DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 415

COAL FIELDS

OF

NORTHWESTERN COLORADO AND NORTHEASTERN UTAH

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1910

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COAL FIELDS OF NORTHWESTERN COLORADO AND NORTHEASTERN UTAH.

By HOYT S. GALE.

INTRODUCTION.

NATURE AND PURPOSE OF THE PRESENT WORK.

This report is the result of investigations carried on during the summer seasons of 1906 and 1907 in northwestern Colorado and northeastern Utah. It is designed to supplement but does not include the previously published work on the Yampa coal field, which is part of the same general region. The work, which was undertaken by the United States Geological Survey in pursuance of a systematic plan for collecting information concerning undeveloped fuel resources of the Western States, has, since 1905, been under the general supervision of M. R. Campbell as geologist in charge of the economic geology of fuels.

The importance of the mineral-fuel resources and the growing realization of the need for their conservation have given the primary impulse to this general work. While the great coal fields of the eastern United States have long been the scene of large commercial activity and through many and extensive surveys their extent and probably available resources have come to be very completely known, yet it is only in recent years that widespread interest has been attracted to the numerous important and extensive fields of the Western States, and especially to those of the Rocky Mountain and northern Great Plains province.

LOCATION OF FIELDS.

The work here described is a continuation of the examination made of the Yampa coal field in Routt County, Colo., in the summer of 1905, the report on which has already been published.[a] In the summer of 1906 work similar to that in the Yampa field was continued southwestward, extending over the Danforth Hills and Grand

[a] Fenneman, N. M., and Gale, Hoyt S., The Yampa coal field, Colorado: Bull. U. S. Geol. Survey No. 297, 1906.

Hogback fields of Routt, Rio Blanco, and Garfield counties, Colo., which were examined and reported on.[a]

The work in 1907 was a continuation of that of the two preceding years and extended the area studied westward through Routt and Rio Blanco counties, Colo., and included some less extensive coal fields in Uinta County, Utah, reaching into southern Uinta County, Wyo.

The location of the fields is given in detail where they are described in the body of this report. The coal fields themselves are irregularly distributed areas reaching over a rather wide extent of territory of somewhat diverse character. The index map of Colorado printed

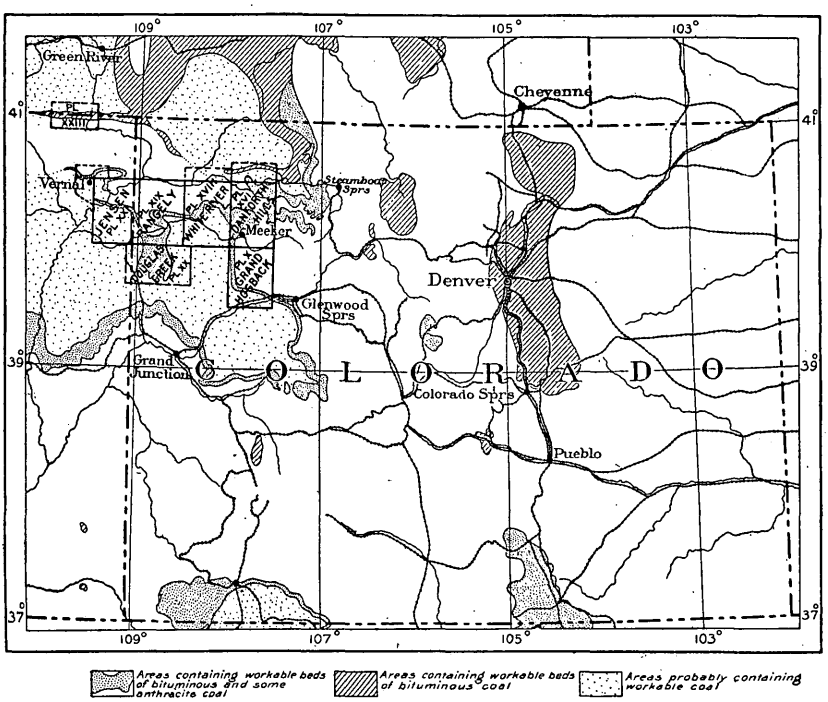


FIGURE 1.—Index map of the Colorado coal fields, showing areas of the larger maps presented in this report.

herewith (fig. 1) shows the outline and relations of the various fields examined.

ACCESSIBILITY.

For the most part the fields discussed in this report are without railroad facilities, the only part reached by existing lines being that situated near Grand River, described in detail on pages 109–136 as the Grand Hogback field. An extensive territory in northwestern Colorado and in northeastern Utah adjacent to the Colorado line is still entirely without railroads, although surveys for several lines have been projected through the region.

[a] Gale, Hoyt S., Coal fields of the Danforth Hills and Grand Hogback, Colorado: Bull. U. S. Geol. Survey No. 316, 1907, pp. 264–301.

Of these the Denver, Northwestern and Pacific ("Moffat road") is under active construction in the eastern part of Routt County and bids fair to push westward near the lower Yampa and White River fields in the near future. An extension of the Uintah Railway has been surveyed from Dragon to Vernal, Utah, crossing the projected route of the "Moffat road" near Green River. The Union Pacific Railroad has made a preliminary survey south from Rawlins, Wyo., intending to reach the Yampa Valley from that direction in the vicinity of Craig.

DEVELOPMENT.

For the present, development is largely in the prospective stage, except on the more favorably situated lands along the river valleys and on the immediate routes of the projected railroads. The only commercial developments are the local coal banks opened for domestic supply, and in comparison with the vast resources as yet wholly untouched these are inconsiderable.

PERSONNEL.

The members of the field party engaged in geologic and topographic work throughout the season in the summer of 1906 were Arthur K. Adams, Albert L. Beekly, Ralph D. Crawford, and the author. In 1907 the party consisted of John Allen Davis, Charles W. Stoops, and the author; Dr. T. W. Stanton spent about three weeks with the party at the beginning of the season for the purpose of collecting fossil evidence bearing on the age of coal-bearing beds.

GENERAL OBJECT OF WORK.

The object of these field examinations and surveys is primarily the classification of the public lands. In addition to this, and it is hoped of even more permanent ultimate value, is the opportunity afforded for the advancement of geologic knowledge concerning these fields, and for making a permanent record of these results in the customary reports. The general plan of the field work had, therefore, as one of its principal objects the compilation of its results in such form that they would be found useful by the general public and might hereafter serve as a base for such further specialized or closely detailed study as may be undertaken in particular parts of the field.

MAPPING.

FIELD WORK.

Plan of work in 1906.—When the examination of the Danforth Hills field was undertaken in 1906 the land-office surveys in that region were in a very unsatisfactory condition. This fact had then been officially recognized and the necessary steps for the accomplish-

ment of the resurveys were then being taken. An act of Congress, approved April 28, 1904, the text of which is quoted on page 21 in this report, had authorized the resurvey of all northwestern Colorado north of the base line, including and west of R. 92. The field work on these resurveys was then in progress in territory north of the coal fields here considered, but unfortunately no assistance could be looked for from it in time to serve as a base for the work of this examination. An attempt to unravel the complexities of the old land surveys, which had frequently baffled the local surveyors, would have been far too slow and expensive to be practicable and probably would never have accomplished a useful result. It was, therefore, necessary to construct a map independently of the land surveys.

In the Danforth Hills and Grand Hogback fields the topographic work of the present survey was made the base of the geologic mapping, the location of all geologic notes being recorded by means of a network of meander traverse lines run throughout the field examined. A main line of traverse forming a complete circuit of the Danforth Hills and extending along the Grand Hogback to Newcastle on Grand River was run with a plane table with as much care as seemed advisable to devote to that part of the work. For this purpose a 15-inch plane table and an open-sight alidade were used, elevations being recorded by means of aneroid barometers. Topography adjacent to the main traverse lines was sketched on the plane table with contours, and mountain peaks or other prominent features were located by intersecting sights taken from stations along the line of traverse. During the progress of the work a number of plane-table triangulation stations were occupied on the highest summits in the region and a system of triangulation was worked out by which to check and adjust the main plane-table traverse. The plane-table work was used as a control within which to adjust the notebook meander traverse. Notebook traverse lines were platted in the field either on the notebook pages, or, wherever the old survey land corners found gave a tie for adjustment, on township plats ruled in blank which were folded and carried in the notebook covers. In running these meander lines, courses or directions were taken with a pocket compass, distances measured by pacing, and elevations recorded by means of an aneroid barometer. The lines were platted in the field as the readings were taken, using a small celluloid protractor for measuring the angles and a scale for lineal measurements graduated to fit the scale of the township plats.

During the field work special effort was made to locate all then existing land corners that could be found by search and inquiry. It was supposed that these corners would serve as a basis for subsequent adjustment of the township and section lines on the map. Fences and fence corners, irrigation ditches, and houses that lay

along the routes traveled were platted on the traverse lines as a guide for the adjustment of land-survey lines, and much additional material for the same purpose was furnished through courtesy of the county surveyor and county clerk at Meeker and the county surveyor at Glenwood Springs.

Plan of work in 1907.—In the work of the following season (1907), when the examination of the western Yampa, lower White River, and Utah fields was made, the conditions on the ground were somewhat different. The work was undertaken with the express intention of examining and mapping both geologically and topographically a specified area of about 1,500 square miles of supposed coal lands and the territory immediately adjacent to them. Much of the field work was based on the recently established lines of the township resurveys which had then been extended into this part of Colorado. In each township or portion of a township that contained coal, a considerable proportion of the section lines were retraced for the purpose of locating the coal. This was done with a pocket compass, the distance being measured by pacing and checked by the corners that were found along the lines. An average of about five working days for one man was devoted to each township, and this may serve as a rough measure of the detail that could be obtained in such a review of the area. In addition to this work, meanders were made along roads and trails or in gulches and canyons for the purpose of examining the most favorably exposed geologic sections for such additional data as were needed and could not be obtained by the other methods.

In the territory where the new surveys had not then been completed, it was necessary to pursue a method of traverse similar to that of the Danforth Hills and Grand Hogback work, for which both plane table and compass and notebook were used. In the absence of the constant checks on well-established land corners it was not possible to obtain so satisfactory a result as by the land-line retracement method.

Tracing of coals.—As regards the collection of data relating to the coal-land classification itself, the conditions may be briefly stated as follows: For by far the most part the valuable coal croppings are concealed at the surface, so that they usually can not be traced and often can not be discovered at the outcrops. The presence of valuable coal in much of the region examined can not be positively determined from the surface indications and can only be inferred from a study of the stratigraphic sections that are most favorably exposed. In general, it is fair to state that individual beds can not be traced from place to place except in less common instances. There may first have to be accomplished a great amount of prospecting and development work along the outcrops to make the exposures

more complete. Indeed it is extremely doubtful if a large part of the field can ever be thoroughly understood until the more important coals are actually opened up by thorough prospecting by digging or drilling or in mining operations. More and more detailed examinations and study of these same fields will doubtless become necessary from time to time as the work of development progresses and the coal lands become more valuable.

OFFICE WORK.

EARLY MAPS.

The earliest complete maps of Colorado are those of the King and Hayden surveys. These were published in the form of two large atlases that accompanied those early reports. Since the time of these surveys most of the readily accessible and valuable lands of the State have been surveyed and subdivided under the direction of the General Land Office, and township plats have been made of the area thus surveyed. From these township plats, and from the maps of the Hayden and King surveys, numerous state and county maps have been compiled.

The field covered by the present work lies almost entirely within the area mapped by the Hayden survey in the summer of 1876. The Hayden atlas sheets are published on a scale of 4 miles to the inch, with relief shown in 200-foot contours. These surveys extend north to latitude 40° 30′. As a representation of the general features of the region these maps are most excellent. Considering the unsettled condition of the country at the time the work was done, the great extent of territory mapped in so short a time, the comparative difficulty of access to the region at that date, the lack of previous knowledge of conditions to be encountered, and also the hostile attitude at times of the Ute Indians who then held possession, one can not but be impressed with the remarkable accuracy, in many cases extending to minor details, brought out by a review of that early work. Some inaccuracies there are, of course, and the generalization necessary for so small a scale loses much of the detail important to closer work.

PRESENT MAPS.

The maps (Pls. X, XV–XXI) that accompany this report are compiled from the field traverse notes of the present field work.

By a special arrangement the Geological Survey will keep on hand a stock of the topographic maps published with this report, but without the addition of the geologic patterns, for general distribution separate from this report. They may be obtained by addressing the Director, United States Geological Survey, Washington, D. C., at the nominal cost of 5 cents each. In general these maps are planned to conform in style and size with the standard topographic sheets of this

Survey. They make no claim to the precision obtained by the more refined methods of topographic mapping. The main object of the work was the geologic and economic study of the coal field, and the topographic map work was done in a reconnaissance way merely to afford a base map on which to show the geology. The members of the party did not have the time and were not equipped with instruments for great refinement in topographic work.

These maps are put forth in the belief that they will be useful as base maps and will give a satisfactory delineation of the field. They are at present, and perhaps will be for some time to come, by far the best maps available of the fields they cover. It is expected that when more complete and accurate surveys of this area shall be made they will differ from the present maps chiefly in detail and accuracy secured mainly by instrumental control by levels and triangulation.

DANFORTH HILLS AND GRAND HOGBACK MAPS.

Original compilation.—For the office compilation of the Danforth Hills and Grand Hogback maps no triangulation more recent than that of the Hayden Survey was available for use as primary control. In compiling the field notes it became necessary to accept a few of the stations that had been occupied and described in that early work, as a base upon which to adjust the present more detailed work, in order to secure an approximately correct geographic adjustment. After a study of the records of the Hayden work it was decided to adopt the two stations described below, they being principal positions of the original triangulation work and therefore assumed to be as reliable in location as any part of that former work. The positions established by these early surveys in other parts of Colorado have been frequently checked by later more accurate work, and while modern results do not agree exactly with those of the older work they have commonly shown the former work to have been remarkably accurate and the early maps to be reasonably consistent throughout. The first station accepted was in the Yampa River valley, at the south end of the summit of Juniper Mountain, which was known as Yampa Peak in all the old surveys. This is station XVI of G. R. Bechler's work under F. V. Hayden in 1876.[a] Its position is recorded as longitude 108° 0′ 46″, latitude 40° 26′ 30″, and its elevation as 8,220 feet above sea level. The other point accepted was station XXIX of S. B. Ladd's work in the Hayden Survey of 1874. This same point was later reoccupied by George B. Chittenden of the same survey, being his station I of 1876. It is situated on a broad rounding summit known as the L. O. 7 Hill, nearly due south of Meeker and about 4 miles distant. A third principal point that checked closely with the

[a] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1876, p. 377.

adjustment of the other work was station XXXI of Ladd's 1874 work, situated on a high point on a long spur from Sleepy Cat Mountain east of Yellow Jacket Pass. This was, however, used only in a secondary way. All the other triangulation points of the Hayden Survey lying within the area remapped were also platted, but were accepted only as checks where they agreed with the present work.

Readjustment.—After the construction of the first adjustment of the Danforth Hills and Grand Hogback maps, and when the present report was nearly ready for publication, the preliminary field plats of the recent resurveys of a part of this area became available for comparison with the map that had been prepared. As some discrepancies were found between the measurements and positions of the land lines as adjusted from the old survey notes and as shown by the results of the recent resurvey notes, it was decided to readjust all the topographic material to the newly established base of these later surveys.

WESTERN YAMPA, LOWER WHITE RIVER, AND VERNAL FIELDS MAPS.

The office compilation of the topographic and geologic maps of the Western Yampa, Lower White River, and Vernal fields was based entirely on an adjustment to a net of land-survey lines plotted from the measurements given in the recent resurveys. Therefore, the present set of maps as a whole now depends for primary horizontal control on the results of the latest land surveys, which do not agree precisely with the adjustment obtained from the Hayden control. The recent land-office work is accepted, however, as it is supposed to be the more accurate of the two. In this way the results of both years' field work, although originally carried out on somewhat different plans, are combined on the same base.

ACCEPTED GEODETIC CONTROL.

The adjustment of parallels and meridians shown is obtained by using the chained measurements along the state lines, base line, guide meridians, and correction lines. By this means the work is tied to the locations established in the Encampment quadrangle in Wyoming and in the Marsh Peak quadrangle in Utah, both of which have been surveyed topographically by the United States Geological Survey and their geographic position determined. The method pursued in obtaining this control is indicated in figure 2.

As indicated above, the position of 109° 30′ at the southeast corner of the Marsh Peak sheet coincides with that of the range line between townships 21 and 22 E. of the Salt Lake meridian. The distance from this range line to the state line, measured along the first standard parallel, is 23.53 miles on a parallel about 22 miles north of the fortieth parallel. The equivalent distance on the fortieth parallel between this range line (or 109°) and the state line, assuming that they

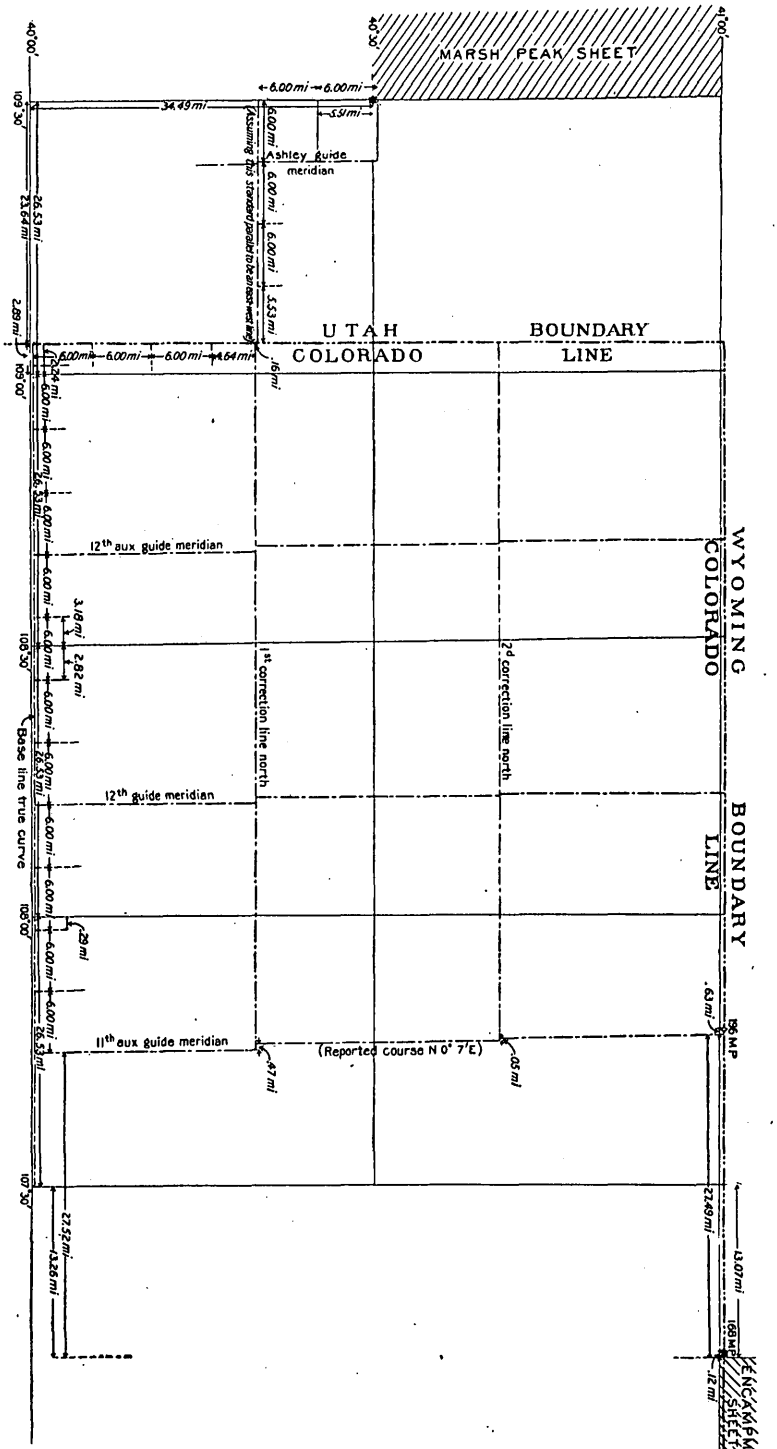


FIGURE 2.—Diagram explaining determination of geodetic control used in the maps of this report. Stars indicate the accepted control points of former triangulation surveys, and lines and distances given show the measurements used to tie the adjustments of the present maps.

are both true north and south, is 23.64 miles, obtained from the proportion $23.53 : x = 22.00 : 22.11$, the latter figures being those obtained from the tables for map projections at the two parallels named.

The distance between 109° 30′ and 109° 0′ on the fortieth parallel is 26.53 miles. Thus the distance between 109° and the state line appears to be 2.89 miles, obtained by subtraction.

The Colorado base-line measurements, obtained by the latest surveys, give a distance of 56.24 miles from the state line east to the corner between Rs. 94 and 95. This distance is in excess of the length of 1° on the fortieth parallel plus the added distance from 109° to the state line (viz, 55.95) by 0.29 mile, and this gives one determination for the position of this range line with reference to the 108° meridian.

A check on the foregoing calculation is obtained from the opposite direction from positions in the primary control used in the surveys in the Encampment quadrangle, Wyoming. Here measurements along the Colorado-Wyoming state line and on the eleventh auxiliary guide meridian are used. On the Encampment sheet the line of 107° 15′ W. falls 0.12 mile east of the one hundred and sixty-eighth mile-post of the north boundary of Colorado. By state-line measurements the distance to the intersection of the eleventh auxiliary guide meridian is 27.49 miles. On the fortieth parallel the equivalent distance is found from the proportion $27.49 : x = 26.14 : 26.53$ to be 27.90 miles. The two values in the second ratio of the equation are obtained from the tables for projection of maps for the forty-first and fortieth parallels.

Two offsets on the eleventh auxiliary guide meridian of 0.05 and 0.47 mile introduce a correction of 0.52 mile to the east on the fortieth parallel. Furthermore, late determinations are reported to have shown that the eleventh auxiliary guide meridian was run 7′ east of true north, and this introduces a further correction of 0.14 mile to the west on the fortieth parallel. Hence the actual distance on the fortieth parallel from 107° 15′ to the intersection of the eleventh auxiliary guide meridian thus obtained is 27.52 miles, and on extending the calculation to the township corner nearest 108°, already used, the distance obtained is 39.52 miles. By the tables for projection of maps the distance from 107° 15′ to 108° on the fortieth parallel is 39.79 miles. The difference between the distance to the township corner and to the meridian thus obtained is 0.27 mile, which is another value for the same distance obtained in the first set of calculations from the opposite direction.

In brief, by calculating from the west, the 108th meridian appears to be situated 0.29 mile west of the base-line township corner between Rs. 94 and 95 W., and by calculating from the Encampment sheet to be 0.27 mile in the same direction, a difference of only 0.02 mile,

or about 100 feet, for the positions obtained by these two independent methods.

For determination of the position of the fortieth parallel with reference to the base line the same methods with only the western points of comparison were used. On the Marsh Peak sheet the 40° 30′ parallel falls 0.49 mile south of the township corner previously referred to. The first standard parallel south is 11.51 miles south of this township corner by land-survey measurements. The standard parallel is assumed to be true east and west, as stated in the survey notes, and measurements south are continued from its intersection on the Colorado-Utah state line. From the standard parallel to the true corner projected along the base line is a distance of 22.80 miles by chained measurements. This gives a total of 34.31 miles between the parallel 40° 30′ and the projected curve of the Colorado base line. The length of the half degree of longitude from 40° 30′ to 40° is 24.49 miles (table of projections), giving a northing of 0.18 mile for the position of the projected curve of the Colorado base line. The actual base line is somewhat irregular (that is, does not follow the true parallel), but its departures from the true curve of projection are indicated in the field notes of the latest resurvey.

LAND SURVEYS.

As stated on page 14, resurveys of an extensive territory in the extreme northwestern part of the State have been undertaken and largely completed (Pl. I) under an act passed at the second session of the Fifty-eighth Congress, 1904. The text of this act (chap. 1768, public laws) is as follows:

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Interior be, and he is hereby, authorized to cause to be made a resurvey of the lands in Routt and Rio Blanco counties in the State of Colorado, embraced in and consisting of townships one, two, three, four, five, six, seven, eight, nine, ten, eleven, and fractional township twelve north, of ranges ninety-two, ninety-three, ninety-four, ninety-five, ninety-six, ninety-seven, ninety-eight, ninety-nine, one hundred, one hundred and one, one hundred and two, one hundred and three, and fractional range one hundred and four west, including a retracement of the base line and resurvey of the first and second correction lines north, through ranges ninety-two to one hundred and four west, inclusive, and the eleventh auxiliary guide meridian west, from the base line to the north boundary of Colorado through townships one to twelve north, all of the sixth principal base and meridian; and all rules and regulations of the Department of the Interior requiring petitions from all settlers of said townships asking for resurvey and agreement to abide by the result of the same so far as these lands are concerned are hereby abrogated: *Provided*, That nothing herein contained shall be so construed as to impair the present bona fide claim of any actual occupant of any of said lands to the lands so occupied.

Approved, April 28, 1904.

More recently further agitation for a similar provision allowing resurveys in the eastern part of Routt County and elsewhere resulted (60th Cong., 1st sess.) in another act, the text of which is as follows:

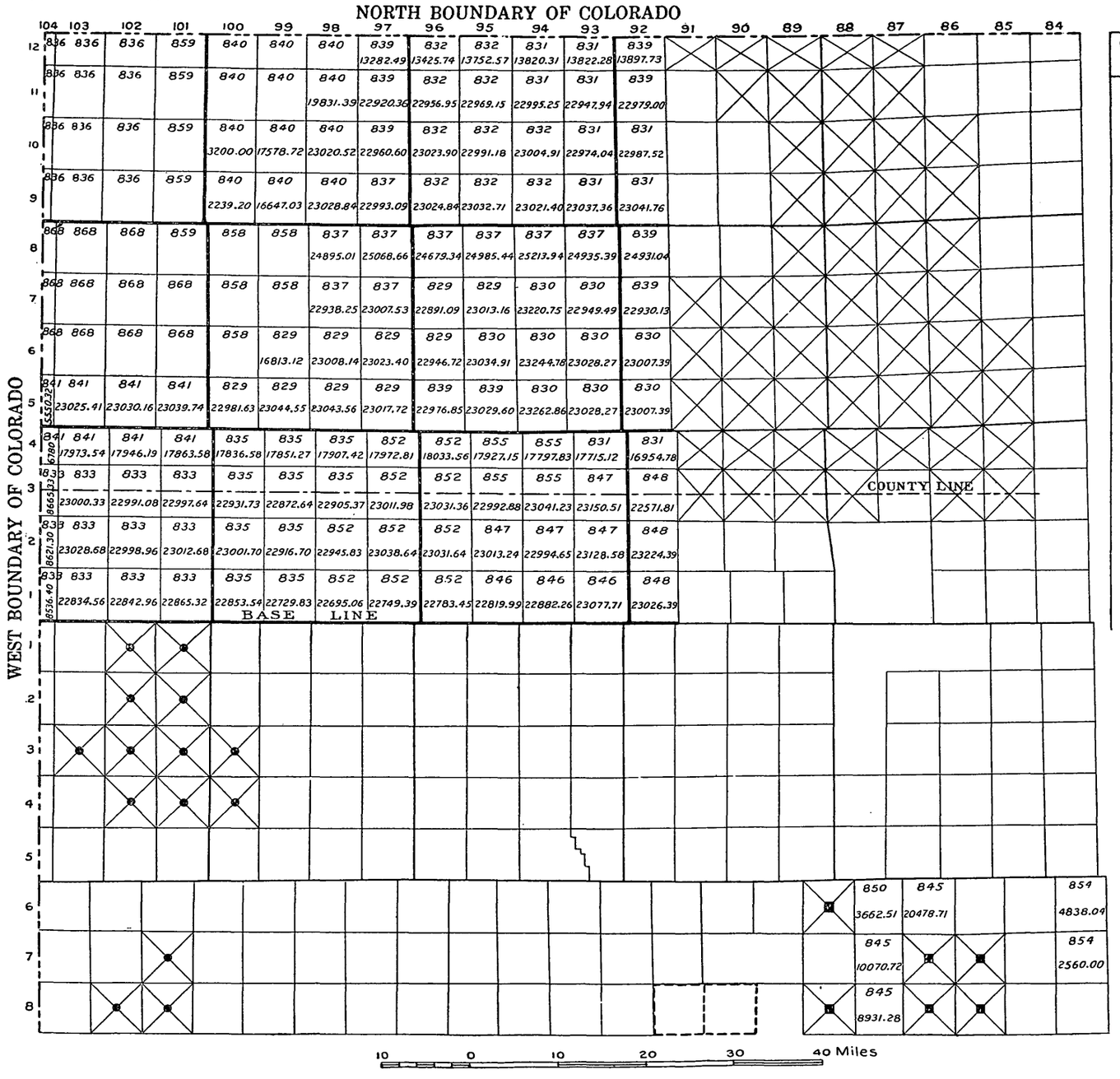
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Interior be, and he is hereby, authorized to cause to be made a resurvey of the lands in the following townships: nine north, ranges eighty-six to eighty-nine, inclusive; eight north, ranges eighty-six to eighty-nine, inclusive; seven north, ranges eighty-six to ninety-one, inclusive; six north, ranges eighty-five to ninety-one, inclusive; five north, ranges eighty-five to ninety-one, inclusive; four north, ranges eighty-five to eighty-nine, inclusive, and ninety-one; three north, ranges eighty-five and eighty-six; one south, ranges one hundred and one and one hundred and two; two south, ranges one hundred and one and one hundred and two; three south, ranges one hundred to one hundred and three, inclusive; four south, ranges one hundred to one hundred and two, inclusive; seven south, range one hundred and two; eight south, ranges one hundred and two and one hundred and three; ten south, range ninety-seven; eleven south, ranges ninety-seven and ninety-eight; twelve south, ranges ninety-three to ninety-eight, inclusive; thirteen south, ranges eighty-nine to ninety-six, inclusive, and ninety-eight; fourteen south, ranges eighty-nine and ninety-six; twelve north, ranges eighty-seven to ninety-one, inclusive; eleven north, ranges eighty-seven to ninety, inclusive; ten north, ranges eighty-six to eighty-nine, inclusive; four north, range ninety; three north, ranges eighty-eight to ninety-one, inclusive; fifteen south, range eighty-nine; nineteen south, range fifty-four; all west of the sixth principal meridian, also of the lands in townships thirty-three and thirty-four north, of range two west of the New Mexico principal meridian, and of the lands in Cheyenne County, all in the State of Colorado; and all rules and regulations of the Interior Department requiring petitions from all settlers in said townships asking for resurvey and agreements to abide by the result of same, so far as any of these lands are concerned, are hereby abrogated: *Provided*, That nothing herein contained shall be so construed as to impair the present bona fide claim of any actual occupant of any of said lands so occupied: *And provided further*, That before any survey is ordered under this act it shall be made to appear to the Secretary of the Interior that the former official survey of said lands is so inaccurate or obliterated as to make it necessary to resurvey the lands, and only such parts of the lands described herein where the survey is so inaccurate or obliterated shall be resurveyed.

Approved, May 29, 1908.

The condition of the resurveys in this part of Colorado is represented in Plate I, the data for which are furnished through the courtesy of Mrs. Martha C. Ballard, chief of land division, office of United States surveyor-general at Denver, from the records on hand in that office, April, 1909.

ACKNOWLEDGMENTS.

The author wishes to express his thanks for assistance given and good will shown throughout the course of the work. Acknowledgment for this voluntary cooperation has been made in a personal way, and is hereby stated as a matter of more formal record. For maps, blueprints, railroad profiles, alignment and level notes, and other assistance, acknowledgment is due to Mr. A. H. Adams, of Meeker; Mrs. Martha C. Ballard, of Denver; Mr. Paul Blount, of the Denver, Northwestern and Pacific Railway; Mr. W. H. Clark, of Meeker; Mr.



Contract No.	Deputy	When resurveyed	Total area in acres	Year accepted by G. L. O.
*828	W.H.Clark	1904		1905
829	B.F.Clark	1905-1906	200801.46	1908
830	J.M.Clark	1905-1906	207801.25	1908
831	Taylor	1904-1905	200296.39	1907
832	Schrontz	1905	211203.35	1907
833	Adams	1905	232395.24	1907
852	Kidder	1907	219293.72	1908
837	Young	1906	218716.65	1908
839	Whitney	1905-1906	189907.24	1907
840	Carstarphen	1905	105545.70	1907
841	Wilson	1905	135208.94	1906
846	W.H.Clark	1907	67985.96	1909
847	Taylor	1907	92286.98	1908
848	B.F.Clark	1907	68822.59	1908
835	O'Brian	1907-1908	213806.78	1909
836	Booth	Being resurveyed—Deputy now in field		
859	Adams	Being resurveyed—Deputy now in field		
858	Whitney	Being resurveyed—Deputy now in field		
855	Cole	1907-1908	104740.72	Awaiting acceptance
868	Hedlund and Froelich	Being resurveyed—Deputies now in field		
845	Huntington	1906	39480.71	1908 (Part of contract)
850	J.W.Irion and E.Irion	1907	3662.51	Awaiting acceptance (Part of contract)
854	W.H.Lea	1907	7398.04	1909

Total of land resurveyed to date: 2519354.23 acres

* Guide meridians and standard parallels as shown by heavy lines

Authorized to be resurveyed—Act of Congress, approved May 29, 1908

Field Examiner Van Winkle now investigating as to obliteration of evidences of survey—for resurvey (April, 1909)

A portion (usually valley portion) has been resurveyed. Dates 1888 to 1893

These townships are to be surveyed

Upper figures in townships: contract numbers

Lower figures in townships: acreage

Revised to April, 1909

MAP SHOWING STATUS OF RESURVEYS IN NORTHWESTERN COLORADO.

Perry Coryell, of Newcastle; Mr. Edgar F. Harmston, of Vernal; Mr. Henry J. Hay, of Meeker; Mr. F. F. Mallon, of Colorado City; Mr. J. D. Moog, of Meeker; Mr. Theodore Rosenberg, of Glenwood Springs; Mr. H. A. Sumner, of the Denver, Northwestern and Pacific Railway; and Mr. A. G. Wallihan, of Lay. Acknowledgment for assistance in the field is also due to Mr. John Allen, of Coalbasin; Mr. Arthur Burnham, of Meeker; Mr. Ira Chadwick, of Newcastle; Mr. Charles Meerdink, of Newcastle; Mr. W. S. Smith, of Pocahontas; and Mr. J. P. Thomas, of Glenwood Springs.

CHAPTER I.

GEOGRAPHY.

COLORADO PLATEAU.

Northwestern Colorado is a part of the plateau region of the western United States, extending from the Rocky Mountains westward and including the territory south of the Uinta Mountains. It is drained by the tributaries of Colorado River. The Colorado portion of this region is in reality only a border of the larger plateau province which extends in its more typically desert-like character west and southwest into Utah, Arizona, New Mexico, and beyond. While plateau surfaces are still conspicuous features of the northwestern Colorado region, these upland plains have been largely cut away by erosion along the drainage courses, and have probably also been much modified by uplift or folding of the once flat-lying strata, deforming their original low horizontal surfaces. There are mesas, "flat tops," and table-lands of various elevations, ranging in size from the small protected remnants or buttes among the highest summits of the Rocky Mountains down to the many successions of perfectly developed terraces bordering the modern river bottoms. In general, present existing plateau surfaces in the sedimentary rocks west of the Rocky Mountain ranges represent simple or nearly horizontal structure in the underlying rocks, the flat upper surfaces being slowest to yield to erosive action where they are unbroken and but slightly tilted.

The coal-field districts are in general of more involved geologic structure than the younger Tertiary areas that form most of the general level of the Colorado Plateau. In the coal fields the plateau character is largely replaced by hogback or monoclinal ridges, strike valleys, and other features of a folded complex of alternating hard and soft strata. In some parts of the coal districts, topography and geologic structure are also complicated by the presence of intruded masses of igneous rocks. These latter features are found, however, in much greater development outside of the areas principally concerned in this report, as, for example, in the eastern Yampa River valley, on the White River Plateau, and among the West Elk Mountains south of Grand River. Although this whole region is known as a part of the Colorado Plateau, the general level of the upland is frequently interrupted by higher summits and ranges of mountains and is cut by deep valleys and canyons that have been carved by the streams.

MOUNTAINS AND UPLANDS.

DANFORTH HILLS.

The largest single compact mountain group in the foothills province of this region is that known as the Danforth Hills. This group was named in honor of the Rev. F. H. Danforth, former Indian agent at the White River Agency.[a] As it is also one of the most extensive coal-field units of the area to be discussed, it will be described in much detail later (pp. 137–178); here, however, only its broader geographic features will be mentioned.

The group lies north of Agency Park between White and Yampa rivers, and includes a total area closely approximating 300 square miles. It is situated west of the "flat tops" or White River Plateau, south of Axial Basin, and east and northeast of the valley of Strawberry Creek and the Gray Hills. It has a maximum relief of somewhat more than 2,000 feet, this being approximately the difference in elevation between the highest summits and the main river valleys both north and south of the hills. There is but little settlement within the area, scarcely a dozen families living in it, exclusive of those in the adjoining parks or valleys at the very margin of the hilly area.

The highest summits of the Danforth Hills lie along the drainage divide between White and Yampa rivers. This divide follows through the southwestern and south-central portion of the group, and for this reason the steeper and more rugged topography is found on the southern or White River drainage, and the gulches heading off toward Yampa River on the north are of lighter grade and usually of greater length. Here, as elsewhere in the Colorado Plateau province, the water grades are largely influenced or determined by the attitude of the harder ledges in the rock strata through which they flow. The highest summits and the main watershed as a whole have been determined by the geologic structure of the region, for they lie on a principal anticlinal axis which extends from one end of the field to the other and from which the rock strata dip down more steeply toward the south and west than in the opposite directions.

The highest peaks of the group are near its center. One of these is known as the Devils Hole Mountain, the name being derived from the precipitous slopes and gulches that drain its western sides. This peak is characteristic of many of the summits of the Danforth Hills that are conspicuously conical in shape, rising a few hundred feet above the general level of the surrounding ridges. Many such peaks appear bright-red as seen from a distance, the color originating in the baking of the shale and sandstone that cap the summits. This baking and fire reddening of the rock is the result of combustion of coal beds in place and along their surface outcrops. The burned portion

[a] Hayden, F. V., Tenth Ann. Rept. Geol. and Geog. Survey Terr., 1876, p. 8.

of such coal beds extends underground to uncertain and probably various depths, apparently limited in some places by ground-water level, or, more commonly, by the distance from the surface to which the air necessary to support combustion can penetrate. On closer examination the burned rock is seen to be of varied and locally brilliant colors, among which are shades of red varying from brick to vermilion and bright-yellow, probably resulting from the oxidation and possibly subsequent alteration of the iron contained in the strata before they were burned. Beds of ashes and slag are also of common occurrence. At some places the coal beds exposed in natural outcrop are unburned; this, however, is less common.

The origin of these conical peaks and many of the high, broad summits is probably the direct result of the baking process, in which the summit rocks have become so hardened that they have withstood erosion of wind and water. The indurated rock has formed a protecting cap, and those parts protected by it have remained, while surrounding softer strata have been worn away. These summits at many places were found to exert considerable local magnetic attraction, the source of which was discovered to be in the baked rock or slag itself. This is thought to be due to the reduction of the iron contained in the beds to the metallic state, or to its alteration to a magnetic oxide, through the action of the heat of burning in combination with the carbon of the coal beds. This local attraction will probably always prove a source of annoyance and possibly also of error in the attempt to run magnetic surveys in the vicinity of such rocks. While the local attraction is brought to attention principally in the work along the summits of the ridges, there is every reason to expect it near any beds where coal has been burned at the outcrop.

From the Devils Hole Mountain the main divide extends northwest on the one hand and takes an easterly course on the other, at approximately uniform elevation. The summit ridge is a succession of peaks separated by gaps and saddles. The highest tops and ridge summits are commonly bare of vegetation, but many of the gaps and steeper slopes on the northward side are brushy. Protected patches of ground on the flatter slopes where the soil probably retains some moisture are characteristically covered with quaking aspen; the drier and more exposed slopes with scrub oak. Cattle trails are to be found along most of the ridge summits, and, except for the brush that sometimes becomes rather troublesome, one may comfortably travel on horseback over most of this territory.

The slopes on either side of the higher crests are usually precipitous. They are steepest at the extreme heads of the gulches and for the first 500 to 1,000 feet of descent; beyond this the grades change somewhat abruptly, and the narrow valley bottoms below have a uniform and much lighter rate of fall. The ridges and gulches of the

Danforth Hills are very similar throughout the area. As has been stated, the White River side of the divide is more rugged than that toward the Yampa. The upland surface that slopes off toward Axial Basin corresponds to a long, gentle dip of the strata in that direction and is terminated at its lower end by an abrupt tilting of all the strata in conformity with the Axial Basin anticline. On this long northerly slope the uplands or ridge tops are characteristically broad and smoothly rounding, while most of the streams that drain this district are incised into this surface in steep, narrow gulches and canyons. The narrow strips of valley bottoms along these gulches furnish the only agricultural land of the district, and where any water is available these are fenced and farmed for hay, or furnish a rich though limited pasturage for stock. A considerable number of springs occur at more or less frequent intervals along most of these valleys. Those noted during the progress of the field work are indicated by a symbol on the topographic maps.

The northern border of the Danforth Hills presents a scarp or bluff facing and overlooking Axial Basin, markedly similar even in its details to the escarpment wall that bounds this basin on its north side. These escarpments are readily recognized as the eroded edges of rock strata that in all probability once extended across and over the present Axial Basin in a continuous broad arch, whose crest has now been worn away, exposing the soft valley-making shales beneath. It is this gap of erosion that now separates the coal-bearing rocks of the Yampa from the White and Grand River fields, a structural geologic separation of two huge synclinal basins that will be described under the heading "Structure" (p. 95). The lower resistant sandstones of the coal-bearing formations form protecting caps where they still cover the softer shale below and thus stand up as ridges above the shale valleys. Pass Butte, now locally better known as Thornburgh Mountain, is a somewhat isolated mass of sandstone and clinker-topped ridges at the northeastern extremity of the Danforth Hills area, almost surrounded by the low rolling valleys formed upon the underlying shale.

MONUMENT BUTTE.

Monument Butte, at the east end of Axial Basin, 5 miles northeast of Thornburgh Mountain, is a conspicuous peak of the same type as that mountain. It stands at the west end of a subordinate structural basin containing coal-bearing strata that lies between Williams Fork and the White River Plateau region. Monument Butte is capped by the gently folded beds of one of the lowest sandstones of the Mesaverde formation. It is practically isolated from the mountain group to the east, to which it naturally belongs, by the deep valleys of Deer and Morapos creeks on the one side and is closely circumscribed by Stinking Creek valley and Axial Basin on the other.

ILES AND DUFFY MOUNTAINS.

The upland forming the northern escarpment border of Axial Basin is the western extension of the Yampa coal field, as its coal-bearing strata are in strict continuity with those of the main body of the field to the east. This may also be said of the minor basin of coal-bearing rocks which was mentioned above as south of Williams Fork and of which Monument Butte is the western extremity. The broad, open structure of the rocks in the western part of the field gives rise to correspondingly open and simple topographic features, and where the harder strata lie above stream level they give rise to gently inclined uplands or plateaus. West of the junction of Williams Fork with Yampa River the uplands had been named Junction and Sage plateaus on the maps of the Hayden and King surveys. Junction Plateau, now better known as Iles Mountain, is that portion of the upland lying between Williams Fork and the lower canyon of Milk Creek. Sage Plateau, locally better known as the Duffy Mountain, lies west of the Milk Creek canyon. Yampa River flows through these plateaus in a moderately narrow deep canyon. At the western end of Duffy Mountain Yampa River emerges from its canyon and enters the lower valley of Axial Basin.

UPLAND NORTH OF YAMPA RIVER.

North of Yampa River is an extensive area of rolling prairie, broken in places by more or less prominent hogback or cuesta ridges. As a whole, the territory west of the Elkhead Mountains is a broad stretch of rolling prairie of moderate relief and monotonous topography. It includes a roughly triangular area lying between Little Snake and Yampa rivers. To its general aridity is due much of the lack of distinguishing characteristics. The climate of this region, although not that of a desert, is exceedingly dry with little rainfall during the summer, and, it is said, with little snow in the winter. Springs are scarce throughout the region, and settlement is consequently scattered and is chiefly confined to the river valleys.

JUNIPER MOUNTAIN OR YAMPA PEAK.

Juniper Mountain is the eastern of two isolated summits standing in the midst of the broad plains on lower Yampa River north of the Danforth Hills. The name Yampa Peak was given by the early surveys, and its peculiar geologic and physiographic interest has caused its frequent mention in the literature dealing with these fields.[a] It is now widely known in a local way by the name of Juniper Mountain.

[a] White, C. A., Geology and physiography of a portion of northwestern Colorado; Ninth Ann. Rept. U. S. Geol. Survey, 1889, pp. 677-712.

It stands as a broad rounding summit in the midst of the desert-like waste that forms the broad western end of Axial Basin. Its summit rises about 2,000 feet above the level of Yampa River, which passes through a canyon in its northern end. The main top is a double-ended summit connected by a slightly sagging ridge a quarter of a mile or so in length from north to south. An old monument, probably that of the triangulation station of the early surveys, stands upon its southern end. The top is formed of a mere patch of cherty fossiliferous limestone lying nearly horizontal. The main mass of the mountain is composed of conglomeratic red quartzite, described more at length on a later page. It is covered with a scattering growth of cedars, piñons, and scrub oak. The summit limestone shows in rough weather-blackened ledges. A few hundred feet south along the crest of the main ridge is an almost continuous outcrop of flat-lying red quartzite ledges, showing apparently glaciated surfaces. The flanks are steep and rocky, buried in a talus of red quartzite bowlders.

A few arrowheads and many broken flint chips of various colors found along the summit that have apparently been brought there by the Indians seem to indicate that this has perhaps been a signal point and camp ground in former times.

CROSS OR JUNCTION MOUNTAIN.

A second peak, similar to Juniper Mountain in manner of geologic formation and in its isolated position, lies in the valley of Yampa River, about 16 miles west of Juniper Mountain or Yampa Peak. This was named Junction Mountain by the early surveys, but is now more widely known in a local way as Cross Mountain. Through it Yampa River passes in a steep-walled, almost inaccessible canyon. This mountain is visible from an extensive region surrounding that part of Yampa Valley, but no especial examination of it was made in the present work.

WHITE RIVER PLATEAU.

The coal fields are bordered on the east by summits and spurs of the White River Plateau. This higher territory is a wild, unsettled region and is in greater part included in the national White River Forest Reserve. It is made up of upland plateau surfaces ranging from 10,000 to 12,000 feet in elevation, of very irregular outline. The remaining portions of this upland surface have been preserved from erosion largely through the protection afforded by great sheets of basaltic lava that overflowed the surface and were intruded into the underlying strata, this volcanic rock now being the most resistant of the region. These plateau features are referred to locally as the "flat tops." They are commonly bordered by precipitous rock

ledges, or "rim rocks" of basalt, and this rock, together with protected sedimentary beds underneath, is characteristically exposed in cliffs or escarpments.

The high plateaus surround as a rim and almost completely inclose the great amphitheater valley in which White River heads, and these plateaus and headwater drainage basin are in turn completely encircled by the longer drainage valleys tributary to Yampa and Grand rivers. The upper valley of White River is ruggedly mountainous and is practically without settlement except on a narrow strip of agricultural land at the lower edge of the reserve; much of it is accessible only over pack trails. A number of high peaks surmount the plateau surfaces or rise above that general level. Among these are Mount Marvine, Mount Orno, Darby Peak, Dome Peak, Pyramid Peak, Pagoda Peak, Shingle Peak, Sand Mountain, Sleepy Cat Mountain, and Burro Mountain. Lakes, ponds, and marshes are scattered about the high plateau surfaces below the rim-rock borders. Some of these are renowned among tourists and sportsmen for their mountain trout, probably the most famous in this respect being Trappers and Marvine lakes.

This region is important to the coal-field districts that lie to the west, as it furnishes the source of the only pure fresh water now available for their settlement and development. White River, as it enters Agency Park, is a pure, clear mountain stream in spite of a rather considerable amount of settlement and cultivation along its banks above that place. Nearly all the smaller streams that head on the forested slopes of the White River Plateau contain perennial water. Only the western margin of this plateau, however, is directly adjacent to the coal-field area, and the region as a whole was not studied in the present investigation.

The divide between waters of Yampa and White rivers passes eastward from the Danforth Hills into the White River Plateau at Yellow Jacket Pass. The route of the old government road from Rawlins, Wyo., to the White River Indian Agency was through this pass, this being for some time the nearest railroad communication for the White River valley. From Yellow Jacket Pass to the east the main divide rises sharply to a peak at an elevation of some 9,400 feet on a western spur from Sleepy Cat Mountain. Sleepy Cat Peak itself lies about 9 miles east of the first high summit and has an elevation of approximately 10,800 feet above sea level. The peak is apparently typical of the many lofty pinnacles that surmount the high plateau level.

South of White River the Grand Hogback field is bordered on the east by high ridges also a part of the White River Plateau, here composed of sedimentary rocks in part without the basaltic lava flows or intrusions.

GRAND HOGBACK.

The Grand Hogback is a somewhat remarkable physiographic feature extending southward from the Danforth Hills to and across Grand River. Beyond Grand River it also continues, under the name of Coal Ridge, to a point where it merges with and loses its identity in the more ruggedly mountainous region of the West Elk Range. It is bordered on either side by long continuous valleys, both of which are followed by wagon roads between White and Grand rivers. As this ridge is composed almost entirely of the coal-bearing strata it is considered in some detail later (pp. 109–136). Its summit is at places a single, at others a double crested hogback ridge, formed by the outcrops of massive sandstone ledges inclined at rather steep angles. It is, therefore, exceedingly rugged along most of its length and is bordered by steep and precipitous flanks on either side. A dense growth of oak brush, western service berry, choke cherry, and juniper makes it still more difficult to explore, while huge wash banks in marls and shales, with minor rock ledges, on its western and southern flanks, make the summit itself difficult to scale. The stream valleys in the hogback contain a small amount of red fir. Its summits average about 2,000 feet above the valley bottoms. Aside from its general aspect, its most remarkable features are its singular continuity and uniformity of structure—its extension with so little change of character for so great a distance. It is broken through by a number of stream gaps, which afford excellent opportunities for a study of the strata composing the ridge.

ROAN OR BOOK PLATEAU, GRAY HILLS, AND CATHEDRAL BLUFFS.

The coal-field districts are very sharply delimited on the west by huge bluffs or escarpments, which are variously named in their different parts, as the Roan or Book Cliffs on Grand River, the Gray Hills north of White River, the Citadel Plateau north of Deep Channel Creek, and Cathedral Bluffs on lower White River and Douglas Creek. The strata of all these bluffs represent the same geologic formation and although varying somewhat in elevation above the adjacent valley regions are essentially of the same character throughout their entire length. The same holds true for the escarpments of the Roan Cliffs (beyond the area covered by this report), in which they may be followed continuously for several hundred miles westward into Utah along the northern side of the Grand River valley.

The beds of these younger formations, as they show in this part of the field, are usually flat lying and cover a great area on the back or dip slopes of the Roan or Book Cliffs, where they constitute the extensive upland surface known as the Roan or Book Plateau. Their relations to the rocks of the older underlying formations indicate that

both were deposited before the principal movements that tilted the latter to their present steeply inclined positions. The fact that the younger strata now remain only in horizontal or nearly horizontal position is attributed to their ready erosion when tilted so as to expose to the weather the edges of the bedding planes; for although composed of material of apparently weak constitution, such as soft thin-bedded shales or friable sandstones, they are evidently very resistant to erosion in their normal flat-lying position. In tilted outcrops, however, or where subjected to the mechanical action of water-transported material, as in the actual channels of drainage courses, these rocks have been worn down into lowlands or cut by deep canyons.

WAPITI PEAK AND PINYON RIDGE.

North and west of Coyote Basin the divide is a broad semicircular ridge, composed of the hogbacks and cuestas of the sandstones of the Mesaverde or coal-bearing formation. Wapiti Peak, the highest summit on the northern part of the ridge, is but one of a series of tops of nearly equal height that occupy the White and Yampa river divide in this locality. Opposite Cross Mountain the trend of these higher hills bends to the south, following the structure of the underlying rock formations, and forms the broken topography of Pinyon Ridge. In general these features somewhat resemble the forms of the Danforth Hills.

RED WASH HOGBACK.

A rather conspicuous hogback continues west from Pinyon Ridge, extending from the mouth of Wolf Creek as far as the channel of Red Wash. West of this point the more markedly distinct features of the coal-field rocks lose their identity in the complex of more or less perfectly developed cuestas that surround the Raven Park uplift and related structures.

RIM ROCK AND RAVEN RIDGE.

Surrounding Raven Park the lowest sandstone stratum of the coal-bearing formations makes a single distinct and rather conspicuous rim, the steep escarpment edge facing inward toward the lower "park" or valley lands. This innermost escarpment edge is locally known as the rim rock. Beyond the rim rock the ridges rise, in successive steps, upon cliffs of overlying sandstone strata. Higher escarpments and steep bluffs above and beyond the rim rock face inward in concentric arrangement, roughly parallel to the valley margin. Sharply cut rocky canyons intersect these ridges and drain toward the central valley area.

Raven Ridge is the long, straight line of hogbacks and escarpments that forms the western limit of the Raven Park area. It extends

continuously from the mouth of the lower White River canyon below Raven Park to and beyond the Utah line in a due northwest course. Its hills, like much of the adjacent valley lands, are almost devoid of vegetation, and present a dry and desolate aspect. Its continuation west of Green River is known as Asphalt Ridge, from the deposits of that material found in the vicinity of Vernal.

BLUE MOUNTAIN, MIDLAND RIDGE, AND SECTION RIDGE.

The most prominent feature of the landscape north of the area mapped in the western Colorado territory is the so-called Blue Mountain. Blue Mountain is a part of the Yampa Plateau, as it was first named by the Hayden Survey. It includes the southernmost of the larger uplifts of the Uinta Mountain Range and forms a northern limit of the lower foothill and plateau features that lie farther south. The summit is relatively flat, as it is capped and protected from erosion by the nearly horizontal beds of resistant sandstones of the basal Cretaceous and latest Jurassic rocks.

Midland Ridge, which also received its name from the early Hayden work, is a part of Blue Mountain that extends from the highest part of that upland east and southeast toward the mouth of Wolf Creek. It forms a great wall 1,000 to 1,500 feet in height, facing toward the south, banded in gray and vivid red, which may be clearly seen from an extensive territory to the south, to and beyond the White River valley, and is a most conspicuous and extraordinary feature of the landscape.

Section Ridge, a lofty spur of the Yampa Plateau, extends west from the main summit of Blue Mountain, reaching within a few miles of Green River. It is capped both on its summit and down its steeper southern flank by the massive sandstone ledges already referred to as forming the resistant top of Blue Mountain. The great fold in these massive rocks is clearly revealed in a precipitous wall 3,000 feet in height, rising abruptly out of the broad expanse of lower and more open topography that stretches away to the south.

SPLIT MOUNTAIN.

Split Mountain is very similar to Section Ridge, although formed on a somewhat larger scale, as it rises higher and extends farther west from the summit of the Yampa Plateau. It lies north of and approximately parallel to Section Ridge. Both of these features owe their position and form to the underlying geologic structure, the relation being very clearly revealed in their bare, rocky slopes. Split Mountain is cut completely through by Green River, this being the last and southernmost canyon by which that stream emerges from the old and harder rocks of the Uinta Mountain system. North of Split

Mountain and between it and the main Uinta Mountain axis is the valley in which Island Park is situated. West of Split Mountain is the broad open park of Ashley Valley, in which lies the town of Vernal.

DRAINAGE, VALLEYS, AND PARKS.

PRINCIPAL STREAMS.

Northwestern Colorado is drained toward the west by three principal streams, Yampa, White, and Grand rivers, all of which are tributary to Green and so also to Colorado River. Green River itself flows through the Uinta Mountains in a series of almost inaccessible canyons, emerging on the south side in the valley of Ashley Creek adjacent to the coal-field areas. The area described in this report is in greater part on Yampa and White river drainage.

YAMPA RIVER.

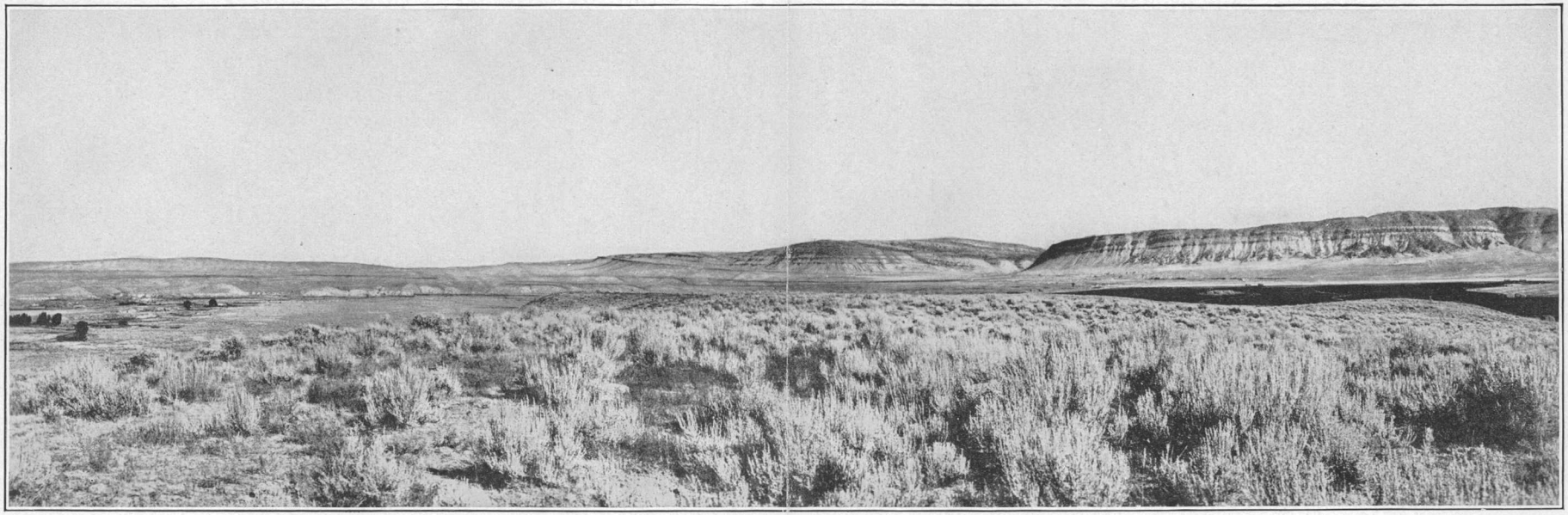
Yampa River heads among the many smaller streams that drain the western slopes of the Park or Gore Range. Its three principal tributaries are Elk River, Williams Fork, and Little Snake River. In almost its entire course it flows through an alternating succession of canyons and open valleys. Below Lily Park, for the last 25 or 30 miles of its course, it passes through a deep and continuous canyon to its junction with the Green near the Colorado-Utah state line, beyond which the canyon increases in depth. In 1905 surveys for a railroad were extended down the canyons of the Yampa and thence down Green River into Utah, whence they continued westward to Salt Lake City.

The upper valley of the Yampa lies within a coal-field area which has already been described in a number of publications under the name of the Yampa coal field. A number of the minor tributaries of the Yampa rise in the Danforth Hills, or in adjacent territory which is not considered a part of the Yampa coal field as that field is usually defined.

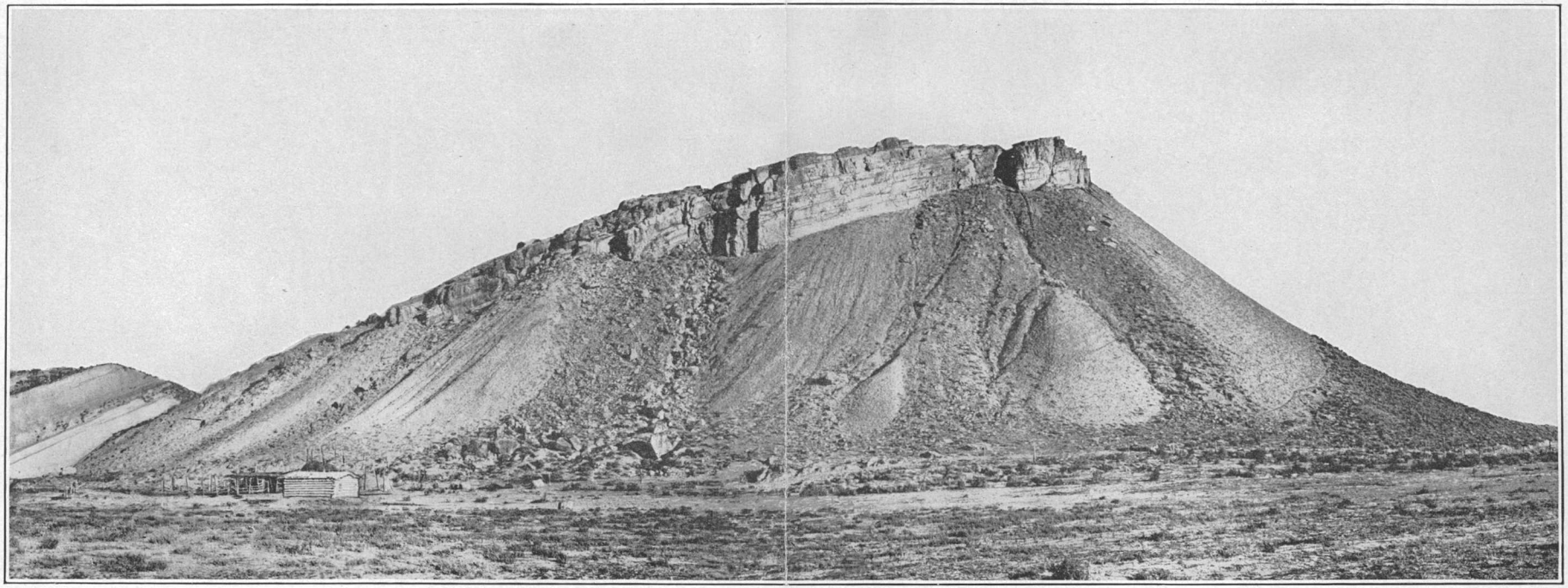
AXIAL BASIN.

Axial Basin was so called by C. A. White,[a] of the Hayden Survey, who used the name as "a term to facilitate geologic description." In this case a name originally chosen for its structural geologic significance has passed into general use and has become very firmly established. It is in fact a topographic basin or valley eroded on the weak or relatively less resistant shale exposed along an anticlinal axis, as described later (pp. 97–98). It is not, however, the single continuous valley of any one particular stream, but is drained into Yampa River by a number of relatively subordinate branches that

[a] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1876, p. 363.



A. MILK CREEK VALLEY IN AXIAL BASIN, SHOWING ESCARPMENTS OF ILES AND DUFFY MOUNTAINS.



B. RIM-ROCK LEDGE AT MOUTH OF WOLF CREEK, LOWER WHITE RIVER.

cross the basin and cut the marginal escarpments apparently irrespective of the hard or soft strata, or paths of least resistance. Yampa River enters this valley in its central to western part, flowing westward to the lower canyons below Lily Park. Axial Basin is as a whole a rolling sage-covered prairie, containing only a very few scattered ranches at points where some water for irrigation is available. In its eastern part the topography is chiefly that of clay shale hills buried in the cover of residual clay soil. Toward the west loose white sandy deposits of more recent lake beds cover the underlying shale and clay, and the surface is strewn with scattered pebble and bowlder deposits (p. 87). Plate II, *A*, shows the valley of Milk Creek in the eastern part of the basin, where the largest extent of cultivated lands is found. It shows the entire breadth of the valley at this place, including the escarpments of Iles and Duffy mountains in the background with the lower canyon of Milk Creek between them.

WHITE RIVER.

White River originates on the White River Plateau, already described, and its headwaters are now included within the White River National Forest. A very narrow strip of its valley bottom is settled and cultivated within the borders of the forest, but the only considerable settlements along its course lie below in Agency and Powell parks. The lower parts of its valley are described more at length in the following paragraphs.

AGENCY PARK.

Agency Park, formerly known as Simpsons Park, is south of the Danforth Hills, east of the Grand Hogback, and west and north of the White River Plateau. The old Ute or White River Indian Agency was situated on the river bank at the extreme upper end of the park, about 8 miles above the present settlement at Meeker. Agency Park contains the largest expanse of irrigable bottom and terrace lands along White River and is the natural center for the main settlement of that region.

White River enters the park a clear, fresh mountain stream. Coal Creek, the one other stream of perennial water, enters the park from the north, but its waters are all taken out for irrigation before it reaches the White. The usually dry channels of Sulphur Creek and Curtis Creek enter the park from the coal-field ridges on the north, and Flag Creek, although heading with a good flow of clear fresh water in the wooded slopes to the south, rapidly becomes alkaline and dries or is diverted for irrigation as it enters the open valley from the south. Of these streams only those flowing directly from the wooded slopes on the older geologic formations contain any water at all or furnish any supply that is fit for the use of man. A number of ditches take

water from White River above the park and, skirting both sides of the valley, bring many acres of fertile terrace and bottom lands under cultivation.

The surface of Agency Park is made up of a series of terraces, or "mesas" as they are locally known, of which at least two above the present river bottoms are very distinctly discernible. The first or lower is quite extensive and lies about 90 to 100 feet above the river level. This forms the principal "mesa" both north and south of the river bottoms. The others are but scattered remnants showing here and there, especially at the foot or flanks of the slopes that border the park. These terrace surfaces are cut into at places so as to expose the underlying tilted shales, which are sharply truncated and are capped by bowlder and gravel deposits. These gravels are in places slightly agglomerated, and are composed of much-rounded and water-worn materials.

About 2 miles below (west) of Meeker the river valley narrows and passes through a rather broadly open canyon in the "coal-hogback" strata. This locality is described in detail on page 141, where the nature and occurrence of its coal beds are considered.

Below or west of the gap in the Grand Hogback the valley of White River again broadens. This locality is known as Powell Park, being named for Prof. J. W. Powell, who is said to have made a winter camp there at the time of his early explorations in the region. It was also the site of the Indian agency for a time, and at the time of the uprising in 1879 it was here that Meeker, then in charge, was killed by Ute Indians. This valley is of less extent than Agency Park, but contains some excellent farming lands, irrigated for the most part by ditches on the north side of White River. Strawberry Creek (Unga-too-wis of the Hayden maps) opens into Powell Park from the north and Sheep Creek valley enters from the south. Both streams are deep, dry channels during the summer and afford no available water supply. Terraces similar to those noted in Agency Park are also apparent in Powell Park. Of these the lower is the most extensive and is about 75 to 100 feet above water level. On the south side of the river this "mesa" may be traced well into the river canyon in the Hogback and is doubtless of the same period of formation as the most extensive of the terraces in the vicinity of Meeker.

WHITE RIVER VALLEY BELOW POWELL PARK.

The canyon of White River below Powell Park is cut in Tertiary strata for a distance of 15 miles or more, or nearly to the mouth of Deep Channel Creek. This part of the valley, although moderately wide and open in parts, is bordered by almost continuous bluffs of the nearly horizontal strata of the Green River formation. Near

White River post-office, at the mouths of Blacks and Farnsworth gulches, the valley opens out so that a view to the north may be obtained showing the Twin Points, described by the Hayden Survey, and Colorow Mountain. From the agricultural standpoint it is a desolate stretch of country, only a small portion near the river being under cultivation. Cottonwoods grow in clumps along the river banks, the river flats are green, and some short ditches are taken out to irrigate a narrow strip of land above the lower flats. The higher slopes on the hillsides above are composed of bare bluffs or cliffs of sandstone and clay, or covered by wash and débris, and there is a scattering growth of piñon or cedars. A local uplift or dome of the underlying strata has brought the badlands strata of the Tertiary Wasatch formation to the surface through the plateau-forming beds of Green River strata, and these lower beds are conspicuous in their red and white banding. Natural monuments and pinnacles, commonly eroded in fantastic shapes and positions, present at times picturesque features in the landscape. Near the mouth of Piceance Creek the public road crosses the river, following the south side downstream or toward the west. Leaving the bridge, the road climbs across the lower end of a large flat truncated delta cone of coarse alluvial material built out at the mouth of Piceance Creek. Along the valley below that stream the road continues on the south side of the river, crossing terrace after terrace and climbing in and out of the gulches tributary to the main stream that cut across them.

Beyond the immediate valley of the river itself some of the tributary drainage courses have valleys of more or less individual character and manner of development. From the north Deep Channel, Wolf Creek, and Red Wash are the principal gulches entering east of Raven Park. From the south the extensive drainage basins of Piceance Creek and Yellow Creek and other smaller streams heading along Cathedral Bluffs or the Book Cliffs Plateau are the largest tributaries east of the valley of Douglas Creek.

COYOTE BASIN OR CROOKED WASH.

A broad area of comparatively gentle structure and low relief, lying west of the Danforth Hills, in the headwaters of Deep Channel and Crooked Wash creeks, was named Coyote Basin at the time of the Hayden Survey. It is in form a topographic as well as structural basin or depression eroded from the soft clays of the Wasatch formation. These have been carved over a rather large area into a surface very nearly approaching typical badlands in character, and from this feature the local name of Crooked Wash is probably derived. This part of the area is a desolate waste, of little practical use at present, and chiefly of interest as overrun by herds of wild horses.

RAVEN PARK.

Raven Park is a broad valley developed along lower White River near the western margin of Colorado. This valley also depends on the structure of the underlying formations, since it is the direct result of erosive action on the softer beds that have been exposed at the surface. In this it is entirely analogous to Agency Park, although in other respects there is not much resemblance between the two. It is a broad expanse of almost bare clay ridges, whose hard dry soil supports but little vegetation. The clay ridges are sparsely covered with the interminable sage, greasewood, and prickly pear. Along the immediate channels of the dry washes the same growth is found in greater abundance. The bare ground of the parched ridges is the most characteristic feature. At times of heavy showers the rain wets only a thin layer at the surface and runs off rapidly, leaving the soil to harden again and crack in the dry air. Lack of water supply, absence of feed for cattle or horses, and the general destitute character of the region as a whole caused little value to be attached to the land until oil was discovered in this region.

GREEN RIVER.

Only a small part of the valley of Green River is included in the territory considered in this report. The main stream heads in southern Wyoming north of the Uinta Mountains, and crossing the Union Pacific Railroad at Green River City flows nearly due south to about 2½ or 3 miles beyond the state line, where it enters the first of the series of canyons by which it makes its way through the Uinta Range. Its course is graphically described by Powell[a] in his narrative of exploration of these canyons by boat. Below Split Mountain the river valley broadens and some extensive bottom lands are developed. A large part of these are under cultivation, and this forms a part of a rather extensive agricultural community, including a still larger settlement at Vernal on Ashley Creek, 12½ miles from Jensen on Green River.

GRAND RIVER.

Grand River, the largest stream of western Colorado, heads in Middle Park, east of the Park or Gore Range. Passing through those mountains in Gore Canyon and cutting the high plateaus to the west by other deep and rugged canyons, it enters the western coal-field districts below its junction with Roaring Fork. It cuts diagonally across the southeastern apex of the Uinta Basin, thus passing through the structural basin that contains the coal-bearing formations, so that at either border it intersects the upturned out-

[a] Exploration of the Colorado River of the West, 1869–1872: Rept. Smithsonian Institution, 1875.

crops of the coal rocks themselves. Its chief interest in a consideration of the fields described in this report is as a means of access to them both from the east and the west, being at present the only route followed by railroad lines in the northwestern part of the State. About 15 miles of its course between Rifle and Newcastle is shown on the map of the Grand Hogback quadrangle (Pl. X) and it marks the southern limit of the detailed survey work undertaken in the season of 1906.

Several tributaries drain from the coal-field area into Grand River. Elk Creek, a good-sized stream of clear, fresh water direct from the older strata of the White River Plateau, enters on the east side of the Hogback at Newcastle. Rifle Creek also heads on the western slopes of the White River Plateau in several branches, which unite just above the narrow gap in the Grand Hogback, about 7 miles north of the town of Rifle.

CLIMATE.

The climate of the region as a whole may be described as semiarid. The winters are long and rather severe, so that the season for crops is short. The possibilities of land for agricultural purposes are limited to those districts in which water is available for irrigation. In the eastern part, especially in the vicinity of the higher forested slopes of the White River Plateau, and in the Yampa Valley near the western slopes of the Park or Gore Range, precipitation is somewhat more plentiful than in the greater part of the area here described. Toward the western part of Colorado, south of the Blue Mountain or Yampa Plateau, the aridity of the climate is relatively greater; the precipitation, though not that of a true desert, is scant in the summer, and but little snow falls in the winter.

To permit a more definite comparison of the climatic conditions in this area, the maximum, minimum, and mean monthly temperatures and the total precipitation for the last two years at a number of stations distributed in the northwestern Colorado region are given in the following table. The total annual precipitation is shown by these tables where the record is complete; for the greater part of the region it is somewhat less than that in the vicinity of Denver, where it is normally about 17 inches, or that in Salt Lake City, where it is normally about 20 inches. The annual precipitation of the central Great Plains is about 30 inches. The precipitation in the semiarid region is also very irregular, much of it coming in very heavy showers with long intervals of drought and hot, dry winds.

Climatological record from stations in northwestern Colorado.

[Compiled from reports of Weather Bureau.]

	Hahns Peak.				Lay.			
	Temperature (°F.).			Precipitation (inches), rain and melted snow.	Temperature (°F.).			Precipitation (inches), rain and melted snow.
	Maximum.	Minimum.	Mean.		Maximum.	Minimum.	Mean.	
1906.								
January	37	−26	13.6	2.23	42	−29	15.2	1.29
February	42	−15	14.6	1.63	51	−13	21.1	1.42
March	42	−20	22.9	2.67	63	−26	28.7	1.48
April	67	10	34.8	2.39	73	18	42.0	2.34
May	70	15	43.8	3.49	80	17	48.6	2.64
June	82	21	48.3	.67	89	20	55.1	.35
July	79	30	53.3	2.40	91	32	64.5	.45
August	80	26	54.2	1.60	89	29	62.6	1.33
September	75	23	48.2	1.98	85	30	55.1	1.91
October	70	0	43.0	.98	78	11	41.6	1.21
November	65	−18	35.2	1.20	61	−18	27.4	.55
December	60	−18	26.7	2.32	55	−21	24.1	.63
The year	.....	.....	.....	23.56	.....	.....	.....	15.60
1907.								
January	51	− 3	18.2	2.85	45	−15	22.6	1.66
February	42	0	25.1	1.49	52	9	33.4	.94
March	58	− 4	27.7	2.38	73	13	38.9	.51
April	55	5	32.0	3.00	74	12	41.4	1.27
May	.....	.....	.....	.....	80	16	44.8	1.73
June	.....	.....	.....	.....	84	22	52.8	.65
July	.....	.....	.....	.....	92	35	64.0	1.14
August	.....	.....	.....	.....	89	26	62.7	1.04
September	.....	.....	.....	.....	84	20	55.8	1.73
October	65	16	42.6	.....	75	20	47.0	.34
November	62	− 3	25.4	.29	64	− 4	28.4	.14
December	34	−20	13.9	3.21	54	−25	21.2	.75
The year	.....	.....	.....	.....	.....	.....	.....	11.90

	Meeker.				Rangely.			
	Temperature (°F.).			Precipitation (inches), rain and melted snow.	Temperature (°F.).			Precipitation (inches), rain and melted snow.
	Maximum.	Minimum.	Mean.		Maximum.	Minimum.	Mean.	
1906.								
January	47	−20	18.1	0.81	.....	.....	.....	.....
February	55	− 4	27.4	.66	.....	.....	.....	.....
March	63	−22	31.8	2.86	.....	.....	.....	.....
April	74	22	43.8	4.12	.....	.....	.....	.....
May	80	24	50.8	2.43	.....	.....	.....	.....
June	89	25	57.2	.34	.....	.....	.....	.....
July	90	36	63.4	.97	93	40	66.3	0.49
August	86	32	62.3	1.17	90	33	65.0	1.83
September	85	30	56.4	2.98	84	29	57.4	2.28
October	78	8	42.8	1.35	80	14	46.6	.66
November	69	−14	32.2	1.74	71	− 7	33.5	1.73
December	55	− 3	28.8	.92	49	− 5	24.3	.07
The year	.....	.....	.....	20.35	.....	.....	.....	.....
1907.								
January	50	− 8	29.2	1.21	45	− 9	23.8	.32
February	56	15	37.2	.60	62	12	35.7	.21
March	72	4	40.4	.98	77	9	42.0	.57
April	76	13	43.8	.99	.....	16	.....	.49
May	80	17	46.7	2.55	81	21	49.9	1.36
June	84	26	54.0	1.04	82	25	55.5	.58
July	88	36	63.0	2.41	89	38	64.0	.71
August	88	33	62.6	2.57	83	35	60.6	1.90
September	83	25	55.6	3.12	79	25	54.8	1.28
October	75	18	48.3	.60	76	17	48.9	1.32
November	65	1	31.4	.22	67	1	31.0	(a)
December	54	−20	24.3	1.64	49	−23	19.2	1.64
The year	.....	.....	.....	17.93	.....	.....	.....	10.38

a Less than 0.005 inch.

