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GEOLOGY AND OIL AND COAL RESOURCES OF THE OREGON BASIN, MEETEETSE, AND GRASS CREEK BASIN QUADRANGLES WYOMING

BY

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GEOLOGY AND OIL AND COAL RESOURCES OF THE OREGON BASIN, MEETEETSE, AND GRASS CREEK BASIN QUADRANGLES, WYOMING

By D. F. Hewett

INTRODUCTION

OBJECT OF WORK

The work upon which the following report is based was begun in 1911, before any explorations for petroleum had been made on the west side of the Big Horn Basin. The principal purpose of the work was to study the nature and structure of the rocks and any other features of the region that might yield a conclusion concerning the possible presence of petroleum. It was also the purpose to collect such data concerning the number, thickness, and distribution of the coal beds as could be obtained by simple prospecting with a pick and to gather any other geologic data that the region might yield.

That part of the work which was concerned with petroleum was completed in 1914, when large areas covering the anticlines that had been discovered were withdrawn from entry. A preliminary report on the occurrence of petroleum was published in 1917.[1] The present report contains all the data that were collected during the progress of the field work.

FIELD WORK

The field work was done chiefly in 1911, 1912, and 1913. In October, 1916, three weeks was spent in examining the recent developments in the oil and gas fields of the region, and in 1919 two months was devoted to making the surveys of the oil and gas fields described in this report. The total period covered by the field work was about 13½ months.

Most of the geologic field work was carried out in close cooperation with the Survey's topographic work in these quadrangles and at the same time. For more than half of the period of field work in 1911 to 1913 the writer accompanied the topographic party in charge of C. C. Gardner. Although a complete topographic map was thus not available while the geologic work was in progress, all the triangulation stations were known and were used to locate geologic observations.

In the survey of the Oregon Basin quadrangle and part of the Meeteetse quadrangle locations were made by compass sights on triangulation stations, and formation boundaries and coal beds were drawn on notebook sheets carried in the field. The horizontal position of points located by this method were shown to be correct within an allowable limit of error. The only vertical control was the barometer, whose readings were checked several times a day.

As work progressed southward into a region where surface relief is greater and coal beds crop out on steep escarpments, it seemed desirable to use a more accurate method. Therefore, in the southeastern part of the Meeteetse quadrangle and in the Grass Creek Basin quadrangle all points were located by telescopic alidade on a plane table, the triangulation stations established by the topographer being used for control. This method assured precise determinations of altitude as well as of horizontal position.

All stratigraphic sections less than 200 feet thick were measured by the clinometer method with a Brunton compass.[2] Thicker sections were measured by plane-table methods with telescopic alidade, but the details were filled in by the clinometer method.

ACKNOWLEDGMENTS

M. R. Campbell, geologist in charge of the section of western mineral fuels, supervised the work upon which this report is based from the initiation of field work to the completion of the original manuscript. During that period he was repeatedly a source of helpful criticism and suggestion, and appreciative acknowledgment is hereby made. E. G. Woodruff, assistant to Mr. Campbell, visited the writer in the field in 1911 and made valuable suggestions. The writer is also much indebted to David White for kindly consideration of many of the problems encountered in the region, and to W. T. Thom, jr., who succeeded Mr. Campbell, for reading and revising the manuscript. M. I. Goldman generously gave much helpful assistance in the preparation of the sediments for microscopic examination.

Millard Massey acted as teamster when the oil fields were revisited in 1916, and C. F. Hewett served as chauffeur in 1919. Without exception the residents

[1] Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 656, 1917.

[2] Hewett, D. F., Measurements of folded beds: Econ. Geology, vol. 15, pp. 382–384, 1920.

of the region gave cordial assistance and cooperation whenever the need was suggested. It is not possible to give the names of all who helped in one way or another from time to time. Special mention should be made of Quintin Littlejohn, E. L. Gwynne, David Dickie, Henry Dorrs, Fred A. Whitney, O. B. Mann, Ed. Pearson, Joseph Christopherson, and B. E. Wilson.

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GEOGRAPHY

SURFACE FEATURES

The area covered by this investigation lies along the west side of the Big Horn Basin, in northwestern Wyoming. In general the basin is a rather flat region bordered on the east, south, and west by high mountains. The Big Horn Mountains, on the east, rise nearly 9,000 feet above the lowlands of the basin. The Bridger and Owl Creek mountains, on the south, rise about 4,000 feet above the adjacent parts of the basin, and the Absaroka Mountains, on the west, rise about 6,000 feet above the stream valleys. Toward the north the basin merges into the plains region of southern Montana.

Although the basin as a whole appears flat by comparison with the surrounding mountains, it contains several mountains and ridges that rise 1,000 to 1,500 feet above the near-by valleys and basins. The most conspicuous mountains, Squaw Buttes (6,200 feet), McCulloch Peak (6,200 feet), Tatman Mountain (5,800 feet), and Heart Mountain (8, 080 feet), lie near the central part of the basin, east of the quadrangles described in this report. The valley of Big Horn River, which ranges from 3,800 feet above sea level in the northern part to 4,200 feet in the southern part, is the lowest part of the basin. The principal tributaries of the Big Horn—Clark Fork and Shoshone and Greybull rivers—flow in rather narrow valleys cut from 200 to 600 feet below the neighboring uplands.

The surface features as well as the stratigraphy and structure of the Big Horn Basin can be better understood if the basin is considered as being made up of two parts, although there is no natural sharp division between them. The central part of the basin coincides roughly with the area underlain by Wasatch and younger beds and is about 75 miles long measured in a northwest direction by 45 miles wide measured in a northeast direction. (See fig. 1.) For a considerable distance along the southwest side of the basin the limit of the central part is an escarpment which coincides with a bed of conglomerate at the base of the Wasatch formation. The central part may be regarded as surrounded by a border belt from 10 to 20 miles wide, the outer limit of which is the area of Wasatch and younger volcanic rocks on the southwest side of the basin and the higher part of the Big Horn Mountains on the northeast side. As shown in Figure 1, the three quadrangles considered in this report include portions of the central part of the basin and mountains on the southwest, but by far the largest part of the quadrangles lies in the border belt.

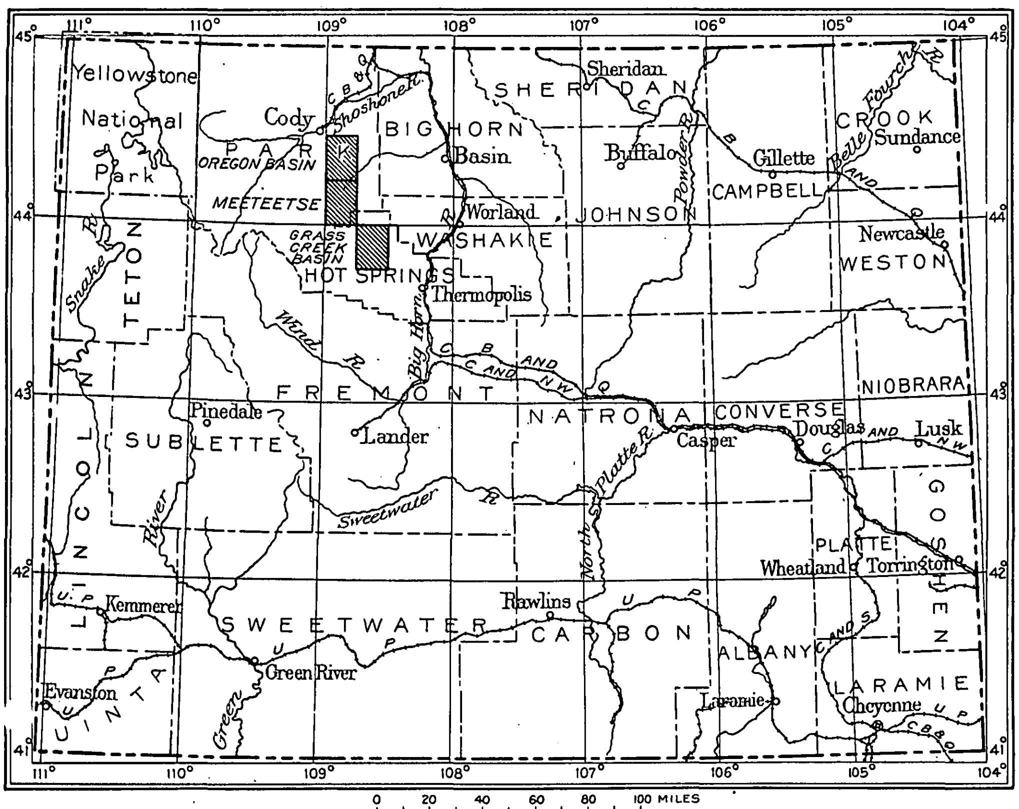


FIGURE 1.—Map of Wyoming showing location of Oregon Basin, Meeteetse, and Grass Creek Basin quadrangles (shaded areas).

THE CENTRAL PART

The central part of the basin is underlain by nearly flat rocks, most of which do not readily resist erosion. The higher hills and ridges, such as Tatman Mountain and Squaw Buttes, are rugged, as they are made up of numerous terraces that coincide with the harder outcropping sandstones. They lie midway between the stream courses of the region and present many local badland areas. McCulloch Peak [3] is bordered by badlands on the east, north, and west and gently sloping terraces on the south but owes its preservation to several local blocks of limestone that are the remnants of an extensive overthrust block.

The southwestern limit of the central part of the basin crosses these three quadrangles and roughly coincides with the escarpment produced by the conglomerate at or near the base of the Wasatch formation. The escarpment is well developed in the Oregon Basin quadrangle, where it faces west and ranges from 100 to 300 feet in height. East of the escarpment there are traces of a nearly level upland from which rather smooth, gently sloping ridges extend generally east or northeast. Here and there the courses of intermittent streams terminate headward in local rugged badlands.

This portion of the central part of the basin presents a forbidding aspect. The lack of water prevents the growth of vegetation except a few grasses and dwarfed sage brush, so that the naturally brilliant colors of the rocks are unsoftened. The region is uninhabited except during the late fall and the winter, when roving sheep herders guide their flocks over it.

[3] Hewett, D. F., The Heart Mountain overthrust: Jour. Geology, vol. 28, pp. 536–557, 1920.

Southeast of Greybull River the escarpment turns eastward near Meeteetse and passes out of the Meeteetse quadrangle north of the Hole in the Ground. The nearly level upland surface east of it is intricately trenched to a depth of 200 or 300 feet by narrow valleys, through which intermittent streams flow northward to Greybull River and eastward to Fifteenmile Creek.

In the northeast corner of the Grass Creek Basin quadrangle the Wasatch escarpment marks the southwestern border of the central part of the Big Horn Basin. Blue Ridge and its eastward extension, Blue Mesa, are remnants of a level upland which merges on the north into a group of rugged ridges that slope gently northeast toward Gooseberry Creek.

THE BORDER BELT

A large part of the area of the three quadrangles lies within the border belt of the Big Horn Basin. There are five principal features of the border belt in this region—(1) a group of rudely elliptical basins cut 300 to 500 feet below an extensive upland surface; (2) the major valleys occupied by the main streams, which rise in the mountains and flow generally northeastward to Big Horn River, on the east side of the basin; (3) the minor valleys of the tributary intermittent streams, which flow in widely different directions; (4) the remnants of two nearly level gravel-covered upland terraces; and (5) the remnants of two nearly level gravel-covered valley terraces, best developed along the valleys of the main streams.

BASINS

The basins are a characteristic feature of the border belt throughout the Big Horn Basin but are best developed on the west side. Some are nearly simple ellipses in shape, such as Little Buffalo Basin east of Meeteetse; others are curved, such as Grass Creek Basin; in others, erosion has proceeded so far that two basins have been merged to form a depression of rather irregular shape, such as the area near Wagonhound Bench. Most of the basins are nearly surrounded by rough escarpments 300 to 500 feet high, which are almost impassable. In general those parts which face south or southwest are steeper and more rugged than those which face north or northeast.

The basins range in size from the largest, Oregon Basin, 5 by 13 miles, to the smallest, that along Gooseberry Creek at Renner's ranch, which is scarcely a mile in diameter. They coincide with anticlines or similar upfolds and have been developed where erosion has first removed an overlying group of hard massive sandstones and then cut deeply into an underlying group of soft sandstones and shales. The local features are largely determined by the presence or absence of through-flowing streams, the attitude of the rocks, and the presence or absence of faults. Thus the floors of those basins that are traversed by through-flowing streams, such as Grass Creek and Cottonwood basins, are rather smooth and featureless, and there are remnants of flat gravel-covered terraces near the streams. Oregon and Little Buffalo basins have more uneven floors and no broad, flat terraces. The escarpment around Little Buffalo Basin is unbroken except for the gaps through which an intermittent stream flows, whereas the eastern escarpment of Oregon Basin is interrupted by numerous gaps, most of which coincide with faults.

In the northern part of Oregon Basin there is an unusual depression, about 8 square miles in area, which demands specific consideration. It practically coincides with the Loch Katrine Bird Reservation. This part of the basin is uncommonly flat, and near the center of it there is an intermittent lake which contains water only in winter and spring. During the rest of the year the lake is marked by a thin alkali efflorescence. The soil for half a mile or more around the border of the lake is only loosely coherent, so that the feet of passing horses quickly sink to a depth of several inches. Except near the borders of the intermittent lake the basin is exceptionally barren of vegetation. This part of Oregon Basin is bounded on the west and north by a rugged escarpment of hard sandstone. Similar sandstone crops out locally on the east, but a large part of the eastern boundary is a flat terrace locally covered with a thin layer of gravel. On the south there is a series of low ridges along which thin-bedded sandstone crops out.

As the lowest part of the basin is 92 feet lower than the lowest part of the limiting ridges, which appear to be cut in hard rocks an uncommon explanation of its origin is evidently demanded. If it is assumed that the material removed from the basin was transported by running water, it would be necessary to assume also that an extraordinary deformation of the rocks had taken place since that time. A clue to the probable mode of origin is afforded by the sand dunes that are found in the region southeast and east of the depression. Sand dunes are common in many parts of the west side of the Big Horn Basin but are more numerous in the region east and southeast of Oregon Basin than elsewhere. It is known through the experience of travelers in the region that during windstorms, especially, in the summer and autumn, enormous quantities of silt and fine sand are caught up and carried farther east or southeast. The shale near the base of the Cody shale is readily weathered and under the action of rain and frost forms a light, porous soil in many parts of the Big Horn Basin. It is apparent that the wind is constantly removing thin loose soil and that this process long continued has produced the depression. In order to explain the absence of similar depressions near by, it is necessary to assume that the location and form of Oregon Basin are favored by the prevailing winds.

Other evidence of the movement of considerable quantities of soil by the wind is found near Oregon Basin. In sec. 16, T. 52 N., R. 101 W., a small watercourse has been dammed by sand dunes so that water collects during the wet season (Pl. IV, *C*). In sec. 26, T. 52 N., R. 100 W., wind-blown soil covers nearly every outcrop for several square miles, and an intermittent lake about 80 acres in extent has been formed.

MAJOR VALLEYS

The valley of Greybull River is the largest and agriculturally the most important in the region, but that of its tributary Wood River is nearly as large and important. These rivers flow in narrow channels cut 10 to 30 feet below a terrace that commonly ranges from 4,000 to 5,000 feet in width. As the terrace is covered by a layer of gravel and soil, and water may be drawn from the river by ditches, it is extensively cultivated; probably one-half of its area is constantly under cultivation.

MINOR VALLEYS

Sage, Gooseberry, Grass, and Cottonwood creeks rise in the mountains, but their flow is small and their channels are cut only 5 to 15 feet below the adjacent terraces. These terraces are much narrower than those along Greybull River, but they are cultivated here and there. Bedrock crops out locally along the banks and in the channels.

It is noteworthy that although the prevailing strike of the rocks on the west side of the basin is northwest, only one of the four major streams, Grass Creek, deviates appreciably from a general northeasterly course in traversing the belt of folds.

Only a glance at the topographic maps is needed to show that the valleys of the many minor intermittent streams of the region have widely diverse forms, and they also differ greatly in their relations to the underlying rocks. A few are simple, smooth, straight valleys, several miles long, such as Long Hollow, which normally carries no water on the surface, whereas many others, such as Iron Creek, Spring Creek, and Little Prospect Creek, have highly sinuous courses with steep, rugged bordering slopes. Such sinuous valleys rarely show any definite relation to the structure of the underlying rocks. On the other hand, in several parts of the region broad, rather smooth valleys occupied by short intermittent streams closely follow belts of soft rock. Such valleys almost encircle the basins and are particularly well developed south of Oregon Basin and around Little Buffalo, Grass Creek, and Cottonwood basins. These valleys are formed by the erosion of the Meeteetse formation and locally of the Lance formation.

HIGH TERRACES

One of the most striking features of the Oregon Basin and Meeteetse quadrangles consists of the remnants of high gravel-covered terraces. The largest of these remnants form a chain 20 miles long and are known as the Meeteetse Rim. They are nearly flat treeless surfaces, which are limited abruptly by the steep slopes of the neighboring valleys. They are uniformly underlain by a layer of coarse gravel and boulders, 10 to 50 feet thick. In some places there is sufficient soil to conceal the gravel. By comparing the altitudes and slopes of these terrace remnants, it has been possible to identify two high terraces as well as two lower terraces that are confined to the valleys of the present streams. The distribution and features of the four terraces are summarized in the table on page 7.

There are only three remnants of the highest or Cottonwood terrace, whose aggregate area is less than a square mile. The remnants are too small to yield more than a general impression concerning the form and extent of the surface of which they were once a part. The altitude of the highest remnants underlain by gravel is about 6,500 feet, and all lie within 2 miles north of the Greybull Valley. It is noteworthy, however, that in the region between Wood River and Cottonwood Creek there are many smooth, nearly flat-topped hills and ridges that range in altitude from 6,600 to 7,200 feet and lack a cover of gravel. It appears probable that at the time when the region north and west of Meeteetse was being reduced to a plain and covered by gravel brought from the mountains farther west, the region south of Meeteetse was being reduced to smooth flat or rounded hills and ridges that did not rise far above the level of the surrounding country.

The gravel that underlies this terrace consists largely of dark lava and reddish and gray quartzite. The quartzite cobbles are clearly those derived from the conglomerate at the base of the Fort Union formation. The largest are 10 inches in diameter, whereas the lava cobbles are as much as 3 feet. Glacial striae have not been detected on any cobbles or boulders from this terrace.

There are a sufficient number of remnants of the next lower or Rim terrace to permit a fair interpretation of its original distribution and features. On Figure 2 contour lines with 100-foot intervals have been drawn on the inferred surface. Although the lines are smooth rather than broadly sinuous, they convey a rather accurate impression of the surface. The terrace was largely developed west of Wood River (Pl. IV, *B*) and northwest of Greybull River (Pl. IV, *A*), and in that region, with the exception of the single remnant of the higher Cottonwood terrace, no hill or ridge appears to have risen above it. The terrace was made up of two broadly curved but nearly flat surfaces which met in a low depression near the present position of Meeteetse Creek. The slope of these surfaces ranges from 50 to 100 feet to the mile.

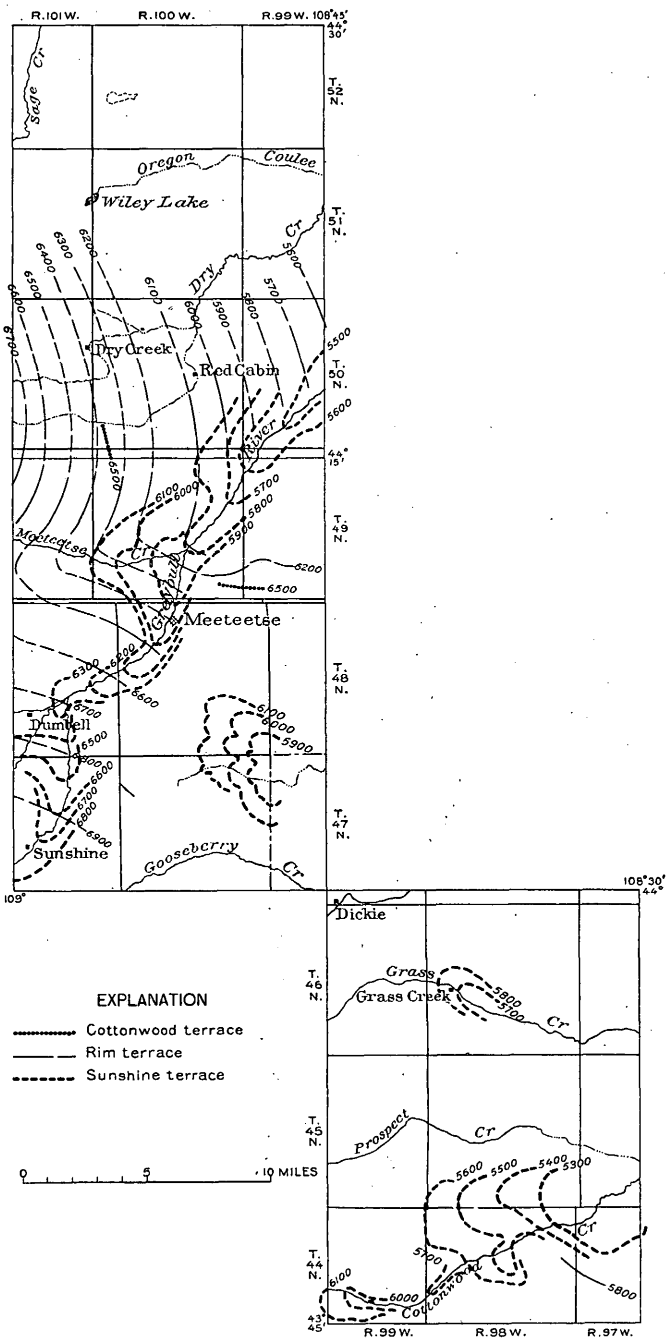


FIGURE 2.—Sketch showing partly restored contours on surfaces of the Cottonwood, Rim, and Sunshine terraces. Contour interval 100 feet.

If the contours are projected southeastward across Greybull River, they intersect higher surfaces cut in the rocks that underlie the region. On the other hand, there is a single small remnant of the terrace east of Wood River and separated from it by a ridge which rises 200 to 300 feet above the terrace.

In sec. 18, T. 44 N., R. 97 W., in the Grass Creek Basin quadrangle, there is a small remnant of a terrace that is correlated with the Rim terrace farther north. A larger remnant lies in sec. 35, T. 44 N., R. 99 W., south of this quadrangle. The surface slopes gently northeastward, and even though no other remnants exist near by, it is apparent that this terrace was not as extensive as that north of Greybull River.

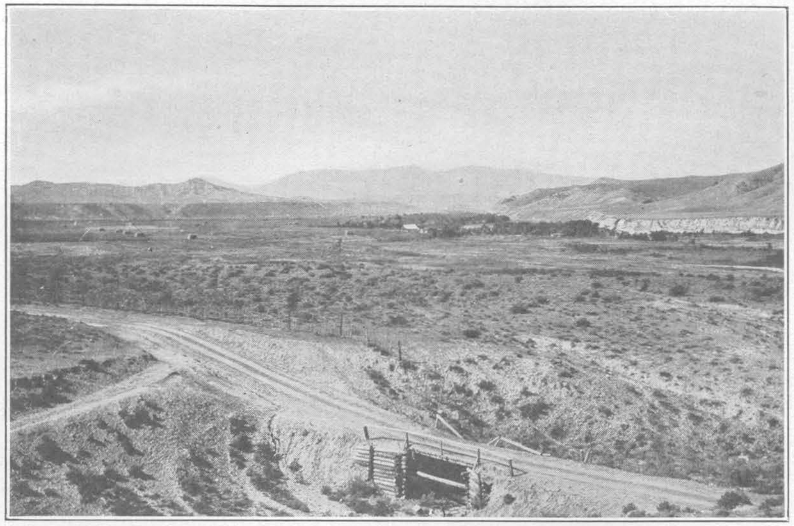
The thickness of the gravel that lies upon this terrace ranges from 30 to 50 feet; the maximum thickness is found nearest the mountains. Dark lavas predominate throughout the area, and the largest lava boulder, 4 by 4 by 5 feet, was found in sec. 11, T. 49 N., R. 101 W. The exposed parts of the lava boulders are commonly weathered, so that a thin outer shell has been set free. Reddish and gray quartzite are persistently present, but the largest cobbles of these rocks rarely exceed 10 inches in diameter. Cream-colored limestone is generally present in the areas north of the Meeteetse Rim but is absent south of it. As a rule the size of the pebbles of each variety of rock is smaller the greater the distance from the mountains. Glacial striae have not been observed on any of the boulders.

