UNITED STATES DEPARTMENT OF THE INTERIOR

THE BOOK CLIFFS COAL FIELD IN EMERY AND GRAND COUNTIES UTAH

GEOLOGICAL SURVEY BULLETIN 852

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BY

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THE BOOK CLIFFS COAL FIELD IN EMERY AND GRAND COUNTIES, UTAH

By D. JEROME FISHER

ABSTRACT

The part of the Book Cliffs coal field here described lies between Sunnyside, Utah, and the Utah-Colorado line and embraces a long belt of country in Grand and Emery Counties and a small area in Carbon County, in the east-central part of the State. It lies in the Colorado Plateaus just south of the dividing line between the Uinta Basin on the north and the Canyon Lands to the south. The Book Cliffs themselves are a great southward-facing escarpment.

The coal field is a portion of the southern outcrop zone of an extensive area of Cretaceous strata, in large part coal-bearing, which underlie the Uinta Basin and the Wasatch Plateau. The strata of the Book Cliffs field dip in a general northerly direction under the thick series of Tertiary (largely Eocene) strata that surface the Uinta Basin, but the strike parallels closely the general line of the Book Cliffs. The strata are disturbed by a considerable number of normal faults, most of which have small throws; there are but few folds, and in the main these are rather broad and gentle. Some of the anticlines have been drilled for oil and gas, and commercial quantities of gas have been obtained near Cisco.

The Utah portion of the Book Cliffs coal field, on the basis of characteristics of coals, topographic position of the coal outcrops, and ages of coal-bearing strata, is conveniently divided into two parts by the Green River, the area to the west constituting the Sunnyside district, which contains coals of the age of the type Mesaverde, and that to the east the Thompson district, which contains coals of Fruitland age. All the coal is bituminous, but that in the eastern part of the field is of somewhat lower rank than that in the western part. The estimated quantity of coal that occurs in beds of minable thickness in the area within 2 miles of the generalized outcrop line is 500,000,000 tons. The area has but 1 shipping mine and 2 local mines.

INTRODUCTION

LOCATION AND GENERAL RELATIONS

This report describes the geology and coal resources of the Utah portion of the Book Cliffs coal field, which lies south and east of the Sunnyside quadrangle and extends to the Utah-Colorado State line. This area, about 40 by 75 miles in extent, stretches across Grand and Emery Counties and the southern edge of Carbon County, in the east-central part of the State. (See fig. 1.) The Book Cliffs coal field is a part of the southern outcrop zone of an extensive basin of

Cretaceous strata, in large part coal-bearing, which underlie the Uinta Basin and the Wasatch Plateau. An arbitrary line of separation from the Wasatch Plateau coal field on the west is drawn at the 111th meridian; on the east the field extends into Colorado, where it is separated from the Grand Mesa coal field by the Colorado River.

The rocks of the Book Cliffs field dip in a general northerly direction under the thick series of younger (Tertiary) beds that surface the Uinta Basin, south of the Uinta Mountains, but their strike parallels closely the general line of the Book Cliffs. The beds now appearing in the Book Cliffs formerly extended far to the south but have long

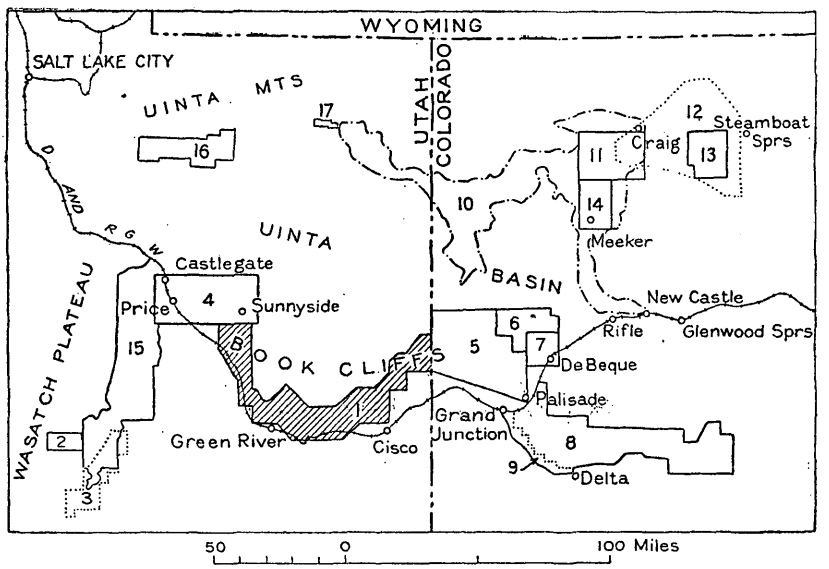


FIGURE 1.—Index map of the part of the Book Cliffs coal field described in this report (1) and other nearby coal fields that are described in publications of the United States Geological Survey. 2, Salina Canyon, Bull. 796-C; 3, Castle Valley, Bull. 628; 4, Castlegate, Wellington, and Sunnyside quadrangles, Bull. 793; 5, Book Cliffs, Colo., Bull. 851; 6, Book Cliffs, Colo., Bull. 371; 7, DeBeque, Bull. 531; 8, Grand Mesa, Bull. 510; 9, Gunnison Valley, Bull. 471; 10, Northwestern Colorado and northwestern Utah, Bull. 415; 11, Axial and Monument Butte quadrangles, Bull. 757; 12, Yampa, Bull. 297; 13, Twentymile Park, Bull. 748; 14, Meeker, Bull. 812; 15, Wasatch Plateau, Bull. 819; 16, Blacktail Mountain, Bull. 471; 17, Deep Creek, Bull. 471.

since been removed by erosion over that area, and older rocks now form the surface of the San Rafael Swell, to the southwest, and the Uncompahgre uplift, to the southeast. Still farther to the south Cretaceous rocks are present in the San Juan Basin of southwestern Colorado and northwestern New Mexico; in Black Mesa, Arizona; near the Henry Mountains of Utah; and in the southwestern Utah coal region. The coal-bearing strata of southwestern Utah are probably continuous with those of the Wasatch Plateau coal field, though buried under a thick cover of Tertiary rocks, largely volcanic in nature.

The Utah portion of the Book Cliffs coal field, on the basis of characteristics of coals, topographic position of the coal outcrops, and ages of coal-bearing strata, is conveniently divided into two parts by the Green River, the area to the west constituting the Sunnyside district, which contains coals of the age of the type Mesaverde, and that to the east the Thompson district, which contains coals of Fruitland age. All the coal is bituminous, but that in the eastern part of the field is of somewhat lower rank than that in the western part.

PREVIOUS GEOLOGIC WORK

Several old reports have dealt in a very cursory way with the mineral resources of the Book Cliffs; these are listed by Richardson,[1] who in 1906 made the first general study of the coals within the area covered by this report. Richardson's party covered a large area in a 3-month field season. His published descriptions were of great value, but the details of stratigraphy, such as the widespread correlation of coal beds, could not be determined in the short time available. Between Richardson's work and the present study the region was not covered as a whole, but three localities were examined in considerable detail by Clark [2] and by Spieker and Baker.[3] These studies were not correlated with each other, as they covered isolated districts, and only Clark's results have been published. In 1909 Forrester [4] criticised some of Richardson's stratigraphic conclusions. Campbell [5] described the Book Cliffs area in nontechnical fashion. Clark [6] has given a detailed description of the coals and enclosing strata of the part of the Book Cliffs coal field lying north and west of the area herein described. In 1926 and 1927 Erdmann [7] mapped and studied the coal series of the Colorado portion of the Book Cliffs coal field.

PRESENT INVESTIGATION AND ACKNOWLEDGMENTS

The present investigation of the coals of the area was made for the purpose of supplying a basis for the classification of the land, most of which constitutes a part of the public domain, and to serve as a guide to prospecting and development. The writer's parties spent the

[1] Richardson, G. B., Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, pp. 5–6, 1909.

[2] Clark, F. R., Coal near Thompson, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 453–477, 1914.

[3] Spieker, E. M., and Baker, A. A., Report of examination of Horse Canyon district, Utah, in Tps. 15 and 16 S., Rs. 14 and 15 E., Salt Lake base and meridian (manuscript report), 1924; Coal near Crescent, Grand County, Utah (manuscript report), 1924.

[4] Forrester, J. B., A short comment on Bulletin 371 of the U. S. Geological Survey: Utah Acad. Sci. Trans., vol. 1, pp. 24–31, 1918. This paper was read before the Academy in 1909.

[5] Campbell, M. R., Guidebook of the Western United States; Part E, The Denver & Rio Grande Western Route: U. S. Geol. Survey Bull. 707, pp. 195–211, 1922.

[6] Clark, F. R., Economic geology of the Castlegate, Wellington, and Sunnyside quadrangles, Carbon County, Utah: U. S. Geol. Survey Bull. 793, 1928.

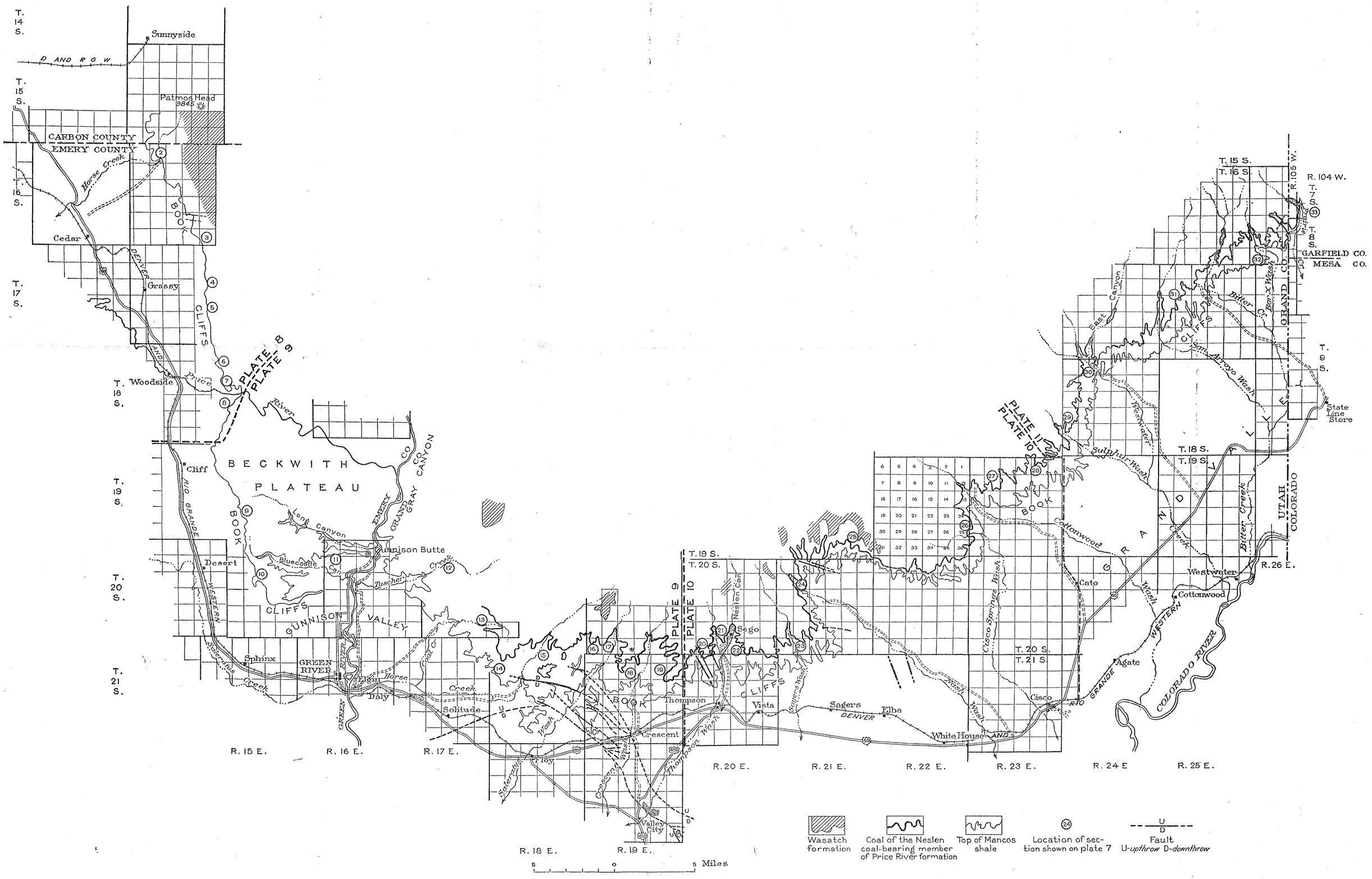
[7] Erdmann, C. E., The Book Cliffs coal field in Garfield and Mesa Counties, Colo.: U. S. Geol. Survey Bull. 851, 1934 [1935].

summers of 1925 and 1926 in the Book Cliffs coal field. H. F. Moses and K. D. Owen, in 1925, and K. K. Landes and R. M. Leggette, in 1926, were assistants. J. H. Hengst was cook in 1926. Much credit is due to these men for their arduous and painstaking labor. The courtesy of the inhabitants of the area in giving information and aiding in other ways is greatly appreciated. Special acknowledgment is due to Mr. Oscar Turner for his hospitality in allowing the party the use of a house on his ranch, northwest of Cisco.

It was originally planned to map the strata by means of intersections along the cliffs made from a stadia traverse run parallel to the cliffs, a mile or so from them. This plan, however, was soon abandoned because of the unavoidable errors of the method, which could hardly be carried out except as a very long hanging traverse, and because of the slow rate of progress. Instead, a system of triangulation was adopted, and points along the cliffs were tied in by intersection from the triangulation points or other points located by resection. East of the Green River the triangulation system also extended up on to the cliffs. All the control and mapping were done by means of small explorer's type telescopic alidades on plane tables 15 by 15 inches, the scale being 2 inches to the mile. No special control sheets were made, and no one person carried the control throughout the area. At many points, indicated on the maps (pls. 8–11), corners established by township surveys of the United States General Land Office were accurately tied in. No regular horizontal correction was made on account of the curvature of the earth, but periodically, where found advisable, adjustments were made with what were taken to be well-established and accurately determined section corners. A little stadia work was done in Price, Bluecastle, Long, and Tuscher Canyons. In certain canyons in the eastern part of the area (east of Thompson), owing to the demand for speed in mapping, it was found necessary to take long "shots" (as much as 4 miles) based on the reading of double flags with the gradienter (Stebinger drum). With control points so widely spaced, the mapping of the part of the area shown on plates 10 and 11 is of necessity rather sketchy as compared with that of the remainder of the area described in this report.

Altitudes taken from mileposts along the Denver & Rio Grande Western Railroad were carried by means of vertical-angle readings. These were checked at variable intervals, where convenient, and it is believed that few altitudes as determined were more than 10 feet in error. The difference of altitude between adjacent triangulation points was generally computed by using the average of several vertical-angle readings.

For certain localities the mapping of the coals and in places of beds at other stratigraphic positions is taken from maps accompanying the



GENERALIZED MAP OF THE PART OF THE BOOK CLIFFS COAL FIELD IN EMERY AND GRAND COUNTIES, UTAH.

reports by Clark [8] and by Spieker and Baker.[9] Their coal sections are also incorporated in the present report. Other materials of these and other geologists of which use was made have been specifically acknowledged at appropriate places in this report. The writer feels under particular obligation to J. B. Reeside, Jr., for the determination of fossils in the collections made by the writer's parties, as well as for furnishing lists of fossils he collected, for correcting the manuscript report, and for many other courtesies not individually mentioned. E. M. Spieker also kindly furnished unpublished sections and other useful data. The work was begun under the general supervision of W. T. Thom, Jr., and completed under the direction of H. D. Miser. Mr. Miser, with A. A. Baker, bore a large part of the duties in connection with the publication of the report, and it is a pleasure to acknowledge indebtedness to them.

GEOGRAPHY

SURFACE FEATURES

The Book Cliffs coal field lies in the Colorado Plateaus, in the southeastern part of the great Intermontane Plateau region between the Rocky Mountain and Sierra Nevada systems. The Book Cliffs themselves lie just south of the dividing line between the Uinta Basin on the north and the Canyon Lands on the south. They constitute a great S-shaped escarpment about 180 miles long and 4 to 15 miles wide, extending from Grand Junction, Colo., to a point just west of Castle Gate, Utah. Their drainage and topography affiliate them with the Canyon Lands, and so does their areal shape, which is due in large part to their position on the flanks of the San Rafael Swell and the Uncompahgre uplift, two great domal structures lying to the south. With regard to their coal content they are, however, more satisfactorily classified as a part of the Uinta Basin. Extending southward from the west end of the cliffs is the Wasatch Plateau.

South of the Book Cliffs lies a great shale "valley" known at different places as Castle Valley, Clark Valley, Gunnison Valley, and Grand Valley. This is not a river valley in the ordinary sense of the word (although some streams flow along it for moderate distances), as several rivers flow directly across it. Adjacent to the Book Cliffs of Utah the valley ranges in width from 3 to 15 miles and closely parallels the cliffs. Its altitude ranges from about 4,050 feet near the town of Green River to over 6,000 feet at the foot of the cliffs in the northwestern part of the area. It formerly was mantled by a gravel apron or compound alluvial fan that sloped gently away from the cliffs. Now only remnants of this apron are left throughout the area, appearing as gravel-capped benches whose smooth tops contrast with the

[8] Clark, F. R., op. cit. (Bull. 541).
[9] Spieker, E. M., and Baker, A. A., op. cit.

intricately sculptured, rugged surface of the shale in the intervening areas. These benches, which stand up 50 to 200 feet in general, are found at three or more distinct levels, showing that the original apron was more or less thoroughly dissected at several different stages, succeeding each of which less extensive gravel deposits were formed.

From this lowland the Book Cliffs, a great southward-facing escarpment, majestically rise toward the highlands of the Uinta Basin, the southern part of which is the Roan Plateau, sometimes referred to as the "Tavaputs Plateau." This plateau is separated into eastern and western parts by the canyon of the Green River; an extension from the western part is known as the "Beckwith Plateau" or, locally, as "Elliot Mountain", and lies south of the canyon of the Price River. The ascent to the Roan Plateau is very irregular, especially east of the Green River, owing to the intricate carving of the cliff front into canyons separated by salients or headlands. In general the rise is made in two steps; of these the Book Cliffs are the first or more southerly, and a varying distance back to the north of them rise the brilliantly colored Roan Cliffs. At places, as in the northwestern part of the area and northwest of Cisco, Utah, these two sets of cliffs are so close together as to constitute what is virtually a single escarpment. Elsewhere, as along the Green River or in the northeastern part of the area, the two are 10 miles or more apart. The divide at the south edge of the Uinta Basin in Grand County lies at an altitude ranging from 8,000 to more than 9,000 feet. In the area mapped the altitude reaches 9,500 feet in the northwestern part, 7,135 feet on the Beckwith Plateau, 6,684 feet near Tuscher Canyon, and 8,037 feet northwest of Cisco.

The eastern and western parts of the Book Cliffs, separated by the Green River, are topographically dissimilar. (See pl. 1.) In the western part they rise as a single escarpment, whose appearance along the Beckwith Plateau is shown in plate 2, *A*; here the steep shale slope constitutes the lower half of the rise, which is capped by massive vertical-walled sandstones interbedded with soft shales that weather to steep slopes. West of the Green River the cliff is inaccessible except along the few canyons or where it is broken by faults. East of the river a pronounced shale unit (Buck tongue of Mancos shale) appears immediately above the Castlegate sandstone. Here the sandstone constitutes the surface of a dip-slope bench (pl. 3, *A*), which has a maximum width of 2 miles, and from the rear of which rises a second line of cliffs (pl. 2, *B*). Access to the second line of cliffs, along which most of the coal crops out, may be gained by way of all the larger canyons and some of the smaller ones. Throughout this eastern part of the area the cliff front is very irregular, with innumerable salients and canyons, in remarkable contrast to the relatively unbroken front of the western part.

DRAINAGE

The area lies a short distance northwest of the Colorado River. The major tributary of the Colorado, the Green River, has cut the famous Gray Canyon through the cliffs in the west-central part of the field. The Price River, a western tributary of the Green, flows southeastward through Castle Valley and then passes through a deep canyon, isolating the Beckwith Plateau from the high country to the north. There are many smaller streams, the chief of which are indicated on plate 1. A few are perennial through the cliff portions of their courses, but none carry sufficient water to make a noteworthy streamlet across the wide, dry, barren shale flat south of the cliffs. After rain storms, however, they may become roaring, turbulent masses of silt-laden liquid in which boulders crack like the rattle of a muffled snare drum. A few of the available discharge data are given in the township descriptions.

CLIMATE AND LIFE

The area is arid to semiarid, with an average annual precipitation between 5 and 10 inches—one of the driest parts of the State outside of the Great Salt Lake Desert. Further climatic data appear in the table below.

Climatic records for Green River and Cisco, Utah

[From Summaries of climatological data by sections, U. S. Dept. Agr., 1926]

	Average annual precipitation (inches)	Temperature (° F.)					Average annual snowfall (inches)	Killing frosts	
		Mean annual	Mean maximum annual	Mean minimum annual	Highest	Lowest		Last	First
Green River	5.62	52.1	69.7	34.6	112	−31	10.0	May 30	Sept. 11
Cisco	6.50	51.9	67.7	36.0	109	−26	17.3	June 8	Sept. 21

Most of the surface water outside of the Green River is nonpotable. At most camps it was found necessary to haul water for drinking from the nearest settlement, and at some camps water had to be hauled for the animals. Details regarding water are given in the township descriptions.

The amount and kind of vegetation vary with the altitude and rainfall. It is heavier at the two ends of the area than elsewhere, though much of the Nash reentrant, northwest of Cisco, is well covered. Between the Nash reentrant and Grassy (sec. 18, T. 17 S., R. 14 E.) the shale flat has an exceedingly barren appearance except along the Green and Price Rivers, at Thompson, and perhaps at another spot or two, where cottonwoods are found. In the favorable areas the gravel benches are dotted with scrubby cedars and some

piñons. Sagebrush is locally rather abundant, and cactus of the pricklypear type is not uncommon. Some of the valleys have greasewood, thickly grown in a few places. Other bushes or shrubs are present here and there. Coarse grass grows in some places. The bench on the Castlegate sandstone, as well as the top of the Beckwith Plateau, supports in most places a moderate growth of gnarled cedars, sagebrush, and coarse grass. The slopes of the second line of cliffs east of the Green River are sparsely dotted with cedars. The higher slopes, where not too steep, and the higher flats have in general a heavier and larger growth, with an increasing number of piñons.

TRANSPORTATION AND SETTLEMENTS

The Denver & Rio Grande Western Railroad roughly parallels the cliff front 1 to 10 miles south of the Book Cliffs. The only branch line is that from Thompson to the coal mine at Sego. United States Highway 50, which approximately follows the route of the railroad, is surfaced with gravel and offers a good route for automobile travel. Through part of its course this highway follows essentially the route of the old Spanish trail [10] that led from Santa Fe to Los Angeles. Secondary roads lead from highway 50 into the canyons at the edge of the cliffs, but none of them are suitable for automobile travel to the Uinta Basin. Some additional ways of access to the cliffs are described in the township reports. The railroad and the principal roads are shown on plate 1.

The area is very sparsely populated, the city of Green River, which in 1930 had a population of 474, being the only incorporated settlement. The population of certain precincts in 1930 was as follows: Woodside, 83; Elgin, 128; Thompson, 93; Sego, 223; Cisco, 193; Westwater, 44. There is an active fruit and alfalfa growing area above Green River. Thompson and Cisco serve as railroad supply depots for settlements to the south and as shipping points for cattle, sheep, and wool. One or more ranches are located at Woodside, Green River, and Thompson, as well as in Saleratus, Nash, Cottonwood, Westwater, Bitter, and Bar X Canyons. The only shipping coal mine is that of the Chesterfield Coal Co. at Sego, north of Thompson. There are gas wells near Cisco, and small amounts of petroleum and gas have been obtained near Crescent, west of Thompson.

STRATIGRAPHY

GENERAL FEATURES

The outcropping strata of the Book Cliffs coal field all belong to the Upper Cretaceous and Eocene series, with the exception of the younger alluvial-fan and terrace-gravel deposits, which are Pleisto-

[10] Gannett, Henry, A gazetteer of Utah: U. S. Geol. Survey Bull. 166, p. 10, 1900.

cene (?), and the Recent alluvium. No obvious erosional or structural unconformities are present in the rocks of pre-Quaternary age, although it is fairly certain that erosional unconformities occur at the base of the Upper Cretaceous (base of the Dakota (?) sandstone) and at the base and top of the Tuscher formation (Tertiary?). The lower sandstone strata of the Book Cliffs proper show a pronounced tongue arrangement with respect to the Mancos shale and disappear to the east, where they pass into shale. The stratigraphic relations of the various lithologic units are shown on plate 7. A more detailed description of the stratigraphy will be given in a later report.

Exposed rocks of the Book Cliffs area between Sunnyside, Utah, and the Utah-Colorado State line

Geologic age		Group and formation	Member	Character	Thickness (feet)
Quaternary.	Recent.			Sandy alluvium along stream courses; the larger areas occur only along the Green River.	
Quaternary.	Pleistocene (?).			Terrace deposits of gravel along the Green River. Remnants of alluvial-fan gravel deposits capping benches of Mancos shale sloping away from the Book Cliffs; recognized at three levels.	25±.
Unconformity					
Tertiary (Eocene).		Wasatch formation.		Varicolored, predominantly purplish-red shales with heavy cliff-forming gray sandstones. Basal portion carries a conspicuous conglomerate at many places. Fresh-water fossils.	250± to 4,000±.
Unconformity (?)					
Tertiary (?).		Tuscher formation.		Light-colored sandstones with minor interbedded shales. No fossils.	130(?) to 600.
Unconformity (?)					
Upper Cretaceous.		Mesaverde group [1] Price River formation.	Farrer non-coal-bearing member.	Somber-colored sandstones with greenish-tinged gray shales. Fresh-water fossils. Recognized in the upper part of the second escarpment of the Book Cliffs east of the Green River.	410 to 1,095 (average 690).
Upper Cretaceous.		Mesaverde group [1] Price River formation.	Neslen coal-bearing member.	Series of relatively light-colored alternating sandstones and shales in about equal proportions. On the whole a rather heterogeneous unit of brackish- to fresh-water origin, but sandstones were recognized at three definite horizons, and these are here named "Bluecastle sandstone bed", "Thompson Canyon sandstone bed", and "Sulphur Canyon sandstone bed." Carries coal in the Palisade, Ballard, Chesterfield, and Carbonera (?) coal zones, as well as in minor amounts in other unnamed and lenticular beds. Not recognized northwest of the Beckwith Plateau as a distinct unit.	250 to 410 (average 350).
Upper Cretaceous.		Mesaverde group [1] Price River formation.	Sego sandstone member.	Dominantly sandstone; buff-weathering in the main, massive and cliff-forming to thin-bedded and shaly. Makes one to four cliffs; this variation is due to the presence of local irregular shaly zones. Carries a marine fauna of Lewis age. Not recognized northwest of the Beckwith Plateau.	140 to 210.

[1] "Mesaverde group" is the name applied by the United States Geological Survey to a succession of shales and sandstones of Upper Cretaceous age, largely of nonmarine origin, overlying a great body of marine shale (the Mancos) and usually overlain by a marine shale (the Lewis). In the writer's opinion this name is not properly applicable to the upper (post-Castlegate) strata so classified in this report, because numerous marine invertebrate fossils identical with forms found in the Lewis shale have been collected from the Buck tongue of the Mancos shale and the Sego sandstone member of the area.

Exposed rocks of the Book Cliffs area between Sunnyside, Utah, and the Utah-Colorado State line—Continued

Geologic age	Group and formation		Member	Character	Thickness (feet)
Upper Cretaceous—Continued.	Mesaverde group—Continued.	Price River formation—Contd.	Buck tongue of Mancos shale.	A westward-thinning tongue of shale, lithologically identical with the Mancos shale farther east. Not recognized northwest of the Beckwith Plateau. At the Colorado line it merges into the Mancos shale, owing to the disappearance of the Castlegate sandstone member. It carries marine invertebrates like those of the Lewis shale.	0 to 350.
			–Local disconformity (?)–		
			Castlegate sandstone member.	An eastward-thinning unit of massive buff-weathering, fairly coarse to very fine grained cliff-making sandstone. East of the Green River its upper part forms the surface of a pronounced dip-slope bench, as much as 2 miles in width, that separates the Book Cliffs into two major escarpments. Brackish-water to shallow marine origin. Gradational contact with underlying shale.	0 to 190 (averages 90 feet east of the Green River).
		Blackhawk formation.	Upper member.	Gray shale north of Desert. Between Desert and Floy consists of an upper cliff-forming sandstone and a lower shale. East of Floy only the upper sandy part can be differentiated from the Mancos shale. Not present east of Nash Wash. Carries lenticular beds of coal at several unnamed horizons. Brackish-water fossils.	70 + to 230.
			Middle sandstone member.	Massive cliff-forming sandstone, shaly in lower part. Not present east of Floy. The Sunnyside coal (present only west of the Green River) is found 25 to 75 feet below its top. Brackish-water fossils.	100 to 245.
			Middle shale member.	Medium-gray shale, locally limy and with minor sandstone lenses. East of the Green River it cannot be distinguished from the Mancos shale. Carries the Kenilworth coal at or near its base in two small districts.	100 to 160.
			Lower sandstone member.	Massive to thin-bedded and cross-bedded friable quartz sandstone with a calcareous cement; medium-grained to very fine grained (siltstone) and cliff-forming. Brackish-water origin. Not traced east of the Green River.	150 to 170.
				A lower shale member and the underlying Aberdeen sandstone member, the latter at the base of the Blackhawk formation, are present to the northwest but are absent in the area described in this report.	
	Mancos shale.			Gray marine shales with relatively minor beds of sandstone and limestone at varying horizons at different localities. Upper contact is gradational, with a tongue arrangement, the shale tongues pointing to the west, and the top of the formation rising stratigraphically to the east. Ferron sandstone member locally present in lower part.	3,450 to 4,120.
	Dakota (?) sandstone.			Extremely varied lithologically. Friable to quartzitic sandstone and conglomerate with interbedded gray shale and rare limestone lenses. Fossil leaves, tree trunks, and pelecypods, indicating fresh-water conditions. Forms a hogback.	2 to 126.
Unconformity					
Jurassic.	Morrison formation.			Not examined.	

CRETACEOUS SYSTEM

DAKOTA (?) SANDSTONE

The Dakota (?) sandstone of the area is a thin, resistant, cuesta-making, heterogeneous unit that lies conformably beneath the Mancos shale. It rests on typical variegated shale of the Morrison formation

(Jurassic). Although at most places this contact is not well exposed, it seems to be essentially conformable; however, in a few places an undulating surface marking an unconformity has been observed. Richardson[11] collected typical Dakota fossil plants from the Dakota (?) sandstone near Elgin and Woodside. The formation in east-central Utah, therefore, seems to be of approximately basal Upper Cretaceous age, but nevertheless the name is here applied with a query to indicate that its relations to the type Dakota are indefinite.

As this sandstone forms an outlying cuesta 3 to 18 miles distant from the Book Cliffs, and as it is not known to be coal-bearing in this area, it was only cursorily examined at a few places. Parts of it are mapped on plates 8 and 9. It ranges from 2 to 126 feet in thickness, as far as shown by measured sections; the greater thickness was found in the eastern part of the area. It is composed of friable to quartzitic sandstone and conglomerate with considerable interbedded shale. The sandstone ranges from light-gray fine-grained, sugary, friable rock to hard black quartzite. The pebbles in the conglomerate are as much as 4 inches in diameter and consist of varicolored chert, white to reddish quartzite, and granite, with less well rounded fragments of limestone. The shale is commonly light greenish gray but in places is dark gray. The lithologic character changes abruptly both horizontally and vertically. Most of the material seems to be of fluviatile origin.

MANCOS SHALE

All strata between the Dakota (?) sandstone and the lowest pronounced sandstone of the Book Cliffs proper are here classed with the Mancos shale. As thus defined, the formation is a well-marked lithologic unit rather than a time unit. It includes equivalents of the Benton, Niobrara, and much of the Montana (well through the Pierre), but is certainly older than the Fox Hills. A distinctive Telegraph Creek fauna has been recognized only near Green River. The upper contact, which is gradational, rises stratigraphically to the east through a system of westward-pointing tongues of Mancos shale interfingering with sandstone, as is shown on plate 7. In 165 miles (240 miles along the cliffs), from the Wasatch Plateau, Utah, to the Fairview mine, 12 miles north of Delta, Colo., this rise in the top of the Mancos amounts to about 2,000 feet.

The thickness of the formation ranges from 3,450 to 4,120 feet, and west of this area it becomes more than 5,000 feet.[12] Lithologically the Mancos is composed chiefly of slightly bluish medium to dark gray marine shale which weathers to a drab-gray when dry. It is generally limy, without pronounced fissility, and feels gritty when

[11] Richardson, G. B., Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, p. 14, 1909.