CHAPTER II.

GEOLOGY.

STRATIGRAPHY.

GENERAL STATEMENT.

The deposits in which the coal was originally formed are a part of a great series of sedimentary strata that were laid down at a time when this part of the continent was largely submerged. The submergence probably ranged from deep sea to shallow water and swampy conditions, as well as from salt-water or marine to brackish and fresh water stages. These strata were deposited in an approximately horizontal position. Subsequent movements of the earth's crust have folded or even broken the originally continuous deposits, so that it is now necessary to study their attitude and order of superposition in order to explain the relations of one set of beds to another. Their position in the stratigraphic section indicates in a general way their relative geologic age, although there are also evidences that great time intervals have elapsed in which no deposits were being formed, or in which material was being laid down that was subsequently removed, leaving little or no record of its existence.

The coal-bearing strata of northwestern Colorado are for the most part of Upper Cretaceous age, although they also belong, in part, to the lower Tertiary, with an occasional and relatively unimportant bed of coal or carbonaceous material in rocks older than the Cretaceous. For this reason the areas examined in the present work were limited largely to those regions occupied by Upper Cretaceous and Tertiary formations. The territory adjacent to the coal fields proper exhibits strata representing a wide interval in the geologic time scale, including a series of rock formations ranging in age from the ancient pre-Cambrian gneisses and granitic rocks to the modern deposits now forming in the river valleys.

Two general sections of this region, which are as complete as present information allows, are represented in figure 3, one showing the stratigraphic succession in the Green River Basin and the western Rocky Mountain foothill region, and the other that in the Grand River Basin and the foothill strata of the eastern Uinta Mountains. These two mountain systems form the extreme limits of the coal fields here described, and by relatively greater amount of deformation and uplift reveal the older rocks that underlie the coal-field areas. Since the

chief interest in the coal fields is limited to the upper part of the stratigraphic section, namely the Cretaceous and overlying Tertiary

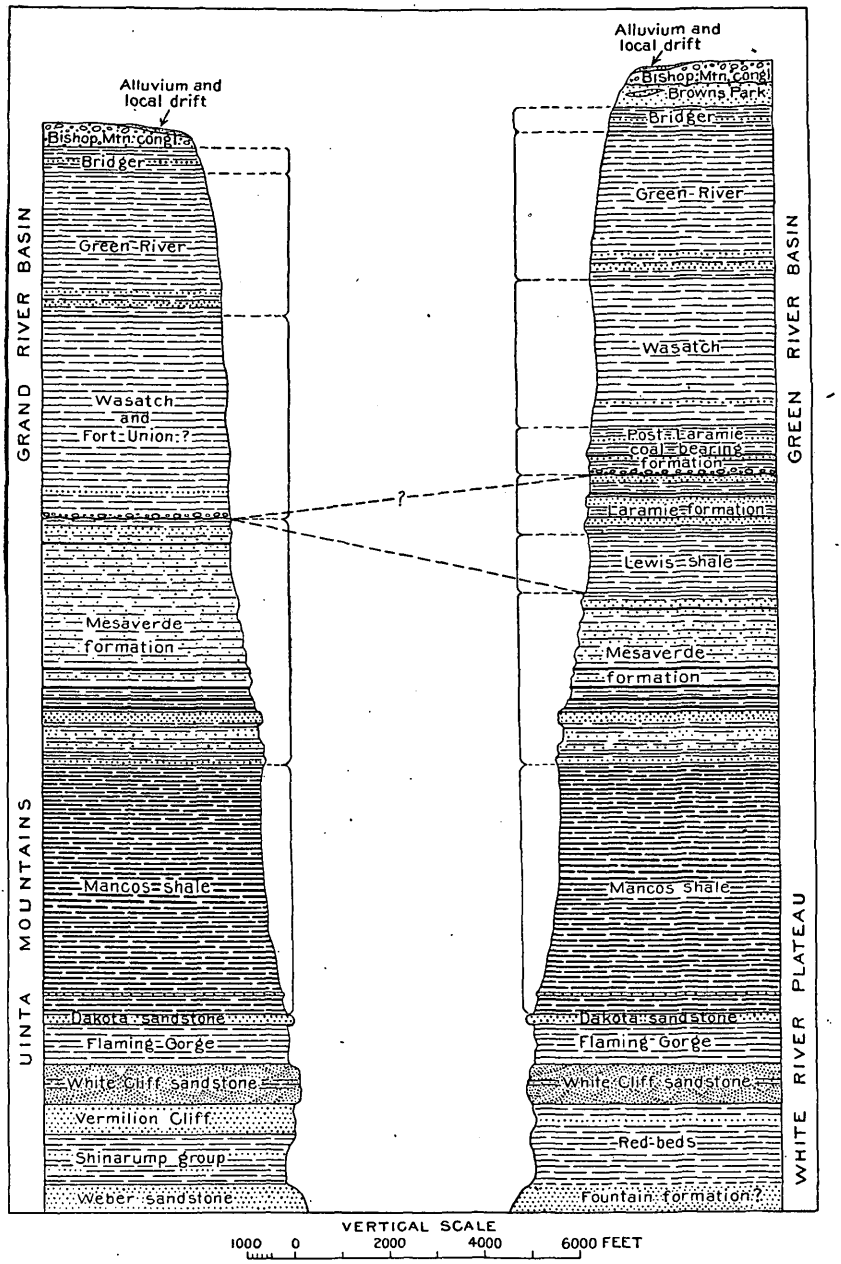


FIGURE 3.—Generalized stratigraphic sections of Grand River Basin (Uinta Mountains) and Green River Basin (Rocky Mountains foothills).

strata, a description of the older rocks is not included in the summary and only a brief review of them is included in this report.

The following summarized description of the Cretaceous and younger strata is given in tabular form for convenience of reference and direct comparison. It thus includes that part of the stratigraphic section that is most important to the study of the coal fields by themselves. More detailed descriptions follow (pp. 46–94).

Rock formations of the northwestern Colorado coal fields.

Geologic age.	Formation.	Description of strata.	Topographic features.	Thickness.	Economic value.
Probably late Tertiary or younger.	"Browns Park" formation.	Consists of loose or slightly consolidated sandy material with local harder sandstone beds and some beds of gravel. Contains much calcareous material in the form of cement or filling between the quartz sand grains. Its color is everywhere chalky or limy white.	Forms low sand hills or valley country, commonly covered sparsely with sagebrush, greasewood, cedar, or piñon. Typically exposed in Axial Basin about Juniper Mountain, and supposed to extend continuously northwestward into Browns Park.	Not determined.	
		Marked unconformity.			
Tertiary.	Green River formation.	Composed of shale, sandstone, and beds of oölitic rock. The shaly beds predominate and are very compact and firmly bedded. They are generally exposed in escarpments and high bluffs in which the weathered beds have a very characteristic chalky-white aspect. The shales are, however, of various shades of gray, drab, and light brown and are in many places hard and thin bedded. In some districts the lower part contains much massive white sandstone.	Characterized by plateaus where it is flat lying; these regions being bordered by high and abrupt escarpments at the margins or near the uptilted areas. This formation is only slightly affected by weathering except where broken or exposed in a tilted position. It is cut by deep canyons along the stream channels, as it readily gives way to erosion by the attrition of mechanically transported harder material. It is well represented in the Roan or Book Cliffs Plateau, the Cathedral Bluffs, and the Gray Hills.	Measured sections exceed 2,400 feet; upper limit not reached.	Gilsonite and related hydrocarbons in the Uinta Basin.
	Wasatch formation.	Composed chiefly of clay or soft clay-shale; commonly variegated, but various shades of red and drab predominate. It also contains beds of pebbles or conglomerate of very perfectly rounded silicious material, such as jasper, colored vein quartz, chert, or flint. Sandstones in places very massive and hard.	Commonly weathers to low valley or ridge country, at some places scarred by badland washes. It is usually distinguished by the banded or colored clays in the bluffs underlying or adjacent to the escarpments of the Green River formation. Cactus Valley, on Grand River, is eroded from these beds.	From 4,000 feet on the eastern side of the Uinta Basin to about 2,500 feet near the Utah line.	Oil and asphaltum deposits near Vernal, Utah.

Rock formations of the northwestern Colorado coal fields—Continued.

Geologic age.	Formation.	Description of strata.	Topographic features.	Thickness.	Economic value.
Tertiary—Continued.	Post-Laramie coal-bearing formation.	Beds not readily distinguished from the Wasatch in the Uinta Basin, but apparently more clearly differentiated in the Yampa field. As developed in the latter region they consist of massive white or light-colored sandstones and shales containing valuable coal beds sharply defined at the base by a conglomerate or conglomeratic sandstone, without doubt marking an unconformity of considerable magnitude.	Forms ridges and hilly country, especially where the sandstone members are prominent and numerous. Topography resembles that of the other coal-bearing formations, although not commonly so rugged as that of the Mesaverde.	Estimated as about 800 feet on Lay Creek north of Lay.	Workable coal.
			Unconformity.		
Cretaceous.	Laramie formation.	Consists of massive sandstones and light-colored sandy or clay shales and many beds of lignite or subbituminous coal. As mapped, this formation includes the strata in which the massive sandstones are most prominent as distinguished from the softer strata of the underlying Lewis shale. As a whole the formation represents the transitional deposits of brackish or fresh-water origin, conformably overlying the uppermost marine formation. The lowermost sandstones mapped with the Laramie contain a marine fauna similar to that of the underlying Lewis shale.	In the eastern part of the Yampa River valley the Laramie is clearly distinguished from the underlying Lewis both lithologically and in its effect on the topography. It is similar to the overlying and supposedly lower Tertiary beds, from which it is distinguished only by the presence of the intervening conglomerate and evidence of unconformity. In the western part of the region the lower limit of the Laramie is less clearly defined, as the sandstones probably occur lower than they do farther east. The base of the formation is well represented at Hayden, in the escarpment bluff north of Yampa River.	Estimated as 1,200 feet between Craig and Lay.	Workable coal.
	Lewis shale.	Composed largely of soft dark-gray or black clay shale with calcareous seams and sandy beds, the latter developing in many places as massive and continuous ledges. The absence of the sandstones is the most prominent distinction between the Lewis and the overlying and underlying formations.	The outcrop of the Lewis shale is commonly marked by low valleys bounded on one side by the sandstone ridges of the Mesaverde and on the other by the escarpments of the Laramie. In the western part of the Yampa field the distinction is not so well marked, as sandstone occurs within the interval assumed to represent the Lewis.	Roughly estimated 1,000 feet in the valley of Horse Gulch.	Develops some valuable agricultural land on alluvial material along the valley bottoms.

Rock formations of the northwestern Colorado coal fields—Continued.

Geologic age.	Formation.	Description of strata.	Topographic features.	Thickness.	Economic value.
Cretaceous—Continued.	Mesaverde formation.	Includes an alternating succession of sandstone, sandy shale, and coal beds. The most prominent members are the massive white or light-colored sandstones. The weaker shaly members are more commonly covered by débris of the harder beds. The coal beds are even more generally concealed, although their positions are rendered conspicuous by the great amount of burning that has taken place along the outcrop.	Forms hogback ridges and rugged, hilly country. The topographic forms are usually strong, contrasting with the valleys of overlying and underlying formations. The character of the ridges is chiefly dependent on the attitude of the underlying strata. Where steeply tilted the harder beds form sharp-crested hogbacks, and where more nearly horizontal they form broader flat or round-topped ridges bordered by escarpments or long, gentle dip slopes.	From about 3,000 to over 5,000 feet.	Coal. This formation commonly includes many thick beds of good bituminous coal.
	Mancos shale (including Benton fossils in its lower part).	A thick mass of dark drab or gray shale, containing lenticular members of sandstone or sandy strata, and near its base very constantly one or more beds of fine-grained dark sandstone and some limestone. In Utah the lower sandstone is lighter colored, coarse, and more prominent. In that part of the field coal is also found associated with these lower sandstone members. At the base is a compact dark slaty shale.	Forms open valleys and broad parks, many of which are extensive. These are commonly traversed by some of the larger streams, and in places broad bottom lands are developed. The sides of the valleys generally show terraces or "mesas" at various elevations above the valley bottoms. All these features are well represented in Agency Park, Axial Basin, Raven Park, and elsewhere.	5,000 feet.	Oil in the Rangely district. Agricultural lands where favorably situated. Workable coal near the base in the Vernal district.
	Dakota sandstone.	Commonly consists of two or more members of massive sandstone or quartzite, in many places conglomeratic, with sandy or clay shale intervening. In places carbonaceous shale is found in this formation. It is limited at the base by varicolored clays, clay shales, and associated strata now supposed to belong to the Jurassic.	Is developed as an independent hogback where tilted, and differentiated by intermediate shale bodies from the underlying Jurassic sandstones. Very commonly combined with the latter in high, sharp hogbacks with elevated broad dip slopes usually covered with brush or timber.	From 100 to 300 feet or possibly more.	

PRE-CRETACEOUS ROCKS.

Work on the older rock formations of the region is very incomplete and the present knowledge of these rocks somewhat meager. The only direct comparison of the older Mesozoic, Paleozoic, and still more ancient rocks of the Uinta and Rocky Mountain systems available at present is to be found in the literature of the King and Hayden surveys. Although the Cretaceous and Tertiary formations may be traced continuously from one province to the other, the older rocks are not continuous at the surface, but are exposed in a few isolated patches and also in somewhat uncertain structural relations. The problems of more precise correlation of these older formations in the two mountain groups are of much geologic interest, which will probably demand much further study before they can be thoroughly understood.

The following fragmentary descriptions of the pre-Cretaceous rocks are therefore but a preliminary contribution to the future study of this part of the subject, and in view of the present rather uncertain correlation between the older rocks of the two extremities of the coal-field area these two mountain regions are separately described.

EASTERN UINTA MOUNTAIN REGION.

GENERAL STATEMENT.

The pre-Cretaceous section of the eastern Uinta Mountains has been studied in somewhat more detail in the northwestern Colorado region than has the corresponding section of the western Rocky Mountain foothills. The literature on the subject will be found in the reports of the King, Powell, and Hayden surveys; in a paper by C. A. White,[a] and in more recent papers by Berkey[b] and Weeks.[c] The following summarized table is based on the descriptions of these writers, together with the author's somewhat slight acquaintance with the stratigraphy in territory beyond the area of this report.

Pre-Cretaceous formations of the eastern Uinta Mountains.

		Approximate thickness (feet).
Jurassic	Flaming Gorge formation	800
	White Cliff sandstone	800
Triassic	Vermilion Cliff sandstone	600
	Shinarump group	1,000
Carboniferous	Weber sandstone	2,500
	"Wasatch" limestone	1,000
Ordovician	Ogden quartzite	Absent.
Cambrian	Lodore shale	500
Algonkian (?)	"Uinta" quartzite	12,000+

[a] White, C. A., On geology and physiography in a portion of northwestern Colorado and adjacent parts of Utah and Wyoming: Ninth Ann. Rept. U. S. Geol. Survey, 1889, pp. 677–712.

[b] Berkey, C. P., Stratigraphy of the Uinta Mountains: Bull. Geol. Soc. America, vol. 16, 1905, pp. 517–530.

[c] Weeks, F. B., Stratigraphy and structure of the Uinta Range: Bull. Geol. Soc. America, vol. 18, 1907, pp. 427–448.

The terms "Wasatch" and "Uinta" have also been applied to formations in the Tertiary beds of this same general region, but in the foregoing table they are used in the sense in which they were applied to the older rocks.

"UINTA" QUARTZITE.

The oldest sedimentary rocks of the Uinta Mountains exposed in the territory adjacent to the coal fields are the red and white quartzites that form so prominent a feature throughout the entire length of that mountain range. These rocks were named the Uinta group by Powell in his early work in that region, the name first appearing in his report,[a] in which the formation is provisionally referred to the Devonian.

It is described as the Weber quartzite in the reports of the Fortieth Parallel Survey and was then considered equivalent to the Weber quartzite of Nevada and of Carboniferous age.[b] In a later article, based on C. D. Walcott's work, S. F. Emmons suggests its Algonkian age. The name "Uinta" was used by C. A. White in the Hayden Survey report,[c] although in the main body of the same report the formation is referred to as the Weber quartzite. Later,[d] White applies the term "Uinta" to the same formation, describes the various views relating to its age, and includes it in the Paleozoic in the tabular statement of formations.

The "Uinta" quartzite forms the crest and core of the main axis of the Uinta Mountains, and extends eastward into Colorado nearly as far as the junction of Little Snake and Yampa rivers. It is also exposed in the valley of Yampa River east of Little Snake River, and in isolated patches on the Cross Mountain and Juniper Mountain uplifts in Axial Basin.

The formation in the Uinta Mountains is composed largely of heavy-bedded sandstone and quartzite with intervening bodies of shale and some massive conglomerate beds. The color characteristic throughout the Uinta Range is a dark brick-red or reddish brown, although some beds of light-colored or white sandstone and quartzite occur. At places the rock is banded or of a gneissoid structure. The thickness is said to exceed 12,000 feet, although the base of the formation is nowhere exposed. It is the oldest formation recognized in the Uinta Range. No fossils are reported to have been found in these rocks, and their pre-Cambrian age is merely inferred from their stratigraphic position and suggested correlation with beds in the Wasatch Mountains of Utah, where the evidence of their age is somewhat clearer.[e]

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[a] Powell, J. W., Geology of Uinta Mountains: U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1876, pp. 41, 61, 141.

[b] U. S. Geol. Expl. 40th Par., vol. 2, 1877, pp. 343 et seq.

[c] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, p. 20.

[d] White, C. A., Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 687.

[e] Emmons, S. F., Orographic movements in the Rocky Mountains: Bull. Geol. Soc. America, vol. 1, 1890, p. 258.

Late work on the stratigraphy of the Wasatch Mountains has suggested the possibility, at least, that the "Uinta" quartzite may in fact be largely Algonkian, but that it may also include a considerable Cambrian section (corresponding to Walcott's Brigham formation of the Wasatch Mountains) in its upper part, and has suggested a search for evidence of unconformity similar to that which has been discovered in the great Cambrian and pre-Cambrian quartzite sections at a number of widely separated localities of the Cordilleran region, from Canada to Nevada.

LODORE SHALE.

The Lodore shale is described as next succeeding and overlying the "Uinta" quartzite in the eastern Uinta Mountains section. These beds were not studied nor recognized in the present work and the descriptions given are taken from other sources in order to record the complete sequence in this part of the field. The beds are described and named from Lodore Canyon of Green River below Browns Park. They are said to be about 500 feet thick and are now thought to be of middle or upper Cambrian age, although no authentic record of fossils from this formation is known for this general region. They are described by Weeks[a] as "argillaceous and sandy, green, red, and purple shales overlying the greenish sandstones which form the upper part of the Uinta sandstone."

OGDEN QUARTZITE.

The Wasatch section, as interpreted by the geologists of the Fortieth Parallel Survey, contained a middle Paleozoic quartzite, the Ogden, lying between the lower Carboniferous limestone above and the early Paleozoic limestones below. Recent studies of Wasatch stratigraphy by Eliot Blackwelder indicate that the prominent body of quartzite in Ogden Canyon, which is the typical locality of this formation, has proved to be but a repetition of the Cambrian quartzite due to faulting. Blackwelder states that there are thin beds of quartzite in the midst of the Paleozoic section, but that they do not constitute either a thick or a persistent formation.

According to Weeks,[a] the formation is apparently absent in the eastern end of the Uinta Range and on its north side, leaving the underlying Lodore shale immediately succeeded by the Mississippian limestones.

"WASATCH" LIMESTONE.

Rocks in part of Mississippian (lower Carboniferous) age were denominated the Wahsatch limestone by King,[b] Emmons,[c] and Hague.[d] The formation is described as made up of a great thickness,

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[a] Op. cit., pp. 436–437.
[b] Am. Jour. Sci., 3d ser., vol. 11, 1876, pp. 477–480; U. S. Geol. Expl. 40th Par., vol. 1, 1878, pp. 127–248.
[c] U. S. Geol. Expl. 40th Par., vol. 2, 1877, pp. 343 et seq., 446.
[d] Idem, pp. 401–422.

largely of limestone of various shades of color, in part abundantly filled with chert. As described, it undoubtedly includes the Mississippian, but its upper part is generally conceded to be Pennsylvanian. The name Wasatch has been accepted, on the grounds of priority and established usage, to define a formation in the Tertiary of this same general region, and therefore is not officially accepted by the Geological Survey as the name for this older group of strata. When these rocks shall be studied in greater detail, this whole group will doubtless be subdivided into formations for which new names will be adopted.

WEBER SANDSTONE.

Overlying the massive limestone formations of the eastern Uinta region is a considerable thickness of massive sandstone that has been correlated with the Weber quartzite of the western Uinta and Wasatch Mountain section. The formation is described as quartzitic farther west, but is a rather soft sandstone in the areas adjacent to the fields studied in the present work. As there observed, it is largely composed of massive white sandstone commonly forming prominent bluffs or canyon walls. The localities at which this formation was observed in the present work include both flanks of the Uinta Range. The Weber sandstone is exposed by erosion at the crest of the Midland anticline at the south side of Blue Mountain in Colorado, where it forms the center of the oval basin south of the Midland Ridge. It was also observed in the Horseshoe Canyon just south of Flaming Gorge on the north side of the range, where it very clearly underlies the mass of shale, including minor harder layers, next described as the Shinarump group.

SHINARUMP GROUP.

The Shinarump group was named by Powell from the Shinarump Cliffs in southwestern Utah and northern Arizona, where it is typically exposed. As observed in the canyon of Green River, at the Flaming Gorge and at other localities, and also as described by Powell, it is composite, including two or more formations which will probably be distinguished and separated with more detailed work. The term Shinarump has already been used in a more restricted sense as applied to a conglomerate bed which may be considered one of the formations of that group. As a group it is, however, a very convenient unit for purposes of description. It was thought by Powell to be Triassic in age, but later work is said to have obtained Permian fossils from its lower part, so that it is now generally conceded to be Triassic above and Carboniferous below.

It comprises a considerable thickness (on the south side of the Uinta roughly estimated at 1,000 feet, although possibly more) of

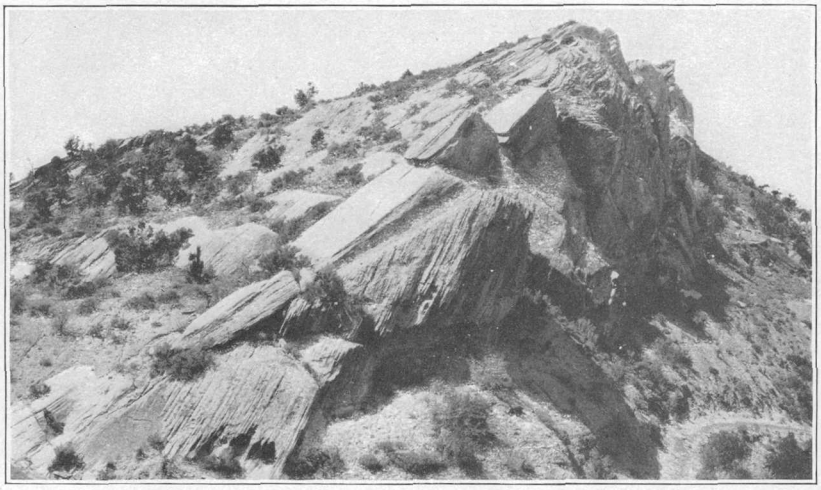
characteristically soft and bright-colored clays and shales. As these beds were not studied in much detail, only a general description will be included here. On the south side of Midland Ridge, which is a part of Blue Mountain in western Routt County, Colo., the beds immediately underlying the massive white cross-bedded Jurassic sandstone consist of a considerable thickness of red, brightly colored strata, probably in large part shale containing some limestone and sandstone layers. The Vermilion Cliff sandstone, which would be expected to occur at the top, was not distinguished in the present work. At one place in the valley of Skull Creek the total thickness of the group was found by rough measurement to be approximately 900 feet. The upper part of this is exposed as a broad band of vivid red in the long, continuous escarpment wall of the Midland Ridge. The lower shales or clays are gray, in marked contrast to the bright red, but include a streak of red through their middle. At places the red above appears to encroach irregularly into the gray beds below, but this is evidently due to the slipping and washing down of the material from the overlying beds.

The section of these same beds observed in the Green River canyon (Pl. VII, *B*) on the north side of the Uinta Mountains shows a rather striking correspondence to that of the Blue Mountain or Yampa Plateau region. As described by Powell, the section at the latter place is as follows:[a]

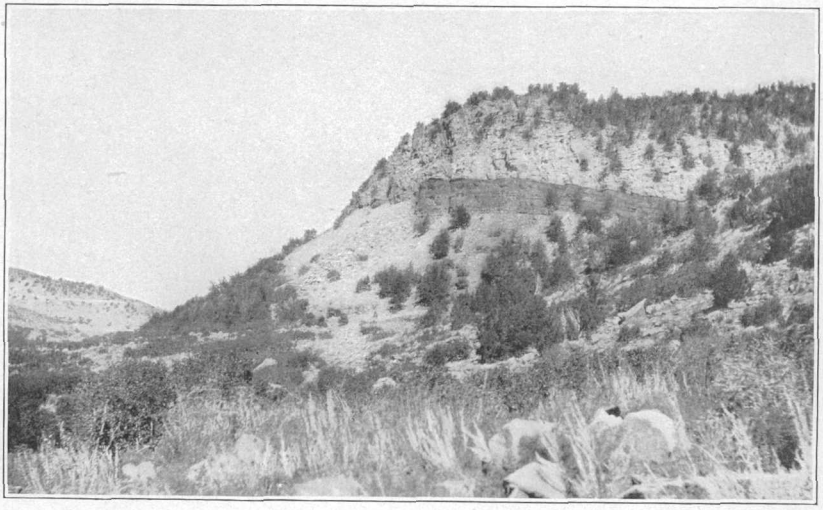
Section of the Juratrias groups in Flaming Gorge district.

	Feet.
FLAMING GORGE GROUP.	
1. Gray, greenish gray, pink, purple, and chocolate beds; very friable; badlands beds	110
2. Bluish-gray limestone; "Mid-Group" limestone	200
3. Coarse red sandstone; (Unio beds)	500
4. Limestone; bluish-buff; compact; sometimes shaly and interstratified with orange shales and thin beds of gypsum	250
WHITE CLIFF GROUP.	
5. Massive sandstone; light-gray and light-orange; everywhere exhibiting false stratification in many directions and at many angles	1,025
VERMILION CLIFF GROUP.	
6. Sandstone; massively bedded; gray, drab, and brown within, but weathering with bright vermilion surfaces; well exposed on the summit of Flaming Gorge	300
7. Shales somewhat argillaceous	6
8. Sandstones; rather friable, with intercalated shales; the latter containing much gypsum; weathering in variegated bright colors	359

[a] Powell, J. W., Geology of the Uinta Mountains, 1876, p. 152.



A. CROSS-BEDDING IN THE WHITE CLIFF SANDSTONE ON SKULL CREEK SOUTH OF BLUE MOUNTAIN.



B. UNCONFORMITY IN THE PRE-CRETACEOUS ROCKS ON WHITE RIVER ABOVE AGENCY PARK.

SHINARUMP GROUP.

	Feet.
9. Shales and sandstones containing much gypsum; weathering in many colors, but brown and chocolate tints prevailing; in many places constituting badlands beds [extending to the summit of the Bellerophon limestone]	1,095

This section was taken at about the locality represented in Plate VII, *B*, in which is shown practically the entire section of the Shinarump capped by the Vermilion Cliff group.

The strata of this same locality had already been described by Hayden.[a]

VERMILION CLIFF SANDSTONE.

As stated, the Vermilion Cliff sandstone described by Powell was not differentiated from the Shinarump group in the present work. As originally defined in the plateau country, the Vermilion Cliff sandstone is entirely distinct both geologically and topographically from the White Cliff sandstone overlying. In the eastern Uinta Mountain region, however, no well-defined line of distinction was observed. Red sandstone occurs in the escarpments of the White Cliff and Shinarump formations. A part of this may represent the Vermilion Cliff sandstone of the sections farther south, but without further study nothing can be added to the simple statements quoted above from Powell's report.

WHITE CLIFF SANDSTONE.

The name White Cliff was used by Powell to denote a massive white sandstone formation composing a high escarpment of that name north of Kanab River and the Grand Canyon of the Colorado, in southern Utah. He also states that the limestone immediately overlying that sandstone has been traced from point to point along the intermediate country for the entire distance from the White Cliffs to the Flaming Gorge.[b] As this correlation has been well borne out by subsequent work in the intermediate regions, the name is still retained in the northwestern Colorado section. The author has examined the exposures at the Flaming Gorge on the north of the Uintas and is well satisfied that the correlation of this formation with that south of the range is also correct. In each case it is underlain by "red beds" described as the Shinarump group, and is overlain by a corresponding and evidently equivalent section to be described (p. 53). Fossils obtained from the White Cliff sandstone on both sides of the range have been examined by T. W. Stanton, who assigns them to the marine Jurassic.

The White Cliff sandstone in the eastern Uinta region is composed of medium to coarse-grained massive white sandstone, whose predominating characteristic is a marvelous development of false or

[a] Hayden, F. V., Second Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1870-71, p. 61.

[b] Powell, J. W., Geology of the Uinta Mountains; Rept. U. S .Geol. and Geog. Survey Terr., 1876, p. 52.

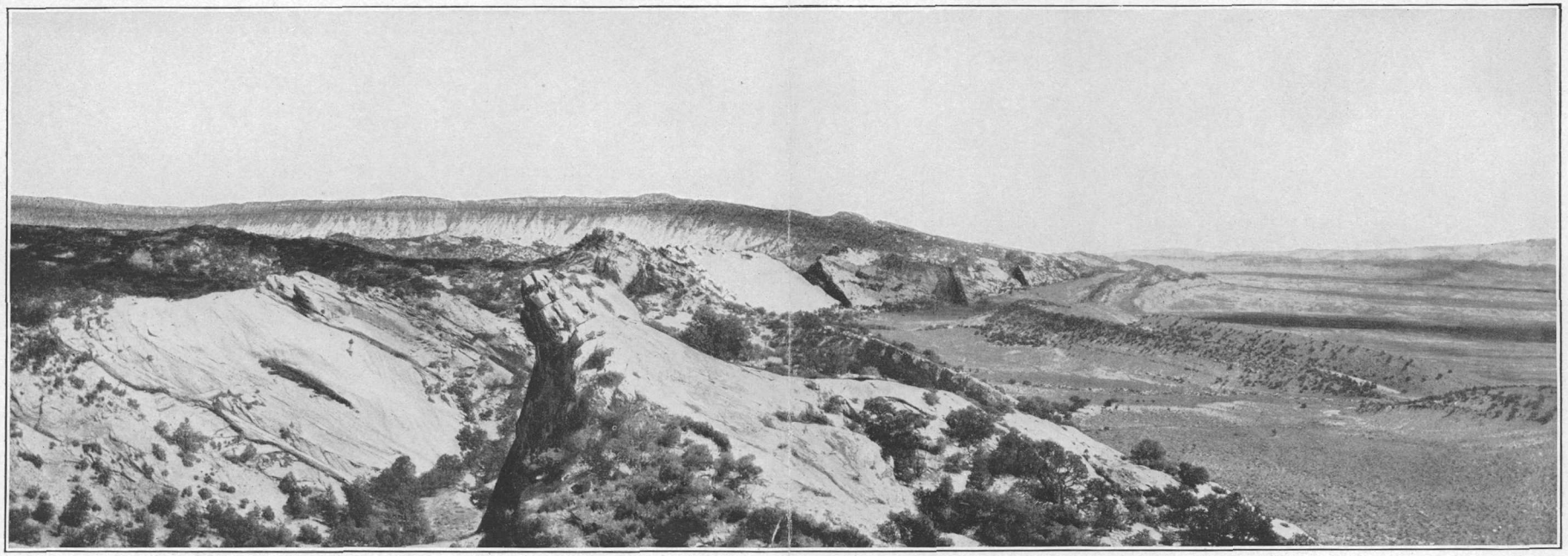
cross-bedding structure. This structure is a constant characteristic throughout the eastern Uinta region, as also in the eastern margin of the coal-field area, along the foothills of the White River Plateau, which will be mentioned in a subsequent paragraph. Plate III, *A*, shows its occurrence on Skull Creek, east fork of Red Wash, (sec. 36, T. 4 N., R. 101 W.), and shows a small portion of the large thickness of similar beds and structures that are well exposed at that place. The panoramic view shown in Plate IV, *A*, overlooks the locality of this detailed view and better illustrates the general character of the whole formation, which includes the rock from which the view was taken, and extends directly away from the point of sight along the strike of the strata. The thickness of these beds measured at the Skull Creek locality is about 800 feet, including an interval of bright-red sandy shale or clay about the middle of the formation. This red clay resembles the brilliantly colored beds of the underlying shales already described. The thickness here given is thought to represent a fair average of the formation for this part of the field.

The White Cliff sandstone is commonly exposed in prominent ridges or cliffs, many of them composed of bare rock ledges with little soil or vegetation. By reason of its nature, being more resistant than either of the formations immediately overlying or underlying, it is usually a distinct topographic feature, especially where exposed in a tilted position. Its character is well illustrated in Plate IV, *A*. In more horizontal position it caps much of the high summit of Blue Mountain or Yampa Plateau, and is a most prominent feature at the lower end of Green River canyon near Vernal, Utah, where it forms the upper walls of the Split Mountain Canyon, and composes a great, bare, rocky escarpment, known as Section Ridge on the old Hayden, King, and Powell maps. On the north side of the Uinta Mountains it is well exposed in the Boars Tusk, just east of the Flaming Gorge, and also at the entrance to the Flaming Gorge Canyon itself, as well as at many other localities east and west of that place.

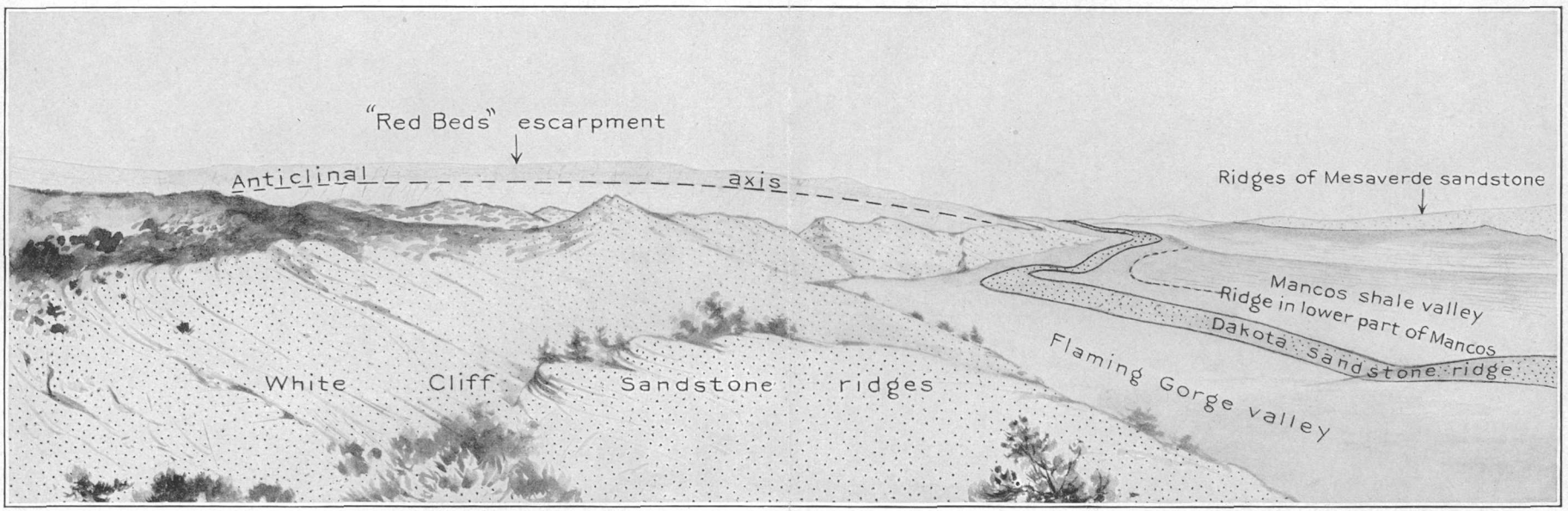
The only fossils reported in this formation so far as the author knows were collected in this field during the present work. The locality of one of these collections south of the mountains has been mentioned in a description of the Blue Mountain carnotite deposits.[a] Here, imbedded in the massive sandstone, were found two species of shells, which have been determined by T. W. Stanton as *Trigonia quadrangularis* H. and W. and *Tancredia* sp.

Collections from this formation gathered on Green River near the mouth of Flaming Gorge Canyon were determined by T. W. Stanton as containing *Rhynchonella myrina* H. and W., *Trigonia* sp., *Ostrea strigilecula* White, *Lima occidentalis* H. and W., and *Camp-*

[a] Carnotite and associated minerals in western Routt County, Colo.: Bull. U. S. Geol. Survey No. 340, 1908, pp. 257-262.



A. SOUTHERN MARGIN OF BLUE MOUNTAIN.



B. DIAGRAM EXPLAINING STRUCTURE AND STRATIGRAPHY OF THE BLUE MOUNTAIN VIEW.

tonectus bellistriatus Meek. These are distinctive of the Jurassic age of these beds.

FLAMING GORGE FORMATION.

Next succeeding and overlying the White Cliff sandstone is found an almost equal thickness of softer shaly beds, also of Jurassic age as determined by their fossils, that were described by Powell in the Uinta Mountain report by the name of Flaming Gorge group. The name is derived from the Flaming Gorge, a cliff at the point where Green River enters its canyon in the Uinta Range about 2 miles south of the Utah-Wyoming state line. Since the locality from which this name is derived lies within a part of the field described in this report, a rather complete account is given of the type locality.

The Flaming Gorge itself is cut from strata older than those of the formation to which the name has been applied, and the beds of the Flaming Gorge formation are not exposed in the outcrops at the mouth of the Flaming Gorge Canyon. The Flaming Gorge formation is, however, fairly well exposed about 5 miles to the west in the narrow longitudinal valley south of and parallel to the Lucerne Valley. The beds outcropping at this locality have been described in some detail by Powell and also by Hayden, who are quoted on the subject elsewhere (pp. 50–51). As observed and measured by pacing in 1907, this part of the section is about 1,000 feet thick. At the base is a bed of compact limestone lying on the upper dip slope of the White Cliff sandstone ridge, which here dips 22° NW. Above the limestone, clays are exposed of bright pink and whitish or marly beds higher up, these soft light-colored deposits extending up in the section to a stratum of white sandstone that occurs about midway in the whole formation. Above the white sandstone variegated clays or shales continue throughout the remainder of the formation, up to the double ledge of massive white sandstone supposed to represent the overlying Dakota. Powell records the following fossils from these beds in the vicinity of Flaming Gorge: *Pentacrinus asteriscus* M. and H., *Rhynchonella gnathophora* Meek, *Ostrea strigilecula* White, *Trigonia americana* Meek, *Trigonia conradi* M. and H., *Unio stewardi* White, and *Belemnites densus* M. and H.

South of the Uinta Mountains the Flaming Gorge formation is exposed continuously from the vicinity of Lily Park westward beyond Green River in Utah and probably also much farther. Its character is very similar to that in the section already described near the type locality.

In sec. 35 T. 4 N., R. 104 W., Colorado, 2 miles south of K ranch, near the Colorado-Utah state line, the following section was observed: At the base, immediately overlying the massive cross-bedded white sandstone of the White Cliff, there is an interval com-

posed of fine-grained, dark-greenish sandstone and sandy shale, including some dark-colored calcareous beds containing abundant fossils. (See list below.) Above these fossiliferous strata beds of fine dark-colored shale are succeeded by about 75 feet of thin-bedded ripple-marked sandstone of rather fine grain and dark color. These darker, somber-colored beds occupy the lower 130 feet thickness of strata, and are thought to be the marine Jurassic part of the formation at this place. Above them is found about 650 feet of varicolored beds characteristically of shades of clear light pink and green, but containing also some greenish sandstone and conglomerate of hard, dark, siliceous material, sometimes cross-bedded, closely resembling the thick bed above, which has usually been classed with the overlying Dakota sandstone, though possibly representing part of the period of fresh-water Jurassic deposition. The total thickness measured is 780 feet.

Another similar section measured on Skull Creek, about 20 miles east of this locality, also gave a total thickness of 780 feet for the whole formation.

As these beds are relatively weak and easily eroded they commonly form low valleys except where protected by overlying beds of more resistant sandstone and conglomerate. Where exposed in tilted positions, as is commonly the case, they form narrow longitudinal valleys between the ridges of the White Cliff sandstone on the one side and of the Dakota conglomerate or sandstone on the other. Where capped and preserved by the Dakota ledges they frequently show in escarpments of bright banded and mottled colors, washed and gullied into a badlands surface.

The fossils occur near the base of the formation and are determined as marine Jurassic forms. The following species from these localities have been determined by T. W. Stanton: *Ostrea strigilecula* White, *Eumicrotis curta* (Hall), *Belemnites densus* M. and H., *Cardioceras cordiformo* var. *distans* Whitfield?, *Trigonia* sp., *Tancredia? inornata* Whitfield, *Ostrea* sp., and *Astarte* sp.

The Flaming Gorge formation is thus shown to be of marine origin in its lower part. By analogy with other and better known sections the upper and predominatingly varicolored beds are supposed to be of fresh-water origin, corresponding to the Morrison formation of the section east of the Rocky Mountains. It may prove possible to distinguish the marine from the fresh-water Jurassic beds of this formation, perhaps even by the difference of lithologic character alone, when sufficient fossil evidence has been obtained to establish the change; but this subdivision was not attempted in the present work.

The Flaming Gorge is, with little doubt, the equivalent of the McElmo formation, as this has been mapped and described in

southwestern Colorado, and is probably equivalent in part to the Gunnison formation as defined in the Anthracite-Crested Butte region of Colorado, although the Gunnison probably also includes the equivalent of the White Cliff sandstone.

ROCKS OF JUNIPER MOUNTAIN.

The easternmost occurrence of the pre-Cretaceous rocks of the Uinta Mountain region is in Juniper Mountain, an isolated summit that has received special mention in former publications under the name of Yampa Peak. In this locality a unique type of structure has brought the oldest of the sedimentary formations into intimate association with the latest Cretaceous and Tertiary rocks in the midst of the coal-field areas. This peak and a similar feature farther west known as Cross Mountain (Junction Peak of the early surveys) are isolated upthrust masses which have evidently reached their present position by sharp flexing and faulting combined. Whatever the forces that produced these peculiar structures, they have had but little influence upon the surrounding strata. In Juniper Peak the main body of the mountain is composed of hard red quartzite and sandstone, including conglomeratic layers similar in all respects to the typical quartzite and sandstone of the main core of the Uinta Range. The summit and northern flanks of the peaks are composed of massive or irregularly bedded white, gray, or pinkish limestone, some of which is very completely recrystallized. This contains much chert in seams or knots, and is also abundantly fossiliferous. A collection gathered at the main summit of the peak has been examined by G. H. Girty, who identified the following forms: *Menophyllum ulrichanum, Fenestella* sp., *Schuchertella inflata?, Chonetes illinoisensis,* and *Spirifer centronatus.* In this connection Doctor Girty says: "The age of this lot is lower Mississippian, a fauna resembling that from the upper part of the Ouray limestone of Colorado, the lower part of the 'Wasatch' limestone of Utah, and the Madison limestone of Wyoming. It is also the equivalent of the Leadville limestone of Colorado."

The formations succeeding this limestone are not well exposed in the vicinity of Juniper Mountain, as most of them are weaker and more easily eroded and are covered by the recent unconformable Browns Park beds, if not cut out near the surface by faults.

WHITE RIVER PLATEAU REGION.

GENERAL STATEMENT.

Knowledge of the stratigraphy of the pre-Cretaceous rocks in the general region of the White River Plateau is even more incomplete than that relating to the eastern Uinta Range. The White River

Plateau is structurally a spur of the Rocky Mountain system. The details of the correlation of the pre-Cretaceous section of this part of the Rocky Mountains with the corresponding section of the eastern Uinta Mountains will probably be worked out in the areas adjoining the fields here described. The fragmentary evidence that has been collected is here given as a contribution toward this future work.

As shown in the Hayden atlas of Colorado, ancient igneous and metamorphic rocks are known to be exposed in the interior of the White River Plateau region. They have been described in the Hayden reports as of Archean age, and are similar to the complex of older rocks that forms the main cores or axes of uplift of the Rocky Mountains. These are surrounded by superimposed sedimentary strata that have been designated and mapped as Silurian and "Lower," "Middle," and "Upper" Carboniferous of the Paleozoic era. Only some comparatively meager descriptions of these older rocks are given in the Hayden reports, and to these but little detail has been added in later days or in the present work. The Carboniferous formations are composed largely of massive limestone and intercalated shales, such as are exposed in the vicinity of Glenwood Springs on Grand River. No more than mere suggestions as to the correlation of these rocks with the section described for the eastern Uinta Mountains can be made here.

JURASSIC AND TRIASSIC ROCKS.

Two localities have been visited where the sequence into older Mesozoic rocks below the Cretaceous shows much similarity to that of the corresponding formations in the Uinta Mountains. These are the sections exposed in the canyon of White River within the first 6 or 8 miles above or southeast of the open valley of Agency Park, and that of upper Coal Creek on the western flanks of Sleepy Cat Mountain.

White River section.—White River leaves its canyon and enters the broadly open valley of Agency Park about 9 miles above Meeker. At this point it crosses ledges of supposed Dakota sandstone, which dip northwestward to northward at an inclination of about 10°. The roadway, which is dug into the hillside 50 feet or so above the level of the river, exposes 20 to 30 feet of the hard, massive, white quartzite that constitutes the ledges. Below the uppermost of these a small thickness of dark-greenish clay rock outcrops, and under this is a considerable thickness of hard sandstone and quartzite, with some conglomerate, a rock that has been supposed to be characteristic of the Dakota in its basal part.

Below the supposed Dakota is an interval of about 700 feet of softer beds which are probably equivalent to the Flaming Gorge formation of the Uinta Mountain section. These rocks consist of

indurated clays of a dark-greenish cast, together with some sandstone beds; also white clay, and clays of mottled colors, such as green, purple, gray, red, pink, etc. These clays include also one or more beds of hard, dense, or compact gray limestone speckled with grains of glassy quartz, like that said to be characteristic of the Morrison formation east of the Rocky Mountains; this rock is frequently found strewn in the débris slopes, although it was not discovered in place. The lower 300 feet of the interval is composed predominantly of thick, slabby sandstone of whitish color. These rocks are exposed along the roadside just north of the old 10-mile post from Meeker.

Immediately below the white slabby sandstone is a massive white sandstone, finely banded and amazingly cross-bedded; outcrops occur at the roadside immediately opposite and south of the 10-mile post. This formation appears to be about 500 to 600 feet thick, at a rough estimate. By reason of its stratigraphic position and its constitution, color, and cross-bedding, it is thought to represent the horizon of the White Cliff sandstone of the Uinta Mountain section.

Below the cross-bedded white sandstone, and separated from it along a rather distinct line of demarcation, is a similar thickness of brilliantly colored vermilion sandstone or sandy shale, apparently grading downward into brilliant red shale or clay, composing a thickness of several hundred or possibly a thousand feet.

The base of the bright-red strata and the top of an underlying group of light-colored sandy and shaly beds has the appearance of an erosional unconformity. The view shown in Plate III, *B*, is taken from the public road a little over half a mile south of the 10-mile post from Meeker. The distinct line of division near the middle of the cliff sharply separates the brilliant red strata above from the paler red or whitish beds below, and also discloses a noticeable divergence of dip in the bedding. Although in formations as markedly cross-bedded as many of those found in the stratigraphic section in this part of the field mere divergence of dip even on a relatively large scale can not be accepted as very strong evidence of a regional unconformity, this line nevertheless possibly marks an important stratigraphic horizon, and should be more carefully traced and studied in future work.

These rocks, below the cross-bedded white sandstone and underlying red sandstone strata, are thought to be equivalent, in part at least, to the Shinarump group of Powell in his eastern Uinta Mountain section. At some places, below the more brilliantly colored strata, are also found white and creamy-colored beds, including some of mottled red and white sandy and calcareous rock. At the base of the softer clays and shales of this interval and to a lesser extent intercalated with those beds there are several horizons of slabby or flaggy sandstone, in all 50 to 100 feet thick. This thin-bedded sandstone is

dark blue gray when fresh and white to yellow when weathered, resembling the Lyons sandstone of the Boulder section on the east side of the Rocky Mountains in Colorado.[a] It is found in strongly cross-bedded and also in compact thin-bedded exposures. These beds outcrop on the river bank just across the public road from the dwelling on the 5/T ranch.

Below these formations, a little east of the 5/T ranch, is found the first exposure on the river road of a rough red sandstone. It is somewhat differentiated from the overlying sandstones by its coarse arkosic texture as shown by the abundance of micaceous and feldspathic material. The rocks supposed to be equivalent to these beds in the Uinta Mountain section have been described as Weber sandstone. It is thought that these formations may be correlated with a sandstone of similar character and position on the east of the Rocky Mountains, there known as the Fountain formation, and assigned to the base of the Triassic and the top of the Carboniferous systems.

Here, as in the Uinta Mountain section, the massive, cross-bedded white sandstone (White Cliff?) seems to be the most resistant member of the whole series, and caps the summit of the highest cuesta, whose broad dip slope faces the open valley of Agency Park. Here also the vivid coloring of the "Red Beds" underlying shows on the lower steep slope of the ridge facing the upper river canyon to the south.

Coal Creek section.—In the upper valley of Coal Creek a section similar to that of the upper White River valley is revealed. The section there is also readily accessible, being traversed by a road leading up the canyon that cuts almost directly across the strike or outcrop of the tilted beds. At the lower end of the canyon, on the western slope of Sleepy Cat Mountain, the beds supposed to represent the Dakota sandstone are crossed. These dip 50° to 60° W. In these outcrops an upper group of two small quartzite ledges are now provisionally assigned to the true Dakota. The stratigraphic interval below these is largely concealed, but appears to be composed of softer strata of about 400 feet total thickness. Underneath these there is a heavy stratum of massive white sandstone or quartzite, underlain by another 400 feet or so of weaker shaly beds. Of the beds thus described, the upper interval of shales is probably the equivalent of the Flaming Gorge formation of the eastern Uinta Mountain section.

The representative of the White Cliff sandstone is found in the next succeeding and underlying beds. A total thickness of 700 feet was measured from the uppermost massive white sandstone, below the beds assigned to the Flaming Gorge formation, to the base of the massive white sandstone ledges. Here also the most prominent characteristic is the great development of cross-bedding in the white sand-

[a] Fenneman, N. M., suggestion made in personal conference.

stone. The beds occupy the summit and escarpment front or edge of the highest ridge extending north and south from the creek valley.

Below the White Cliff sandstone the steep bluff is composed of brilliantly colored strata, chiefly of sandstone and sandy shale of various shades of red. These beds extend down in the section for more than 1,000 feet, according to the measurements made, and at their base are found other sandstones similar to those noted in the White River section. The lower sandstones are probably of Carboniferous age (Fountain formation?), and may be provisionally correlated with the Weber sandstone of the Uinta Mountain section.

CRETACEOUS ROCKS.

GENERAL STATEMENT.

Except for one or two minor occurrences among strata of older geologic age, the northwestern Colorado coal fields all belong in the Upper Cretaceous and Lower Tertiary. The formations of these systems are, therefore, of chief interest in a study of the coal fields, as bearing the most direct relation to the occurrence and nature of the valuable coals.

The stratigraphic section of the Yampa coal field occupying the large structural basin north of Axial Basin is more complete than that of the Grand River Basin farther south. (See fig. 3, p. 42.) While two distinct coal-bearing formations, the Laramie and the Mesaverde, separated by a thick body of the Lewis shale, are present in the Yampa field, there appears to be but a single series of strata containing coal beds in the fields of the southern basin. As explained in detail later (pp. 220–232), the oldest important coal-bearing formation of the Yampa field is the equivalent of the whole coal-bearing formation of the fields of the Grand River Basin, and the Laramie formation is not present at all south of Axial Basin, the anticlinal axis that separates these two regions.

The section of Upper Cretaceous rocks as represented in the Yampa coal field is subdivided into the following formations: Laramie formation, Lewis shale, Mesaverde formation, Mancos shale, and Dakota sandstone. Beginning with the oldest, these formations are described in detail.

DAKOTA SANDSTONE.

The remarkable persistence of the lithologic character of the Dakota sandstone and its continuity of exposure over extensive areas has led to the acceptance of that formation as a key stratum for the correlation of widely distributed stratigraphic sections of the Mesozoic both above and below its horizon. Few fossils have ever been obtained from it in the territory adjacent to these coal fields, and its recognition there is based on tracing from other fields, on its

position immediately below the abundantly fossiliferous shales of the lower Mancos, and on its lithologic correspondence to the type widely accepted as characteristic of the Dakota sandstone in other western Cretaceous fields.

Character and distribution.—The Dakota is composed of sandstone or quartzite and sandy shale, with some conglomerate or conglomeratic sandstone strata. As mapped by the older surveys it also included some varicolored shales similar to those of the underlying Jurassic beds. The reason for this inclusion was that a second and in many places a most prominent zone of sandstone or sandstone and conglomerate strata was commonly found below the first occurrence of the varicolored shale, and the whole was naturally classed together as a single formation included between overlying and underlying softer clay shale formations. Evidence derived from recent stratigraphic work in neighboring fields tends, however, to indicate a necessity for subdividing this group and limiting the part to be classed as Dakota to the sandstones lying above the varicolored clays. Thus defined the Dakota would have a total maximum thickness of only about 200 feet, of which probably less than one-half is generally composed of the supposedly typical massive sandstone. In view of the uncertainty relating to the true delimitation of the base of this formation, estimates of its thickness are to be accepted as tentative only.

The lower sandstones (possibly older than true Dakota) are commonly more prominent as ridge makers than the upper beds mentioned in the preceding paragraph, and consequently form the highest parts of the hogbacks in which the whole group is characteristically exposed owing to the more or less tilted positions of the beds.

These rocks may be traced almost continuously, with relatively inconspicuous breaks where they happen to be concealed by overlying alluvium or post-Cretaceous basalt and lava flows, around the area of older strata of the White Plateau region, southeast of the coal fields here described, and similarly around the east end of the Uinta uplift. Granting that the lower members should be classed with the underlying Jurassic beds, the Dakota itself as a formation shows great uniformity of constitution throughout the area thus defined.

Fossils.—No identifiable fossils have ever been obtained from the Dakota in these fields. Some collections made by M. R. Campbell and G. B. Richardson in the Grand River valley near the Colorado-Utah state line contained leaves considered distinctive of this formation; and a few indeterminable fragments of leaves were found in the Dakota beds on the south side of Blue Mountain during the present work.

MANCOS SHALE.

Geologic relations.—The next formation above the Dakota is the Mancos shale, a thick mass of homogeneous clay shale with occasional more sandy layers. In this field it is considered as a single stratigraphic unit, although it has been formerly described and subdivided as indicated in the correlation table (opp. p. 90) into various formations largely on paleontologic grounds. The relation of Mancos shale to the subdivisions of the early geologic reports of this region is indicated by the horizontal arrangement of the intervals of the table corresponding to the Mancos interval in the part relating to later work. From these it may be seen that the Mancos includes all the Colorado and part of the Fox Hills, as classed in C. A. White's work, and that it also includes the Benton, the Niobrara, and a part of the Pierre, according to the classification of the Cretaceous that originated in the Meek and Hayden section of the upper Missouri River region and was later extensively applied in the Great Plains. In brief, the Mancos is intended to include all of the predominantly dark-colored shaly strata that conformably overlie the Dakota sandstone and apparently conformably underlie the massive sandstones of the next succeeding or Mesaverde formation.

Lower members.—Over a greater part of the region where the Mancos shale is exposed a portion at the base may be readily distinguished as a separate member of the formation. Immediately overlying the Dakota sandstone there occurs almost invariably 200 feet or more of dense, black, slaty shale, which usually forms long, narrow strike valleys next to the dip slope of the Dakota ridges, where these formations are exposed in their customary tilted positions. Above these lower slaty shales is found a similar thickness of shaly and sandy strata containing some more resistant beds of sandstone and calcareous rock. The harder beds commonly form a distinct line of minor hogbacks similar to those of the Dakota or underlying beds, though of lesser elevation and more largely composed of shaly strata. The sandy layers are ordinarily of dark color and of moderately fine and even grain and are usually flaggy or somewhat thinly bedded. These harder sandy beds, as well as the calcareous ones, are also commonly fossiliferous; in places abundantly so. Collections from this horizon at many localities have been examined by Doctor Stanton, who has assigned them to the upper part of the Benton. The member is probably equivalent to that mapped as Mowry shale member by Darton, who applied the name originally in the Bighorn Mountains region of Wyoming. The following species were identified from Willow Creek, at the southern side of Blue Mountain: *Ostrea lugubris* Conrad, *Inoceramus fragilis* H. and M., *I. dimidius* White, *Scaphites warreni* M. and H., and *Prionocyclus* sp.

Character and distribution.—Above the lower sandstones which yield the Benton fossils the Mancos shale formation maintains a very

constant thickness in all parts of the field where measurements have been made, approximating 5,000 feet, or about a mile. It is to all appearances of very homogeneous composition throughout, but the records of some deep wells drilled through it in the Rangely oil field distinguish layers described by the drillers as sandy. In some places also sandy beds or even occasional strata of massive and consolidated sandstone are known to occur along its outcrop. An example of this is found in Agency Park, where such sandy beds form a minor hogback. In this locality the horizon at which these beds occur passes directly through the center of the town of Meeker in the northeast-southwest direction, and the beds themselves are exposed along the ridge northeast of the town, as well as in the river bank along the south side. A similar horizon is noted in the upper valley of Coal Creek east of the "Transfer" in eastern Rio Blanco County. These beds are apparently of lenticular character and the examples given are probably as large as any similar lenses known in this region.

The upper part of the Mancos shale is perhaps more commonly exhibited at outcrops than any other portion of the formation except the lowest few hundred feet already described. By reason of the protection offered by the lowest sandstone layers of the next succeeding formation these topmost beds frequently occupy nearly the whole face of escarpment bluffs up to heights of 600 or 800 feet. Of this interval the lower portion is normally buried in the débris that slides down the steep slopes. As a whole, the shale in this part appears to be of lighter, more sandy aspect than that of the main body of the formation, but it is uncertain whether this is the result of its elevation in outcrops where it is subjected to long exposure to weather and consequent drying out of its natural moisture, or is due to difference of constitution in the upper part of the formation.

Disintegration.—By reason of its nonresistant nature this formation commonly weathers to a heavy clay soil cover with low, rounded slopes, and is rarely exposed in fresh condition. The soil is deep and compact, very hard when dry, but becoming a heavy, plastic mud when thoroughly wet. During the summer its surface usually cracks and fissures deeply in the dry air. Rains of short duration, such as frequently occur in that season, scarcely penetrate the soil at all, except as they fill these cracks. Surface water runs off rapidly, cutting narrow, vertical-sided channels or miniature canyons at places to depths of 50 feet or more. The gullies rapidly extend and deepen with each succeeding storm or flood, and in places the dissection becomes so intricate as to produce typical badlands. Such topography is developed in its greatest extreme near the western part of the districts here described, as, for instance, in Raven Park. In general, such districts are penetrable only with difficulty and by avoiding so far as possible the stream channels and traversing the dividing ridges.

The soil of the Mancos shale is commonly strewn with scattered fragments of selenite, which is the crystalline gypsum. This lies about on the surface of the ground, where it readily attracts the attention even at great distances by the brilliant glint of the sunlight on its flat, apparently polished crystal surfaces. It appears to be residual in the soil from the disintegration and removal of the original shale.

Fossils.—The fossils that have been found in the Mancos shale were mainly near the base (see list on p. 61) and in the upper layers, near the base of the next succeeding formation. The latter are of marine types, and were formerly considered by Doctor White to be characteristic of the so-called Fox Hills formation. The following is a list of species obtained during the recent work:

Fossils from the upper part of Mancos shale.[a]

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

MESAVERDE FORMATION.

Geologic relations.—The Mesaverde formation is the uppermost or youngest formation of the Upper Cretaceous section in the Grand River Basin, which includes all those coal fields south or southwest of Axial Basin. In the Yampa coal field and its extension northward into southern Wyoming the Mesaverde is overlain by still other Cretaceous formations, which have no representatives in the stratigraphic succession of the southern fields. In both basins the Mesaverde conformably overlies the Mancos shale, from which it is distinguished chiefly by its generally more sandy character and by the prominence of its massive sandstones.

Character and distribution.—As a whole the Mesaverde formation is composed of massive sandstones, interbedded with sandy shales and many beds of coal and carbonaceous shale. Of these the sandstones are most conspicuous by reason of their greater resistance to erosion. The formation is thus typically represented by more or less rugged hilly topography, characterized by escarpment ledges and cliffs. The massive sandstones are commonly of medium to rather coarse grained texture, at places showing some cross-bedding, although this latter is not a distinguishing feature. They commonly

[a] Determinations by Dr. T. W. Stanton; collections deposited in National Museum.

weather near the surface to a variety of shades, usually of reddish or yellowish brown, which probably are a result of the oxidation of some iron constituents. Where these beds are exposed in mines or in freshly cut rock faces they are commonly of white color and are firmly cemented when fresh, but they crumble and soften readily on exposure to the weather. Much of the cementing material in the sandstone is probably of calcareous or alkaline nature, since calcareous, magnesian, and ferruginous salts are almost invariable constituents in the waters that leach from among these rocks. Such salts commonly occur as efflorescent deposits in natural cavities in the massive sandstone, or under projecting ledges where sheltered from the solvent action of rain and snow water.

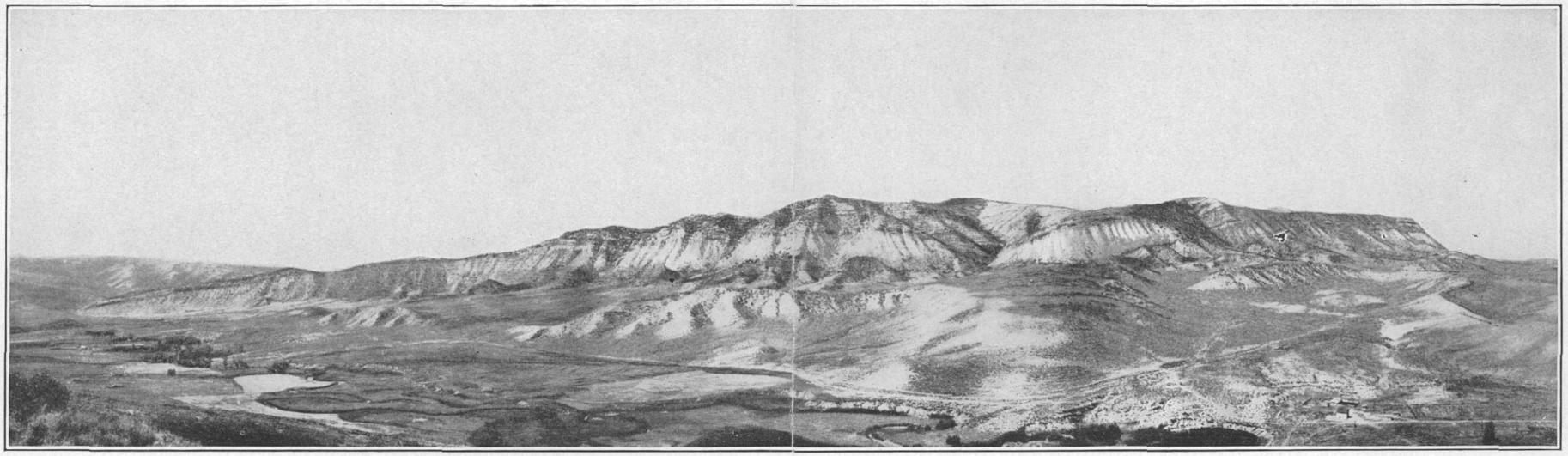
In general the shales differ from those that constitute the main body of the Mancos, being usually of lighter color as well as more sandy. They show much variation of constitution, ranging from compact clay shale somewhat similar to the typical Mancos to sandy shale and thin-bedded or flaggy sandstone.

The coal beds constitute one of the most important economic resources of the whole district, and as they are the main subject of later chapters in this report (pp. 109–239) they are not described here.

In general there are a number of features that distinguish various parts of the formation throughout the coal fields, and serve a useful purpose in the subdivision of the more valuable coal-bearing part.

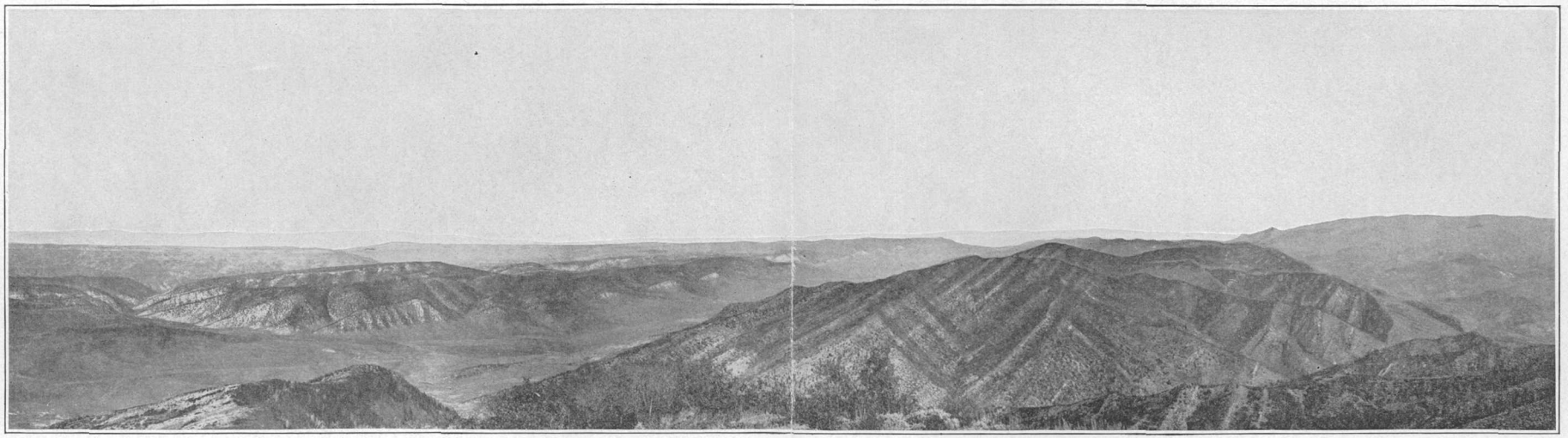
Lower part of Mesaverde formation.—The lower part of the Mesaverde formation is especially characterized by the predominance of massive sandstone beds. This group of strata usually forms ridges or mountains, and is thus more prominent as a topographic feature than the underlying shale, and is commonly more so than the overlying upper portion of the same formation. The base of the formation in a large part of the field is distinctly defined by the lowest sandstone bed that may be naturally classed with this group of ledges. In Raven Park this horizon is perhaps most distinct and is locally known as the "rim rock." Erosion of the lightly dipping beds has left the outcrop of this member as a distinct and separate ridge around the margin of the park. At some places this horizon is rendered somewhat less well defined by the occurrence of sandstone beds of more or less lenticular character within the underlying mass of strata already defined and distinguished as the Mancos shale. The most notable occurrence of this sort is that already referred to in Agency Park and on upper Coal Creek, northeast of that valley. At both of these places the minor hogbacks formed upon these lower beds are relatively so distinct from the main body of the Mesaverde strata that they may be readily distinguished from them.

The "rim rock" as observed in Raven Park is probably not actually continuous as a single stratum far beyond that part of the field. While that particular stratum may not be traceable to a great dis-



A. THORNBURGH MOUNTAIN FROM A POINT OVERLOOKING THE "BATTLEGROUND."

Showing escarpment of basal Mesaverde rocks.



B. SUMMIT OF GRAND HOGBACK OVERLOOKING GAP OF PICEANCE CREEK.

tance, one or more beds of approximately the same horizon are almost everywhere to be found, commonly exhibiting much the same relations to the overlying beds as the rim-rock bed and similar character and composition. For example, such a bed may be traced almost continuously eastward from the Utah state line south of Blue Mountains to Axial Basin, where it borders both sides of the valley along that anticlinal axis. Around the east end of Axial Basin the basal members of the Mesaverde show the same characteristics, and bend southward in Thornburgh Mountain, passing around the north side of Agency Park, and thence southward along the eastern base of the Grand Hogback. The total length of the outcrop thus described is over 150 miles to the crossing of the Grand Hogback on Grand River. This feature is illustrated in Plates II, *B*, and V, *A*. Plate V, *A*, shows the basal part of the Mesaverde section in Thornburgh Mountain from the south, overlooking the "battleground" and the upper valley of Milk Creek where the rim rock is not distinct, as a topographic feature, from the overlying beds. Plate II, *B*, represents the detail of the rim-rock ledge at the mouth of Wolf Creek on White River.

The rim rock itself is a sandstone, in general ranging from 20 to 50 feet or even more in thickness. Above it is an alternating succession of shale and sandstone which varies greatly from place to place, but shows a correspondence of general features that warrants a more detailed correlation of the various members. In general the sandstones and shales occur in somewhat frequent alternation through the lower 1,000 to 1,500 feet of the section. In the course of field work the larger sandstone beds were separately distinguished in recording notes by the letters A, B, C, etc., A being adopted for the lower or rim-rock sandstone. While the members A, B, C, and locally D are fairly distinct, E and F are more or less indistinct, in many sections constituting an irregular zone of somewhat broken or discontinuous bedding, above which there is another more prominent and readily distinguished stratum, presently to be described as the "white rock." Among the lower beds at some places in the horizon of A and at others as high as sandstone C, one or more thin beds of coal occur very constantly, and these have been designated in the more recent coal-field reports the "lower coal group" of the Mesaverde coals, although they were not included in the classification first proposed in the Yampa coal field.

The lower coals are almost everywhere unimportant from a commercial standpoint, chiefly on account of their thinness and their prevailingly bony character. In places they are rather thick, however, as in the escarpment north of the Thornburgh "battle ground," where one bed measures at least 10 feet but is broken by so many seams of shale and bone as to be practically worthless. On

Coal Creek, near the "Transfer," an entry has been driven on one of the beds of this group (see p. 164), but there also the coal bed is very badly split up and bony.

The lower portion of the Mesaverde formation is thus relatively barren of workable coal. It is also distinguished by a predominance of massive sandstone members and is thus prominent as a ridge maker. This part is distinguished on the geologic maps from the upper more important coal-bearing portion by use of a separate pattern for the "lower or barren sandstone part of the Mesaverde formation."

Fossils from the lower part of the Mesaverde formation.—The fossils obtained from this lower part of the Mesaverde formation are largely of marine types, and are therefore more or less distinct from those obtained in the beds of the upper part of this same formation, the latter consisting largely of fresh or brackish water forms. Occasional fresh-water beds are found in the lower zone, however, and, conversely, true marine types are also found at places among the upper coal-bearing beds. The following is a summary of the species identified by T. W. Stanton in the collections from the basal or relatively barren coal-bearing zone of the Mesaverde formation. They were collected by Doctor Stanton and the members of the field parties engaged in this work.

Fossils from basal or barren portion of the Mesaverde formation.

Inoceramus cripsi var. barabini Morton.
Inoceramus sagensis M. and H.
Inoceramus crectus Meek.
Mactra formosa M. and H.
Baculites ovatus Say?
Baculites compressus Say.
Scaphites nodosus Owen.
Ostrea patina M. and H.
Ostrea glabra M. and H.
Ostrea subtrigonalis.
Syncyclonema rigida H. and M.
Cardium speciosum M. and H.
Patella.
Leda sp. cf. L. inclara White.
Avicula nebrascana E. and S.
Avicula linguiformis E. and S.
Nucula.
Siliqua?
Liopostha (Cymella) undata M. and H.
Turritella.
Mytilus subarcuatus M. and H.?
Modiola attenuata M. and H.
Sphærium.
Campeloma.
Viviparus.
Sphæriola? cordata M. and H.
Pholodomya sp.
Worm burrows.
Callista deweyi M. and H.
Tellina sp.
Pinna.
Lucina sp.
Lunatia.
Goniomya americana M. and H.
Baculites compressus Say.
Baculites ovatus Say.
Actæon.
Leptosolen sp.
Anatina sp.
Fish scales.
Legumen sp.
Spironema? sp.
Bone fragments.
Donax? sp.
Corbula.
Corbicula cytheriformis M. and H.
Odontobasis sp.
Serpula sp.
Cinulia sp.
Anisomyon.
Halymenites.

Most of these fossils are of marine types. *Sphærium*, *Campeloma*, and *Viviparus* are exceptions.

Upper part of Mesaverde formation.—The upper part of the Mesaverde formation is distinguished from the lower as a separate member on the geologic map, the division being made at the horizon that marks the lower limit of the principal group of workable coals. The strata of the upper part of the formation resemble very closely the underlying beds except that the predominance of the massive and resistant sandstone members is not usually so pronounced and the resulting topography is consequently not so rugged. This is referred to as the upper or coal-bearing part of the Mesaverde formation, both in the following text and in the legend on the geologic map.

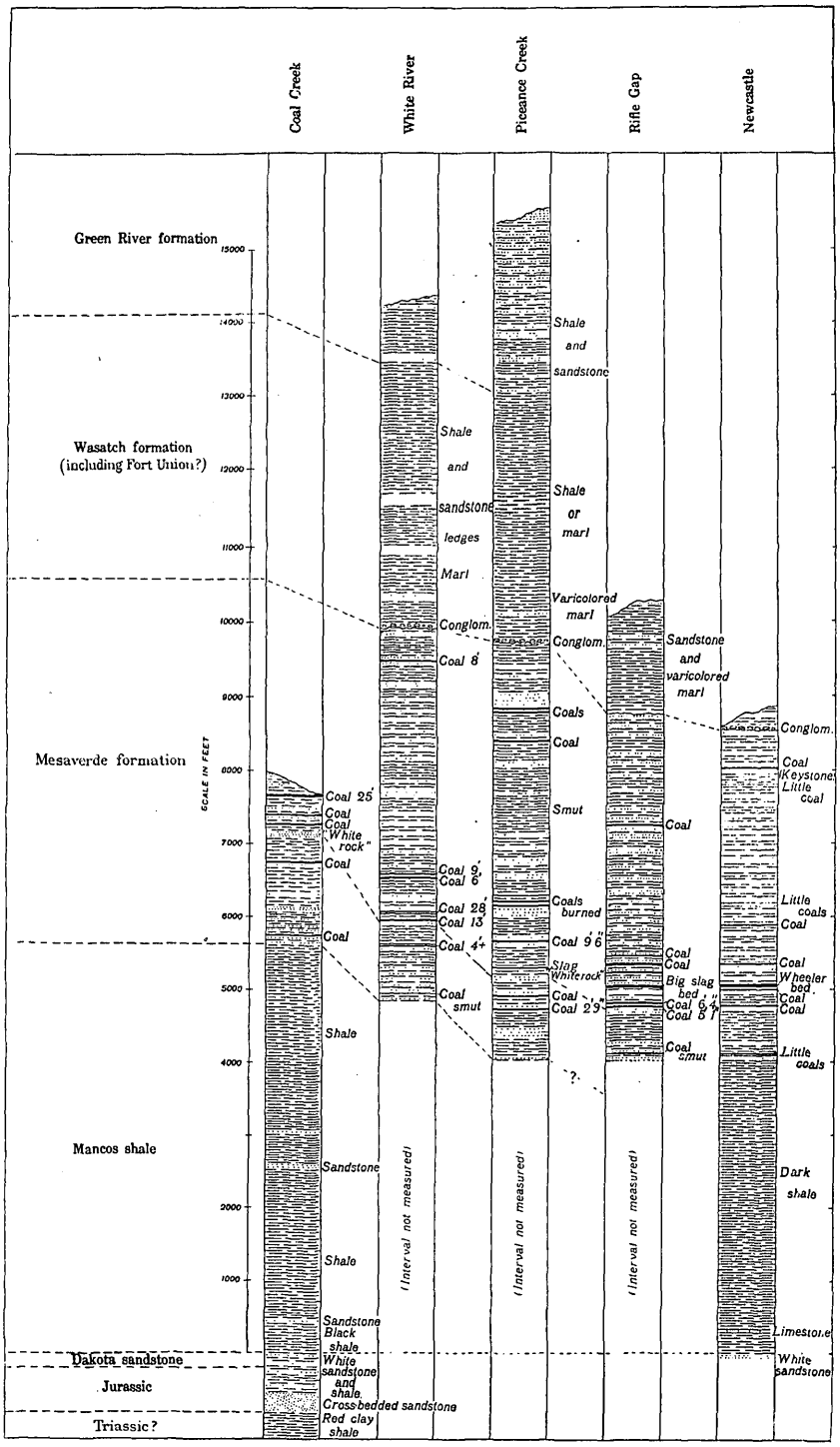
The base of the principal group of workable coals is one of the most distinctly marked horizons in the whole formation, both by the presence of the coal beds above and by the frequent occurrence of a large and conspicuous white sandstone ledge very commonly present at that horizon throughout a large part of the coal fields. This bed has come to be referred to in a local way as the "white rock" in a considerable part of the Danforth Hills, the name having been originally applied to that bed in the vicinity of Axial post-office, where it is well developed. As this member is traced westward it disappears at places, reappearing intermittently, so that its position is a matter of some conjecture at times, even in a well-exposed section. Wherever its position can be recognized, however, it furnishes a convenient key rock by which to identify the various positions of the valuable coal beds above it. In the geologic maps it has been the intention to include this "white rock" stratum with the upper or coal-bearing portion of the Mesaverde formation.