LOW TERRACES

The valleys of most of the streams, intermittent as well as perennial, show traces of two terraces. The terraces are wider, more nearly level, and more extensive in the valleys of the perennial streams, which rise in the mountains. Also the cover of gravel is thicker and more persistent along the perennial streams.

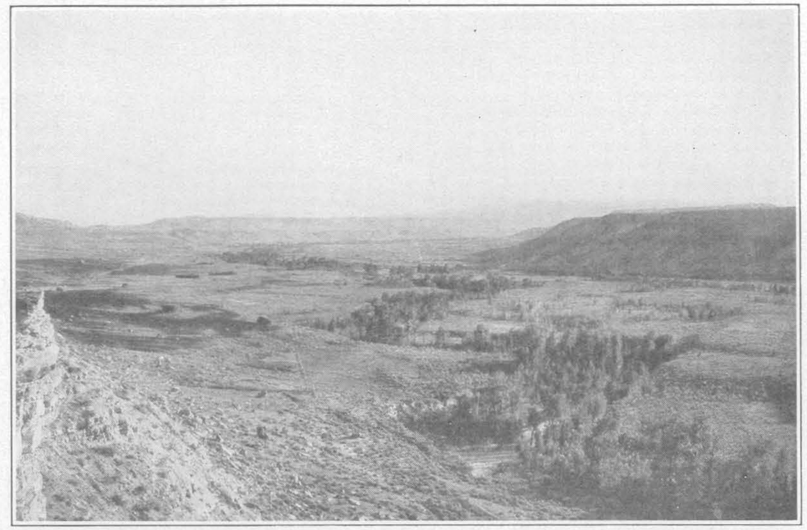
The higher or Sunshine terrace is well developed along Wood River near Sunshine (Pl. IV, *B*), Meeteetse Creek, Greybull River (Pl. IV, *A*), Grass Creek, and Cottonwood Creek. The larger remnants of the terrace are commonly found on the north and west sides of these streams. The cover of gravel ranges from 8 to 15 feet in thickness, and the lithologic varieties are the same as those on higher terraces near by. Few of the cobbles exceed 10 inches in diameter.

In most of the smaller valleys, such as those in Oregon Basin near Elk Butte, in Spring Creek Basin, and in Little Buffalo Basin, there are smooth, locally gravel-covered surfaces adjacent to the narrower and steeper valleys in which the streams flow. Such terraces are well shown in sec. 6, T. 50 N., R. 100 W., in Oregon Basin; in sec. 4, T. 48 N., R. 101 W., in Spring Creek Basin; and in sec. 2, T. 47 N., R. 100 W., in Little Buffalo Basin. Although the difference in altitude between these terraces and the streams near by is much less than in the valleys of perennial streams, they can doubtless be correlated with the Sunshine terrace.



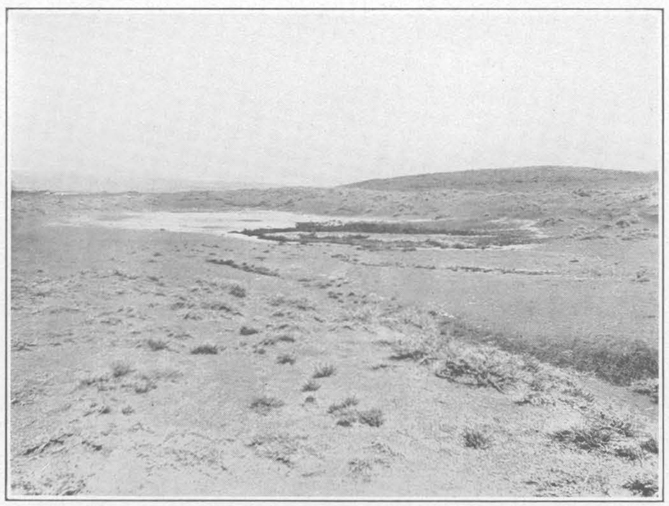
A. VIEW SOUTHWEST UP THE GREYBULL RIVER VALLEY 1 MILE ABOVE MEETEETSE, IN SEC. 8, T. 48 N., R. 100 W.

Terraces of the Sunshine stage are well shown on the left side of the valley

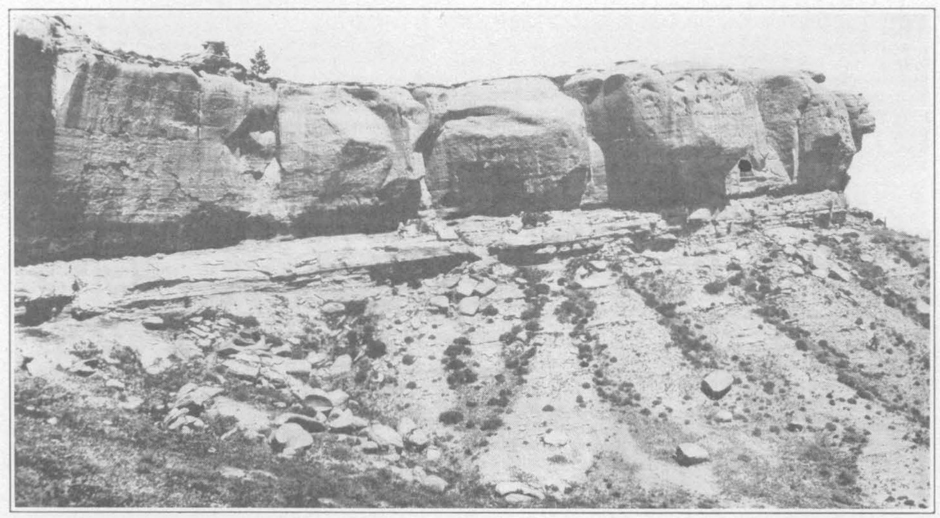


B. VIEW SOUTH UP THE WOOD RIVER VALLEY FROM GREYBULL RIVER, IN SEC. 27, T. 48 N., R. 101 W.

Terraces of the Sunshine stage and the Rim stage are shown on both sides of the river



C. SEASONAL PLAYA CAUSED BY DAMMING OF SMALL WATER-COURSE BY SAND DUNES, SEC. 16, T. 52 N., R. 101 W.



D. BASAL SANDSTONE OF THE MESAVERDE FORMATION IN SEC. 1, T. 51 N., R. 101 W.

Showing character of uppermost beds of Cody shale and massive bedding of the lower sandstones of the Mesaverde. Photograph by E. G. Woodruff

The lowest terrace constitutes the floor of the valleys of through-flowing streams and is best developed along Greybull River, for which it is named. The Greybull terrace is also fairly well developed along Cottonwood and Meeteetse creeks. In Grass Creek Basin it is represented by the smooth, gently sloping surface adjacent to the creek on the south side of the basin. The streams of the region flow in narrow channels cut from 10 to 40 feet below this valley-floor terrace. It is largely covered by a layer of gravel that attains a maximum thickness of about 10 feet, and this in turn is covered by a layer of soil that rarely exceeds 5 feet in thickness. Most of the land that is cultivated in the region and all that is irrigated lies on this valley-floor terrace.

In other words, the difference in altitude between each pair of terraces increases from the lower part of the Big Horn Basin southwestward toward the mountains. A reconnaissance up Greybull River to Fourbear and up Wood River to Kirwin shows that this tendency continues to the points where the streams leave the mountains.

The purposes to be served by the investigation of these quadrangles did not permit the detailed studies and regional observations that would be needed to interpret satisfactorily the extent to which several possible factors enter into an explanation of the origin of the four groups of land forms observed in the region. The following paragraphs set forth briefly some of the tentative conclusions that have been reached.

Features of terraces of the west side of Big Horn Basin, Wyo., and correlation with terraces of Wind River valley

Big Horn Basin						Wind River valley [a]	
Name	Areal distribution	Height above near-by stream (feet)	Height above next lower terrace (feet)	Thickness of gravel (feet)	Character of gravel	Name	Height above near-by stream (feet)
Greybull or Valley Floor	Valleys of major streams such as Meeteetse Creek, Wood River, Greybull River, and Grass and Cottonwood creeks; also some minor streams.	10-40		5-10	Largely andesite with minor assortment from higher terraces, covered with soil; range in size, 1-6 inches.	Lenore	10-60
Sunshine	Valleys of major streams, especially Wood and Greybull rivers and Meeteetse, Grass, and Cottonwood creeks.	Lower Greybull 180 Upper Greybull 225 Upper Wood 225 Grass Creek 150 Cottonwood 140	Lower Greybull 150 Upper Greybull 225 Upper Wood 250 Grass Creek 125 Cottonwood 125	8-15	Largely andesite with minor assortment from higher terraces; soil practically absent; range in size, 1-8 inches.	Circle	100-200
Rim	Meeteetse Rim and region north of Greybull River and west of Wood River; upper Iron Creek; Cottonwood-Owl Creek divide; Elk Butte.	Lower Greybull 450 Upper Greybull 550 Upper Wood 550 Lower Cottonwood 450 Upper Cottonwood 450	Lower Greybull 250 Upper Greybull 300 Upper Wood 300 Lower Cottonwood 200 Upper Cottonwood 250	Elk Butte 40-50 Meeteetse Rim 30-50 Wood River 30-40 Cottonwood 10-15	Largely andesite with Fort Union quartzite; some limestone north of Meeteetse Rim; maximum boulder 4 by 4 by 5 feet.	Black Rock	500-800
Cottonwood	Divide between Dry and Cottonwood creeks 3 miles northeast of Meeteetse.	Dry Creek 650 Meeteetse 850	Dry Creek 150 Meeteetse 250	Dry Creek 30 Meeteetse 25	Largely andesite, 2 by 2 by 3 feet maximum size; some quartzite, 3 by 5 by 10 inches maximum size.		

[a] Blackwelder, Eliot, Post-Cretaceous history of western Wyoming: Jour. Geology, vol. 23, pp. 306-321, 1915.

INTERPRETATION OF EROSIONAL HISTORY

An element that has considerable bearing on the interpretation of the origin of the higher terraces is their actual and relative gradient. The gradient of Greybull River, a graded stream, deviates but little from 50 feet to the mile in the 19 miles of its course in these quadrangles. The average downstream gradient of the Sunshine terrace is about 55 feet to the mile, and the steepest gradient of the Rim terrace, eastward along Meeteetse Rim, is 88 feet to the mile. The difference in altitude between Greybull River and the Sunshine terrace is 250 feet on the western border of the quadrangles and 200 feet on the eastern border. Similarly, the difference in altitude between the Sunshine terrace and the Rim terrace is 450 feet on the western border and 250 feet on the eastern border.

It has been shown elsewhere[4] that the Tertiary period brought a complex succession of processes in this region—deposition of sediments, deformation, and erosion. The age of the highest or Cottonwood terrace, which is the oldest of the surface forms found in these quadrangles, is not definitely known, but it is tentatively regarded by Alden as possibly Miocene. Before this terrace was dissected it was probably a nearly level surface that extended over the entire area from points several miles southeast of Greybull River northward to Shoshone River and possibly farther. A river, probably the predecessor of the Greybull, flowed in a broad flat valley several miles northwest of the present course of that stream. The region between Greybull River and Owl Creek was

[4] Hewett, D. F., The Heart Mountain overthrust: Jour. Geology, vol. 28, pp. 536-557, 1920.

not reduced to a plain but was an area of low, irregularly disposed hills. At this time the principal western tributaries of the Big Horn River appear to have flowed N. 30°–60° E.

Later the Absaroka Mountains were uplifted; the streams cut deeper channels and almost completely destroyed the Cottonwood terrace. Finally, a new plain, now represented by the Rim terrace, was established over the area northwest of Greybull River and in local tracts near Cottonwood Creek and possibly farther southeast. This plain appears to have been nearly level over the entire region except for one or more small remnants of the higher plain and the broad valleys of the ancient Greybull River and a stream that flowed eastward near the present course of Meeteetse Creek. The absence of striated boulders in the gravel on this terrace suggests that the material consists of outwash from vigorous glacial streams that rose in the mountains and spread over the plain to the east. The absence of limestone in the gravel on the Meeteetse Rim and farther south shows that the streams which deposited the gravel flowed east rather than northeast or north. The lack of the customary evidence of advance and retreat of glaciers seems to preclude the assumption that the largest boulders on this terrace were moved by glaciers.

With renewed uplift the streams cut into the Rim terrace, became graded, and meandered sufficiently to cut the broad, flat valleys indicated by the remnants of the Sunshine terrace. During this period of down-cutting there were apparently numerous local changes in drainage. Several of these changes will be indicated, although to obtain clear proof of them the areas should be more closely studied. Long Hollow, which is a distinct valley but has no inner stream channel, was apparently cut by a stream that flowed eastward from the mountains but has been beheaded by Meeteetse Creek, cutting headward along a belt of soft rock (Cody shale). Similarly Grass Creek appears to have originally flowed northeastward across Grass Creek Basin, nearly following the general course of Canyon Coulee to Gooseberry Creek. The waters of upper Grass Creek were captured by a stream cutting northwest along the outcrop of Cody shale from the vicinity of Gwynn's ranch. There is reason for suspecting that the broad eastward sweep of Shoshone and Greybull rivers and Gooseberry and Cottonwood creeks near the center of Big Horn Basin is to be attributed to the successive periods of uplift that followed the cutting of the Cottonwood and Rim terraces.

The formation of the Greybull or valley-floor terrace in the several valleys indicates a third uplift of the mountain region, and the cutting of the present stream channels indicates a fourth. The present inquiry has not determined the extent to which changes of climate have played a part in the rapid cutting of valleys or the distribution of layers of gravel over plains or terraces. Although this factor may deserve consideration, there can be little doubt that successive uplifts following periods of quiescence have been the principal cause of these changes. The evidence of the removal of considerable soil by the wind indicates that the present dry climate has persisted for some time, possibly since the latest uplift.

STREAMS AND WATER SUPPLY

STREAMS

Greybull River is the largest stream in the region under consideration and with its principal tributary, Wood River, determines the distribution of most of the settlements. From the point where it leaves the mountains at Fourbear, 22 miles above Meeteetse, to its junction with Big Horn River, a distance of about 80 miles, its waters are drawn for the irrigation of ranches in or near its valley. The discharge of the river has been measured from time to time by engineers of the United States Geological Survey,[5] and gages have been read by local observers. In 1903 a gage was installed on the bridge at Meeteetse, but in 1910, 1911, 1912, 1915, and 1916 readings were made at the bridge to Wilson's coal mine, in sec. 13, T. 48 N., R. 101 W. The available records extend from March to November in these years; none have been collected during the winter.

The records indicate an extreme range from 80 cubic feet a second in April to 4,400 cubic feet in July. Commonly the range is from 120 cubic feet in April to 2,200 cubic feet in July and 150 cubic feet in November. Although the water carries much clay in times of flood, it is generally clear. It is widely used for domestic supplies, either drawn directly or from ditches.

Wood River leaves the mountains 17 miles above its junction with Greybull River and is repeatedly drawn upon for irrigation in its valley as well as that of Sunshine Creek, which parallels it on the west. Measurements of the discharge have been made by engineers of the United States Geological Survey and by local observers in 1910, 1911, 1912, 1915, 1916, and 1917.[6] The gage is placed on the left bank of the river 400 feet above the bridge, near its junction with Greybull River. The records generally extend from March to November. They show an extreme range from 30 cubic feet a second in April to 867 cubic feet in June. Commonly the range is from 40 cubic feet in April to 600 cubic feet in June and 50 cubic feet in October. The water is clear and cool and is widely used for domestic purposes.

[5] See U. S. Geol. Survey Water-Supply Papers 99, p. 88, 1904; 286, p. 186, 1911; 306, p. 201, 1914; 326, p. 198, 1914; 406, p. 145, 1917; 436, p. 135, 1919.

[6] U. S. Geol. Survey Water-Supply Paper 456, p. 126, 1921.

The portion of Sage Creek lying within the Oregon Basin quadrangle carries a surface flow most of the year, though in dry seasons the part in sec. 9, T. 51 N., R. 101 W., contains only a few pools of water. The water is used for irrigation in the lower Sage Creek valley but is unfit for domestic use. Estimates in August and September indicate a surface discharge of 5 to 10 cubic feet a minute.

During the summer Oregon Coulee, Dry Creek and its South Fork, and Cottonwood Creek contain many pools of alkaline water that is unfit for drinking. Springs at Dry Creek and Red Cabin augment the flow of Dry Creek.

Meeteetse Creek maintains a vigorous surface discharge until midsummer, when drafts for irrigation reduce its lower course to pools here and there. Its water is fit for drinking throughout the year.

Spring Creek, in the Meeteetse quadrangle, yields a small flow until midsummer, when only a few pools of alkaline water remain for the greater part of its course.

Rawhide Creek carries water on the surface, which is used for irrigating at Whitney's ranch, in sec. 23, T. 48 N., R. 101 W.

Iron Creek rises in some ferruginous seeps in sec. 31, T. 48 N., R. 100 W., but in summer contains only a few pools of alkaline water.

Sunshine Creek yields a flow on the surface until midsummer, when only a few pools of alkaline water remain.

Little Buffalo Creek rises in a seep in sec. 5, T. 47 N., R. 100 W., and yields a surface flow of alkaline water for most of its course during the entire year. The flow in August, 1919, at the point where the stream leaves Little Buffalo Basin, was estimated at 3 to 5 cubic feet a minute. The water is unfit for drinking.

Gooseberry Creek yields a flow on the surface for its entire course in the Meeteetse quadrangle throughout the year. Near Dickie's ranch, below the intake of several ditches, the flow in August, 1912, was estimated to range from 5 to 10 cubic feet a minute. Although the water has a noticeably alkaline taste it is used for domestic purposes.

Canyon Coulee is dotted with pools of highly alkaline water during the summer but the water is fit only for use by stock.

Grass Creek rises in the mountains and, although drawn upon for irrigation in Grass Creek Basin, yields a surface flow throughout the year in the Grass Creek Basin quadrangle. In September, 1913, the surface flow was estimated to range from 3 to 8 cubic feet a minute. Before oil wells were drilled in this area and their waste contaminated the stream the water was used for domestic purposes.

Spring Gulch is so called on account of several springs of clear alkaline water that rise from the gravel in its bed in sec. 5, T. 45 N., R. 98 W. In August, 1913, the flow was estimated at 1 to 2 cubic feet a minute. After flowing on the surface for 500 feet the water sinks into the ground.

Prospect Creek contains numerous pools of water throughout its course, in some of which an appreciable current may be noted. The water in the pools above its junction with Little Prospect Creek may be used for drinking even late into the summer. The water in its lower course and in Little Prospect Creek is unfit for drinking.

Wagonhound Creek is dotted with pools of alkaline water during the summer and in used only by stock.

Cottonwood Creek yields a surface flow throughout the year above Richman's ranch. The discharge in August, 1913, was estimated at 3 cubic feet a minute. During the summer the entire flow is diverted for irrigation, and the lower course contains only a few pools of water that is scarcely fit for drinking.

SPRINGS AND WELLS

Except those who live in the valleys of Greybull and Wood rivers, most of the inhabitants of the region depend upon water drawn from springs or wells. At a few sheep camps, used only in the spring when sheep are sheared, water is collected from roofs and stored in cisterns.

Mud Springs, in sec. 24, T. 52 N., R. 100 W., yield a small flow that is used for drinking by sheep herders. The spring in sec. 15, T. 50 N., R. 101 W., yields several gallons a minute of clear nonalkaline water whose source is obscure.

Wagonhound Spring, in sec. 25, T. 45 N., R. 99 W., rises in a ravine which is cut in thin sandstones near the top of the Cody shale. It yields several gallons a minute of rather alkaline water which from time to time is used for drinking.

In many parts of the region springs are found where deep ravines cut through the beds of sandstone near the top of the Mesaverde formation. The discharge of such springs rarely exceeds a few gallons a minute, and the water is commonly too highly charged with iron and alkali to be usable for drinking. The spring at Dry Creek, in sec. 12, T. 50 N., R. 101 W., is an exception.

Water of fair quality is obtained at many ranches in the valleys of the smaller streams by digging wells within several hundred feet of the stream channels. Such wells range in depth from 5 feet in Long Hollow to 50 feet in Grass Creek Basin. They derive their water from layers of gravel adjacent to or considerably deeper than those upon which the present streams flow. There are several in Long Hollow and a number in the valleys of Gooseberry, Grass, and Cottonwood creeks. The domestic supply of the Ohio Oil Co.'s camp at Grass Creek is drawn from four wells drilled with a portable rig to depths of 20 to 64 feet. Each well yields 20 to 25 barrels of water daily.

In order to avoid the uncertainties of surface supplies some residents of Meeteetse and vicinity have drilled deep wells to obtain water. The water from these wells is cool and clear but is perceptibly alkaline to the taste. A well 437 feet deep, in J. Faust's stable, drilled in beds of the Meeteetse formation, flows 10 gallons an hour. In another well in the same beds at R. J. McNally's house, east of Meeteetse, drilled to a depth of 150 feet, water stands 70 feet below the surface. The water is raised by a windmill and used for irrigating. Another well 80 feet deep, at A. A. Linton's house, yields a small flow.

In 1899 a well was drilled to a depth of 275 feet near the stable on O. B. Mann's ranch, in the SW. ¼ sec. 8, T. 48 N., R. 100 W. The water was at first used for drinking, but recently the taste of iron and alkali has become strong. The flow, derived from upper sandstones of the Mesaverde formation, ranges from 30 to 40 gallons an hour.

In a well drilled to a depth of 375 feet near the barn on F. A. Whitney's ranch, in the NW. ¼ sec. 23, T. 48 N., R. 101 W., water stands at a depth of 40 feet below the surface but has never flowed.

A well whose depth is unrecorded but is probably more than 200 feet and which therefore is in beds of the Meeteetse formation near David Dickie's house in sec. 23, T. 47 N., R. 99 W., yields a flow of several gallons a minute.

A well drilled to a depth of 247 feet near the house of Q. Littlejohn, in the NW. ¼ sec. 28, T. 46 N., R. 98 W., failed to find water. It penetrated shale and thin sandstone belonging to the Cody shale.

By way of summary, it may be stated that wells drilled into the sandstones in the Frontier formation, near the top of the Cody shale, near the top of the Mesaverde formation, or near the base of the Meeteetse formation at places where the beds are inclined, are likely to encounter water susceptible of domestic use. The beds of the lower half of the Cody shale are not likely to yield water.

Several wells drilled for oil have encountered water in deeply buried sands which are elsewhere oil-bearing. In several localities the water is used for domestic purposes. Well No. 6, in the NW. ¼ sec. 32, T. 52 N., R. 100 W., in Oregon Basin, yields a flow of several cubic feet a minute which is the sole source of water for the camp of the Enalpac Oil & Gas Co., a mile to the south. The quality of the water from oil wells in this region is discussed on page 89.

CLIMATE AND VEGETATION

Although the United States Weather Bureau commonly maintains 10 or 12 observation stations in the Big Horn Basin, none of them are within these quadrangles. Records are available for Cody, 3 miles northwest of the northwest corner of the Oregon Basin quadrangle, since 1906.

The records at Cody show that for the period 1914 to 1917 the temperature ranged from the minimum of −33° F. in January, 1917, to the maximum of 97° F. in July, 1917. The coldest month is January, when the temperature is frequently as low as −20° F. and the maximum ranges from 45° to 60° F. The warmest month is August, when the minimum is frequently 35° to 40° F. and the maximum 91° to 97° F. The daily range in winter is commonly 25° to 30° and in summer 30° to 35°. The proportion of clear days is commonly about 60 per cent; of partly cloudy days, 30 per cent; and of cloudy days, 10 per cent.

The precipitation ranges from 7.18 to 11.34 inches a year, of which 60 or 70 per cent falls as rain in April, May, and June. Thunderstorms, sometimes accompanied by a heavy fall of hailstones, are common during July and August.

