by a laccolithic intrusion. To sum up the evidence the intrusion closely resembles a laccolith, and no oil can be expected from drillings in the igneous rock.

OIL POSSIBILITIES OF THE TOW CREEK ANTICLINE

There are various indications of the presence of oil within the strata of this area. At three points along the Moffat Highway water seeps carry small amounts of oil which have accumulated as a residue in the earth around these seeps. That saline matter is also present is shown by the thin crust of alkali around the borders of these seeps. These seeps come from the sandstones lying just above the Tow Creek sandstone. The saturated earth gives a decided oily smell when heated with a match, and in some places where it has been hardened and concentrated by the sun's rays will almost ignite. An oily scum is also present on the small puddles around these seeps.

About three hundred feet above the forks of Tow Creek on the east bank of the east branch is a ledge of sandstone very close to the base of the Mesaverde formation which is saturated with a dark tarry oil. The surface of this ledge has been opened up for about 4 feet vertically and 10 feet horizontally, the top and bottom of the layers are shale contacts toward which the oil decreases in amount. There are occasional shale partings at intervals of from 2 to 10 inches. This layer of sandstone is just full enough of oil so that it does not ooze from the surface, which is of a dark brown color. In each direction this ledge is covered with debris from the slope above, and about a half mile up the creek the surface has been uncovered again and here a short tunnel was being driven into the ledge to drain the oil from the rock. The oily rock taken from the tunnel was, in August, 1919, being heated in a small crude

still to extract the oil. Some of the oil thus obtained was examined and found to be very similar to crude petroleum from oil wells.

In a sandstone ledge the thickness of which was undetermined on account of the debris covering it, and which is about a hundred feet above the still, is an oil spring described in bulletin 297 of the United States Geological Survey, page 79. A small pool has been formed where it issued from the rock. When examined the surface of this pool was covered with a scum of dark, tarry oil which was very slowly trickling over the edge with some water. The water seemed to be just enough to keep the pool at a constant level and trickle over the side for a few feet where it was absorbed and dried up. The slope below was covered with waste from above, but a considerable amount of brea, presumable overflow from the pool above, had accumulated on the surface from which the earth and brush had been removed over an area about fifty feet wide and two hundred feet down the slope. This layer was not uniform in thickness, and in most places did not exceed three inches. The prospectors had uncovered some chunks six or seven inches thick without reaching bottom. This patch, including the spring, was fenced in to keep out the stock, for which these seeps, probably on account of their salt, have great attraction. One of the prospectors working on the little tunnel below, said that he had skimmed about a bucket of oil each evening for the past seven years from this pool.

Past experience has been largely against the possibilities of obtaining oil in districts into which igneous rocks have been intruded, but in certain Mexican fields their presence has been shown to be favorable to very productive areas. A district in which the structure, rocks, and conditions are quite similar to this is that between Tuxpam and Tampico where very productive wells have been obtained around the igneous intrusions. For a fairly complete discussion of these occurrences consult "The Mexican Oil Fields," by L. G. Huntley, in the Transactions of the American Institute of Mining Engineers, Volume 52, pages 281-321. It is not at all certain that the conditions in Mexico are reproduced exactly enough in this district to warrant drilling on the limbs of the fold adjacent to the intrusion, but provided that the Chimney Creek crest was found to be productive, and other nearby fields show good quantities of oil in the strata below the Trout Creek sandstone, the west limb of this fold would be worth prospecting. In any event the dike running northward from this intrusion to the south crest of Wolf Mountain may trap oil coming up the strata

from the south and west, and if such is the case, wells could be drilled to tap the reservoir along a line roughly parallel to this dike and at no great distance from it. On the east side of the structure the seeps indicate a leakage of oil from some reservoir or else the accumulation of very small amounts close to the surface due to the action of circulating waters. The conditions on this side of the structure seem far less favorable to the accumulation of oil in strata than on the west side.

The Mancos shale forms broad valleys, rolling hills and plains between the Dakota ridges or hogbacks and the harder basal ledges of the Mesaverde formation. This shale formation has numerous fossils, especially in the basal and upper parts, and contains considerable carbonaceous material. These carbonaceous beds of shale are directly overlain by a thick cover of sediments which also carry large amounts of material such as seems to be productive of oil. That oil is actually contained in the strata can be seen by the various seeps of the district. Granting that the substances from which oil could be produced are contained in the strata it is only necessary to have the proper forces acting and it will form. The forces generally considered necessary are heat or pressure, or both. That such forces have been at work is quite certain. The accumulation of any oil formed will generally be accompanied and aided by ground waters. That sufficient ground waters have been present seems highly probable, and that they have been in more or less constant motion, especially since deformation began, is almost certain. Since the essential conditions necessary to produce, accumulate, and store oil have probably been represented here, it seems from this standpoint that the field is favorable to the production of oil.

This anticline is as yet unproved. The conditions seem to be favorable to careful tests, and of these the first should be made on the Chimney Creek crest where the sandstone in the Mancos might be reached near the center of the dome at a depth of about 600 feet, and the Dakota sandstone at about 1,100 feet. In drilling, both of these possible reservoirs should be tested. In the southern crest, which seems to have conditions second in favor to the one above, the Mancos sandstones should be about 1,800 to 2,000 feet, and the Dakota sandstone 2,300 to 2,500 feet below the surface, but thickening of the Mancos formation would increase these figures. The conditions in the Tow Creek or middle crest are the least favorable of the three, and prospective drilling should follow the conditions previously discussed.

ANTICLINES NEAR STEAMBOAT SPRINGS[17]

BY V. C. PERINI

SEDIMENTARY ROCKS

The stratigraphic column is made up of rocks mostly of the Upper Cretaceous age. There are some unconsolidated gravels and boulders that lie unconformably upon the Cretaceous rocks that probably belong to the Tertiary or Quaternary system.

In studying the formations the report by Fenneman and Gale[18] was used almost entirely. A generalized section of the rocks was taken from this report and studied and followed wherever possible. A check was made of the thickness of the Mesaverde formation in Yampa canyon. A complete section of the Mancos formation could not be found in this vicinity, but a part was obtained on Poose Creek, southwest of Williams Park.

"DAKOTA" FORMATION

This formation is approximately 150 feet in thickness and is made up of sandstones, shales and conglomerates. The lower part at some places contains a conglomerate composed of gray flint and feldspar pebbles. The upper part is characterized by a grayish-white, even-grained, massive sandstone and beds of sandy shales and slabby sandstones.

At Steamboat Springs, this formation forms a prominent ridge and the beds are clearly shown where a railroad cut has been made through part of the formation. The strata dip about 35° to the west at this place, and are found overturned to the north of the Yampa River.

The characteristic cross bedding, ripple marks and flow and plunge structures, that are usually found in this formation of other regions, were not found to any great extent.

MANCOS FORMATION

The shales of the lower part contain sand, and where weathered are very brittle and light colored. Some of the shales found near

[17]What follows is an abridgment of a thesis submitted by Mr. Perini in June, 1920, to the Graduate Faculty of the University of Colorado in partial fulfilment of the requirements for the degree M. S. To publish the entire paper would necessarily nearly duplicate part of what appears in previous pages of this bulletin. Accordingly only the statements that apply more particularly to the area mapped by Mr. Perini appear here. This area includes the southern part of the Tow Creek anticline, the Curtis anticline and the Trull anticline.—R. D. C.

[18]Fenneman, N. M., and Gale, Hoyt S., The Yampa coal field, Routt County, Colorado. U. S. Geol. Survey Bull. 297, 1906.

Steamboat Springs in the vicinity of Deer Mountain, are platy and exceedingly hard. When dug into they separate into large, regular, smooth-surfaced sheets. They are usually thick bedded with regular bedding planes. The shales of the upper part are dark, calcareous, and thin bedded. In some places, however, the beds are thicker and rather hard with very definite bedding planes.

A 38-foot bed of sandstones and sandy shales was found south of the Elk River near the Trull schoolhouse, section 28, T. 7 N., R. 85 W. The section of this bed is as follows:

Fine-grained, fossiliferous sandstone	7 feet
Alternating sandstones and shales	16 feet 8 inches
Thin-bedded sandstones	14 feet 7 inches
	38 feet 3 inches

It was impossible to determine how far this bed occurred above the base of the Mancos. It probably lies approximately 400 feet above the base as a similar bed found on Poose Creek southwest of Williams Park, and the bed shown in the columnar section in Bulletin 297, United States Geological Survey, are about this distance from the base.

MESAVERDE FORMATION

This is the most conspicuous formation in the field, and it is approximately 3,500 feet in thickness.

The more prominent sandstones and coal beds form rather definite horizons which are the basis of this formation, being divided into lower, middle, and upper coal groups. From the base of the Mesaverde to the lower coal group, alternating beds of sandy shales and sandstones are found. The sandstones are massive at some places, the beds being from 80 to 100 feet thick. There are also thin sandstones which alternate with the sandy shales. The sandstones are usually hard and fine grained. They differ in color from a cream to a grayish white and in some places have weathered to a dark yellow.

The Tow Creek sandstone is the most outstanding rock of this group. It is very massive and at some places is 100 feet thick. The freshly broken surfaces are cream-colored which weather to a distinctive yellow. The texture differs at the various outcrops, but in general it may be classified as a medium-grained sandstone. The most prominent exposures of these sandstones and shales are found on the eastern limb of the Tow Creek anticline where the Yampa River has cut its channel through them.

The Trout Creek sandstone is the most important stratum between the lower and middle coal groups. It is a massive white rock, and usually forms ledges wherever it is exposed. These ledges are 50 to 100 feet high which are weathered in part into pinnacles. Wherever the slightly dipping sandstone has been exposed to any great extent, cracks appear at the surface making odd-shaped outlines. These cracks form an easy place for erosive agents to work, and the surface is usually roughly and irregularly marked by five-sided and six-sided figures. The cracks are probably formed by expansion and contraction due to the differences in daily temperatures.

The beds between the Trout Creek sandstone and the top of the lower coal group consist of alternating shales and thin sandstones.

Between the top of the middle coal group and the top of the Mesaverde, sandstones and shales are found. The lower part consists of alternating beds of sandy shale and thin sandstones with an occasional stronger bed of sandstone.

The Twentymile sandstone is very similar to the Trout Creek sandstone. It is also white and massive and forms prominent ledges. The most prominent ledge found was on the western limb of the Tow Creek anticline where the dip averages 9° to the west. Here the sandstone forms a vertical ledge about 75 feet high which is almost continuous around the southern end of the anticline. This sandstone is generally softer than the Trout Creek sandstone and usually weathers into more prominent pinnacles. These pinnacles stand from 4 to 10 feet high at the southern exposure around Twentymile Park. Some have small diameters and their pitted markings indicate that they were probably formed partly by wind erosion. They are in places capped by a harder sandstone layer.

On the eastern flank of the Tow Creek anticline where the dip averages about 25°, this sandstone has been eroded to a greater extent. It forms a series of white humps which are separated by shallow depressions. This condition probably is due to the atmospheric agents, which have more erosional effect on the upturned edges.

Above the Twentymile sandstone, shales, thin sandstones and a prominent white sandstone are found. This white sandstone is massive with an average thickness of about 50 feet.

LEWIS FORMATION

The main outcrops of Lewis shale are found on the western flank of the Tow Creek anticline, and in Twentymile Park.

TERTIARY OR QUATERNARY BEDS

The hills east of Trout Creek and south of the Yampa River towards Steamboat Springs are, in part, covered by a mantle of recent gravel and boulders. This mantle lies unconformably on the Mancos shales and is conspicuous on the rounded hill tops to the east of Trout Creek.

The gravel is unconsolidated and made up of a mass of coarse igneous material. Pegmatites, granites, gneisses and basic rocks were found which were probably washed from the crystalline rock area to the east.

There is also a mantle of the same material covering the top of Deer Mountain. The material found here is coarser and more angular than the material east of Trout Creek. When Deer Mountain is viewed from a distance, the top of the mountain and the crystalline area to the east appear to have been a continuous slope at one time. This indicates that the gravels were probably washed from the area to the east. Deer Creek has cut a deep valley through this material and the shales beneath, and now separates Deer Mountain from the main range.

STRUCTURE

GENERAL FEATURES

Sedimentary rocks are usually laid down by water in an approximately horizontal position. At a later period, by the processes of mountain-making movements, these rocks are sometimes lifted many thousands of feet. Anticlines, domes, synclines, and other structural features are the result of these movements. Structure means the attitude which the rocks have acquired since they were formed. Faulting usually accompanies these movements, especially in the sandstones.

Owing to the fact that there has been such intense folding in this region, there are probably many faults and fractures that do not express themselves at the surface. It can not be determined as to how much faulting has occurred in the underlying Mancos formation, and in the lower sandstone members of the Mesaverde formation. If there has been any considerable amount of faulting in the Mesaverde formation, the accumulation of gas and oil would be seriously hindered, and the greater part that may have accumulated would probably escape through the fissures and other openings caused by the faulting. If the faults do not extend beyond the lower sandstone members of the Mesaverde formation, the oil and

gas, if accumulated in the Mancos formation, may find a way to the sandstones of the Mesaverde formation, and there be sealed, making a large reservoir.

Throughout this region the basal complex is overlain by thousands of feet of sedimentary rocks. These rocks were probably horizontal at earlier times, and there were minor movements that resulted in the advance and retreat of the sea. This is indicated by the presence of sandstones, shales, and conglomerates. These sediments were uplifted during Tertiary (?) times, and the main folds now present were formed as a result of the forces originated. The folds that were formed at this period were probably those having axes roughly parallel to the Front Range. These folds are: the Tow Creek anticline, the Trull anticline, the Sage Creek anticline, and the fold passing through Williams Park.

There are also anticlines and synclines whose axes are almost at right angles to the above folds. These are: the Curtis anticline, the Twentymile Park syncline, and the syncline roughly parallel to the Yampa River. These folds were probably formed at a later time, and might have been formed in a long, wide syncline that existed between the Tow Creek anticline and the Trull anticline, by forces from the north or south. Mr. Willson states that the evidence found indicates that the intrusion of igneous rocks forming Elk Mountain, and the many dikes and other igneous bodies north of the river, were intruded after the main folding had taken place. The forces generated by the intrusion of Elk Mountain might have been sufficient to form the Curtis anticline.

RELATION TO TOPOGRAPHY

The topography depends to a considerable extent on the structure and hardness of the underlying beds. Throughout this region wherever the strong resistant sandstones of the Mesaverde are the underlying beds, the slopes follow the structure of these rocks. When the field is observed from the higher points this feature is well demonstrated. Twentymile Park, which lies to the east of the Tow Creek anticline, is a structural basin about 4 miles wide and 9 miles long, the strata dip towards the center on all sides. The central part is a low-rolling plain in the easily eroded Lewis shales. As the edges are reached the relief increases where the sandstones of the Mesaverde come to the surface and form escarpments to the south. This makes an abrupt slope on one side and a long gentle slope toward the plain within, which follows the general dip of the formation.

The Tow Creek anticline is another example where the slopes on each limb follow the structure of the underlying beds. Where the sandstone beds are upturned to any great extent, and are of unequal hardness, erosion acts more rapidly on the softer beds and leaves the harder layers as long, narrow, sharp-crested, parallel ridges. The lower part of the Mesaverde develops this kind of topography on the east limb of the Tow Creek anticline near the Yampa River, and also in Dunkley Canyon.

Where the Mancos or Lewis shales are the underlying beds, which are practically of equal hardness throughout, rolling or gently undulating plains usually result. The topographic features are seldom controlled by the shales. In comparison with the sandstone areas, when the shale areas are observed from the higher points, the general structural features can not usually be determined by the slopes of the hills. The slopes are very deceiving at times, and indicate promising reverse dips. Closer examination, however, shows that the dip of the sediments is, at some places, opposite to the slope of the ground. This is especially true near Steamboat Springs.

TOW CREEK ANTICLINE

The Tow Creek anticline is roughly oval in outline with minor modifications to the northwest and northeast where a syncline crosses the axis of the anticline. Mr. Willson, who was in charge of the mapping of this anticline, north of the river, reports that it has a closure of about 600 feet at the northern limit of the axis. The crest is in sections 5, 6, 7, and 8, T. 6. N., R. 86 W. (See Plate II.) This fold, south of the Yampa River, pitches to the southwest. The dips to the east are very steep, especially in the northern part where they average about 40°. The dips to the southeast and south are more gentle and average 20°. The dips to the west and to the southwest average 9°.

The gathering area for this fold, from which the gas and oil, if present, are accumulated, is limited on the east by a steep syncline that separates it from the Curtis anticline, the syncline parallel to the Yampa River, and the Twentymile Park syncline. It is limited on the southeast and on the southwest by synclines that separate it from the Foidel Canyon fold, and the fold that passes through Williams Park. The main area from which oil or gas may have been gathered is, therefore, the broad low area to the west. Smaller quantities may have accumulated from the Twenty-

mile Park syncline, the syncline parallel to the Yampa River, and from the syncline to the south.

This anticline was partly tested by a well that was drilled in 1902 (?) in the southeast corner of section 7, T. 6 N., R. 86 W. The well at the present time is inactive, and no reliable information could be obtained as to its depth or sands encountered. The information obtained indicates that it was a dry well. It appears that this well was drilled slightly too far to the east. The axial plane of the anticline, as estimated from the structural map, dips 85° to the west. This would place the crest of the possible Mancos oil-bearing sandstone almost immediately beneath the well. If this anticline produces gas, as the Williams Park anticline from the "Dakota," the well would more probably encounter the oil, if present, if drilled farther to the west on the western limb of the anticline, and farther to the north, nearer to the crest.

The Mancos sandstone at the crest is approximately 1,700 feet below the level of the Yampa River. The "Dakota" sandstone at the crest is approximately 2,200 feet below the level of the Yampa River. This approximation is fairly accurate if there has been no local thinning or thickening of the Mancos formation at this place.

The Tow Creek anticline is structurally favorable for the accumulation of oil and gas. If the petroleum is present in any of the underlying rocks, and is associated with water under pressure, it will probably migrate up the dip. The oil would then be expected to accumulate near the crest of the anticline. The writer did not examine the area to the north to determine the influence of the igneous rocks present on the accumulation of the oil or gas, hence he does not feel justified in recommending or condemning this anticline.

CURTIS ANTICLINE

The Curtis anticline lies in the central and southwestern part of T. 6 N., R. 86 W. (See Plate I.) Its axis, which trends northwest and southeast, is almost at right angles to the Tow Creek anticline. This anticline plunges to the west and is separated from the Tow Creek anticline by a steep syncline. The dips to the northwest and southwest average 15°. The dips to the north average 20°. The dips to the south average 10°. The dips taken on the massive sandstones west of Trout Creek are not reliable, as these sandstones were almost level and no definite bedding planes could be found. There also appeared to be some slumping caused by weathering. The average dips taken on these sandstones were 2° to the south-

west, and 2° to the northwest, which places this fold in the terrace type of folds rather than the true anticlinal type. These dips were probably away from the axis of the fold where the anticline has its broadest limit. The narrowest part is to the west where it closes.

Sufficient time was not available to examine the eastern boundaries of this fold as closely and carefully as was desired. The dips recorded, however, along the eastern side of Trout Creek indicate that the fold opens to the southeast and therefore would allow the escape of any gas or oil.

Bulletin 297 of United States Geological Survey, referred to before, shows a probable fault near Trout Creek. This fault was not definitely found by the writer, but the appearance of a massive white sandstone east of Trout Creek below the general level of the Trout Creek sandstone, indicates that there was a displacement of some kind. If this fault is present, and the displacement is of any great extent, there is a probability that it has sealed any gas or oil accumulated to the west of the fault.

The gathering ground for this fold is limited on the west by the Tow Creek anticline, on the north by a narrow syncline parallel to the Yampa River, and on the south by the Twentymile Park syncline.

It is suggested that this fold be studied and investigated more carefully, in order that more definite conclusions may be deduced as to its oil and gas possibilities.

TRULL ANTICLINE

The Trull anticline extends from section 4, T. 7 N., R. 85 W., to section 9, T. 6 N., R. 85 W., where it disappears under the alluvium south of the Yampa River. Mr. Willson mapped this anticline north of the Trull schoolhouse, which is on Elk River.

The dips recorded on the western limb between the Yampa River and the Elk River average 50°. Those north of Elk River, where the anticline becomes broader, average 42°. The dip of the shales on the eastern limb at the Yampa River is 42°. Between this dip and Elk River no reliable dips were recorded on the eastern limb, as the shales are covered by a gravel and boulder deposit, and slumping hindered the obtaining of accurate dips near the Elk River. The dips taken on the eastern limb north of the Elk River average 50°.

This anticline is in the lower part of the Mancos formation, as shown by the outcrops of the Mancos sandstone in sections 28

and 4, T. 7 N., R. 85 W. It closes at the northern end where the dips are 60° to the northeast and 50° to the northwest. These dips were taken on the Mancos sandstone where the Elk River cuts its channel through the fold. The elevations of the two sandstone outcrops were approximately determined, and it was found that the anticline plunges slightly to the south towards the Yampa River syncline, where it then probably opens again to the south. The general dip of the strata south of the river is to the northwest.

The outcrops found along both banks of the Yampa River do not indicate that the anticline closes or plunges to the south. The dip of the shales south of the river could not be obtained as they are covered by a mantle of alluvium.

It was noticed that there is an abrupt change in the trend of the axis where it crosses the Yampa River. This change may be due to a bend in the fold, or it may be due to a fault which crosses the fold. If it is a fault, the displacement, according to the bend of the axis, must be approximately 1,500 feet. There is no expression of such a fault on the surface to the east or west.

The gathering area is limited on the west by the intrusion of igneous rocks which form Elk Mountain, to the south by the syncline parallel to the Yampa River, and to the north by a sharp syncline. The greatest gathering area is to the east, and to the south of Elk Mountain.

If there is a fault present at the Yampa River, it would also limit the gathering area. It might also seal any gas or oil accumulated south of the river. The syncline parallel to the Yampa River is about two miles from the Yampa River, so if the fault did seal any oil or gas, the gathering area would not be sufficient to allow the accumulation of any commercial quantities of gas or oil.

The gentle plunge of the anticline to the south may change before it reaches the Yampa River. There is also a possibility of the presence of minor folds or wrinkles that do not appear at the surface. If these are present they would reduce the amount of accumulation at the highest point of the anticline to the north. The folding is sharp at the crest.

With such folding there was undoubtedly a great deal of fracturing within the sandstones. Any fractures present might allow the escape of gas or oil. The Mancos sandstone is open at two places which would permit the escape of gas and oil. If the "Dakota" sandstone contains gas and oil there is a probability of its being accumulated at the highest point of the anticline in section 4, T. 7 N., R. 85 W.

It does not seem justifiable to recommend a test of the Dakota sandstone as the structural conditions are not pronouncedly favorable, and because this sandstone is the only possible reservoir. The best location for a test well would be about 600 feet south of Elk River near the axis of the fold, in section 4, T. 7 N., R. 85 W. Wells drilled here should encounter the "Dakota" sandstone at a depth of about 600 feet.

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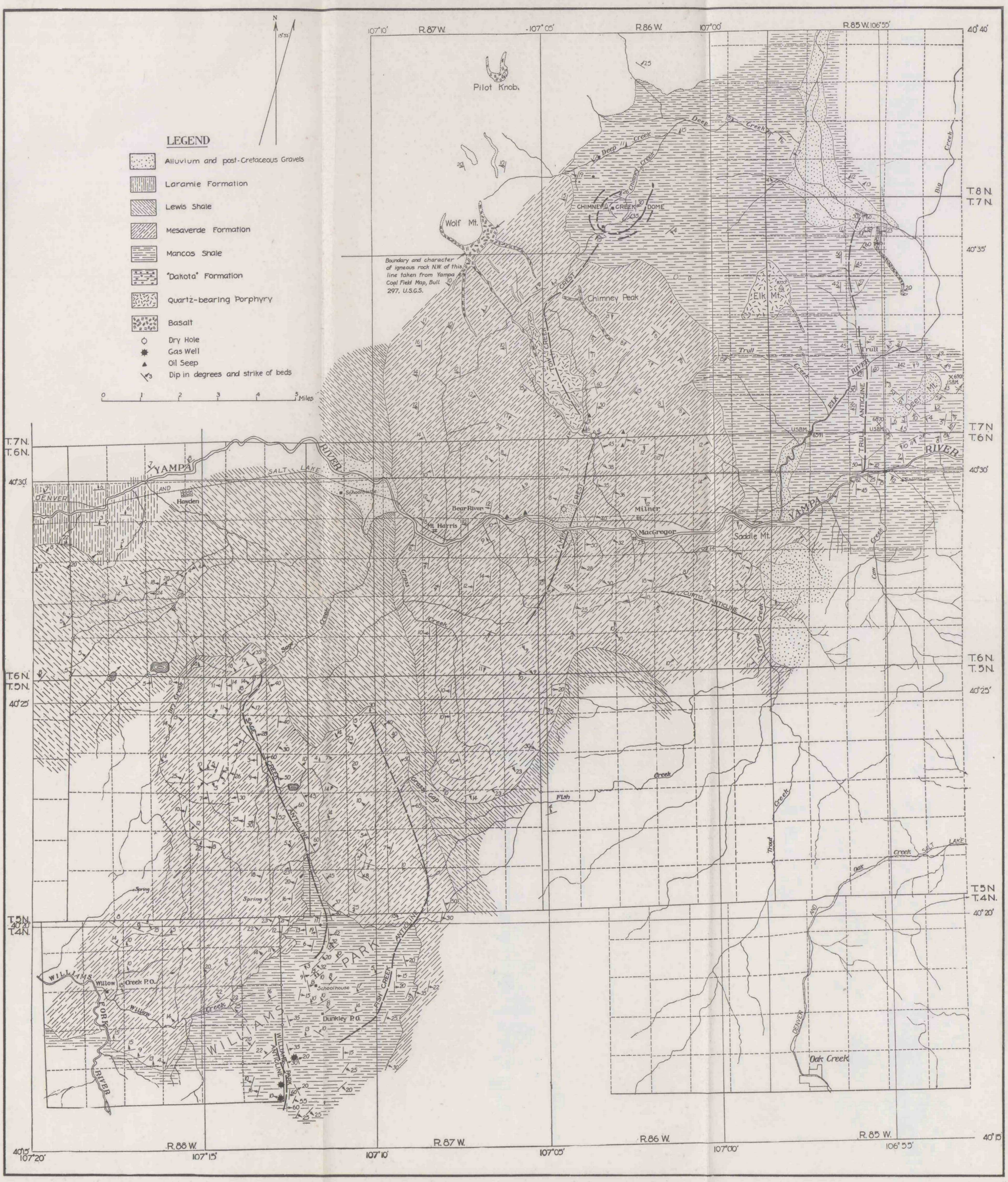
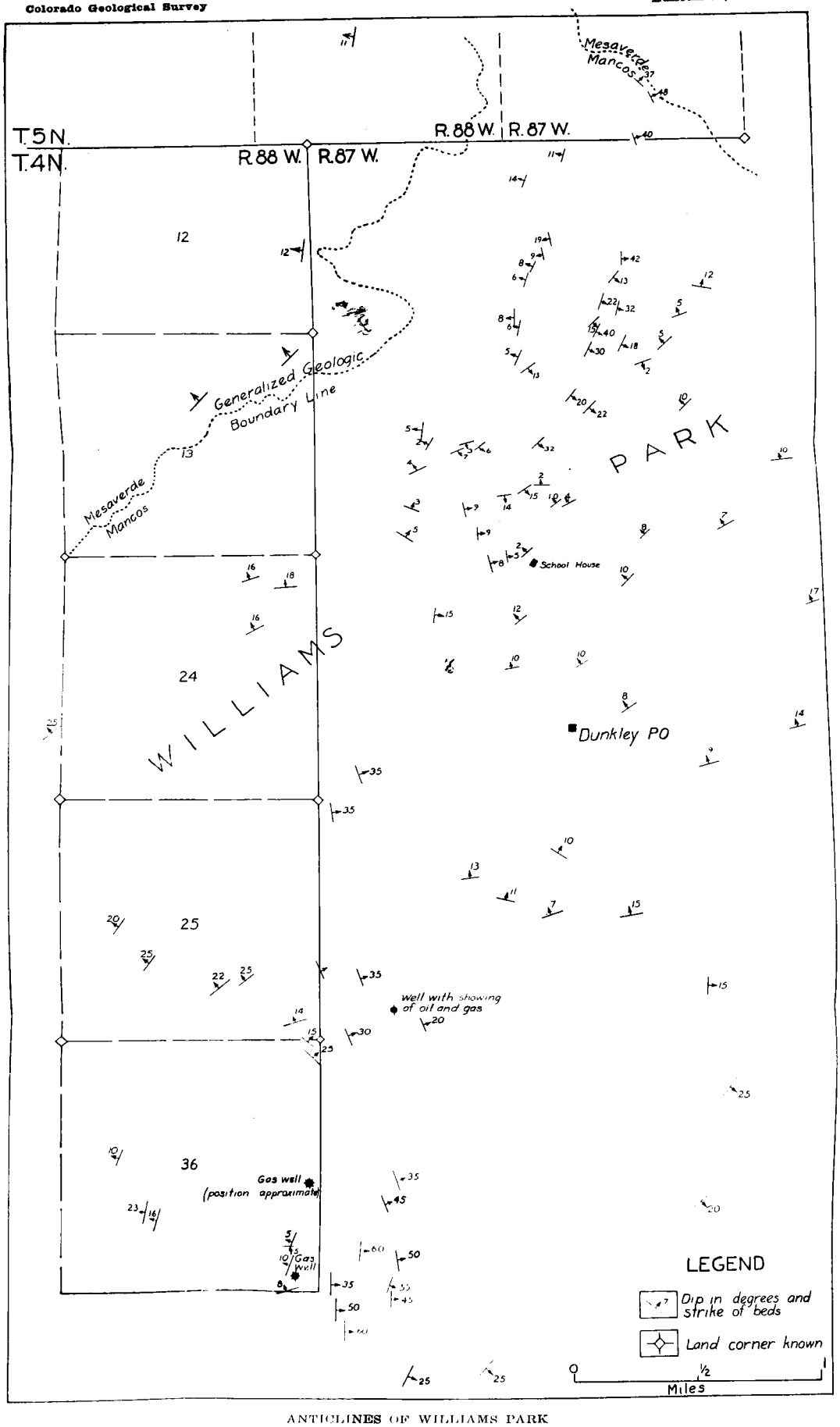
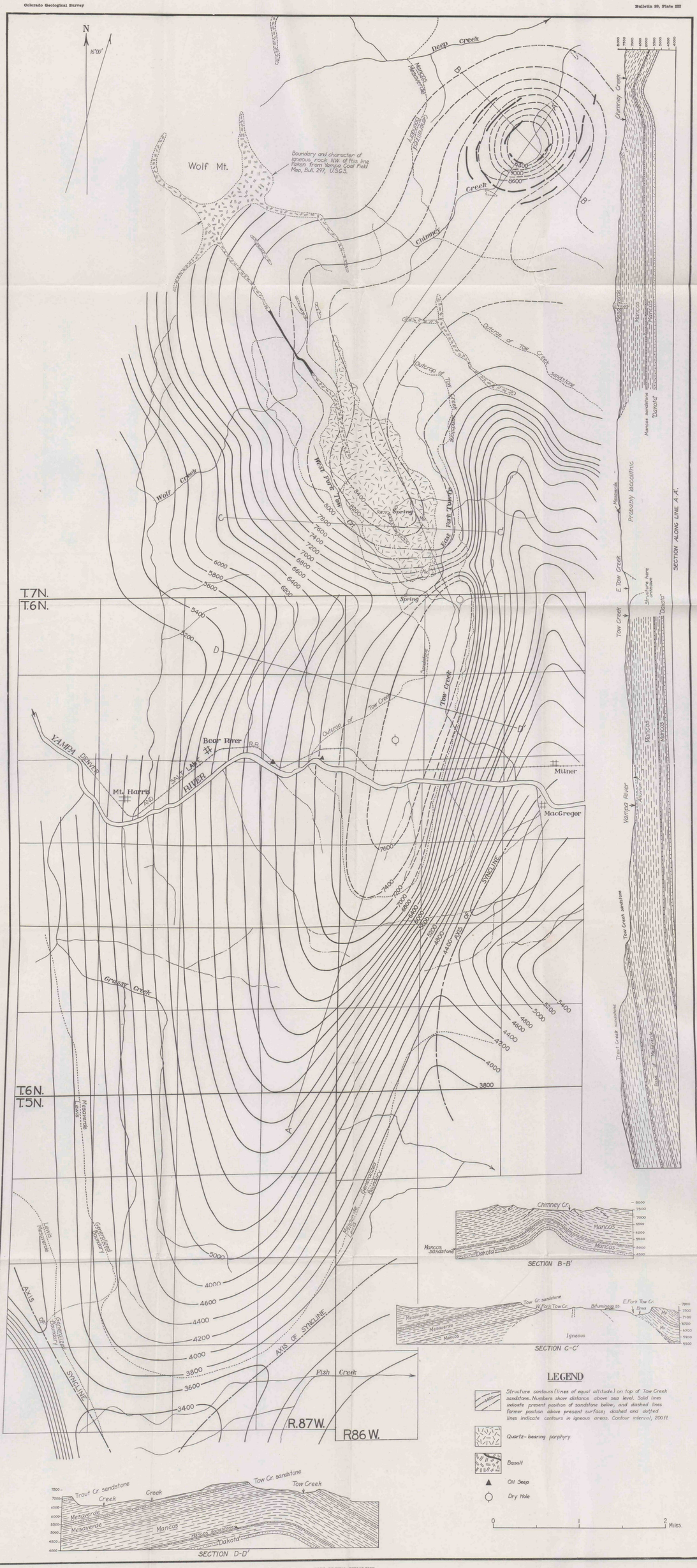


SOME ANTICLINES OF ROUTT COUNTY, COLORADO

Geology by R. D. Crawford, K. M. Willson, V. C. Perini, J. C. Myers and J. R. Murphy. Land lines and drainage taken from United States Geological Survey topographic maps of the Hahns Peak and Daton Peak quadrangles and United States Surveyor General's township plats



ANTICLINES OF WILLIAMS PARK
Geology by R. D. Crawford, V. C. Perini, K. M. Willson and J. C. Myers



TOW CREEK ANTICLINE

Geology north of Yampa River by K. M. Willson and J. C. Myers; geology south of Yampa River by V. C. Perini and J. R. Murphy

COLORADO
GEOLOGICAL
SURVEY

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 24

(Reprinted with parts of Bulletin 23,
"Some Anticlines of Routt County)

SOME ANTICLINES OF WESTERN COLORADO

BULLETIN 24 BY
R. C. COFFIN, V. C. PERINI, JR., and M. J. COLLINS
BULLETIN 23 BY
R. D. CRAWFORD, K. M. WILSON, and V. C. PERINI, JR.

BOULDER, COLO.
THE DAILY CAMERA, PRINTERS
1924

GEOLOGICAL BOARD

His Excellency, William E. Sweet, Governor of Colorado.

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LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, June 3, 1924

Governor William E. Sweet, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 24, (combined with parts of Bulletin 23), of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,

State Geologist.

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SOME ANTICLINES IN WESTERN COLORADO

INTRODUCTION

The intense interest in oil has created such a demand for the Survey publications bearing on the oil possibilities of the state that Bulletins 23 and 24 are out of print. The present bulletin is a reprint of the greater part of Bulletin 24 with which are included the most important parts of Bulletin 23. The parts of Bulletin 23 omitted are chiefly descriptions of formations, as the same formations are described in Bulletin 24. One of the maps accompanying the Bulletin is taken from Bulletin 23, and the other is taken from Bulletin 24.

ANTICLINES IN ROUTT AND MOFFAT COUNTIES

GENERAL GEOLOGIC AND PHYSIOGRAPHIC FEATURES

In most of the area covered by this report sedimentary rocks of Cretaceous age or younger predominate and occupy the greater part of the surface. In a few places, however, igneous rocks are found as remnants of former sheets, dikes, necks or craters. In general, it might be stated that the area in the vicinity of the Park Range is more likely to contain necks, plugs and craters than that country to the west and northwest.

The drainage of this area is essentially the same as that given by Fenneman and Gale[1] in their bulletin on the Yampa Coal Field. The largest stream, and hence the main channel for run off, is Yampa River. The largest tributary of Yampa River in the field is Williams Fork. In many places this stream has meandered and built up alluvial plains with rich black soil which makes the river bottoms desirable places to farm.

As a general rule the streams follow the crests of anticlinal folds, the Hamilton dome and Craig anticline having streams following the crest of the folds quite closely. It is an observed fact that in some cases the streams cut across the crest of the folds. This was noted in the Pagoda structure and in several other folds.

The relief of the Daton Peak and Monument Butte quadrangles, especially that bordering Williams Fork and its tributaries, is very rugged and irregular. The Mesaverde formation with its sandstone members weathers into cliffs and irregular escarpments sometimes 800 feet in height. In some places the lower part of the Mesaverde formation, where the massive sandstone members are interbedded with shale, weathers into a steplike cliff which resembles, to a great extent, the roof of a Japanese pagoda. This peculiar phenomenon has given the name Pagoda to the postoffice on Williams Fork located at a point where this feature is best developed.

In the same quadrangles high mesas and sharp peaks have been developed and preserved as a result of lava caps and lava sheets which have protected the softer underlying rocks. Other mesas are present which are capped by lava boulders and other detritus.

The valleys and rounded hills, which are present in certain parts

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[1]Fenneman, N. M., and Gale, Hoyt S. The Yampa Coal Field, Routt County, Colorado; U. S. Geol. Survey Bull. 297, p. 8, 1906.

of the quadrangle, are usually formed in the Mancos shale—so in general it might be said that shales are typically valley formers.

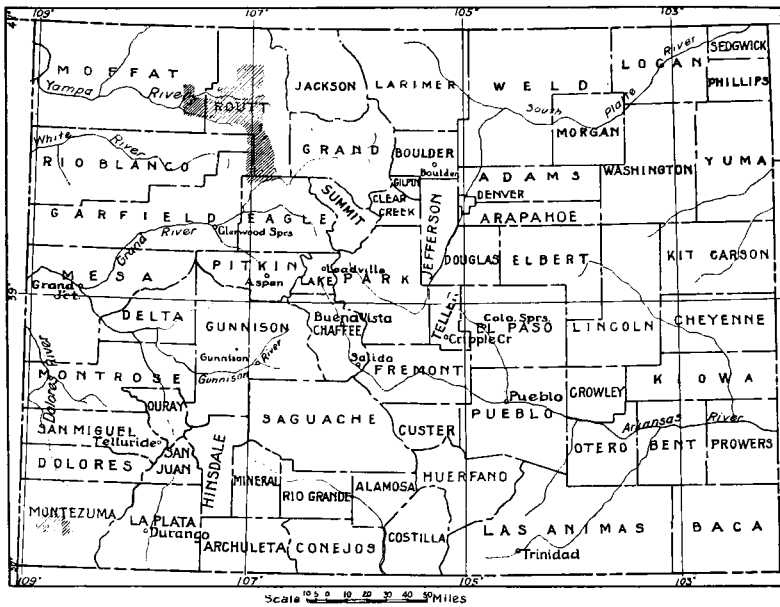

Fig. 1. Index map of Colorado showing position of areas covered by this report

In the vicinity of Yampa, Mancos shale is the outcropping formation and as usual valleys and rounded hills are the prominent physiographic features. Occasionally a neck, plug, or dike towers above the general surface of the country and makes quite a contrast with it. There are calcareous zones in the lower part of the Mancos which are hard and very resistant, and quite commonly form ridges in this district.

WATER AND FUEL

This country is well supplied with water, and in all of the structures considered it would not be difficult to obtain it. In regard to fuel this region is copiously supplied since coal mines or prospects are easily accessible.

SEDIMENTARY AND IGNEOUS ROCKS.

Only rocks of Cretaceous or younger age are described in the report of the Yampa field. Approximately 600 feet of pre-Cretaceous "Red Beds" underlie the Cretaceous rocks. They are not described here as sections taken indicate that they are probably not important in the derivation or accumulation of oil or gas.

"DAKOTA" FORMATION

The prominent "Dakota" formation overlies the Jurassic, and is

easily recognized in the field. It is very persistent in its lithological character and continuity of exposure. Very few fossils have been obtained from it throughout this territory, but its identity is based on its position below the fossiliferous Mancos formation and its similarity to the known Dakota of other fields. This formation was studied north of Steamboat Springs and on Grand River where several sections were made. It is made up of sandstones, shales, and conglomerates which vary in texture and appearance.

The upper sandstones are usually hard and often quartzitic. They are composed of quartz grains with a siliceous cement, and vary in color from white to a yellowish gray. Abundant carbonaceous material is often disseminated through the sandstones. The beds vary in thickness from a few inches up to 50 or 75 feet. Beneath these sandstones are thin, black, carbonaceous shales which, at some places, are parted by thin sandstones and sandy lenses. These shales on Grand River showed small seams of lignite and a great deal of finely divided carbonaceous material.

The lower part of the formation contains other beds of siliceous sandstones and carbonaceous shales, and the characteristic basal "Dakota" conglomerate. This conglomerate on Elk River north of Steamboat Springs is 11 feet thick and is made up of flint, jasper, limestone, quartz, feldspar, and granite pebbles. The pebbles are pea sized and usually rounded. In Grand Canyon this conglomerate could not be found in place where the sections were obtained. Float, however, was noted, indicating that it was present. In one section gray, green, and purple variegated shales are beneath the typical "Dakota" sandstone. These shales are probably of Jurassic age and have taken the place of the basal conglomerate. This formation varies in thickness from 100 to 150 or 200 feet.

Section of "Dakota" on Cabin Creek, a Branch of the Grand River, Near McCoy.

	Feet
Sandstone, hard siliceous; underlies black, slaty Mancos shale	75
Shales, sandy and carbonaceous	4
Sandstone, siliceous, carbonaceous	20
Shales, sandy, carbonaceous; small irregular seams of coal	4
Sandstone, siliceous, hard	50
Shales, gray, green and purple, with thin sandstones (Jurassic?)	20
Total	173

Section of "Dakota" on Elk River North of Steamboat Springs

	Feet
Debris-covered slope; Mancos-Dakota contact not determined	--
Sandstone, hard, siliceous, yellowish; beds 3 to 4 feet thick	13
Sandstone, siliceous, hard; beds 1 inch to 1 foot thick	17
Sandstone, massive, hard, gray	7.5
Shales, thin, sandy, carbonaceous	4
Sandstone, soft, yellow	10

Sandstone, coarse grained, and conglomeratic	26
Sandstone, massive, coarse grained, interbedded with thin seams of fine-grained siliceous sandstone	15.5
Conglomerate	11
Total	104

Other exposures of Dakota occur as follows: Three miles east of Elk Mountain; near Hahns Peak; at Steamboat Springs; near Poose Creek about 6 miles southwest of Williams Park. It has been encountered in three wells drilled near the south boundary of Williams Park.

Mancos Formation.

The "Dakota" formation is succeeded conformably by the Mancos. This marine formation includes all the sediments between the "Dakota" and the Mesaverde formations. In order to give a description which may be of more use in the field, it will be better to divide the Mancos formation into three members, namely: lower, middle and upper. This subdivision is based on the lithological dividing lines existing in the strata, and is made as a matter of convenience with no intention of raising them to the rank of formations.

Lower Member

The basal, or lower member of the Mancos shale includes the sediments above the "Dakota" to the base of the first calcareous zone above the Mancos sandstone. This lower member is readily distinguishable as a distinct division and contains the characteristic fossils of the Benton formation of the Colorado group as defined by earlier geologists. The Benton fossils listed below were collected from the lower member, and have been identified by Professor Junius Henderson, as follows:

Scaphites warreni Meek and Hayden
Inoceramus fragilis Hall and Meek
Ostrea lugubris Conrad
Prionocyclus wyomingensis Meek

Thin-bedded, black, carbonaceous, iron-stained shales characterize this member from the"Dakota" to the Mancos sandstone. These shales are often very slaty. Sandy zones are found as the "Dakota" and Mancos sandstones are approached. At some places these shales near the Mancos sandstone change into thin-bedded sandstones and very sandy shales. The shales are often locally calcareous. A dense, black, thin limestone is present locally. A valley is usually formed in this member between the "Dakota" ridge and a minor ridge formed by the Mancos sandstone and calcareous shales.