[12] Clark, F. R., op. cit. (Bull. 793), p. 13.

chewed. It carries veinlets of gypsum and calcite and locally shows streaks of alkali on the weathered surface. Included in it are relatively thin beds of sandstone, which vary in thickness and stratigraphic position. Of these the Ferron sandstone member, in the lower part of the formation, well recognized west of the present area, is the most extensive. Its outcrop in the northern part of this area is shown on plate 8. Thin beds or lenses of dense limestone are also present. Marine invertebrates and fish teeth have been found in abundance at many horizons and localities; details will appear in a later report. Topographically the Mancos shale forms the broad flat paralleling the Book Cliffs, which is known at different localities as Castle Valley, Clark Valley, Gunnison Valley, and Grand Valley. It does not form a valley for any single stream. Approximately the upper 500 feet of the formation makes the steep basal slopes of the Book Cliffs (pl. 2, *A*), beneath which badlands are commonly present (pl. 3, *C*). The contained sandstone beds cause cuestas, which vary in size with the resistance and dip of each bed.

MESAVERDE GROUP [13]

BLACKHAWK FORMATION

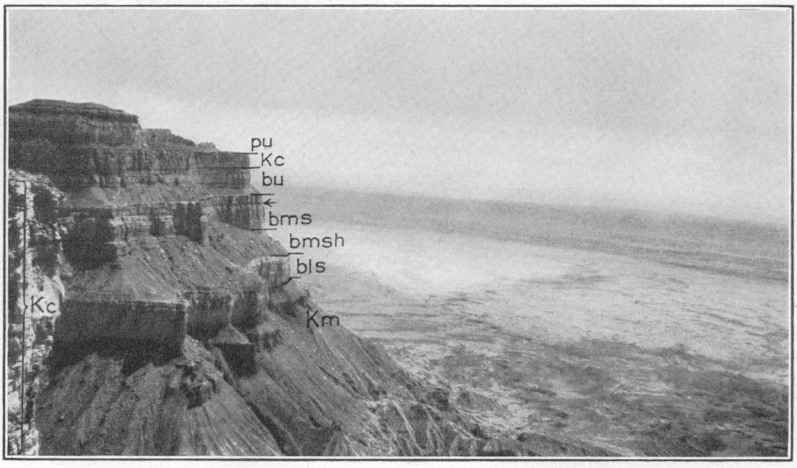
The Blackhawk formation of this area includes all but the lower part of the formation as exposed a few miles to the west, where it was first defined by Spieker and Reeside [14] as the coal-bearing unit of the Wasatch Plateau. Within the area herein described the formation consists of three sandstone-bearing members; both the lower and middle members are overlain by tongues of shale that locally contain coal. (See pl. 7.) The still lower sandstone found farther northwest and named by Clark [15] the Aberdeen member is absent in the area here described. In eastern Utah these sandstones give way to Mancos shale. The subdivisions of the Blackhawk formation recognized in this area are shown in the table on page 10.

The sandstone members of this formation were formed as great coastal-plain deposits that extended out from the highlands on the west into the edge of the Mancos sea. They are composed of particles which are finer toward the east, where they finally grade into shale. Similarly they change eastward from fresh-water to brackish-water deposits and even to shallow-water marine deposits. However, only brackish- to fresh-water fossils of Montana age were actually collected. Each sand plain was built out farther into the Mancos sea than the next older one. On portions of these plains that were not under the Mancos sea and yet not so far west of the seashore that the climatic or topographic conditions were unfavorable, luxuriant forests thrived

[13] See footnote to table on p. 9.

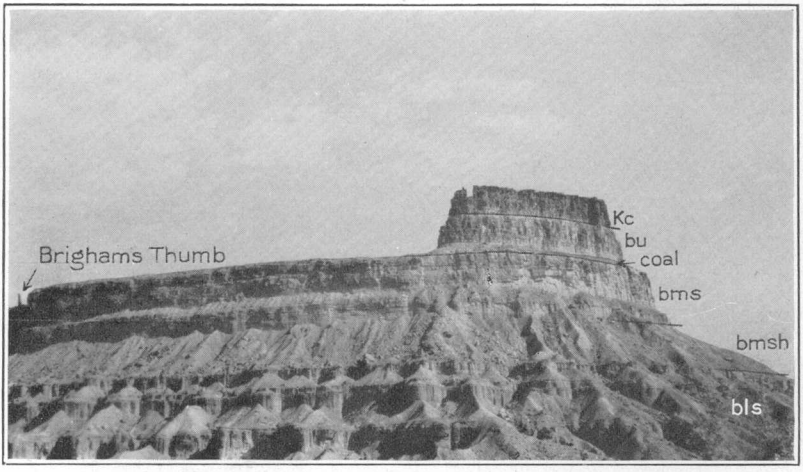
[14] Spieker, E. M., and Reeside, J. B., Jr., Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geol. Soc. America Bull., vol. 36, pp. 443-445, 1925.

[15] Clark, F. R., op. cit. (Bull. 793), p. 16.



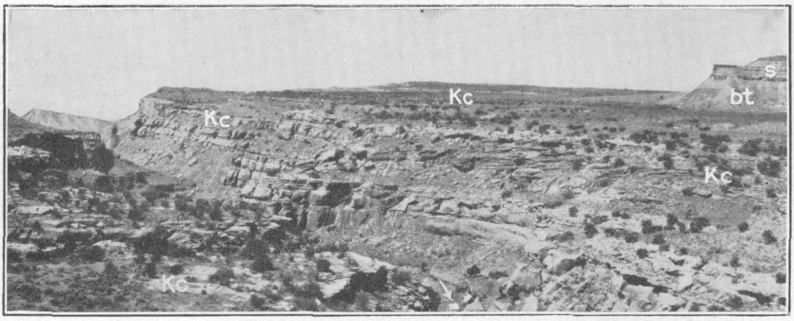
A. VIEW LOOKING NORTH ALONG THE SOUTHWEST EDGE OF THE BECKWITH PLATEAU.

Km, Mancos shale; *bls*, lower sandstone member of Blackhawk formation; *bmsh*, middle shale member of Blackhawk formation; *bms*, middle sandstone member of Blackhawk formation with Sunnyside coal seam in its upper part; *bu*, upper member of Blackhawk formation; *Kc*, Castlegate sandstone; *pu*, upper Price River formation.



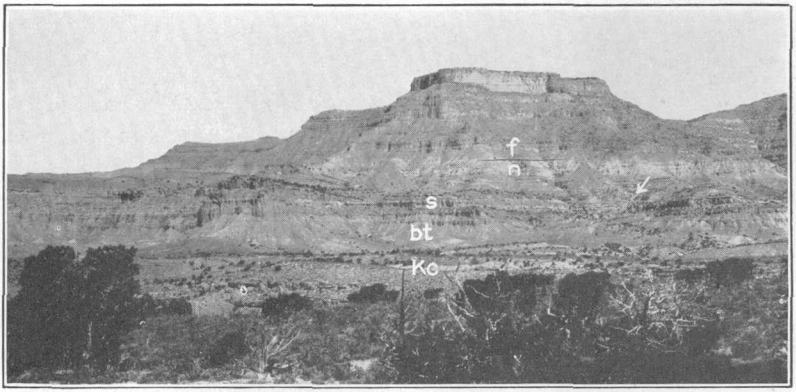
B. GUNNISON BUTTE, 8 MILES NORTH OF GREEN RIVER.

This prominence rises 1,140 feet above the river. *bls*, Lower sandstone member of Blackhawk formation; *bmsh*, middle shale member of Blackhawk formation; *bms*, middle sandstone member of Blackhawk formation with Sunnyside coal seam in its upper part; *bu*, upper member of Blackhawk formation; *Kc*, Castlegate sandstone.



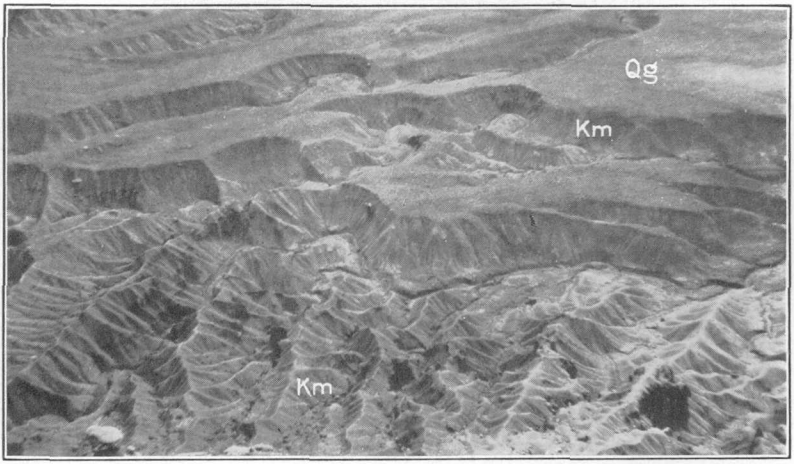
A. VIEW LOOKING SOUTHWEST ALONG THE CASTLEGATE BENCH ACROSS CRESCENT CANYON.

Kc, Castlegate sandstone; *bt*, Buck tongue of Mancos shale; *s*, Sego sandstone. Arrow indicates camp in Crescent Wash.



B. VIEW LOOKING NORTHWEST ALONG THE CASTLEGATE DIP SLOPE ACROSS CRESCENT WASH TO CRESCENT BUTTE.

Kc, Castlegate sandstone; *bt*, Buck tongue of Mancos shale; *s*, Sego sandstone; *n*, Neslen member; *f*, Farrer member. Arrow indicates Crescent mine.



C. VIEW LOOKING DOWN ON THE SHALE SLOPE AT THE BASE OF THE BOOK CLIFFS ALONG THE BECKWITH PLATEAU EAST OF DESERT.

Shows the badland character of the Mancos shale (*Km*) near the cliff where not protected by gravel aprons (*Qg*).

during certain intervals. Figs, palms, magnolias, and similar plants were probably common, as is indicated by fossil remains of these forms found in adjacent beds. These forests lasted for exceedingly long intervals as measured by ordinary human standards, so that many generations died of old age and, falling into the swampy soil, formed the floor on which their descendants grew. But gradually changing conditions finally resulted in the burial of the thick vegetable debris thus accumulated. In some parts the forest was inundated by the sea; in others it was buried by sand brought in by rivers that flowed from the highlands to the west. During succeeding geologic epochs these vegetable deposits have been changed into coal beds. The coal beds, like the sandstones, die out toward the east, and those mined near Castlegate are older than those in the same formation in the Book Cliffs to the east.

The lower sandstone member in this area is very prominent as the basal sandstone of the Beckwith Plateau (pl. 2, *A*) but is also well marked to the west. In this area it is 150 to 170 feet thick. Its character is given in detailed sections 5 and 10 (pp. 22–25). Near the Green River it becomes very shaly, as is well shown at Gunnison Butte (pl. 2, *B*), and east of that place it can be distinguished for but a short distance, as it gives way rather abruptly to shale. Its lower contact is gradational into the underlying Mancos shale. Its upper contact, which is sharp at most places, is conformable with the overlying middle shale member, which is lithologically like the Mancos (see detailed sections), as is indicated on plate 2, *A*. It is between 100 and 160 feet thick where measured. It is traceable over the same area as the lower sandstone member. Farther east it becomes part of the Mancos shale. In the extreme northern part of the area (pl. 8) and along the southwestern part of the Beckwith Plateau (pl. 9) the Kenilworth coal seam is present at or near its base. No determinable fossils have been found in this shale or the underlying sandstone in the present area.

The massive character of the next overlying unit, the middle sandstone member, is shown on plate 2, *A*. Its lithologic nature is described in sections 5 and 10 (pp. 22–25). It is mapped as far east as the east side of Horse Canyon and is not distinguishable from the Mancos shale a short distance east of the canyon of Saleratus Wash (pl. 9). Its thickness ranges from 100 to 245 feet (pl. 7). It is conformable with the enclosing beds; its upper contact is sharp in most places, but its lower contact is gradational. West of the Green River it carries the Sunnyside coal seam 25 to 75 feet below its top.

The upper member of the Blackhawk formation is somewhat more complex than lower members because, though dominantly shale, its upper portion in the eastern part of the area consists of a massive

sandstone, as is indicated on plate 7. For this reason part of this member could be traced as far east as the Nash reentrant (pl. 10). From west to east this sandy unit first appears prominently in the southwestern part of the Beckwith Plateau (pl. 2, *A*); it is well developed on Gunnison Butte (pl. 2, *B*), where it makes a cliff nearly integral with that of the overlying Castlegate sandstone. While the shale was forming there was an influx of sand from the northwest or southwest into the present Green River embayment area, forming a sort of peninsula. The combined thickness of this upper shale and the locally overlying sandstone ranges from 70 to 230 feet where sections were taken, but the lower figure includes only the sandstone east of Saleratus Canyon. The shale and sandstone resemble the enclosing beds and are described in all the sections given on pages 22 to 34, except the last. This member carries thin discontinuous coal lenses in its upper, middle, and lower portions in different parts of the area. These have not been given specific names but are referred to as "coals of the upper member of the Blackhawk formation" or simply as "upper Blackhawk coals." With the exception of the coal zone near the top they are of little or no value; even this upper zone is of minor value, but it is of interest as being the only coal bed older than the Price River formation in the area east of the Green River.

PRICE RIVER FORMATION

The Price River formation was defined by Spieker and Reeside [16] as consisting of all post-Blackhawk but pre-Wasatch sediments in the Price River Canyon above Castle Gate, where the formation is about 1,100 feet thick. Traced to the east it thickens greatly, and beyond the Price River it is divisible into four members, which are, in ascending order, the Castlegate sandstone, the Sego sandstone, the Neslen coal-bearing member, and the Farrer non-coal-bearing member. In the area here described the Castlegate and Sego sandstones are separated by the Buck tongue of the Mancos shale. The strata of the upper three members correspond to the upper Price River of Spieker and Reeside.

CASTLEGATE SANDSTONE MEMBER

Clark [17] named the Castlegate sandstone after a town on the Price River, near which the unit is 400 feet or more in thickness. The member thins from 500 feet of conglomeratic sandstone in the northern part of the Wasatch Plateau to a featheredge of siltstone near the Utah-Colorado line. In the area here described it reaches a maximum thickness of 190 feet; west of the Green River it is not pronouncedly different from the underlying Blackhawk sandstones, as is shown on plate 2, *A*. East of the river, owing to the presence of a soft overlying

[16] Spieker, E. M., and Reeside, J. B., Jr., op. cit., p. 445.
[17] Clark, F. R., op. cit. (Bull. 793), p. 119.

shale, it has caused the development of a prominent bench or dip slope as much as 2 miles in width, which caps the first line of the Book Cliffs, as shown on plate 3, *A*, and on the maps. Its lithologic character is described in the detailed sections (except no. 5), pages 22–34, and its variation in thickness is shown graphically on plate 7.

In the area described it rests conformably on the underlying beds. Where shale is beneath, the lower contact is gradational; this agrees with Clark's observations,[18] but Spieker and Reeside[19] noted an erosional unconformity at the base in one place farther west. In parts of the area east of the Green River the upper few inches of the sandstone shows some evidence of reworking and is locally more firmly cemented. On the bench on the west side of Horse Canyon (sec. 7, T. 21 S., R. 18 E.; see pl. 9) there seem to be a few shallow hollows containing the overlying shale. The relations are obscure, but there is some indication that in this part of the area the upper surface of the member marks a minor disconformity. No identifiable Castlegate fossils were found in the area west of the Saleratus Canyon, shown on plate 9; a few found farther east are mainly upper Pierre marine forms, with one brackish-water species. The mode of origin of the Castlegate was similar to that already sketched for the Blackhawk sandstones. The member is mapped as a unit as far east as the east side of Horse Canyon, shown on plate 9; farther east the unit as mapped includes the underlying sandy beds in the upper part of the upper member of the Blackhawk formation, as well as the overlying Buck tongue of the Mancos shale.

BUCK TONGUE OF MANCOS SHALE

The Buck tongue is a westward-pointing tongue of the Mancos shale, here named from Buck Canyon, in T. 19 S., R. 23 E. (pl. 10). From west to east it may first be seen in poor development in the Beckwith Plateau, where it is about 50 feet thick (pl. 2, *A*); east of the Green River it stands out above the Castlegate bench (pl. 3, *A*, *B*). It thickens to the east, as shown on plate 7; and near the Utah-Colorado line, where it merges into the beds of Mancos shale, owing to the disappearance of the Castlegate sandstone, it is 350 feet thick. Its upper contact, which is gradational, is mapped east of the west side of Horse Canyon (pl. 9). It carries a marine fauna of Lewis (Montana) age.

SEGO SANDSTONE MEMBER

The Sego sandstone, here named after the settlement of Sego, in T. 20 S., R. 20 E. (pl. 10), is a cliff-forming member traced from the neighborhood of the Beckwith Plateau into Colorado, where Erd-

[18] Idem, p. 20.

[19] Spieker, E. M., and Reeside, J. B., Jr., op. cit., p. 446.

mann [20] has shown it to be split into two units by the westward-pointing Anchor Mine tongue of the Mancos shale. The lower of these sandy units fades into the Mancos about 21 miles east of the Utah State line. The upper unit extends a short distance into the Grand Mesa and is the basal sandstone [21] in Lee's "Grand River" section.[22] West of Horse Creek (pl. 9) it is not a well-developed unit, though sandy beds are common at this horizon of the Price River formation (pl. 2, *A*). No attempt was made to distinguish it northwest of the Beckwith Plateau. East of the Green River in Utah it makes one to four cliffs in the basal part of the second escarpment of the Book Cliffs (pl. 3, *B*). Its lithologic character is described in the detailed sections on pages 22–34, from which it is clear that it resembles in a general way the lower sandstones, though it is slightly less massive at most places. Its general range in thickness is from 213 to 140 feet, but it is only 115 feet where section 13 (pl. 1) was taken. East of the Green River in Utah it averages 175 feet. The variations in thickness are shown graphically on plate 7. Its lower contact is gradational; its upper contact is conformable with the overlying Neslen member. Where the basal portions of the overlying beds are not sandy the contact is sharp. Local channel unconformities were noted within the Sego sandstone. A very rich fauna has been collected from this member; in the eastern part of Utah the forms are mainly marine and like those of the Lewis shale; farther west, near the Green River, brackish-water fossils are present. No coal is known in the Sego sandstone in Utah, but in Colorado [23] a minor seam is locally present near the top of the Anchor Mine tongue of the Mancos shale, which splits the Sego sandstone into two units.

NESLEN COAL-BEARING MEMBER

Above the Sego sandstone lies a series of shales and sandstones that has an average thickness of 350 feet and carries valuable coal beds. These rocks have a generally lighter shade than the overlying ones, and the series is here named the Neslen coal-bearing member, from Neslen Canyon, in which the town of Sego (pl. 10) is situated. It is composed of about equal proportions of alternating sandstones weathering buff to light gray and shales weathering light gray. These rocks form minor ledges with intervening slopes (pl. 3, *B*) that at a distance contrast with the somber, brown-stained sandstones and olive-greenish tinged medium-gray clay shales of the overlying Farrer non-coal-bearing member. The sandstones of the Neslen

[20] Erdmann, C. E., The Book Cliffs coal field in Garfield and Mesa Counties, Colo.: U. S. Geol. Survey Bull. 851, p. 35, 1934 [1935].

[21] Boyer, W. W., unpublished data.

[22] Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colo.: U. S. Geol. Survey Bull. 510, p. 50, 1912.

[23] Erdmann, C. E., op. cit., p. 37.

member do not have the continuous and pronounced cliff-making habit of the older sandstones, because they are thinner and in general less persistent. Variations in thickness and lithology are shown on plate 7 and in much more detail on plates 13 to 15. Detailed descriptions are presented on pages 23–33.

The member was not distinguished from the adjacent beds west of the Green River; however, it includes all strata that overlie the Sego sandstone member in the Beckwith Plateau. Strata of the same age as those included in the member extend eastward into Colorado along the Book Cliffs and the Grand Mesa, where their top may be approximately at the top of Lee's Paonia shale.[24] Erdmann [25] applied the name "Mount Garfield formation" to the coal-bearing strata that are younger than the Sego sandstone. His columnar section shows the top of the Mount Garfield to be approximately equivalent to the top of the Paonia. But the Mount Garfield formation of Colorado is much thicker than the Neslen member of Utah. This difference may mean that the Neslen and Mount Garfield are not strictly equivalent, but it is no doubt due in the main to the fact that the upper contacts of these coal-bearing units are gradational and therefore are arbitrary. The differences in color and lithology between the Neslen and the overlying Farrer member have been noted above; a further difference is the greater proportion of sandstones in the higher member, of which they constitute about two-thirds, except near the Green River, where the shale content is higher. Erdmann's criteria [26] for separation of the Mount Garfield from his overlying Hunter Canyon formation are as follows:

> The overlying Hunter Canyon formation is differentiated from the Mount Garfield formation chiefly by the difference in character of its sandstones, which are more numerous and also coarser, grayer, and more massive than those below. The carbonaceous shale of the Mount Garfield formation practically disappears in the Hunter Canyon formation, which also shows a diminution in the total amount of shale, some of which has a greenish cast.

The writer found these differences to exist between the Neslen and Farrer members in his area, except that there was no appreciable difference in grain size, the average maximum size of grain of any sandstone unit in either member being one seventy-fifth of an inch. Also, the sandstones of the Farrer member are not "grayer" than those of the Neslen. The brownish weathered surfaces of the sandstones may be due to the relatively large content of kaolinized feldspar, which is readily stained by iron compounds. The contact between the two members stands out much better from a distance than it does when a detailed section is being measured.

[24] Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colo.: U. S. Geol. Survey Bull. 510, p. 50, 1912.
[25] Erdmann, C. E., op. cit., p. 40.
[26] Idem, pp. 40–41.

Though one of the characteristics of the Neslen member is its heterogeneity, certain sandstone and coal horizons were recognized at different places and varying stratigraphic levels. About 200 feet above the base of the member in the Beckwith Plateau and a short distance east of it, a minor cliff-making sandstone was taken as a unit, mainly because it was strong enough to determine the present dip-slope surface on the remnant of undissected cap of the Beckwith Plateau. It is here named the "Bluecastle sandstone bed", after the canyon that nearly transects the Beckwith Plateau (pl. 9). It has a thickness of 100 feet or more on the plateau, but to the east it thins rapidly and loses its identifying characteristics, as is shown on plate 7. No attempt was made to trace it to the northwest. It appears to have something of the nature of a lens. Aside from the characteristics already mentioned, it is similar to most of the other sandstones of the Neslen member—that is, cross-bedded, medium- to fine-grained, and weathering buff to gray.

The middle part of the Neslen member carries a minor sandstone ledge, here named the "Thompson Canyon sandstone bed", which was traced between Saleratus Canyon (pl. 9) and Cottonwood Canyon (T. 19 S., R. 23 E.; pl. 10). Its appearance is indicated in plate 5, *A*, *B*. It consists of 10 to 15 feet of massive, faintly cross-bedded straw-colored sandstone, which weathers into rounded surfaces. It is commonly overlain by a few feet of sandy shale capped with a foot or two of impure platy limestone. A sandstone about 15 feet higher was traced from Buck Canyon (T. 19 S., R. 23 E.; pl. 10) to the Colorado line. It is 20 to 25 feet thick, a massive to medium-bedded ledge maker, buff to gray except for a "white" upper part, and weathers into blocky forms due to joints. It is here named the "Sulphur Canyon sandstone bed", from Sulphur Canyon (T. 18 S., R. 24 E.; pl. 11). This sandstone and the Thompson Canyon sandstone bed are thought to occupy essentially the same stratigraphic position as the Rollins sandstone [27] of Lee's type locality, but these sandstones are not continuous, as Erdmann [28] considers that the Rollins sandstone cannot be traced west of sec. 36, T. 9 S., R. 100 W., in Colorado.

Four coal zones are present in the Neslen member. The Palisade coal zone (pl. 4, *A*), in the lower part of the member, generally less than 50 feet above its base, was traced from Saleratus Canyon (T. 20 S., R. 19 E.; pl. 9) to the Colorado line, and other workers have traced it into the Palisade district of Colorado. Immediately below the Thompson Canyon sandstone bed, and approximately coextensive

[27] Lee, W. T., op. cit. (Bull. 510), p. 30.
[28] Erdmann, C. E., personal communication.

with it, is the Ballard coal zone (pl. 5, *B*), so named from a prospect in Neslen Canyon. This coal zone is of less value than the Palisade zone. Immediately overlying or only a short distance above the Thompson Canyon sandstone bed to the west, or the Sulphur Canyon sandstone bed to the east, is the Chesterfield coal zone, named from the mine at Sego; this zone carries the most valuable coal seam of eastern Utah and the only one now being exploited on a large scale (pls. 4, *B*; 5, *A*, *B*; 6, *A*, *B*). The Chesterfield coal zone was traced from Coal Canyon (T. 20 S., R. 17 E.; pl. 9) to the Colorado line, and it is there seen to be at essentially the same stratigraphic position as the Cameo coal zone of Colorado, but the two are not definitely correlated, as the Cameo coal zone, according to Erdmann, has not been definitely traced as far west as the Utah line. About 50 feet above the Chesterfield coal zone, in the eastern part of the area, a fourth coal zone is present. It is here of no economic importance and is tentatively correlated with the Carbonera coal zone of western Colorado. Details regarding other local coal beds are given in the township descriptions.

Fossils collected from the basal beds of the Neslen member in the central part of the area (pl. 9) are mostly brackish-water or marine forms (Mesaverde); farther west, in the lower part of the member, and farther east, well up in the member, is found a fresh-water fauna which, according to Reeside, is close to that of the Fruitland and Kirtland formations of the San Juan Basin.[29]

FARRER NON-COAL-BEARING MEMBER

Beds above the Neslen member are here discussed only briefly, because they have little bearing on the coal resources of the area; more details will be given in another report. These higher strata of the Price River formation are here named the "Farrer non-coal-bearing member" (pronounced "fair'er"), from the name of the local mine in Coal Canyon (pl. 9), above which the unit stands as a prominent escarpment. The appearance of these beds, which have already been described briefly along with those of the Neslen member, is shown in plate 3, *B*. In seven measured sections the member ranges from 410 to 1,095 feet in thickness, with an average of about 690 feet. Thin coal lenses of no economic importance are present at several horizons. The sandstones show excellent cross-bedding of the current type and locally carry a few small pebbles; lenses of clay galls are fairly common. The member has been traced from the Green River eastward into Colorado, where it seems to be the approximate equivalent of the "undifferentiated part of the Mesaverde" of

[29] Reeside, J. B., Jr., Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin, Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 134, pp. 20-24, 1924.

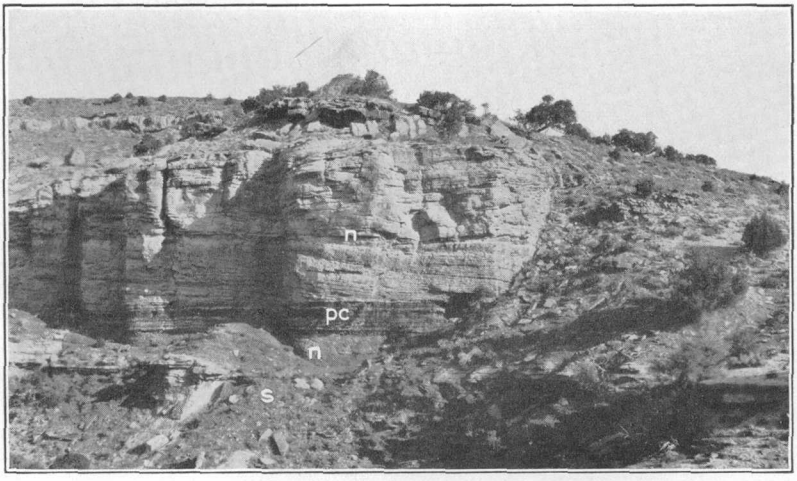
Lee,[30] in the Grand Mesa. Its top probably coincides with the top of Erdmann's Hunter Canyon formation.[31] Its fossil content includes fresh-water shells and plants.[32]

TERTIARY (?) SYSTEM

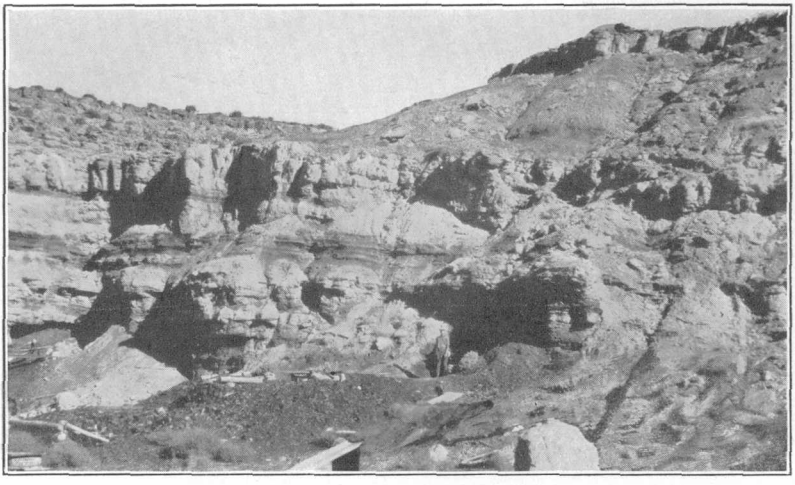
TUSCHER FORMATION

Above the somber Farrer beds and below the varicolored typical Wasatch beds is a series of nonfossiliferous light-gray sandstones separated by thin beds of shale. These beds are here grouped as the Tuscher formation, named after the canyon just east of the Green River (pl. 9). Although from a distance this formation stands out clearly, on close inspection at many places in Utah the contacts at both top and bottom are obscure. The individual beds of the unit cannot as a rule be traced far, because of lithologic changes. Measured sections show a range in total thickness from about 130 to 600 feet. The lowest measurement, taken from a section in Horse Canyon (T. 15 S., R. 14 E.), is of doubtful value, as at the time it was made the Tuscher formation had not been recognized as a separate and distinct unit; the next lowest, taken northwest of Cisco, is 267 feet. No pronounced erosional unconformity was seen at either the top or the base of the formation, but both surfaces are considered to mark disconformities; this conception is in the main based upon the great variation in thickness of both this formation and the underlying Farrer member of the Price River formation. Locally there is a conspicuous conglomerate at the base of the overlying Wasatch beds. The Tuscher formation is largely quartz sandstone but contains buff to gray shales that in many places show a very light greenish cast. The sandstone is typically massive, cross-bedded, friable, and light-gray to creamy white and weathers to rounded surfaces. Rare layers are conglomeratic, carrying a few pebbles of quartz and black chert as much as 1 inch in diameter. The presence of conglomerate and the fact that the sandstones closely resemble those of the Wasatch favor assignment of these beds to the Tertiary. The Tuscher is perhaps the equivalent of the Ohio Creek formation of Eldridge,[33] or of beds elsewhere designated "post-Laramie" or Fort Union. Erdmann[34] regards the probable continuation of the Tuscher beds to the east to be the Tertiary (?) sandstone underlying his Wasatch formation.

[30] Lee, W. T., op. cit. (Bull. 510), p. 43.
[31] Erdmann, C. E., op. cit. (Bull. 851), p. 48.
[32] Richardson, G. B., op. cit. (Bull. 371), p. 18.
[33] Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.
[34] Erdmann, C. E., op. cit., p. 53.



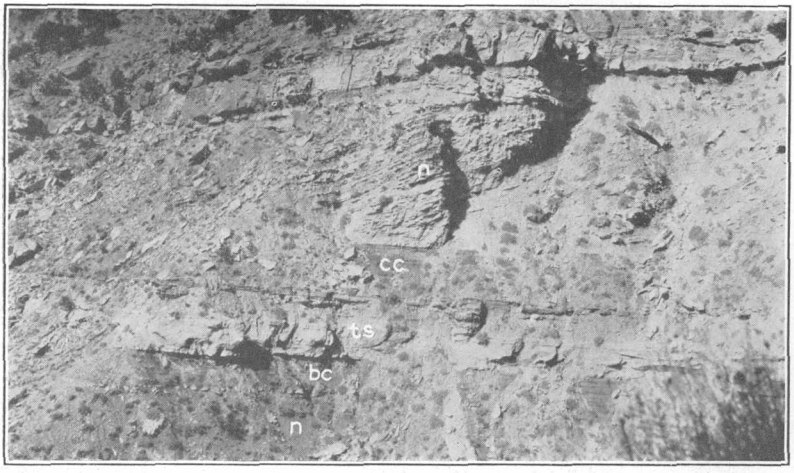
A. PALISADE COAL IN THOMPSON CANYON.
Location 155, plate 10. *s*, Sego sandstone; *n*, Neslen member; *pc*, Palisade coal.



B. FARRER MINE, COAL CANYON.
Location 54, plate 19. Chesterfield coal.

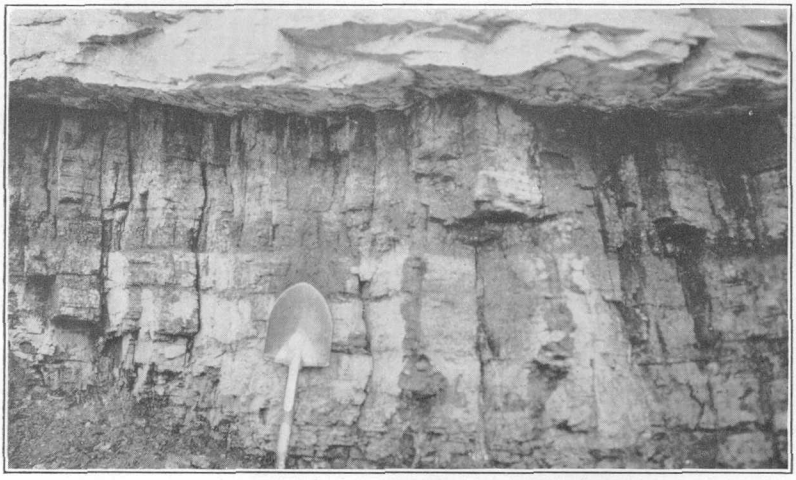
A. TIPPLE OF CHESTERFIELD MINE, SEGO.

pc, Palisade coal; *bc*, Ballard coal; *ts*, Thompson Canyon sandstone; *cc*, Chesterfield coal zone; *n*, Neslen member.