On account of the low rainfall, vegetation is restricted to a sparse growth of the few species adapted to the climate. Trees are confined to sandstone ridges and banks of streams; low shrubs and grasses constitute most of the varieties found on the valley slopes and upland terraces. The badlands, eroded on the Meeteetse and Wasatch formations, are almost without any vegetation whatever.

Clusters of cottonwood trees are found here and there along most of the perennial streams and some of the intermittent streams. Gravel bars and sloughs are locally heavily covered with willows. The commonest trees on the sandstone ridges are the limber pine (*Pinus flexilis*) and spruce (*Pseudotsuga mucronata*), which rarely exceed 15 feet in height. The sandstone ridges also contain a sparse growth of the juniper (*Juniperus scopulorum*).

The principal shrub, the common sagebrush (*Artemisia tridentata*) is found everywhere, from the rather fertile valley bottoms, where it frequently attains a height of 10 feet and is useful as a fuel, to the bleakest uplands, where it commonly ranges from 10 to 15 inches in height. Three other varieties of sagebrush (*Artemisia cana*, *A. frigida*, and *A. gnaphaloides*) are common but have a more restricted range.

Grasses of several varieties are widespread, especially the so-called buffalo grass, but the quantity shows a sensitive adjustment to the rainfall.

SETTLEMENTS

The region covered by these quadrangles is sparsely settled; in 1920 there were probably less than 900 persons in the 660 square miles which they cover. Although there are many ranches along perennial streams, there are only three post offices, Meeteetse, Sunshine, and Grass Creek. About 600 persons live in the two towns, Meeteetse and Grass Creek.

The settlements date from three distinct waves of immigration, which are not sharply separable. The

Correlation of formations of the Big Horn Basin described in earlier reports

System	Eldridge, 1894: U. S. Geol. Survey Bull. 119. Big Horn Basin	Fisher, 1906: U. S. Geol. Survey Prof. Paper 53. Entire Big Horn Basin	Washburne, 1909: U. S. Geol. Survey Bull. 341, p. 167. East side of basin	Woodruff, 1909: U. S. Geol. Survey Bull. 341, p. 202. West side of basin	Hewett, 1914: U. S. Geol. Survey Bull. 541, p. 91. Shoshone River	Hintze, 1915: Wyoming Geol. Survey Bulls. 10 and 11. West side of basin	Lupton, 1916: U. S. Geol. Survey Bull. 621. East side of basin	Hares, 1917 (unpublished report). Elk Basin field	Hewett and Lupton, 1917: U. S. Geol. Survey Bull. 656; also the present report: Formation	Thickness in feet	Character of rocks
Quaternary.	Valley alluvium.	Alluvium. Hot-spring deposits. Later terrace gravels.					Alluvium.	Alluvium.	Alluvium. Hot-spring deposits.	0–50	Valley and flood-plain deposits along streams. Local deposits of calcareous tufa.
							Terrace gravels.	Terrace gravel.	Terrace gravels: Sunshine terrace	5–15	Gravel and boulders washed from adjacent streams.
Tertiary.		Early terrace gravels.							Terrace gravels: Rim terrace. Cottonwood terrace.	0–50	Gravel and boulders washed from adjacent mountains.
	Volcanic breccias.								Volcanic rock.	(?)	Andesitic tuffs and flows on west side of basin.
	Wasatch. —Unconformity	Wasatch.	Wasatch. —Unconformity	Wasatch. —Unconformity	Wasatch. —Unconformity			Wasatch.	Wasatch. —Unconformity	1,300—	Red and drab clay; buff and white sandstone with gravel lenses. Many areas of badlands around border of basin.
	Laramie. Upper.	Laramie and associated formations.	Fort Union. —Unconformity(?)	Fort Union. —Unconformity(?)	Fort Union. —Unconformity(?)	Fort Union.	Undifferentiated Fort Union and Lance.	Fort Union.	Fort Union. —Unconformity	2,000–5,600	Buff and white gritty sandstone, with drab, red, and green clay; lenses of gravel and lenticular beds of coal.
Tertiary?			Laramie(?).	Laramie(?).	Ilo.	Ilo.		Lance.	Lance.	840–1,800	Buff and drab sandstone with drab and green shale. No red shale or coal beds.
			Montana group. {Bearpaw. Judith River. Claggett. Eagle.	Montana group. {Undifferentiated Montana. Eagle.	Meeteetse.	Montana. Meeteetse.	Montana. Mesaverde.	Bearpaw. Judith River.	Montana. Meeteetse.	250–1,400	Soft gray and brown shale; gray and buff sandstone and lenticular beds of coal.
	Laramie. Lower.				Gebo.	Eagle.		Claggett. | Parkman ss.	Mesaverde.	1,120–1,410	Buff and white sandstone, gray and brown shale, and lenticular beds of coal near base.
Cretaceous.	Pierre.	Pierre.			Colorado. Upper member.	Pierre. Basin. (Niobrara).	Cody.	Eagle. Niobrara. Carlile.	Cody.	1,900–3,400	Gray, green, and black shale, with calcareous concretions near base merging with buff sandstone at top. No persistent sharply marked beds.
	Niobrara.	Colorado.	Colorado.	Colorado shale.	Middle member.	Colorado. Benton.	Colorado. Frontier.	Frontier.	Colorado. Frontier.	494–648	West side: Seven or more beds of gray and buff sandstone with gray and brown shale and bentonite. East side: Two to six or more beds of sandstone.
	Benton.				Lower member.		Mowry.	Mowry.	Mowry.	160–375	Hard gray shale containing fish scales, with lenses of gravel-bearing sandstone.
							Thermopolis.	Thermopolis.	Thermopolis.	400–800	Gray to black shale with one persistent sandstone, the Muddy sand of the drillers.
	Dakota.	Cloverly.	—Unconformity Cloverly.	Cloverly.	"Cloverly."	Cloverly.	Cloverly.	Cloverly.	Cloverly.	110–300	Two beds of massive buff sandstone separated by gray or variegated shale. Upper sand is the Greybull.
Cretaceous?	Jura.	Morrison.			Morrison.			Morrison.	Morrison.	150–580	Purplish and pale greenish-gray shale with sandstone interbedded.
Jurassic.		Sundance.			Sundance.			Sundance.	Sundance.	250–530	Greenish-gray sandstone and shale with a little limestone interbedded.
Triassic.	Trias.	Chugwater.			Chugwater.			Chugwater.	Chugwater.	700–1,100	"Red Beds": Red sandstone and shale with a thick bed of gypsum near top.
Carboniferous.	Coal Measures.	Embar.						Embar.	Embar.	250–480	Gray limestone, with gray and red sandy shale and gypsum interbedded. Limestone very thin on east side of basin.
		Tensleep.							Tensleep.	30–230	Massive gray sandstone, containing thin layers of limestone.
		Amsden.							Amsden.	150–200	Red sandy shale and sandstone, with layers of limestone and chert.
	Sub-Carboniferous.	Madison.							Madison.	600–1,000	Gray massive limestone.
Ordovician.	Silurian.	Bighorn.							Bighorn.	150–300	Siliceous gray limestone, very hard and massive.
Cambrian.	Cambrian.	Deadwood.							Deadwood.	700–900	Sandstone, shale, conglomerate, and limestone.

first, beginning in the seventies and continuing until about 1900, was based upon the cattle industry. During this period ranches started along Greybull and Wood rivers served as centers for cattle raising. From these centers the cattle were grazed over the grass-covered valleys, near-by good range, and timbered foothills. The second period, beginning about 1900 and continuing until about 1916, was characterized by the settlement of ranches along the intermittent streams, so that herds of sheep could be grazed over the hills that were too barren and inaccessible for cattle. From 1905 to 1910 some ranchers forsook cattle for sheep. During this period practically all the water in every stream, spring, and water hole was preempted. The third period began with the drilling of the first well for oil in 1912 and is not yet ended. Several permanent settlements have resulted from the search for oil or gas, and others will probably be made. Other waves of immigration will come when irrigation projects make more land available for cultivation, as in Oregon Basin, and when the coal resources of the region are exploited.

GEOLOGY

STRATIGRAPHY

CARBONIFEROUS SYSTEM

EMBAR FORMATION (CARBONIFEROUS AND TRIASSIC)

The only information available concerning the Embar formation in these quadrangles is derived from well No. 3 of the Petroleum Producers Co., in the NE. ¼ NW. ¼ sec. 24, T. 44 N., R. 98 W. The collar of this well is on beds of the Thermopolis shale, but at a depth of 2,245 feet, after passing through the Cloverly, Morrison, Sundance, and Chugwater formations, the drill entered beds interpreted to be the upper part of the Embar formation. The upper stratum of the formation is considered to be that which underlies the lowest red sand of the Chugwater formation. The hole yielded the following record:

Beds of Embar formation in well No. 3 of Petroleum Producers Co.

	Thickness	Depth
	Feet	*Feet*
Sand and lime	47	2, 292
Sand, soft, gray, oil bearing	5	2, 297
Sand, hard, brown	5	2, 302
Sand, soft, brown and gray	15	2, 317
Sand, hard, brown and gray	5	2, 322
	77	--------

As the Embar formation is from 200 to 250 feet thick on the west side of the Big Horn Basin, it appears that the oil-bearing bed lies near the top of the formation. Beds at this horizon are oil bearing in the Lander field [7] and near Maverick Springs,[8] both in Fremont County, Wyo. The character of the oil is shown in the table on page 88.

TRIASSIC SYSTEM

CHUGWATER FORMATION

The Chugwater formation does not crop out in these quadrangles, but each of the wells on the Cottonwood anticline explores a part of it, and one well, Petroleum Producers Co. No. 3, passed through the entire formation. The following beds were recorded:

Beds of Chugwater formation in well No. 3 of Petroleum Producers Co.

	Thickness	Depth
	Feet	*Feet*
Shale, pink	40	1, 020
Red beds	120	1, 140
Shale, pink	111	1, 251
Red beds	132	1, 383
Shale, gray; show of oil and gas	38	1, 421
Sand, gray, oil bearing	50	1, 471
Red beds	102	1, 573
Shell, hard	2	1, 575
Sand, oil bearing	10	1, 585
Red beds	105	1, 690
Shale, red, sandy	5	1, 695
Sand, gray, oil bearing	25	1, 720
Red beds, hard	45	1, 765
Red beds, soft	15	1, 780
Red beds	35	1, 815
Sand; show of oil	5	1, 820
Red beds	70	1, 890
Sand, hard, red	5	1, 895
Sand and shale, gray	5	1, 900
Red beds	30	1, 930
Sand; show of oil and gas	42	1, 972
Red beds	10	1, 982
Sand, gray	33	2, 015
Red beds	90	2, 105
Shale, gray, sandy	15	2, 120
Red beds	85	2, 205
Sand, red and gray	10	2, 215
Shale, red, sandy	10	2, 225
Lime, red, sandy	10	2, 235
Sand, red, and lime	10	2, 245
	1, 265	--------

The thickness of the formation commonly ranges from 700 to 1,100 feet in the Big Horn Basin. The surface outcrops that have been examined in the basin [9] are composed largely of red sandy shale but include also red sandstone, gypsum, and limestone. Beds of gypsum undoubtedly exist under the Cottonwood anticline, but their presence is probably obscured by the red shale.

In the well mentioned above oil was reported in five sands and one shale zone, but in commercial quantities only in the two sands at depths of 1,421 and 1,695 feet. An oil seepage in beds of the Chugwater formation occurs on the Red Spring anticlines,[10] east of Big Horn River.

In these quadrangles the Chugwater formation is probably all of Triassic age, for to the south, in the Wind River and adjacent regions, it rests on the

[7] Woodruff, E. G., The Lander oil field, Fremont County: U. S. Geol. Survey Bull. 452, p. 27, 1911.

[8] Collier, A. J., Anticlines near Maverick Springs, Fremont County, Wyo.: U. S. Geol. Survey Bull. 711, p. 165, 1920.

[9] Lupton, C. T., and Condit, D. D., Gypsum in the southern part of the Bighorn Mountains, Wyo.: U. S. Geol. Survey Bull. 640, p. 147, 1917.

[10] Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 656, p. 135, 1917.

Triassic Dinwoody formation. On the east side of the Big Horn Basin and in central and southern Wyoming, however, the Chugwater or red-bed sediments occupy the stratigraphic interval of the Dinwoody and older formations, and there the Chugwater is of Triassic and Carboniferous (Permian and Pennsylvanian) age.

JURASSIC SYSTEM

SUNDANCE FORMATION

The Sundance formation does not crop out in these quadrangles, but the logs of the deep wells of the Cottonwood anticline, several of which are drilled to the Embar formation, record beds that may be correlated with the Sundance. The known surface exposures of the beds warrant the conclusion that they extend under the entire basin. The following record was obtained in drilling the Petroleum Producers Co. well No. 3:

Beds of Sundance formation in well No. 3 of Petroleum Producers Co.

	Thickness	Depth
	Feet	*Feet*
Shale, gray	5	655
Sand, gray	10	666
Shale, gray	50	715
Shale, sandy	75	790
Sand, gray	5	795
Lime, sandy, hard	10	805
Shale, blue	85	890
Sand, gray	5	895
Lime, hard	20	915
Sand, light	5	920
"Talc"	60	980
	330	--------

The chosen limits are based on the assumption that the formation does not contain any red shale. As the Sundance is a marine formation the proper limits would depend on the distribution of characteristic marine fossils. The general character of the sediments appears to persist unchanged throughout the west side of the Big Horn Basin. The measurement given above is thicker than most of the others that have been made in the Big Horn Basin, which range from 194 to 530 feet.

CRETACEOUS (?) SYSTEM

MORRISON FORMATION

The Morrison formation does not crop out in the Oregon Basin quadrangle, but three wells, the Pauline, New No. 5, and Hallene, penetrated some of the beds. The following beds were recorded in the lower part of the Pauline well, on the north Oregon Basin dome:

Beds of Morrison formation in Pauline well

	Thickness	Depth
	Feet	*Feet*
Lime, red	24	1,694
Mud, red	2	1,696
Lime, red, hard	3	1,699
Red rock, soft	11	1,710
Sand, light; yielded gas and water	76	1,786
Sand, broken, and shale	3	1,789
Shale, green	1	1,790
Red rock	40	1,830
Sand, broken	17	1,847
Red rock	53	1,900
Shale	15	1,915
Sand	7	1,922
Shale	70	1,992
Sand	6	1,998
Shale, gray	162	2,160
	490	--------

The New No. 5 well, 2,300 feet northwest of the Pauline well, also encountered gas and some black oil in a 4-foot layer of hard black sand 17 feet below the top of the Morrison formation.

Two wells in Grass Creek Basin and three on the Cottonwood anticline penetrate the Morrison formation. The following beds were reported in the log of Petroleum Producers Co. well No. 3:

Beds of Morrison formation in well No. 3 of Petroleum Producers Co.

	Thickness	Depth
	Feet	*Feet*
Shale, pink	95	490
Shale, gray, sandy	25	515
Shale, pink	40	555
Sand, coarse gray	50	605
Sand, fine gray	45	650
	255	--------

The interpretation of the limits of the formation in this region is based upon the features of the Shoshone River section. The base is considered to be the lowest bed, generally sandstone, that overlies the highest marine beds of the Sundance formation. The top is considered to be the bed, generally red or gray shale, that underlies the lowest sandstone of the Cloverly formation. Within these limits the formation is about one-third sandstone, one-fourth red shale, and the remainder gray shale.

Considerable gas was encountered in a sandstone near the top of the formation in the Pauline well, in Oregon Basin, and sufficient heavy black oil to warrant pumping at a similar horizon in the L. U. Sheep Co. well No. 13, in Grass Creek Basin.

CRETACEOUS SYSTEM

CLOVERLY FORMATION

The only data available concerning the Cloverly formation in this region are derived from nine wells in the Oregon Basin and Grass Creek Basin quadrangles. As the formation underlies the black Thermopolis shale, the uppermost bed, which is persistently a sandstone, may be readily identified. The basal bed may not be so readily determinable, because the sediments closely resemble those of the underlying Morrison formation. In the type locality, near Cloverly,[11] on the northeastern border of the Big Horn Basin, the formation is made up of a thick basal sandstone, variegated shale, and a nonpersistent upper sandstone, the whole showing a range in thickness from 80 to 200 feet.

Beds in the position of the Cloverly formation in these quadrangles are reported as "sandstone," "red shale," and "sandy shale." Within the limits that have been chosen, the range in thickness is 30 to 145 feet (Pl.V). The following beds were reported in the log of well No. 9 of the L. U. Sheep Co., in the NW. ¼ sec. 19, T. 46 N., R. 98 W.

Beds of Cloverly formation in well No. 9 of L. U. Sheep Co.

	Thickness	Depth
	Feet	*Feet*
Sand, considerable gas	10	1, 700
Shale, blue	36	1, 736
Sand, water	19	1, 755
Shale	5	1, 760
Sand, hard	25	1, 785
	95	--------

Although showings of oil are reported from the formation in the Pauline well, in Oregon Basin, oil is not persistently present. On the other hand, five of the nine wells drilled into the beds before 1920 encountered considerable gas, and the flow has been variously estimated from several to 25 million cubic feet daily.

The upper sandstone bed of the Cloverly formation s known as the Greybull sand in the eastern part of the Big Horn Basin. It is the source of the oil and gas in the Greybull field.[12]

THERMOPOLIS AND MOWRY SHALES

The oldest rocks that are exposed at the surface n these quadrangles are those near the middle of the Thermopolis shale, which crop out at the crest of the Cottonwood anticline. Beds near the same position undoubtedly crop out at the crest of Sunshine anticline, but they are wholly concealed by the alluvium of the valley of Wood River and the gravel on the terraces near by. Inasmuch as the boundary between the two formations, the lower limit of the gray shale carrying fish scales which is characteristic of the Mowry formation, can not be recognized in wells and has been observed only on the Cottonwood anticline, the two formations will be considered together.

The Thermopolis shale consists largely of dark carbonaceous shale but includes one very persistent bed and several nonpersistent beds of sandstone. Numerous thin beds of bentonite are present in the upper part of the section on Shoshone River (see pp. 55–58), but none have been reported in wells. In a broad way the number of beds of sandstone is greatest in the northern part of the field and decreases steadily southward, so that on Big Horn River none are reported (Pl. V).

The name Muddy sand has been applied by well drillers in the oil fields near Basin and Greybull to a rather persistent bed of sandstone about 275 feet above the base of the Thermopolis shale. As a similar bed that ranges from 7 to 60 feet in thickness is present on Shoshone River and is reported in each deep well as far south as the Cottonwood anticline, it also will be designated the Muddy sand. It is not reported in the Cottonwood anticline nor along Big Horn River, however. The interval between the top of the Cloverly formation and the base of this sandstone in this area ranges from 151 to 242 feet.

The sand carries a little gas and water on the east side of the basin. In the Grass Creek field it yields considerable gas, but none is reported in the other anticlines farther north.

The Thermopolis shale is readily weathered and eroded. It therefore underlies depressions, such as that which occupies the crest of the Cottonwood anticline (Pl. XXIV, *B*).

The following section of the Mowry shale was measured northward from the crest of the Cottonwood anticline, in sec. 14, T. 44 N., R. 98 W.:

Section of Mowry shale in NE. ¼ sec. 14, T. 44 N., R. 98 W.

	Feet
Shale, light to dark bluish gray	130
Shale, light gray, with several beds of sandstone 2 to 4 inches thick which weather to square slabs	48
Shale, gray, platy; numerous fish scales	45
Shale, dark gray	6
Shale, sandy, buff to gray; forms crest of low ridge; fossil collection 8535	15
Shale, light to dark gray	100
	344

The following report on collection 8535 obtained in this locality was submitted by T. W. Stanton:

> Inoceramus labiatus Schlotheim.
> Metoicoceras? sp.
> Fish scales and bones.

Benton fauna, the abundance of fish scales, and lithologic character suggest the Mowry shale.

[11] Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, pp. 50–53, 1906.

[12] Lupton, C. T., Oil and gas near Basin, Big Horn County, Wyo.: U. S. Geol. Survey Bull. 621, p. 168, 1916.

The general lithologic character of the Mowry shale is shown on Plate V. In addition to several beds of sandstone, one or more beds of bentonite from 4 to 20 feet thick are reported from most of the wells in Oregon Basin. Although the Mowry shale weathers almost as readily as the Thermopolis and therefore forms part of the basin that occupies the crest of the Cottonwood anticline, the sandstone layers form rather persistent low ridges.

Traces of oil and gas are present in the sandstone beds of the Mowry shale in Oregon Basin, but commercial quantities are not yet reported on the west side of the Big Horn Basin.

The total thickness of the two formations ranges from 839 feet in the L. U. Sheep Co. well No. 9, in the Grass Creek field, to 1,016 feet along Shoshone River.

FRONTIER FORMATION

General features.—The Frontier formation includes a group of sandstones, sandy shales, and shales which conformably overlie the Mowry shale (Pl. V). The entire formation is exposed on the Sunshine anticline along Wood River and on the crest of the Cottonwood anticline, but considerable information concerning it has been derived from wells drilled on each of the other anticlines. The sandstones of the lower part are the source of most of the oil and gas produced on the west side of the Big Horn Basin. The thickness of the formation commonly ranges from 370 to 520 feet, but several sections in wells drilled through inclined beds on the limbs of anticlines are as much as 640 feet thick. In a broad way the thickness decreases southward from Shoshone River and eastward from the mountain front.

A number of graphic sections of the formation are presented in Plate VI. Sandstone beds that commonly range from 5 to 40 feet in thickness but locally attain 130 feet make up from one-third to one-half of the formation. The remainder is sandy shale, shale, bentonite, and thin lenses of coal. The sandstone beds are commonly laminated but are only locally ripple-marked. A few are cross-bedded.

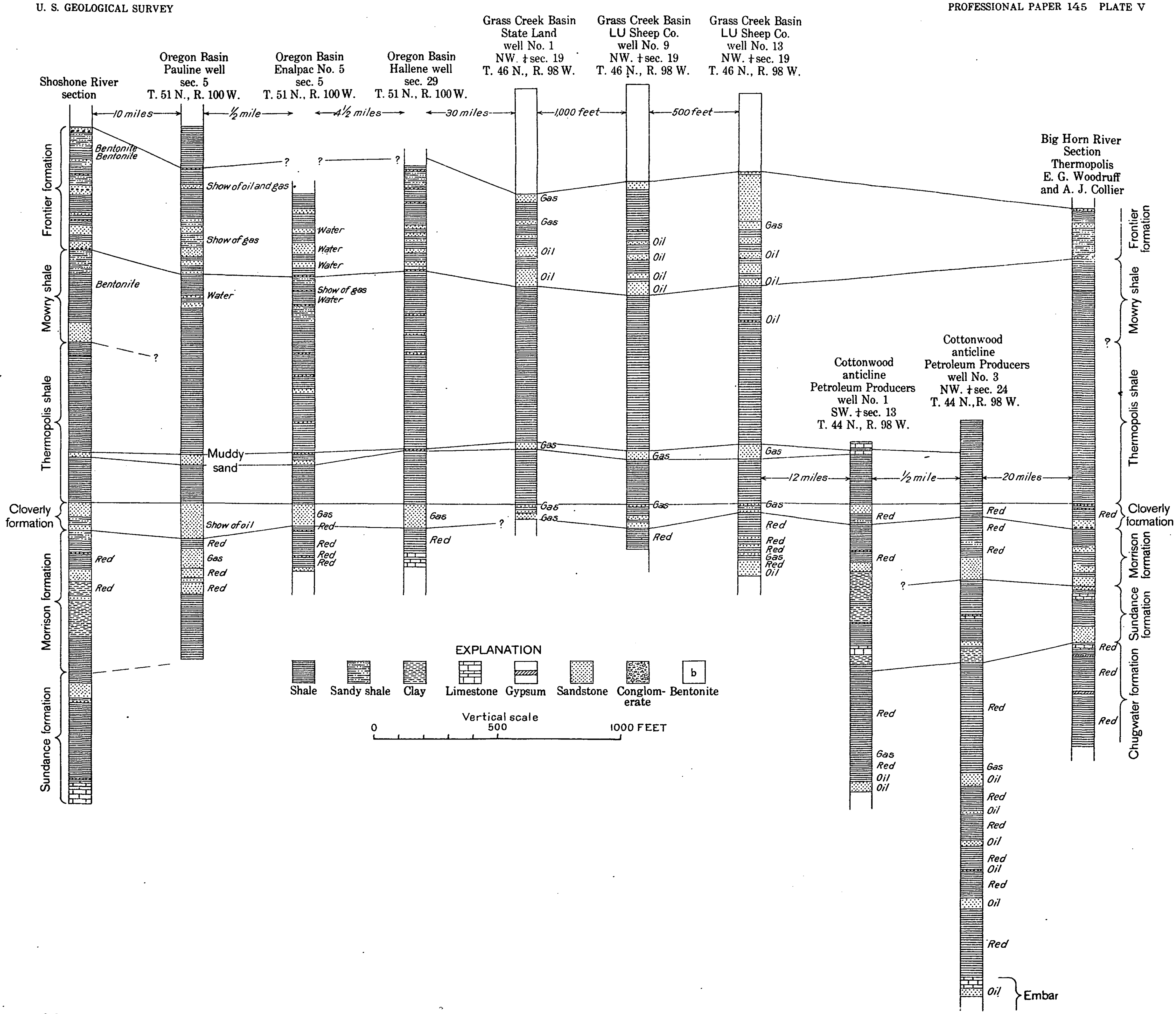
The color of the sandstones is generally light gray; several beds weather to a light buff, and here and there a bed is nearly white. Concretions are uncommon. Thin but persistent layers of dark chert pebbles are generally present at several horizons. The pebbles are well rounded, are rather uniform in size, and rarely exceed an inch in diameter. Close inspection shows that the fine sandstones contain numerous dark grains which are also chert. A study of the graphic sections indicates that the individual sandstone beds are not persistent layers of uniform thickness but are relatively nonpersistent lenses. In general there are more sandstone beds and they are probably more persistent in the lower half of the formation than in the upper half. The sandstones in the lower half contain most of the oil, although the higher beds locally contain traces. The uppermost bed of the section on the Cottonwood anticline, 45 feet thick, appears to extend at least 5 miles along the north side of the fold. Any adequate explanation of the process of accumulation of the oil in these beds in any field should probably be based upon the assumption that most of the beds more than 10 feet thick persist for several miles, possibly here and there as much as 8 to 12 miles.