The Mancos sandstone, which is near the top of the lower member, is easily recognized in the field by its fossiliferous character. The fossils listed above are from this sandstone and the sandy shales which lie above and below it. This sandstone member is usually made up of thin-bedded sandstones separated by sandy shale partings. A heavier, yellowish sandstone bed is often present. The sands of this bed are fine grained and firmly cemented with silica and calcite.

The Mancos sandstone is generally highly bituminous; the bituminous

odor is strong when the rock is struck with a hammer. This is usually the case where fossils are abundant. The sandstones and sandy shales are often very crystalline and compact, and have a brown to black color. This color for the most part is given by the bituminous material present. Parts of this sandstone member were studied at five different places in the field, and all indicated that it was an ample reservoir for the storage of gas and oil. The sandstone itself for the most part is compact and tight, but the many bedding planes parting the thin beds and the abundant fracture and joint planes present, make it a porous, open formation. This member was more open and porous in the southern parts of the field than in the northern. The sections obtained give an average thickness of 40 feet for this sandstone member.

Fig. 2. Mancos Limestone on the Yampa-Steamboat Springs road.

Above the Mancos sandstone are sandy, limy shales which underlie the lowest calcareous zone of the middle Mancos member. These shales are also often fossiliferous and contain bituminous materials.

Middle Member

The middle member of the Mancos formation includes the highly calcareous portion of the formation which is probably equivalent to the Niobrara formation of other fields. The fossils obtained from this member as identified by Professor Junius Henderson are:

Ostrea congesta Conrad, on fragments of large Inoceramus
Inoceramus probably deformis Meek
Inoceramus sp.

There are three, and sometimes four, prominent limy zones which can be recognized in the field by the ridges they produce, and by the white-surfaced, hard, brittle shales that result when they are exposed to weathering.

The lower calcareous zone at one place is a massive limestone. (See

Fig. 2.) This limestone is not continuous throughout the field as a limestone, but changes and grades into calcareous shales. The limestone is made up of massive and thin beds from 6 inches to 7 feet thick. It is a very fine-grained, dense, bluish-gray rock which weathers white. Fractures and water courses in the limestone are filled with water-deposited calcite. A similar limestone bed lies below the Mancos sandstone, on the Yampa River three miles north of Phippsburg. Owing to the fact that this lower limestone is not present in other sections obtained, it was decided that a fault must have placed it in the abnormal position it now occupies.

Above this lower limestone or calcareous zone there are two, and at some places three, limy shale zones. As stated before they consist of hard, platy, brittle, white-surfaced shales. The bedding planes are very definite and regular, which allow the shales to part in large perfect sheet-like masses when dug into. The limy zones consist usually of from 50 to 200 feet of calcareous shales separated by less calcareous and sandy gray shales. The two lower zones contain a few fossils. The main fossiliferous zone is the third calcareous zone above the Mancos sandstone where the limestone is present, and the second limy zone where the limestone is absent. This fossiliferous ridge-maker is the key zone to the middle member on account of the abundant fossils present. These fossils at some places form solid fossiliferous shale beds from 2 to 5 feet thick and are often scattered in the shales for greater distances. This zone is from 500 to 700 feet above the Mancos sandstone, and makes a handy division line when the Mancos thickness is being determined. In nearly every section obtained this ridge was used as a dividing line within the formation. In certain areas beds above this ridge are exposed while the beds beneath it are covered by wash and vegetation. It was only by the use of this dividing line that a complete study and the measurement of a section of the Mancos formation were made possible.

The calcareous zone at the top of the middle Mancos member contains few fossils.

Upper Member

The upper member of the Mancos formation is distinguished from the middle member by the sandy gray shales present, and the absence of so much calcareous material. There are, however, a few very local limy shale beds of little consequence. The shales of the member are more like the Pierre formation of other fields. Two very sandy zones and a black shale zone are present in the upper Mancos. The black thin shales are between 500 and 700 feet above the upper calcareous zone of the middle Mancos member. These shales are thin bedded and fine. The color is probably due to the iron and small amounts of bituminous material present. A few fossils are found in this member similar to those of the middle member.

The two sandy zones are respectively about 400 and 1,000 feet below the base of the Mesaverde formation. Local small sandstone lenses occur at these places and when they are not present sandy shales predominate. The sandy shales of this member gradually increase in their sand content until they change into the thin-bedded yellowish sandstones of the next

succeeding Mesaverde formation. An exact dividing line at no place could be determined with any degree of accuracy. It was therefore necessary to use a prominent known sandstone in the Mesaverde formation as a stratum to tie section measurements, and then divide the two formations approximately at the known zone of transition from thin sandstones to sandy shales. With this method more accurate information can be gained as to the distances to the known beds of the Mancos formation.

*The lower part of the Mancos formation is composed mainly of black carbonaceous shale. This is overlain by a sandstone member that was seen by the writer in only three exposures. Near the south border of Williams Park the exposed part of this member is composed of alternating sandstones, shales, and limestones. The beds are dominantly sandstone with some limestone and numerous shale partings. Individual layers range in thickness from less than an inch to five inches. The limestone is fossiliferous and on breaking, gives a distinct though not strong bituminous odor. The sandstone is of medium grain and only moderately porous. The zone as a whole is a fair water carrier as shown by the spring at one outcrop. Both sandstone and limestone weather to brownish gray. From surface indications the thickness of the sandy member was estimated at 20 to 40 feet. The log of the first well drilled by the Twentymile Oil Company shows "sand and shale" at depth 1,266 to 1,309 feet with an estimated dip of 29°. These figures give an actual thickness of 38 feet. Near Poose Creek, about 6 miles southwest of Williams Park, the sandy member is 25 feet thick. The well log mentioned gives 450 feet as the distance from the top of the Mancos sandstone to the top of the "Dakota" sandstone. Using the same dip as before, which the writer thinks is a little too high, the thickness of the Mancos sandstone and underlying shale is about 390 feet. On Poose Creek where measurements were taken the sandstone and underlying shale have a thickness of about 425 feet. Owing to difficulty in accurately locating the boundary between the "Dakota" and Mancos formations, on account of mantle rock, the figure given may be in error 10 to 20 feet.

On Poose Creek 30 feet above the sandstone member is a limestone stratum 15 inches thick. Another limestone stratum 12.5 feet thick lies 217 feet above the sandstone. The same limestone strata are found near the south border of Williams Park.

The remainder of the Mancos formation is nearly all shale. For some distance above the limestone the shale is at intervals very calcareous and weathers to thin plates. At least one thin limestone layer an inch or two in thickness and composed principally of Ostrea fossils is found in the shale. Much of the shale higher in the formation is dark and carbonaceous, but near the top, for several hundred feet, it is ligther in color and weathers to a light gray clay. A few hundred feet below the top of the Mancos is a limestone bed at least 18 inches thick. Outcrops of this may be seen near the northwest part of Williams Park.

The Mancos shale was long ago shown by its fossils to be of marine origin. No systematic search for fossils was made for the present report*

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*From Bulletin 23 of the Colorado Geological Survey.

In Bulletin 23 a shaly sandstone succeeding the great mass of shale is taken as the basal member of the Mesaverde. The boundary between the Mesaverde is generalized on the maps.

The thickness of the Mancos formation has been determined as follows: Fenneman and Gale 2,000 to 2,500 feet; K. M. Willson, north of Yampa River, 2,100 feet; Gale, for northwestern Colorado in general, about 5,000 feet; Lee, for Axial, 5,800 feet; George, Milk Creek, T. 3 N., R. 92 W., 4,100 feet.

In their wells in Williams Park the Twentymile Oil Company found only 300 feet of Mancos. In the area covered by Bulletin 23 the average thickness of the Mancos is probably about 4,400 feet. Near the south border of the Williams Park, the exposed part of the lower part of the Mancos is composed of alternating sandstones, shales and limestones, with the sandstone predominant. The limestone is fossiliferous, and gives out a bituminous odor when broken.

The table below gives the approximate thickness between the main horizon of the Mancos, and the average thickness of the formation. (See also Fig. 12 on Plate I.) The variation in thickness indicates a probable irregular shore line at the time of deposition.

Location	Tow Creek sandstone to base of Mesaverde	Base of Mesaverde to main fossiliferous calcareous zone of Mancos	Main fossiliferous calcareous zone of Mancos to top of Mancos Sandstone	Top of Mancos sandstone to top of "Dakota"	Thickness of Mancos
Oak Hills, west of Oak Creek and east of Oak Creek	±1,700	±3,200			
Junction City on Oak Creek to east	±1,400	±2,700	±400	±500	±3,600
Yampa River west of Steamboat Springs		±3,800			
Chimney Creek, northwest of Steamboat Springs	±1,400	±2,200			
Elk River at Trull anticline.			±600		
Yampa River east of Oak Creek			±700		
Grand River near Catamount Creek				±400	
Poose Creek				±400	
Yellow Jacket Pass, near Pagoda				±426	±4,000
Average	±1,500	±3,000	±550	±450	±4,000

MESAVERDE FORMATION

The Mesaverde formation lies conformably above the Mancos formation. It is readily distinguished from this formation by the presence of massive sandstone ledges and the absence of large bodies of shale. In general, the formation is composed of sandstones parted by sandy and carbonaceous shales and coal beds. It is from 3,500 to 4,500 feet thick. A complete description of the formation may be found in Bulletin 297 of the United States Geological Survey, which deals with the coal beds within the Mesaverde formation of

this area. The formation as a whole was not studied in detail, but sections were measured to the lower group of workable coals in order to have a known stratum for the purpose of determining the depth to horizons within the Mancos formation.

The lower part of the Mesaverde formation is composed of thin sandstones interbedded with carbonaceous shales and silts. There is a more massive sandstone, known as the Tow Creek sandstone which lies beneath the lowest workable beds of coal. The thin-bedded yellowish to brown sandstones at the base of the formation overlying the Mancos shales, are very characteristic in this field. The bedding planes are usually very irregular and discontinuous, and there is some local cross-bedding. These sandstones often contain many marine fossils which are different from the fresh and brackish-water fossils of the middle Mesaverde.

Above these sandstones there is a bed of gray carbonaceous shales and silts which varies in thickness within short distances. These shales contain more carbonaceous and sandy materials than the Mancos shales. Above these shales to the base of the Tow Creek sandstone there are alternating sandstones and carbonaceous shales. The sandstone beds increase in thickness, and less shale is present. The Tow Creek sandstone is the most continuous and characteristic member in the lower Mesaverde. It is a massive sugary, rather coarse-grained sandstone which varies in color from white to gray. In the northern part of the field this sandstone has more of a brown color. Its thickness varies between 50 and 100 feet. Above the Tow Creek sandstone, sandstones and shales alternate with the lower beds of workable coals which they include. These coals are of an excellent bituminous grade and form a large economic resource in this area. Further discussion of these coals is omitted here as a detailed explanation may be found in the above named bulletin.

The lower Mesaverde formation is represented by a rugged country with many cliffs and ridges as the more massive sandstones offer greater resistance to erosion than the softer alternating shales and sandstones.

LEWIS FORMATION

The Lewis formation is composed of soft clay shale, dark to light gray in color, and it lies conformably on the Mesaverde. It is often almost black at some places. Calcareous zones are common to this shale. Small lenticular masses of limestone and calcite seams are found in these limy zones. The shales at some places are sandy, but this is not a characteristic feature of the formation.

There are no complete or continuous sections of the Lewis formation in this field to determine its thickness[2]. Other geologists have estimated it to be between 1,000 and 1,200 feet.

LARAMIE FORMATION

*Along the Yampa River in the vicinity of Hayden the Laramie formation, as determined by previous workers, overlies the Lewis shale with apparent conformity. It is composed for the most part of friable sandstone

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*From Bulletin 23 of the Colorado Geological Survey.
[2]U. S. Geol. Survey Bull. 415, p. 72.

that commonly is cross bedded. The sandstone locally carries bands of concretions several feet in diameter. In a few gullies may be seen outcrops of gray shale. At least one coal seam has been opened in the Laramie near Hayden*

TERTIARY OR QUATERNARY FORMATIONS

At one locality on Beaver Creek, a tributary stream of South Fork Creek, an exposure is found which showed a conglomerate bed about 8 feet thick unconformably overlying the Mancos shale. Immediately overlying this conglomerate bed is 20 feet of sandy material, more or less arkosic in character, with several thin beds of conglomerate intercalated with the sand. Capping this sandy horizon is a bed of sandstone several feet thick with

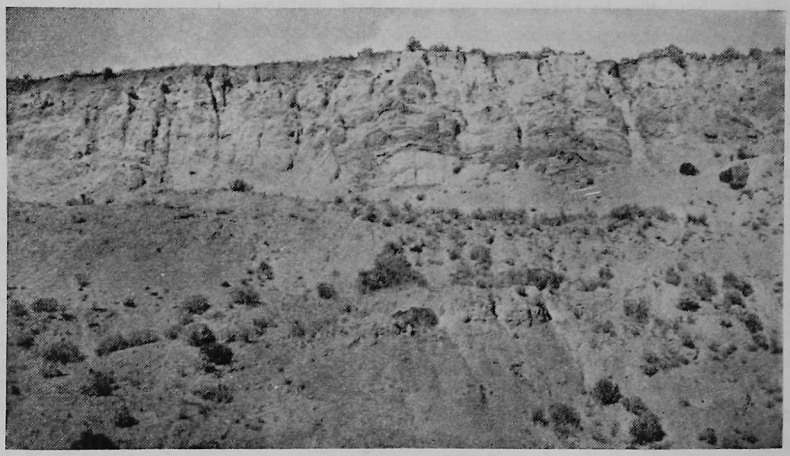

Fig. 3. Tertiary (?) or Quaternary Sandstones of the Pagoda fold.

large angular basalt bowlders scattered irregularly through it. At another locality the conglomerate was not present, but approximately 200 feet of white coarse sandstone, rather soft on account of its calcareous cement, was observed to occupy essentially the same stratigraphic position. And in parts of the sandstone there were tubular forms which suggested plant stems, worm tubes or burrows. From the lithological character and the stratigraphic position this formation would probably correspond more or less closely to the Browns Park group found a few miles west of the area under discussion in Axial Basin. In some places this sandstone is capped by sheets of basalt which forms high mesas. Most of the flat tops within this area showed this sandstone member associated with the basalt sheets. The character of the sediments, the close association of the basalt and this sandstone formation indicate that it is at least Tertiary or younger in age. There would have to be a sufficiently long time for erosion to remove the Mesaverde, (possibly the Lewis and Laramie), and part of the Mancos before this formation could occupy the horizon which it does. And if this period of erosion took place

previously to the deposition of the sandstone it would probably be later than the beginning of Tertiary, because the period of erosion would mark a time interval between the Cretaceous and Tertiary.

The thickness of the Browns Park group varies from 150 to 400 feet. It is probable that the formation under discussion will approach 400 feet in thickness in most of the localities where a fair exposure can be found. Similar deposits, which probably belong to this group, are present near Yampa.

*South of Williams Park soft, friable cross-bedded sandstone, protected by a basalt flow or sheet, stands in a nearly vertical cliff 300 or 400 feet high. The white to gray rock above the green timber of the lower elevations and below the green timber of the basalt-capped table-land makes a conspicuous landmark visible for many miles. The thickness of the sandstone is not readily determined since sandhills from the disintegration of the sandstone that breaks from the cliff are piled up near the cliff as well as throughout an area about half a mile wide. Small remnants of sandstone in place and near the base of the formation are found farther west.

Inasmuch as the sandstone lies nearly level while the underlying Mancos shale has a pronounced dip in its nearest exposure, it is evident that the unconformity at the contact between shale and overlying sandstone is angular. Since no fossils were collected from these beds their age has not been determined. In appearance the sandstone cliff resembles the cliff of Green River sandstone west of the Grand Hogback, in Garfield and Rio Blanco counties, Colorado. Lithologically and structurally the sandstones south of Williams Park resembles the Laramie sandstone north of Hayden; but the unconformity below the former, representing a long erosion period, points to an age younger than Laramie for the beds under consideration.*

SURFICIAL DEPOSITS

At numerous localities within the area described there are alluvial deposits of sand, gravel and soil. The character of the material composing these deposits depends to a large extent upon the nature of the land from which the detritus or eroded material is derived. If the stream in general follows a sandstone formation, the nature of the deposit would probably be sandy and if it follows a shale formation, the deposit would probably be clayey in character varying from gray to black in color.

Another form of surficial deposit frequently encountered in the field is talus. A great many talus deposits are present in the Daton Peak quadrangle, and in many places they entirely obscure the geology.

POST-CRETACEOUS IGNEOUS ROCKS

The purpose of investigating the igneous rocks near Yampa was to determine the possibilities of oil accumulation in the sediments in connection with the igneous intrusions present. The problems offered in the field, therefore, dealt more with the mode of occurrence of the bodies relative to the structure of the sediments than to the petrography, and no microscopic work was undertaken for this report.

*From Bulletin 23 of the Colorado Geological Survey.

The sedimentary rocks have been intruded by igneous rocks in the form of dikes, plugs, necks, and sheets. As far as known all of the igneous rocks of this area may be classified as intrusive and of the same period of igneous activity. There are two general basalt types; the dense basalt type and the agglomeratic basalt type. The dense basalt type is the predominating rock It is a dark gray to black rock on fresh surfaces and weathers to a light

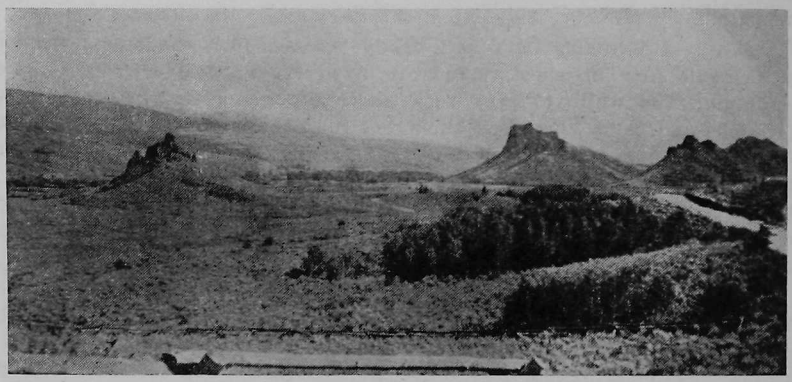

Fig. 4. Igneous Intrusions Near Yampa

gray or reddish brown. Locally, at the contact with sediments, the basalts have a more or less cellular structure. The scattered amygdules are composed of secondary calcite which gives the rock a spotted appearance. Water-deposited calcite and quartz veins are also at some places near the contact with the shales. Slaggy crusts are not common. Wherever the dikes project above the surface columnar structure is usually present. The mass is made up of horizontal columns several inches in diameter, which are often regular hexagons.

The basaltic agglomerates which make up parts of the larger intrusions are composed of angular pieces of quartz, feldspar, chert, granites, limestones, sandstones, and basalts which are held together by other basalt materials. The agglomerates weather to a reddish brown and are usually spotted by lighter patches where calcite has been deposited. These agglomerates indicate an explosive stage of eruption or the basalt lava may have picked the angular particles from the rocks through which they have intruded.

The igneous activity took place after Cretaceous times and probably late in Tertiary times. The greatest amount of igneous activity has taken place near Yampa. There are many plugs, necks, and dikes present to the southeast toward Toponas and to the northwest toward Phippsburg. The necks and plugs are usually large irregular bodies that stand high above the general level of the valley. The main outcrops of dikes north and west of Yampa are from 6 inches to 8 feet in thickness, though the majority are from 2 to 4 feet. These dikes decrease in thickness and number when they enter the sandstones of the Mesaverde formation. This is general and not the case in every instance. They usually have a straight or slightly curved course and stand almost vertical At some places where the dikes outcrop,

they project above the surface as wall-like masses for many feet (See Fig. 7.) The dikes vary in length from a few hundred feet to a mile or more. The outcrops are not always continuous for this distance, as they have been covered with wash materials, and in some cases may have never reached the surface. The outcrops also show that they have been displaced at many places by minor faults and have split into smaller dikes. Whether or not faulting has been the cause of the irregularity is questionable. The basalt lava may have filled smaller fissures in the general fissure system which would cause the interruption in the outcrops and would shift them to a parallel position some distance from the main outcrops. The general course of the outcrops indicates that they are of the same dike system and probably have connections not far below the surface.

Another center of activity may have been at Pinnacle Mountain to the northwest of Yampa, where there is a large necklike intrusion with connecting dikes. This may, however, be a part of the main Yampa system of dikes which are united beneath the surface. A more detailed discussion of the modes of occurrence of the igneous bodies relative to the structure of the sediments can be found in the description of the folds and the Devils Grave "structure."

Metamorphism

The contact metamorphism produced by the intrusion of the igneous rocks in the sedimentary rocks has generally been very slight throughout this field. At many places there are well exposed contacts which show little or no metamorphism. At other places, however, there has been a partial fusion of the wall rocks but no metamorphic minerals are at the shale or sandstone contacts. Generally, there is less alteration at the sandstone contacts than at the shale contacts. The sandstones at the immediate contact usually have not been perceptibly hardened. On the southeast slope of Pinnacle Mountain, where a dike cuts the lower sandstones of the Mesaverde formation, considerable metamorphism was noticed. At this place the dike has split into several small dikes which have baked the sandstones for approximately 50 feet on each side of the main intrusion.

The contact zones in the shale formation are usually marked by a slight hardening of the shale. This may have developed new planes which can be seen at right angles to the normal bedding planes. This alteration seldom reaches but a few feet from the intrusion. Wherever the dikes have split into several small parallel intrusions more metamorphism is noticed. At these places and at others where the main intrusion is rather large the shales are black where they have been baked and burnt. These shales may show alteration for 10 or 15 feet from the intrusion. It appears that the liquid basic magna suddenly followed and filled definite fissures. This probably accounts for the slight amount of metamorphism. The fact that no noticeable tilting of the sediments accompanied the intrusion of the dikes also indicates that the dikes are fissure fillings.

The large intrusions in the form of necks and plugs have caused more metamorphism than the dikes. Definite contact zones are scarce and little detailed study could be made. These larger intrusions have tilted and at some places overturned the sediments.

POSSIBLE OIL AND GAS BEARING ZONES

The Mancos formation is lithologically an ideal formation for the accumulation of oil and gas. The Mancos sandstone is a suitable reservoir for oil and gas, and the shales above and below it are sufficient for capping purposes. There are other possible reservoirs in sandstone lenses that may be in the Mancos shales. The limestone and calcareous shales show jointing, fracturing, and water courses which might make them open enough to receive oil or gas. The lower members of the Mancos formation are highly bituminous and carbonaceous. They probably contain sufficient material from which oil and gas may be derived.

Oil has been found in the Mancos formation at Rangely, Colorado, and in similar formations in Wyoming.

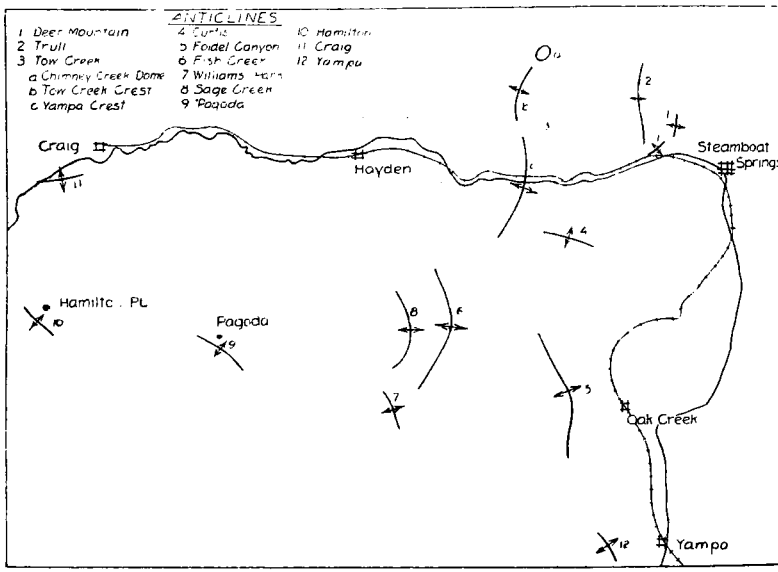

Fig. 5. Index map showing position of known anticlines of Routt and Moffat counties.

The Wall Creek horizon, also called the Frontier and the Nio-Benton, is in the lower third of the Mancos.

The "Dakota" sandstone is another possible reservoir. It has furnished considerable gas in three wells which have recently been drilled in Williams Park.

The highest sandstone of the "Dakota" is the Muddy sand of the Wyoming fields.

STRUCTURE

MAJOR FEATURES

The Yampa coal field, as described by Fenneman and Gale in Bulletin 297 of the United States Geological Survey, occupies a huge basin. The

axis of this basin seems to have a northwest-southeast trend extending through Yampa on the southeastern end to a point some miles northwest of Craig. The large basin is bisected by a cross fold which is known as the Tow Creek anticline. As a result of this, a small basin is formed to the southeast of the Tow Creek anticline in the region drained by Fish Creek, Trout Creek, and Oak Creek.

Axial Basin, although somewhat to the south and west of the area described, occupies a valley roughly following the crest of the Axial Basin anticline. This anticline, was formed by the inceptive forces of the Uinta uplift, and the trend of the axis is northwest-southeast in general. A few miles northeast of Axial Basin is a syncline, which passes through Round Bottom, with an axis which is roughly parallel to that of the Axial Basin fold. The folds of the Yampa field with few exceptions have the same general trend as that of the Axial Basin structure. In some parts of this field there has been some cross folding such as the Tow Creek fold, and there are numerous other minor folds trending in the same general direction as the Tow Creek structure.

FAULTS

North and northwest of Yampa and east of Williams Park there are several large faults and many smaller ones. The major system of fracturing follows a northwest-southeast course which coincides with the fissure-filled dike system near Yampa. Minor fractures follow a northeast-southwest course. This system is apparent in the minor faults which have displaced the main dikes. The faults do not influence the structure of the sediments to any great degree as the displacements are usually less than 100 feet.

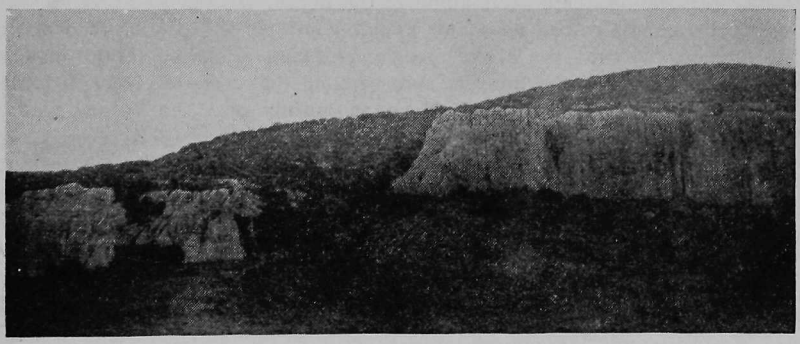

Fig. 6. Fault in the Twenty-Mile sandstone in Foidel Canyon.

The most easily recognized fault is in Foidel Canyon south of the Foidel-Williams Park road, where the Twenty-mile sandstone member of the Mesaverde formation has been displaced approximately 100 feet. (See Fig. 6.) It is probably a normal fault with the downthrow on the south block. This fault trends northwest. South of Fish Creek and between Williams Park and Foidel Canyon it may be traced nearly to Dunkley Canyon. The upper thin sandstone of the Mesaverde and parts of the Lewis shales have been tilted and buckled by this fault. Abnormal south dips

were found in the fault zone, which are probably due to a pivotal movement which raised the south block of sediments to the northwest and lowered them to the southeast in Foidel Canyon. This area is partly covered by wash materials which make a detailed study impracticable.

Another fault is present on Middle Creek in the Trout Creek sandstone member of the Mesaverde. In the displacement the north block has dropped about 50 feet.

Faults are reported in the coal mines near White City. Mr. Guy S. Newkirk, Engineer for the Moffat Coal Company, stated that there are three faults present which have a northwest trend and have displaced the lower coal groups from 25 to 90 feet.

A small fault shows on the east bank of Trout Creek one mile south of Pinnacle postoffice. The downthrow is on the south block with a displacement of about 25 feet. This fault is questionable as the sediments are for the most part covered, and the fault shows only in one massive sandstone.

About 4½ miles north of Phippsburg on the Yampa-Steamboat Springs road the "Dakota" and the lower members of the Mancos formation have been faulted considerably. Since sufficient time was not available to study this fault system in detail, only a very general discussion will be possible. The "Dakota" formation at this place has been overturned, and a block fault appears to be present in Yampa Valley. The "Dakota" and "Red Beds" have been thrown to the south in an abnormal position. A pivotal motion appears to have accompanied the fault which has raised the sediments to the south. This fault may run close to Yampa River and extend nearly to Yampa. North of Yampa the middle members of the Mancos formation are above the upper members, and the Mesaverde beds to the east are also in an abnormal position in respect to the beds to the west. The Yampa River apparently follows this fault plane to the north.

Approximately one mile and a half south of the "Dakota" overturn on the Yampa river at the above mentioned place, a diagonal fault has placed the Mancos limestone below the Mancos sandstone member. Small faults are noticeable between Yampa and Toponas, mainly near the county road. The folding and overturning which have taken place have been accompanied by minor faults and fractures.

A small fault with a displacement less than 100 feet was noted in Section 9, T. 4 N., R. 90 W. The sedimentary rocks, in which the evidences of faulting were noted, are lower Mesaverde in age. The nature of the fault was not definitely determined but, in general, it seems to have been of the normal dip-slip type. It seems probable that the movement of one block was towards the west in the direction of the dip, but owing to the fact that evidence was meager, the conclusions put forth above are more or less speculative in character. It is not probable that this fault was of magnitude enough to materially affect the oil possibility of the Beaver Creek structure.

On Williams Fork, on the western side of Peck Homestead Gulch, a small vein or fissure of solid bituminous material about one inch in thickness similar to elaterite was found. This vein was exposed in two places. The presence of this bituminous material in such a deposit indicates that some movement has taken place of sufficient magnitude to develop a fissure through which the hydrocarbons could pass. The vein has a northeast trend

and is so narrow and local that the writer does not consider it large enough to have drained whatever accumulations of oil may have taken place below the surface.

FOLDS IN RESPECT TO OIL AND GAS POSSIBILITIES

Foidel Fold

The axes of the Twentymile Park-Toponas syncline and the syncline roughly parallel to Williams Park converge as they extend to the north in Twentymile Park. (See Pl. I, in pocket.) Between these two synclines there is a large terrace-like fold in the Mesaverde formation which extends almost to Flat Top Mountains to the south. It has been called the Foidel fold as Foidel Creek has cut its channel through the prominent Twentymile sandstone member of the Mesaverde formation in Foidel Canyon. This stands as a high white cliff and follows the lines of the fold to the east and the west in the shape of a horseshoe. Fenneman and Gale[4] mapped part of this fold.

The sediments along Foidel Creek, Middle Creek, and Trout Creek dip 7° to 11° to the north and northwest. In Foidel Canyon the direction of the dips starts to swing to the northeast. The amount of dip increases to the southeast. East of Foidel Canyon the dip is about 15° and increases to 35° and 40° at Trout Creek. Between Trout Creek and the Devils Grave mesa the dips gradually decrease. About a mile west of the town of Oak Creek they average 5° northeast. East of Oak Creek valley and about about three miles west of Phippsburg the dips vary from 1° to 3° northeast.

The greater part of the area is covered by vegetation and a mantle of soil and rock. This is especially true between Oak Creek and Trout Creek where there are few outcrops. The outcrops are usually made up of thick-bedded sandstones which have either been eroded a great deal or show signs of slumping. For this reason most of the slight dips recorded are questionable. The general direction of dip is to the northeast and northwest. These gentle dips give a broad and almost flat crest to this fold between Oak Creek and Trout Creek. The general amount of dip increases to the south from 4° to 12° in a north and northeast direction.

This broad gentle crest makes the determination of the position of the axis almost impossible. The fold was mapped by the general methods used in reconnaissance work, and no structural contour map was attempted which would determine the position of this axis accurately.

The upper and middle members of the Mesaverde formation are exposed around the outer limb of the fold, and lower members outcrop along Trout and Oak creeks and near Pinnacle. West of Pinnacle Mountain along the Pinnacle-Williams Park road the carbonaceous shales and silt of the lower Mesaverde are exposed. The lower thin sandstones of the Mesaverde extend from Pinnacle Mountain to the east to Devils Grave Mesa. Some distance to the south of the above-mentioned road the Mancos shales

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[4]U. S. Geol. Survey Bull. 297, Plate I.

outcrop occasionally where they are not covered by wash materials and soil.

Pinnacle Mountain, a prominent land mark between Trout and Oak creeks, stands as a high, sharp knob. (See Fig. 7). It is an igneous intrusion of basalt, probably in the form of a neck or plug with dikes extending from it to the northwest and southeast. The dikes are similar to the Yampa dikes and have the same general course. It is believed

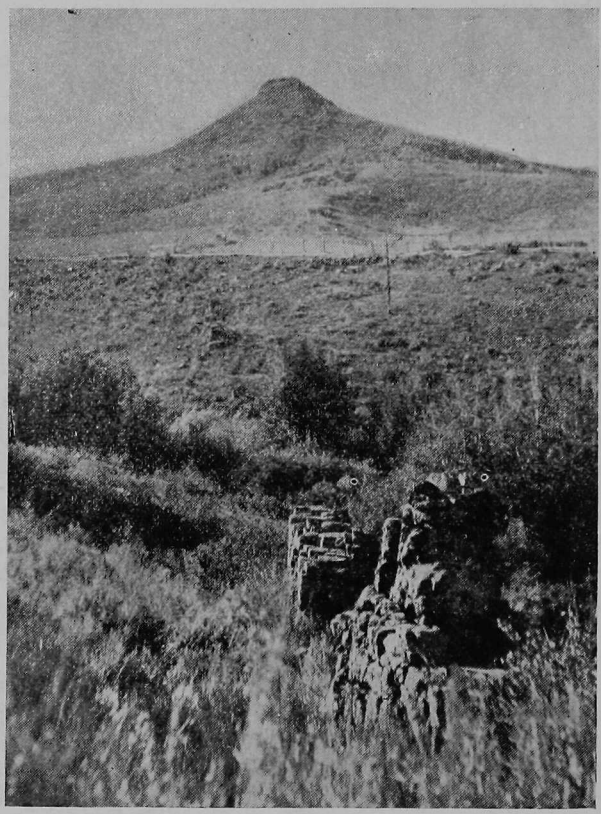

Fig. 7. Pinnacle Mountain, Showing Connecting Dike.

that the Pinnacle and Yampa dike systems came from a common reservoir and are probably connected not far below the surface of the ground. Outcrops of this dike were searched for between the known outcrops, but none could be found. The dikes extend almost to Trout Creek.

Oil and Gas Possibilities.—There are two possibilities of oil and gas accumulation in this fold. The fold may be considered as a terrace type which is shown by a marked lowering of the angle of dip; at places the fold becomes almost flat. Any oil and gas migrating up the steep dip might accumulate in the reservoir where the beds start to flatten. The

water pressure would have to be low enough not to produce further movement to the south. Or, if the water pressure were great enough to produce movement to the south, there is a possibilty of another accumulation to the north and northeast of the dikes. If there is a laccolith present which has caused the arching of the strata, favorable and unfavorable occurrences of igneous bodies may or may not be present. If a laccolith is below the reservoir, the dikes and plug at Pinnacle must have extended through about 4,500 feet of sediments. This is possible, especially when continuous dikes are thought of which extend for many miles at the surface. If this extension is present there is a possibility of oil and gas accumulation. The dike itself may change from a small plug or short dike beneath the surface and radiate and widen as higher beds are reached. Any occurrence of these bodies which is not continuous through the reservoirs and which does not seal it tightly would be unfavorable. A laccolith, if present, may have replaced the reservoir entirely, which would make chances for oil and gas accumulation at its borders slight. There is also a possibility of many sprouts from the main igneous body being present which do not outcrop and which may easily trap possible oil, or ruin the reservoirs for any accumulation.

The dikes and plug may extend from the basalt complex through the entire series of sediments with no laccolith present at all. The outlet at Pinnacle might have been large enough to prevent the formation of a large sill or laccolith.

In the section on faults (page 21) the different displacements occurring in this area have been discussed. The displacements have not been great enough to seriously affect any great leakage as they probably do not extend as faults through the Mancos shales. An oil seep was reported at the Foidel Canyon fault, but the writer could not find any traces of bituminous matter. Investigation brought out the possibility that the oil was "canned oil" placed there with the idea of helping a stock-selling scheme.

In order to ascertain a fairly accurate depth to the Mancos sandstone throughout the fold, the lowest seam of the lower beds of workable coal of the Mesaverde was used as a reference bed. The Mancos sandstone lies about 5,100 feet below this seam, and the top of the "Dakota" is about 450 feet lower. The Tow Creek sandstone was not used as a reference bed as it is considerably covered, while the coal beds have been exposed by mining. The thickness between the Tow Creek sandstone and the lowest coal bed varies from 20 feet to over 100 feet.

According to the topographic work done by Fenneman and Gale, Trout Creek has a rise of about 700 feet between the junction of the Trout Creek-Oak Creek road at a point on Trout Creek due west of Pinnacle Mountain. With this rise in elevation to the south the creek cuts lower strata in the lower Mesaverde formation and finally into the Mancos formation. In a line not far from the Pinnacle plug an dikes to the north, and on a level with Trout Creek, the Mancos sandstone lies at a depth of about 3,700 feet. In Trout Creek Canyon about three-fourths of

a mile south of the Oak Creek road the Mancos sandstone lies about 4,500 feet below the level of the creek.

The formations along this limb dip about 30°. This dip was considered in the above estimate.

Until the known domes and closed anticlines of this area are completely tested, and until the Mancos formation is known to contain oil in commercial quantities, the writer does not recommend that this fold be tested. The expense involved in the deep drilling which would be necessary is too great to warrant any test in an unproven formation under these circumstances.

The Devils Grave "Structure"

Anticlines, domes, synclines and other structural features are usually the result of mountain-making movements. Structure means the attitude rocks have acquired since they have been formed. The popular word structure, however, is probably used incorrectly in many cases to mean a definite structural feature as a dome, syncline, anticline rather than the attitude of the rocks which gives form to these features. It has also been used as a name for any area which may have an oil or gas possibility even if no definite structural feature is present. This name, for example, has been given by other persons to the area under discussion near a narrow dike where there is a possibility of oil and gas accumulation.

The Devils Grave mesa lies approximately 3½ miles northwest of Yampa, north of the Yampa-Pinnacle road. This mesa is a prominent landmark and stands several hundred feet higher than the Hunt creeks to the west and to the south. The thin-bedded, yellowish and gray sandstones of the lower Mesaverde form the cap rocks of the mesa. These sandstones look like a Tertiary deposit from a distance and form cliffs at the edges of the mesa. At the southeast end of the mesa a high tomblike remnant of these sandstones stands out from the main body of the sandstones forming the cliffs. It was this tomblike mass that suggested the name Devils Grave. Beneath the sandstone cliffs are slopes in the easily eroded Mancos shales. At places badlands topography has been developed. The so-called Devils Grave "structure" includes the area to the north and northeast of a dike which is south and southeast of the Devils Grave mesa. This dike is about four miles long and is the most significant dike in the area. There are many other shorter and narrower dikes present.

The main dike can be found south of the Cromer ranch where it crosses the main road to Heart Mountain. From this point it may be traced northwest to Middle Hunt Creek, where it disappears. It outcrops again west of the Gumlick ranch and may be followed to the Yampa-Pinnacle road. (See Pl. I, in pocket.) From a point south of Cromer's ranch it may be traced in a southeast direction approximately one-half a mile from the Wood-Stark ranch. This dike is not found at every place as it often disappears under the wash materials. It has been faulted or shifted at many places, which also makes it difficult to follow.

Another dike about one mile long is half a mile south of the tomb of the Devils Grave mesa. The southeast end of this dike stands above the general level of the surrounding land as a sharp knoll.

The axis of the main Twentymile Park-Toponas syncline passes through the northwest corner of the Devils Grave mesa. The lower Mesaverde sandstones dip 25° due west at the northwest end of the

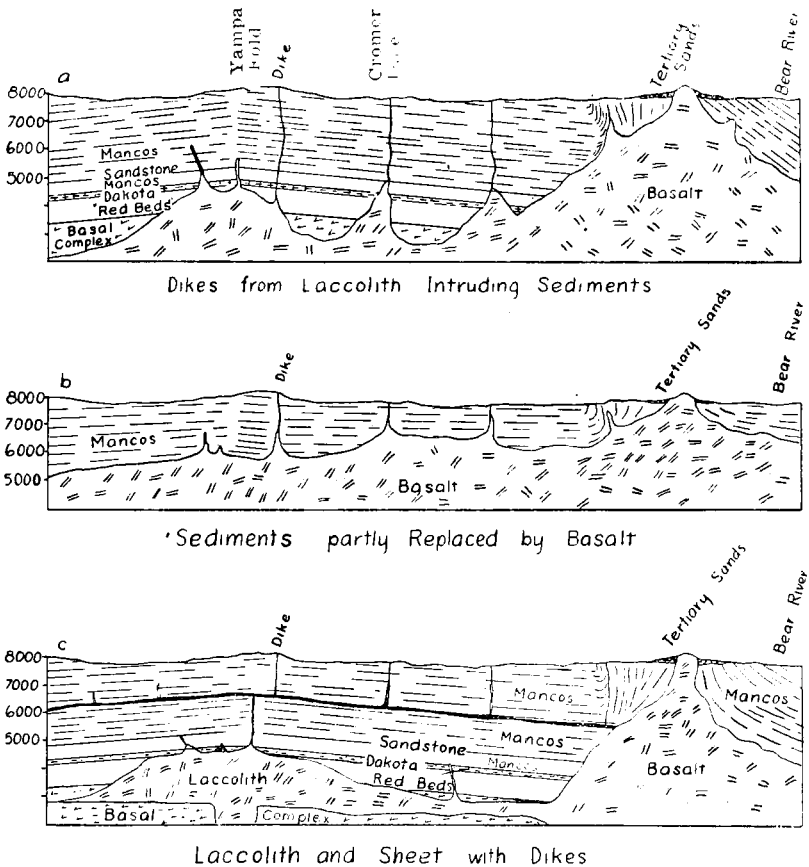

Fig. 8. Hypothetical cross-sections showing possible relationships of rocks in the Devils Grave "structure."

mesa. The Mancos shales on the east limb of this syncline near Yampa are overturned and dip 60° to the northeast. The dips on the west limb are more gentle, and are from 2° to 20° northeast.

The Mancos shales south of the Devils Grave mesa and north and northeast of the main dike have a general northeast dip. This is especially true along the northeast exposures of the dike. The dips recorded vary between 2° and 12° N. 5° E. to N. 30° E. The direction of dips to

the north along the dike changes slightly to the north and northwest, but northeast dips were also found. The dips average approximately 5°. The shales south of the dike also dip to the northeast and northwest, and are a part of the northeast limb of the Yampa fold. Owing to the fact that the sediments dip away from this dike, and that the dike itself follows a slightly curved course which would form a possible check or trap for oil or gas in any reservoir below, there is a possibility of oil and gas accumulation to the north and the northeast of the dike. The mode of occurrence of this dike and other dikes, and their relationship to the sediments below is the paramount problem which must be considered. If this main dike, which averages about 3 feet wide at the outcrops, continues as a dike through approximately 4,000 feet of sediments, there is a possibilty of oil and gas accumulation. (See figure 8a.) This would be the ideal occurrence. These dikes are possibly stringers from a laccolith which may have caused the arching of the Yampa fold. (See figure 8a.) It is probable that these dikes, or igneous bodies below have cut the "Dakota" or pre-Cretaceous rocks, as a sulphur spring giving off hydrogen sulphide gas is on the north side of the dike at the Wood-Stark ranch. Field study leads to the conclusion that all of the sulphur springs originate in the "Dakota" or older rocks. This spring, therefore, indicates a leak in the sediments below with a water course along the dike to the surface.