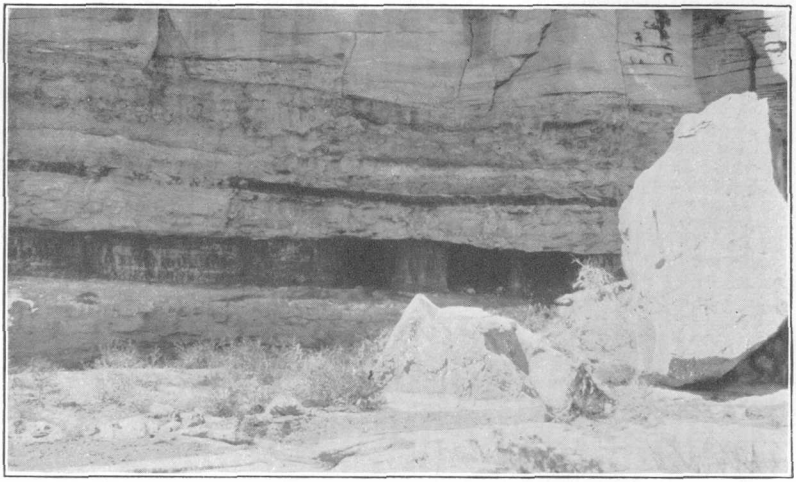


B. NESLEN STRATA NORTHWEST OF THOMPSON.

Near location 150, plate 10. *n*, Neslen member; *bc*, Ballard coal; *ts*, Thompson Canyon sandstone; *cc*, Chesterfield coal zone.



A. CHESTERFIELD COAL NORTHWEST OF THOMPSON.
Location 150, plate 10.



B. CHESTERFIELD COAL AND NESLEN STRATA IN THE EAST FORK OF WESTWATER CANYON.
Location 244, plate 11.

TERTIARY SYSTEM

EOCENE SERIES

WASATCH FORMATION

Only the basal part of the Wasatch formation was examined in the present study, except in Horse Canyon (pl. 8). The beds grouped in this report as Wasatch consist of variegated shales, cliff-making sandstones and conglomerates, and gray fresh-water limestones. The shales are characterized by their bright colors, the limestones by their fresh-water Eocene fossils. The colors of the shales include grays, brick-reds, purples, and yellows. The unit contains large amounts of cliff-making gray sandstones, some of which weather buff. These sandstones are similar to those in the Tuscher. The formation in or near its base commonly carries a conglomerate layer similar to that described by Eldridge [35] and by Lee [36] as marking the base of the Wasatch (Ruby) formation east of Paonia, Colo. Different workers have shown that the thickness of the Wasatch formation decreases toward the east from over 4,000 feet in Horse Canyon (pl. 8) to about 2,000 feet in the central part of the area covered by this report and to about 250 feet just east of the Colorado-Utah line.

QUATERNARY SYSTEM

GRAVEL DEPOSITS

From the great shale flat or "valley" that lies at the foot of the Book Cliffs rise more or less numerous low mesas or benches (pl. 3, *C*) capped by gravel. These are obviously erosion remnants of once extensive piedmont alluvial plains that formerly sloped gracefully from the cliffs out toward the low part of the flat. These remnants are found at three or more levels, but those at the intermediate level seem to be best preserved. Their locations are shown on plates 9–11. The writer believes that they are of purely local significance and that they were formed very late in the present geomorphic cycle. Evidence for these conclusions will appear in a later report.

ALLUVIAL DEPOSITS

Isolated remnants of terrace gravel along the Green River are shown on plate 9. These probably originated contemporaneously with the nearby fan-gravel deposits but are differentiated from them by their attitude and lithologic content. Tiny remnants of similar deposits were noted also in some of the canyons cutting the Book Cliffs to the east.

Sandy alluvial flats are found in the valleys of the Green and Price Rivers and in Saleratus Canyon (pl. 9); elsewhere the tracts of recent alluvium are small.

[35] Eldridge, G. H., op. cit., p. 7.
[36] Lee, W. T., op. cit., p. 51.

LOCAL SECTIONS

Six detailed sections of the coal-bearing strata (Blackhawk to Neslen, inclusive) are given below.

Sections of coal-bearing strata in the Book Cliffs coal field in Utah

[Sections are given in order from west to east, and their numbers correspond with those on pl. 7]

(5) 4 miles northeast of Woodside, in SE¼ sec. 23, T. 17 S., R. 14 E.

[See pl. 8. Section measured by H. F. Moses]

	Feet
Blackhawk formation (in part):	
Upper member (not measured).	
Middle sandstone member:	
14. Sandstone, massive, very light gray	15±
13. Sandstone, thick-bedded buff layers alternating with medium- to thin-bedded carbonaceous layers	25±
12. Sandstone, massive	3
11. Sunnyside coal zone (see location 18)	18
10. Sandstone, massive, very light gray	22
9. Sandstone, massive, cross-bedded, gray and buff, coarse-grained; mainly quartz, but contains 10 percent of dark mineral grains; thin films of carbonaceous material between the bedding planes	38
8. Shale and siltstone; soft, thin-bedded, gypsiferous, very carbonaceous	8
7. Sandstone, thick-bedded, buff	38
Total middle sandstone member	167±
Middle shale member:	
6. Shale, gray, with thin layers of interbedded siltstone and sandstone; highly carbonaceous	121
Lower sandstone member:	
5. Sandstone and siltstone with minor interbedded layers of finely laminated gray-black shale, in part carbonaceous; sandstone is massive, cross-bedded, very light gray, coarse- to fine-grained	98
4. Shale, dirty gray, gypsiferous, in part silty and limy, with fragments of carbonized wood	17
3. Siltstone, light gray, thin-bedded	33
2. Sandstone and shale, interbedded; sandstone, buff, medium- to thin-bedded, with a few sandy limestone layers; shale like Mancos	73
Total lower sandstone member	221
	509±
Gradational contact.	
Mancos shale:	
1. Shale, blue-gray and drab.	

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(10) 3 miles east of Desert, in sec. 17, T. 20 S., R. 15 E.

[See pl. 9. In part the descriptions are taken from studies made in sec. 8, same township]

	Feet
Price River formation (lower part only):	
Neslen coal-bearing member (all but upper part):	
21. Sandstone, buff; the ledge-making unit (Bluecastle sandstone bed) capping the Beckwith Plateau; massive, blocky, with minor shaly beds	96
20. Shale, gray, with minor sandstones, forming a slope; shale carries carbonaceous zones at top and base and near the middle, in which are coaly beds or lenses not over 2 inches thick, except the middle zone, which has coal as much as 6 inches thick	210
Total Neslen member (all but upper part)	306
Sego sandstone member:	
19. Sandstone, buff, massive, cross-bedded; resembles the Castlegate	84
Buck tongue of Mancos shale:	
18. Shale, gray, gypsiferous, in small part carbonaceous; resembles no. 3	98
Castlegate sandstone member:	
17. Sandstone, massive cliff-maker, very light gray, weathering medium buff-brown; in part very fine grained, quartzitic, elsewhere medium-grained, friable; locally cross-bedded; upper part shaly in places; some beds carry clay galls	78
Total Price River formation (for Beckwith Plateau)	566
Contact conformable.	
Blackhawk formation:	
Upper member:	
16. Mudstone, silty, limy, medium gray; carries a little fine-grained gray sandstone, a little somewhat carbonaceous shale, and 2 inches of coal	7
15. Sandstone, massive, cross-bedded, blocky; cliff-maker; resembles the Castlegate	87
14. Sandstone, mudstone, and coal; coal, bony, gypsiferous, in two 2-inch seams separated by 3 feet of dirty-brown rotten sandstone; upper part is mudstone like no. 16	7
13. Mudstone, like no. 16, with minor sandstone	13
12. Mudstone, like no. 16, with coal; badly split; coal in seams 12, 12, 6, and 4 inches thick, as well as thinner seams; section changes rapidly laterally; coal of no economic importance (see location 31)	12

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(10) 3 miles east of Desert, in sec. 17, T. 20 S., R. 15 E.—Continued

	Feet
Blackhawk formation—Continued.	
Upper member—Continued.	
11. Shale, like no. 3, with thin-bedded sandy layers (20 percent)	28
Total upper member	154
Middle sandstone member:	
10. Sandstone, massive, indistinctly cross-bedded, very light gray, like no. 6	17
9. Sandstone, massive, light buff-brown, fine-grained	17
8. Sandstone, like no. 9, but extremely fine grained; carries fucoids	31⅓
7. Coal (Sunnyside; see section at location 31)	1⅔
6. Sandstone, massive, indistinctly cross-bedded, very light gray, locally stained light buff-brown; composed of 95 percent of fine quartz grains, 3 percent of kaolinized white feldspar, and 2 percent of dark mineral grains; rather friable	16
5. Sandstone, massive, cliff-forming, medium buff-brown, extremely fine grained; 92 percent quartz, 4 percent limonite-stained, kaolinized feldspar, 2 percent dark mineral grains, and 2 percent mica (?)	30
4. Sandstone and shale (25 percent) in alternating beds; sandstone like no. 5 but in beds about 1 foot thick	111
Total middle sandstone member	224
Middle shale member:	
3. Shale, with minor amounts of sandstone, siltstone, and coal; shale is medium gray (in part with brownish cast) to light gray, soft, powdery, gypsiferous; 10 feet above base is a 2½-foot coal bed (Kenilworth; see section on p. 68); upper part silty, with minor sandstone layers; also local limy layers; carries carbonized wood	148
Lower sandstone member:	
2. Sandstone, massive, forming an impassable precipice; upper 30 feet is very light gray, fine-grained; rest is buff; lower half of unit is less massive and carries some intercalated shale; upper part weathers to rounded surfaces and carries small depressions that hold water	171
Total Blackhawk formation	697

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(10) 3 miles east of Desert in sec. 17, T. 20 S., R. 15 E.—Continued

Gradational contact.

Mancos shale:

1. Shale, medium gray, forming lower part of slope and underlying a broad flat; upper part carries two zones containing thin sandstone beds that cause weak ledges.

(15) East side of Horse Canyon, near locations 62 and 69, T. 21 S., R. 18 E.

[See pl. 9]

Price River formation:

Farrer non-coal-bearing member (not measured).

Neslen coal-bearing member:

		Feet
30.	Sandstone and shale (30 percent), forming a slope; sandstone, buff, friable, medium- to coarse-grained, thin-bedded; shale, gypsiferous, medium gray, limy, silty	65
29.	Sandstone, buff, very friable, medium fine grained; minor ledge-maker (Bluecastle sandstone bed)	30
28.	Shale, limy, silty, medium to light gray, carbonaceous at top (Bluecastle sandstone bed)	14
27.	Sandstone, gray to buff; minor ledge-maker (Bluecastle sandstone bed)	18
26.	Shale, medium gray, gypsiferous, silty, limy; lower part carries two coal seams between 1 and 2 feet thick (Chesterfield coal zone at location 69)	49
25.	Sandstone, buff, cross-bedded, fine-grained, with calcareous cement; minor ledge-maker; this is probably the Thompson Canyon sandstone bed	9
24.	Shale, like no. 26; 7 inches of coal in upper part (Ballard coal zone at location 69)	11
23.	Sandstone, buff, ledge-maker, like no. 25; shows well-defined polygonal drying cracks near the top	12
22.	Shale, like no. 26	44
21.	Sandstone, buff; minor ledge-maker	10
20.	Shale, silty, limy, with minor sandstone layers	90
19.	Sandstone, highly calcareous, buff; carries abundant shells of *Ostrea glabra*	2
	Total Neslen coal-bearing member	354

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(15) East side of Horse Canyon, near locations 62 and 69, T. 21 S., R. 18 E.—Continued

	Feet
Price River formation—Continued.	
Sego sandstone member:	
18. Sandstone and shale, like no. 16 but with a much higher proportion of sandstone	58
17. Sandstone, forming first cliff above the Castlegate sandstone; upper part very light gray, friable; remainder buff, 90 percent fine-grained quartz, 8 percent somewhat limonite-stained kaolinized feldspar, and 2 percent dark mineral grains, all in a very firm calcareous cement; highly cross-bedded; carries clay pellets, concretions, carbonized wood, and fucoids; pronounced channel unconformity locally present at base; average thickness 50 to 60 feet, but here only	35
16. Shale and sandstone in alternating beds; more shale in lower part than above; sandstone is cross-bedded, light gray to buff, medium fine-grained; shale is gray	84
Total Sego sandstone member	177
Buck tongue of Mancos shale:	
15. Shale, dark gray to drab, gypsiferous; upper part is silty and limy	137
Castlegate sandstone member:	
14. Sandstone, massive, cross-bedded; cliff-maker; friable, buff-brown, light gray near top; concretions size of peas to walnuts common in upper part; consists mostly of medium-fine subangular to rounded colorless glassy quartz grains cemented by calcite but carries a little kaolinized feldspar; forms a pronounced dip-slope bench; caps front of Book Cliffs	75
Total Price River formation (except Farrer member)	743
Contact conformable.	
Blackhawk formation:	
Upper member:	
13. Mudstone, silty, limy, medium gray; weathers to nodular masses; contains particles of carbonized wood; carries a 4-inch carbonaceous zone (no coal) and a little sandstone	16
12. Sandstone, like no. 10	4½
11. Mudstone, like no. 13	8
10. Sandstone, light gray (fresh) to buff (weathered), medium fine grained, highly cross-bedded; makes minor ledge	20

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(15) East side of Horse Canyon, near locations 62 and 69, T. 21 S., R. 18 E.—Continued

Blackhawk formation—Continued.

Upper member—Continued.

	Feet
9. Mudstone, like no. 13, with carbonaceous zone (no coal) in upper part	20
8. Shale, in part carbonaceous, with a little coal and bone (location 62)	7
7. Sandstone, like no. 5, except upper part weathers light gray	12
6. Sandstone, like no. 4	16
5. Sandstone, highly cross-bedded, minor ledge-maker; carries limonite-stained concretionary masses; like no. 4, but less shaly	14
4. Sandstone, light gray (fresh) to buff (weathered); thin-bedded, locally cross-bedded and somewhat shaly; extremely fine grained, friable, with calcareous cement; carries a little carbonized wood; a few beds are 8 to 12 inches thick	42
3. Shale, medium gray (fresh) to drab-gray (weathered); in places silty and limy	110±
Total upper member	270±
Middle sandstone member:	
2. Sandstone, very fine grained, and siltstone, interbedded with shale; whole forms a drab-gray, weak cliff; this member has here nearly given way to the Mancos shale	120±
Total Blackhawk formation	390±

Gradational contact.

Mancos shale:

1. Shale, medium dark gray with faint bluish cast to drab-gray.

(20) 3 miles north of Thompson, in W½ sec. 4 and NE¼ sec. 5, T. 21 S., R. 20 E., and SE¼ sec. 32, T. 20 S., R. 20 E.

[See pl. 10. Castlegate and Blackhawk strata measured by J. H. Hengst in sec. 10, T. 21 S., R. 20 E.]

Price River formation:

Farrer non-coal-bearing member (not measured).

Neslen coal-bearing member:

	Feet
32. Sandstone, light gray to buff; minor ledge	2
31. Shale, medium gray	17
30. Sandstone, with shaly zone in upper part; sandstone carries thin slabs (pebbles) of shale; lower 20 feet forms a light-gray ledge	45
29. Shale, medium gray	17
28. Sandstone, light gray to buff, cross-bedded, friable	14
27. Shale, with minor sandstone, light gray to buff; shale medium gray above, partly dark gray below; slope-forming unit, largely concealed	90¾

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(20) 3 miles north of Thompson, in W½ sec. 4 and NE¼ sec. 5, T. 21 S., R. 20 E., and SE¼ sec. 32, T. 20 S., R. 20 E.—Continued.

	Feet
Price River formation—Continued.	
Neslen coal-bearing member—Continued.	
26. Sandstone, light gray to buff	2
25. Coal, bone, and shale (Chesterfield coal zone; see section at location 153)	6¼
24. Shale, brown	8
23. Sandstone, buff-yellow; massive ledge with rounded surface (Thompson Canyon sandstone bed)	18
22. Coal and shale (Ballard coal zone)	5
21. Shale, buff to medium gray	7
20. Sandstone, buff, massive, cross-bedded, blocky ledge; lenticular, giving way laterally to shale	32
19. Shale, buff to medium gray, with four thin coal seams	29
18. Sandstone, buff to gray, forming a rather blocky minor ledge	19
17. Shale, sandy, medium to light gray	1
16. Coal (Palisade zone)	1
15. Sandstone and shale, making a slope; lower third is thin-bedded light-gray sandstone; upper part is medium- to light-gray sandy shale	45
Total Neslen coal-bearing member	359
Sego sandstone member:	
14. Sandstone, massive, cross-bedded, buff to light gray; cliff-maker	58
13. Sandstone and shale (20 percent); forms a slope with minor sandstone ledges; carries poorly preserved fossil plants; sandstone like no. 12; shale like no. 11	86
12. Sandstone, fairly massive, buff to light gray	49
Total Sego sandstone member	193
Buck tongue of Mancos shale:	
11. Shale, medium gray, gypsiferous; lower part concealed by wash; carries a few lenses of fine-textured gray limestone, which weathers buff; upper part carries thin beds of buff sandstone	193
Castlegate sandstone member:	
10. Sandstone, buff, weathering reddish brown; massive, cross-bedded; ledge-maker	40
9. Sandstone with minor shale, nodular-weathering; sandstone is thin-bedded, reddish brown, fine-grained; cliff-maker	14

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(20) 3 miles north of Thompson, in W½ sec. 4 and NE¼ sec. 5, T. 21 S., R. 20 E., and SE¼ sec. 32, T. 20 S., R. 20 E.—Continued

	Feet
Price River formation—Continued.	
Neslen coal-bearing member—Continued.	
8. Sandstone, massive, cross-bedded, buff (weathering reddish brown); cliff-maker; weathered surface shows white areas the size of birdshot	30
Total Castlegate sandstone member	84
Total Price River formation (except Farrer member)	829
Conformable contact.	
Blackhawk formation:	
Upper member:	
7. Shale and very thin bedded sandstone, intercalated	2½
6. Bone and coal	1⅓
5. Shale	1⅔
4. Sandstone and shale; sandstone is light buff, cross-bedded; shale, which is in small part carbonaceous, constitutes about one-third of the unit	20
3. Sandstone, fine-grained, light gray, weathering buff, carbonaceous	½
2. Sandstone, buff to reddish brown, medium-grained, massive, cross-bedded; cliff-maker	95
Total Blackhawk formation	121
Gradational contact.	
Mancos shale:	
1. Shale, bluish gray, limy, gypsiferous; thin beds of fine-grained sandstone in upper part.	

(23) East side of Sagers Canyon in NW¼ sec. 32, T. 20 S., R. 21 E.

[See pl. 10]

	Feet
Price River formation:	
Neslen coal-bearing member (except the uppermost portion):	
39. Sandstone, massive, cross-bedded, buff-gray, friable	25
38. Shale; weathers medium gray; slope	27
37. Sandstone, buff-gray; minor ledge	5
36. Shale, brown, weathering medium light gray; carries a few thin layers of sandstone and nodules of brownish silty clay ironstone; 1 foot of coal and bony shale 3 feet below top	29
35. Sandstone, shaly, thin-bedded, buff to gray; lower part contains some shale and a lens of fine-textured limestone	23

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(23) East side of Sagers Canyon in NW¼ sec. 32, T. 20 S., R. 21 E.—Continued

	Feet
Price River formation—Continued.	
Neslen coal-bearing member—Continued.	
34. Bone and coal	1¼
33. Shale, brown	5
32. Coal, bone, and shale, carbonaceous (Chesterfield coal zone at location 203)	5½
31. Shale, sandy in lower part	12½
30. Sandstone, buff, thin-bedded, and shaly except for upper 1½ feet, which makes a minor ledge	11
29. Sandstone (Thompson Canyon sandstone bed); lower 11 feet is buff-brown, blocky; upper 9 feet is buff-yellow, massive, weathering to semirounded surfaces	20
28. Coal, bone, and shale (Ballard zone at location 203)	5¼
27. Concealed, probably shale, more or less sandy	34¼
26. Sandstone, shaly, thin-bedded, buff	10
25. Sandstone, fairly massive, cross-bedded, buff to gray; minor ledge	9½
24. Coal, bony, and carbonaceous shale (higher Palisade)	2¼
23. Sandstone, thin-bedded, shaly, buff	41
22. Shale, brown to medium gray	2½
21. Coal, bony, with a 1-inch brown-shale parting (lower Palisade)	1¼
20. Shale, like no. 22	3¾
19. Sandstone, thin-bedded, light gray-buff; minor ledge	2
18. Sandstone, thin-bedded, shaly, buff; mostly concealed	23
Total Neslen coal-bearing member (except uppermost part)	299
Sego sandstone member:	
17. Sandstone, very massive cliff-maker; mostly buff-brown, but near top is buff-gray; ripple marks (current) with amplitude of slightly over 1 inch	43
16. Sandstone and shale slope; shale, limy, nodular in part; lithology like no. 12 except that all the sandstone is thin-bedded	49½
15. Sandstone, massive, buff to gray; cliff-maker; semirounded weathering surfaces in upper part	24
14. Sandstone, shaly, cross-bedded, thin-bedded, buff; forms a slope with a few minor ledges of more massive sandstone; probably a little shale is present	54
13. Sandstone, massive, cross-bedded, buff, capping first cliff above the Castlegate sandstone; semirounded weathering surfaces	10

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(23) East side of Sagers Canyon in NW¼ sec. 32, T. 20 S., R. 21 E.—Continued

	Feet
Price River formation—Continued.	
Sego sandstone member—Continued.	
12. Sandstone and shale; sandstone is shaly, thin- to medium-bedded, buff, with some interbedded shale in upper part; lower part is sandstone, locally massive but elsewhere medium-bedded	32½
Total Sego sandstone member	213
Buck tongue of Mancos shale:	
11. Shale and sandstone, grading into no. 12; lithologically like upper part of no. 12, but with slightly more shale	34
10. Shale, medium gray with bluish cast, gypsiferous; carries a few thin beds of gray sandstone; also has lenses of fine-textured medium-gray, buff-weathering limestone as much as 2 feet thick and 15 feet long; closely resembles Mancos shale	170
Total Buck tongue of Mancos shale	204
Castlegate sandstone member:	
9. Sandstone, thin-bedded, cross-bedded, medium gray, except basal stratum 8 inches thick, which is hard, blocky, and brown; locally carries limy lenses full of *Corbula subtrigonalis*	6
8. Sandstone, shaly, locally grading laterally into shale, in part carbonaceous, with an inch or so of dirty coal	16
7. Sandstone, massive, cross-bedded, buff	40
Total Castlegate sandstone member	62
Total Price River formation (except Farrer member and uppermost part of Neslen member)	778
Gradational contact.	
Blackhawk formation:	
Upper member:	
6. Sandstone and shale, like no. 2	41
5. Sandstone, buff, massive, except for a few inconspicuous shaly partings	30
4. Sandstone (85 percent) and shale (15 percent); like no. 2, except that it carries a few beds of sandstone 6 to 10 inches thick	42

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(23) East side of Sagers Canyon in NW¼ sec. 32, T. 20 S., R. 21 E.—Continued

Blackhawk formation—Continued.

	Feet
Upper member—Continued.	
3. Sandstone, massive, hard, cross-bedded	1
2. Sandstone (80 percent) and shale (20 percent); generally forms a weak cliff due to harder overlying beds but has a pronounced shaly appearance; shale weathers medium light gray; sandstone is buff, fairly thin bedded, slightly shaly, and intercalated with shale	30
Total Blackhawk formation	144

Gradational contact.

Mancos shale:

1. Shale, gray; not examined in detail.

(32) About 2 miles west of Utah-Colorado State line, in sec. 31, T. 16 S., R. 26 E.

[See pl. 11]

Price River formation:

	Feet
Neslen coal-bearing member (lower part only):	
39. Sandstone, massive ledge-maker, buff except near top, where it is light gray	27
38. Sandstone, buff, thin-bedded, locally shaly	28
37. Bone	1½
36. Shale, medium dark gray to brown, with a little thin-bedded buff sandstone	2½
35. Sandstone, thin-bedded, buff	1
34. Shale, like no. 36, with 4 inches of bone 2 feet below top	5½
33. Bone, with a little bony carbonaceous shale; this and no. 37 possibly mark the Carbonera coal zone	1½
32. Shale, like no. 36	10
31. Sandstone, buff, thin-bedded; carries a little shale with half an inch of bone	57
30. Shale and sandstone, like no. 28	10
29. Bone and coal (Chesterfield coal zone at location 256)	2⅓
28. Shale, brown, carbonaceous; interlaminated with light-gray sandstone	14
27. Sandstone, medium- to thin-bedded in general, though locally massive in lower part; cross-bedded; mainly buff, but upper part is light gray; forms a ledge (Sulphur Canyon sandstone bed)	14
26. Shale, dark gray, with some thin-bedded sandstone in the upper part	18
25. Sandstone, medium to thin-bedded, cross-bedded, mostly light gray but locally buff	4
24. Shale, dark gray	3
23. Sandstone, like no. 25	10

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(32) About 2 miles west of Utah-Colorado State line, in sec. 31, T. 16 S., R. 26 E.—Continued

	Feet
Price River formation—Continued.	
Neslen coal-bearing member—Continued.	
22. Shale, dark gray to brown, carbonaceous, with some thin-bedded sandstone, especially in the upper part; 7-inch seam of bone 4 feet above base	12
21. Sandstone, thin-bedded, light gray to buff	7
20. Shale, brown to dark gray	6½
19. Sandstone, massive to medium-bedded, except upper third, which is thin-bedded; cross-bedded; medium light gray	18
18. Shale, medium gray to black, carbonaceous; 4 inches of bone 1 foot below top	3
17. Sandstone, highly cross-bedded, medium light gray; grades from massive double ledge (1-foot shale break 25 feet above base) to thin-bedded shaly slope	48
16. Bone (Palisade coal zone)	1⅓
15. Shale, mostly rich brown, weathering to medium light gray	2
14. Sandstone, thin-bedded	1
13. Shale, like no. 15; basal part concealed	16
Total Neslen coal-bearing member (lower part only)	324⅙
Sego sandstone member:	
12. Sandstone, very massive, cross-bedded; cliff-maker; like no. 7	46
11. Sandstone, shaly, thin-bedded (except a small part slightly below the middle, which is medium-bedded), medium gray, with some interbedded shale; forms a slope	33
10. Sandstone, massive, like no. 7, but carries a few irregular limonite-stained concretions; locally nos. 7 to 10 form a single cliff	21½
9. Sandstone; medium light gray, forming a slope at most places; thin-bedded; rather shaly in upper part	30
8. Sandstone, like no. 7, but thinner-bedded	18½
7. Sandstone, massive to thick-bedded, cross-bedded; light gray, locally stained buff; cliff-maker; composed mainly of rather fine, fairly well rounded glassy quartz grains, with 1 percent feldspar stained light buff and a smaller amount of dark mineral grains, all weakly cemented; contains shark teeth (*Lamna* sp.)	33
6. Siltstone, buff, thin-bedded, interbedded with shale	27
Total Sego sandstone member	209

Sections of coal-bearing strata in the Book Cliffs coal field in Utah—Continued

(32) About 2 miles west of Utah-Colorado State line, in sec. 31, T. 16 S., R. 26 E.—Continued

	Feet
Price River formation—Continued.	
Buck shale tongue of Mancos shale:	
5. Shale, interbedded with siltstone, buff, thin-bedded; grades upward into no. 6	27
4. Shale, medium light drab-gray, like Mancos; lower third concealed by wash	319
Total Buck tongue	346
Castlegate sandstone member:	
3. Sandstone, thick-bedded, cross-bedded, buff with white stainings along joint planes; composed mainly of extremely fine, fairly well rounded quartz grains, with a little feldspar; makes a very weak cuesta and dies out entirely a short distance to the east	1
2. Siltstone, thin-bedded, shaly, and shale, in alternating layers; largely concealed; marks gradation zone to Mancos	14±
Total Castlegate sandstone member	15±
Total Price River formation (except Farrer member and upper part of Neslen member), as measured	894±
Gradational contact.	
Mancos shale:	
1. Shale, drab-gray.	

STRUCTURE

GENERAL FEATURES

The Book Cliffs form a southward-facing escarpment near the south border of the Uinta Basin, a great synclinal area of Tertiary rocks lying south of the Uinta Mountains in northeastern Utah and northwestern Colorado. Thus the regional structure is that of a gently northward-dipping monocline, which has been locally modified by the domal uplifts of the San Rafael Swell and the Uncompahgre Plateau and by the Salt Valley graben.

The attitude of the strata along the Book Cliffs is shown on plates 8–11 by means of structure contours drawn on the base of the lower Sunnyside coal (pl. 8) or on the top of the Castlegate sandstone (pls. 9–11). The top of the Castlegate sandstone is stratigraphically 250 to 300 feet higher than the base of the Sunnyside coal bed. The structure contours are lines drawn through points on these datum surfaces that have equal altitude above sea level. The position of the contour lines is determined by obtaining altitudes upon the surface to be contoured or upon a bed at any other stratigraphic horizon,

provided the stratigraphic interval between that bed and the surface to be contoured is known. The contour interval used for plates 8–11 is 50 feet. Broken contour lines indicate the absence of sufficient data for determining the exact position.[37]

The San Rafael Swell is an elongated asymmetric domal fold, capped largely by Jurassic and Triassic strata, that lies in east-central Utah, southwest of the Book Cliffs. As a result of this dome the trend of the Book Cliffs and the Book Cliffs monocline bends sharply to the north in T. 20 S., R. 15 E., a few miles west of the Green River (pl. 9). The strata, which dip east to north of east at angles ranging from 3° to 10° or 12°, are broken north of the Price River (pl. 8) by several normal dip faults with a maximum vertical displacement of 200 feet.

Owing to the domal structure of the Uncompahgre uplift, which lies in western Colorado southeast of the Book Cliffs, the line of the cliffs trends northeast from Nash Canyon (pl. 10) to the Utah-Colorado State line. The general attitude of the strata is that of a monocline, which has a dip of about 3° NW. The monocline is only slightly faulted but is greatly modified by minor flexures, mostly northwestward- to westward-plunging anticlines or noses separated by less pronounced synclines plunging in the same general direction. Of these anticlines the only one known to have closure is the Cisco dome, in the Nash reentrant northwest of Cisco. The parallelism between the trend of the cliffs and the attitude of the rocks is particularly noticeable in the Nash reentrant, where the trend of the cliffs outlines the Cisco dome. The canyons east of Nash Canyon as far as Bitter Creek also mark local structural features, but this is not true for Bitter Creek Canyon and those still farther east in Utah.

The Book Cliffs area between the Green River and Nash Canyon (pls. 9 and 10) may be subdivided into two belts differing in geologic structure. In the western belt, that between the Green River and Horse Canyon (pl. 9), the strata constitute a northeastward-dipping monocline. The angle of dip at most places is about 3° or 4°. This belt is rather closely related to the portion of the Book Cliffs west of the Green River, which owes its structural characteristics to the San Rafael Swell. In the belt between Horse Canyon and Nash Canyon the strata have the general structure of a monocline dipping 2°–3° N., but this has been modified by faulting, especially in the western part of the belt. This faulting marks the north end of a zone of faults and faulted folds that extends for many miles to the southeast. These faulted folds have recently been mapped by C. H. Dane and E. T. McKnight for the United States Geological Survey,[38] and the

[37] The Castlegate contours are approximately 7,435 feet stratigraphically above those given by James Gilluly (Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, pl. 30, 1929).

[38] Preliminary map showing geologic structure of parts of Grand and San Juan Counties, Utah, U. S. Geol. Survey, 1931.

area has been described by Harrison,[39] by Prommel and Crum,[40] and by other geologists. This pronounced belt of faulted and folded strata dies out within a short distance in the Book Cliffs (pl. 9), where it fails to affect the coals of the Neslen member; it has nevertheless greatly influenced the topography of this part of the cliffs. The major structural feature is a graben about 3 miles wide, with subsidiary faults that slice the strata in the dropped block into warped strips parallel to the limiting faults. Subsequent erosion has attacked the cliff-making sandstones most readily along the fault planes, resulting in the isolation of two large, high masses from the cliffs, and the eastern one of these has been cut by erosion along two faults into three nearly isolated masses. An anticlinal axis apparently coincides with the graben, and several smaller flexures have been formed. Just west of Thompson Wash, 8 miles to the east (pl. 10), another but much smaller belt of parallel faults cuts the cliffs.