Above the "white rock" the sandstones and shales alternate in a varying succession, showing almost everywhere some signs of coal beds that they include. The coals themselves are often made conspicuous by the burning which has taken place along their outcrops. In many places this has baked the inclosing strata to brilliant shades of red and yellow, and has hardened the clay and shale to a flinty texture. Less commonly the coals themselves are found in natural outcrop, or show as black streaks along the hillside. By reason of the weaker character of this carbonaceous material it is usually broken down and concealed by the débris of harder materials of adjacent strata. From the "white rock" up to the top of the Mesaverde formation coals occur at more or less irregular intervals, the largest group of principal beds being almost always grouped or concentrated near the base or within an interval of about 1,000 feet immediately above the "white rock."

Thickness.—In Plate VI are represented a number of stratigraphic sections measured at various points along the Grand Hogback and

in the Danforth Hills, where unusually satisfactory cross sections of those beds are exposed and accessible for study and measurement. As there represented, the thickness of this formation, like that of the Mancos shale, is approximately one mile. Opportunities for measurement of the Mesaverde in the extreme western part of the State are not so favorable as those afforded along the eastern margins of the coal fields, near the White River Plateau. The principal difficulty in obtaining satisfactory measurements in the lower White River territory lies in the uncertainty regarding the upper limit of the formation. In a number of places an apparently very complete section of the whole formation is fairly well exposed, as for instance at the mouth of Wolf Creek and in the hogback west of that point; but nowhere in this part of the field is the upper limit of the formation known with precision. It seems clear, however, that the formation as there represented is much thinner than it is found to be in the districts described farther east.

The relative thinning of the Mesaverde formation toward the west may be accounted for in at least two ways. It is possible that during Mesaverde time a smaller amount of sediment was deposited in the Raven Park region than in the Danforth Hills and fields farther south of that region. On the other hand, the relatively great thickness of that formation in the eastern part of the Grand River Basin is thought to be better explained by the assumption that most of the beds originally deposited on that side of the basin still remain, while in the western districts a large amount of rock was probably eroded from the upper part of that formation after it was deposited and before the next succeeding strata were laid down. The latter explanation is preferred, because the section of the Mesaverde formation observed near Raven Park and farther west in Utah corresponds in the general grouping and the thickness of the recognizable members to the lower part only of the thicker section farthest east. It may be noted from a study of the sections of the Mesaverde formation near the Grand Hogback and in the Danforth Hills that the principal group of workable coal beds is in the lower part of that formation immediately overlying a relatively barren zone of 1,000 feet or more. The principal coal-bearing group itself is in turn overlain by a considerable thickness of strata containing occasional coal beds or carbonaceous streaks, some of which are of workable thickness. It appears from a general study of the western part of the field that the lower or relatively barren part of the formation is comparatively constant there, including also a section of the overlying beds. It therefore seems as if a portion of the upper part of the formation only is lacking in that part of the field. Additional evidence of the removal



STRATIGRAPHIC SECTIONS OF DANFORTH HILLS AND GRAND HOGBACK COAL FIELDS, COLORADO.

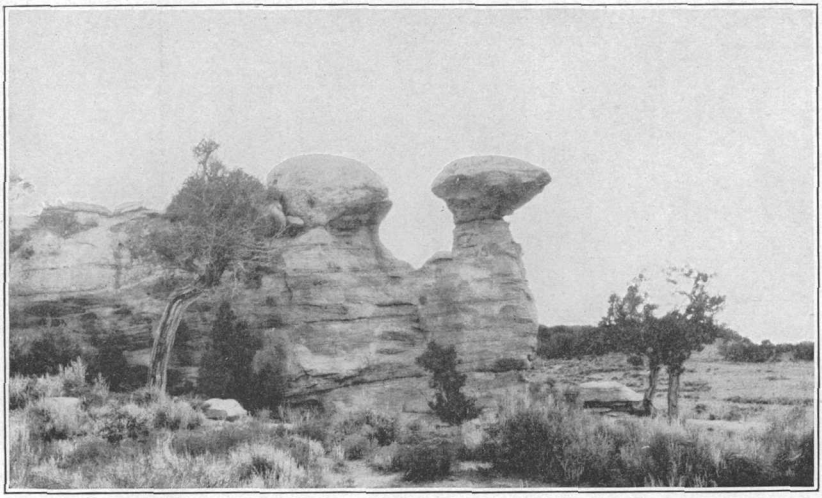
by erosion of the upper beds in the western part of the field is found in the fact that erosion appears to have gone deeper and deeper into the formation as these rocks are traced northwestward into Utah without showing any notable change in the character or grouping of the basal members. The Mesaverde formation may be traced continuously to and beyond Green River, and its outcrop crosses that stream just below the mouth of Ashley Creek in Utah. At this place nearly all of the workable coal group seems to be lacking (except only one or two beds which occur at the top of the remaining section) and the whole thickness is estimated to be approximately only 1,000 feet.

Not only has a great part of the Mesaverde formation evidently been eroded from the western part of the White River region, but other and higher Cretaceous formations also were probably removed from the entire Uinta basin. No evidence of the presence of later Cretaceous formations in that region has been obtained, although they are known in adjacent fields to the north and east. As stated, the Lewis shale and the Laramie formation overlie the Mesaverde in the Yampa coal field, intervening between the Mesaverde and the succeeding Tertiary formations, the latter being similar to those that rest directly on the Mesaverde in the Rangely field. It is therefore presumed that, as in the case of the uppermost Mesaverde strata of the same district, either beds corresponding to the Lewis and Laramie of the Yampa field were eroded from the region south of the Uinta Mountain axis before the deposition of the Tertiary beds began, or such beds were never deposited there. The evidence bearing on this problem in geologic history has not yet been fully interpreted. In case extensive formations were once continuously deposited and later removed, it would seem likely that some remnants would be left at one part or another of the area; in case such formations were never deposited, the time during which they were being laid down in other fields must have been marked by dry-land conditions and probably by removal of some material by erosion from this region.

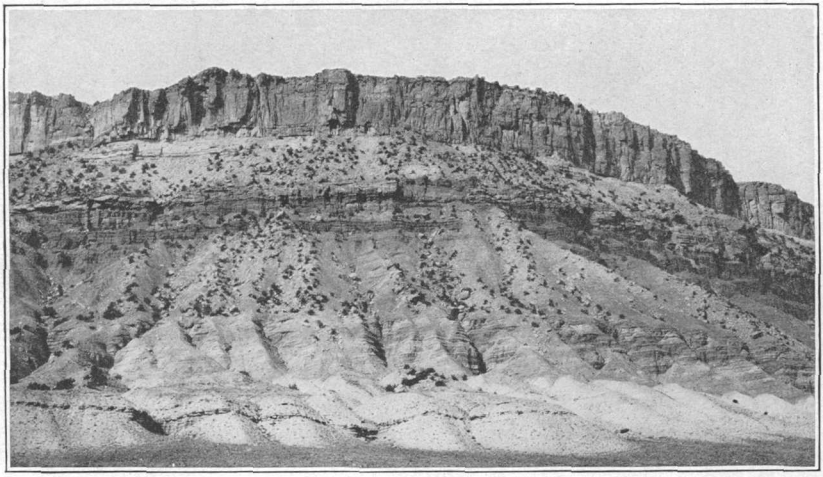
The stratigraphic horizons marking the disappearance of beds which are thought to have once been deposited and later eroded before succeeding deposits were laid down upon them probably represent intervals in geologic history as important as those represented by many of the geologic formations that remain to the present day. Earlier and later deposits are often separated on the stratigraphic evidence of an interval of geologic history represented only by the absence of certain deposits, the contact being marked by an "erosional unconformity." Such a hiatus is frequently associated with a period of crustal movements, whose direct effects are now to be interpreted from a study of the structural geology.

The precise determination of the upper limit of the Mesaverde is a particularly perplexing problem in certain parts of the region. Near Meeker, and along the Grand Hogback between White River and Grand River, a bed of coarse bowlder and pebble conglomerate, or "puddingstone," with a coarse white-sand matrix, marks the boundary between characteristic Mesaverde beds below and the variegated marl and sandstone of the overlying Tertiary. This bed can usually be readily found and identified. In the Raven Park district, however, no such clearly defined stratum has been discovered, although some beds of conglomerate, of composition not closely resembling that of the Grand Hogback beds, were found. These appear to be at or near the top of the Mesaverde formation, but in many places they were not discovered at all, and the sandstones of the Mesaverde could not be distinguished from those of the overlying beds. Consequently the exact upper limit of the formation was not in all places definitely determined. Many of the sandstones of both Mesaverde and overlying Wasatch are practically identical in composition, texture, and manner of weathering. In and near the Rabbit Parks south of Raven Park, sandstones from both formations weather into more or less conspicuous and oftentimes very picturesque natural monuments, one of which is shown in Plate VII, *A*. In some parts of the Raven Park district the variegated colors of the overlying Tertiary beds are not very conspicuous, although they are usually recognizable if the section is completely exposed, and serve as almost the only distinguishing mark of the transition from Cretaceous to Tertiary strata. The occurrence at this horizon of some species of unios and one or more gastropods, including at many places a form that is probably a *Goniobasis*, were considered not determinative, though probably indicative of the Tertiary age of the beds including them, and have been accepted as useful clews in the mapping of the Cretaceous-Tertiary boundary at the top of the Mesaverde in these fields.

Fossils.—Fossils have been found in almost all parts of the Mesaverde formation. They indicate that the lower part is largely of marine origin, up to and probably including the "white rock." As noted, this basal portion of the formation is distinguished as a separate member on the geologic map. Above the "white rock," fresh and brackish water invertebrates and plants indicate a change of character in the body of water in which the succeeding beds were formed. The fresh or brackish water conditions, however, were not permanent, and gave way to true marine conditions again near the top of that formation. The following is a list of the fossils found in the upper or coal-bearing part of the Mesaverde, all of which are therefore more or less intimately associated with the principal group of workable coal beds.



A. NATURAL MONUMENT TYPICAL OF WEATHERING OF THE MESAVERDE AND LOWER SANDSTONES OF THE WASATCH FORMATION IN THE REGION SOUTH OF RAVEN PARK.



B. ESCARPMENT OF SHINARUMP GROUP IN THE GREEN RIVER CANYON NEAR FLAMING GORGE.

Fossils from the upper or coal-bearing part of the Mesaverde formation in White River districts.

INVERTEBRATES.

[Determined by T. W. Stanton.]

Tulotoma thompsoni White.
Melania wyomingensis Meek.
Neretina bruneri White?
Turritella sp.
Ostrea subtrigonalis E. and S.
Ostrea glabra M. and H., var.
Ostrea glabra var. arcuatilis Meek.
Anomia micronema Meek.
Modiola laticostata (White).
Unio sp. cf. U. brachyopisthus White.
Unio cf. danæ M. and H.
Corbicula cytheriformis M. and H.
Corbicula occidentalis M. and H.
Corbicula fracta Meek?
Cardium speciosum M. and H.
Mactra? sp.
Corbula subtrigonalis M. and H.
Corbula sp.
Viviparus sp.
Campeloma? sp.
Goniobasis? sp.
Lymnæa sp.
Sphærium sp.

PLANTS.

[Determined by F. H. Knowlton.]

Halymenites major Lesq.
Cunninghamites elegans? (Corda) Endl.
Ficus speciosissima Ward.
Ficus squarrosa? Knowlton.
Ficus sp.
Ficus wardi Knowlton.
Ficus planicostata Lesq.
Sapindus sp.
Sequoia reichenbachi (Gein.) Heer.
Dammara cf. D. acicularis Knowlton.
Corylus cf. C. macquarrii (Forbes) Heer.
Magnolia tenuinervis Lesq.
Zizyphus sp.?
Celastrus sp.
Platanus sp.
Geinitzia sp.
Myrica torreyi Lesq.
Viburnum whymperi? Heer cf. Lesquereux.
Salix sp.

LEWIS SHALE.

Character and distribution.—As described in the report on the Yampa coal field,[a] the Lewis shale is the formation next succeeding and conformably overlying the Mesaverde in the Green River Basin. Beds corresponding to the Lewis in age appear to be entirely absent in the territory south of Axial Basin; that is to say, in the Grand River Basin, which is structurally separated by the Axial anticline from the basin including the coal-bearing rocks of the Yampa field.

The formation is mainly composed of soft clay shale, characteristically of dark color, often closely resembling the Mancos shale. Its topography is of low, rounded slopes, commonly yellowish in aspect, possibly due in part to vegetation favored by its soil, and in part to an iron-rust stain or color. Concretions in the form of large spherical masses of limestone or calcareous rock are common, and may be said to be characteristic of the formation in places. These are commonly fractured and recemented by pure white calcite, and then often broken up at the surface of the ground, forming piles of angular chips that stain in the weather to colors of yellow or red. Some sandstones also

[a] Yampa coal field, Routt County, Colo.: Bull. U. S. Geol. Survey No. 297, 1906.

occur, especially in the upper part, where in places they are rather massive. For this reason the precise limit between this formation and the overlying Laramie is a rather indefinite horizon, as the Laramie as mapped is chiefly distinguished from the Lewis lithologically by the predominance of massive sandstones closely resembling the sequence of strata observed in the Mesaverde formation. As mapped, the Lewis is intended to include the predominantly shaly formation, the upper limit chosen being that of the most conspicuous sandstone beds overlying. These sandstones characterize the topography, forming the hills, ridges, and escarpment ledges, while the low valley or rolling slopes are more commonly developed on the softer shale.

The Lewis shale forms a belt of low rounded slopes or valley country extending westward in Routt County from the Hayden Valley and lying approximately parallel to Yampa River. The river valley near the Yampa at Craig is eroded largely from this formation. West of Craig the river swings southward, entering the Mesaverde rocks, while the Lewis shale continues westward in the direction of Lay, at which point it disappears under the unconformable cover of the Browns Park formation.

Thickness.—No good measurement of the thickness of the Lewis shale has yet been obtained. Owing to its nonresistant character it is seldom exposed in anything like complete or continuous sections, and no favorable opportunity for obtaining a thoroughly reliable estimate of its thickness was observed. From several rough calculations, however, it is assumed to be 1,000 to 1,200 feet.

Fossils.—These beds are evidently of marine origin. Fossils are commonly found in or near the lenticular sandstone beds in the shale or in the concretionary masses already mentioned as occurring in the shale. The following is a list of the species collected from the formation in the Yampa field:

Fossils from the Lewis shale of the Yampa field.

[Determined by T. W. Stanton.]

Scaphites nodosus Owen.	Lingula nitida M. and H.
Lucina occidentalis Morton.	Gervillia recta M. and H.
Baculites sp.	Cardium speciosum M. and H.
Fish scales.	Protocardi sp.
Nucula cancellata M. and H.	Tellina scitula M. and H.
Mactra warrenana M. and H.	Dentalium gracile H. and M.
Pecten sp.	Luniata occidentalis M. and H
Leda? sp.	Actæon?
Pholodamya sunventricosa M. and H.	Thracia subgracilis Whitf.
Fasciolaria sp.	Molluscan burrows.

LARAMIE FORMATION.

Geologic relations.—The Laramie, as the term is now accepted, is used to designate the uppermost conformable Cretaceous formation, overlying the Lewis shale where that formation is recognized, and

in the Yampa field being limited at the top by an unconformity. It is constituted largely of beds deposited in brackish or fresh water, and is supposed to represent the period of transition from the distinctly marine conditions of late Cretaceous time to those of fresh-water submergence that represent the Tertiary in this part of the earth. As mapped, the formation is intended to represent a group that is distinguished from those adjacent by a difference of rock composition, and that may be recognized by this distinction in the field. In the case of the Laramie the feature that distinguishes it from the underlying Lewis is the presence of sandstone beds that form prominent ridges or ledges in the topography. Unfortunately the horizon of its lowest sandstone does not appear to be constant in different parts of the field, so that if it were possible to fix on a single definite plane as marking the basal member of that formation and trace it throughout the field, it would not everywhere lie in the same relation to the lowest of the principal group of sandstones overlying. Furthermore, though the formation as a whole is considered to mark the transition from marine to brackish and fresh water deposits, the fossils found in the lowest part of the sandstones included in the Laramie, including those in the massive sandstone beds, are distinctly marine and include a fauna apparently not distinguishable from that of the Lewis underneath. There are some sandstone ledges among the beds that are clearly a part of the Lewis, as it has been described and limited in the Yampa field farther east, and where these are more or less prominent they add uncertainty to the problem of distinguishing between these two formations.

Character and distribution.—As described in the Yampa coal field report, a section of part of the Laramie formation is to be found in the escarpment on the north side of Yampa River near the town of Hayden, where about 900 feet of the beds from the base up are represented. The formation consists of sandstone and shale, both of which are of weaker constitution than similar beds of the Mesaverde and in places are but slightly consolidated. Locally there are massive sandstone beds very similar in physical characteristics to the large and more massive beds of the Mesaverde. These strata contain subbituminous coal at many horizons, and some of these coals are of considerable thickness. At the base of the section exposed at Hayden in the beds outcropping near river level the Laramie appears to rest conformably on black clay shale, which has been described as the Lewis. At this place a transition from dark clay shale to lighter sandy beds is quite distinct and sharp.

Unfortunately for purposes of geologic mapping, the distinction is not so clear west of Hayden. North of Craig the base of the Laramie formation has been assumed to be at the base of the ledge that forms the prominent cliff or rock wall just north of the town.

The outcrop of this stratum may be traced almost continuously for about 6 miles west of Craig, but beyond that it is concealed by the overlapping deposits of the Browns Park formation. Similar beds are again revealed farther west, where they outcrop in the Round Bottom syncline, in the valleys of Fuhr, Sand Springs, and Horse gulches. In that region the identity of the horizon already adopted as marking the base of the Laramie is, however, much in doubt. Here also other sandstones occur in the Lewis, producing the uncertainty that has been noted.

The top of the Laramie formation in this field is more definitely marked than the base, as there is an unconformity between it and the base of the succeeding Tertiary formations. It is likely that this unconformity is not found everywhere at a single horizon in the Laramie beds, as the erosion that took place on the Laramie strata before the later deposits were laid down probably cut to greater depth in some places than in others. If this irregularity of contact were very marked at any point, it could perhaps be recognized in the attitude of the bedding above and below the break. On the other hand, the old land surface upon which the Laramie was laid down for the most part seems to have been a very even one, so nearly parallel to the former level of deposition that it rarely shows any noticeable discordance of dip.

Thickness.—The thickness of the Laramie formation is estimated as about 1,200 feet in the section exposed along Fortification Creek north of Craig. A considerably greater thickness of the Laramie may be present in the section north of Hayden, as its upper limit has not been recognized near that place. The top of the Laramie has not, however, yet been traced eastward as far as the Hayden locality.

Fossils.—The following is a list of fossils obtained from the Laramie formation in this field, largely from collections made by T. W. Stanton:

Laramie fossils from Yampa field.

INVERTEBRATES.[a]

[Determined by T. W. Stanton.]

Ostrea-glabra var. arcuatilis Meek.
Corbicula cytheriformis M. and H.
Corbicula occidentalis Meek.

PLANTS.

[Determined by F. H. Knowlton.]

Eriocaulon? porosum Lesq.
Cissus parrotiæfolia Lesq.
Ficus lanceolata Heer.
Sabalites grayanus Lesq.
Sequoia acuminata? Lesq.
Equisetum sp.?
Coniferous wood.

[a] Obtained near the base of the formation.

TERTIARY ROCKS.

GENERAL STATEMENT.

Geologic relations.—The existence of an unconformity at the base of the rocks assumed to be Tertiary in this report is represented in figure 3, which shows the generalized stratigraphic sections of both the Green River and the Grand River basins. As there indicated, the Tertiary rocks rest directly on the Mesaverde formation in the fields of the southern basin, while in the Yampa field the Lewis and Laramie intervene.

The horizon that marks the base of the Tertiary is evidently that of an extensive unconformity. This position in the stratigraphic column represents, in part at least, a period of uplift above water level, or at least a withdrawal of the water so that the beds that had once been deposited there were subjected to erosion for a period before the succeeding deposits were laid down. The lack of correspondence in the two stratigraphic sections gives some idea of the period of time thus represented, but it affords no true measure of the length of time that elapsed nor of the quantity of material that was removed in the hiatus indicated by comparison with the larger section.

The lowest stratum of the succeeding formations probably represents the first deposits laid down after this land surface was once more submerged. The material the basal beds contain may be assumed to represent the rocks exposed on the adjoining land areas, from which they might have been derived either just before, during, or after the submergence. In a conglomerate this material is often so coarse that the identity of its different constituent rocks may be recognized and inferences drawn as to the earth history of the place whence it was derived during the interval when it was being eroded and transported.

The horizon of the unconformity is marked by a very persistent bed of coarse pebble and bowlder conglomerate in the Yampa, White, and Grand River fields. The rocks it contains are very completely rounded, evidently waterworn, and seem to have been so thoroughly sorted that all but the most resistant have been worn away. In the Grand Hogback, Danforth Hills, and Yampa fields the materials composing this bed are very constantly alike. Some of the pebbles appear to be more or less characteristic of the outwash that occurred at that particular period, as they are not recognized in the material brought in by the streams of the present day. The following is a list of the rocks contained in the pebbles of this conglomerate: Red quartzite (evidently formed from the "Uinta" quartzite); white quartzite and hard sandstone (in less amount than the red, probably also from the "Uinta"); conglomeratic quartzite (still more rare,

evidently also from the "Uinta"); vein quartz; chert of various colors, especially in irregularly rounded lumps, weathering yellow, many containing impressions of fossils[a] (pebbles of a jet-black chert are especially noticeable); a feldspathic porphyry, with small phenocrysts in a fine red or gray groundmass; gneissoid granitic or felsitic rocks; silicified wood in waterworn fragments.

A probably significant point noted in a study of this material is the scarcity of crystalline granitic rocks, which form so large a part of the material washed down from the Rocky Mountains by the streams of the present day.

West of the Danforth Hills, in the lower White River and Utah portions of the area, the base of the Tertiary is not so clearly defined. A conglomerate bed was noted at numerous localities throughout the field, and this where found was assumed to mark the unconformity just as the bed in the Danforth Hills had been interpreted. The material found in the conglomerate pebbles of the western districts was, however, quite different from that already described. The pebbles found in the lower White River country in the vicinity of Raven Park included more angular material whose source of derivation is much less readily traced. The only rocks found among them resembling those of the Yampa, White, and Grand River fields were some perfectly rounded black-chert pebbles and waterworn fragments of fossil wood. Besides these the conglomerate contained irregular pieces of sandstone, some limestone, and other rocks that were not carefully described in the notes. Near Green River in Utah the conglomerate becomes more prominent and recurs at several horizons above the basal beds in the lower Tertiary formation, where it constitutes a part of the asphaltum-bearing strata. No special study of the material in this formation of this extreme western part of the fields has been made.

C. A. White's descriptions.—The mapping of Tertiary and later formations in the present work agrees very closely with that of C. A. White in the early Hayden reports, the differences being chiefly those relating to minor details of location or cartographic representation. Doctor White made trips in two successive seasons through this region and reference to his excellent descriptions has already been made (p. 16). The report of his second season's expedition contains in narrative form much valuable descriptive material, as well as the summary of paleontologic evidence that had there been collected for

[a] The fossils in the chert pebbles have been examined by G. H. Girty, who makes the following statement: "The chert pebbles from the Eocene present a problem to the solution of which I can probably add very little. So far as anything can be made out at all they are clearly Paleozoic. I can see no evidence that more than one period is represented by them. I believe that some, and very likely all, of the fossils belong to the Carboniferous. Probably the most diagnostic of the Carboniferous is a spiniferous *Spirifer* (*Reticularia* or *Squamularia*). There have also been noted other Paleozoic brachiopods (*Composita?* sp.), Paleozoic Bryozoa (*Fistulipora?* sp.), and trilobites (*Phillipsia?* sp.), together with round crinoid stems."

this region. The following quotation from this report,[a] while not confined specifically to any one distinct subject here under discussion, is more or less pertinent as indicating in a general way the nature of the evidence then collected, and as showing Doctor White's attitude on several important questions of stratigraphic subdivisions and correlation. After listing and describing the fossils that he had collected from the Cretaceous and basal Tertiary formations in northwestern Colorado, he concludes the discussion of the fossils from the Wasatch "group" in White River valley by saying:

The fossiliferous horizon that furnished the fossils of the foregoing list was also found among the upturned strata of Raven Ridge, west of Raven Park. The ridge has its southeastern end at the western side of Raven Park and its northwestern end near Section Ridge, a spur of Yampa plateau. In the upper portion of the Wasatch group, near the northwestern end of Raven Ridge, I obtained an abundance of specimens of *Goniobasis tenera* and a few of *Viviparus paludinæformis*. Near the southeastern end of the ridge and at the same horizon I obtained a few examples of both those species together with some of *Unio washakiensis* and *U. shoshonensis*. The Green River group is abundantly shown in this region, in all the peculiarities which characterize the group at its typical localities, and yet no distinct plane of demarkation or place of separation between it and the Wasatch group could be anywhere recognized.

While passing down the valley of White River from Agency Park to Raven Ridge the strata of the Laramie group came frequently under observation. They were there found to possess all their usual lithological characteristics, and also to contain the great abundance of plant remains that was observed in the Danforth Hills. The only invertebrate fossils, however, that were found in its strata in that region were occasional examples of *Ostrea glabra*, which was found to range nearly to the base of the group. Directly north of Raven Park and about midway between White River and Midland Ridge I found numerous examples of *Halysites major* Lesquereux in layers that belong either to the base of the Laramie or to the top of the Fox Hills group. The horizon is doubtless precisely the same as that at which this fucoid occurs at the mouth of the Saint Vrains and elsewhere in eastern Colorado.

From a point on White River about 20 miles below Raven Park I crossed to Section Ridge over the broad badlands district that lies to the northward. The dip of the Green River strata which border the lower portion of White River valley is gently to the northward where I traversed them. About 8 or 10 miles north of White River I found them to pass beneath characteristic strata of the Bridger group, containing fragments of mammalian and chelonian remains. These Bridger strata occupy only a very small area of surface in the immediate valley of Red Bluff Wash, and are overlain by the strata of the Uinta group, which occupy the greater part of the surface of this badlands district bordering Green River valley. They rest unconformably upon strata of all ages in this region from those of the Colorado to the Bridger group, inclusive. As to its unconformity upon the Bridger strata, however, my observations south of the Uinta Mountains alone would not prove, but I found such unconformity a few years ago in the valley of Snake River, north of Junction Mountain.

Leaving the region of the White and Yampa rivers, I crossed Green River by a ford a few miles below Split Mountain and continued my journey westward after making some observations from that mountain to add to my report for the year 1876. After crossing Green River I spent some time in examining the geology of the district on the

[a] Hayden, F. V.; Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., pt. 1, 1877, pp. 227-229.

west side adjacent to the southern base of the Uinta Mountains, especially in the valleys of Brush Creek and Ashleys Fork. In this district, as well as in that which lies immediately upon the other side of Green River, I made some observations that have a most important bearing upon the proper correlation of the different groups of strata which geologists have recognized, but more especially those of Cretaceous age. In a large part of Colorado, Wyoming, and Utah the two Cretaceous groups, which in the classification modified from that which was originally adopted by Hayden and Meek for the Upper Missouri River region are designated as the Colorado and Fox Hills groups, have been found so constant in their general lithological characteristics that field geologists have usually made these the basis of their classification of the strata, often ignoring the paleontological features entirely. My own investigations have led me to the conclusion that the paleontological characteristics of these groups are far more constant and reliable than the lithological, and this fact is especially exemplified in the district in question. Generally the plane upon which the Colorado and Fox Hills groups are separated is marked by a more or less sudden change from a shaly or uncompacted sandy material below to ordinary stratified sandstone above. A large part of the Colorado group, especially toward its base, is also usually made up of bluish clayey and sandy shales, with usually a horizon of bluish fissile shales at or very near the base of the group. Often, however, the lithological change from the Colorado to the Fox Hills group is very obscure, the sandy shales of the lower group extending far up into the upper one.

In the district adjacent to Green River, at the southern base of the Uinta Mountains, more than half the thickness of the Fox Hills group is inseparable from the Colorado group by lithological characters, and their separation is thus practicable only by means of their respectively characteristic fossils. It is true that the relative thickness of these two groups varies very considerably in different districts, and this fact is never more plainly or truthfully shown by lithological than by paleontological features. In short, there is, as a rule, in all the great western region, a distinctly recognizable paleontological horizon separating the two groups in question, irrespective of lithological variation, above and below which certain species respectively do not pass. For example, on both sides of the Rocky Mountains I have found *Inoceramus deformis* Meek, *I. problematicus* Schlotheim, and *Ostrea congesta* Conrad quite common, if not abundant, in the Colorado group, while none of the Cretaceous species of any of the foregoing lists in this report have been found in that group, but all belong above it.[a]

In the valley of Brush Creek I observed several more or less massive layers of sandstone distributed in the softer layers of the Colorado group, the like of which I have not seen elsewhere in that group. Just north of Dodd's ranch, in the valley of Ashleys Fork, a high hogback of sandstone rises up toward the flank of the mountains from the valley plain of that stream. As one approaches it by going up the valley it has the appearance of the usual hogback of the Dakota group, which appears almost everywhere at the flanks of the mountains, especially as the plain is known to be in part, and so far as the lithological characters of the strata can be observed beneath the surface débris, appears to be wholly occupied by the strata of the Colorado group. In fact, however, as proved by the fossils, a large part of the valley plain is occupied by strata of the Fox Hills group, which are as soft and easily eroded as those of the Colorado group are; and the hogback referred to constitutes the lower portion of the former group. From the strata of this hogback I collected the following fossils: *Inoceramus howelli* White, *Cardium speciosum* Meek and Hayden?, *Mactra* (*Cymbophora*) *warrenana* Meek and Hayden, and *Anchura* ——?.

[a] In my report upon the invertebrate fossils of Professor Powell's collections, in Chapter III of his Geology of the Uinta Mountains, a considerable number of the Cretaceous species there discussed are referred to the Colorado group (=Sulphur Creek group of Powell), which I have now no doubt properly belong to the Fox Hills group (=Salt Wells group of Powell). The error made by the collectors, of referring the fossils to wrong groups, no doubt occurred in consequence of the lithological changes that have taken place in their strata, which has just been explained.—C. A. W.

* * * Proceeding westward from Ashleys Fork, my journey, after the first 3 or 4 miles, was over the Uinta group until we reached Lake Fork. This group is much more extensively developed in this region than I have anywhere seen it before. It is many hundred feet in thickness, and it is quite as regularly stratified as any of the other fresh-water Tertiary deposits of the West. In some places, as for example, in the vicinity of Green River, south of the Uinta Mountains, it is largely composed of soft badlands sandstones, having a general reddish color; but farther westward it assumes a somewhat darker hue and character of quite regularly bedded sandstones, some of which are soft, but many of the strata are firm and even massive. At Wonsitz Ridge, 4 miles west of Dodd's ranch, it rests unconformably upon the Laramie group, and at Lake Fork, on the Uinta and Salt Lake trail, it is found to rest upon the Bridger group, as it was shown to do near White River in my report for 1876.

POST-LARAMIE COAL-BEARING ROCKS.

Geologic relations.—Beds determined by F. H. Knowlton on paleontologic evidence to be of Fort Union age have been distinguished by their fossil plants collected from several localities in this region. So far as now known, these beds occur at the very base of the Tertiary system in the Grand River and possibly also in the Yampa River basins. While some of the plants obtained from the lowest Tertiary beds in the vicinity of the Grand Hogback have been classed as of Fort Union age, it is still very uncertain whether any distinct formation of that age can ever be separated from the overlying Wasatch in that place.

The derivation of the term Fort Union may be briefly explained as follows: In 1861 Meek and Hayden first gave geographic names to the formations of the so-called upper Missouri River section; they subdivided the Cretaceous section and called the beds overlying these and forming the base of the Tertiary system the "Fort Union or Great Lignite group." From the section at old Fort Union, at the mouth of the Yellowstone on Missouri River, named as the type locality, a very characteristic flora is said to have been obtained.

Along the Grand Hogback and on the western side of the Danforth Hills the lower several hundred feet of Tertiary beds is somewhat distinct from the main body of the varicolored strata overlying. This group occurs just above the conglomerate which has already been described as marking the unconformity at the base of the Tertiary, this being properly classed with the overlying formation as the lowest bed of the superimposed strata. In the Grand Hogback region this lower division consists of marly clay, of a dull-gray or drab color, showing as broad, lumpy exposures, with an efflorescent cracked surface on the westward dip slope of the conglomerate or puddingstone ledge. Among these beds Doctor Stanton found in several localities a thin bed of sandstone containing well-preserved leaves. A collection made from this horizon west of Rifle Gap, where that creek cuts the Hogback ridge, contained plants determined by F. H. Knowlton as *Sapindus grandifolius* Ward, *Populus daphnogenoides* Ward, and

Populus rotundifolia Newberry. They were considered by him to be distinctive of Fort Union age.

The name Shoshone has been adopted by a recent decision of the committee on geologic names of the United States Geological Survey as a general time term to apply to the period in which all those beds above the major unconformity at the top of the Laramie and below the base of the Fort Union or lowest recognized Tertiary may have been laid down. No decision has been reached as to the proper correlation of these beds in the various separate basins in which they seem to have been deposited, and for the present none as to the geologic system to which they may ultimately be assigned.

In this group are included such formations as have been called the post-Laramie, including the Denver and Arapahoe formations of the Denver Basin, to which the provisional name of "Upper Laramie" was given in some of the geologic work done in southern Wyoming.

The name Shoshone may perhaps be advantageously used to signify the beds which overlie the true Laramie of the Yampa River field, or, more broadly speaking, the whole Green River Basin, and which are succeeded by the softer clays or shales that characterize the more typical Wasatch.

The term "post-Laramie coal-bearing formation" is now used in the description of the Yampa field only, and tentative correlation with the Fort Union will be restricted to the White and Grand river fields south of Axial Basin, this usage being adopted to conform with the determinations of the paleontologists. The evidence of the stratigraphic and lithologic sequence obtained by a comparison of the two sections points very strongly to the equivalence of these two stratigraphic divisions, at least in their lower part, as they have been defined for this general region. Since this correlation has not been accepted as logical from the paleontologic standpoint, the question is presented and must remain open pending the gathering of further evidence.

The post-Laramie coal-bearing formation of the Yampa field resembles the Laramie in the constitution of its beds and also in the fact of its containing a number of valuable and workable coals. To these belong the beds known as the Blevins coal on Lay Creek, and without much doubt also the Seymour coal on Dry Fork of Little Bear, north of Craig. Like the Laramie, it is composed of sandstone and shale, some sandy and also some finer-grained clay. It is characterized topographically by ridges and escarpments or cliffs, not so prominent as those of the Mesaverde, but very similar in general appearance. The thickness of this formation in the vicinity of Lay Creek is 800 feet or possibly more.

Fossils.—The fossils obtained from this formation were collected by Doctor Stanton and the author, and the following determinations have been made:

Fossils from the post-Laramie coal-bearing rocks from the Yampa field.

INVERTEBRATES.

[Determined by T. W. Stanton.]

Campeloma multilineata M. and H.
Viviparus trochiformis M. and H.
Bulimus disjunctus White.
Goniobasis tenuicarinata M. and H.
Columna? sp.
Sphærium sp.

PLANTS.

[Determined by F. H. Knowlton.]

Rhamnus salicifolius?
Ficus sp.
Rhamnus sp.
Woodwardia? sp.
Glyptostrobus sp.
Dicotyledonous fragments of several kinds.
Sapindus cf. S. grandifolius Ward.
Grewiopsis populifolia? Ward.
Viburnum.

WASATCH FORMATION (POSSIBLY INCLUDING THE FORT UNION).

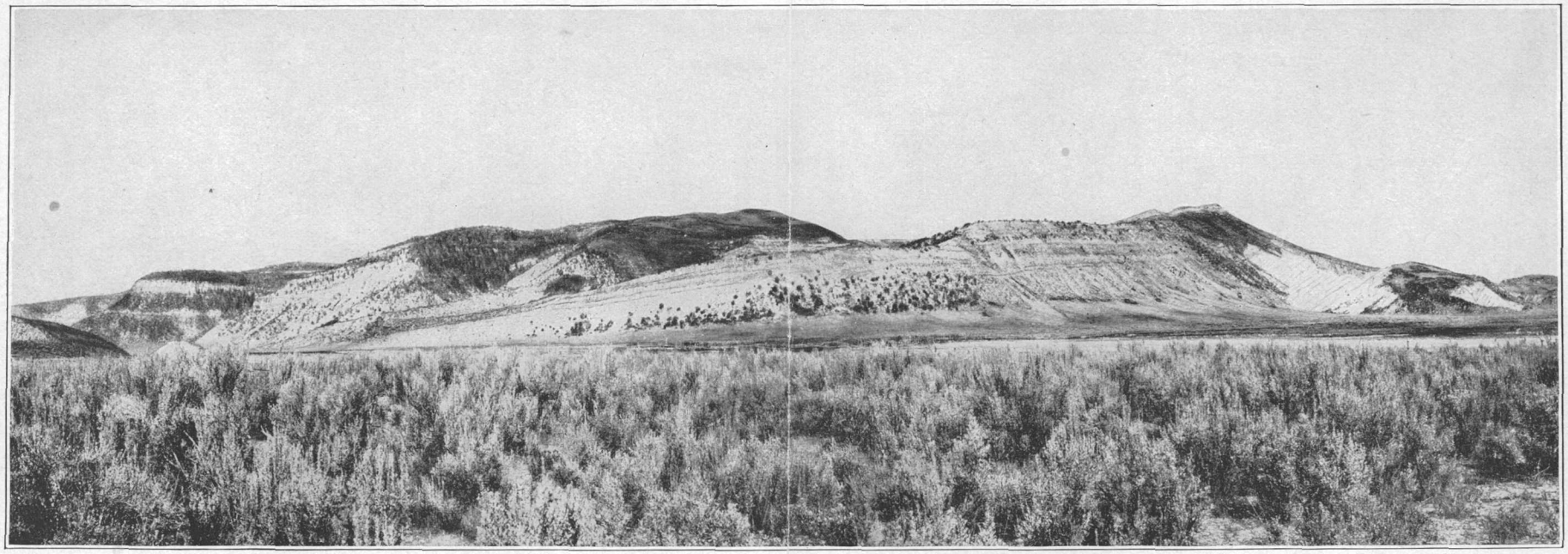
On the geologic maps no attempt has been made to separate Fort Union from Wasatch beds in the Grand and White River region, as it is not yet clear that two such formations can be differentiated or at least are to be distinguished by any recognizable lithologic features in this region. On the other hand, a separate formation described as the post-Laramie coal-bearing rocks has been distinguished in the Yampa coal field at the base of the Wasatch and overlying the unconformity marking the top of the Laramie formation at that place. The unconformity at the top of the Laramie of the Yampa field is supposed to correspond to the unconformity at the top of the Mesaverde in the fields farther south, and this suggests, although does not necessitate, the correlation of the beds immediately overlying that horizon in the two regions. That they have not yet been correlated, as has already been explained, is due to the lack of corroboration of this inference by the paleontologic evidence, and also to the apparent lack of similarity of the rock strata themselves in the two regions. In view of the possibility therefore of the lack of correspondence of the intervals mapped as Wasatch in the two separate basins, they are separately described.

The Wasatch of the Grand River Basin may include or be distinguishable from the Fort Union, if such a formation shall ever be separated out and mapped in this field. As here shown and also as formerly mapped by the Hayden Survey, all the beds overlying the coal-bearing or Mesaverde formation were included in the Wasatch,

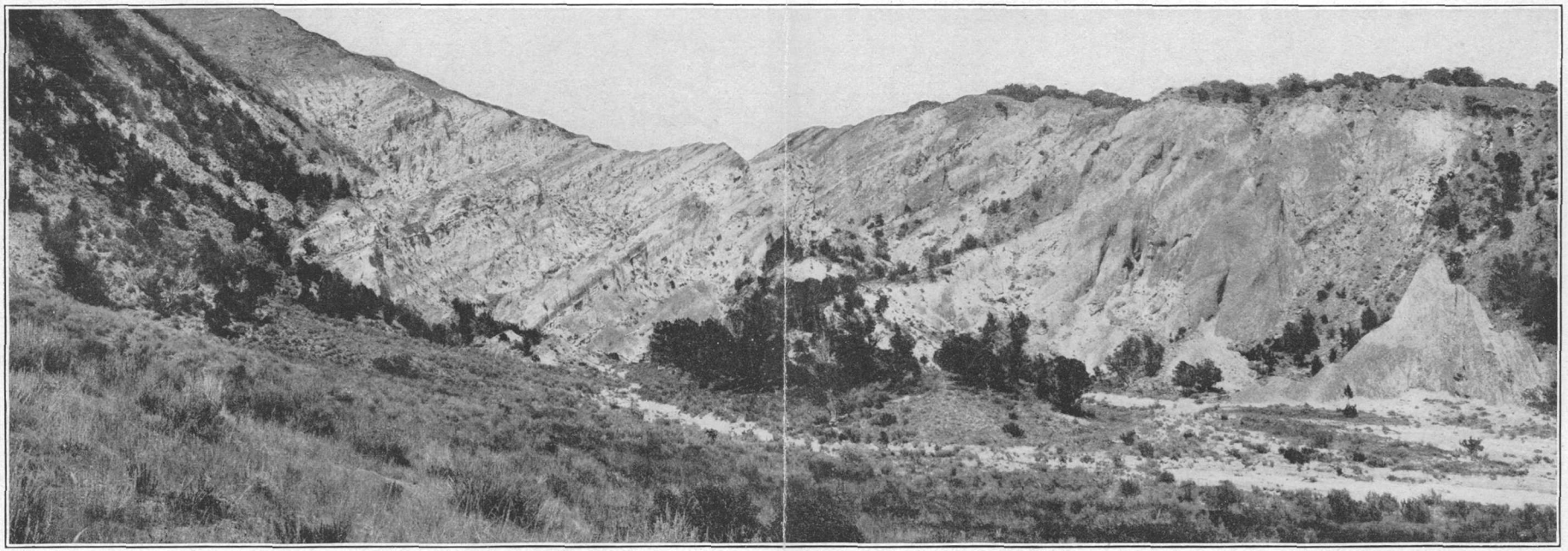
up to the sandstones that form the basal portion of the next succeeding or Green River formation. Neglecting the gray marls at the base, the whole formation may be described as composed of soft shaly or marly material, commonly described as badlands-forming, whose most characteristic feature is the bright variegated banding of its beds. These display a great variety of contrasting shade and color, including pink, brick red, vermilion, yellow, drab, brown, chalky white, and coal black. Shades of pink and red predominate. Interbedded with the shales or marls there are also conglomeratic beds composed of pebbles of perfectly rounded and very hard material such as jasper, chert, flint, or other siliceous rock such as vein quartz, all of which are commonly stained in bright colors, and some of quartzite. Some beds of firm compact sandstone occur, at places very similar in character to the underlying Mesaverde rocks, but commonly coarser and more loosely consolidated than those older formations. The general character of these beds is well represented in the detailed view given in Plate VIII, *B*, which shows a wash bank in the upper Wasatch beds at a locality north of the Keystone Basin, west of the Danforth Hills.

The thickness of this formation, including all the beds from the top of the Mesaverde to the lowest conspicuous ledges of the overlying Green River beds, was calculated to be about 3,400 feet across the valley on upper Piceance Creek. (See graphic section, Pl. XIII.)

Near White River the proportion of sandstone in the Wasatch appears to be greater, but no satisfactory measurement of the whole interval has been obtained at that place. The prominence of sandstone members throughout at least 4,000 feet of this section is illustrated in the graphic section on Plate XVII. From that point westward or down White River the character of the Wasatch formation changes somewhat. In the vicinity of Raven Park, where these beds have again been studied in some detail, much difficulty has been experienced in determining precisely the horizon at which the basal unconformity occurs, as the conglomerate marking that horizon appears either to be obscure or to be only locally developed. No marked discordance of dip has been noted. Since definition of the top of the Mesaverde as well as the base of the Tertiary depends on the identification of this horizon, the difficulty of tracing it as a horizon has led to some uncertainty in the mapping. Both the Mesaverde below and the overlying Tertiary contain massive sandstones and sandy shales in alternation, and these are so similar that in many places they can not be distinguished from one another. In this part of the field the variegated colors are much less conspicuous. Below Cathedral Bluffs only occasional red patches are exposed and the massive white sandstones closely resemble those of the Cretaceous formation below.



A. ESCARPMENT PEAK AS SEEN FROM KEYSTONE RESERVOIR BASIN.



B. DETAIL OF WASATCH EXPOSURES AT BASE OF ESCARPMENT PEAK.

Thus in the western part of this basin the beds at the base of the Wasatch bear a much closer resemblance than do those in the eastern part to the post-Laramie coal-bearing formation of the Yampa field and the Green River Basin.

The Wasatch as mapped in the Green River Basin is the soft clay or shaly formation succeeding the post-Laramie coal-bearing beds. It is there composed of soft or badlands-forming clays and soft sandstones similar to those most characteristic of the same formation in the Grand and White River fields. It has the same variegated colors that are shown along the Grand Hogback and elsewhere in fresh exposures, and it also contains beds of conglomeratic material.

In the Yampa field northward from the ridges in which the post-Laramie coal-bearing beds are exposed the Wasatch assumes a lower dip almost at once, so that no consecutive section such as was found in the fields farther south is available for study. Almost the whole triangular block of territory included between the Little Snake and the older rocks adjacent to Yampa River in northwestern Colorado west of the Elkhead Mountains is supposed to be composed of the soft strata of the Wasatch formation. The beds observed at outcrop are varied in composition, including marls of red or variously colored and banded appearance; loose coarse-grained sandstone or sandy beds, either white or of darker weathered hues, and occasional banks of more regularly bedded shale. At some places the varicolored beds of marl or shale that commonly distinguish the Wasatch are exposed in great scars or badlands washes. These beds are covered in part by the later deposits, especially by the Browns Park formation, to be described (p. 86).

GREEN RIVER FORMATION.

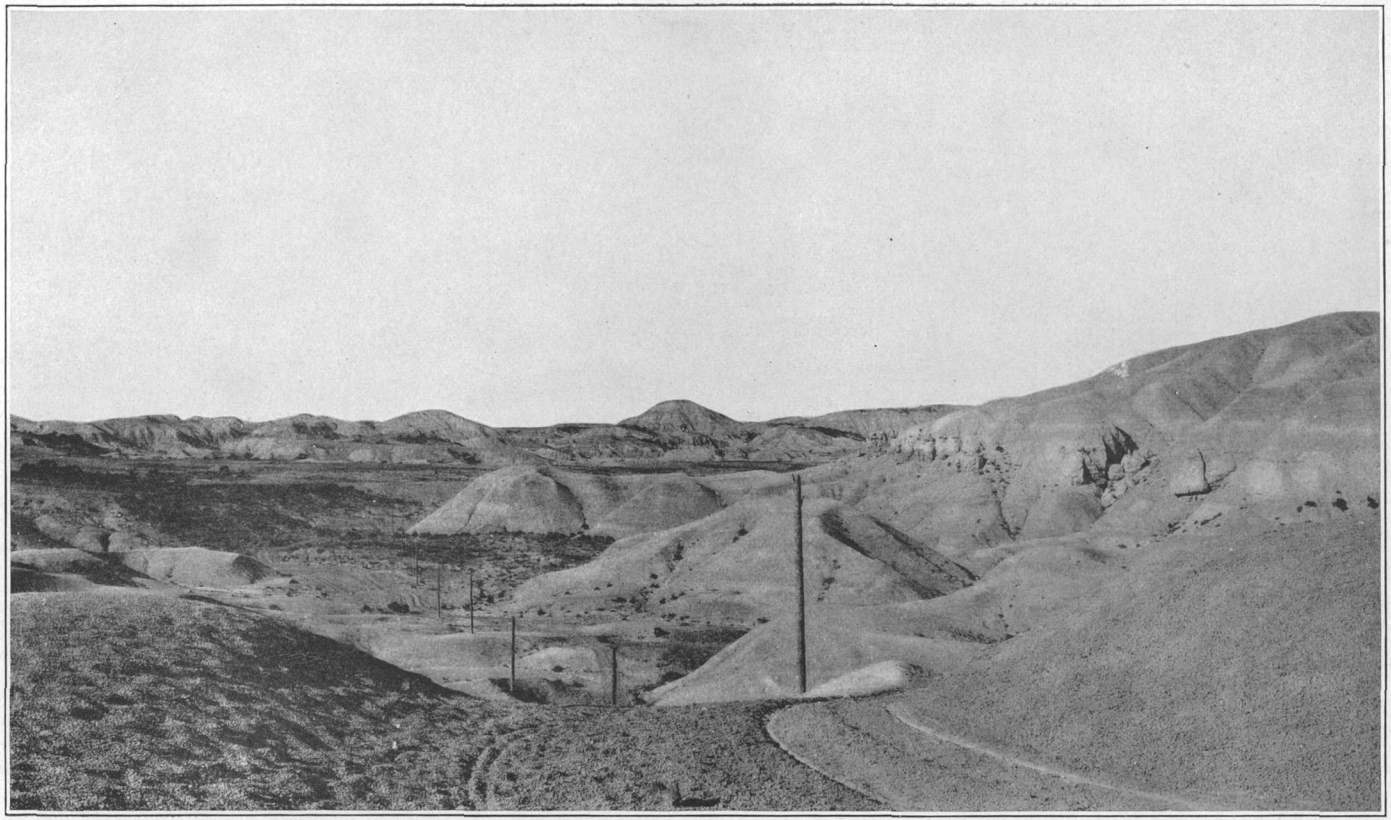
Character and distribution.—The valleys and lowland ridges commonly formed in the Wasatch clays are generally bordered by the escarpment ridges of more resistant beds that overlie them. This escarpment-forming group of strata is known as the Green River formation. It is exposed in what may be considered its typical characteristics at the town of Green River, Wyo. Among the best examples of similar development in the area of the present work may be mentioned Roan or Book Cliffs, Gray Hills, Citadel Plateau, and Cathedral Bluffs, and also the walls of White River canyon below Raven Park, and the canyons of Evacuation Creek and tributaries near Dragon, Utah. The steep outward-facing scarps that border the upland areas composed of these rocks stand at elevations of 1,500 and 2,000 feet above the neighboring valleys and are almost everywhere characterized by the chalky-white appearance of their weathered cliffs as seen from a distance. The Green River beds commonly lie in nearly horizontal position or with only slight inclination, and within the bordering escarpment rims they form high mesa

or plateau surfaces occupying the undisturbed interiors of the great structural basins.

In detail the Green River formation is composed of sandstones, thinly bedded slaty shales, and beds of limestone and calcareous shale. Many strata of oolitic or pisolitic lime rock occur, and in places these ledges form the major part of the harder beds which the formation contains. Some of the thin-bedded shale is of dark or brownish color when freshly exposed, in quite marked contrast to the almost universal whitish aspect of nearly all these beds on their weathered exposures.

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

Both the Wasatch and Green River formations were involved in the folding that produced the uplifts that have been described. This is shown in certain favorable localities where beds of the younger groups are tilted in the same structure with the older beds. One of the best illustrations is found on the eastern face of Escarpment Peak, north of Keystone Basin. At this place the variegated clays of the upper part of the Wasatch are clearly exposed in a badlands wash at the foot of the Green River escarpment. Although quite steeply tilted in the valley and at the foot of the main slope, the dip gradually decreases higher up the ridge. The apparent conformity of all the beds at this place is even more clearly revealed in perspective by a view from the valley to the south, where this escarpment is seen to be situated approximately on the axis of flexure. Plate VIII, *A*, which is a view from the basin at the south, shows the abruptly folded strata toward the east and the broad gently folded syncline in the Green River strata toward the west down Deep



BADLAND TOPOGRAPHY OF THE BRIDGER FORMATION, NORTH SIDE OF HENRYS FORK, WYOMING.

Channel Creek below the basin. Plate VIII, *B*, is a nearer and more detailed view of the Wasatch strata, looking in the same direction.

Fossils.—Very few fossils have been obtained from the Green River formation of this part of the country. A single collection by T. W. Stanton from Piceance Creek, west of the Grand Hogback, about 2,400 feet stratigraphically above the base of the formation, has been examined by F. H. Knowlton, who reports the following plants: *Cinnamomum scheuchzeri* Heer, *Rhus coriarioides* Lesq., *Sapindus angustifolius* Lesq., *Ilex* cf. *L. subdenticulata* Lesq., and *Zizyphus?* sp.

BRIDGER FORMATION.

Character and distribution.—The Bridger formation was named from Fort Bridger, in Uinta County, southern Wyoming.[a] Although it is not known to occur at any point within or closely adjacent to the larger coal fields here described, it is represented on the King maps as occupying a considerable extent of territory west of Little Snake River in Colorado between that valley and Browns Park. These beds are characteristically developed from Fort Bridger, Wyo., to the foot of the Uinta Mountains, where they form a prominent part of the geology of the Henrys Fork field (p. 233). The formation is also represented on the maps of the Hayden atlas as occupying a limited area in the Uinta Basin in northeastern Utah south of the Uinta Mountains. (See quotation from Hayden, 1877 report, p. 77.) In the latter locality it is also reported to have been distinguished by its fossil vertebrates.[b] The descriptions here given are for the formation as represented near and south of its type locality, Fort Bridger.

It is composed almost wholly of gray or drab badlands-forming clays or marls, with occasional bands of vivid green, which are commonly in sandy layers or at places composing a firm, compact sandstone. The vivid green and monotonous drab clay on the bare slopes that often support practically no vegetation at all are the most striking surface features.

Plate IX, which is a view from the summit in the main road between Henrys Fork and Bridger, about 3 miles north of Lonetree, looking northward, shows the typical appearance and topography of these beds.

Fossils.—The Bridger formation was found to contain beds with many very perfectly preserved shells, among which W. H. Dall has reported *Planorbis* near *planoconvexus* M. and H. and a small multispiral species, also *Physa* near *subelongata* M. and H. These are also described in the Hayden reports. Unfortunately these forms are not

[a] Hayden, F. V., Second Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1870, 1871, p. 58.

[b] Osborn, H. F., Fossil mammals of the Uintah basin, Expedition of 1894; Bull. Am. Mus. Nat. Hist., vol. 7, 1895, pp. 71–106.

now known to be distinctive of any of the Tertiary formations, which are at present recognized by means of their fossil vertebrate bones.

TERTIARY(?) OR QUATERNARY ROCKS.

BROWNS PARK FORMATION.

Character and distribution.—As shown on the geologic maps (Pls. XVI, XVIII), deposits later than the Tertiary formations described on the preceding pages are found in a rather extensive area in Axial Basin, and north and northwest of that region. These rocks overlie the older formations in marked unconformity, so that outcrops of nearly all of the older rocks are in one place or another capped and concealed by them.

The deposits consist of soft friable material made up largely of rounded quartz grains more or less consolidated by calcareous cement, with few harder consolidated strata. They are everywhere of chalky-white color. They extend eastward as far as Cedar Mountain, whose summit is composed of these beds protected by an overlying cap of basalt. They correspond to the strata of the "Browns Park group" as described by Powell and others, and occur almost invariably in essentially horizontal position. At places near the margins of their present exposures they appear to tilt up slightly as though laid down over a topography somewhat similar to that of the present day. They thus have the appearance of comparatively recent deposits laid down in a restricted lake basin, which may be as old as the Tertiary, but is possibly more recent.

Although these beds at another locality are described very briefly, and with much doubt as to their age, in the Fortieth Parallel Survey reports, they are there mapped with the Green River group, as shown in the King atlas maps. They do not seem to have been recognized at all at the time of that survey as occurring in the territory east of Little Snake River. C. A. White,[a] who afterward studied this region, described the eastward extension of the beds from Browns Park to Fortification Butte (now better known as Cedar Mountain), and regarded these beds as equivalent geologically to the Uinta or latest Eocene strata exposed south of the Uinta Mountains. His reasons for this correlation are not clear, and the assumption now seems to have been unwarranted by the evidence.

The term Uinta was originally applied to the Tertiary formations of the Uinta Basin south of the Uinta Mountains by King in the reports of the Fortieth Parallel Survey.[b] The following description from that report is explicit:

> When the Tertiaries south of Uinta Range are carefully unraveled, as they doubtless will be by Powell and Gilbert, it will probably be found that the most recent Eocene

[a] On the geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming: Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 691.

[b] U. S. Geol. Expl. 40th Par., vol. 1, 1878, p. 407.

group, as developed in White River valley, is unconformable with all the earlier Eocene groups. It is a shallow deposit, of which not over 400 feet are seen, and in all probability is the sediment of a very restricted post-Bridger lake, wholly south of Uinta Range, and the last member of that remarkable series of Eocene lakes whose great deposits are piled unconformably over one another in the region. To this group alone should the term Uinta be applied. As provisionally used on the Fortieth Parallel atlas, Uinta group was a term stretched for convenience to cover all the Tertiaries south of Uinta Range, of whose true subdivisions we were ignorant.

Fossils.—The only fossils found in any of the Browns Park beds are some tubular forms of whitish substance that seem rather widely distributed and that in places are quite numerous. These forms vary from one-tenth inch in diameter to two or three times that size, and many of them are an inch or more in length. They have an internal cellular structure that suggests the interior structure of bones, although they may represent some form of fossil vegetation, such as roots or stems.

BISHOP MOUNTAIN CONGLOMERATE.

This formation was named by Powell from Bishop Mountain, in Wyoming, just north of the Colorado state line. The same beds were mapped by the King Survey as the Wyoming conglomerate, and that name has been used by other writers on the region. The term "Wyoming," however, has now been rejected as applied to these beds, on account of the confusion caused by its application to older rocks in the Rocky Mountain region.

The Bishop Mountain conglomerate is found in more or less isolated patches, possibly remnants of former outwash plains reaching out from the mountains, some of whose ridges or peaks it still caps. It forms the upper surfaces of many flat-topped mesas or buttes. As the present surface features are quite clearly of a more recent date than the time of distribution of these gravel and bowlder beds, probably only the more consolidated and resistant portions of the former extensive deposits remain. These beds are at places rather firmly agglomerated.

DRIFT.

The Bishop Mountain conglomerate is probably related to or the source of the scattered drift that becomes so conspicuous in the western part of Axial Basin and north of Yampa River. This unconsolidated material, therefore, seems to be of a later period of distribution than the original deposition of the Bishop Mountain beds. These unconsolidated beds are discussed in the Hayden report by White, who concludes that their deposition may have been contemporaneous with that of the great northern glacial drift, and suggests that they were of glacial origin. Powell and Emmons suppose them to have been of subaerial origin, resulting chiefly from the action of rains and streams, or, according to Emmons, representing littoral or shore deposits. A description somewhat more detailed than that

given here of some of these beds is contained in a brief statement concerning the gold-placer deposits near Lay, in Routt County.[a]

LATE IGNEOUS ROCKS.

Extensive outflows and intrusions of lavas have occurred, especially in or near the eastern part, in the areas here described or between them and the main Rocky Mountain range. Of these rocks much the greater part is a basaltic lava, either in the form of surface flows or of intrusive dikes or sheets. These rocks compose a considerable mass in the Elkhead Mountains, north of Yampa River, and are found in many isolated patches south and southwest of there. They are also quite extensive in the "flat tops" of the White River Plateau. Most of these areas are beyond the limits mapped in the present work. Cedar Mountain, near Craig, and Sleepy Cat Mountain, east of the Danforth Hills, were visited in the present work and the following observations were recorded:

In Cedar Mountain the basaltic lava appears to be a remnant of a dike and possibly also of a surface flow. Being more resistant than the surrounding softer sediments, it has held its present elevation. The basalt is clearly seen to overlie, as it probably also cuts, the white sandy beds of the Browns Park formation, so that it is of more recent age than the time of deposition of those beds. The evidence presented tending to show the late Tertiary or possible Quaternary age of the Browns Park therefore applies equally to this basalt, which may thus be, in part at least, of comparatively modern derivation. However, the high basalt-covered flat tops in the Elkhead Mountains and White River Plateau are very clearly much older than the present land forms, as they evidently indicate a time when the country was reduced to very near one general level, since which there have occurred earth movements and much erosion.

The summit of Sleepy Cat Mountain is apparently a remnant of an old lava cap, and possibly also a dike, the greater part of which has been worn away by erosion. It is a sharp summit surmounting a high plateau surface of broad rounding slopes, the latter corresponding to the general level of the White River Plateau region. The summit of the peak itself is about 10,800 feet (barometrical reading). The top is narrow, about one-half mile long, extending from north to south. At the south end of the main peak is a cliff of basalt, revealing in cross section a succession of separate flows, which have evidently spread out and cooled upon the surface one after the other, each solidifying before the next successive layer was added. Each constitutes a distinct bed, dense and compact at the base, and becoming vesicular or slaggy at the top. The alternating layers of vesicular and compact lava rest upon loose white sandy sedimentary

[a] Gale, Hoyt S., Bull. U. S. Geol. Survey No. 340, 1908, pp. 84-95.

beds, which are at places baked to a reddish color near the contact with the igneous rock.

From the summit of the peak an abrupt slope drops off 300 feet or more, grading into smoothly rounded ridges and open glades or parks, a large part of the whole extent of which is heavily timbered. A natural lake of clear water is situated just east of the summit. South of the peak the upper plateau surface is represented for a distance of several miles by the low, rounding slopes and gentle grades and meandering courses of the streams. Beyond, these same waters plunge off into deepening canyons to the lower country. The rolling upland is covered with heavy grass, where not forested, and is strewn with an abundance of basalt bowlders.

NOMENCLATURE.

All the formation names applied to the Cretaceous section by the Hayden, King, and Powell surveys, with the single exception of that of Dakota sandstone, have been superseded by other names in the foregoing descriptions. The relations of this recently adopted nomenclature to the old classifications and also the relations of those groups to each other are indicated in the accompanying table of correlations. As there presented, the classification of the Upper Cretaceous strata above the Dakota as Laramie, Lewis, Mesaverde, and Mancos has been used to replace altogether the older grouping of Laramie, Fox Hills, and Colorado as used by the King and Hayden surveys for this general region. Although the term Laramie is retained in the present classifications as the name of the uppermost of the formations of Cretaceous strata as they are now recognized, this term is no longer accepted as it was formerly applied by any of the early investigators in this particular field. This more recently adopted nomenclature has already been introduced into the literature of northwestern Colorado geology.[a] Still more recent stratigraphic studies have confirmed the first tentative conclusions of the Yampa coal field report, relating to the necessity for a revised nomenclature and confirming the expediency of the names there adopted for the northwestern Colorado region.

While the classifications and conclusions of the early geologic writers on this field have gained wide recognition and become very firmly established in a popular as well as a more technical way, there is ample justification, and indeed urgent necessity, for abandoning entirely this older terminology and revising the basis of that stratigraphic grouping. This revision is required for three specific ends: (1) To do away with the uncertainty that prevails with regard to the precise definitions and limits assigned to the same terms by the

[a] Yampa coal field, Colorado: Bull. U. S. Geol. Survey No. 297, 1907. Geology of the Rangely oil district, Rio Blanco County, Colo.: Bull. U. S. Geol. Survey No. 350, 1908.

various authors in the older work—the differing significance attached to the geologic term Colorado is the principal instance; (2) to establish a stratigraphic and lithologic basis of subdivision of the formations instead of the previously adopted paleontologic one, which depended on distinctions which are always difficult and often locally impossible of recognition; (3) to correct and call attention to an old and now widespread misinterpretation of the age of the beds formerly called Laramie in this field, a group of strata which should never have been included in the formations to which that name was applied, even according to the original somewhat uncertain definition of the term. These points are considered in more detail as follows:

(1) Use of the same geologic formation name with varying significance is found in the application made of the term Colorado by the King and Hayden surveys. This disagreement is indicated in the correlation table. In the reports of the Fortieth Parallel Survey the term Colorado is defined so as to include a considerably wider stratigraphic range than in its later use by Doctor White in his work with the Hayden Survey. The reasons for this confusion are largely paleontologic, as contained in the following statement by Doctor White:[a]

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

While the restriction of the term Colorado was not successfully applied in the mapping of this general field, where such a subdivision could not be traced on lithologic basis, Doctor White's usage of the term has been generally and consistently followed for thirty years, and it is still of great value as a correlation term. It is a natural division east of the Rocky Mountains from a lithologic as well as a paleontologic standpoint, where the calcareous Niobrara separates the two dark shales, Benton below and Pierre above.

(2) The necessity for the use of stratigraphic and lithologic distinctions as the primary basis in geologic mapping is well brought out by the difficulties encountered in the northwestern Colorado region. Doctor White himself says that "all groups of strata that referred to the Cretaceous period in this report[b] are within this district not only strictly conformable with each other as regards their stratification but I have never been able to fix upon a plane of demarkation between any of them with entire precision." Doctor White's grouping of the strata was made upon a purely paleontologic basis, a

[a] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 20–21, 30.
[b] Idem, p. 29.

Table of correlations of geologic names used for western Colorado strata.

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

	Hayden, 1861–1870+, various writings.	King, 1875, Rept. U. S. Geol. Expl. Fortieth Parallel.	Powell, 1876, Geology of Uinta Mountains.	White, 1878, Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr.	White, 1889, Ninth Ann. Rept. U. S. Geol. Survey.	Cross, 1899, San Juan folios, U. S. Geol. Survey.	Fenneman and Gale, 1907, Yampa coal field report, Bull. U. S. Geol. Survey No. 297.	Present report.	
Recent.					(Alluvium.)			(Alluvium.)	Recent.
Glacial?			Morainal deposits.	"Scattered drift."	(Local drift.)			(Local drift.)	Pleistocene?
		Wyoming conglomerate.	Bishop Mountain conglomerate.		Bishop Mountain conglomerate.			Bishop Mountain conglomerate.	
			Browns Park.	Uinta.	Browns Park.			Browns Park.	Post-Tertiary?
		Uinta.							
	Bridger.	Uinta. Bridger.	Bridger.	Bridger.	Bridger.			Bridger.	
	Green River.	Uinta. Green River.	Green River.	Green River.	Green River.			Green River.	Tertiary.
Tertiary.	Wasatch.	Uinta. Vermilion Creek. (a)	Bitter Creek.	Wasatch.	Wasatch.			Wasatch.	
	Fort Union or Great Lignite group.			(Neither unconformity nor hiatus recognized.)				Fort Union(?) (a)	
			(b)			Laramie.	Laramie.	Laramie.	
						Lewis.	Lewis.	Lewis.	
		Laramie.	Point of Rocks.	Laramie. c	Laramie. c	Mesaverde.	Mesaverde.	Mesaverde.	Cretaceous.
	Fox Hills. Pierre. Niobrara. Benton.	Fox Hills.	Salt Wells.	Fox Hills.	Fox Hills.	Mancos.	Mancos.	Mancos.	
Cretaceous.		Colorado.	Sulphur Creek.	Colorado.	Colorado.				
	Dakota.	Dakota.	Henrys Fork.	Dakota.	Dakota.	Dakota.	Dakota.	Dakota.	
	Jurassic.		Flaming Gorge.	Jurassic.	Jurassic.	McElmo. (Gunnison.)		Flaming Gorge.	Jurassic.
			White Cliff.			La Plata. (Gunnison.)		White Cliff.	
Jura-Trias.	Triassic.		Vermilion Cliff.	Triassic.	Triassic.	Dolores.		Vermilion Cliff. ("Red Beds.")	Triassic.
			Shinarump.			Cutler.		Shinarump. ("Red Beds.")	
								Weber.	Carboniferous.

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

policy which he considered imperatively necessary[a] for the purpose of establishing at once wide-range correlations over extensive areas. Thus the division planes which he adopted depended entirely on scattering and frequently inadequate fossil evidence and not on recognizable changes in the rock strata themselves, with which they confessedly did not agree. His planes of demarkation were thus impossible of precise definition and could never or very rarely be identified exactly in the field. The geologic boundaries he has shown on his maps are, therefore, scarcely more than mere estimates or are purely arbitrary lines which had to be assumed in the absence of criteria necessary to establish the actual subdivision. Even if sufficient fossil evidence were everywhere at hand to make this division it is extremely doubtful if it would serve the most useful purposes, as no one without paleontologic training could appreciate its value when drawn.

Though it now appears to be more practical to map geologic formations in any particular field largely on the basis of lithologic distinctions—that is, on changes in the character of the rock strata—no one will question the necessity of paleontologic evidence in determining the position of these rocks in the geologic time scale, and as a means of establishing their correlation across the larger areas or in discontinuous fields. As many and as serious errors as those of some of the older surveys have been the result of attempted correlation on a basis of lithologic similarity of rock formations occurring in discontinuous areas. The argument as here presented is in favor of what is the more practical method of subdivision of this specific stratigraphic section. In general, it seems fair to assume that in any one field or basin marked changes in the constitution of the rock strata themselves furnish as important evidence of changes in geography and in conditions of sedimentation during past geologic time as do the fragmentary records of the animal life that now happen to be preserved.

A part of the confusion in the early geologic mapping based on paleontologic distinctions was probably due to a failure at that date to understand the significance of the so-called Fox Hills fauna. It is likely that the use of the term Fox Hills to define any particular formation representing a specific time interval in the Cretaceous history of the Rocky Mountain region will now be abandoned. This conclusion has been reached by Stanton and others after an extensive study of western Cretaceous stratigraphy, and, so far as known to the author, is not now disputed by anyone familiar with these problems. As stated by Stanton:[b]

> Faunas similar to that of the Fox Hills sandstone have a great vertical range and are likely to be found at any horizon within the Montana group where a littoral or

[a] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., p. 30.

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

shallow-water facies is developed. The use of the term Fox Hills as a formation or horizon name outside of the original area in South Dakota is therefore of doubtful propriety, as experience has shown.

In most of the fields west of the Rocky Mountains or the Great Plains the term Pierre has also led to some confusion. Published sections in central and northern Montana have included the name Pierre to define a shale body (later named Bearpaw, although still assigned to Pierre age) overlying the Judith River, Claggett, and Eagle formations. The three last-named formations are now considered to be in greater part the equivalent of the Mesaverde formation of the northwestern Colorado and southern Wyoming sections. In the latter fields, however, Pierre has been used to denote beds which normally underlie the Mesaverde formation. The shales above and below the Mesaverde are of similar lithologic composition, resembling the Pierre shale of the Great Plains region and also containing faunas that are commonly found in the Pierre of that section. Although Pierre is certainly valid and is a useful term in the large area where the Niobrara is typically developed and the Mesaverde and similar formations do not exist, it does not apply as the name of a formation to be distinguished by its fauna in most of the Cretaceous fields in the western Rocky Mountain foothills province.

(3) With regard to the former misinterpretation of the term Laramie so far as it pertains to either the Uinta or the Green River Basin, the solution is clear. None of the rocks in those regions to which the name Laramie has hitherto been applied are properly classed as such. The Laramie formation in the sense in which the name was originally adopted is almost certainly not represented at all by any of the strata exposed south of the Axial Basin anticline. Either this formation was never deposited in that region, or if it was deposited it was completely eroded at a later time, before the overlying Tertiary beds were laid down. While Laramie strata are now described in the Green River Basin north of Axial Basin, the formation may not correspond entirely to that distinguished as Laramie in the early mapping of the region. The Fortieth Parallel geologists, as well as those of the Hayden Survey, mapped the upper or brackish-water beds of the Mesaverde as the Laramie formation in this part of Colorado.

The name Laramie was adopted by agreement between King and Hayden to describe the uppermost Cretaceous strata then thought to rest conformably at the top of that system above the marine deposits. It was assumed at that time that marine conditions existed in a large part of the interior province during most of Cretaceous time, and that these conditions terminated with a succession of crustal movements that uplifted the Rocky and Uinta mountain ranges. Portions of this interior sea were supposed to have been

cut off in interior basins at the time of that upheaval, so that they gradually became filled with fresher and fresher water, until the wholly fresh-water conditions which marked Tertiary time were fully established. It was clearly the intention of the early investigators to denote the beds laid down during this transitional stage by a formation name, and for this purpose Laramie was adopted. In terms of later geologic nomenclature, therefore, Laramie was originally intended to include all of the brackish-water deposits which succeeded the Montana, or latest marine deposits then recognized in the Cretaceous system. The upper limit of this formation was less distinctly defined, but Laramie was in all probability intended to include all strata above the last main body of marine deposition and below whatever beds shall be considered as belonging to the fresh-water or Tertiary basins established after those mountain-building movements were completed. The application of the term to a part of the Mesaverde formation was, therefore, clearly due to misinterpretation of the significance of those beds.

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

The fact that Mesaverde time was succeeded by a considerable period of true marine deposition was entirely unrecognized at the time of the earlier surveys. Evidence of this return of salt-water conditions is found in the existence of a normal succession of marine strata overlying the Mesaverde formation, in the Yampa River valley, which is included in the Green River Basin and is north of the fields structurally included with those of the White River districts. As already described, the Green River Basin contains a great body of dark clay shale with lenticular interbedded sandstones and cal-

careous layers, overlain by a second large body of sandstones, sandy shales, and coal beds. Of these deposits the lower or shale group (Lewis shale) is of marine origin and the overlying beds indicate a second transitory stage, reintroducing brackish and fresh water conditions. The later beds are thought to represent, at least in part, the Laramie, so far as the best interpretation of that term is at present understood. The unconformity that is assumed to limit the Laramie formation at its top doubtless represents a considerable period of nondeposition and erosion, so that it is quite likely that only a partial representation of all deposits laid down in Laramie time may now be present in this region.

STRUCTURE.

REPRESENTATION OF GEOLOGIC STRUCTURE.

The geologic structure of a region is perhaps best described by means of graphic or diagrammatic representation, which is usually incorporated in or accompanies the geologic map, although some general verbal description is also useful for the purpose of outlining the broader, more general features or explaining the more or less obscure details.

The usual methods of representing geologic structure on a map are by means of structure sections or by structure contours. The structure section is a familiar and popular method of illustrating a geologic report. It generally represents in more or less diagrammatic way and with necessary generalization for a small scale an idealized view of the cross section of strata as they would presumably be exposed by a vertical cleft along some stated line. The section usually also includes a profile of the surface along the same line. Structure sections are included in this report with Plates XIII, XVII.

In areas of complicated or irregularly folded strata structure sections are not so satisfactory, and they are not sufficient for recording a complete general statement of the structural features. In this case the method of structure contours, by which elevations of some key horizon of the geologic section are recorded, is commonly adopted. Thus the horizon selected for structure contours on several of the maps (Pls. X, XVI, XVIII, XIX) accompanying this report is that of the "white rock," which is approximately the base of the principal workable coals of the Mesaverde formation. These structure contours where shown should therefore show the elevation of the lowest workable coal beds at the given point. Since the elevation of the surface of the ground is also shown on the same map by means of the surface contours, the depth of the lowest coal is indicated by the difference between the two. Where the structure contour of a given elevation intersects a surface contour of the same elevation, the stratigraphic horizon upon which the structure contour is drawn

would be found in outcrop, if the map is correct. Where the stratigraphic interval of any given coal from the key-rock horizon is known, the depth of that coal may be calculated by taking into account the depth of the key-rock horizon, the stratigraphic interval of the given coal above or below that key horizon, and the vertical element of the stratigraphic thickness for the dip of the strata at that place.

It is obvious that the construction of maps stating the underground structure of beds solely by inference from the surface observations can not ordinarily be made absolutely correct. The conditions are generally estimated on the assumption that the beds observed at the surface maintain a uniform thickness in depth. Occasionally mining operations or deep wells are available and furnish more precise data, but even in such cases much has to be based on inference between points of determination. The depth of a given horizon is shown as determined by the thickness of strata observed to overlie it where exposed at the surface outcrops.

MAJOR FEATURES.

UINTA AND GREEN RIVER BASINS.

The coal fields of northwestern Colorado are contained in two broad structural basins or depressions of the rock strata, surrounded by areas of older rocks that are relatively uplifted as compared with the fields that contain the coal. The farther north of these two is the Green River Basin, the greater part of which belongs to Wyoming, but which also extends into Colorado along the upper valley of Yampa River (this part has been described as the Yampa coal field). The Green River Basin is terminated by the uplifts of the Uinta Mountains on the south and by those of the Rocky Mountain system on the east. The Yampa coal field of Colorado, the Henrys Fork, Rock Springs, Rawlins, Carbon, and Hanna fields of Wyoming are all a part of this broad structural feature.

The Uinta Basin lies south of the Green River Basin and is separated from it by an anticline or axis of uplift that appears to unite the uplifted areas of the Uinta Mountains of Utah with the Rocky Mountains of Colorado. It is limited by the Uinta Mountains on the north, by the Rocky Mountains and their foothills on the east, and by the uplifts of the La Sal Mountains and the San Rafael Swell on the south. This basin extends west to the Wasatch Range in Utah. The Colorado portion includes an area of approximately 7,000 square miles, and the Utah portion is much greater.