Other possible occurrences must be taken into consideration. The presence of several sheets north and northeast of Yampa suggests that the dikes are stringers from a larger sheet following the bedding of the Mancos shales (Figure 8c). This would account for so many small stringers from 6 inches to 1 foot wide that are present at some distance from the main longer dikes. If this were true there would be no possibility of oil and gas accumulation other than in the sandstone lenses that may be present in the Mancos shales. One of the most prominent sheets follows the strike of the overturned and almost vertical shales. It is possible that these are dikes which have been intruded subsequent to the folding and have followed the bedding planes in this shattered and fractured zone. Other possible occurrences, such as a laccolith or thick sill near the surface, would take the place of the sediments below (Figure 8b). Or the dikes and larger plugs may fill channels from the basal complex below, through which the lava has come to the surface and now forms the basalt sheets of the Flat Top Mountains. The other dikes north of the main dike, the plug and dikes on the Devils Grave mesa and the dikes northwest of this mesa may affect this area to a considerable degree. These bodies may localize the oil and gas if present and thereby limit the gathering area of the main "structure." For instance, the dike south of the Devils Grave mesa may connect with the main dike beneath the surface. This would extend in a line passing south of the Cromer ranch house and would probably trap any gas or oil to the north of this point.

In areas where intruded igneous rocks are found, the possibilities for oil and gas accumulation are usually questionable. In certain Mexican fields, however, intrusions are found in many of the productive fields, so it would

not be fair to condemn a field on account of the presence of igneous activity. The dikes were probably intruded subsequent to the folding or simultaneously with it. The slight amount of metamorphism would not seriously carbonize the bituminous materials for any great distance from the intrusions. The general belief that the entire area has been "burnt out" is incorrect. This, of course, depends on the form of the intrusions below the surface and also their position relative to the sediments, but surface conditions do not suggest this. If this "structure" is tested by wells drilled at no great distance from the main dike, or by wells drilled near the Cromer ranch, the Mancos sandstone, if present, should be encountered at a depth of about 3,200 feet below the general level of Hunt creeks.

The writer does not feel justified in recommending that any test wells be drilled in this area. The Mancos formation in this field has not as yet been proved as an oil-bearing formation. The closed anticlines* and domes, which are present near this area and which are almost structurally perfect for the accumulation of oil, should be thoroughly tested. If it is then proved that these folds contain oil in commercial quantity other possible traps such as the Devils Grave "structure" might be tested. It also appears that the depth of this reservoir is almost prohibitive under the rather questionable structural conditions.

The Yampa Fold

About 5 miles west of Yampa there is a slight fold in the Mancos shales. This fold is in the nature of a "nose" which plunges to the northwest and gradually opens to the southeast. Southwest dips are at Heart Mountain and to the west in the sandstones of the lower Mesaverde formation. The dips are from 5° to 8°. The direction of the dip gradually swings to the north and northeast on the northeast limb and then swings again to the north and northwest, which opens the fold. Most of the dips are low and vary from 2° to 10°. The sediments forming the southwest limb are mostly covered by a dense mantle of wash materials and vegetation which made close study impossible. Southwest and west dips from 2° to 5° are found, but no closing southeast dips could be accepted. The sediments at the southeast end of the fold dip gently to the north and northwest. Occasional reverse dips are present, but they are not accurate, as they change in very short distance. Horizons in the upper Mancos were followed as closely as possible, but no closure could be obtained. There are several dikes near the axis of this fold, which are probably stringers from a sill or laccolith which has arched the strata. (See Figure 8c.)

A nose or a pitching anticline is not generally accepted as a suitable structural feature for the accumulation of gas and oil. There would be a leakage at the open end which would allow the escape of any oil or gas which might migrate up the dip when associated with water under pressure. The writer does not recommend that any test wells be drilled in this anticline.

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*Colorado Geological Survey Bull. 23, 1920.

Pagoda Fold

The Pagoda structure is composed of two anticlines having axes trending northwest and southeast with a syncline between them.

The anticline to the north, or that structure which lies along Williams Fork River, has a small dome on the western end of the structure in the immediate vicinity of Deakins ranch. To the east of this dome, along the same axis, it is found that this anticline proper does not close on the eastern end, but swings around more or less in the shape of a horseshoe. This anticline has a curved axis, as a whole, pitches gently to the northwest so that the eastern end is the structurally highest point. The dips along the northern limb of the structure are fairly uniform, averaging about 12°. Along the southern limb of the structure the dips are steeper than those of the northern limb and range from 9° to 30° in most cases. The fold is therefore asymmetrical in character and the axis will be closer to the southern limb than to the northern.

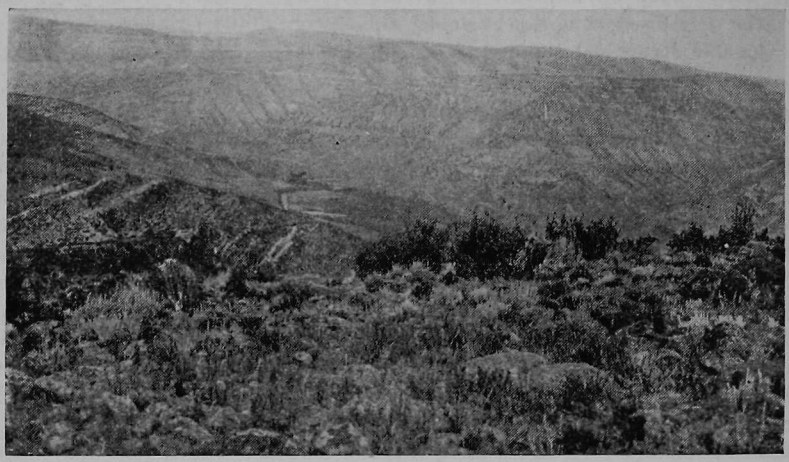

Fig. 9. Upper beds of the Mesaverde formation on the Williams Fork dome

There appears to be somewhat of a constriction or closure on this structure in the vicinity of Pagoda postoffice. The only part of this anticline that holds any structural possibility whatsoever of oil or gas would be the small dome extending in general from Pagoda postoffice to Deakins ranch. There is one dip shown on the map, Plate I, of this area, of 17° S. 70° W, which does not adjust itself well to the rest of the data taken for this structure and might indicate local movement of some kind, possibly faulting. No other evidence of faulting was observed in that locality, but evidences may have been obscured that they were not noted.

The syncline, which parallels the anticline just described, is pitching from the southeastern end in Section 28, T. 4 N., R. 89 W., to the northwest.

It can be traced more or less accurately to Peck Homestead Gulch in Section 35, T. 5 N., R. 90 W. The dips on the northern limb of the syncline range from 10° to 30°, but those of the southern limb are not so steep. They range from 4° to 10°, thus effecting an asymmetrical syncline.

The southernmost anticline, or the Beaver Creek structure, pitches rather gently in a northwesterly direction. The dips on the northern limb of the fold vary from 5° to 10°. On the other limb the dips are higher, and range from 10° to 58° probably averaging 30°. A closure on the western end of the anticline was found in Section 9, T. 4 N., R. 90 W. In Section 5,

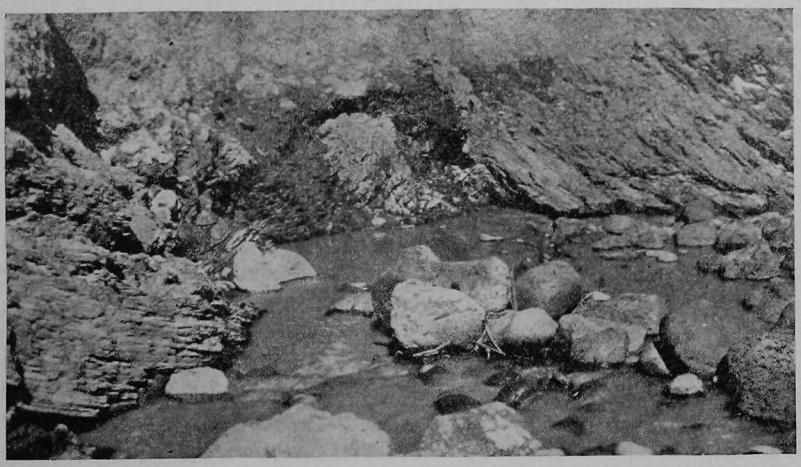

Fig. 10. Showing Intense Folding of Mancos Shale, Beaver Creek

T. 3 N., R. 89 W., the swing in the strike of the beds indicates a closure on that end, but inasmuch as no northeast dips were obtained nearer than the northwest quarter of Section 32, T. 4 N., R. 89 W., there is a possibility that this axis curves and does not close. Had it been possible to obtain dips and thus find the general attitude of the formation in Section 35, T. 4 N., R. 89 W., and in Section 5, T. 3 N., R. 89 W., the general structure could have been worked out more closely. In view of the fact that the only evidence tending to complete a closure on this end of the fold is the swing in the strike of the beds taken on the southern limb and considering the deficiency of dips and reliable information concerning the southeastern end of this anticline the writer does not feel justified in asserting that there is an unquestionable closure for this structure. It was very difficult to determine the true geologic relations of this end of the fold because of the covering of the Mancos shale and Mesaverde formation by the Browns Park (?) formation and the lava sheets which are very numerous in this part of the field.

Near Shirkey's ranch in Section 31, T. 4 N., R. 89 W., the dips indicate a constriction, but probably not a closure, since the sandstones on the south limb are very constant and continuous. In Section 15, T. 4 N.,

R. 90 W., a dip of 9° N 70° E. was obtained in the shale of a newly made gully. This dip was the only one obtainable on the northern limb of this anticline owing to the capping of basalt and sandstone which seems to be ever present in the Daton Peak quadrangle above elevations of 7,500 feet. This dip of 9° would indicate a constriction at this point, but since other dips were not available it is not conclusive or worthy of great consideration.

Oil and Gas Possibilities.—The dome located on Williams Fork, previously described, is a structural possibility for oil and gas since the dips taken point to a closed structure. The outcropping formations in this structure are the lower part of the Mesaverde formation and the upper part of the Mancos. Approximately 200 feet of Mancos has been eroded from the crest of the anticline. The possible oil sands in this region are the "Dakota" sandstone, the Mancos sandstone lying about 400 feet above the base of the Mancos, and possibly some lenticular sands within the Mancos formation. From a section taken of the Mancos formation in the vicinty of Yellow Jacket Pass near Wyman's ranch the thickness was found to be 4,000 feet. It is possible that this thickness may be a trifle low because of the following facts: (1) Exposures were so scarce that the exact attitude of the beds may not have been determined; (2) The contact between the Mancos and "Dakota" was not sharply defined.

In calculating the depths of wells necessary to reach the "Dakota" formation, the thickness of the Mancos was taken as 4,000 feet. Taking the above thickness for the Mancos the "Dakota" sand could probably be reached at a depth of 3,800 to 4,000 feet in this dome, but the sandstone in the Mancos should be reached at approximately 3,500 feet. This would mean a deep well, and the structure is so small that the writer does not see fit to recommend it for drilling until production is found in the general region.

From the crest of the Beaver Creek anticline about 1,600 feet of Mancos shale has been eroded. On account of this fact a well drilled to the "Dakota" formation would probably be at least 2,500 feet deep. The highest point on the structure, according to data collected, is in Section 5, T. 3 N., R. 89 W., very close to the center of the section, and this would probably be the proper position for a test well. Until production is assured in Williams Park or neighboring structures which look more promising than this one, the writer would suggest that definite action be delayed and that a very thorough examination be made of the geology in Sections 5 and 8, T. 3 N., R. 89 W. As mentioned previously, there is a possibility that this end of the structure swings rather than closes, and to effect a closure the strike symbols of beds in outcrops two miles apart must be prolonged to an intersection.

HAMILTON DOME

In Section 33, T. 5 N., R. 91 W., and in Section 4, T. 4 N., R. 91 W., there is a dome, elliptical in shape, known as the Hamilton dome. The axis of this elliptical dome trends almost due northwest. The dips along

the northeastern limb of the structure are fairly gentle and range from 5° to 12°. The southern or southwestern limb has dips considerably higher than those of the other limb. Dips on this limb vary from 13° to 34°, averaging about 25°, and thus make an asymmetrical dome. The formation which outcrops in this structure is the Mancos.

Oil and Gas Possibilities.—The Mancos shale, to a depth of 800 feet, has been eroded from the crest of the Hamilton dome. Judging from the thickness of the Mancos to the north of Yellow Jacket Pass and allowing 10 per cent for possible error the "Dakota" formation should be reached at a depth of 3,500 feet. This figure would be much higher if the thickness of the shale should be more than 4,500 feet. This structure is one of the most favorable structures for a possible oil reservoir in Moffat county, but is at a disadvantage because of its size. It is very small and would be expensive to drill, but it would make a splendid location for a test well. For a test well the writer would suggest a location about three-eighths of a mile S. 20° west of Weyand's house.

CRAIG ANTICLINE

There is a small structure about 3 miles southwest of Craig with a general northeast-southwest trend. The Yampa River follows the axis of this anticline very closely. The outcropping formation on which the dips were taken was mapped by the United States Geological Survey[5] as upper Mesaverde, and, since this structure was not mapped in detail, the geology as worked out by the United States Geological Survey was accepted. The general map accompanying this report agrees closely with that shown in the bulletin mentioned. The dips on the northern limb of the structure range from 5° to 10°. On the southern limb the dips are slightly higher, averaging about 9°. This structure is small and probably about 500 feet of upper Mesaverde has been eroded from its crest. This figure is a very rough estimate since the work done by the writer and party was more in the nature of a general reconnaissance.

Oil and Gas Possibilities.—Owing to the fact that the surface of this structure is in the upper Mesaverde formation and that the most probable oil sands in this region are located in the lower part of the Mancos formation and the "Dakota" which lies below the Mancos, the writer is not disposed to recommend this structure as favorable for oil. It has been suggested by some people that there is a possibility of finding oil in some of the lower sandstone members of the Mesaverde formation. There are three sandy horizons in the lower part of the Mesaverde formation, alternating with shale beds. These conditions would make it possible for the sand members mentioned to be oil bearing, but in the well drilled by the Richmond Petroleum Company on Wilson Creek these sandy horizons were

[5]Gale, Hoyt S., Coal Fields of Northwestern Colorado and Northeastern Utah; U. S. Geol. Survey Bull. 415, Plate XVI, 1910.

not found to be productive. In no locality has the writer observed any oil seeps or other favorable signs of oil in the lower sandstones of the Mesaverde formation and hence is disposed to regard them as more or less barren. However, should oil in commercial quantity be found anywhere within the Yampa field this structure would be worthy of further investigation. On account of the depth of possible oil-bearing sandstone a test well would be expensive.

WILLIAMS PARK ANTICLINE

*This name is here applied to the highest structure in the Park—that lying southeast of Willow Creek. The structure might be considered a bulge on an extension of the Sage Creek anticline, but it is separated by at least one synclinal fold from a closed structure several miles north of the anticline named. Whether or not it opens directly into Fish Creek anticline without intervening synclinal folding has not been determined because of the absence of outcrops from a considerable area.

The thickness of Mancos shale remaining along the axial plane of this fold is less than 300 feet. Erosion has removed the Mancos sandstone from the crest and exposed this member for short distances along both limbs of the fold. The limestone bed that lies a little higher in the formation outcrops on the east limb, but is covered with mantle rock on the west limb. These lowest exposed beds have a dip of 35° to 60° on the east limb and a fairly uniform northward strike throughout the area of limited exposure. The sandstone on the west limb of the fold has a dip of 5° to 10° where it is exposed, and the direction of dip changes greatly and frequently along the short line of outcrop. Several of the determined dips are shown on Plate II. It is evident that there are local wrinkles on the main fold; this is brought out more clearly when the strike of the lower beds is compared with the strike of the shale beds higher in the formation. Although the southernmost determined dip on the west limb indicates a northward pitching anticline, it is obvious that the southward convergence of the strike directions of the higher beds on opposite limbs of the fold tend to close the structure. (See Pl. II.) Further, the presence of gas in the "Dakota" sandstone, as shown by the flow in two wells, points to the possibility of a closed structure. Owing to the scarcity of outcrops the structurally highest point on the anticline has not been located.

FISH CREEK ANTICLINE

A prominent anticline with curving axis can be followed along the east side of Williams Park, thence west of north to a point two miles or more northwest of Grassy Gap. Near the south border of the park the axis of this fold trends southwest. This anticline was mentioned as part of the Tow Creek anticline by Fenneman and Gale,[10] but since it is separated from the main Tow Creek anticline by a deep synclinal fold while

*From Bulletin 23, Colorado Geological Survey.
[10]U. S. Geol. Survey Bull. 297, p. 14.

the axis near its north end trends in a direction greatly different from that of the Tow Creek anticlinal axis it seems advisable to treat this structure separately. Owing to the fact that Fish Creek runs near its axis for several miles it is here called the Fish Creek anticline.

Like most of the anticlines in this general region this fold shows a higher dip on the east limb than on the west. The dip on the west limb is 15° or less throughout the length of the fold excepting at the north part where it increases to more than 20°. For the most part the dip of the east limb is between 15° and 50°. The anticline pitches northward throughout its known length. Toward the south side of Williams Park the axis bends sharply toward the west, and the anticline merges with the Williams Park structure previously described. There is, however, an area of about a square mile in which no outcrop appears and which may possibly contain a structural terrace or even a shallow syncline.

SAGE CREEK ANTICLINE

The Sage Creek anticline was mapped by Fenneman and Gale[11] from Williams Park to a point about four miles south of Hayden where it dis-

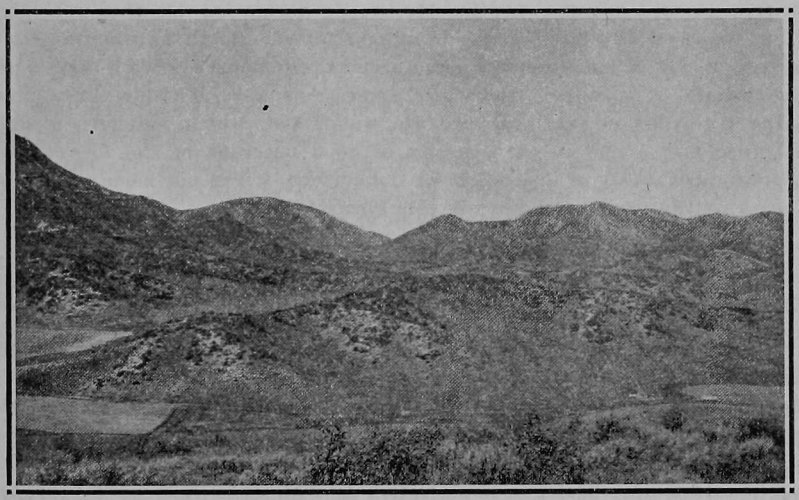

Fig. 11. Sage Creek anticline looking north from Williams Park

appears under the Lewis shale. These geologists, who were concerned chiefly with the coal-bearing Mesaverde formation, did not work out the structural details in the Mancos shale in Williams Park. This anticline also is asymmetric with the east limb dipping more steeply than the west. One prominent nose on the west limb in section 15, T. 5 N., R. 88 W., is the only notable minor feature where the Mesaverde beds are exposed.

The Sage Creek anticline, pitching northward, can be easily followed

[11]Op. cit., pp. 15, 54.

from section 35, T. 6 N., R. 88 W., southward for seven miles or more to Williams Park. In the park the most evident broader structural and topographic features seem to combine to obscure the details of structure, and in a rapid reconnaissance one might easily receive the impression that this anticline passes without interruption into the Williams Park structure previously described. It was only by close attention to details and after much digging with pick and shovel that a closure about half a mile north of the Dunkley schoolhouse was proved. Dependable readings of southeastward dips of 3° to 40° were taken. While some of these observations were made where weathering may have increased the dip of the shale near the surface there is no evidence that weathering has affected the strike. It will readily be seen from the convergence of the strike directions on the opposite limbs of the fold that there is a good closure between the schoolhouse and B. A. Long's farm house. (See Pl. II.) It is further evident from the approximate parallelism of strike of the beds on the opposite limbs that the intersection of the axial plains with any bedding plane is nearly horizontal for about a mile.

MINOR FOLDS

One prominent nose in the Mesaverde formation on the west limb of the Sage Creek anticline has been mentioned. South and southwest of Hayden in a few localities the general north to northwestward dip of the Lewis shale is very low and even approaches zero. About three miles south of Hayden a southeastward dip was noted, which indicates a small anticline; but, owing to the scarcity of good outcrops of the Lewis shale and the unreliability of dips taken at the surface, it has not been practicable to work out details of structure in this formation.

OIL AND GAS POSSIBILITIES OF THE STRUCTURES DESCRIBED

The chief factors to be considered in connection with the oil and gas possibilities of the region are: (1) the capacity of the sedimentary rocks for the formation of oil and gas; (2) the presence or absence of suitable reservoirs for the reception and storage of oil and gas; (3) the depth of such possible reservoirs from the surface; (4) the ground-water conditions; and (5) the degree of regional alteration to which the beds have been subjected.

The lower beds of the Mancos shale are highly carbonaceous, and there is no apparent reason to doubt their capacity for the generation of oil and gas. In Wyoming, sandstones in similar shales of approximately the same age have in recent years yielded much petroleum. In the Rangely, Colorado, field, near the Colorado-Utah line, oil has been found in the Mancos formation. Formations below the Mancos in the region under consideration contain a relatively small amount of shale. In the Mesaverde formation overlying the Mancos there are, in addition to the coal seams, many shale beds that carry considerable carbonaceous material.

The "Dakota" sandstone, though in places quartzitic and nearly tight, is usually open enough for the free circulation of ground water. In the Williams Park anticline a considerable flow of gas is reported from two wells that have been drilled into this sandstone since the Survey party was in the field.

About 400 feet above the "Dakota" sandstone is a persistent sandstone member of the Mancos shale. (See p. 13.) This member, which is 25 feet or more in thickness, is composed chiefly of sandstone with intercalated beds of shale and limestone. The sandstone is only moderately porous, but these beds have openings enough for the circulation of ground water as evidenced by at least one spring at the outcrop in the Williams Park anticline. It is believed that the porosity is sufficient for the reception and circulation of oil and gas. The overlying shale furnishes a compact cover that would prevent the escape of petroleum where structural conditions are favorable to accumulation.

Several anticlines of this region are open at one end and have a fairly constant angle of pitch. Owing to the probability of leakage at the open end such anticlines are generally not suited to the accumulation of oil and gas. Only those will be considered here which are closed or which do not furnish conclusive evidence of being open.

Conditions indicating the southward closure of the Williams Park anticline were mentioned on page 34. Even if the change in dip and strike of the beds should not be sufficient to effect a closure, leakage might be prevented by basalt dikes. A dike, or sheet, dipping 20° southward, may be seen a mile or two southwest of the exposed crest of the fold. This rock is in part nearly compact and similar to the basalt that overlies the sandstone of the cliff farther east; it is in part vesicular, with cavities that have a maximum diameter of about two inches. It is obvious that the basalt might form either an impervious cover or a good reservoir, depending on the degree of compactness and the dip of the dike or sheet.

The removal of part of the sandstone member of the Mancos shale and consequent outcropping of the sandy beds afford opportunity for the leakage of any oil that may have found its way to these beds. The chances of finding oil or gas in commercial quantity in the remaining Mancos beds in this anticline are slight. However, the remaining Mancos shale is 200 feet in thickness, or more, and is probably ample to form an impervious cover for the "Dakota" sandstone. The gas already found in this sandstone may have been generated in underlying beds or, possibly, in the overlying Mancos shale.

From the crest of the Sage Creek anticline there has been removed by erosion perhaps 700 or 800 feet of Mancos shale. If the thickness of this formation has not been materially affected by folding it may have been originally about 4,400 feet in all, or about 4,000 feet from the top down to the first prominent sandstone. (See p. 13). The sandstone would ac-

cordingly be about 3,200 or 3,300 feet below the present surface. But accurate determination of the thickness of the formation and depth to the sandsone must await the drill. It is not improbable that local thickening has accompanied folding and that the thickness of the shale in the anticline a few miles south may be different from the thickness here. Uniformity of thickness is hardly to be expected in a heavy shale formation between competent sandstone strata in a region of much folding. Hewett and Lupton[12] have found that the shale on opposite limbs of a single anticline may differ several hundred feet in thickness, being thicker on the steeper side.

The same factors that could produce local thickening might cause a bulge on an anticline and show a closed structure at the surface where none exists at depth. There is, however, no observed indication that the closure of the Sage Creek structure does not hold through the Mancos shale. Of those mentioned in previous pages it should be the first to be tested. Fully to test the structure to and including the "Dakota" sandstone the driller should be prepared to bore 4,000 feet, but it is possible that the Mancos sandstone would be reached within 3,000 feet. Whether or not sandstone lenses or other possible reservoirs exist above the main sandstone member can only be determined by drilling. Jointing, fracturing, or solution might make the limestone or calcareous platy shale sufficiently open to receive oil and gas. Though the highest part of the anticline is limited in width by the syncline on the east, the most promising drilling area extends much farther in a general north-south direction where the axis of the folded sandstone is evidently nearly level for about a mile. A further advantage is found in the wide area of possible drainage which extends far north of Yampa River and includes much of the general synclinal basin.

Should the Sage Creek anticline prove to be productive a careful examination of other hitherto untested areas within the region would be advisable. Among these may be mentioned the Fish Creek anticline northeast of the Williams Park anticline and sections 11 and 15, T. 5 N., R. 88 W. Though the writer has not examined in detail the area in the two sections named the dip and strike of the beds, as mapped by other members of the party, are significant.

GROUND WATER

Very little is known about ground-water conditions at depth within the area under consideration. Shallow wells in the Lewis and Mancos shales furnish sufficient water for stock and household use. In all probability any sandstone within the region is sufficiently porous to carry water. Mr. W. A. Dawson, of the Twentymile Oil Company, states that when the first well of his company reached the "Dakota" sandstone water rose in the well 1,000 feet, that is, to within 725 feet of the surface.

[12]Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyoming: United States Geol. Survey Bull. 656, 1917.

DEGREE OF CARBONIZATION OF MESAVERDE COAL

David White[13] has pointed out the close relationship that exists in oil fields between the character of oil and the degree of carbonization of coal in the same or overlying formations. He says:[14]

Noting the gradual elimination of the volatile hydrocarbons—the so-called volatile matter—from the oil shale simultaneously with the devolatilization of the associated coals in the course of the progressive regional alteration of the organic deposits, I have called attention to several other points which seem to indicate a mutual relationship between coal and petroleum in the second or geochemical stage of development, and that both react to the same geophysical influence, as follows: (1) That in regions where the coals and other carbonaceous debris in the strata are of the rank of brown lignites, the oils in the same or closely associated geological formations are also of low rank, averaging 20° to 26° Baume; (2) that where the organic debris (coals, etcetera) has advanced to the sub-bituminous rank, the oils of the same or of nearly contemporaneous underlying formations are of higher rank, averaging 28° to 35°; (3) that when the deposits of organic debris have been regionally transformed by elimination of volatile matter) until they have reached the bituminous rank, the oils have in general attained a rank of 35° or more, the highest grade of petroleum being formed in the areas where the regional alteration of the organic debris has progressed farthest; except (4) that in those regions where the organic debris, whether it be represented by beds of coals, by bogheads, or by carbonaceous matter in shales, has passed the point corresponding to a content of 65 per cent of fixed carbon, pure coal basis, the oils which may formerly have been present in the same or in the underlying formations have mostly disappeared; and (5) that wherever the devolatilization of the coals, etcetera—that is, the solid residues in the strata—has progressed so far that they have a fixed carbon content of 70 per cent or more, oils, if present, will be "freak" oils, and in pockets or amounts too small to be of commercial importance, though gas pools may persist. I know of no commercial oil pools in the world that are found in or beneath formations in which the regional carbonization of the organic debris has passed 75 per cent fixed carbon, pure coal basis; in fact, I have not yet been able to learn of an oil pool in or beneath a formation in which the fixed carbon percentage of the organic debris exceeds 70, and it is most improbable that oil pools exist under such conditions.

It will at once be seen that these conditions seem to define a law restricting the distribution of productive oil pools, and to afford a basis on which to eliminate many areas of great extent in which fruitless and costly exploration by the drill is now going forward.

In Doctor White's third paper cited, page 5, he states:

More observations and tests are necessary to fix more exactly the stage of regional alteration beyond which commercial oil pools, though formerly present, will not have survived, but it is probable that the limit falls, in general, slightly lower than the point at which coals of the ordinary bituminous type show a fuel ratio of 2.2 or 68 per cent of fixed carbon in the pure coal; it may approach nearer the ratio of

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[13]White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.

———, Late theories regarding the origin of oil; Geol. Soc. Am. Bull., vol. 28, pp. 727-734, 1917.

———, Genetic problems affecting search for new oil regions: Mining and Metallurgy, No. 158, pp. 1-20, 1920.

[14]Geol. Soc. Am. Bull., vol. 28, p. 732.

2.0, or 66 per cent fixed carbon. Coals verging toward the sapropolic type, such as are believed by many to approach more closely the typical mother substance of oil, are more fatty and accordingly richer in hydrogen and lower in fixed carbon (pure coal basis) than the other types, until, in the course of alteration by geologic processes, they approach the above limit, when the volatile matter seems to disappear rapidly. At the semi-bituminous stage (fuel ratio 3.0, fixed carbon 75 per cent), their carbonization is approximately on a parity with typical bituminous coal.

Gale[15] gives analyses of 43 samples of Mesaverde coal from mines and prospects over a wide area extending from Pilot Knob north of Yampa River to Meeker on White River. Of these 43 analyses 39 show fixed carbon between 52 and 62 per cent on a pure coal basis—that is, after eliminating moisture and ash. Only 2 of the 39 contain over 60 per cent fixed carbon. Two others, from Pilot Knob, where the coal has been locally affected by basalt intrusion, show respectively 71.6 and 95.6 per cent fixed carbon. The remaining 2 of the 43 fall considerably below the general lower limit of 52 per cent, having 46.4 and 48.6 per cent fixed carbon, respectively. Gale states that these two analyses were made from weathered samples.

Insofar as the Mesaverde beds are concerned, excepting the areas of local metamorphism, alteration, as shown by coal analyses, has been sufficient, yet not too much for the production of oil, according to the limits set by White. It is to be expected that the regional alteration of the older Mancos beds would be somewhat more than that of the Mesaverde, yet well within the limits mentioned.*

PRE-CRETACEOUS AREA NEAR McCOY

PRE-CRETACEOUS FORMATIONS

The area of pre-Cretaceous rocks near McCoy is distinctly marked off from the Cretaceous area of the Yampa coal fields by the absence of shales and the presence of many strata of red and white sandstones. An alternating succession of these older sediments comprising several thousands of feet exists between the metamorphic and igneous pre-Cambrian rocks to the east and the Cretaceous "Dakota" formation to the west. These older sediments occupy the area around McCoy and are also found to the north and west in the Cretaceous region where folding or river erosion has exposed them.

The Cretaceous outcrops to the west are composed mainly of the typical yellowish siliceous sandstones of the "Dakota" and scattered portions of the basal black slaty shale of the Mancos formation.

Sections of the older rocks may be examined on Rock Creek, on the south bank of Grand River west of McCoy, and northeast of Yarmony. The "Dakota" Cretaceous, Jurassic (?), Triassic (?), and the Permian (?), and part of the Pennsylvania of the Carboniferous system are excellently exposed on the west limb of an anticline on Grand River. The Mississippian (?) series and older rocks are partly exposed northeast of Yarmony and

[15]Gale, H. S., Coal fields or northwestern Colorado and northwestern Utah: U. S. Geol. Survey Bull. 415, pp. 248-249.

east of Rock Creek. There are several other places within this limited area where portions of sections may be obtained owing to the extensive folding which has taken place.

Generalized Columnar Section

	Feet
Cretaceous: Dakota sandstone, shale and conglomerate	±150
Jurassic (?): Light colored sandstones and shales	±500
Triassic (?): Bright red thin-bedded sandstones, sandy shales, and thin beds of limestone	±1,100
Carboniferous: Sandstones, conglomerates, shales, limestones (overlap?)	±3,000
Devono-Carboniferous (?): Limestones, quartzites, sandstones, shales	±200
Archean: Crystalline and metamorphic rocks	-----
Total	4,950

DEVONIAN-CARBONIFEROUS (?) SYSTEMS

Lying unconformably on the metamorphic and igneous rocks are 200 feet of massive limestones, sandstones, and clay shales. The limestones are very hard and fine grained. They usually have a blue color on fresh surfaces and weather to a white or a light yellow or brown. The sandstones are often quartzitic and when not altered are coarse grained. The small beds of shales are limy and sandy and have a red and yellow tinge. No fossils were found in these lower beds, but they may be correlated in a very indefinite way on a lithological basis with the Devonian-Carboniferous rocks of the Rico Mountain[6]. These rocks include the lower Paleozoic rocks of the Hayden atlas.[7]

Section of the Lower Paleozoic Rocks East of McCoy, Colorado

	Feet
Sandstones, massive, soft sugary; somewhat conglomeratic	30
Shales, red and yellow, calcareous, sandy (partly covered)	50
Sandstones and sandy micaceous shales	12
Limestones, massive, bluish gray, fine grained	14
Sandstones and shales, alternating sandstones are coarse grained and pink; shales are limy, considerable crumbling and alteration shown	28
Limestones and calcareous sandstones; beds are massive and weather to a light yellow and brown	55
Shales, quartzites, sandstones; shales are blue and calcareous	55
Sandstones, white, coarse grained, some conglomerate seams	5
Metamorphic and igneous rocks	--
Base of formation	--
Total	249

CARBONIFEROUS SYSTEM

Above the lower Paleozoic rocks and below the so-called "Red Beds" is a series of sandstones, shales, and limestones. The fossils found indicate that the greater part of these rocks belong to the Pennsylvanian system. Invertebrate fossils are numerous throughout parts of the formation. Brachiopods predominate over the mollusks, and the characteristic foraminifer,

[6]Cross, Whitman, and Ransome, F. L., Description of Rico Quadrangle; U. S. Geol. Survey, Geol. Atlas, Rico folio (No. 130), p. 2, 1905.

[7]Hayden, F. V., Atlas of Colorado: U. S. Geol. and Geographical Surveys of the Territories, Pl. XI, 1881.

Fusulina cylindrica, is also present. The fossils are most nearly characteristic of the Hermosa formation of southwestern Colorado. Collections from these beds near McCoy were examined by Professor Junius Henderson, who has identified the fossils that are listed below:

Hyalostelia (?) sp.
Fusulina cylindrica (Fischer)
Crinoid plate and stems
Syringopora sp.
Fenestella sp.
Bryozoa undetermined
Chetetes? milleporaceous Milne, Edwards and Haime
Campophyllum torquium (Owen)
Productus cora d'Orbigny
Productus gallatinensis Girty
Productus punctatus Martin
Productus semireticulatus Hermosanus Girty
Marginifera haydenensis Girty
Marginifera muricata (Norwood and Pratten)
Composita subtilita (Hall)
Squamularia perplexa (McChesney)
Spirifer boonensis Swallow.
Spirifer cameratus Morton
Spirifer rockymontanus Marcou
Allorisma terminale Hall
Pelecypod undetermined
Cf. Pleurotomaria scitula Meek and Worthen
Worthenia tabulata (Conrad)
Euomphalus catilloidea (Conrad)
Euomphalus pernodosus (Meek and Worthen)
Naticopsis altonensis (McChesney)
Platyceras parvum Swallow
Scleniscus cf. anguliferus (White)

Sandstones are by far the predominating rocks of the Carboniferous system. Some of the beds attain a thickness of 300 feet, while others are thin bedded and intercalated with sandy shales and limestones. The sandstones are usually coarse grained and of even texture, having siliceous and calcareous cementing materials. Many, however, change in texture and become conglomeratic, arkosic, or fine grained in very short distances. Red, maroon, and pink are the predominating colors, with an occasional white or mottled sandstone. The reddish sandstones are often banded with white stringers and some are highly micaceous.

The shales are for the greater part very sandy and increase in their sand content until they change into thin-bedded sandstones. They also have the different red colors and when fossiliferous are dark and bluish gray. The small bodies of dark shales contain carbonaceous material, and at two places there is a seam of poor coal. Highly micaceous sandy shales predominate in the lower rocks.

A columnar section of the more calcareous and fossiliferous part of the Pennsylvania series is given on plate I. The limestones are generally blue and gray in color and very fine grained. In nearly every case they are hard and are often fossiliferous.

Above this more calcareous division and below the typical "Red Beds" alternating coarse and fine-grained red sandstones and shales are present. There are several thick strata of thin-bedded sandstones and sandy shales,

and an occasional massive bed of coarse-grained sandstone or conglomerate. Several hundred feet of thin-bedded buff and brown sandstones, a massive white sandstone and grayish shales are near the top of the Carboniferous series. These rocks are interbedded with red and white-banded coarse sandstones and sandy shales.

Section of Part of the Pennsylvanian Rocks Northeast of Yarmony

	Feet
Conglomerates, red, massive and coarse grained	160
Sandstones, red, coarse grained alternating with red and gray sandy shales; partly covered	34
Clay shales, red	25
Sandstone, massive, coarse grained, with white bands	40
Sandstones, thin bedded, alternating with sandy shales	30
Shales, sandy, micaceous, in occasional bluish gray shale layer	38
Sandstone, coarse grained, red and sandy shales; sandstones and shales highly micaceous	40
Conglomerate, red, and contains small quartz and feldspar pebbles	10
Talus slope	243
Sandstone, massive, gray, coarse grained	18
Shales, red, yellow and sandy, a few thin-bedded sandstones, partly covered	171
Coarse-grained sandstones alternating with light red micaceous shales	343
Total	1,151

TRIASSIC (?) SYSTEM

A series of over a thousand feet of bright red thin sandstones and sandy calcareous shales is made up of typical "Red Beds." The dividing line between these beds and the Carboniferous rocks below is questionable. At the base are variable beds of thin sandstones, thin limestones, and calcareous shales. Above these variable beds is a more persistent succession of thin-bedded sandstones and shales interbedded, occasionally, with gypsum. These beds vary in thickness, and are at some places massive. A limestone bed is present near the base of these sandstones, which varies in thickness and is discontinuous at several places. Fresh surfaces show that it is a white limestone which weathers brown and black. From a distance it appears to be blue. It usually has a conglomeratic appearance with a honeycombed surface There is a rather massive bed of coarse white conglomerate near the top divided by red sandy shales. Very little carbonaceous material is found in this formation.

Section of Triassic (?) Rocks on Grand River

	Feet
Sandstones, bright red, thin bedded; fine grained and sandy shales	285
Conglomerate, white, coarse grained	2
Shales, sandy, red	10
Conglomerate, white, coarse grained, with pebbles, mostly quartz, and feldspar	20
Sandstones, red, thin bedded, fine grained	75
Shales, red, sandy, gypsiferous	15
Sandstones, red and thin bedded, and sandy shales (commonly calcareous)	550
Limestone, brown and black, sandy, conglomeratic	15
Sandstones, red, thin bedded, and sandy, gypsiferous shales	180
Shales, red, blue, gray, interbedded with thin sandstones and limestones, Carboniferous (?)	132
Total	1,285

JURASSIC (?) SYSTEM

The bright red sandstones of the supposed Triassic system stand out in contrast to the lighter-colored sediments of the overlying probably Jurassic beds. At the base of this system is a rather massive thick and thin-bedded sandstone. It is rather fine grained, and south of Grand River attains a thickness of over 150 feet. Approximately 35 feet from the top of this sandstone there is a 10-foot bed of slightly bituminous and calcareous shales. The bituminous odor was noticeable when the rock was struck with a hammer. These shales divide the sandstone member into two parts. The lower part of this sandstone member probably corresponds to the La Plata and White Cliff sandstones of southwestern Colorado. Between this sandstone and the overlying "Dakota" sandstone are beds of shale, clay, sandstone, and limestones similar to the McElmo formation. The shales are gray, red and green, and often show no bedding planes. They are usually sandy and calcareous. The calcareous shales and limestones predominate near the base of the formation while the sandstones and sandy shales are at the top.

The shales are divided by an occasional strong bed of sandstone or limestone. A massive coarse-grained sandstone 20 feet thick is present approximately 200 feet from the top of the formation. The limestone beds are thin and have a grayish blue color. They are hard and fine grained. One fossil *Unio sp.* was found in this formation where it is exposed northeast of Yarmony. This formation is between 400 and 550 feet thick.

Section of Part of the Jurassic Rocks as Found Near Burns, on the Grand River

	Feet
Debris-covered slope	--
Shales and clays, hard, green, compact, with few or no bedding planes	75
Shales, coarse grained, massive and white	20
Limestone, hard, grayish blue	2
Shales and limestones, gray, calcareous shales; limestones, thin and hard; occasional thin sandstones	35

Section of Part of the Jurassic Rocks as Exposed West of McCoy, on the Grand River

	Feet
Shales and clays, green, red, sandy and calcareous shales	50
Sandstones, white, thin bedded, fine grained	34
Shales, carbonaceous and bituminous	10
Sandstones, white, thick and thin bedded, fine grained	135
Sandstone, red, thin-bedded Triassic (?) (base of formation)	--
Total	229

OIL AND GAS POSSIBILITIES

Reconnaissance work was done on the structural features in this area merely to find the approximate position of the folds. Detailed work was not attempted.

There are two parallel anticlines several miles west of McCoy, whose axes cross Grand River in an almost north and south direction. These folds are probably closed anticlines. The Pennsylvanian series of the Carboniferous system is exposed on the limbs of these folds near the axes.

There are also folds on Cabin, Derby, and Red Dirt creeks west of Burns. These creeks are branches of Grand River and flow in a southeast

direction along the axes of the folds. The Jurassic (?) rocks are exposed on Cabin and Derby creeks, and the Upper Carboniferous on Red Dirt creek.

Northwest of McCoy there are two prominent folds. In Smiths Basin in the western part of Egeria Park there is a probably closed anticline in the "Dakota" formation, whose axis trends northwest. King Mountain to the southeast of Smiths Basin is structurally a dome. This fold was not examined in detail, but the position of the formations indicates that the "Dakota" formation dips away on all sides from a central point. The Triassic (?) and probably part of the Carboniferous systems are exposed by this folding.

The greater part of the pre-Cretaceous rocks is made up of sandstones and conglomerates. Of the entire series there are two possible horizons where oil may have originated. The rest of the formations appear too "dead" or "dry" with little or no chance of any oil formation. The greater part of the sandstones is coarse grained with no fossils or carbonaceous materials present. The shales when present are usually sandy and micaceous, and probably would not generate any gas or oil.

The fossiliferous part of the Pennsylvania series is shown in Figure 13 on Plate I. These beds are about 3,800 feet below the top of the "Dakota." In this section there are five fossiliferous beds of limestones and shales. Each bed contains many fossils and in places shows as many as fifteen species. (See page 42.) Others who have collected fossils from this area have reported many more. These animals buried in the marine sediments may give sufficient material for the formation of oil. The oil would be derived from the decomposition of the bodies which would later accumulate into so-called "pools" It is very probable that oil and gas have been distilled by the heat generated by the pressure of the overlying sediments and the folding which has taken place. This, of course, is questionable, and it is not known how much was generated. Small amounts of bituminous materials under certain conditions may generate commercial bodies of oil and gas, and it is also equally proper to believe that under other conditions they may generate little or no oil or gas. In this section the most important question appears to be the position, character, and amount of sandstones present, and their position in relation to the fossiliferous beds. The fossiliferous beds alternate with sandstones, conglomerates, shales, and limestones for about 500 feet. The sandstones are very probably suitable reservoirs for oil and gas as they are coarse grained and not tight. The capping shales, however, do not appear sufficient to retain oil and gas in commercial quantities. It may be stated that, in general, the sandstones are too extensive for the small amounts of shale and fossiliferous beds present.

Near the base of the Jurassic (?) system there is a bituminous shale and sandstone member about 10 feet thick. The source of this bituminous material is not known, but there are probably fossils within it. There is little chance that this could develop oil or gas in commercial quantities.

AN ANTICLINE IN MONTEZUMA COUNTY

BY R. C. COFFIN

GENERAL CONSIDERATIONS

NAME AND LOCATION

The fold which is discussed in the following pages has been named the McElmo anticline. It lies in Montezuma county, Colorado. The center of the area affected by the fold is approximately 25 miles north and 12 miles east from the southwest corner of the state. Dolores, which is the nearest railroad point, is situated on the Rio Grande Southern 13 miles north and east of Cortez, or 22 miles from the highest point of this fold.

Only the important points which are involved in the oil possibilities of this fold are considered.

FIELD WORK

The field work which supplied data for the present discussion was done by the writer in the Spring of 1918.[1] A triangular skeleton had been established in this region during a reconnaissance of the carnotite area of western Colorado.