Most of the faults and folds of the area are described below, but a few of them are described in the later part of the report, in the description of the townships in which they occur. The faulting probably took place at about the same time as the folding, which is thought to have occurred, in the main, late in the Eocene or later, but very much earlier than the stages during which the alluvial-fan deposits of gravel were formed. Although there was pronounced pre-Wasatch folding to the west along the west side of the Wasatch Plateau and to the north along the Uinta Mountains, there is no marked pre-Wasatch structural unconformity in the area described. However, it seems probable that there was slight doming in the San Rafael Swell and Uncompahgre uplift at the end of the Cretaceous period, as well as in late Wasatch or early Green River time. At Thousand Lake Mountain nearly horizontal lower Eocene beds rest directly on the Jurassic sandstone, which, along with Cretaceous strata here missing, was involved in the Waterpocket monoclinal folding.[41] However, it should be noted that near Thousand Lake Mountain this flexure bends off to the northwest, and so in its relations to the time of folding in the present area it may be of as little significance as the deformations on the west face of the Wasatch Plateau.

FOLDS AND FAULTS

The folds and faults are here described in order from west to east. The rocks in T. 21 S., Rs. 18 and 19 E., are cut by many normal

[39] Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 111–133. 1927.

[40] Prommel, H. W. C., and Crum, H. E., Salt domes of Permian and Pennsylvanian age in southeastern Utah and their influence on oil accumulation: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 373–393, 1927.

[41] Dutton, C. E., Geology of the High Plateaus of Utah, p. 280, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

faults with a southeast trend, the net result of which is to split them into a series of more or less warped stips. Because of the alternation of hard and soft strata and subsequent erosion, a topography that is unique for the Book Cliffs has been produced. None of the faults extend far enough to the northwest to displace the coal beds of the Neslen member. One of the major faults, striking a little south of east, passes through the north-central part of the westerly township and extends over a gentle arc as far as its east side. The throw along this fault gradually increases from almost nothing at the ends to a maximum of about 415 feet near its central part. The fault has the downthrown side on the north, and the fault surface dips to the north at an angle of slightly over 60°. Along the middle part of the fault the top of the 30-foot sandstone that occurs about 60 feet above the base of the Neslen member has been dropped to the level of the top of the Castlegate sandstone. From this middle part streams have cut canyons leading east and west along the fault zone. This fault line makes possible the trail leading from Horse Canyon to the western branch of Saleratus Wash.

Another fault about 2 miles to the southwest, which has a trend south of west, is marked by no scarp, as erosion along it has cut down into the soft Mancos shale, isolating a mass or "island" of the Castlegate bench to the south. As shown by the structure contours, its maximum throw is about 90 feet down on the south. To the east this fault is cut off by another one; to the west it possibly connects with the fault in sec. 33, T. 21 S., R. 17 E., shown on plate 9, but no attempt was made to trace it over this area in the field. The fault in sec. 33 was mapped by Lupton,[42] who says that it has a maximum displacement of 450 feet down on the south, and that, traced eastward, it disappears in sec. 34.

A fault that apparently terminates the one just described has a southeasterly strike, a downthrow of about 100 feet on the north side near its west end, and a dip of 65° N. It has not been traced to the southeast but probably joins the fault mapped by Evans and Weeks[43] in the southwestern part of sec. 31, T. 21 S., R. 19 E. The throw of this fault increases rapidly to the southeast, reaching about 1,500 feet at the east line of T. 21 S., R. 18 E., and 1,700 feet half a mile farther east. The contouring shown on plate 9 in the southeast corner of T. 21 S., R. 18 E., is adapted from the map by Evans and Weeks. The cliff just northeast of this fault at the east edge of this township is a good example of a rather completely dissected fault-line scarp.[44]

[42] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, p. 130, pl. 6, 1914.

[43] Evans, F. G., Jr., and Weeks, A. W., in Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 122, 1927.

[44] Blackwelder, Eliot, The recognition of fault scarps: Jour. Geology, vol. 36, pp. 289–311, 1928.

A fault cuts the cliff on the west side of Saleratus Canyon in the SW¼ sec. 7, T. 21 S., R. 19 E. It has a downthrow of 22 feet on the south, and the fault surface dips 65° S. The fault strikes northwest but does not extend over half a mile in this direction. Its throw is slightly over 100 feet in the NE¼ sec. 18 but is less than 100 feet in the SW¼ sec. 17. Farther southeast it again increases, according to the map by Evans and Weeks, which was followed in mapping the faults east of the west tier of sections of the township.

In the northern part of sec. 19, T. 21 S., R. 19 E., a fault cuts a narrow neck of Castlegate sandstone. It strikes west-northwest and has a downthrow to the south of 60 feet. The fault surface dips 65°–75° S. Its extension to the southeast is taken from the map by Evans and Weeks. To the northwest it appears to be essentially in alinement with the large fault in T. 21 S., R. 18 E., already described, which has its downthrown side on the north. It is possible, but hardly probable, that the two faults are one, involving a hinge motion in Saleratus Canyon. In the southern part of sec. 19, two nearly parallel faults cut another neck of Castlegate sandstone. Both faults have the downthrow on the south. The north fault has a vertical displacement of 114 feet and dips 65° S. The south fault has a vertical displacement of 90 feet and dips 55° S. A fault passes through the SW¼ sec. 30, and the map by Evans and Weeks shows another northwest fault cutting the NW¼ sec. 30, with downthrow on the south of 200 feet, but this fault was not observed by the writer. The faults shown in T. 22 S., R. 19 E., are taken from Evans and Weeks. The exceptional width of Saleratus Canyon is largely due to the faulting the area has undergone.

Minor folds are associated with the faults in T. 21 S., R. 19 E. The largest fold is the anticline heading at the northwest corner of the township, running south nearly 2 miles to a saddle in the NW¼ sec. 18, and thence continuing south, bending gradually to the southeast. Evans and Weeks consider that this fold extends into Salt Valley at a locality 2 miles east of Valley City, in sec. 27, T. 22 S., R. 19 E. There is a southward-plunging syncline in the NW¼ sec. 31 and the S½ sec. 30, T. 21 S., R. 19 E. To the syncline and the two faults is due the isolation by erosion of the small butte in the north-central part of sec. 31.

The Cisco dome, a marked structural feature of the Book Cliffs, in T. 20 S., Rs. 21 and 22 E., is shown by structure contours on plate 10. It was first mapped in 1923 by E. S. Shaw, assisted by J. H. Wilson, for the Midwest Refining Co. In September 1924 C. H. Dane made a plane-table reconnaissance map of the dome for the United States Geological Survey. In June and July 1924 R. C. Coffin, assisted by R. K. DeFord and J. W. Hunter, made a very detailed map of the dome for the Midwest Refining Co., which kindly furnished a copy

for the writer's use. The data on this map for the Mancos shale area within the reentrant were used with slight modification in the preparation of the structure contours on plate 10. The present writer did not examine either the stratigraphy or the structure of this shale on the dome, but altitudes were obtained at numerous places on higher beds. The other workers used the sandy bed whose top is about 1,025 feet below the top of the Castlegate sandstone member as the key bed on which to draw structure contours. The distribution of this sandy bed as shown on plate 10 is partly taken from their maps.

The dome is a quaquaversal fold elongated in a northwesterly direction. Dips on the Castlegate sandstone reach a maximum of 10° on the southwest side of the dome but are only about 5° on the northeast side and even less on the ends. The structure contours are accurately located along the Castlegate bench, and they are probably accurately located between this bench and the outcrop of the key bed; but on the crest of the dome and along its south end the position of the contours is based on dip and strike readings and here may be in error.

Contours drawn on the top of the Dakota (?) sandstone on the basis of well-log data show that the buried axis of the dome lies west of the surface axis as mapped. This casts some doubt on the correctness of the location of the Castlegate contours on this portion of the dome. This is of interest, as it is rather uncommon to find the axis migrating toward the steep-dip side of a fold with increasing depth. No allowance for this apparent shift was made in transferring the contours from the key bed, about 1,025 feet below the top of the Castlegate, to this horizon, as shown on plate 10.

Regarding the two main faults shown at the south edge of the Cisco dome, Dane [45] says:

> They are [in] the northernmost [part] of a broken area not mapped. These parallel faults trend about N. 15° W. and drop the beds to the east. The west fault has an estimated throw of 150 feet; the east fault is somewhat smaller. From the general character of the faulting observed to the south it is probable that they die out a short distance north of their indicated extent. A fault zone with a throw of about 50 feet [down on the southeast] is exposed in the creek bed in the N½ sec. 29, T. 20 S., R. 22 E., but could not be traced and evidently does not extend a mile to the north, where it would displace the key bed.

Two parallel normal dip faults are present in the northwestern part of T. 20 S., R. 21 E., on the northwest end of the Cisco dome. The north fault has a downthrow on the south of 65 feet. The other fault extends farther to the northwest. In the eastern part of section 4 it has a downthrow of 165 feet to the north, and the fault surface dips 60° N. No attempt was made to trace it to the east through the Mancos shale.

[45] Dane, C. H., Geology and oil and gas prospects of areas near Crescent and Cisco, Grand County, Utah (manuscript report), p. 19, 1924.

The nature of the structure at the Cottonwood reentrant along Cottonwood Wash is only partly known. On the structure contour map (pl. 10) it appears as a northwestward-plunging anticline, with strike about parallel to the first line of cliffs. Whether this is a closed fold (such as the Cisco elongated dome) or not could not be definitely determined in the time available. But the fact that the sandstone in the upper part of the Mancos shale forming a hogback near the south side of T. 19 S., R. 23 E., appears from cursory examination to conform to the general regional structure as shown to the east of Cottonwood Canyon indicates that the anticline lacks closure—that it is probably a nose.[46] Like the Cisco dome, this fold is asymmetric, with the steeper flank, which dips as much as 9°, on the southwest side. Time was not available for determining the exact stratigraphic position of this hogback-making sandstone, but projected contour lines indicate that it is about 1,300 feet below the top of the Castlegate sandstone.

Along and near Antone Canyon, in T. 18 S., R. 23 E., is a distinct northwestward-plunging syncline or trough. As in the canyons to the west, the reentrant of the canyon of Westwater Creek, which is very broad, has been cut on a nose or northwestward-plunging anticline. About 3 miles to the north there is another nose or anticline that plunges to the west. Between these two folds is a westward-plunging syncline or trough. One or two coal zones reappear in East Westwater and Bryson Canyons, north of the places where their outcrops first cross the canyons, as a result of the folding. The coal does not reappear in the other branches of Westwater Canyon.

There is a less pronounced northwestward-plunging nose or anticline in the general neighborhood of the place where Bitter Creek emerges from the cliffs, but here the canyon walls do not parallel the strike of the strata. The Palisade coal zone reappears in this canyon (see pl. 11) as a result of the combination of an eastward-striking syncline and anticline. The flanks of the syncline show apparent dips of 2° on the south side and 8° on the north side. The upper parts of Bryson and San Arroyo Canyons were not visited, but if the folds in Bitter Creek Canyon extend far to the west it seems fairly probable that some or all of the coal zones may crop out again in San Arroyo Canyon, in the southwestern part of T. 16 S., R. 25 E. Wild Cow, Bar X, and Prairie Canyons do not seem to be cut along minor folds.

A dip of 9° S. 50° W. observed near the northeast corner of sec. 13, T. 17 S., R. 25 E., on a thin sandy layer in the upper part of the Mancos shale, is nearly at right angles to the general dip of the beds in this

[46] Work by an oil company in 1929 indicated that there is a reversal of dip along the trend of this nose and that there is closure in and near sec. 22, T. 20 S., R. 23 E. The strike of this fold is considered to bend sharply to the south in the NE¼ sec. 29, T. 19 S., R. 23 E.

region. No time was available for determining its possible significance.

Eight faults, all minor, are shown on plate 11. The one on the east side of East Westwater Canyon, in sec. 15, T. 17 S., R. 24 E., cannot be traced to the west side of the canyon. It has a downthrow on the northeast of 31 feet. The fault in Jim Canyon, in secs. 20 and 21, T. 16 S., R. 26 E., has a downthrow of about 225 feet on the southeast side. The strike fault in T. 17 S., R. 25 E., has a throw of only 10 feet in sec. 20. The largest of the other five faults is the one in sec. 5, T. 18 S., R. 24 E., which has a downthrow of 80 feet on the north side. The two faults south of this one have measured throws of 44 and 30 feet, the block between constituting a minor graben. Measured throws on the other faults are 36 feet (in sec. 5, T. 18 S., R. 24 E.) and 16 feet (in sec. 19, T. 17 S., R. 25 E.)

OIL AND GAS

Much prospecting for oil and gas has been carried on at two places in the area. Very small amounts of oil have been obtained near Crescent, and gas has been produced in the Cisco district. In 1930 two test wells for oil were drilled—one 2 miles southwest of Cisco, the other 7 miles north-northwest. No drilling was reported in 1931. In 1932 a well 2 miles south of Crescent reached 3,400 feet. No drilling was reported in 1933 up to September.

About half a dozen wells have been drilled to depths of much more than 100 feet in the northward extension of the Salt Valley graben near Crescent (pl. 9). No commercial production of oil or gas, however, has been obtained. The developments are noted briefly below.

On Saleratus Wash, in the SW¼ sec. 7, T. 21 S., R. 19 E., 5 miles northwest of Crescent, a well was drilled for petroleum in the first half of 1925 by the Sandburg Petroleum Co., of Los Angeles, Calif. A depth of 2,470 feet was reported before funds gave out. This well did not reach the base of the Mancos shale. Very small showings of gas were obtained. The top of the drive pipe at this well has an altitude of 5,103 feet. According to the structure contours, this well is about half a mile east of the outcrop of the crest of the major anticline of the area and almost exactly on the trace of a fault that here has a downthrow to the south of about 20 feet. It is fairly certain that at depth the well is northeast of the fault surface, if the bore hole is nearly vertical. The location appears to be a good one for a test well, especially if it can be shown that there is a suitable source rock and if there has been migration up the dip, from the east of north.

In 1926 the Western States Development Co.[47] was drilling a well (McCarthy No. 1) with a Star rig near Crescent, in the NW¼ sec. 34, T. 21 S., R. 19 E. In April 1930 the trade journals reported McCarthy No. 1 as drilling below 2,200 feet; it had not yet reached the Dakota (?) sandstone. No log of this hole is available. Its altitude is about 4,900 feet, and it is located essentially on the outcrop of a minor dip fault with 100 feet of downthrow on the south, as mapped by Evans and Weeks,[48] and a short distance east of the Salt Valley graben; the dip is monoclinal to the northeast at an angle of about 10°.

Several wells have been drilled in T. 22 S., R. 19 E. A little oil has been found, and carnallite [49] ($KCl.MgCl_2.6H_2O$) has been discovered in the Crescent Eagle well, in the SE¼ sec. 4, which is about 4,000 feet deep. The log of this well reports shows of oil and gas at many horizons between 780 and 3,911 feet. At 2,130 feet high-pressure wet gas was encountered. Late in 1924 the well produced 10 gallons of light-gravity petroleum daily; from just what horizon this came is not known, as the hole was open below about 2,000 feet. The Dakota (?) sandstone apparently lies at 1,808 to 1,829 feet. Below this are greenish Morrison clays for 152 feet, underlain by 32 feet of sandstone and 47 feet of variegated shale. The rest of the log is irregular and shows large amounts of rock salt.

The Armstrong well, near the southeast corner of sec. 9, was drilled late in 1926 and apparently went through 660 feet of Mancos shale, 50 feet of Dakota (?) sandstone with a show of heavy oil near the base, 408 feet of Morrison formation,[50] of which the lower 150 feet or so belonged to the Salt Wash sandstone member, and 105 feet of Summerville formation, mainly variegated shale but with a minor sandstone near the base showing oil.

In 1928 Randall No. 1 well was drilled near the northeast corner of the SE¼ sec. 10, to a depth of 1,725 feet (Navajo-Wingate horizon). Gas was reported at 1,600 feet, but the hole was full of water at 1,725 feet.

In 1928 the Brendell Oil & Gas Co. started to drill a hole 400 feet south of the Crescent Eagle well. Operations ceased shortly but were resumed in 1932, when a depth lower than 3,400 feet was reported [51] to have been reached; gas was encountered at this depth.

[47] According to information in the files of the Geological Survey, drilling on the Western States Development Co.'s well 1, in the SW¼SW¼ sec. 27, T. 21 S., R. 19 E., was begun Dec. 30, 1924, and was carried to a depth of 1,375 feet. A report in the Survey files May 1928 states that it had been shut down at 1,375 feet since Oct. 1, 1927.

[48] Evans, F. G., Jr., and Weeks, A. W., in Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 122, 1927.

[49] Lang, W. B., Potash investigations in 1924: U. S. Geol. Survey Bull. 785, p. 38, 1926.

[50] The Morrison formation of this area is from 475 to 640 feet thick, according to Lupton, Gilluly, and Reeside. See Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 81, 1928.

[51] Oil and Gas Jour., Aug. 25, 1932, p. 73.

Developments near Cisco include about 15 wells that have been drilled to depths of much more than 100 feet on the Cisco dome, about 12 miles northwest of Cisco, and about 9 shallow wells near Cisco. The Cisco dome wells furnished gas for the manufacture of carbon black; the Cisco wells supplied gas for local consumption for a short while but are now abandoned. With regard to development on the Cisco dome, Dane[52] says:

> The Utah Oil Co., in [August to October] 1924, drilled its no. 1 well in the NE¼ sec. 25, T. 20 S., R. 21 E. The drill reached the Dakota (?) formation at 1,930 feet. * * * 6,000,000 cubic feet a day of dry gas came from this sandstone bed, which later proved to be 17 feet thick. The drill then went through 13 feet of shale and early in October struck a flow of gas [at 1,954 feet] estimated at 90,000,000 cubic feet a day, which came with such force as to partially wreck the derrick but which is reported to have fallen off considerably soon after. The gas was used as a fuel in drilling the no. 2 well, in sec. 30, which encountered a steady flow of 5,000,000 to 6,000,000 cubic feet of gas in the top of the Dakota at 1,910 [1,950] feet.

At the time of the writer's study of the area (August 1926) these wells had been taken over by the Perfection Oil & Gas Co. The old Utah Oil Co. No. 1 was known as "Crystal Carbon Co. No. 1" (altitude, 5,051 feet). It had been deepened to 2,414 feet. An unpublished manuscript bearing date of September 1927 in the files of the Geological Survey states that it was making 1,000,000 cubic feet of gas. The Utah Oil Co. No. 2 well of Dane—called in 1926 "Utah Oil No. 1"—in the northwest corner of the SW¼ sec. 30, T. 20 S., R. 22 E. (reported altitude 4,880 feet), was drilled late in 1924 and early in 1925. It made 2,000,000 cubic feet of gas at 1,950 feet at a closed-in pressure of 150 pounds to the square inch, and the gas carried 0.0025 gallon of gasoline to the 1,000 cubic feet. It was deepened to 3,045 feet and later abandoned. The Perfection Oil & Gas Co.'s well 1, in the same quarter section (altitude, 4,978 feet), was drilled to a total depth of 1,940 feet in July and August 1926. It struck the Dakota (?) sandstone at 1,878 feet and yielded 4,126,000 cubic feet of gas at depths of 1,917 and 1,925 feet, under a pressure of 525 pounds to the square inch and with a gasoline content of 0.164 gallon to the 1,000 cubic feet.

The Perfection Oil & Gas Co.'s well 2, recorded in the United States Geological Survey as in the SE¼NE¼ sec. 31, T. 20 S., R. 22 E., made 5,000,000 cubic feet of gas at 1,936 feet. A manuscript report dated May 1928 in the files of the Geological Survey says that this well was deepened to 2,207 feet, but this deepening did not improve gas production. The writer observed a rig in the northwest corner of sec. 32 of the same township (altitude, 4,880 feet). This may be Perfection Oil & Gas No. 2, and if so, that well is not in sec. 31. The writer also observed a rig just south of the SW¼SE¼ sec. 36, T. 20 S.,

[52] Dane, C. H., op. cit., p. 20.

R. 21 E. (altitude, 4,922 feet), of which the United States Geological Survey seems to have no record. These wells were accurately located by intersection from triangulation stations, but time was not available to visit them.

These wells, except the last one mentioned, which is some distance from the crest, are all near the surface crest of the elongated dome, as shown by the structure contours. There is little possibility that the Dakota (?) itself is the original source of the gas—at least not in the immediate area—as Dane [53] states that this formation here lacks fossils and carbonaceous material. As deepening the wells below the Dakota (?) does not aid production, it seems probable that the source is in the lower part of the Mancos shale. Alternative hypotheses are that the gas has migrated considerable distances up the dip along the porous Dakota (?) sands, possibly originally having come from the Dakota (?) or a lower formation, or that the gas has migrated more or less vertically from a deeper zone which has not yet been reached by the drill, or, if reached, is now barren, which seems unlikely. The gas shows a small gasoline content, and petroleum in commercial amounts may be present at or near the source locality and horizon, if the Mancos of the immediate area is not the source. The wells that have been drilled leave little hope of oil production on the Cisco dome from the Dakota (?) sandstone.

Nine wells near Cisco (T. 21 S., R. 23 E.) are shown on plate 10. Of these, all but the one nearest the southeast corner of sec. 13 (which was being drilled in 1926) were mapped by Dane in September 1924. Regarding these, Dane [54] says:

> The wells of the Arizona-Utah Gas & Oil Co. are located immediately around Cisco station, not far from the southern border of the Mancos plain. The Dakota (?) formation passes under the Mancos about 5 miles south of Cisco and 3 miles east.
>
> Dips in the shale are uniformly small, and exposures are poor near the wells, owing to alluvial fill and surface wash. The regional dip of the monocline is about 2° N. 70° W., as judged from the Dakota (?)-capped hills east of the town. One mile northwest of the station the dip is 2° N. 20° W.; 1 mile southwest the dip is 2° N. 75° W.; and 1 mile south the dip is 3° S. 30° W. These dips and a few others combine to give the impression of a slight anticlinal flexure on the general monocline. No closure is indicated.
>
> In 1923 and 1924 the Arizona-Utah Gas & Oil Co. drilled six shallow holes near Cisco station to the Dakota (?) and upper Morrison sandstones. These wells encountered oil shows, much gas, and considerable water.

All these wells, which with one exception were about 600 feet deep, were abandoned in 1928.

In 1930 the Utah Southern Oil Co.'s well No. 1 State was drilled near the center of the SE¼ sec. 26, T. 21 S., R. 23 E. It was "abandoned at 2,431 feet, 34 feet in granite. It topped the red beds at

[53] Dane, C. H., op. cit., p. 10.
[54] Idem, pp. 16, 20.

2,085 feet and the Pennsylvanian at 2,300 feet."[55] Cisco Springs Syndicate Moss No. 1 well was also drilled in the same year near the southeast corner of the SW¼ sec. 9, T. 20 S., R. 23 E. It was reported[56] to have been abandoned at 2,030 feet after getting a show of gas in the top of the Dakota (?) sandstone at 2,010 feet. A well was started in 1929 in sec. 4 of the same township by the Western Crude Oil Co. Two wells were drilled in 1926 on the Harley dome, in the NE¼NE¼ sec. 4, T. 19 S., R. 25 E. (pl. 11). These were reported[57] to have obtained heavy flows of nonflammable helium-bearing gas at about 600 feet.

COAL

GENERAL OCCURRENCE

The coals of the Book Cliffs field of Utah, east of Sunnyside, are bituminous, or sometimes called "western type" of bituminous. The coal beds are found in the Blackhawk formation and in the Neslen member of the Price River formation. Those in the Blackhawk are older and of somewhat higher rank than those in the Neslen. On the basis of age of coal, as well as other features, the Book Cliffs coal field of Utah may be divided conveniently into two subfields. The Sunnyside subfield includes the part west of the Green River; it carries no Price River coals but contains essentially all the coals of the Blackhawk formation. The Thompsons subfield lies east of the river; it carries all the Price River coals but only very minor amounts of the older Blackhawk coals. Between these two coal-bearing units are found (in ascending order) the Castlegate sandstone member, the Buck tongue of the Mancos shale, and the Sego sandstone member. The stratigraphic positions of the coals are summarized below.

Stratigraphic positions and thickness of coals of the Book Cliffs coal field in Utah, east of Sunnyside

Price River formation:		*Feet*
Farrer non-coal-bearing member (unnamed lenses of coal of no economic importance)		410–1,095
Neslen coal-bearing member		250–410
	Feet above base of member	
Carbonera (?) coal zone	200±	
Chesterfield coal zone	150±	
Ballard coal zone	130±	
Palisade coal zone	30±	
Also minor unnamed lenses of coal more common in the lower part.		

[55] Oil and Gas Jour., Jan. 29, 1931, p. 156.
[56] Idem, Nov. 27, 1930, p. 112.
[57] Idem, June 18, 1931, p. 95.

Stratigraphic positions and thickness of coals of the Book Cliffs coal field in Utah. east of Sunnyside—Continued

	Feet
Price River formation—Continued.	
Sego sandstone member (no coal in Utah)	140–210
Buck tongue of Mancos shale (no coal)	50–350
Castlegate sandstone member (local coaly layers in upper part, but these are of no value; average thickness about 100 feet)	15–190
Blackhawk formation:	
Upper member (lenticular beds of coal at several unnamed horizons, referred to as "coals of the upper member of the Blackhawk formation")	70–230
Middle sandstone member (Sunnyside coal 25 to 75 feet below top)	100–245
Middle shale member (Kenilworth coal at or near base in two small districts)	100–160
No coal present below Kenilworth in this area.	

The Kenilworth coal is present in the extreme northwestern part of the area (pl. 8) and in a small district at the southwest corner of the Beckwith Plateau (pl. 9). Where present, its outcrop line essentially coincides with that of the top of the lower sandstone member of the Blackhawk formation. The Sunnyside coal is present through most of the area west of the Green River. What is here called the "Sunnyside bed" is probably in most places the lower Sunnyside bed of Clark,[58] though locally the upper bed appears to be present. Coals of the upper member of the Blackhawk formation are present as far east as Crescent Canyon; those of possible economic importance east of the Green River are shown on plate 9. Detailed sections of the Blackhawk coals are shown on plate 12.

The Price River coals are grouped into zones, rather than individual beds. This has been done because time was not available for the tracing of individual beds, even if this were possible. Plates 13, 14, and 15 show in general for each location a stratigraphic section (on the right), starting at the base of the Neslen member. The parts of the section that contain coal zones or beds of possible economic importance are indicated by an arrow pointing to a narrower section on the left that shows in detail, on a scale six times as large, the character of the coal zone. For the sake of uniformity the Blackhawk coals (pl. 12) have been plotted in the same manner, though otherwise this would be necessary for only the coals of the upper member. The datum for these sections is the top of the Blackhawk formation. All the coal sections are plotted in order of townships from west to east along the cliffs. Each section has a number, corresponding to that of a location indicated on the maps.

The Palisade coal zone (pl. 4, *A*) was traced from Saleratus Canyon (pl. 9) to the Colorado line, and Erdmann and Boyer have traced

[58] Clark, F. R., op. cit. (Bull. 793), p. 34.

it into the Palisade district [59] of Colorado. In the area discussed in this report it is almost certainly not represented by a single continuous coal bed, as is indicated on plates 13 to 15. It is mined spasmodically in Crescent Canyon but not elsewhere at present, though it was formerly mined at Sego. The Ballard coal zone [60] perhaps carries a single coal bed over a large area. It immediately underlies the Thompson Canyon sandstone bed (pl. 5, *B*) and has about the same extent—that is, from Saleratus Canyon to Cottonwood Canyon (pl. 10). Its position on the maps is shown by this sandstone. The Chesterfield coal zone (pls. 5, *B*; 6, *A*, *B*) immediately or closely overlies the Thompson Canyon sandstone bed or the Sulphur Canyon sandstone bed, and on the maps these sandstone beds are taken to indicate its outcrop line, except at certain places where the position of the coal is appreciably different, at which the coal zone is indicated by another line. This coal zone was traced from Coal Canyon (pl. 9) east to the Colorado line. There it lies in essentially the same stratigraphic position as the Cameo coal,[61] according to Erdmann, but direct correlation is not made, as the typical Cameo coal apparently plays out some distance east of the Colorado-Utah line. The name in Utah is taken from the Chesterfield Coal Co., of Sego, which operates the only shipping mine of the area. In the eastern part of the area the stratigraphic and coal sections at several locations show a higher coal zone that is probably to be correlated with the Carbonera coal zone [62] of western Colorado, according to Erdmann's sections. It was not mapped, as nowhere in Utah is it of economic importance. Most of the coal beds have been burned to a small extent at one locality or another. This is most notable along salients or projecting spurs. Burning is indicated by the conventional symbol on the maps and is discussed in the township descriptions.

PHYSICAL AND CHEMICAL CHARACTER

The coals of the area are black and have a brownish to black streak. They appear to withstand shipment and weathering well, if piles near closed mines are a safe criterion. A large proportion of the product is lump, owing to the presence of well-spaced joints. The Ballard coal shows this jointing most conspicuously on the outcrop, though the Chesterfield coal also shows it locally. In general the coal beds are thin and contain a high percentage of ash. The nature of the coal beds and partings is shown in the graphic sections (pls. 12–15), and the various beds are described in detail in the township reports.

[59] Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colo.: U. S. Geol. Survey Bull. 510, p. 74, 1912.

[60] Name taken from that of an old mine or prospect at Sego, Utah. The entrance to this mine is shown in the upper right part of plate 5, *A*, covered by the shadow cast by the massive Thompson Canyon sandstone bed. See Richardson, G. B., U. S. Geol. Survey Bull. 371, p. 38, 1909.

[61] Lee, W. T., op. cit. (Bull. 510), p. 75.

[62] Richardson, G. B., op. cit. (Bull. 371), p. 36.

Much of the coal shows alternating bright and dull layers; fusain or mineral charcoal is a minor constituent. As in most other Cretaceous coals, specks of resin are common. Seamlets of gypsum, calcite, or iron disulphide (pyrite or marcasite) are present at many places. Richardson [63] reports that films of material collected from the coal in Horse Canyon (pl. 8) consist of hydrous aluminum silicate containing a small amount of calcium carbonate. So far as known, no tests for coking properties have been made on the coals of the area. The Sunnyside bed in the Horse Canyon district (pl. 8) is doubtless a good coking coal, as coal from this bed at Columbia and Sunnyside, nearby, is coked by both byproduct and beehive methods. Only one sample has been tested for specific gravity. In 1926 J. J. Bourquin and W. F. Murray collected a sample (no. A23383) from the Palisade seam at the Crescent mine (same place and section as sample 7, laboratory no. A23382; see table, p. 50), and H. M. Cooper at the Pittsburgh laboratory of the United States Bureau of Mines found it to have a specific gravity of 1.367 as referred to water at 20° C.

Only 21 analyses have been made of the coals of the area; in 5 of these no heating value was determined, and only 8 were of the ultimate type. In the descriptions of the coal samples, nos. 5, 9, and 12 are reported as weathered, and no. 6 as somewhat weathered. By comparison with other analyses it appears that nos. 4, 20, and 21 are also probably weathered samples, and nos. 2 and 16 seem to have been slightly altered. No analyses are available of the Kenilworth or Carbonera (?) coals of the area, and only one of a coal from the upper member of the Blackhawk formation. The available data are summarized in the table on pages 50–51, which is followed by descriptions of the specimens. The analyses of coals in nearby or competing areas are not included, because a comparison of coal analyses is only one phase of comparing the coals of any two areas; it is equally important to compare thickness and purity of seams, availability of coal, transportation, markets, and similar subjects. For comparisons of this sort, reference should be made to publications on nearby areas, in which all these factors are covered.

In making use of coal analyses, it is highly desirable that methods of sampling and analyzing be understood, to avoid misinterpretations. These subjects are covered in detail in available published reports.[64] A brief outline follows.

[63] Richardson, G. B., op. cit., p. 43.

[64] See particularly the following: Holmes, J. A., The sampling of coal in the mine: U. S. Bur. Mines Tech. Paper 1, 1918; Stanton, F. M., Fieldner, A. C., and Selvig, W. A., Methods of analyzing coal and coke: U. S. Bur. Mines Tech. Paper 8, 1929; Fieldner, A. C., Notes on the sampling and analysis of coal: U. S. Bur. Mines Tech. Paper 76, 1914; Ralston, O. C., Graphic studies of the ultimate analyses of coals: U. S. Bur. Mines Tech. Paper 93, 1915.

In sampling, after cleaning the face of coal a clean canvas is spread on the floor and a V-shaped niche is cut down the full exposed face. The coal thus removed is collected on the cloth, ground to pass a ½-inch screen, and quartered; a 3-pound sample is sealed in a can and then shipped for analysis as soon as possible. Impurities are removed before quartering, as specifically stated in the descriptions of the samples collected. Often impurities are thus removed that would not be taken out during mining and preparation of commercial shipments.

After weighing the sample, the first step in analysis is to "air-dry" it. Until recently this was done by keeping it in a drying oven at 30° to 35° C. until essentially constant weight was reached.[65] Although the air-drying loss is not regarded as an accurate determination, all the subsequent analytical determinations are made on the air-dried sample. It is obvious that some oxidation and possibly other changes may occur during air-drying. "Moisture" is the loss in weight suffered by a 1-gram pulverized sample on being held at 105° C. for 1 hour; some water may still remain, and some other volatile materials may be driven off; other chemical changes, such as oxidation, may take place. "Volatile matter" is determined by heating a 1-gram pulverized sample for 7 minutes at 950° C. in a covered platinum crucible;[66] the loss in weight, less the moisture content, is given as volatile matter. Ash is determined as the residue obtained by heating a moisture-free sample to 700° to 750° C. in a muffle to constant weight. The remainder after these three determinations is computed by subtraction and called "fixed carbon." The figures thus obtained are called the analysis "as received" and are shown in line A of the table (p. 50). The figures in lines B, C, and D are computed from the results obtained as given above by methods described elsewhere.[67] The method of running an ultimate analysis is given in the Mines Bureau publications cited.