These two basins outline the dominant geologic structure of nearly the whole of northwestern Colorado. They are in form broad synclinal folds or troughs of the rock strata, which narrow to an apex toward the southeast. Within the State of Colorado their longer

axes are approximately parallel, extending from southeast to northwest. The strata that form the margins of these basins, though complicated at many places by minor folds and irregularities, have a general dip toward the basin interiors, and are tilted away from the uplifted older rocks that surround them. In these structural basins the axes or deepest portions of the folds lie, in the main, parallel to the major axes of the uplifts that border them. Thus within the influence of the Rocky Mountain system all the folds exhibit marked parallelism in a northwest and southeast direction. The axes of the Uinta uplift trend more nearly east and west, and an extension of that mountain uplift eastward as a comparatively simple anticline through Axial Basin bends southeastward and merges into the corresponding uplifts and folds of the White River Plateau, which are clearly a part of the Rocky Mountain system. This connecting axial uplift is of comparatively slight magnitude as a structural deformation, but is important as separating the two huge basins of the younger Cretaceous and Tertiary rocks that lie north and south of it. That to the north is described in part as the Washakie Basin in Wyoming; it belongs to the greater structural unit known as the Green River Basin, which comprises the whole south part of that State and extends southeastward across the upper valley of Yampa River in Colorado.

The Colorado portion of the Uinta Basin has been termed the Grand River Basin, and is in a minor way naturally distinct from the larger extension of that feature into Utah, being separated from it by a series of anticlinal or domal uplifts of which the Raven Park fold is one. The line of uplifts that almost separates the Tertiary strata of the Uinta Basin of Utah from the corresponding formations in the Grand River Basin in Colorado forms an approximately north and south axis. This uplifted area is, however, composed of three or more distinct structural domes, presently to be described in detail, whose axes of greater elongation are approximately parallel to each other, but oblique to their north and south alignment as a group. The longer axis of the Raven Park anticline lies apparently in extension of the major axis of the whole Grand River Basin. As will be described (p. 103), the similar and more pronounced fold of the southern Blue Mountain region lies north of the Raven Park anticline. A similar and less pronounced fold south of the Raven Park anticline will be described as the Douglas Creek uplift (p. 104). South of the Douglas Creek uplift and beyond the area here considered in detail the Uinta Basin as a whole terminates against the flexures bordering the Uncompahgre Plateau south of Grand River valley, just as it does against the Uinta axes on the north.

COAL-FIELD AREAS.

The coal-bearing rocks outcrop in practically continuous rims around the borders of the basins, the only exception being some locali-

ties where they have been overlapped or buried by later deposits. As these strata dip in general toward the interiors of their respective basins, they probably extend to great depths beneath the younger and overlying deposits. Thus coal fields that are actually available in a commercial way are limited for the most part to the territory adjacent to the outcropping coal beds. While there is probably ample justification for assuming that coal beds extend beneath the entire area around which is found a practically continuously outcropping coal-bearing formation, it is extremely doubtful if more than a very small portion of this great area will be worked as a coal field for a long while to come.

Where the strata that border the structural basins are steeply tilted in simple and regular structure the coal-field areas are usually limited very closely to the neighborhood of the actual outcrop of the coal-bearing formations. With the flattening out of the structure, however, the coal beds may be so situated as to extend to a much greater horizontal distance from the point of outcrop before they pass below workable depth. Furthermore, in many places, the structure at the outcrop of the coal-bearing rocks is not a constant dip in one direction and the workable area may be much expanded by a repetition of folds bringing the coal near the present land surface. As an instance the Danforth Hills as a whole may be cited. Details of the structures thus produced are important in a study of the depth and availability of the coal beds they affect.

As the coal fields lie in structural basins, that is to say the broad general depressions of the strata, they are surrounded by uplifted areas against which the coal-field rocks are tilted and from which they have probably been removed by erosion. Thus an area of uplift that has later been eroded normally exposes rocks that are older than the rocks that surround it, and if the older formations at the center are of weaker or less-resistant material than the younger the structurally uplifted areas are now represented by valleys, parks, or topographic basins. There are many such anticlinal valleys in the foothill region of the Colorado Plateau province. Where, however, the older formations brought to the surface and exposed by erosion are of harder composition, the uplifted areas are represented by mountains or mountain ranges. This is true in most of the major uplifts.

UINTA MOUNTAINS AND THE AXIAL BASIN ANTICLINE.

The principal anticlinal fold of the region appears to be a continuation of the Uinta Mountain axis, extending eastward to join the Rocky Mountain system. This fold separates the Green River and Uinta basins by a valley of erosion that has been opened out on the thick shale formations that overlie the Dakota sandstone and under-

lie the coal beds. As already described, it extends from the main axis of the Uintas through Axial Basin to the White River Plateau and into the Rocky Mountain system.

In the lower parts of Axial Basin this fold is of no greater magnitude, so far as its intensity of uplift is concerned, than other folds that occur within the coal fields themselves, but it evidently marks a line of uplift that served as a barrier between the extensive basins north and south during a part of late Cretaceous or early Tertiary time. Whatever the conditions may have been that caused the separation of these two major basins, they evidently made possible either nondeposition or deposition and subsequent erosion of some of the later Cretaceous beds on the southern side of this barrier, while they permitted corresponding deposits only a few miles distant on the northern side of that axis to remain undisturbed. For this reason it is classed as one of the major structural axes of the region.

FOLDS.

THE GRAND HOGBACK.

The Grand Hogback fold is a simple monocline. Like almost all the folds of this general region, it is of the type described by Powell[a] as "Uinta structure"—a term used to define flat-topped or plateau-like uplifts bounded by monoclinal flexures, or flexures and faults, on either side. Similar structures are characteristic of the folds that occur along the foothills of the older uplifted areas. The hard and more resistant strata are commonly eroded to the steeply tilted portions of the folds, where they hold their sharply inclined position as the present outcrop of those beds. Such is the case in the Grand Hogback fold, where the resistant sandstones of the coal-bearing strata form the principal hogback ridge. South of White River a second hogback ridge, consisting of the massive Dakota and Jurassic sandstone ledges, parallels the first on the east. The hogbacks of the older rocks rise to as great or greater elevations than the hogbacks of the coal-bearing rocks, but do not appear to be so prominent, because they are not bordered or set apart by low shale valleys on both sides, as is the Mesaverde hogback.

Detailed study of this monocline reveals a great amount of minor irregularity among the component strata that make up the apparently simple fold of the structure as a whole. The westward dip of the beds across the outcropping section is not constant in amount either across any single continuous section or on particular horizons followed along the strike. At White River the angle of dip in the hogback

[a] Geology of the eastern portion of the Uinta Mountains; Final Rept. U. S. Geol. and Geog. Survey Terr., 1876, p. 11-14.

strata varies from 36° on the east side to 60° or more on the west. A short distance south of White River this increases to vertical and is even overturned on the western side of the ridge. Between Thirteenmile, Fourteenmile, and Piceance creeks the dips vary from 30° on the east to 50° on the west, while at Rifle Creek Gap the strata on the west side are vertical. At Grand River the steeper beds are at the base of the hogback ledges on the east side of the ridge, where the dip is about 50°; on the west the dip flattens, becoming 18° to 25° at the Keystone mine and even less in the Cactus Valley beyond.

The Piceance Creek section may be taken as typical of many parts of the fold and is illustrated in one of the cross sections published herewith (Pl. XIII).

DANFORTH HILLS.

The Danforth Hills are composed of a complex system of folds by which the strata are bent into irregular anticlines and synclines. The strata lie tilted against the older rock formations on the north, east, and south, and plunge beneath the younger formations on the west. On all sides except the west the field is therefore bounded by a much-dissected monoclinal ridge, presenting an escarpment front toward the surrounding valleys and, where not further complicated, either a gentler slope toward the interior of the field or a more gradual rise toward its higher summits. In the following descriptions a few specific names are given to structural features, where they clearly apply to some compact and distinctly recognizable unit.

The present drainage divide between White and Yampa rivers follows approximately the crest or axis of a principal anticlinal fold, the strata dipping more steeply on the southern limb than on the northern. As this anticline is traced toward the northwest the beds on the northern side rise and stream gulches and canyons grow deeper, so that the harder ledges that occur in the lower half of the coal-bearing formation lie at or above the water level of the main stream. Temple Canyon and Maudlin Gulch have thus been cut below the horizons of the principal coal beds. Northwest of Temple Canyon, beyond Lone Pine and Bob Hughes gulches, erosion has removed all of the more resistant beds from the northern limb of this anticlinal fold and there remain only the low shale ridges on the north side of the monoclinal ridge of steeply tilted coal-bearing strata that forms the westward extension of the Danforth Hills coal field.

Through the center of the district erosion has removed the upper members of the Mesaverde formation along the crest of this principal anticline, and some of the deeply eroded canyons or gulches in that part of the field have cut down below the lower principal group

of coal beds (Pl. XVI). These include localities at the head of Wilson Creek, and also along the upper forks of Devils Hole Gulch, the latter being on the Strawberry Creek or White River side of the divide. This feature is the result of local uplift of this portion of the principal anticlinal axis, producing the effect of doming of the strata—a quaquaversal fold in which strata dip away in all directions from the center of uplift.

Toward the eastern part of the Danforth Hills field the axis of the principal anticline is less definitely distinguishable, owing to the prevailing light dip of the strata on the northern limb of the fold. The anticline is continued, however, being most clearly defined by its southern limb, which is limited by the steeper dips of the strata that plunge off into the Sulphur Creek syncline, as described below. East of the coal field it continues as an axis of uplifted strata, merging into the Coal Creek uplift in the direction of Sleepy Cat Mountain. Probably the most marked and readily recognizable structural feature of the Danforth Hills field is the synclinal axis that extends from east to west across the upper valleys of Sulphur, Curtis, and Coal creeks, including the valley of Ninemile Draw. This axis is apparent in the V-shaped ledges that show in the divide west of the stage road in the vicinity of the Harp and Moulton ranch on Curtis Creek, where it may be readily seen from the Meeker-Axial stage road. The broad open valley of upper Sulphur and Curtis creeks and Ninemile Draw are eroded on the weaker more shaly part of the Mesaverde strata that outcrop along the axis of this syncline. Farther east this fold crosses Coal Creek and, bending south, terminates in a canoe-shaped apex in the southeast corner of the Danforth Hills field. West of Sulphur Creek the two limbs spread broadly, one extending northwest as a western limit of the Danforth Hills, and the other continuing in an almost due south direction and becoming the monocline of the Grand Hogback ridge.

On the north side of the main divide the spurs and ridges reaching out toward Axial Basin extend across another syncline broader and more gently flexed than that of upper Sulphur Creek, which is parallel to and coordinate with the anticline of the main divide. The long gentle northerly dip of the strata toward the axis of this syncline is abruptly terminated near Axial Basin by a sharp upturning of these beds at the edge of the Axial Basin anticline. Thus the axis of this synclinal fold lies parallel to and near the margin of Axial Basin.

The principal anticline of the Danforth Hills field, the Sulphur Creek syncline, and the synclinal depression that occurs at the southern margin of Axial Basin may be traced almost if not quite the entire length or breadth of the field. These structures have, however, been somewhat complicated by cross-folding, which gives to the whole the effect of minor domes and basins. The effects of

the resultant folds have already been mentioned so far as the low quaquaversal uplift of upper Wilson Creek is concerned, and also so far as shown by the rise in the strata toward the northwest end of the field; but the depressions intervening and coordinate with those uplifts are also important on account of their influence on the position of the coal beds.

A depression of the strata follows the valley of Morgan Creek, with a longer axis apparently lying directly across that of the principal folds of the field. The structure is made evident by its influence on the topography in that district. The harder and more resistant ledges of the lower part of the coal-bearing series, which are almost everywhere most prominent as ridge makers where they lie at the surface of the ground, pass below water level in the valley of Morgan Creek. A region of comparatively low rounded summits and flat-topped ridges surrounded by the higher peaks of the bordering areas thus gives, at least in the general aspect of the region, the effect of a topographic basin which marks the corresponding depression of the rock strata. This feature may be recognized in the topographic map accompanying this report (Pl. XVI), although the Morgan Creek district is not actually a topographic basin in the sense in which Axial Basin would be so described.

The only other distinct structural feature of considerable extent within the coal-field area is found in the northeastern extremity of the Danforth Hills. Sharp folding of the strata, which may in this instance be better described as buckling, has produced in the vicinity of Thornburgh Mountain a narrow inclosed structural basin with steeply tilted flanks on all sides but the west. This is described more at length in connection with the detailed description of its coal-bearing rocks (p. 169).

An uplift exposing Jurassic and Triassic and possibly older beds occurs in the upper valley of Coal Creek on the west side of Sleepy Cat Mountain. This forms the eastern termination of the coal-field basin, as it lies beyond and east of the Danforth Hills area.

Agency Park owes its origin to a domal uplift similar to the quaquaversal folds already mentioned. As this happened to bring a broad area of soft shales to such an elevation along White River valley that they were easily eroded, it is now represented by an open park. In the center of this park, at the apex of the dome, about 3 miles east of Meeker, ledges of the Dakota sandstone are exposed along the river bank, and the black shale overlying that formation is readily recognized, as it is observed to dip from this center of uplift on all sides, except where concealed by wash along the river bottoms. Around the northern margin of the park the sandstone hogback ridges also swing in concentric arrangement around this structural center. The outcropping Dakota ledges in the midst of the park

seem to have been overlooked in the publication of the geologic maps of the Hayden atlas, although their occurrence had been previously noted and described in the annual reports of that Survey.

COYOTE BASIN SYNCLINE.

West of the Danforth Hills a broad area of comparatively gentle structure constitutes in effect a syncline with an open side on the south, so that it merges with the main Uinta or Grand River Basin. The axis of greatest depression lies near the eastern side of this fold. The term basin is applied to a part of this area in a topographic sense, referring to a low valley district at the western side. A minor anticlinal fold, the crest of which crosses White River near Blacks Gulch and White River post-office, traverses this region in a north and south direction. This low dome exposing the Wasatch strata at the surface is surrounded by the Green River beds on all sides. Its dips are very light, probably not over 3° to 5° toward the east, 5° toward the west, and perhaps 10° toward the south as the axis crosses the river.

Along the river valley between the mouths of Piceance and Yellow creeks, a synclinal axis correlative with that of the minor anticline just described crosses White River in a northeasterly direction. This is a rather abrupt fold with the steeper tilting on the west side, where the beds dip eastward 50° to 60° as far as the mouth of Deep Channel Creek.

RAVEN PARK ANTICLINE.

The structure of Raven Park is essentially a simple anticline or dome of the underlying strata, the valley itself having been eroded from the crest of the uplifted portion. The strata are inclined outward, dipping in all directions from the center or axis of the uplift. The dome is roughly oval in form, the axis or longer diameter lying in an almost due northwest-southeast direction. At either end of the axis the fold flattens and is lost to view, merging into the flexures of adjoining areas. Toward the northwest the two flanks of the flexure unite, the strata becoming approximately horizontal with a number of minor irregularities, the arch or axis disappearing a short distance west of the Colorado-Utah state line. Beyond that point all trace of subordinate folds is lost, the strata being tilted in a uniform southward dip away from the higher uplifts to the north, extending in this way westward to the Green River valley. To the southeast of Raven Park the Raven Park anticline apparently terminates in the flat-lying beds of the high escarpment wall known as the "Cathedral Bluffs."

The Raven Park anticline is not a symmetrical fold. Toward the northeast the strata dip away at light angles averaging from 4° to 6°; toward the south and southwest they dip much more steeply, the point

or axis of flexure being very abrupt, a feature characteristic of most of the folds produced in the western Cretaceous foothill strata. At the steeper side of the fold the strata dip at angles varying from 15° to about 35°. This condition is found along Raven Ridge and the south side of White River.

As previously stated, the Raven Park anticline lies midway between similar flexures on the north and on the south. Each of these folds exhibits striking features of symmetry and apparent relationship to the others. Most prominent of these relationships is the character and position of the abrupt flexures themselves, together with correspondence in the direction of their longer axes. It is of interest to note the gradation of the intensity of uplift in the relations of these various folds. The Midland fold to the north was great enough to bring up rocks as old as Carboniferous, but even that was of much less magnitude than a similar and greater fold immediately north of it. The Raven Park fold exposes the Mancos shale of Upper Cretaceous age at its center. The Douglas Creek flexure is broader and of less intensity than that of Raven Park, so that its upper portion is now largely covered by the younger Mesaverde strata.

MIDLAND UPLIFT.

The Midland uplift was named and described by Doctor White [a] in the reports of the Hayden Survey. The name is intended to include the anticlinal flexure that forms the southern margin of Blue Mountain (Yampa Plateau of the earlier work), a portion of which was then designated the Midland Ridge. The southern margin of this region of uplift is included in the area of the geologic map (Pl. XIX). It is in many respects the most striking feature of the region and is of especial interest in connection with a study of the Raven Park uplift by reason of its similarity in form, parallelism of structure, and the great magnitude of the stratigraphic displacement which it represents. By reason of the greater intensity of its uplift and also of subsequent erosion along its axis, it brings to view a considerable section of the older strata that underlie Raven Park, but are not there exposed.

Like the Raven Park anticline the Midland uplift exposes at its center beds of weaker composition than those which compose the flanking ridges, and thus a portion of the axis or crest of the uplift is eroded to a valley of comparatively low relief. This valley is in form a great amphitheater about 15 miles in length, inclosed by an almost continuous wall of brilliantly colored strata. This escarpment is a striking feature of the landscape and can be seen from a great expanse of territory south as far as and beyond White River valley. It is in form a precipitous wall 1,000 to 1,500 feet in height,

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

composed of brilliantly colored clay or shaly strata, capped by ledges of massive white sandstone.

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

RED WASH SYNCLINE.

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

DOUGLAS CREEK UPLIFT.

The Raven Park anticline is terminated on the south by a narrow and rather abrupt syncline, separating the region of that uplift

from another of low anticlinal structure in the valley of Douglas Creek farther south. This is a broad, low arch of far greater areal extent than the Raven Park fold, but of less intensity of uplift, so that the strata exposed at the crest on the eroded surface and in the valley bottoms are mainly those of the Mesaverde formation. It occupies chiefly the drainage basin of Douglas Creek, a broken and somewhat roughly mountainous district surrounded by the higher escarpment ridges and plateaus of Tertiary strata. This broad basin of anticlinal structure extends west approximately to the state line in the vicinity of Dragon, Utah, and is terminated on the south by the high summits of the divide of the Roan or Book Cliffs Plateau. It is limited on the east by the high precipitous wall of the Cathedral Bluffs. The areal extent of this fold is estimated as at least 250 square miles. A large part of the district is coal-bearing, and it may eventually prove to be an important coal field.

This uplift lies intermediate between the Raven Park anticline on the north and the uplifted area south of Grand River, which forms the northern margin of the Uncompahgre Plateau. It thus completes a north-and-south alignment of dome structures which constitute a natural separation of the Grand River Basin of Colorado from the Utah portion of the Uinta Basin, a feature that has already been referred to (p. 96).

The dips on the flanks of this broad, low fold are very gentle, but they show many irregularities, and the main fold is not, therefore, so well defined nor so readily discerned as the simpler uplifts to the north. The prevailing dips over a larger part of the district are approximately equivalent to the grades of the streams. The oldest strata are exposed on West Fork of Douglas Creek, about a mile above the N-Bar ranch (which lies in the main forks of the creek) and about 18 miles above White River. Here a small topographic basin is eroded in a shale that belongs clearly near the base of the Mesaverde, but the writer is not certain whether it actually occurs below the lowest sandstone, corresponding to the rim rock of Raven Park, or is just above that bed.

SECTION RIDGE ANTICLINE.

North of the Midland anticline and extending west from the Yampa Plateau a westward-pitching anticline continues beyond the termination of the Midland fold and, as recognized in the outcrops of the harder strata involved, passes beneath water level at Jensen on Green River. Here sandstones which carry Benton fossils show in the river bank just above water level. This anticline is clearly revealed in Section Ridge, where it stands as a great rock wall over 3,000 feet in height on the north side of and parallel to the upper course of Cliff Creek. The point of greatest flexure is near the south

side of the fold, and therefore the southern side of the ridge shows the steeply tilted beds of the hard Jurassic sandstones, with the lightly dipping strata of the same formation capping the summit. Toward the west as the whole fold pitches in that direction the harder strata form concentric curved ridges at the foot of the higher rocky escarpment. In form the fold resembles that of the Midland uplift as already described, but is evidently of greater magnitude, both in the amount of uplift it represents and in its horizontal extent.

SPLIT MOUNTAIN ANTICLINE.

Farther north of Section Ridge Split Mountain anticline forms a craggy sandstone ridge, through which Green River passes in a deep canyon. This fold corresponds in form to both the Midland and Section Ridge folds, but is higher and reaches farther west than either. Its axis pitches toward the west and, as represented by the harder ledges at the base of the Cretaceous section, it disappears near the lower course of Brush Creek. At the western foot of this mountain the harder formations stand out as concentric curved ridges, passing around the end and continuing back to the east on its northern side in the direction of Island Park. Along Brush Creek some minor irregularity of the larger anticlinal structure is noted, as is shown by the symbols on the geologic map (Pl. XXI).

ISLAND PARK SYNCLINE.

North of Split Mountain and between it and the uplift of the main Uinta Range is a broad, open valley extending from east to west, from Ashley Valley near Vernal to Green River. At Green River, where it forms a broadened valley, terminated by canyons above and below, it is known as Island Park. Except along the larger stream valleys, this depression is occupied by the yellow-clay hills and ridges of the Mancos shale, much of which is very near badlands in character.

UINTA MOUNTAINS.

The main range of the Uinta Mountains is a broad, flat-topped anticline of east-west trend and over 150 miles in length. The present mountain mass is somewhat dissected by erosion, but in general the larger features are those determined by the underlying rock structures. It forms the northern limit of the Uinta Basin, which lies to the south, and the southern limit of the broad area known as the Green River Basin that lies to the north.

The Uinta Mountains present an extensive and fruitful field for both structural and stratigraphic geologic work, a large part of the detail of which remains still to be worked out. This broad subject lies beyond the scope of the present report.

WESTERN YAMPA FIELD.

Along the valley of Yampa River west of the mouth of Williams Fork the Mesaverde rocks are tilted in several broad folds. The principal structure of this part of the field is the Axial Basin anticline, which forms the southern limit of the Green River Basin. The strata rise toward the axis of that uplift, from the summit of which the Mesaverde rocks have been eroded, so that the coal field terminates with the southward-facing escarpments of Iles and Duffy mountains. Northeast of the Axial Basin uplift a corresponding syncline passes through Round Bottom on Yampa River with an axis approximately parallel to the major anticlinal fold. Northeast of the Round Bottom syncline a secondary anticline with axis parallel to the other two folds extends northwestward from the mouth of Williams Fork. This is exposed as far as Sand Springs, near the Craig-Lay wagon road, and doubtless influences the underlying structure to the northwest much beyond that point, although concealed by the overlying unconformable deposits. The prevailing dips of all these structures are light, commonly not exceeding 10° to 15°.

FAULTS.

Within the coal-field areas the structure of the region is affected only in a very subordinate way by faults, although extensive faulting has taken place along the major structural axes of the mountain ranges. Along the north side of the Uinta Mountains in the Henrys Fork field these faults so obscure the geologic relations in a number of localities that it is somewhat difficult to understand the true relations of all the beds, including in part localities in which coal is found. In the rest of the area discussed the faults exert but minor influence on the distribution of the coal.

Several minor faults on Douglas Creek south of Raven Park are described later (p. 200).

In the absence of readily distinguishable beds or horizon markers among the coal-bearing strata, and by reason of the similarity of the various members in those formations, minor slips or dislocations within the field are very likely to pass unnoticed. Where they occur, however, they are of considerable practical importance to the development of the coal.

SLUMPS.

Slumps or land slips are numerous, and on account of their prevalence in certain districts may be considered a quite serious hindrance to ready access to the coal beds. They seem especially common on steep escarpment slopes where the upturned strata face lowlands or valleys eroded from older and softer underlying beds.

The displacements noted near the outcrops may be traced to two general causes. Possibly the most common has had effect where a block of strata has broken off and settled down a slope. In so doing the beds that may have been normally nearly horizontal or only slightly inclined tilt up at their outer edges as they settle, so that the rocks at the surface appear to have a steeper dip into the hill than the rock in place has. This leaves a local depression at the top and back of the slumped-off block, which, as it is very likely not to have any natural drainage, is commonly marshy or may contain a pond, if the rocks are sufficiently impervious to hold the water. The effect is of course comparatively superficial, but may interfere seriously with the preliminary tracing of a coal bed by means of outcrop indications, or by key-rock horizons that occur above or below it. Sulphur Creek offers many good examples of such displacement, nearly every spur along the lower course of that gulch or canyon on the west side being broken off and slumped in this manner. At many places the blocks show the line of the break and displacement along which they have slipped forward and downward toward the gulch, tilting up at the outer edge and leaving benches or flats at the top and back of the slumped-off portion. Along Sulphur Creek most of these are now covered with a thick growth of brush, such as scrub oak or service. The slumps also occur on the east or dip-slope side of the gulch. Some of these slumps were discovered only after entry drifts had pierced them to depths of 50 to several hundred feet, where the offset in the strata was encountered at the back side of the block. Similar occurrences may also be found in almost all parts of the Danforth Hills, as well as elsewhere. Coal has in several cases been mined from the displaced blocks of strata, and in some cases this circumstance or the significance of the situation seems not yet to have been recognized by the miners. This feature accounts for some of the difficulties met in the attempt to trace particular horizons or coals from point to point along the outcrops.

A second cause of local displacement of blocks of strata along the outcrops is the burning of the coal beds in place. Where this has been extensive it has sometimes caused much settling among overlying strata, at places giving the appearance of a fold or even a fault. This feature is well represented in the burned and reddened strata on the south side of Rifle Gap in the Grand Hogback. Such displacement probably also shows somewhat in the section exposed at the White River Gap below Meeker.

Such structures as these are of too local a nature to be represented on the maps.

CHAPTER III.

GRAND HOGBACK FIELD, COLORADO.

The area surveyed in the Grand Hogback field is shown in detail on Plate X. The limits of the map are in part determined by parallels and meridians of latitude and longitude; the base line itself falls just north of the area here represented, being slightly north of the fortieth parallel according to the best information now at hand

OUTLINE AND EXTENSION.

The Grand Hogback itself constitutes the coal field. It is a very distinct geographic feature, as is quite clearly brought out by the contours on the topographic map. The name seems to be more commonly applied in local usage to that portion of the monoclinal ridge included between White and Grand rivers than to the extension of the same feature beyond these limits in either direction. Southeast of Newcastle and south of Grand River, in the Glenwood Springs district, the ridge is found to be continuous, with a very similar prominent hogback, which is really the simple extension of the same rocks, and is thus in a sense the same ridge; but this part seems more widely known as Coal Ridge in that district. North of White River the Grand Hogback merges with the Danforth Hills.

LOCATION.

As a field the Grand Hogback is about equally divided between Rio Blanco and Garfield counties. It lies west of the bordering limit of the elevated table-land known as the White River plateau or locally as the "flat tops." The hogback crosses White River about 3 miles by wagon road southwest of Meeker, extends almost due south from that point for about 20 miles, and then southeast for a similar distance, crossing Grand River at the coal-mining town of Newcastle.

ACCESSIBILITY.

The valley of Grand River is at present the principal route by which travel and commerce reach northwestern and western Colorado. Both the Denver and Rio Grande and the Colorado Midland have separate tracks as far west as Newcastle. Beyond this point, down Grand River, both roads use the tracks of the Denver and Rio Grande. Rifle is the principal point from which an extensive territory to the north in Garfield and Rio Blanco counties is reached.

Alignment surveys have been made, extending north along the valleys on both sides of the Grand Hogback, starting from Newcastle. Preliminary surveys were run by the Colorado Midland Railway in 1886 and 1887 in extension of that road from Newcastle northwest, following the southern and western sides of the Hogback to White River both by way of the present stage road and with an alternative line by way of lower Piceance Creek. These preliminary surveys were also continued westward into Utah. A branch line from Newcastle, known as White River Valley Railroad, was surveyed to Meeker, following the valley on the west side of the hogback. While both of these routes are probably entirely feasible, neither project has yet been pushed beyond the preliminary-survey stage.

COAL.

COAL-BEARING ROCKS.

The Mesaverde formation contains all of the valuable coal of this field, and as it appears to be as fully developed here as in any of the fields south of Axial Basin the general descriptions of the stratigraphy (p. 63) apply well to this part of the field, at least so far as the nature of the strata immediately associated with the coal is concerned.

THICKNESS AND NUMBER OF COAL BEDS.

As explained in the general descriptions of stratigraphy, the coal-bearing or Mesaverde formation is approximately a mile in thickness, and many beds of valuable coal are found in one position or another within this mass. The total number, thicknesses, and stratigraphic horizons at which the workable beds occur vary from place to place along the outcrop of the formation. In very few localities is anything like a complete measurement of the coals now obtainable. The section at Newcastle has been very thoroughly prospected in the past, and probably all of the workable beds of that section have been opened and are known. All of the larger beds have been developed by mines under the management of the Colorado Fuel and Iron Company, and some of these workings have been extensive. At the present time the large beds in all the mines on the north side of the river have been on fire for a number of years, and the fire has as yet proved uncontrollable. All these properties were, therefore, closed and entirely inaccessible at the time of visit. The locality as a mining camp is a dangerous one, as much trouble has been experienced with explosive dust and gas and spontaneous combustion of the coal.

Measurements of the various beds taken from a published report of a chief engineer of the Colorado Fuel and Iron Company[a] are evi-

[a] Hosea, R. M., The Newcastle mines, Colorado: Colliery Engineer, vol. 17, 1897, pp. 377-382, 425-429.

dently more complete than the measurements of stratigraphic sections made during the present survey. Opportunities for obtaining the most complete and satisfactory measurements depend almost entirely on the state of development, which at certain favorable times may show the true thickness of all the beds in a way rarely available by a somewhat hasty examination of conditions as they happen to be found at the time of a single visit. The list of coal beds given in that report is as follows:

Thickness of coal beds at Newcastle.

	Feet.
"C seam"	5
"Anderson seam"	8
"Allen seam"	20
"D seam"	5
"Wheeler seam"	45–48
"E seam"	18
"F seam"	4
Total workable coal	105–108

The thickness of the stratigraphic intervals separating these beds is shown in Plate XV. The Wheeler coal is approximately 1,000 feet above the base of the formation, and the Allen is about 600 [a] feet above the Wheeler. The only coal now worked on the north side of Grand River is a bed known as the Keystone, which is somewhat higher than any in the section detailed above, and which is only 22 to 24 inches thick. The Keystone bed is 4,000 feet stratigraphically above the base of the formation, and with the exception of two smaller beds, is the highest known coal bed in this locality. The beds of the Newcastle section dip southwestward at angles ranging from 50° at the base of the formation to 25° at the Keystone mine.

Other good cross sections of the Mesaverde formation are readily available at water level in the several minor stream gaps that intersect the Hogback between White and Grand rivers, as well as along the banks of both these rivers. Sections may also be measured at any point along the Hogback—as the rocks are well exposed and steeply tilted—although such measurements are perhaps less readily made where it is necessary to take into account the vertical element in the measurements as well as the horizontal breadth of the outcrop and dip of the beds. This ridge is cut to water level at Thirteenmile Creek, Fourteenmile Creek, Piceance Creek, Rifle Creek, and at Harvey or Dry Gap. Scattering prospects, nearly all of which are caved at the present time so that they show only very incomplete sections of the coals, afford only fragmentary evidence from which to form estimates of total available coal. A detailed investigation of any such field must be supplemented either by extensive prospecting or

[a] Note correction of this figure as published in Bull. U. S. Geol. Survey No. 316, p. 274.

will have to be postponed until demand for the product and local interest in the field shall have accomplished such work in advance. For the present the general sections and coal beds observed at Newcastle and near Meeker on White River, with some scattering evidence at intermediate points, are assumed to indicate the coal-bearing character of the greater part of the Mesaverde formation, especially that part above the "white-rock" horizon.

The figures given in the following table show in round numbers the approximate area of probable coal lands in the Grand Hogback field:

Total estimated area of coal lands in the Grand Hogback field.

	Acres.
T. 6 S., R. 91 W.	1,480
T. 5 S., R. 91 W.	5,400
T. 5 S., R. 92 W.	5,000
T. 5 S., R. 93 W.	4,200
T. 4 S., R. 93 W.	1,640
T. 4 S., R. 94 W.	4,960
T. 3 S., R. 94 W.	7,360
T. 2 S., R. 94 W.	6,480
T. 1 S., R. 94 W.	5,200
	41,720

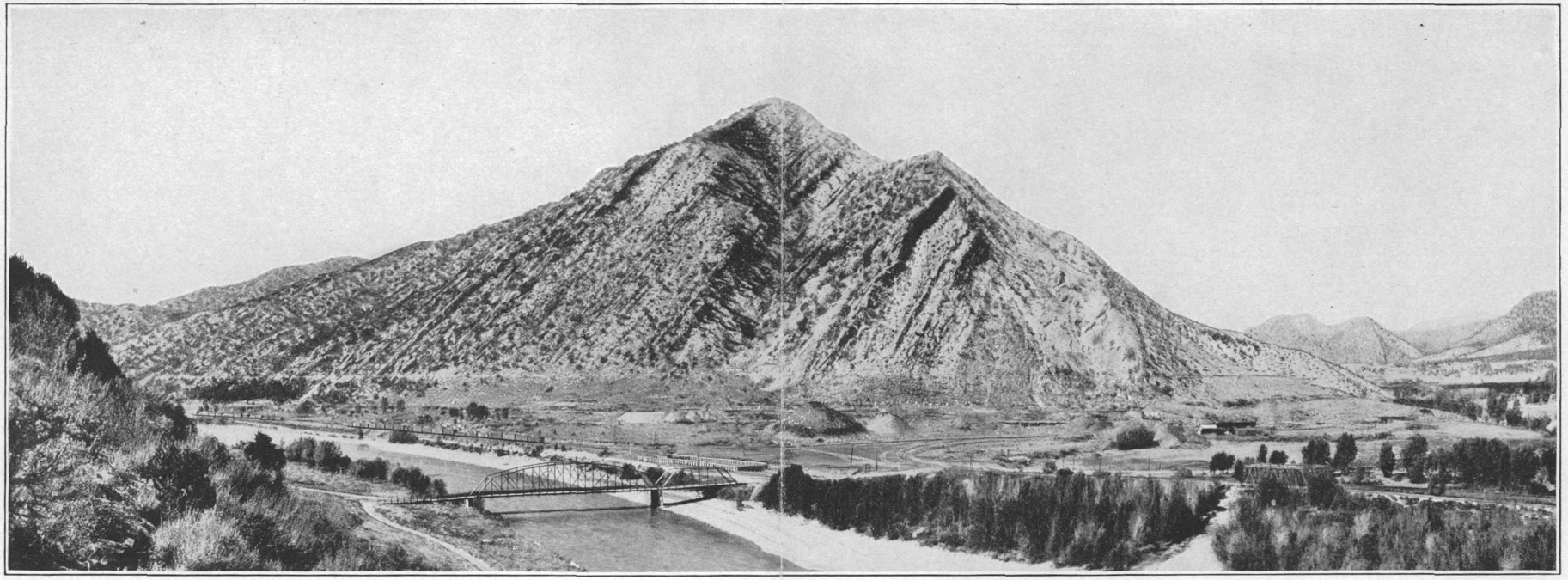
DESCRIPTION BY TOWNSHIPS.

GENERAL SUMMARY.

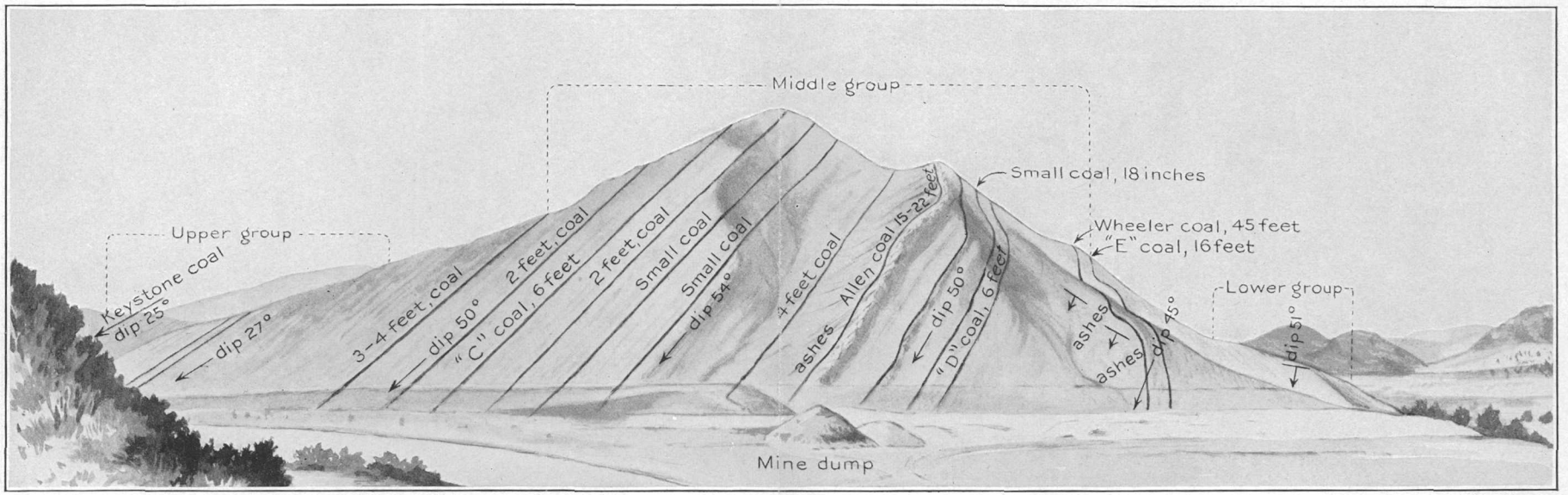
The foregoing list includes all the townships in which the existence of workable coal has been recognized and which are described in the following pages under the title of Grand Hogback field. T. 6 S., R. 91 W., though lying in greater part south of Grand River, and probably more properly included with Coal Ridge than with the Grand Hogback (if these are considered as distinct geographic features), is described here, for the reason that the properties visited in that district were examined at the same time and in the same way as those in the field on the north side of Grand River. Other properties along Coal Ridge at South Canyon and south and southwest of Glenwood Springs were not mapped topographically in the present work, the mines described having been visited and sampled without attempting to trace the formations or coal beds in detail between the most important entries. The field lies wholly in Colorado, and all the townships are referred to the sixth principal meridian. It has not been feasible to describe the townships in exact numerical order, and any particular one can be most easily found by referring to the table of contents, page 5.

T. 6 S., R. 91 W.

Introduction.—The Keystone mine and in part the Coryell mine of the Newcastle district lie south of the second correction line and are therefore described under the title of T. 6 S., R. 91 W. This township in-



A. MESAVERDE SECTION AT NEWCASTLE, COLO.



B. DIAGRAM SHOWING POSITION OF COAL BEDS IN THE NEWCASTLE SECTION.

Identification of coals based on information furnished by Mr. Perry Coryell, of Newcastle.

cludes the extension of the Grand Hogback southeast from Newcastle where Grand River cuts through the ridge, beyond which point it is commonly known in a local way as Coal Ridge.

The coal-bearing Mesaverde rocks are limited to the northeast corner of the township in sections 1, 2, 3, 4, 11, and 12, where they dip steeply to the southwest. The ridge is bounded by a steep escarpment slope on its north side, Grand River running parallel to and near the foot of this slope for about 2 miles, as far as the northeast corner of the township. The Wheeler and Allen beds outcrop along the north face of the ridge, being low on the slope in the vicinity of Newcastle and rising toward the crest as they go eastward. The upper coal group, of which the Keystone bed is a representative, outcrops at the base of the south slope of the ridge along a line approximately parallel to Alkali Creek, a small gulch entering Grand River from the south just below Newcastle.

A representative view of this rather typical section, except only the uppermost beds, is shown in Plate XI, which shows the site of the old mines at Newcastle.

Coryell mine.—The rather extensive developments on the many thick beds of the Newcastle section north of Grand River have been idle for a number of years, and all machinery and equipment have been removed. A single property known as the Coryell mine, on the south side of the river, half a mile or so east of Newcastle, was operating under the management of the Coryell Mine Leasing Company of Newcastle when visited. It is opened on the Allen bed, the old workings on the Wheeler being caved and inaccessible at this place. Although the entrance and mine buildings are just north of the second correction line it appears that the property and recent underground workings have extended across that line into the township under which this description is given.

The mine consists of a main entry starting in at the base of the hogback below the coal and drifting 600 feet in the direction of the dip to the point where the coal bed is struck. A side drift or heading turns eastward from this point, and this had penetrated the coal bed a distance of 625 feet at the time of visit (October, 1906). The Allen bed is 14 feet thick and has a southerly dip of about 50°, measured in an upper lift, where the whole bed was well exposed. A seam or parting of soft coal of irregular thickness averaging somewhat more than a foot occurs from 4 to 6 feet above the floor. This is apparently good coal, but it is badly crushed, has a foliated texture, and yields much dust in handling. The dust is inflammable in this as in other mines of the district, and for this reason the workings are sprinkled regularly to avoid explosions.

The coal bed is cut by a considerable number of sandstone dikes, which have, however, been found only in the lower bench of the coal.

They are in all shapes and attitudes in the coal, most of them transverse to the bedding. When separated from the coal these dikes seem very dense and heavy.

The coal is of excellent quality, as shown by the analyses (Nos. 3933, 3935, 3937, 3938, and 3939, p. 249), comparing very favorably with many representative eastern bituminous coals. It has a low ash and low moisture content and should prove an excellent steam coal. The output when the mine was visited was about 175 tons a day, of which 90 tons daily was being used by the engines of the Colorado Midland Railway, the main track of that road passing close to the entrance of the mine.

Keystone mine.—The Keystone mine, at Newcastle, was being worked at the time of visit and is of especial interest as being one of the most extensive developments on a thin coal bed reported in the Rocky Mountain coal fields. The coal itself varies from 20 to 24 inches in thickness, with a roof of hard compact clay or shale of lenticular character, such that this clay is said to pinch out and leave a roof of hard sandstone in places, sandstone being the next stratum overlying. The clay roof slacks readily when exposed to the air, and where it is thick makes a poor roof, as it drops sooner or later. The floor is soft carbonaceous shale, which is undercut in mining so that the coal falls or is shot down. The coal breaks out in large blocks, with practically no slack or waste in handling.

The mine consists of a main slope, along which side headings on the upper lifts have been worked out for a considerable distance and abandoned. At the time of visit the slope extended to a depth of 500 feet or more. The work then being done was on the two headings from the lowest level. The coal is taken out by the long-wall method, the entire bed being removed and the gob or waste being used to pack the space mined out below the working face. The analyses (Nos. 3932 and 3936, p. 249) indicate that the coal is high-grade bituminous, similar to other samples collected near and south of Grand River, and distinctly superior to any sampled in the region north of White River.

The Keystone bed has also been opened and mined on the south side of Grand River, as well as at other points back from the river, but these entries were not examined in detail.

As these rocks dip to the west and south they doubtless underlie all of the remainder of this township and extend much beyond it in those directions. Although the dips are steep in the vicinity of the outcrop, it is presumed that they quickly flatten and that the uppermost coals may be buried to depths of which there is as yet not sufficient evidence to permit an estimate. Further work on the details of structure and stratigraphic thicknesses of the overlying beds is necessary to warrant more definite estimates in this connection.

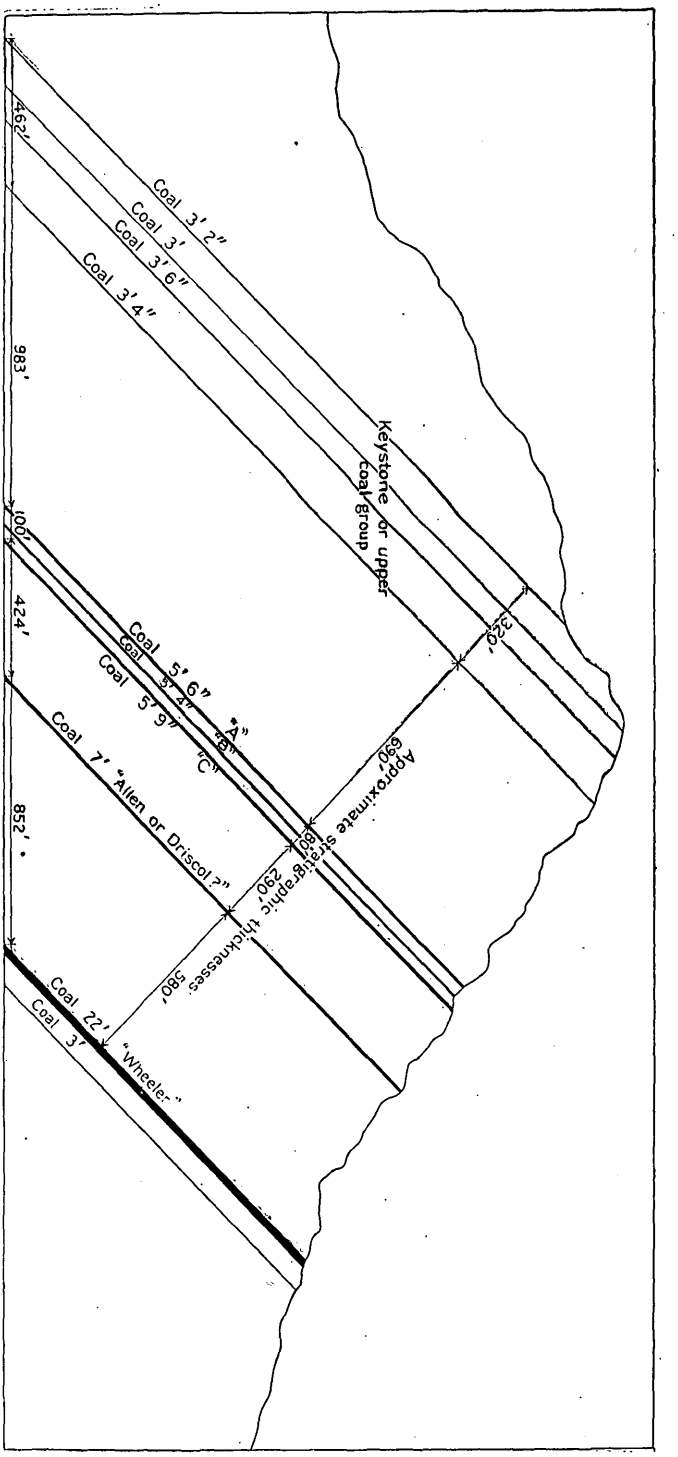


FIGURE 4.—Hypothetical profile of the Newcastle, Colo., section at the Coryell mine, showing the measured intervals between the various coal beds. Compiled from detailed surveys and sketches by Theodore Rosenberg.

T. 5 S., R. 91 W.

The Grand Hogback extends across the southern half of T. 5 S., R. 91 W., containing a belt of coal-bearing rocks somewhat over a mile in width of outcrop. The coal beds are indicated by a great amount of baked rock, with slag and ashes, where the beds have been burned at their outcrops. Along the top of the ridge near the center of the township (sections 21 and 27) the coal is still on fire, and is reported to have been burning as far back as the records of the present white settlers go. The outcrop of the bed at that place is a loose mass of warm or hot ashes, from which gases of combustion and sulphur fumes are escaping. The fire becomes most noticeable on windy days, at which time the combustion is fanned into greater activity, and smoke, plainly visible from the valley below, issues from the rocks. From this feature a part of this ridge is known as "Burning Mountain."

The stratigraphic section and coals at Newcastle, at the southeast corner of the township, have already been described, and the section is supposed to be typical in a general way of the rocks and coal beds in the rest of this area. An exception may be noted in the case of the Wheeler bed, the thickness of which is unusual in the Newcastle section, being probably greater than is known for the same bed or any other Mesaverde coal in the whole region. From the river level at Newcastle the hogback rises abruptly 1,500 to 1,800 feet, with a steep escarpment slope facing to the northeast. The valley of Elk Creek, where it runs parallel to the hogback, is opened out on the Mancos shale and is limited on the side opposite the hogback by rocky ridges of the older rocks, including the Dakota, Jurassic, and Triassic strata and also the Carboniferous limestones that cap the White River Plateau. Southwest of the hogback Cactus Valley is eroded on the varicolored marls of the supposed Wasatch, the strata of which flatten abruptly to a much lighter dip than that of the Mesaverde rocks in the hogback itself.

As represented in the plat of the Doll mine (fig. 5), the outcrops are projected in the direction of the strike of the rocks from the locations made at water level in the gulch. They should not therefore be interpreted as the horizontal projections of the outcrops of these beds as they come to the surface on the higher slopes.

The larger coal beds, such as the Wheeler and Allen of the Newcastle section, may be traced almost continuously along the outcrops by means of the conspicuous burning that has taken place. At Newcastle the Wheeler bed outcrops low on the east side of the hogback, but as traced westward it rises to the crest of the ridge in a distance of 2½ miles, beyond which point it is found either on the summit or a short distance down the southwest slope. The

main escarpment face of the ridge is composed chiefly of the lower and relatively barren sandstone members of the Mesaverde forma-

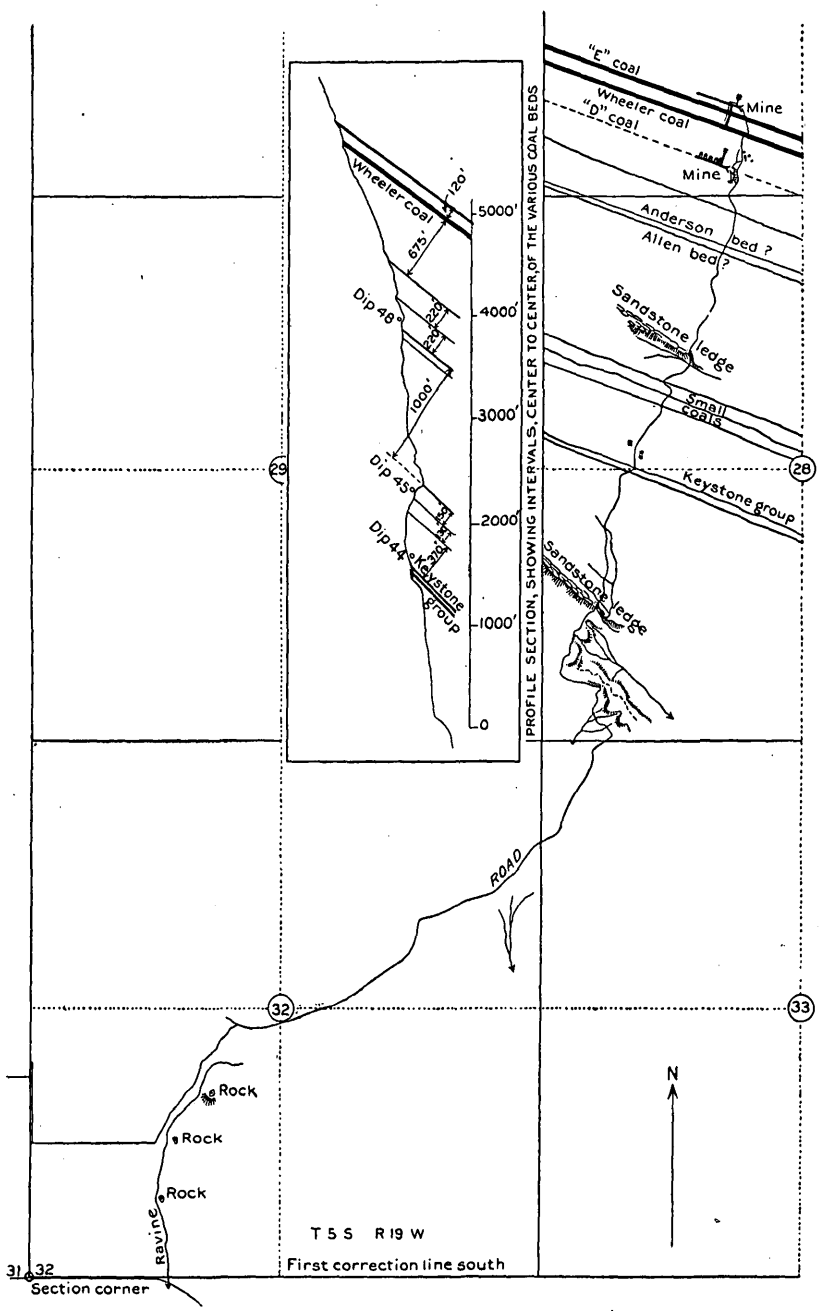


FIGURE 5.—Diagram and section of coal beds at Doll mine, from surveys by Theodore Rosenberg.

tion, thus corresponding to the situation and expression of the same beds in the escarpments bordering Agency Park and Axial Basin.

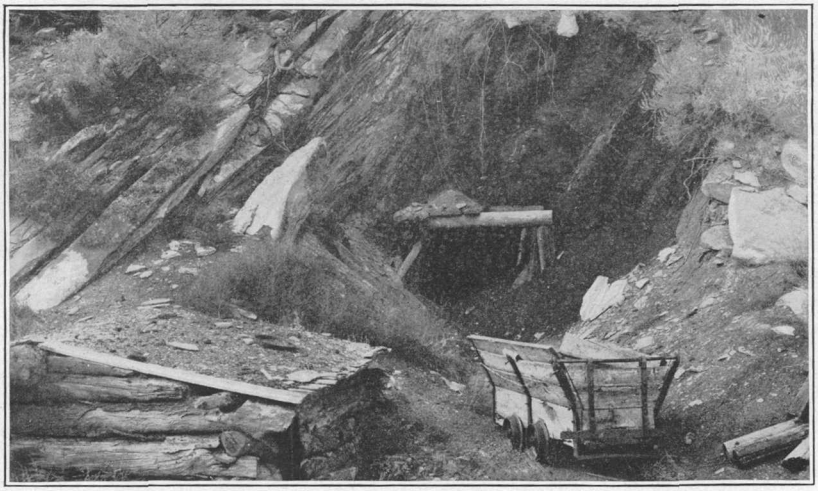
T. 5 S., R. 92 W.

Introduction.—The Grand Hogback crosses T. 5 S., R. 92 W., near its center in a course slightly north of west. Near the east side of the area the ridge is cut across at surface drainage level by Harvey or Dry Gap and similarly by Rifle Gap on the western side of the area. The ridge presents its steepest slope to the north, overlooking a broad valley of the Mancos shale and the rough and brushy foothills of the White River Plateau. On the south side the country is composed of the variegated marly clays and clay soils of the lower Wasatch beds, forming almost typical badlands in places. Near the hogback the rock ledges of the ridge itself give way abruptly to broad gentle slopes, composed of a series of beautifully distinct terrace or mesa levels, all with a rather marked inclination toward the river valley. Irrigation has brought a small area in the lower valleys and terraces under cultivation, while the greater part is covered with sage, greasewood, and an abundant growth of prickly pear or cactus, from which latter the whole of the lower lands south of the hogback have received the name of Cactus Valley.

Harvey or Dry Gap.—Harvey or Dry Gap evidently once formed a part of Rifle Creek or Elk Creek, or perhaps of both, but was later abandoned by those streams in favor of their present channels. A recent ditch from upper Rifle Creek has again turned water back through this gap, with a storage reservoir in the valley at the head, as indicated on the map (Pl. X).

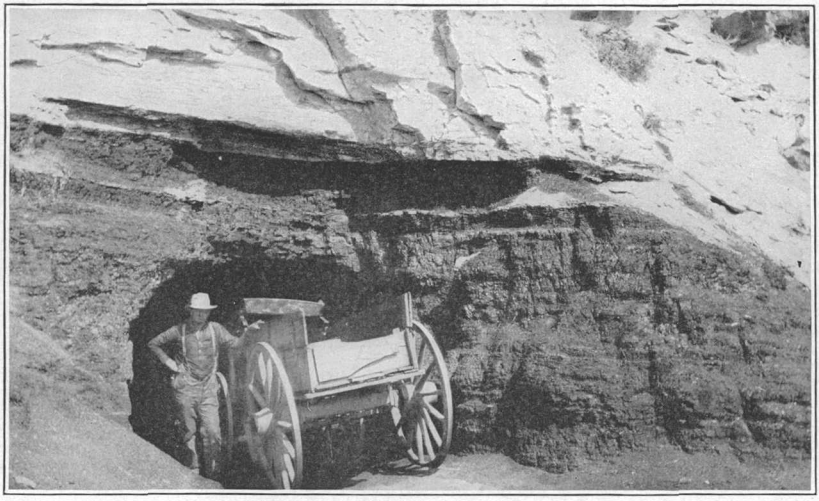
The stratigraphic section exposed in Harvey Gap is similar to that at Newcastle in a general way, but owing to the unsatisfactory state of the exposures no attempt was made to obtain a complete set of measurements of the various coal beds. Several coals are still exposed, and in one place an old mine, now somewhat caved, shows evidence of considerable work in the past. The view (Pl. XII, *A*) at this mine shows something of the thickness and attitude of the bed and the character of the roof. The conditions are characteristic of the many small prospects or entries found in the steeply tilted beds of the hogback, especially in the various stream gaps. The coal is 12 feet or more in thickness, the lower portion being obscured by slide débris from the slope above. The roof is an irregular bed of carbonaceous shale a foot or two thick, above which is a heavy-bedded flaggy sandstone.

Local reports state that a coal bed supposed to be the same as the Wheeler of the Newcastle section, and measuring about 40 feet in thickness at this place, has been uncovered in past developments, but it could not be readily exposed at the time of examination. A thick coal is exposed in the road cut near the reservoir dam, and is probably one of the group occurring near the base of the principal coal-bearing division of the Mesaverde formation.



A. COAL ENTRY AT HARVEY GAP.

Exposure typical of the coals in the Grand Hogback field.



B. BLEVINS MINE ON LAY CREEK, YAMPA FIELD.

Summit of the ridge.—West of Harvey Gap the main summits of the Hogback lie on more or less isolated spurs south of the drainage divide of the ridge itself. The southward-flowing drainage has cut down on the dip-slope faces of the massive sandstones and intervening shales, for the most part reaching back nearly to the base of the whole formation at the divide, the channels cutting the other beds at low grades and in rocky gorges. The rocks along these summits dip 40° to 60° S. The steep escarpment on the north side of the hogback forms a long, almost continuous, straight wall with a 35° slope near the top, flattening abruptly as it merges into the alluvial fans and débris slopes at the valley margins.

Dutton & Hasley mine.—Near the summit of the ridge, about 2 miles east of Rifle Gap, is situated one of the properties worked at the time of the present field examination for supply of the valley settlement, and especially for the town of Rifle. This is known as the Dutton & Hasley mine, and is situated in the NE. ¼ NE. ¼ sec. 17. It is reached by a wagon trail crossing the mesa from the main road on Rifle Creek. An entry extends in 400 feet, with upraises 40 feet apart extending to a height of about 80 feet on the coal. The coal measured in the main entry about 150 feet in showed a bed 10 feet 11 inches thick with a bony parting that is 5 feet above the floor and varies from practically nothing to about a foot in thickness. The roof is said to be soft sandstone and the floor soft bony coal ("blackjack," according to the miners), varying up to about a foot in thickness. A sandstone dike transverse to the bedding, similar to that noted in the Coryell mine at Newcastle and elsewhere, is exposed in the entry about 100 feet from the mouth.

A second 12-foot bed of coal is reported as occurring about 18 feet above the bed mined. The coal lies just above a huge, massive, white sandstone ledge, which forms the summit and main crest of the hogback just northwest of the mine. This is thought to be the "white rock" described with the general stratigraphic sections and so would indicate that this coal occupies a position near the base of the principal or middle group of workable coals as described on page 67. Evidence is not at hand to show whether this is the horizon of the Wheeler bed at Newcastle or not, but it is thought to be approximately that horizon.

From the rocky summit previously mentioned—just northwest of the mine—an excellent view may be obtained, looking along the north slope of the ridge, which shows an almost continuous outcrop of the same large white sandstone ledge, the point of view being directly in line with the strike of that rock ledge. The bed may thus be traced to where it is cut by Rifle Creek in a gap to be presently described, beyond which it is continuous with the ledge immediately below the lowest coal mined, namely, that of the McLearn mine.

Rifle Gap.—Rifle Gap exposes an excellent cross section of the coal-bearing formation, intersected by the creek canyon in a direction practically at right angles to the strike of the beds, which dip very steeply throughout the section.

In the canyon by which Rifle Creek cuts the hogback a number of prospects and old mines are situated, all of which were idle and most of them caved at the time they were visited. The report of a former survey shows the section of coal beds and intervals measured at this place as indicated in figure 6. Taken in order, beginning with the lowest beds that show at the northern end of the gap, these may be briefly described as follows: A small burned streak and carbonaceous shale shows just above the lowest sandstone ledge of the section, but the coal may not be of much practical importance. The lowest beds that have been worked in the Rifle Gap section consist of drifts on halves of a double bed, locally known as the "Songer vein," which is said to be owned by Messrs. Fred and Frank Bulkey, of Denver. This coal is about 550 feet stratigraphically above the lowest outcropping sandstone ledge of the coal-bearing series at this place. The Songer bed lies just above a very massive ledge of white sandstone that is almost exactly 100 feet thick in outcrop. The following measurements were made of the coal and the intervening shale:

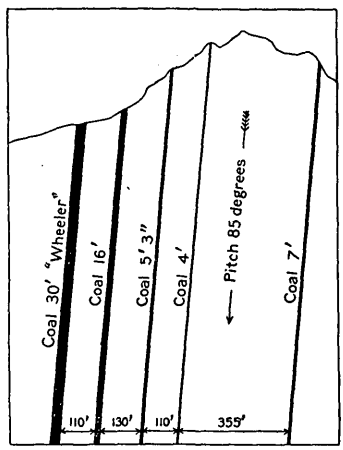


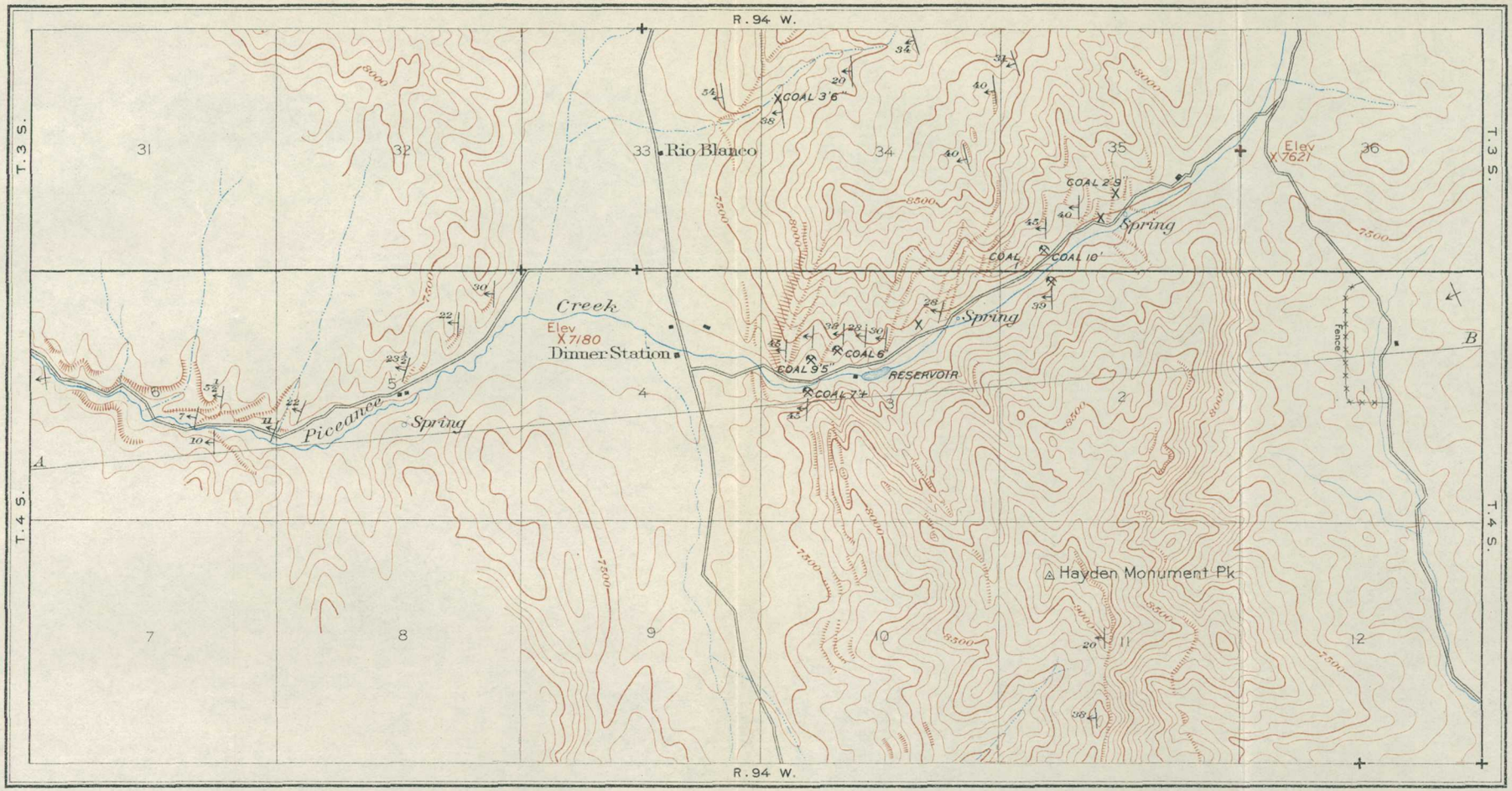
FIGURE 6.—Hypothetical profile of the Rifle Gap (Colorado) section, showing measured intervals between the various coal beds. Compiled from detailed surveys and sketches by Theodore Rosenberg.

Section measured at the Songer entries in Rifle Gap.

	Ft.	in.
Coal (west entry)	6	4
Shale	5	8
Coal (east entry)	5	1
Shale floor.		
	17	1

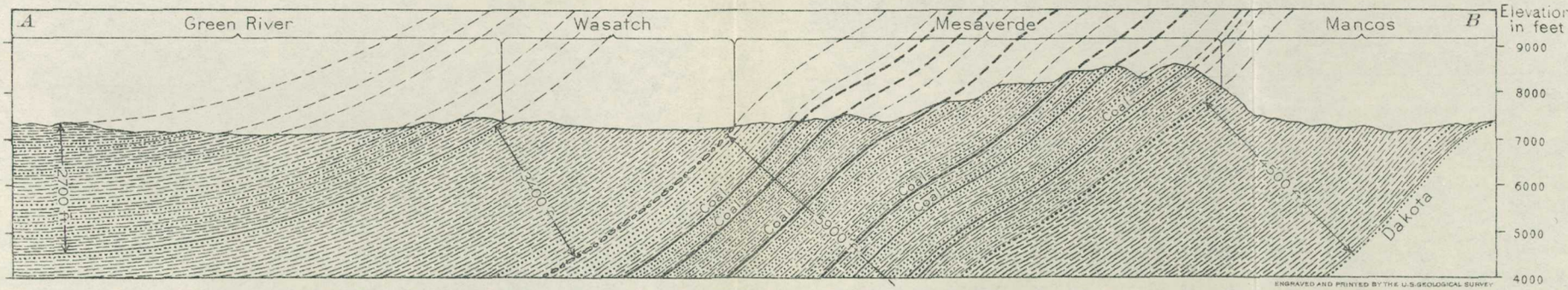
Much coal has been taken out from these entries, which have been run in to a considerable depth. Above this bed, within the next 500 to 1,000 feet of strata, there are indications of the presence of many beds of coal along the canyon walls, shown by the abundant baking of the rocks and the considerable quantity of slag and clinkers.

In the SE. ¼ SW. ¼ sec. 7 there are two old prospects, and also a shaft that showed some coal on the dump. One of these is a simple drift 100 feet or so in, showing a 5-foot coal with thin shale above and below.



LEGEND

- Strike and dip
- Mine
- Prospect
- Cliff or ledge
- Corner found



TOPOGRAPHIC MAP AND STRUCTURE SECTION OF PICEANCE GAP LOCALITY, COLORADO

SHOWING RECORDED OBSERVATIONS FROM WHICH THE STRATIGRAPHIC THICKNESSES ARE OBTAINED

Topography by Hoyt S. Gale, in charge,
A. K. Adams, A. L. Beekly, and R. D. Crawford
Geology by Hoyt S. Gale

0 ½ 1 2 Miles

0 5000 10000 Feet

Contour interval 100 feet

1909

Note: Geologic boundaries are shown on the general map Plate X

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South of the property on which the shaft is located a considerable interval of the stratigraphic section as exposed is comparatively barren of the signs of coal, such as smut, baked and reddened rock, commonly found in this position, and this character continues in the section exposed as far as the NE. ¼ NW. ¼ sec. 18, where a coal has been mined on both sides of the canyon. This development is said to be known as the Maxfield claim. Coal in the entry on the west side of the gulch measured 2 feet 10 inches at the entrance and 2 feet 7 inches about 150 feet in. This bed has been correlated locally with that of the Keystone mine at Newcastle, although it is very uncertain if any particular coal of the section has actually been traced for that distance. No other coals were noticed higher in the sequence than this, although a great mass of huge sandstone ledges belonging to the coal-bearing series are exposed above it.

The strata of the Rifle Gap cross-section dip southwestward at a more or less uniform angle, varying according to measurements taken from 70° to 84°. The total thickness of the Mesaverde rocks measured from the lowest sandstone ledge outcropping at the north end of the gap to the lowest of the overlying varicolored beds among the sandstone ledges at the south is 4,700 feet. The outcrop of a few hundred feet of sandstones normally classed with the Mesaverde at the base of this section has probably been eroded at that place and concealed in the valley wash.

The relation of the coal beds of the Rifle Creek section to the bed opened at the McLearn mine, three-fourths of a mile northwest of the north end of the gap and just across the line in the next township west, is not perfectly clear from the evidence now at hand. Although possibly offset and apparently not directly in the line of strike with the recognized beds of the Rifle Gap section, the McLearn coal is thought to be one of the lowest beds of the principal or middle group of coals just above the "white rock" horizon.

T. 5 S., R. 93 W.

The Grand Hogback, consisting of the coal-bearing strata, passes diagonally across the north side and northeast corner of T. 5 S., R. 93 W. The greater part of the township in the valley of Dry Rifle or Government Creek is occupied by the strata of the supposed Wasatch formation, while strata of the Green River formation of the Tertiary age are exposed in the high escarpment of the Book Cliffs at the western edge of the area. Thus practically the entire township is underlain by coal at depths varying from nothing at the outcrop in the hogback to 4,000 feet and possibly even more at the base of the Book Cliffs. The only part thus excluded as positively not coal bearing is the small triangular area in the Rifle Creek valley in the northeast corner, which is composed of rocks older than the

coal-bearing formations; but the coal in much of the rest of the area may be too deep to work according to modern mining practice. The coals probably sink to somewhere near their maximum depth in the area adjacent to the hogback, the fold flattening to a more nearly horizontal attitude abruptly, as is characteristic of most of the structure in these Cretaceous and Tertiary formations.

The section exposed in Rifle Gap is as representative of this township as it is of the next township to the east, as that section lies almost on the line between the two. A single mine working for the local trade is situated in the eastern face of the hogback, in the NE. ¼ NE. ¼ sec. 12, three-fourths of a mile northwest of the north end of Rifle Gap. This is being worked on the lowest coal bed that is of workable thickness. The mine, known as the McLearn, consists of a simple drift driven into the eastern face of the hogback, cutting across the basal beds of the coal-bearing series in the direction of the dip and encountering the coal at a distance of 200 feet. This coal is estimated to be some 500 to 600 feet from the base of the sandstone ledges. Side headings are turned off in both directions along the strike of the coal bed, the northern end penetrating the coal somewhat over 700 feet. The heading leading toward the south had been caved by an explosion and was inaccessible at the time of visit.

The coal bed is 7 feet 3 inches thick and is without bony seams or partings, although a foot or so at the upper or hanging-wall side is softer coal than the rest and usually breaks up in mining so that it is lost as slack. The following partly estimated section was taken in the mine. The thicknesses of the coal beds themselves were measured with a tape.

Section in main entry way of McLearn mine, Rifle Creek.

	Ft.	in.
Sandstone, flaggy (roof).		
Coal (mined)	7	3
Shale, brown, carbonaceous		
Interval, mostly sandstone	10+	
Coal	2	
Sandstone	20	
Coal	2	
Clay, soft, sandy	0	2
Shale, fine, dark gray	30±	
Sandstone, white, very massive	60±	
Alternating massive white sandstones and shale to entrance of mine.		
Total coal	11	3

The coal is under tension, frequently "jumping" out when struck with a pick, sometimes in large blocks. The pillars flake off and also the foot wall along the main entry, but the foot wall is reported to rise as a whole in the rooms and not to flake as it does in the narrower entry. The strata dip 70° W. and strike about N. 75° W.

Two samples (Nos. 3943 and 3946) were taken from the mine. The analyses (p. 249) show a rather marked change in character as compared with those from the coals north of White River, a difference which seems to apply generally to all of the coals found throughout the field from this point south. Such comparison shows a somewhat marked increase in efficiency as determined by calorimeter tests, as indicated by a decrease in the moisture content, with a corresponding increase in the proportions of the fixed carbon and volatile matter.

This mine, in common with many others of the southern portion of the field, is seriously menaced by explosive dust and gas. The dust collects on timbers and when allowed to accumulate soon becomes dangerously explosive; hence the mine is regularly washed with water every few days. An air shaft cut up to the surface from one of the rooms produces a natural system of ventilation except at the extreme end of the workings. The mine is entered each morning with a Davy safety lamp to test for explosive gas, which, when found at the back of the workings, is fanned forward to where it will be caught in the circulating air currents and carried off. There is a strong smell of gas in the mine, which may also be noticed apparently clinging to the coal when it is taken out into the open air, or when lumps are pounded up, indicating that it is occluded in the coal. There have been two explosions in this mine, both causing caving and destroying timbering to a considerable extent. Both occurred at the time of firing shots. For this reason the firing is done at the end of the day's work, so that the dust settles by the following morning. The slack pile at the mouth of the mine is on fire, and is now burning in a circular rim about its base, frequently fanned to a brisk blaze in windy weather. This dump is reported to have been burning for six years and now stands on a thick layer of ashes.

T. 4 S., R. 93 W.

Coal-bearing rocks occupy only a relatively small part of T. 4 S., R. 93 W., being restricted to the southwest corner. The summit of the hogback passes through secs. 30, 31, and 32. The rocks show dips ranging from 35° to 50° on the summit of the ridge, which is here narrow and very precipitous on both sides. Much structural irregularity is revealed in the minor sandstones of the Dakota and underlying formations in the valley of Rifle Creek, northeast of the hogback, but does not seem to have affected the coal-bearing Mesaverde rocks to a marked degree. The bright, banded colors of the basal Wasatch marls are well exposed near the stage road in the extreme southwest corner of the township.

No coal exposures or developments were noted in the township, and the position of the coal beds is inferred from the continuity

of the big sandstone ledges in the hogback, and also from several burned ledges that are especially noticeable on the upper slope of the northeast face of the ridge.

T. 4 S., R. 94 W.

Introduction.—The main valley of Piceance Creek intersects the hogback at the northern edge of T. 4 S., R. 94 W. A small settlement in the valley on the west side of the hogback, and the intersection of the main stage road from Rifle to Meeker with that from Lower White River by way of Piceance Creek, make the place a local crossroad center. The post-office is named Rio Blanco.

Several prospect entries have been opened on the coal in the Piceance Creek gap, all of which are supposed to be on public land, several having been worked to a small extent for the use of neighboring ranches.

The hogback ledges bend sharply in or near sec. 14 of this township, possibly indicating some displacement of the strata transverse to the crest of the ridge; this, however, is probably not of great extent, since the main trend of the hogback as a whole seems but slightly influenced. Evidence of an apparent offset corresponding to that postulated in the Mesaverde rocks of the ridge is furnished by the discontinuity of the Cretaceous and Jurassic formations just south of the reservoir site on Rifle Creek (sec. 18, T. 4 S., R. 93 W.), and there may be a continuous east-west fault or zone of faulting along this line, possibly extending westward into the Green River Tertiary strata.

Piceance Gap.—Piceance Gap crosses from T. 3 S. to T. 4 S., in R. 94 W. More of the upper or coal-bearing part of the section probably lies south of the township line as exposed in the creek section, although the rocks are as typical of the area north as they are of that south. (See Pl. XIII.)

Coal-bearing rocks occupy about one-fourth of the total area, in the eastern part of the township. The hogback ridge itself reaches its maximum height in this area, and is bounded on either side by narrow longitudinally parallel valleys, which also reach their highest grade level at the watershed or divide between White and Grand rivers. The highest peak of the ridge, in sec. 11, a summit more or less typical of the ridge, is illustrated in Plate XIV, *A*, with the "dinner station" of the Rifle-Meeker stage road in the foreground. A panoramic view (Pl. V, *B*) from the summit of this peak looking along the crest of the hogback toward the north shows well the relations of the bedding of the strata to the topography, and also the character of the ridge top and adjacent valleys in the northern half of the field. These tops are more rounding and somewhat less rugged than the peaks and ridges of the Grand River part of the field.