PHYSIOGRAPHY

The beds of the area are essentially horizontal except in the immediate vicinity of the fold. In the northeastern part of the area examined the surface is, in general, smooth, but in other parts McElmo Creek and its tributaries have cut canyons which are separated by flat-topped divides. The area in which erosion has reached a maximum lies in Sand Gulch which crosses the fold at approximately its highest point.

Goodman Point, which includes the highest ground north of McElmo Creek, is approximately 1,500 feet above the bottom of the canyon. South of McElmo Canyon the Ute Mountains rise to an elevation of slightly more than 9,500 feet, 3,000 feet above the surrounding country. Sedimentary rocks dip gently away from these mountains on all sides.

STRATIGRAPHY

GEOLOGIC SECTION

The following geologic section represents the thickness of formations above the Dolores in the walls of McElmo Canyon, and the thickness of lower formations as found in areas contiguous to the McElmo Canyon.

Approximate Thickness of Formations in McElmo Canyon and Contiguous Areas

System	Name of Formation	Thickness in Feet
Cretaceous	Mesaverde	880±
Cretaceous	Mancos	500 to 1,000
Cretaceous	"Dakota"	100 to 200
Jurassic or Cretaceous	McElmo	650
Jurassic	La Plata	175 to 210
Triassic	Dolores	1,000 to 1,600
Permian (?)	Cutler or Moenkopi	300 to 1,800
Pennsylvanian	Hermosa or Goodrich	1,000±

[1]—Coffin, R. C., Report on the Main Carnotite Area of Southwestern Colorado; Colorado Geol. Survey Bull. 16, 1920.

In the region of the McElmo Canyon the streams have removed practically all the sedimentary rocks down to the "Dakota" formation which caps the mesas and which constitutes the surface material over large areas. Where the "Dakota" has been cut through, the sandstones and conglomerates of this unit form the so-called "rim rock." In the canyon proper, cutting has reached the Dolores formation, and in places along Sand Gulch depths of 300 feet have been reached within this formation.

ROCKS EXPOSED IN McELMO CANYON

Inasmuch as the formations exposed in McElmo Canyon are of secondary importance they are described briefly.

Upper Part of the Dolores Formation.—The upper 300 feet of Dolores formation is exposed along Sand Gulch. The materials consist of massive and thin-bedded standstones separated by seams of red shale. Two of these massive beds form separate cliffs which characterize the exposures of this unit.

La Plata Formation.—This formation consists of a massive sandstone which is characterized by its smooth-weathering outcrops. This sandstone forms a white to pink cliff 200 feet high, which generally forms the base of a steep slope extending from the bottom of the canyons to the "Dakota" formation above. (See Fig. 11.)

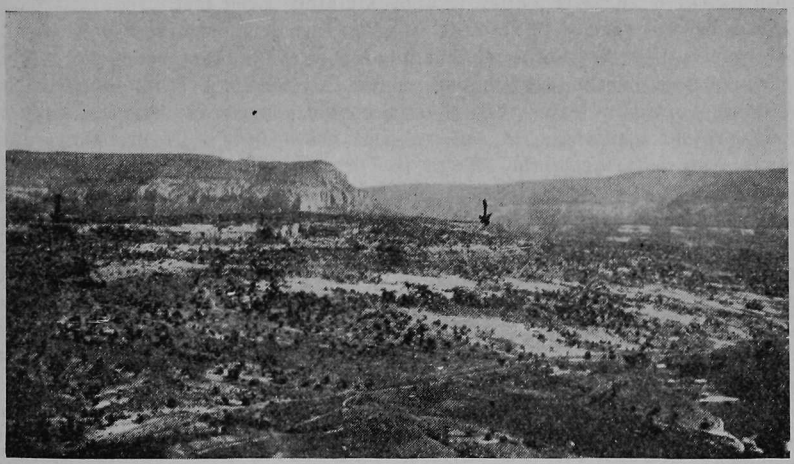

Fig. 12. View looking northeast from Battle Rock
Arrow to the right indicates recommended drilling site; arrow to the left indicates position of shallow well previously drilled.

McElmo Formation.—The McElmo formation consists of a lower portion predominantly sandstone and an upper portion predominantly shale. The lower portion includes massive and thin-bedded sandstones separated by lenses or seams of red to maroon shale. The upper portion includes variegated shales, and a massive conglomerate near the top. This conglomerate forms a cliff secondary to the "Dakota" above and can generally be separated from the upper one by its brown color and an abundance of green pebbles which characterize this bed.

"Dakota" Formation—This formation consists of a massive sandstone conglomerate at the base and a sandstone near the top of the formation with shales and shaly sandstones intervening. The outcrop of this unit forms the top of most of the canyon walls.

Other Formations.—Mancos shale occurs as remnants along the foot of the Ute Mountains and in an area south of Cortez. This formation and younger ones need not be described.

Instrusive Rocks.—The different intrusive rocks which form the Ute Mountains are of the same general composition but different in texture. They include coarse and fine-textured andesite porphyries. Metamorphism due to this intrusion has affected the shales in one place at least one-fourth mile from any known igneous rock. The sandstones, however, have been practically unaffected.

FORMATIONS NOT EXPOSED IN THE McELMO CANYON

No exposure of beds below the Dolores formation occurs within 25 miles of the McElmo anticline and it is impossible to determine the exact nature of beds which are not exposed in the anticline.

Lower Part of the Dolores Formation.—These beds as exposed in the Dolores Canyon north of the area consist of maroon to red shales and thin-bedded sandstones. The total thickness of the Dolores formation as determined in Paradox Valley is approximately 1,000 feet.

Cutler Formation.—The beds of this formation which are exposed in Dolores Canyon to the north include deep red shales near the top, and arkose, sandstone and conglomerates at the base. A study of these beds at many points indicates that their probable source was north and east of their present outcrops. It follows that these beds will probably contain less coarse material in the site of the present fold than is included in the sections along Dolores River. The general character of the Moenkopi formation (equivalent to the Cutler) farther south indicates such a change.

Hermosa Formation.—Beds of this formation are exposed in the Rico Mountains 45 miles southeast of the McElmo anticline, in Gypsum Valley and vicinity, 35 miles north, and along the San Juan River near Bluff, 45 miles to the west of the anticline. It is not to be expected that the exact order of beds as shown in any one exposure will prevail in the McElmo anticline.

A section of this formation which occurs in Klondyke near the head of Gypsum includes approximately 500 feet of beds which show the following sequence:

Section of Carboniferous Rocks in Klondyke

Top
1. Limestone
2. Sandstone, red, very friable
3. Sandstone, massive
4. Limestone, highly fossiliferous
5. Sandstone, coarse grained
6. Limestone, fossiliferous
7. Conglomerate sandstone, gray and red
8. Limestone
9. Shale, fossiliferous
10. Sandstone
11. Limestone, abundantly fossiliferous

12. Sandstone, thick bedded
13. Limestone and shale, fossiliferous
14. Limestone and shale, about 300 feet
15. Limestone
16. Limestone and shale, about 100 feet

Gypsum occurs stratigraphically below the section given but its exact position could not be located. Over 75 per cent of the fossils collected from these exposures occur in the Carboniferous beds of the San Juan oil field.[2]

The section of the Goodrich formation (equivalent to the Hermosa) of the San Juan oil fields as measured by Woodruff[3] includes 1,541 feet of beds not unlike those exposed in Klondyke. The Hermosa formation in the Rico Mountains[4] includes over 1,800 feet of sandstone, grits, shales, and limestones. The limestones are generally fossiliferous.

A correlation of individual beds of the three sections mentioned cannot be made. Fossils collected from the three regions show conclusively that the beds are of the same age and their general character shows that they are essentially the same formation.

STRUCTURE

NATURE OF THE FOLDING

The area involved by the folding of the McElmo anticline is approximately 20 miles long and 8 to 10 miles wide. Beds dip away from this fold at small angles, 10 degrees being the maximum dip recorded. These maximum dips occur on the south side of the anticline and suggest that this is the direction from which the forces came which produced the fold.

The structure as indicated by the map is that of a distinct dome whose major axis is curved. This axis extends north from the east edge of the Ute mountains crossing McElmo Canyon and extending west to Yellow Jacket Canyon. An axis of secondary folding extends from the top of the dome in a direction N. 30 degrees E. Another secondary axis passes through the town of Cortez running in a westerly direction. This axis is not well defined west of Trail Canyon.

HEIGHT OF THE DOME

The height of the dome indicated by the contour map is 200 feet. This 200-foot closure occurs at the foot of the Ute Mountains where the sedimentary rocks are upturned very gently along the main axis toward the south. These adverse dips were limited to the immediate vicinity of the igneous rocks. Inasmuch as the elevation of the "Dakota" formation south of Ute Mountains is less than it is at any point north of the Ute Mountains it is probable that the deeply buried beds in this region are not affected by the igneous material as suggested by the "Dakota" formation now at the surface. If so, the height of this dome may not be limited by the 200 feet as indicated, but may be determined by the position of the syncline

[2]Woodruff, E. G., Geology of the San Juan Oil Field, Utah; U. S. Geol. Survey Bull. 471, pp. 83-85, 1910.
[3]Op. cit., pp. 81-82.
[4]Cross, Whitman, U. S. Geol. Survey, Geol. Atlas, Rico folio (No. 130)

which follows Yellow Jacket Canyon, and the lowest closing contour is the one whose elevation is 5,700 feet, making the height of the dome 450 feet.

FAULTS

The faults indicated on the map are such as to have practically no effect on the structure as an oil reservoir. Displacements of over 30 feet are unusual, and most of the dislocations are less than 15 feet. The outcrop of the La Plata sandstone is such as to reveal all faults even to displacements of one foot, and many here visible would under ordinary conditions be passed over without notice.

AREAS TRIBUTARY TO THE STRUCTURE

Applying generally the anticlinal principle of oil accumulation, a considerable area is structurally so situated that if its beds ever contained oil, it has probably accumulated in this structure.

Beds which dip southwest from the McElmo anticline maintain their gentle dips without interruption to the southwest over areas which include parts of Utah and Arizona. The same conditions prevail on the southeast side of the structure where beds dip south from the secondary axis which passes near Cortez, extending without interruption into the San Juan basin. To the east of the structure drainage is cut off by the syncline which comes within the area mapped and on the north by the one which follows Yellow Jacket Canyon. The interruption offered by the Ute Mountains to these southern dipping beds is not serious.

This structure is situated along the edge of a huge structural basin which comprises the northeast part of New Mexico and adjoining parts of Colorado. The relation of this structure to this huge basin is such that if its deeply buried beds ever contained oil its partial accumulation is to be expected in the McElmo anticline.

RELATIONSHIPS AND OIL POSSIBILITIES

POSSIBLE OIL-BEARING FORMATIONS

Inasmuch as the beds above the Dolores formation are all exposed, only those below this formation need be considered.

The lower part of the Dolores formation and the beds of the Cutler formation are deposits of sand and shale which contain no appreciable amount of either animal or carbonaceous residues. They cannot be considered possible sources of oil in the present structure. The Cutler formation, however, includes a combination of beds—the arkose beds at the base capped by shales above—which might constitute a reservoir for oil if it were present. It is possible that oil migrating upward would be caught in these basal sandstones.

The Pennsylvanian beds which underlie the Cutler are known to be oil-bearing in the San Juan oil field, and oil seeps elsewhere in this part of the Plateau country are reported to be in beds of this system. In connection with the occurrence of oil in the San Juan oil field and known seeps in different parts of southeastern Utah Woodruff[5] says: "* * * * It

seems probable * * * that oil in varying quantity is deposited over large areas in Utah and contiguous regions to the south."

STRUCTURE OF UNDERLYING BEDS

The structure of the deeply buried Pennsylvanian beds is not without its uncertainties. An unconformity is known to exist at the base of the Permian formation in different parts of Colorado. In Gypsum Valley and vicinity Pennsylvanian beds abut against Triassic beds at an angle of 30 degrees. Gypsum Valley appears to be an old line of weakness established in pre-Permian times by a folding process which resulted in the removal of the Cutler formation and most of the Hermosa formation previous to Triassic deposition. A similar order of events may explain a series of folds which is parallel to the Uncompahgre Plateau. The Dolores anticline, 30 miles north of McElmo Canyon, appears to be a southern limit beyond which these parallel folds do not exist.

The unconformity at the base of the Permian (?) will admit of three posibilities: that the area of the McElmo anticline was folded and beds of the Hermosa formation were removed previous to Triassic deposition; or that the region was gently folded and these beds partially removed; or that the unconformity noted in Gypsum Valley is not pronounced in the McElmo anticline and that the Hermosa beds exist in this area folded in the same manner as those now at the surface.

No evidence is recorded that would indicate that this area was mountainous or subjected to any extreme folding between the time of the deposition of Pennsylvanian beds and those next above. No angular unconformity has been reported in the beds in question south of Disappointment Valley.

H. E. Gregory[6] who examined a large area in New Mexico and Arizona gives as his opinion the following:

> It seems probable that strata of Pennsylvanian age underlie the entire Navajo country, and that deep burial by Mesozoic sediments permits their exposure only at the summits of eroded domes and in the bottoms of profound canyons.

There is every reason to believe that Pennsylvanian rocks exist below the structure in question. However the exact sequence of the several sandstones as found in the Goodrich formation of the San Juan oil field or elsewhere is not to be expected.

RELATION OF THE STRUCTURE TO THE IGNEOUS MASS OF UTE MOUNTAIN

The existence of a large mass of igneous rock adjacent to the structure needs consideration. The Ute Mountains have been considered a mass of igneous rock which was intruded between layers of sedimentary rock, the present mountains are considered remnants of this laccolithic intrusion whose capping sediments have been removed. Such an origin would suggest that the McElmo anticline might have been formed by a similar intrusion

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[5]Woodruff, E. G., Geology of the San Juan Oil Field, Utah; U. S. Geol. Survey Bull. 471, p. 104, 1910.

[6]Gregory, H. E., Geology of the Navajo Country; U. S. Geol. Survey Prof. Paper 93, page 19, 1917.

which does not appear in the present stage of erosion. This point can not be definitely settled without drilling, but certain facts tend to show that the present fold has not been formed by such a process. The McElmo anticline does not present the usual circular outline which is possessed by folds resulting from such intrusion. The present anticline extends 25 miles east and west and possesses its maximum deformation opposite Ute Mountain. There seems to be little doubt that the intrusion of such a mass as Ute mountain would necessitate a shortening of the beds into which it was intruded; this shortening of beds could have been accomplished by the formation of the McElmo anticline and the syncline which separates it from the Ute Mountains. The sagging of the beds near the mountains was probably due to the removal of material from great depths to the present site of the intrusion. No evidence of hydro-thermal action was noted in the vicinity of the McElmo anticline. There is some evidence that the present Ute Mountains were formed by an igneous mass whose bounding walls were more or less vertical, forming a huge igneous plug or column. Such an origin of these mountains would argue against the probability of the structure being complicated by masses of buried igneous rock.

RELATION OF THE STRUCTURE TO THE SAN JUAN OIL FIELD

The San Juan oil field is the nearest point where oil has been found in strata of the same age as those involved in the McElmo anticline. This field lies along San Juan River 45 miles west of the area examined. In the San Juan Canyon several beds of the Carboniferous formation are exposed which are known to be oil-bearing.

The San Juan oil field has been studied by E. G. Woodruff[7] and H. E. Gregory.[8] Some of the points which they established are summarized as follows:

1. Oil was found in the Goodrich formation.

2. At least five sands are known to contain more oil than others. These sands are distributed within the top 400 feet of the formation but others which lie 1,000 feet below the top of the formation are supposed to be oil-bearing.

3. The ability of the field to produce oil in commercial quantities has not been determined.

4. The oils which yield more than the average amount of gasoline and burning oil are unusually light in specific gravity and are of good quality.

5. Productive wells are located down on the side of an anticline or up on the side of a syncline.

6. The aridity of the region and the deep cutting of the adjacent San Juan River have been controlling factors in the present location of the oil.

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[7]Woodruff, E. G., Geology of the San Juan Oil Field, Utah; U. S. Geol. Survey Bull. 471, pp. 74-199, 1910.

[8]Gregory, H. E., The San Juan Oil Field, San Juan County, Utah; U. S. Geol. Survey Bull. 431, pp. 11-26, 1911.

PROSPECT OIL WELLS

About the time of the drilling in the San Juan oil field local excitement resulted in the drilling of a well in McElmo Canyon. The location of this well is shown on the map, and the information available was supplied by Mr. Downey of Cortez, who gave the following points concerning the prospect.

Well started in 1911.

At 150 feet, showing of oil and fresh water in considerable quantities.

At 500 feet, more water.

At 1,370 feet, salt water carrying gas; water flowed after well stood two days.

At 1,500 feet, showing of oil in last 130 feet with some water.

Tools caught in the hole and well abandoned.

The casing record is given as follows:

First 300 feet cased with 14-inch casing.

From 300 to 500 feet, 12-inch casing.

From 500 to 800 feet, 10-inch casing.

The well was started 150 feet below the top of the Dolores formation, but in as much as no log was kept of the drilling, the position of the bottom of the hole within the series can not be determined. The character of the material brought from the well would indicate that the drilling was confined to the Dolores and Cutler formations. The showings of the well have little, if any, bearing on the structure. The other prospect well shown on the map south of Cortez was drilled entirely in Mancos shale and its findings have no bearing on the present structure.

DEPTH OF PENNSYLVANIAN BEDS

The depth of the Pennsylvania formations cannot be estimated except within wide limits. The thickness of the several formations as determined in different exposures is not uniform. The exposures near Bluff include the following:

Dolores	1,330 feet
Moenkopi (Cutler)	1,280 to 1,264 feet
Total	2,610 to 2,594 feet

In the Navajo county south of Ute Mountain the same interval shows:

Triassic (Dolores)	1,202 to 1,262 feet
Permian (?) (Cutler)	300 to 1,285 feet
Total	1,502 to 2,547 feet

In the Rico Mountains these beds measure:

Dolores	400 feet
Cutler	1,600 feet
Total	2,000 feet

The thicknesses observed in these three rather widely separated areas range from 1,502 to 2,610 feet. In as much as the larger measurements were made nearer McElmo Canyon than the smaller ones, the maximum depths probably prevail in the region of the McElmo anticline. If the distribution of the oil-bearing sandstones, as they occur at Bluff, prevails in the McElmo anticline, 1,000 feet should be added to the thickness of the Dolores and Cutler formations to determine a depth which is necessary to thoroughly prospect the dome. Such a computation gives 2,500 to 3,600 feet, which must be the depth of a well below the top of the Dolores formation in order to make a complete test.

Depending upon the point of starting this depth might be more or less than the figures given. Some points favorably situated may be found where a well could be started 300 feet below the top of the Dolores formation, which gives a necessary depth for such places from 2,500 to 3,400 feet. There is no way of limiting these depths to narrower estimates than the figures given, and any scheme of prospecting would start with a possibility of reaching the greater depth.

OIL SEEPAGE AND RESIDUES

Oil occurs in a sheeted zone which passes through Battle Rock in cavities in calcite, and minor saturation occurs at several points south of McElmo Creek.

GROUND WATER CONDITIONS

This part of Colorado possesses an arid climate which, considered by itself, would be an important factor in oil accumulation. Dolores River passes about 15 miles north of the structure and runs generally northwest. Its canyon is cut in the Dolores and Cutler formations to depths that in places reach 1,000 feet. From this river the strata dip to the south without interruption to the dome under consideration. This arrangement affords excellent opportunity for intake of water for the lower beds, and when considered with the fact that McElmo Creek crosses the edges of strata near the top of the dome, it is to be expected that the lower strata in this dome will carry more water than might be present under ordinary conditions in such an arid climate. Certainly the scarcity of water in strata of the San Juan oil field, which appears to be a controlling factor in oil accumulation at that point, cannot be duplicated here.

POSSIBLE WELL SITES

The highest point of the dome is probably near the center of Section 25, T. 36 N., R. 18 W. Starting at this point would necessitate the drilling of a thousand feet that could be avoided by a site along Sand Gulch. Points along this gulch can be found which are so near the highest point of the dome that any disadvantage that might arise from such location would be negligible. The writer recommends a drilling site along Sand Gulch in the northeast quarter of Section 25, T. 36 N., R. 18 W. The site

should be as far east as consistent with the cutting of the canyon. Points in this quarter section can be found that are on the axis of the folding.

A second choice would be to locate near the point where the main axis crosses the boundary line which divides Section 30, T. 36 N., R. 17W., and Section 25, T. 36 N., R. 18 W. Such a location might be favored by the fact that the secondary axis of folding which runs west from Cortez suggests that accumulation might be greater in the east side of the fold than elsewhere.

WATER AND FUEL

At certain times of the year many water holes along this gulch could supply the necessary water for drilling purposes. It would be reasonable to suppose that a drill hole would supply water from no great depth. The closest available coal, so far as the writer is aware, is south of Cortez.

SUMMARY

The points to be considered in prospecting the McElmo anticline are the following:

Unfavorable points:

1. The strata involved have not thus far produced oil in commercial quantities in this region.
2. Great depth which must be reached to prospect the structure.
3. Distance from market and poor railroad facilities.

Favorable points:

1. A closed anticline of considerable height.
2. The favorable location of this anticline in relation to the San Juan Basin.
3. The presence of oil in adjoining regions within strata which are involved in the structure.
4. Presence of oil seepages or residues in a portion of the structure.
5. The large area which will probably be productive if productive at all.

CONCLUSION

The prospecting of the McElmo anticline would probably determine the worth of neighboring structures which involve the same beds. Although the cost of prospecting this structure would be large the risks involved are not inconsistent with the chances for reward. The writer considers the prospecting of this structure a legitimate venture.

TOW CREEK ANTICLINE*

STRATIGRAPHY

The stratigraphy of the region has to deal with sedimentary and igneous rocks. The sediments consist of sandstone and shale, and the igneous rocks, which are all intrusive, are both acidic and basic in character. The rocks in this district range in age from the pre-Carboniferous gneisses and granites which form the basal complex to later Tertiary in the form of dikes, sheets, and laccolithic, and stocklike bodies, and to Quaternary alluvium.

As the sedimentary formations are fully described elsewhere in this publication, only the following summary will be given here.

Summarized description of the strata

Geologic Age	Formation name	Description	Topographic Forms	Thickness Feet
Cretaceous	Lewis	Composed largely of dark gray to black, calcareous, marine, clay shale containing lenticular beds of limestone.	Slopes, valleys and rolling plains	1200-1800
	Mesaverde	Includes a succession of alternating sandstone, shale and clay, and coal seams. Three very prominent ledges of massive sandstone. The shale and clay form valleys and slopes covered with debris and waste. The coal seams are generally hidden by debris.	Steep, rough ridges with narrow valleys between the sandstone ledges.	3000-3700
	Mancos	A thick mass of dark shale containing lenticular beds of sandstone and several hard calcareous layers near the base.	Slopes, valleys and rolling plains.	2000-2500
	Dakota	Two heavy sandstones with a thin layer of interbedded black shale.	Hogbacks	160±
Undetermined	"Red Beds"	Red sandy clay and shale with a thick, massive red sandstone bed near the middle.	Slopes and valleys.	?
	Basal complex	Gneisses and granite rocks.	Mountainous masses.	--

*The remainder of this bulletin is taken from Bulletin 23, Colorado Geological Survey.

IGNEOUS ROCKS

The main part of this paper is not to consider the petrography of the area, and what is reported here is limited. Specimens and slides were made and examined only from the main bodies of igneous rocks The igneous rocks of this district are all intrusive in character, and consist of two general types. The laccolithic and stocklike bodies are of acidic porphyry, and the dikes and sheets are of basalt. There are two varieties of basalt; one contains quartz and the other does not.

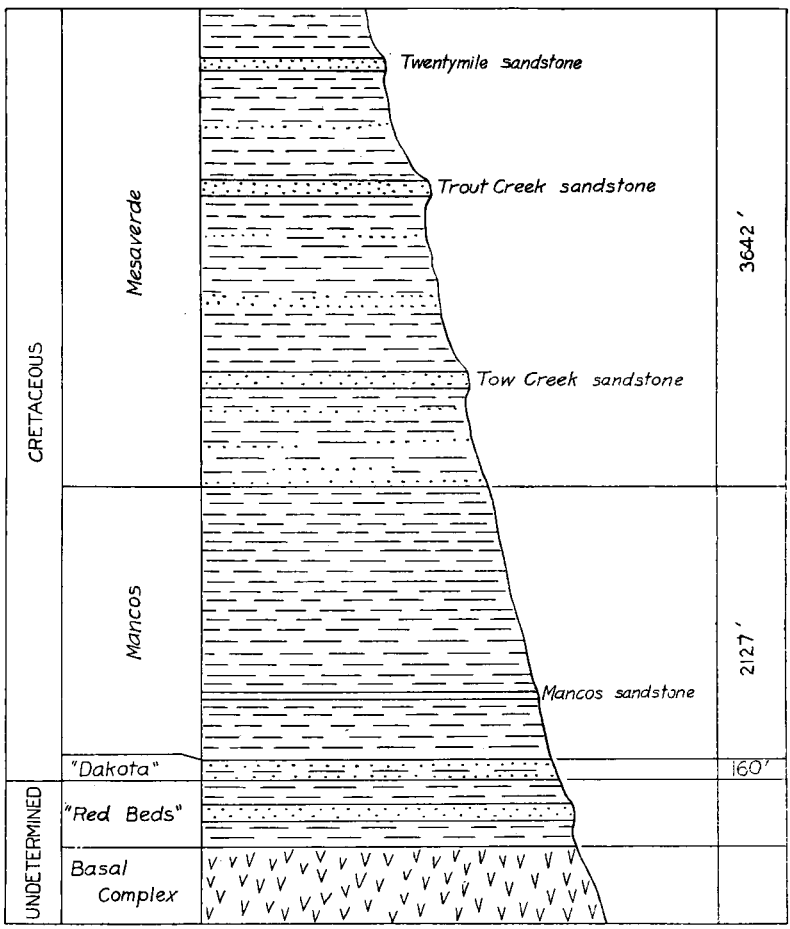

Fig. 13. Vertical section of sedimentary rocks of the Tow Creek anticline

RHYOLITE PORPHYRY

The rocks of acidic type were studied in less detail than the basalts. They occur in the laccolithic body in the Tow Creek crest and on Elk Moun-

tain. They are reported to be present on Sand Mountain. The Tow Creek intrusive, the only body strictly within the area, when seen from a distance was so light colored and apparently stratified, that it was thought to be sandstone. It was found that this apparently bedded part of the intrusion near the north central part of the body changes quite rapidly into a finer-grained and structureless rock toward the borders of the intrusion.

The hand specimen of the most acidic part shows many quartz phenocrysts about one-fourth of an inch in maximum diameter, numerous colorless feldspar phenocrysts of about equal size, and many small but quite perfect hexagonal crystals of biotite embedded in a fine, light groundmass. The rock presented a chalky appearance except where it was stained with iron. The texture ranges from felsite to almost holocrystalline.

OLIVINE BASALT

The quartzless variety of basalt is the most basic of these igneous rocks. It is found in the dikes extending from the south crest of Wolf Mountain into the Tow Creek laccolithic body. It is a very dark, compact rock with many small phenocrysts of olivine.

QUARTZ BASALT

The variety of basalt containing quartz is found in Chimney Peak and in sheets around the Chimney Creek dome. It is a heavy rock of bluish-gray color containing numerous imperfect crystals of bright green olivine about 3 mm. in diameter, and less numerous grains of quartz of about the same size embedded in a dark bluish-gray groundmass.

AGE

The age of these rocks is post-Mesaverde and probably Tertiary, since they came approximately into their present position subsequent to the deposition and solidification of the Mesaverde formation, and accompanying or subsequent to the folding. There seem to have been two periods of igneous activity. The earlier rocks were acidic in type, for the heavy olivine basalt which extends from the south crest of Wolf Mountain cuts the acidic porphyry in the Tow Creek crest. The dikes and sheets may be of the same age, as their close resemblance in composition suggests. Nowhere was a dike found cutting a sheet. The rocks of this area so closely resemble those in the Hahns Peak and Rabbit Ears district that it seems quite probable that they are of nearly the same age, and came from the same general reservoir.

METAMORPHISM

The metamorphism of this area is chiefly confined to very narrow contact zones of intruded igneous rocks in the form of dikes, sheets, and laccolithic bodies.

In the case of dikes very little effect could be noticed. Nowhere was there a well exposed contact of sedimentary beds and dike rocks, but exami-

nation a very few feet away from the contact shows nothing beyond a slight hardening, and not always that. The beds into which the dikes were intruded have not been perceptibly tilted, or otherwise changed by the intruded rock. It seems probable that they were fissure fillings in part, with some absorption and minor fracturing.

The sheets intruded into the Mancos shale and showing in nearly circular outcrop in three successive beds around the Chimney Creek dome have caused very little metamorphism. On the upper and under sides the effects seem to be about equal. The effects extend from a foot to 10 feet with a fairly constant average of 18 inches. The shale at the contact has for an inch or two been baked to a material resembling porcellanite, and the succeeding layers vary in hardness from that rock to ordinary shale in about a foot and a half. The effect is most noticeable on the innermost and outermost sheets. The middle sheet is thinner and less continuous than the others, and has caused less metamorphism. The contact metamorphism as seen along the borders of the Tow Creek laccolithic mass is very slight. Though the mass is largely acidic porphyry and must have been intruded at a higher temperature than that of the dikes and sheets, its effect is apparently no more pronounced. No good exposure of this contact with shale was found, but a sandstone at the south end and near the forks of Tow Creek showed only a slight hardening of the rock. None of the intrusions seems to have been accompanied by any appreciable amount of water and this likely accounts for the very slight effects thus produced.

STRUCTURE

GENERAL

The structure in this district is an asymmetrical anticline having three crests located along an axis of northward trend which bends northeast at its northern extremity and slightly southeast at its southern extremity. This axis plunges to the south and hence the northern crest is the highest. These three crests are separated from each other by synclines crossing the anticline almost at right angles to the axis. The fold produced lies approximately parallel with the mountain uplift with the steep side facing toward it. The general trend of the axis is roughly parallel with the major folds in bordering districts, such as the Trull anticline, and the Sage Creek anticline. The west limb has a rather constant dip of about 12° westward and the east limb a steep dip of from 40° to 50° eastward in the Yampa River valley but lessening considerably to the north. (See Pl. III., in pocket.)

YAMPA CREST

The southern and lowest crest occupies the area along Tow Creek below its forks and along the Yampa River in sections 7, 8, and 17, T. 6 N., R. 86 W. The anticline has been tested by two wells, neither of which gave favorable results. The logs are not reliable and there is no certainty of the depth attained. The well along the Moffat Highway in sec-

tion 7, T. 6 N., R. 87 W., is a dry hole, and from reports concerning its depth went down a considerable distance into the Mancos shale without obtaining any oil. The other well located in section 32, T. 7 N., R. 87 W., is on the east side of Tow Creek about a quarter of a mile below the forks. It flows a small amount of water steadily. This well begins near the base of the Mesaverde and probably went some distance into the Mancos. This well is seemingly fairly well located to test the structure, but perhaps is a little too far to the east and may have gone principally into the Mesaverde beds, which have a very strong dip to the east at this place. This seems to be indicated by the fact that artesian water was obtained. A more favorable and decided test would be about a half mile farther south and on the west side of Tow Creek. The possibility that the intrusion resembling a laccolith, to the north of the well, but separated from it by a syncline, has caused leakage in this dome, cannot be overlooked. Its nearness suggests that it may have fractured or replaced a part of the possible oil reservoir south of the syncline and thus rendered the crest unproductive. From the contact slopes of the intrusion it seems quite probable that downward it breaks into and fractures the possible reservoir rocks.

CHIMNEY CREEK DOME

The northern crest is a quaquaversal structure in Mancos shale on Chimney Creek with its center in section 4, T. 7. N., R. 86 W. This structure is a nearly perfect dome as shown by the almost circular outcrop of calcareous layers and the rather equal dip of about 25° in every direction. These dips flatten out in every direction quite rapidly. It is possible that an intrusion of igneous rock, laccolithic in type, may underline this fold. (See fig. 14.) It may also have been formed by a combination of these forces. The possibilities of igneous intrusion beneath this crest are strengthened by the presence of three dikes or sheets which show in irregular and interrupted outcrop around the dome. These sheetlike bodies of basalt do not follow the bedding planes of the shale exactly, but are intruded at practically the same angle and cut across the bedding only for short distances. That dikes would be intruded in a circular form at such nearly equal distances from the center of the fold seems rather improbable unless connected to a laccolithic body underlying the dome. Assuming this to be the case, oil may still be found in the dome, as their metamorphic effect on the shale is very slight. If the oil had accumulated previous to intrusion there would likely be some seeps around the intrusions. No such seeps were found nor was there anything along the contact to indicate that oily matter had been passed through. In case the accumulation is taking place at present the dikes would not materially injure the chances of obtaining oil from this structure, but it might restrict the district in which it could be obtained to that part of the dome lying outside of the area inclosed by them. The metamorphism of the possible oil reservoirs is probably not much greater than that seen in the shales.

The possibility suggested above that the crest is underlain by a lac-

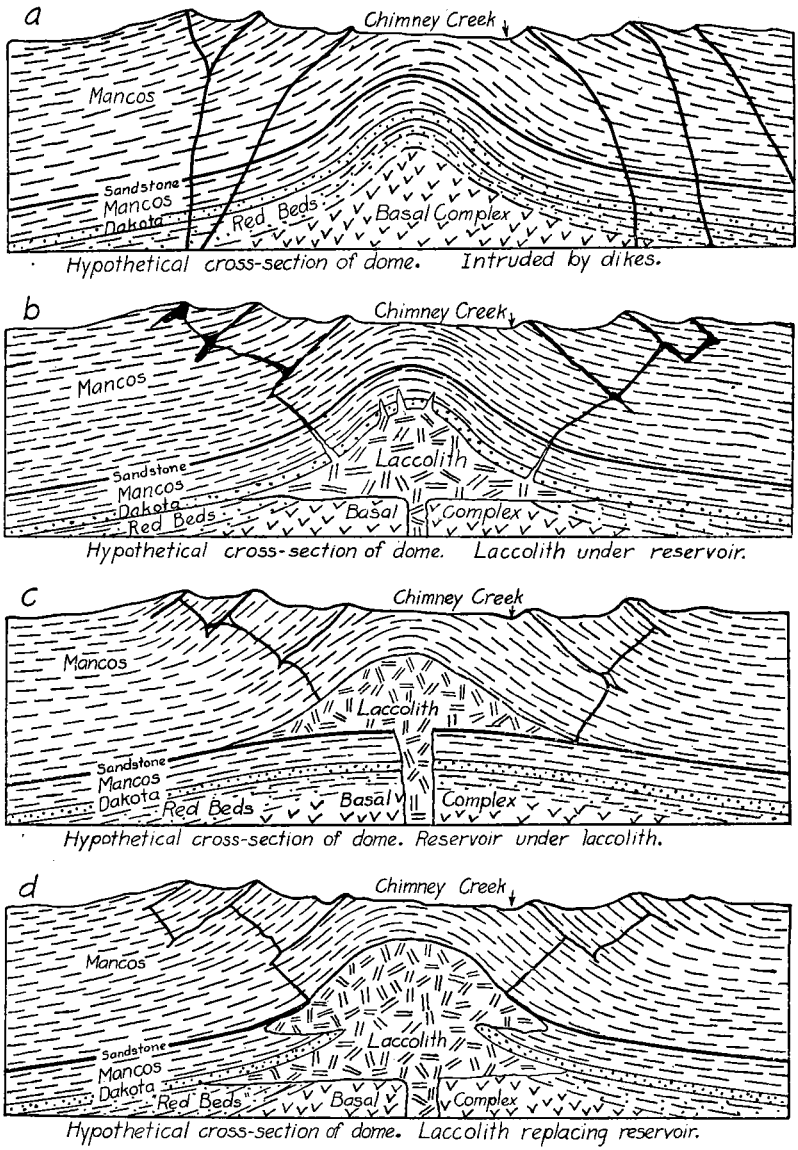

Fig. 14. Possible relationship of rocks in the Chimney Creek dome

colithic body deserves much consideration, but nothing more than hypotheses can be advanced until data obtained from drill holes are available. If a laccolith or thick sill has caused or accentuated the arching and doming of this structure it would still be possible for oil to accumulate under certain conditions as follows:

(a) If an oil reservoir lies above the laccolithic body and it is not materially changed by the intrusion, the possibilities of obtaining any oil which may have accumulated are not affected by the presence of the intrusion. (See fig. 14b.)

(b) If a reservoir lies underneath the laccolith and has not been too much altered it probably has sufficient arching for the accumulation of a commercial quantity of oil. (See fig. 14c.)

(c) If the possible reservoir has been displaced or broken up by the igneous intrusion it would probably be necessary to go beyond the borders of such disturbed area to find an iol reservoir. (See fig. 14d.)

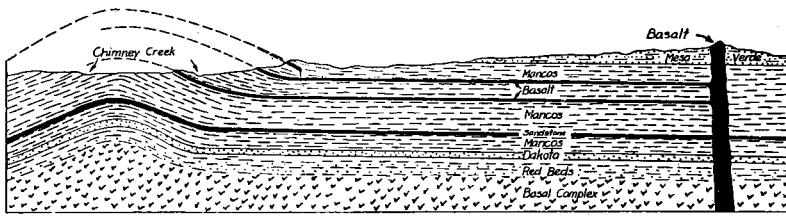

Fig. 15. Possible relationships of sedimentary and igneous rocks in the Chimney Creek dome.

Evidence of channels which would allow the movement of magma upwards is seen in the thickened bodies at four or five places in the line of these intrusions. That these channels seem to diverge upwards from a point near the center of the dome may indicate that arching movement took place subsequent to their opening. That these thickened places probably represent channels which connect the sheetlike intrusions seems likely. If such is the case they would not materially affect the foregoing discussion as they may or may not indicate a laccolithic intrusion. The size of one such body appearing in a hill on the south side of Chimney Creek at the southwest side of the dome is such as to give evidence of outlet sufficient to almost, if not quite, prevent the formation of a laccolith.

TOW CREEK CREST

The middle crest of this anticline, of which the structure contours are shown on the map, is filled with an igneous intrusion which resembles a laccolith. On all sides the Mesaverde sandstone dips away at angles varying from 10 to 45 degrees. On the igneous rock near the central part of the southern half is a small patch of basal Mesaverde sandstone, the lower part of which contains a layer of bituminous sandstone very similar to that from which oil seeps to the east along the creek. Near the border at the south end of the igneous rock is another small patch of Mesaverde sandstone similar to the one above and also to those connected with the oil seeps. The significance of these patches of sandstone seems to be that the Mesaverde formation once covered at last the greater part of the intrusion.

If the igneous rock is a laccolith, it would appear to be intruded be-

tween the top of the Mancos and the base of the Mesaverde. Oil, if present, must be in the Mancos below.

OIL POSSIBILITIES OF THE TOW CREEK ANTICLINE

There are various indications of the presence of oil within the strata of this area. At three points along the Moffat Highway water seeps carry small amounts of oil which have accumulated as a residue in the earth around the seeps. That saline matter is also present is shown by the thin crust of alkali around the borders of these seeps, which come from the sandstones lying just above the Tow Creek sandstone. The saturated earth gives a decided oily smell when heated with a match, and in some places where it has been hardened and concentrated by the sun's rays will almost ignite. An oily scum is also present on the small puddles around these seeps.

About three hundred feet above the forks of Tow Creek on the east bank of the east branch is a ledge of sandstone very close to the base of the Mesaverde formation which is saturated with a dark tarry oil. The surface of this ledge has been opened up for about 4 feet vertically and 10 feet horizontally, the top and bottom of the layers are shale contacts toward which the oil decreases in amount. There are occasional shale partings at intervals of from 2 to 10 inches. This layer of sandstone is just full enough of oil so that it does not ooze from the surface. In each direction this ledge is covered with debris from the slope above, and about a half mile up the creek the surface has been uncovered again and here a short tunnel was being driven into the ledge to drain the oil from the rock. The oily rock taken from the tunnel was, in August, 1919, being heated in a small crude still to extract the oil.

In a sandstone ledge the thickness of which was undetermined on account of the debris covering it, and which is about a hundred feet above the still, is an oil spring described in Bulletin 297 of the United States Geological Survey, page 79. A small pool has been formed where it issued form the rock. When examined the surface of this pool was covered with a scum of dark, tarry oil which was very slowly trickling over the edge with some water. The water seemed to be just enough to keep the pool at a constant level and trickle over the side for a few feet where it was absorbed and dried up. The slope below was covered with waste from above, but a considerable amount of brea, presumably overflow from the pool above, had accumulated on the surface from which the earth and brush had been removed over an area about fifty feet wide and two hundred feet down the slope. This layer was not uniform in thickness, and in most places did not exceed three inches. The prospectors had uncovered some chunks six or seven inches thick without reaching bottom. This patch, including the spring, was fenced in to keep out the stock for which these seeps, probably on account of their salt, have great attraction. One of the prospectors working on the little tunnel below, said that he had skimmed about a bucket of oil from this pool, each evening for the past seven years.

Past experience has been largely against the possibilities of obtaining oil in districts into which igneous rocks have been intruded, but in certain Mexican fields their presence has been shown to be favorable to very productive areas. A district in which the structure, rocks, and conditions are quite similar to this is that between Tuxpam and Tampico where very productive wells have been obtained around the igneous intrusions. For a fairly complete discussion of these occurrences consult "The Mexican Oil Fields," by L. G. Huntley, in the Transactions of the American Institute of Mining Engineers, Volume 52, pages 281-321. It is not at all certain that the conditions in Mexico are reproduced exactly enough in this district to warrant drilling on the limbs of the fold adjacent to the intrusion, but provided that the Chimney Creek crest was found to be productive, and other nearby fields show good quantities of oil in the strata below the Trout Creek sandstone, the west limb of this fold would be worth prospecting. In any event the dike running northward from this intrusion to the south crest of Wolf Mountain may trap oil coming up the strata from the south and west, and if such is the case, wells could be drilled to tap the reservoir along a line roughly parallel to this dike and at no great distance from it. On the east side of the structure the seeps indicate a leakage of oil from some reservoir or else the accumulation of very small amounts close to the surface due to the action of circulating waters. The conditions on this side of the structure seem far less favorable to the accumulation of oil in starta than on the west side.

This anticline is as yet unproved. The conditions seem to be favorable to careful tests, and of these the first should be made on the Chimney Creek crest where the sandstone in the Mancos might be reached near the center of the dome at a depth of about 600 feet, and the Dakota sandstone at about 1,100 feet. In drilling, both of these possible reservoirs should be tested. In the southern crest, which seems to have conditions second in favor to the one above, the Mancos sandstones should be about 1,800 to 2,000 feet, and the Dakota sandstone 2,300 to 2,500 feet below the surface, but thickening of the Mancos formation would increase these figures. The conditions in the Tow Creek or middle crest are the least favorable of the three, and prospective drilling should follow the conditions previously discussed.

TOW CREEK ANTICLINE

This anticline was partly tested by a well that was drilled in 1902 (?) in the southeast corner of section 7, T. 6 N., R. 86 W. The well at the present time is inactive, and no reliable information could be obtained as to its depth or sands encountered. The information obtained indicates that it was a dry well. It appears that this well was drilled slightly too far to the east. The axial plane of the anticline, as estimated from the structural map, dips 85° to the west. This would place the crest of the possible Mancos oil-bearing sandstone almost immediately beneath the well. If this anticline produces gas, as the Williams Park anticline from the "Dakota," the well would more probably encounter the oil, if present, if drilled farther

to the west on the western limb of the anticline, and farther to the north, nearer to the crest.

The Mancos sandstone at the crest is approximately 1,700 feet below the level of the Yampa River. The "Dakota" sandstone at the crest is approximately 2,200 feet below the level of the Yampa River. This approximation is fairly accurate if there has been no local thinning or thickening of the Mancos formation at this place.

The Tow Creek anticline is structurally favorable for the accumulation of oil and gas. If the petroleum is present in any of the underlying rocks, and is associated with water under pressure, it will probably migrate up the dip. The oil would then be expected to accumulate near the crest of the anticline. The writer did not examine the area to the north to determine the influence of the igneous rocks present on the accumulation of the oil or gas, hence he does not feel justified in recommending or condemning this anticline.