The main value of these analyses lies in their use for comparison of coals with others analyzed in the same fashion. For commercial comparisons, the heating values given in the table are for many reasons too high. Complete moisture content is considered by some people to be of little significance, but the writer believes that where samples are collected with great care and are strictly fresh this figure is of value, especially for coals not too high in rank collected from an arid region such as the one here described. It is generally agreed that

[65] This method of air-drying was in vogue between 1907 and 1928. Recently the Bureau of Mines has reverted to its original method (used from 1904 to 1907), in which samples are not heated to constant weight, but are heated for just a few hours with the intent of driving off only surface moisture. Comparison of analyses of coal samples on the air-dried basis, always of somewhat questionable value, is therefore now rendered meaningless.

[66] This procedure was formerly carried out over a Bunsen burner, but for analyses made subsequent to one numbered about 16500 it has been done in the electric furnace. It was found that determinations of the volatile matter with the electric furnace were for some samples several percent higher than the determinations made on the same samples with the Bunsen burner.

[67] Stanton, F. M., Fieldner, A. C., and Selvig, W. A., op. cit., pp. 4–6.

the figures in lines C and D, though of scientific value, are of little practical value. The only reason for neglecting ash is because this may be regarded as more or less fortuitous as far as the clean coal substance is concerned; it depends to a very large extent on terrigenous matter carried into the coal-forming swamp, unless large amounts of secondary material are present, and for this reason it is deemed wise to omit the ash in comparing coals. From the practical point of view, ash, if present in any but minor amounts, is at least as important as any other constituent.

Chemical analyses of coal samples from Book Cliffs coal field in Utah

1. Lower Sunnyside coal bed, T. 16 S., R. 14 E.

[A, As received; B, air dried; C, moisture free; D, moisture and ash free]

No.	Location or map no.	Laboratory no.	Air-drying loss	Form of analysis	Proximate				Ultimate					Heating value		Ash-softening temperature (°F.)
					Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British thermal units	
1	2 or 3	2200	1.0	A	4.8	38.2	52.0	5.0	0.7	----	----	----	----	7,330	13,190	----
				B	3.8	38.3	52.2	5.0	.7	----	----	----	----	7,400	13,330	----
				C	----	40.1	54.7	5.2	.8	----	----	----	----	7,690	13,840	----
				D	----	42.3	57.7	----	.8	----	----	----	----	8,115	14,610	----
2	2	4015	2.9	A	5.2	36.0	52.7	6.1	.8	5.3	71.2	1.3	15.3	7,240	13,030	----
				B	2.4	37.1	54.3	6.3	.9	5.1	73.4	1.3	13.1	7,455	13,420	----
				C	----	38.0	55.6	6.4	.9	4.9	75.1	1.4	11.3	7,640	13,750	----
				D	----	40.6	59.4	----	.9	5.3	80.3	1.5	12.0	8,160	14,690	----
3	3	A13910	.5	A	3.9	38.0	54.3	3.8	.8	----	----	----	----	7,365	13,260	----
				B	3.4	38.2	54.6	3.8	.8	----	----	----	----	7,405	13,330	----
				C	----	39.5	56.6	3.9	.8	----	----	----	----	7,665	13,800	----
				D	----	41.1	58.9	----	.9	----	----	----	----	7,985	14,370	----
4	Northeast of 5	4013	4.1	A	9.0	31.8	51.0	8.2	.5	5.0	62.2	1.3	22.8	6,035	10,860	----
				B	5.1	33.1	53.2	8.5	.5	4.7	64.9	1.3	20.1	6,295	11,330	----
				C	----	34.9	56.1	9.0	.5	4.4	68.4	1.4	16.3	6,635	11,940	----
				D	----	38.4	61.6	----	.6	4.7	75.1	1.5	18.1	7,290	13,120	----
5	----do	4014	3.5	A	9.8	33.4	50.4	6.4	.6	----	----	----	----	----	----	----
				B	6.5	34.6	52.3	6.6	.6	----	----	----	----	----	----	----
				C	----	37.0	55.9	7.1	.7	----	----	----	----	----	----	----
				D	----	39.8	60.2	----	.7	----	----	----	----	----	----	----
	2. Upper Blackhawk (3957) and Palisade coals															
6	25	3957	2.3	A	4.8	33.6	50.2	11.4	1.2	----	----	----	----	----	----	----
				B	2.5	34.4	51.4	11.7	1.2	----	----	----	----	----	----	----
				C	----	35.3	52.7	12.0	1.2	----	----	----	----	----	----	----
				D	----	40.1	59.9	----	1.4	----	----	----	----	----	----	----
7	100	A23382	2.0	A	7.1	35.8	44.5	12.6	.6	5.2	64.3	1.4	15.9	6,280	11,300	2,580
				B	5.2	36.5	45.4	12.9	.7	5.1	65.6	1.4	14.3	6,405	11,530	----
				C	----	38.5	47.9	13.6	.7	4.7	69.2	1.5	10.3	6,755	12,160	----
				D	----	44.6	55.4	----	.8	5.5	80.0	1.7	12.0	7,820	14,080	----
8	100	A23634	1.8	A	7.4	36.7	43.3	12.6	.7	5.2	63.4	1.5	16.6	6,240	11,230	2,600
				B	5.7	37.4	44.1	12.8	.7	5.1	64.5	1.5	15.4	6,355	11,440	----
				C	----	39.6	46.8	13.6	.8	4.7	68.5	1.6	10.8	6,740	12,130	----
				D	----	45.9	54.1	----	.9	5.5	79.2	1.9	12.5	7,800	14,040	----
9	West of 176	83341	3.2	A	5.2	37.2	48.1	9.5	.7	----	----	----	----	6,695	12,050	2,510
				B	2.0	38.2	49.4	9.7	.7	----	----	----	----	6,915	12,450	----
				C	----	39.2	50.7	10.1	.8	----	----	----	----	7,065	12,720	----
				D	----	43.2	55.9	----	.9	----	----	----	----	7,860	14,150	----
10	Southwest of 176	17578	1.3	A	6.4	37.8	45.2	10.6	.6	----	----	----	----	6,590	11,860	2,670
				B	5.1	38.3	45.9	10.7	.6	----	----	----	----	6,680	12,020	----
				C	----	40.4	48.3	11.3	.7	----	----	----	----	7,040	12,670	----
				D	----	45.5	54.5	----	.7	----	----	----	----	7,935	14,280	----

Chemical analyses of coal samples from Book Cliffs coal field in Utah—Continued

3. Ballard (17577, 83342, and 3856) and Chesterfield (3945 and A15503) coals

No.	Location or map no.	Laboratory no.	Air-drying loss	Form of analysis	Proximate				Ultimate					Heating value		Ash-softening temperature (°F.)
					Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British thermal units	
11	North of 175	17577	2.0	A	7.1	37.0	45.5	10.4	0.7	5.6	66.0	1.5	15.8	6,510	11,720	2,960
				B	5.3	37.8	46.3	10.6	.7	5.5	67.3	1.5	14.4	6,640	11,950	------
				C	----	39.9	48.9	11.2	.7	5.2	71.1	1.6	10.2	7,010	12,620	------
				D	----	44.9	55.1	-----	.8	5.8	80.0	1.8	11.6	7,895	14,210	------
12	Northwest of 176	83342	18.1	A	20.0	28.7	38.4	12.9	.5	----	----	----	-----	5,165	9,300	2,910
				B	1.9	35.0	46.8	15.7	.6	----	----	----	-----	6,310	11,350	------
				C	----	35.9	48.0	16.1	.7	----	----	----	-----	6,455	11,620	------
				D	----	42.4	56.8	-----	.8	----	----	----	-----	7,695	13,850	------
13	176	3856	2.3	A	6.4	31.9	42.7	19.0	.6	5.0	59.1	1.3	15.0	5,890	10,600	------
				B	4.1	32.6	43.8	19.5	.6	4.9	60.5	1.4	13.2	6,030	10,850	------
				C	----	34.1	45.6	20.3	.6	4.6	63.1	1.4	10.0	6,290	11,320	------
				D	----	42.7	57.3	-----	.8	5.8	79.2	1.8	12.4	7,895	14,210	------
14	54	3945	1.9	A	5.6	32.8	43.6	18.0	.7	----	----	----	-----	------	------	------
				B	3.8	33.4	44.5	18.4	.7	----	----	----	-----	------	------	------
				C	----	34.7	46.2	19.1	.8	----	----	----	-----	------	------	------
				D	----	42.9	57.1	-----	.9	----	----	----	-----	------	------	------
15	55	A15503	4.9	A	7.9	36.2	43.1	12.8	1.0	5.2	62.4	1.4	17.2	6,140	11,050	2,570
				B	3.1	38.0	45.5	13.4	1.0	4.9	65.7	1.5	13.5	6,455	11,620	------
				C	----	39.3	46.8	13.9	1.1	4.7	67.8	1.5	11.0	6,660	11,990	------
				D	----	45.6	54.4	-----	1.2	5.5	78.7	1.8	12.8	7,735	13,920	------

4. Chesterfield coal at Sego

16	North of 175	81824	5.6	A	8.0	33.6	47.1	11.3	0.7	----	----	----	-----	6,380	11,480	2,800
				B	2.5	35.6	49.9	12.0	.7	----	----	----	-----	6,755	12,160	------
				C	----	36.5	54.2	12.3	.7	----	----	----	-----	6,935	12,480	------
				D	----	41.6	58.4	-----	.8	----	----	----	-----	8,060	14,510	------
17	----do	81825	5.6	A	8.1	35.3	46.2	10.4	.6	----	----	----	-----	6,430	11,570	2,910
				B	2.5	37.2	48.7	11.0	.6	----	----	----	-----	6,810	12,260	------
				C	----	38.2	50.0	11.2	.6	----	----	----	-----	7,110	12,800	------
				D	----	43.0	56.3	-----	.7	----	----	----	-----	8,005	14,410	------
18	----do	81826	5.2	A	8.0	36.1	46.8	9.1	.6	----	----	----	-----	6,550	11,790	2,450
				B	2.8	37.9	49.2	9.5	.6	----	----	----	-----	6,910	12,440	------
				C	----	39.0	50.5	9.8	.7	----	----	----	-----	7,110	12,800	------
				D	----	43.3	56.0	-----	.7	----	----	----	-----	7,880	14,190	------
19	----do	81827	5.5	A	8.0	35.7	45.9	10.4	.7	5.6	65.4	1.4	16.5	6,415	11,550	------
				B	2.3	37.6	48.4	11.0	.7	5.3	69.2	1.5	12.3	6,790	12,220	------
				C	----	38.8	49.9	11.3	.7	5.1	71.1	1.6	10.2	6,970	12,550	------
				D	----	43.7	56.3	-----	.8	5.7	80.1	1.8	11.6	7,860	14,150	------
20	North of 176	3857	2.5	A	9.6	32.4	47.0	11.0	.5	----	----	----	-----	------	------	------
				B	7.3	33.2	48.3	11.3	.5	----	----	----	-----	------	------	------
				C	----	35.8	52.1	12.1	.5	----	----	----	-----	------	------	------
				D	----	40.7	59.3	-----	.6	----	----	----	-----	------	------	------

5. Chesterfield coal from Nash Canyon

21	208	3854	4.5	A	12.7	33.0	50.1	4.2	0.5	----	----	----	-----	------	------	------
				B	8.6	34.6	52.4	4.4	.5	----	----	----	-----	------	------	------
				C	----	37.9	57.3	4.8	.5	----	----	----	-----	------	------	------
				D	----	39.8	60.2	-----	.6	----	----	----	-----	------	------	------

Descriptions of coal samples collected for chemical analysis

[Laboratory numbers of samples are given in parentheses. An asterisk (*) indicates parts included in sample]

1 (2200). Prospect in Horse Canyon, sec. 3, T. 16 S., R. 14 E. Measured and sampled by J. A. Taff in 1905, as follows:

	Ft.	in.
Sandstone:		
Coal	2	
Shale and sandstone	4	
*Coal, clean and massive	14	11
Sandstone, massive.		

Analysis made in United States Geological Survey fuel-testing plant at St. Louis; F. M. Stanton, chemist in charge.

2 (4015). Prospect on the west side of Horse Canyon, sec. 3, T. 16 S., R. 14 E. Measured and sampled by G. B. Richardson in 1906. Sample was taken 400 feet from opening and represents 13 feet 5 inches of coal. Analysis made in United States Geological Survey fuel-testing plant at St. Louis; F. M. Stanton, chemist in charge.

3 (A13910). Prospect on east side of Horse Canyon, sec. 3, T. 16 S., R. 14 E. Sample was taken by D. J. Fisher, in 1925, from north rib of south drift, 30 feet from end of drift and about 600 feet from the entrance. Bed thought to be about 10 feet thick, of which 4 feet is in roof of entry, which is 6 feet high. Sample included 30 inches of coal, with base of section 2½ feet above floor of entry. Lower part not sampled, as it appeared to be somewhat altered. Sample taken from hard coal that appeared fresh but had probably been exposed in the entry a decade or so. Analyzed by H. M. Cooper at Pittsburgh laboratory of United States Bureau of Mines.

4 and 5 (4013 and 4014). Prentiss prospect, sec. 9, T. 16 S., R. 14 E. Measured and sampled by G. B. Richardson in 1906 as follows:

	4013	4014
	Ft. in.	Ft. in.
Sandstone, thin-bedded:		
Coal		2 4
Shale and sandstone		3
*Coal	6	6
Bone	3	3
*Coal	10	10
Sandstone, white.		

Sample 4014 was taken at the end of the prospect, which was not being worked; the coal was weathered. Analyses made in United States Geological Survey fuel-testing plant at St. Louis; F. M. Stanton, chemist in charge.

6 (3957). Peterson's prospect, sec. 17, T. 18 S., R. 15 E. Measured and sampled by G. B. Richardson in 1906, as follows:

	Ft.	in.
Bone	1	2
*Coal	4	

The sample represented coal somewhat weathered. The coal from this prospect breaks easily after mining. The lumps as mined are 30 inches or less in diameter, and there is a large amount of slack. Analysis made in United States Geological Survey fuel-testing plant at St. Louis; F. M. Stanton, chemist in charge.

7 (A23382). Crescent mine, sec. 34, T. 20 S., R. 19 E. Measured and sampled by J. J. Bourquin and W. F. Murray in 1926, as follows:

	Ft.	in.
Sandstone.		
Slate		3
Coal, bony		7
Slate		3
*Coal	4	3¼
Slate.		

Sample cut from face of room 1 off main entry. Analyzed by H. M. Cooper at Pittsburgh laboratory of United States Bureau of Mines.

8 (A23634). Crescent mine, sec. 34, T. 20 S., R. 19 E. Measured and sampled by D. J. Fisher in 1926, as follows:

	Ft.	in.
Shale, carbonaceous		6
*Coal	4	2
Shale, brown to gray		3

Sample taken from northwest rib at end of southwest branch off main drift, 310 feet from mine entrance. Branch takes off 150 feet from mine entrance. Coal where sampled consisted of well-jointed bright and dull layers with no partings. Coal has many specks of resin and carries films of iron disulphide and calcite along the joint planes. Analyzed by H. M. Cooper at Pittsburgh laboratory of United States Bureau of Mines.

9 (83341). Chesterfield Coal Co., Sego, Utah, SE¼NW¼ sec. 27, T. 20 S., R. 20 E. Measured and sampled by H. I. Smith in 1921, as follows:

	Ft.	in.
Sandstone, massive.		
Shale, sandy.		
Bone		8
*Coal		9
Bone		4
Sandstone, white		2
*Coal	3	10
Bone		3
Coal, bony (floor).		

Sample cut 300 feet from outcrop, no. 3 mine, and had been exposed several years. Analysis made at Pittsburgh laboratory of United States Bureau of Mines; A. C. Fieldner, chemist in charge.

10 (17578). Sec. 27, T. 20 S., R. 20 E. Sample taken by F. R. Clark in 1913 from the fresh face of a prospect then being cut, but coal may have been slightly weathered. The entire lower bench of coal (4 feet 3½ inches thick at the nearby location 176) was sampled. Sample taken 85 feet from opening. This bed is apparently more constant in thickness and freer from bone and shale partings than the Ballard bed in this locality. Analysis made in Pittsburgh laboratory of United States Bureau of Mines; A. C. Fieldner, chemist in charge.

11 (17577). Sec. 27, T. 20 S., R. 20 E. Sample cut by F. R. Clark in 1913. Taken from face of main entry of no. 1A mine of Chesterfield Coal Co., Sego, Utah, 1,200 feet east of mine opening. The section is as follows:

	Ft.	in.
Sandstone, massive.		
Shale		6
*Coal, bright, blocky	1	3
*Coal, dull, probably high in ash	1	1
*Coal, bright, massive	1	

	Ft.	in.
*Shale		½
*Coal, bright, massive, hard	1	2
*Bone, low in ash		1
*Coal, bright, massive, hard	1	1
Shale, sandy		4
Shale.		

The bed varies in thickness, and is generally badly split by bone and shale partings. Coal unweathered. Analysis made in Pittsburgh laboratory of United States Bureau of Mines; A. C. Fieldner, chemist in charge.

12 (83342). Chesterfield Coal Co., Sego, Utah, NW¼ sec. 27, T. 20 S., R. 20 E. Sample taken by H. I. Smith in 1921 of coal that had been exposed several years. The section follows:

	Ft.	in.
Sandstone.		
Shale, sandy.		
*Coal, with bony seams	3	5
Coal, bony		4
*Coal, with bony seams	1	9
Coal, bony		4
Coal, bony (floor).		

Sample cut 100 feet from outcrop, no. 2 mine. Analysis made in Pittsburgh laboratory of United States Bureau of Mines; A. C. Fieldner, chemist in charge.

13 (3856). Ballard prospect, Sego, Utah, SE¼ NW¼ sec. 27, T. 20 S., R. 20 E. Sampled and measured by G. B. Richardson in 1906, as follows:

	Ft.	in.
Sandstone, shaly.		
*Coal	1	3½
*Coal, bony		2¾
*Coal	1	10½
*Coal, bony		1½
*Coal	2	3
Shale, carbonaceous.		

The coal breaks easily after mining. The lumps are 30 inches or less in diameter and there is a large amount of slack. Analyzed at United States Geological Survey fuel-testing plant at St. Louis; F. M. Stanton, chemist in charge.

14 (3945). West entry of Farrer mine; sec. 35, T. 20 S., R. 17 E. Sample taken 20 feet from mouth by G. B. Richardson in 1906. Section measured as follows:

	Ft.	in.
Shale, carbonaceous.		
*Coal		3
Bone and shale		3
*Coal	2	3
Bone		8
*Coal	2	
Bone and shale	1	3
*Coal	1	

The coal breaks easily after mining. The lumps are 30 inches or less in diameter, and there is a large amount of slack. Analyzed at United States Geological Survey fuel-testing plant at St. Louis; F. M. Stanton, chemist in charge.

15 (A15503). East entry (no. 1) of Farrer mine, sec. 35, T. 20 S., R. 17 E. Sample taken by D. J. Fisher in 1925 from north rib at end of entry, about 365 feet from entrance. Section measured as follows:

	Ft.	in.
Shale, dark gray	2	4
*Coal		¾
Shale, gray-black		3
*Coal		6½
Bone		¾
*Coal	1	
Shale, gray-black		2
*Coal		6½
Bone		1¾
Shale, gray-black		5
*Coal		7½
Shale, gray, hard, smooth.		

Coal was badly jointed and stained but otherwise appeared fairly fresh. Analyzed by H. M. Cooper in Pittsburgh laboratory of United States Bureau of Mines.

16 to 19 (81824 to 81827). Chesterfield Coal Co.'s mine at Sego, Utah, probably from SE¼ sec. 21, T. 20 S., R. 20 E. Sample 81827 is a composite made by combining the other three samples. Bed sampled and measured at three points by W. H. Carrick in 1921, as follows:

	81824		81825		81826	
	Ft.	in.	Ft.	in.	Ft.	in.
Sandstone (roof).						
*Coal	1	11	6	8	1	8
Sandstone and bone						2
*Coal, bony		½				
*Coal	5	5½			2	6
Bone						3
*Coal					1	8
Bottom coal		3		3		10
Coal (floor).						

Samples taken from no. 1 mine: 81824 from no. 3 west back entry, off main north slope, 4,000 feet from portal; 81825 from room 14, no. 2 west entry, off main north slope, 4,340 feet from portal; and 81826 from face of no. 1 east back entry, off main north slope, 3,960 feet from portal. Analyzed at Pittsburgh laboratory of United States Bureau of Mines; A. C. Fieldner, chemist in charge.

20 (3857). Sec. 27, T. 20 S., R. 20 E. Sample cut 11 feet in from a prospect tunnel 75 feet above the Ballard mine by G. B. Richardson in 1906. Sample represents 4 feet 6 inches of coal. Analysis made in United States Geological Survey fuel-testing plant at St. Louis; F. M. Stanton, chemist in charge.

21 (3854). Sec. 7, T. 20 S., R. 21 E. Sample cut and section measured by G. B. Richardson in 1906, as follows:

	Ft.	in.
*Coal	1	3
Bone		2
*Coal	1	10½
Bone		1½
*Coal	2	3

Analysis made in United States Geological Survey fuel-testing plant at St. Louis; F. M. Stanton, chemist in charge.

TONNAGE ESTIMATES

Tonnage estimates were made for the area, in accordance with the plan outlined in Bulletin 537.[68] Beds less than 14 inches thick were not considered. Beds having partings or splits were assumed to have an "effective" coal thickness equal to the total thickness of coal less the thickness of all partings. The estimates are based on an area extending along the cliffs not over 2 miles back from the very generalized outcrop line. This arbitrary width was chosen because, owing to the uneven character of the coal beds, it seemed unsafe to make predictions covering a larger area and because development to this distance will not take place for a very long time, except possibly in the Thompson area. In some districts of lenticular coals the coal reserve was computed for an area of even less width, details of which are given in the township descriptions. The estimates given in the table below are rounded and are believed to be high rather than low.

Summary of estimated coal tonnage available in the Book Cliffs of Utah east of Sunnyside, extending back not more than 2 miles from the generalized outcrop line.

Location and name of bed	Average thickness (feet)	Estimated area (square miles)	Millions of tons
T. 15 S., R. 14 E. (only the part shown on pl. 8):			
Sunnyside	14.0	4.32	70
T. 16 S., Rs. 14 and 15 E.:			
Sunnyside, northern two-thirds	13.0	9.15	137
Sunnyside, southern third	6.0	2.98	21
T. 17 S., Rs. 14 and 15 E.:			
Upper Blackhawk	2.0	2.91	7
Upper Sunnyside, northern third	4.0	5.12	24
Upper Sunnyside, southern half	2.5	1.13	3
Lower Sunnyside	5.0	8.27	48
T. 18 S., Rs. 14 and 15 E.:			
Upper Blackhawk	3.0	1.00	3
Sunnyside, northern half	3.5	6.24	25
Sunnyside, southern half	2.0	5.69	13
T. 19 S., Rs. 14 and 15 E.:			
Upper Blackhawk, higher part	1.5	.75	1
Upper Blackhawk, lower part	6.0	.80	6
Sunnyside, northern third	2.5	3.66	11
Sunnyside, southern two-thirds	1.17	3.09	4
T. 20 S., R. 15 E.:			
Upper Blackhawk	1.17	2.00	3
Sunnyside, near center	2.5	1.00	3
Sunnyside, northwest of center	1.5	.75	1
Kenilworth	2.0	2.00	5
T. 20 S., R. 17 E.:			
Chesterfield	1.5	2.45	4
T. 21 S., R. 18 E.:			
Chesterfield	2.0	.68	2
Ballard	1.5	.07	.1
T. 21 S., R. 19 E.:			
Palisade	2.0	.30	.7
Upper Blackhawk, higher part	2.0	1.90	4
Upper Blackhawk, lower part	2.0	.02	.10
T. 20 S., R. 19 E.:			
Chesterfield	2.5	.65	2
Palisade	2.5	1.35	4
T. 20 S., R. 20 E.:			
Highest coal	1.5	.12	.2
Chesterfield	2-4	8.87	30
Ballard	2-4	10.23	35
Palisade	1.5-4	8.21	[1] 30
Lowest coal	1.5	.50	1
T. 19 S., R. 21 E.:			
Ballard	1.5	.57	1
Palisade	2.0	.99	2
T. 20 S., R. 21 E.:			
Chesterfield	1.8-2	2.40	5
Ballard	1.5	3.35	6
Palisade	1.5-2	3.51	6
			518

[1] Includes 0.31 million tons in T. 21 S., R. 20 E.

[68] Smith, G. O., and others, The classification of the public lands: U. S. Geol. Survey Bull. 537, p. 70, 1913.

In reaching this estimate certain minor areas that are badly faulted, as described under the townships, have been omitted. The figure given is for total coal, but for recoverable coal it should probably be cut in half, owing in part to the impurities present. If the day comes when bony material can be profitably mined for hydrogenation or analogous treatment, the lower figure may be considerably augmented.

DEVELOPMENT

The only shipping mine in this area is that of the Chesterfield Coal Co., at Sego (pl. 5, *A*). Coal is now being removed at only two other places—the Crescent mine, in Crescent Canyon, and the Farrer mine (pl. 4, *B*) in Coal Canyon (pl. 9)—which are worked in a small way during part of the winter. The development at Sego is described under Tps. 20 and 21 S., R. 20 E.; that at Crescent under T. 20 S., R. 19 E.; and that at the Farrer mine under Tps. 20 and 21 S., R. 17 E.

TOWNSHIP DESCRIPTIONS

Detailed descriptions of the coal beds are given in the following descriptions of the townships which also include information concerning surface features, stratigraphy, and geologic structure and descriptions of mines and prospects. The townships are described in sequence from west to east, according to range number and township number. The locations at which coal sections were measured are numbered consecutively in this same order on plates 8 to 11, and the coal sections with their numbers are shown graphically on plates 12 to 15.

TPS. 15 AND 16 S., R. 14 E.

Only the southern third of T. 15 S., R. 14 E., is included in the present study, as is shown on plate 8. Clark[69] has described the northern two-thirds of the township. The writer made no careful study of the coal in these townships, as this had already been done by Spieker and Baker[70] in October 1923, and much of the following material is abstracted from their report. Their mapping is shown on plate 8 and their coal sections on plate 12.

The Book Cliffs cut diagonally through these townships, rising abruptly from the lowlands on the west. The Mancos shale flat is here largely covered by slightly dissected gravel-capped benches, which are heavily coated with cedars and other vegetation. The cliffs rise about 1,200 feet above the flat in a series of massive sandstone ledges that can be scaled at but few places. Horse Canyon is the only one that cuts completely through the cliffs. Above the

[69] Clark, F. R., op. cit. (Bull. 793), pp. 71–77, 1928.

[70] Spieker, E. M., and Baker, A. A., Report of examination of Horse Canyon district, Utah, in Tps. 15 and 16 S., Rs. 14 and 15 E., Salt Lake base and meridian (manuscript report), 1924.

steep westward-facing escarpment the stream courses occupy gently sloping channels in wide valleys for short distances before they plunge through the gorges cut in the cliffs, but most of the area back of the cliff front is rugged. It rises 4,000 feet above the flat to an altitude of 9,851 feet at Patmos Head, which is just south of the center of sec. 23, T. 15 S., R. 14 E., less than a quarter of a mile north of the area shown on plate 8. Horse Creek is the only perennial stream, but in normal times even its bed is dry a short distance west of the cliffs. The water is too alkaline to be palatable for man, but stock will drink it. There are no inhabitants in this area, but the ruins of two or three cabins are present in the western part of sec. 3, T. 16 S., R. 14 E. The approximate position of a road suitable for automobiles leading from the main highway to the entrance of Horse Canyon is shown on plate 8. There is no other route of access by car at the present time.

Geology.—The stratigraphy of this area is shown graphically in sections 2 and 3 on plate 7. The strata along the cliff front slope east or north of east with a monoclinal dip, as shown by contour lines on plate 8. The dip as measured on the flat west of the cliffs is as much as 9°, but it decreases to the east and is only about 3° just east of Patmos Head. The only observed dislocations are the four normal dip faults near the south edge of T. 16 S., R. 14 E., in secs. 26 and 36. The throws of these faults are indicated on the map; their extent is unknown, as they were studied only where they cut the face of the cliffs. A trail leads up the cliffs along the trace of the fault in sec. 36.

Coal.—The Kenilworth coal, at or very near the base of the middle shale member of the Blackhawk formation, and the Sunnyside coal, about 75 feet below the top of the middle sandstone member of the Blackhawk formation (see pl. 7), are the only coal beds known in the southern part of T. 15 S., R. 14 E. The Kenilworth bed is of no economic value, though farther north in this township Clark[71] found a thin, lenticular bed at this horizon. Most of Clark's sections show about 2 feet of Kenilworth coal.

The description of the Sunnyside coal given by Spieker and Baker may be summarized as follows: In the Horse Canyon district only one bed is of commercial importance, and this is correlated with the lower Sunnyside coal. A 2-foot bed of coal, 2 to 4 feet above the main bed in the northern part of the area, may represent the upper Sunnyside coal bed, or it may be merely a split from the thick lower bed. The two beds are jointly called the "Sunnyside coal bed." North of Horse Canyon the coal is burned at the outcrop practically everywhere, and south of Horse Canyon it is burned at the outcrop for short distances at several places. The Sunnyside coal bed between

[71] Clark, F. R., op. cit. (Bull. 793), p. 72.

locations 2 and 6 is divided into two benches, a thick lower bench and a thin upper bench, separated by a parting of sandstone and shale. The Sunnyside coal at Sunnyside and Columbia is of coking quality, and no doubt this also holds true in the Horse Canyon district, though so far as known no tests have been made.

Sections at locations 1 to 12 (see pls. 8 and 12) show graphically the character of the coal beds in these townships. Sections 2 to 11 were taken by Spieker and Baker, who state that the lower parts of the sections at locations 8 and 9 are concealed. The section at location 12, shown on plate 12, was made by H. F. Moses. A section at this same location made by Spieker and Baker is given below:

	Ft.	in.
Roof:		
Coal	6	2
Shale, carbonaceous	12	3
Sandstone, very light gray.		

The thickness of coal indicated at location 1 is a minimum, as the bed is here overlain by 2 feet of light-brown clay with variegated colors which may indicate that some of the coal formerly present has been burned. A section taken by the writer at location 5 and another by H. F. Moses 100 yards to the southeast are given in this order below. The first includes 14 feet 3 inches of coal ("effective" thickness, 11 feet 5½ inches), and the second has 14 feet 2 inches of unsplit coal. These average about the same as the section given on plate 12, measured by Spieker and Baker at this location.

	Ft.	in.
Sandstone, massive	61	
Siltstone, micaceous, carbonaceous, dark gray	1	6
Coal	2	6
Coal, bony		4
Siltstone, as above	2	
Shale, carbonaceous		4
Coal, somewhat resinous	2	8
Bone		½
Coal, somewhat resinous	7	4
Shale, carbonaceous, yellow stain		5
Coal	1	
Coal, bony		5
Siltstone, slightly carbonaceous, yellow stain		6
Sandstone, very light gray, friable, cross-bedded	17	5
Total clean coal	13	6
Siltstone, shaly, concretionary	1	
Coal, very bony	2	5
Shale, carbonaceous, gypsiferous		4
Siltstone, nodular, with coal streaks	3	
Coal	2	10
Coal, bony		1
Coal	3	
Coal, bony		1

	Ft.	in.
Coal	2	8
Coal, bony		1
Coal	2	11
Coal, bony		6
Coal	1	
Coal, bony	1	
Sandstone.		
Total clean coal	12	5

A section by Clark[72] at the south edge of sec. 21, T. 15 S., R. 14 E., at the north edge of the area shown on plate 8, gives 13 feet 11 inches of lower Sunnyside coal, and he notes that this seam is here thickening toward the south.

Development.—Four long entries have been cut in the Sunnyside bed at locations 2 and 3, in Horse Canyon. According to information furnished by Richardson, tunnels 1 and 4 at location 2 were cut in 130 and 140 feet, respectively, by 1906.[73] These two tunnels serve as a double entry and join about 300 feet in from the entrance. In 1925 the northern tunnel was in about 650 feet and had steel track laid in it. It is not known when these tunnels were thus lengthened, but probably it was shortly after Richardson's visit in 1906. These entries strike N. 45° W. A third and minor tunnel enters the bed a few yards down the canyon and crosses the other two about 100 feet from their entrances. Small amounts of coal have been taken out at only two places in addition to that removed in cutting the entries. Tunnels 2 and 3 at location 3 operate as a double entry striking S. 45° E. In 1906 these were in 120 and 150 feet, respectively. They now join at about 430 feet, and there are crosscuts 100, 275, and 325 feet from the mouth. The total length of the southern tunnel is about 625 feet, and steel track reaches to its end. When visited in 1925 the canyon was uninhabited, and there were no indications that any coal had been taken out in recent years.