Coal exposures.—The section at Piceance Creek affords an excellent opportunity for stratigraphic measurements. (See stratigraphic section, Pl. XIII.) But few of the coals had been prospected so that they could be measured, however, and only a very limited amount of mining has been done to supply the few ranches in the immediate neighborhood. Of these properties the coal lowest stratigraphically and the easternmost of the prospects in the canyon is in the NE. ¼ SW. ¼ sec. 35, T. 3 S., R. 94 W. Here a short slope about 20 feet in depth exposes coal 2 feet 9 inches thick. This is overlain by a solid sandstone roof and has a white or drab shale floor, all of which are favorable to the future development of the bed when the thicker coals have become less readily available than they are at present. The bed has a westerly dip of 39°. Other carbonaceous beds show near by above and below this horizon, but so far as present information goes this is the lowest workable bed at this locality.

Half a mile southwest of the prospect above described, an old mine by the roadside, in the SW. ¼ SW. ¼ sec. 35, T. 3 S., R. 94 W., shows 10 feet of coal, which is also opened on the south side of the creek. The following section is well exposed at the entrance:

Section at coal entry in sec. 35, T. 4 S., R. 94 W.

	Ft.	In.
Sandstone and sandy shale	3+	
Clay, white, carbonaceous streaks	3+	
Sandstone, block jointed	1	6
Clay, drab or bluish gray	2	6
Coal, good	1	6
Coal, brown or woody		6
Coal, good (mined)	3	
Clay, brown		½
Coal, good (mined)	5	
Shale, brown, carbonaceous.		
Total coal	10	

The strike of the beds is due north and south and the dip 45° W. The old entry on the north side of the gulch runs in 100 feet or more along the strike. The mine is now abandoned and caving. The roof is weak and not very good for mining purposes. No sample was obtained of this coal for analysis. The same bed had been partly opened on the south side of the creek, the entry being in the NW. ¼ NW. ¼ sec. 2, T. 4 S., R. 94 W. The bed is apparently very similar to, although not identical with, that just described. In the next several hundred feet above this coal there is a very considerable exposure of burned and reddened rock and some slag, apparently indicating the presence of a number of coal beds of considerable size.

The only other developments on Piceance Creek are near the western end of the canyon in the S. ½ NW. ¼ sec. 3, T. 4 S., R. 94 W. Of these there are four in number, three small drift entries on the

north side of the creek and an old abandoned and caved mine on the south. The following measurements were made on the bed stratigraphically lowest of this group:

Section measured at coal entry in sec. 3, T. 4 S., R. 94 W., Piceance Creek.

	Ft.	In.
Shale, fine compact clay	5	
Coal	3	6
Clay, white, hard, slickensided		1
Coal, good	2	6
Shale, brown, foliated.		
	11	1

The coal dips 38° W. and the old entry runs in toward the north a distance of 50 feet or more. The coal showing at the time the examination was made was considerably slacked, as it had been exposed to the air for some time.

About 200 yards west of this entry, in the SW. ¼ NW. ¼ sec. 3, two beds have been opened close together, the uppermost entry having been abandoned on account of caving. This coal bed measured 9 feet 5 inches, with a roof of white clay or shale. The coal has a soft, rotten appearance, even when freshly dug, while that exposed on the dump for some time had slacked completely. The mine is wet, and it was thought that the entry would soon cave entirely.

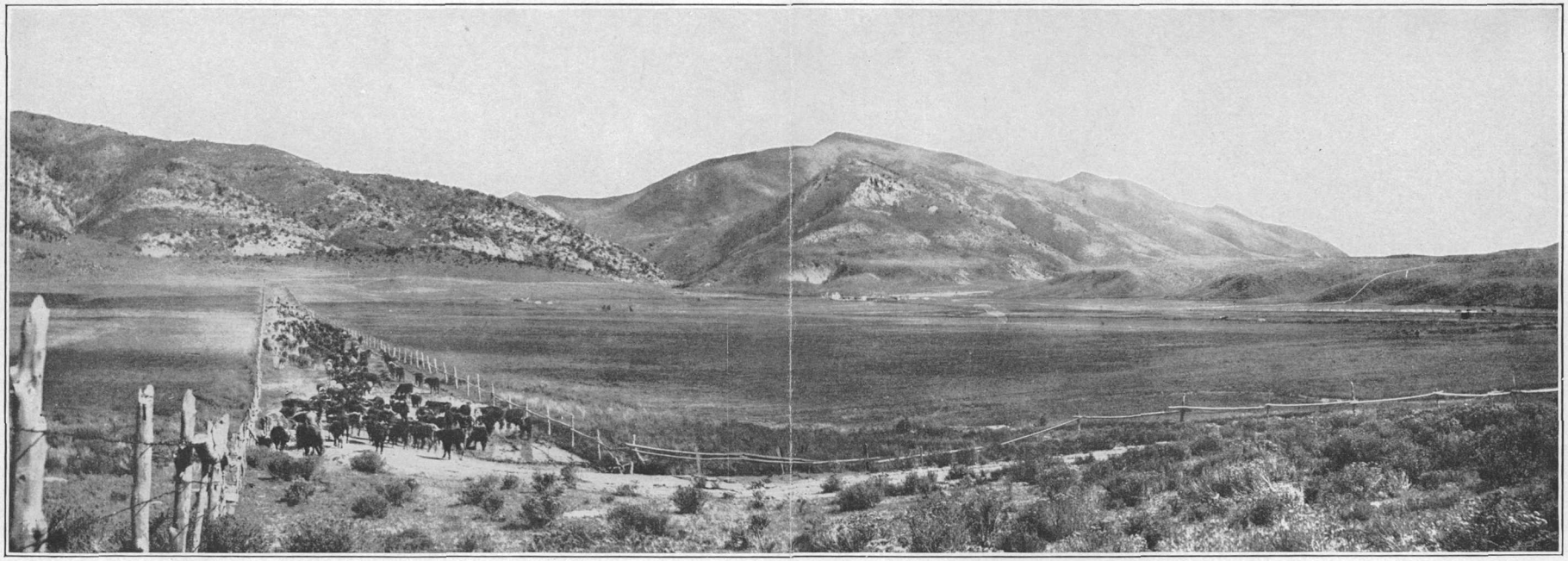
An older entry near by, now completely fallen in, was opened on a coal 50 to 75 feet stratigraphically lower. This coal measured 3 feet 9 inches at the mouth of the old drift. The roof is of gray sandy clay shale containing impressions of tree leaves, and overlain by massive sandstone.

The old entry on the south side of the gulch shows a bed of coal at least 7 feet thick, with a solid white sandstone roof. The floor was concealed by caving, but probably contains still more coal below that measured. This bed, therefore, probably corresponds to the thickest of the three beds noted on the opposite side of the gulch. The mine was evidently worked to a considerable extent in the past, as a considerable dump of slack remains at the entrance. The dip of the strata at this place is 45° S. 80° W.

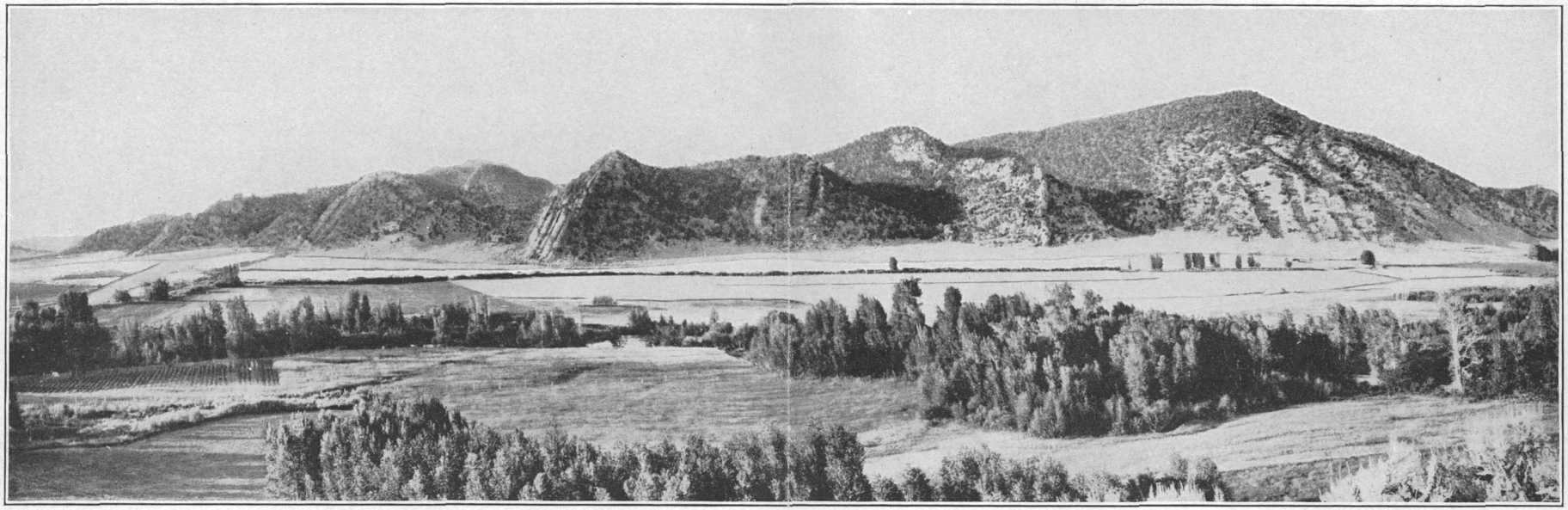
These beds are the highest coals recognized in the formation at this locality, although others may be present in the overlying strata and may have been overlooked in the present investigation. These beds probably correspond approximately to the horizon of the Keystone or upper coal group of Newcastle.

T. 3 S., R. 94 W.

In addition to Piceance Creek Gap, already described, the hogback is crossed, in T. 3 S., R. 94 W., by two similar gaps cutting the rocks to stream level. These are occupied by Thirteenmile and Fourteenmile creeks, both tributaries of Piceance Creek, which cross the ridge



A. HAYDEN MONUMENT PEAK FROM PICEANCE CREEK VALLEY AT THE "DINNER STATION."



B. COAL-BEARING STRATA IN WHITE RIVER CANYON, 4 MILES WEST OF MEEKER.

a little over a mile apart near the northern side of the township. The stratigraphic sections exposed in both of these gaps are very similar to that of Piceance Creek, except that little or no development of the coal seems ever to have been made in these localities. The breadth of the Mesaverde outcrop in this part of the field is about 2¼ miles and the strata range in dip from 20° to 35°, or 40° to 50° in places, with an average of approximately 30°. This indicates a total of nearly 6,000 feet of strata as the thickness of the formation at this place.

Across the township from north to south the hogback is broken into a double or more complex ridge with minor and intermediate longitudinal valleys. Coal is abundantly indicated by the usual signs of burning and baking of the inclosing rocks, but at no place in the township north of Piceance Creek was any development of the coal beds noted. The only estimate of the total amount of coal obtainable that can be given must be based on the assumption of the continuity of beds similar to those in the better exposed sections north and south of this locality.

T. 2 S., R. 94 W.

The hogback and the coal-bearing rocks extend from north to south through the center of T. 2 S., R. 94 W. The public roads on either side of the ridge follow the narrow lateral valleys. The hogback is relatively broad at the southern edge of the township, but narrows markedly toward the north, owing to the more steeply tilted position of the beds at that place and to the removal by erosion of some of the upper members of the Mesaverde formation at the west, so that the resulting topography in the upper beds blends with that of the valley to the west. North of a point near the center of the township the fold by which the hogback strata are tilted steepens, so that the upper strata of the Mesaverde are vertical and overturned in several places. The channel of Sheep Creek, which is closely followed by the public road, swings east into the outcrop of the upper Mesaverde beds, in contrast with the more characteristic development of the drainage valleys along the rest of the Grand Hogback fold, where the minor longitudinal streams have cut their courses along the weaker shale or clay formations. Thus the hogback narrows to a single-crested ridge not more than a mile in breadth in this part of the field.

Coal is exposed in natural croppings and is also indicated by burning, as elsewhere along the ridge. Some prospects in section 16, about one-fourth mile east of the public road, show coal at least 12 feet thick. Little work has been done in recent years on these beds except the mere clearing off of the coal at the surface of the ground.

A local coal bank has been opened on the east face of the ridge, near the summit and in a position overlooking Flag Creek valley.

This is situated in the SE. ¼ SE. ¼ sec. 4. The property was not examined, but is evidently opened on one of the lowest beds of the principal workable group.

T. 1 S., R. 94 W.

Coal land along the summit of the hogback in T. 1 S., R. 94 W., was filed and patented ten or fifteen years ago. Evidences of prospects, supposedly opened about that time, are still to be found along the ridge, but few are in such condition that they show much about the coal at the present time. The total area of land thus withdrawn is 4,160 acres in a strip 1 mile wide, extending south from White River 6½ miles. As the rocks are very steep throughout this area and the structure uniform and simple, the greater part of the outcrop of the coal-bearing portion of the Mesaverde along that section of the field is included in the area thus withdrawn. Some beds of the upper coal group, possibly similar to those in and near the Lion Canyon mine in character of the coal, may be found on public land, near the stage road on the west side of the ridge.

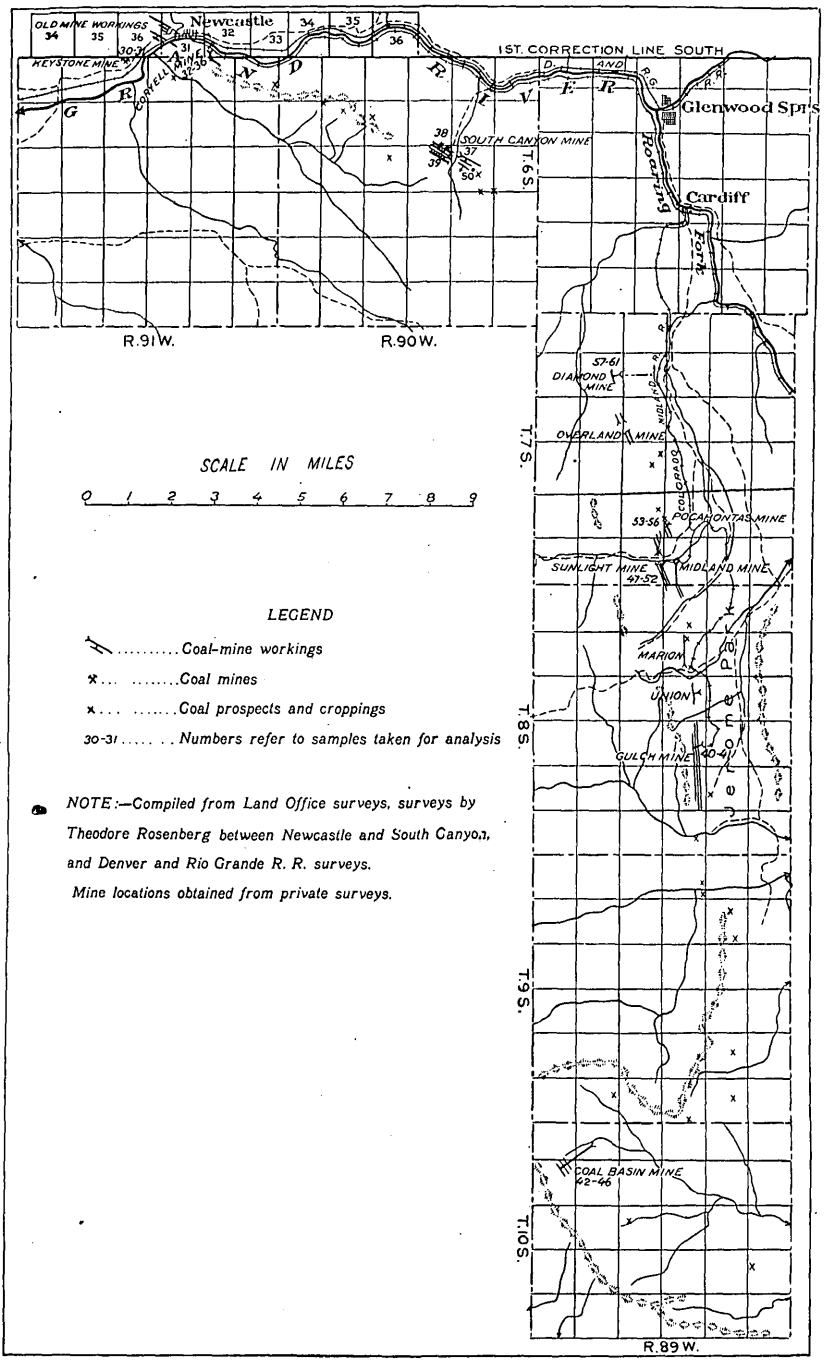
Two beds of coal in the S. ½ sec. 33 were noted, one of which is evidently at least 12 feet thick. A thick bed that measured 22 feet at the surface, although broken by parting, has been opened near the middle of the south side of section 21 by a small entry, possibly for local use.

There is an exposure of coal in the southeast corner of the SW. ¼ SE. ¼ sec. 20, T. 1 S., R. 94 W. The bed is cut by Sheep Creek and exposed on the south side only, but is evidently about 10 feet thick. A similar and possibly the same bed is cut by the channel of Sheep Creek, 1 mile north and one-fourth mile west of this point, at the quarter section corner on the south side of section 17. Two beds of coal are there exposed, one about 2 feet thick and another 100 feet farther west about 20 inches thick. The strike of the rocks is N. 3° W. These beds are near the top of the Mesaverde formation.

GLENWOOD SPRINGS DISTRICT.

RELATIONS TO THE GRAND HOGBACK FIELD.

As explained on page 109, the Grand Hogback as a topographic feature and as a more or less distinct ridge is continuous east and southeast of the areas mapped topographically in detail with the present work. South of Grand River and east of Newcastle the hogback of the Mesaverde rocks is commonly known by the name of Coal Ridge, although it is clearly a part of the same general coal field as the Grand Hogback so far as conditions of accessibility, character and age of the coals, general structure or attitude of the strata, and geologic relations of the beds are concerned. There is, however, considerable variation in detail in the constitution of the individual parts of the formation, as well as in the thickness, number,



MAP OF GRAND HOGBACK SOUTH OF GRAND RIVER.

and grouping of the coals at various points along their outcrop. The district extending southeast from Newcastle and south from Glenwood Springs is in a geologic sense directly continuous with the well-known coal fields still farther south on the upper branches of Gunnison River. The topography of the district thus outlined merges in a rather indefinite way with the more ruggedly mountainous region of the West Elk Mountains. The volcanic intrusions and uplifts that produced that mountain group have interrupted, offset, or concealed the otherwise continuous outcrop of the Mesaverde rocks that doubtless formerly extended from one field across to the other.

NATURE OF THE EXAMINATIONS.

The field work of the party as a whole at the close of the season in 1906 was discontinued in the vicinity of Newcastle. The systematic examination of the coal-field areas, including the topographic sketching, was also stopped at that time. After the disbanding of the party as a whole, the various operating coal properties in the Glenwood Springs district were visited by Arthur K. Adams, field assistant, under the author's instructions, in part continuation of the plan of inspection that had been carried on during the progress of the work to the north. The principal object of thus continuing and extending the work was to obtain representative analyses from the southern portions of the field for comparison with the analytical data already obtained. Such additional information as was obtained is given in the following paragraphs, which are compiled chiefly from Mr. Adams's notes. The small outline map of this part of the field (Pl. XV) is compiled from the township plats of General Land Office surveys, by Theodore Rosenberg, covering the Coal Ridge area between Newcastle and South Canyon, and from surveys of the Denver and Rio Grande Railroad. The mine locations shown on this map and stated in the following text are taken from plats kindly furnished by the operators of the various properties.

During the summer of 1909 surveys in considerable detail, covering most of the Glenwood Springs district from Newcastle to near the Coalbasin mines, have been carried on under the direction of A. L. Beekly in extension of the work already done. Reports of this work will doubtless be forthcoming at an early date, and will supersede the present somewhat incomplete descriptions of this part of the field.

MINES AND RAILROADS.

The district extending from Newcastle to the southeast as far as Coalbasin finds an outlet for the coal produced by railroad branch connections with the main lines along Grand River and Roaring Fork. It is at present the most important part commercially of the various coal fields here described, as it has been the most completely devel-

oped and prospected. The following working mines were visited: South Canyon, Black Diamond, Pocahontas, Sunlight, Spring Gulch, and Coalbasin. Descriptions of these follow in the order named.

DESCRIPTION OF PROPERTIES.

South Canyon mines, Garfield County.—South Canyon joins Grand River from the south about 7 miles east of Newcastle and 5 miles west of Glenwood Springs. The mines are situated in the valley for which they are named, nearly 2 miles south of Grand River. The developments are located in the NW. ¼ sec. 14 and the NE. ¼ sec. 13, T. 6 S., R. 90 W.

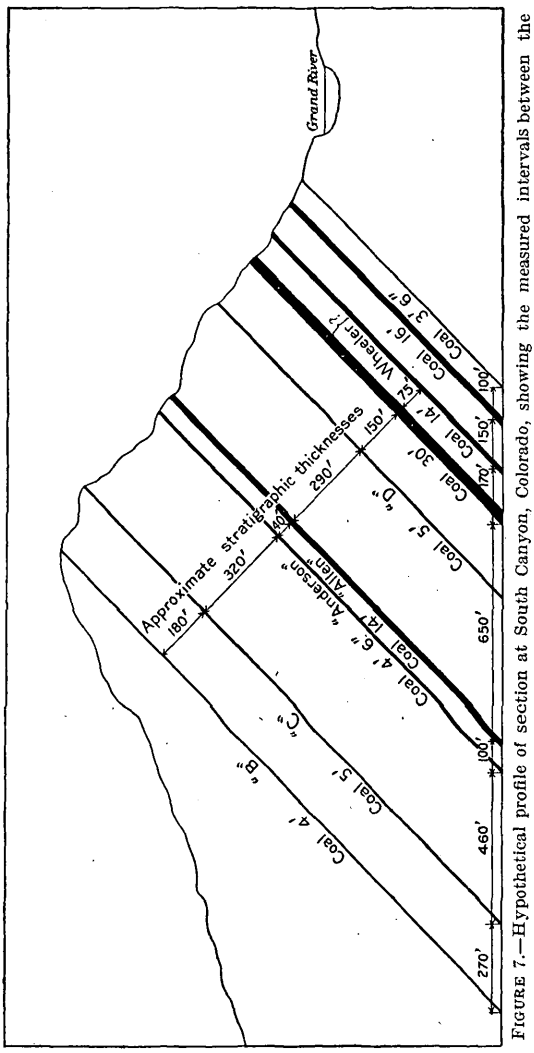


FIGURE 7.—Hypothetical profile of section at South Canyon, Colorado, showing the measured intervals between the various coal beds. From detailed surveys and sketches made by Theodore Rosenberg.

South Canyon cuts directly across the part of the Grand Hogback known as Coal Ridge, and the coal beds are exposed on both sides of the valley. (See fig. 7.) The developments consist of two drift openings, one on each side of the canyon. On the east side a bed supposed to be the same as the Wheeler at Newcastle is the only one developed; on the west this bed and one other correlated with the "D seam" of the Newcastle section are mined. The west Wheeler coal is on fire, and efforts at control had not been successful at the time of visit. Thus the main entry has been run in on the "D" coal beyond the fire, and from it a crosscut through 87 feet of rock is made to the Wheeler. Beyond that point the Wheeler is again mined. The beds dip steeply toward the south, the measurements taken recording 52°, and strike N. 60° W.

The Wheeler coal bed is 18 feet thick on the east side of the canyon, where it is the only one mined. This bed has a peculiar bedded fault or slip that is constant throughout the workings. This slip is everywhere 4½ to 5 feet from the roof or hanging wall. In mining, the entry is advanced on the coal below the slip a distance of about 50 feet. The upper coal is then removed by itself. No other partings were observed in the coal.

The "D" bed, which is worked only on the west side of the gulch, is about 5 feet thick, but is said to be better coal than the Wheeler.

In mining, the coal is both hand picked and shot down. Breast auger drills are used and shot firers do the shooting at stated times. The coal is on a steep dip (52°); it slides readily down the rooms to chutes on the main entries, where it is loaded into cars and hauled to the surface by mules. The mine workings have a gravity haul and are self-draining. The main entry serves as a haulage way and air intake. A train of eight or ten cars is then made up and hauled by electric-motor power down to the tipple at Grand River. There the coal is washed and shipped via the Colorado Midland Railway to Denver and Cripple Creek. There is a large amount of gas in the coal, and Wolff safety lamps are used. The capacity reported is about 700 tons daily. The analyses of three samples (Nos. 3959, 3960, and 3961) taken in this mine are given on page 249.

The analyses bear out well the local report as to the superior quality of the "D" coal as compared to the Wheeler. The "D" has an exceptionally low percentage of ash, and shows high efficiency in the calorific determinations, giving 8 per cent more heat, according to the tests made.

Black Diamond mine, Garfield County.—East of South Canyon the next operating mine is the Black Diamond. This was said to be owned by the Empire Coal Company. It is the northernmost of a group of working properties on Spring Gulch, all of which are accessible to a branch railroad line that joins the main Colorado Midland at Cardiff. The Black Diamond or Diamond mine is about 8 miles south, a little west of Glenwood Springs. The mine had been lying idle for seven years just before the present visit was made and was then being reopened. The whole section at that place is said to contain seven beds of coal. Of these, the lowest is 5 feet thick without partings, and is known as the Black Diamond. A drift entry made on this bed serves as a main haulage way. Crosscuts are made from the main entry into a 16-foot and 12-foot bed overlying. These beds strike N. 27° W. and dip 52° SW. The Black Diamond bed is said to furnish the best coal, and is locally considered an excellent domestic coal. The 16-foot bed is split by a lens of shale which is said to pinch

out within 300 feet. The following measurements were made of the upper bench, of which the lower 2 feet is very soft:

Measurement of upper portion of 16-foot seam where sampled.

	Ft.	in.
Coal	2	2
Mother coal		1
Coal	1	10
Parting		2
Coal	5	
	9	3

The 12-foot bed was caved at the time of visit. That bed is said to have contained a persistent slip or parting 4 feet below the roof, which had been traced a distance of 1,000 feet. From the similarity of this slip to that of the Wheeler at South Canyon it is reasoned that they may be the same coal. It is the expressed intention of the operators to open all three coals mentioned above.

The mine is reported not gaseous, and has excellent natural ventilation. The Mitchell tipple and 5,000-foot tramway were under construction, and when completed will be like those at Pocahontas. The probable output is estimated as about 600 tons daily.

Five analyses of samples (Nos. 4030, 4037, 4038, 4040, and 4050) from this mine are given on page 249.

Pocahontas mine, Garfield County.—The Pocahontas mine is situated about a mile north of Sunlight, and is owned and operated by the Rocky Mountain Fuel Company. There are four beds at this place, only two of which are worked, namely, those known as the "A" and "D." The main entry is driven in about 2,500 feet. The "A" bed is reported to be 16 feet thick, but the lower portion contains so much bone that it can not be worked advantageously, the upper bench of 7 feet being the only portion extracted. The "B" bed is too thin to be worked at a profit. The "C" bed contains about 7 feet of coal, but has in the middle a 4-foot shale parting that makes it difficult to work.

Section of "C" bed, Pocahontas mine.

	Ft.	in.
Shale roof.		
Coal	3	11
Shale	4	
Coal	3	6
Shale floor.		
	11	5

The "D" bed is thick, with no partings, and is easily extracted. The following is a section of the beds exposed at this locality:

Section near the Pocahontas mine.

	Ft.	in.
Coal ("D bed")	12	
Shale	17	

	Ft.	in.
Coal ("C bed")	7	6
Shale	7	6
Coal	1	
Interval	4	
Coal ("B bed")	3	5
Interval; estimated	20	
Coal ("A bed")	7	
Shale, bony	9	
	88	5

The strike of the beds at this mine is N. 14° W. and the dip 42° W.

From the entrance of the drift to the tipple below there is a straight double-tracked gravity incline 5,200 feet long. Seven cars are let down at a trip. The output is reported to be about 150 tons daily. At the tipple the coal is graded with shaking screens and marketed in different grades or sizes.

Four analyses of samples (Nos. 4031, 4035, 4036, and 4039) taken at this mine are given on page 249.

Sunlight mine, Garfield County.—The Sunlight mine is situated north of the properties at Gulch, about 9 miles by railroad up Four Mile Creek from Cardiff, and about a mile south of Pocahontas. Four workable beds are exposed, only two of which are worked. The following is a section at the mine:

Section at Sunlight mine.

		Ft.	in.
"D" bed—Coal		9	
Shale		25	
"C" bed	Coal	3	
	Shale	1	6
	Coal	3	
Shale and sandstone		6	10
"B" bed—Coal		6	
Shale		9	
"A" bed—Coal		7–10	
		73	4±

The "A" and "D" beds are worked. The "A" varies somewhat in thickness and runs high in slack. The "B" is too soft and crumbly to be of use. The "C" is considered impracticable for mining at present on account of the parting in the middle. The "D" is considered good coal.

The main entry is a drift and runs in a total of 2,500 feet, the first 1,100 feet of which is in the rock along the strike of the beds, that part of the coal bed being on the property of the Colorado Fuel and Iron Company. The "A" bed is first struck; drifts are run on it and crosscuts driven from it to "D," with drifts also on the latter.

Section of "D" coal.

	Ft.	in.
Coal	1	9
Parting		1
Coal	6	5½
	8—	3½

The rocks strike N. 10° W. and dip 44° W. The coal is said to be noncoking, and the whole output is used for roasting ore.

About 800 feet above this lower group of coal beds is an old working on a bed known as the Sunshine. This was formerly worked by the Colorado Fuel and Iron Company, but is reported to have proved unsatisfactory as a coking coal.

Six analyses of samples (Nos. 4032, 4033, 4034, 4045, 4046, and 4048) taken at this place are given on page 250.

Gulch mine, Pitkin County.—Gulch, or Spring Gulch, is about 21 miles nearly due south of Glenwood Springs and is reached by a branch of the Colorado Midland Railway that leaves the main line at Cardiff. The coal produced is of coking quality, the dividing line between the coking and the noncoking coals being reported as approximately at the Pitkin-Garfield county line. The old workings, which have been abandoned for seven years, were on three thin beds known as the "A," "B," and "C," which constitute a lower coal group. The present developments are on coals about 800 feet stratigraphically above this group, the beds being known as the Sunshine and Anderson. This corresponds well with the section at Sunlight. The Sunshine is the lower and ranges from 9 to 14 feet in thickness, averaging about 12 feet. The Anderson bed is about 50 feet above the Sunshine and ranges from 4½ to 6 feet in thickness. The coal beds dip 35° W. A number of faults have been encountered in the workings on these coals; one has a throw of 80 feet and one of 40 feet, and still another that seems to affect the Anderson only has an unknown throw. The entrance to the mine is down a slope of 25°, beyond which the entry turns southward along the strike of the rocks. The upper set of workings is extensive, being over a mile in length. From the entrance of the mine cars are let down to the tipple over a gravity plane 1,400 feet long. At the tipple the coal is loaded into railway cars and shipped to Cardiff, where it is screened, the coarse lump coal being shipped for fuel and the fine coal coked. The output of this mine is reported to be about 500 tons daily.

Two analyses of samples (Nos. 4009 and 4010) taken at this mine are given on page 250.

Coalbasin mine, Pitkin County.—The next developments south of Gulch are at Coalbasin, on a branch of Crystal River, 12 miles west of Redstone and about 40 miles by railroad south of Glenwood Springs, in secs. 5, 6, 7, and 8, T. 10 S., R. 89 W. The coal now worked is

of coking quality. These mines belong to the Colorado Fuel and Iron Company.

The following general description of the locality is taken from a report of R. C. Hills:[a]

> The name Coal Basin has been applied to a broad amphitheater bounded on three sides by the steep slopes and escarpments of the coal measures, which rise abruptly 2,500 feet and form a high sheltering wall to the basin. The exposures in the central part of the amphitheater consist of soft Montana shales, through which protrudes an eruptive mass less than 1,000 feet high. The strata around the basin are inclined away from this body, so that the structure is characteristically that of a laccolith, even to the dikes formed during the eruption. The intrusion of the eruptive body took place subsequent to the formation of the hogback fold, producing a dome-shaped uplift in the nearly horizontal measures immediately to the west of it, without apparently changing the course of the fold or the inclination of the strata affected by it. Hence the outcrop on both sides of the basin as it nears the line of flexure resumes the steep southwesterly dip common to the northeastern boundary.

The author himself has not visited any of the properties here described south of Glenwood Springs. The progressive increase in fuel value as shown by the calorific determinations and also the development of coking quality in the coal as traced toward the south are naturally of much interest in the study of this field, and may give rise to speculation as to their cause. Mr. Hills's description, quoted above, is of especial value in this connection as recording the relations of the intrusive rocks to the Coalbasin mines. So far as known to the author the details of this association and its effects are still to be worked out. Further mention of this subject is made in the last chapter with the discussion of the chemical analyses of the samples collected. (See p. 252.)

In the present developments at the Coalbasin locality the main haulage way extends in about 2,000 feet toward the southwest, in the direction of the dip, and from this entry a number of side headings have been driven on various levels. A double coal bed has been opened at this locality, the two benches being separated by a parting that ranges in thickness from 2 inches to at least 4 feet. The upper bench is from 7 to 10 feet thick and is the only one mined, the lower part of the bed being dirty and not of coking quality. The rocks have a much lighter dip than at the localities farther north, measurements taken ranging from 21° to 16° W. The strike of the beds is about N. 35° W.

Many step faults of the normal type occur. The floor heaves rapidly as the coal is taken out, and a gang is kept constantly "brushing" the levels and entries—that is, lowering the tracks by cutting the entry deeper as the floor rises. Many props, which are the only timbers used, are buckled and broken. As the mine is very gaseous Wolff safety lamps are used, and all of the coal is picked down instead of being shot. Powder is used only in the rock crosscuts.

[a] Hills, R. C., Coal fields of Colorado: Mineral Resources U. S. for 1892, U. S. Geol. Survey, 1893, pp. 349-352.

The tipple is below the entry, and the steel cars holding 2 tons each are let down by means of a main and tail rope system of haulage. About 100 men are employed at the mine, about half being miners. The output is said to be 450 to 500 tons daily. The entire product is made into coke at Redstone, whence it is shipped to the company's plant at Pueblo.

Five samples (Nos. 4041, 4042, 4043, 4047, and 4049) were taken of the coal from this property, four of which were taken in the mine, and the results of these analyses are given in the table on page 250.

CHAPTER IV.

DANFORTH HILLS FIELD, COLORADO.

LOCATION AND EXTENT.

The Danforth Hills coal field lies in Rio Blanco and Routt counties, Colo., and is practically coterminous with the mountainous area of the same name. The Danforth Hills are north of White River, west of the White River Plateau, south of Axial Basin, and east of the valley of Strawberry Creek and the extension of that valley toward the north. Strawberry Creek is in a continuous narrow valley at the western margin of the hilly area and is the natural line of separation of the Danforth Hills from the Gray Hills, which occupy the region to the west with more recent geologic formations. This valley is also a natural western limit to the coal field because the coal-bearing strata dipping in that direction pass beneath it to so great a depth that the coals are probably not workable far into or beyond that district. The other sides of the field are limited by escarpment ridges, formed of the upturned and eroded strata of the lower coal-bearing rocks, whose steeper cliff slopes face outward from the coal-field area and overlook the low valley areas that are almost everywhere eroded on the shale that underlies the coal rocks.

SETTLEMENT AND MARKETS.

The valleys that surround the coal-field hills contain the greater part of the settlement of the district. The principal settlement is at Meeker, the county seat of Rio Blanco County, which also affords the largest present market for the consumption of the coal produced. The population of Meeker, according to the census of 1900, was 507, but present estimates place it at about 1,000. The town is, however, the center of a rather extensive though scattering settlement in that part of the State. Aside from the limited use of coal for steam at the local electric-light plant and in a planing mill and a traction engine, demand for domestic and blacksmithing purposes gives the only present market for this field.

RAILROADS.

The nearest railroad point to the field is Rifle, on the Denver and Rio Grande Railroad. This point is 45 miles from Meeker by wagon road, with which it is connected by daily stage. The projected line

of the Denver, Northwestern and Pacific Railway (Moffat road) passes through Routt County, the preliminary alignments following near the course of Yampa River. In 1909 this road had been completed as far as Steamboat Springs. West of Steamboat Springs a route that may be considered alternative to the one surveyed (through the lower Yampa River canyon to the junction of the Green), and that may ultimately be adopted, is to be had by crossing from the Yampa to the White in the vicinity of Meeker, and thence going by way of the White River valley and canyons to Utah. While such a course would introduce an additional divide to be crossed, the route by way of the lower White passes through most of the settled area of Rio Blanco County and would also tap these coal fields, equal to or greater than the Yampa field of Routt County both in total area and amount of coal available. In reference to such a statement, however, it should be remembered that a considerable portion of the Danforth Hills field is situated in Routt County and is most readily accessible from the Yampa River drainage.

COAL.

AGE OF THE COAL-BEARING ROCKS.

As explained in the section on stratigraphy (p. 63) the valuable coals of the Danforth Hills field are all in the Mesaverde formation, which is of Cretaceous age. Though several distinct coal-bearing formations are present in the Yampa field, only that stratigraphically lowest and oldest is present in the coal fields south of Axial Basin, an anticlinal axis that separates the two areas by only a narrow interval. A general description of the character of the coal-bearing rocks is given under the heading "Stratigraphy" (pp. 63–71).

GENERAL SECTION OF COAL BEDS.

The group of rock strata that contains the coal is approximately a mile in thickness, and many beds of valuable coal are found in one position or another within this mass. Both the total number and the thickness of the individual beds vary from place to place along the outcrop, as may be observed in the thickening or pinching out of the beds where they can be traced. Only along the western side of the Danforth Hills field is anything like a complete measurement of the coals now obtainable. Of these the section on White River below Meeker, like that at Newcastle on Grand River, may be taken as representative of the stratigraphic section of that field in its total quantity of coal, which is somewhat less than that of the Newcastle section. Similar sections are probably exposed at other localities

in the various gulches that cross the steeply dipping beds on the western margin of the coal field, but owing to the lack of development it was not practicable in the present work to measure the coals.

Coal in the section at Meeker has been developed mainly to supply the small demand for domestic use in that vicinity. The beds dip to the west at angles ranging from 31° to 68°, and most of the thicker coals are exposed by a series of prospects along the north side of White River. The following coals were accessible when visited and were measured in the present investigation:

Thickness of coal beds exposed on White River below Meeker.

	Ft.	In.
Lion Canyon, upper entry	5	8
Lion Canyon, W. B. Blythe coal mine	8	5
A. H. Adams mine, 3 benches, not including bone	8	5
Old Meeker bed, A. H. Adams property	5	10
F. W. Fairfield property, west entry	6	3
F. W. Fairfield property, middle entry, upper bench	9	8
F. W. Fairfield property, middle entry, lower bench	9+	
F. W. Fairfield property, east entry (old Major bank)	13+	
Mrs. Grace H. Adams property, prospect	3	3
Mrs. Grace H. Adams property, mine	4	1
	73	7

Without doubt a considerable number of workable coals that are not included in the foregoing list occur in the White River section. It is therefore entirely conservative to assume a minimum thickness of 75 feet as representing the workable coal of this section.

Though all the coal-bearing strata may be found in regular sequence in a small portion of the field where the beds are so steeply tilted as to bring the uppermost down to water level (a condition fulfilled for the most part only along the western margin of the field), the remaining and greater part of the coal field is underlain only by a portion of the formation, the upper strata having been worn away. Synclines and structural basins commonly retain a larger number of coal beds below water level than regions uplifted and dissected by canyons or broader valleys. The geologic map shows several such areas within the Danforth Hills, from which it seems clear that nearly all the valuable coals have been removed.

Fortunately for the economic development of the Danforth Hills field, the principal coal beds occur low in the formation and many of the important coals remain, even where a great thickness of Mesaverde has been removed. Thus these beds outcrop at the surface along the ridges and gulches in the interior of the field, and by reason of their light dips may prove readily accessible for development in a large part of it.

The following table is given to indicate approximately the extent of lands underlain by coal at workable depths in the Danforth Hills field, as here defined:

AREA OF COAL LANDS.

Summary of estimated area of available coal land north of base line in Danforth Hills field, Colorado.

	Acres.
T. 1 N., R. 94 W.	7,680
T. 1 N., R. 93 W.	160
T. 2 N., R. 95 W.	560
T. 2 N., R. 94 W.	17,840
T. 2 N., R. 93 W.	22,000
T. 2 N., R. 92 W.	3,080
T. 3 N., R. 95 W.	12,520
T. 3 N., R. 94 W.	23,040
T. 3 N., R. 93 W.	23,040
T. 3 N., R. 92 W.	11,160
T. 4 N., R. 95 W.	9,760
T. 4 N., R. 94 W.	16,460
T. 4 N., R. 93 W.	8,040
T. 4 N., R. 92 W.	2,160
T. 5 N., R. 95 W.	2,000
T. 5 N., R. 94 W.	200
	159,700

DESCRIPTION BY TOWNSHIPS.

GENERAL STATEMENT.

The area surveyed and mapped in this field is represented on Plates XVI and XVIII. The limits of these maps are determined by parallels and meridians of latitude and longitude. According to the best information available, the base line falls a short distance north of the south boundary of these maps, and therefore a narrow strip of the Grand Hogback field as defined on page 109 is included here. On some considerations White River itself would be as convenient a line of separation as any to mark the division between the Danforth Hills and Grand Hogback fields, and would probably have been used here were it not that the base line offers a far more convenient land subdivision for purposes of most estimates and areal measurements. All townships are referred to the sixth principal meridian, Colorado. It does not seem as feasible to describe the townships in numerical order as by an arrangement with reference to their distribution along the coal outcrops, but any particular township can be easily found by referring to the table of contents, page 6.

T. 1 N., R. 94 W.

Meeker district.—The principal developments of the Danforth Hills coal field are the small mines and prospects grouped about the town of Meeker, which is situated in the open valley lands of Agency

LEGEND

Strike and dip

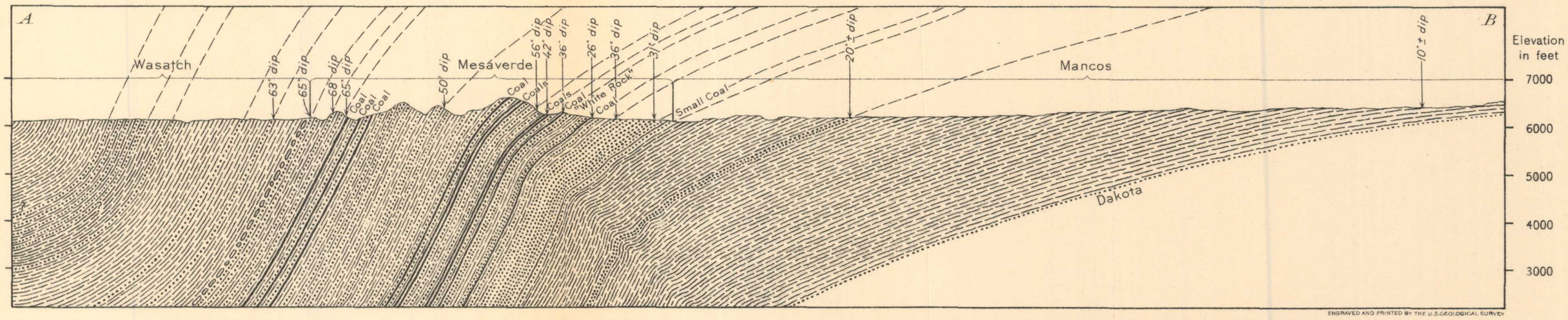
Mine

Prospect

Cliff

Mining entry

Strawberry Creek
Lion Canyon
Lion Canyon
Sulphur Creek
Fourmile Gulch
Creek
Ditch
West Fork
East Fork
MEEKER
Ditch
AGENCY PARK
POWELL PARK
Cross L Ranch
WL 6050
WHITE RIVER
Flag Creek
Sheep Cr
A
B



ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

TOPOGRAPHIC MAP AND STRUCTURE SECTION OF THE MEEKER DISTRICT, COLORADO

T. 1 N., R. 94 W., SIXTH P. M.

Topography by Hoyt S. Gale, in charge,
A. K. Adams, A. L. Beekly, and R. D. Crawford
Geology by Hoyt S. Gale

0 ½ 1 2 Miles

0 5000 10000 Feet

Contour interval 100 feet
1909

Note: Geologic boundaries are shown on the general map Plate XVI

Park, in T. 1 N., R. 94 W. Agency Park is bounded on the west, north, and northeasterly sides by an escarpment rim of the lower coal-bearing rocks. In the canyons and gulches which cut through this rim, for the most part draining the higher territory beyond, the coal beds are most accessible and lie within a radius of a few miles of the settled valley lands, and it is there that most of the developments have been made.

White River canyon.—The most complete and best-exposed section of the coal-bearing strata is that of the White River canyon, by which that stream leaves Agency Park, cutting across the strata of the Grand Hogback in regular succession and nearly at right angles to the direction of their outcrops. As nearly all of the workable beds have at one time or another been opened in prospects or mining entries at this locality, this is an excellent place for the study of a section which may be assumed to be typical of almost the whole field to the north as well as much of the Grand Hogback extending south from that district.

As the strata of the Grand Hogback are rather sharply tilted to the west where they are cut by the White River valley west of Meeker, the lowest or oldest coals are those exposed at the eastern end of the canyon, while the highest or youngest are the ones at the western end. Thus, within an interval of a little less than 2 miles along the valley side, practically at the side of the public road, one sees a typical section of all the coal-bearing strata that compose the broader and more extended coal fields to the north and east.

In view of the more extensive development and interest in this part of the field, a separate map (Pl. XVII) of Meeker Township (T. 1 N., R. 94 W.) is published herewith on a larger scale than the general map. With this is included a graphic cross section showing the relations of the coals in the inclosing rocks to each other and to the adjoining formations. The boundaries of private tracts established by the resurveys are not shown on this map. Geologic colors and patterns have also been omitted, but location of present mining entries and the tracing of continuous ledges as horizon markers is indicated so far as possible from the present data. The map should serve a useful purpose in further economic development as well as in detailed study of the coals in this important part of the field.

The panoramic view in Plate XIV, *B*, shows the locality of the White River section, as seen from the first mesa level near the middle of the north half of section 32, about 90 feet above the river and near its bank. This is an excellent general view, showing nearly the whole Mesaverde section in a lower or topographically more subdued form than that in which these rocks are most commonly found. The contrast with the rugged topography of the Danforth Hills area to the north is especially striking.

Lower coal group.—The lower coal group in the vicinity of Meeker does not appear to be of any commercial value. It is represented by a number of very thin and bony beds of coal and lignite, occurring among the lower ledges of the escarpment series north and northwest of the town. These are clearly visible in the lowest massive sandstones of the bluff rising just north of the northwestern town-site corner, on either side of the gulch leading to the Lord and Black Diamond coal mines. By tracing these beds toward the southwest it may be seen that they are eroded and pass beneath the valley wash as the mouth of the main river canyon is approached; they therefore lie stratigraphically beneath the ledges visible there.

Grace H. Adams property.—The lowest beds that have been worked in the White River canyon are found on the NE. ¼ SW. ¼ sec. 28, T. 1 N., R. 94 W., on the Grace H. Adams property. They are marked by an old mine dump, a drift, and a slope entry, together with an old whim and tipple. Two entries have been made, opening two of the lowest workable coal beds recognized in this stratigraphic section. The following section was measured in the vicinity of these coal entries:

Section on Mrs. Grace H. Adams's property, Meeker.

	Ft.	in.
Shale, blue clay	2+	
Coal, weathered outcrop	1	6
Shale or blue clay, lenticular bed		7+
Coal, weathered outcrop	2	10
Sandstone, single stratum	4	
Coal, weathered outcrop	3	3
Shale, brown	2	8
Sandstone, massive	1	10
Coal (sample No. 3483)	4	1
Floor not exposed.		
Total coal exposed	11	8

The principal development here is an idle entry on the lowest coal in the preceding section. This consists of a slope about 200 feet long driven approximately north at a pitch of about 15°. The strata are inclined 36° N. 60° W. The entry has been opened in two rooms of considerable size, which have been driven up the dip on the coal bed from the main slope. A sample (No. 3483) was taken for analysis July 28, 1906. (See p. 249.)

Northeast of the entry just described, about 200 feet along the outcrop of the strata, a coal bed has been opened which probably corresponds to one of those measured in weathered outcrop in the section given above. It is exposed by a slope driven for ventilation of the main entry, running down on the coal at an angle of about 35° into one of the rooms. In this bed at least 3 feet of coal is exposed, the base being covered by caving at the mouth of the pit.

The roof is poor, being a weak blue clay shale. A local report states that this coal is of semicoking quality, but as no sample was obtained and no tests were made nothing can be said on this point.

All of the coals described in the preceding paragraphs occur above a prominent white sandstone, which may represent the horizon described as the "white rock;" and this group of coal beds would thus be at the base of the middle coal group, as defined elsewhere, occurring just above the "white rock" ledge; but, as will be explained in the description of the property lying next west, it seems more likely that it is slightly below the horizon usually marking the base of the middle coal group and that a still higher overlying massive white sandstone represents the normal horizon of the "white rock" ledge. This group of comparatively thin coal beds, separated by shale and sandstone, is supposed to unite into a single bed and to lie at the same horizon as a single 11-foot coal bed opened on the Oldland and Pollard tract just northeast of this. (See p. 150.)

Fairfield or Welch property.—A 40-acre tract of patented coal land, said to be the property of F. W. Fairfield, of Meeker, adjoins the Grace H. Adams property on the west. This is the NW. ¼ SW. ¼ sec. 28, T. 1 N., R. 94 W. Three entry drifts start on this property near to and on the north side of the stage road. The lowest coal bed is opened in what is locally known as the "old Major" bank, so called for Mr. Newton Major, formerly of Meeker, who did the first work on the property. The entry lies in the Fairfield tract, but in a short distance the bed crosses toward the northeast into the Adams tract, and it is from this claim that the bed will probably be worked when it is reopened. The entry was originally driven from a short side gulch and penetrated directly along the strike of the coal bed. A slack pile of considerable size and an old bin and wooden tipple indicate that considerable work had been done in the past. The coal opened is about 400 to 500 feet stratigraphically above the bed last described on the Adams property and is 20 to 30 feet above a great white sandstone ledge 100 feet or more in thickness that intervenes between the two groups of coal beds. It is thought that this sandstone is the stratum already referred to as the "white rock" which so commonly marks the base of the workable coals of the middle group in the Danforth Hills and Grand Hogback fields. In support of this supposition is added the evidence of a collection of fossils made from a ledge about 200 feet lower in the series, but above the coal of the Grace H. Adams mine, which includes specimens of a large *Inoceramus* and *Cardium speciosum,* marine forms found elsewhere either in or below the white ledge forming the base of the middle coal group.

A drift entry has been driven in along the coal bed in a direction about N. 25° E. The coal itself dips 36° NW. The bed is com-

posed of several benches of coal separated by bone or clay, the total thickness being at least 14 feet. The whole thickness of the coal bed has been removed along the main entry beyond the first 60 feet, and this, together with considerable caving of the roof, leaves a high chamber. The entrance is timbered with stulls and lagging for about 20 feet, then stulls for 40 feet more, beyond which the roof, where it can be reached, is supported by numerous props 12 feet or more in length. A thin coal roof still remains in places, but much of it has now fallen, leaving overhead a slabby or flaggy surface, which offers a rather serious menace to further work by way of this entrance. As the coal bed has a rather steep dip toward the west, only the upper bench of coal has been worked along the lower or west side of the entry, and the middle and lower benches of coal have been taken down on the upper or east side. The following section was measured at this mine:

Section at "old Major" coal bank, on White River, west of Meeker.

	Ft.	in.
Shale, sandy or soft sandstone.		
Sandstone, flaggy	1+	
Coal, upper bench	4	11
Bone, with coal streaks		8
Coal, middle bench	5	3
Parting, hard clay		3
Coal, base not exposed	2+	
Total coal	12	1+

No sample of this coal was obtained for analysis because of the poor condition of the entry and the much-weathered state of the coal that was accessible. The coal contained in the mine dump is in greater part slacked, but a few large lumps still remain as evidence of a favorable capacity for resistance to weather.

Fairfield entries.—A few hundred feet west of the "old Major" bank several entries have been driven and a considerable amount of coal taken out from what is probably the principal group in the stratigraphic section. These entries are just north of the public road, in the base of the bluff, and lie within the tract described above as the Fairfield property. They are marked by a heap of slack coal of considerable size with a miner's cabin standing between it and the road. These beds are a hundred feet or more stratigraphically above the coal of the "old Major" bank; their size and distribution is shown in the following section:

Section on Fairfield property, White River, west of Meeker.

		Ft.	in.
1.	Sandstone, massive, good roof	15	
2.	Coal, with small bony streak near bottom	5	3
3.	Sandstone and shale (estimated interval)	70	
4.	Coal (bed mined in 1907) measured face	7	4½

		Ft.	in.
5.	Sandstone, massive, white	70	
6.	Coal, upper drift on double bed, measured face	9	8
7.	Shale, carbonaceous	3	
8.	Clay, white, sandy, kaolin-like	2	9
9.	Coal, lower drift on double bed	10	
	Total coal exposed and measured	32	3½

The lower or easternmost of the two entries starts in as a simple drift on the lower bench of the double coal bed noted as Nos. 6, 7, 8, and 9 of the above section. Its direction, which is the strike of the beds at this place, is N. 17½° E., with a dip of 42° W. At 110 feet from the mouth of the entry the drift forks, an opening to the west passing through the roof of the lower bench into the upper coal of this double bed. The straight entry, which continues in on the lower bench of the coal bed, is said to have run 800 feet or more from the entrance, but it was blocked by caving, which had opened through the roof into the mine above. It is reported that within 15 feet of the end of this entry the coal bed takes an abrupt change in direction, bending to the northeast. Such a structure may be accepted as in apparent conformity with the bend in the rocks of the Grand Hogback in which the lower ledges swing around the northern border of Agency Park, changing from the north-south course with which they crossed White River to a northeasterly course. It is also said that at this point the coal itself pinches to a thickness of only 5 or 6 feet, the overlying white clay also thinning correspondingly. For this reason the mining work was discontinued there. Coal at that place seemed to be softer and of poorer quality, probably from crushing and possibly also because of proximity to the surface in the side gulch that passes near the "old Major" bank.

The drift into the upper bench in this mine ran in about 540 feet beyond the point at which it turned from the main entry, making its total length about 650 feet from the mouth of the mine. A good measurement of the coal bed taken at this face showed 9 feet 8 inches of coal with a 1¼-inch clay parting 1 foot 11 inches below the roof. The floor is the hard white sandy clay that forms the roof of the coal bed below. A track for the mine car runs the length of both entries. A sample (No. 3482) from the upper bench was taken July 28, 1906; for analysis see page 249.

Another and separate entry on the bed numbered 4 in the section on page 144, is driven on a coal that is separated from the lower two by about 70 feet of white sandstone. These two entries are about 40 yards apart and nearly on a level. The upper drift was reopened in the spring of 1907 for the local trade at Meeker. The coal bed measured 5 feet 6 inches where first struck in the entry and thickened gradually to 7 feet 4½ inches at the face of the main drift. The entry

starts below the coal and runs about 75 feet a little west of north until it strikes the coal bed, where it turns along the strike in a direction of N. 22° E. for about 450 feet. The dip is 38° NW. At the face there showed a local bony streak not noted in other parts of the mine. The roof is a sandstone of apparently favorable strength. This entry is equipped with a mine car, tracks running to the face of the mine, and a covered tipple and grizzly.

A sample (No. 3498) taken on July 28, 1906, gave on analysis a result (see p. 249) very similar to that obtained from the next underlying bed.

An unopened bed 60 or 70 feet higher in the series above this mine measured 5 feet 3 inches of coal at the outcrop. Within the next 200 feet of strata above this point there is exposed a great cliff of baked and fire-reddened shale, sandstone, and slag, apparently indicating the presence of other valuable coals that may prove important when they are opened beyond the burning. Including the "old Major" bank, it is thought that 50 feet of workable coal, at a conservative estimate, is now exposed on this 40-acre tract of land. This is approximately the stratigraphic horizon of the Wheeler bed at Newcastle, although it is not intended to make specific correlation of any individual coal beds through the 45 miles of outcrop that separate these two localities.

A. H. Adams property.—The next group of entries west of the F. W. Fairfield property is on a 40-acre tract (the NE. ¼ SE. ¼ sec. 29, T. 1 N., R. 94 W.) of coal land belonging to Mr. A. H. Adams, of Meeker. The eastern entry is an old one, now abandoned and caved, that was originally worked from an entrance that passed through the dwelling house close to the public road. This coal bed is said to be the first opened for use at the old Meeker Indian Agency when it was in Powell Park, although a similar claim is made for the so-called "old government bank" on Coal Creek, which was probably worked for the agency at the upper location. A measurement made at the outcrop of this bed showed 5 feet 10 inches of coal without partings or bone. The coal is apparently clean and hard and of good quality. A massive sandstone, 15 feet or more in thickness, immediately overlying the coal bed, should afford a good roof. The floor is a bony coal one-half inch to about 6 inches thick, underlain by sandstone. The strike was measured as N. 8° E. and the dip as 42° W. It is said that work in this mine was discontinued at a fault face, beyond which the coal was not traced. As already noted, the strata become steeper toward the west as the section is followed through the canyon.

Mr. A. H. Adams adds the following information:

The longest of the three tunnels (the one on the old Meeker bed) penetrates the coal a distance of about 325 feet. About 5,300 cubic yards of coal have been mined from this seam. An analysis of this coal from a sample taken by Mr. Noble, of the Colorado

Fuel and Iron Company, showed 53 per cent fixed carbon. It is of uniform thickness; shows no bone or slate and very little ash. There are no important seams between my property and the Lion Canyon mine. There are several smaller ones, the largest of which I have any knowledge being on my property and measuring about 28 inches, lying about 175 feet above the west seam.

The westernmost coal opened in a mining entry on the Adams property is estimated to be about 130 feet stratigraphically above the "old Meeker" bed. This entry is at present marked by a whim and small wooden frame tipple. It runs down a short slope and ends in a small room, the whole being less than 100 feet in length. An upper drift from the same entrance about 300 feet long was the first part opened, but has since been abandoned. Several very massive sandstone ledges occur just above the coal, the immediate roof being a few inches (3±) of blue clay shale. The strike of the rocks was N. 17° E. in the entry and the dip approximately 45°, though no satisfactory determination of the latter was obtained. The following is a detailed section taken in the mine; the measurements, however, do not hold constant even in the small opening on this coal:

Section measured in west entry, Adams property, west of Meeker.

	Ft.	in.
1. Coal, good	5	1½
2. Clay, hard		1
3. Coal, good	1	4
4. Bone, black, flinty, not a constant		[a]5
5. Coal, apparently good	1	
6. Coal or bone, soft, flaky	1	
7. Bone or carbonaceous shale floor.		
	8	11½

The coal is apparently very similar in quality to the others that were sampled in this vicinity (see analyses, p. 249). Lump coal said to have been standing in the mine car five months was cracking and breaking, but the lumps still retained their original shape.

Above the west mine of the A. H. Adams property the main ridge of the hogback rises along the outcrop of the heavy yellow weathered sandstone stratum that occurs a short distance above the small 2-foot coal mentioned in Mr. Adams's note quoted above. The coal itself now shows in natural exposure underneath 7 inches of blue clay, which is in turn capped by 20 inches of sandstone. The coal bed measured 20 inches, but was probably not completely exposed.

As this sandstone stratum appears to form a single nearly straight continuously rising hogback or ridge, it seems fair to assume that there are no faults of great consequence transverse to the strike of this section. There are, however, many minor faults or slips in the various workings of this district that are said to have caused more or less difficulty along the lower spurs of these ridges. Just above the

[a] Maximum measurement.

Adams mine is a good illustration of the slumping of the strata caused by the burning out of coal beds. The fault reported in the Adams mine is not apparent in the surface outcrops.

West of the Adams property no other coals were observed among the outcropping ledges for a distance of a little over half a mile to a point near the Lion Canyon mine. This interval is occupied by a number of huge cliff-making sandstone ledges that dip westerly at angles varying from 50° to 60° and by some thick masses of shaly strata.

Lion Canyon property.—The Lion Canyon mine is the property of Mr. W. B. Blythe, whose house stands a short distance back from the public road and near the mine entrance. The mine is located in the SE. ¼ NW. ¼ sec. 29, T. 1 N., R. 94 W.

The mine is opened on an 8½-foot bed of coal. The entry runs in straight along the strike, giving a good determination of N. 11° E., with dips varying from 55° to 65°, the average probably being about 63°. In 1906 the entry extended in to a depth of 1,140 feet. In driving the entry the coal has been worked out to a height of from 25 to 40 feet in the steeply dipping bed. The entry is then braced above with stulls and lagging. The mine is equipped with a 1-ton car and track running the entire length. The entry is of such grade that the car is hauled in by means of a burro, and when loaded runs out by gravity. At the mouth is a substantial wood-frame tipple. This was the only property in the Meeker district that was being worked when visited in 1906. The price of coal at that time was $2 a ton loaded at the mine, or $3 delivered in Meeker, about 3 miles distant.

On both sides of the entrance to the mine huge bare sandstone ledges stand up like ramparts. The following section was measured, the thickness of the coal being taken at the face where the sample was cut, and the rest of the measurements from the surface near the mine entrance.

Section measured at Lion Canyon mine.

	Ft.	in.
Sandstone, very massive (roof)	75±	
Coal (as sampled)	8	5
Clay, hard (weathers readily to a friable bluish shale)	25±	
Sandstone, massive, white (good building stone)	40±	
	148	5±

The sample (No. 3502) was taken at the face of the mine; for analysis see page 248. This coal is reported to have a local reputation for being the hardest and in other ways the most favored for domestic use of those mined about Meeker. Its reputation for hardness seems to depend upon its tenacity or pitchlike character, making it a more difficult coal to break down than that of the lower beds, which break along joining or bedding planes. It has a dull spotted

appearance which causes it to be described by local residents as "sorry looking." One point mentioned in its favor is that it burns without soot, but it is also admitted that the coal does not stand well, slacking rapidly when exposed to the weather. Its analysis does not appear to be quite as favorable as that of the other coals obtained from this vicinity, being somewhat lower in its percentage of fixed carbon and slightly higher than the other fresh-coal samples in its content of moisture in the air-dried product.

An abandoned coal entry just west of the Lion Canyon mine measured 5 feet 8 inches of coal in one good solid bed overlain by pale blue clay 2 feet thick and above that by a great bed of massive white sandstone. The stratigraphic interval between this coal and the Lion Canyon bed as mined is calculated to be 120 feet. The intervening strata are largely white sandstone. The white ledge next above this coal is the one forming the prominent cliff just above and extending back from the Blythe dwelling.

Mr. Blythe reports that he has opened several small coals still higher than this bed, and that they are 2 to 3 feet in thickness. Other coal beds exposed near by in the lower end of Lion Canyon are very evidently of somewhat lower horizon than the bed worked in the mine. One or two of these lower coals appeared from surficial evidence to be of workable thickness, but no measurements of them could be obtained without a considerable amount of fresh development. All of these coals are included within a stratigraphic interval of a few hundred feet, and constitute the upper coal group as known in this part of the field. The topmost limit of the Mesaverde formation is to be found in the third prominent ridge-forming ledge that projects southward toward the river valley east of the Lion Canyon mine. That stratum is composed of the coarse conglomerate or puddingstone that has already been described as marking the base of the Tertiary rocks in this field.

In the basal Tertiary beds just south of this township some lignite or woody coal is noted. At that particular place, moreover, massive sandstones, similar to and locally almost indistinguishable from those of the Mesaverde formation, are found at intervals extending into the overlying strata through a thickness of nearly 3,000 feet, as shown in the cross section attached to the map of Meeker township (Pl. XVII).

In the valley east of the coals a small kiln has been used in which a so-called "streak of lime rock" has been burned for use in building. The lime ledge is a bed of fossiliferous rocks varying from 2 to 10 or more feet in thickness, occurring in association with the upper group of coal beds. From these beds of lime rock T. W. Stanton has identified *Ostrea glabra* var. *arcuatilis*, *Anomia*, and *Corbicula occidentalis* M. and H.?

South side of White River.—On the south side of White River near the Rifle Bridge several beds of coal of approximately the same horizon as the Lion Canyon beds were found. These are opened by shallow prospects at the upper edge of the mesa just east of Mr. Robert Reynolds's house. A bed of coal about 6 feet thick is exposed at one place in a shallow pit near the center of the NW. ¼ sec. 32. The following measurements were made at this place:

Section at coal prospect one-fourth mile southeast of Rifle Bridge, 4 miles west of Meeker.

	Ft.	in.
Sandstone	1	6
Shale, crinkled blue clay	4	
Coal, weathered face exposed	5	9
Shale, blue clay (floor).		
	11	3

The strike of the beds is N. 23° E. and the dip 63° W.

A short distance north of this point another prospect, opened at the bank of the irrigation ditch, showed coal 5 feet 10 inches thick with a shale floor. A third entry pit just south of that last mentioned was nearly caved, but showed 1 foot of coal, with indications of a still thicker bed, overlain by finely laminated blue clay shale 1 foot to 1 foot 2 inches thick, with 7 feet of white sandstone above it. The latter is probably of the same horizon as that first described at this locality, and is 25 to 35 feet stratigraphically below the other coal.

All of these coals were very completely slacked in exposure, forming a light, loose, dusty powder. No definite statement can be made as to the quality of the coals, but the indications are that they resemble the beds at Lion Canyon.

Other beds representing the coals lower in the stratigraphic series have doubtless been opened in the past on this side of the river, but no other development was noted in the present work.

Other properties north of White River.—Other coal properties have been opened north of White River to supply the local trade in and about Meeker. These are described in the following pages in the order of their position along the outcrop of the coal-bearing beds from White River northward.

Oldland and Pollard property.—An 80-acre tract of coal land, said to be owned by Messrs. Oldland and Pollard, of Meeker, contains the next developments north of the White River section. This includes the E. ½ NW. ¼ sec. 28, and contains in part the abandoned mine known as the "old Fairfield mine." This mine is said to have been opened in 1884 or 1885 by Mr. F. W. Fairfield, of Meeker, and the coal is generally conceded to have been a favorite with the local residents about Meeker. The old entry is reached by way of a small tributary gulch joining White River valley from the north, about 300 yards east of the center of section 28. The old mine is some-

what over one-fourth mile north of the main river road. At the time the locality was visited a more recent entry a short distance below the "old Fairfield" mine in the same gulch was mistaken for the mine itself.

This more recent working is in a situation probably similar to that of the "old Fairfield," but is east of the Oldland and Pollard 80-acre tract. The coal is probably of the same, or nearly the same, horizon in both properties. The openings examined are said to have been made by Mr. D. Pollard, of Meeker, for the local trade.

In this recent working, the location of which is shown on the map (Pl. XVII), the tracks lead to a drift or slope starting in to the southwest. Another entry starts in to the northeast, but both are so badly caved as to be practically inaccessible. A slope has been driven down the dip of the coal, but beyond 40 feet was filled with water. Coal is exposed at the mouth of the entry to a thickness of at least 7 feet. The bed is reported to be 11 feet thick. The coal occurs 200 to 300 feet below a huge white sandstone bed and is thought to correspond to the horizon of the beds in Mrs. Grace H. Adams's property in the White River section. The big white sandstone appears to be duplicated in its outcrops on the hillside, as it is also at the Black Diamond mine farther north, and the whole development has the appearance of being situated in a large slumped block. It may perhaps be found on closer examination that the old slope at this place is in an outer block of strata, and that the drift entry is in a separate block, situated between the outer slide and the rock in place in the hillside, and considerably larger than the outer one. On this assumption the horizon of this coal bed is placed about 75 feet below the "white rock."

The following description of the "old Fairfield" mine itself is obtained from reports of those who have worked in the mine. The coal occurs in two principal benches 5 feet or so-thick with a soft brown clay between. The roof is of slabby shale or sandstone that has not held up well, and there occur also lenticular masses of hard clay or shale at the roof that fall unexpectedly after exposure in the mine workings. One fatal accident in the old mine was caused by powder fumes, but other serious accidents were caused by the falling roof. The old mine is reported to have been finally abandoned on account of its dangerous condition. The workings are said to have consisted of a drift running in 1,000 feet to the northeast. This is now entirely closed by caving.

D. Pollard mine.—The Pollard mine, formerly known as the Jones mine, is situated 200 yards S. 25° E. of the center corner in T. 1 N., R. 94 W., and the entrance is therefore in section 22. The mine is located in part on the 40-acre tract of patented coal land that is said to be the property of Mr. D. Pollard, of Meeker. This mine is situ-

ated in a narrow rocky canyon that opens into Agency Park near the northwest corner of the townsite, and the mine is about 1½ miles from the town itself. The measurements taken of this bed, as mined in different parts of the developments, showed considerable variation, but a fair average would give about 5 feet 9 inches of good hard coal with a shale roof and shale floor. The total section as measured in this locality follows:

Section at D. Pollard mine, Meeker, Colo.

		Ft.	in.
1.	Coal and bone	2±	
2.	Sandstone, massive, single stratum	4	
3.	Shale, gray clay	3+	
4.	Coal, not mined	1	8
5.	Shale, gray clay	1	1
6.	Coal as mined, no seams or partings	5	8
7.	Interval, mostly shale covered by slide (paced)	45	
8.	Sandstone, white massive ledge (estimated)	20	
9.	Shale (estimated)	15	
10.	Coal	4	
11.	Shale and 1 foot sandstone	9	
12.	Coal	1	
13.	Shale, sandy	1	6
14.	Sandstone	3	
15.	Shale, sandy	6	
16.	Coal		6
17.	Sandstone	4	
	Total section	126	5
	Total coal	14	10

From this section it will be seen that a considerable number of coal beds are grouped at this locality, most of them being comparatively thin. Below the bed developed in the principal entries some drifts have been driven on a 4-foot coal with a very poor roof of weak clay shale. On the north side of the gulch the entry extends in 50 feet or more, but is so filled by falling of the roof as to be unsafe to enter. A few coal smuts show in the gulch below the section above, but did not appear important. This coal group is evidently at the extreme base of the workable beds of the section, and for this reason (and also on account of its position several hundred feet more or less stratigraphically below a most prominent white sandstone ledge) is thought to correspond in a general way to the group represented on the Grace H. Adams property on White River. The big white ledge is very conspicuous for a long distance along the west wall of the canyon, and is thought to be directly traceable into the one just below the "old Major" bank on White River. A thick coal shows in natural outcrop just above the white ledge at the Pollard mine, and the canyon wall above that point is burned and reddened to brilliant hues, probably thus representing the other

thick coals of the middle group for this locality. The lowest coals are the only ones readily accessible by wagon road at the gulch bottom and were therefore the first to be opened for use.

The coal of the principal mine has been opened on both sides of the gulch, the main entry starting in toward the north down a slope and later turning northeast along the strike. The strike of the beds is about N. 20° E. and the dip is northwesterly about 28°. It was reported that two abandoned slopes on the south side of the gulch had encountered a fault, but this is not shown at the surface. The measurements numbered 1 to 6 in the preceding section were taken on the north side of the gulch, at the entrance to the main workings.

A sample (No. 3849) was taken here; for analysis see page 249. The following measurements were made in the mine at the place where this sample was cut:

Section in Pollard mine, 510 feet from entrance.

	Ft.	in.
Coal	2	9
Coal, pyritiferous		½
Coal	3	4
	6	1½

When it was visited in 1906 the mine was equipped with 1-ton cars, track, and covered wooden bins for loading into wagons. The coal is locally considered to be of very fine quality; one point mentioned in its favor is a small percentage of ash, which is relatively heavy and does not blow about. The output is reported to be 150 to 190 tons a month during the winter months.

Black Diamond mine.—The Black Diamond mine is situated near the middle of section 15, about three-fourths of a mile northeast of the Pollard mine, on a coal of approximately the same horizon. This is the property of George M. Lord, of Meeker, and the bed is known as the Lord coal. The mine is situated at the bottom of a steep, narrow gulch, about 2 miles a little west of north from Meeker. The main entry is a drift running in to the northeast; when visited it was 430 feet in depth, including a room 300 feet from the entrance measuring about 50 by 30 feet. The whole thickness of the coal bed is exposed near the entrance to the mine. Roughly measured, this appears to total about 20 feet, including a number of sandstone, shale, and bone seams. The coal now worked includes 7 to 8 feet near the middle of the bed, which is a bench underlain by a brown carbonaceous shale 1 foot thick on the floor, with a hard, blue, sandy clay seam below. The roof in the mine is coal. The coal bed outcrops close underneath a great ledge of massive white sandstone. A general view of the Black Diamond mine suggests the possibility that all of the present workings are

located in a large slumped block of strata, and that the original position of the coal was somewhat higher than it now is. If so, a large mass of the overlying sandstone ledges has also settled in the same block, and this may account for the apparent great thickness of these sandstone beds where exposed in the cliff above the mine. It is said no indications of faulting have as yet been encountered in the mine.

The stratigraphic position of the Black Diamond or Lord coal is possibly higher in the series than the coal of the Pollard mine, about three-fourths of a mile southwest. This statement is made on the assumption of the general continuity of the great white sandstone ledges overlying the beds, which are much nearer the coal at the Lord mine than at the Pollard mine. For analysis of sample (No. 3847), see page 249. The following section was measured in the mine where the sample was taken:

Section in Black Diamond mine near Meeker.

	Ft.	in.
Coal roof.		
Coal	3	11
Coal, soft, powdery ("mother coal")		½
Coal	3	10
	7	9½

Sulphur Creek.—The next developments on these beds are the prospects and mines in the valley of Sulphur Creek, about 1½ miles a little east of north of the Black Diamond mine. These consist of a working mine, known as the Sulphur Creek coal mine, and several abandoned entries and prospects. They are situated in the immediate valley of the main creek, about 3½ miles due north of Meeker. The mines are on the P. P. Harp ranch, said to be the property of T. D. Riley and Arthur Burnham, of Meeker.

There are in all four entries, two on each side of the gulch. The one farthest south, near the wagon road on the west side of the gulch, is in the NE. ¼ NE. ¼ sec. 10. This evidently old mine is reported as extending in to a depth of about 250 feet and ending against a fault in a room to the west of the main entry. The entry starts in as a drift in a direction S. 20° W., the bed dipping 19° to 23° NW. A part of the coal taken from this entry is said to have been of good quality, but beyond a depth of 150 feet it was found to become softer, and the mine was finally abandoned, partly on this account and partly on account of some controversy over property lines.

Sandstone and shale are exposed above the mine, much reddened by the burning of other coal beds. A sample (No. 3850) for analysis (see p. 249) was taken and the following measurements were made about 180 feet in from the entrance:

Section measured in old mine on southwest side of Sulphur Creek.

	Ft.	in.
Shale (roof, poor).		
Coal	1	4
Parting, sandy		½
Coal (sample)	3	9
Bone (floor).		
Total coal	5	1

The whole entry is supposed to be in a block of strata broken off from the hillside above and slumped down. This view was expressed by Mr. Arthur Burnham, who has done much prospecting in this vicinity, and is corroborated by the general appearance of the ridges and spurs all along the west side of Sulphur Creek.

The Sulphur Creek mine, which is the principal mine of this locality, is on the east side of the valley, about one-half mile N. 30° E. of the entry last described, in the NE. ¼ SE. ¼ sec. 3, near the eastern limit of that tract. The coal bed is at least 7 feet thick at this place. The coal is hard and rather tough. A sample (No. 3845) was taken and the following section measured 470 feet from the entrance:

Section in main entry, Sulphur Creek mine, north of Meeker.

	Ft.	in.
Sandstone, massive	20	
Bone	1	
Coal	1	3
Bone (sandy)		1
Coal		8
Bone (sandy)		1±
Coal	4	
Bone (floor).		
Total coal	5	11

A second sample (No. 3848) was taken from the face of a side entry some 200 feet east of the first, where the following section was measured:

Section in side entry, Sulphur Creek mine, north of Meeker.

	Ft.	in.
Coal roof (not measured).		
Coal	1	2
Parting (sandy)		½
Coal		11
Parting (sandy)		½
Coal	3	1
Bone (floor).		
Total coal	5	3

The mine is equipped with two 1-ton cars and a tipple with grizzly. Mr. Arthur Burnham reports that the longest entry is 520 feet deep and that the upper entry runs in 480 feet on a higher level. He also

gives the following general section as representing the succession of the beds at the mine:

General section at the Sulphur Creek mine.

	Ft.	in.
Coal	2	6
Interval	40	
Clay	3	
Coal as mined	7	
Shale	12	
Coal	3	
Total coal	12	6

The dip in the mine is 15° to 17° NW. The entries run in under a spur among the lower ridges on the east side of Sulphur Creek and during the winter of 1906–7 the workings were driven back so that they approached the surface under a small side draw or gulch. This situation shows its effect by a deterioration in the quality of the coal, which becomes softer and slacks more rapidly on exposure to the air after it is taken out. In the summer of 1907 the coal was being used at the planing mill and in the traction engine at Meeker and also for domestic purposes at a few houses.

The bed opened at the Sulphur Creek coal mine is situated stratigraphically below the "white rock" in a position approximately corresponding to that of the Lord or Black Diamond bed already described (p. 153). As exposed in the hillside the entry appears to be about 300 feet below the outcrop of the "white rock" ledge, although it is possible and even probable that a portion of the interval between the coal and exposed ledge is also occupied by a part of that heavy bedded stratum that is concealed by the surface débris or slide rock.

The Sulphur Creek mine is worked chiefly in the winter, when an average output is reported to be 120 tons a month. The total output is reported as 600 tons in the winter of 1905–6, and about 300 tons in that of 1906–7.