CURTIS ANTICLINE

The Curtis anticline lies in the central and southwestern part of T. 6 N., R. 86 W. (See Plate I.) Its axis, which trends northwest and southeast,, is almost at right angles to the Tow Creek anticline. This anticline plunges to the west and is separated from the Tow Creek anticline by a steep syncline. The dips to the northwest and southwest average 15°. The dips to the north average 20°. The dips to the south average 10°. The dips taken on the massive sandstones west of Trout Creek are not reliable, as these sandstones were almost level and no definite bedding planes could be found. There also appeared to be some slumping caused by weathering. The average dips taken on these sandstones were 2° to the southwest, and 2° to the northwest, which places this fold in the terrace type of folds rather than the true anticlinal type. These dips were probably away from the axis of the fold where the anticline has its broadest limit. The narrowest part is to the west where it closes.

Sufficient time was not available to examine the eastern boundaries of this fold as closely and carefully as was desired. The dips recorded, however, along the eastern side of Trout Creek indicate that the fold opens to the southeast and therefore would allow the escape of any gas or oil.

Bulletin 297 of United States Geological Survey, referred of before shows a probable fault near Trout Creek. This fault was not definitely found by the writer, but the appearance of a massive white sandstone east of Trout Creek below the general level of the Trout Creek sandstone, indicates that there is a displacement of some kind. If this fault is present, and the displacement is of any great extent, there is a probability that it has sealed any gas or oil accumulated to the west of the fault.

The gathering ground for this fold is limited on the west by the Tow Creek anticline, on the north by a narrow syncline parallel to the Yampa River, and on the south by the Twentymile Park syncline.

It is suggested that this fold be studied and investigated more care-

fully, in order that more definite conclusions may be deduced as to its oil and gas possibilities.

TRULL ANTICLINE

The Trull anticline extends from section 4, T. 7 N., R. 85 W., to section 9, T. 6 N., R. 85 W., where it disappears under the alluvium south of the Yampa River. Mr. Willson mapped this anticline north of the Trull schoolhouse, which is on Elk River.

The dips recorded on the western limb between the Yampa River and the Elk River average 50°. Those north of Elk River, where the anticline becomes broader, average 42°. The dip of the shales on the eastern limb at the Yampa River is 42°. Between this dip and Elk River no reliable dips were recorded on the eastern limb, as the shales are covered by a gravel and boulder deposit, and slumping hindered the obtaining of accurate dips near the Elk River. The dips taken on the eastern limb north of the Elk River average 50°.

This anticline is in the lower part of the Mancos formation, as shown by the outcrops of the Mancos sandstone in sections 28 and 4, T. 7 N., R. 85 W. It closes at the northern end where the dips are 60° to the northeast and 50° to the northwest. These dips were taken on the Mancos sandstone where the Elk River cuts its channel through the fold. The elevations of the two sandstone outcrops were approximately determined, and it was found that the anticline plunges slightly to the south towards the Yampa River syncline, where it then probably opens again to the south. The general dip of the strata south of the river is to the northwest.

The outcrops found along both banks of the Yampa River do not indicate that the anticline closes or plunges to the south. The dip of the shales south of the river could not be obtained as they are covered by a mantle of alluvium.

It was noticed that there is an abrupt change in the trend of the axis where it crosses the Yampa River. This change may be due to a bend in the fold, or it may be due to a fault which crosses the fold. If it is a fault, the displacement, according to the bend of the axis, must be approximately 1,500 feet. There is no expression of such a fault on the surface to the east or west.

The gathering area is limited on the west by the intrusion of igneous rocks which form Elk Mountain, to the south by the syncline parallel to the Yampa River, and to the north by a sharp syncline. The greatest gathering area is to the east, and to the south of Elk Mountain.

If there is a fault present at the Yampa River, it would also limit the gathering area. It might also seal any gas or oil accumulated south of the river. The syncline parallel to the Yampa River is about two miles from the Yampa River, so if the fault did seal any oil or gas, the gathering area would not be sufficient to allow the accumulation of any commercial quantities of gas or oil.

The gentle plunge of the anticline to the south may change before

it reaches the Yampa River. There is also a possibility of the presence of minor folds or wrinkles that do not appear at the surface. If these are present they would reduce the amount of accumulation at the highest point of the anticline to the north. The folding is sharp at the crest.

With such folding there was undoubtedly a great deal of fracturing within the sandstones. Any fractures present might allow the escape of gas or oil. The Mancos sandstone is open at two places which would permit the escape of gas and oil. If the "Dakota" sandstone contains gas or oil there is a probability of its being accumulated at the highest point of the anticline in section 4, T. 7 N., R. 85 W.

It does not seem justifiable to recommend a test of the Dakota sandstone as the structural conditions are not pronouncedly favorable, and because this sandstone is the only possible reservoir. The best location for a test well would be about 600 feet south of Elk River near the axis of the fold, in section 4, T. 7 N., R. 85 W. Wells drilled here should encounter the "Dakota" sandstone at a depth of about 600 feet.

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GEOLOGICAL SURVEY
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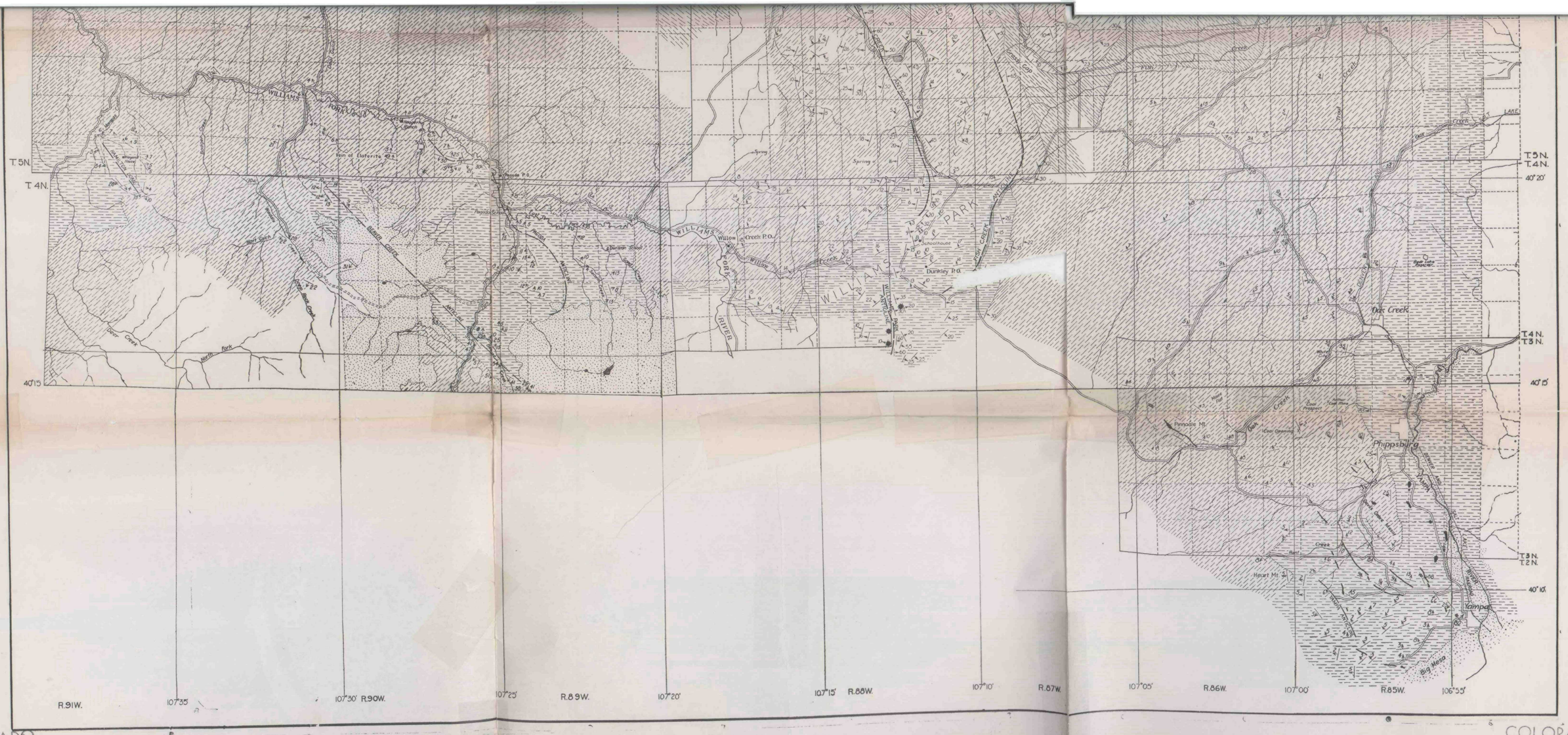

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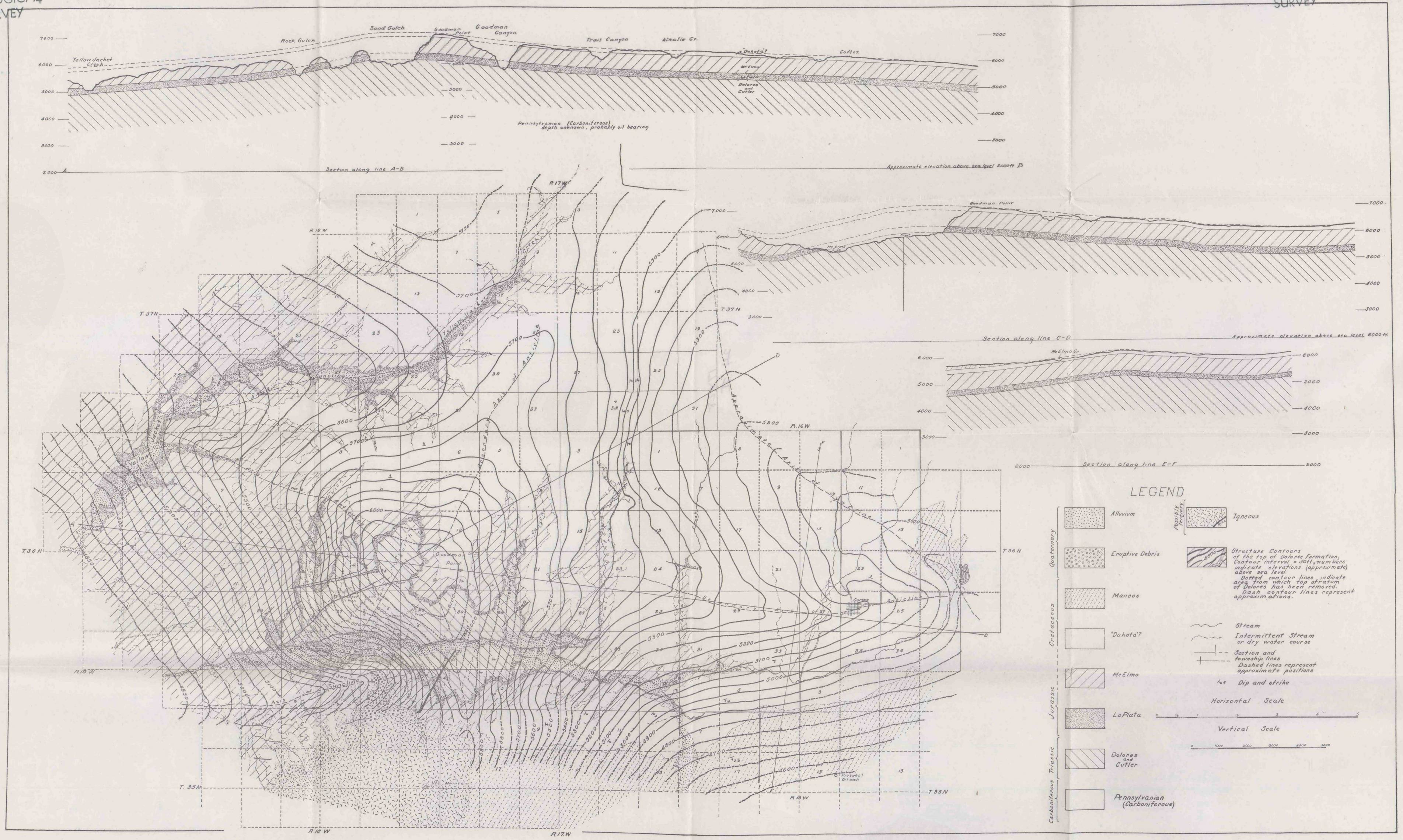

MAP OF THE McELMO ANTICLINE, MONTEZUMA COUNTY, COLORADO

By R. C. Coffin

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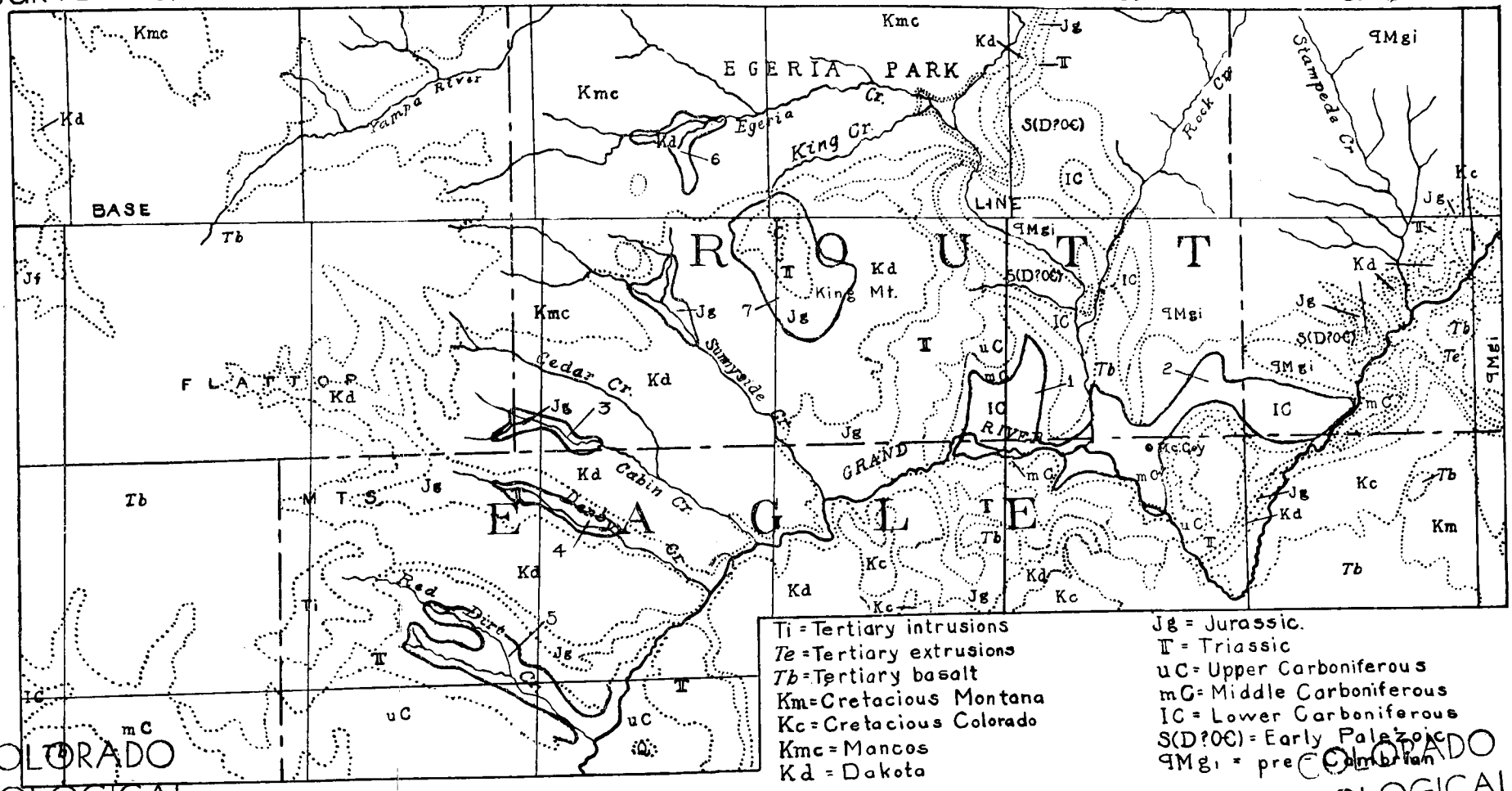

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R. D. GEORGE, State Geologist

BULLETIN 25

OIL SHALES OF COLORADO

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LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, November 30, 1920.

Governor Oliver H. Shoup, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 25 of the Colorado Geological Survey.

Very respectfully,

R. D. George,
State Geologist.

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PREFACE

The bulletin here presented is not offered as the result of a comprehensive and systematic study of the problems of oil shale, but rather as a selection from a large body of facts and results which have accumulated from somewhat disconnected, and at times incomplete investigations in field and laboratory work extending over a period of fourteen years. Several portions of the material here brought together have been used in addresses and in articles in various magazines and other publications.

The writer began his study of the shales in 1906, when he followed the southern outcrops of the shale beds from near Tucker, Utah, to Rifle, Colorado, collected samples of the shales and made a series of tests of the shales as possible future sources of oil, and as material for road building. After these first studies, except for a few tests of material sent to the Colorado Geological Survey laboratory, very little was done until 1915, when, at the request of certain officers of the United States Navy, the study was resumed in a more systematic and purposeful manner. A laboratory was fitted up with the essential apparatus for retorting, and the distillation tests were made in the University laboratories. But the pressure of other Survey work, especially during the war, tended to force the shale problems into the background.

In compiling the second part of the report the writer has selected what he considered most valuable from the results of his own laboratory work and from those of advanced students and instructors working under his direction. It has been found impossible, except in a few instances, to make specific acknowledgments of the contributions. Those whose work has proved most valuable are: C. F. Poe, now Assistant Professor in the Department of Chemistry; Q. R. Dungan, of the Empire Gas and Fuel Co., and M. J. Wilson. The last two prepared theses for the Master's degree under the writer's direction.

Individuals and companies for whom the writer has made investigations have kindly given him permission to use the results of those studies as he desires. The Survey is indebted to the Empire Gas and Fuel Company for the use of its map of the southern part of the shale area. This is reproduced as Plate II.

Descriptions of the Scotch retorts, and the Scotch processes of retorting and refining have appeared in so many different publications that it seems unnecessary to give space to them in this Bulletin. As to the costs of installation and operation, the unsettled industrial conditions and the rapidly fluctuating prices of materials render any statement little better than guesswork. In pre-war times the cost of a retorting plant having a capacity of 1,000 tons per day, and a refining plant to take proper care of the crude obtained, and provided with adequate storage facilities, trackage and other necessary equipment, was placed by various responsible engineering firms at about $2,500,000.00. This provided only for mining, crushing, tramming and retorting the shales; condensing and refining the oils into motor, burning and lubricating oils; separating and refining the wax; separating and refining the ammonia. It did not provide for the saving of any of the many possible by-products which may or may not prove commercially profitable. It did not provide for such marketing facilities as tank cars and other equipment.

In Colorado the securing of a water supply may add considerably to the initial outlay necessary.

R. D. GEORGE.

OIL SHALES OF COLORADO

INTRODUCTION

Before the discovery of the vast oil resources of Pennsylvania, and their development in the early sixties, there were over fifty companies in the United States producing oil by the distillation of coals and shales. But the rapid development of the Pennsylvania field forced the producers of shale oil to the wall. After Pennsylvania came Ohio, West Virginia and California, in the seventies, and a host of others in the eighties. The possibility of oil from shale was forgotten in this country. But in Scotland, France and other countries not provided with petroleum, the distillation of shales went on, methods were improved, the operation costs cut, and the output increased.

Pennsylvania reached her maximum production in the nineties, and is now pumping less than one-third as much as she did in 1891. Ohio began to decline in the nineties and is now producing only one-third of her greatest yields. West Virginia, through the extension of her fields and much new drilling, has made a hard fight, but is falling off. Colorado, Indiana, Illinois and Kansas reached their high oil mark about 1916. New states have become producers, and Texas, California and one or two others have increased their output. But the fact remains that in proportion to the wells drilled the production of the United States is declining.

When the ever-increasing demand is taken into consideration, it is evident that the time is not far distant when a part of the supply will again come from the distillation of shales. When that time comes Colorado will unquestionably take a prominent place.

THE OIL SHALE MAP OF PART OF GARFIELD COUNTY[1]

PRIMARY CONTROL

A base line was taken from the DeBeque, Colo., topographic sheet and extended from the summit of Red Pinnacle in Sec. 16-7-97 to the summit of Mt. Logan in Sec. 35-7-97. From this base line a triangulation net was carried over the whole area by means of a plane table and telescopic alidade. Prominent, well-defined natural objects were used as stations in some cases, but nearly all of the stations were pine or aspen poles braced at the base.

[1]By R. L. Heaton, Geologist, Empire Gas and Fuel Company.

MAPPING

All mapping was done by plane table and open-sight alidade, using the triangulation stations for control.

Besides occupying the primary stations, the geologists located themselves at intermediate points by resection and intersection, and sketched the geology between these points. Unoccupied points were also located by intersection and used in the same manner.

The two roughly parallel lines shown on this map represent the upper and lower ledges of richer shale. They are designated as (A) and (B) on the map legend, as well as on the photographs. A center line representing the steep white cliff which occurs so prominently over all of this area was shown on the original map, but was omitted from this one because it contains no beds of commercial shale.

Fig. 1 shows the general relationship of the beds containing the richer shale. The ledges represented at (A) vary greatly throughout the area in thickness and oil content. They are composed almost entirely of the massive variety of shale, and the thickness and number of separate beds mapped as the upper group (A) increase from the western to the eastern part of the area. Fig 2 shows the characteristic weathering of these ledges on Mt. Callahan, where there are five beds varying in thickness from 3 to 10 feet, and in oil content from 25 to 45 gallons per ton.

Ledge (B), as seen in Fig. 1, is about 50 feet thick and is easily recognizable throughout the area. About the middle of this cliff there occurs the bed of rich paper shale varying in thickness from 4½ feet in places on Carr and Clear creeks to 9 feet 8 inches on Mt. Callahan at the mouth of Parachute creek. Samples from this bed ranged from 35 to 85 gallons to the ton, using a field retort, and the average for the whole area was 54 gallons to the ton. The letter (B) on Fig. 3 is at the center of this bed at a locality on Carr creek where it is 6 feet thick and runs approximately 60 gallons to the ton. Fig. 4 shows the same stratum near Newton's trail on Clear creek, where the characteristic paper weathering has given way to a more massive appearance by reason of its being partly protected from the weather by the cliff of leaner shales above.

This bed has by far the best commercial possibilities of any in the field. It is being mined at Mt. Logan. There is a similar bed a few feet lower in ledge B, which is from 3½ to 4½ feet thick and runs about the same in oil content.

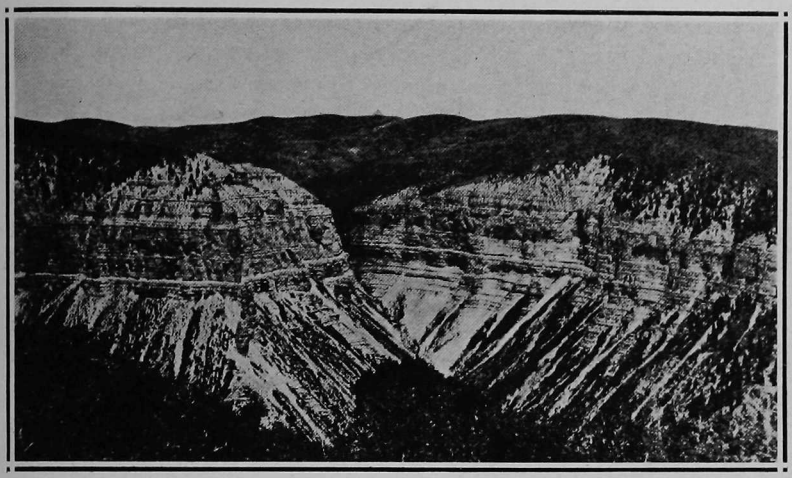

Fig. 1. View showing upper and lower ledges of rich shale (A and B). Sec. 33, T. 5 S., R. 98 W., Clear Creek.

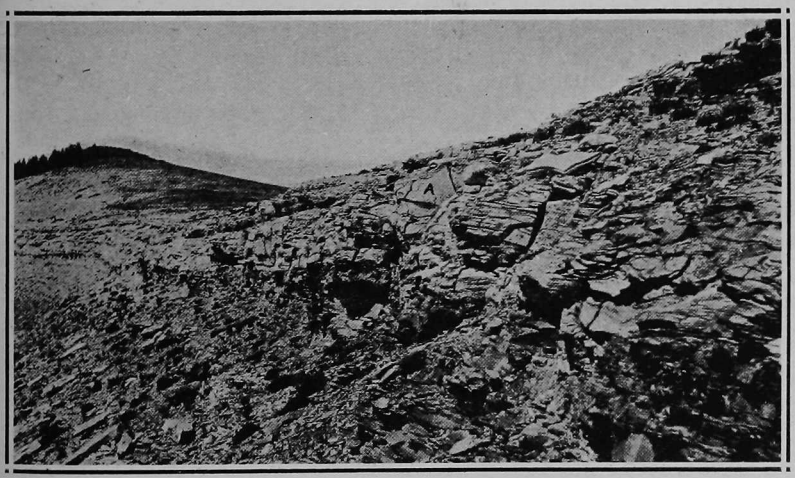

Fig. 2. Upper shale ledge (A) showing typical massive shale. Sec. 16, T. 7 S., R. 96 W., Mount Callahan.

Minor drainage was sketched. Points were located along the main streams and the water courses sketched between them as in the geologic mapping. All roads were shown in like manner. Trails were sketched in a general way only. The showing of ranch houses was not considered important enough to warrant the time necessary in locating them.

LAND SURVEY

It was borne in mind that the value of this map would depend upon the accuracy of the geological mapping, and upon the showing of all areas of shale in the proper section, according to the existent land survey.

This plan was carried out as far as possible by locating on the map, by triangulation methods, all land survey marks that could be found and checking them by reference to copies of the land plats from the U. S. Land Office at Glenwood Springs. Where section and township corners could be checked in this way, results were very satisfactory. In case no government marks were present, the land survey was taken directly from the land plats and checked, wherever possible, with marks left by private surveys which were run from official government marks.

Twp. 5 S., Ranges 95 and 96 W. and Twp. 6 S., Ranges 96 and 97 W. have been recently surveyed, and corners are plentiful. According to this survey the off-set along the First Correction Line South is about three miles, instead of about one-third of a mile, as shown farther west by the old survey. Both are correct, and this necessitates the cutting out of a part of Twp. 5 S., R. 98 W. by Twp. 5 S., R. 96 W. of the recent survey. Many maps erroneously continue this off-set of three miles, on westward to the Utah line.

The drainage, roads and land survey of Twp. 8 S., Ranges 97 and 98 W. were taken from the DeBeque topographic sheet. For Twp. 8 S., R. 96 W. these were taken from the land office plat.

ELEVATIONS

The elevations shown on this map were taken, for the most part, by aneroid. Some of them, in the western part of the field, were taken from Hayden's Atlas.

GEOGRAPHY

LOCATION

The Green River shales of northwestern Colorado occupy an area which will aggregate approximately 2,000 square miles in Garfield, Rio Blanco and Mesa counties. There is also a considerable area in Moffat County, but of this less is known.

TOPOGRAPHY

The topographic features of the area are those of a broad, northward-sloping dissected plateau, from which Grand and Battlement mesas have been detached by erosion. Along the broader valleys the shaly parts of the formations have been carved into steep, pointed hills characteristic of the badlands. In places the plateau area is similarly eroded. The lesser valleys are canyon-like, and even the outer margin of the main valleys presents abrupt faces wherever sandstones form any considerable portion of the strata. On the southern border of the main plateau area, facing the Grand River, are the Book Cliffs which rise to a height of 2,000 to 3,000 feet above the valley floor. On the east side are the Petrolite and Gray hills, and on the west are the Cathedral Bluffs. In many places the Book Cliffs present very steep slopes and vertical walls which cannot be scaled, though at numerous points trails lead to the pasture lands above.

DRAINAGE

The Grand River flows along the southern border of the main shale area, but cuts off from this considerable volumes of shale in Battlement and Grand mesas. The smaller streams tributary to the Grand are Rifle, Parachute, Roan, Kimball and East and West Salt creeks. Cutting through the northern part of the area is the White River, with its tributaries, Flag, Sheep, Piceance, Yellow and Douglas creeks, on the south. The Yampa River, with its broad valley merging into that of the White, cuts off the shale area of Moffat County from that of Rio Blanco to the south. The Snake River crosses the Moffat County area.

The rivers and their larger tributaries are perennial, but many of the streams are intermittent. The level parts of the valleys are occupied by irrigated ranches wherever the water supply is sufficient. The waters of the scantier streams become strongly alkaline as their flow decreases.

CLIMATE

The total annual precipitation of the region is between 12 and 14 inches, of which a considerable portion comes in the spring and early summer months. On the high plateau area the winter temperatures are low, but the dry atmosphere is bracing and invigorating, and conditions are rarely such as to prevent the pursuit of outdoor occupations. There is nothing in the strictly climatic conditions which would interfere with all-year operation of shale oil plants.

VEGETATION

The vegetation is sparse. The trees include mainly sage brush, pine, cedar and aspens. Grass is scarce, except on the more favored parts of the flat plateaux and mesas, where it is fairly abundant and very nutritious. In many parts of the shale area there is sufficient timber to meet all ordinary operation requirements.

All kinds of grains, maize and vegetables grow abundantly. The fruits of this part of the state are noted in all markets. The natural rainfall, especially on the table lands, is such that a total failure of crops is rare, and frequently unexpectedly large yields are obtained.

TOWNS

The principal towns of the area immediately tributary to the shale deposits are: Rifle, Grand Valley, DeBeque and Meeker. Glenwood Springs is on the railway to the east, and Palisade and Grand Junction to the south and west. In the northern part of the area, Rangely is a small trading point. Rio Blanco, Highmore, Sulphur and Piceance are postoffices within the shale area.

INDUSTRIES

The principal industries of this part of Colorado are ranching, cattle raising, fruit growing and coal mining. Coal mining is an important industry, and the coal produced is of excellent quality and could be secured at a reasonable price for power purposes in case it should prove desirable to supplement the fuel products of the oil shale industry by the use of coal.

CULTURAL FEATURES

The southern part of the area is served by the Denver and Rio Grande Railroad, Uinta and Book Cliffs railways. To the north the Denver and Salt Lake is completed as far as Craig, the county seat of Moffat County. Surveys have been completed for the extension of the road to Salt Lake City. The Denver and Rio Grande Railroad follows the Grand River from Glenwood Springs to the western border of the state. The Uinta Railway leaves the Denver and Rio Grande at the town of Mack, near the western border of the state, and takes a north or northwesterly course to Watson and Dragon, in Utah. The Book Cliffs Railroad is a short line from Grand Junction to Carpenter, about ten miles north of the river.

A well-built state highway follows the Grand River from Glenwood Springs to DeBeque. At DeBeque it makes a considerable detour to the south, but returns to the river valley at Almond. Another state highway runs from Rifle northward to the valley of

the White River, where it joins the state highway, which follows the White River to and beyond the Utah boundary. Good highways follow a few of the larger stream valleys. Fair roads are found in others, and mere trails afford access to many parts of the shale territory. Steep trails, rarely suited to the use of vehicles, lead from the valleys to the high plateau areas.

GEOLOGY

STRUCTURE AND FORMATIONS

In the Rocky Mountain region the mountain-making movements at the close of Cretaceous and the opening of Tertiary times caused the formation of a great basin-like depression of roughly rectangular outline, occupying the northwest corner of Colorado, the southwest quarter of Wyoming, and the northeast corner of Utah. This depression was roughly 300 miles from north to south, and 200 miles from east to west. The drainage from the surrounding country poured into this great basin, forming a lake having an area nearly double that of Lake Superior.

The Uinta Mountain fold almost completely divided the southern one-third of the lake from the northern two-thirds, but the same conditions of deposition prevailed north and south of the Ridge. At the present time the area south of the Uinta Mountains is known as the Uinta Basin, while that north of the Range is divided into the Green River Basin and the Red Desert Basin. The streams flowing into the lake carried with them vast quantities of sediment from the surrounding country, and the waves spread this material rather uniformly over the floor of the lake, building from it four great Eocene rock series—the Wasatch, the Green River, the Bridger and the Uinta—having a total thickness of several thousand feet.

In the course of time the gradual filling of the basin with sediments and the deepening of the valley of the Green River caused the disappearance of the lake and the emergence of a broad, slightly undulating expanse of soft sedimentary rocks consisting mainly of shales with a relatively small percentage of sandstone and a still smaller proportion of limestone. On this new surface the Green, the White, the Yampa, the Duchesne, and the Grand rivers and their tributaries immediately began the work of carving out the present topography, the main features of which consist of broad mesas or plateaus deeply cut by canyons and bordered by steep slopes and cliffs. The most striking topographic feature of today is a great plateau from 8,000 to 9,000 feet above sea level, facing the Grand River and sloping gently northward. South of the

river, Grand and Battlement mesas are but remnants of a more ancient plateau, separated from its northern neighbor by the valley of the Grand River. Most of the strata of these great Tertiary formations still lie in horizontal position, but here and there, as against the southern slope of the Uinta Mountains, they are tilted at angles varying from a few degrees to as high as twenty degrees.

Of these four great rock series, the second from the bottom, the Green River, is the one of special interest at the present time on account of the oil shales which occur mainly in the upper half of the formation.

The oil shales occur in bands and strata ranging in thickness from a few inches to 75 or 80 feet. In many instances they are sharply set off from the underlying and overlying strata, while in others there is a gradual transition from rock practically free

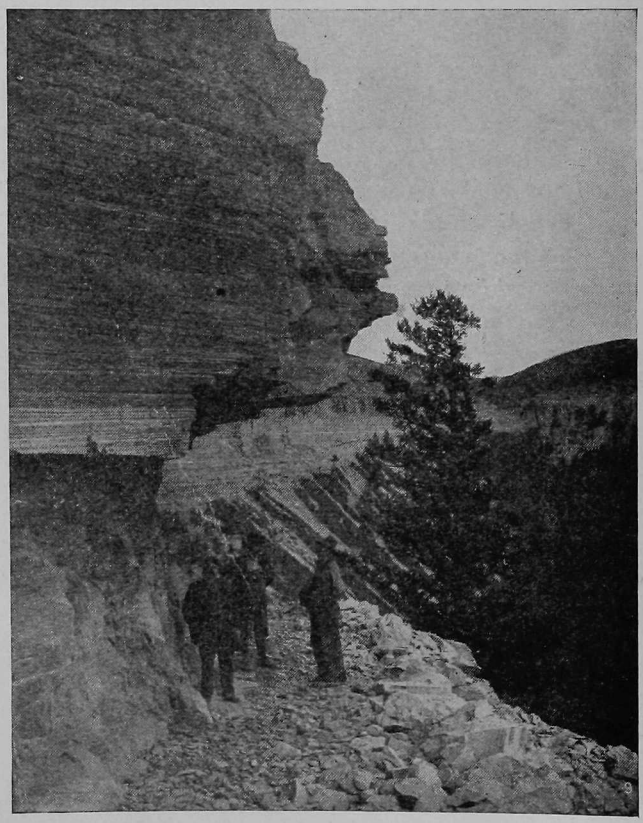

Fig. 3. Close view of oil shale deposits in northwestern Colorado (near Grand Valley) having a thickness of over 500 feet. Oil content varies from 35 to 90 gallons to ton of shale.—Courtesy Denver & Rio Grande Railroad.

from bituminous matter to layers which will yield as high as 60 to 80 gallons of oil per ton, and from this again to the almost barren rock above. Within the thicker oil shale bands the oil content varies widely. Thin layers may be selected which will yield as high as 90 gallons per ton, and strata from 5 to 10 feet in thickness may be found which will average from 60 to 70 gallons per ton. Between these will be leaner strata ranging down to barrenness.

The oil shale differs widely in color, composition, specific gravity, hardness and brittleness.

The lean shales are commonly of lighter color, ranging from whitish gray to buff, and sometimes blue gray.

As a rule, the lighter the color of the shale the greater is the proportion of very fine sand, while the darker the shale the greater the proportion of clay substance and organic remains. The richest shales range in color from a deep brownish mahogany to almost jet black on fresh surfaces.

A very little experience with shales enables one to select the rich and discard the lean by the weight of the material alone. The leaner material has nearly the usual specific gravity of common shales, 2.4 to 2.7, while the richest ranges from 1.6 to 1.85 (water 1.0).

Under the hammer the leaner strata behave as do ordinary shales. The more siliceous rock breaks with a smooth conchoidal fracture and is very brittle, while the richest is exceedingly tough and hard to break, especially in the direction of its structure. Across the bedding it breaks with a smooth conchoidal fracture, frequently exposing a delicate color banding of black and brownish black. The fresh fracture surfaces of the rich shale are silky or satiny in appearance. If such surfaces are scratched with a pointed instrument the mark left has a waxy surface, and the powder formed along the scratch resembles a grayish wax, cohering in masses and not falling apart in fine grains. The stroke of the hammer on the rich shale yields a sound similar to that produced when a hard, heavy wood is struck. The leaner shales give out the usual sounds when struck.

The rich shales withstand weathering much better than do the lean shales and non-bituminous rock, and, as a consequence, the edges of the rich strata project somewhat beyond the general surface presented by the leaner oil shales and the non-bituminous shales.

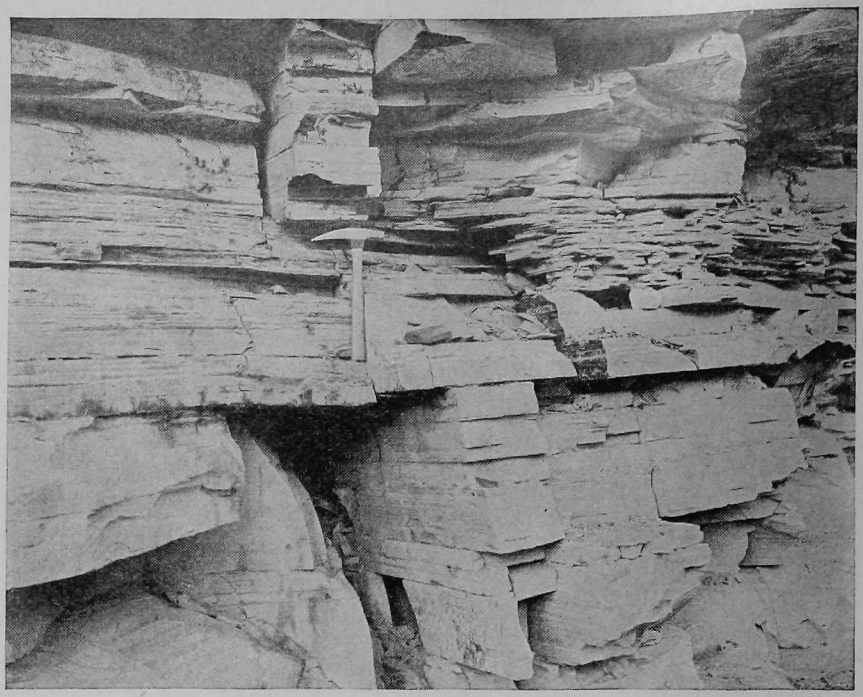

Fig. 4. A close-up view showing a rich deposit of oil shale.—Courtesy Denver & Rio Grande Railroad.

In weathering, the oil shales develop two rather characteristic types: First, the massive form in which the fracturing cuts the exposed edges of the strata into irregular patterns with relatively little reference to bedding planes, although fractures along bedding planes form some of the boundaries of the blocks. The weathered surfaces of some of these massive shales bear small lumpy projections, usually of lighter color and composed of sedimentary matter, with but little bitumen or organic content. The other type of shales, known as the paper shales, weathers into thin flexible laminæ with smooth, clean-cut surfaces. Some bands of the massive shale have a rough, wavy, concentric, or lens-like structure, the center of which frequently weathers into small caverns and openings filled with fine papery material and often highly charged with iron sulphate and other soluble salts. This structure appears to occur more commonly in the strata that contain a considerable amount of iron sulphide.

Thin slivers of either the paper shales or the massive shales burn quite readily, and hot, smoky fires may be developed with but

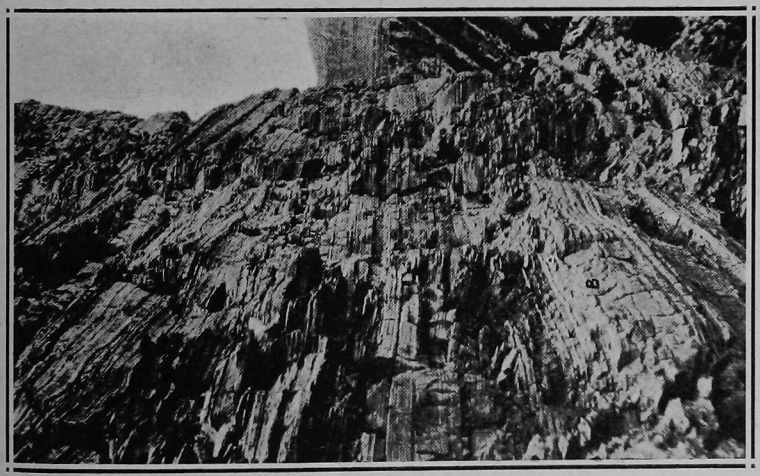

Fig. 5. Lower shale ledge (B) showing typical paper shale.
Sec. 26, T. 5 S., R. 100 W., Carr Creek.

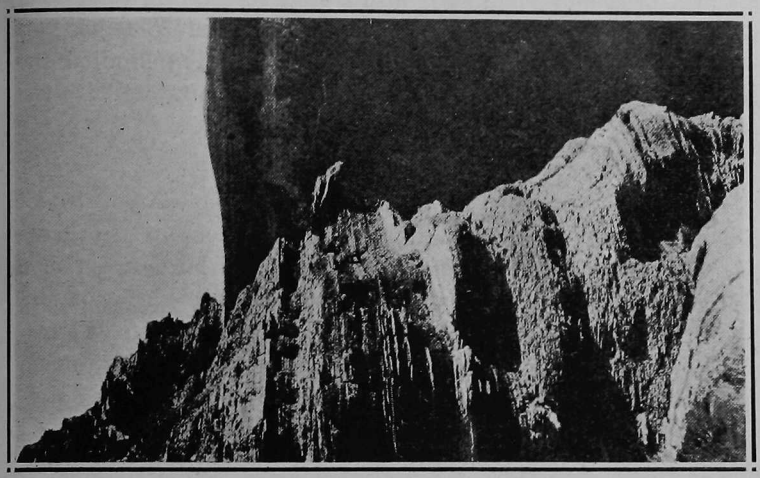

Fig. 6. Detail of lower shale ledge (B) in cliff, with lean shale above.
Sec. 10, T. 6 S., R. 98 W., Clear Creek.

little trouble from any of the richer shales. At a number of points along the cliffs the shales have been kindled, and fires have burned for a considerable time, converting some of the shale into red, brick-like debris, and some of it into a slag resembling that from furnaces. The origin of the fires can only be guessed. The position of the points suggests the possibility that lightning kindled the brushwood and the heat so developed was sufficient to ignite the shales.

PETROLOGY OF THE OIL SHALES

These great deposits of oil shale may be spoken of as an unfinished oil field. The shales, with their great content of organic matter, were laid down in horizontal position and large areas have remained but slightly disturbed since the time of their formation. The whole series of rocks in which the shales occur consists of alternating layers of shale with little organic material, shale with much organic material, and sandstone with little or no organic remains. It is reasonable to suppose that if the oil shale area were subjected to great earth movements, compressing and folding the strata and arching them into anticlines and bending them into synclines, the heat and pressure developed as a result of such movements would cause the distillation of oil and gas from the organic remains. The oil and gas so formed would find their way into the porous sandstones and would be prevented from escaping by the overlying impervious shales. As these substances are lighter than water they would travel through sandstone strata charged with ground water to the crests of the anticlines, and the gas, oil and water would arrange themselves in the order of specific gravity in the anticline, and we should have a duplication of the commonest form of oil structure and the commonest condition of the occurrence of oil and gas.