In addition to these tunnels in Horse Canyon, there are three small prospect pits in the Sunnyside bed in these townships. The Calkins prospect pit is near location 6, the Prentiss pit is between locations 4 and 5, and a third pit is a short distance northeast of location 4.

T. 17 S., R. 14 E.

The Book Cliffs (here a single cliff) run through the eastern part of T. 17 S., R. 14 E. The top of the Castlegate sandstone, which, as shown on plate 8, locally forms the top of the cliff, has an altitude of 6,300 to 6,700 feet at the front of the cliff (decreasing toward the south). West of the cliff is the dissected gravel-capped bench, which

[72] Clark, F. R., op. cit. (Bull. 793), p. 76.
[73] Spieker, E M., and Baker, A. A., op. cit., p. 22.

contains steep-sided valleys that are about 200 feet deep near the cliff but become wider and shallower away from it. This bench about half a mile west of the cliff has an altitude of 5,000 to 5,500 feet (decreasing toward the south). At the highway in the southwestern part of the township the gravel bench reaches an altitude of about 4,800 feet. The benches are sprinkled with scrub cedars and an occasional piñon near the cliff, but this growth is much less abundant than in the Horse Canyon district, a few miles to the north. Bunch grass is commonly present on the benches.

No road leading from the main highway into the Book Cliffs was found between the Horse Canyon road and Woodside, but during the field work automobiles were operated along a route, indicated on plate 8, extending northeast from the highway in the NE¼ sec. 5, T. 18 S., R. 14 E. Elsewhere near the cliff the surface is so badly cut up by steep-sided and fairly deep gullies that even horseback travel is slow and difficult. The cliff is unscalable, except where cut by faults, and no canyon cuts through it. A trail leads up the cliff along the southern fault in the SE¼ sec. 26.

Because of the dip of the sandstones, the top of the cliff serves as a drainage divide. The township is entirely lacking in surface water, except for the Price River, in the southwest corner, which is a perennial stream. The area is uninhabited. Grassy (sec. 18) merely marks a railroad siding and telephone box. The western two-thirds of the township was surveyed in 1894, and the corners were marked with notched stones. Where these lie on the gravel-capped benches, they are difficult to find. Three section corners were located, as indicated on plate 8.

Geology.—Sections 4 and 5 on plate 7 show graphically the stratigraphy of this township. Section 5 is described in detail on page 22. The structure of the area is a simple eastward-dipping monocline, modified by normal dip faults. The structure contours on plate 8 show the dip of the monocline to be from 4° to 5° in most places. Dip readings taken with a Brunton compass on the shale flat, as indicated on the map, are somewhat steeper. These may represent only local dips, or it is possible that the dip changes, owing in part perhaps to the change in lithology. Fourteen normal dip faults are mapped in a distance of less than 4 miles; 6 of these have throws between 70 and 175 feet, the others from 5 to 44 feet.

Coal.—Two coal zones were found in the area. The Sunnyside coal occurs as a double seam about 60 feet below the top of the middle sandstone member of the Blackhawk and is persistent along the cliff. A lens of coal near the top of the upper member of the Blackhawk, about 135 feet above the Sunnyside coal, is present in secs. 11, 14, and 23. Eight sections (locations 13–20) of the Sunnyside bed and

two sections (locations 16–17) of the upper Blackhawk coal are shown on plate 12. Of these, the sections at locations 14, 17, and 19 were taken by alidade from the lowland at the foot of the cliffs and so cannot be regarded as highly reliable.

The section of the Sunnyside coal at location 13 shown on plate 12 was taken by Spieker and Baker and is believed to be correct. The writer took a section here by alidade from the foot of the cliff with the following result:

	Ft.	in.
Roof (massive sandstone).		
Coal	6	9
Shale	12	2
Coal		6
Floor (massive sandstone).		

At location 15 the Sunnyside coal is badly weathered but shows north-south and east-west jointing, with gypsum veinlets along some of the joints. Location 15a is 450 feet northwest of location 15. At location 18 the upper bed of Sunnyside coal, 4 feet 2 inches thick, is lined into thin squares by cracks stained with an iron mineral and a canary-yellow powder. Fragments of fusain as much as three-fourths of an inch in length were noted. At location 20, immediately below the lower bed of Sunnyside coal, is found 8 inches of sandy coal of no economic value. The coal itself contains a little resin and a few veinlets of gypsum.

Details of the stratigraphy of the coal near the top of the upper member of the Blackhawk are shown in the following section, taken at location 16:

	Ft.	in.
Sandstone (Castlegate).		
Mudstone, limy, nodular-weathering	1	4
Coal	2	4
Mudstone, like that above	3	2
Coal and black shale in alternating bands 3 to 4 inches thick	2	8
Coal, dirty; some bone	1	2
Shale, black, fissile; some bone	2	8
Coal, rather dirty		9
Shale, black, fissile, carbonaceous, with thin streaks of bone, coal, and sandstone	15	

No coal appears at this horizon north of the fault in the center of sec. 11, and from indications along the outcrop the bed is of possible economic importance only through secs. 14 and 23, where it averages perhaps 2 feet in thickness.

The upper bed of Sunnyside coal is thickest in sec. 2. (See section at location 13.) It thins rather regularly to the south and through sec. 14 averages less than 14 inches in thickness. Farther south it thickens and is about 4 feet thick at locations 18, 19, and 20, south of which it thins again. It is considered to average 4 feet in thickness

through secs. 2 and 11 and 3 feet through secs. 23, 26, 35, and 36. The lower bed of Sunnyside coal has a maximum observed thickness of 8 feet at location 17 and 19 but is considered to average 5½ feet throughout the township. It is rather badly broken up by faults where thickest.

Through secs. 23 and 26 the coal is cut by 11 faults of such size and complexity that it can probably never be profitably extracted. The general character of these faults is well shown on the structure-contour map (pl. 8). The fault in the SE¼ sec. 26, which has a throw of 175 feet down on the north, appears as shown in figure 2 to one looking east at the cliff.

T. 18 S., RS. 14 AND 15 E.

The continuity of the Book Cliffs is broken in T. 18 S., R. 15 E., by the canyon of the Price River, which has isolated the small Beckwith Plateau from the Roan Plateau, to the north. Otherwise the topography of the township is very similar to that of T. 17 S., R. 14 E. The altitude of the gravel benches in the lowlands about half a mile west of the cliff in the northern and southern parts of T. 18 S., R. 14 E., is about 5,000 feet, and the altitude of the lowland in the central part of the township near the Price River is about 4,700 feet. At the entrance to the canyon the river has an altitude of 4,500 feet. Cottonwood and greasewood grow on the alluvial bottoms of the river, and some alfalfa is cultivated on the irrigated farms. The top of the Castlegate sandstone, which locally forms the top of the cliff, has a maximum altitude of 6,400 feet; variations in the altitude of the top of the sandstone may be determined from the structure contours on plate 8. These contours are drawn on the base of the Sunnyside coal bed, which is about 285 feet below the top of the Castlegate sandstone.

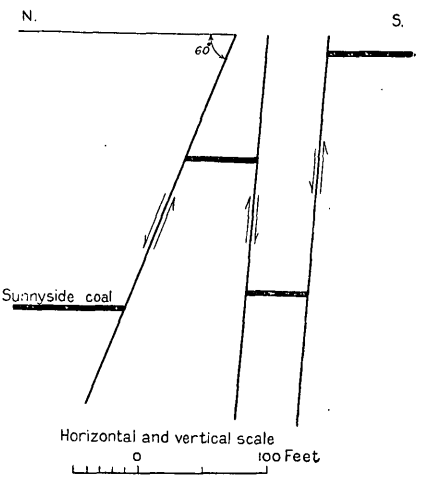


FIGURE 2.—Diagram of fault in sec. 26, T. 17 S., R. 14 E.

Woodside lies at an altitude of 4,628 feet. The precinct of Woodside, which includes the outlying ranches, had a population of 83 in 1930. There are two stores, a post office, and a schoolhouse. The Denver & Rio Grande Western Railroad and United States Highway 50 go through the settlement and pass within 3 miles of the cliff. The Price River is the only perennial stream. The only place where

its flow is regularly measured is at the station 2 miles south of Helper, Utah; just below that place much water is removed for irrigation. The maximum recorded flow was between 9,000 and 10,000 second-feet in 1927; the minimum was 2 second-feet in 1930. The railroad obtains water at Woodside by pumping from a well near the station.

The cliff is best reached by the road along the north side of the river (pl. 8), though a similar road runs along the south side leading in as far as Peterson's ranch, in the SE¼ sec. 15, T. 18 S., R. 14 E. The road on the north side is passable by automobile as far as the east side of sec. 14, where it becomes a trail leading down the canyon to May's ranch, at the mouth of the Price River, about 16 miles east-southeast of Woodside. This road could be extended about 1½ miles east of sec. 14 with little difficulty, but farther east it would be costly to make a road and keep it open. A railroad could be laid in the same distance, but its extension farther east would be very expensive.

T. 18 S., R. 14 E., has been surveyed only partly (as shown on pl. 8), and this was done in 1884. The only corner found was the quarter-corner stone on the east side of sec. 9. T. 18 S., R. 15 E., has not been surveyed.

Geology.—The stratigraphy is shown graphically by sections 6, 7, and 8 on plate 7. The rocks dip east, forming a fairly regular monocline. The dip is about 10° along the cliffs near the mouth of the Price River Canyon but decreases to 5° to 6° three-fourths of a mile downstream, near the point where the Mancos shale disappears below the river. Along the cliffs in the southern part of T. 18 S., R. 14 E., the dip is 3° or 4°, but in secs. 11 and 25 dips of 12° were read on bedding planes in the Mancos shale (pl. 8). Only three small normal faults (throws 10 to 25 feet) were found.

Coal.—Coal worthy of mention was found at three horizons. The only persistent bed is the Sunnyside, about 40 feet below the top of the middle sandstone member of the Blackhawk formation. Sections of this bed were taken at locations 21, 22, 24, and 26 (the last by alidade), as indicated on plate 12. The other two coal beds, both of which are lenticular, are in the upper member of the Blackhawk. The higher one (location 21) is approximately at the same horizon as the higher coal of T. 17 S., R. 14 E., at the top of the member, and is considered to be of no economic importance, as its best section shows but 1 foot 8 inches of "poor coal," and it probably does not extend over a mile in either direction along the cliff from location 21. The lower coal bed was observed only in the main reentrant on the north side of the Price River Canyon (in secs. 17 and 18, T. 18 S., R. 15 E.). It lies in the upper middle part of the upper member of the Blackhawk formation. It was examined at locations 23 and 25, at

both of which prospecting has been done, although only at location 25 (Peterson's prospect) has much coal been removed. The section at location 23 of coal that is probably at the same horizon shows a thicker bed, but it is split by several thin partings.

No coal at the Kenilworth horizon was seen in T. 18 S., R. 14 E. The cliff is inaccessible in the main, except at the faults or in the Price River Canyon, and it is possible, though not probable, that slump covers this bed.

The Sunnyside coal, except at location 26, is represented by but a single bed, which is thought to be the equivalent of the lower bed of T. 17 S., R. 14 E. It is somewhat thicker in the northern half of T. 18 S., R. 14 E., and for purposes of estimating tonnage it is here taken to have an average thickness of 3 feet 6 inches and the average for the southern half is assumed to be 2 feet. At all locations where sections were measured one or more partings 1 to 4 inches thick were present. The section at location 26 was taken by alidade from the foot of the cliff and is of doubtful value.

T. 19 S., RS. 14 AND 15 E.

The Book Cliffs, in which the coal crops out, run diagonally in a north-northwest direction across the boundary between T. 19 S., R. 14 E., and T. 19 S., R. 15 E. They form an abrupt westward-facing escarpment that rises to an altitude of 7,135 feet east of Cliff siding. This point is more than 2,000 feet above the shale flat at the base and is the highest point on the Beckwith Plateau. The top of the plateau is an intricately dissected eastward-dipping surface.

Throughout this area the cliff is absolutely inaccessible from the front. It can be approached from the rear, however, on horseback by riding the circuitous route up Bluecastle or Long Canyon. (See pl. 9.) Access probably can be had also from the Price River Canyon, though the writer had no opportunity to make the attempt. The broad flat or valley at the base of the cliff underlain by the Mancos shale is only slightly over 3 miles wide at the north end of the area—its narrowest place along the Book Cliffs; it is narrowest here because of the presence of the Woodside anticline immediately to the west.[74] The shale in this flat is capped with the remnants of gravel benches, once continuous but now greatly dissected. About a mile west of the cliff the altitude is about 5,000 feet. At milepost 575 on the Denver & Rio Grande Western Railroad, just north of Cliff, the altitude is 4,846 feet. The Dakota (?) sandstone hogback, slightly over a mile farther west, has an altitude of about 5,000 feet.

This part of the area is unhabited except for one family at Cliff, which formerly served as the outlet for the helium gas recovered from

[74] See Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, p. 123, 1929.

the well on the Woodside anticline, about 4 miles to the west. The railroad and United States Highway 50 cross the western part of the area, as shown on plate 9. No branch roads lead into the cliff, but little trouble was experienced in driving an automobile along the gravel bench for a distance of 1 mile east of the railroad at Cliff. Within a mile or two of the cliffs, however, the surface is dissected into steep-sided valleys which make traveling very tedious, whether on horseback or afoot. There is no perennial stream, though Saleratus Wash, near the southwest corner of T. 19 S., R. 14 E., usually contains water—so nonpotable, however, that horses do not like to drink it. The western third of this township was surveyed in 1923, and two corners placed at this time were found in the present survey. The rest of the area is unsurveyed, so far as known, though the map in Richardson's report [75] indicates that a line was surveyed south 4 miles from the northwest corner of sec. 2, T. 19 S., R. 14 E., then east 2 miles, then south 2 miles to the township corner.

Geology.—The stratigraphic sequence exposed in these townships is shown in section 9 on plate 7. The Bluecastle sandstone is a resistant bed that forms the dip-slope summit of the Beckwith Plateau. The Sego sandstone and Buck tongue are here not clearly differentiated within the Price River formation, though farther east they stand out as well-marked units. Structurally, the area consists of a monocline, with strata dipping slightly north of east. At the west edge of the Beckwith Plateau the dip is 4° to 5° in most places (see structure contours, pl. 9). Farther west dips of 8° were read on the shale flat and 10½° on the Dakota (?) sandstone hogback. In the southeastern part of T. 19 S., R. 15 E., the bed of Long Canyon shows an inlier of Mancos shale. This does not appear to be due to structural irregularities but is a result of the peculiarly changing gradient of the bed of the canyon. No faults were noted in the area.

Coal.—Owing to the inaccessibility of the cliff, only two coal sections were taken, and these were made by alidade from its foot. A traverse was run up Long Canyon from a point near Gunnison Butte, in sec. 4, T. 20 S., R. 16 E., but no coal of value was seen.

The Sunnyside coal was measured at locations 27 and 28. At location 28 it is split by a 3½-foot sandstone parting into an upper bed 14 inches thick and a lower bed 12 inches thick. Between locations 27 and 28 coal was seen only at the upper horizon. From studies made up the Green River and in the canyons on the east slope of the Beckwith Plateau it is clear that one boundary of the old swamp in which the vegetable material making up this coal bed was deposited lay near the present position of the Book Cliffs; or else erosion removed the vegetal debris prior to the deposition of the younger strata. Accordingly, it is assumed that at the north end of the area the bed

[75] Richardson, G. B., op. cit. (Bull. 371), pl. 1.

extends at least 2 miles east of the cliff face, but that in the southern half it extends only about 0.7 mile. It is assumed that the bed has an average workable thickness of 2 feet 6 inches in the northern third of the area but only 14 inches in the southern two-thirds, owing to the presence of a sandstone parting. The altitude of the bed is easily obtained from the structure contours on plate 9, as the coal is about 250 feet below the top of the Castlegate sandstone, the horizon contoured.

In the northern part of the area the upper member of the Blackhawk formation is largely shaly, and any coal that may possibly be present is obscured. In the neighborhood of location 28 the upper part of this member is a cliff-making sandy rock that closely resembles the Castlegate. The separation is based largely on the relative thickness of the units but partly on the presence of the carbonaceous material in the lower beds and the absence of such material in what is here called Castlegate. Owing to the cliff-making character of the beds near the top of the Blackhawk formation at location 28, it was possible to measure five coal beds, three of which are of possible economic value, as shown on plate 12. The upper one of these three is 1 foot 8 inches thick and is thought to be a lens, though at about the same horizon as the coal in the upper Blackhawk in T. 17 S., R. 14 E. (locations 16 and 17). The other two beds are each about 3 feet thick and are separated by 9½ feet of sandstone and shaly sandstone. No coal at this horizon was seen very far to the north. To the south the horizon may be the same as that shown in the section taken at location 31, where there is about 3 feet of coal, but so badly split that it is of no value.

T. 20 S., R. 15 E.

T. 20 S., R. 15 E., includes the south end of the Beckwith Plateau (pl. 2, *A*). The west and south sides of the plateau here are marked by the steep escarpment of the Book Cliffs, which is fairly regular in general outline. The east side is dissected into three canyons, the main and northernmost one of which is Bluecastle Canyon. This canyon gets its name from Bluecastle Butte, a prominent hill (altitude 4,717 feet) of Mancos shale in the northeastern part of the township. Bluecastle Canyon extends headward to a point within half a mile of the west cliff of the plateau; it has cut through the Sunnyside coal bed, an outlier of which has been isolated to the south. The south edge of the plateau is a mere wall. This is a very striking feature but would not be suspected in viewing the plateau from the town of Green River. To the west and south the surface is plain-like, sloping gently away from the cliff. This flat is underlain by Mancos shale, locally capped by gravel benches, some of which are shown on plate 9. This plain has an altitude between 4,500 and 5,000 feet at

most places in the township. Near the cliff it is badly dissected, as shown in plate 3, *C*.

The township lacks perennial running water, though the Green River flows about 2 miles to the east. A few water holes were found in the lower sandstone member of the Blackhawk formation in Bluecastle Wash and its tributaries, and the water in these, though small in quantity, is suitable for watering horses. The township is without habitations or roads. The Denver & Rio Grande Western Railroad lies a short distance to the west and south, with sidings at Desert and Sphinx. Desert has a house or two; Sphinx, merely a telephone box. United States Highway 50 closely parallels the railroad. A trail leads up Bluecastle Canyon, ascending the cliff a quarter of a mile northeast of location 39. Some blasting has made this trail passable for a horseback rider.

The greater part of the lowland in this township was surveyed in 1912. Six corners were found and tied in with the present survey; these are indicated on plate 9.

Geology.—The stratigraphy of the township is shown in section 10, plate 7, and on pages 23–25. The Bluecastle sandstone is a resistant bed that forms the dip-slope summit of the Beckwith Plateau. The Sego sandstone and Buck tongue are here not well differentiated within the Price River formation, though farther east they stand out as well-marked units. The beds dip 3° to 4° a little north of east. Irregularities in this general dip are present in the west-central and southeastern parts of the township, as shown by the structure contours on plate 9. Local dips in the Mancos shale of 5° and 6° were read in secs. 11 and 33, respectively.

Coal.—Sections of coal were taken at locations 29 to 41. Coal was found at the Kenilworth and Sunnyside horizons; also in the lower part of the upper member of the Blackhawk. Post-Castlegate coals here, as elsewhere in the Book Cliffs west of the Green River, are of no economic value.

The Kenilworth coal bed was not seen south of the Horse Canyon district (pl. 8) except in this township. Near location 31 the following section was taken:

	Ft.	*in.*
Shale (roof).		
Coal, with a 1-inch gypsum parting in the middle	2	6
Shale, medium to light gray (locally brownish), gypsiferous	8	
Coal		1
Shale, as above	2	
Sandstone (lower Blackhawk), shaly in lower part	171	

The coal, which is weathered, is dull velvety black to brown-black and carries some resin, fusain, and carbonized wood. Cracks in it contain veinlets of gypsum. At location 33 alidade measurements

indicated the presence of 1½ to 2½ feet of coal at this horizon. It was not seen more than half a mile farther east. Observations in Bluecastle Canyon indicate that it does not extend much more than a mile east of the main cliff face, which here is the west side of the Beckwith Plateau. The bed extends north to a point within a mile of location 28, but it is probably of no value north of sec. 8, T. 20 S., R. 15 E., partly because of thinning and partly because it has been so much dissected by erosion in sec. 5 of the same township. It may be assumed to have an average thickness of 2 feet over 2 square miles in this township, but it seems unlikely to be of any economic value owing to its thinness, its probable high ash content, its inaccessible position, and its shale roof and floor.

Sections of the Sunnyside coal bed were taken at locations 29 to 35 and 37 to 40, as shown on plate 12. All but one of these (that at location 31) were taken by alidade and so are of doubtful accuracy. At location 31 there is 1 foot 4 inches of coal over 4 inches of coaly, silty shale between massive sandstone beds. The coal is jointed, is highly weathered, has a brown-black streak, and carries a little resin. Inasmuch as the southeastern limit of the Sunnyside coal bed is within this township, the different sections of the bed show considerable variations in thickness. The greatest thickness, 3 feet 8 inches at location 40, was taken on an isolated mass of the coal bed only about 20 acres in extent. Because of its relative inaccessibility, such a small isolated mass, which probably is considerably weathered, can hardly be regarded as of value. At location 39 the Sunnyside coal bed is double, the upper part being 3 feet thick and the lower part 2 feet 3 inches. The thicker bed here cannot be considered to be of economic importance, as it is on a small point, and apparently the bed thins very rapidly to the west. The central part of the township contains almost exactly a square mile of coal thought to average 2 to 3 feet in thickness. Northwest from this area toward locations 32 and 31 the bed thins to 25 inches and 16 inches, respectively. Farther east down Bluecastle Canyon, there is no evidence of the presence of coal of workable thickness in the north wall. From location 30, where 10 inches of coal was measured, the bed apparently pinches out rapidly to the east.

A coal bed near the base of the upper member of the Blackhawk was measured at locations 31, 32, 33, 36, and 41. All the measurements except that at location 31 were made by alidade. The best section, at location 36, is on an isolated mass that is considered to be of no economic value. This bed appears to be of no economic importance where exposed along the north side of Bluecastle Canyon, if the section at location 41 may be regarded as typical. It seems probable that the coal is present over about 2 square miles in the southwestern part of the Beckwith Plateau, with an average thickness of 14 inches,

as shown by the sections at locations 32 and 33; but inasmuch as the section at location 32 showed the presence of a parting as much as 4 inches in thickness, 14 inches must be regarded as an optimum figure until the area is more thoroughly prospected. This is perhaps best indicated by the section at location 31, where in a 12-foot coaly zone two 10-inch beds (each split by ½-inch partings) separated by a 10-inch parting constituted the best coal. This zone also carries a 6-inch and a 4-inch seam of coal.

T. 20 S., R. 16 E., AND AREA TO THE NORTH

The Green River, the largest river cutting the Book Cliffs, flows south through the western part of T. 20 S., R. 16 E. The irregular line of cliffs crosses its northern and northeastern part, but Gunnison Valley, the big reentrant in the cliffs made by the river, occupies the larger part of the township. Irrigation has made this reentrant an oasis in the semidesert. Gunnison Butte, in the SE¼ sec. 4 (altitude about 5,200 feet), is a conspicuous surface feature (pl. 2, *B*). The butte and the valley were named after Capt. J. W. Gunnison, who crossed the river September 30, 1853, while engaged in surveying a tentative route for a railroad across the mountains. Gunnison Valley is underlain by the soft Mancos shale, largely capped with the remnants of gravel aprons sloping away from the cliffs or by river terrace gravel. These have an altitude between 4,150 and 4,300 feet at most places in the township.

The Green River is the dividing line between Emery County on the west and Grand County on the east. West of the river the Book Cliffs rise in the main as a single topographic feature; to the east the cliffs form two escarpments with the Castlegate sandstone surfacing a terrace or benchlike break as much as 2 miles wide between. West of the river, in the northwest corner of the township, the cliff rises to an altitude of 5,500 feet; east of the river the first line of cliffs rises to an altitude of about 5,200 feet and the second line reaches about 6,300 feet within the township limits.

Long Wash has cut a deep canyon in the northwestern part of the township, and Tuscher Creek flows through a deep canyon in the eastern part. The Green River is, however, the only perennial stream. Measurements at the gaging station near the city of Green River have shown a maximum discharge of 68,800 second-feet on May 29, 1897, and a minimum of 510 second-feet on December 1, 1919.

Green River, a few miles to the south, in sec. 16, T. 21 S., R. 16 E., is the largest city near the Book Cliffs of Utah southeast of Sunnyside. Its population in 1930 was 474, with 137 more people in the Green River precinct as a whole. Farms along the river above the city are noted for their fruit and alfalfa. The locations of the farmhouses in T. 20 S., R. 16 E., are shown on plate 9, but those in T. 21 S., R. 16

E., are not shown. The precinct of Elgin, which had a population of 128 in 1930, lies on the east side of the river in T. 21 S., R. 16 E.

A dam across the Green River in the SE¼ sec. 17, T. 20 S., R. 16 E., furnishes water for generating electric power and for the two low-level irrigation ditches shown on the map. The power house, in the SW¼SE¼ sec. 17, also pumps water into the high-level ditch on the west side of the river. The locations of the power house, power line, and irrigation ditches within the township limits are shown on the map.

This area, like the rest of the Book Cliffs, is served by the Denver & Rio Grande Western Railroad and United States Highway 50. On both sides of the Green River good roads branch off to the north from the highway, serving as outlets for the farmers' produce. All but the northeastern part of the township was surveyed in 1898, and nine corners located in the present survey are indicated on the map.

Geology.—The stratigraphy of the township is shown in section 11 on plate 7. The lower sandstone member of the Blackhawk formation gives way to shale and is not mapped east of the Green River. As a result of the disappearance of this sandstone it is impossible to distinguish the middle shale member of the Blackhawk, and so its mapping was also discontinued at the same place. The shaly nature of the sandstone is shown in plate 2, *B*. Few data bearing on the structure of the rocks in the southern part of the township were obtained, though some dip and strike readings in this part of the township east of the river are shown on plate 9. The structure contours indicate that the beds in the northern part of the area are part of a rather regular monocline that dips about 3° NE.

Coal.—No coal was seen at the Sunnyside horizon near the top of the middle sandstone member of the Blackhawk. The Kenilworth horizon, just above the lower sandstone member of the Blackhawk, is similarly barren. Sections at locations 42 to 45 (pl. 12), all but the first taken with an alidade from the foot of the cliffs, show the presence of coal in the upper member of the Blackhawk, the upper part of which is here sandstone. These sections indicate the absence of coal of economic importance in this member on the east side of the Green River. On the east end of Gunnison Butte (location 43) a coal bed 3 feet 2 inches thick is present (pl. 2, *B*). This bed is inaccessible, and as it underlies only 3 acres, it is of no value. At location 42 a bed 1 foot 4 inches thick was found. It also is very small in areal extent and being only difficultly accessible is considered to have no economic value. It is possible that a bed at the general horizon of the upper member of the Blackhawk is present in the north wall of Long Canyon at the north edge of the township. However, no coal of any economic importance was seen here, and so it is considered that the township is lacking in workable coals.

On September 4, 1925, the writer made a hasty survey up the Green River [76] as far as Rattlesnake Creek (pl. 9), tying in several horizons by means of Brunton compass bearings. The results of this survey are shown on the map, dotted lines being used for the somewhat indefinite boundaries between members. The outcrop line of the only coal of any possible economic value that was noted is indicated on the map, and a section taken at location 46 follows:

	Ft.	in.
Sandstone, thick-bedded.		
Shale, sandy	3	
Sandstone, medium gray, cross-bedded, shale in lower part	3	6
Coal		2
Shale, sandy, gray-brown, with coal stringers		5
Coal, little bone near base	1	3
Bone		6±
Shale, medium light gray, in part concealed	1	5
Sandstone, very light gray, massive	20±	

This coal has been prospected to a slight extent half a mile farther upstream. The bed is at the base of the upper member of the Blackhawk and is thought to be about 20 feet above the Sunnyside horizon, here barren. A bed of coal about 6 inches thick was observed through field glasses at the same horizon in the west wall of the canyon of the Green River near the head of the island a mile below the mouth of the Price River.

All these observations tend to indicate that there is a more or less continuous bed of coal near or at the base of the upper member of the Blackhawk in the Green River embayment; but they also show that this bed is too thin to be worthy of exploitation.

TPS. 20 AND 21 S., R. 17 E.

All but the southwest corner of T. 20 S., R. 17 E., lies back of the Book Cliffs front, but only the northeast corner of T. 21 S., R. 17 E., lies within the Book Cliffs proper. The cliff front trends in a general southeasterly direction and divides the area into two topographic units. The lowland portion on the southwest is underlain by the soft Mancos shale, locally capped with remnants of a once continuous gravel apron sloping gently away from the cliffs. The altitude of the lowland is 4,400 to 4,500 feet a mile or so out from the cliffs, and the ground is relatively smooth compared to that in a similar topographic position west of the Green River. The highland section includes two lines of cliffs. Capping the lower escarpment is a bench sloping 3°-4° NE. and surfaced by the Castlegate sandstone. This bench, which has a maximum width of nearly 2 miles, supports scrub cedars, small brush, and an occasional piñon (pl. 3, *A*). A trail follows the inner

[76] The base used was sheet A of the Plan and profile of Green River, Green River, Utah, to Green River, Wyo., U. S. Geol. Survey, 1924. This sheet was also used in the preparation of plate 9.

side of the bench. The altitude of the front of the bench is about 5,500 feet, or about 1,000 feet above the shale flat at the base of the cliffs. From the rear of this bench the second line of cliffs rises to an altitude of 6,000 to 6,400 feet (pl. 3, *B*).

East of the Green River the Book Cliffs lose the regular monotonous appearance that is their characteristic to the west. Here many canyons with large branches break the cliff front into salients and reentrants, which succeed one another in bewildering fashion. Tuscher Canyon has a large canyon tributary from the southeast just back of the first cliff line and farther up has two very large branch canyons. A trail leads up the eastern one to the Wilcox ranch, and it was reported that water was present in the first northern tributary canyon of this branch. Just above this branch a very steep-sided narrow gorge has been cut by the main stream in the Castlegate sandstone, barely wide enough for a horseback rider. The western branch leads up to the Soulier Mesa, a dip-slope surface on the Tuscher formation. The road up Tuscher Canyon branches from the road along the east side of the Green River in the northern part of sec. 28, T. 20 S., R. 16 E. This road is sandy, but an automobile can be driven up the dry bed of Tuscher Creek from the road crossing in sec. 16, T. 20 S., R. 16 E., as far as the east side of this township. The Castlegate bench can be reached on horseback by the trail near location 47, shown on plate 9.

Coal Canyon, which is southeast of Tuscher Canyon, can be reached by a road that leads northeast from Elgin. It is passable by automobile up the bed of the canyon to the entrance of the Farrer mine. Near the center of the south side of the SW¼SW¼ sec. 27, T. 20 S., R. 17 E., in the south wall of Coal Canyon, there is a small but excellent spring. Two large reentrants have been cut in the Castlegate bench southeast of Coal Canyon in these townships, but the streams in these canyons have dissected the upper cliffs much less.

None of the streams of these townships are perennial, and the only water available other than that previously mentioned is the rain water that accumulates in rock depressions on the Castlegate bench, which may be a temporary source of supply. The district is without habitation; Solitude, like Daly, to the west, has only a railroad siding and a telephone box.

The land lines in all but the northeastern part of T. 21 S., R. 17 E., were surveyed in 1906. In T. 20 S., R. 17 E., secs. 35 and 36 were surveyed in 1907; the rest is unsurveyed. The corners located in these townships by the writer's party are indicated on the map.

Geology.—The formations present in these townships, together with their approximate thicknesses, are shown in sections 12 and 13 on

plate 7. At the horizon of the lower sandstone member of the Blackhawk, which is so prominent in all townships to the west and north, only indistinct sandy layers are present. The middle sandstone member of the Blackhawk contains considerable shale in approximately the lower 50 feet. On the other hand, the upper 90 feet of the upper member of the Blackhawk is a massive sandstone, closely resembling the Castlegate, from which it is separated by a shale and coal zone. The Buck tongue of the Mancos shale is a well-recognized unit, but the Sego sandstone is split in its middle portion by a shale, locally sandy, that thickens to the east. Thus the Sego stands out as a double ledge-making member. Neither of these ledges is very different from a third ledge about 40 feet thick and about 45 feet above the base of the Neslen member. The Wasatch formation crops out in the southeastern part of T. 19 S., R. 17 E., as shown on plate 9, forming brick-red slopes that terminate in a red-stained sandstone-capped butte, which rises above the Soulier Mesa to an altitude of 6,685 feet.

Structurally the area is a monocline dipping 3°–5° NE., as shown by the structure contours. Dips taken on the shale flat in the northeastern part of T. 21 S., R. 17 E., were as high as 7°. Minor variations in the monoclinal dip are shown by the structure contours.

Coal.—Coal was found at three horizons—one just below the base of the Castlegate sandstone, another probably the horizon of the Palisade coal zone near the base of the Neslen member of the Price River formation, and the third probably the horizon of the Chesterfield coal, about 150 feet above the base of the Neslen.