The shale is largely sandy and light gray, but some of it is dark bluish gray, dense, and free from lamination. On the Cottonwood anticline beds of laminated light-gray shale which weathers white and resembles the characteristic Mowry shale persist as high as the middle of the Frontier section. Bentonite is present in all the outcrops, commonly in two zones, one near the top and one near the middle. The beds generally range from 3 to 8 feet in thickness, but thicker beds are reported in some well records. At good exposures the base of the bed of bentonite is sharply separated from the underlying material, whereas the upper part merges upward into the overlying sediment. Surface exposures of the formation are too obscure and meager and well records are not sufficiently accurate to indicate the probable persistence of the individual beds of bentonite in the Frontier formation. One 3-foot bed near the middle of the section undoubtedly extends from a point on the west end of the Cottonwood anticline eastward about 2 miles without change in thickness.

On the other hand, an 8-foot bed near the top of the Shoshone River section does not appear to be present in two sections in Oregon Basin, 11 and 15 miles to the southeast. The records of oil wells do not aid in determining the persistence of the beds, because it is not uncommon to find that the log of one well has no record of the presence of a 10-foot bed that is recorded in the log of another well only 1,000 feet distant. From the available data it would appear that the individual beds that are 2 feet or more thick probably persist for 3 to 10 miles and locally for greater distances. One or more beds of bentonite appear to be present in the Frontier section throughout the west side of the Big Horn Basin.

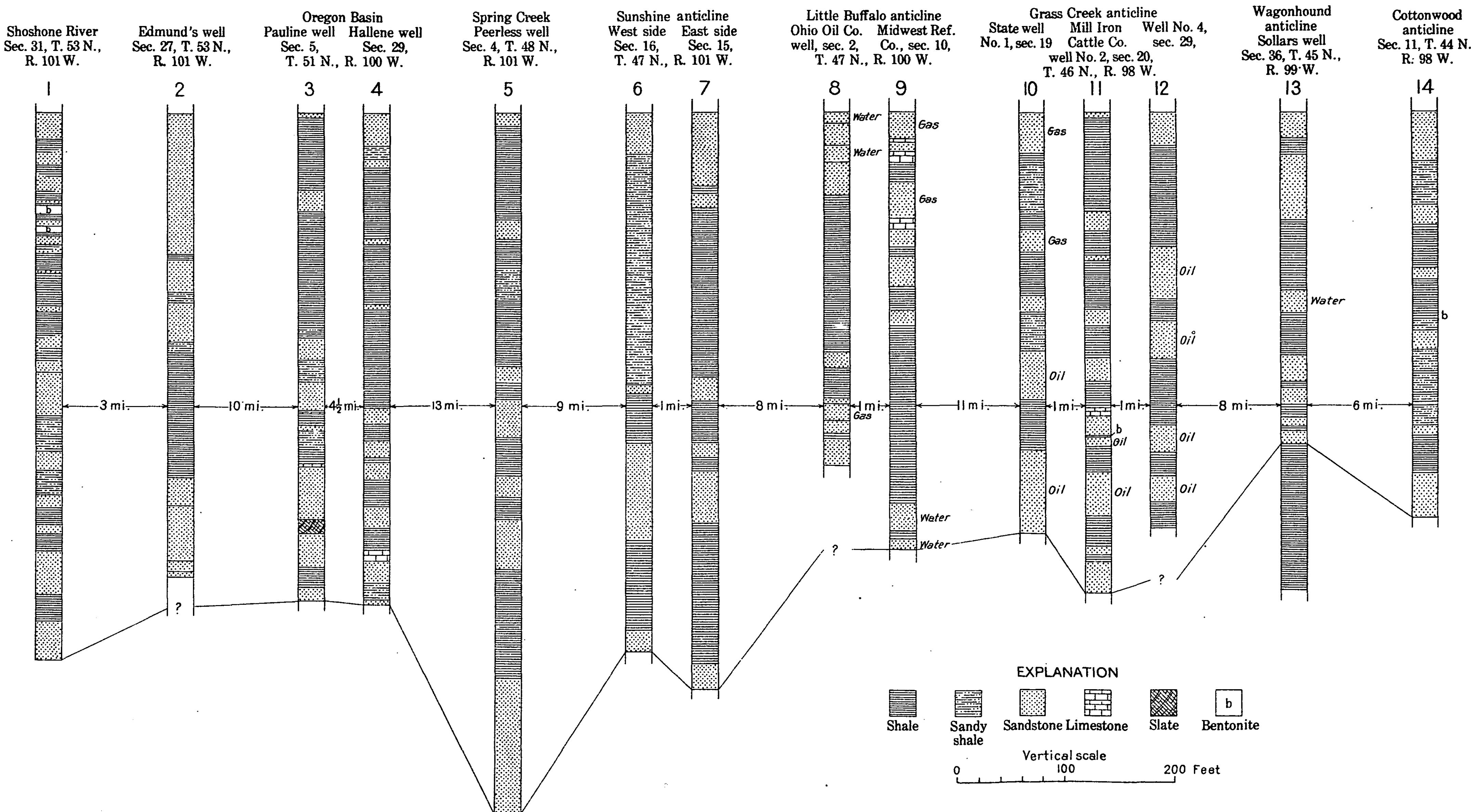
The Frontier formation has yielded very few fossils in this region. The following collection of fossil plants (No. 6660) was derived from a layer of shale 90 feet below the top of the formation in the W. ½ sec. 10, T. 44 N., R. 98 W. The identifications were made by F. H. Knowlton.

Pteris cf. P. dakotensis Lesquereux.
Quercus sp., probably new.
Salix proteaefolia Lesquereux (Salix flexuosa Newberry).
Sequoia gracillima (Lesquereux) Newberry.
Dakota flora.



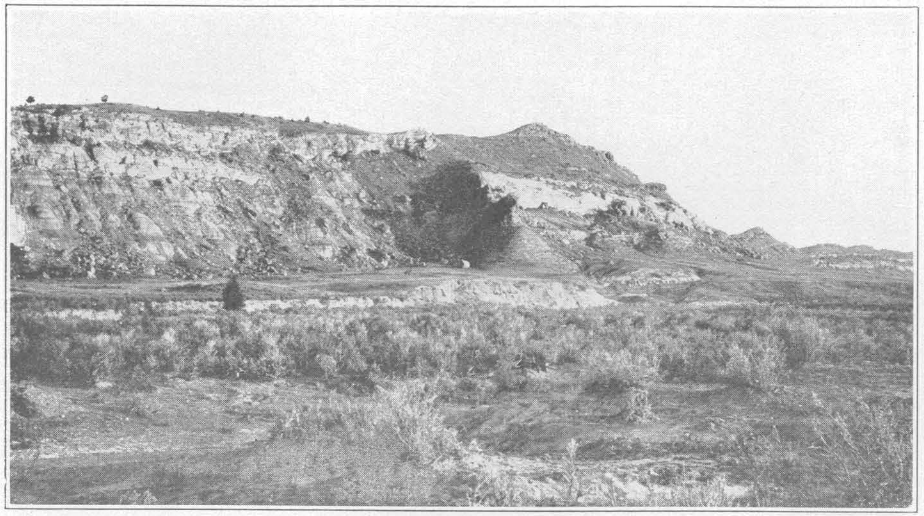
CORRELATION OF DEEP-WELL SECTIONS FROM SHOSHONE RIVER AT CODY TO BIG HORN RIVER AT THERMOPOLIS, WYOMING

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



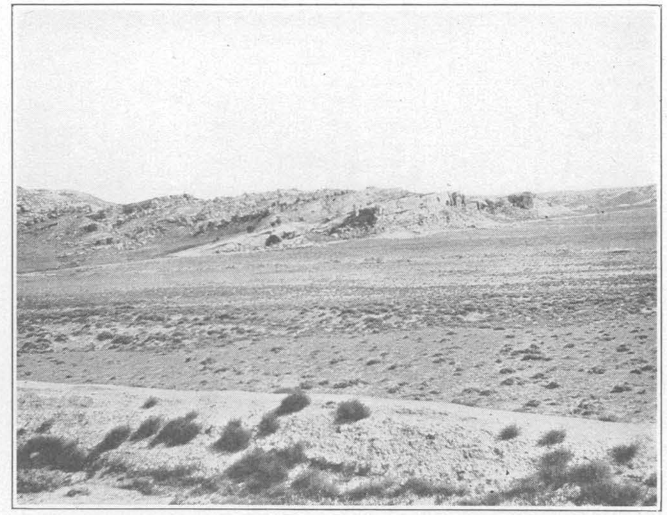
SECTIONS OF THE FRONTIER FORMATION, WEST SIDE OF BIG HORN BASIN, WYOMING

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



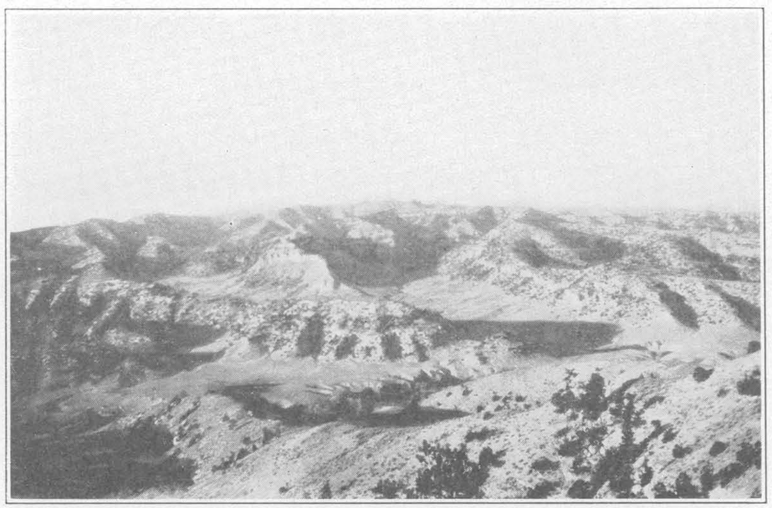
A. FAULT BETWEEN SHALE AND SANDY SHALE OF MIDDLE PART OF MEETEETSE FORMATION (LEFT) AND MASSIVE SANDSTONE OF MIDDLE PART OF MESAVERDE FORMATION (RIGHT), SEC. 2, T. 50 N., R. 100 W.

The stratigraphic displacement is 1,250 feet. Photograph by E. G. Woodruff



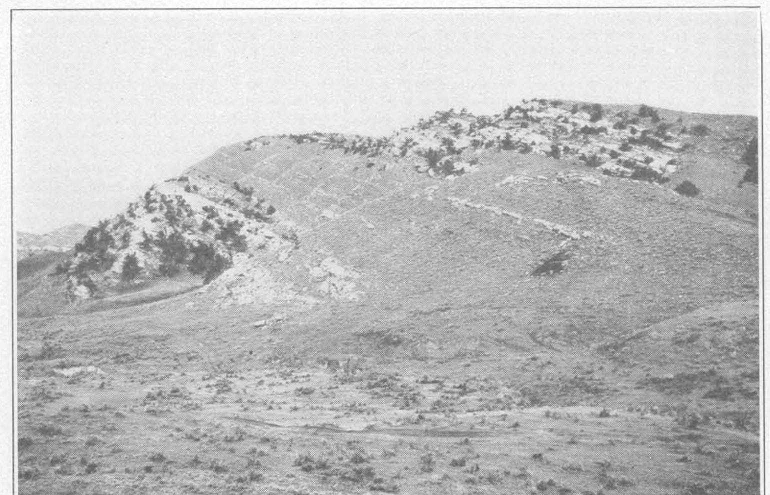
B. LOWER PORTION OF MESAVERDE FORMATION AT NORTH END OF OREGON BASIN, SEC. 13, T. 52 N., R. 101 W.

Looking northeast



C. ESCARPMENT OF THE BASAL SANDSTONE OF THE MESAVERDE FORMATION DISSECTED NEAR CREST OF GOOSEBERRY DOME, SECS. 15, 16, 21, AND 22, T. 47 N., R. 100 W.

Looking north



D. BASAL SANDSTONE AND COAL-BEARING PORTION OF THE MESAVERDE FORMATION AT NORTH END OF GRASS CREEK BASIN, SEC. 5, T. 46 N., R. 98 W.

Some of the beds of the formation may have been deposited in the sea, but the absence of marine fossils and the presence of land plants and thin beds of coal indicate that most of the formation was deposited under nonmarine conditions.

Local details.—The upper part of the Frontier formation is exposed around the crests of both of the Oregon Basin domes, and the complete section is recorded in five wells. The thickness ranges from 405 to 455 feet. Estimates of the lithologic composition indicate that it is from one-third to nearly one-half sandstone, in beds that range from 5 to 42 feet in thickness (Pls. V and VI). The remainder is made up of shale, sandy shale, and bentonite; commonly there are two or three beds of bentonite from 5 to 20 feet thick. Beds of limestone are reported in the logs of several wells, but the material is probably shale, as no limestone has yet been observed in the outcrop. The thin coal beds in the section on Shoshone River are not present here, but there are thin layers of brown to black shale.

The sandstones near the top of the formation form sinuous outcrops around the crests of several domes, but unlike those of the higher formations they generally do not bear a sporadic growth of small pine trees.

The entire section of the formation is well exposed on both sides of the Sunshine anticline where it is cut by Wood River, and the wells on the Spring Creek and Little Buffalo anticlines record either a large part or all of the formation. (See sections 5 to 9, Pl. VI.) The thickness appears to range from 399 to 640 feet, although the latter measurement, recorded in the log of the Peerless well, in sec. 4, T. 48 N., R. 101 W., may be excessive because the beds are inclined. About one-third of the formation is composed of layers of sandstone, and, as on Shoshone River, the upper bed contains several 6-inch layers of chert pebbles. Beds of bentonite are present but are not conspicuous.

The entire section is also well exposed around the crest of the Cottonwood anticline (section 14, Pl. VI) and is recorded in the logs of one well on the Wagonhound anticline and numerous wells on the Grass Creek anticline. The thickness here appears to range from 372 to 470 feet. Beds of sandstone, commonly from 5 to 45 feet thick, make up 40 to 50 per cent of the formation. Bentonite is present but does not appear to be so conspicuous or to cause so much trouble in drilling as it does farther north. In a few logs beds of limestone are reported, but as no limestone can be recognized in outcrops, the record is probably not correct.

The upper sandstones weather so as to form parallel chains of low ridges that almost completely surround the basin that lies on the crest of Cottonwood anticline. There are only a few stunted pines along the outcrops of these beds. (See Pl. XXIV, *B*.)

The following section of the upper part of the formation is presented to show the relations of a bed of bentonite and of the only fossils collected from the formation in the region:

Section of Frontier formation in the W. ½ sec. 10, T. 44 N., R. 98 W.

Cody shale.	
Frontier formation:	Feet
Sandstone, buff, thin bedded	14
Sand, clayey, buff, with several persistent thin sandstones	32
Sand, clayey, gray, not indurated	43
Shale, dense, blue-gray, fossil leaves (collections 6660 and 6661)	2
Sandstone, buff, persistent, transitional to underlying bed	12
Sand, clay, gray, unindurated	22
Shale, sandy, dense, gray	½
Sand, clayey, buff, unindurated, transitional to bentonite below	10
Bentonite, drab, transitional to overlying sand	2½
Shale, sandy, gray	5
Sandstone, white, ripple marked on top	25
	168

The sandstones of the Frontier formation are the source of most of the petroleum produced in the Grass Creek field. Until 1920, however, the same beds in the Wagonhound field had yielded only traces of oil and gas.

CODY SHALE

General features.—The name Cody shale is applied to a thick group of shale and shaly sandstone beds that conformably overlie the Frontier formation and conformably underlie the Mesaverde formation and that are especially well exposed in the canyon of Shoshone River at Cody, Wyo. The relations of the beds to those which overlie and underlie them are shown in Plate V.

In contrast with the overlying Mesaverde and higher formations, the Cody shale is readily weathered and eroded, so that it is worn away to rather monotonous lowlands which are bounded by ridges of rugged escarpments made up of the underlying and overlying beds. In the three quadrangles under consideration the beds are folded into a group of anticlines and synclines, and erosion has progressed to the stage where the Cody shale is exposed in a group of isolated rudely elliptical basins. Local uplift and erosion have produced extensive flat terraces on the beds, and these terraces have later been covered with layers of gravel. The beds that make up the formation are so readily weathered that in flat areas not covered by gravel the fresh rocks are commonly covered with a layer of loam. This material is locally picked up by windstorms and redeposited as sand dunes. This process has been so effective in Oregon Basin that a local depression has been thus carved out below the general level of the adjacent region. (See p. 4.) For the most part good outcrops are restricted to the upper 300 to 500 feet of the formation, under the escarpments of the overlying hard rocks, and to sections 50 to 100 feet thick locally exposed in deep ravines. There is no part of the region where a complete continuous section of fresh rocks may be studied.

Measurements of thickness range from 1,900 to 3,400 feet in the three quadrangles. A part of this variation is undoubtedly due to original differences in thickness of sediment laid down, but a larger part is probably due to local thickening and thinning of the soft shale during the deformation of the rocks by folding. In a broad way the thickness appears to increase southward from 2,150 feet on Shoshone River to 3,600 feet in Little Buffalo Basin and then to decrease to about 2,000 feet along upper Owl Creek. According to Woodruff [13] the thickness on Big Horn River below Thermopolis is 1,900 feet. Although outcrops are unsatisfactory, the succession of beds appears to be essentially the same throughout the region. The lower half is largely laminated dull to dark gray or olive-gray shale. Green shale in which the color is due to glauconite is present in the lower part of the formation on Shoshone River but has not been recognized farther south. The upper half of the formation is characteristically sandy, the sand being added at first in the form of thin laminae between layers of shale. In the higher zones, most conspicuously 300 to 800 feet below the top, there is more sand than clay, and except for a few sporadic lenses, which increase toward the southeastern part of the area, the sand and clay are intimately mixed rather than sharply separated. The transition from the Cody shale to the overlying sandy Mesaverde formation is discussed in connection with that formation (pp. 19–22).

Marine fossils are common in the lower part of the Cody shale throughout the region, and although several collections have been made from the upper 300 feet in the northern part of Oregon Basin, none have been found after careful search in any exposures south of it. The following list shows the numbers and locations of the collections, and the table gives a list of the fossils, which were identified by T. W. Stanton.

4960. SW. ¼ sec. 29, T. 53 N., R. 101 W., Shoshone River; 200 to 300 feet above base. Collected by E. G. Woodruff.

4991. Same locality as 4960. Collected by T. E. Willard.

5032. SE. ¼ sec. 21, T. 53 N., R. 101 W., Shoshone River; 450 to 725 feet above base. Collected by T. E. Willard.

7369. Same locality as 5032. Collected by D. F. Hewett.

[13] Woodruff, E. G., personal communication.

7371. SW. ¼ sec. 31, T. 51 N., R. 100 W., Elk Butte; 300 feet above base.

7372. SE. ¼ sec. 21, T. 51 N., R. 101 W.; 700 feet above base.

7373. Same locality as 7371; 500 feet above base.

7374. NE. ¼ sec. 31, T. 51 N., R. 100 W., Elk Butte; 100 feet above base.

8533. NE. ¼ sec. 18, T. 44 N., R. 97 W.; 200 feet above base.

8534. NE. ¼ sec. 18, T. 44 N., R. 97 W.; 300 feet above base.

10255. SW. ¼ sec. 22, T. 53 N., R. 101 W., Shoshone River; 265 feet below base of Mesaverde formation.

10256. SW. ¼ sec. 22, T. 53 N., R. 101 W., Shoshone River; 277 feet below base of Mesaverde formation.

10257. SW. ¼ sec. 22, T. 53 N., R. 101 W., Shoshone River; 282 feet below base of Mesaverde formation.

10258. SW. ¼ sec. 22, T. 53 N., R. 101 W., Shoshone River; 302 feet below base of Mesaverde formation.

10259. SW. ¼ sec. 22, T. 53 N., R. 101 W., Shoshone River; 349 feet below base of Mesaverde formation.

10260. SE. ¼ sec. 1, T. 51 N., R. 101 W., 295 feet below base of Mesaverde formation.

10261. SE. ¼ sec. 6, T. 47 N., R. 99 W., 650 feet below base of Mesaverde formation.

10262. SE. ¼ sec. 6, T. 47 N., R. 99 W., 600 feet below base of Mesaverde formation.

Shark teeth identified by J. W. Gidley as belonging to *Corax falcatus* Agassiz, *Lamna mudgei* Cope, and *Otodus appendiculatus* Agassiz were obtained from a bed of sandstone in the SE. ¼ sec. 3, T. 50 N., R. 100 W., about 1,400 feet above the base of the formation.

Oregon Basin quadrangle.—Although the Cody shale underlies a large part of Oregon Basin, extensive good exposures are uncommon and are limited to the beds that make up the upper 300 feet. In the southern part of the basin there are several good exposures, each 100 feet or more thick, of the beds in the lower part of the formation. On account of the poor exposures and numerous faults around the border of the basin, measurements of thickness are unsatisfactory; the only reliable measurement, which extends from Elk Butte southwestward to Frost Ridge, indicates a thickness of 2,300 feet.

In the vicinity of Elk Butte the lower 300 feet of the formation is fairly well exposed. This part is made up of dark-gray to dark olive-gray thin-bedded shale. The surface layer of such material is commonly disintegrated and weathered to a depth of a foot or more. Sand and sandy shale are uncommon in this locality. The shale yields ellipsoidal concretions from 5 to 30 inches long which are composed of the carbonate of calcium and iron and commonly contain numerous fossils. These concretions break up when they are exposed to weathering and set the fossils free; consequently the near-by slopes yield many fossil fragments, particularly *Baculites*, *Scaphites*, and *Inoceramus*.