A rough analysis of the shale made as proximate analyses of coal are made, shows that it contains a varying percentage of organic material which can be converted into vapors and gases, and which is known as volatile matter. This volatilized matter is largely hydrocarbon gases condensible into oil. There is also a percentage of fixed carbon, which is not convertible into gases and vapors by the methods used, and a residue of inorganic material, mainly extremely fine sand and clay corresponding roughly to the ash of the coal. In the gases formed there is also a small amount of nitrogen which, in the workable shales, ranges from 0.5 per cent to 0.75 per cent. Other tests appear to show that the hydrocarbons developed from the shales naturally belong mainly to the paraffin

series, commonly known as the saturated hydrocarbons. But in the retorting process a large percentage of unsaturated hydrocarbons, chiefly olefins, is formed.

As nature left this oil undistilled and the oil field unfinished, man must supplement her work before he can obtain the oil. This may be done by heating the shales in retorts, converting the organic substances into vapors, and condensing a part of the vapors into liquid oil, while the uncondensable part contains methane, the principal constituent of natural gas, together with the products of combustion. The moisture of the shale is converted into steam which is condensed with the oil.

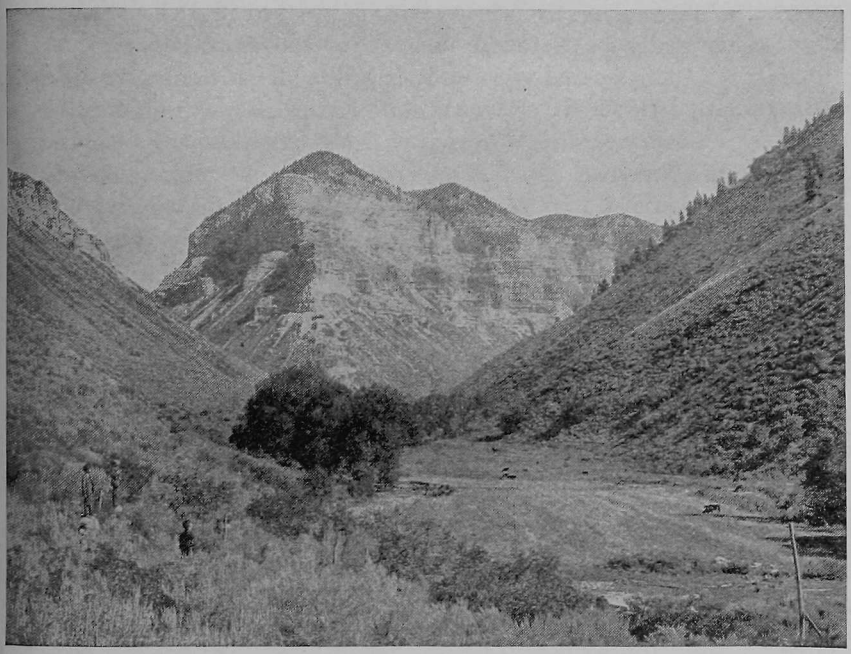

Fig. 7. Vast bodies of oil shale awaiting development on Parachute Creek, near Grand Valley, Colo.—Courtesy Denver & Rio Grande Railroad.

As to the quantity of oil contained in the shales of Colorado, Utah and Wyoming: It is as yet impossible to speak with any certainty, but there can be little doubt that there is in workable beds of shales in Colorado alone ten times as much oil as has been produced in the United States since the discovery of petroleum in Pennsylvania in 1859. The areas underlain by oil shale in Utah and Wyoming are much larger than those in Colorado, but the oil shale strata are thinner, and the oil content is lower, but it is

not unreasonable to assume that each of these states contains as much oil in workable beds of shale as does Colorado's smaller area.

Many other states also contain workable beds of oil shales, though they are for the most part much leaner than those here described. The Nevada shales, and some of those of California, are equally rich, but the areas are smaller.

ORIGIN OF THE SHALES

An examination of the shales does not reveal the presence of oil as such. They are not merely porous shales into which oily or other bituminous matter has seeped or penetrated. Within the body of the shales there are no pores or pockets filled with oil. If the oil of the Green River formation had seeped into the strata, it would naturally have found its way to the most porous layers which are the sandstones. But it is a notable fact that the sandstones of the Green River formation contain little or no oil or oil-yielding substance, while the richest shales are those in which the mineral matter such as sand and clay is the most finely divided and would naturally be the least porous. The conditions of deposition must have been in some respects similar to those which have given us our great accumulations of coal. The only approach to a developed bituminous material found in the shales is the occurrence of very minute specks and occasional lens-shaped masses from one-sixty-fourth to one-thirty-second of an inch in diameter of a lustrous solid hydrocarbon closely resembling gilsonite. Solution tests of the shales substantiate the view that but little of the oil obtainable from the shale exists in the rock as true organized hydrocarbon. An examination of thin sections from some of the shales shows countless fragments of plant material, such as pollen grains, spores, leaf and stem fragments, and others. When a chip of the shale is leached of its sand and clay substance it forms a soft, spongy mass, consisting of a matrix of extreme fineness in which plant fragments are buried.

From a consideration of these facts it would appear probable that the oil obtainable from the shale comes from two sources:

(1) The small specks of true hydrocarbon scattered through the shale, and which have doubtless been derived from the organic remains buried in the rock.

(2) From the distillation of plant (and possibly, but not probably, animal) remains composing the spongy mass remaining after the inorganic matter is dissolved out.

Some of the plant remains were found by Dr. C. A. Davis, of the United States Geological Survey, to be in upright position as

though the plants had grown on the floor of the lake and had been buried in their growing position by the accumulation of plant fragments and extremely fine inorganic sediment.

For the purpose of detailed study a series of 50 to 60 thin sections were cut from shales in various relations to the bedding planes and ground down to a thickness of one-thousandth of an inch for examination under high power microscopes. The sections represented shales of all grades, from those containing a trace of bituminous or plant matter to others giving an oil yield of 90 to 100 gallons per ton.

In sections from the leaner of these shales the organic materials are extremely scarce, and only the merest fragments of highly altered plant fibre and occasional spores or pollen grains proved the presence of vegetation in the lakes in which the sediments were deposited. At first thought one would expect the microscope to reveal in the richest shales the largest amount of recognizable organic material, but contrary to this expectation, comparatively few of the sections of the richer shales gave even fair opportunities for the study of the organic remains responsible for the bituminous matter they contained. In these the organic matter appeared to be reduced to much smaller particles and to be much more completely bituminized than in some of the shale having a much smaller oil content. The lustrous black shales rarely afforded sections in which recognizable plant remains could be found. In the writer's experience, by far the best material for microscopic examination is the dark mahogany brown, faintly lustrous shale. In some of the sections from this type of rock shreds of plants, fragments of fruits or seeds, pollen grains and spores were often so numerous as to occupy more than half the field of the microscope. Cell structures are, in some cases, beautifully preserved, and the paleobotanist should be able to recognize and classify broadly a considerable number of plants represented in the shales.

The peculiar waxy appearance of the material formed by scratching or scraping the richer shale is believed by some observers to be due to the presence of a solid hydrocarbon, possibly a paraffin wax of very high melting point. But heating and solution tests do not appear to support this view. It seems improbable that in even the richest shale there could be a sufficient amount of true hydrocarbon present to give the waxy luster to the powder. It is noticeable also that some of the richer shale yields a brown, noncoherent powder without waxy luster. It is more probable that the waxy luster is due to the presence of kaolin or a related hydrous

aluminum silicate. McCoy[2] succeeded in getting a little oil by subjecting certain shales to extremely high pressure, but it is not clear that the oil was not generated in the process of compression. It is known that at certain points along the Petrolite Hills, and at other places in the shale areas, there are indications of a liquid hydrocarbon in the shales. But these indications are found where the folding and compression have been pronounced, and where, as a natural consequence, greater heat would have been developed.

Considering the shale deposits as a whole, the following points appear to be established:

(1) The shales contain no hydrocarbons liquid at atmospheric temperatures.

(2) Solid hydrocarbons in minute particles and in widely differing quantities occur in the shales.

(3) There appears to be no direct relationship between the oil yield and the presence of these hydrocarbons. Shales apparently free from the hydrocarbon particles may give a high yield of oil, while others in which such particles are numerous may give a low yield.

(4) The shales contain much partially bituminized vegetable matter (and possibly some animal matter), and the quantity of this and the hydrocarbons together, determines the possible oil yield.

(5) The degree of bituminization of the vegetable matter differs from place to place, and from stratum to stratum. This change in the vegetable matter is comparable to the evolution of coal from plant matter.

(6) The oil-yielding materials of shales are related to lignite, or coal, on the one hand, and to the true hydrocarbons on the other. The closeness of the relationship to each depends upon the nature and degree of the alteration of the vegetable matter of the shale. While the facts just stated throw much light on the origin of the shales, there remain many problems which must be worked out before the whole story of the oil shales can be written.

STRUCTURAL FEATURES OF THE SHALES

In the field the geologist readily recognizes two broad classes of shale strata. By far the most important of these are the massive strata, which, throughout the greater part of the area, form 75 per cent to 90 per cent of the total volume of workable material. The other type, on account of the weathering of the outcropping edges of the strata into very thin laminæ, is known as paper shale.

[2]Notes on Principles of Oil Accumulation. Jour. Geol., vol. 27, pp. 252-262, 1919.

In some places these two types appear to be quite distinct, and for long distances one may look in vain for the evidence of paper shale in the strata which are predominantly of the massive type. But here and there, especially in the areas in which iron sulphide and the weathering product, iron sulphate, occur, even strata predominantly massive may take on the paper structure. There are, in many places, strata which are prevailingly of the paper type, but in some places the papery shales give place to the massive forms.

A third, but very subordinate type, may be called wavy or curly shales. These occur in strata of both massive and papery types. In a few places these curly shale strata form good horizon markers.

The distribution of joints in the shale strata is extremely irregular and inconstant. In some places one may follow the outcropping edges for hundreds of yards without finding a prominent joint, while in other places prominent joint planes are somewhat closely spaced, but their vertical courses are rarely long enough to cut the thicker strata from top to bottom. This will also prove of considerable importance in the mining of the shales.

Along the outcrop of the shales one may observe widely varying conditions of stratification. In some places a large body of shale may appear to form but a single stratum which will reach a thickness of 10 to 12 feet. In other places the outcropping edges may be distinctly divided into strata a few inches to 2 or 3 feet in thickness. In places the laminæ of the paper shale may become less and less distinct, until all evidence of their existence is lost and the whole bed presents the appearance of a single compact stratum.

The importance of jointing and stratification as aids to mining is naturally very great, and while it may be impossible to select areas in which both are well defined and prominent, it is rarely impossible to take advantage of one or other of these structural features.

WEATHERING

The bitumen content has rendered the oil shale strata more resistant to the processes of weathering than are the enclosing barren clay shales and the softer sandstones. Small fragments of oil shale are notably scarce in the debris and alluvium at the foot of the precipitous cliffs in which the oil shales outcrop. Large blocks bounded by joint planes are common in the coarser talus at the foot of the cliffs and on the steeper slopes. An examination of the exposed edges of the massive shale strata impresses one with the

idea that, except for the breaking away of the larger joint blocks, the erosion of the shales must be quite largely a process of solution and disintegration into the extremely fine sand and clay particles which form the inorganic matrix in which the organic material is contained. By exactly what agencies the bituminous matter is removed in this process of disintegration it is impossible to say. But it is certain that the process of the removal of this material is slow and goes but slightly ahead of the separation and disappearance of the inorganic material. The removal of the bituminous material from the richer shales leaves a grayish white layer over the surface, which, on unfractured blocks, ranges from a mere film to rarely more than one inch in thickness. Where the shale is finely laminated by closely spaced joints the weathering has penetrated to a greater depth. But it is a notable fact that the oil content of the massive shale has rarely been diminished by weathering to a depth of more than 2 or 3 inches.

In the case of the paper shales, weathering has opened up the fine layers and separated them in fan-like forms, into which the weathering agencies have penetrated for a considerable distance. But even in these, with rare exceptions of deep jointings, has the oil content been markedly reduced beyond 3 or 4 feet from the outer surface.

COMPARISON OF SCOTCH AND COLORADO SHALES

COMPOSITION

Analyses of the Scotch and the Colorado shales show that they vary from place to place and from stratum to stratum, both in their organic and inorganic contents. The Scotch deposits vary in both these particulars much more than do the Colorado shales. Lean shales alternate with the richer both vertically and along the bedding plane. The Colorado shales are much more uniform in oil content along the strata, and there is probably much less rapid variation in a vertical direction. The inorganic materials of the shales appear to have little bearing upon the problems of the oil shale industry. The more siliceous or sandy beds of Colorado shale may break more readily in mining than do the more clayey strata, but in the retorting the character of the inorganic matter plays no part so far as the writer has been able to observe. It was thought that the sandy shales would yield their oil more readily than would the clayey, but tests do not substantiate this idea.

POSITION OF THE SHALE BEDS

The Scotch shales are much less accessible than are large volumes of those of Colorado. Most of the shales of Scotland are mined through shafts or slopes. The Colorado shales outcrop in nearly horizontal strata along the Book Cliffs front and along the walls of valleys cut into the great plateau area. But it must be kept in mind that back of these outcrops lies the great mass of shales miles from any possible frontage on the valleys. The mining difficulties confronting the shale operator owning claims without such frontage are comparable to those of the Scotch operator, with the additional problem of a very scanty water supply.

STRUCTURAL FEATURES

The Scotch shale beds are folded and faulted, and thicken and thin rapidly along the strata, while the Colorado shales lie mainly in horizontal strata, rarely folded or faulted, and of remarkably uniform thickness. These conditions are most favorable for mining operations, and should greatly reduce the cost of getting the shale to the retorts. The amount of timbering required should be much less, and the cost of timber per prop should be much less.

THE OIL CONTENT

The average yield of the Scotch shales is reported at about 18 to 20 imperial gallons, or 22 to 24 U. S. gallons, per ton. There are billions of tons of shale in the Colorado deposits which will yield double this amount of oil, and vast quantities that will yield from 50 to 60 gallons per ton. In addition to these are immense tonnages which will equal the Scotch in oil content.

The ammonia yield of the Scotch shales is probably double that which may be expected from the Colorado shales, but there can be no reasonable doubt that the ammonia will prove a valuable product, and will add considerably to the profits.

THE CRUDE OIL

There is but little real difference between the qualities of Scotch and Colorado crude shale oils. Both present serious refining difficulties as compared with well oils, but products of the highest commercial quality may be secured. Prejudices will have to be overcome, and possibly a campaign of education will be necessary. But *need* and *scarcity* are the most potent factors in overcoming prejudice, and are very apt teachers.

ESTIMATE OF TONNAGE IN SHALE STRATA

The specific gravity of shales yielding from 40 to 60 gallons per ton is about 1.6, and approximately 20 cubic feet will weigh one ton. An acre contains 43,560 square feet, and an acre-foot of shale contains 43,560 cubic feet, or 2,178 tons. Assuming a yield of one barrel of oil per ton of shale, each acre-foot would contain 2,178 barrels of oil.

For many miles along the sinuous face of the southern exposures of the Green River shales there is an aggregate thickness of upwards of 35 feet of workable shale in beds exceeding 3½ feet in thickness and containing an average of over one barrel of crude oil per ton. An acre of such territory would contain over 76,000 barrels of oil, and a square mile would contain 48,640,000 barrels. The total shale area of Colorado exceeds 2,000 square miles. Assuming that it averages 20 feet of workable shale containing 1 barrel of oil per ton, the total crude oil content would be approximately 56,000,000,000 barrels. This is ten times the estimated remaining supply of petroleum in the known oil fields of the country.

MINING SHALE

The problems of shale mining are much the same as those of coal mining, and will be solved in the same way. The Colorado shales lie mainly in almost horizontal beds between strong shale roof and floor rocks, or occasionally sandstones. The thickness of the beds and the oil content are remarkably constant.

Timbering will be necessary in places, but not nearly so generally necessary as it is in coal mining in Colorado. Permanent entries, air ways and haulage ways can be maintained largely by walls of lean shale and waste.

The conditions appear to be favorable for long wall and panel methods of mining.

Much has been said regarding the possibilities of gas in the workings. Nothing is positively known. It would be very reasonable to expect the same gases as are found in coal workings, both from open pockets in the shales and from slow filtration from the body of the rock. The writer made a few tests by plugging the mouths of drill holes in the solid shales to see whether they would fill with gases, but the results were negative. This is not conclusive, and only experience will answer the question.

Cutting machines, such as are used in coal mining, can be adapted to the needs of shale mining. Greater strength and different cutting devices will be necessary, but the principles and general design of the machines will serve the purpose.

Since the shales are tough and non-friable, they will be much harder to break than is coal. But as no precautions are necessary to avoid the formation of slack and to secure lump, much heavier charges of powder may be used.

Along the southern front of the great shale area the beds are at an elevation of 1,200 to 2,000 feet above the valley floors. If plants are located in the valleys the mined shale can be lowered by gravity trams or milled down to loading tunnels near the level of the valley floors.

Much has been said about steam shovel mining. Not one acre in a thousand of the shale deposits offers any possibility of handling by such a method. Here and there a few acres of good shale are exposed at the surface. But the amount of shale which will be mined by steam shovel will be negligible as compared with the vast tonnage which must be reached by entry and shaft.

As to the cost of mining, the only guides we have are American or Colorado coal mining and Scottish shale mining. It would seem probable that the costs of opening and equipping a shale property would be much the same as those of opening a coal mine for a like tonnage production. The costs per ton thereafter should also be comparable, and will probably range from 80 cents to $1.20. They certainly should not exceed the higher figure.

SHALE OIL PROBLEMS

The obtaining of oil from shales is a chemical process, and chemical reactions depend upon physical conditions. The physical conditions are imposed by the apparatus we use and the way in which we handle that apparatus. If our apparatus or our handling of it imposes physical conditions out of harmony with the results desired, it is useless to look for success.

The secret lies in knowing what reactions must take place to produce the desired results, and in shaping the apparatus and operating it to secure those reactions.

The writer has tested the Scotch oil shales and oil shales from England, South America, Canada, California, Nebraska, Colorado, Utah, Wyoming, and other states. These shales differ in details, but the fundamental problems of treatment are the same—the problems of hydrocarbon chemistry. These problems have been solved in Scotland, France, and Australia. The history of the Scotch shale oil industry is a story of scientific research by chemists and engineers of the highest rank. It is a story of evolution—the survival of the fittest in apparatus and in manipulation. The road

is strewn with discarded apparatus—the best in its day. It is marked by abandoned theories and processes, each having played its part in reaching the goal.

Instead of profiting by the half century of experiment and experience of Europe, most of our experimenters have ignored all the progress made at the expense of ceaseless toil and millions of money, and have chosen to be "pioneers," secretly cherishing the thought that chance, inspiration, revelation, or their own superior mentality will enable them to present to the world a process beside which the poor old Scotch process will recall the days of the stage coach.

They are presenting theories and "inventing" apparatus and processes abandoned twenty or thirty years ago. If they want to improve on the Scotch process why not start from the best and advance? The exact form of the retort is not vital, but the physical conditions it imposes are vital. The form of the retort may be the best ever, but the operation of that retort may produce the worst results ever.

It is highly probable that modifications of the Scotch retorts and processes may be needed to meet peculiarities of our Colorado and Utah shales, but the broad needs are the same.

Our shales far exceed the Scotch shales in oil content, and, consequently, the tendency to coke and clog will be greater. This is not an insuperable difficulty. Our shales contain a smaller percentage of nitrogen available for ammonia. This fact may make certain modification of treatment desirable. But it is not fundamental. Our shales appear to contain more pyridines than do the Scotch. This will modify the refining process, and certain changes in the retorting may help us to avoid the difficulties they present.

Much has been said about extracting the oil in 20 minutes, 30 minutes and other short times. Possibly it can be done, but the getting of the oil (or oil and fixed gas) is not the final goal. The ultimate purpose is the refined products. Will the 20-minute oil yield them?

The scientific problems to be faced by those who seek to establish a shale oil industry fall into two groups:

(1) The problems of retorting.

(2) The problems of refining.

In this country, up to the present, attention and effort have been directed almost entirely to the solution of the problems of the first group. This is due to the natural, but erroneous assumption,

that crude shale oil is like crude well petroleum, and may be successfully refined by the same processes.

This assumption would be reasonably safe if oil shale were merely shale saturated with petroleum. True oil shales like those of Colorado and Scotland contain no ready-made oil, but are rich in the materials from which oil may be formed if the shales are properly treated.

The problems of retorting are:

(1) To convert as much as possible of the oil-making material of the shale into oil or other useful products.

(2) To secure a crude oil containing the largest possible percentage of the most valuable constituents, such as gasoline, kerosene, and lubricating oils, and the smallest possible percentage of worthless and harmful materials which must be removed as waste in refining.

(3) To secure a crude oil which is easily fractionated into gasoline, kerosene, lubricating oils and others, and which yields fractions or cuts which are easily refined.

(4) To secure as large a yield of ammonia and other valuable by-products as possible without sacrificing more desirable results.

(5) To reach the highest commercial efficiency without sacrificing the raw materials of the company or of the country.

The cost of equipment and operation of the refinery will depend very largely upon the efficiency of the retorting plant in meeting and solving these problems. It will be found that a little greater care in retorting will be rewarded by a great reduction in refining costs.

RETORTING PROBLEM 1

The carbonaceous material of Colorado oil shales appears to occur in three forms: (1) true hydrocarbons in the solid form occupying extremely small pits and intergranular spaces in the shale; (2) plant and possibly animal matter which has undergone changes akin to those by which vegetable matter is converted into coal, and (3) fixed carbon. The relative proportions of these three materials are far from constant. In some thin layers of rich shales the true hydrocarbons, probably paraffins, greatly exceed the other two materials. Such shales, when examined under a powerful microscope, show great numbers of grains of true hydrocarbons, and very little, if any, vegetable tissue. The fixed carbon content of such shale is generally low. On the other hand, there are shales in which the vegetable tissue greatly exceeds the hydrocarbons in quantity.

In retorting, the true hydrocarbons appear to vaporize at a comparatively low temperature, while a higher heat is necessary to develop hydrocarbon gases from the vegetable matter, and the last hydrocarbon gases are given off at a very high temperature. Whether these last come from the true hydrocarbons or from the altered vegetable tissue it seems impossible to determine. The fixed carbon cannot be converted into hydrocarbon gases unless, in some way, the necessary hydrogen is supplied, and it is doubtful whether the hydrogen and carbon can be made to unite under the conditions prevailing in the retort.

From the above facts it will be clear that the shales are not simple homogeneous materials yielding their gases by volatilization at a definite temperature or within a narrow range of heat.

Two questions arise: Is the gas which comes off at the highest temperature worth getting, or is it secured at too great cost of fuel and time? Is there any means of securing these last hydrocarbons at lower temperatures? To the first question the answer must depend upon the proportion of these high temperature hydrocarbons to the total yield, and their character and value. The proportion will be different in different shales. Their value is probably questionable, as the high temperature necessary is likely to make a large percentage of uncondensable gases valuable only for fuel, and other compounds which will add greatly to the difficulties of refining. The second question may, with reasonable certainty, be answered in the affirmative. The use of superheated steam in the retorts seems to reduce considerably the temperature required to drive them off. And with low temperature retorting there is a notable reduction in the proportion of uncondensable gases, and the formation of undesirable compounds. To secure these last gases for their fuel value would be penny-wise and pound-foolish, since equally good fuel can be obtained much less expensively.

The fixed carbon has a high fuel value, but unless air is admitted it cannot be directly utilized as fuel, and will remain in the spent shale.

When steam is used in retorting, the conditions in the retort resemble those which obtain in the manufacture of water gas, but the best temperature for the formation of the oil vapors is too low to convert the carbon into carbon monoxide. If, after the oil vapors are driven off, the shale is passed on to another section or chamber of the retort or to a secondary retort and there raised to a much higher temperature to get the maximum yield of ammonia, steam passing through this highly heated mass will not only aid in

getting the ammonia, but will cause the formation of water gas by the union of the oxygen of the steam with the fixed carbon of the shale, and the freeing of the hydrogen. In this way the fuel value of the carbon may be saved, and the fuel value of the hydrogen added. A temperature of 1300° F. is necessary.

When superheated steam is used the desirable gases are given off at lower temperatures. Its value in the solution of other problems will be discussed later.

RETORTING PROBLEM 2

Some well petroleums yield a large percentage of gasoline, kerosene and other light oils; others yield little or none of these light fractions. Some yield high grade lubricating oils; others are worthless for this purpose. Some well petroleums would yield so little of any refined products that they are valuable only for fuel. Others contain valuable constituents, but yield them only at prohibitive cost, and so cannot be profitably refined.

Crude shale oils differ just as widely in their possibilities, but the differences are due to the methods of manufacture, not to uncontrollable natural causes. Oils are composed chiefly of hydrocarbons, but there are many different forms of hydrocarbons. In the formation of common petroleums in the earth, the character of the original materials, the heat and pressure to which they are subjected, the presence or absence of water, the character of the rocks and mineral substances with which they come into contact, are all factors in determining what hydrocarbons will be formed, and, consequently, the character and value of the oil which will result. It is equally true that the conditions of retorting will determine the character and value of the shale oil produced.

What are the controllable conditions in retorting shales for the manufacture of oil?

(1) The rate of applying heat.
(2) The maximum temperature reached.
(3) The presence or absence of water in the retort.
(4) The access of air.
(5) The time the shales are held at different temperatures.
(6) The pressure in the retort.
(7) The removal of the vapors from the retort.
(8) Added materials as catalysts or as actual chemical reagents, etc.
(9) The size of the material.
(10) The heat distribution—even, uneven, etc,

As to the rate of applying heat.—Time must be given for the heat to penetrate the shale, and for the gases to form and escape. Experience shows clearly that certain gases are formed at low temperatures, others at intermediate temperatures, and others at high. Time is a factor in all chemical reactions. If the gases formed at low temperatures are the best for oil making, the heat must be applied slowly to give time for it to penetrate the shale and for the gases to form. In lime burning this is a most important factor. Too rapid application of heat causes sintering of the stone and the closing of the pores by which the gases escape. A similar condition results in the shales by the excessive formation of fixed carbon through the cracking of the hydrocarbons of the shale and the cracking of the gases, both of which are wasteful and result in excessive production of fixed or non-condensable gases, and an oil low in gasoline. Objectionable compounds are formed which must be removed in refining, and some of them present the greatest difficulties encountered in refining and greatly add to its cost.

The gases evolved at low temperatures are the best, the proportion of condensable gases is largest, the percentage of paraffin gases is highest, and that of impurities is lowest. The oil obtained is more easily refined, and the proportion of light oils is greatest.

The maximum temperature.—Retorting at too high temperature results in the formation of much fixed gas, a low content of gasoline and kerosene in the crude oil, inferior lubricating oil and a crude hard to refine. The Scotch call it "burnt oil." It is possible to raise the temperature so high as to decompose the hydrocarbons into the elements hydrogen and carbon, in which case no oil would be obtainable. But the shales contain varying proportions of material which can be converted into hydrocarbon gases only at temperatures so high as to be very injurious to those gases formed at low temperatures. Similar high heat is required to get the best yield of ammonia. In some shales the amount of carbonaceous material convertible only at high temperature is negligible, but in others it may reach 15 to 20 per cent. The problem suggests several possible solutions.

(a) Sacrificing the high temperature material and the high yield of ammonia. This would save fuel and time and increase the throughput, and might compensate for the loss of oil and ammonia.

(b) Doing the principal part of the retorting at a relatively low temperature and passing the shale on to another section of the retort, or to a finishing retort, where it may be subjected to the high temperature necessary for securing the last of the hydro-

carbons and the higher yield of ammonia. This is largely practiced in Scotland, possibly because the ammonia is relatively a more important product than it would be in America.

(c) Intermittent retorting—securing the main yield of condensable gases at low temperature and finishing the charge at high temperature. It is known that the high temperature gases contain a lower percentage of condensable gases than do the low temperature gases, and are of less value.

It should be stated that with the use of superheated steam in the retort the last hydrocarbons and the larger yield of ammonia are secured at lower temperature than by dry distillation. In fact, it is impossible to secure the full possible yield of ammonia without the superheated steam.

Experiment and experience and markets will decide which of these solutions of the problem will be best.

Presence or absence of water in retort.—The beneficial effects of superheated steam in the retort appear to be:

(a) Evolution of gases at lower temperature, saving time and fuel.

(b) Twice or three times the yield of ammonia.

(c) A lower percentage of unsaturated hydrocarbons, possibly as a result of the protection afforded by the steam, and a lower yield of uncondensable gases, and of compounds which render refining more difficult.

(d) A higher percentage of lighter oils in the crude.

(e) The prevention of coking and clogging.

(f) The more rapid removal of the oil vapors from the retort preventing decomposition.

(g) It serves as a heat distributor and equalizes the temperature throughout the retort.

Under certain conditions the use of superheated steam is unsatisfactory. In tests made on samples of Kimmeridge shales from England the superheated steam caused the formation of an obstinate emulsion which made fractionation and refining difficult and slow. This was also noticed in testing a California shale. Once or twice obstinate emulsions were formed in treating Colorado shales, but the manipulation was at fault.

As to the quantity of superheated steam required: The best results were obtained by the use of water at the rate of about 650 to 750 pounds per ton of shale.

Access of air.—It is argued that the admission of air will increase the yield of ammonia. This is more than doubtful, since

hydrogen and nitrogen unite at temperatures above 500° C. and at very high pressure. It is highly probable that both the nitrogen and the oxygen of the air may form injurious combinations. Air certainly causes mechanical difficulties. Some Scotch operators admit air at the bottom of the retort where the temperature is run up to get the last of the ammonia. The oxygen of the air unites with the fixed carbon forming monoxide, a fuel gas.

Time required at different heats.—The low temperature distillation requires much more time than does the finishing high temperature.

Pressure in the retort.—Experience in the cracking of oils suggests the desirability of retorting under pressure to prevent the cracking or decomposition of the paraffin hydrocarbons. But experiments in retorting under pressure have proved unsatisfactory. On the other hand, the longer the gases are allowed to remain in the hot atmosphere of the retort the greater the cracking and decomposition. A slight suction reducing the pressure about one pound below that of the atmosphere causes a quick removal of the gases formed and probably prevents much decomposition. The Scottish retorts are run under slightly reduced pressure.

The removal of vapors from retort.—This should be as rapid as possible. Many attempts have been made to remove and keep separate the vapors formed at different temperatures and effect a selective condensation. But, while this is possible in small measure, it is doubtful whether it will be possible or profitable commercially. It is highly desirable to have numerous outlets for the gases so that they may escape from the retort without passing a long distance through the hot shale.

Added materials to facilitate or improve results.—Various materials have been mixed with the shales in the retort with a view to bringing about reactions and improving the products. Such materials belong to two classes:

(a) Catalysts—substances which induce or condition reactions but which do not take part chemically.

(b) Substances which enter into the chemical reactions.

Definite beneficial results have been obtained in laboratory work along this line, but considerations of cost of materials, bulk and handling appear likely to offset the advantages gained. To be commercially valuable and practical the materials must be cheap, readily available, effective in small amounts, and must produce positive results which tell in the quality of the finished products or in the operation of the retorting and refining processes.

Perhaps one of the most desirable results to be aimed at would be the elimination of the very persistent coloring matter which characterizes shale gasoline and kerosene.

The size of the material.—The heat penetrates the shale very slowly. It is, therefore, desirable to crush it rather fine, so as to give large surfaces in proportion to the volume of the fragments. It should not be so fine as to pack and clog.

Heat distribution.—On account of the slowness with which heat penetrates the shale, it is of the greatest importance that the body of shale should not be too thick. In certain forms of retorts stirring devices may be used to facilitate heat penetration of the mass, and so prevent overheating or spot heating and the objectionable results which follow it. Heat distribution is greatly aided by superheated steam.

Even the best crude shale oil contains a large percentage of unsaturated hydrocarbons called olefins. Until recently the refining methods used in the United States removed the olefins from kerosene and gasoline. This led to the erroneous notion that olefin hydrocarbons could not be used in motor fuel, and a number of writers have stated that shale oil could not be used for the production of gasoline. If by "gasoline" is meant a motor fuel consisting mainly or wholly of paraffin or saturated hydrocarbons, their contention is correct, for the loss would be prohibitive. But if the term "gasoline" is made to include all fuel suitable for use in internal combustion engines similar to those used in automobiles, the contention is far from correct. The motor spirit put on the market by the Scottish shale oil companies contains from 60 to 70 per cent of olefins, and 30 to 40 per cent of paraffins, and it gives highly satisfactory results.

It is an established fact that the diolefins, and not the olefins, are the chief trouble makers in gasoline produced by cracking. They are responsible for the foul odor, for the change in color, and for the formation of the heavy resinous oil which commonly forms in such gasolines. If the diolefins are completely removed the olefin-rich gasoline will not deteriorate with age to a greater extent than will ordinary paraffin gasoline. The chemical properties of the olefins and diolefins are so very similar that the problem of separating them is a very difficult one. The sulphuric acid treatment can be so modified as to remove practically all the diolefins without serious loss of olefins. A gasoline containing over 60% of olefins has stood in the Survey laboratory (in direct sunlight a large part of the time) for over two years without noticeable change of color.

Other methods of removing the diolefins have been worked out in the laboratory, but whether they will prove to be of commercial application has to be determined. Certainly, a method will be found, if, indeed, the Scotch refiners are not using such a process.

In European countries large quantities of benzol are used as motor fuel. This is obtained by the distillation of coal and consists of members of the benzene series of hydrocarbons, and contains no paraffins. And yet it is a satisfactory motor fuel.

Some of the cracked gasolines on the market in this country contain as high as 25 per cent of unsaturated hydrocarbons (olefins), and the users do not even know it.

The problem is not to secure from shales a "gasoline" or motor spirit composed of paraffin hydrocarbons, but to secure a motor spirit or motor fuel which will do the work regardless of its composition. Experiments have shown that the explosive energy of an olefin motor spirit is delivered more slowly, but through a longer period of time, than is that of a paraffin gasoline. They have also shown that the total energy delivered weight for weight is from 10 to 15 per cent greater for the olefin motor spirit than for the paraffin gasoline, and that the mileage obtained is correspondingly higher. Olefin gasoline vaporizes at a lower temperature than does ordinary gasoline of the same gravity, and is, therefore, a better winter motor fuel.

The gist of these facts is that shale oil "gasoline" will deliver 10 to 15 per cent more energy, and will deliver it in a steadier or less jerky fashion, causing less vibration and, therefore, less strain upon the motor and the machinery driven by it.

It is contended that the olefins deposit more carbon in the cylinders. This is a problem of carburation and has been solved.

RETORTING PROBLEM 3

Some shale oils are hard to fractionate, hard to refine and yield but little of value. Some are so spoiled in the making as to be unrefinable and worthless except for fuel. Colorado shale oil should yield 16%-22% natural gasoline, and 40%-45% kerosene.

The crude oil should be easily fractionated and the fractions should be easily refined.

The best results in this direction are obtained by low temperature retorting with superheated steam. High temperatures and dry distillation tend to unnecessary reduction of the light oil content, the formation of crudes from which but little gasoline can be obtained without cracking, and the production of obstinate sulphur

compounds and nitrogen-containing compounds which render refining difficult and costly and reduce the grade of the products obtained. It also reduces the yield of condensable gases and increases that of the fixed gases.

The advocates of certain retorts make the boast that they yield enough fuel gases to do the retorting. This boast means simply that they are doing poor retorting—making fixed gases instead of condensable gases, and by the same token are getting a low yield and inferior oil. It is infinitely better to secure as high a yield as possible of condensable gases; in other words, to accomplish the purpose for which retorting is done; namely, to make oil, and that of the highest grade possible. If fuel is needed it can be made to much better advantage and of better quality by installing a producer plant using shales as raw material. A single producer plant would supply several retorts.

It is impossible to avoid the formation of fixed gases, but if the retorting is properly done the volume need not exceed 3,000 to 4,000 cubic feet per ton of shale, depending upon its normal yield of oil. The proportion of hydrocarbons in this should not exceed 35 per cent. If a successful effort is made to convert fixed carbon into combustible gases the volume will be larger.

The essential features of the successful retort will include as many as possible of the following: Large daily capacity, ease of operation, perfect control as to temperature and the movement of the charge, the rapid withdrawal of the vapors, provision for the use of superheated steam, a possible gradation of temperature, inexpensive construction and upkeep and long life. It should also be so constructed as to make possible the conversion of the non-oil making carbonaceous matter of the shale into fuel for operating purposes.

AMMONIA YIELD

A large number of analyses of Colorado shales show an average nitrogen content of 0.6 per cent, which would correspond to 56 pounds of ammonium sulphate per ton. Only a part of the nitrogen is available for the formation of ammonium sulphate, probably not more than one-half. In retorting, a part of the available ammonia comes off at low temperature, and a part at high temperature. Superheated steam increases the yield of ammonia from two to three times, but a large part of it comes off at the high temperature. Unless it is found desirable and profitable to use the high temperature for the purposes of oil extraction, it may be doubtful whether the increased yield of ammonia would justify the high heating

which would surely injuriously affect the hydrocarbon gases if they were heated to the same degree. Under certain conditions of market and demand for ammonium sulphate, it might be profitable to pass the shales directly from the main retort into a separate finishing chamber in which the full yield of ammonia could be secured. The gases formed could be turned directly into the fuel supply.

OTHER BY-PRODUCTS

Much nonsense has been written about the many valuable by-products of oil shales. It is true that many commercial products can be made from the shales, but most of those commonly listed can be made much more cheaply from other forms of raw materials. This is true of dye stuffs, medicinal salts and many other chemical substances which are now made from coal tar and the accompanying liquors.

A substance resembling ichthyol has been made, but it is very doubtful whether true ichthyol has been produced.

Synthetic rubber has been much talked of, but it is safe to say that nothing approaching a commercial process or a commercial quantity has been discovered.

A substance resembling gilsonite and possibly suitable for a rubber filler may be separated from the tarry residues.

Paraffin wax of high grade and readily marketable may be produced in commercial amount and profitably.

Analyses of several samples of spent shale showed an average potash content of 18 pounds per ton of spent shale. This is water-soluble and could be leached out at little cost.

The spent shale has been proclaimed a fertilizer, but it contains nothing of value in this way except the potash, and it would be absurd to list it with fertilizers.

It has also been talked of as raw cement material, and as brick material. It is of less than average value for either of these purposes.

One advertiser of shale oil stock has found that it is the best of material for glass and porcelain making. This is nonsense.

It is not even good road material and its disposition will present a problem.

The tars, still carbon, or coke, and the heavy residual oils will be utilized about the plants or converted into marketable products.

Lubricating oils of the highest grade are made from the Scottish shale oils, and laboratory quantities of lubricating oils made from Colorado shale oils have given extraordinary results when

tested in actual use. They retain their viscosity or body at much higher temperatures than do oils of similar density and flash point made from well petroleum.

GOLD, SILVER, PLATINUM, ETC.

Much misinformation is being given out regarding the precious metal content of the spent shales. A large number of assays by thoroughly reliable and competent chemists and assayers have failed to give a single return which could by any reasonable means be called commercial. Traces of gold were found in possibly one-half the tests made by the Colorado Geological Survey.

PROBLEMS OF REFINING

The problems of refining may be summed up:

To refine, without undue waste, an oil containing from 50 to 60 per cent of unsaturated hydrocarbons, a considerable percentage of pyridines and other compounds.

To secure good color and permanence of color.

To secure a reasonably sweet odor.

To secure an oil which will not corrode the cylinders of the engines in which it is used.

To secure the largest possible percentage of valuable marketable products from the crude.

It has been shown that the unsaturated hydrocarbons (olefins) yield more energy, and yield it in a steadier and more sustained thrust than do the paraffin hydrocarbons; that an olefin gasoline of the same gravity will vaporize more readily, and is, therefore, a better winter motor fuel than a paraffin gasoline; that the shale lubricating oils, rich in olefins, hold their body (or viscosity) better under high frictional heat than do the paraffin-rich lubricating oils of the same density, and are, therefore, from this standpoint more desirable lubricants. It is evident, then, that the first problem of the refiner is to work out a refining process which will save all the olefins and give the user the benefit of their superior qualities, whether in the engine or on the bearings. The Scotch shale oil producers are doing this, and it is entirely reasonable to say that the American refiner can and will do it.

Today the makers of cracked gasoline are putting on the market a good-looking and well-behaved gasoline containing over 20 per cent of olefins. If they can do this the shale oil refiner can surely meet his problem. But it must be remembered that shale oils contain constituents which are not found in well petroleum, and these must be taken into account. In the laboratory this has been

done, and the gasoline is water white and "sweet smelling" after two years. Commercial refining is a somewhat different problem, but there is no reason for discouragement. It can be done commercially.

A well-made crude shale oil should yield 16% to 22% of motor spirit (or gasoline), and about 40% of the kerosene fraction. These will contain roughly 60% to 70% of olefins. If the kerosene is not desired, a fraction containing it and a considerable percentage of heavier distillate may be taken off and cracked. The resulting gasoline will bring the total yield of gasoline up to 40% or over.

The odor of shale gasoline is not like that of common gasoline, but it is not more unpleasant. Some people believe it induces headache more readily, but it need not be used as a perfume or as a substitute for smelling salts.

The color problem appears to many experimenters very serious. It is hard to remove the dark brownish-purple color which characterizes the light fractions of shale oil, but it has been and can be done. Is this coloring matter injurious? Must it be removed? In the early days of the Pennsylvania oil industry the kerosenes put on the market were of many shades of color from water-white to greenish, violet, bluish and reddish. Did the color affect the quality? Refiners say it did not.

It may be that a campaign of education would remove the color problem.

It has been said that shale gasoline has a corroding effect on the motor. This is specifically denied by oil technologists familiar with the facts. Tests were made in the Geological Survey laboratory with laboratory-made shale gasoline from Colorado shales and no injurious results could be found on brass, bronze, steel or iron parts after tests lasting for weeks.

Another problem of the refiner is to secure the largest possible yield of marketable products from the shale oil. Only a few years ago kerosene was practically the only marketed product from well petroleum. Today such products are legion, and the profits are millionaire-making. It is entirely probable that many similar by-products will be made from shale oil. At present, gasoline, kerosene, lubricating oils, waxes, tars and cokes and ammonium sulphate may reasonably be counted upon as commercial products. Hundreds of others are chemically possible since the best of shale oil is more complex than is well petroleum, but many of the chemical possibilities do not appear to be commercial possibilities since the substances can be produced more cheaply from other raw materials.

The fundamental problems of the shale oil industry are solved. Details will have to be worked out, and apparatus and manipulation will have to be modified to meet the peculiarities of our various American shales. In the opinion of the writer, the retorting presents fewer difficulties than does the refining. But many of the refining problems will vanish if the retorting is done scientifically and in obedience to chemical laws. It must not be supposed that the same methods of refining can be successfully applied to oils which are chemically very different. If this is kept in mind and the chemistry of the unsaturated hydrocarbons is mastered, the refining problems will very soon yield to chemical skill.

LABORATORY STUDY OF COLORADO SHALES

HISTORICAL SKETCH

At the present time the distillation of shale for oil and the various by-products is an important industry in Scotland, France, Australia and New Zealand. In Germany a brown coal (lignite) is distilled in much the same way for tar and ammonia.

In 1681 an English patent was issued for the making of tar and pitch from coal; in 1694 the making of "pitch, tar and oyle out of a kind of stone" was protected by a patent. The first commercial plant for such work appears to have been established in Sunderland, England, and produced "petroleum" and ammonia from coal as early as 1815.

In France the distillation of shales began about 1830, and has maintained the rank of an industry ever since.

Though the distillation of oil from shales and shaly coals has been carried on in many countries, in no other has the industry reached the magnitude or the success to which it has been carried in Scotland, and today the Scotch process is standard the world over. Previous to the development of the Pennsylvania oil fields there were between fifty and sixty plants making oil from cannel coal, cannel shales and bituminous shales in the United States. The manufacturers used the Scotch process and paid the Scotch patentees a royalty. These plants were located in Massachusetts, New York, Pennsylvania, Ohio, Kentucky, Virginia, Connecticut, and West Virginia. In Canada several shale oil plants were in operation at the same time. When the abundance and cheapness of petroleum products made the shale oil industry unprofitable, many of the American shale oil plants were converted into well oil refineries.

At the present time there are seven plants in Scotland handling a total of about 4,000,000 tons of shale per year.

The lamp oil of a few years ago was called coal oil, because of the fact that at first it was derived almost exclusively from low-grade coals. But later the distillation of shales yielded a similar oil. The name coal oil was retained and was handed down to the lamp oil obtained from petroleum.