A third entry visited on Sulphur Creek is located in the NW. ¼ SE. ¼ sec. 3, on the west side of the creek. This prospect had been drifted in about 65 feet, the coal bed opened being about 7 feet thick at the entrance and pinching down to 3 feet at the back. The coal at this entry is also thought to be situated in a slip or locally displaced block of strata, which is therefore below its normal position.

A fourth entry observed on Sulphur Creek is located in the SW. ¼ NE. ¼ sec. 3, as shown on the map. This entry is reported to have been drifted in on a 24-foot bed of coal, work having been discontinued at a fault at a depth of 100 feet. According to statements received, the coal bed broke off sharply at a face of massive white sandstone. Along the plane of contact 3 or 4 feet of mud is described, "slick"

at both sides, at the back end of the coal and also at the face of the sandstone, all of the intermediate material being filled with pyrites. At this point it is said that a good spring was encountered. The entry was then turned along the face of the ledge and driven 90 feet farther, but without tracing the continuation of the coal bed. As it appears to be in a block of strata broken from the hillside above, the thick bed may very probably be found in place by search. Above the position of the entry a high bluff in which much burning has taken place without doubt indicates the existence of a number of large coal beds.

Some notes on the occurrence of the Lion Canyon coal group (upper coals) on Sulphur Creek are included in the description of T. 2 N., R. 94 W., on page 158.

Summary.—According to present information only 960 acres of coal land out of about 7,500 acres in the Meeker township have been patented at the present time. Without much doubt this region will eventually prove to be a part of an active coal-mining district. A rather unusual section of coal beds containing a large amount of coal is found in the Mesaverde formation of this part of the field. The coal is bituminous of an excellent grade, the calorific value of which ranges from 11,000 to 12,000 British thermal units in air-dried samples, It may thus be classed as a good bituminous, noncoking coal. An arbitrary lower limit of calorific value of approximately 12,000 British thermal units on good fresh coal has been suggested for distinguishing a class of high-grade bituminous from a class of bituminous coal ranging down to high-grade subbituminous with a fuel value of more than 9,500 British thermal units on unweathered air-dried samples. In use the coal serves well for both domestic and steam purposes. The present limited demand and the abundant available supply, together with the total lack of transportation facilities to make available more distant markets, retard the immediate development of the field.

As a practical suggestion for opening up the Meeker district on a more extensive plan than that followed in the present scattered banks for local supply, the following plan may be offered: Entry drifts driven into the coal hogback toward the east from almost any favorable point on the east fork of Lion Canyon would cut the upper coals of the middle group at no considerable depth, as some of these beds lie already exposed on the upper dip slope face of the ridge, and many thick beds are known to be present below. The advantages of thus entering from the west would be that the coal beds could be tapped from below, with a large reserve lying above the main entry levels, and all of the beds of the section could be crosscut in a single entry at stream-grade level, with an easy haul down to White River. The entries could then be graded to run the cars out loaded and the coal as

mined would slide down the chutes into the side headings. It seems that such a policy would be more economical in the long run than the present development at the croppings of the beds on the less easily accessible side of the ridge.

T. 1 N., R. 93 W.

The greater part of T. 1 N., R. 93 W. lies in the open valley lands of Agency Park. As its surface is thus formed largely from the Mancos shale, it lies stratigraphically below the valuable coals of the Mesaverde formation. The Mesaverde ridges, however, extend into sections 1, 2, 3, and 4, and coal has been prospected in the northern part of section 3. The coal at that place doubtless belongs to the lower coal group, and so far as the author knows has not been shown to be of practical value.

T. 2 N., R. 95 W.

Only a small portion (in sec. 1) of T. 2 N., R. 95 W. is considered to be coal land. The greater part of the township is composed of Tertiary strata, including Strawberry Creek valley and the Gray Hills. Some indications of coal are found in the basal Wasatch beds near the public road, one-half mile south of the locality known as "White Rocks." These beds are not, however, thought to be of much importance. The upper or Lion Canyon coal group of the Mesaverde formation is represented by a series of beds, some of which are burned, and these beds were noted in outcrop at the extreme northeast corner of the township. The strata dip 40° to 45° SW. and follow a very uniform trend toward the northwest. All of the coal beds of the Mesaverde formation doubtless pass underneath the entire township, although they are probably buried to such a depth beneath the later formations that but a small portion can be available for mining by the methods and mining practice in vogue at the present day.

T. 2 N., R. 94 W.

The axis of the Sulphur Creek syncline passes through T. 2 N., R. 94 W. from east to west, and this structure determines the attitude and distribution of the strata. The rocks in the southern part of the area are the direct continuation of the Grand Hogback topography and structure, the trend of the whole outcrop swinging to the east with a northerly dip along the northern margin of the Agency Park uplift.

The axis of the Sulphur Creek syncline follows a somewhat tortuous course from east to west, following very closely, however, across the center line in the township. The syncline pitches to the west so rapidly that at the valley of Strawberry Creek the flanks of the fold spread apart widely, and the influence of that structure in the Gray Hills to the west is shown only by a very gentle flexure in the general trend of the ridge, and to a less extent by the very light dips of the

beds. In effect the syncline is a subordinate structure and becomes merged in the steep westward monocline of which the Grand Hogback fold forms a part. As a result the rocks in the southern half of the township strike northeast and dip northwest, while those in the northern half of this area strike northwest and dip southwest. In general the southerly dips on the northern flank of the syncline are steeper than those in corresponding positions on the southern flank. The effect of this structure is that any single horizon among the upper beds of the Mesaverde formation, if traced continuously along the outcrop, is found to extend northeast as far as that synclinal axis and from that point turns back to the northwest along the western margin of the Danforth Hills field. The lower beds may be traced continuously still farther east, conforming to the same structure, but passing to a greater depth along the axis of depression, and in part at least not exposed at all on the northern side, some of them being capped by the overlying beds that have not been worn away.

The middle or principal coal group extends to the northeast from the locality of the outcrops already described on Sulphur Creek in the Meeker township. These beds occupy the high ridge lying between the upper valley of Sulphur Creek and Agency Park, and by reason of their northerly and northwesterly dips pass beneath the Sulphur Creek valley. Coal beds of the same group again rise to the surface on the northern flank of the syncline, and outcrop in the ruggedly mountainous country in the vicinity of Devils Hole Gulch, and in the spurs on the northern side of upper Sulphur Creek. The middle coal group may be traced toward the northwest, where outcrops are found in sections 4, 5, 6, 9, 10, and elsewhere. The northern forks of Devils Hole Gulch are evidently eroded below the "white rock" and cut into the lower relatively barren strata of the Mesaverde formation. Very little indication of coal is to be seen in that part of the field. So far as known to the author no development had been made on any of the coal beds of the middle group in this township at the time of this examination.

The upper or Lion Canyon coal group may be readily traced northward from White River, where the coal is opened by the mine already described. It continues parallel to the long, straight strike valleys of the two forks of Lion Canyon, which are lined by continuous sandstone cliffs. This group of coal beds crosses to the Sulphur Creek side of the drainage divide at or near the township line on the south side of section 33. From this point northward the coal beds are found outcropping in the high escarpment slope on the west side of Sulphur Creek. The big white ledge at the bend of the gulch near the township line forms a very conspicuous horizon from that point northward and is provisionally correlated with the big ledge observed below the coal of the Lion Canyon mine. This stratum forms

a prominent ledge at the Meeker stage road about one-fourth of a mile east of the intersection of the main east-west road and that to the Rifle Creek bridge in sec. 29, T. 1 N., R. 94 W. A local report states that seven beds of coal have been opened on the west side of Sulphur Creek below the Goff ranch, all of them small except one bed about 6 feet thick. It is said coal has been mined to a small extent in the hillside west of Goff's ranch. At that point the large white sandstone taken to mark the base of the upper group in this district sinks nearly to water level, exposing nearly 1,000 feet of strata in the hillside above and including the ledges in the base of the Wasatch formation at the top of that section. Pebbles from the conglomerate marking the unconformity between the two formations are found in the débris that washes down that slope. North of Goff's ranch the strata including the upper coal group bend sharply westward, following a very straight course to the locality of the "White Rocks." The latter is a local name taken from a white sandstone stratum considerably higher stratigraphically than that elsewhere referred to in this report as the "white rock."

T. 2 N., R. 93 W.

Nearly all of T. 2 N., R. 93 W., is considered to be coal land. A small area in the southwestern part of the district should be excluded from such classification as being occupied by strata that are older than the workable coals. The stage road from Meeker to Axial and northward to the Yampa River valley passes through the township by way of Curtis Creek, Ninemile Hill, and thence down Spring Creek.

The continuation of the Sulphur Creek syncline east from that part already described in T. 2 N., R. 94 W., passes through the center of this township in a somewhat irregular course. The axis is marked by lower and more open valley lands than the bordering ridges of the underlying sandstone beds that rise toward the north and south on either flank of the syncline. The fold extends across the upper valley of Curtis Creek, beyond which it follows the general course of Ninemile Draw. Across the northern boundary of the township the strata have apparently reached a maximum elevation and from that position northward toward Axial Basin the structure flattens to a broad, gentle northerly dip.

Although the upper beds of the Mesaverde, including the Lion Canyon group of coal beds, are probably entirely removed from this part of the field, there is evidence that a large part of the principal or middle coal group still remains and that many of the beds are situated within such depth that they are accessible for mining. Only a very small amount of prospecting or development has yet been done in this area, a few local banks being opened for domestic supply.

The base of the workable coal group may be traced with much distinctness northeast from the developments on Sulphur Creek, and then east to where it crosses the valley of Curtis Creek, 4 miles distant. One of the coal beds has been opened in Curtis Creek canyon near the Meeker-Axial stage road, 6½ miles from Meeker. This entry is near the line between secs. 29 and 32, T. 2 N., R. 93 W., and is reported to be the property of Mr. W. H. Miller. A drift runs in along the coal bed for 70 feet. The following measurements were made at this place:

Section at Miller prospect on Curtis Creek, northeast of Meeker.

	Ft.	In.
Shale (roof).		
Coal, good	2	3
Coal, dirty		3
Coal, good	1	4
Bone		1
Coal (peacock colors)[a]	1	4
Shale (floor).		
	5	3

This bed is one of the lowest of the middle group. About 200 feet above the entry is exposed a huge, white sandstone ledge, thought to be the "white rock" elsewhere described. The coal bed mined, therefore, probably corresponds very closely to that of the principal mine on Sulphur Creek and at the Black Diamond, Lord, and G. H. Adams mines near Meeker.

The beds dip 17° due north. The coal is apparently of good quality, clear and hard, except that the one mined is much broken by partings. (See analysis No. 3851, p. 249.)

Above or north of the "white rock" the canyon walls are brilliant red, from the baking of the rocks adjacent to the burned coal beds. There are thus indicated a large number of important beds not yet exposed. As the beds are traced north toward the axis of the syncline the dip decreases in amount.

About one-half mile north of the summit of the road on Ninemile Hill, on the east side of the road, is a thick bed of coal, entered by an old prospect drift, now completely closed by caving. The man who opened the prospect states that he found 6 feet of good coal, with a dirty coal roof and similar floor. At least 12 feet of coal can be seen above the roof of the entry, although, judging from the weathered exposure, only a part of it has the appearance of good coal.

[a] The iridescent colors on "peacock" coal are due to the presence of a film of iron stain, probably of the oxide. At the natural outcrop of a coal bed the sulphides, so commonly present as an impurity, decompose with weathering, and the iron they contained gives rise to the common yellow and brown stains resembling rust. At somewhat greater depth, the sulphide alteration products frequently take the forms that give the iridescent colors. At still greater depth, beyond the influence of surface alterations, the coal is normally free from these stains, and the pyrite is unaltered. The degree to which the iron sulphide is oxidized is an indication also of the degree of alteration of the coal, so that, contrary to a prevalent popular notion, the appearance of the peacock colors is indicative of a deterioration in quality of coal.

A prospect on Spring Creek about 2½ miles northwest of Ninemile Gap, on a west branch of the creek about one-fourth of a mile from the main road, was sampled for analysis. The coal was badly weathered, and the face from which the sample was cut had evidently been exposed to the atmosphere for a considerable time. The analysis of the coal as received at the laboratory shows excessive moisture, but on air-drying the sample compared more favorably with others obtained from this field. (See No. 3846, p. 249.) The sample represented 4 feet 6 inches of coal and was taken in the pit only 15 feet back from the surface of the ground. No other developments were observed in this township.

From Curtis Creek to the eastern edge of the field the strata dip northward, and it is probable that most of the principal coal beds of the lower group pass beneath the upper valleys of Sulphur and Curtis creeks and the Ninemile Draw, in conformity with the structure of the Sulphur Creek syncline. North of the axis of this syncline these same beds rise again to the surface and the coals are found outcropping from place to place over all of the hilly country between the main divide and Axial Basin. East of Curtis Creek the trend of the strata swings slightly southward, bending conformably about the dome of uplifted strata in the center of Agency Park. The ledges of the lower strata thus pass westward across Coal Creek, where they swing sharply northward, terminating the coal-field area in a triangular area, which is in structure the nose of a northwestward-pitching syncline. Numerous outcrops of coal and ash beds are noted along the escarpment front and the ridge tops between Curtis and Coal creeks, but none are sufficiently opened to show the true thickness of the coal beds they represent.

Prospective development in the valley area in the central part of the township might well be done with the aid of the drill. In advance of such specific information it will be practically impossible to state precisely how much coal may be available or how deep it lies. In a general way it may be said that the base of the principal coal group probably does not pass to a greater depth than about 2,000 feet, and many of the upper beds of that group would therefore not reach so great a depth. A large part of this will probably be considered workable at some future time.

T. 2 N., R. 92 W.

T. 2 N., R. 92 W. includes only a small portion of the eastern margin of the Danforth Hills field. The greater part of the area is composed of the older rocks that form the western foothills of the White River Plateau. Some description of the geology of this township, including a small map, has already been published, with special reference to the occurrence of carnotite and associated minerals just east of the coal field.[a]

[a] Carnotite in Rio Blanco County, Colo.: Bull. U. S. Geol. Survey No. 315, 1907, pp. 110–117.

Coal Creek district.—The lower valley of Coal Creek is followed by the old government road, which was the main route of travel at the time of the early settlement of the region, being the means of access to the nearest railroad station, then at Rawlins, Wyo. Coal Creek enters the coal-bearing strata at the eastern border of their outcrops and, flowing diagonally across the southeastern corner of the coal field, emerges into the open valley lands of Agency Park, where it joins White River. This creek is one of the few within the coal-field area that contain perennial water, drawing an abundant supply from its upper valley on the wooded slopes of Sleepy Cat Mountain. The locality known as the "Transfer" is a lumber camp at the upper end of this valley in the coal-bearing rocks. Although a number of coal beds are certainly available for development in this locality, comparatively few have even been prospected, and only a small amount of coal has ever been taken out for actual use. This is one of the few localities in which the presence of workable coal beds seems to have been recognized in the early geologic reports of northwestern Colorado, the following statement by C. A. White having been published in 1876:[a]

> Among the best exposures of coal that were observed during the progress of the survey are those of two principal beds, one of which is found in and near Canyon Park, and another in the Danforth Hills, northwestward from White River Indian Agency. Both of these belts occur among the strata of the Laramie group,[b] one being near the base and the other near the top of the series. Comparatively little search will doubtless reveal these and other beds of coal in those places, from which supplies may be obtained with comparatively little labor. The bed that occurs in the Danforth Hills is also seen exposed in the valley sides of Yampa River below Canyon Park. This bed doubtless represents one of those at the well-known mines at Rock Springs station, on the Union Pacific Railroad, Wyo. The bed that occurs in the upper strata of the Laramie group, and which is exposed in Canyon Park, doubtless represents one of those beds which were formerly worked at Point of Rocks and Black Buttes stations on the railroad just named.

The bed in the Danforth Hills referred to above is doubtless that now locally known as the "old government bank" on Coal Creek, from which coal was used at the Indian agency. This is an abandoned and caved entry situated close to the creek bank on its east side, about a quarter of a mile above the mouth of Ninemile Draw and a half mile below the "Transfer." No measurement of the coal was obtained at this place. It is apparently a lower bed than that of the Wesson bank next described.

On the west side of Coal Creek, in sec. 30, T. 2 N., R. 92 W., almost directly west of the "Transfer," Mr. Gilbert Wesson has opened a prospect drift showing an excellent bed of hard, bright coal somewhat more than 25 feet thick. Nearly the whole thickness of the bed is exposed at the mouth of the entry, but the height of the coal

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[a] White, C. A., Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1876, p. 60.

[b] For discussion of the significance and use of the term Laramie, see pages 92-94.

and the timbering of the entry made a good measurement impracticable. The coal bed dips N. 75° W. at an angle of about 22°. The entry is situated structurally at the flattened nose of a westward-pitching syncline, the end of the Sulphur Creek syncline as shown by the structure contours on the geologic map (Pl. XVI). Coal beds of the same, or nearly the same, horizon extend southward in outcrop, and beyond a narrow spur or ridge they are prospected in the banks of Ninemile Draw. The outcrops of the Wesson bed and those closely associated with it are also continuous toward the north, as indicated along the face of the ridge in a course approximately parallel to the public road, as far as and beyond Yellow Jacket Pass, and they may also be the same coal as that opened just northwest of the pass and also at the Wilson mine in Milk Creek canyon.

At the entrance to the Wesson mine an ash bed indicates that the lower part of the coal bed has been partly burned, but this burning extends only a few feet in from the surface. The total thickness of the Wesson coal is probably over 25 feet from top to bottom, including two or three small dirty or bony streaks. The present entry is run in near the middle of the bed, leaving much coal above and below, both as roof and in the floor. The following is a section measured of the coal exposed at the face of the mine:

Section measured in Wesson mine, Coal Creek.

	Ft.	in.
1. Coal (roof).		
2. Coal, good	3	
3. Coal, dirty seam ("miner's" clay)		2
4. Coal, good	1	6
5. Coal, dirty seam ("miner's" clay)		2
6. Coal, good	4	3
7. Coal (floor).		
Total exposed at entry face	9	1

A sample (No. 3791) was taken September 11, 1906 (for analysis, see page 249).

By a measurement of the stratigraphic section near the locality of the "Transfer" the Wesson bed is estimated to be 2,000 feet above the base of the Mesaverde formation. Here as at many other points throughout the field the "white rock," a prominent massive white sandstone ledge, occurs in the coal-bearing series just below the principal group of workable coals. The Wesson coal lies about 500 feet stratigraphically above this ledge. Below the ledge several indications of coal were noted, but with the possible exception of beds near the "white rock" horizon the coal appears to be of comparatively little value. Above the white sandstone ledge at least two other coal beds are exposed below the Wesson coal, with the possibility of others obscured in the débris-filled bottom of the Coal Creek valley.

Above the Wesson mine the canyon wall rises steeply to a height of 600 or 700 feet and the rocks are fairly well exposed. A few sandstones outcrop, but these are not prominent as ledge-makers, showing chiefly where they have been hardened by burning of coal beds. These form brecciated cliffs of bright vermilion to brick-red color, interspersed with patches of unaltered white sandstone. Such ledges are usually much broken up, both jointed across the bedding of the strata and broken parallel to it. As elsewhere noted, the coal beds rarely show at outcrop, having been almost universally burned, and therefore marked only by slag, cinders, and reddened rock at the surface of the ground. Coal Creek appears to be an exceptionally favorable locality for the commercial development of the thick coal beds that undoubtedly occur in the stratigraphic section exposed at that place. The strata containing the coal beds dip westward, with flattening pitch, and almost certainly underlie at workable depth a large territory extending along the axis of the Sulphur Creek syncline. The advantage of the Coal Creek locality as a point of access to this structural basin lies in a more moderate and uniform pitch of the beds in the direction of the synclinal axis than will be found anywhere along the sides of the basin.

T. 3 N., R. 95 W.

T. 3 N., R. 95 W., is a part of the western margin of the Danforth Hills field and is reached by way of Strawberry Creek, or Hogback Valley, as it was named on the early Hayden maps. The coal-land area occupies the northeast half of the township, along the southwest margin of which the rocks dip steeply toward the southwest, passing under the Tertiary strata represented in the variegated clays of the Strawberry Creek valley and the sandstones and shales of the Gray Hills. The southwestward monoclinal dip of this area is practically a continuation of the Grand Hogback fold, which here begins to break up as a simple structural feature, showing the influence of the cross-folding structure of the Danforth Hills area. Although much burning gives evidence of the presence of many beds of coal in various parts of the field, no development or prospecting is known to have been done and no specific data relating to the thickness or quality of the coal were obtained.

The Strawberry Creek valley is practically without water for agricultural purposes, and consequently is almost without settlement, but two ranches being located along it north of the immediate vicinity of Powell Park and White River. For this reason there has been little demand and no development of the many outcrops of coal that are found on nearly all of the gulches that drain the westward slope of the Danforth Hills.

T. 3 N., R. 94 W.

T. 3 N., R. 94 W., is situated in the interior and more rugged portion of the Danforth Hills area. It includes part of the main divide between the Yampa and White River drainage. Of this the most precipitous slopes are on the southwest in the headwater gulches tributary to Strawberry Creek and White River. Toward the northeast long evenly graded canyons extend out to Axial Basin. Of these Wilson Creek and Morgan Creek are the principal streams. In all these features the topography conforms in a general way to the structure of the underlying rock strata.

While the whole township is occupied by the outcrop of Mesaverde rocks, a part of the area is probably eroded below the horizon of the principal group of workable coal beds. The area thus differentiated is indicated by the patterns on the geologic map. This feature outlines a region of relatively greater uplift than that of surrounding territory. The structure indicated possibly resembles that of the Agency Park uplift, although of decidedly different topographic effect owing to the more resistant character of the strata exposed at the surface.

About 6 miles southwest of the lower end of Wilson Creek canyon at the margin of Axial Basin, at a point near the forks of the main gulch, and also near the line between Rs. 93 and 94, the "white rock" dips beneath water level, passing down in a northeasterly direction. Southwest of this point this ledge is readily traced along the sides of the gulches and canyons, rising as it approaches the main divide, below which the creek valley and deeper tributary gulches are eroded. The upper part of Wilson Creek thus includes an area probably eroded below all of the more valuable coal beds. Little or no indications of coals are shown in this part of the valley.

Coal in abundance is noted all along the high summits and principal divides surrounding this valley. In the vicinity of the Devils Hole Mountain thick beds were observed in outcrop along the main summits. Extensive burning of many of the coals has produced the clinker and red shale cones that are so common in this part of the field.

A subordinate depression or basin of the strata corresponding to the uplift noted on upper Wilson Creek is to be observed in the northwestern part of the township on the headwaters of Morgan Creek. Burned coal beds and croppings have been noted from place to place throughout that part of the area. No developments or prospects on the coal beds were observed in any part of the township.

T. 3 N., R. 93 W.

The Meeker-Axial stage road traverses T. 3 N., R. 93 W., which lies just south of Axial post-office. It is occupied in the main by the valley of Spring Creek, though a smaller area in the northwest includes

part of the canyon of Wilson Creek. The whole area is covered by the Mesaverde rocks at the surface, and nearly all is supposed to be coal-bearing. The general structure is shown by very light dips, revealing minor irregularities not clearly defined as folds included between the major anticlinal axis of the Danforth Hills field and that of the Axial Basin fold.

Wilson Creek canyon.—The canyon of Wilson Creek in the northwestern corner of this area is lined by great bluffs of vermilion-colored strata, evidently indicating a great amount of burning in the coal beds. Beyond the surface zone of burning there is doubtless a great thickness of valuable coal, although no opportunity to measure the beds was found at the time of this examination.

Spring Creek district.—Coal has been opened at a number of places near the main stage route, to supply the scattered ranches that occupy the narrow canyon-valley bottoms. These developments are probably indicative as well as fairly representative of a large number of other unopened beds, numerous signs of which are to be found as though scattered at random over the surrounding hills and gulches. Of these the Collom and James mines were accessible at the time of the present investigation.

Collom mine.—One of the most widely known local coal banks of the whole district is that belonging to Mr. Joseph Collom, situated in the hillside opposite the dwelling on his ranch. This is in Spring Creek valley on the main road 1½ miles south of Axial post-office, and has been worked to a considerable extent for local domestic use.

The bed is a very thick one, measuring, as nearly as could be determined, 24 feet 11 inches, with a one-half inch bony seam 16 feet 3½ inches from the base. Besides having this feature of rather exceptional thickness for a clear, practically solid coal bed, the coal lies nearly horizontal, dipping lightly to the east or southeast, and is an unusually bright, black, shiny coal. It breaks irregularly, showing uneven conchoidal fracture and little dirt or smut, being locally reputed for its property of not soiling the hands in use. It shows an excellent analysis as compared to other coals of this part of the field, with an exceptionally low ash. The following is a section measured at the mouth of the mine:

Section in mine at Collom's ranch, Axial, Colo.

	Ft.	in.
Sandstone	30±	
Shale	10+	
Sandstone	1	6
Shale	1	
Coal	8	6
Shale or bone		½
Coal	16	3
Shale	3+	
	70	3½

The coal is of the bituminous class. In general, the physical characteristics of the Collom coal, like those of the Wesson bank on Coal Creek and very many of the best exposed beds in the Danforth Hills, are more nearly allied to those of the subbituminous class, showing as they commonly do dense unfractured pitchlike surfaces with no considerable development of joints or cleavage. This may be significant of the lack of that regional metamorphism to which may be ascribed the higher efficiency and possibly also the coking quality of some of the coals of the same geologic age south of Glenwood Springs.

The Collom bed appears to be several hundred feet stratigraphically above that of the Miller bank, situated just north of it in T. 4 N., but the irregularity of the structure north of the Collom property forbids a close estimate of this distance. In fact there is much uncertainty in the continuous tracing of any of these beds, owing to the distortion of the outcrop by slides or slumps, which are very common along this valley. Assuming the two beds do not represent the same horizon, there are at least 50 feet of coal in this part of the section alone, while a considerable number of other coals are indicated on the sides of the gulch between these two and above the Collom bed that would undoubtedly prove of workable value if they were prospected.

The Collom mine is worked in the entry to such height and breadth that wagons and teams are driven directly to the face for loading, and may be turned inside the mine and driven out. A number of short side entries from the main drift are utilized for storing farming machinery, implements, and wagons.

A sample (No. 3466) was taken at the face of the mine, which showed neither seams nor parting; for analysis, see page 249.

James mine.—The James coal bank is situated on Spring Creek, 4 miles south of Axial, on the west side of the stage road. It consists of an entry 100 feet in depth showing coal at least 8 feet thick with a coal roof and bone floor. Shale overlies the whole bed. The rocks dip about 8° in a direction S. 20° E. The coal is hard, with a high luster, and shows no partings. For analysis of sample (No. 3704) see page 249. The mine seemed to be not regularly worked at the time of examination, although the coal was fresh and the analysis shows it be of good quality and similar to the rest of the better coals of this part of the field.

T. 3 N., R. 92 W.

Thornburgh Mountain, the principal topographic feature in T. 3 N., R. 92 W., was named Pass Butte by the Hayden Survey, but since 1879 has become locally better known as named for Maj. T. T. Thornburgh, U. S. Army, who was killed in a battle with the Ute Indians which took place at its foot. His company was attacked and besieged for several days (from September 29 to October 5, 1879) in the Milk Creek valley on the south side of the mountain. The view in Plate

V, *A*, overlooks the battle ground from the south and shows the escarpment rim that borders the mountain. It illustrates well a typically representative section of the basal Mesaverde rocks. The valley of Milk Creek in the foreground is formed upon the Mancos shale.

The whole township, including a northeast corner of the Danforth Hills field, is of considerable structural irregularity. The district is a minor structural basin bordered on all sides, except the west, by the uptilted strata that terminate the coal field at this place. So sharply do these folds buckle or bend back upon themselves that it is difficult to conceive how such structures could have been produced without much dislocation among the individual beds by faulting. While there can scarcely be any question that a great deal of readjustment by crumpling or slipping in the strata must have taken place, no signs of extensive faults along well-defined planes have been noted.

The prominent ledge of massive white sandstone, already referred to as the "white rock," may be readily traced, as it outcrops in an almost continuous rim a half mile more or less back from, but approximately parallel to, the escarpment rim that nearly surrounds this hilly area. A number of coal beds and carbonaceous horizons were discovered below this horizon, near the base of the formation, but, as in other parts of the field, they appear to be too thin or too much broken or divided by shale and bone to be of much value. It can not now be stated definitely that no valuable coals exist below the "white rock" here, but so far as known none have yet been discovered in prospecting. Close above the "white rock" the thick beds of the lower coal group show by extensive burning, and have been opened and mined at two places in Milk Creek canyon.

Several prospect drifts have been opened at the upper end of Milk Creek canyon in the coal field 2 or 3 miles below the Thornburgh battle ground. Of these, the only one that was in condition for sampling was an entry situated in the NW. ¼ SE. ¼ sec. 29, T. 3 N., R. 92 W. (old survey), on the property of Mr. J. F. Wilson, of Thornburg, Colo. Three openings have been made close together on the same coal bed, of which the northernmost is the only one worked at present. The coal appears to be of good quality and is hard, withstanding well the action of the weather when taken out. The following section was measured at this place:

Section at the J. F. Wilson bank in Milk Creek canyon.

	Ft.	in.
Shale.		
Coal	2+	
Shale, carbonaceous	1	
Coal	11	1
Shale, carbonaceous	2	
Coal	2+	
	18	1+

The bed dips 15° N. 80° W. A sample (No. 3792) for analysis was taken from the middle of the three openings, where the coal, although it had not been worked for some time, seemed fresh and hard and showed a good, clear face. The analysis (p. 249) runs a little higher in ash than the average, and seems to show deterioration from exposure, as in the case of one of the samples at the Morgan Ranch mine.

A quarter of a mile north of the Wilson entries, also on the west side of Milk Creek, there are two prospects on coals that appear to have been formerly worked, but are at present completely caved. The dip is 5° N. 80° W.; the strike is N. 10° E. The following measurements were made at this place, but this section is very incomplete:

Section in Milk Creek canyon, one-fourth mile north of Wilson Bank.

	Ft.	in.
Shale.		
Coal	1	
Shale, carbonaceous		10
Coal, at least	5	
	6	10

The second of the two entries opened a coal about 30 feet lower, but was totally inaccessible. Both of these beds are several hundred feet higher in the series than the Wilson coal. The Wilson bed is roughly 400 or 500 feet above the "white rock."

T. 4 N., R. 92 W.

T. 4 N., R. 92 W., is situated near the eastern end of Axial Basin and includes a small triangular patch of the Danforth Hills coal field in its southwest corner. At its eastern margin on and near Monument Butte it also includes the outlying hogbacks or cuestas of a coal basin south of Williams Fork, which should probably be considered a part of the Yampa field.

Structurally the part of the Danforth Hills field in the southwest corner is a portion of the syncline or basin already described with the Thornburgh Mountain locality. A rather closely compressed synclinal fold extends to the north from that area, the axis rising in that direction. The dips on either side range from 20° to 70° among the upper beds included in the fold. The fold is cut by the canyon of Milk Creek, exposing the sandstones and coals on the west flank of the basin.

The only other development in this part of Milk Creek canyon is an entry near its lower or north end, known as the Shafer mine, situated a couple of miles east of Axial post-office. In that locality the strata dip in nearly the opposite direction from those of the Wilson coal bank in the upper part of the same canyon. The Shafer mine has evidently been worked to a considerable extent for the sup-

ply of the few ranchers who live in the immediate vicinity along Milk Creek and in Axial Basin. The following rough measurements were made, the exposures not being favorable to more accurate or complete determinations:

Measurements at the Shafer mine on Milk Creek, south of Axial Basin.

	Ft.	in.
Shale (roof).		
Coal, at least	12	
Bone		2
Coal, at least	2	
Coal (floor).		
	14	2

The coal is hard and apparently of very good quality. (For analysis see No. 3707, p. 249.) A sandstone dike was observed in the mine, cutting the coal bed transversely to the bedding. Such a feature was also noted in the Coryell mine on Grand River. The entry runs down a slope on the dip of the bed for 25 feet; there a drift swings to the left or north at a lesser pitch, and the last 25 feet of the entry length turns up-grade slightly, the total depth being about 125 feet. This bed is estimated to be 100 feet above the "white rock," and there is another heavy sandstone stratum about 50 feet above the coal. Another coal bed is prospected in a small gulch tributary to Milk Creek north of the mine, its position being stratigraphically between the Shafer bed and the "white rock."

There has been much burning of coal beds at outcrop in the vicinity of the Shafer mine and above the "white rock," and there are doubtless a number of other valuable coals in this locality. A few small coals were noted as occurring stratigraphically below the "white rock." Many outcrops of coal and much baked rock indicating the presence of coal beds are conspicuous along the valley of Milk Creek throughout its entire course between the Shafer and Wilson entries, but at no place are any of these coals known to have been prospected so as to show their value.

T. 4 N., R. 93 W.

T. 4 N., R. 93 W., is situated at the northern margin of the Danforth Hills field, the northern part of the township lying in the more open prairie lands of Axial Basin. The structure embraces the southern flank of the Axial Basin anticline and a correlative syncline that lies between that uplift and the uplifted areas of the Danforth Hills and along the northern edge of the coal-field area. The strata are tilted more steeply on the southern flank of the major Axial Basin fold than they are to the north along the margin of the Yampa coal field, so that the anticline is not a symmetrical fold, and the axis, if it could be traced, would probably be found to lie nearer the southern edge of the basin. The southward dips recorded in the

lower Mesaverde rocks, at the edge of Axial Basin, range from 17° to about 35°. The drainage of the township is a part of the system of long parallel gulches that cut the northern dip slope of the Danforth Hills field. Of these a part of Spring, Taylor, Wilson, and Coal or Jubb creeks are included in this township.

Spring Creek gulch.—Spring Creek enters Axial Basin 1½ miles west of the mouth of Milk Creek canyon. Axial post-office is situated near the mouth of Spring Creek gulch or canyon at the southern margin of Axial Basin, and the stage road from Meeker by way of Ninemile Hill passes down Spring Creek valley and continues by way of Hamilton, Craig, Hayden, and other towns of the Yampa River valley.

On the west side of the gulch, opposite the Axial Hotel and the country store, a small coal has been dug into, exposing about 2 feet of coal, said to be of good quality, but now considered too thin to be of value. This is one of the smaller beds mentioned as occurring in the stratigraphic interval below the "white rock," and near the base of the Mesaverde formation. About half a mile south of the post-office the "white rock" may be observed on either side of the gulch dipping southwest, and beyond this to the south there is much evidence of the presence of coal in the strata.

The first mine to be encountered going south along this valley is on the east side of the gulch almost exactly 1 mile south of the post-office. This is said to have been opened by Mr. W. H. Miller, and later by a man named Smith. The entry consists of a simple prospect drift running into a depth of 120 feet from the entrance. The coal bed is 27 feet in thickness, according to as careful measurement as the present exposure would allow. The bed dips 10° SW. A sample (No. 3703) was taken 15 feet from the face of the entry, where the following section was measured (for analysis, see page 249):

Section at W. H. Miller mine, 1 mile south of Axial post-office.

		Ft.	in.
1.	Clay (roof).		
2.	Coal, good	3	
3.	Coal, dirty, powdery		4
4.	Coal, good	5	
5.	Bone		1
6.	Coal, base not reached.		
	Total of measured section	8	5

The above section represents only a part of the lower half of the bed. Most of the coal removed from the entry has been taken from below the 4-inch parting. The horizon of this parting is festooned with a fringe of long silky white fibers of a soluble mineral, which was tested in the laboratory and found to be epsomite (magnesium sulphate).

Wilson Creek.—About 2 miles west of the mouth of Spring Creek gulch the next large valley that opens into Axial Basin is that known as Wilson Creek or Wilson Canyon, a single shorter valley known as Taylor Creek intervening. One small ranch has been located 5 miles up Wilson Canyon, which is otherwise without settlement. The narrow bottoms at its lower end above Axial Basin have been fenced for use as pasture. Wilson Creek retains a small flow of water in its lower course, and there are numerous springs and seeps along the canyon bottoms of its various branches. It is of much the same character through its entire length above Axial Basin, reaching back at least 10 miles to the main divide, constituting a narrow flat-bottomed valley bounded by steep rocky canyon walls 600 to over 1,000 feet in height.

There are no prospects worthy of note on any of the coals in Wilson Creek valley or on adjoining hill slopes. The strata dip from 19° to 26° S. near the mouth of the canyon at Axial Basin. The stratigraphic interval below the "white rock" shows one or two indications of coal beds, apparently small and assumed to be unimportant. Above the "white rock" the strata show the usual effect of strong burning, so as apparently to indicate a considerable number of thick coal beds. The dips flatten rapidly as traversed toward the south, the strata rising slightly still farther in the same direction, so that for a mile or two along the canyon the ledges lie approximately at water grade. About 6 miles south of the mouth of Wilson Canyon, beyond the limits of this township, near the main forks of the gulch, the "white rock" again comes above stream grade and, rising in outcrop along the upper canyon walls, shows the headwater portion of Wilson Creek valley to be eroded to such an extent that this area is assumed to be stratigraphically below all of the more valuable coal beds.

T. 4 N., R. 94 W.

The position and structure of T. 4 N., R. 94 W., is very similar to that of the adjoining township on the east. Long parallel valleys traverse the area from southwest to northeast, opening into Axial Basin at or near the northern boundary of the township, which is the first correction line north of the base line. In a general way the area occupies the broad dip slope of the northern flank of the Danforth Hills uplift. The gentle northerly dip is terminated rather sharply near Axial Basin by the upturning of the beds at the southern flank of the Axial Basin anticline. It is further influenced by the axis of depression, already noted in the area to the southwest, which passes across the Danforth Hills area transverse to the general trend of the principal axes of folding in the whole field. Thus Morgan Creek itself is approximately the position of the minor axis of the transverse depression, the influence of which is shown quite

markedly in the lower and more open topography, as viewed across the ridge summits, by comparison with the higher and more rugged ridges to the northwest.

Morgan Gulch district.—West of Wilson Creek the next long valley opening into Axial Basin and reaching back as far as the main divide is Morgan Gulch, the two valleys being 4 miles apart at the margin of Axial Basin. Between these two gulches a broad flat upland is sharply cut by two long, straight gulches that head between the basins of the larger valleys on either side. These two intermediate valleys contain only small streams or are dry most of the time, and are known as Jubb or Coal Creek on the east next to Wilson Gulch, and Collom Creek on the west, the latter having two principal branches. At the mouth of Jubb Creek and between that and Collom Creek the lower portion of the coal-bearing formation is tilted up at angles ranging from 25° to 42°. This part of the edge of the field rises in the form of a distinct knob on the end of the long spurs that reach north from the Danforth Hills.

Of the stratigraphic section exposed between Jubb and Collom creeks the basal portion is composed, as elsewhere, of 900 feet of predominantly massive to slabby sandstone members, which are mostly stained a rusty yellow along their outcrops. About 1,000 feet up in the series from the base of the sandstone ledges is the massive white sandstone stratum already noted as the "white rock." In the next several hundred feet of strata above this ledge other sandstones outcrop and many coal beds show by smutty streaks and by the brilliant red color of the strata where the coals have been burned in outcrop. One coal is indicated by burning at the upper surface of the massive sandstone, and two other beds show within the next 75 feet, above which still other croppings give many signs of coal.

At the mouth of Morgan Gulch a sequence apparently similar to that of Jubb Creek and Wilson Creek canyon is exposed. Rough stratigraphic measurements give the interval of strata containing massive sandstone ledges below the "white rock" as 750 feet. Small beds of coal or carbonaceous material were noted near the base of the Mesaverde formation, while the remainder of the lower relatively barren interval is a continuous succession of flaggy and massive yellow sandstone ledges, whose débris has almost obscured the intervening shales. Above the "white rock" about 850 feet of beds of similar character, showing many indications of coal, dip southward at approximately the same angle as the lower group of ledges; beyond these to the south the dip rapidly flattens to 10° or even less.

There is one ranch in this gulch, the property of Mr. David Morgan, of Axial, Colo., whose house is situated about a mile from the southern edge of Axial Basin. Mr. Morgan has opened a small coal bank on a side gulch a quarter of a mile west of his house, in which two samples were taken; for analyses, see Nos. 3688 and 3690, page 249.

The following section was measured at the mine:

Section at Morgan mine, 7 miles west of Axial, Colo.

	Feet.
Sandstone	7
Shale	3
Coal	10+
Floor.	
	20+

The coal seems much broken, very soft, and slacks very readily, according to reports, going to pieces after only a week's exposure to sun and air. There is some evidence that the whole mine has been driven in on a block that has slumped or slid down the gulch side, and this may account for the shattered condition of the coal. So far as observed, no sign of the slip has yet been encountered in the mine, but this structural relation seems indicated by the attitude of the beds in the hillside above. The coal dips 6° south as measured in the mine. It has been taken out for use at the Morgan ranch only.

For a number of miles south of the Morgan ranch and mine the strata are very nearly horizontal, and as this district is one of relative depression of the coal-bearing strata, a considerable thickness of the coal-bearing beds almost certainly underlies the whole territory. The rocks rise gradually to the south toward the main divide and also toward the west, so that most of the thicker coal beds soon pass above water grade in those directions and are found only along the ridgetops in Maudlin and Temple canyons. Morgan Gulch has an extensive drainage area in the Danforth Hills, and all of this territory south of the edge of Axial Basin is almost certainly underlain by valuable coal at workable depth.

Boxelder district.—West of Morgan Gulch are two small gulches, on the eastern of which, known as Boxelder, a single thick coal bed has been partly opened, although the entry had caved at the time of visit. Although the coal was dripping with water and was badly weathered, a sample (No. 3689) was taken (see p. 249 for analysis) and the following section measured:

Section at coal prospect in Boxelder Gulch.

	Feet.
Sandstone	7
Shale	2
Coal	5
Coal, clayey	1
Coal (base not reached)	4
	19

T. 5 N., R. 94 W.

A very small area at the southern margin of T. 5 N., R. 94, W., is possibly coal-bearing. Coal has been extensively burned along the correction line, notably at one rather conspicuous conical peak named the Red Cone, in the middle of the south side of section 32. This is

very near the extreme northern limit of this part of the workable coal field, however, and it is doubtful if more than a very limited amount of land north of the correction line will be found to contain workable beds of coal at the present time. The greater part of the township consists of the open prairie lands of Axial Basin eroded from the Mancos shale, and it therefore lies stratigraphically below the horizons of the Mesaverde coals.

T. 4 N., R. 95 W.

T. 4 N., R. 95 W. (Pl. XVIII) includes both flanks of the main anticlinal axis of the field. In the northwestern part of the area the structure and position of the beds is very similar to that already described for the whole northern margin of the Danforth Hills.

Maudlin Gulch.—The next large gulch or canyon beyond those already described opens into Axial Basin about 5 miles west of Morgan Creek. This is known as Maudlin Gulch and the ranch situated at its lower end, the property of Mr. Zene Maudlin, is the only settlement in the vicinity. This gulch has much the same character as those of Wilson and Spring creeks, being a narrow flat meadow along the bottom with high canyon walls on either side. As stated above, the strata rise gradually toward the west from Morgan Gulch, so that in Maudlin Canyon the "white rock" and burned material indicating the coal beds above that horizon are to be seen only along the higher ridge summits throughout the length of most of this valley. A slight depression of the strata near the border of Axial Basin brings these coals down lower toward water grade than at any other place in the gulch. The structure at the head of Maudlin Gulch is that of a rather low domal uplift, through the crest of which the headwater valley of that stream has been eroded.

No development of the coal was noted in this vicinity, the nearest being the prospect at Boxelder Gulch, already described. Coal Mountain, so named by the geologists of the King and Hayden surveys, is one of the high rounding summits of the divide between Maudlin and Temple canyons, upon which there is coal in natural outcrop and also at places much slag and baked rock.

Keystone Basin.—Southwest of the main divide between the White and Yampa river drainages precipitous rocky slopes are eroded from the more steeply dipping beds of that side of the field. Probably the entire section of Mesaverde coals is exposed in the strata on this side of the divide, and these beds are abundantly indicated by burned rock, clinker, and ash beds.

This part of the field is accessible from the Keystone Basin, which consists of a small oval valley and short tributary gulches extending north and south on the head of Deep Channel Creek. The limit of outcropping coal beds is east of this basin, as it is east of Strawberry Valley, but as the coal-bearing strata there pass beneath

the surface, dipping in a westerly direction, the coals undoubtedly underlie the territory west of this limit. A portion of the district west of the actual coal outcrops may therefore be considered as coal land, the precise determination of the limits of which depends entirely upon the depth at which the uppermost workable coal shall be considered available.

There is but one ranch near Keystone Basin, and a single small coal bank has been opened there for domestic use. This coal bank is situated in the gulch due northeast of the Keystone reservoir, in the E. ½ sec. 30, T. 4 N., R. 95 W. An entry has been driven in 90 feet or more, penetrating a bed of coal at least 7 feet thick, with a sandstone roof and apparently without partings. Two samples (Nos. 3569 and 3571) were taken for analysis at this place, as it seemed to offer the only opportunity to obtain even a moderately fair basis of an estimate for any of the coals in all the western margin of the Danforth Hills field. In view of the unsatisfactory condition of the coal, however, the results obtained (see p. 249) are not considered of much value. All of the coal was much broken and slickensided, and stands rather below the average in the table of analyses. This is indicated by the moisture content, which is considerably higher than the average obtained from the whole field, although the variation in this case may be the result of the weathered condition of the coal where the sample was taken.

T. 5 N., R. 95 W.

The narrow syncline separating the Axial Basin uplift from that of the Danforth Hills continues to the northwest through T. 5 N., R. 95 W., following very closely the margin of the Danforth Hills area. As in the townships to the southeast, the prevailing structure south of the Axial Basin anticline is a part of the light northerly dip of the northern flank of the Danforth Hills. As this general region has been subjected to a relatively greater amount of uplift than the Mesaverde rocks in the main body of the field, the principal coal group has been elevated to such an extent above the principal drainage level that it now occupies the summits of the dividing ridge, and thus in large part has been removed by erosion. As a result the total area underlain by coal-bearing rocks in this township is somewhat limited.

West of Maudlin Gulch (see p. 176) the strata continue to rise very gradually, and in Temple Canyon, about 5 miles to the northwest, the principal or lower valuable coals are found only at the summits of the highest ridges. Although there are doubtless a number of beds of sufficient thickness and extent to prove commercially valuable in this part of the field, by reason of their position they are not so readily accessible as the corresponding horizons in the districts farther east. Adjacent to Temple Canyon a broad area is eroded into beds lying below the principal coals, the canyon itself being cut into rocks

similar to the coal-bearing beds in appearance, although practically barren of valuable coal. These rocks have been referred to as the lower relatively barren part of the Mesaverde formation. In the immediate vicinity of Temple Canyon erosion has not progressed deep enough to expose the underlying Mancos shale south of the Axial Basin fold. West of Temple Canyon, however, the same structure continues to rise, so that in a distance of a few miles more the anticlinal character of this end of the Danforth Hills field disappears completely so far as it may be observed in the coal-bearing rocks. The hard ledges of the northern limb of the fold being entirely removed, only a single monoclinal ridge marks the extension of the Danforth Hills field westward and southward to White River.

T. 4 N., R. 96 W.

Only a comparatively small area in the northeastern part of T. 4 N., R. 96 W., is considered as available coal land, although probably the whole area is underlain by valuable beds. In most of the district, however, they are too deep to work, at least by present mining practice. The upturned section of coal-bearing strata exposing practically all of the strata of the Mesaverde formation above the "white rock," and thus probably including all of the valuable coal beds of this part of the field, is found between or near the headwater branches of Deception Creek, just north of the correction line. No prospects or well-exposed sections showing the coal beds were noted in this district, however.

CHAPTER V.

LOWER WHITE RIVER FIELD, COLORADO.

GENERAL DESCRIPTION.

As has already been stated, the outcrop of the Mesaverde strata and of the valuable coal beds that they contain is continuous westward from the Danforth Hills. This western field occupies in part the drainage divide between White and Yampa rivers, but lies for by far the greater part of its extent in the drainage basin of White River in Colorado (Pls. XVIII and XIX). As White River joins the Green about 40 miles west of the state line in Utah and the coals are mostly confined to the Colorado portion of this drainage basin, it has seemed most appropriate to designate it the Lower White River coal field.

As thus defined this field includes the part of the continuous outcrop of the Mesaverde rocks that extends from the northwestern part of the Danforth Hills, describes a rough arc or semicircle around the north end of Crooked Wash or Coyote Basin, and trends southward along Pinyon Ridge to White River at the mouths of Wolf and Yellow creeks. From this point on White River the coal rocks bend abruptly westward and, with steeper dips, form a narrow hogback on the north side of White River. In the vicinity of Raven Park they again spread out in broader folds and cover an extensive territory reaching from Blue Mountain on the north to the Book Cliffs divide at the head of Douglas Creek on the south. Northwestward from Raven Park the coal-bearing strata have been traced as a narrowing belt continuously along their outcrop into Utah, where their occurrence will be described later (pp. 204–219) as the Vernal field.

As a direct continuation of the Danforth Hills field the Mesaverde constitutes the only important coal-bearing formation of the lower White River field, the Laramie being absent from the geologic sequence south of the Axial anticline separating the two major basins of this part of Colorado. Furthermore, the post-Laramie formations appear to be barren of the valuable coals, and it is still uncertain if the basal Tertiary strata of the Grand River Basin, of which the White River fields are a part, are strictly to be correlated with the coal-bearing strata that overlie the Laramie formation of the Yampa field.

COAL.

DESCRIPTION BY TOWNSHIPS.

As in the case of the Yampa field, the territory is described by township units, beginning at the northeastern part, adjoining the area mapped and described as a part of the Danforth Hills, from which,

except for the geographic significance attached to that name, it would scarcely be feasible to separate it. All townships are referred to the sixth principal meridian, Colorado. Any particular township will be most readily found by referring to the table of contents, page 7.

T. 5 N., R. 96 W.

The Mesaverde formation is exposed in the form of a broadening and rising anticline as it approaches the northwestern extremity of the Danforth Hills area. Almost exactly at the eastern limit of T. 5 N., R. 96 W., the northern limb of this anticline disappears from topographic expression by the erosion of the harder sandstones that constitute the base of the Mesaverde, and west of that locality there remains only the southward-dipping monocline of these coal-bearing strata.

The township is occupied by successive belts of the various formations extending diagonally across it from southeast to northwest. In the southwest corner the summit of the Citadel Plateau is capped by massive flat-lying sandstones, which occur in the lower part of the Green River formation. Below these beds toward the northeast the variegated Wasatch beds tilt up abruptly to angles of 50° or 60°. At the base of the Wasatch is the pebble or conglomerate bed which, as previously explained (p. 75), is mapped as the base of the Tertiary formations.

The Mesaverde formation itself occupies a belt from 2 to 2½ miles in width, running from the southeast corner to the vicinity of Cedar Springs, 1½ miles south of the northwest corner of the township. Coal itself has been noted in place and has been indicated by burning at many places throughout this belt. These rocks have an average dip of 40° to 60° SW., and the coals are best exposed in the several gulches tributary to Deception Creek that cut directly across the beds. At no place has the coal been opened or developed, so far as observed, but it is certain that many large beds of workable thickness are contained in the section.

Northwest of the coal-bearing rocks the surface of the rolling sand-hill country of Axial Basin is occupied largely by the Browns Park formation and by scattered gravel and bowlder deposits, but is also probably underlain by and largely formed from the Mancos shale.

T. 5 N., R. 97 W.

In T. 5 N., R. 97 W., a considerable part of the geology is obscured by the surface cover of scattered gravels and bowlders and by the sandy deposits of the Browns Park formation. These occupy most of the northern half of the township, reaching to the summits of the high rounding tops along the divide between Yampa and White rivers. South of the divide the coal-bearing rocks are again exposed, showing an abrupt change in strike from that of the formations in

the township east. The coal-bearing strata strike toward the southwest and dip from 45° to 70° SE. The coals are therefore doubtless continuous beneath or near to the site of Cedar Springs, although wholly covered and concealed at that place. The southern part of the township is occupied by badlands topography developed on the variegated strata of the Wasatch, and is locally known as Coyote Basin, a part of Crooked Wash.

A prospect noted on the west side of sec. 21 exposes a 6 to 8 foot bed of coal dipping at an angle of 71°. A slope has been run down 30 feet or more, following the coal. A considerable number of other coals show as indications, but have not yet been opened up.

T. 5 N., R. 98 W.

The Mesaverde coal-bearing rocks occupy the southeastern part of T. 5 N., R. 98 W., swinging from an east-west trend at the east boundary to a north-south trend at the south boundary in a very uniformly curved arc approximating a quadrant of a circle. The dips of the strata vary, ranging from less than 10° to more than 60°, chiefly in a southeasterly direction.

The coal beds are represented by several prospects opened in secs. 25, 26, and 34, south of Twelvemile Springs, exposing 8 feet or more of solid coal, apparently of good quality, on a dip of 15° to 20°.

The geology of the area northwest of the coal rocks, including the greater part of the township, while doubtless involving more or less detail of structure of the underlying rock formations, is almost wholly represented by the Browns Park formation and the scattered gravels on the surface. These form the capping strata on the upland "mesa," named Promontory Plateau on the early Hayden maps, which overlooks Lily Park from the south.

T. 6 N., R. 98 W.

Coal has been reported from a number of sources as occurring, in stratigraphic position, near the base of the Cretaceous section, in the vicinity of Lily Park in T. 6 N., R. 98 W. Probably the first printed mention is in the Hayden reports, in which C. A. White includes the following note[a] in his summary description of the Colorado group:

> Near the base of the Colorado group there is almost always to be found a bed of dark fissile shales, containing the remains of teliost fishes. This bed not only occurs at all places in this district where the base of the Colorado group is exposed, but it is equally characteristic of the lower part of the group in the adjoining districts. Overlying the bed of shales containing the remains of teliost fishes there is often to be found a bed of coal. The only place in this district that I observed this bed of coal is a couple of miles south of the west end of Lilys Park, and southward from Junction Mountain [Cross Mountain, as now better known in a local way]. It is there 3 or 4 feet in thickness.

[a] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, p. 31.

The horizon described is evidently that of the principal coal worked near Vernal, referred to in this present report on that field as the lower Mancos coal group (p. 205).

The bed referred to was observed in section 34 by C. W. Stoops in the course of the present examination of the district, and the following description is taken from his notes. An old entry or mine has been opened in a gulch at a point about 1¾ miles south, a little west of the lower end of the Cross Mountain Canyon on Yampa River. It is thought that this locality is the same as that referred to by Doctor White as lying southward from Junction Mountain. The bed appears to be at least 10 feet thick, although only the upper bench of 5 feet has been opened at the prospect. The coal does not seem to be of very promising appearance, and as a large part is intimately mixed with clay or shale, may prove too bony or too high in ash to be of much value. The roof is soft adobe clay, and the floor of the entry is a carbonaceous material, passing downward into adobe clay at a depth of 30 feet. The entry is a drift extending to a depth of 20 feet. About 14 cubic yards of coal has been removed. The dip of the beds is 28° S. 60° W.

Six or eight beds of coal or streaks of lignite occur in the group. All of these underlie beds of massive sandstones, the lower of which is 50 to 75 feet thick. The whole succession of beds at this place very closely resembles that of the lower Mancos coal group near Vernal.

T. 4 N., R. 97 W.

While the greater part of T. 4 N., R. 97 W. is occupied by the badlands topography of the Wasatch formation, and is hence doubtless underlain by all of the thick coals of the Mesaverde formation at depths ranging from a few hundred to perhaps 5,000 feet or more, only a part at its western edge near the actual coal croppings may be at present considered as available coal land. Numerous coal indications were noted near the township line in the southwestern part of the township. The trend of these outcrops is from north to south, with dip of 14° to 16° E. The resurvey of the land lines in this area had not been completed at the time of the examination in the field, and mapping was not extended across the entire area.

T. 4 N., R. 98 W.

T. 4 N., R. 98 W. includes the northern part of Pinyon Ridge on the west side of Crooked Wash or Coyote Basin, a somewhat more rugged region than the adjacent areas previously described. The dip of the rocks to the east is very uniform, ranging from 5° or 6° to 20° or possibly more in some places. Owing to the uniform structure of the rock formations and prevailing light dips, the Mesaverde rocks occupy the surface over almost the entire area of the town-

ship. The coal beds represented by the croppings appear to be concentrated in three groups similar and in general corresponding to those elsewhere recognized, as, for instance, in the detailed studies of the Danforth Hills and Grand Hogback fields.

The lower coals of the Mesaverde consist of a small group of relatively unimportant beds, noted in the face of the escarpment formed by the lowest sandstone ledges. These were found at several points on the western side of the Wolf Creek valley. The middle coals in this district occur, as previously noted, just above the "white rock," which forms a rather distinct and readily traced horizon through the center of the township from north to south. Coal of this group has been opened in the gulch approximately in the NW. ¼ sec. 15 or the NE. ¼ sec. 16, where a bed of coal 5 feet 3 inches thick, with an easterly dip of 17°, is developed under a good sandstone roof.

The upper coals of the same formation are extensively exposed along the eastern margin of the township, except in the northeast corner. No estimate has been obtained of the actual value or total thickness of the entire series of beds in either of these groups. As the coals appear to be restricted to the several intervals described, with relatively barren strata between, the outcrops of the rocks between the two upper groups might be classed as unavailable as coal land or the coal as too deep to be available for mining beyond a certain distance west of the actual outcrops. It is not likely, however, that the barren interval between the two principal coal groups exceeds 2,000 feet at any point, and for the most part it probably is not that great. So far as known, coals of the lower group are not considered to be of workable value at any point in this part of the field.

No attempt to classify the land by subdivisions has as yet been made, as no corners were found within the township, and all of the mapping done was based on the adjustment obtained from the retracing of the lines and locations of corners set by a rejected survey of the township boundary on the east side. The general outline of the coal land is indicated on the geologic map, and a regular net of land lines projected across the area from the land corners located to the north and east.

T. 3 N., R. 98 W.

T. 3 N., R. 98 W., like that adjoining it on the north, is somewhat more rugged than the average in this part of the coal-field area. It includes the southern half of Pinyon Ridge, of which the geology and structure are very similar throughout. The greater part of the township is occupied by the outcrop of the Mesaverde formation, of which the prevailing light dip and the change in trend of strike produce a considerable broadening on the surface exposures in this district.

The three coal groups are represented in a manner very similar to that described for the township next north (p. 182). As mentioned in the description of that area, the lower coals near the base of the formation are relatively unimportant, and in fact are completely lost sight of at the mouth of Wolf Creek and beyond for an interval of several townships to the south and west.

The middle coal group appears to be the most important, and has been traced from the central-northern part of the township to near the southwest corner. The upper coal group of the same formation was also traced along the eastern margin of the township to White River, at which it turns abruptly westward.

A drift about 30 feet deep in the east side of section 25 exposes at least 6 feet of apparently good coal, which dips 53° SE. and is assumed to represent the upper coal group at the locality. Coal of the same general group of beds has been opened at the McAndre ranch, near the township line, on the south bank of White River, where a thickness of only 2 feet appears to have been worked. This is, however, only one of five beds exposed at this place with apparent individual thicknesses of from 3 to 5 feet. The McAndre mine runs in about 75 feet on a southerly dip of 29°.

Other developments in or near section 31 consist of several prospects and one local coal bank mined for domestic use, all situated at the river bank. The latter is known as the Jesse Bassett mine, and is on the west river bank just south of Mr. Bassett's house. The strata at this locality have assumed a general east-west trend, which is continued for about 15 miles west of this point. The dip in the entry is 25°. The coal mined is 3 feet 7 inches thick, in a single solid bed, apparently of excellent quality. As mined it breaks out in rectangular blocks. This bed occurs about 30 feet stratigraphically above a big white sandstone that may represent the "white rock" in this locality. The outcrop of the same coal bed shows a few feet higher up in the edge of the bluff, but beyond that point is entirely obscured by terrace gravels, slide, and débris, and would be very difficult to trace without extensive development.

Other workable coals are not conspicuous in the well-exposed section of Mesaverde rocks along the river bank at this locality. While some beds have doubtless been overlooked, owing to concealment of their outcrops, the general estimate based on the evidence obtained at various points throughout the district is that the workable coal thins out markedly in this general region and is probably at a minimum as compared with the normal occurrences of these beds in the Mesaverde formation.

Owing to the fact that the resurvey of the land lines in this township had not been started at the time of the examination, no complete classification of the coal lands of this district has yet been attempted.

T. 3 N., R. 99 W.

The Mesaverde formation in T. 3 N., R. 99 W., is represented by a comparatively narrow strip of outcrop, extending from east to west through the southern third of the township. As explained (p. 179), the rocks swing westward at the southern end of Pinyon Ridge, conforming to the structure of the vanishing end of the Midland anticline of Blue Mountain. The axis of this broad arch of the strata enters the township from the northwest, crosses White River approximately at the mouth of Wolf Creek, and passes southeast toward the mouth of Yellow Creek, where it is lost in the more nearly horizontal beds of the high escarpments of the Green River formation. The northern two-thirds of this township, known as the Wolf Creek valley, or formerly as a part of the Midland Basin, from the names assigned to this area by the Hayden Survey, is occupied by low clay hills of the Mancos shale. The coal rocks form a sharp distinct hogback that rises along a narrow rocky summit about 700 feet above river level. The dips in this part of the field are relatively steep, ranging from 25° to 45° S.

Coal is exposed at numerous places along this hogback, and has been opened in several local entries on both sides of the river. As a whole the total amount of workable coal found or indicated in the complete stratigraphic section is very small compared with that of the average section of many other localities. In fact, so far as observed, one or possibly several beds of approximately the same horizon seem to offer the only prospects of availability for commercial or domestic supply. Two of these beds are opened in a gulch approximately 1 mile northeast of Angora post-office.

According to the locations obtained in the present work, the Angora mine will fall in the NE. ¼ sec. 32 of the resurvey (Pl. XIX). It is said to have been opened by Mr. J. D. Lewis, and worked in the winter for the local supply for domestic use at the ranches in the river valley near by. Two entries are situated on the west side of the gulch near together. That most recently worked at the time of examination was highest up the gulch (northernmost) and exposes the following section:

Section at J. D. Lewis coal bank, Angora.

	Ft.	in.
Sandstone, thin-bedded, and sandy shale.		
Coal	1	3
Shale, brown, carbonaceous	1	3
Coal, mined in recent entry	6	4
Shale, brown, lignitic	2+	
	10	10

An entry has been driven in on the coal for at least 75 feet. The bed appears black, bright, and hard in the mine, and is doubtless a

good quality of bituminous coal. The strike of the rocks at the mine was recorded as N. 80° W. and the dip as 45° S.

About 35 yards down the gulch and about 80 feet stratigraphically higher another bed of coal is opened by an old entry, apparently abandoned for the one described above. This also is a drift entry running in along the strike to the west. The dip is 46° S. at this point. This coal measured 3 feet 7 inches, and has a rather weak shale roof of fine grain and smooth brownish color at least 4 feet thick. It appears to have been worked to a considerable extent as a local bank, reaching a depth of at least 100 feet, the working including also some mining on the bed above the main entry. The floor, like the roof, is a soft brown shale, much darker and more woody than the overlying beds. The lower coal is about 130 feet stratigraphically above a big white sandstone ledge, at first thought to represent the "white rock." Judging from the estimated distance to the base of the Mesaverde formation at this place, however, it seems that this bed is somewhat higher in the formation than the "white rock" horizon should be expected to be. Other dark and smutty seams show near by, constituting a sort of coal group, but are apparently small and unimportant.

The Henry Stadtman bank on White River is about a mile east of the J. D. Lewis mine, situated on the north side of the river, and according to the provisional locations of the present work will fall in sec. 33 of the resurvey. It evidently opens a bed of the coal group developed at the Angora or Lewis coal banks. The entry has apparently stood idle for some time. The following section of strata is exposed along the river bank at this place:

Section at the Henry Stadtman bank, near Angora, White River.

	Ft.	in.
Sandstone, white (roof).		
Coal	3	8
Shale, gray	1	8
Coal		6
Shale and bony coal	1	4
Shale, brown, woody	2+	
	9	2

This coal bed is about 180 feet stratigraphically above a conspicuous white sandstone ledge which, like the ledge last discussed, was assumed to be the "white rock." Upon further consideration it seems to be somewhat higher in the formation than the normal horizon of the "white rock." A number of other coals show near by, but all appear to be small except that opened in the mine.

The beds exposed at the Stadtman bank very evidently pass across White River in a nearly due east course, and are exposed on the east river bank under the brow of the bluff a little less than one-half mile away. Beds of apparently the same horizon continue eastward with

little deviation from the true east-west course, and a bed of coal 3 feet or more in thickness is exposed one-fourth of a mile south of Mr. R. E. Thompson's house. The dips of the beds exposed are 30° to 40° S.

About three-fourths of a mile farther east, in a position that will fall about the middle of the north side of sec. 35 of the resurvey as shown on the map (Pl. XVIII), is an old coal entry known as the McGruder bank. This is on the south side of White River, one-half to three-fourths of a mile southeast of the mouth of Wolf Creek, at the mouth of a small gulch. The old entry runs in about 50 feet under a poor roof that is now badly caved. The coal mined is from a bed at least 8 feet thick, as shown in the following section measured at the entry:

Section at W. W. McGruder bank, White River.

	Ft.	in.
Sandstone, white, massive stratum	15	
Shale, brown, carbonaceous, with thin coal streaks	8	
Coal and bone, much mixed	4	
Shale, brown, carbonaceous	3	6
Coal		6
Bone, approximate measurement	1+	
Coal, apparently good; at least	8	
Base not exposed.		
Total coal exposed	12	6±

At the entrance to the drift the coal appears to be about 5 feet thick, overlain by 3½ feet of brown carbonaceous shale, but this thins down or is replaced by coal almost immediately upon entering the workings and continues so to the face of the mine. The beds dip from 30° to 40° S. Across the narrow gulch only 50 feet away the outcrop of this bed is wholly obscured by the slide rock, and offers a good illustration of the difficulties encountered in attempting to trace individual beds from place to place by their croppings. The coal appears to be of good quality, clear, hard, and bright, and may doubtless be classed as bituminous of a good grade. The admixture and variation of the bony streaks in nearly all the coal beds of this district suggest that some difficulty may be experienced in obtaining a wholly satisfactory coal, or in freeing the product mined from an objectionably high percentage of ash.

Some smaller coal or carbonaceous beds were noted in this general locality, as for instance, a cropping in the mesa edge and along the river bank near Mr. R. E. Thompson's house and in the river bank east of that point. It is thought that these do not represent commercially valuable coals, and for this reason the lower mesa lands north of the McGruder bank have not been considered to be coal lands.

Owing to the fact that the resurvey of this township, for which contracts have been let, had not been made at the time of the examination, no detailed classification of the lands has yet been accomplished.

T. 3 N., R. 100 W.

The position and general attitude of the coal-bearing rocks in T. 3 N., R. 100 W., is very similar to that described in the township next adjoining on the east. This portion of the hogback is not so readily accessible to the river valley as is the area farther east, and so far as known no attempt has as yet been made to develop any of its coal beds.

As indicated on the geologic map, the Mesaverde formation forms a belt of outcrop about a mile in width, crossing the township from east to west.

The northern part of the township includes a portion of the southeastward-pitching axis of the Midland uplift or anticline, and the southern part includes a corresponding portion of the similarly pitching axis of the Angora syncline. Thus the formations exposed range from Jurassic and Dakota (Cretaceous) in the northern part to the Wasatch (Tertiary) in the southern part.

Numerous coal beds were observed in natural outcrop along the southern slope of the Mesaverde hogback. A fairly complete section, assumed to be representative of the general succession of coal-bearing rocks in the township, may be observed along the twelfth auxiliary guide meridian on the west side of the township, or, more strictly speaking, on the west side of section 19. Here several apparently thick coal beds and numerous smaller ones show in natural exposures along a minor gulch that approximately follows the township line. The total thickness of the Mesaverde formation at this place is estimated as about 2,500 feet, of which the coals appear to occupy an interval of about 1,000 feet near the center of the stratigraphic section exposed. The base of the coal group and apparently some of the thickest coal beds lie immediately above a massive white sandstone ledge, one of the most conspicuous in the formation, thought to represent the "white-rock" horizon, previously mentioned.

The only corners found during the present examination were those of the recent resurveys on the western boundary of the township. No classification of the coal lands has been attempted, pending the completion of the resurvey of this district, for which contracts have already been let.

T. 3 N., R. 101 W.

The Mesaverde formation, including the valuable coal-bearing beds, expands considerably in breadth of outcrop as it extends westward into T. 3 N., R. 101 W. The structure is in general a continuation of that described as the Red Wash syncline (p. 104). As the axis of this

fold rises in a westerly direction, the Mesaverde rocks outcrop in roughly concentric outline, changing from a somewhat steep southerly dip at the north to a horizontal and then to a light northeasterly dip at the south. The northern part of the township is occupied by the broad open valley of the Mancos shale, and north of that by a small portion of the southern foot of Blue Mountain, all consisting of rocks older than the coal-bearing Mesaverde.

Numerous outcrops of coal beds were observed in the township. Since the more valuable or apparently thicker beds seem to occur rather low in the group, the larger exposures are to be found among the outcrops of these lower strata. Roughly these may be traced through secs. 24, 23, and westward into secs. 19 and 30, and they probably occur elsewhere within accessible depth of the surface. At no place noted has any development or prospecting been done, as the township is without settlement, except for the camp on Skull Creek in the northeast corner, and it is not sufficiently accessible to any present settlement to create a demand for coal.

T. 3 N., R. 102 W.

The greater part of T. 3 N., R. 102 W., is occupied by the strata of the Mesaverde formation. It includes a long, relatively narrow valley about a mile in width, across its northern margin, which is formed by the steeply tilted beds of the Mancos shale, and a smaller area of still older rocks at the southern foot of Blue Mountain in its northwest corner. The structure is a still further extension of the axis of the Angora syncline, broadened and flattened to such an extent that its identity as a fold is nearly lost to view except at its northern, more steeply dipping limb. As represented on the map of the Rangely quadrangle (Pl. XIX), the upper and more valuable coal-bearing portion of the Mesaverde is confined chiefly to the eastern half of the township, where these rocks are represented in the elevated ridges of the divide between Red Wash and the Raven Park drainage. On this divide the steeper escarpment side faces westward, and the light easterly dip is rendered somewhat conspicuous by the burning of the contained coal beds along the outcrops. So far as known no prospecting or development has been done in the township, which is without settlement and is not readily accessible to any settlement likely to create an immediate demand for the coal, unless one should result from the opening up of the Rangely district as an oil field.

T. 3 N., R. 103 W.

No part of T. 3 N., R. 103 W., appears to be valuable as coal land. Although somewhat over half is composed of Mesaverde strata at the surface of the ground, these beds are all of the lower portion of that formation, which is, so far as observed, relatively barren of workable

coals. Coal croppings have been observed and some are noted on the land-office township plat in section 24, but unless there is an instance of local thickening of the coals of this lower group, such as has not yet been observed elsewhere in this general region so far as the author knows, it seems likely that none of these lands will be considered valuable coal land.

The strata in the southern half of the township lie approximately horizontal, tilting up to some 6° or more at the extreme southern edge, as the beds rise on that flank of the Raven Park anticline. Along an east-west line across the center of the township the beds bend up abruptly in the other direction, conforming to the southward dips at the southern flank of the Midland uplift of Blue Mountain. The southern half of the township is therefore a rather open, very broadly arched syncline. The northern half of the township is occupied by strata older than the Mesaverde, including the Jurassic, and possibly is eroded almost to the "Red Beds," of Triassic or Permian age.

T. 3 N., R. 104 W.

T. 3 N., R. 104 W., is one of the fractional townships adjoining the Utah state line. As shown on the map, it includes a belt of outcrops of some of the more valuable Mesaverde coals on the western flank of the Raven Park anticline, or what may be termed in Utah the Raven Ridge monocline.

Workable coal was observed at a number of localities close to the state line, the strata dipping from 9° to 25° W. A single mine was noted in the southern part of section 10 about 200 yards east of the state line, from which coal had evidently been hauled in the direction of Green River in Utah, possibly as far as the settlement along the river valley. At the time of examination the property did not appear to have been worked for a considerable time. The following measurements were obtained at the mine entrance:

Section at old entry in sec. 10, T. 3 N., R. 104 W., Colorado.

	Ft.	in.
Sandstone, hard	2	
Shale, brown and carbonaceous	6	
Clay, white		4
Coal and bone, alternate beds	4	3
Coal, good quality, mined	4+	
Base not exposed.		
	16	7+

All of the above section has been mined out below the brown shale in the working on the entry, and the bone appears to vary much from place to place.

Other coal beds are exposed in the rocks above and below this horizon, but none of them appear to have been opened up or are naturally well exposed.

T. 2 N., R. 98 W.

A narrow strip of the coal-bearing rocks in the northern part of T. 2 N., R. 98 W. (Pl. XVIII), has already been noted in connection with the township next adjoining on the north (T. 3 N., R. 98 W.). The McAndre mine there mentioned (p. 184) is probably actually situated in this township, although its exact position with reference to the land surveys was somewhat uncertain when the property was visited, owing to the fact that the recently ordered resurveys had not yet been completed. The greater part of the township is occupied by high escarpments and hills composed of the Green River formation, in which territory the coals of the Mesaverde formation are almost certainly too deep to be considered available at the present time.

T. 2 N., R. 99 W.

No coal croppings are known to occur in T. 2 N., R. 99 W. (see Pls. XVIII and XIX). The geologic structure is very similar to that of T. 2 N., R. 98 W., the Mesaverde formation outcropping just north of the area, dipping southward, and almost certainly underlying the whole township, but at such depth as to render them practically inaccessible at the present time. The north border or crest of the Cathedral Bluffs exposes the Tertiary strata of the Green River formation overlying the Wasatch, the latter being exposed along the White River valley.

T. 2 N., R. 100 W.

Structurally, T. 2 N., R. 100 W., represents the southern limb of the Angora syncline, or a part of the eastern flank of the Raven Park anticline (Pl. XIX). The general northeasterly dip varies from 6° to about 10° throughout the western half of the township. The coals are exposed in the southwest corner in the Spring Creek canyon, where they have been extensively burned. About 2,080 acres in the southwestern part of the township have been considered to be coal land. The eastern part of the township is occupied by the Wasatch strata, containing some exposures of variegated clays and many sandstone ledges.

Although the new land surveys were not yet completed at the time of the examination of this district, an approximate subdivision was provisionally projected through the area from the auxiliary guide meridian on the west, and the estimates of area as stated are made on this basis.

T. 2 N., R. 101 W.

T. 2 N., R. 101 W., lies at the southeast end of Raven Park. Its structure conforms to that of the southeastern flank of the Raven

Park anticline, the general dip throughout the township being about 5° to 10° NE. The more valuable coal-bearing part of the Mesaverde formation occurs in outcrop in the northern and eastern parts of the township. These beds form for the most part the highest ridges or the upper walls of the deepest canyons. Workable coal is indicated in many places, and much of the principal coal group is rendered conspicuous by extensive burning of the beds at their outcrops.

The section on White River where that valley intersects the coal-bearing strata near the mouth of Red Wash appears to be the most complete and readily available in this part of the district. To judge from observed indications in adjacent areas the workable coal here appears to be very near the minimum developed in the Colorado portion of this field.

Several prospects on the various beds of the section and a single working mine were visited. The mine is situated in the SW. ¼ NE. ¼ sec. 11, on the north bank of White River, between the mouths of Scullion Gulch and Red Wash. The main entry extends down at least 75 feet and has been worked out in a room of considerable size. The dip at the entry is 9°. The coal bed measured 3 feet 8 inches of apparently bright, hard coal at the face in the mine. A sample (No. 5516) was taken; for analysis, see page 250. This shows good coal of bituminous grade, containing a considerable percentage of ash, but not as high as had been expected from the general appearance of the coal. The coal contains much bone, in irregularly distributed layers, which are very difficult to separate in mining. The roof is thin-bedded sandstone for a thickness of several feet above the coal bed, and large slabs of it loosen and drop into the mine, where not adequately supported by timbers. The floor is bony coal to as great a depth as it had been exposed.

A considerable number of prospects, most of which had apparently been abandoned as not worth working, are situated under the bluff on the edge of the mesa along the south side of the river. In each of these, so far as could be determined by superficial examination, the coal was either too thin or too bony to be of commercial value. It is nevertheless clear that some of the coal underlying this ground may at some time prove to be valuable and workable, and in the lands beyond the immediate limits of the agricultural flats the presumption is given in favor of a predominating coal-land value. About 2 miles south of the river-valley region described above, a great amount of burned slag and baked rock ledges on Spring Creek are taken to indicate the presence of larger coals, several of which are probably workable. Similar judgment may be passed on the rocks exposed in the hills west of this part of the White River area, where a number of the coal beds themselves are exposed in natural outcrop.

The southern and southwestern part of the township is occupied in part by escarpment ridges of the relatively barren lower strata of the Mesaverde formation and chiefly by open valley lands developed from the Mancos shale.

T. 2 N., R. 102 W.

The greater part of T. 2 N., R. 102 W., is occupied by the Mancos shale as exposed at the surface in the valley lands of Raven Park. The lower relatively barren portion of the Mesaverde formation outcrops in the northeastern part of the area, the strata including sandstone ledges dipping at a fairly uniform inclination of 5° or 6° NE. As indicated on the map (Pl. XIX) the coal-bearing rocks are restricted to sections 1 and 2 and a smaller part of sections 11 and 12. At the extreme northeastern part of the township one or more thick coals are exposed at outcrop in several places.