Table 2.—*Invertebrate fossils from the Cody shale*

[Identified by T. W. Stanton]

	4960	4991	5032	7369	7371	7372	7373	7374	8533	8534	10255	10256	10257	10258	10259	10260	10261	10262
Anomia sp		×		×													×	
Ancyloceras (?) sp	×																	
Avicula linguiformis Evans and Shumard		?		×														
Avicula sp			×															
Baculites asper Morton	×	?	×		×		×			×								
Baculites sp	×	×		×		×		×					×	×		×		×
Cinulia sp				×														
Corbula sp		×	×	×														
Crassatellites n. sp		×	×					×										
Dentalium sp			×	×									×	×				
Fusus sp			?															
Gyrodes conradi Meek and Hayden			×															
Inoceramus acuteplicatus Stanton	×	×	×					×										
Inoceramus exogyroides Meek and Hayden		×																
Inoceramus lobatus Goldfuss											?				?			
Inoceramus umbonatus Meek and Hayden			×															
Inoceramus undabundus Meek and Hayden		×																
Inoceramus sp	×	×				×			×	×			×	×				
Leda sp						×												
Legumen sp		×																
Lucina sp														×				
Mortoniceras shoshonense Meek	×			×														
Mortoniceras sp		×																
Mytilus sp						×												
Nemodon sp				×		×												
Nucula sp						×	×											
Ostrea congesta Conrad									×	×								
Ostrea sp																×		
Pholadomya papyracea Meek and Hayden	×			×														
Scaphites hippocrepis De Kay												?	?	?		?		
Scaphites ventricosus Meek and Hayden	×	×	×	×	×													
Scaphites vermiformis Meek and Hayden									×									
Turritella sp		×	×				×											
Veniella sp				×														
Volutoderma sp				×														
Yoldia sp												×	×	×	×	×		

In a broad way the successively higher beds in the formation contain more sand than the lower beds, so that the upper 1,500 feet is largely thin-bedded sandstone with little shale. A 200-foot section about 800 feet above the base is well exposed on the north side of the hill in sec. 27, T. 51 N., R. 101 W. It shows the progressive upward change from finely laminated dark-gray shale that yields a few fragile marine fossils through finely laminated micaceous sandstone with carbonized plant remains to coarsely laminated ripple-marked sandstones. In the S. ½ sec. 3, T. 50 N., R. 100 W., such sandstones, which are about 1,300 feet above the base, yielded numerous shark teeth, but other marine fossils are scarce. A specimen of sandstone from this locality has been disintegrated, sized, and closely examined under the microscope, with the results shown in No. 6 in the table on page 50. It consists of fine and very fine quartz sand with a little orthoclase. In contrast to most of the sandstones in the higher formations that have been examined, it appears to contain no chert grains.

The upper 300 feet of the formation as exposed along the north slope of Frost Ridge and north of the Wiley ranch is made up of alternating beds of buff sandstone and buff sandy shale, each ranging from 1 to 20 feet in thickness and composed of ripple-marked laminae from a quarter of an inch to 3 inches thick. The beds have well-developed parallel joints, so that when they weather on a slope they yield numerous long, narrow flat slabs of sandstone. This part of the Cody shale in Oregon Basin does not show outcrops of massive sandstone 20 to 30 feet thick such as occur in other basins farther south.

Marine fossils are very scarce in the upper part of the formation in Oregon Basin but numerous specimens of a few species were found 295 feet below the base of the Mesaverde formation in sec. 1, T. 51 N., R. 101 W.

Meeteetse quadrangle.—The entire section of the Cody shale is exposed along the limbs of the Sunshine anticline, but only the upper part is exposed on the crests of the Spring Creek, Little Buffalo, and Gooseberry anticlines and the Gooseberry dome. On the Sunshine anticline the outcrop is largely obscured by the gravel that covers the extensive terraces on both sides of Wood River. As terraces are also well developed in the basins that mark the crests of the other folds, exposures are poor. The upper 600 feet of the formation is well exposed in the eastern part of Little Buffalo Basin, and the upper 300 feet in the east end of Spring Creek Basin and near Renner's ranch. The best section of the entire formation in the region is found along Gooseberry Creek and its tributaries in the southern part of T. 47 N., R. 101 W. Well logs also record the character of the lower part of the formation in the Spring Creek, Sunshine, Little Buffalo, and Gooseberry anticlines.

Estimates of the thickness of the formation in the Meeteetse quadrangle range from 2,200 feet on the northeast side of the Spring Creek anticline to 3,400 feet on the west side of the Sunshine anticline. The thickness on the east side of the Sunshine anticline and the northeast side of Little Buffalo Basin is estimated at 2,500 feet.

So far as information is available concerning it, the lower half of the formation in this quadrangle has the general characteristics shown by that part of the section farther north. The records of wells drilled in Little Buffalo Basin, however, indicate the presence of a persistent layer of sand 30 feet thick, about 950 feet above the base. This sand yielded a little gas in one hole. The greensand zone that is present in the lower half of the section on Shoshone River has not been observed in this quadrangle but may be present.

In the eastern parts of Spring Creek and Little Buffalo basins, where the upper 600 feet of the formation is well exposed, it is made up largely of alternating layers of soft sandy gray shale from 4 to 12 feet thick and hard buff sandstone 4 inches to 3 feet thick. In general the proportion of sandstone is greater in the higher part of the section than below. Where several layers of sandstone occur close together they preserve a low ridge. There are therefore several parallel chains of such ridges, one of which is conspicuous around the east end of Little Buffalo Basin, 300 feet below the top of the formation. The sandstones are devoid of fossils, but here and there the shaly layers contain a few marine fossils. The shale also contains considerable carbonized plant material, but no well-preserved plant remains have been found.

Grass Creek Basin quadrangle.—The complete section of the Cody shale is exposed on the flanks of the Cottonwood anticline, and all but the lower 400 feet on the crest of the Grass Creek anticline. The details of a large part of the formation, however, are obscured by terrace gravel and wash. The upper 500 feet is well exposed along the escarpments north of Grass Creek, Wagonhound Creek, and Owl Creek. Most of the good exposures of the lower beds are found in ravines cut below the terraces, and only rarely is more than 100 feet continuously shown.

The measurements of thickness of the Cody shale in the Grass Creek Basin quadrangle range from 1,900 feet on the southwestern flank of the Cottonwood anticline to 2,950 feet on the northeastern flank. These measurements are exceptional—first, because in the region farther north the measurement on the steep flank is generally greater than on the flat flank; second, because the measurements near by rather uniformly range from 2,300 feet (Wagonhound anticline) to 2,450 feet (north limb of Grass Creek anticline). After a review of all the information available, it has been assumed that the thickness on the north flank of the Cottonwood anticline is only 2,400 feet and that the beds are locally flatter at some place along the flank; this is the same as saying that a structural terrace exists in this locality.

About 150 feet of beds near the base are exposed on the south slope of a conical hill on the border of secs. 17 and 18, T. 44 N., R. 97 W. The material is largely dull and dark gray laminated shale with thin sandy layers. It is locally fossiliferous (collections 8533 and 8534) but does not yield the highly fossiliferous concretions found in the same zone farther north.

The beds from 400 to 600 feet above the base exposed near the wells in sec. 6, T. 44 N., R. 98 W., are thin-bedded dark greenish-gray shale and sandy shale. From this horizon upward the proportion of sand in the Cody shale steadily increases. On the other hand, in Grass Creek Basin there appear well-defined lenses of massive sandstone such as are characteristic of the overlying Mesaverde formation several hundred feet below its base. These lenses are found on the northeast side of Grass Creek Basin and are conspicuous along the escarpment west and south of the Wagonhound anticline. This escarpment is formed by a bed 30 to 50 feet thick and may be traced several miles.

The upper 300 feet of the Cody shale, which is well exposed for 12 miles along the escarpment north of Wagonhound Creek and eastward, is made up largely of alternating persistent beds of hard buff sandstone 4 to 18 inches thick and soft gray shale 4 to 10 feet thick. There are several beds of sandstone that attain a thickness of 10 feet and several beds of shale as thick as 32 feet, but the section gives the impression of rather persistent beds of uniform thickness. These beds have yielded no fossils.

Marine fossils are not uncommon in the lower 800 feet of the Cody shale in this quadrangle, and as the common fossils of this zone (*Baculites asper* and *Scaphites ventricosus*) appeared to be the same as those in the same zone farther north, no particular effort was made to collect them. On the other hand, close search of several sections of the upper 500 feet, especially in sec. 27, T. 44 N., R. 98 W.; sec. 28, T. 45 N., R. 98 W.; and sec. 16, T. 46 N., R. 98 W., failed to bring forth any marine fossils, such as were found in Oregon Basin and on Shoshone River. Likewise, no marine fossils were found in the shale near the base of the overlying Mesaverde. There is reason, therefore, for concluding that marine conditions ceased earlier in this part of the region than farther north.

MESAVERDE FORMATION

General features.—The outstanding features of the Mesaverde formation in this region are its coal beds, its dominantly sandy character, and its greater induration compared with the beds that overlie and underlie it, which permits the outcrops to resist erosion and survive as persistent rugged ridges. It makes up the ridges that surround the basins that are such characteristic features of the border of the Big Horn Basin. Thus the outcrop almost surrounds Oregon Basin, Spring Creek Basin, Little Buffalo Basin, and Grass Creek Basin and presents striking escarpments along Wood River, Gooseberry Creek, Cottonwood Creek, and Owl Creek. Where faults break the beds erosion readily cuts deep ravines, and if the faults are not far apart the outcrop may be worn down nearly to the level of the near-by streams.

For the most part, in the two northern quadrangles the outcrop forms a single ridge, of which one slope is the slightly dissected uppermost sandstone, and the other is made up of successive steplike outcrops of the massive sandstone near the base and middle of the formation. (See Pl. VII, *A*, *B*.) Farther south, where thick, massive sandstones are largely absent near the middle of the formation, the outcrop is locally made up of two narrower and lower ridges underlain by the massive sandstone beds near the base and top of the formation.

In contrast with the underlying and overlying rocks, the beds support a sparse growth of cedar and pine. Beds of massive sandstone 40 to 80 feet thick occur near the base of the formation throughout the area and near the middle in the northern part. Massive beds 10 to 20 feet thick occur in all parts of the section here and there throughout the region. The upper limit of the formation is the top of a group of such beds, commonly 100 to 200 feet thick. Thin-bedded sandstones are found in every part of the section. The color of the sandstones is generally buff, but they are nearly white in places near the base and uniformly so near the top.

The shale units range from 1 to 30 feet in thickness, but most of them are less than 10 feet thick. They commonly merge at the bottom and top into thin-bedded sandstone. The shale is generally gray except near the coal, where it is locally black. In some localities, as along Gooseberry Creek and along the Owl Creek escarpment, the second bed of coal above the base is underlain by a bed of light-brown soapy clay, which lacks lamination but contains leaf impressions. Although it does not appear to have contained root impressions it may be an underclay.

Beds of coal are found at a number of horizons as high as 880 feet above the base of the formation. The most valuable beds, however, commonly occur in a zone from 120 to 340 feet thick that overlies the basal massive sandstone. In this zone from two to seven separate beds may be found, of which two commonly contain more than 14 inches of coal. The greatest recorded thickness of coal in a single bed in the formation in this region is 118 inches, measured at station 239 (Pl. XXVIII), near Cottonwood Creek. The beds observed above the basal zone do not exceed 12 inches in thickness.

Although casual examination creates the impression that numerous individual beds of sandstone and coal persist from one basin to another, close study leads to the conclusion that most of them are highly lenticular. On pages 92–94 the conclusion is reached that the longest axes of the coal lenses trend generally north, and here and there the parts more than 14 inches thick may be from 6 to 12 miles or more long. On the other hand the shortest axes appear to trend east, and the parts more than 16 inches thick to range from 1,500 feet to 3 or possibly 4 miles in length. As the vegetation that later changed to coal flourished where sediments were not being deposited, it follows that the limits of the coal beds were determined by the deposition of sediments. It therefore seems a reasonable assumption that in so far as the lenses of sandstone are of simple form, their longer and shorter axes tend to lie parallel to those of the coal. Many beds of sandstone, however, particularly the thin ones, may have very irregular shapes.

The only evidence of distinct change in the character of the sediments in the region is the progressive disappearance from Shoshone River southeastward to Owl Creek of the thick lenses of massive sandstone near the middle of the formation.

The thickness of the formation ranges from 995 to 1,450 feet, but there is no evidence of progressive increase from one part of the region to another. It is possible that in several places, where measurements less than about 1,100 feet were made, a bed was chosen as representing the top which was lower than that chosen in the rest of the region.

Fossils.—Comparatively few fossils have been found in the Mesaverde formation in this region. A few marine fossils were found in a thin bed of shale immediately overlying the lowest coal bed at the Thompson mine (collections 7375, 7958, 7959), in the northern part of the region, but careful search elsewhere has failed to yield any evidence of them at this or any higher horizon. There can be little doubt that none of the higher beds on the west side of the Big Horn Basin were laid down under marine conditions. Fragments of vertebrate bones have been found at several horizons, but although they are rather common on the dip slopes that coincide with the top of the uppermost sandstone, none have served for the determination of genera or species. Several good collections of fossil plants have been obtained from several horizons, and fragmentary material is rather common. The best material has been obtained from the shales in the upper part of the coal-bearing zone. The fossils are listed below.

Fossil plants from the Mesaverde formation

[Determined by F. H. Knowlton]

Oregon Basin quadrangle

6169. SW. ¼ sec. 7, T. 50 N., R. 100 W.; 400 feet above base of formation. A single fragmentary specimen of a fern, an *Anemia*, but not sufficient to fix age.

6170. Sec. 34, T. 51 N., R. 101 W.; 100 feet above base. *Sequoia brevifolia?* Heer, dicotyledonous fragment. If this species is correctly determined the age should be Montana, pretty near to the Judith River.

6179. NW. ¼ sec. 1, T. 51 N., R. 101 W.; 130 feet above base. *Diospyros judithae?* Knowlton. Age uncertain, but probably not far from the Judith River.

6350. SE. ¼ sec. 34, T. 51 N., R. 101 W.; 150 feet above base. *Anemia* cf. *A. supercretacea* Hollick, fragments of a narrow *Ficus*-like dicotyledon. Age evidently Montana.

Meeteetse quadrangle

6182. NW. ¼ sec. 34, T. 49 N., R. 101 W.; 100 feet above base. *Anemia* sp., *Juglans? missouriensis* Knowlton, *Platanus? wardii* Knowlton. These species if correctly identified should indicate the Eagle sandstone.

Grass Creek Basin quadrangle

6348. SW. ¼ sec. 1, T. 46 N., R. 99 W.; 100 feet above base. Two dicotyledons not known to me.

6662. SW. ¼ sec. 21, T. 44 N., R. 98 W.; about 1,000 feet above base. *Ficus* sp., *Gleichenia?* sp. perhaps new, *Nelumbo intermedia* Knowlton, *Populus cretacea?* Knowlton, *Protophyllocladus* sp.?, *Sequoia reichenbachi* (Geinitz) Heer, *Trapa microphylla* Lesquereux. Age Judith River.

6663. Center of sec. 25, T. 44 N., R. 99 W.; parting in lowest coal bed. Dicotyledonous fragments, fern, apparently new, *Myrica torreyi* Lesquereux, *Podozamites* sp.? I am not able to place this lot with certainty. The *Myrica* has been found in lower Montana, but the cycad has the appearance of being older. The matrix and mode of occurrence suggest the Montana of the Rock Springs area, Wyo., but the species are different. More material will be necessary before this can be settled.

6664. SE. ¼ sec. 29, T. 44 N., R. 98 W.; roof of prospect on lowest coal bed. *Ficus lanceolata?* Heer, *Salix stantoni?* Knowlton, *Sequoia reichenbachi* (Geinitz) Heer, *Sequoia brevifolia* Heer. Age apparently Montana, near the horizon of the Belly River.

Invertebrate fossils from the Mesaverde formation

[Determined by T. W. Stanton]

Oregon Basin quadrangle

7375. SE. ¼ sec. 34, T. 51 N., R. 101 W.; roof of Thompson mine, on lowest coal bed. *Astarte* sp., *Nucula* sp.

7958, 7959. SE. ¼ sec. 34, T. 51 N., R. 101 W.; roof of Thompson mine, on lowest coal. *Crassatellites* sp., *Nucula* sp. The chief interest in these fossils is in the fact that they are the highest marine fossils found in this general section. They can not be identified with species occurring elsewhere.

Vertebrate fossils from the Mesaverde formation

[Determined by C. W. Gilmore]

Oregon Basin quadrangle

87. NW. ¼ NW. ¼ sec. 21, T. 52 N., R. 101 W.; 350 feet above base of formation. Indeterminable fragments, reptilian.

Grass Creek Basin quadrangle

149. NW. ¼ sec. 2, T. 46 N., R. 99 W.; 1,100 feet above base. Fragments of fossil bones; not determinable.

179. NW. ¼ sec. 10, T. 46 N., R. 98 W.; 1,200 feet above base. Fragments of dinosaur bone; not otherwise determinable.

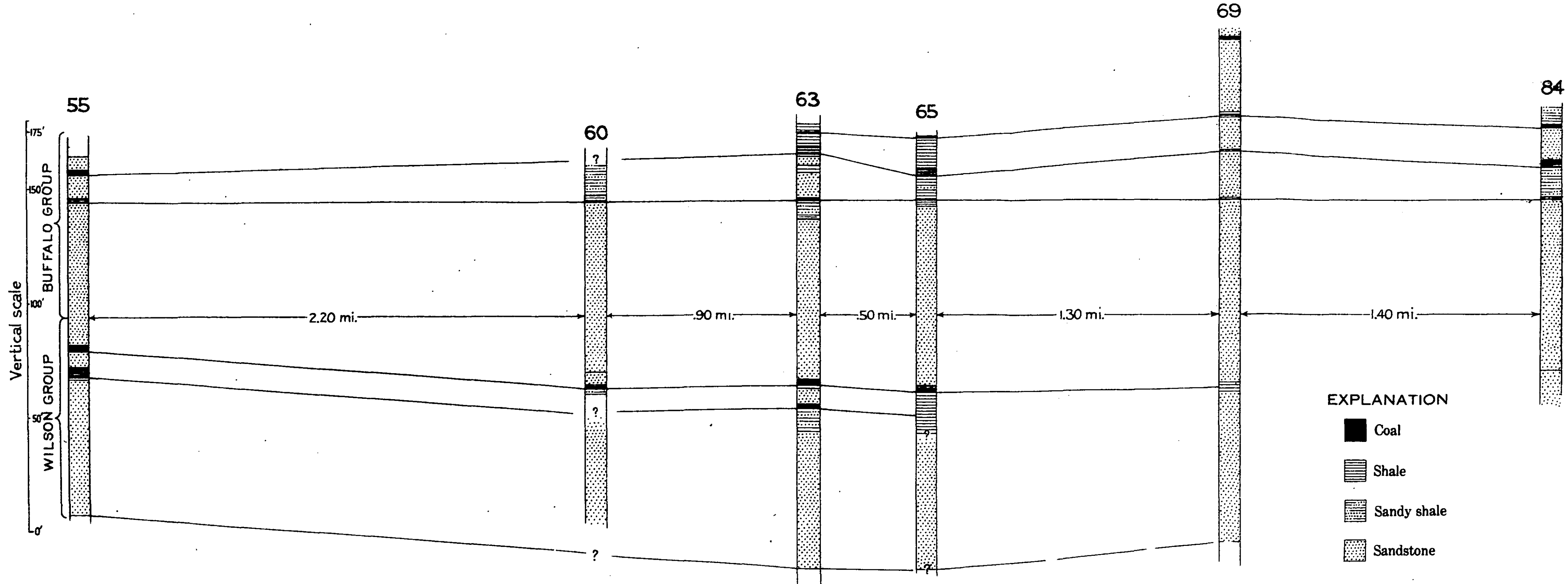
248. NE. ¼ sec. 21, T. 45 N., R. 97 W. Fragments of turtle and dinosaur bones. None are otherwise determinable.

Oregon Basin quadrangle.—The detailed features of the formation are well shown in several parts of the Oregon Basin quadrangle, especially in the rugged ridge between Sage Creek and Oregon Basin, in the ridge east of the Wiley mine, and in the ravines that cut through the ridge that limits Oregon Basin on the south. In general the northern exposures do not show as much detail as the others. In the southeastern part of T. 51 N., R. 100 W., the massive sandstones that are characteristic of the formation are concealed by wash. As there are numerous faults both north and south of this area, others may be present here. Farther north, in the south half of T. 52 N., R. 100 W., the exposures are poor and not continuous, but they permit a fairly reliable interpretation of the position and structure of the beds.

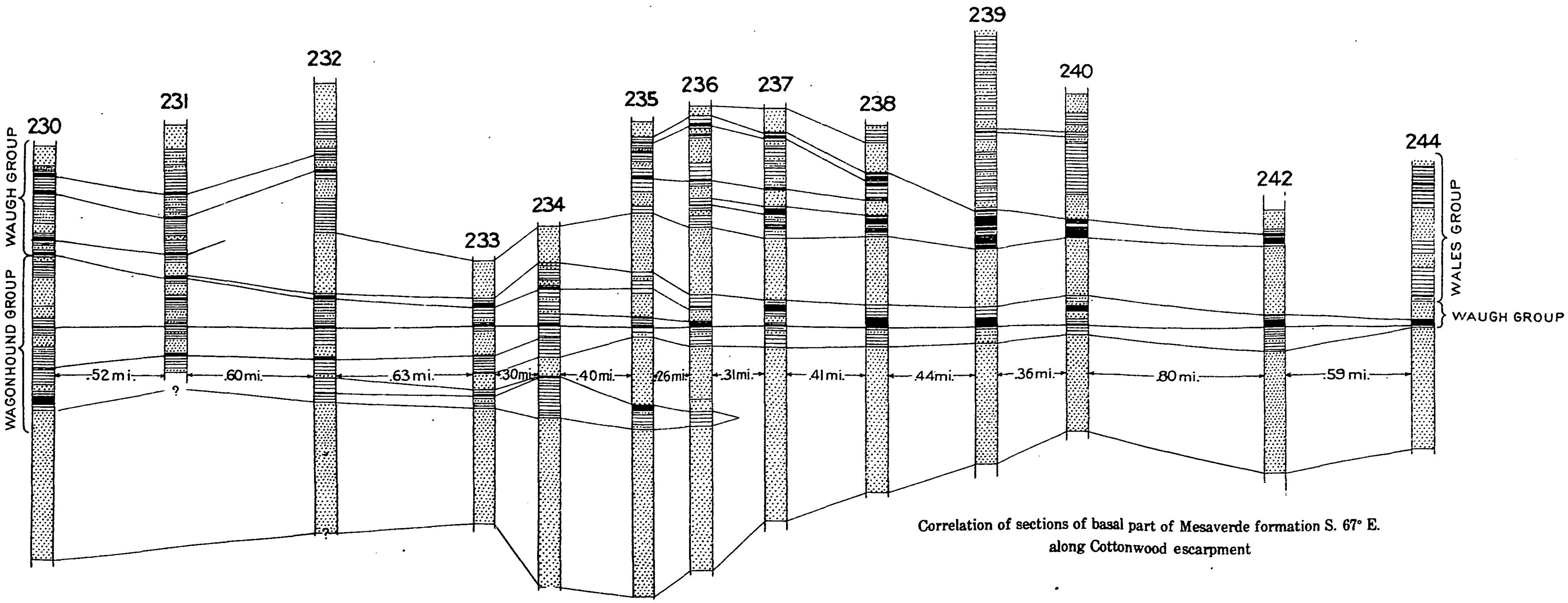
The beds of the Mesaverde formation are sufficiently resistant to preserve much of the evidence of faulting. The two groups of faults in the southern and southeastern parts of Oregon Basin are clearly shown, and one of them in sec. 2, T. 50 N., R. 100 W., is remarkably well exposed (Pl. VII, *A*). The coincidence of faults and deep ravines is common enough in these localities to suggest that faults are the determining cause of the positions of some of the other ravines, but after close examination it has been concluded that this is not the case.

The base of the formation is considered to be the first massive sandstone that underlies the lowest coal bed. Although locally exposures are adequate to show that both the lowest sandstone and the lowest coal persist for 4 or perhaps 5 or 6 miles, as in the northeast quarter of T. 51 N., R. 100 W., and the center of T. 50 N., R. 100 W., the correlation of numerous stratigraphic sections in parts of the region that do not permit satisfactory traverses indicates that neither the coal beds nor the basal sandstones are persistent throughout the quadrangle. This conclusion is fortified by the features of the coal beds and sandstones of the basal part of the Mesaverde formation farther south. The correlations of the coal-bearing part of the formation indicated on Plate VIII are undoubtedly much nearer the truth than those based on the assumption that the lowest coal bed of each section is the same bed.