RETORTING

The experimental work in retorting was carried on with the following aims in view:

(1) The most favorable temperature to secure the largest yield of the best oil, keeping always in mind the problems of the refiner.

(2) The possibility of securing valuable by-products without sacrificing the cardinal aim of the shale oil industry—to secure *oil.*

(3) Economy of operation as to fuel, speed of throughput and construction.

The apparatus consisted of:

(1) Common pot retorts, such as are used for mercury distillation, fitted for the use of superheated steam if desired, and provided with thermometers in wells, for accurate records of temperature.

(2) Horizontal pipe retorts fitted as above.

(3) Inclined and horizontal pipe retorts arranged to rotate.

These were all small and capable of holding charges up to about ten pounds of crushed shale.

(4) Condensers, ammonia and oil scrubbers, gas collectors, gas meters, absorbers, etc.

(5) A vertical cylindrical retort having a capacity of 75 pounds of crushed shale.

DESCRIPTION OF PLANT

The principal units of this larger plant are: (A) the steam unit; (B) the retort unit; (C) the condensing unit, and (D) the scrubbing unit. (See the figures.) A description of each unit, in order, follows:

The Steam Unit.—This consists of a boiler (1) equipped with a water-gauge, (2), a pressure gauge, (3), a pressure relief valve, (3a), and two heaters (4) and (5). The boiler (1), which is an ordinary water tank tested to 250 pounds pressure, and having a capacity of about ten gallons is placed on a small iron stand (6) and is supplied with water through pipe (7), equipped with drain-

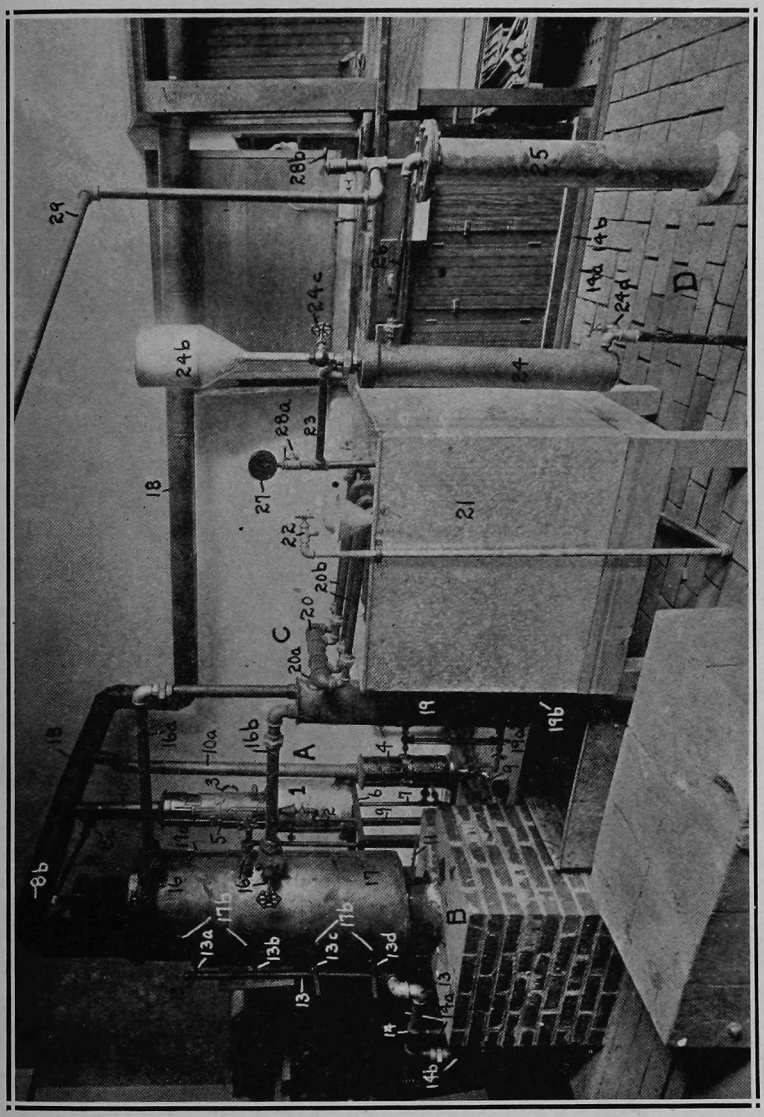

Fig. 8. Side view of eduction plant.

cock (7a). Heater (4) is used to raise the steam, while heater (5) is used as a super-heater, the steam passing out through pipe (8) into the super-heater and through valve (8a) into the retort. The heaters are ordinary "Lion" gas water-heaters (4) being size 1½, while (5) is size 1. Both are supplied by pipes (9) with gas. The copper coil of heater (5) is covered with graphite paint to prevent burning out, since the coil contains only steam and air. The products of combustion in the heaters are led to the main stock pipes (18) by pipes (10) and (10a).

The Retort Unit.—This unit consists of the retort proper, with the necessary heating apparatus, outlets for the gases formed, and control valves, most of which is enclosed in the shell (17). The relative positions are shown in figure 9 by the dotted lines. The retort proper (12) was made by rolling a piece of ¼″ iron into a frustum of a cone, six inches in diameter at the top, seven inches in diameter at the bottom, and forty-five inches high. The retort was then butt-welded and flanges welded on at the top and bottom. The bottom was closed by screwing on a plate which had four circular apertures in it. On the inside of this plate is a similar plate, which, however, is not screwed to the retort, but is rigidly fastened to a lever (11) by means of which one can change the relative positions of the two plates, and thus the retort can be emptied by bringing the holes together, or can be sealed by turning the lever (11) so that the holes are not coincident. The top is closed by means of a plate fastened on by set screws, and through which the steam line (8) is run. This steam line runs to within six inches of the bottom of the retort, and the steam is diffused by means of a rosette. Fitting (8b) is a gate valve, through which the thermo-couple of a pyrometer can be inserted if it is desired. The inside of the retort is perfectly plain.

The retort is heated by means of four circular burners (13a, b, c, and d) made of ¼″ pipe, drilled, and bent in the form of a semi-circle. One of these burners is placed on each side of the retort, at four different places, one about three inches from the bottom, and the other three at intervals of twelve inches above this. The burners lead off from a common gas supply pipe (13), which is in turn supplied with gas by pipe (14a), and with compressed air by pipe (14b). In fitting (14) is a cone with a small aperture, through which the air is forced under pressure, and the suction created by this jet tends to draw in the gas and form a perfect mixture for combustion. Each burner is protected from the burner below by thin iron shields being placed around them.

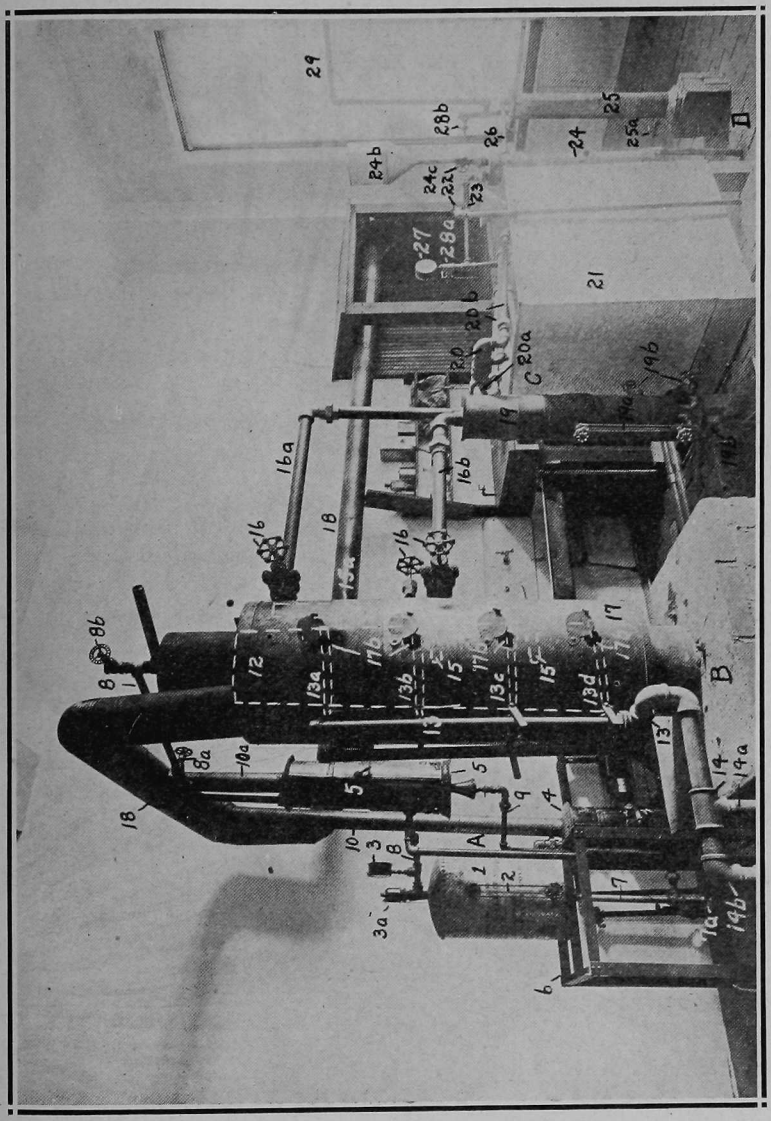

Fig. 9. View of education plant from retort end.

The vapors formed during distillation are led off by means of four ¾″ pipes, welded to the sides of the retort, two on each side and staggered, the first on one side being three inches from the top, and the second twenty-one inches from the top. On the other side, the highest one is twelve inches from the top, and the other thirty inches from the top. These pipes are designated on the photographs as (15). They are curved to meet in a common main (15a), which is a 2″ pipe standing parallel to the retort. This main, then, discharges into either of the 2″ take-offs (16a or 16b), according to the way in which the valves (16) are adjusted.

The retort proper, with the burners, shields, vapor outlets, and vapor mains, are all enclosed in a shell (17) made up of two thin sheets of iron with a sheet of asbestos between them, and provided with a door (17a) and peep-holes (17b), through which the burners can be lighted and their behavior observed. The products of combustion from the burners are led off through the pipe (18) and into the stack by means of a slight suction in the stack. The whole unit is set upon a brick foundation and is provided with an ash pit to care for the spent shale.

The Condensing Unit.—The condensing unit consists of two condensers, viz.: an air condenser (19) and a water condenser (21). The air condenser (19) is a sheet iron cylinder, six inches in diameter and thirty-four inches high. It is provided with a sight-glass (19a) and with drain cocks (19a) set at different levels. The pipes (16a and 16b) lead nearly to the bottom of the condenser, and the vapors are then allowed to rise in the cylinder, while any part which will condense collects at the bottom of the cylinder, and is drawn off. The condensation is caused by the temperature of the surrounding air, no cooling water being used in this case. The vapors not condensing here are drawn off through the pipe (20a) into the header (20), where they are divided through four ¾″ coils (20b), which are immersed in running water, supplied by faucet (22) and taken off by siphon (22a). The four coils lead into a common receiver (21a), which is a small iron tank eight inches in diameter and twenty-four inches long, immersed in the tank (21). This receiver has a drain cock (21b) by means of which the liquid collecting in (21a) can be drawn off.

The vapors and gases still uncondensed are led off by pipe (23) to the next unit.

The Scrubbing Unit.—This unit consists of the oil scrubber (24) and the ammonia scrubber (25). The oil scrubber (24) is a cast iron cylinder four inches in diameter and twenty-eight inches

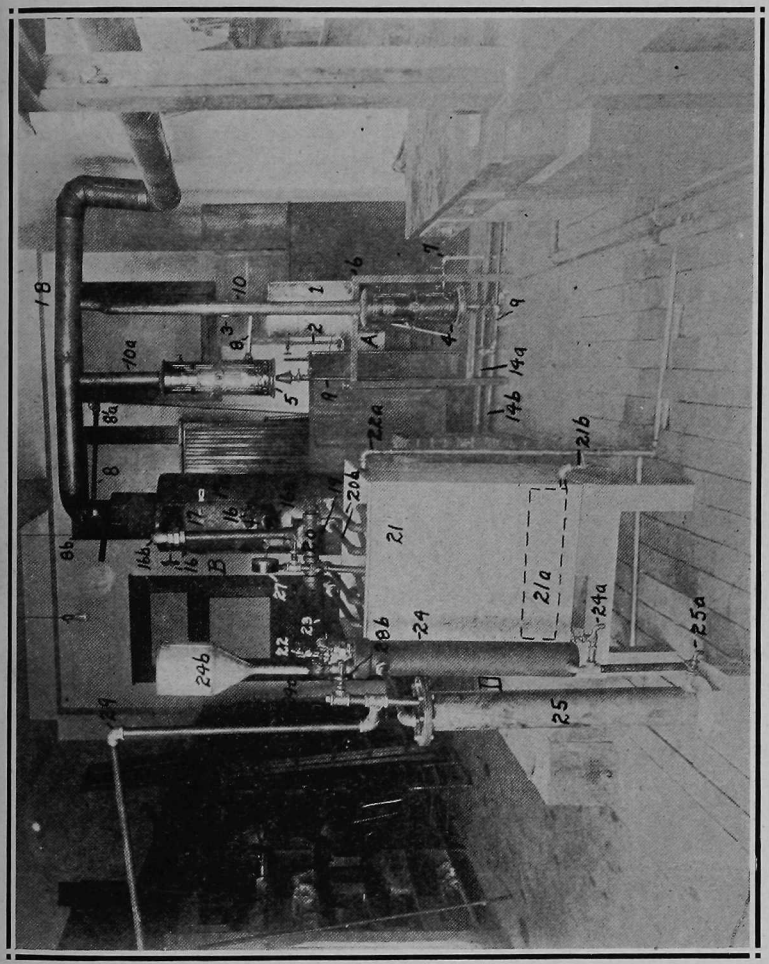

Fig. 10. View of eduction plant from scrubber end.

high, having a drain cock (24a) at the bottom and equipped with an oil reservoir and feed (24b). The cylinder is filled with pebbles, and the pipe (23) leads nearly to the bottom of the cylinder. The gases then bubble up through the pebbles, meeting the oil from (24b) as it trickles down over the pebbles. This oil absorbs any gasoline which may be left in the fixed gases. The gases are led into the next scrubber by the pipe (26), which, as before, leads nearly to the bottom of the scrubber (25). This scrubber is four inches in diameter and thirty inches high. It is made of sheet lead, and, while designed for an ammonia scrubber, it may be used as an auxiliary oil scrubber. For use as an ammonia scrubber it is partly filled with pebbles and a dilute solution of sulphuric acid used as the scrubbing medium. This scrubber is equipped with a drain cock (25a) and with a tube through which the tank can be filled. On this tube is placed the vacuum gauge (27). The stop cocks (28a and b) are used to test the suction and also to sample the gases at those places.

The gases from the last scrubber are led off through pipe (29) by means of a small suction pump, and are wasted up the stack. This small suction pump is connected directly to the series of pipes, and by means of it a slight vacuum is maintained in the system constantly.

Matthew J. Wilson made a large number of retortings under the direction of the writer, using a small pot mercury retort connected with a steam superheating device on the one side, and a water-cooled condensing coil and a series of receivers on the other. The retort was fitted with a thermometer placed in a well, and the temperatures were watched, controlled and recorded. The uncondensed gases were passed through an ammonia scrubber, and a gasoline scrubber to trap the last of the ammonia and any light condensable hydrocarbons which might pass the main condenser. In the first series no steam was used.

The crude oils recovered were fractionated, and the gasoline and kerosene were analyzed for unsaturated hydrocarbons. The results of the work are presented in a thesis which may be consulted at the University Library at Boulder.

The conclusions he reached may be stated as follows:

The most favorable range of temperature for retorting Colorado shales is between 280° C. and 340° C. (536° F. and 644° F.), and the best temperature appears to be about 320° C., or about 608° F.

Crude oils obtained within this range of temperature yielded an average of 33.7% of straight run gasoline (cut at 460° F.), and 20.7% of kerosene (cut at 600° F). The gasoline fractions averaged 54% of saturated hydrocarbons and 46% of unsaturated.

The kerosene fractions averaged 44.2% saturated hydrocarbons, and 55.8% of unsaturated.

The ammonia yield was small. To secure the best yield of ammonia it would be necessary to raise the temperature very considerably.

The yield of gasoline in the scrubber averaged 6.4 gallons per ton. The absorbing oil was a light kerosene cut.

The gravity B of the crudes ranged from 26.2 to 37.1 B, and averaged 30.2 B.

The results of many tests with the big retort, both with and without superheated steam, point to a temperature ranging between 320° C. and 420° C. (608° F. and 788° F.) as the most favorable when quantity and quality of oil are both considered.

Another series of retortings was made by Wilson, using superheated steam. The results obtained differ so widely among themselves and from many others obtained in the Survey laboratory that one is forced to the conclusion that a part of the retortings are not representative. For this reason the conclusions which follow are based upon those retortings which appear consistent with the great body of results previously obtained by steam distillation.

(1) The yield of crude is higher.

(2) The yield of ammonia is nearly double.

(3) The saturated content of the gasoline fraction is higher, averaging 63.3%.

(4) The kerosene yield is larger, but the gasoline yield is smaller.

(5) The saturated content of the kerosene is higher.

(6) The gasoline recovery in the scrubber averaged 9.3 gallons per ton.

(7) In general the crude is better than that resulting from dry retorting.

A series of tests was made in the large retort, using a general running temperature of 410° C. (770° F.), and after practically all the oil was taken off at this heat, the temperature was raised to over 600° C. (1,112° F.), and superheated steam was added in large volume. The purpose was to get all the ammonia and to convert the fixed carbon into fuel gases. The results were highly satisfactory. The ammonia yield was increased from 19.5 pounds

per ton to 25.2 pounds per ton. The fixed carbon was almost entirely converted into gases. The spent shale was a pale ash-gray, showed no tendency to cohere in masses, and ran from the retort without the slightest clogging. At temperatures below 1,400° F. in the presence of superheated steam, some of the Colorado shales begin to mass by fusion. This causes more trouble than does coking.

The fuel gas obtained was a fair grade of water gas having a fuel value of 330-340 B. t. u. per cubic foot. The volume and fuel value will depend upon the fixed carbon present in the shale and the volume of steam used.

FORMS OF RETORTS IN COMMERCIAL USE

The vertical shaft retort, consisting of a cast iron or steel upper section and a firebrick lower section, is almost universally used in Scotland. Recently, two or three types of retorts resembling certain forms used in carbonizing coal, have been tested and put into use. The patent records would lead one to the conclusion that every conceivable modification of furnace or retort design had had its advocates, and that there can henceforth be nothing new (in this line) under the sun, but the mill still grinds, and the "best" appears every day.

LOCATION OF RETORTING PLANTS

The considerations which will determine the location of retorting plants are: Water supply, available sites, dumping ground, refinery possibilities, pipeline facilities, transportation and others.

In a shale oil plant water is used for the following purposes: The generation of steam for power, the making of superheated steam for retorting purposes, condensing vapors both in retorting and refining, and for steam distillation. It is estimated that the total use of water in these ways in the Scotch plants exceeds a ton of water for each ton of shale put through. But the actual consumption of water probably falls far short of this figure, since much of it is recovered and used over and over again. Even if the consumption is but one-third the use, the problem becomes a formidable one in a semi-arid region.

The shale fronts lie far back from the rivers. Many of the creeks flowing to the rivers head far back in the shale area. But most of them are intermittent and are dry in the midsummer, and frozen up and nearly dry in the winter. Even if their waters were not appropriated for irrigation purposes they would be a very unsafe dependence for a large industry. The only reliable source of waters is the rivers.

The question naturally arises as to whether it would be better to bring the shale by gravity to the water or to take the water to the shale against gravity. The logical place for refineries is along the rivers and along the railways. Shale oil will not move easily through pipe lines. The narrow canyons which cut into the shale beds do not furnish the best of dumping grounds.

To build a refinery at and for every retorting plant would be a very wasteful procedure, since a single large refinery could take care of the crude produced by several large retorting plants, thus reducing overhead and operating expenses. The building and maintenance of railways in the narrow canyons would be attended by many difficulties.

Plant sites affording water, dumping room, storage room and all the requirements of a large industry are not plentiful in the canyons.

FIXED GASES FROM RETORTING

In discussing the question of the fixed gases formed in the process of retorting, both the quality and the quantity must be considered. In general, it may be said that the total fuel value of the fixed gas from a ton of shale of given oil content would afford the best ground upon which to judge of the efficiency of the retorting in this regard. But, as will be shown later, this method may be very misleading.

The volume and quality of fixed gases formed will depend upon several factors, such as: The quality of the shale, the use or non-use of superheated steam, the admission or exclusion of air, the temperature of retorting and other conditions.

Other things equal, the richer the shale the larger will be the yield of fixed gases, since they come mainly from the organic matter of the shales. The addition of superheated steam may result in the dissociation of a certain amount of water into hydrogen and oxygen. Some of the oxygen may be used up in oxidizing carbon, and there will be an excess of hydrogen. It is even possible that a certain small measure of hydrogen may combine in the process of hydrogenation of unsaturated hydrocarbons, but it is much more probable that hydrogen will be freed in the process of cracking heavier hydrocarbons into lighter forms, as in the cracking of petroleum.

The admission of air to the retort will mean the addition of oxygen and nitrogen to the fixed gases. Some of the oxygen may be used in forming carbon dioxide and carbon monoxide.

The temperature at which the gases are driven from the shales is one of the most important factors in controlling the formation of fixed gas. It is possible to convert the entire hydrocarbon-forming content of the shale into the fixed gas methane and solid carbon. This is an extreme case. It is also possible by retorting at too high temperature to crack much of the hydrocarbon gases formed into the fixed gas methane and a condensable gas.

In Scotland it is customary for operators to convert a large part of the fixed carbon of the shale into carbon monoxide in much the same way as water gas is formed in commercial gas making. After the main part of the retorting is done the impoverished shale is heated to a high temperature to secure the larger yield of ammonium sulphate. Steam is driven or drawn through the heated shale and the oxygen of the steam unites with the carbon, forming carbon monoxide and carbon dioxide. A part of the hydrogen of the steam unites with the nitrogen of the shale, forming ammonia, and the remainder passes on to the condensers. In this way the volume of fixed gases is greatly increased, and much fuel is formed for retorting purposes.

In general (unless the fixed carbon is converted into gaseous fuel as just mentioned), it may be said that the lower the total fuel value of the fixed gases in proportion to the oil content of the shale, the more efficient is the retorting process, and the higher the fuel value of the fixed gases in proportion to the oil content, the less efficient is the retorting.

It is sometimes argued that fuel is needed for further retorting and that it is profitable to make it in the process of retorting. This is entirely wrong, since a retorting practice which results in the formation of a gas of high fuel value is bad from other standpoints and yields a poor grade of oil.

If it is desirable to secure fuel from the shale, it would be much better to install a producer gas plant, using shale for the generation of producer gas, and piping it as needed to the retorts.

In judging the significance of the fixed gas formed in any retorting process it is necessary to know the oil content of the shale and the volume and fuel value of the fixed gases formed. For example: Two operators may be retorting the same shale. One may get a large yield of fixed gas of low fuel value. The other may get a small yield of fixed gas having a high fuel value. Referring to the following table of fixed gas analyses: There is a considerable range in the fuel value per cubic foot of the gases, but unless the oil content of the shale and the volume of the fixed gas formed

are known, it is impossible to say which retorting was the more efficient from the standpoint of loss by the formation of fixed gases.

To illustrate: Sample 5 of the following table was from a shale which yielded 50 gallons of oil per ton, and the total yield of fixed gas was 4,586 c. ft. per ton. The total fuel value of the fixed gases per ton was 4,586x322.30=1,478,067.8 B. t. u., or at the rate of 29,561 B. t. u. per gallon of oil content. Sample 6 was from a shale which contained 19 gallons of oil per ton, and the total yield of fixed gas was 3,658 c. ft. per ton. The total fuel value of the fixed gas per ton was 515,641.4 B. t. u., at the rate of 27,139 B. t. u. per gallon of oil content. From the standpoint of fixed gas formation the retorting of sample 9 was more successful than was that of sample 6. However, it must be stated that neither sample shows highly efficient retorting. It is quite possible to reduce the fuel value of fixed gas formed to the rate of 15,000 B. t. u. per gallon of oil content of the shale. The methane content should be lower in both these samples.

ANALYSES OF FIXED GASES FROM RETORTINGS

	Gal. oil per ton (2000)	Gas Volume per ton	Carbon Dioxide	Illum. Gases	Oxygen	Carbon Monoxide	Methane	Hydrogen	Nitrogen	B. t. u. per Cubic Foot
1. Colorado shale	63.0	.....	14.2	3.8	0.8	0.9	22.7	41.2	16.4	462.9
2. Colorado shale	63.0	.....	32.3	1.0	3.4	0.6	6.7	34.9	21.1	213.8
3. Colorado shale	63.0	.....	40.0	0.4	1.8	0.1	1.6	46.3	9.8	180.9
4. Colorado shale	.....	.....	11.7	4.8	2.7	1.7	28.2	32.2	18.7	466.6
5. Colorado shale	50.0	4,586	11.8	1.9	5.5	25.0	17.2	4.6	34.1	322.3
6. Colorado shale	19.0	3,658	41.2	0.0	4.4	17.5	10.2	0.0	26.7	168.3
[3]7. New Brunswick	40.1	.....	28.67	1.33	0.0	5.06	11.02	52.92	0.0	319.8
[4]8. Scottish shale (Henderson retort)	.....	.....	0.0	2.19	0.0	0.0	34.2	64.44	0.0	630.34
[5]9. Scottish shale	.....	.....	22.08	1.38	1.18	9.77	3.70	55.56	6.33	293.0
10. Broxburn, Scotland. Survey laboratory, Boulder	28.5	2,960	13.0	3.5	2.5	2.1	21.3	39.4	18.2	441.3
11. Broxburn, Scotland. Survey laboratory, Boulder	28.5	.....	12.4	3.1	2.4	2.5	28.8	24.5	21.3	561.2

The analyses here given were chosen for the purpose of showing the wide range of composition of the fixed gases formed in retorting shales.

[3]Ells, R. W., Bituminous or Oil-Shales of New Brunswick and Nova Scotia, etc. Canada Dept. Mines, No. 55, 1909, p. 16.
[4]Redwood, I. I., Mineral Oils and their By-Products, 1897, p. 250.
[5]Jour. Soc. Chem. Ind., 1897, p. 983.

The question is often asked as to whether, in the process of efficient retorting, the yield of fixed gas will be sufficient to carry on the retorting. Unquestionably it will not. It is only a matter of arithmetic to show the insufficiency of the heat from this source. But the conversion of the fixed carbon into carbon monoxide will also play a part. However, it is reasonably certain that a considerable amount of other fuel will be necessary. This may be obtained, as already suggested, from shale, or it may be got from coal. The Scotch use coal to supplement the fuel formed in the process.

THE NITROGEN OF THE SHALE

AMMONIA YIELD

A series of analyses made in the Survey and University laboratories showed an average nitrogen content in the Colorado shales of 0.60%. A similar series of analyses made by the U. S. Geological Survey[6] gave an average nitrogen content of 0.64%. But the nitrogen content is not at all regular. A few samples of rich shale had a nitrogen content exceeding 2.00%, while other shales containing from 30 to 40 gallons of oil per ton contained from 0.35% to 0.50%. If all the nitrogen of the shale were recoverable in the form of ammonium sulphate, the yield from shales running 0.6% nitrogen would be 56.7 pounds per ton. That from shale containing 0.64% nitrogen would be 59.4 pounds per ton.

The dry retorting of the shales as shown by scores of tests fails to give an ammonium sulphate yield comparable to the theoretical amount. The average nitrogen content of the shales used in making the tests recorded in the tables on p. 69 was 0.60%, or equivalent to an ammonium sulphate yield of 56.7 pounds per ton. The actual average recovery from the gases by dry distillation was 4.62 pounds, or 8.15% of the theoretical possibility. By steam distillation (with gypsum), the average recovery from the gases was 17.93 pounds per ton, or 33.7% of the theoretically possible.

Analyses of the oils show that a fairly large part of the nitrogen passes over into the oil mainly in the form of pyridine compounds. Four determinations at Boulder gave an average content of pyridine compounds of 3.74%. However, the number of such determinations was too small to give a safe basis for a generalization. A series of fifteen analyses made by D. T. Day for the U. S. Geological Survey[7] shows an average pyridine content of 3.93%.

[6] U. S. Geol. Survey Bull. 641, p. 159, 1916.
[7] U. S. Geol. Survey Bull. 691, p. 48, 1918.

The question arises: Is the larger yield of ammonium sulphate obtained by steam retorting due to the breaking up of pyridine compounds? This might be answered by comparing the pyridine content of oils obtained by steam and by dry distillation from the same shale.

Dungan tested samples of shale gasoline for pyridine and got negative results.

In the case of most of the Scottish shales the ammonia yield is larger from those poor in oil than from the higher grades. There appears to be no such relationship between ammonia content and oil content in the Colorado shales.

Analyses and other tests show that the Colorado oil shales contain carbonates of calcium (lime), iron and magnesium. Of these, by far the most important is the calcium or lime carbonate. Occasionally one may find a stratum which may be called a calcareous oil shale, but in the greater body of the shale the carbonate content is too small to justify the name. It is a noticeable fact, however, that the ammonia water collected in the oil reservoir is almost always somewhat carbonated, and from some shales as much as 25 per cent of the ammonia may be recovered as carbonate. It is even possible to cause the ammonium carbonate crystals to form on the walls of the condensing chamber above the oil.

Ammonia also passes over in the form of the hydrate to such an extent as to give the water a strong odor. In the laboratory the easiest and most convenient method of collecting the ammonia is by passing the gases containing it through a sulphuric acid solution in a tall bottle containing beads, coarse sand or small pebbles. The beads break up and distribute the gases and complete contact with the acid is secured.

In the larger apparatus in the Survey laboratory a pebble-filled lead chamber three feet high forms an effective ammonia scrubber.

PHENOLS

All true shale oils, as well as oils from lignitic shales, contain phenolic compounds, and may be regarded as a possible source of carbolic acid. But there is serious doubt as to the quantity being sufficient to warrant an expensive installation to save them, as they occur so much more plentifully as a by-product in coking. Six samples of shale kerosene and six samples of the skimmed oil were analyzed for phenols, but no analyses of the crude oil were made. The results are given in the following table:

		Phenols in Kerosene	Skimmed Oil
8	Parachute Cr.	1.10%	0.54
14	Parachute Cr.	1.60	0.76
16	Parachute Cr.	1.66	0.77
17	Parachute Cr.	1.70	1.05
18	Parachute Cr.	2.00	1.35
19	Parachute Cr.	1.92	0.77
	Average	1.66%	0.87%

POTASH IN THE SHALES

Practically all shales contain a small amount of potash derived largely, and in many cases wholly, from the igneous rocks from which the shale material originally came. It is possible that a small amount of the potash of some shales comes from imprisoned marine waters. In some instances land plants may have contributed to the potash of certain shale strata, but as the potash so derived is largely or wholly water-soluble, it would be carried away by ground water.

The fossil plants of the oil shale beds are largely algae, and are not likely to have contributed appreciably to the present potash content of the shales. Analyses of the raw shales show that the potash is what chemists call insoluble potash; that is, potash not soluble in water.

The high temperature to which the shales are subjected in the retorting process renders a part, possibly all, of the potash water-soluble. Analyses of the spent shale from Parachute and Conn creeks showed an average water-soluble potash (K_2O) content of about 0.9%, or about 18 pounds per ton of spent shale. The range of water-soluble potash shown by the analyses was from 0.25% to 2.02%. There is no apparent relationship between the oil content and the potash content.

As to the commercial possibilities of the potash: It is very easily extracted and it would seem possible that the spent shale could be deposited in dumping basins filled with water, and allowed to remain there a short time for the dissolving of the potash, and then dredged out or removed by belt conveyors to the final dump. When the water became highly charged or saturated with potash it could be drawn off into salterns or could be allowed to evaporate and deposit its potash in the basins. The process would be simple and inexpensive and would probably prove profitable in large plants. For example, a plant handling 1,000 tons of shale per day would deposit from 600 to 700 tons of spent shale which would yield, roughly, 10,800 to 11,600 pounds of potash. This is a possible by-product worthy of consideration.

The large ammonia yield of the shales, the possible potash yield and the proximity of the great phosphate beds of Idaho, Utah and Wyoming suggest the possibility of an artificial fertilizer industry. The Salt Lake and Colorado smelters working on sulphide ores should be able to furnish an abundance of sulphuric acid to meet the needs of such an industry.

REFINING TESTS

The following is a brief summary of the results of a very large number of refining tests made in the Survey and University laboratories by and under the direction of the writer.

The purposes of the tests may be stated as follows:

(1) To find out in what respects the regular refining processes used for well petroleum would apply to shale oils, and in what respects they would have to be modified.

(2) To determine what refined products could be obtained from shale oil, and to compare them with the corresponding products from well petroleum.

(3) To reach well founded conclusions as to the commercial possibilities of the shale oil industry.

The apparatus used included:

(1) The regular glassware equipment commonly used in oil laboratories, consisting of flasks, condensers, heating devices, etc.

(2) A series of small tubular and box stills of iron and steel, condensers and treating apparatus.

(3) Cracking stills similar in form to the Burton commercial pressure still, and several others, including vertical stills with and without dephlegmators and arranged to condense under still pressure or under atmospheric pressure.

FRACTIONATION

Crude oil ranging in quantities from 100 cc. up to 5 or 6 gallons was fractionated in various forms of apparatus. Except for special experiments the usual cuts were made—crude gasoline at 392°-410° F., crude kerosene at 572° F. Beyond this, test cuts were made at various temperatures for lubricating oils, cracking distillates, asphalts, etc.

The remarkably close relationship between the methods of retorting and the results of fractionation was evident at every point.

In general, it may be said that the best results were got from crudes obtained by retorting at temperatures not exceeding 725° F. Such oils yield, rather uniformly, 15 to 20 per cent of crude gasoline

and 30 to 35 per cent of crude kerosene. A very large part of the kerosene fraction comes over at temperatures between 392° F. and 465° F.

The Survey laboratory records show the results of about 750 distillation tests and probably over 1,500 tests and partial tests, in refining. The tables beyond give the results of tests which may be regarded as typical. They were made at different times, in different apparatus and by different operators.

	1	2	3	4	5
Gravity of crude, B.	26.8	27.0	27.0	27.2	26.4
Gasoline, per cent	15.4	15.0	15.35	15.3	16.8
Gravity of gasoline	51.0	51.0	50.5	50.5	50.8
Kerosene, per cent	32.3	32.5	31.0	33.3	30.7
Kerosene, gravity	36.0	36.0	35.5	35.0	36.2
Gas oil, per cent	23.1	22.5	26.0	20.0	18.4
Gas oil, gravity	33.5	34.0	33.0	34.0	33.8
Light lubricating, per cent	17.0	17.0	15.5	18.5	17.8
Gravity, light lubricating	30.0	30.5	31.0	30.5	31.2
Heavy lubricating, per cent	10.0	11.5	9.5	11.7	12.4
Gravity heavy lubricating	24.5	25.0	26.0	25.5	24.7
Coke and loss	2.2	1.5	2.7	1.4	3.9

	6	7	8	9	10
Gravity of crude, B.	30.7	31.2	26.9	32.2	29.4
Gasoline, per cent	18.9	20.4	14.8	21.1	18.2
Gravity of gasoline	52.1	53.0	51.1	53.6	51.6
Kerosene, per cent	30.0	27.8	35.0	25.6	28.2
Kerosene, gravity	37.4	37.6	38.0	37.7	38.0
Gas oil, per cent	18.9	14.4	13.0	20.4	19.7
Gas oil, gravity	34.1	30.3	30.7	30.6	32.8
Light lubricating, per cent	14.6	18.4	17.4	15.9	20.5
Gravity, light lubricating	30.4	31.0	31.2	30.2	30.5
Heavy lubricating, per cent	14.2	15.4	12.8	10.1	9.9
Gravity heavy lubricating	24.9	26.2	26.0	24.8	24.4
Coke and loss	3.4	3.6	7.0	6.9	3.5

UNSATURATED AND AROMATIC HYDROCARBONS

These tests were conducted according to standard methods, and the following summary presents in generalized form the results obtained:

(1a) Crude obtained by dry retorting at temperatures above 800° F. commonly contains from 60% to 75% of unsaturated hydrocarbons, and measurable percentages of such aromatic hydrocarbons and derivatives as benzol, toluol, phenols, and pyridine compounds. The crude is considerably cracked and the yield of gasoline is consequently higher than that from less cracked shale oil. Extremely high temperatures cause excessive cracking and the formation of an unduly large amount of fixed gas. The yield of crude is reduced thereby.

(1b) The gasoline fraction from such crude oil carries approximately the same percentage of unsaturated hydrocarbons. The average of fifteen samples was 68% of olefins. The aromatic substances do not appear in the gasoline in proportionate quantity. In fact, tests sometimes fail to show their presence.

The kerosene fraction commonly carries a higher content of unsaturated hydrocarbons than does the gasoline, and aromatic compounds may appear.

(2a) The crude from dry distillations at temperatures between 725° F. and 800° F. contains 50% to 60% of unsaturated hydrocarbons, but much less aromatic material, though strong traces are found. Some cracking has occurred, but the gasoline yield is smaller than that from the higher temperature retortings.

(2b) The gasoline and kerosene fractions are more nearly equal, and the residue after they are taken off is comparatively easily cracked and will add considerably to the total yield of gasoline. The percentage of unsaturated hydrocarbons ranges from 50 to 60.

(3a) Crude shale oil from retorting at temperatures below 725 gives the highest yield of gasoline and the lowest of kerosene. The unsaturated hydrocarbons often fall below 45 per cent, and are sometimes as low as 35 per cent. The distillate ranging in gravity from 26 to 32 B′ is good cracking material and yields readily at a pressure of 75 pounds per square inch, and a temperature of 755° F. to 825° F.

(4a) The crude from steam retorting at intermediate temperatures is the best. The percentage of light oils is commonly higher, the percentage of unsaturated and aromatic compounds is lowest, and the oil is more easily refined. But even in this the percentage of unsaturated hydrocarbons ranges around 35% to 40%.

The large percentage of unsaturated hydrocarbons (olefins and diolefins) in shale oil makes it necessary to adopt methods of refining differing widely from those used in refining well petroleum. The olefins yield a little more power than do the paraffins, and they deliver it in a steadier and more sustained stroke. They must be saved and used. To remove them would be a criminal waste, both of good motor fuel and of good sulphuric acid. The average content of olefins in shale gasoline and kerosene will be 50 per cent or over. To remove them would be to cut the gasoline and kerosene yields in half, and make the acid treatment so expensive as to be prohibitive.

Good, clean, sweet-smelling gasoline containing 60 per cent olefins is made on a fairly large scale in Scotland. It has been made in the laboratory of the Survey, but by methods which may not prove commercial. However, the obstacle to success was not the saving of the olefins. That is relatively easy. The difficulty lay in removing the coloring matter.

Unrefined shale gasoline and kerosene are dark brownish purple, and the coloring matter is very persistent. It appears to be an oxidation product, and its development is aided by bright sunlight. Samples of gasoline may be cleared to a very pale straw yellow, but if allowed to stand in an open vessel exposed to light and air they will darken to brownish or purplish red in a few hours. A thin purplish-brown film forms on the walls of the vessel and the deposition may continue for several days. This is readily soluble in alcohol. The color change takes place very slowly in well-filled bottles closely stoppered, and the film is scarcely perceptible.

The decolorization of oils is commonly accomplished by one or other of the following methods:

(1) The changing of the coloring substance into one which is soluble in, and may be removed by, one of the washing agents used in refining—sulphuric acid, sodium hydroxide (or sodium carbonate), or water.

(2) The absorption of the coloring matter by filtering material such as fuller's earth, boneblack, charcoal, clay, etc.

It should be noted that the coloring matter in the shale oils is closely associated with the non-paraffin matter of the oil, but whether it is an unsaturated hydrocarbon derivative or an aromatic derivative the writer is unable to state. When the entire non-paraffin matter of the oil is removed by acid and other treatment methods, a water white gasoline or kerosene is easily secured. But if the unsaturated hydrocarbons are preserved the coloration persists very stubbornly. Experiments appear to show that it is not due merely to the oxidation or other sub-atmospheric change of olefins, since several samples of gasoline rich in olefins have been kept for periods of several months to two years with no more coloration than commonly occurs in straight run paraffin gasoline. There are in the Survey laboratory samples of gasoline and kerosene over three years old. The gasoline may still pass for "prime white," while the kerosene is pale lemon yellow.

In the attempt to render the coloring matter removable by washing with acid, alkali or water, the following reagents were used: Hydrochloric acid, nitric acid, aqua regia, acetic acid, tannic acid, acid sodium carbonate, potassium dichromate, potassium permanganate, chlorine water, chlorine, zinc dust and acetic acid, potassium nitrate, stannous chloride, hydrogen peroxide, ferrous and copper sulphates and common salt, ferric chloride, sodium phosphate, lead acetate, ammonium molybdate, potassium ferrocyanide, potassium ferricyanide, potassium cyanide, ammonium hydroxide,

dimethyl glyoxime, mercuric chloride, barium chloride, and others. The tests show that equally good results may be obtained with 2% of concentrated sulphuric acid and 4% of caustic soda solution having a gravity 14 B′.

Complete contact of the oils with the reagents was secured by agitating with compressed air, but it is doubtful whether the agitation was, in all cases, continued long enough. A desirable modification of the method would have been to agitate by mechanical means without introducing compressed air.

In carrying out the filtration tests the filter materials were used both separately and in various combinations. When two or more materials were used they were sometimes mixed, and sometimes used in separate layers. Both deep and shallow filters were used, and experiments were made by putting the filtering material in a flask with the oil and agitating for a considerable time. The filter materials used include: American and foreign fuller's earth, animal charcoal, wood charcoal, common salt, a variety of clays, spent shale, slacked lime, partially slacked lime, quick lime, diatomaceous earth, Portland cement, gypsum plaster, pumice and various others.

So far as the writer's own tests are concerned the best results were obtained with a stratified filter, composed of layers of clay from the Pierre shale, layers of wood charcoal and layers of common salt. By one such test an almost water-white gasoline was obtained which remained water-white at least eight months, when an admiring promoter of a shale oil company carried it away to show what he himself had obtained from his own shale. However, it is not certain that the filtration was entirely responsible for the results obtained, as the gasoline had gone through some of the chemical tests already mentioned.

A long fuller's earth and animal charcoal column gave through a small amount of very good looking gasoline, but the effectiveness of the filter declined rapidly. Quick lime appeared to improve the color temporarily, and other experimenters, including a former member of the staff of the U. S. Bureau of Mines, claims permanent results.

Redistillation tests were carried out in various ways, using filtering or absorbing materials in the flasks, and passing the vapors through such substances. The resulting gasolines were subjected to acid and alkali treatment. The following materials were used: American and English fuller's earth, animal charcoal, diatomaceous earth, caustic soda, caustic potash, solid phosphoric acid, anhydrous

aluminum chloride, common salt, partially slacked lime, slacked lime, iron turnings, black copper oxide, powdered copper, litharge, barium chloride, and others.

These substances were used both alone and combined. The results obtained were no better than the results of repeated distillation without them.

It was thought by Dungan that the color might be due to furfuran or furfuraldehyde, but the usual tests for these substances gave negative results. He also tested for turpenes but got negative results.

In order to determine whether the color resulted from colloidal matter, the gasoline was subjected to an electrostatic stress of about 50,000 volts for one and one-half hours. The results appeared to show the absence of colloidal coloring matter.

Many tests and analytical determinations have been made, the results of which have but little bearing upon the problems of refining. For this reason they are not described.

Several grades of lubricating oils have been made, and comparative tests as to their value have been carried out with impartial care.

The lubricating fractions were treated with 4% of concentrated sulphuric acid, followed by 6% of caustic soda at a temperature of 94° F. The oil was then treated with fuller's earth and filtered hot.

The lighter lubricating oils were cherry red, but the heavier were almost black. Descriptions of the oils follow:

Light oil:

Gravity	31.0 B.
Flash	220° F.
Fire	240° F.
Viscosity	Saybolt
At 60° F.	53
At 100° F.	44.5
At 200° F.	34.6

Heavy oil:

Gravity	19.7 B.
Flash	448° F.
Fire	490° F.
Viscosity	Saybolt
At 60° F.	Too thick to test.
At 100° F.	3340.
At 200° F.	732.