T. 2 N., R. 103 W.

T. 2 N., R. 103 W., is situated on the west side of the Raven Park anticline. (See Pls. XIX and XXI.) As this flank of the fold is much more abruptly tilted than that of the east or north sides, all the formations exposed occupy relatively narrow belts in more steeply inclined positions. The Mesaverde and overlying Tertiary rocks form high ridges, extending diagonally across the township from southeast to northwest. The coal-bearing rocks are found as a part of the ridge that forms the western limit of Raven Park, to which the name of Raven Ridge has been applied on most of the older maps of the region.

Several thick coal beds were observed in the outcrops along the western side of this ridge, and in at least two places beds over 12 feet thick were noted. The only development found was a mine in Dripping Rock Gulch in section 7, a short distance northeast of the west quarter corner. Two entries have been made on the lowest of several beds. One of these, situated next to a small dry gulch, has been run in to a depth of 40 feet. Coal 6 feet thick has been mined and three more beds are exposed above, making about 9 feet of coal in all. Another entry about 50 feet farther east is caved, but seems to indicate about the same thickness of coal. Other coals show some 150 and 200 feet above these beds, but have not been opened by prospecting. The strike of the beds is N. 48° W. and the dip is 29° SW. Coal from these entries is said to have been mined for use in White River valley, notably at the gilsonite properties near the state line, from which the entries have been reached by a road up the Dripping Rock Canyon.

T. 2 N., R. 104 W.

Only a small portion in the northeast part of fractional T. 2 N., R. 104 W., is included in the area of workable coal (see Pl. XXI), this

being the northwestward continuation of Raven Ridge. The greater part of the township is covered by the Tertiary formations and the coal is doubtless too deep to be considered workable, at least so far as conditions in the present or near future are concerned. Croppings of some thick beds in section 12, adjacent to the mine in Dripping Rock Gulch already described, were noted in the examination, and similar beds are doubtless continuous to the northwest, but are not known to have been opened at any point within the limits of the township.

T. 1 N., R. 100 W.

In a structural sense T. 1 N., R. 100 W., includes the southeastern termination of the major axis of the Raven Park anticline (Pl. XIX). The formations exposed within its boundaries range from the horizon of the principal coal-bearing group of the Mesaverde in the northwest well up into strata of the Green River formation of Tertiary age in the southeast. A general light dip to the southeast prevails.

The coal-bearing rocks are exposed in the valley of Spring Creek and are restricted to a rather small area so far as actual croppings are concerned. No land-survey corners were found within this district, and the tracing of the boundaries was based on triangulation and random lines from the twelfth auxiliary guide meridian, with the west side of the township as a base.

So far as known no development or coal exposures worthy of especial note have been found in this township. There is no settlement in the district and the comparative difficulty of accessibility renders it unlikely to prove of importance so far as the near future is concerned.

T. 1 N., R. 101 W.

A large part of T. 1 N., R. 101 W., is occupied by the outcrops of the Mesaverde coal-bearing rocks. Structurally the area lies between the Raven Park anticline on the north and the Douglas Creek fold or uplift on the south, so that its coal-bearing rocks lie in the form of a broad, very gently depressed syncline.

The base of the workable coals in the Mesaverde formation appears to be a fairly definite horizon, commonly marked by a conspicuous white sandstone ledge, which is assumed to be the "white rock," as elsewhere noted. Above this horizon burned and reddened shale and ashes mark the position of coals that are in all probability of workable thickness at depth sufficient to be beyond the zone of burning. At one locality the unburned coal beds have been opened in the NW. ¼ sec. 15, at a local coal bank on Gillam Draw about 3½ miles south of White River. Coal has been mined for use in this valley. Several thick beds, one of which contains at least 8 feet of good coal with but a single thin parting, have been noted in this vicinity.

Coal in the lower part of the Mesaverde formation is exposed at a number of places, as for instance, in the southeast corner of section 7, where several beds 6 to 10 inches thick occur in black shale. These are considered representative of the lower coal group as defined on page 65, and are probably of no commercial importance. The hills along the rim of Raven Park and the lower part of the bluffs along Douglas Creek are considered to be stratigraphically below the horizons of the workable coals and are therefore not included in the area classed as coal land.

A total area of 11,720 acres, or about one-half of the township, is estimated to contain coal beds of probable workable thickness, either at the surface or within an approximate limit of 500 feet depth from the surface, as approached from the most favorable points of access.

T. 1 N., R. 102 W.

The attitude and distribution of the strata in T. 1 N., R. 102 W., are very similar to those described for the township next adjoining on the east (p. 194), except that the more abrupt fold of Raven Ridge and western flank of the Raven Park anticline show a rather marked influence at the western side of the area. The township lies immediately south of the Raven Park anticline. Near White River the strata dip 15° to 25° S. At about the center of the township the beds become horizontal and beyond that rise very gradually toward the south. Along the western side of the area included within the township the structure merges into a gradual westward dip and the coal-bearing rocks disappear beneath the overlying Tertiary formations. Throughout the eastern two-thirds of the township and south of the outcrop of the "white rock," as indicated on the geologic map (Pl. XIX), coal is exposed at a great many places along the gulches and hillsides.

Some thick coal beds have been opened and mined in section 14, at what is known as the J. W. Rector coal mine, about 2½ miles south, a little west of Rangely, the post-office in Raven Park. This property is said to have been opened in 1898, when the first workings were driven in on a bed stratigraphically above that of the present mine, on the east side of the gulch and opposite the latest workings. In the fall of that year the lower bed ("B" of the following section) was opened and mined and was apparently as thick as the coal bed in the present mine on the west side of the gulch. The latter is caved and has been abandoned, reports stating that the entry was not properly timbered while working, and so became unsafe. A single sale of coal from this mine to the Meeker No. 1 oil well in Raven Park is said to have amounted to 100 tons. All of this development is still on government land, having been worked under vari-

ous filings which were renewed from year to year. The following measurements were made at this locality:

Section near the J. W. Rector mine, Rangely, Colo.

	Feet.
Sandstone and yellow sandy shale	2
Shale, clay	4
Coal	1
Shale, brownish	5
Coal (A), old entry caved and inaccessible (incomplete measure)	4+
Shale, gray and whitish, either clay or sandy	15±
Coal (B), good, old entry, bottom covered; bed probably much thicker than now exposed	5+
Interval, covered	15
Sandstone, rusty brown	2
Shale, with some sandstone	(?)
Coal (C), apparently good, measured at least	5+
Section is covered by slide débris below.	
Total coal (minimum measurement)	15–22

Coal "B" in the above section is equivalent to that mined at the latest Rector mine, which is known to be 12 feet thick in the entry on the west side of the gulch.

The present J. W. Rector mine is a drift running in N. 68° W. for about 300 feet. The entry is cut on the middle portion of the large bed of coal, leaving coal both above and below. Several rooms or slopes have been worked above and below the main entry. The mine is fitted with a track, small mine car, and wooden frame tipple and bin. The coal bed measures 11 feet 11 inches at the face of one of the slopes that runs down, 90 feet in from the entrance. At that place a seam of bone about 2 inches thick was noted 4 feet 3 inches below the roof. This bone forms the roof of the main entry in the mine. The strike of the beds is N. 68° W. and the dip 9° SW. The mine is situated at the flattening edge of the Rangely anticline, the beds being more sharply tilted to the north and becoming nearly horizontal just south of this place. The roof is composed of 12 to 15 feet of compact clay shale underlying a rusty colored sandstone ledge. Where exposed in the mine this forms a good smooth roof, apparently holding up well. The floor is smooth and composed of brown or bony shale for a depth of a few inches. To judge from the exposure at the entrance the floor is a mass of shale at least 10 feet thick.

Two samples (Nos. 5519 and 5520) of this coal were taken for analysis, and the results are given on page 250. This shows a good grade of bituminous coal, very similar in appearance, composition, and efficiency to that of the Meeker district. Local reports state that it will stand weathering for about two months in the open air.

The coal from all the beds of this general locality is about the same in this respect.

The estimated area of coal land in this township is 15,000 acres, or about two-thirds of the total area, calculating on a basis of an available-depth limit of only 500 feet.

T. 1 N., R. 103 W.

The greater part of T. 1 N., R. 103 W. (Pls. XIX and XXI), is occupied by the Tertiary strata of the Wasatch and Green River formations, which are doubtless underlain by most of the valuable coals of the Mesaverde formation, although probably buried at considerable depth, roughly estimated as 5,000 feet or even more in much of the area.

The only coal beds now available at the surface are found in the northeast corner of this area at the southern end of Raven Ridge along or near the valley of White River. Owing to the accessibility of the locality the coal land of that part of the district will doubtless be considered desirable as soon as any active demand for the coal is created in the neighboring valley. At present the only prospect or attempt at mining noted is an unimportant bank in the NE. ¼ sec. 12 near the township line on the south side of White River at the lower end of Raven Park. It consists of a small entry about 20 feet in depth, said to be located on Mr. B. Rector's ranch. The coal exposed was but 2 feet 10 inches thick, with a dip of 35° SW., and underlies a massive sandstone stratum 25 feet thick.

There is little doubt that other and thicker beds may be found in the section exposed near this locality, although no precise locations can now be given.

An estimated area of 680 acres in this township is provisionally classed as coal land, although the assignment of these limits depends chiefly upon the arbitrary assumption of a 500-foot depth as the ultimate limit to which the coal may be considered available.

DOUGLAS CREEK DISTRICT.

LOCATION.

The coal-bearing rocks of the White River field are continuous south of the base line in the vicinity of Raven Park, covering a total area of several hundred square miles, mainly in the drainage of Douglas Creek and its tributaries, all of which will probably be classed as coal land. The district is continuous with the lower White River field, of which it is here considered a part, and is arbitrarily separated by the base line from those townships already described. (See Pl. XX.) This distinction is made on account of the difference in the character of the land surveys north and south of the line.

LAND SURVEYS.

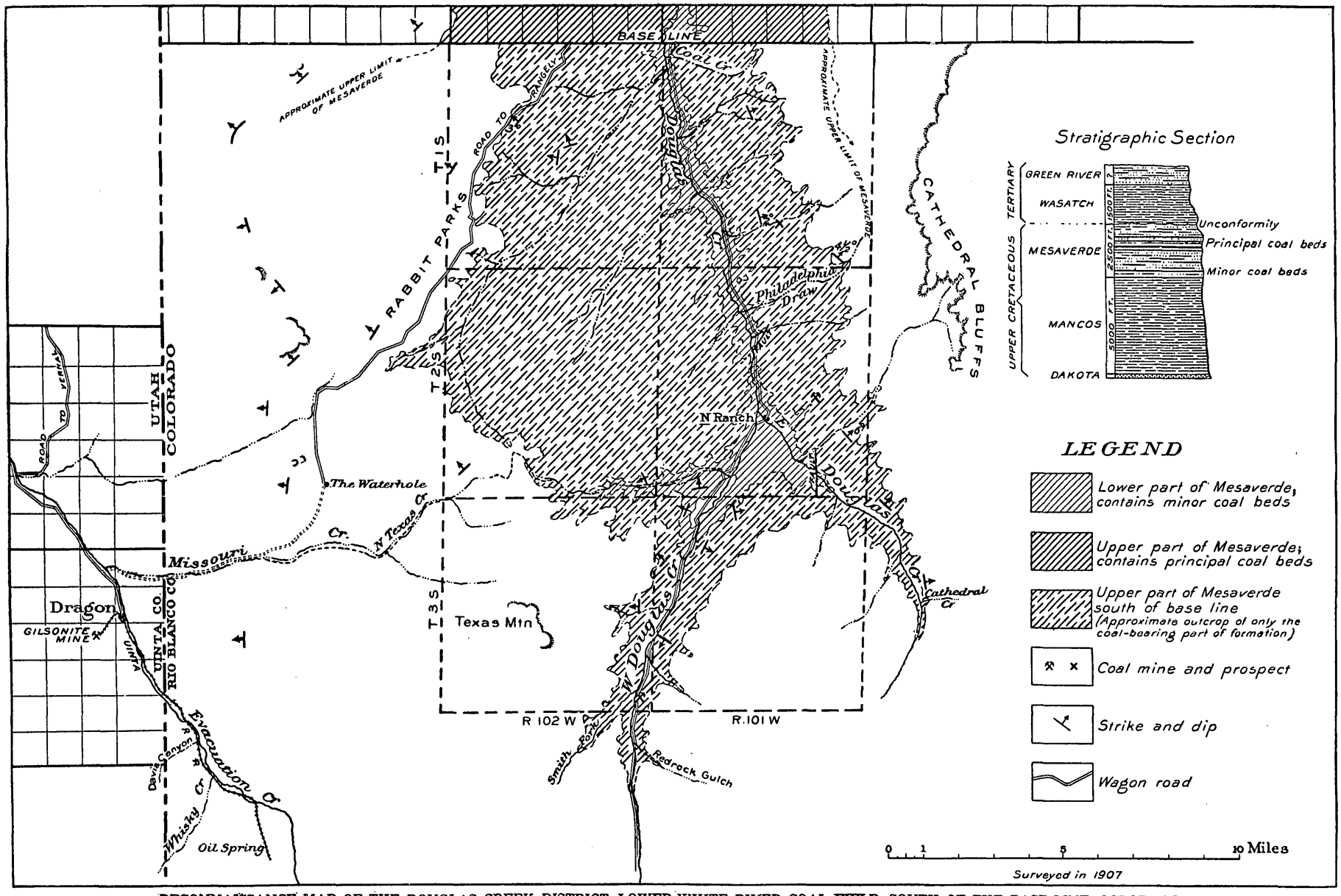
As explained in the foregoing descriptions, most of the territory north of the base line has either recently been resurveyed under the rules of the General Land Office, or the contracts have been let, and it is expected that the work will be completed in the near future. On the other hand, in the territory south of the base line and west of the twelfth auxiliary guide meridian the old land surveys are believed to be in large part practically without value, and very few corners were discovered in the examination made. On the Douglas Creek drainage only three land corners were found during the present examination, and there seems to be good reason for assuming that these neither check with each other nor agree with their stated distances and directions from the base line. These corners are situated in the immediate valley of Douglas Creek, and it is extremely doubtful if many corners were ever set by the original survey in the adjoining hills.

WATER SUPPLY.

The region as a whole is practically without water, especially in its northern part. Douglas Creek usually flows in its main channels throughout the year, with possible exceptions in unusually dry seasons. The greater part of the district is, however, devoid of any constant supply of water and can be used for grazing purposes only, and is used so chiefly as a winter range when there is snow on the ground on which the stock can subsist. At the headwaters of the main streams, near the Book Cliffs divide and the Cathedral Bluffs, springs are more numerous, and good water is found in many of the smaller creek beds.

TOPOGRAPHY.

The topography is rough and broken, being carved from the nearly horizontal beds of the Mesaverde and overlying Wasatch formations, whose massive sandstone ledges everywhere prevail as continuous lines of crags, cliffs, canyon walls, and cappings of mesa buttes. Much of the territory is covered with scrub oak or other brush, and this with the numerous ledges and cliffs makes it difficult to travel over except along the cattle trails in the valley bottoms. The whole is surrounded by the high escarpment ridges of the Green River Tertiary strata, occupying the Book Cliffs Plateau, the Cathedral Bluffs, and the higher escarpments on the west, and reaching from north to south along the state line. Thus, a part of the field naturally included in this somewhat roughly defined topographic basin lies on the drainage of Evacuation Creek on the Utah side of the state line and on one or two other smaller tributaries of White River in the northwest.



RECONNAISSANCE MAP OF THE DOUGLAS CREEK DISTRICT, LOWER WHITE RIVER COAL FIELD, SOUTH OF THE BASE LINE, COLORADO

By Hoyt S. Gale, J. A. Davis, and C. W. Stoops

GENERAL STRUCTURE.

The broad domal structure of the district is perhaps most clearly revealed by a general view from the high escarpments surrounding the valleys and somewhat broken and hilly "parks." These bordering escarpments expose the bare ledges of the Tertiary strata, dipping away in nearly all directions from a lower eroded center, although the dips are at almost imperceptible angles, which are for the most part revealed by the plateau surfaces and dip slope features of the topography of the district as a whole. In traveling up the valley of Douglas Creek south from White River, the strata may be observed to dip south near Raven Park, conforming to the structure of the Raven Park anticline. Before the base line is reached, however, they assume a practically horizontal position and thence may be seen to rise toward the south approximately at the grade of the stream channel. This structure is for the most part very regular, and except for a few offsets along faults (see p. 200) the beds continue to rise gradually southward to a point about 2 miles south of the N Bar ranch, which is the only settlement in the district, and is situated in the main forks of the creek about 18 miles south of White River. At the locality south of the N Bar ranch, on the west fork of Douglas Creek, a small basin opens out, evidently eroded from the shale at the base of the Mesaverde formation. This is therefore a center of an anticlinal dome or uplift, from which the beds may be observed to dip outward in all directions. At a point just above or south of this valley the strata bend abruptly down (southward), and there may also be a fault at this place. Beyond this point the beds again assume a nearly horizontal position and farther along rise approximately at water grade as far as the headwaters of the forks of Douglas Creek. Here the coal-bearing rocks, although still rising in the southerly direction, pass beneath the general surface at valley levels. Thus, these beds are clearly continuous under the Roan or Book Cliffs Plateau only 10 to 15 miles north of the outcrops on the south side of the Book Cliffs divide, where the same formation, including similar coal beds, is found on Grand River drainage.

In the western part of the Douglas Creek district the strata lie very nearly horizontal, though more or less irregularity of structure along the margin of the basin country is evident from the sinuosity of the limiting rim of the escarpments of Green River formation. The general light dip toward the west or into the main Uinta Basin of Utah is revealed in the overlap and succession of higher and higher beds, as traced in that direction; so that the coals are probably buried at greater and greater depths by the accumulation of younger beds.

FAULTS.

A number of faults, as well as numerous more local slides or slumps, were observed in the strata of the Douglas Creek district. One fault 2 miles north of the N Bar ranch crosses Douglas Creek in a direction approximately N. 30° E., with a downthrow of 200 feet more or less on the south side. This brings the coal-bearing strata down to stream grade for a short distance, but a short distance southward they rise again to the ridge tops, which is their ordinary situation in this part of the field. Another fault, observed on the east fork of Douglas Creek about 2 miles above the N Bar ranch, apparently strikes about N. 4° W., with a downthrow of 200 or 300 feet on the east side. The fault plane seems to be inclined toward the west at a steep angle on the north side of the gulch and in reversed attitude dips steeply toward the east on the south side of the gulch. The strata are sharply bent, showing drag near the fault, and the burned coal-bearing strata have been dropped to water level on the east side of the displacement. The abrupt fold above the small anticlinal basin on West Douglas Creek is probably accompanied by one or more faults, in these instances the downthrow being on the south side.

STRATIGRAPHY AND COAL.

The stratigraphic section exposed at the main forks of the creek near the N Bar ranch is more or less typical of the Mesaverde rocks so extensively exposed along the canyon walls that line Douglas Creek. The lower 400 feet above water level, composed of huge white cliff-forming sandstone beds and some intervening shale, is made conspicuous in contrast with the overlying beds by absence of any signs of burning. These beds are thought to represent in part at least the lower relatively barren sandstone portion of the Mesaverde formation. At the base of the bluff near creek level, a coal bed about 8 inches thick and noticeably of lenticular character is thought to belong to the lower coal group as described on page 65. This bed shows much variation, thickening and thinning and dividing in a manner similar to one sketched by Endlich in the Hayden Survey report.[a] This horizon is doubtless 300 to 400 feet or more above the base of the Mesaverde formation as more completely exposed around the margin of Raven Park. The strata above the big white sandstone ledges show a section of about 300 feet, reaching to the summits of the adjacent peaks and ridges, composed of shale and sandy beds, all fire-reddened or colored by heat and baked as hard as pottery ware. This burned rock is exceedingly magnetic, probably owing to the reduction of the iron from the ferruginous seams contained in the strata before they were burned.

[a] Endlich, F. M., Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., Pl. V, p. 81.

In a rather extensive territory adjacent to the lower valley of Douglas Creek and including nearly all except the farthest headwaters of that stream, the middle or principal coal group of the Mesaverde can be readily traced by the eye from any prominent point overlooking the district, or by traveling along the canyon bottoms. The brilliant color of the rocks may be seen to occupy in large part the summits of the ridges, while the canyons are commonly cut into the more massive white sandstone beds that everywhere underlie these coals.

On the west fork of the creek above the small anticlinal basin mentioned near the N Bar ranch the principal coal group may be traced approximately at water level to a point within 5 miles of White's ranch in the upper valley of the main stream. The lower bluffs bordering the canyon form an almost continuous rim of brilliant vermilion rocks, the most conspicuous forming a zone 100 to 300 feet or more in thickness. At the forks of West Douglas, about 8 miles above the N Bar ranch, an old entry exposes a bed of coal that has been worked for domestic use at a former settlement said to have been known as Smith's ranch. Now, however, both ranch and coal entry are abandoned and fallen into ruins.

The east fork of Douglas Creek runs approximately parallel to the high escarpment of the Green River formation known as the Horseshoe of Cathedral Bluffs. It also follows approximately along the upper limit of the outcrop of the coal-bearing rocks, a geologic boundary concentric or roughly parallel with that high rim of the overlying Green River beds. All these strata have light dips. In the formation above the principal coal-bearing group there is found a great series of massive sandstone beds of cliff and ledge-forming character that appear to be almost identically like the unbaked sandstones of the coal-bearing rocks. Between the sandstone ledges of the upper Mesaverde or lower Wasatch and the foot of the main escarpment of the Green River shales there is found on Cathedral Creek and elsewhere a deep open valley indicative of a zone of weaker or less resistant beds in the upper part of the Wasatch or the lower part of the Green River formation. Some clays of red and white color occur, but the color seems not to be so universally characteristic of the Wasatch as it is in the Grand Hogback and Danforth Hills areas.

The principal coal district immediately accessible in this part of the White River field is restricted to the Douglas Creek drainage. Baked rocks indicative of the burning of coal beds are conspicuous in nearly all the bluffs that border the main stream southward to and beyond the principal forks of the creek. These burned rocks were described by Endlich,[a] who thought they represented the red-

[a] Endlich, F. M., Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1876, p. 80.

dish strata of the Wasatch formation, evidently failing to recognize the significance or cause of their color. The red cliffs, slag, ashes, baked and hardened rock and clinker are so conspicuous that it seems as though they could scarcely be overlooked by anyone traveling through the region. There are also a few natural exposures of the coal itself. For some distance along the gulch or canyon walls the sandstone on the west side of Douglas Creek south of the base line outcrops in brown and weather-stained ledges with numerous reddened bands, having a slight resemblance to the beds found in the red and white banded Wasatch strata that normally overlie these Mesaverde rocks in the fields of the Uinta Basin.

Owing to the sparsity of settlement in this district but little demand has been created for the development or use of any of the coals that may eventually be discovered. A single local bank in a gulch about 1¼ miles northeast of N Bar ranch has been worked within the past few years for domestic use at the ranch. The entry consists of a short slope running down N. 25° E. on a pitch of 5°. The dip of the beds is about 7° N. 10° W. The coal itself is 5 feet and possibly more in thickness, the floor being concealed so that a complete measurement could not readily be obtained. The roof consists of a thin-bedded, sandy, carbonaceous shale 2 feet 3 inches thick, overlain by a massive sandstone stratum at least 15 feet thick. The coal is apparently of good quality, similar to the coals of the Meeker district; but it seems to have been somewhat affected by the heat from the huge burned zone that overlies it. This bed is one of the lowest of the middle coal group of the Mesaverde formation. The strata do not appear to be burned at all on the east side of the gulch at this place, and the coal should be available there from the higher beds as well as from the one opened at the mine. Owing to its peculiar situation it is very doubtful if all of the coal of the Douglas Creek district can be assumed to be of commercial value at the present time. The almost universal burning in this part of the field has destroyed practically all of the coal at its outcrops, and by reason of the location of these beds in the summits of the ridges the burning may also have extended to considerable depth. The fact that much of the coal is situated wholly above ground water would make the complete burning of practically all the valuable beds very probable in many and perhaps most of the narrow ridges. Such a condition is all the more likely on account of the intricate network of steep canyons that intersect the region, and subdivide the coal into patches of an almost infinite detail of outline. Toward the flanks of the broad, gently arched uplift, however, the coal-bearing beds descend to and below water level or are more deeply covered, and are thus rendered available for mining in more favorable positions and attitudes.

Throughout the western part of the district, or west of the actual drainage basin of Douglas Creek itself, no coal was noted, but as it is evident that erosion has cut deeply into the Wasatch formation at many points it is very likely that some of the more valuable coals may prove to be accessible at no great depths within these valleys, should demand ever be made for their development.

East of the settlement at Dragon, which is the termination of the Uintah Railway, the upper valleys of Evacuation, Missouri, and Texas creeks are evidently eroded in the Wasatch beds underlying the Green River formation. These strata are shown by the bluffs of red and white banded clays and soft sandstones that line the lower canyon walls or form the bare washes in the lower valleys. These valleys are covered with slabs and blocks of oolitic rock and sandstone. Remnants of many mesa buttes, eroded into fantastic shapes, stand out on the outcrops of these formations.

COAL AREA.

The estimated total area of the Douglas Creek coal district south of the base line is about 120 to 150 square miles. This is probably a very conservative figure as an estimate of the available coal field itself, in view of the fact that the coal-bearing rocks underlie all of the territory surrounding that included in the estimate, and that their availability as a coal field depends merely on the depth of the coal or the facility with which it may at some time be reached in mining. As explained, a considerable area near the state line, which so far as known shows no signs of coal at the surface and is not included in the estimate, is very likely to be found available as a coal field at some future date.

CHARACTER OF THE COAL.

The character and thickness of the coal may fairly be assumed to be similar to that of the White River districts to the north and to that of the better known and exploited fields on the south side of the Book Cliffs divide. Analyses of the coals from the south side of Raven Park (Nos. 5519 and 5520, p. 250) are doubtless as truly representative of the Douglas Creek district as they are of the White River field in general. Description and discussion of the coals from the same horizons on the Grand River side of the divide are to be found in a separate report on that field.[a]

[a] Richardson, G. B., Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: Bull. U. S. Geol. Survey No. 371, 1909, pp. 43–45.

CHAPTER VI.

VERNAL FIELD, UTAH.

LOCATION AND SETTLEMENT.

The valley of Ashley Creek, in which the town of Vernal is situated, contains perhaps the most extensive settlement near the east end of the Uinta Mountains, or at least in the northern part of Uinta County. Together with the farming lands in the Green River valley just south of the point at which that stream flows out from the canyons of the Uinta Mountains, this whole district comprises a prosperous agricultural community of considerable importance.

CHARACTER OF LAND SURVEYS.

The examination of the Vernal field was carried westward in extension of the Colorado work. West of the state line and east of the Green River valley, no land-survey corners were found that could be identified with certainty, and although some satisfactory surveys may at one time have been made in this territory, it seems very likely that the corners if ever established were not permanently marked, and little evidence of them remains to-day. It also seems clear that the original surveys of Utah extended east of the state line, probably owing to the uncertainty regarding the correct location of the boundary at the time of that work. Thus the map of the Utah field presented here (Pl. XXI) depends for its adjustment primarily on the control obtained from a railroad alignment survey extending from Colorado down Cliff Creek to Green River, and on plane-table and triangulation work done during the present operations. East of Green River the land lines shown on the map are projected through from corners found in the valley lands. West of Green River the more extensive settlement and farming lands laid out by subdivisions and largely fenced afford more complete evidence of an accepted land-survey system.

RELATIONS TO THE COLORADO FIELDS.

The Mesaverde coals of the Utah field in this part of the Uinta Basin are a direct continuation of the same group from the White River fields of Colorado. For reasons explained in a subsequent paragraph the Mesaverde coals become progressively of less and less value as traced toward the west, and the state line offers a convenient division by which to distinguish a separate field in which these coals have not yet been shown to be of much importance, at least

when considered in comparison with the richer and more extensive fields of Colorado. The Utah fields are further distinguished by the fact that where the Mesaverde coals become relatively unimportant older beds near the base of the Cretaceous section develop workable coal, presenting, in fact, the only coal at present considered worth exploitation in or near the settlements in the Green River valley.

COAL.

MESAVERDE COAL.

West of the state line the basal sandstones of the Mesaverde are the most conspicuous members of that formation, forming a rim-rock ridge somewhat analogous to the rim rock of Raven Park. This ridge is very distinct and easily traced to and beyond Green River, and the position of the Mesaverde coals may be inferred from it, even where they are not actually exposed. As a whole, however, the Mesaverde formation is relatively much thinner in this extremity of the Uinta region, and the thinning is apparently due to the absence of upper members of the formation. Thus the Wasatch strata, overlying the Mesaverde and separated from it by an unconformity, appear to sink deeper and deeper as traced to the west. It appears that the coals which are commonly found in the upper part of the Mesaverde formation in other fields are probably wanting here. The whole formation, which measures approximately 5,000 feet in the Grand Hogback field and only 2,500 feet on Red Wash Creek in Colorado, is probably not over 1,500 feet, and possibly less near Green River. In each case the barren interval at the base of the formation appears to remain more or less uniformly constant, the coal occurring relatively high in the decreased thickness of the Mesaverde strata.

MANCOS COAL.

GEOLOGIC AGE.

The older coal of the Vernal field is associated with fossiliferous strata both above and below the workable bed, and fossils from these horizons are reported to be distinctive of the Benton shale of other fields. The group of sandstones and shales in which the coal occurs is undoubtedly equivalent to the beds mapped as the Mowry shale member in several fields of Wyoming. The name Mowry is derived from a locality on the east side of the Bighorn Mountains in northern Wyoming, and has been used in publications dealing with the coal fields of southern Wyoming. In this report this member is distinguished only where it becomes of economic importance, while it is not separated from the Mancos in any of the Colorado mapping, although it can be as readily distinguished and traced in that territory as in Utah.

DESCRIPTION OF COAL-BEARING STRATA.

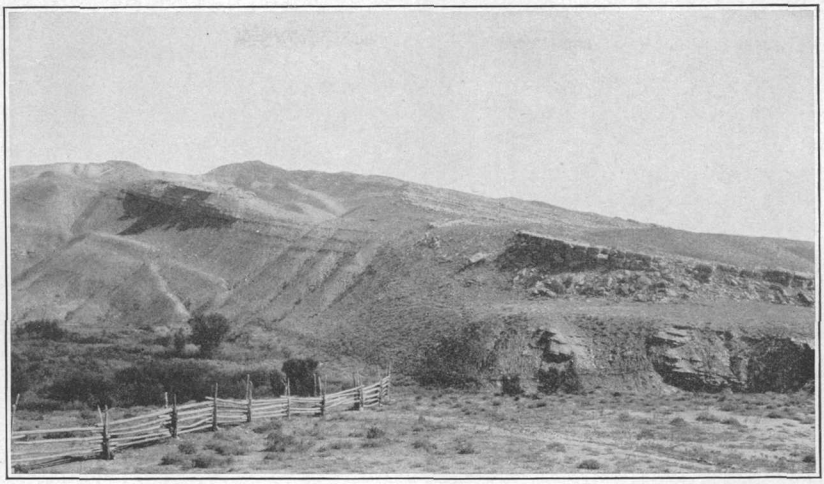
Throughout the Colorado regions examined the sandstones normally occurring near the base of the Mancos shale are very uniform, of moderately fine texture, of rather dark-drab, gray, or possibly faint-greenish cast, and are commonly more or less thinly bedded, so that they break or weather out in flaggy or slabby blocks. As traced into Utah the beds of this same horizon become more prominent, the sandstone is coarser, much of it has a white color, and the thickness of the sandy beds becomes greater. It thus forms a considerable group of more or less massive white sandstone beds and sandy shale, including so far as at present recognized one principal bed of coal and in some localities thinner beds of doubtful value above the principal bed. Throughout the Vernal field, from Green River westward as far as these beds were traced in the present work, a single stratum of massive sandstone above the coal is found characterized by large spherical concretions. These weather out along the outcrop and strew the surface of the ground. Pl. XXII, *B*, shows the external form and also the internal structure of a representative specimen found near the Bowen mine on Brush Creek, 7 miles east of Vernal.

POSITION OF THE OUTCROP.

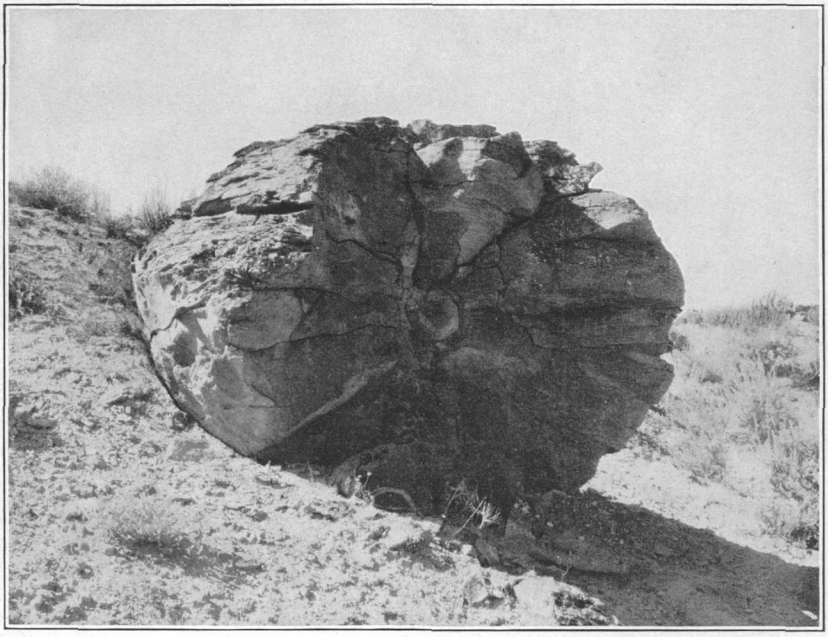
The coal group in the lower part of the Mancos shale presents a sinuous outcrop in the vicinity of the Green River valley near Vernal. The beds follow the sharp folds of the older strata of the Uinta Mountain axes as continuous curved ridges around the ends of the pitching anticlines and into the deep reentrant valleys of the synclines. Only a small portion, considerably less than one-half of the length of outcrop exposed, is known to contain valuable coal. Thus the sandstone beds of this horizon are exposed in the banks of Green River at Jensen, but so far as known do not contain coal at that locality. They are also exposed west of Green River around the foot of Split Mountain. On Brush Creek the coal thickens and is of workable character at a few places. Very little is known concerning the coal around the northeast end of the Island Park syncline, but it is said to be of small practical value. Along the cropping of this bed north and northeast of Vernal it is or has been mined at a few places in the valley of Brush Creek (Pl. XXII, *A*), but the principal developments on this coal are grouped in a locality 7 to 8 miles northwest of Vernal, southeast of Little Mountain.

CHARACTER OF THE BED MINED.

Wherever mined, the number and thicknesses of the partings of the coal are similar and the bed worked is doubtless the same throughout the field. One or two other small beds of coal are reported at various places, but only the large bed has ever been shown to be of value. Most of the accessible mines and prospects were visited and



A. COAL-BEARING STRATA IN LOWER PART OF MANCOS SHALE AT THE BOWEN MINE ON BRUSH CREEK, VERNAL FIELD.



B. CONCRETION TYPICAL OF A SANDSTONE STRATUM OVERLYING THE MANCOS COAL OF THE VERNAL FIELD.

measurements taken of the coal, as well as a set of representative samples for chemical analysis. The results of the analyses are included in the list on page 250. The thickness of the bed and the nature of its partings are well shown in the table of measurements below, in which they are arranged in the order of their position along the outcrop from northwest to southeast. The more detailed descriptions of these mines are given on subsequent pages.

Measurements of the lower Mancos coal as mined near Vernal.

	George Gray mine.	Joseph Rich mine.	A. N. Timothy mine.	C. C. Rich mine.
Roof (white sandstone).	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*
Coal	1 10.5	2 3	1 11.5	1 6.5
Bone	11	9	8.5	10
Coal	7	9.5	10	9
Bone	7.5	5.5	3.5	4.5
Coal	10.5	11	11.5	9
Bone	2	3.5	5.5	4
Coal	6.5	6.5	6	4
Floor	Bone.	.....	Bone.	.....
Total coal	3 10.5	4 6	4 2	3 4.5
Total bed	6 7	5 11	5 8.5	4 11

The coal bed at the Gibson mine north of Vernal, that in the prospects near the Pollard mine on Brush Creek northeast of Vernal, and that at the Bowen mine farther south on Brush Creek east of Vernal, all show much resemblance to the sections given above, especially in the character of bony beds and partings contained, although the actual thicknesses vary considerably from place to place.

QUALITY OF THE COAL.

As may be seen by reference to the analyses given, the coal from the various mines is of very much the same quality and degree of fuel efficiency. It is very similar to the average Mesaverde coal of the Meeker district, and is quite distinctly inferior to the better coals of the Newcastle and Glenwood Springs districts. The abundance of bony material in the bed is the chief disadvantage and interferes rather seriously with economical mining. This feature may also result in a relatively high percentage of ash in the product marketed.

The variation along the outcrop of the bed is relatively slight, probably not greater than that likely to occur in almost any coal bed. The only apparent exception is found in the mine due north of Vernal, which had not been worked for some time when the sample was taken, and the coal of which had evidently deteriorated somewhat by exposure to the air.

The lower limit of efficiency of high-grade bituminous coals as shown by such calorific determinations is approximately 12,000 British thermal units, so that the best of the coals in this region fall just within that class.

DEMAND AND MARKET.

The coal directly available in this district is limited in amount, especially when compared with the extensive coal fields in the adjacent parts of Colorado. The local demand for domestic use is already a considerable factor, probably as much so as it will be later when the coming of a railroad may open up the competition with the larger fields to the east.

DESCRIPTION BY TOWNSHIPS.

According to the plan followed in description of the Colorado coal fields, the townships known to contain coal are here briefly reviewed separately. They are considered in the order in which they are encountered in tracing along the outcrop, beginning at the state line on the east. The field lies wholly in Utah, and all townships are referred to the Salt Lake meridian and base lines. Description of any particular township is most easily found by reference to the table of contents, pages 7–8.

T. 6 S., R. 25 E.

The coal-bearing rocks of the Mesaverde formation extend across the state line from Colorado into Utah, where they are in unsubdivided territory south of T. 6 S., R. 25 E. As the outcrops of these beds swing north in this locality around the western termination of the Midland anticline, they extend into the valley of Cliff Creek on the south side of Cliff Ridge and then turn west. In this township there is little surface indication of the coal beds that are included in the Mesaverde strata. The most prominent features of the whole formation are a small group of basal sandstones forming a ridge of similar stratigraphic position and resembling the rim rock of Raven Park. The outcrops of these beds form a distinct hogback, which traverses the southern half of the township in a broad, smoothly rounding curve. The dips in these lowest Mesaverde strata are steep, ranging from about 60° to 70°, in a southerly and westerly direction, being inclined away from the mountain uplifts. The upper part of the Mesaverde rocks, including the coal-bearing beds, are almost entirely concealed in the broad flat valley that lies between the rim rock and Raven Ridge. Occasional exposures and one or two coaly beds were found in the wash gullies that cut the valley. No evidence of the value of the coals was obtained, and the area indicated as coal land on the geologic map is based on the assumed continuity of the group of workable beds observed in neighboring parts of Colorado. The limits assigned to the area mapped as coal land are based on a calculated interval stratigraphically overlying the rim rock. Raven Ridge to the southwest of the Mesaverde rocks is composed of the variegated beds of the Wasatch formation, doubtless representing an

interval near the upper part of that formation. Beds at the summit of Raven Ridge contain an abundance of perfectly preserved gastropods (*Goniobasis* near *convexa* M. and H., as determined by Dr. W. H. Dall) similar to forms elsewhere found in the Wasatch.

Owing to the failure to locate any of the undoubted government corners of the original surveys in this part of the field no attempt to classify these coal lands has yet been made. A comparison of the old township plats of the area with the map of the present survey (Pl. XXI), which was adjusted on a basis entirely independent of any data from the plats, seems to indicate that surveys must have been made in part at least and that they were probably very nearly in correct position, and might even be fairly satisfactory to-day had the corners been permanently set and properly marked. It is, however, hard to explain how secs. 27, 28, 33, and 34 could have been neglected as "unavailable mountains" by the original surveyors, when they are in truth chiefly comprised in a rather smooth open valley.

T. 6 S., R. 24 E.

The condition of the land surveys in T. 6 S., R. 24 E. is evidently very similar to that just discussed. Some corners may be known to and accepted by the inhabitants of the neighboring region, but owing to the necessarily hasty nature of the present examination, and the failure to obtain any satisfactory information from the inquiries made in the field concerning such corners, it was not considered advisable to do more than make a rapid reconnaissance survey of the area.

The Mesaverde coal-bearing rocks extend through the central part of the township from east to west with very uniform trend and a southerly dip ranging from about 30° to 70°. The southern part of the township is occupied by the Tertiary strata, some of which approach badlands in character in their manner of dissection by drainage channels and were designated "unavailable mountains" on the present land office survey plats of the region. The northern part includes a portion of the end of Section Ridge, with the sharply folded Jurassic white sandstone and ridges of the Dakota and lower Mancos to the south. The valley on the outcrop of the Mancos shale, which occupies the interval between the Dakota and Mesaverde ridges, is a broad rolling prairie, and the bottom lands on Lower Cliff Creek are locally known as "Cocklebur."

The Mesaverde formation appears to have been reduced to a thickness between 1,000 and 2,000 feet by erosion and the overlap of the Wasatch strata. Owing to the unsatisfactory nature of the land surveys only a hasty examination of this territory was made, and the coals were traced in a rather general way.

A single development was noted in a gulch about 2 miles south of Cocklebur. At this place an old mine, from which a considerable

amount of coal appears to have been dug at some time in the past, seems not to have been worked recently. A claim stake and posted notice 120 yards northwest of the mine, stating the location as 40 rods north of a section corner whose description is not now legible, is signed by "H. & E. Bennion and Benson, owners." The entry runs down the dip, which is 35° S. 85° E., and is accessible for 30 feet or more. The mine has a roof of sandstone, which is apparently sound. The coal bed is at least 7 feet thick, the lower part of the bed being concealed so that it could not readily be measured. About 2 feet from the top of the coal there is a streak of bone about 1 inch thick, which is the only visible break in an otherwise solid bed. The mine is about 400 yards south of the rim rock, and if a constant dip of 35° is assumed for the intervening section this distance gives an estimate of 700 feet for the stratigraphic thickness of the Mesaverde below this coal. As the lower part of the section is, however, of much steeper dip where measured along the rim-rock ridge near by, this figure is probably an underestimate by several hundred feet. The mine is equipped with a wooden track and whim for hauling out the coal. The mine is 9 to 10 miles from the ferry at Jensen on Green River, which is the nearest present market for the coal, over a rather poor and hilly road. This fact probably accounts for the present suspension of work in the entry, as there is considerable demand for the coal in the Green River valley, and the coal itself has the appearance of a very satisfactory grade, well suited for domestic use.

T. 6 S., R. 23 E.

The Mesaverde coal-bearing rocks continue westward through T. 6 S., R. 23 E., in a manner very similar to that described for the townships to the east, this formation outcropping as a relatively narrow strip with dips of 30° to 50° S. Although the rocks as a formation were traced continuously within one-half mile of Green River, very little indication of the coals which may be included was observed. A bed of coal is said to have been opened and used to some extent in the bluff on the east side of the river bottoms, but this was not located or examined. From the evidence of coal known both east and west of the township it is fair to assume that more or less coal may be discovered at the locality. The southern part of the township is occupied by the badlands formed of the lightly dipping Wasatch strata, under which the coal-bearing Mesaverde is doubtless continuous. This, however, can hardly be considered coal land until further evidence of the continuity and depth of workable beds can be obtained.

T. 6 S., R. 22 E.

As already noted, coal is reported in the bluff on the east side of Green River, in T. 6 S., R. 22 E. So far as known no beds have ever

been opened on the west side of the river, although the Mesaverde rocks may be readily traced diagonally across the northwestern corner of the township with a fairly constant dip of about 35° S. The Mesaverde rocks are limited above by a very constantly occurring bed of coarse conglomerate, marking the unconformity as a horizon that appears to be sinking relatively deeper and deeper into the underlying formations as it is traced to the west. This feature probably accounts for the disappearance of the more valuable coal beds of the Mesaverde coal groups. To the south and west from the Mesaverde ridge the red-banded Wasatch strata can be seen dipping away at lighter angles, becoming horizontal and even rising slightly in the far distance. These later Tertiary rocks thus occupy a great extent of barren or badlands topography south of the Green River valley.

T. 5 S., R. 23 E.

So far as known no coal has been observed in T. 5 S., R. 23 E., but the horizon of the older Vernal coal (Mancos) is represented in section 21 along the banks of Green River, just north of the Jensen ferry. These rocks and the older formations here encircle the westward-pitching apex of the Section or Cliff Ridge anticline, the outcrops swinging back into a broad reentrant syncline between that fold and the Split Mountain anticline to the north. Coal is found at this lower horizon around the western base of Split Mountain in the next township north.

T. 5 S., R. 22 E.

The greater part of T. 5 S., R. 22 E., is occupied by the Mancos shale, the surface of much of which approaches badlands in character, being eroded into bare yellow clay hills intricately dissected by wash gullies. The Mesaverde formation crosses diagonally through the extreme southwest corner, and coal has been mined from these rocks in section 31. This old mine is reported to have been opened by Mr. George A. Slaugh and others of the town of Vernal about fourteen years ago, and has been worked at intervals until about 1904. At the depth then reached the bed is said to have broken off abruptly, probably owing to a local fault or slump. The mine is on the northeast side of an isolated hill on the west side of the valley. A slope for mining was driven down the dip a distance of 100 feet or more under a good sandstone roof. The old entry had caved much at the time of visit and did not appear to be in a safe condition. The coal exposed near the entrance was 3 feet 5 inches thick, but the whole bed is reported to have been about 5 feet as worked. The coal has a strong smell of asphaltum or oil, and as it occurs just below the outcrops of the asphaltum deposits that material has very likely saturated the coal as it has also much of the neighboring rock. The coal is said to have caked somewhat when burned,

spreading over the grates and forming a heavy clinker, a property possibly due to the asphaltum it contains. It is also reported to slack rapidly—within a month after being taken from the mine if left in the open air. The strike of the beds at the mine is N. 42° W. and the dip 22° SW.

Above the coal is the stratum of coarse conglomerate supposed to mark the base of the Tertiary formations, and southwest of the ridge and in rocks stratigraphically overlying the Mesaverde are the badlands developed on the red and white Wasatch strata.

T. 5 S., R. 21 E.

The Mesaverde coal-bearing rocks outcrop in a continuous narrow strip along the eastern base of Asphalt Ridge, which passes diagonally through T. 5 S., R. 21 E., from southeast to northwest. So far as known to the author no workable coal has ever been opened in this area, although mines, as described, have been opened just beyond its limits on the Mesaverde outcrops in both directions. The greater part of the township, including and southwest of Asphalt Ridge, is occupied by the Tertiary strata.

T. 4 S., R. 22 E.

T. 4 S., R. 22 E., includes the western termination of the Split Mountain anticline, which pitches toward the west and disappears very abruptly in the general valley level. Brush Creek cuts across the extreme western end of the fold, and along this valley the lower Mancos coal has been opened and mined at several points.

Bowen mine.—The Bowen mine presents what is probably the best showing of the lower Mancos coal in the eastern part of the Vernal field. This is probably the identical horizon of the coal mined northwest of Vernal and, judging from the similarity of the bed at the two localities, is probably a single continuous coal bed. The mine is located in section 25 on the west side of Brush Creek. (See Pl. XXII, *A*.) The coal occurs about 50 feet or more below an upper sandstone of the group in the lower part of the Mancos, which is especially characterized by the occurrence of large spherical concretions. The roof consists of 6 feet of bluish to brownish gray shale overlain by massive sandstone 8 feet thick. The coal itself measures approximately 5½ feet in thickness, and owing to its badly weathered condition near the mouth of the old entry it was not possible to distinguish the precise limits of the various benches. A well-defined seam of hard white to brownish clay, 2 inches thick, occurs underneath the top 2 feet 8 inches of coal. Mr. John O. Evans, who had worked in the mine, states that it was opened sixteen years ago (1891); he gives from memory the following section of the coal worked:

Section of bed as mined at Bowen mine, on Brush Creek.

	Ft.	in.
Bone		4–5
Coal	2–2½	
Dirt		6–8
Coal, about	3	

Both benches were mined for sale. A clay seam noted at the entrance to the mine that formed the center of the dirty streak described in the section above is said to have pinched out in the mine. The depth of the entry is reported to be 175 feet.

Green mine.—A coal bank known as the Eph. Green mine, situated at the northern edge of section 24, near Brush Creek, has been worked to a small extent, and although the entry was not examined in detail in this work, it doubtless opens the same bed of coal as that in the Bowen mine. The coal is said to have contained too much dirt to be worked to advantage. Coal exposed near the Brush Creek road just north of this locality is apparently bony and of doubtful value. North of section 13 the ledges of the Dakota and of the lower sandstone of the Mancos are folded in a rather sharp westward-pitching anticline, a subordinate or minor wrinkle in the main Split Mountain anticline, but forming the northern limit of that structure as exhibited by the outcrops of harder formations involved. Coal of the same horizon as that already described is exposed again at the northern flank of the anticline a little over one-fourth mile south of the Jensen ranch on Brush Creek, the latter being near the township corner. Here the beds are tilted at an angle of 54° N. The coal shows as a bed about 7 feet thick, but is apparently too much mixed with sandstone and shaly material to be of any practical value. The ledge characterized by the large spherical concretions is also exposed overlying the coal. The coal is about 300 feet stratigraphically above the ledges supposed to represent the Dakota sandstone.

Island Park.—At the locality on Brush Creek last described the strike of the rocks is N. 80° E., and the trend of these beds is said to continue for a number of miles toward Island Park, but no examination of that part of the field was made. Coal is reported to be traceable for at least 3 or 4 miles northeast of Brush Creek, but is generally supposed to be too poor to mine. In conformity with the general structure of the Island Park syncline the Dakota and overlying ridges are probably continuous, following the deep reentrant curve of that fold toward the east between Split Mountain and the main Uinta Range still farther north. Thus the same beds are to be found on the other flank of the syncline where their outcrops cross Brush Creek about 10 miles upstream from the Island Park road. According to local report an old entry known as the John Packard mine has opened the coal at that place, but the coal is said to be very bony. As these beds are on the northern flank of the

Island Park syncline the dip is there to the south, and the trend of outcrops is southwestward, continuous with those in the Vernal mines.

T. 4 S., R. 21 E.

Both the Mesaverde and lower Mancos coals are found in T. 4 S., R. 21 E., the former extending diagonally across the southwest corner and the latter similarly crossing the northwest corner. The two, however, lie almost at right angles to each other in general trend of outcrop. The main center of the town of Vernal is situated in section 23. The greater part of this township is on the broad valley of the Mancos shale.

The Mesaverde coal is represented by an old entry at or near the quarter corner on the east side of section 32. No good measurement of the coal could be obtained, but as nearly as the limits of the bed could be ascertained it appeared to be 2 feet 8 inches to 3 feet 4 inches thick. According to present information this is the farthest northwesterly occurrence of Mesaverde coal in the field that has been studied. The sandstones of that formation were traced for several miles beyond the coal prospect. As in the next township south, these beds lie in the margin of the valley at the eastern foot of Asphalt Ridge and parallel to it.

The Mancos coal is here a more important bed than any known to occur in the Mesaverde formation. The single bed already mentioned as characterizing this lower horizon in the Vernal field has been opened and prospected in many places along the face of the sandstone ridge in which its outcrop is found.

The principal development in this township is a small mine on a 40-acre tract of patented coal land (the NE. ¼ NW. ¼ sec. 2) on the William Gibson ranch, 3½ miles due north of Vernal. The entry is close to the public road on the north side. The principal opening consists of a 15° slope running down toward the north for a distance of about 50 feet, beyond which the slope turns northeast along a lighter grade, under shallow cover.

The present face of the mine lies under a small wash gully, from which seepage might be expected to soften the coal, as it is near the surface. The mine has an excellent roof of massive sandstone. The following measurements were made at this place:

Section at the Gibson mine, Vernal.

	Ft.	in.
Shale, fine, dark	10+	
Sandstone and shale in thin beds, alternating	15	
Sandstone, massive, white	11	
Coal (A), hard, apparently good	1	10
Coal (B), soft (like slack, but apparently good coal)	3	6½
Clay		1
Coal (C), hard, apparently good	1	9
Floor not exposed.		
Total coal	7	1½

Three samples (Nos. 5515, 5517, and 5518) were taken from the three benches for analysis. (See p. 250.) The lower bench (C) is a bright black coal, apparently the best in the bed. All of the coal in this entry has been exposed to the air for a long time, and has evidently deteriorated much in quality. It therefore probably does not give as representative a test as fresher coal at greater depth from the same bed might have done.

Southwest of the Gibson ranch the horizon of the lower Mancos coal may be easily traced to the Ashley Creek valley where it is buried in alluvial deposits for a space of about a mile. West of that valley, in the NW. ¼ sec. 18, another mine was visited, evidently opening the same coal bed. This is an old mine, and consists of three openings or entries. Two of these are situated at the mouth of a little draw, while another and apparently the last worked is on the side of the rocky hill slope about 50 feet higher. All open the same coal bed. The strike of the beds is N. 80° E. and the dip 27° S. The coal developed in this entry appeared to be broken into several benches, of which an upper 3 feet or more was the best. The lower part had not been used, probably on account of its bony character.

T. 4 S., R. 20 E.

T. 4 S., R. 20 E., includes most of the working mines near Vernal. These are all on the same bed of coal, which, as previously stated, is of Mancos age and is associated with Benton fossils. Of these mines four were in active operation at the time the district was visited (September, 1907). They are situated about 7 to 8 miles northwest of Vernal and were known and located as follows: C. C. Rich mine, lots 1 and 2, NW. ¼ sec. 11; Almy N. Timothy mine, lot 10, SW. ¼ sec. 2; Joseph E. Rich mine, W. ½ SW. ¼ sec. 2; and George Gray mine, NE. ¼ SE. ¼ sec. 3.

The C. C. Rich mine consists of several entries situated in a little gulch that intersects the lower Mancos hogback. From the gulch bottom, drifts and slopes have been driven in several directions, along the strike of the beds and at various pitches down the dip. The massive white sandstone forming the roof of the coal is well exposed at this mine, the lower stratum lying immediately over the coal and being about 4 feet thick. Above this, other sandstone strata are exposed, as at the Timothy mine. The overlying sandstone previously noted as characterized by large brown-stained spherical concretions is about 200 feet above the coal at this place, and is almost identical in appearance with that bed as shown at the Gibson mine north of Vernal, and also at the Bowen mine on Brush Creek (Pl. XXII, *A*). The entry working at the time of examination ran in nearly on a level for about 900 feet toward the northwest, reaching nearly to the workings on the Timothy property. Side headings both above and below the main entry have been driven at

intervals. The strike at this place is N. 53° W. and the dip 12° SW. From one of these slope headings, about 540 feet in and 150 feet or so down the dip, two samples (Nos. 5513 and 5510) of the bed were taken. For analyses see page 250. The section from which these samples were taken is published in the summary on page 207.

The Almy N. Timothy mine is situated on the property next to that of the C. C. Rich mine on the northwest. The main entry starts in S. 35° W. on a slope of 12°. The roof is a large, massive, white sandstone, well exposed at the entrance to the mine. A small bed of coal above the one mined is also exposed, but is not large enough to be of any value. The main entry turns to the south and southeast, approaching the workings on the C. C. Rich property. The dip in the mine is 11°. Mr. Timothy says that it increases considerably southeast of his mine, and that this is one reason why coal has not been more extensively opened beyond the C. C. Rich mine. The following section was measured in the mine:

Section in the Timothy mine, Vernal.

	Ft.	in.
Coal	1	11½
Bone		8½
Coal, blacksmithing quality		10
Clay or shale		3½
Coal		11½
Bone		1½
Clay, white, hard		2½
Bone		2
Coal		6
Bone floor, thickness reported		4
Total coal	4	3

The Joseph Rich mine is situated northwest of the Timothy mine on the property next adjoining the latter. As in the C. C. Rich mine, the various entries on this property are in a small gulch cutting back into the lower sandstones of the Mancos, which include the coal outcrops. The entry worked at the time of visit was a slope and drift, reaching a depth of about 600 feet to the southeast. This starts in due south on a slope of 11½°, but soon turns eastward nearly on a level. From this entry a considerable number of side headings or slopes have been run down on the coal, the slopes being worked as far as ground-water level and there abandoned. The longest slope is reported to be about 1,300 feet in length below the main entry. The dip of the coal bed is 15°. Sections of the bed mined were measured at the faces of two of the entry slopes, and are as follows:

Sections in the Joseph Rich mine, Vernal.

	1.	2.
	Ft. in.	*Ft. in.*
Coal, good	2 2	2 3
Bone	6.5	9
Coal, good	1 1	9.5
Bone	7	5.5
Coal, good	10.5	11
Bone	2.5	3.5
Coal, good	6.5	6.5
Total coal	4 8	4 6

As in the other mines, the upper benches of coal are considered the best and are sold separately on the local market at $2.50 a ton at the mine. The lower benches constituting the second grade sell for $2. Samples (Nos. 5512 and 5509) from each, representative of all the coal of the bed, were taken for analysis; for results, see page 250. The analyses indicate but very little difference between the two coals so far as their chemical constitution is concerned.

Another small coal bed about 8 or 10 inches thick crops in the hillside above the main entry, but is not considered of value.

The George Gray mine is north of the Joseph Rich property, and is situated on the east slope of the coal ridge. As in the other mines the roof is a solid, massive white sandstone. The main entry runs in S. 40° E. down a short slope, which turns to the northwest on a level, with side headings at intervals running down the dip. The general section of the coal is similar to that of the other mines, as shown by the following measurements at the working faces in several of the headings:

Sections in the Gray mine, Vernal.

	1.	2.	3.
	Ft. in.	*Ft. in.*	*Ft. in.*
Coal, good quality	1 10.5	2 0.5	2 5
Bone	11	1	11
Coal, good quality	7	9.5	7
Bone	7.5	?	.....
Coal	10.5	8.5	.....
Bone	2	10	2 4
Coal, good quality	6.5	2.5	.....
Total coal	3 10.5	4 9+	3+

The strike of the rocks is N. 80° E. and the dip 14° S. Two samples (Nos. 5753 and 5511) were taken in this mine; for analyses, see page 250.

Some of the coal from this mine is separated into two grades as at the other mines, being marketed from the upper and lower benches for first grade and from the intermediate benches for second grade.

T. 3 S., R. 21 E.

Coal in the lower sandstone beds in the Mancos formation may be traced continuously from the Gibson mine northeast to Brush Creek and beyond, as has been previously stated (p. 206). Numerous prospects were noted in T. 3 S., R. 21 E., along the gulch that follows south of the outcrop of these beds, this being a minor strike valley parallel to and south of Stanaker Draw. In section 36 an entry fitted with a mine car and track had been opened, evidently to supply local demand if the coal proved of sufficiently desirable quality. The bed somewhat resembles that of the Gibson mine, as is shown by the following measurements obtained at this place:

Section of lower Mancos coal in sec. 36, T. 3 S., R. 21 E.

	Ft.	in.
Sandstone, massive	6+	
Shale, dark and carbonaceous	3	
Sandstone (roof of entry)	3	
Shale, brown		8
Coal, quality uncertain	2	9
Shale, brown	2	2
Coal	1	6
Total height in entry	7	

The thickness of the workable coal is doubtful, and it seems very questionable if the coal can be made to pay for mining, on account of the great percentage of shaly and bony material.

An old entry along the same belt of outcrop, situated approximately in section 13 or possibly across the township line to the east, is near the northeastern limit of the observed coal as traced from this township. This is just north of the road where it passes over the summit between Brush and Ashley Creek drainage, at the head of a little dry fork of Ashley Creek. A broad open entry, 10 feet or more wide and 8½ feet high, has been well worked out, running down a 16° slope S. 65° E. for a distance of 100 feet or more. The true dip of the beds was measured as 19½° S. at this place. The coal did not appear to be workable at the surface, and the entry had evidently been driven in with the idea that the brown or black shale exposed in the outcrop would change to a better quality of coal at depth. No appreciable change of this character was noted in the entry, however. The following section was obtained:

Section at entry 6 miles northeast of Gibson mine, Vernal.

	Ft.	in.
Sandstone, solid, massive bed as roof	4+	
Shale, carbonaceous		4
Coal, black, much broken, quality doubtful	1	8
Shale, brown, carbonaceous	5	
Coal, apparently good and hard		8
Clay, white, a seam like that in the Gibson mine		2
Coal, probably of fair quality		12±
Total coal	3	4±

The total thickness of the bed is evidently much increased in this direction, as compared to the other sections noted in the vicinity of Vernal.

The Pollard mine is situated on the Brush Creek side of the divide, on the northeastward extension of the lower Mancos coal, as already described, but east of T. 3 S., R. 21 E. This is just east of the prospect already described (p. 218), near the road gap between Ashley and Brush Creek drainage. The roof is a good firm sandstone. The dip of the bed is 24° SE. and the strike is N. 75° E. The total thickness of the bed is 6 feet 8 inches, a considerable portion of which is of bony material, but enough coal has evidently been found to make the bed pay for working. A single entry drift runs in 200 feet and is equipped with a wooden track and mine car.

WESTWARD EXTENSION OF THE VERNAL FIELD.

In the northwestern part of the Vernal district the continuation of the lower Mancos coal was not traced in the present work for more than about a mile beyond the George Gray mine. Numerous prospects have been opened from place to place, but it is evident that the more readily accessible croppings are being utilized first at the present working mines.

Local reports state that the coal may be followed continuously from this Vernal district around the north slope of Little Mountain where the beds bend to the southwest, and that this bed is doubtless the same as that opened at the Bob Reynolds mine on Deep Creek northeast of Fort Duchesne. The Reynolds mine is situated in T. 1 N., R. 2 E. of the Uinta base and special meridian.

Other reports state that coal has been found at several points along the south side of the Uinta Mountains, notably at localities north of Strawberry Valley on Currant and Red creeks. During 1907 a mine opened on Currant Creek was worked and the coal hauled across the Wasatch Mountains by wagon to Heber, Utah. It is thought that these beds may and probably do represent approximately the same horizon.

CHAPTER VII.

WESTERN YAMPA FIELD, COLORADO.

DISTRICT COVERED IN PRESENT REPORT.

The examination of the Yampa field in the former work in that region was not carried on in detail west of the mouth of Williams Fork, although the coal-bearing rocks of the Mesaverde and overlying formations outcrop continuously westward from the main part of the Yampa field, at least as far as Lay, Colo. In view of the recent completion of the township resurveys west of the line between Rs. 91 and 92 W., that part of the field was examined in more detail during the past season.

COAL.

MESAVERDE COAL.

DISTRIBUTION AND STRUCTURE OF MESAVERDE ROCKS.

Along the valley of Yampa River, west of the mouth of Williams Fork, the Mesaverde rocks are tilted in several broad folds. The principal structure of this part of the field is the Axial Basin anticline, which forms the southern limit of the Green River Basin. The strata rise toward the axis of that uplift, from the summit of which the Mesaverde rocks have been eroded, so that the coal field terminates with the southward-facing escarpments of Iles and Duffy mountains. Northeast of the Axial Basin uplift a corresponding syncline passes through Round Bottom on Yampa River with an axis approximately parallel to the major anticlinal fold. Northeast of the Round Bottom syncline a secondary anticline, with axis parallel to the other two folds, extends northwestward from the mouth of Williams Fork. This is exposed as far as Sand Springs, near the Craig-Lay wagon road, and doubtless influences the underlying structure much beyond that point, although concealed by the overlying unconformable deposits. The prevailing dips of all these structures are light, in the greater part not exceeding 10° to 15°.

TYPICAL SECTIONS AND COAL GROUPS.

The complete section of the Mesaverde formation exposed in the western part of the Yampa field is about 3,500 feet thick. This resembles the section of the same formation exposed in the Danforth Hills, although in the Western Yampa field it appears somewhat thinner. The evidence on which the lower members of the formation in the two fields are correlated consists of (1) the structural relations

in Axial Basin, (2) the striking correspondence in arrangement in the basal group of sandstones and shales on either side of the erosional break, and (3) the correspondence of fauna and flora obtained from the two sections, from which some representative collections have been made and studied by T. W. Stanton (p. 66). The arrangement and grouping of the coal beds in the western Yampa field correspond well with the sections exposed in the Danforth Hills. Above the lower and relatively barren zone no distinction can be made between the lower and middle coal groups, as these were described in the report on the Yampa field, and the latter thus merge into a single large coal group. The lower coal group of this part of the field, as in the Danforth Hills, is recognized as a group of relatively inconspicuous beds occurring lower than any distinguished in the groups that were formerly described in the main Yampa field.

THICKNESS OF WORKABLE COAL.

Little additional evidence beyond that contained in the former report has been obtained as to the probable total amount of available coal in the Mesaverde formation in the Yampa field. Owing to the lack of more complete exposures, these figures must still remain largely as estimates. The section exposed at the Greely prospects on Yampa River, below the mouth of Williams Fork, reveals 30 to 50 feet of coal at a minimum estimate. According to former measurements, the section so well exposed at Lay shows 55 feet of coal opened in prospect entries within a stratigraphic range of only 320 feet. The total amount of coal at that place is doubtless greater.

LOCAL DEVELOPMENT.

The most extensive development is at Lay, Colo., where the beds have been well prospected by Mr. A. G. Wallihan. Other prospects visited are those of the Greely group, a single entry in Horse Gulch, and several small prospects near Round Bottom. From none of these has any great amount of coal been mined.

AREA.

Owing to the impracticability of determining under present conditions the actual extent, thickness, and limit of outcrop of the particular beds in the Mesaverde formation, estimates of the areal extent of the workable coal lands can not be precise nor should they be taken as final. All such figures depend entirely on the depth to which beds shall be considered workable as well as on the actual limit of the lands in which the coal croppings occur. All land in which this upper coal-bearing portion of the Mesaverde formation outcrops or lies within approximately 500 feet of the surface is here assumed to be coal land. Coal is already mined in adjoining fields at least to that depth. This

estimate is also based on an assumption that one or another of the workable beds will be available from whatever point of access may prove most favorable to mining. The following summary shows the estimated area of coal land contained on these assumptions in this portion of the Yampa field.

Area of Mesaverde coal land in western Yampa field.

	Acres.
T. 6 N., R. 92 W.	9,160
T. 5 N., R. 92 W.	12,680
T. 7 N., R. 93 W.	880
T. 6 N., R. 93 W.	13,320
T. 5 N., R. 93 W.	920
	36,960

LARAMIE COAL.

DISTRIBUTION.

The outcrop of the Laramie formation extends westward from the border of the main Yampa field in a belt several miles wide, passing just north of Craig. The Laramie is doubtless continuous farther west, but is so largely concealed by overlapping beds of the Browns Park formation that its outcrops cover a relatively small area on the geologic map (Pl. XVI). The total thickness of the formation is roughly estimated as 1,200 feet in the vicinity of Craig. There is a prevailing light dip to the north and a very uniform westerly trend of outcrop except where it is deflected from this course by the Round Bottom syncline and adjacent folds.

COAL BEDS.

Coal is found at various horizons, apparently irregularly distributed throughout the formation. Near Craig and also at Hayden some large beds are found near the base of the formation. Coal of considerable thickness is found higher up in this formation, and is exposed in secs. 6 and 7, T. 7 N., R. 92 W. Other probably smaller beds of approximately the same horizon as these were observed near Lay Creek in sec. 7, T. 7 N., R. 93 W. No estimate is available of the total amount of coal in the Laramie section, as exposures are far too scattering and incomplete to afford the necessary data. About the best example observed is at the Kimberly bank just east of Craig, where an 8-foot bed of solid coal with a dip of 14° N. has been opened in a prospect entry. It does not, however, seem to have found favor with the local residents of Craig, who prefer to make a considerably longer haul to get the Mesaverde coal, rather than mine and use this coal. It is of lighter weight than the older coal and is said to slack more rapidly.

POST-LARAMIE COAL.

NOMENCLATURE AND STRATIGRAPHIC POSITION.

A considerable group of workable coals is found in the formation succeeding and overlying the unconformity at the top of the Laramie. As explained more in detail under "Stratigraphy" (pp. 79–80), these coals are for the present referred to as post-Laramie on account of the uncertainty as to whether they should be called Fort Union and classed as a part of the Tertiary system, or are an upper and unconformable part of the Cretaceous system. They form the only recognized coal group overlying the Laramie formation in this field. The principal coal group appears to be in a zone 400 to 500 feet above the basal conglomerate member already described (p. 75) as marking the unconformity at the top of the Laramie.

DISTRIBUTION OF COAL-BEARING STRATA.

The coal-bearing beds immediately succeeding and overlying the Laramie in the Yampa field outcrop in a belt of hills and ridges north of the Laramie district. They extend continuously westward from the vicinity of Cedar Mountain to and probably beyond the vicinity of Maybell. At the western end of the traced outcrops the formation is concealed by the unconformable Browns Park beds.

CHARACTER OF THE COAL.

The analysis of this coal (No. 5514), given on page 248, shows it to be of somewhat lower efficiency than the average Mesaverde coals of the Yampa field. The coal would probably fall in the class of subbituminous coals formerly described as black lignite. The amount of moisture (12½ per cent in air-dried coal) is rather too high to permit it to be placed in the class of bituminous coals, although the percentage of fixed carbon (50 per cent) compares very favorably with many of the high-grade coals. The ash (7½ per cent) is a fair average for much commercial coal. Its appearance when first mined is very like that of the high-grade bituminous coals. The principal disadvantage among its physical properties is its ready slacking when exposed to the air. Its grade is considerably better than that of many coals considered valuable in coal fields elsewhere in the United States where the better bituminous coals are not so readily available.

Some of the coals of this group are also opened in Spring Creek gulch in T. 7 N., R. 95 W., where several local banks have been worked at various times.

THICKNESS OF WORKABLE BEDS.

All of the coal beds of this group are not exposed in any one section, and hence complete measurements were not obtained in the present

work. Mr. A. G. Wallihan, of Lay, states that some good exposures are to be found in the ridge west of Emerson's ranch on Lay Creek, where he claims to have opened by digging about twelve different coal beds, ranging from 4 to 20 feet in thickness and aggregating a total of over 100 feet of workable coal as measured at the croppings.

AREA.

The total estimated area of coal land in which the coals of this group may be considered available is as follows:

Area of the post-Laramie coal land in western Yampa field.

	Acres.
T. 7 N., R. 92 W.	560
T. 8 N., R. 92 W.	4,520
T. 8 N., R. 93 W.	5,160
T. 7 N., R. 94 W.	2,520
T. 8 N., R. 94 W.	2,720
T. 7 N., R. 95 W.	2,400
	17,880

DESCRIPTION BY TOWNSHIPS.

In conformity with the plan adopted for giving the detailed descriptions of the other coal fields considered in this report, the townships known to contain coal in the Yampa field will be reviewed in order, according to the tracing of the various groups of coal, beginning at the eastern limit of that part recently examined and following the separate groups west, township by township, as far as they are now known. All the townships are referred to the sixth principal meridian, Colorado. It has not seemed feasible to arrange the township descriptions in a strictly numerical order, but any particular area may be readily found by reference to the table of contents, page 8.

T. 7 N., R. 91 W.

Owing to the incompleteness of the land surveys and the lack of land corners on which to base the work, no attempt has yet been made to classify the coal lands included in T. 7 N., R. 91 W. Coal of workable thickness undoubtedly occurs in various parts of the area. The lower coals of the post-Laramie beds extend into the township from the northwest corner of section 7, and are readily traceable to the southeast for a distance of a little over a mile, where they are overlapped and concealed by the white sandy material of the Browns Park formation. If not so buried the outcrop of these coals could doubtless be traced continuously under the southern end of Cedar Mountain and thence eastward to where they are again exposed in the eastern half of the township. Here, as elsewhere, though the coals themselves are concealed their position can often be inferred as occupying a position at a fairly uniform interval above

the outcrop of the conspicuous white sandstone and the overlying pebble or bowlder beds marking the base of the post-Laramie rocks. No measurements of the thickness or number of beds in this group can be given as representative of this area, but exposures at the outcrops indicate several beds that are very probably of workable thickness, and are assumed to be of quality similar to those opened at the Blevins, Richardson, and Seymour mines.

A lower and older coal group also outcrops in the southern part of the township, extending entirely across the area in an approximately east-west course. This coal consists of a group of several beds, one of which is opened by an entry slope known as the Kimberly bank, 2 miles east of Craig, and exposes an 8-foot bed of solid coal. This is one of a group of coals, there being several other beds exposed near by along the hillside. An old prospect in this township on one of the coal beds of this group is situated just south of the northwest corner of section 35, 1 mile northwest of the center of the town of Craig.

T. 7 N., R. 92 W.

The greater part of T. 7 N., R. 92 W., is covered by the unconformable white sandy deposits of the Browns Park formation. In its northern half the Laramie and post-Laramie beds are well exposed, dipping northward at light angles. Coal was noted in the Laramie formation in section 7, and also in the southern part of section 6, where an outcrop exposes a bed apparently 10 feet thick or more. No other occurrences of coals of this group were observed, although they may and doubtless will be revealed on further search or prospecting.

The lower coals of the post-Laramie strata may be traced almost continuously across the northern margin of this township and the southern part of the adjoining township to the north. (See Pl. XVI.) The coals of this group are opened at one place in the SE. ¼ NW. ¼ sec. 2 by a mine that has been worked for local supply. This entry is reported to be 100 feet or more in depth on a bed of coal 7 feet 2 inches thick. The coal at this place is overlain by 2½ feet of soft clay or shale that makes a rather weak roof, and about 2½ feet of the top of the coal has been left to support the entry. No information was obtained regarding the quality of this coal, as the mine did not appear to have been worked for some time, and the coal exposed on the dump was reduced to fine slack. There are doubtless other coal beds of workable thickness in the section exposed near by, but no further data regarding them have been obtained.

T. 8 N., R. 92 W.

As already explained, the outcrops of the coals of the lower group of the post-Laramie beds have been traced into T. 8 N., R. 92 W.

along its southern side. They extend to the west across the township to the northwest corner of section 31. They have a light dip to the north, and thus pass under the valley formed on the soft Browns Park and Wasatch formations within a distance of about 2 miles. Although the outcrops of one or more of the coal beds can be readily traced across the township, at no place noted was the coal sufficiently well exposed to obtain any measurements of its thickness. There are assumed, however, to be at least one and probably more beds of workable thickness. This coal is thought to be fairly comparable in quality with that from the Blevins mine, the analysis of which is given on page 248.

T. 8 N., R. 93 W.

The lower coal group of the post-Laramie beds outcrops in the southern part of T. 8 N., R. 93 W. The horizons of some of the larger coals may be traced by black or smutty indications almost continuously across the township from the northeast corner of section 36, to approximately the southwest corner of the area. These beds have been mined at one place, there being a mine in the NW. ¼ sec. 28 known as the Blevins mine, from which coal has been obtained for use at the placer dredge and a steam pumping plant near by. Since the party has left the field, report has been received stating that another mine in the same locality has been opened by another of the operators in the placer mining fields. The coal at the Blevins mine appears to be representative of the character of most of the coals of this group.

It has been estimated that about 5,160 acres of land in the township are underlain by workable coal, accessible either near the outcrop or by shaft or slope within 500 feet depth from the surface. The strata dip toward the north at light angles averaging from 4° to 6°. While workable coal doubtless underlies the whole northern part of the township, it is evidently under a considerable thickness of superimposed beds, the surface, where not concealed by the alluvium and scattered drift, being largely composed of the variegated Wasatch strata.

The Blevins mine is situated in the NW. ¼ sec. 28 on the west side of the canyon of Lay Creek, about 7 or 8 miles north of Lay post-office, just below the valley in which the placer dredge is located. The view given in Plate XII, *B*, (p. 118) was taken at the entrance to this mine. The entry is started in a N. 38° W. direction, on a light pitch in a broad high slope, so that wagons are driven directly to the face of the mine for loading. The height of the entry measured along one of the props was found to be 11 feet 9 inches, of which 5 inches at the top represent part of the roof, and should be excluded from the true measure of the actual coal bed. The roof is composed

of a fine laminated blue or gray clay above the solid bed of bright black coal. Above the clay is a massive coarse white sandstone, apparently a double stratum, at least 40 feet thick, which forms the actual roof in the mine, for the blue clay comes down in mining with the coal. The dip of the beds is about 4° N. 5° E. The coal bed itself is apparently without seam or parting. The floor is covered by 4 or 5 inches of bony coal, below which is a solid white sandstone. There are no signs of burning at the outcrops in this immediate vicinity. The coal is brittle and breaks down at the face of the mine very easily when loosened; but it is so tough that it can not be picked out before it is broken and has to be shot. A considerable amount of coal has been taken out chiefly for use at the dredge. It is reported that three weeks' exposure to the open air will slack the coal completely. When first fired the coal emits a pale blue smoke resembling that of light wood, which soon burns off to a clear smokeless flame.

The analysis of this coal, given on page 248, shows it to be of somewhat lower efficiency than the average Mesaverde coals of the Yampa field. It is, nevertheless, of much higher quality than many coals considered valuable in other fields where the higher grades are not so readily accessible, and with scarcely any doubt it will prove to be a valuable asset when these fields are most completely developed.