The upper sandstone is fairly well exposed throughout the quadrangle, because it is overlain by the unconsolidated materials of the Meeteetse formation, and these are readily removed by erosion. The upper sandstone forms the smooth south slope of the ridge which limits Oregon Basin on the south. Near Red



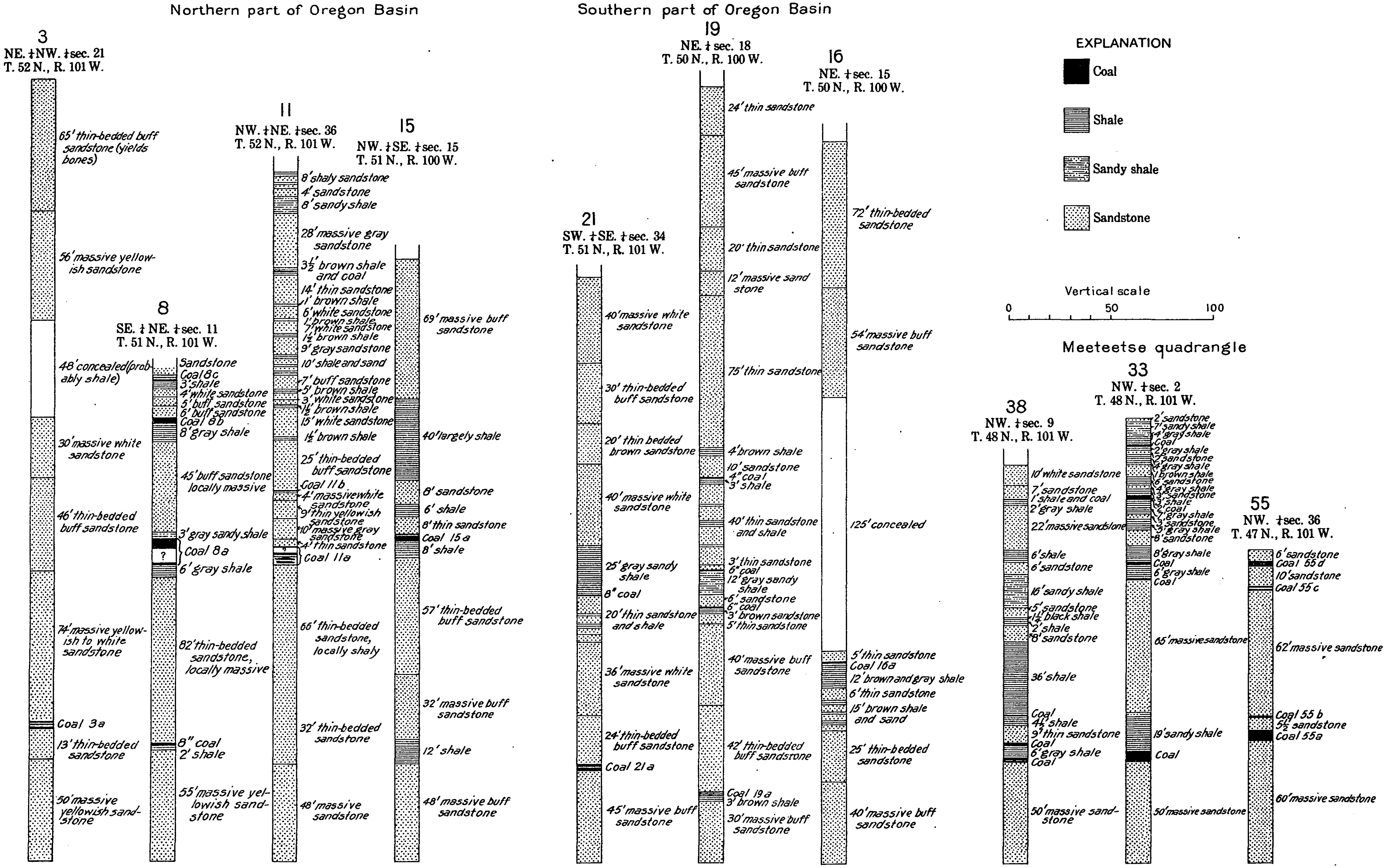
Correlation of sections of basal part of Mesaverde formation N. 67° E. from upper Gooseberry Creek to Little Buffalo Basin



Correlation of sections of basal part of Mesaverde formation S. 67° E. along Cottonwood escarpment

DIAGRAMS SHOWING CONVERGENCE OF SOME COAL BEDS AND DISAPPEARANCE OF OTHERS, MEETEETSE AND GRASS CREEK BASIN QUADRANGLES, WYOMING

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



STRATIGRAPHIC SECTIONS OF THE COAL-BEARING PART OF MESAVERDE FORMATION
OREGON BASIN AND MEETEETSE QUADRANGLES, WYOMING

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Cabin the ridge is covered with numerous flat rectangular blocks of the sandstone, which range from 3 to 8 feet in diameter. These blocks were probably bounded by joints that originated when the beds were sharply flexed around the end of the fold.

Measurements of the thickness of the formation in this quadrangle range from 1,150 feet in T. 52 N., R. 101 W., to 1,375 feet in the northeast quarter of T. 51 N., R. 100 W. Three measurements made on the southern escarpment of the basin range from 1,240 to 1,350 feet. Within these limits the formation commonly contains several massive ledges of sandstone 30 to 85 feet thick, numerous beds of thinly laminated sandstone, and thin layers of light and dark gray shale. The coarsest material in the entire formation is in a zone, not more than 4 inches thick, of chert pebbles which occurs above the uppermost sandstone in the NE. ¼ sec. 11, T. 50 N., R. 101 W. Thin zones of clay balls, however, are found in sandstones near the middle of the formation in the NW. ¼ sec. 14, T. 50 N., R. 100 W., and elsewhere. The massive sandstones are largely confined to the lower 700 feet, and most of them are of light-buff color. The thick beds near the base clearly persist for 10 miles or more without great variation in thickness. On the other hand, the massive beds near the middle persist only 4 to 7 or 8 miles. Locally one or two sandstones near the base are nearly white; these appear to overlie or underlie zones of coal-bearing shale. The uppermost sandstone is generally also nearly white. In a number of localities, but particularly in sec. 1, T. 51 N., R. 101 W., there are numerous log-shaped concretions in the top of the lowest sandstone. In the locality mentioned the concretions are 1 to 2 feet in diameter and 10 to 20 feet long, and here and there the longer axes are parallel. The superficial layer of each concretion is dark brown, but the interior is light brown to buff. The cementing material in these concretions is apparently a carbonate of calcium and iron, which by weathering and oxidation is converted to hydrated oxide of iron. Some of the higher sandstones also contain reddish-brown concretions, but most of these are only 1 to 3 inches in diameter and are composed of nearly pure limonite. The centers of some contain granular pyrite, and it is apparent that the unweathered concretions were largely this mineral.

The coal beds of the Mesaverde formation are the most valuable coals in this quadrangle. On account of the proximity of Cody and the ranches near by, there is a ready market for the coal, and three mines have been opened in the Oregon Basin escarpment. Plate IX shows the character of the beds that make up the lower 300 to 400 feet, or coal-bearing portion, of the Mesaverde formation. The nature and distribution of the coal beds are discussed under "Coal" (pp. 92–97).

The formation has yielded only a few fossils in this quadrangle. Marine fossils, crushed *Baculites*, and some small indeterminable mollusks were collected from the shale that forms the roof of Thompson's coal mine, in sec. 34, T. 51 N., R. 101 W. These represent the latest marine fossils found on the southwest side of the Big Horn Basin. Fragments of saurian bones were found 300 feet above the base in sec. 21, T. 52 N., R. 101 W. Fragmentary leaves have been found in the shales and thin sandstones throughout the formation, but the best collections were obtained from the shales near the coal beds in the lower 250 feet.

Meeteetse quadrangle.—Although the beds of the formation underlie a large area in the Meeteetse quadrangle, only those of the lower portion are well exposed. The lower 300 to 600 feet crops out conspicuously in the eastern part of Spring Creek Basin, along the valleys of Wood River and Gooseberry Creek, and in the southeastern part of Little Buffalo Basin. The beds of the upper portion are well exposed only in the region north of Spring Creek and along the high ridge northeast of Little Buffalo Basin. In the high smooth hills between the Wood River valley and Little Buffalo Basin there are few outcrops. The uppermost beds of the formation have been removed from large areas in Tps. 47 and 48 N., R. 100 W.

Throughout a large part of the region the lower portion of the Mesaverde, made up of alternating massive sandstones and thin layers of coal-bearing shale, presents an impressive rugged escarpment toward the valleys carved in the softer underlying Cody shale. In the region north of Spring Creek, however, although the lower massive sandstones present a rugged escarpment toward Spring Creek Basin, the middle portion of the formation occupies a valley that is roughly parallel to the strike of the beds, and the uppermost sandstones form a prominent parallel ridge.

Although in this quadrangle, as farther north, the lowest massive sandstone (commonly 50 to 70 feet thick), underlying the lowest coal bed, is considered to be the base of the formation, the correlation of the coal beds indicates that this sandstone is not continuous in an eastward direction across the southern part of the quadrangle. According to this correlation the lowest sandstone along Wood River valley and upper Gooseberry Creek either thins out and disappears or merges into a similar overlying sandstone between Gooseberry Creek and Little Buffalo Basin. (See Pl. VIII.)

The choice of the upper limit of the formation is not as simple in this quadrangle as it is farther north. In the region southeast of Meeteetse a group of nearly white massive sandstones that appear to be typical Mesaverde beds form the northeast slopes of the ridges, but overlying these beds and separated from them by layers of soft shale and sandy shale 10 to 40 feet thick, characteristic of the Meeteetse formation, there are one and locally two layers of massive white sandstones 15 to 30 feet thick. These white sandstones are conspicuous along the road southeast of Meeteetse and resemble the material of the Mesaverde formation. In field mapping, these layers of sandstone have been included in the Meeteetse formation. Measurements of the thickness of the formation do not differ greatly from 1,050 feet throughout the quadrangle. As the range in thickness in the Oregon Basin quadrangle is 1,150 to 1,375 feet, it may be questioned whether it would not have been better to include the overlying white sandstone in the Mesaverde formation. This question is discussed further on page 25.

Although in this quadrangle the formation is made up of buff massive and thin-bedded sandstone, gray and black shale, and coal, the beds appear to be thinner and less persistent than they are farther north. The lenses of massive sandstone 40 to 60 feet thick near the middle of the formation in Oregon Basin are distinctly missing in the Little Buffalo Basin escarpment. The occurrence of coal in the formation is discussed on page 95.

Grass Creek Basin quadrangle.—The long escarpments north of Grass Creek Basin and north of the valleys of Cottonwood and Owl creeks present the features of the Mesaverde formation in great detail. Many partial sections are shown on Plates XXVI–XXX.

In general the outcrops along the flat northeast flanks of the anticlines are deeply dissected by intermittent streams that drain northward. At places, as in the east half of T. 46 N., R. 98 W., and the west half of T. 45 N., R. 97 W., the upper and lower massive sandstones resist erosion and form two parallel groups of ridges. Where the beds dip steeply on the southwest flanks they generally form continuous high ridges. Where the beds are nearly flat, as in the east half of T. 44 N. and T. 45 N., R. 99 W., the streams have cut deep winding channels, and as the massive sandstone beds weather to nearly vertical cliffs, travel in these areas, either on horseback or afoot, is extremely difficult.

Except near the main streams the basal massive sandstones crop out high on southward-facing escarpments and therefore form impressive serrated walls toward the basins that hinder or even prevent travel across them for distances of several miles. By contrast the basal sandstones crop out low on northward-facing escarpments and, though locally rough, may be crossed at will.

On the southwest flanks of the Grass Creek and Wagonhound anticlines the limit of the uppermost white sandstones is clearly defined, but on the northeast flanks, as in the Meeteetse quadrangle, there are beds of massive white sandstone separated from characteristic Mesaverde sandstones by light clays and sandy clays of Meeteetse type. Thick beds of massive sandstone are not present near the middle of the formation.

The thickness of the formation has been measured at many localities in the Grass Creek Basin quadrangle and appears to range from 995 to 1,450 feet. The minimum measurement, made in sec. 6, T. 46 N., R. 98 W., appears to be in error because accurate measurements made 1 mile west and 2 miles east of it were 1,250 and 1,200 feet, respectively. With this exception 1,200 feet was the minimum observed in the quadrangle. There appears to be no constant relation between the thickness of the formation and the inclination of the beds, because measurements on each side of the anticlines range from about 1,250 to 1,450 feet.

The occurrence of beds of coal in this formation is discussed on pages 95–97.

MEETEETSE FORMATION

General features.—In several respects the Meeteetse formation presents a striking contrast with the underlying Mesaverde formation and the overlying Lance formation. Most of the sediments that make it up are only slightly indurated; consequently it is readily eroded, and the outcropping belts underlie valleys. Although other causes have determined the distribution and location of the major stream courses, the ease with which the Meeteetse formation is eroded has led to the development of numerous valleys parallel to the strike of the beds, and these valleys are largely occupied by intermittent streams. There are stretches of these strike valleys, locally 3, 4, or even 5 miles long, which do not contain a single outcrop except a thin bed of sandstone here and there. Other parts of such valleys show sections of the rocks from 50 to 100 feet thick in fair detail. The best exposures are found where intermittent streams cutting back headward in such valleys develop badlands against hillside slopes. In several localities these conditions have laid bare 300 to 500 feet of beds in extraordinary detail over areas that range from 1 to nearly 3 square miles. The exposures appear to be best where the streams drain northward or eastward. (See Pl. X, *A*, *C*.) The badlands are practically devoid of vegetation. Elsewhere the only plants that thrive along the belts of this formation are dwarfed forms of sagebrush and grasses.

The base of the Meeteetse formation is considered to be the lowest gray clay and sandy clay that is characteristic of the formation. It is readily recognized over a large part of the region, for it overlies several hundred feet of thick-bedded resistant white sandstone, which makes up the upper member of the Mesaverde formation. Here and there, however, especially in the region southeast of Meeteetse, beds of similar sandstone 15 to 30 feet thick, which are uncommon in the Meeteetse formation, are separated from the underlying Mesaverde sandstones by 50 to 150 feet of gray clay and sandy clay.

The upper limit of the Meeteetse is the base of a persistent buff to white sandstone which is regarded as the base of the Lance formation. Even where the upper beds of the Meeteetse formation are obscured by wash, this sandstone forms a persistent ridge. The thickness of the formation ranges from 660 to 1,360 feet; but most of the measurements range from 850 to 900 feet. A review of all the measurements indicates that there is a tendency for the formation to thicken slightly in a northwesterly direction and to be thinner on steep limbs of anticlines than on flat limbs.

The formation is made up of many alternating beds of gray and brown clay and sandy clay, gray to white sand and clayey sand, brown shale, coal, and bentonite. Its composition has been estimated as sand and sandstone 75 per cent, shale 20 per cent, bentonite 3 per cent, and coal 2 per cent. Locally there are lenses of gray to buff sandstone from which round concretions weather out. Throughout the region beds of coal are absent in the lower half of the formation, but, with the associated brown shale, they are conspicuous in the upper part. In general, the beds of the lower part range from 15 to 100 feet or more in thickness, and as the range in color is not great they are not conspicuous features in the region. In the upper half, on the other hand, although one or two beds in each section may exceed 65 feet in thickness, most of them range from 1 to 25 feet, and the numerous alternating beds of white, gray, brown, and black sediments produce a striking banded appearance, especially where sections 200 to 400 feet thick are exposed along bluffs in badlands (Pl. X, *A*, *B*). Beds of sandstone, brown shale, and coal resist erosion and therefore form successive terraces, which add to the unusual appearance.

This examination has not yielded accurate information concerning the shape or extent of the beds of sand, clay, or coal in the Meeteetse formation. In comparison with those in the lower part of the Mesaverde formation, the lenses appear to be smaller. No coal bed has been traced with assurance more than 3 miles, and the beds of sand and clay may not be more persistent. A distinct local unconformity is well shown in sec. 3, T. 50 N., R. 101 W.

Fossils.—The only fossils that have been found in the Meeteetse formation thus far are plants. Although it was not difficult to discover traces of *Trapa microphylla* in nearly every exposure of a certain variety of fine gray shale, other species are uncommon. The best material was derived from fine clayey sandstone in the lower half of the formation. The beds near the coal rarely yield good specimens of fossil plants, although the brown shale appears to contain considerable carbonized plant material.

The available material has not been closely studied, but the fact that silicified plant material is rather common in the lower half of the formation and coal beds are numerous in the upper half indicates that plants thrived throughout Meeteetse time but that conditions of sedimentation changed. Probably the material which became coal was quickly buried under new sediments, whereas that which was silicified lay for a longer time partly decayed in the swamps of that period.

Fossil plants from the Meeteetse formation

[Determined by F. H. Knowlton]

Oregon Basin quadrangle

6163. NE. ¼ sec. 3, T. 50 N., R. 101 W.; 100 feet above base of formation. A single minute fragment of *Sequoia reichenbachi* (Geinitz) Heer. Age presumably Montana, somewhere near the position of the Judith River.

6164. NE. ¼ sec. 11, T. 50 N., R. 101 W.; 100 feet above base. Stems and fragment of a small fern, apparently new. It is nearest to a species from the Montana at Point of Rocks, Wyo.

6168. SW. ¼ sec. 14, T. 50 N., R. 100 W.; 100 feet above base. *Sequoia reichenbachi* (Geinitz) Heer, fragment of dicotyledon, stems, etc. Presumably in or near the Judith River.

6351. SW. ¼ sec. 3, T. 50 N., R. 101 W.; 900 feet above base. A single specimen of a conifer with a fragment of a dicotyledon. The conifer appears to be *Geinitzia cretacea* Heer, and the other may well be *Populus cretacea* Knowlton, though no margin is preserved. The age should be Montana, in the approximate position of the Judith River.

6352. SW. ¼ sec. 3, T. 50 N., R. 101 W.; 950 feet above base. This is new, being apparently a kind of *Cyperus*-like plant with a large attached tuber.

6353. SW. ¼ sec. 3, T. 50 N., R. 101 W.; 1,000 feet above base. *Trapa? microphylla* Lesquereux; *Trapa?* new, gigantic; *Alga*, peculiar, with trifid sharp-pointed lobes. Age apparently Judith River (?).

6354. NE. ¼ sec. 14, T. 50 N., R. 100 W.; 250 feet above base. *Trapa? microphylla* Lesquereux, fragments of dicotyledon, *Cyperacites* sp., fern, fragmentary but probably new. Age apparently Judith River.

6355. NE. ¼ sec. 14, T. 50 N., R. 100 W.; 900 feet above base. *Trapa? microphylla* Lesquereux. Age apparently Judith River.

6357. NW. ¼ sec. 23, T. 51 N., R. 100 W.; 130 feet above base. *Dammara acicularis* Knowlton, fern of unknown genus, *Ficus praetrinervis* Knowlton, *Ficus speciosissima?* Ward, *Geinitzia formosa?* Heer, *Sequoia reichenbachi* (Geinitz) Heer, *Viburnum?* sp. This material appears to be in the approximate position of the Mesaverde.

6358. NE. ¼ sec. 14, T. 50 N., R. 100 W. Species not stated. Age apparently Judith River.

Grass Creek Basin quadrangle

6362. E. ½ sec. 4, T. 46 N., R. 98 W.; 580 feet above base. *Trapa? microphylla* Lesquereux. Age apparently Judith River.

6363. SE. ¼ sec. 10, T. 46 N., R. 98 W., 550 feet above base. *Anemia* sp., *Dicksonia* sp., new, fruiting, *Ficus asarifolia* Ettingshausen, *Nelumbo* sp., roots and rootlets, *Trapa? microphylla* Lesquereux, *Trapa?* n. sp. This is of the same age as Point of Rocks, Wyo., which has been called Mesaverde, and is apparently the same as Judith River.

6364. SE. ¼ sec. 32, T. 47 N., R. 98 W.; 800 feet above base. *Trapa? microphylla* Lesquereux or a new species of gigantic size, fragment of another dicotyledon. Age apparently Judith River.

6366. NE. ¼ sec. 13, T. 45 N., R. 99 W.; 650 feet above base. *Sequoia reichenbachi* (Geinitz) Heer, *Typha?* sp., fern in fragments only. This should probably be Judith River.

6367a. NW. ¼ sec. 13, T. 45 N., R. 99 W., 650 feet above base. *Trapa? microphylla* Lesquereux. Age apparently Judith River.

6368. NW. ¼ sec. 13, T. 45 N., R. 99 W.; 700 feet above base. *Trapa? microphylla* Lesquereux. This is very peculiar as regards nervation and may prove to be a new species. Age apparently Judith River.

6665. SE. ¼ sec. 10, T. 45 N., R. 99 W.; 900 feet above base. *Ficus speciosissima?* Ward, *Persea?* sp. Age appears to be Montana, but there is not enough material to be certain.

6670. NE. ¼ sec. 2, T. 45 N., R. 98 W.; 600 feet above base. *Abietites cretacea* Newberry, *Dammara acicularis* Knowlton, *Nelumbo?* sp. fragment, *Populites amplus?* Knowlton, *Trapa? microphylla* Lesquereux, *Viburnum* sp. Age Montana, near horizon of the Belly River. The species of *Abietites* is supposed to be of Dakota age—that is, it came originally from Whetstone Creek, N. Mex., in beds called Dakota. So far as known, this is the second time it has been obtained.

Oregon Basin quadrangle.—The outcrop of the Meeteetse formation forms a belt which extends from Sage Creek valley on the north around the north, east, and south sides of Oregon Basin. The width of the outcrop varies with the dip of the beds, and ranges from nearly 3 miles along the trough of the Sage Creek syncline to 1,500 feet in the area east of Oregon Basin, where the Meeteetse is partly overlapped by the Wasatch formation. Several parts of this belt, such as those north and east of Oregon Basin and between Dry Creek and South Fork, coincide with nearly flat surfaces that slope gently away from the near-by ridge of Mesaverde sandstone. Within these areas the surface is underlain by a layer of wash and there are practically no outcrops of the beds. Here and there the outcrops coincide with the valleys of the principal streams, such as Sage Creek and South Fork, and here also there are only a few outcrops. Another part of the belt coincides with ravines tributary to main drainage lines, and although there are a few outcrops in these ravines, several of them terminate headward in badlands where 300 to 500 feet of beds are exposed in great detail. Such badlands are found in secs. 2, 3, 11, and 13, T. 50 N., R. 101 W.; and sec. 14, T. 50 N., R. 100 W.

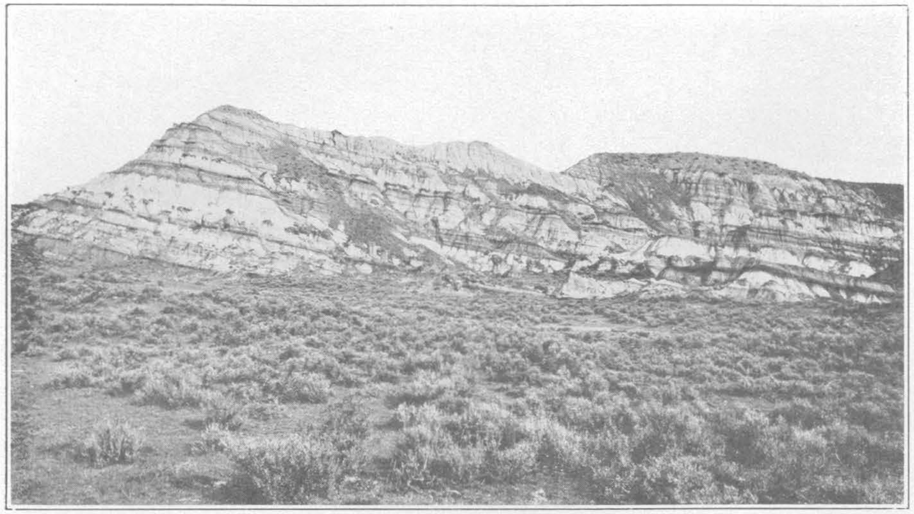
Wherever the uppermost white sandstone of the Mesaverde formation crops out there is no difficulty in recognizing the base of the Meeteetse formation. The resistant beds of white sandstone that are conspicuous near the base of the formation southeast of Meeteetse are not present in the Oregon Basin quadrangle. The upper limit of the formation is a persistent bed of buff concretionary sandstone that marks the base of the overlying Lance formation. This sandstone is conspicuous and may be traced readily through T. 50 N., Rs. 101 and 100 W. Farther north it is overlapped by the basal beds of either the Fort Union formation or the Wasatch formation. In T. 52 N., R. 100 W., the upper limit can not be determined with assurance.