Record of a test of the light oil on a Tinius Olson machine:

Journal-steel. Bearing-brass.
Area of bearing, 7 square inches.
Total load on bearing, 300 pounds.
Pressure per square inch, 42.9 pounds.
Revolutions per minute of journal, 800.

Time	Temperature of Bearing	Load	Friction	
			Total	Coefficient
4:53	78	300	35	0.117
4:56	98	300	7	0.023
4:59	110	300	4	0.013
5:02	114	300	4	0.013
5:05	120	300	4	0.013
5:08	123	300	4	0.013
5:11	124	300	4	0.013
5:14	124	300	4	0.013
5:17	124	300	4	0.013
5:20	124	300	4	0.013

Maximum Temperature, 124° F.
Minimum Coefficient of Friction, 0.013.

The following statements regarding the lubricating oils are quoted from a thesis by Q. R. Dungan.

The lubricating oils obtained from the shale were excellent. The light lubricating oil resembled so-called "gas engine oil" in gravity, and flash and burning points, but the viscosity was much lower. In the friction test, the oil gave a much lower coefficient of friction, and kept the bearing at a much lower temperature than is usually the case with heavier oils. The coefficient of friction of lard oil is 0.035, while this oil gave a minimum of 0.013, under the same conditions. The maximum temperature of the bearing in this test was only 124° F., while the ordinary lubricating oils usually allow a maximum temperature of about 160° F. This is a remarkable performance, especially in view of the fact that the load on the bearing was much greater than would be used with an oil so light as the one tested. The heavy lubricating oil would probably be called a "heavy cylinder oil." On account of its high paraffin content it was nearly solid at 60° F., slightly below room temperature. Its viscosity, and flash and burning points would show it to be well adapted to cylinder lubrication. A small quantity was vigorously agitated with an equal volume of water at 100° F., and the resistance to emulsion also showed its excellent qualities. In

the friction test, the coefficient of friction reached a minimum of 0.01, while the maximum temperature of the bearing was only 146° F. In comparing the shale lubricants with petroleum lubricants, the superiority of those derived from the shale is apparent.

The calorific value per pound of the gasoline by Junkers calorimeter was 18,660 B. t. u.

PARAFFIN WAX

Only a few tests were made to determine the quantity of paraffin wax per ton of shale of given oil yield. But these tests showed the close relationship between retorting methods and the wax yield. In general, it may be said that a yield of wax ranging from 2% to 6% of the crude oil can be secured by the usual commercial processes. The wax was not fully refined in the Survey laboratory, but a pale yellow product was obtained.

The Scotch wax is of very high grade, and commands a price considerably higher than that from well petroleum. The highest melting point wax on the market is that from Scotch shales.

ASPHALT

The percentage of asphalt in crude shale oil appears to vary with the methods of retorting. An oil produced in an internal combustion retort contained 5.6 per cent of asphalt, whereas, crude produced from the same shale in a closed retort using superheated steam contained 1.4 per cent of asphalt. Another retorting of the same shale without steam gave an oil containing 2.5 per cent of asphalt. It may be said that the average asphalt content of shale oil is between 2.5 and 3.5 per cent.

The answers to the problems proposed on p. 60 are as follows:

The ordinary methods of refining mineral oils must be greatly modified to meet the needs of shale oil refining. .The most important modifications have been indicated.

The refined products obtainable from shale crude are: Gasoline, kerosene, light and heavy lubricating oils, paraffin wax, residual tars and cokes. The gasoline and kerosene will be hard to clarify. But in matters of use they will equal, if not surpass, those from well petroleum. The lubricating oils are superior to those from well oil. The wax is of superior quality. No satisfactory tests of the uses and value of the residual tars and coke have been made.

As to the commercial possibilities of the shale oil industry there can be no reasonable doubt. But it must be kept in mind that the happy-go-lucky methods of petroleum winning will spell ruin if followed in the shale oil industry. It is an industry demanding

technical skill of a high order. Large expenditures of capital are necessary to success. It is anything but a gambler's enterprise, or a get-rich-quick proposition. It is essentially a manufacturing industry, and is destined to be the largest in Colorado.

THE CRACKING OF SHALE OILS

Cracking may be defined as the breaking up of heavier hydrocarbons into lighter hydrocarbons. (The real chemical process is by no means so simple as this definition would suggest.) The products of cracking are mainly lighter hydrocarbons and carbon or coke. The character and relative quantity of the products of cracking will depend upon the hydrocarbons subjected to cracking, and upon the temperature and pressure to which they are subjected. Thus, there may result only lighter hydrocarbons which are liquid at atmospheric temperatures, or these and gases, or liquid and gaseous hydrocarbons and residual carbon. The liquid hydrocarbons may belong to the saturated or the unsaturated groups. At low pressures unsaturated hydrocarbons are very likely to form. Saturated hydrocarbons are best secured by cracking at high pressure. A charge of Parachute Creek shale retorted at a pressure of 80 to 85 pounds per square inch yielded a crude oil containing 46.2 per cent of unsaturates, whereas the same shale retorted at atmospheric pressure gave a crude containing over 60 per cent of unsaturates.

Permanent gases and coke are accompaniments of all cracking, but the smaller the quantity of these the more efficient is the process.

The extraction of oil from shale is essentially a process of destructive distillation, and there can be no doubt that a large percentage of the unsaturated hydrocarbons in shale oil is due to cracking. The large percentage of hydrogen in the fixed gases is in keeping with this view. In some measure the percentage of "straight run" gasoline obtained from the crude depends upon the formation of light hydrocarbons by cracking in the retort.

In the Survey laboratory the writer directed two series of experiments in which the operators used the same shales but different methods of retorting. The results are interesting and instructive. Taking seven tests in each case the results stand as follows:

Series D

	Gallons per ton	Ammonium Sulphate, Pounds per ton	Gasoline Average	Kerosene Average
1	48	16.49	...	...
2	45	16.48	...	...
3	55	18.16	...	...
4	55	18.82	16.5%	40.0%
5	67	20.12	of the crude oil.	
6	55	17.17	...	...
7	57	18.29	...	...
Average	54.6	17.93		

Average yield of the two light fractions, 56.5%.

Series W

	Gallons per ton	Ammonium Sulphate pounds	Gasoline percentage	Kerosene percentage
1	28	3.27	48.0	19.0
2	46	3.87	32.0	19.5
3	34	5.94	31.0	21.5
4	36	6.22	31.0	20.0
5	48	3.82	40.0	23.0
6	31	4.21	38.0	22.0
7	20	5.00	35.0	22.0
Average	34.7	4.62	36.4	21.0

Average yield of the two light fractions, 57.4%.

In the first series raw gypsum was put into the retort to furnish superheated steam by the slow yielding of its water. In the second, dry distillation was used. The results speak for themselves.

With superheated steam the yield of crude was increased 20 gallons per ton, or nearly 60 per cent; the ammonium sulphate was increased 13.31 pounds per ton, or almost 300 per cent. The gasoline yield from the crude by dry distillation was more than double, while the kerosene was approximately half. These differences were due to excessive cracking in the dry retorting. The average percentage of light oils from the two crudes was about the same—56.5% by steam distillation and 57.4% by dry distillation. But when total results are compared a notable difference is apparent all along the line. Calling each charge one ton, we have the following comparison:

Retorting

	Steam	Dry	Difference
Crude, gallons	382.2	242.9	139.3 in favor of steam
Gasoline, gallons	66.9	88.1	21.2 in favor of dry
Kerosene, gallons	152.9	51.03	101.87 in favor of steam
Ammonium Sulphate, lbs.	125.51	32.34	93.17 in favor of steam

These examples are not regarded as showing average possibilities. They have been chosen from many similar comparative tests because they illustrate the points of difference between the results of the two methods of retorting. The average differences between the yields of crude oil by the two methods are much smaller. The relative differences in the gasoline and kerosene yields are representative ,and the notable difference in ammonia yield may be taken as fairly representative of what may be expected in practice. The steam-produced crude cracks more easily than the other, and the total available gasoline yield is higher.

CRACKING TESTS

In general, it may be said that shale oil cracks readily, if it is produced by proper methods of retorting. In our experience, well-made shale crudes yield from 14 to 20 per cent of the "natural" gasoline fraction, and the average may be placed at 16 per cent. Such a crude will yield a distillate which cracks readily at a pressure of 70 to 80 pounds per square inch, and a temperature of 720° F. to 770°F. The most satisfactory procedure seems to be as follows:

The gasoline and kerosene are taken off as usual. The residual oil is then run down in a coking still until only a soft asphaltic tar is left in the still.

If the yield of light oils has been about 50 per cent, by volume, of the crude, the distillate so formed should be about 20 to 24 per cent, by volume, of the crude. This oil cracks readily at a comparatively low temperature, yielding from 40 to 50 per cent of its volume of a gasoline equal in quality to the "straight run." In this way the gasoline yield is raised by about 12 to 15 per cent, or to approximately 28 to 30 per cent by volume of the crude.

Experiments in cracking the kerosene fraction were not quite so satisfactory. A series of experiments under a pressure ranging from 70 to 100 pounds, and a temperature ranging from 420° C. to 460° C. (788° F. to 860° F.), gave a yield averaging 17.7 per cent of gasoline of 51 Be′ gravity. Assuming that the kerosene fraction was 40 per cent of the crude, the cracking of the kerosene

would add to the general gasoline yield about 3.5 per cent of the volume of the crude oil.

By these methods the total yield of gasoline would be as follows:

Straight run	16.0%
From kerosene	3.5%
From residue, say	13.5%
Total	33.0%

Better results were obtained by taking off the gasoline fraction and running the remainder down to a tarry residue. The distillate so formed would be about 60 per cent, by volume, of the crude. This cracks readily and yields, by ordinary cracking methods, about 40 to 50 per cent of its volume of gasoline. If it is cracked in two or three stages, allowing the still to cool, and removing the settled carbon, the yield may be brought up to 60 or 65 per cent of the volume of distillate used. By this process the yield of gasoline from shale oil would run about:

Straight run	16.0%
From distillate	27.0%
	43.0%

If the distillate is cracked intermittently the yield can be raised to:

Straight run	16.0%
From distillate	36.0%
	52.0%

The following summary records the results of a series of cracking tests made on shale kerosene:

Oil used cc.	500	500	500	500
Gravity B′	35.5	35.0	33.5	35.0
Gasoline yield cc.	69	73	100	105
Percentage yield	13.8	14.6	20.0	21.0
Gravity B′	52.0	51.0	51.0	51.0
Pressure used (pounds per sq. in.)	70.0	70.0	100.0	100.0
Maximum temp. C.	420	420	460	460
Loss per cent	5.0	8.0	8.0	7.0

The pressure ranged from 70 to 100 pounds per square inch, and the temperature from 785° F. to 860° F.

It is a recognized fact that kerosene is the hardest fraction there is to crack, whether well oil or shale oil is used. The results here shown are remarkably good. It will be noted that the yield of gasoline at the higher pressure and high temperature averaged over

40% higher than that at the lower pressure. Based on the percentage by volume of distillate the results are: For the lower temperature and pressure 14.2%; for the higher 20.5%.

A test of a distillate somewhat heavier than kerosene at a temperature of 815° F. and a pressure of 105 pounds per square inch gave a gasoline yield of 41% of the volume of the distillate.

It should be remembered that a gasoline composed largely of unsaturated hydrocarbons and having a gravity of 51 to 53 B′ vaporizes as easily as a gasoline composed of saturated hydrocarbons having a gravity of 58 B′ or higher.

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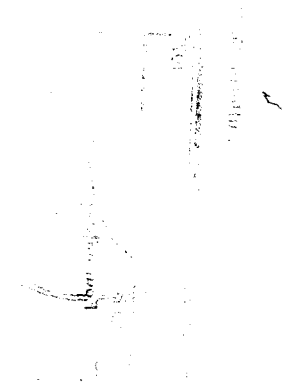
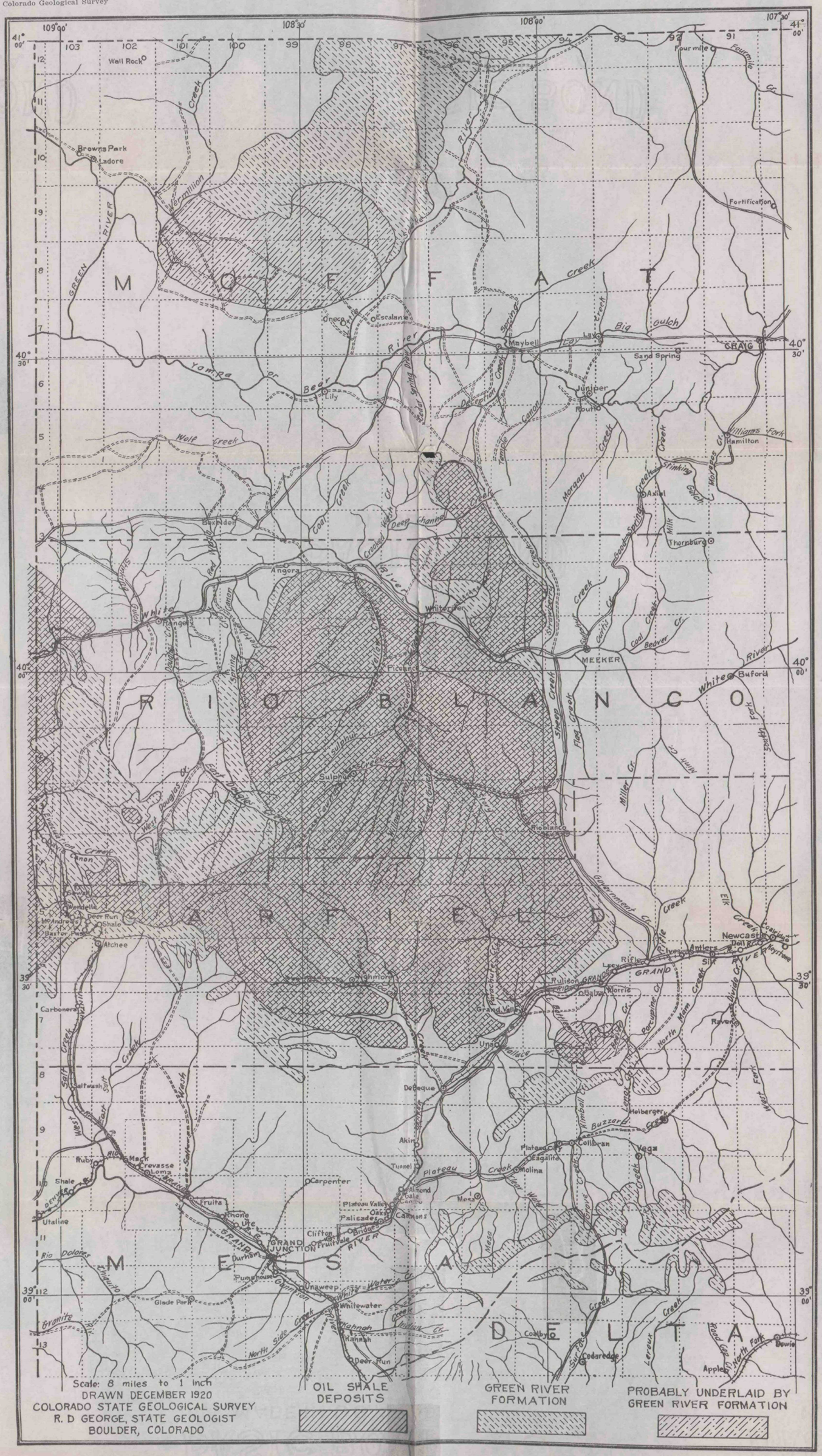


OIL SHALE DEPOSITS OF NORTHWESTERN COLORADO



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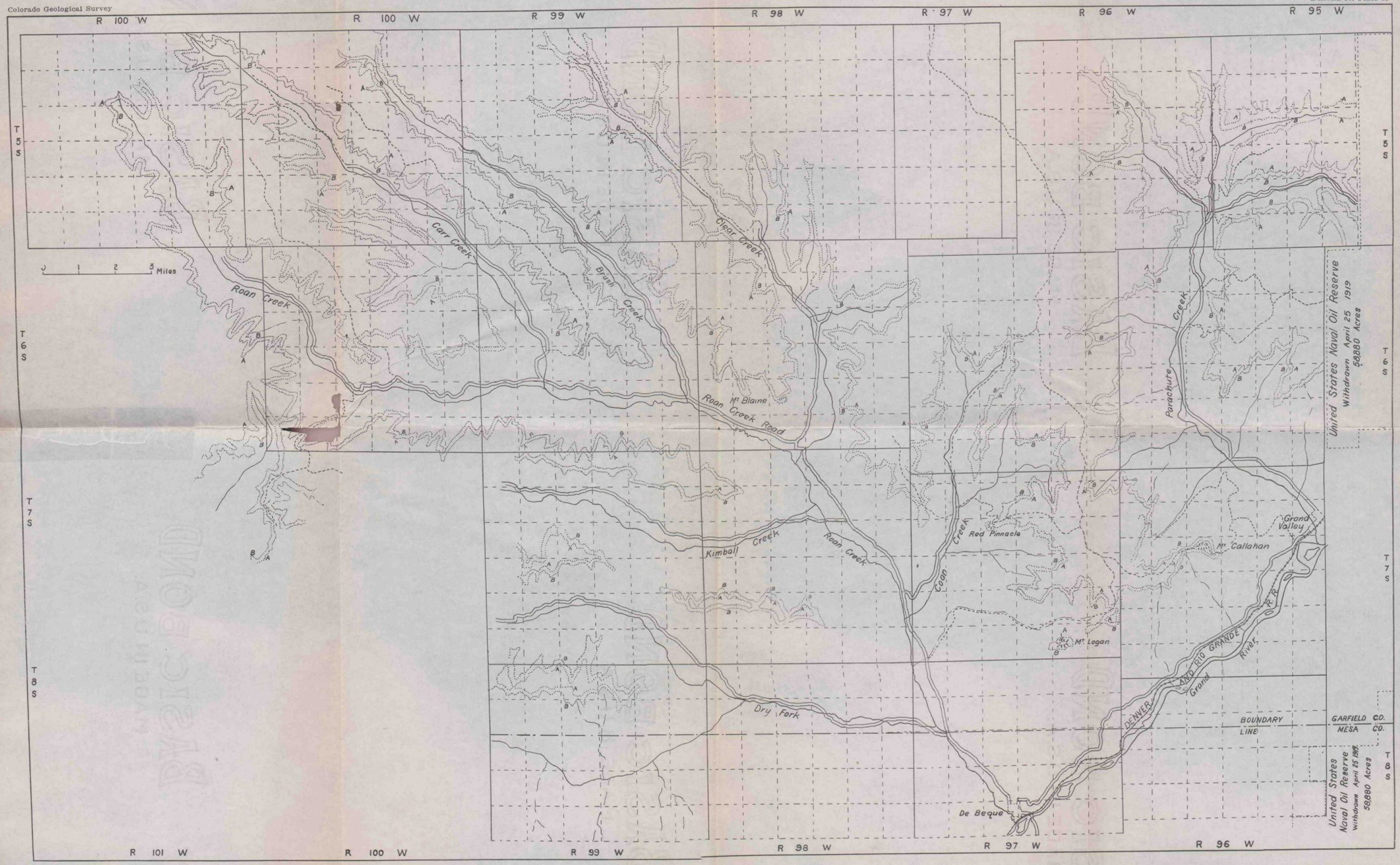

Oil shale map of part of Garfield County.

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 26

PRELIMINARY REPORT

ON THE

Underground Waters of a Part of Southeastern Colorado

By
R. C. COFFIN
AND
A. J. TIEJE

DENVER, COLORADO
EAMES BROTHERS, STATE PRINTERS
1921

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GROUND WATERS OF PARTS OF ELBERT, EL PASO, AND LINCOLN COUNTIES

By R. C. Coffin

INTRODUCTION

The area examined by the Colorado Geological Survey in eastern Colorado during the summer of 1919 included parts of El Paso, Lincoln, and Elbert counties. The center of this area, which is discussed in this preliminary report, lies 38 miles east, and 5 miles south of Colorado Springs. V. J. Hendrickson and D. R. Knowlton assisted the writer during the examination, which covered approximately 225 square miles. The object of the investigation was to obtain data which would be of help in directing the search for well water in the area.

In as much as sand and gravel cover practically the entire area, information as to possible water-carrying beds was limited, for the most part, to questionable data obtained from water wells. For this reason the boundaries which appear on the accompanying map are generalized.

The area is a part of the Great Plains of eastern Colorado, being an undulating surface covered with a sandy soil. Farming, stock-raising, and dairying in limited amounts constitute the industries of the region. Water for irrigation is not present in the area, and in many places as yet no well water has been found. Aside from small areas adjacent to streams, the ground water of the region comes from local rains and snows.

GENERAL GEOLOGY

Tertiary and Quaternary deposits.—The surface material over practically the entire area is a sandy soil covering sand and gravel. In places the basal part of these materials has been consolidated into a conglomerate. The materials are considered Eocene in age and constitute the Nussbaum formation as it has been described in reports that deal with areas farther south. In many places soil and sand have been shifted by winds and deposited in dunes. These dunes represent the youngest deposits of the region. The thickness

of these Tertiary sands and gravels is 200 feet in places, but is less than 100 feet over the larger part of the area examined.

Laramie formation.—In the northwestern part of the area mapped the Tertiary gravels are underlain by beds of the Laramie formation. Exposures of these beds occur along Horse Creek near the Forder ranch and at Signal Rock. The exact boundary between this formation and the Fox Hills formation was not determined in these exposures. The basal part of the Laramie includes sandstones similar to the upper ones in the Fox Hills formation. Coal, which occurs locally within 50 feet of the base of the Laramie formation, is mined at one point. Beds above the coal were not exposed and need not be considered, as the areas wherein the Laramie beds are present seem to have no well-water problem. During the examination no well was found which had been drilled a reasonable depth within these areas which failed to encounter water.

Fox Hills formation.—Sandstones make up approximately 125 feet of the beds immediately below the coal horizon of the Laramie formation. The upper part of this interval includes beds of the Laramie group, but the presence of fossils in the lower sandstones proves that the greater part of the interval is a part of the Fox Hills formation. Beds of the Fox Hills formation are exposed along Horse Creek between the Forder ranch and the east boundary of section 29, T. 13 S., R. 58 W. In this distance the truncated edges of approximately 400 feet of beds are exposed below the sandstones already mentioned. These 400 feet of beds include from the top downward the following units.

Partial section of the Fox Hills formation measured along Horse Creek

1. Shale and sandy shale 50 feet. This unit probably includes locally water-carrying beds.
2. Shale 200 feet. The unit includes no water-bearing bed.
3. Sandy shales and sandstones 150 feet. Two distinct sandstones occur near the base of the unit which are sufficiently porous to allow for the free circulation of ground water. These beds are the lowest ones in the region which could act as a reservoir for well water.

Data from wells south of Tructon indicate that in this region beds equivalent to the 400-foot section given are much more sandy than in their exposures on Horse Creek. Beds which apparently

come in the stratigraphic position of No. 2 of the Horse Creek section include sandstones which, in places, are water bearing. It is probable that the exposures of shale which come within the area examined along the lower part of Horse Creek include beds of the Pierre formation.

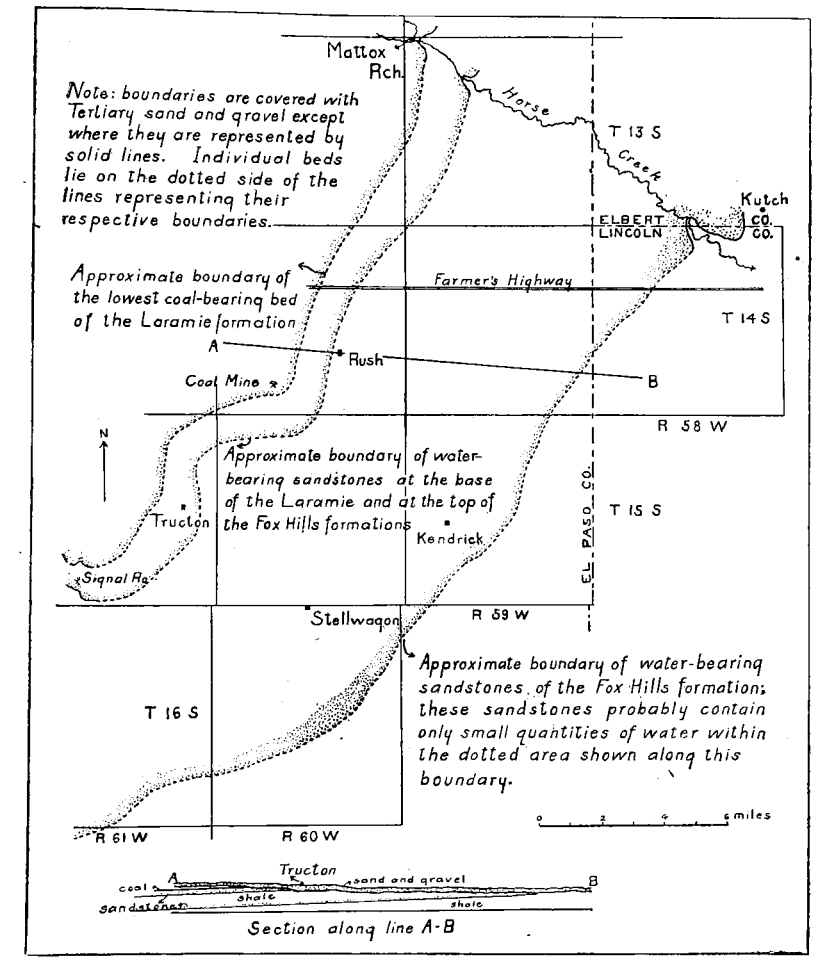

Fig. 1. Sketch map showing approximate positions of important geologic horizons.

Geologic history.—Only a few points which have to do with the geologic history of the region need be considered. After the deposition of the Laramie and older formations, the area was affected by processes of folding which tilted these beds toward the northwest. Erosion which followed carved from these beds an undulating sur-

face whose general slope was toward Arkansas River. This undulating surface probably possessed differences of elevation comparable to the present surface. Stream courses and flat-bottomed depressions existed in this ancient plain. The beds of the Laramie formation were at that time exposed in the northwestern part of the area under consideration, and beds of the Fox Hills and Pierre formations were exposed in the south and southeastern parts.

Sand and gravel were eventually scattered over this area by streams which flowed generally east and southeast from the present mountains. These sands and gravels filled the depressions and obliterated the ancient stream courses. Since the deposition of these materials in late Tertiary times they have been partially consolidated and in some places have been removed by the present streams.

WATER-BEARING BEDS

The water-bearing beds of the region are as follows:

1. Basal part of the Tertiary sands and gravels.
2. Sandstones at the top of the Fox Hills formation and at the base of the Laramie formation.
3. Sandstones within the Fox Hills formation.

Basal part of the Tertiary sands and gravels.—There is no uniformity as to presence of water in these materials. In the northern part of the area mapped the Tertiary sands and gravels contain water in most regions, except those adjacent to Horse Creek. In the southern part of the area many wells did not encounter water in these surface gravels, but had to be drilled to the sandstones of the lower formations. The depth of wells which supply water from these sands and gravels ranges from 10 feet to 200 feet. The water from these wells is uniformly of good quality.

Sandstones at the base of the Laramie formation and at the top of the Fox Hills formation.—These beds constitute a single water-bearing unit and can be considered under one head. The accompanying map shows approximately the limits within which these sandstones would be encountered by drilling. Aside from an area southwest of Tructon, all wells drilled to these sandstones contain an abundance of good water. The small quantities of water in this area can be explained by the present topography and the structure of the underground beds. It is probable that these sandstones are not 300 feet deep within any of the area examined.

Sandstones within the Fox Hills formation.—The approximate limits within which these sandstones would be encountered by drilling are shown on the reconnaissance map of this region. With the exception of areas near the edge of these sandstones, all wells which have been drilled to these lower beds have supplied enough water for the domestic use and stock of the average farmer. In a few wells which have been drilled to these sandstones the water is hard, but at no place is it unusable.

The experience gained by drilling south and east of the limits mapped for the Fox Hills sandstone has established a rule which is followed by many drillers. The prevailing notion is that no water is found in or below "blue shale." Drillers are reluctant to continue operations after striking shale. Many wells drilled within the limits of the lower Fox Hills sandstones encountered no water in the Tertiary gravels, and they continued into the lower beds, but were abandoned when they encountered shale, which, in many places, overlies the lower Fox Hills sandstones. Although the rule would appear to be applicable to areas which do not involve the Fox Hills sandstones, it should not apply to areas within the limits of these sandstones. No well was found by the Survey party which had been drilled to these beds without encountering water. It is to be noted that wells near the edge of these sandstones may encounter only small quantities of water.

STRUCTURE AND DEPTH TO DIFFERENT WATER-BEARING BEDS

All beds below the Tertiary dip to the north and west at angles which average approximately 1°. It follows that any bed becomes deeper toward the north and west, owing to its dip and a rise in the present surface in that direction. To understand the ground-water conditions it is necessary to keep in mind that the beds below the Tertiary gravels dip to the northwest, and that the present surface and the surface upon which the gravel rests are inclined to the southeast. Where the Tertiary deposits rest upon shale which is relatively impervious, the ground water entering from the surface passes down to the base of the gravels and follows near the contact between the Tertiary and older formations. The tendency in such areas is for the water to accumulate in and follow the depressions in the shale which lead, in general, in a southeasterly direction. Where the Tertiary deposits rest upon the sandstones already described, water which passed down through the surface gravels enters the sandstones and is carried toward the

northwest with a constant increase in its depth. The depth to water which is found in the basal part of the Tertiary materials seldom exceeds 150 feet, and the average is less than 100 feet. Wells which are drilled within the limits of the basal beds of the Laramie formation are seldom over 200 feet deep, but many such wells encounter water in beds above the basal sandstone of the formation.

In areas immediately south and east of the line representing the limit of the upper Fox Hills sandstones, should wells fail to find water in the Tertiary gravels, known conditions would justify that drilling be continued to the lower sandstones of the Fox Hills formation. These sandstones should be encountered at depths which range from 350 to 525 feet immediately south or east of the line mentioned above. In areas nearer the line which represents the limit of the lower Fox Hills sandstones this depth is less.

GROUND WATER CONDITIONS BEYOND THE LIMITS OF THE FOX HILLS SANDSTONE

Several deep wells and an examination of beds which outcrop along Horse Creek, below the ones already described, would suggest that the lower Fox Hills sandstones, as outlined, constitute the lowest persistent water-bearing beds of the region. No data have come to the Survey thus far in this examination which would justify drilling below the Tertiary sands and gravels in areas beyond the limits of the lower Fox Hills sandstones. Small quantities of water have been encountered in sandy streaks in wells drilled below these sandstones, but the water has been too salty for the use of stock,

The principles which determine the distribution of water in the Tertiary gravels cannot be expanded in this short paper.

ARTESIAN-WATER POSSIBILITIES AND DEPTH TO OTHER SANDSTONES

The structural conditions would make it impossible for water to flow at any point from wells which might encounter the different sands within the area examined. No water-bearing sandstones are known to exist between those described and the Carlile and Dakota sandstones of lower formations. In as much as these sandstones are more than 2,500 feet deep in the area discussed they cannot be considered possible sources of ground water under present conditions.

UNDERGROUND WATERS OF PARTS OF LINCOLN AND CROWLEY COUNTIES

By A. J. Tieje

INTRODUCTION

During the summer of 1920 the writer examined an area in southeastern Colorado, which is mainly comprised in Townships 13, 14, 15, 16, 17 S., Ranges 56, 55, 54 W., and in T. 18 S., R. 57 W. He was assisted by A. N. Murray. The aim of the examination was to aid residents of this area in their search for well water.

The area is a portion of the Great Plains of eastern Colorado, a region predominantly of almost level divides between occasional intermittent streams. Farming and stock raising are the industries. Karval, with 50 inhabitants, is the only town.

GENERAL GEOLOGY

In this area only three formations are of practical importance to the water seeker. The lowest of these is:

The Pierre shale.—These shales, of Cretaceous age, underlie the entire area mapped, and extend beyond it in all directions. In the vicinity of the Arkansas River below Pueblo the lowest 500 feet consist of medium-gray unfossiliferous shale, and the uppermost zone of sandy yellowish-green shale, with fossils suggesting those of the Fox Hills formation. In the area mapped, only the middle zone of the Pierre is present. An understanding of the nature of this shale would save the water seeker from many "dry holes."

Extended beds of shale are essentially hardened mud, deposited in a sea; in the case of the Pierre shale, this sea lapped the shore of mountains somewhere to the west. The hardening was caused by the pressure of overlying sediments. Much later, the shale was uplifted and became land.

The middle zone of the Pierre shale, as now visible in the creek valleys, consists of a thin-bedded rock, almost black, except where

long exposed to the air; then it is whitish. It contains many 2-foot oval masses of iron-stained sandstone and limestone. Of importance to the water seeker is the presence of crystals of gypsum, often mistaken for mica or "isinglass." It is this gypsum which renders much of the water in wells bitter. Mica is flexible and elastic. Gypsum is not. Moreover, gypsum is easily soluble in hot water.

Of importance to the water seeker, also, is the occurrence of the "tepee buttes," which rise as rudely conical hills above the softer and more easily eroded shale. These buttes are conspicuous along Adobe Creek, Stanley Gulch, and farther to the southeast. They consist, not of shale, as is commonly supposed, but of a dark-gray, coarse-grained limestone, which may be a water carrier. Probably these "buttes" were limy banks in the ancient sea.

The shale is further distinguished by its fossils. The most common are *Scaphites nodosus*, a small, coiled form; *Lucina occidentalis*, the so-called "peachstones"; and *Baculites compressus* and *Inoceramus sagensis*, the "petrified fish" and the "clam shells" of the well digger.

The Nussbaum formation.—Other formations, such as the Fox Hills and the Laramie, may once have overlain the Pierre shale. If so, they were eroded after the uplift. On all the divides the Pierre shale is now overlain by the clays, sands, and gravels of the Nussbaum formation, supposed to be of Pliocene age. These clays, sands, and gravels were laid down by streams flowing from the western mountains. The thickness of the Nussbaum formation ranges from 10 to 20 feet on the stream bluffs, to 200 feet on some divides. The understanding of the nature and history of this formation should greatly aid the water seeker.

The lowest 3 to 5 feet of the Nussbaum formation is not everywhere present; it consists of moist, coarse gravel or fine sand. The next 2 to 15 feet is best exposed at Stony Point on the Karval-Limon road or at the springs of Adobe Creek on J. F. Lockwood's ranch. This material is to all appearances a conglomerate; that is, a cemented mass of water-rounded pebbles. Even where disintegrated into small masses, the conglomerate has a whitish-gray color, and a limy cement binds together pebbles of granite, quartz, feldspar, bits of Pierre iron concretions, and fragments of petrified wood. Extended exposures of the massive rock show cross bedding.

Well logs best explain the character of the sediments overlying this conglomerate.

Well at Karval

	Ft.	In.
Loam, blackish	1	6
Sand, massive, yellow, medium-grained, slightly clayey	6	..
Clay, bluish to reddish, hard, greasy, gritty, limy; lumps of "magnesia"	8	..
Sand, loose, white, coarse; suggestions of conglomerate	16–20	..
Clay, whitish, sandy, somewhat plastic	10	..
"Soapstone"—really a ferruginous clay, giving fire test for ordinary brick; smooth, even talc-like, fine grained, very plastic, barely gritty to teeth	4	..
Sand and clay, moist	2	..
	46–51	6

Shale

Miller well, south half section 26, T. 15 S., R. 56 W.

	Ft.	In
Soil and subsoil	6	..
Gravel and sand, coarse	3	..
Gravel, fine	10	..
Sand, fine	8	..
Gravel, coarse, wet, suggestions of conglomerate	35	..
Sand, fine, moist	10	..
Gravel, coarse, wet, mixed with clay	20	..
Gravel, medium	3	..
Conglomerate	2	..
Conglomerate, much coarser; water rose slowly to four feet below this	24	..
	121	..

Shale

The Pleistocene alluvium.—Alluvium is a term applied to unconsolidated deposits in river beds or at the sides of rivers where the waters reach only in flood times (flood plains), or where, as the streams slowly cut deeper, they no longer reach at all (terraces). Such deposits, of a comparatively recent period, are of considerable width southward along Horse Creek from the point where it enters the area mapped. Along Adobe Creek, there is little alluvium, except in the beds of small tributaries. In these the alluvium may be 8 feet deep; in Horse Creek Valley it may be 12 to 15 feet deep. The alluvium is mainly sand or fine gravel, chiefly due to side wash from the disintegrating Nussbaum on the divides. In this case it often carries water of good quality. If the alluvium consists of shale decomposed in place, any water it may carry will be bitter.

THE MOVEMENT OF UNDERGROUND WATER

To sink a well intelligently, the water seeker should understand the nature and movements of ground water. When rain falls, the water either stands upon the surface, runs off, evaporates or sinks. Certain rocks with large pore spaces, like sandstone, allow considerable downward flow; other rocks with minute pore spaces, like shale, tend to stop downward movement. Thus, when water moving downward through sandstone encounters shale, the water can more easily move sideways than downward. This fact tends to saturation of the beds above the shale, the depth of the so-called ground-water zone then depending chiefly on the supply from above. The upper level of the saturated zone is called the ground-water table.

The ground-water table, however, is not flat. Under elevations, the water, though farther from the surface, is constantly domed up by fresh supplies. Thus, it stands higher than under valleys. Flow lines are established toward any point of escape at a lower level.

The ground water, also, moves very slowly, its rate depending on the shape and diameter of the pore spaces, and, hence, upon the sizing and packing of the rock grains. Shale is not impervious to water; it may even be saturated. *But it will not yield water readily.* On the other hand, water moves with enough practical rapidity in saturated sandstones and gravels to make them, not only water carrying, but *water yielding.* If, now, a well penetrates the saturated sandstones or gravel, and water is removed by pumping, the ground-water table is lowered in the immediate vicinity. Artificial flow lines toward the well are established. A new supply enters the well. When water rises rapidly in a so-called artesian well, the situation is not really different. The "artesian" bed carrying the water must be inclined. It must be exposed at the surface at some fairly distant point, and at an elevation above the highest level to which it is hoped the water will rise. Finally, the bed must be capped above by a so-called impervious layer, such as shale. Under such conditions, the pressure under which the water is flowing down the incline will cause it to rise in the well. For rough calculations as to height of rise, only the difference in elevation between the locality where the bed is exposed at the surface, and the point where the bed is pierced, need be known. Ability to rise is lessened because of (1) friction; (2) loss of water upward or even downward through leaky beds; (3) change in diameter of pore spaces; (4) change of temperature of the water; (5) improper sizing and

casing of the well. Roughly, a decrease of 1 foot per mile must always be allowed for.

The water seeker should further remember two facts. Water seldom or never moves underground from streams. Streams are always below the ground-water table and movement is toward them. Secondly, the doming of the ground-water table is much less marked than would be suggested by surface elevations. In the area here considered, the relative size of elevations and depressions in the surface of the Pierre shale, far below the ground, is of prime importance. Given the light rainfall of southeastern Colorado, any considerable depression in the surface of the Pierre shale would tend to become a small local reservoir of water-yielding gravel.

GROUND-WATER POSSIBILITIES

The beds below the Pierre shale.—Water-bearing beds below the Pierre shale are: (1) the Timpas limestone; (2) the sandstones of the Carlile shale; (3) the Dakota sandstone. The laws governing the rise of water in artesian wells prohibit expectation of securing water from the Dakota sandstone in this area. It is at least 2,000 feet below the surface. The Timpas limestone is about 1,250 feet below the surface, the Carlile sandstones about 1,500 feet.

The Pierre shale.—Water is very rarely found in the Pierre shale, because of conditions previously explained. Hendrix's spring, section 1, T. 17 S., R. 55 W., is the only exception known to the writer. This spring, however, is in a fissured "tepee butte," which, very possibly, is here a portion of a continuous limestone lens of some thickness. Surface water has sunk downward to this limestone because erosion of the Pierre had removed all overlying shale before the deposition of the Nussbaum gravels. The water seeker who advances this spring as proof that " water is in the shale" should consider these special conditions.

The Nussbaum formation.—The topography of the surface of the divides is such that the ground-water supply is governed by *local, scanty* rainfall. Much water, furthermore, seeps away at creek bluffs. Well logs indicate, also, that the ground water is seldom or never found in adequate quantity except between the conglomerate and the shale. Accordingly, the conditions under which the Nussbaum formation was laid down must be understood by one who seeks water on the divides.

When the Cretaceous sediments were tilted up so as to slope away from the rising western mountains, the deposits made by the mountain streams were dependent upon the climate. At first, it seems to have been moderately wet. The streams cut deep east-west valleys, and from these valleys northwest-southeast tributaries worked back. The climate then probably became drier. But at intervals, just as now, violent floods burst from the fountain canyons. The streams, overloaded with sediment, were forced to deposit it because of (1) lessened gradient; (2) lessened velocity; (3) evaporation and the sinking of water into the thirsty soil. Thus the streams gradually filled in former valleys; as they dwindled in volume, they spread out into numerous "branchlets," meeting branchlets from neighboring canyons and forming an intricate interlacing network not unlike the small-scale one of the Big Sandy near Limon; and the result was the probable formation of a vast "apron" of sand, clay and gravel, sloping gently southeastward from the mountains. On this apron, any given stream might at one time dig a shallow temporarily persistent channel, its bed covered with coarse material. Later, another temporary stream in a different channel might, by overflow, deposit clays and finer sands above this coarse material. Thus, would arise such sediments as make up the Nussbaum, mainly: (1) irregularly alternating courses of gravel, sands and clays in east-west lines, or (2) discontinuous stretches of gravel bounded on all sides by finer, less pervious sediments. Through all of these the surface water slowly sinks, being finally held in between the irregular belts of the conglomerate and the underlying shale.

This discontinuity of both the water-yielding gravels and the conglomerate "cap" is probably the chief reason for "dry holes." But, furthermore, water does not always underlie the conglomerate. The Pierre shale has been spoken of as probably cut into slight depressions and elevations, with a general southeast slope, before the deposition of the Nussbaum sands and gravels. Ordinarily, such shallow depressions would not greatly affect the lateral movements of the ground water. The position of many springs shows that the ground water does not constantly move southeast. But the depth of the ground water above the Pierre shale is so slight that very frequently the water may not have the power to flow over even low divides, and is impounded in longitudinal depressions. It may even flow from all directions into four-sided basins. Naturally, wells piercing the conglomerate on one of the gentle under-surface divides will get no water.

The following suggestions may prove of value to those seeking water in the Nussbaum formation. (1) Outcrops of the conglomerate may show the direction in which ground water is moving, and their width may indicate the width of water-bearing gravels in the vicinity. Buried conglomerate may be suggested by a line of successful wells. Conglomerate, even if disintegrated, is indicated by the presence of bluff-side springs. (2) The direction of source of flow from springs indicates probable water-yielding gravels. (3) In the absence of all such aids, the water seeker may select the lowest point on his land. If he fails to secure water, he should note the presence or absence of conglomerate, the depth to shale on both sides of the well, etc. He should dig his second well in a remote corner of his land. If he now makes allowance for the slope of the surface topography from well (a) to well (b), he can roughly figure the slope of the shale and locate a third well with better chances of success. (4) A well which shows feeble seepage may be improved as follows: Drain tunnels should be dug, sloping slightly upward and at right angles to the direction whence the seepage comes. In general, the flow should increase. (5) If the diameter of a large shallow well is doubled, the flow will increase. (6) Tubular wells set in the bottom of a large dug well sometimes increase the flow. (7) With caution, a well may be torpedoed to increase flow. The water seeker, finally, should always remember that too many wells exhaust a limited quantity of ground water.

The Pleistocene alluvium.—The water seeker will usually find water very near the surface. It may, however, be bitter, because of the well entering decomposed shale. He should avoid "enlarging the basin" if the presence of gypsum is suspected.

REQUEST

Ranchers who are digging wells on their land will greatly aid the work of the Survey by tabulating the beds passed through, after the fashion of the section given for the Karval well. Such data and specimens of rocks should be sent to the State Geological Survey office at Boulder when requests for information are made.