Sections of the coal near the top of the upper Blackhawk member were taken at locations 47, 49, 50, and 57 (pl. 12). All but the first were taken by alidade from the foot of the cliffs. The section at location 47, taken in Tuscher Canyon, shows but 4 inches of coal, and so this bed is here of no economic importance. All the other sections were taken at locations showing an optimum thickness of coal. Location 57 is on an isolated knob, and the bed is of no value in the cliffs nearby; so the portion of the area south of Coal Canyon contains no valuable coal beds at this horizon. A bed of coal appears along the cliffs between locations 49 and 50, which may average as much as 14 inches in thickness—indeed, two 14-inch beds separated by 15 inches of shale appear at location 50. This coal, however, is thought to thin rapidly to the northeast, as shown by observations in the reentrants north of locations 49 and 50.

At location 48, in Tuscher Canyon, a 24-inch carbonaceous zone is present about 5 feet above what is taken to be the top of the Sego sandstone. This is mainly bone with velvety black shale containing stringers and thin beds of coal, the thickest of which is 3 inches thick. This is approximately at the Palisade coal horizon, but it is only a

lens, as is shown by the other coal sections graphically presented on plate 13.

Sections of the Chesterfield coal zone were measured at locations 51 to 56, as shown on plate 13. No coal at this horizon was found in Tuscher Canyon. At location 51 only 1 inch of coal is present. At location 65 (sec. 6, T. 21 S., R. 18 E.) 6 inches of coal was found. Between these two locations the bed thickens in lenslike fashion, with optimum sections at the Farrer mine (locations 54 and 55). Location 54 is at the entrance to entry 2. Location 55 is in entry 1, and the section shown is one furnished by the lessee of the mine. A section taken in entry 1 is given on page 55 under the description of sample 15. The lessee reported that the coal within the mine workings changes within a short distance from 6 feet of pure bright coal to less than 1 foot of poor bony coal. This maximum thickness is larger and the minimum smaller than those observed by the writer. Richardson [77] gives the following section at the Farrer (Black Baby) mine:

	Ft.	in.
Shale, carbonaceous.		
Coal		3
Bone and shale		3
Coal	2	3
Bone		8
Coal	2	
Bone and shale	1	3
Coal	1	

The coal seems to be of workable thickness from the approximate position of location 52 to the south boundary of T. 20 S., R. 17 E.

Development.—The Farrer mine is a local wagon mine 14 miles northeast of the city of Green River. Plate 4, *B*, shows a man standing by entry 2, with entry 4 on the left. It is owned by a Mr. Peale of Salt Lake City, who leases it to Dr. King, of Green River, who subleases it to Mr. Splitoff, a farmer on the west side of the Green River at Willow Bend, 7 miles north of the city. It was opened in 1904, and 300 tons was produced that year. Since then the production has varied. It was operated in the late fall and winter of 1924–25, and 400 tons was reported to have been mined. This was sold to the people of Green River and environs at $5.50 to $7 a ton, the price dropping as the season advanced, owing to competition from the coals mined near Castlegate.

In 1925 there were four short entries. Entry 3, which had been abandoned for some time, is more of a circular room with a bulge to the west than it is a tunnel. Many props were used to support the roof, much of which has now fallen in. Entries 1, 2, and 4 are recent; entry 1 leads in 220 feet; entry 2, 110 feet; and entry 4, 45 feet. These resemble tunnels, there having been little attempt to get out

[77] Richardson, G. B., op. cit. (Bull. 371), p. 39.

extra coal by cutting laterally. Simple, crude mining methods with hand tools and blasting are used.

TPS. 20 AND 21 S., R. 18 E.

Tps. 20 and 21 S., R. 18 E., are unsurveyed. If the township boundary is a continuation of the boundary between the two townships adjoining on the west the coal outcrop line barely enters T. 20 S., R. 18 E. The following description, therefore, refers only to T. 21 S., R. 18 E., unless some other township is specifically mentioned. The Book Cliffs here consist of a double escarpment separated by a dip-slope bench capped by the Castlegate sandstone. (See pl. 9.) This bench is more pronounced here than at any other place in the Book Cliffs, as it extends from sec. 1 to sec. 33, across nearly the whole township. Several faults cross the bench, and erosion along them has caused the isolation of two "islands" of the bench, one in the south-central part of the township, the other in and near the southeastern part.

The lowland area south of the cliffs is underlain by Mancos shale, which is capped in places, as shown on the map, by the erosion remnants of a gravel apron that once spread out from the cliffs. A hog-back caused by a sandstone bed in the Mancos shale crosses the southwestern part of the township. Altitudes on its top run close to 4,800 feet. The railroad in the southwestern part of the township has an altitude of about 4,500 feet. The Castlegate bench has an altitude of as much as 5,600 feet along its south edge but declines to 4,900 feet or less to the north. The second line of the Book Cliffs rises to an altitude of nearly 6,100 feet just southwest of location 72, over 6,500 feet just east of location 65, and 6,030 feet just south of location 70. The fault just east of the spring near the center of the township (shown on pl. 9) has dropped the Castlegate bench 400 feet on the north side.

Horse Canyon is the only pronounced canyon in the area. Saleratus Wash crosses the southeastern part of the township. It has a small flow of nonpotable water that disappears here and there, leaving a dry bed, but is sufficient to irrigate three small ranches. It is the only source of perennial water in the area, except the two very small springs or seeps shown on plate 9, one near location 61 and the other in the center of the township, both of which furnish potable water. These springs are high in the canyon wall but may be reached readily by trail. Potable water may be obtained from a well at the section house at Floy, just south of this township. The area is nearly barren of vegetation except for greasewood and coarse grass along Saleratus Wash, small cedars and scrub brush on the Castlegate bench, and cedars with an occasional piñon on the rocks capping the second line

of the Book Cliffs. The area is without inhabitants except for the Hatch family, who live on a ranch 2 miles northeast of Floy, and the station agent at Floy, less than a mile south of the township. The Denver & Rio Grande Western Railroad and United States Highway 50 are near the south edge of the township. At Floy a spur formerly ran south from the railroad to remove gravel. A road leads from Floy up Saleratus Wash as far as the Moore ranch, in sec. 7, T. 21 S., R. 19 E., but has not been kept in good repair since the test well in the same section was abandoned; in 1926, however, it was readily passable by automobile. A road leading up Horse Canyon leaves highway 50 just before it crosses the railroad in sec. 19, T. 21 S., R. 17 E., and can be followed by automobile (the last mile or so in the bed of the wash) as far as the spring near location 61. A trail that can be followed on horseback leads across the north edge of the Castlegate bench. It forks at Horse Canyon, near location 61, one branch leading down into the canyon a short distance above the spring. The trail continues east, crossing the divide along the fault near the center of the township. It is also possible to ride from Horse Canyon to Saleratus Wash, across the divide at location 70, but travel by this route is slow and difficult.

Geology.—The stratigraphy of the area is shown in sections 14 and 15, plate 7, and on pages 25–27. Along the west side of Saleratus Wash, in the southeastern part of the township, a minor sandstone bed in the Mancos shale, about 960 feet below the top of the Castlegate sandstone, crops out, as shown on plate 9. A more effective hogback-making sandstone bed, 20 to 25 feet thick and about 80 feet lower in the section, shows in secs. 2 to 4, T. 22 S., R. 18 E., and farther northwest.

The middle sandstone member of the Blackhawk formation becomes very shaly in this area, and its mapping is discontinued near location 63, though it can be traced intermittently for 7 miles farther east to Crescent Canyon. Where it dies out the shaly lower part of the upper member of the Blackhawk is not distinguishable from the Mancos shale and is here grouped with the Mancos. However, the upper part of the upper member of the Blackhawk, which is sandy from the southwestern part of the Beckwith Plateau as far east as Nash Canyon, is quite distinct from the Mancos. As its topographic expression is like that of the Castlegate, eastward from location 63 the two are lumped as far as mapping is concerned, the only line of demarcation being that at the contact between the massive sandstone unit in the upper part of the upper member of the Blackhawk and the underlying shale. As in T. 20 S., R. 17 E., the Sego sandstone member does not stand out as a very distinct unit, as the lower part of the

Neslen member is marked by a ledge-making sandstone, similar to the two or three ledge-makers in the Sego sandstone. This sandstone in the Neslen member is about 30 feet thick and about 60 feet above its base.

The several faults in T. 21 S., R. 18 E., are described on pages 36–37.

Coal.—Coal was found at 4 horizons, 2 in the Neslen member and 2 in the upper member of the Blackhawk.

Coal near the middle of the sandstone unit of the upper member of the Blackhawk occurs in Horse Canyon, as shown by the sections taken at locations 59 to 63 (pl. 12). At locations 59 to 62 a lens of coal, split by a shale parting 2 to 3 feet thick, was carefully examined. It had previously been prospected in a very small way. As clearly shown on plate 12, it has no possible economic value. The lower part of the section at location 63, which was observed by alidade from a distance and so is of doubtful reliability, was taken at an optimum exposure. It shows two coal beds split by 3 feet 4 inches of siltstone. The lower of these two beds is 1 foot 8 inches in thickness. It is probable that these beds should be correlated with those at locations 59 to 62, but there is no evidence tending to show that they are continuous. It is believed that the 1-foot 8-inch coal bed at location 63 is a lens, and because of this and its relative inaccessibility in the cliff wall, it can be regarded as of no present economic value.

High in the cliff face on the point just west of Horse Creek a coal bed slightly over 14 inches thick could be traced for nearly a mile. The section at location 58, observed with an alidade from the foot of the cliffs, shows 16 inches of coal near the top of the upper member of the Blackhawk. Observations taken farther along the cliffs in both directions indicate, however, that this is a lens too small to be worth considering for possible exploitation. Not over 2 inches of coal was observed at this horizon at location 64, in Saleratus Canyon.

The character and stratigraphic positions of the two coal beds in the Neslen member are shown by sections taken at locations 65 to 75 (pl. 13). The Palisade zone is barren, except for 3 inches of coal possibly at this horizon at location 65. The sections at locations 65 to 69 show that there is no coal of economic value in the Neslen member in Horse Canyon. The other sections, taken along the west wall of the West Fork of Saleratus Wash, show coal more than 14 inches thick at both the Ballard and Chesterfield horizons. The only place where the Ballard coal is thick enough to be of economic value is at location 71. Though this measurement was taken on an outlier with an area of only 0.07 square mile (45 acres), it is possible that the coal could be mined in a small way in conjunction with the overlying Chesterfield bed, which is here of workable thickness. The outlier to the south, which lacks good exposures of the coal beds, was not prospected thoroughly, but the section taken at location 72 would tend

to indicate that the coal here is of no economic importance. The sections at locations 74 and 75 do not show workable coal, although at the extreme east edge of the township the coals thicken, as shown by the sections at locations 76 to 78. Between locations 71 and 73 there is probably a bed of coal of value, as shown by the sections taken at these two locations and at location 70. The thickness of the bed here averages very close to 2 feet.

T. 20 S., R. 19 E.

The surface of T. 20 S., R. 19 E., is rugged, as nearly all of it lies in or back of the second line of the Book Cliffs. Further data appear in the description of T. 21 S., R. 19 E. The area was surveyed in 1924, but the only corners located in the present mapping lie along the south boundary. Water is present in the bed of Saleratus Creek, but it is saline. There is a seep of good water at the Harris ranch, in sec. 32. The township plat shows seeps also in Crescent Wash in and north of the NE¼ sec. 26. The only inhabitants are Gilmore A. Harris and his family, except when the mine in sec. 34 is being operated.

Geology.—The geologic features of T. 20 S., R. 19 E., are described with those of T. 21 S., R. 19 E. (p. 83).

Coal.—Coal is found at three horizons in the Neslen member. The writer is under obligation to E. M. Spieker and A. A. Baker for the mapping and discussion of the Neslen coal from location 87 eastward in this township and for all the sections shown on plate 13 at locations 87 to 117 except the first one at location 100.

Coal at the Palisade horizon, which is here 45 to 70 feet above the Sego sandstone member, is too thin to be of economic importance at any place to the west of this township. Its outcrop line is shown on plate 9 from location 87 eastward. It lies 300 to 400 feet above the Castlegate bench. Its character is shown on plate 13 (locations 79, 86 to 91, and 99 to 117). Though it has a thickness of 16 inches at location 79, it appears to be a valueless lens. A similar lens near locations 86 and 87 on the west side of Saleratus Canyon is 18 to 19 inches thick but is too small to be of economic importance, as is indicated by the absence of coal at this horizon at location 83, and its worthless character at location 88.

In the gulch east of the Harris ranch the Palisade bed is somewhat thicker on the whole than at locations 87 and 88 but is none the less irregular. The section at location 90 was measured in a low cliff at the forks of the gulch, where the coal bed is perfectly exposed in a narrow box canyon for several hundred feet. East of location 90 a sandstone parting appears between the 10-inch bench of coal and the carbonaceous shale, and in 200 feet of horizontal distance the parting reaches a thickness of 10 feet. Between locations 90 and 91 the bed

thins down to a comparatively insignificant layer of dirty coal enclosed in a considerable thickness of black carbonaceous shale, which gives the erroneous impression to a casual observer that much coal is present.

The presence of some relatively thick coal at locations 89 and 90, on the west slope of Crescent Butte, with even better coal at locations 98 to 101, on the east slope, indicates the possibility that large parts of secs. 33 and 34 are underlain by a workable bed of coal. This would be a safe surmise if the coal of the area did not occur in several benches, with rapid lateral changes. All these data, in addition to the sections at locations 91, 92, 102, and 103, lead the writer to conclude that about 1.35 square miles in secs. 33 and 34 may be classed as coal land, with an average thickness of coal in the Palisade zone of 2.5 feet. The thicker coal in this area is near the present mine, at location 100.

The section at location 105 shows 2 feet of coal, but considered in connection with the sections at locations 106 and 107 and with Spieker and Baker's statement that in the gulch west of location 105 the horizon of the bed shows practically no coal at all, it does not appear to be of any economic importance.

In the two gulches east of Crescent Wash, in sections 35 and 36, the coal of the Palisade zone is of no value, the only section at all favorable being the one at location 111 showing 2 feet of coal. As this is on the salient between the two gulches, the area of such coal is too small to be of value.

The Ballard coal zone immediately underlies the Thompson Canyon sandstone bed, and is about 140 feet above the Sego sandstone member. The Ballard coal is too thin at all locations west of Crescent Butte (location 95) to be of any value, except perhaps near location 71, in T. 21 S., R. 18 E. In fact, many sections in this area show this horizon to be barren. Spieker and Baker report that near locations 89 and 90, in the gulch east of the Harris ranch, a bed of dirty coal 1 to 3 feet thick occurs 70 feet above the Palisade bed, and this bed may be the equivalent of the Ballard coal bed. Between the gulch and location 95 they found no evidence of commercially valuable coal above the Palisade bed.

At location 99 the coal is 14 inches thick, but other sections nearby show less coal at this horizon. At locations 110 and 112 it is thicker, and in the gulch at these locations, according to Spieker and Baker, it contains 3 to 4 feet of good coal and might be mined on a small scale if an active market for domestic coal existed within easy reach of the area. The bed is split, however, throughout the gulch by

partings of carbonaceous shale that would reduce considerably the profit of mining. Farther east within the township the bed is valueless, and it is barren of coal at location 115.

At the one place within the township (NE¼ sec. 35) where the Ballard coal might be of some value, the other seams are of no value.

The outcrop of the Chesterfield coal zone is shown by a heavy black line in the southwestern part of the township. In the southeastern part the outcrop of the Thompson Canyon sandstone bed is shown; as the Chesterfield coal lies at the top of this sandstone or just above it, the outcrop line is essentially the same. The coal appears to be of possible value at locations 76 to 84, but farther east within the township it is thought to be worthless. For example, at location 104 it carries 2 feet 6 inches of coal, but at location 105, only 900 feet to the southeast, the coal has given way to carbonaceous shale. A bed so irregular could not be mined with profit.

The value of the bed in sections 30 and 31 might easily be exaggerated, as this area is now relatively inaccessible. However, it is probable that a road could be made at nominal cost, leading west from Saleratus Wash along the trail near the township line. In this area the bed has an average effective minable thickness of about 2½ feet. Just east or west of these sections it is valueless. It is impossible to tell how far north the bed continues under cover with the same thickness.

J. B. Eby measured a section up Crescent Butte and found three coal beds above the Chesterfield, as follows:

	Ft.	*in.*
520 feet above Sego sandstone	1	2
490 feet above Sego sandstone	2	2
410 feet above Sego sandstone	4	

All these beds are above the coal zones shown in the section taken at location 100 (pl. 13). These beds are thought to be lenticular, and this, together with their relative inaccessibility, seems to indicate that they have no value.

Development.—The Crescent mine (pl. 3, *B*), in section 34, was opened several years prior to 1925 by John G. Adams, of Green River. From 1925 to 1927 it produced several hundred tons of coal. In 1926 it consisted of a single entry heading northwest, about 260 feet in length, with branches at 45 feet in, 85 feet to the northeast; at 110 feet in, 115 feet to the northeast; and at 160 feet in, 165 feet to the southwest. Only in the last two was there evidence of recent work having been done. No rooms had been started. The entries are about 20 feet wide and 5½ feet high.

Following is a section [78] of the coal at the Crescent mine (not given on pl. 13) taken near the mine portal:

	Ft.	in.
Sandstone (roof)	10	
Slate		8
Coal		7
Slate		6
Coal	4	2
Shale		7
Coal (covered by wash), probably only a few inches.		

Two sections taken in connection with the collection of coal samples (nos. 7 and 8) are given on page 53.

The coal has a notable amount of resin in it, and thin veinlets filled with paperlike sheets of a mineral, probably marcasite or pyrite (FeS_2), are common. Films of calcite ($CaCO_3$) are also present along the joint planes. About half the coal is bright, and it is well jointed in one direction. From the appearance of lumps that had presumably been dumped at the portal for some time, the weathering and shipping qualities would seem to be good.

Crude hand-mining methods are used. The coal is not cleaned, except as picked while loaded in the mine. The shaly beds are used as gob. Black powder and dynamite are the explosives. The mine is worked only in the fall and winter, and the product is hauled out by autotruck. Jack H. Richardson and Roy G. Mead remove the coal.

T. 21 S., R. 19 E.

The Book Cliffs occupy about the north half of T. 21 S., R. 19 E., and there is also an islandlike remnant in the southwestern part. South of the cliffs is the Mancos flat, which west of Crescent Wash is largely covered by remnants of a gravel apron. Two salients of the second line of the Book Cliffs project into the township from the north, one on each side of Crescent Wash. The western one is shown in plate 3, *B*. Altitudes along the railroad range from 4,750 feet at the west to 5,000 feet at the east. The top of the front line of cliffs similarly rises toward the east from about 5,800 to 5,950 feet; the outlier in the southwest rises from 5,300 feet at the south to 5,900 feet at the north, but in irregular fashion. Crescent Butte, just north of the township line, has an altitude of 6,850 feet, and nearly this altitude is reached in the eastern part of sec. 1.

The drainage flows southward. The only perennial stream is that in Saleratus Wash, and its water is not potable except for stock. Potable water is found at a seep near the Moore ranch, in Saleratus Wash, as is indicated on plate 9, and in a seep in an eastern branch of Crescent Wash in the east-central part of sec. 10. All these

[78] From a letter by J. J. Bourquin, of the Salt Lake City office of the U. S. Geological Survey, dated Aug. 5, 1925.

sources of potable water have a very small flow. Water can be obtained from a tank at Crescent. The only habitations in the area are on the ranch of Mr. Moore, on Saleratus Wash, and a house at Crescent siding which is usually occupied. The Denver & Rio Grande Western Railroad and United States Highway 50 run across the southern part of the township. A branch road leads from Crescent to highway 450 north of Valley City, in the township to the south. The road from Crescent to Saleratus Wash is nearly impassable by automobile. The road direct to Thompson is in slightly better condition. A road also leads up Crescent Wash; it goes into the bed of the wash in sec. 16 and climbs out in sec. 10, leading to the Crescent mine, in sec. 34, T. 20 S., R. 19 E. A trail skirts the inside of the Castlegate bench. The road leading up Saleratus Wash is passable by automobile as far as the Moore ranch, and it is possible to drive up the bed of the creek at least as far as the Harris ranch, in the next township to the north. The area was surveyed in 1919, and 10 corners located during the field work are shown on the map. The area is practically barren of vegetation except for the cedars and scrub brush on the Castlegate bench (pl. 3, *A*) and the greasewood and coarse grass in the valley flats of Crescent Wash and Saleratus Wash.

Geology.—The stratigraphy of Tps. 20 and 21 S., R. 19 E., is shown in secs. 16 to 19 on plate 7. From this area as far east as the Grand Mesa of Colorado the Sego sandstone stands out as a distinct unit. The structure of the rocks is complex in the southwestern part of T. 21 S., R. 19 E., where the rocks are faulted, as described on page 38. The remainder of the area consists of a monocline, with strike nearly east. The dip of the rocks is 2°–3° in the northeastern part of the township, and slightly steeper to the west. There are no pronounced minor structural features in the northern part of the area, but certain local irregularities are shown by the structure contours.

Oil and gas.—Test wells for oil and gas have been drilled in this township in the SW¼ sec. 7, on Saleratus Wash, and in the NW¼ sec. 34, as further described on pages 41–42.

Coal.—Coal occurs in the upper part of the upper member of the Blackhawk formation and at three horizons in the Neslen member.

Coal is found at two horizons in the upper member of the Blackhawk, as shown in the sections taken at locations 134 to 146 (pl. 12). The higher bed is essentially at the top of the member; the lower bed is 15 to 40 feet below the top and possibly represents a split from the higher one, the two converging toward the southeast. The lower bed, where its outcrop line is essentially different from the higher bed (secs. 22 and 23), is shown by a dotted pattern on plate 9. Along the southern part of the area of outcrop these beds occur high in the

cliff face, but along Crescent Canyon and its tributaries they gradually descend to the level of the stream. The lower bed is of no value except in a very small area near location 140. This bed is not over 2 inches thick at location 141, half a mile to the south. If present in the reentrant at location 139 it is covered by talus. At location 137, three-fourths of a mile northeast of location 140, a prospect has been cut about 20 feet into this bed. The coal here is earthy and carries two partings each a quarter of an inch thick. The section at location 144 is of doubtful value, as it was taken with an alidade from the foot of the cliffs. Moreover, the coal at this location is on an isolated knob less than 5 acres in extent.

The bed near the top of the upper member of the Blackhawk is 15 inches thick at location 134 but is so thin at location 135 that it can be considered of no economic importance on the west side of Crescent Canyon. At location 137 a prospect about 50 feet deep has been made on this bed.

At location 136, half a mile northeast, there is a double bed, the thicker one containing only 15 inches of good coal. This bed is more than 14 inches thick at locations 138, 139, 142, and 145, but the measurement at location 145 is of little value, as it was made with an alidade from the foot of the cliffs. At locations 140, 141, and 143, the coal is absent or worthless. There seems to be a patch of this coal of possible economic importance extending southward from location 136 to about the middle of sec. 14. It ends abruptly on the west, but its extent to the east is unknown. It is probably considerably thinner in the northern part of this area than in the southern part, as far as workable coal is concerned. Spieker and Baker consider that the coal of the upper member of the Blackhawk is not of commercial value anywhere in this area and did not map it. For the coal sections at locations 92 to 98 and 118 to 122, and for the mapping and discussion of the Neslen coal member of the township, the writer is under obligation to Spieker and Baker.

The outcrop line of the Palisade coal zone, which lies near the base of the Neslen member and 15 to 60 feet above the Sego sandstone member, is shown on plate 9. It follows the steep slope along the sides of the two spurs that project into the township on both sides of Crescent Wash. The character of the coal at locations 92 to 98 and 119 to 133 is shown graphically on plate 13. This coal bed has been burned to a large extent along the outcrop east of Crescent Wash.

At location 92 the zone may be split into an upper and a lower division; the only potentially valuable coal here is in the upper division, where it has a thickness of 2½ feet. As traced south through locations 93 to 96 the coal is of no value, except in the lower division at location 96, where beds 15 and 19 inches in thickness are separated by 11 inches of carbonaceous shale. Farther south, at location 97,

the lower division has no coal bed over 7 inches thick, but a 2½-foot bed is present in the upper division or bench. All these sections were taken by Spieker and Baker. The exact interval between this zone and the Sego sandstone is unknown. According to Spieker and Baker, the upper bench of this coal zone is a split from the main bed, and east of location 97 one bench (probably the upper) disappears. Here exposures are not good, and such scattered outcrops as are present show that the bed is thin, variable, and probably worth very little. At location 98, near the north edge of the township, the zone contains a single bed of coal 2 feet 7 inches thick, with three other thin, worthless beds. The coal gets thicker farther to the north. Spieker and Baker consider that the coal of this zone in T. 21 S., R. 19 E., is so badly split by valueless partings that it is not recoverable under present economic conditions. With this conclusion the present writer is in agreement.

The Palisade coal zone crops out in and near secs. 1 and 12, and its character here is shown by the sections taken at locations 119 to 133. It is burned at most places along the outcrop between locations 120 and 122 and between locations 124 and 132. The adjacent rocks have a pronounced reddish color. It is impossible to say how far back this burning has extended; probably some unburned coal is present in sec. 12 and to the southwest, but it is equally probable that any coal southwest of a line extending south-southeast from location 121 cannot be recovered at a profit. Northeast of this line the best coal is found at location 132, where 5 feet 2 inches of coal is split into three beds by partings of carbonaceous shale 6 inches thick and bone 4 inches thick. In accordance with the broad rule adopted by the United States Geological Survey that "any parting or bench of bone included in a bed injures the value of the coal of the bed in amount equal to the thickness of the parting," [79] the bed at this point may be considered to have an effective thickness of 4 feet 4 inches. At location 133 the effective thickness is 2 feet 9 inches. Farther north the sections at locations 147 and 148 (pl. 10) show that the bed has thinned so that it is of no value. At locations 119 and 120 there is 1 foot 9 inches of coal, but the relations shown in the graphic sections indicate that it is lenticular. To the north, at location 117, the bed is of no value.

The Ballard coal lies just below the Thompson Canyon sandstone bed, about 140 feet above the Sego sandstone, and the Chesterfield zone occurs only a few feet higher and lies on or just above the top of the sandstone. On plate 9 this sandstone is shown as a heavy line extending east from the southwest side of Crescent Butte. This line marks with sufficient accuracy the outcrop line of both the Ballard and Chesterfield coals. Sections at locations 95 to 97 and 118 to 133

[79] Smith, G. O., and others, The classification of the public lands: U. S. Geol. Survey Bull. 537, p. 70, 1913.

show the character of the Ballard coal in T. 21 S., R. 19 E. It can be seen at a glance that this bed is here of no value, except possibly near locations 96 and 133, and as the bed is too thin to be of value at short distances on each side of both these locations, the area is considered to be without workable coal at this horizon.

The only place in T. 21 S., R. 19 E., where coal in the Chesterfield coal zone is of any value is near location 92. Though the section at location 92 is a favorable one, at location 95, 400 feet to the south, according to Spieker and Baker, the coal has thinned down to a little over a foot, and a lens of sandstone and shale has appeared between the coal and the thick bed of carbonaceous shale over it. Accordingly, this bed is regarded as of no value in this township.

TPS. 20 AND 21 S., R. 20 E.

The Book Cliffs trend nearly east through Tps. 20 and 21 S., R. 20 E., but the cliff lines are very irregular. As in the townships to the west, there are two lines of cliffs separated by a broad bench floored with Castlegate sandstone. The Denver & Rio Grande Western Railroad and United States Highway 50 lie in the southern part of T. 21 S., R. 20 E. Branches from each lead north from Thompson to a point a short distance beyond Sego, in Neslen Canyon, the east or right fork of Thompson Canyon. A poor road extends up Thompson Canyon from this branch road. Trails follow the north side of the Castlegate bench, as shown on plate 10. The first line of the Book Cliffs is inaccessible on horseback except in Thompson Canyon and in the NW¼ sec. 8, T. 21 S., R. 20 E. A trail leads up Thompson Canyon over the divide in sec. 18, T. 19 S., R. 20 E., into the Uinta Basin near Willow Creek.

Altitudes along the main railroad in the area decline on both sides of Thompson from 5,135 feet to about 5,000 feet. The gravel benches on the Mancos flat rise 50 to 100 feet above the railroad. The south edge of the lower cliff salients rises to about 6,100 feet, but the bench behind them declines gently to the north at an angle of about 3°. The second line of the cliffs rises to an altitude of 6,870 feet in the southern part of sec. 32, T. 20 S., R. 20 E. The drainage goes southward, but a local divide just east of Thompson separates the Green River drainage basin from that of the Colorado River. The only perennial streams flow in Thompson and Neslen Canyons.

All but the northwestern part of T. 20 S., R. 20 E., has been surveyed, secs. 27, 28, 33, and 34 in 1907 and the remainder in 1915. T. 21 S., R. 20 E., was surveyed in 1898, except sec. 6 in 1915. Section corners located during the field work are shown on plate 10.

The precinct of Thompson had a population of 93 in 1930 and contains stores, garages, post office, and a hotel. Sego precinct, with stores, theater, school, and post office, had a population of 223 in 1930.

Most of the people at Sego are connected with the mine of the Chesterfield Coal Co. in Neslen Canyon. Vista has merely a railroad siding and telephone box. A few people live on ranches in Thompson Canyon.

Geology.—The stratigraphy of the area is shown by sections 20 to 22 on plate 7. Section 20 is given in detail on pages 27–29. The structure of the rocks is that of a monocline with a dip of about 3° N., which increases locally to as much as 5° in Neslen Canyon. In the northwestern part of T. 21 S., R. 20 E., the dip is more northwest. The western part of the area is cut by 11 normal faults. Only two of these have a throw exceeding 30 feet; in one it is 85 feet. The details of these faults are shown by the structure-contour lines. The faults, with the exception of the westernmost one, are in pairs and form four small grabens and one horst. The two western grabens are shown rather strikingly by angular valleys on the Castlegate bench. Clark [80] has described the small graben in sec. 28, T. 20 S., R. 20 E. The strike of the rocks in some of the fault blocks is doubtful, as sufficient observations could not be made in the time available.

Coal.—Coal is found at three horizons in the Neslen member. Clark has described in detail those in secs. 27, 28, 34, and part of 33, T. 20 S., R. 20 E., and the writer has taken from Clark's report much information, including the mapping of the coal beds and the graphic sections. The character of the coals at these horizons at the various locations is shown on plate 14. The sections at locations 156 to 159, 161, 162, 164 to 194, and 196 are from Clark.[81] Clark states that the interval between the two lower coals varies irregularly, ranging from 45 to 100 feet, and that the interval between the two upper coals is 30 to 50 feet. Therefore, on the sheet of graphic sections these intervals, as well as the distance above the Sego sandstone member, are only approximate, data not being available to show them in the proper position in the sections taken by Clark.

The outcrop line of the Palisade zone, which is bed A of Clark's report, is shown on plate 10. Through the northwestern part of T. 21 S., R. 20 E., this bed can be regarded as of no economic importance, as shown by the sections at locations 147, 148, and 152 (pl. 14), where the maximum thickness of coal is only 14½ inches. In the northeastern part of this township the bed has been burned to a considerable extent along the outcrop; where not burned a bed having an effective thickness of about 4 feet is present (locations 196 and 198). The sections at locations 149 to 151, in sec. 31 and the SW¼ sec. 32, T. 20 S., R. 20 E., show coal of doubtful value. At locations 149 and 150 the effective coal thicknesses are 20 inches and 19½ inches, respectively; at location 151 the effective thickness is only 12 inches. Considering that

[80] Clark, F. R., Coal near Thompson, Grand County, Utah: U. S. Geol. Survey Bull. 541, p. 457, 1914.
[81] Idem, pp. 462, 464.

locations 149 and 150 are separated by a fault with a downthrow of 84 feet on the east, it seems safe to assume that this little area of coal over 15 inches thick is of no value. Similarly, at location 153 the bed is too thin for consideration. But at location 154 and all locations to the east within the township a bed of possible value is present, where not burned. Plate 4, *A*, shows its appearance at location 155. The thickest effective coal in a single bench is found at locations 167 and 176, where it is over 5 feet thick. On the point of the salient between Thompson and Neslen Canyons, in sec. 33, T. 20 S., R. 20 E., the bed is thin, partly burned, and probably weathered. It thins rapidly north of location 160, in Thompson Canyon. It is much less valuable on the west side of Thompson Canyon at locations 154 and 155, where it appears to be in two benches. Along the east side of Neslen Canyon the sections taken at locations 176 to 196 show Palisade coal 4 to 5 feet thick, except at location 182, where it is 3 feet 3 inches, and location 176, where it is 5 feet 4 inches; the coal has burned at location 195. Between locations 196 and 197 this coal bed is apparently split into two benches, and at 197 the upper one is burned. These benches may be traced east of the township boundary, where the coal of the lower one is of no value west of Nash Wash. The best coal in these benches appears in the section at location 197a, where 3 feet 8 inches and 3 feet 1 inch of coal are present in the upper and lower benches, respectively. At location 199 the upper bench has a thickness of 4 feet 3 inches and the lower bench is worthless. Thus, where not burned, the upper bench is of possible value, but the lower bench is not, except west of the E½ sec. 36.