Between these limits the total thickness of the formation ranges from 850 to 1,360 feet. In a broad way the formation attains a maximum thickness of 1,360 feet in the western part of the quadrangle, in sec. 3, T. 50 N., R. 101 W., and thins eastward to 850 feet in sec. 23, T. 50 N., R. 100 W. In the region of maximum overlap of the Wasatch formation, in sec. 23, T. 51 N., R. 100 W., the thickness of beds exposed is only 510 feet. The formation is readily separable into two parts. The lower part is from 520 to 770 feet thick and is made up of gray to white clayey sand and sandstone, locally concretionary, gray to pale olive-green sandy clay, brown shale, and bentonite. Beds of coal are characteristically absent in this part. The upper part is from 320 to 600 feet thick and contains the same kinds of sediments as the lower part and in addition numerous thin beds of coal. Sections several hundred feet thick exposed in badlands present a striking banded appearance. The bands are composed of alternating light and dark gray, white, olive-green, and dark-brown layers, and although no regularity in the alternation has been detected only rarely do the layers of a single color exceed 60 feet in thickness.

A good illustration of a local unconformity is shown in the exceptionally good exposures of the upper part of the formation in sec. 3, T. 50 N., R. 101 W. Here about 50 feet of beds have been removed, and the resulting channel is filled with sediments that are parallel in bedding with those below as well as those above the unconformity.

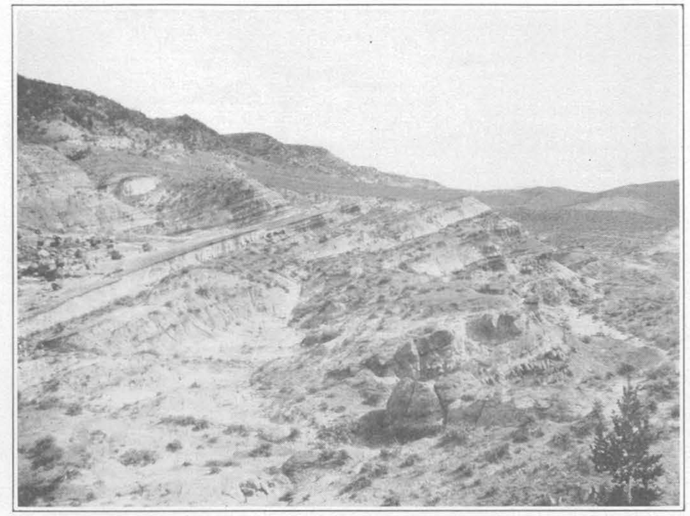
Although fragments of silicified wood are common in the formation in this region, more has been found in the Oregon Basin quadrangle than elsewhere. Four trunks, the largest 18 inches in diameter and 9 feet long, were found in place in a small area in the N. ½ sec. 23, T. 51 N., R. 100 W. Several hundred feet farther north the silicified root of a tree, 6 inches in diameter and at least 18 inches long, is preserved as it grew in the beds, with many attached rootlets.

A description of the coal beds of the formation (see fig. 3) is presented on pages 97-100. By comparison with the beds of the Mesaverde formation those of the Meeteetse are much more lenticular and are more commonly separated into three, four, or five benches by layers of brown shale. Although there are a number of natural exposures on the quadrangle, only two attempts to mine coal from the beds of the formation have been made—at the Eagle mine, in sec. 2, T. 51 N., R. 100 W., and at the Rader mine, in sec. 10, T. 52 N., R. 101 W.



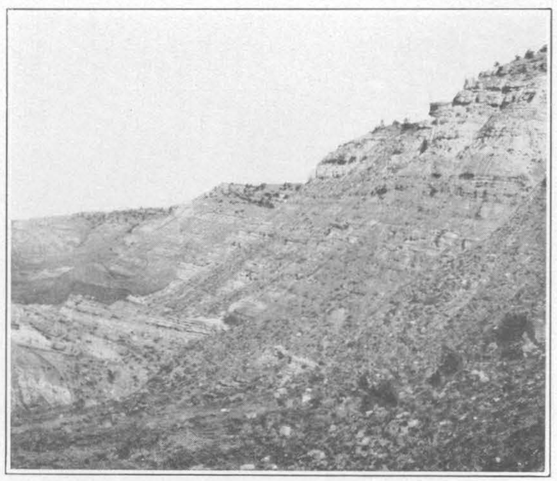
A. SANDSTONE AND SHALE NEAR THE MIDDLE OF THE MEETEETSE FORMATION IN SEC. 33, T. 49 N., R. 100 W., 2 MILES NORTHWEST OF MEETEETSE, WYO.

Photograph by E. G. Woodruff

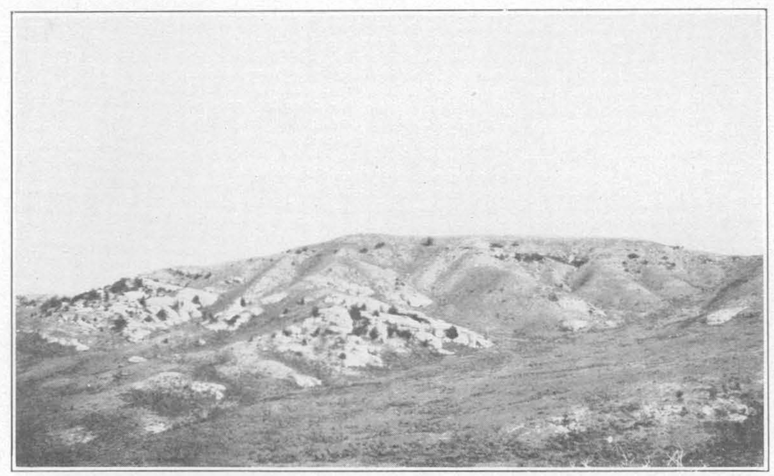


B. SANDSTONE, CLAY, AND BROWN SHALE IN THE MIDDLE OF THE MEETEETSE FORMATION IN SEC. 4, T. 48 N., R. 100 W., 1 MILE SOUTHEAST OF MEETEETSE, WYO.

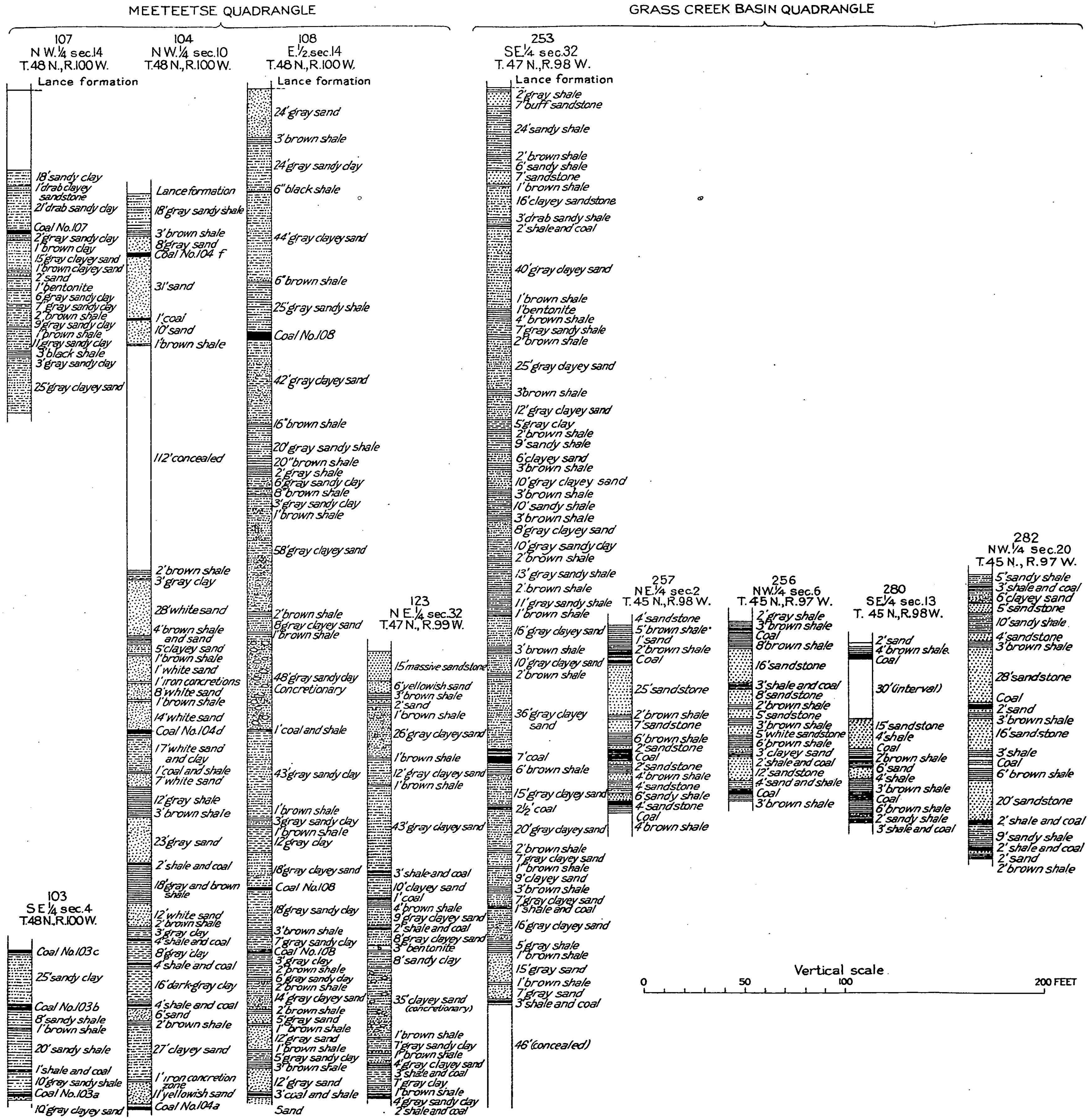
Stratigraphic section 104 given on Plate XI measured in this locality



C. UPPER PART OF THE MEETEETSE FORMATION AND LOWER PART OF THE LANCE FORMATION ALONG ESCARPMENT OF NORTH SIDE OF PROSPECT CREEK, T. 45 N., R. 99 W.

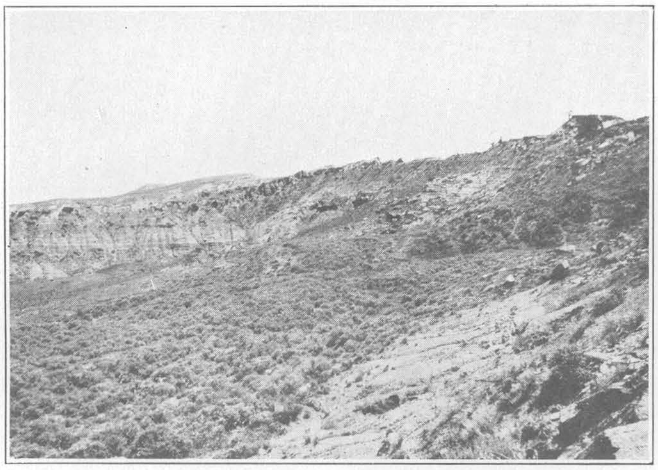


D. MASSIVE SANDSTONE OF THE LANCE FORMATION UNCONFORMABLY OVERLAIN BY GRAVEL OF THE WASATCH FORMATION AT THE HEAD OF IRON CREEK, SEC. 8, T. 47 N., R. 100 W.



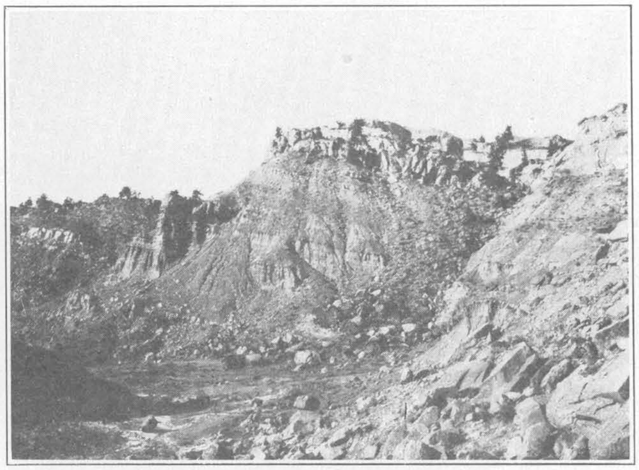
DETAILED SECTIONS OF THE COAL-BEARING PART OF THE MEETEETSE FORMATION, MEETEETSE AND GRASS CREEK BASIN QUADRANGLES, WYOMING

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



A. LOCAL ANTICLINE LYING IN THE TROUGH OF A MAJOR SYNCLINE, SEC. 26, T. 50 N., R. 101 W.

The rocks exposed belong to the upper part of the Lance formation



B. SOFT SAND AND CLAY OF THE UPPER PART OF THE LANCE FORMATION OVERLAIN BY THE BASAL SANDSTONE OF THE FORT UNION FORMATION HALF A MILE NORTHWEST OF GWYNN'S RANCH, T. 46 N., R. 97 W.

C. MASSIVE CONGLOMERATE AT THE BASE OF THE FORT UNION FORMATION IN SEC. 9, T. 45 N., R. 99 W.

D. DETAIL VIEW OF MASSIVE CONGLOMERATE AT THE BASE OF THE FORT UNION FORMATION IN SEC. 22, T. 46 N., R. 99 W.

The pebbles are largely quartzite, probably derived from beds of Algonkian age

Meeteetse quadrangle.—The beds of the Meeteetse formation crop out in three isolated areas in the Meeteetse quadrangle, of which the largest is a belt from half a mile to 2 miles wide that extends from the northwest corner of the quadrangle southeastward for 18 miles to the eastern border. The beds also crop out in an area 4 miles long by 2 miles wide at the head of Iron Creek, largely in T. 47 N., R. 100 W. A smaller area lies along Gooseberry Creek, in the southeast corner, from which it extends into the Grass Creek Basin quadrangle.

Among the major streams only Gooseberry Creek follows the outcrop of the Meeteetse formation for a part of its course. That part of the belt which lies northwest of Meeteetse is crossed by Meeteetse Creek and Greybull River, but except for a few short ravines no well-defined valley follows the outcrop. Southeast of Meeteetse the outcrop is marked by a continuous, narrow valley, through which intermittent streams drain northwestward to Greybull River and southeastward to Buffalo Creek. Well-defined valleys also follow the outcrop at the head of Iron Creek.

In several localities parts of the formation that range from 50 to 200 feet in thickness are well exposed, but there are only a few outcrops that range from 200 to 500 feet in thickness, and these are confined to the region southeast of Meeteetse (Pl. X, *B*) and along Gooseberry Creek. Plate XI presents detailed sections of the beds that make up the upper part of the formation in these localities. The base of the formation is readily determinable at the head of Iron Creek, but elsewhere in the quadrangle there are beds of light-gray and white sandstone 15 to 30 feet thick which resemble those that mark the top of the Mesaverde formation but which are separated from them by 50 to 150 feet of clay and sandy clay of the varieties characteristic of the Meeteetse formation. The clays have been considered to be the base of this formation, so that the sandstone is also included in it. The upper limit of the formation is the buff to white sandstone that marks the base of the overlying Lance formation. As this sandstone is well indurated in this quadrangle, it forms a persistent ridge throughout much of the area (Pl. X, *D*).

The thickness of the Meeteetse formation in this quadrangle ranges from 660 feet in sec. 9, T. 47 N., R. 100 W., at the head of

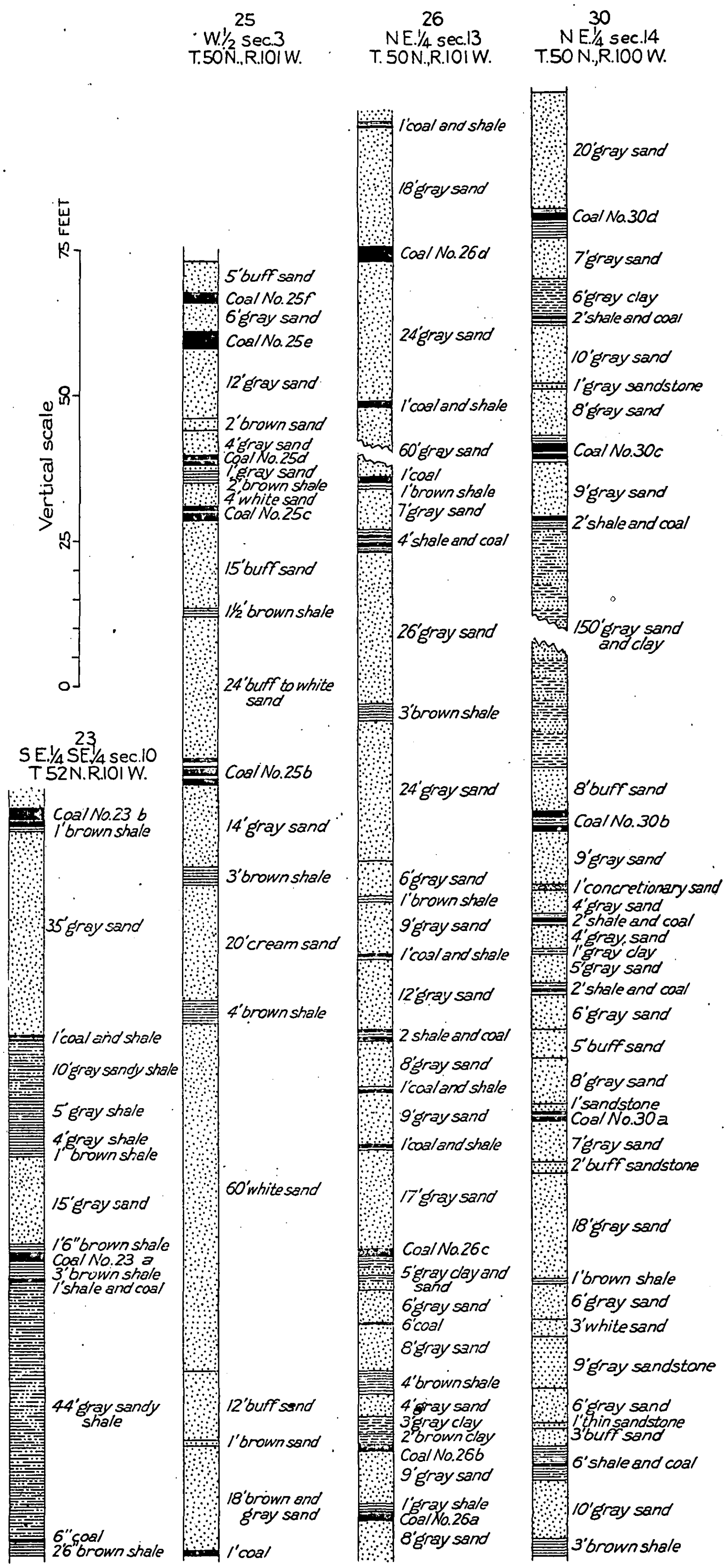


FIGURE 3.—Correlation of stratigraphic sections of the coal-bearing part of the Meeteetse formation in the Oregon Basin quadrangle

Little Buffalo Creek, to 950 feet in sec. 14, T. 48 N., R. 100 W., southeast of Meeteetse. Other measurements along the belt northwest of Meeteetse range from 800 to 900 feet.

Here, as in the Oregon Basin quadrangle, the formation is separable into two parts—a lower part 320 to 415 feet thick, which contains no coal and an upper part, 340 to 550 feet thick, which commonly contains several coal beds. Here, however, the coal beds appear to be localized in two zones—one nearly 200 feet thick near the base of the upper part and the other about 100 feet thick near the top of the upper part (Pl. X, *C*). Although there are in this quadrangle many natural exposures of beds in this formation more than 14 inches thick, there is only one prospect on one of these beds, in the NW. ¼ sec. 14, T. 48 N., R. 100 W. A bed of bentonite crops out in the same locality, about 100 feet below the top of the formation.

Grass Creek Basin quadrangle.—Although the areas of the Meeteetse formation are extensive in the Grass Creek Basin quadrangle, in only a small part of the quadrangle do they offer the opportunity for detailed study. One belt that ranges from half a mile to 1 mile in width extends almost entirely around the Grass Creek anticline. It coincides with a conspicuous valley, only a small part of which is occupied by perennial streams. The only good exposures are found where small badlands have been developed near the heads of intermittent streams, and there are several parts of the valley from 3 to 5 miles long where only a few resistant beds of sandstone crop out. The best exposures in the quadrangle as well as in the entire region are found along the valley of Prospect Creek, the position of which appears to be determined by the formation. Sections from 300 to 450 feet thick are shown in great detail for several miles along upper Prospect Creek in T. 45 N., R. 99 W. (Pl. X, *C*), and thinner sections occur here and there farther east. The Prospect Creek belt is nearly continuous with another area that extends northwestward to the headwaters of Grass Creek, but only a few outcrops can be found in this area. Farther south the formation is fairly well exposed in small badlands at the head of Wagonhound Creek. It passes westward under the sheet of Wasatch sediments.

The same problem that was encountered southeast of Meeteetse in determining the bed that should properly be considered the base of the formation was met along Gooseberry Creek, lower Prospect Creek, and upper Wagonhound Creek. Here the base of the formation was taken as the base of the lowest clay and clayey sand that are characteristic of the formation. There is little difficulty in recognizing throughout the area the persistent buff sandstone that is considered to be the base of the overlying Lance formation. With these limits the thickness of the formation in this quadrangle ranges from 750 feet along Prospect Creek in sec. 13, T. 45 N., R. 99 W., to 900 feet in sec. 14, T. 46 N., R. 98 W., and several other localities. No definite tendency toward thickening or thinning in a given direction has been noticed. It seems probable that there is little variation in the thickness throughout the quadrangle and that the differences observed are due to variations in the choice of the lower limit.

In this quadrangle, as in the region farther north, the formation is separable into a lower noncoal-bearing portion 400 to 500 feet thick and an upper coal-bearing portion 350 to 450 feet thick. The outcrops examined indicate that the coal beds are localized in two zones—one near the base of the upper part, commonly containing three beds more than 14 inches thick, and the other near the top, commonly containing one or two beds more than 14 inches thick. There is no prospect on a bed of coal in this formation in this quadrangle.

No beds of bentonite have been observed in the formation in this quadrangle, but some are undoubtedly present.

TERTIARY (?) SYSTEM

LANCE FORMATION

General features.—Like the underlying Meeteetse formation, the Lance is characterized by dominance of sand and sandstone over clay and shale and general lack of induration of the beds; it contrasts with the Meeteetse in containing practically no coal beds. Furthermore, the colors and the degree of induration of the Meeteetse formation persist throughout the region, whereas these qualities of the Lance formation show considerable variation. In large parts of the region, particularly that northwest of Greybull River and that southeast of Gooseberry Creek, the beds have been readily eroded and with those of the underlying Meeteetse formation occur in valleys. Only the harder sandstone beds resist weathering and form low but locally persistent ridges. At first glance it appears that the beds of highest dip are the most indurated, but this is not true for the entire region. Generally the Lance beds are not so well exposed as those of the Meeteetse formation, and only rarely can sections more than 200 feet thick be studied in detail. Badlands have been developed in a few areas underlain by these beds, but the areas are small and widely separated (Pl. XII, *B*).

The base of the formation has been considered to be a rather persistent bed of massive buff to light-gray sandstone, which overlies the uppermost coal bed of the Meeteetse formation. This bed was chosen because it is the first persistent bed that underlies the lowest zone of characteristic vertebrate fossils and that commonly crops out. In the region northwest of Greybull River it yields by weathering numerous spherical concretions 5 to 10 feet in diameter and therefore may be detected where exposures are poor. It would have been difficult to choose a bed to mark the top of the formation if an unconformity had not been discovered early in the work in the northern part of the area. (See pp. 35–36.) Fortunately, even though rather few fossils of each species have been found, all that were obtained from the beds above the unconformity have been considered by those who have studied them as belonging to the Fort Union formation, and with one exception all those obtained below the unconformity have been considered Lance species. This statement is true not only in the area of unconformity but in the more remote areas into which the top of the formation has been traced by lithologic features.