A number of other beds, said to have been opened by prospects in the past and to have shown a very considerable thickness of workable coal, are indicated on the hillsides near by. These could not be measured at the time this examination was made without rather extensive prospecting.

T. 7 N., R. 93 W.

Both the Mesaverde and Laramie coals occur in T. 7 N., R. 93 W. In the southwestern part, near Lay post-office, a group of well-developed prospect entries on Mesaverde coal has already been described.[a]

The greater part of the Lewis shale interval between the Mesaverde and Laramie is apparently covered at outcrop by the unconformable Browns Park formation, and this is probably also true of a considerable portion of the lower beds of the Laramie formation.

The only observed outcrop of the Laramie coals is near the southeast corner of section 1, already noted in the adjoining township to the east. Some indications of this group of coals have been observed near Lay Creek in section 7, but so far as known no coals of workable thickness have been found in the group near that locality. In the northern part of the township the strata dip from 5° to 10° N. As already described (p. 225) the post-Laramie coals lie north of this township.

[a] The Yampa coal field: Bull. U. S. Geol. Survey No. 297, 1906, p. 63. The Danforth Hills and Grand Hogback: Bull. U. S. Geol. Survey No. 316, 1907, pp. 275, 276, 297.

T. 8 N., R. 94 W.

Coal was observed in this township along its southern border. It is thought the boundary at the base of the Wasatch runs from east to west across the southern part of the township, and as the beds observed have a gentle dip toward the north, the coals probably lie beyond available depth throughout most of the area. A thick bed of smut was observed on the township line near the middle of the south side of section 33. Other outcrops of coal were noted in sections 32, 35, and 36. These coals are of the post-Laramie coal group already described as represented at the Blevins mine. Toward the southwest corner of the township they apparently disappear beneath the unconformable cover of the Browns Park formation and the scattered gravel deposits.

T. 7 N., R. 94 W.

Coal is known only in the northern part of T. 7 N., R. 94 W., the greater part being occupied by the loose white sandy deposits of the Browns Park formation. The greater part of the Laramie formation is also concealed by this cover, and the coal beds noted are post-Laramie beds of approximately the same horizon as the Blevins mine. An old entry drift, now caved, is situated on the township line in the NW. ¼ sec. 2. Here the coal is evidently more than 10 feet thick and has apparently been mined at some time. Another coal thought to be of considerable thickness, and somewhat higher in the section, is exposed near the top of the hill in the NE. ¼ sec. 2. Other similar exposures were noted in sections 3 and 4. West of that point all underlying strata are evidently masked by superficial deposits already mentioned. No authoritative estimate can be made of the quality of the coal observed, but it is assumed to be similar to that of the Blevins mine.

The Mesaverde coals are probably upturned and eroded in a belt somewhere across the southern part of the township, but no information has been obtained as to the depth at which their upper limits have been buried.

T. 7 N., R. 95 W.

As in the case of the township adjoining on the east, the greater part of T. 7 N., R. 95 W. (Pl. XVIII), is occupied to an undetermined depth by the loose white sandy sediments of the Browns Park formation and the scattered gravel deposits. A single well-exposed section of the underlying strata on Spring Creek, about 2½ miles north of Yampa River, shows a portion of the coal-bearing rocks that probably extend continuously across this area. Several local coal banks have been opened in the canyon of Spring Creek at this place (sections 10 and 15), developing coals of the Laramie and post-Laramie beds, doubtless including some of the same horizon as those of the Blevins coal group. The section at this place reveals a thickness of 3,600 to 4,000

feet of strata, underlying the varicolored clays of the Wasatch and containing coal at a number of horizons. Many of these appear to be thin or are probably very incompletely exposed at their outcrops. They appear to be in two groups, the lower distributed through 1,000 feet more or less near the base of the section exposed, and the higher, containing one or more workable beds, about 1,500 feet above the top of the lower. It has been assumed that these represent the Laramie and post-Laramie coals that have been described in other parts of the field, although conclusive evidence on these correlations is not now at hand.

Several local banks or entries were noted in Spring Creek gulch at this locality, and from reports it seems that each of these has been known at various times as the Barber mine. One entry on the east side of the gulch in section 10, near the section line on the south side in the southeast corner, exposes a bed of coal 5 feet 10 inches thick. The dip of the strata is about 60°, which is very much the same as that recorded at various places throughout the section. The roof is solid white sandstone, and the floor is shale underlain by white sandstone. The entry is about 50 feet in, and was reported to have been worked intermittently for a year and a half at the time of visit.

Another entry on the west side of the gulch just across from that described above probably opens a lower bed of coal. No measurement of the thickness was obtained.

A third entry about one-half mile north of the other two and situated on the west side of the gulch exposed a bed of coal about 6 feet thick, but was caved in the entry. The roof is white sandstone.

T. 7 N., R. 96 W.

Coal is reported in T. 7 N., R. 96 W. (Pl. XVIII), in the lower valley of Sand Creek, somewhere in the vicinity of sections 10 and 15, but the locality was not examined in the field work of the past season. The variegated Wasatch beds were observed in the southern parts of sections 2 and 3, with a rather steep northward dip, indicating that a section similar to that described on Spring Creek in T. 7 N., R. 95 W. (p. 228), would be found farther south if not concealed by more recent overlapping deposits. The available coal of this township is doubtless of very limited extent owing to the prevalence of the recent unconformable deposits, which cover most of the area and conceal the underlying beds.

T. 6 N., R. 93 W.

A considerable proportion of T. 6 N., R. 93 W., is coal land, containing the most valuable coals of the field, namely, those of the Mesaverde formation. The outcrops of strata have a general trend from southeast to northwest across the township and dip northeasterly at angles that vary from 3° to 10°, and in some places are

somewhat greater. The base of the workable coals follows approximately the course of Yampa River, although not conforming to the meandering channel of that stream. The coal is represented at the surface by a great amount of burned rock, resulting from the combustion of much of that lying near the surface, with more rarely a natural outcrop of one or more of the beds themselves in the canyon sides or on the hill slopes.

Aside from the well-exposed beds in the Lay district just northwest of this area, there is also an excellent and very complete section exposed along the line on the south boundary of section 6. At that place coal was noted at at least 15 horizons of the rocks exposed, the beds being very uniformly distributed through approximately 1,500 feet of strata.

Other well-exposed and nearly complete sections noted are those of lower Horse Gulch and lower Sand Springs Gulch, which cut the strata almost directly across the general trend of their outcrops. An entry on Horse Gulch, one-fourth mile north of its junction with Yampa River, has been worked to a small extent to supply a local demand in the river valley a few miles farther down. The coal exposed in the entry is 6 feet 10 inches thick, is apparently of good quality, and is hard. The mine consists of a small room entry about 50 feet in depth, fitted with a mine car and a short track. The roof is a very irregular bed of gray carbonaceous clay, apparently overlain by sandstone. The beds have a dip of 10° N. 50° E. The floor is very flat and smooth, but is not exposed at all in cross section, and so may contain more coal than that shown in the present entry. Along the gulch, within the next mile above the mine, other coal beds are exposed, one at least 10 feet thick outcropping near water level about one-fourth mile from the mine.

Many exposures of coal were noted throughout a large part of the township, but no attempt was made to trace individual beds. The general area in which the larger coals or the rocks with which they are commonly associated occur, is undoubtedly valuable coal land. A total area of 13,420 acres in this township is estimated as containing workable coal at a commercially available depth, for which an estimated maximum limit of 500 feet is adopted.

T. 6 N., R. 92 W.

T. 6 N., R. 92 W., like that next west, is underlain in large part by the valuable coal beds of the Mesaverde formation. Structurally this district is rendered somewhat more complicated than the latter by the Round Bottom syncline and an anticline corresponding to it in the northwestern part of the district.

So far as known the valuable coals exposed all belong to the Mesaverde formation, although the base of the Laramie formation occupies the structural depression in the center of the Round Bottom

syncline in the northwestern part of the area. No workable coals in the lower Laramie strata were observed in this part of the field.

Under the influence of the broad gentle folds in the rock structure of this district the outcrops of the strata swing around the apex of the northwest-southeast axis of the Round Bottom syncline, passing through Round Bottom Park on Yampa River. A large part of the outcrop of Mesaverde coal-bearing rocks swing south of Yampa River into T. 5 N., R. 92 W., near Round Bottom, but recross to the north again on the eastern and steeper flank of the syncline, which is the western limit of a corresponding anticline in the eastern half of the township. Since this fold extends northwesterly in the direction of Sand Springs it is referred to by that name. The evident termination on the north of the Mesaverde rocks of the Sand Springs anticline is about a mile south to southwest of Sand Springs. The continuation of this structure to the northwest is indicated by the broadened valley or sand-hill character of the country, but the structure itself is wholly masked on the ground by the unconformable and flat-lying Browns Park formation.

The area that is here referred to as coal land in this township does not include the northwest portion of the Sand Springs anticline. While there are doubtless valuable coals at workable depth in some of the portion thus excluded, the outcrops that were noted at the surface were all small and apparently not important, and inference as to the beds underlying was considered rather problematic. Coal of workable thickness is exposed in many other parts of the area, as in Fuhr Gulch and near Round Bottom, and has been quite extensively developed by prospecting in the canyon of Yampa River just below the mouth of Williams Fork.[a]

T. 6 N., R. 91 W.

T. 6 N., R. 91 W., is wholly included in the area mapped and described in the Yampa coal-field report.[a] Few additional data were obtained in the present work, and no attempt was made to classify these lands, owing to the incompleteness and imperfections of the present land surveys. Remapping of this area in greater detail was undertaken in the summer of 1909 by a party under the direction of J. A. Davis. The townships are to be mapped on the scale of 2 inches to the mile and the coal beds prospected and traced by means of stadia surveys as completely as may prove practicable.

T. 5 N., R. 91 W.

The area included in T. 5 N., R. 91 W., was mapped and described in the Yampa coal-field report.[b] Some additional information about the trend of the strata on Iles Mountain in the eastern part

[a] See description of the Greeley prospects, in Bull. U. S. Geol. Survey No. 297, 1906, pp. 60–61.
[b] Bull. U. S. Geol. Survey No. 297, 1906, p. 58.

of T. 5 N., R. 92 W. has led to a modification of the geologic boundaries drawn in the former work. However, even this revision is provisional, as further detailed investigation was not then considered worth while in the present inadequate state of the land surveys in this part of the country east of R. 92.

T. 5 N., R. 92 W.

T. 5 N., R. 92 W., consists for the most part of the upland known as Iles Mountain (Junction Plateau of the early maps), this being a broad cuesta sloping toward the north, whose abrupt escarpment faces south and overlooks Axial Basin. The southern part of the township is thus barren of coal as far north as the escarpment rim. Among the lower beds of the Mesaverde formation there are one or two small beds of coal which have evidently been dug into in Milk Creek canyon, but which do not appear to be of commercial value. The principal coal-bearing rocks occur considerably higher, as indicated by the boundary shown on the map, the rocks dipping from 5° to 25° N.

North of the outcrop of the "white rock," coal beds are rendered conspicuous by the great extent of the burning that has taken place, which has colored brightly many of the ledges and cliffs. There are some prospect entries on the coal beds in the valley of Yampa River and on some of the tributary gulches, but none have been recorded in sufficient detail to deserve special mention.

T. 5 N., R. 93 W.

T. 5 N., R. 93 W., is occupied in its northern third by an elevated cuesta known as Duffy Mountain, corresponding to that already described as Iles Mountain on the east side of Milk Creek canyon. The escarpment faces southwest and overlooks the broad valley areas of Axial Basin, which composes more than half of the township and is barren of coal. Of the main summit of Duffy Mountain the greater part is composed of the lower relatively barren part of the Mesaverde formation, and the more important coals are apparently restricted to parts of sections 1, 2, and 12. The rocks dip 8° NE. There has been no development in the small area.

CHAPTER VIII.

HENRYS FORK FIELD, UTAH-WYOMING.

Coal has been reported from the vicinity of Henrys Fork in northeastern Utah and southern Wyoming, although very little precise information concerning its occurrence has heretofore been available. About ten days, at the close of the season in 1907, were spent in the field, reviewing the geology and looking up some of the reported occurrences of coal.

LOCATION.

The term Henrys Fork coal field has been applied in a rather indefinite way to include the area of coal croppings in the vicinity of Henrys Fork valley, near the junction of that stream with Green River. This district lies along the State line in northeastern Uinta County, Utah, and southern Uinta County, Wyo. It is 40 to 60 miles from the Union Pacific Railroad at either Green River City or Carter, Wyo., the customary mail route going to the latter point.

SCOPE OF INVESTIGATIONS.

The map (fig. 8) is republished from the former account of this work given with the general progress report for the season of 1907.[a] The present statement is essentially the same as that of the former report with minor revision, the field work being in the nature of a hasty and rather incomplete examination of this interesting and in some respects complex field. As this territory will be more naturally included with coal fields to the north now under examination by other parties in this same general work, a more complete and detailed account will doubtless soon be at hand.

STRUCTURE.

The field lies north of the Uinta Mountains and is structurally a part of the Green River Basin, or of the Bridger Basin, if the larger structural feature be considered as subdivided by the Rock Springs dome. In general, the strata are tilted to the north away from the principal axis of the Uinta Range, which separates the Henrys Fork field from the Vernal field on the south. The Henrys Fork field is

[a] Bull. U. S. Geol. Survey No. 341, 1909, pp. 310-314.

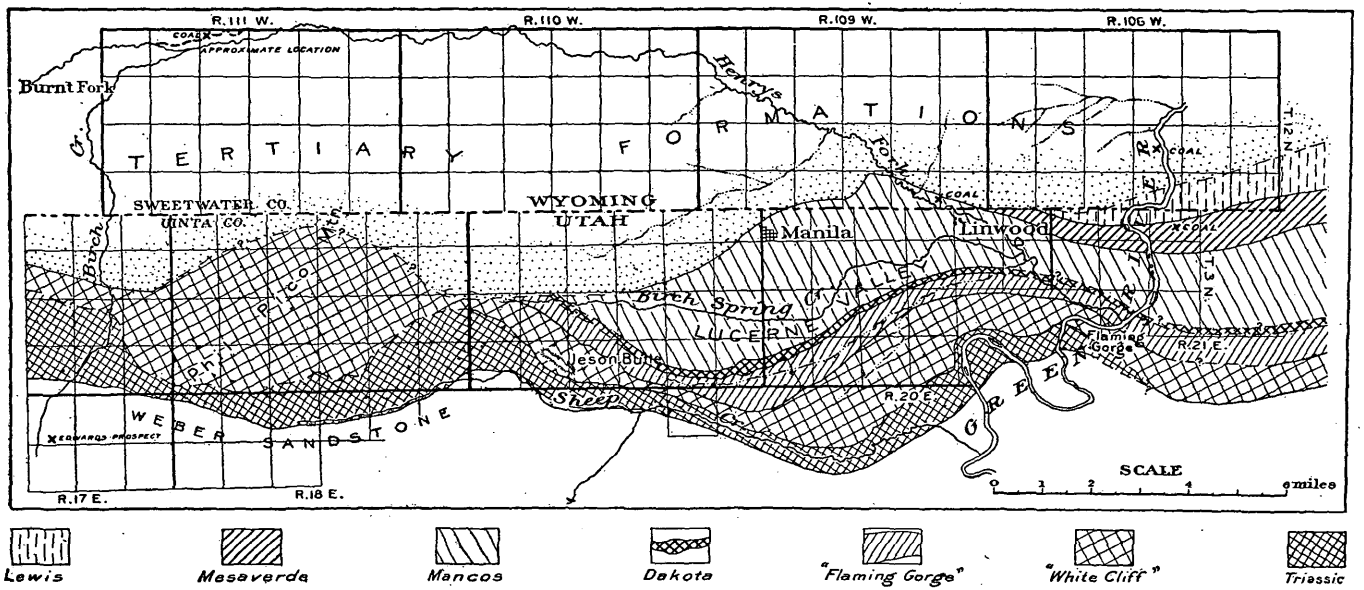


FIGURE 8.—Map of part of the Henrys Fork coal field, Utah and Wyoming.

directly related to the Yampa field, as it lies on the margin of the same broad structural basin, but its direct connection with that field is rendered somewhat obscure by the overlap of Tertiary rocks and displacement of the coal-bearing rocks by faults. It lies on the southern margin of the Green River Basin and the stratigraphic sections where fully exposed are found to be similar to that of the Yampa field. The northern flank of the Uinta Range is much broken by faults, and, as some of these are largely obscured by the Tertiary strata that unconformably overlie the older rocks, the geology of a part of the field is not very clearly revealed.

STRATIGRAPHY.

The Cretaceous formations correspond to those of the Yampa field. Where not faulted out the Mesaverde formation is coal bearing. The relations of the Lewis shale to the overlying Wasatch strata are obscure, but it seems certain that either displacements by faulting or erosional unconformity has obscured the Laramie, at least near Green River, where those beds might be expected on the west side of the valley north of the Flaming Gorge canyon.

COAL.

PENNSYLVANIAN (UPPER CARBONIFEROUS) COAL.

An older coal than any hitherto noted in northwestern Colorado was found on upper Birch Creek, tributary to Burnt Fork, which is in turn a branch of Henrys Fork of Green River. It lies in Utah, in sec. 3, T. 2 N., R. 17 E., south of Mr. Zeb. Edwards's ranch, and occurs in rocks of the same age as the Pennsylvanian coal measures.[a] Beds at the same horizon have been prospected at intervals for several miles along the foothills in this locality, but appear to be of rather uncertain value.

The coal at the Edwards prospect is said to have been tested by the Union Pacific Railway Company and the report has spread that it proved to be of coking quality. The specimens seen had certainly withstood exposure to the weather in a rather exceptional manner. Other reports state that the coal has been used in a local forge, where it burned very well and gave a good heat.

The exposure seen was in a very unsatisfactory condition. Some pits had been dug in a rather densely wooded slope, in a block of strata very evidently slipped from higher on the ridge and tilted out of its normal position. The beds were very soft and broken, in spite of which some of the coal was still hard. The coal itself lies in a very irregular bed of which no great thickness could be readily

[a] Fossils collected in the prospect pit were examined by G. H. Girty, who made the age determination and identified the following forms: *Fenestella*, 2 sp.; *Lingula*? sp.; *Spirifer rockymontanus; Pleurophorella costata*?; *Edmondia* aff. *gibbosa; Aviculipecten herziri*?; *Aviculipecten* sp.; *Naticopsis* sp.

uncovered, apparently at no place more than a few inches, although it was stated by those who had worked the prospect that the coal was 3 feet thick at the bottom of the pit. No trustworthy estimate of the true character of the bed can be made until the coal is found in place and in a normal position.

It is reported that several prospects on Burnt Fork farther west show the same bed in place; in these it is much thicker, but not of commercial value, being carbonaceous shale rather than coal.

The beds are of interest as occurring at an unusual horizon for the western fields.

MESAVERDE COAL.

The Mesaverde formation outcrops at Green River near the center of the broad valley area north of the Flaming Gorge, and just north of the mouth of Henrys Fork. Toward the west the formation is evidently cut off by a fault near Linwood post-office on Henrys Fork. East of Green River the formation may be followed as a long curved double ridge extending up the broad strike valley north of the mountains, apparently bending southward and abutting against the higher mountains, perhaps terminated there by another fault. These beds were not examined far east of Green River.

A well-exposed section of these coal-bearing rocks was found near the east river bank at the mouth of Spring Creek, about half a mile southwest of the 289th milepost on the Utah-Wyoming state line. Here the Mesaverde formation contains many massive sandstones and intervening shale bodies, which are very similar in character to the same formation in the Yampa field. The whole formation was not examined in detail but coal was found in it at several horizons. A small amount of prospecting uncovered some beds at least 5 feet thick, and local reports state that the coal has been taken out at some point west of the river for use at the ranches in the valley.

Opposite Linwood post-office, about one-fourth mile north of Henrys Fork, two thick beds of coal are exposed outcropping in nearly vertical position. These beds have been prospected somewhat but have never been worked to any considerable extent. The following section was measured at that place:

Section of coal-bearing strata north of Linwood, Utah.

	Ft.	in.
Sandstone, coarse, yellowish, flaggy and thin-bedded	15	
Coal, apparently good, and without partings	8	9
Shale, blue and gray, fine	20	
Coal, apparently good, and without partings	10	
Bone, irregular bed	1	
Sandstone, fine-grained, clayey, white	20+	
	74	9

The strike of the beds is N. 67° W., and the dip 80° to 85° S. The outcrop of this bed splits up within 200 yards to the west, and the bed changes in character, becoming chiefly a brown and gray shale with coal streaks. Toward the east the outcrop follows the direction of the recorded strike for a few hundred feet, thence bends abruptly south, and disappears under an upper terrace capped by consolidated river deposits. In the next gulch, about one-fourth mile to the east, beds of soft black shale, evidently representing the same horizon, have been prospected. Although resembling coal somewhat in appearance, the material is merely a dark clay shale. The lands including these outcrops have been filed on as coal land from time to time, but in each case filings have been allowed to lapse without completion of final proof.

As these beds occur close to a line of evident structural displacement, probably a fault of considerable magnitude, it is not certain to what formation they should properly be assigned. The rocks associated with the coal resemble the Mesaverde strata, and their position overlying the Mancos shale suggests that they belong to that formation. Coal is also found in the overlying Tertiary strata, some of which is not easily distinguishable from the Mesaverde.

TERTIARY COAL.

Coal beds in the Tertiary strata have been noted at a number of localities along the north side of Henrys Fork. Outcrops are reported in the bluff on the north of that stream for a distance of several miles east of Burntfork, Wyo., and the coal is probably continuous for a still greater distance, although no further information on this point has yet been obtained.

Some exposures of these beds were examined 3 or 4 miles east of Burntfork post-office, along a road in a little gulch leading up to the mesa, less than one-fourth mile from the creek and opposite the Mass ranch. The coal is exposed at several horizons. A coal bed near the lower end of the gulch measured 2 feet 10 inches, as shown in natural outcrop, and although considerably weathered much of it was a clear glossy black. The roof is a sandy and calcareous shale, alternately thick and thin bedded. The floor is a brown, woody clay, evidently softened by exposure. The beds are nearly horizontal, the dip being very light toward the north. The bed is evidently continuous for a considerable distance, as its croppings can be plainly traced around the hillside. The coal is doubtless of subbituminous grade, although this opinion is based on no more than a rough estimate from the appearance of the weathered exposure.

Another bed, on which a small amount of digging uncovered 2 feet of coal, is exposed 100 yards or so farther up the gulch, but the coal is doubtless somewhat thicker. A prospect drift had been dug at

this place but had later wholly caved. Some very perfect impressions of a symmetrically coiled spiral gastropod were collected from the roof of this coal bed, but unfortunately they do not determine the geologic age of the strata, except to indicate that they belong to the fresh-water Tertiary. The coal-bearing beds are very probably of Wasatch age, as they are succeeded by strata that resemble the shales and sandstones of the Green River formation, and these in turn are overlain by undoubted Bridger beds with their vivid green banding.

This locality in Henrys Fork valley, somewhere near the mouth of Burnt Fork, is described in the early Hayden reports as follows:[a]

At our camp [on Henrys Fork, near present site of Burntfork post-office] the lower Miocene beds [by which is meant the calcareous members that underlie the Bridger, regarded as a portion of the Green River group] rise up on the north side of the creek to a height of 400 to 500 feet. Near the base are layers of thinly laminated slate, limestone, and some beds of cherty limestones with plants. There are also several thin seams of earthy lignite. There are several thin layers, especially near the lignite seams, which vary from an inch to 6 inches in thickness, composed mostly of small fresh-water shells, Melanias and Unios. These layers of shells continue nearly to the mouth of Henrys Fork, and masses of them are found in every ravine and creek. No experience of my own among fresh-water shells of the present day has revealed them in such marvelous profusion as they must have existed in or near this great lake in Tertiary times. Intercalated in the marly layers are thin seams of fibrous calcite and selenite; some of the seams of calcite are 3 inches thick. Three principal features appear in the rocks as we descend the creek—(1) a large increase of lime; (2) silica in the form of black chert or flint; (3) the appearance of impure lignite. There are also petrified wood, masses of stems of plants aggregated together, yet the beds are all purely fresh-water. The style of weathering of the upper and lower Miocene is well contrasted by the character of the surface. The surface occupied by both formations is equally arid and barren, but that of the former is very rugged, forming what is usually termed "badlands," while that of the latter is more rounded and far less rugged. At the junction of Henrys Fork with Green River the geological structure is very complicated and presents one of the most interesting studies I have met with on the trip. At first glance the formations seem to have been thrown into utter chaos, but a careful examination shows the system of formations to be more complete and consecutive than in any other portion of the West. The ridges of upheaval extend from the Uinta Range across Green River, and seem to have almost entirely escaped erosion, so that they are left for our examination nearly as they were thrown up by the internal forces that elevated the Uinta Mountains.

All along the northern slope of the Uintas, from Bear River to Henrys Fork, I have sought for the absent members of the geological series, and noted the evidences of erosions which are displayed on such a stupendous scale. Not only are several members of the geological series swept away, but also the surface is covered with an enormous deposit of drift. But not until we come to Green River can we realize the vast extent of the erosion along the northern slope of the Uintas.

About 8 miles above the mouth of Henrys Fork the calcareous layers gradually disappear or cap the summits of the hills, and beds with a predominance of arenaceous sediments come in. Beds of massive yellow and gray sandstones rise above the water level as we descend, until they reach a great thickness, 300 to 500 feet. About 4 miles before reaching the mouth of the creek the valley expands out on either side. On the north side the upper portion of the bluff is a massive sandstone with a reddish tinge,

[a] Hayden, F. V., Second Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1870, 1871, pp. 59–60.

inclining at an angle of 5° to 10°, while at the base the layers seem to have been pushed up abruptly, as if there was some degree of discordancy. The same beds that dip at a small angle on the north side of the stream incline 50° to 70° on the south side and extend southwest toward the foot of the Uintas. Then comes an open area of about 4 miles, occupied by rather soft beds of yellow and steel-gray indurated clays, which I have regarded as of Cretaceous age, although I did not discover a fossil in them. On the south side of Henrys Fork, at its junction with Green River, is a remarkable exhibition of the ridges or hogbacks, which rise, ridge by ridge, to the distant summits of the quartzite nucleus of the Uintas. The formations at first sight seem to have been lifted up in such a chaotic manner that I could not unravel any system for some time.

Other coal beds in Tertiary strata were observed at the bank of Green River, north of the mouth of Henrys Fork. This locality is about 1.3 miles N. 5° E. of the 290th milepost on the Utah-Wyoming line. The coal was very poorly exposed and could not be shown to be of workable thickness without further development. A collection of fossils from neighboring rocks contains some fresh-water shells resembling clams and gastropods elsewhere found in the Wasatch, but the same species also occur in later Eocene rocks of this region.

SUMMARY OF THE HENRYS FORK FIELD.

Coal is rather widely distributed both stratigraphically and geographically in the Henrys Fork valley. Little effort has yet been made to develop or even to prospect the beds, probably owing to the fact that timber is plentiful and not hard to get. So far as known, possibly excepting the beds at Linwood, no coals of unusual thickness or importance are known to exist in the field. Many of the reported occurrences are probably of thin beds, and in case of the Tertiary coal consist of a rather light-weight (subbituminous) coal. The most promising part of the field is thought to be in the valley and east of Green River, just north of Flaming Gorge, in the Mesaverde rocks that are exposed in that locality. From the hasty nature of the present work, however, it is evident that the examination of this section of strata was too incomplete to warrant any estimate of the quality or total quantity of the coal that may exist there.

CHAPTER IX.

QUALITY OF THE COALS.

ESTIMATION OF RELATIVE VALUE.

The ordinary means of estimating the relative quality of a coal is by study of its chemical composition as shown by analysis and by determination of its heating or fuel value from results of laboratory tests made especially for that purpose. The subject of the chemical analysis of coal has received much attention, especially in the last few years, and is far too broad and technical in its nature to be entered into with much detail here. The methods and results of the experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., have been described in a number of reports.[a] Analyses made from coals collected under uniform conditions from almost every field in the United States are published in the various reports that have been issued from time to time. This growing fund of data has given and will continue to give a broader basis of understanding through analytical methods of the diverse conditions and constitutions of the different grades of coal.

As a part of this general plan, representative samples were obtained from various parts of the fields examined in the present work, and the results of 92 analyses made at the fuel-testing plant of the Geological Survey are published here. As the samples analyzed were obtained from localities widely distributed throughout the whole extent of this territory, and as the manner of collection and subsequent treatment has been uniform, they should furnish the best and most reliable means of direct comparison that has ever been available.

COLLECTION OF SAMPLES.

The samples were all collected and treated according to the following methods of sampling adopted by the fuel-testing plant:

After the face of the coal was cleaned of weathered coal and powder smoke a cut was made across the face of the bed from roof to floor, including all of the benches of coal mined and such impurities as were not removed in ordinary work. This cut was about 3 inches wide and 1 inch deep; the coal obtained from it, amounting to 25 [to 100]

[a] Preliminary report of the operations of the coal-testing plant of the U. S. Geol. Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904: Bull. U. S. Geol. Survey No. 261, 1905, 172 pp.

Report on the operations of the coal-testing plant of the U. S. Geol. Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904: Prof. Paper U. S. Geol. Survey No. 48, 1906, in three parts, 1492 pp., 13 pls.

Holmes, J. A., Preliminary report on the operations of the fuel-testing plant of the U. S. Geol. Survey at St. Louis, Mo., 1905: Bull. U. S. Geol. Survey No. 290, 1906, 240 pp.

Lord, N. W., experimental work conducted in the chemical laboratory of the U. S. fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906: Bull. U. S. Geol. Survey No. 323, 1907, 49 pp.

pounds, was caught upon an oilcloth [or heavy canvas square] spread upon the floor of the mine so as to protect the samples from water and from admixture of shale and clay fragments that usually abound in such places.

The coal composing the sample was then pulverized and quartered down, according to the generally accepted rules for preparing samples, until a quart sample was obtained, the particles of coal being reduced to a size not much greater than one-half inch in diameter. The sample was placed in an air-tight galvanized-iron can, having a screw top, and the can was hermetically sealed by screwing the top down tight and covering the joint with adhesive tape. The can containing the sample was then mailed to the testing plant. When it reached the chemical laboratory, the sample was at once transferred to a glass jar, in which it was sealed until the time arrived for making a chemical analysis.

By being sealed at the mine the sample reached the chemical laboratory with its moisture content unchanged. Part of this moisture is inherent in the coal and part is extraneous, either derived from water in the mine or from the atmosphere. In order to eliminate some of the extraneous moisture, the samples, during the first year's work at the testing plant, were exposed to the air after they were pulverized until they reached a fair degree of constancy of weight and then were analyzed. The amount lost during the exposure to the air is noted in the report as "loss of moisture on air drying." This method, however, was found to be unsatisfactory, since the amount of loss depended almost entirely upon the degree of saturation of the air, and this varied greatly from day to day.

Later, when these samples and those from the Yampa field were analyzed, the method was changed, the samples being artificially dried in order to secure greater uniformity of the moisture content, the method being as follows:

In order to make determinations of the loosely held moisture more uniform and definite, a special drying oven has been designed and introduced into the laboratory. In this oven samples of several pounds weight can be dried in a gentle current of air, raised from 10° to 20° above the temperature of the laboratory. In this way the coal is air dried in an atmosphere with a very low dew-point and not subject to large percentage variations, and the results obtained were considerably more concordant.

DETERMINATION OF HEATING VALUE.

The methods employed in the analyses and the determination of the calorific values of the samples received at the fuel-testing plant in St. Louis have been described in previous publications in a more or less detailed and technical way.[a] A brief résumé of the process in the calorimeter tests, given in somewhat simpler form of statement, is quoted here from another source,[b] and will probably serve a useful purpose for those not acquainted with the technical details of this work. The calorimeter described is similar, although not of the same make, to that of the fuel-testing plant.

[a] Prof. Paper U. S. Geol. Survey No. 48, pt. 1, pp. 179-184.

[b] Voorhees, S. S., Methods of testing coal: Proc. Am. Soc. Testing Mat., vol. 7, 1907, pp. 560-571.

Calorific power or heat value is the amount of heat developed by the combination of a definite amount of fuel with oxygen. It is expressed by the unit calorie or British thermal unit. The calorie is the amount of heat absorbed by unit weight of water when its temperature is increased 1° C. The unit weight of water is either 1 gram or 1,000 grams. The British thermal unit is the amount of heat absorbed by one unit (usually 1 pound) when its temperature is increased 1° F. As a unit weight of the fuel develops a fixed number of calories with the same unit weight of water, it is immaterial what unit weight of fuel and water is taken. To convert calories to British thermal units it is only necessary to multiply by the factor 1.8, which is the ratio between the centigrade and Fahrenheit scales.

There are two general methods of determining the calorific power of fuel, which may be called the direct and the indirect methods. The indirect determination is obtained by calculating from the results of ultimate chemical analysis, based on well-established values of the heat of combustion, when carbon, hydrogen, and sulphur are burned to their final products of carbonic acid, water, and sulphuric acid. The sum of these values, less that part of the hydrogen which might combine with the oxygen in the fuel to form water, gives the calorific value. In general, however, this calculated value agrees with direct determination of heat units by the bomb calorimeter on anthracite coals and cokes to within 1 per cent. On bituminous coals, high in complex hydrocarbons, the agreement is not so close. This is due to inaccuracies in analysis of these complex hydrocarbons and resulting variations in the assigned value for heat of combustion. Lord and Haas have found from working on some 44 samples of Pennsylvania and Ohio bituminous coals that this variation amounts to from −2 to +1.8 per cent.

The direct method of determining heat values is based on actual measurement of the heat produced by combustion. With proper design of apparatus and with proper precautions and corrections this method gives the most accurate results possible to attain. It is used in fact as a standard to determine the accuracy of all other methods.

The two general types of calorimeters are those in which the pressure remains constant or the volume remains constant. In the first type with constant pressure the charge is ignited by means usually of a fuse in an atmosphere of oxygen, or is mixed with a substance which yields oxygen; the products of combustion pass through and give up their heat to a known weight of water which gives the measure of the heat developed. Many inaccuracies result from heat losses due to lack of proper insulation and incomplete combustion, etc.

The constant volume or bomb calorimeter is the instrument which is now accepted as standard in determining heat values. In its original form as designed by Berthelot, it consists of a shell made of high carbon steel capable of withstanding a pressure of 300 atmospheres. The shell is lined with platinum to prevent corrosion from resulting gases. The bomb is surrounded by a known weight of water. The vessel containing this water is insulated by an air space. The air space is surrounded by a jacket of water which is supposed to be at room temperature, and this outside water jacket is further protected by an insulating felt of hair covering to minimize local variation in outside temperatures. The determination is made in a room free from drafts or direct sunlight and of uniform temperature throughout. The temperature measurements are made by a special thermometer very sensitive and accurate, graduated to 0.01° C. The readings are made through a telescope at some distance from the calorimeter, so as to avoid errors due to radiation of heat from the body of the operator.

The instrument may be standardized by several methods: First, the combustion of known weights of a pure substance of accurately known composition and heat value, such as sugar or naphthalene; second, by calculation from the specific heat of the known weights of the metals used in the construction of the bomb; and third, by adding a definite amount of warm water at known temperature to a definite amount of water at some known lower temperature in the calorimeter and noting the resulting

temperature. From these data the actual heat equivalent can be calculated. The determination by each method is duplicated until satisfactory averages are obtained and a mean of these averages insures a figure for the water equivalent of the apparatus which is very near the truth.

The usual method of compressing the powdered sample into tablet form is followed with bituminous coals. With some of the western lignites, high in ash, combustion will not take place if too great pressure is used in making the tablet. Anthracite coal can not readily be compressed into a tablet, but can be fired by the addition of about 0.250 gram of a bituminous coal of known heating value [or by a slight modification of the capsule in which combustion takes place it can be fired directly].

The oxygen is supplied from two cylinders containing 100 gallons under about 1,000 pounds pressure. When the pressure falls below 300 pounds, the amount required for a combustion, the bomb is filled from the low-pressure cylinder and the pressure brought up to the required amount from the high-pressure cylinder. In this way all the oxygen can be used from each cylinder. Failures to fire are rare and combustion is complete if proper precautions are followed. Determinations are always made in duplicate and almost invariably agree to within 50 British thermal units, or about one-third of 1 per cent. The practice of reporting heat values to the decimal or even to the final whole number assumes an extreme accuracy which the determination does not warrant. It would be far better and would not affect values if the British thermal unit were reported to the nearest ten.

As a result of the calorimeter tests the heating value of a given coal is deduced as in the following example:

Omitting, for convenience and simplification of the process, reference to such factors as specific heat, corrections for temperature of maximum density, the water equivalent of the metallic parts in the calorimeter, etc., it may be assumed that if 1 gram of coal raises 2,000 grams of water in the calorimeter 4° C., it will raise 1 gram of water 1° C. 8,000 times, and therefore 1 gram of coal contains 8,000 calories (small French or metric or gram calories).

One gram of such coal would raise the temperature of 1 pound (453.597 grams) of water $8000 \div 453.597$, or 17.637 times 1° C. Therefore 1 gram of coal contains 17.637 pound calories.

Since 1 gram of this coal will raise 1 pound of water 17.637° C., which is equivalent to 31.747° F., 1 gram of coal contains 31.747 British thermal units. One pound would contain 31.747 times 453.597, or 14.400 British thermal units. The relation is therefore simply that of the centigrade to the Fahrenheit scale; and of the calorific values quoted the British thermal units per pound are 1.8, or nine-fifths, times the small calories per gram on the same coal.

Heating value is commonly expressed as calories per gram of coal or British thermal units per pound of coal.

CHEMICAL ANALYSIS.

Coals are commonly analyzed in two distinct ways, in each case the aim being to subdivide the material into its component parts and to show the relative proportion of each. These are known as the proximate analysis and the ultimate analysis of the coal. Each of

these is of itself a complete statement of the component parts of the sample analyzed.

PROXIMATE ANALYSIS.

The proximate analysis subdivides the coal into units of a highly arbitrary nature based on coke-oven practice, so that laboratory tests will accord with manufacturers' results. Early analytical work gradually developed both methods and units that came into more or less general acceptance. Within the last ten years the methods have become much more uniform through the recognition of the necessity for some mutual agreement in these matters in order that the results of different analysts may become more directly comparable.[a]

In the proximate analysis the coal is divided into units as follows: Moisture, to determine which the coal is dried for a specified time at a temperature somewhat above the boiling point of water, the loss in weight being assumed to be the moisture loss of the coal. Ash, in the determination of which the same sample previously dried is completely burned and the amount of residue weighed and its proportion to the whole thereby ascertained. Volatile combustible matter, to determine which a separate sample of the coal is weighed and heated to a full red heat for a specified time in a covered crucible, so that, the air being excluded, only a minimum amount of carbon is burned and the volatile gases are driven off. The loss in weight in this process is determined and its percentage of the whole weight of the sample obtained. This includes also the moisture previously determined, and the difference is considered as the volatile combustible matter. Fixed carbon, which is determined as the difference between 100 per cent and the sum of the moisture, ash, and volatile combustible matter previously obtained. The physical character of the fixed carbon remaining in the crucible after the volatile has been expelled gives an indication of the coking properties of the coal.

In a commercial analysis note is commonly made of the color of the ash. White ash receives a commonly conceded preference over a red on account of an assumed influence the former is supposed to bear on the character of the clinker produced. The red color is essentially due to presence of iron. Iron normally lowers the fusing point of clay, shale, or any siliceous mineral residue, and its combination in the ash is supposed to result in a clinker-forming product. The clinkering properties of coals, like their coking properties, are not fully understood, and both are the subject of much speculation and require further investigation.

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[a] Voorhees, S. S., op. cit., p. 561. On account of the lack of unity in method of analysis the American Chemical Society in 1898 appointed a committee to standardize methods of coal analysis. This committee gave a preliminary report in April, 1898, and a final report in December, 1899, which appears in the journal of that society. The method recommended is well known to chemists engaged in this line of work and needs no further comment.

A separate determination of sulphur is commonly made with the proximate analysis, because of the important influence that element has in the use of the coal in certain industries, especially in the metallurgy of iron and steel, on account of the detrimental effect of sulphur on iron and steel, as well as other metals, and its corrosive action on the furnace and boiler parts with which it comes in contact. Separate determinations of phosphorus are also frequently necessary (p. 246).

ULTIMATE ANALYSIS.

The ultimate analysis of coal subdivides all except the essentially incombustible ash into the uncombined elements, giving the proportion that each is of the whole. The apparatus and operations involved are much more complex than those for the proximate analysis, so that the ultimate analysis is a comparatively expensive process. The elements usually determined are sulphur, hydrogen, carbon, nitrogen, and oxygen. Besides these the analysis includes the ash, which as normally inert residue is not further analyzed except for special purposes, as elsewhere explained. In cases where the determination of phosphorus is important this element is also included in the list. Unless separated the phosphorus remains in the ash.

INTERPRETATION.

The study of the chemical analyses of coal and the interpretation of their significance have not been reduced to any stated rule or method. The influence that each component, element, or factor in the analysis has on the activity of the substance as a whole is the primary consideration involved, but the effect of the combined action or interaction of the elements must also be understood in order that a just estimate may be formed of what final external resultant action may be produced by the combustion of the coal.

In the proximate analyses the components to be considered are moisture, volatile matter, fixed carbon, and ash.

The moisture or water is inert so far as the production of heat is concerned. It not only acts as an impassive substance absorbing the heat required to raise its temperature with that of the fuel in which it is included, but also absorbs the latent heat of volatilization by which it is passed off as steam. The latter is probably the more considerable factor of the two, so that the presence of excessive amount of moisture in a coal effects a serious deterioration of its heat-giving qualities.

The volatile combustible matter includes an important part of the fuel constituents of the coal. They are the gaseous combinations of hydrogen and carbon, which by their oxidation in the processes of burning give off the heat of combustion. As the fuel value of hydrogen is far in excess of that of carbon alone, it is to this that the excess

of calorific power of coal over carbon alone is ascribed. When the volatile combustible matter is of large proportion in coals they are termed soft, they ignite easily, and burn with long, often sooty, flames.

The fixed carbon is the principal fuel constituent of coal. As it undergoes combustion at the grates, and not in the flues and stack like much of the volatile combustible matter of coal not scientifically handled, the fixed carbon is probably the most efficient of the heat-producing factors. The heat evolved is given off by the chemical combination of the carbon with the oxygen of the air.

The ash is an inert constituent so far as heat-giving properties are concerned. It clogs the grates, and so interferes with the free burning of the rest of the coal, and the necessity for its removal causes a loss in the efficiency and economical heat-producing power of the plant.

In the ultimate analyses sulphur, hydrogen, carbon, nitrogen, oxygen, and perhaps phosphorus are added to the list of elements determined.

The sulphur is combustible and develops heat. It corrodes the metal parts of the furnaces, however, and is also objectionable in other ways. As stated, its presence is objectionable in connection with the use of the coal for metallurgical processes, especially of iron and steel, as it has an exceedingly detrimental effect on those substances as finished products.

The phosphorus remains in the ash on combustion, but in coal that is to be used for metallurgical industries it is a more important factor. As the ash of a coal remains in the coke that is made from it, and as all the phosphorus of coal or coke used in the metallurgical processes is combined with the metallic products, it is especially desirable that coal for such purposes should be free of that element. Phosphorus renders iron more brittle, but it also makes it more fluid when molten, so that it is used to a limited extent for certain kinds of castings where strength may be sacrificed for the sake of the greater fluidity useful in the casting of intricate patterns.

Hydrogen occurs in two general conditions, termed disposable and combined. That combined with oxygen in the form of water has already been mentioned as inert so far as heat-producing power is concerned. The rest is probably in greater part free to combine further with oxygen on combustion, and, as previously mentioned, its fuel efficiency in such action is very high.

The true carbon, as is well known, is the principal fuel constituent of the coal.

The nitrogen is inert, being without any heat-producing power, and lacking affinity for combination with the other elements.

The oxygen must be placed on the negative side opposite the productive elements. It lacks the affinity for combination with any of the free elements furnished by the outer atmosphere, and in coal it represents a definite proportion of active elements already neutralized so far as chemical action in combustion is concerned.

The study of the ultimate analysis is still largely in the speculative stage. It is hoped that by its means we shall sooner or later arrive at some more satisfactory basis for estimating the practical value of a coal. It is, nevertheless, quite clear that the commercial value of a coal depends not only on its chemical constitution, but also to a very great extent on its physical characteristics, such as its manner of breaking and its ability to withstand transportation and the action of weather.

FUEL RATIO.

In a commercial way the proximate analysis has long been a basis of comparison among the different grades of coal. Various ratios obtained from the units of the proximate analysis (and also of the ultimate) have been used to establish a chemical classification of coals. While none of these classifications has been satisfactory in more than small part, within certain limits they have served a useful purpose. The well-known fuel ratio which was proposed for use in Pennsylvania [a] is the ratio of the fixed carbon to the volatile matter $\left(\frac{C}{V}\right)$ as shown by the proximate analysis. The figure thus obtained gives a fairly satisfactory basis for the classification of most of the higher-grade coals, such as anthracite, semianthracite, semibituminous, and the better grades of bituminous. When, however, the fuel ratio is below 2 it does not appear to be of any value whatever in determining the relative grade of a coal, and many bituminous, subbituminous (or so-called black lignites) and lignites can not be distinguished at all by its use. Since a large part of the coal from the Colorado fields has a fuel ratio below 2 this is not a satisfactory means of interpreting the analyses of these coals. Unfortunately no other satisfactory chemical standards are now known for these grades of coal, and it seems likely that the use of proximate analyses purely for purposes of classification in this general region will not prove of much actual service. The proximate analysis is, however, of distinct value to the engineer in indicating the most efficient or economical method of use in the furnace.

[a] Frazer, Persifor, jr., Classification of coals; Second Geol. Survey Pennsylvania, Rept. MM, 1879, pp. 128-144.

Analyses of coal samples from northwestern Colorado and northeastern Utah.[a]

Age of coal beds.	Location of property sampled.	Laboratory No.	Total thickness of coal bed.	Thickness of part sampled.	Air-drying loss of sample as received.	Chemical analyses, air-dried basis. Proximate. Moisture.	Volatile matter.	Fixed carbon.	Ash.	Ultimate. Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific values, air-dried basis. Calories per gram.[b]	British thermal units per pound.[b]
			Ft. In.	*Ft. In.*	*Per ct.*											
Post-Laramie.	Lay, Colo., Blevins mine	5514	11 4	11 4	5.70	12.47	29.92	50.02	7.59	1.21	5.33	59.74	0.84	25.29	5,715	10,290
Post-Laramie.	Craig, Colo., Seymour bank, Dry Fork of Little Bear Creek	(c)	15	.....	.....	17.08	35.30	41.97	5.65	.46	5.86	57.50	1.48	28.69	5,180	9,330
Laramie.	California Park, prospect entry on Quaker Mountain	3436	5 10	5	860	23.72	42.34	28.30	5.64	.17	.....	.....	.....	.....	.....	.....
Yampa field, Colorado.	Oak Creek, Shuster coal	1799	11 6½	6 8½	2.30	6.70	36.91	51.37	5.02	1.54	5.57	70.20	1.58	16.09	6,915	12,450
	Trout Creek, prospect in upper canyon	1831	5 8	5 2	4.10	4.68	35.30	49.32	10.70	1.57	.....	.....	.....	.....	.....	.....
	Eddy, Hutchinson bed	1832	5	9 6	6.20	6.72	37.47	50.01	5.80	.45	5.48	67.43	1.52	19.32	6,540	11,780
	Pool, McCrosky mine	1843	10 4½	8 7	4.40	8.00	36.09	44.75	11.16	.49	.....	.....	.....	.....	.....	.....
	Do	1991	10 4½	3 11	3.40	9.27	37.29	44.69	8.75	.55	.....	.....	.....	.....	.....	.....
	Pilot Knob, Crawford:															
	6-foot bed	1936	6 2	6 2	5.70	6.41	37.44	50.22	5.93	.60	.....	.....	.....	.....	.....	.....
	11-foot bed	1937	11 9±	6 7	4.20	2.77	24.88	62.63	9.72	.58	.....	.....	.....	.....	.....	.....
	Do	1902	11±	5 5	4.20	2.86	3.57	78.92	14.65	.59	2.50	76.62	1.35	4.29	6,810	12,260
	Pilot Knob, Miller Gulch prospect	1946	4 1	4 1	5.70	5.41	36.39	52.40	5.80	.62	.....	.....	.....	.....	.....	.....
	Yampa Canyon, Wadge mine	2030	8 3	8 3	2.40	7.26	38.82	48.20	5.72	.42	.....	.....	.....	.....	6,610	11,900
	Do	2034	8 3	8 3	4.00	6.87	38.28	49.51	5.34	.46	.....	.....	.....	.....	.....	.....
	Butcherknife Creek, prospect	2031	6 4	6	3.40	7.79	37.81	48.38	6.02	.62	.....	.....	.....	.....	.....	.....
	Sage Creek, Hayden:															
	11-foot bed	2032	11 5	11 5	2.70	8.56	36.84	48.78	5.82	.53	.....	.....	.....	.....	6,480	11,680
	6-foot bed	2033	6 10	6 8	4.20	7.34	38.70	49.60	4.36	1.67	.....	.....	.....	.....	.....	.....
	Dry Creek, Hayden	2082	11±	7 10	9.20	7.20	36.75	51.51	4.54	.45	.....	.....	.....	.....	.....	.....
	Hayden Gulch, Green coal	2210	10	10	3.40	8.22	35.70	51.32	4.76	.51	.....	.....	.....	.....	.....	.....
	Lay:															
	20-foot bed	3463	20 3	5 7	5.30	9.87	36.67	46.97	6.49	1.05	5.50	63.43	1.16	22.37	6,200	11,160
	Peacock bed	3461	9	7	4.50	9.23	36.84	48.72	5.21	.94	.....	.....	.....	.....	.....	.....
	Sweeney bed	3462	7 10	5 5	4.00	8.66	37.68	47.29	6.37	1.14	5.53	65.33	1.22	20.41	6,420	11,550
	Meeker:															
	Lion Canyon mine	3502	8 5	8 5	3.20	10.33	40.31	43.75	5.61	.70	.....	.....	.....	.....	.....	.....
	A. H. Adams mine	3504	9	6 6	3.30	9.00	41.40	47.28	2.32	.53	.....	.....	.....	.....	.....	.....

Mesaverde.	Danforth Hills field, Colorado.	F. W. Fairfield	3498	7	4½	6	3	2.40	7.18	38.90	46.50	7.42	.76	5.20	64.95	1.26	20.41	6,445	11,600
		Do	3482	21	7	9	8	3.20	7.34	36.01	46.73	9.92	.75						
		Mrs. G. H. Adams mine	3483	4	1	4	1	4.40	8.50	33.24	52.84	5.42	1.42						
		D. Pollard mine	3849	7±		5	3	3.70	9.19	35.97	50.50	4.34	.49						
		Black Diamond mine	3847	20±		7	3	3.60	8.74	35.49	49.20	6.57	.53	5.52	66.71	1.35	19.32	6,620	11,920
		Sulphur Creek	3845	7		5	8	3.70	8.51	34.41	50.16	6.92	.49	5.51	66.34	1.38	19.36	6,540	11,770
		Do	3848	7		5	1	6.10	5.45	35.60	51.95	7.00	.61						
		Do	3850	7	8	3	9	4.20	9.59	35.24	49.76	5.41	.54						
		Curtis Creek entry	3851	5+		4	10	2.50	6.54	34.37	49.35	9.74	.69						
		Coal Creek, Wesson mine	3791	25+		8	9	4.10	9.90	37.72	47.52	4.86	.47	5.47	64.57	1.38	23.25	6,335	11,400
		Thornburg, Wilson mine	3792	18±		7		3.30	7.77	35.10	46.84	10.29	.54						
		Axial:																	
		Shafer mine	3707	14+		7	6	4.90	8.67	38.32	49.99	3.02	.60	5.20	67.42	1.12	22.64	6,655	12,000
		Collom mine	3466	24	11	10		3.50	8.03	40.21	49.66	2.10	.33						
		James mine	3704	8+		6	4	3.40	8.91	37.09	49.22	4.78	.54	5.24	66.12	1.40	21.92	6,535	11,760
		W. H. Miller entry	3703	.....		.....		6.30	8.41	37.12	47.45	7.02	.60	5.46	64.69	1.08	21.15	6,230	11,210
		Spring Creek, near Ninemile Hill	3846	5±		4	6	15.10	11.51	38.05	45.84	4.60	.58						
		Morgan Gulch, ranch mine	3688	10+		6		6.50	9.37	32.83	53.83	3.97	.59						
		Do	3690	10+		5	2	6.20	9.77	37.54	45.96	6.73	1.03						
		Boxelder Gulch, prospect	3689	9+		5		17.60	16.75	39.64	37.51	6.10	.40						
		Deep Channel Creek, Keystone ranch mine	3571	7	2	6	2	4.40	15.49	35.69	42.69	6.13	.62						
		Do	3569	7+		6−		5.70	16.24	41.70	35.61	6.45	.50						
	Grand Hogback field, Colorado.	Rifle Creek, McLearn mine	3943	7	3	7	3	2.10	4.31	37.69	51.93	6.07	1.14	5.36	70.20	1.60	15.63	7,070	12,690
		Do	3946	7	3	5	9	3.10	4.24	37.24	53.04	5.48	.71	5.32	70.39	1.63	16.47	7,075	12,740
		Newcastle:																	
		Keystone mine	3936	2−		1	8	.90	2.81	36.99	53.25	6.95	.44	5.07	72.65	1.40	13.49	7,245	13,040
		Do	3932	2−		1	8	1.00	3.19	35.91	55.49	5.41	.42	5.21	73.98	1.45	13.53	7,365	13,260
		Coryell mine	3938	14		9		.80	2.73	38.69	53.60	4.98	.54	5.05	73.45	1.76	14.22	7,430	13,370
		Do	3933	14		4	2	.70	2.83	38.77	53.72	4.68	.52						
		Do	3937	14		5	3	1.20	2.83	38.88	54.39	3.90	.52						
		Do	3935	14		9		1.10	2.97	38.09	53.14	5.81	.54						
		Do	3939	14		14		1.20	2.90	38.66	53.35	5.09	.52	5.17	73.87	1.73	13.62	7,440	13,390
		South Canyon:																	
		East Wheeler bed	3959	18±		12	8	2.20	4.45	37.45	48.97	9.13	.49						
		West Wheeler bed	3960	.....		15	10	1.70	3.88	36.51	49.60	10.01	.30	5.17	66.79	1.38	16.35	6,720	12,110
		D bed	3961	4	8	4	8	3.10	4.48	37.34	55.62	2.56	.49	5.18	71.96	1.70	18.11	7,375	13,090
		Jerome Park district, Diamond mine:																	
		16-foot bed	4040	9	3	9	3	5.60	4.73	33.71	46.05	15.51	.80						
		Do	4037	8		8		4.30	8.15	36.05	50.64	5.16	.89						
		Do	4038	16±		16±		5.90	5.13	35.17	47.29	12.41	.83						
		Diamond bed	4030	5±		4	1	7.20	6.36	36.00	50.06	7.58	1.22						
		Do	4050	.....		5	1	7.60	7.05	35.40	47.60	9.95	.98	5.04	62.74	1.58	19.71	6,225	11,210
		Jerome Park district:																	
		Pocahontas mine—																	
		A	4035	6	2	6	2	3.00	3.15	37.25	49.26	10.34	.79						
		C	4031	7	6	7	6	2.90	3.56	39.32	53.47	3.65	.82						
		D	4036	9	11	9	3	2.00	4.18	39.25	54.63	1.94	.53	5.49	73.65	1.78	16.61	7,465	13,440
		D	4039	9	11	7	6	2.40	3.57	39.18	53.97	3.28	.59						

[a] Includes all previously published in the progress reports and in Bulletin 297.
[b] British thermal units reported only to nearest ten; calories to the nearest five.
[c] Republished from Hills, R. C., Mineral Resources U. S. for 1892, U. S. Geol. Survey, 1893, p. 364.

Analyses of coal samples from northwestern Colorado and northeastern Utah—Continued.

Age of coal beds.		Location of property sampled.	Laboratory No.	Total thickness of coal bed.	Thickness of part sampled.	Air-drying loss of sample as received.	Chemical analyses, air-dried basis. Proximate. Moisture.	Volatile matter.	Fixed carbon.	Ultimate. Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific values, air-dried basis. Calories per gram.	British thermal units per pound.
				Ft. In.	*Ft. In.*	*Per ct.*											
	Grand Hogback field, Colorado.	Jerome Park district—Continued.															
		Sunlight mine—															
		A	4032	10–	7 6	2.80	2.78	25.39	60.33	11.50	.71	.....	.....	.....	.....	.....	.....
		A	4034	10 9	10 2	3.00	2.39	37.41	51.14	9.06	.78	5.08	69.86	1.63	13.59	7,115	12,810
		B	4046	.....	6 1	3.80	3.25	36.96	54.81	4.98	.69	.....	.....	.....	.....	.....	.....
		C	4045	.....	.....	2.60	3.13	37.26	54.30	5.31	.84	.....	.....	.....	.....	.....	.....
		D	4033	9±	7 4	2.00	3.26	48.74	44.09	3.91	.81	.....	.....	.....	.....	.....	.....
		D	4048	8 3	8 3	3.50	3.10	38.58	55.32	3.00	.96	5.36	74.10	1.86	14.72	7,565	13,610
		Gulch mine—															
		Sunshine bed	4010	14±	9 8	1.20	1.21	35.17	57.30	6.32	.45	5.16	77.05	1.56	9.46	7,860	14,150
		Anderson bed	4009	4 10	4 10	1.50	1.29	35.69	59.57	3.45	.47	.....	.....	.....	.....	.....	.....
		Coalbasin	4041	20±	6 3	.40	.93	21.57	70.52	6.98	.51	.....	.....	.....	.....	.....	.....
		Do	4043	20±	7 6	.30	.85	22.50	69.06	7.59	.48	.....	.....	.....	.....	.....	.....
		Do	4047	20±	9	.20	.76	21.53	69.07	8.64	.52	4.65	79.77	1.83	4.59	7,975	14,360
		Do	4049	20±	9	.40	.82	22.11	68.11	8.96	.59	.....	.....	.....	.....	.....	.....
		Do	4042	Carload.		.40	.87	22.47	67.62	9.04	.50	.....	.....	.....	.....	.....	.....
	Lower White River Field.	White River, mouth of Red Wash	5516	4 2	3 8	3.20	8.02	34.22	48.61	9.15	.75	.....	.....	.....	.....	6,135	11,040
		Raven Park, J. W. Rector mine	5519	11 11	11 11	3.10	8.55	33.40	49.99	8.06	.46	5.30	64.64	1.18	20.36	6,155	11,080
		Do	5520	11 11	7 4	4.80	9.77	33.43	51.27	5.53	.40	5.38	65.28	1.11	22.30	6,380	11,490
Mancos.	Vernal Field, Utah.	Vernal:															
		Gray mine	5511	6 7	3 10½	2.90	5.72	35.34	48.58	10.36	1.62	5.16	64.66	1.03	17.17	6,435	11,590
		Do	5753	6 7	3 9	2.60	6.20	37.39	48.89	7.52	1.28	5.42	67.30	1.12	17.36	6,775	12,200
		Joseph Rich mine	5512	5 11	1 2½	2.80	6.01	37.13	48.57	8.29	1.43	5.41	65.95	1.07	17.85	6,620	11,920
		Do	5509	5 11	3 ½	2.60	6.21	37.12	49.48	7.19	1.67	5.36	66.84	1.12	17.82	6,640	11,950
		Timothy mine	5754	5 8½	1 3	2.30	6.07	36.53	46.85	10.55	1.29	5.36	65.02	1.02	16.76	6,495	11,690
		Do	5755	5 8½	2 7	2.50	6.30	37.68	47.87	8.15	2.14	5.61	67.37	1.04	15.69	6,705	12,070
		C. C. Rich mine	5513	4 11	1 1	2.50	5.86	35.18	46.87	12.09	1.81	5.24	62.60	1.00	17.26	6,310	11,360
		Do	5510	4 11	2 3½	2.90	6.10	37.69	49.77	6.44	1.71	5.56	67.05	1.12	18.12	6,765	12,110
		Gibson mine	5515	7 2½	1 2	3.00	6.62	33.79	46.33	13.26	1.99	4.94	59.59	.93	19.29	5,935	10,690
		Do	5517	7 2½	3 6½	4.40	7.59	35.98	46.55	9.88	2.01	5.38	61.88	.96	19.89	6,145	11,060
		Do	5518	7 2½	1 9	3.30	7.16	33.79	46.38	12.67	.80	5.11	62.09	.99	18.34	6,140	11,050

NOTES.

3436. Coal much weathered.

3502. From across whole thickness of bed at face of mine.

3504. Includes Nos. 1 and 3 of section on page 147, but No. 3 was 1 foot 11 inches thick where the sample was cut.

3482. At face of entry 650 feet from the entrance; represents 9 feet 8 inches of coal, excluding the thin clay parting. Carefully cut across the entire face from a surface that had first been picked clean and showed only fresh, bright coal.

3483. From across whole thickness of the 4 feet 1 inch bench of coal at face of the mine, where coal appeared sound and fresh. A coke-like seam one-half inch thick, a foot or so from top of the coal bed, was included as it could hardly be separated out in mining.

3498. From No. 4 of section on page 144.

3849. Represents the upper 5 feet 3 inches of bed, 510 feet from entrance.

3847. Represents 7 feet 3 inches of coal of section on page 154.

3845. Represents 5 feet 8 inches of coal of the section on page 155.

3848. Taken 280 feet from the mine entrance; represents 5 feet 1 inch of coal from the section on page 155.

3850. Taken about 180 feet in from the entry described on page 154.

3851. Represents 4 feet 10 inches of the good coal of the section on page 161.

3791. Represents Nos. 2, 4, and 6 of the section on page 164.

3466. Represents the 10 feet of coal at face of mine; shows neither seam nor parting.

3704. Cut 8 feet from the face of the mine.

3792. Taken 37 feet from the entrance.

3707. Taken about 6 feet from the face of the mine.

3703. Taken 15 feet from face of entry; represents Nos. 2 and 4 of the section on page 172.

3846. See page 162.

3688. Taken 110 feet in from entrance; cut from a freshly worked face exposing 6 feet of coal.

3690. Taken 60 feet in from entrance; much more weathered than 3688.

3689. Represents upper 5 feet of section on page 175. Coal dripping with water and badly weathered.

3571. Taken at face of drift; represents the lower 6 feet 2 inches of the 7 feet of coal exposed.

3569. Taken 30 feet from the entrance; somewhat weathered, having been exposed for a good while.

3943. From face of upraise 40 feet from the end of the side heading, the beginning of a new room; cut from across the whole thickness of the bed.

3946. From face of the side heading at end of workings; omits 1 foot 6 inches at roof, usually left up in mining.

3959. East side of the gulch; 2,600 feet in from the entrance; represents bench below the slip.

3960. West side of the gulch; 2,100 feet from the entrance to the mine.

3961. West side of the gulch; 2,000 feet from the entrance.

4040. Upper portion of the 16-foot bed; lower 2 feet is very soft.

4037. Lower portion of the 16-foot bed; separated from the upper portion by a locally thick shale parting. Cut from a fresh face exposed in the mine.

4038. Mixture of samples 4040 and 4037 in proper proportions to represent the whole of the 16-foot bed as mined.

4030. Black Diamond bed. There are no partings in this coal.

4050. From a mine face of the Black Diamond bed.

4035. "A" bed; taken 2,500 feet from the entrance to the mine; represents the upper bench.

4031. "C" coal bed; taken 2,200 feet from the entrance to the mine.

4036. "D" coal; represents 9 feet 3 inches of clear coal without partings, the total bed measuring 9 feet 11 inches, with shale roof and shale floor. Taken at face of mine.

4039. "D" coal.

4032. "A" coal; taken 3,000 feet from the entrance of the mine.

4034. "A" coal.

4046. "B" coal; very soft and therefore not mined. Taken 1,100 feet from the entrance from a very wet face.

4045. "C" coal; has a shale parting of 1½ feet near the middle, and is thus not considered worth mining. Sample represents 3 feet and was taken 1,100 feet from the entrance.

4033. "D" coal; taken 2,500 feet from the entrance to the mine. The lower 2 feet of coal were omitted on account of heaving of the floor which made it inaccessible. This bed is said to run high in slack.

4048. "D" coal; taken 3,300 feet from the entrance to the mine, where the coal bed shows a local parting.

4010. Sunshine bed; taken 5,200 feet from the entrance of the mine.

4009. Anderson bed; taken 207 feet from the entrance; represents bed of solid coal.

4041. Taken 600 feet from the entrance on the third level. The coal is 8 feet thick as mined, of which only the upper 6 feet 3 inches are represented by the sample. The roof is of shale and the floor is reported to be 12 feet more of coal of a noncoking quality.

4043. Taken 1,600 feet from the entrance; same roof and floor as No. 4041.

4047. Taken 2,200 feet from the entrance in room No. 44.

4049. Taken 2,500 feet from the entrance in room No. 50.

4042. Taken from a 25-ton carload of Coalbasin coal delivered at Redstone; coal was taken from the various parts of the car, mixed, pounded up, and quartered to a can-size sample.
5516. See page 192.
5519. Entire bed 90 feet in from entrance (p. 196).
5520. See page 196.
5511. Represents all of the minable coal in section 1, page 217.
5753. Includes first, second, and fourth benches of coal in section 2, page 217.
5512. Lower benches; second-grade coal. (See section, p. 217.)
5509. Upper two benches; first-grade coal. (See section, p. 217.)
5754. Second-grade coal, including the lower two benches and excluding the waste. (See p. 216.)
5755. First-grade coal; from the upper two benches, not including the bone or clay. (See p. 216.)
5513. From the lower two benches, omitting the bone between; second or poorer grade of coal. (See p. 215.)
5510. From the upper benches, excluding the bone; first-grade coal. (See p. 215.)
5515. Represents the lower 14 inches of (A) in the section on page 214.
5517. Represents soft coal (B) in the section on page 214.
5518. Bench (C) of the section on page 214.

COKING TESTS.[a]

Many of the mine samples received at the fuel-testing laboratory were tested to determine the cementing property of the coal. A sample of the coal was ground and coked in a small platinum box. The condition of the resulting product varies from a loose powder without adhesion through various degrees of hardness up to firm bars of coke. The strength of the firm material obtained was tested as an indication of the value of the coke. Tests of the same coals in coke ovens gave results that did not always correspond to the predictions made from the grading of the mine sample. For this reason laboratory tests of the coking property were given up as unsatisfactory.

GENERAL SUMMARY.

The moisture content of the air-dried samples of these Colorado coals, as shown in the table, ranges from a fraction of 1 per cent to about 15 per cent, with two somewhat exceptional instances showing higher amounts. Those samples showing the moisture content below 1 per cent are thought to have been affected by heat from more or less local volcanic intrusion, although this has not been proved. In the districts near to and south of Grand River the low-moisture content is a notable feature of most of the coal produced. It is possible that this variation from what may reasonably be considered the more normal types, found in the extensive coal fields to the north of that region, may be wholly the result of the proximity of volcanic intrusive rock. On the other hand, this difference may be largely the result of the dynamic metamorphism that produced the rather more intensely folded structures of that part of the region, and the comparative uniformity of the effect within that limited area seems to favor the latter explanation, at least in greater part. It is also most likely that both influences have been exerted in varying degrees at different localities.

[a] Abstract from Prof. Paper U. S. Geol. Survey No. 48, p. 298.

In the greater part of the coal fields in this general region, including the Yampa, Danforth Hills, and Lower White River fields, the moisture content ranges from about 7 to 9 per cent in the fresh samples. This is high in comparison with the standard bituminous coals of the eastern or Appalachian province, but compares favorably with most of the coals of the Rocky Mountain or western interior province, with which alone they will ever be likely to come into competition.

In a general way it may be pointed out that the majority of northwestern Colorado coals belong to a class of high-volatile fuels, the average ranging from nearly 35 to 40 per cent in volatile combustible matter. From a practical standpoint this means that the heat from the combustion of this coal is more difficult to concentrate in the firebox than that of the low volatile coals, such as are produced largely in the eastern Appalachian fields. Without special construction of furnace equipment having this feature in view, much of the heat is very likely to be generated and lost in the stack. As a steam coal, especially for use in locomotives where forced draft and a high rate of combustion are demanded, the high volatile coals are especially difficult of adaptation. The unconsumed gases are expelled, cooled, and deposited as soot, and thus involve both loss of efficiency and an objectionable feature from the standpoint of comfort to the traveling public. Since they are, however, the only coals available in a large part of the West, this condition should call attention to the need for skillful firing and efficient furnace construction.

The fixed carbon ranges from about 45 to a little over 50 per cent in the greater part of the coal fields described here, the exceptions being the more seriously weathered coals that fall below these values and those altered by metamorphic action already noted in the discussion of moisture.

The ash is as a rule what may be considered normal in a commercial coal, ranging roughly from 5 to 10 per cent, with occasionally greater amounts.

The sulphur, like that of most of the coals from the Rocky Mountain province, is low, markedly so in comparison with many coals from the fields of the eastern and especially the central United States.

Phosphorus determinations have not been made in the present work.

Probably the most satisfactory single standard of comparison obtained in the laboratory tests is the calorific value. A knowledge of this value, and of the physical properties of the coal and the relative amount of ash contained, serves in the main the requirements for general estimation of adaptability for steaming purposes or for domestic use.

A review of a large number of such tests of calorific value, on standard coals that are pretty generally accepted as representing the requirements of the trade in their respective classes, sets the lower limit of the anthracites, semianthracite, semibituminous, and high-grade bituminous and coking coals as about 12,000 British thermal units on the air-dried samples. An intermediate grade of which the samples are often not easily distinguished as either bituminous or subbituminous has fuel values ranging from 12,000 to 10,000 British thermal units. Those having less than 10,000 British thermal units, if they contain approximately normal percentages of the various constituents, may be definitely placed as lignites or subbituminous coals, according to the presence or absence of the brown, woody constitution best characterizing the true lignites.

It will be seen by reference to the calorific determinations in the foregoing table that the greater part of the best (Mesaverde) coal in the Yampa, Danforth Hills, lower White River, and Vernal fields is, according to this standard, barely included in the class of high-grade bituminous coals. In fact a greater number of the calorific values determined fall below the 12,000 B. t. u. limit than above. Here also exception is made of the districts in the vicinity of Grand River and south of Glenwood Springs, where the coal shows a greater efficiency, with recorded values as high as 14,350 British thermal units on the regularly mined and marketed product. Again this difference must be briefly and inadequately explained by ascribing it to greater metamorphism of the coals.

DETERIORATION OF WEATHERED COAL.

One additional feature brought out to a certain extent by the analyses is the inadequacy of weathered samples for purposes of comparison. The coal that has stood in an old entry or at or near the surface of the ground is a very uncertain product. In most cases it is found to have deteriorated seriously in efficiency and the results of its analysis are evidently very much altered by the process. This deterioration differs much in the various kinds of coal, but its very uncertainty is a good argument against placing dependence upon such results. The samples to be used for comparison are naturally those actually representing the marketed product, cut from a freshly worked face at sufficient depth to show little or none of the influence of surface alteration.

SPONTANEOUS COMBUSTION.

The spontaneous combustion of coal is commonly attributed to the oxidation of the pyrite or "sulphur" in the coal. Chemical reactions that become active in the breaking up or weathering of coal that is exposed to the atmosphere generate heat. It has been shown by

calorific determinations on coal that has thus been exposed for varying lengths of time that there is a steady decrease in efficiency of the coal with such exposure; and it is assumed that this decrease is the result of a slow oxidation of the carbon that takes place on contact with the air. From this it seems evident that not only reactions in which sulphur or the iron of the pyrite or marcasite takes part may be the source of the heat generated, but the oxidation of the carbon itself may be one of the most active agents.

Spontaneous ignition probably depends on conditions governing the radiation of the heat thus generated as well as the rapidity of its generation. For this reason ventilation is an important factor controlling or preventing spontaneous combustion in mines.

The whole subject, like that of coking property in coals, is not clearly understood and is receiving considerable attention, which it demands from a practical standpoint.

The great amount of burning that has taken place along the outcrops of the coal beds in almost all parts of the fields described in this report is strong evidence of the natural combustibility of the coal. Specific instances of this effect are encountered in the mining industry in these districts at the present time. It has been stated that in mining the thicker beds at Newcastle it sometimes became necessary to draw all or part of the coal out of the rooms before completion, as the loose coal sometimes heats and would fire if neglected. As a matter of fact, control of all the important coal beds once mined on the north side of Grand River at that place has now been lost for many years, the fire originating either by spontaneous combustion or by accident, and resisting all subsequent attempts to extinguish it. Other mining properties or coal beds have been rendered unavailable in the same way. The slack piles at the Dutton and Hasley mine and at the McLearn mine near Rifle Gap are afire—it is said by spontaneous combustion—and have been burning for years. Other instances are recorded in which such piles have burned completely out.

PHYSICAL PROPERTIES.

The physical properties of coal, such as cleavage, hardness, luster, ability to withstand the action of air or the weather and to undergo transportation without breaking up, are all important factors in determining the commercial value of a coal. In a recent paper by M. R. Campbell [a] it is proposed, in view of the unsatisfactory results that have thus far been obtained in the classification of low-grade coals by means of chemical analyses, that a physical basis of classification be adopted for such coals.

Nearly all of the coal in the northwestern Colorado fields has the clear black massive—including the jointed or fractured—structure of

[a] Campbell, M. R., A practical classification for low-grade coals: Econ. Geology, vol. 3, No. 2, 1908.

much of the eastern bituminous coal. By study and direct comparison of specimens from the various parts of the fields more or less marked physical differences may be distinguished. The greatest difference in this respect is that between the Mesaverde coal, which forms the main bulk of the available product in the whole region, and the coals of the later or younger formations. The Mesaverde coal is admittedly the best of the field, with the possible minor and relatively unimportant exceptions of the still older coals in the Vernal field.

Those younger than the Mesaverde, including chiefly the Laramie and post-Laramie and the Tertiary coals of the Yampa field, mark a distinctly inferior grade and have been considered here as good types of the class defined as subbituminous in the various recent reports of Geological Survey work. In physical appearance and properties the subbituminous coals are thoroughly black, usually a brilliantly glossy jet when fresh, with vitreous or waxy luster. They are extremely tough or tenacious, a property which is frequently described in an inaccurate way as hardness by miners or others on account of the difficulty of working such beds with a pick. A most important distinguishing characteristic is their inability to withstand the action of the weather. On exposure to air, sun, and rain they usually break down to a very fine powder or dust, and as this process takes place with relative rapidity after removal from the mine it usually interferes seriously with the use of the coal. It is of interest to note that this class of coal as observed in the Colorado fields commonly contains much fossil resin scattered in small irregular patches throughout its mass. It usually, though not always, breaks up with checking of the surface and with a conchoidal fracture, and some of it is apparently free from minor jointing or cleavage, although the latter is more or less highly developed in places.

The physical character of the Mesaverde coal is quite varied. That of the upper group described on the preceding pages of this report has been found to be very largely similar to the description just given of the subbituminous coals younger than the Mesaverde. Exceptions to this, however, are noted in the Newcastle district, and also probably are to be found in the districts farther south. At Newcastle the Keystone coal of the upper coal group is essentially of the same quality as the lower coals.

In the main the Mesaverde coal of the Yampa field is very similar to that of the Danforth Hills field. It occurs in beds, often of considerable thickness, showing various degrees of jointing or fracture, and also breaking in many places with an almost purely conchoidal fracture. It is usually a solid black coal, withstanding to only a moderate degree the action of the weather. This coal both checks and cracks when placed in the open air, and without protection, such as roof or cover, will usually break up in a few months. In sheds or

bins affording protection from the sun and rain much of it can be stored without difficulty for a winter season and probably longer. As a whole this coal will probably stand transportation well, depending largely on the character of the individual bed from which it is mined. During the present investigations many small samples have been brought into the office and kept in the dry steam-heated air for periods of one to two years, and in some cases more. Most of these still retain their original shape, while a few have developed one or two major cracks without further crumbling. None of them has disintegrated as the coal exposed to the weather is known to do.

The coals of lower moisture content that are found in the Newcastle and Glenwood Springs districts are not greatly different in physical appearance from those observed in the rest of the fields to the north. The only exceptions noted are those of the coking coals found in the vicinity of Coalbasin. In these coals there is shown a structure recognized as more or less characteristic of some of the well-known coking coals of the eastern United States. As observed, the coking coal from Coalbasin shows a minute cleavage or fractured structure and tends to break down by subdivision, so that as a whole it probably would not stand transportation very well. As the entire product is consumed in the coke ovens, this property is not considered detrimental. The Coalbasin coal also forms a peculiarly smutty or smeary dust and powder, evidently indicating the increased adhesion already mentioned as marking the coking qualities of a coal.

As a whole the Mesaverde coal ranges from the good grade of bituminous noncoking coal, in which it occurs in the major part of all the fields described, to markedly superior products of more restricted occurrences, which include the coking coals of the Coalbasin district and some true anthracites. The latter do not, however, occur in commercial quantities within the area mapped or strictly included in this report. The Mancos coal of the Vernal field has already been compared with the Mesaverde coal (see p. 207), to which it is very similar in many respects, especially in its general appearance and physical properties.

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