The Ballard coal zone is described as bed B by Clark,[82] who states that it "is sometimes known as the Ballard coal, receiving this name from the fact that several years ago a man named Ballard opened a local mine near the center of sec. 27 which produced some coal." This coal zone immediately underlies the Thompson Canyon sandstone bed, as shown in plate 5, *A*. The sections at locations 147 to 154 show a fairly thick Ballard coal zone, but the only favorable sections southwest of location 155, are at locations 150 and 153, where the coal less the thickness of the partings measures 1 foot 11 inches and 2 feet 11 inches. The section at location 153 was taken near the southwest corner of the SE¼SE¼ sec. 32, T. 20 S., R. 20 E., just west of a fault with a 50-foot downthrow on the east. Inasmuch as this bed is badly split by bone and carbonaceous shale at location 152, less than half a mile to the west, and considering the faulted nature of the rocks, this area is believed to have no coal of economic value.

From location 155 to the east edge of the townships, coal is found in this zone with a thickness of at least 15 inches at all locations examined, except at location 195, where it is burned. The coal along

[82] Clark, F. R., op. cit. (Bull. 541), p. 462.

the east wall of Neslen Canyon, including sec. 35, T. 20 S., R. 20 E., may average 4 feet in thickness, although several sections show less than 4 feet of effective coal. The coal thins rapidly to less than 2 feet to the east through sec. 36. Through much of this area the coal is in two benches; these extend from location 178, but only a single bench is found at locations 188, 198, and 199, though at location 198 a lower bed is present. The thinning of the coal through sec. 36 is due in part to the disappearance of good coal in the upper bench but in part to the thinning of the lower bench. Farther east as far as the west side of Nash Canyon the coal cannot be assumed to average over 15 inches. Along the salient between Neslen and Thompson Canyons the coal at most places is between 2 and 3 feet thick, but at the head of Thompson Canyon, as shown by the section at location 156, it is slightly thicker; this and the slightly thicker section at location 174 indicate the possibility of thickening to the north. Along the west wall of Thompson Canyon it is 2 feet 1 inch thick at location 155.

The Chesterfield coal zone lies just above the Thompson Canyon sandstone bed. Through most of the western third of the area the upper boundary of the sandstone marks approximately the outcrop line of the coal zone. Throughout most of the rest of the area the actual outcrop line of the coal zone is shown. Coal at this horizon is described by Clark [83] as bed C. Its appearance at location 150 is shown in plate 6, *A*. This coal is now being mined at Sego by the Chesterfield Coal Co., whence the name given to the bed.

The sections at locations 148 to 150 show about 3 feet of coal. To the west in the next range the coal at this horizon is less than 14 inches thick or is absent. At locations 151 and 152 the bed is of no value. The section at location 153 shows 2 feet 5 inches of coal, but just to the west it is cut out by sandstone (shown by the dotted pattern on pl. 10), and to the east it is cut off by a fault with a 50-foot downthrow on the east.

At location 154 the coal is too thin to be of value, but to the east it is a bed of workable thickness as far as the west side of sec. 36, T. 20 S., R. 20 E. (location 197 a). Otherwise in and near sec. 36 it is of no value, as it contains too much bone. From plate 14 it is clear that the coal in the salient between Neslen and Thompson Canyons averages at least 4 feet in thickness. Along the west wall of Thompson Canyon the coal thins rapidly to less than 1 foot at location 154. Along the east wall of Neslen Canyon the thickness is somewhat variable, but at all locations it lies between 3 feet 1 inch and 5 feet 1 inch except at 179, where it is only 1 foot 11 inches. Though it is somewhat thinner in the SE¼ sec. 27 and somewhat thicker near the center of the west side of sec. 35, T. 20 S., R. 20 E., an assumed average thickness of 4 feet seems a fair estimate. The section at location 195

[83] Idem, p. 464.

apparently shows no coal at this horizon, but it may be represented in one of the burned beds shown, as the correlation of the Thompson Canyon sandstone bed here is doubtful. East of the center of sec. 35 the bed thins very abruptly, and south of the center of sec. 36, at location 198, it is valueless.

As far as determined by the writer's party, the only other coal zone of possible value in these townships is found at location 198, where the section shows 15 inches of coal about 10 feet below the Ballard coal zone. This is, however, considered to be of no economic value. Clark [84] has described thin beds of coal above and below the Palisade horizon and above the Chesterfield horizon. He found beds 16 feet or less below the Palisade horizon at the following localities with the thicknesses indicated: Location 161, 1 foot 4 inches, impure; 172 and 174, 1 foot 8 inches; 176, 1 foot 3 inches; and 183, 1 foot 5 inches. At locations 170, 178, 184a, 187, and 190 the thicknesses of the lower coal are less than 1 foot 3 inches each. With regard to these, Clark says: "It is believed that some of the sections of coal below [the Palisade horizon] represent the same bed, which is probably local and of very little economic importance." This lower coal is absent at location 182 and is badly split at locations 184a and 187. At location 176 there is a 20-inch bed 17 feet above the Palisade horizon. Coal was found not more than 16 feet above the Chesterfield at the following locations (thickness is given if it exceeds 1 foot 2 inches): 156, 157 (1 foot 3 inches), 159, 161, 162, 172, 173, 175 (2 feet 3 inches), 176 (1 foot 9 inches and 1 foot 6 inches), 177, 178, 182 (3 feet), 184 (2 feet, impure), 185 (1 foot 4 inches), 186 (1 foot 6 inches), 187 and 191. Clark suggests that the higher coal at locations 172 to 178 and 182 to 191 may belong to a single bed, but this was not definitely ascertained by tracing. The coal at locations 172 to 178 is not considered to be of value, as the area of possible workable thickness is too small. Between locations 182 and 186 the bed may be of value.

Development.—Clark [85] has discussed the early developments in the area. Operations on a large scale were begun in March 1912 by the American Fuel Co., which started mining the Ballard bed on both sides of Neslen Canyon. The B mine (mine 1) entered the bed on the west side of the canyon, very near the site of the present mine's main entry, and the entrance to the A mine (mine 2) was just across the canyon to the east. This coal was so dirty that it required washing. In addition it was "frozen" to bone or shale partings. The west mine (no. 1) was abandoned after a few months, owing to the large increase of impure material as the development proceeded. Two entries were run in about three-eighths of a mile to the west,

[84] Clark, F. R., op. cit. (Bull. 541), pp. 460, 465.
[85] Idem, p. 474.

and a branch was run 300 feet to the north along the west line of the SW¼NW¼ sec. 27, T. 20 S., R. 20 E. Cutting of rooms was barely started. In July 1913 development of the Palisade bed was begun. The bed was entered (mine 3) just west of location 176, the site of the old Ballard mine, and the coal was worked in an easterly direction. This mine was abandoned, presumably because of the impure character of the coal, about the middle of 1915. The drift ran north a short distance, and then a T led east and west. Within a short distance the east drift (double entry) bent off to the south of east and extended just past the center of sec. 27. It had two branch entries. Very few rooms were turned off these entries. It is not known just when the east mine (no. 2) on the Ballard bed was abandoned, but it was probably prior to 1915. It probably covered nearly 40 acres, mainly in the S½NE¼NW¼ and N½SE¼NW¼ sec. 27. The present mine on the west side of Neslen Canyon was started about the middle of 1914 on the Chesterfield coal. The mine was sold to the Chesterfield Coal Co. in 1925. It is owned by B. F. Bauer (1926).

The main haulageway opens on the west side of Neslen Canyon north of location 175, as a drift along the bed. The air-drift entry is a short distance farther north, near the place where the bed crosses the canyon. The mine covers the NE¼ sec. 28, about a quarter of the S½ sec. 21, and that part of sec. 27 on the west side of Neslen Canyon. It also includes a small part of the SE¼ sec. 28, where development was proceeding in 1926. The coal is undercut with a Jeffrey 35 B machine, shot down with 38 percent dynamite and 62 percent permissible explosive, and loaded by hand, and the loaded cars are gathered by mules. The haulage is mainly by trolley motor. Wheat safety lights are used. Mining is done by the room and pillar system (double entries), with pillars 45 feet wide and rooms 20 by 250 feet. About a quarter of the pillar coal has been robbed. There is no trouble from gas, and there is no dust except from the undercutters. The mine is dry. The entries and rooms are timbered with piñon and cedar brought by wagon from a place about 10 miles up Thompson Canyon. Plate 5, *A*, shows the tipple and screening plant, together with the old wash house, which has not been used since the present mine was started.

The marketed coal includes mine run and also the four following grades:

	Percent
Lump (over 8 inches)	33
Lump (6 to 8 inches)	32
Nut (over 1½ inches)	16
Slack	18

The mine run and nut go mainly to the railroad, the slack is used for raising steam, and the remainder goes for domestic use. About

half of the coal is shipped east to Nebraska, Kansas, and Missouri, and the rest goes west to Utah, Idaho, Nevada, California, Montana, and Washington. The annual output in 1926 was about 120,000 tons.

TPS. 19 TO 21 S., R. 21 E.

Probably the largest reentrant of the whole Book Cliffs, not even excepting Gunnison Valley (pl. 9), is found in Tps. 19 to 21 S., R. 21 E. It is occupied by Nash Wash and its tributaries and is due largely to the presence of an anticline. The cliffs are broken by numerous canyons, and the coal outcrop is extremely sinuous.

Topographically the area is divisible into two parts—on the south the Mancos shale flat, mantled by large remnants of a southward-sloping gravel apron, and on the north the Book Cliffs. The cliffs rise from the flat by a gradually increasing slope that culminates in the escarpment of the Castlegate sandstone. The top of the sandstone forms a dip slope that is a mile or more in width where the cliffs trend east, but very narrow where they trend north. (See pl. 10.)

Altitudes along the railroad on the south edge of the area range from 4,600 feet on the east to 4,900 feet on the west. The gravel benches in the southwestern part of the area have an altitude of about 5,250 feet at a distance of a mile from the cliffs. In the Nash reentrant these gravel benches slope from 5,700 feet or higher down to about 5,000 feet at the southeast edge of the townships. The Castlegate bench on its outer edge ranges from 5,700 to 6,300 feet in altitude, as is shown by the structure contour lines. It dips back from the first line of the cliffs at angles of 3° to 10°. The second line of the Book Cliffs rises to an altitude of more than 8,000 feet in the northern part of the area but less than 7,000 feet in the southwestern part.

The drainage flows south and southeast into the Colorado River through Sagers Wash and its tributaries, Pinto and Nash Washes. Small amounts of rather saline water are present in Sagers Wash in and near the NE¼ sec. 31, T. 20 S., R. 21 E., and at places farther upstream; similar water is found in Nash Wash as far down as sec. 24; in Bull Canyon, in sec. 5; and in a tributary of Nash Wash just southeast of the center of sec. 3, all in this same township. There is no other perennial water in Tps. 19 to 21 S., R. 21 E. A pipe line brings potable water down Nash Canyon to Turner's ranch, in sec. 15, T. 20 S., R. 21 E., and to the gas wells in and near the southeast corner of this township. The only inhabitants of the area are the Turner family, a few people at the gas wells, and a station agent at Sagers. A good road branches from United States Highway 50 and may be followed up Nash Wash past the gas wells as far as Turner's old ranch, from which a trail continues up Nash Canyon. It is possible to drive by automobile up the dry bed of Sagers Wash as far as the NW¼ sec.

32, T. 20 S., R. 21 E. Although the cliffs are inaccessible in most places they can be ascended at some of the canyon heads. Horseback travel is possible throughout the area south of the cliffs, although it is slow near the cliffs. A trail along the inner side of the Castlegate bench is shown on plate 10. In the Nash reentrant sagebrush, coarse grass, cedars, and an occasional piñon are present. The Castlegate bench, dotted with cedars near Sagers Canyon, is so thickly covered in the Nash reentrant that travel is locally difficult. Here the slopes of the second line of the Book Cliffs are also tree-dotted, piñons becoming more common as the altitude increases. T. 20 S., R. 21 E., was surveyed in 1919–20.

Geology.—The stratigraphic sequence is shown in sections 23 to 25 on plate 7. Section 23 is given in detail on pages 29–32. About 2,475 feet above the base of the Mancos shale, which is about 3,450 feet thick, is the base of a sandy bed mapped on plate 10, which varies greatly in thickness but is locally more than 100 feet.

Gas.—The Cisco dome in T. 20 S., Rs. 21 and 22 E:, has been developed as a gas field, as is described on pages 43–44.

Coal.—Coal in this area was examined at locations 201 to 216 (pl. 10). The character of this coal is shown on plate 15. All the coal is found in the Neslen member of the Price River formation.

The main coal bed of the Palisade coal zone is of no possible economic value in these townships except along the west side of the Right Fork of Bull Canyon, near locations 212 and 213. Elsewhere it is too thin to be worth considering, as far as can be determined from the graphic sections, though it is barely possible that a thicker local lens is present between some of the locations studied. Bull Canyon is difficult of access, and it is inconceivable that any coal will be mined there for a long time.

What is taken to be a higher split from this bed appears to be continuous through the western part of the area but is too thin to be of value except possibly at locations 202, 205, and 209, where the effective thicknesses are 1 foot 3 inches, 1 foot 10 inches, and 1 foot 8 inches, respectively. Between locations 202 and 205 about 1 foot 6 inches of effective coal may be continuously present, though it does not extend south to the outcrop line, as shown by the sections at locations 203 and 204. At location 209, on the salient between Nash and Bull Canyons, the area of coal over 14 inches thick must be very small. It is here assumed to cover 0.23 square mile with an average thickness of 1 foot 6 inches. This bed may extend farther, however, as Richardson [86] reports 1 foot 10 inches of coal at a horizon almost certainly the same, near location 208 (location 28 of Richardson). However, it is not certain that this is all clean coal.

[86] Richardson, G. B., op. cit. (Bull. 371), p. 37.

The Ballard coal zone immediately underlies the Thompsons Canyon sandstone bed, whose outcrop line is shown on plate 10. The coal zone appears to be continuous throughout the area except near location 208, where it is missing, and at location 209, where it is probably missing. This coal seems to be of possible value in the southwestern part of T. 20 S., R. 21 E., as shown by the sections at locations 201 to 205, except on the salient at location 204 and the nearby salient to the northeast. In this part of the township the bed is irregular, however, as is indicated in the graphic sections. The only other locality in the area where coal at this horizon appears to be of possible value is near location 210, where the effective thickness is 1 foot 10 inches in a small area in the left fork of Bull Canyon.

The Chesterfield coal zone lies 0 to 30 feet above the Thompson Canyon sandstone bed shown on plate 10, but for all practical purposes the outcrop line of the sandstone may be taken as that of the coal zone. At location 201 the bed is too badly split by bony coal and carbonaceous shale to be of value. In Sagers Canyon at location 202 it contains only 10 inches of coal. It is of possible economic value at locations 203 to 206 but to the north is too bony to be of value except perhaps near location 208, in Nash Canyon. The compound salient between Sagers and Nash Washes, embracing all but the western part of secs. 20 and 29, T. 20 S., R. 21 E., is estimated to be underlain by Chesterfield coal of an average thickness of 1 foot 9½ inches. Although there is a 4-foot coaly zone at location 208, as reported by Richardson,[87] the effective coal thickness where the writer measured his section is only 2 feet 3 inches, as the bed contains four partings. (See pl. 15.) At location 209 coal is absent at this horizon.

At locations 212, 213, and 216 thin beds of good coal are present not more than 30 feet below the Ballard zone. All these are less than 6 inches thick. The sections at locations 213 and 214 show coals, less than 1 foot thick, about 10 feet above the Palisade. The sections at locations 203, 205, 207, 209, 211, and 215 show coals above the Chesterfield zone, but none of these are of value. At location 209 there is a thick bed of coal about 50 feet above the Thompson Canyon sandstone bed, but the coal is bony and not suitable for exploitation. This bed is in a stratigraphic position nearly high enough to be correlated with the Carbonera coal zone of western Colorado.

TPS. 19 TO 21 S., RS. 22 AND 23 E., AND SOUTHERN PART OF T. 18 S., R. 23 E.

Inasmuch as the area embraced in Tps. 19, 20, and 21 S., Rs. 22 and 23 E., and the southern part of T. 18 S., R. 23 E., contains no coal resources of any value, it is discussed as a unit for the sake of brevity.

[87] Idem, location 28, pl. 8.

The Book Cliffs extend across the northern and northwestern parts of this area, rising from the Mancos shale flat, which lies to the south. In a belt about a mile wide lying in front of the main part of the Book Cliffs the Castlegate sandstone makes a pronounced dip-slope bench, terminated on the south by a minor escarpment, which is inaccessible in most places except where indented by canyons. The western part of the Mancos shale flat is in large part covered by gravel remnants which cap benches. Only a few tiny remnants of the benches exist in T. 19 S., R. 23 E.

Altitudes along the railroad at the south edge of the area range from 4,600 feet on the west to 4,350 feet on the east. The altitude of the front of the Castlegate bench is shown by structure-contour lines on plate 10. It reaches over 5,900 feet in the western part of the area but is between 5,250 and 5,000 feet at most other places. Through much of R. 22 E., near the boundary of Tps. 19 and 20 S., the second line of the Book Cliffs is unscalable. The outliers in sec. 8, T. 19 S., R. 23 E., and about a mile north of location 234, rise to more than 6,000 feet.

The drainage flows south and southeast to the Colorado River. Perennial water is present in Nash and Cottonwood Washes, but not throughout their extent. Cisco Springs marks a place where water appears in the stream bed and on the side of Cisco Springs Wash; this water is potable. In these townships Nash Wash was not examined in detail, but probably it has water at many places. Cottonwood Wash has more water near the cliffs than any of the others, but even here it fills only a part of the stream bed except just after rains. All of this water, except that at Cisco Springs, is somewhat charged with saline matter, but potable water may be obtained at Cisco and at Albert Turner's ranch, in Diamond Canyon. Water for irrigating the Turner ranch comes from Cottonwood Canyon.

The precinct of Cisco had a population of 193 in 1930, and the settlement contains stores, railroad station, school, post office, garages, and a hotel. A stage operates to Castleton, about 25 miles to the south. Elba has merely a telephone box and railroad siding. There is a section house at Whitehouse. One family lives at Cato, and another at Albert Turner's ranch in Diamond Canyon. There is an uninhabited cabin at Cisco Springs, another one 2 miles to the north, and about eight to the southeast near the road crossing Danish Flat. These, together with an abandoned schoolhouse in the NW¼ sec. 19, T. 20 S., R. 24 E., were apparently in use in 1923–24, when T. 20 S., R. 23 E., was being surveyed. The rest of the area is uninhabited, except for an occasional sheepherder on Danish Flat. The Denver & Rio Grande Western Railroad and United States Highway 50 cross the southern part of the area. Good roads lead from Cisco to Westwater and to Castleton and from the main highway up Nash

and Cottonwood Washes. The road leading to Cisco Springs was not traversed by the writer's party but is probably passable. Trails follow the Castlegate bench, as indicated on the map.

T. 19 S., Rs. 22 and 23 E., were surveyed in 1909; T. 20 S., R. 23 E., in 1923–24; T. 21 S., R. 23 E., in 1903. The two townships in the southwestern part of the area had not been surveyed at the time of the writer's visit, but T. 20 S., R. 22 E., was surveyed late in 1926.

Geology.—The stratigraphy is shown in sections 26, 27, and 28 on plate 7 and the structure is depicted by the structure-contour lines on plate 10. The area lies along the northwest side of the Uncompahgre uplift, and thus regionally the tendency of the beds is toward a monocline dipping about 3° NW. In this area the structure is considerably modified by three anticlinal uplifts marked by the Nash, Cottonwood, and Westwater reentrants. These uplifts are described on pages 38–41. In addition there appears to be a very gentle anticlinal fold or nose plunging to the northwest in the northeastern part of the area, approximately coinciding with Buck Canyon.

Gas.—Several gas wells have been drilled in these townships, as described on pages 43–45.

Coal.—Coal that is fairly persistent is found at four horizons in the Neslen member; in addition there are local beds of coal, probably lenses, between these main horizons; all are shown graphically on plate 15 as locations 217 to 234.

A coaly bed occurs in the Palisade zone throughout the area, but on examination it is seen to be composed largely of bone and shale. Better coal is present at locations 222 and 225, but even here the clean coal is less than 14 inches thick. Though some of the sections were taken as much as 2 miles apart, it nevertheless appears safe to say that there is no coal of economic value at this horizon throughout the area. The coal correlated with the Palisade at locations 220, 221, and 222 is exceptionally high stratigraphically, and it may be doubted that a single bed is continuous through the area. The coal at location 226 is also high. Time was not available to traverse the coal. The sections show in detail other coaly beds both above and below this horizon, but in none of them is there enough clean coal to warrant specific mention.

The Ballard coal zone contains coal in the western part of the area, but east of locations 229 or 230 coaly material was found at only one or two locations at about this stratigraphic position. This horizon was not traced with certainty east of Cottonwood Wash, though its probable position in the sections as far east as location 232 is indicated on plate 15. The Ballard coal zone immediately underlies the Thompson Canyon sandstone bed throughout the western part of the area. It is of no value, as shown by the detailed graphic sections. Though fairly thick at location 218, it carries only 8 inches of coal, the rest

being bone. It is thick at location 224, but here clean coal is absent. Farther east it is very thin or absent. On the map its areal position may be taken as coinciding with that of the Thompson Canyon sandstone bed.

The position of the Chesterfield coal zone is shown on plate 10, from the west side of Cottonwood Canyon, in sec. 13, T. 19 S., R. 22 E., to the west side of Buck Canyon. Elsewhere in the area its position may be taken as essentially coinciding with that of the Thompson Canyon sandstone bed to the west or the Sulphur Canyon sandstone bed to the east. The maximum coal section at this horizon is at location 220, where 1 foot of clean coal (after deducting for partings) is present. Several coal beds are also shown slightly above this horizon, but none of them contain sufficient clean coal to be worthy of individual consideration.

A high coal zone, tentatively correlated with the Carbonera coal zone of western Colorado, is indicated on plate 15 as extending east from the section at location 232. Though fairly thick and well pronounced at locations 232, 236, 239, and 240 (the last three east of these townships but shown on pl. 11), the thickness of clean coal in any one of them is not sufficient to be of any possible economic importance. Near the top of the section at location 225 a thick coaly zone, possibly at this horizon, shows 14 inches of coal; but even this cannot be considered of economic value, in view of its small extent and relative inaccessibility.

TPS. 16 TO 18 S., RS. 24 TO 26 E., AND SOUTHEASTERN PART OF T. 18 S., R. 23 E.

No coals of possible economic value are present in the eastern townships of the Book Cliffs in Utah (Tps. 16 to 18 S., Rs. 24 to 26 E., and the southeast corner of T. 18 S., R. 23 E., shown on pl. 11). These townships are here described as a unit. The Book Cliffs extend in a northeasterly direction across the northern part of this area. Southeast of the main cliff is a bench capped by the Castlegate sandstone, a mile or so in width. The low cliff at the front of this bench rises above the Mancos shale flat. In the western part of the area the Castlegate bench is a pronounced topographic feature, inaccessible except where notched by canyons. Through T. 17 S., R. 25 E., it becomes much less pronounced, and near Taylor's ranch, on Bitter Creek, it is a mere minor hogback, parallel to the cliffs at a distance of a mile or less. The disappearance of this bench is due to the thinning of the Castlegate sandstone. This member is not mapped east of the SW¼ sec. 31, T. 16 S., R. 26 E., though it can be traced with some difficulty across the Colorado line. The Mancos flat has remnants of once widespread gravel aprons, as indicated on plate 11. Other large remnants in T. 19 S., R. 24 E., and T. 18 S., R. 25 E., are not shown.

The drainage flows southeast into the Colorado River through Cottonwood, Westwater, and Bitter Creeks and their tributaries. Of these Westwater Creek is the only perennial stream through the Book Cliffs proper, though seeps are found well up San Arroyo and Bitter Creek Canyons and in Sulphur Canyon in the SW¼SE¼ sec. 24, T. 18 S., R. 23 E. The water in Westwater Creek in T. 18 S., R. 24 E., is hardly potable except in an emergency, though suitable for animals. Potable water is available at the Roberson ranch in Westwater Canyon, but the ranches in Bitter and Bar X Canyons have only water from cisterns or reservoirs (tanks).

Inhabitants are few. Mr. and Mrs. McBeth occupy the Roberson ranch, in Westwater Canyon. Three miles downstream is the T. Larson ranch. Claude Taylor has a dry farm in sec. 9, T. 17 S., R. 25 E., along Bitter Creek, and Horace Violett has a ranch in Bar X Canyon in sec. 32, T. 16 S., R. 26 E. There are a number of houses on the gravel bench along United States Highway 50, south of Cottonwood Wash, but as far as known those within this area are uninhabited. About 3 miles southeast of the area shown on plate 11, in the NE¼ sec. 11, T. 20 S., R. 25 E., is the settlement of Westwater, on the east side of Westwater Creek between the railroad and the Colorado River. It consists of section houses, a water tank, and one or two farms; the precinct had in 1930 a population of 44. Cottonwood and Agate are merely sidings along the railroad between Westwater and Cisco. Supplies may be obtained from the State-line store (sec. 28, T. 9 S., R. 104 W., Colorado), from Mack (14 miles east of the Utah-Colorado line), or from Cisco (pl. 10).

United States Highway 50 crosses the southern part of the area, and the Denver & Rio Grande Western Railroad is 5 to 8 miles southeast of the highway. A good road branches from the highway in the southwestern part of T. 18 S., R. 25 E., and leads to the Roberson ranch, on Westwater Creek. Wagons can continue on this road up the main canyon and over the divide to the Bryson asphalt deposits, in the Uinta Basin (northern part of T. 16 S., R. 24 E.). A poor automobile road leads from the highway at the State-line store to Taylor's ranch, on Bitter Creek. The road leading from Wild Cow Wash, in sec. 36, T. 16 S., R. 25 E., was washed out in 1926. This joins a road from Violett's ranch, in Bar X Canyon, to Mack, Colo. A trail leads along the Castlegate bench from the west edge of the area mapped to Taylor's ranch, on Bitter Creek. It continues to the east along the Mancos flat but is rather indistinct.

All of this area has been surveyed, except T. 18 S., R. 25 E., and T. 19 S., R. 24 E.

Geology.—The stratigraphy of the area is shown graphically by sections 29 to 33, plate 7. Section 32 is given in detail on pages 32–34. The Castlegate sandstone member is not mapped east of the southwest corner of sec. 31, T. 16 S., R. 26 E., though it can be traced with some difficulty across the Colorado line. Farther east the strata below the Sego sandstone member are grouped with the Mancos shale.

Coal.—The character of the coals of the area is shown on plate 15 (locations 235 to 256). East of Westwater Creek this area was mapped so rapidly that the work must be regarded as of a reconnaissance nature. Moreover, this part of the area has not been carefully prospected; only two coal sections were taken east of the San Arroyo neighborhood (location 254), and none in Bitter Creek Canyon. The apparent absence of good coal in the sections taken, however, leaves little hope for the discovery of any worth-while coal in this area; if present, its areal extent is probably small.

Coal occurs at three general horizons, also in several local beds or lenses, all in the Neslen member. The outcrop line of the Chesterfield coal zone may be taken as essentially the same as that of the top of the Sulphur Canyon sandstone bed, which is shown on plate 11, except on a few points where the difference is sufficient to warrant adding a line for the Chesterfield coal zone. The coals of the Carbonera (?) zone were not mapped, as they are of no economic importance.

As shown on plate 15, the Palisade coal zone is fairly thick, except in the eastern part of the area, but at no place was over 5 inches of clean coal found. The zone includes mostly bone, but some sections show considerable amounts of carbonaceous shale. There is some doubt that the correlation shown in the graphic sections is correct. The coal at location 245, in East Westwater Canyon, may be slightly above this horizon. Near the place where the Palisade zone crosses Prairie Canyon, in sec. 30, T. 7 S., R. 104 W., Colorado, as reported by Erdmann, it carries 14 inches of dirty coal. At the place where it crosses Cottonwood Canyon, in sec. 16, T. 16 S., R. 26 E., the following section was measured at this horizon:

	Ft.	*in.*
Sandstone, white to yellow, massive.		
Bone and carbonaceous shale	1	3
Clay shale	3	6
Coal		11
Clay shale interbedded with white sandstone	3	
Shale, chocolate-colored, carbonaceous	4	
Sandstone (Sego member).		

Richardson [88] gives a section taken near location 241 in which three coal beds occur in the general Palisade zone, as follows:

	Ft.	in.
Shale, carbonaceous	5	
Coal	2	10
Shale, carbonaceous	3	
Sandstone, thin-bedded	4	
Coal	2	5
Shale, carbonaceous	3	
Sandstone, thin-bedded, buff	3	
Shale, carbonaceous	4	
Coal	1	3
Shale, carbonaceous	5	
Sandstone (Sego member).		

Though this section corresponds in a general way with the lower parts of those at locations 239 to 241, no such thicknesses of clean coal as those listed here were found in this general area during the present study. Both above and below what is designated as the Palisade coal zone on plate 15 are shown several coaly beds. None of these carry appreciable amounts of clean coal, and so no attempt was made to correlate them by tracing in the field. At locations 249 to 251 bone (with 10 inches of coal at location 251), is present at a horizon that possibly corresponds to the Ballard coal zone, which has been described for the areas to the west. Erdmann found a 2-foot local coal bed at or slightly below this horizon in Prairie Canyon (sec. 30, T. 7 S., R. 104 W., Colorado). As far as the Utah sections indicate the true character of this coal, it is of no economic importance—in fact, the horizon was not even recognized as carbonaceous at most locations.

The Chesterfield coal zone is present throughout the area, except possibly at location 241, though only carbonaceous shale is present at this horizon at locations 249, 253, and 254. Between locations 242 and 248, and elsewhere it appears to consist of a double bed. It lies at or only a short distance above the top of the Sulphur Canyon sandstone bed. The coal has been burned at a number of places, as is indicated on plate 11. Only at location 246, in East Westwater Canyon, was it found to carry more than 4 inches of pure coal; the section here shows 1 foot 7 inches of coal with considerable bone, both above and below. In this general area a fairly thick amount of bone is shown in all the sections taken. It is believed that the coal at location 246 gives way to bone in a relatively short distance, and so the coal here is considered to be of no practical value. Some years ago a small amount of material was removed from this bed at location 244, as is indicated in plate 6, *B*. It was hauled to the Roberson ranch by wagon, but attempts to burn it met with failure. Although this

[88] Richardson, G. B., op. cit. (Bull. 371), p. 37.

coal varies greatly within short distances, the section at this locality (pl. 15) demonstrates the worthless nature of the coal of the zone. Richardson's section [89] of this coal zone taken near location 241 follows:

	Ft.	in.
Sandstone, thin-bedded, buff	10	
Coal		10
Shale, carbonaceous	5	
Sandstone, thin-bedded, buff	5	
Shale, carbonaceous	1	
Coal	1	10
Shale, carbonaceous	2	
Sandstone, thick-bedded, buff	5	
Sandstone, shale, buff	35	

At the locality in Prairie Canyon in Colorado, Erdmann found 1 foot 3 inches of coal at or only 20 to 25 feet stratigraphically above this zone. Erdmann doubtfully correlates this coal with the Cameo bed, typically developed farther east in Colorado.

The Carbonera (?) coal zone according to Erdmann, carries four coal beds in Prairie Canyon. The horizon is readily correlated with that of the three high "coals" shown in the section at location 256, but farther west it was traced with some difficulty. The sections at locations 236, 239, and 240 show thick carbonaceous deposits at essentially this horizon, but the preponderance of bone over coal is so great that no economic importance can be attached to the bed as here developed. The section at location 242 shows bone present at three horizons well above the Chesterfield zone. It is possible that all of these should be correlated with the Carbonera. They are of no value. The same statement holds true for the "coals" of this zone as far east as location 256, as is shown by the graphic sections. In Prairie Canyon Erdmann took the following section of the coals of this zone:

	Ft.	in.
Sandstone, thin-bedded, shaly	20	
Coal	1	
Shale, carbonaceous	5	
Coal	1	9
Sandstone, platy	3	
Coal	1	5
Shale, carbonaceous		4–6
Shale and sandstone	8	
Sandstone, medium-grained, gray		6
Shale, carbonaceous, sandy		6
Coal	1	2
Shale, carbonaceous	11	9

On the north side of Cottonwood Canyon, just west of the State line, W. D. Johnston, a member of Erdmann's party, noted in the canyon wall at this horizon two coal beds, each about 1 foot thick, separated by 30 feet of strata. Johnston took the following section

[89] Richardson, G. B., op. cit. (Bull. 371), p. 36.

of Carbonera coals near the place where they cross Jim Canyon, in sec. 18, T. 16 S., R. 26 E.:

	Ft.	in.
Sandstone, gray, thin-bedded.		
Clay shale, gray	1	
Coal	1	6
Clay shale, gray.		
Interval	30±	
Sandstone, white, massive.		
Coal		2
Sandstone, white, massive	2	5
Coal	1	2
Clay shale, with intercalated sandstone	13	
Coal		7
Sandstone		½
Coal		11
Shale, brown, carbonaceous.		

These sections indicate that the bed is more promising at the east edge of the area, but none of the coal of this horizon in Utah—so far as can be determined from the data available—is sufficiently thick to encourage attempts at exploitation.

The sections at some of the locations show coaly beds of no value both above and below those that may be correlated with Carbonera.

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