Rough estimates of the best sections (see fig. 4) indicate that 70 to 80 per cent of the total thickness of the formation is sand or sandstone, 10 to 20 per cent is sandy clay or sandy shale, and 5 to 15 per cent is clay or shale. Most of the beds of sandstone are more than 40 feet thick, and some are as thick as 210 feet. Generally the entire layer of sand presents a massive appearance and is not laminated. Here and there the sands show the torrential type of cross-bedding. In addition to the basal bed, numerous others yield by weathering nearly spherical light-brown concretions. Gravel zones are practically absent; a single quartzite pebble 2 inches long was found in a bed of sandstone in sec. 29, T. 46 N., R. 97 W., associated with waterworn bones. The sand grains rarely exceed 1 millimeter in diameter.

Fossils are not common in the formation and were found only in local badlands. Although more careful search would probably yield additional invertebrate fossils and fossil plants, the fact that this investigation has yielded so few is considered good evidence that the formation in this region contains relatively fewer fossils of these varieties than in the regions farther east, particularly east of the Big Horn Mountains. Vertebrate fossil remains are not so rare, and although the material so far discovered is fragmentary, it appears to be sufficient to determine satisfactorily the age and correlation of the beds. Most of the badland areas developed in the middle third of the formation yield fragments of limb bones, plates, and teeth. At one locality, in the NW. ¼ sec. 3, T. 49 N., R. 101 W., sufficient material was found to indicate that systematic exploration for fossil material might be justified in the neighborhood.

Fossil plants of the Lance formation

[Determined by F. H Knowlton]

Oregon Basin quadrangle

6166. NW. ¼ sec. 3, T. 49 N., R. 101 W., 300 feet above base. A single long, narrow dicotyledonous leaf suggestive of a species in the Lance of Montana and eastern Wyoming. Should presume this to be Lance in age, but this is hardly more than a guess.

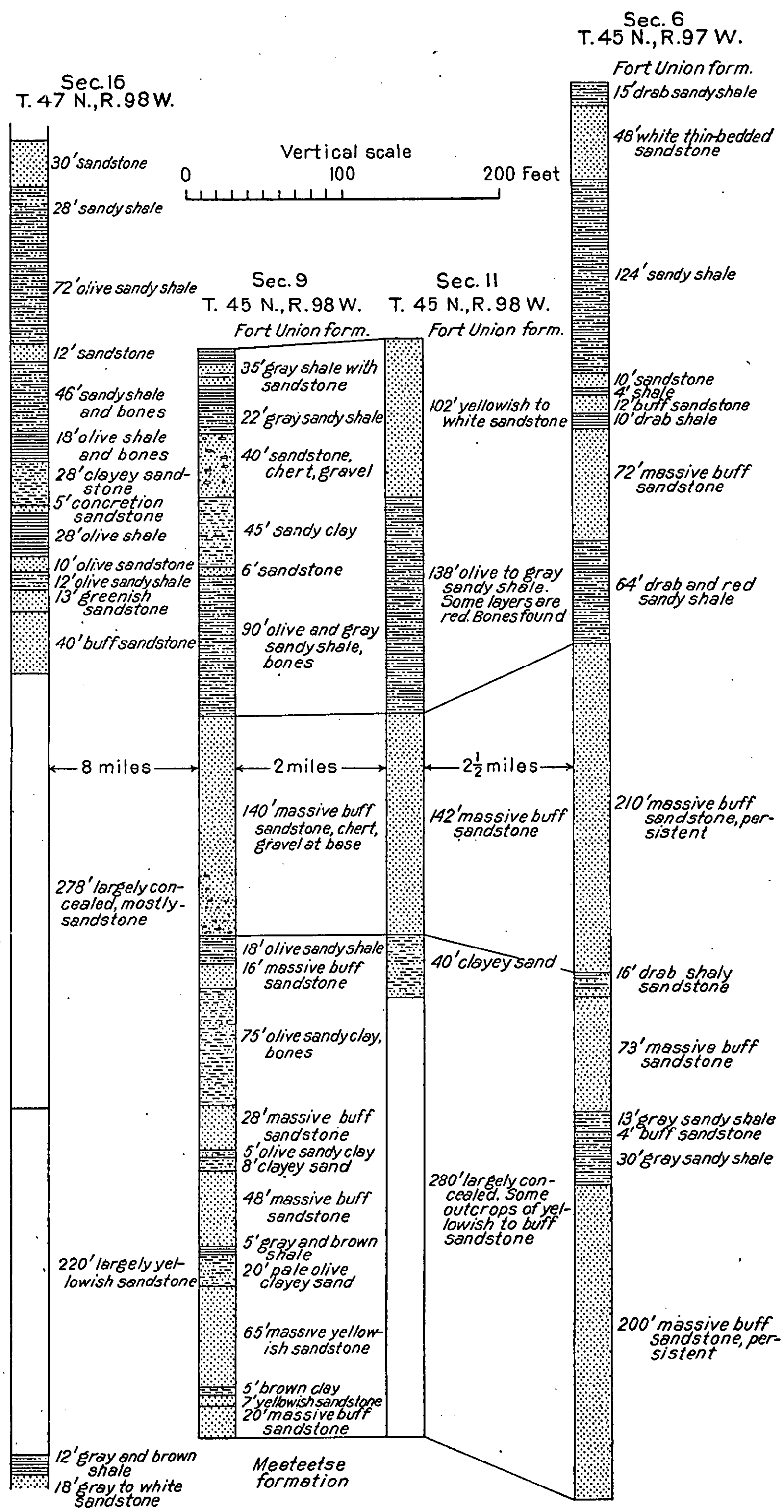


FIGURE 4.—Stratigraphic sections of the Lance formation

6174. W. ½ sec. 24, T. 50 N., R. 100 W., 350 feet above base. *Trapa? microphylla* Lesquereux, *Cabomba gracilis* Newberry. Age Fort Union.

6360. E. ½ sec. 23, T. 50 N., R. 100 W., 350 feet above base; same locality as 6174. *Trapa? microphylla* Lesquereux, *Trapa?*, a new, very fine thing that may not be congeneric, one or possibly two dicotyledons, apparently new, or at least not known to me. Age apparently Judith River.

Meeteetse quadrangle

6183. SE. ¼ sec. 3, T. 48 N., R. 100 W., 500 feet above base. A single species, a long, narrow leaf suggestive of *Dryophyllum subfalcatum* Lesquereux or a species of *Rhamnus*, but uncertain. No accurate age determination can be made from this material.

Grass Creek Basin quadrangle

6667. E. ½ sec. 29, T. 46 N., R. 97 W., 30 feet below base of Fort Union. *Cocculus haydenianus* Ward, *Nelumbo?*, fragmentary, *Trapa?*, fragments only, *Viburnum telioides* Ward. This material is typical Fort Union, and if it occurs in the Lance it is new to me.

6669. W. ½ sec. 33, T. 46 N., R. 97 W., 60 feet below base of Fort Union. A single leaf of *Cocculus haydenianus* Ward. (See 6667.)

Invertebrate fossils from the Lance formation

[Determined by T. W. Stanton]

Oregon Basin quadrangle

7960. NW. ¼ sec. 19, T. 50 N., R. 100 W., 200 feet above base. *Columna?* sp., *Goniobasis tenuicarinata* Meek and Hayden, *Physa* sp., *Sphaerium* sp., *Unio* n. sp., a very broad stout form identical with an undescribed species from the Lance formation in Converse County, Wyo. These fossils indicate the horizon of the Lance formation.

Vertebrate fossils from the Lance formation

[Determined by C. W. Gilmore]

Oregon Basin quadrangle

17. NW. ¼ sec. 3, T. 49 N., R. 101 W., 300 feet above base. *Brachychampsa montana*, teeth; carnivorous dinosaur, tooth; *Compsemys*, fragments; crocodilian teeth and scutes, not determinable; *Lepisosteus*, scales; *Trachodon*, teeth, species not determinable; *Triceratops*, teeth, species not determinable. Age probably Lance.

162. NW. ¼ sec. 26, T. 50 N., R. 101 W., 800 feet above base. *Champsosaurus*, vertebrae; fragments of the skull of a ceratopsian; *Lepisosteus*, scales; fragments of dinosaur bones, not determinable; fragments of turtle shells, not determinable.

163. NW. ¼ sec. 3, T. 49 N., R. 101 W., 300 feet above base. *Triceratops*, section of horn core and other fragments of skull; *Trachodon*, teeth; carnivorous dinosaur, teeth, claw; dinosaur, rib; crocodile, scutes, teeth; *Champsosaurus*, vertebrae; *Compsemys*, fragments. Age probably Lance.

173. E. ½ sec. 23, T. 50 N., R. 100 W. Fragments of bone associated with a number of dermal scutes or plates of an armored dinosaur. These are doubtfully regarded as pertaining to *Ankylosaurus*, a genus described by Barnum Brown from the Hell Creek beds of Montana.

Meeteetse quadrangle

98. NW. ¼ sec. 33, T. 49 N., R. 100 W., 200 feet above base. Bone fragments; nothing determinable.

Grass Creek Basin quadrangle

182. NW. ¼ sec. 32, T. 47 N., R. 98 W., 680 feet above base. Carnivorous dinosaur, fragments of tooth; *Triceratops*, teeth; turtle fragments, not determinable. Age probably Lance.

247. SE. ¼ sec. 4, T. 45 N., R. 98 W., 400 feet above base. Ceratopsian, frill fragments; trionychid turtles, fragments; carnivorous dinosaur, tooth and fragments; *Lepisosteus* scales.

Oregon Basin quadrangle.—The Lance formation underlies a large area in the southwest corner of the Oregon Basin quadrangle, and from this area a belt extends eastward along the northern limb of the Cottonwood syncline until in sec. 24, T. 50 N., R. 100 W., it is concealed by the Fort Union formation, which unconformably overlies it. A similar though wider belt also extends southeastward into the Meeteetse quadrangle along the southwestern limb of the Cottonwood syncline.

The base of the Lance formation is a persistent concretionary buff sandstone that overlies the highest coal bed of the Meeteetse formation. This sandstone is well exposed in the regions west of Dry Creek and southeast of Red Cabin, where it generally forms either a local terrace or a persistent ridge. It has not been observed north of Red Cabin. The upper limit of the formation is a conglomeratic buff sandstone that marks the base of the Fort Union formation and is exposed along Meeteetse Rim and the South Fork of Dry Creek. In secs. 13 and 24, T. 50 N., R. 100 W., this sandstone rests successively on the Lance and Meeteetse formations and therefore marks an angular unconformity. (See pp. 35–36.) With these limits the thickness of the formation in this quadrangle ranges from 1,300 to 1,400 feet.

The Lance formation is poorly exposed in this quadrangle, the good outcrops being confined to a few badland areas along the upper parts of the two branches of Dry Creek. The following section near the top of the formation appears to be characteristic of the whole in this quadrangle.

Section of upper part of Lance formation, sec. 23, T. 50 N., R. 101 W.

	Feet
Sand, thin bedded, buff to yellowish	130
Shale, brown	6
Sandstone, concretionary, persistent	3
Sand, buff, homogeneous	12
Sand, clay, bluish gray	15
Sandstone, concretionary, persistent	6
Sand, buff	15
Sand, buff to yellowish, cross-bedded; several nonpersistent concretion zones	100
Clay, bluish gray	3
	290

In a broad way the formation resembles the lower noncoal-bearing part of the Meeteetse formation. Most of the Lance formation is made up of beds of slightly consolidated buff sand 50 to 150 feet thick. A characteristic feature of the thick as well as the thin beds is the presence of persistent beds from which numerous concretions weather out. Most of these concretions are slightly flattened spheres that commonly range from 2 to 10 feet in diameter. The interior is gray to light buff, but they weather dark buff to brown. The cement appears to be a mixture of calcium and iron carbonates, and the brown color is due to the alteration of iron carbonate to iron hydrous oxide. The beds of clay and shale range from gray to light brown but commonly lack the lamination and dark color of those of the Meeteetse formation. No gravel has yet been found in the Lance, and the coarsest material appears to be less than 0.1 inch in diameter. Here and there in the beds of sand, however, there are thin zones of clay balls that range from 1 to 3 inches in diameter. These are made up of slightly hardened clay that was eroded, rolled, and laid down locally at the time of deposition.

Fossils are not common in this quadrangle and are confined largely to two zones—one about 100 feet thick 200 to 300 feet above the base and the other probably not so thick 800 feet above the base. Numerous bone fragments and teeth have been found, but invertebrates and fossil plants appear to be very uncommon.

Meeteetse quadrangle.—A belt of the Lance formation extends from the northwest corner of the Meeteetse quadrangle diagonally southeastward across the quadrangle. Another area, of triangular shape and scarcely a mile in diameter, lies at the head of Iron Creek, in sec. 8, T. 47 N., R. 100 W. In this quadrangle, as in the region farther north, the base is considered to be the massive, locally concretionary buff sandstone that overlies the uppermost coal bed of the Meeteetse formation. There is no difficulty in recognizing this bed southeast of Meeteetse Rim. The upper limit of the formation is a bed of locally conglomeratic sandstone that marks the base of the Fort Union formation. As gravel is not persistently present, the bed must be traced from those areas where it is well exposed. Measurements of the thickness of the formation range from 910 to 1,010 feet in the northwestern part of the belt to 840 feet in the southeastern part.

In the region northwest of Greybull River, where the dip of the beds ranges from 4° to 9°, the features of the formation, although not well exposed, resemble those in the Oregon Basin quadrangle in that the most abundant material consists of thick beds of unindurated buff to drab sand that locally yield large nearly spherical concretions on weathering. The clay and shale range from gray and drab to brown, and the units are commonly less than 30 feet thick. Southeast of Greybull River, where the dip ranges from 12° to 35°, the beds are much more indurated, and consequently the sandstones form a group of persistent rugged ridges. In this area, as farther to the northwest, sandstone makes up 80 per cent or more of the thickness of the formation, but curiously it is nearly white instead of buff to drab. The cement of the sandstone is locally calcite, but the extent to which silica is present has not been determined. The beds of sandstone are commonly from 20 to 60 feet thick, but the interbedded shales are much thinner.

No coal has been observed in the formation in this quadrangle. No sediments more than a quarter of an inch in diameter have been observed. Some curious siliceous concretions from 1 to 4 inches in diameter were collected from a bed near the top of the formation in the SW. ¼ sec. 20, T. 48 N., R. 99 W. The shape of most of them is that of flattened cauliflower heads, but some are more irregular. They resemble the aggregates of geyserite that are common near the hot springs in Yellowstone National Park, but it is difficult to imagine how such aggregates could have been formed in this region.

The only fossils that have been recovered from the beds in this quadrangle are a few fragments of bones from a zone 200 feet above the base in the NW. ¼ sec. 28, T. 49 N., R. 100 W., and a few leaves from a zone 500 feet above the base in the SE. ¼ sec. 3, T. 48 N., R. 100 W.

Grass Creek Basin quadrangle.—The Lance formation crops out extensively in the northern half of the Grass Creek Basin quadrangle but is not present in the southern half. One belt almost completely encircles the Grass Creek anticline and merges on the south into another belt that extends along Prospect Creek around the northern limbs of the Cottonwood and Wagonhound anticlines. The belt northeast of Grass Creek Basin is not well exposed except locally in bad lands near the southeast end (Pl. XII, *B*). That part of the belt southwest of Grass Creek which lies west of Spring Gulch is also not well exposed. On the other hand, that part of the same belt which lies east of Spring Gulch, as well as most of the belt north of Prospect Creek, presents numerous nearly complete sections in great detail (Pl. X, *C*).

If the unconformity at the base of the Fort Union is present in this quadrangle it is not apparent either from the evidence of local difference of strike and dip of the beds or from the thickness of the Lance formation. The base of the formation here, as farther north, is the massive buff sandstone that overlies the uppermost Meeteetse coal bed, and this sandstone is readily recognized either where it is cut by streams or in a persistent ridge along the valley that is cut in the Lance and the underlying formation. It does not yield the numerous spherical concretions common at this horizon farther north, however. The upper limit is also a massive buff sandstone, locally conglomeratic and very conspicuous, which is considered to be the base of the Fort Union formation.

The Lance formation includes a number of beds of massive sandstone which range from a few feet to as much as 210 feet in thickness. The color ranges from buff to slightly yellowish and white. The beds of intercalated shale are generally thinner than the sandstones, and their color ranges from gray through pale drab to olive-brown and brown. The coarsest material seen in the Lance formation in this region consists of several rounded quartzite pebbles about 1 by 1½ by 2 inches, found associated with waterworn bones in sec. 29, T. 46 N., R. 97 W. The grains of sand rarely exceed 1 millimeter in diameter. In the same section several beds of coal, each less than 6 inches thick, occur in the uppermost 15 feet of shale under the basal sandstone of the Fort Union. These are the only coal beds observed in the Lance formation in the entire region.

The thickness of the Lance in this quadrangle ranges from 640 to 910 feet. For the most part the smaller measurements were made in the southernmost belt, along Prospect Creek, and the larger in the northwest corner of the quadrangle.

The only fossils that have been found here include several collections of teeth and fragmental bones from zones 400 to 680 feet above the base of the formation.

TERTIARY SYSTEM

FORT UNION FORMATION

General features.—Although the Fort Union formation crops out over a large area, the maximum thicknesses are exposed only here and there along the belt that lies between the group of folds and the central part of Big Horn Basin. In general the exposures are good—much better, in fact, than those of any of the lower formations except the Mesaverde. Estimates indicate that 60 to 70 per cent of the formation is made up of sandstone or conglomerate. These rocks show a wide range in induration, but in a broad way they are intermediate between the harder Mesaverde sandstones and the softer rocks of the Lance and Meeteetse formations. The sandstones resist erosion more than the intervening shales; consequently they weather as low ridges or flat ledges. The badlands that are rather common in the two underlying formations are uncommon in the Fort Union.

The base of the formation was placed at an angular unconformity that separates a lower group of beds which persistently yield a fauna assigned to the Lance formation from overlying beds whose flora is considered to belong to the Fort Union formation. The extent of the unconformity is indicated by the fact that in a distance of 3 miles along the strike as much as 1,800 feet of beds has been eroded. However, the basal beds have been traced southeastward in a region of folds for a distance of 60 miles without the detection of additional evidence of unconformity, unless slight variations in thickness of the underlying beds are so considered.

The character of the basal sandstone of the Fort Union formation in the region of unconformity differs greatly from its character where no unconformity has been recognized. In the region of unconformity neither this sandstone nor those higher in the formation contain any sediment more than an inch in diameter, and most of the material is less than 0.1 inch. On the other hand, the basal as well as higher beds contain thick lenses of conglomerate that are made up largely of material more than an inch in diameter.

The thickness of the exposed part of the Fort Union formation in this region depends on the position of the Wasatch beds which overlap it. The maximum thickness of 3,140 feet is found in T. 46 N., R. 97 W., and although there is apparent conformity between it and the Wasatch beds, other evidence indicates unconformity, and a part of the formation may be covered. The formation is nearly 5,600 feet thick on Shoshone River.[14] In the Hole in the Ground, at the head of Fifteenmile Creek, in T. 48 N., R. 99 W., where it is apparently conformable with the Wasatch beds, 2,000 feet was measured. A few miles west of this area, in T. 51 N., R. 100 W., the formation is completely concealed by Wasatch beds. These relations show clearly that a profound unconformity separates the two formations in this region—an unconformity that indicates much more widespread uplift and erosion than that which locally separates the Fort Union from the underlying Lance formation.

Like the two formations that underlie it, the Fort Union formation is dominantly sandy, but in several respects it differs greatly from them. It contains at least three persistent beds of conglomerate and two others that are probably lenticular. In the hope of obtaining light on the source of the materials and their relative resistance to abrasion, close attention was paid to the pebbles that make up the conglomerate. The results of the examination of the fossils found in the pebbles are presented on pages 36–37. The following tables present estimates of composition by rock types. In the region of unconformity the formation contains only traces of coal, whereas farther southeast, in the region of apparent conformity with the Lance formation, one to four important beds are present. The areal distribution of some of the coal beds coincides roughly with that of underlying beds of conglomerate, but some of the beds of conglomerate underlie larger areas than the near-by beds of coal.

[14] Hewett, D. F., The Shoshone River section, Wyo.: U. S. Geol. Survey Bull. 541, p. 106, 1914.

Composition of basal conglomerate of Fort Union formation

Range in size (inches)	Oregon Basin quadrangle		Meeteetse quadrangle				Grass Creek Basin quadrangle			
	1. SW. ¼ sec. 10, T. 52 N., R. 100 W.; 10-foot zone at base of formation		2. NW. ¼ sec. 8, T. 49 N., R. 100 W.; 15-inch zone at base of formation		3. SW. ¼ sec. 21, T. 49 N., R. 100 W.; 6-inch zone at base of formation		4. SW. ¼ sec. 16, T. 46 N., R. 99 W.; 10-foot zone at base of formation		5. NW. ¼ sec. 22, T. 46 N., R. 99 W.; 10-foot zone at base of formation	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
4-8							5	Quartzite, gray, round 75 Quartzite, red, round 25	20	Quartzite, gray, round 40 Quartzite, red, round 40 Chert, gray and brown, round 20
2-4	10	Chert, subangular, fossiliferous 95 Silicified wood, subangular 5					25	Quartzite, gray, round 60 Quartzite, red, round 20 Chert, black, round 10 Sandstone, fine, round 10 Granite, pink, round Tr.	10	Quartzite, gray, round 30 Quartzite, red, round 50 Chert, gray, round 20 Andesite, dark, round Tr.
1-2	30	Chert, brown and gray, many fossils, round 85 Chalcedony 10 Silicified igneous rock 5	5	Chert, brown, subangular 60 Chert, white, subangular 30 Silicified wood, subangular 5 Hard shale, subangular 5	Trace	Largest pebble, red quartzite, 2 by 1 by ¾ inches.	30	Quartzite, gray, round 60 Chert, black, round 10 Chalcedony, red, round 5 Sandstone, red, round 20 Quartz, rose, round 3 Granite, red, round 2	15	Quartzite, gray, round 25 Quartzite, red, round 40 Chert, black, round 5 Chert, gray, round 30 Silicified wood, round Tr.
½-1	40	Quartzite, round Tr. Chert, brown, subangular 95 Silicified wood, subangular 5 Silicified igneous rock Tr. Hornstone Tr.	10	Chert, brown, subangular 70 Chert, white, subangular 20 Silicified wood, subangular 3 Hard shale, subangular 7	5	Quartzite, red, round 100	8	Quartzite, gray, round 20 Quartzite, red, round 45 Chert, black, round 15 Chert, white, round 5 Sandstone, round 10 Quartz, rose, round 5	10	Quartzite, gray, round 40 Quartzite, red, round 30 Chert, black, subangular 5 Chert, gray, subangular 25 Silicified wood, subangular Tr.
¼-½		(Included with ½-1 inch)	15	Chert, brown, subangular 80 Chert, white, subangular 15 Quartz, subangular 5	15	Chert, black, gray, and white, round 100	2	Quartzite, gray, round 20 Quartzite, red, round 45 Chert, black, subangular 15 Chert, white, subangular 5 Sandstone, subangular 10 Quartz, rose 5	5	Quartzite, gray, round 35 Quartzite, red, round 25 Chert, black, subangular 5 Chert, gray, subangular 35
<¼	20	Chert, brown and gray Chalcedony. Hornstone.	70	Chert, black 20 Quartz 80	80	Chert Quartz.	30	Not determined	40	Quartz 10 Chert 90

Composition of basal conglomerate of Fort Union formation—Continued

Range in size (inches)	Grass Creek Basin quadrangle									
	6. NW. ¼ sec. 1, T. 45 N., R. 99 W.; 20-foot zone at base of formation		7. SE. ¼ sec. 25, T. 46 N., R. 99 W.; 12-foot zone at base of formation		8. NE. ¼ sec. 5, T. 45 N., R. 98 W.; 35-foot zone at base of formation		9. SE. ¼ sec. 9, T. 45 N., R. 98 W.; 15-foot zone at base of formation		10. SE. ¼ sec. 11, T. 45 N., R. 98 W.; 3-foot zone at base of formation	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
4-8	10	Quartzite, gray, round 60 Quartzite, red, round 35 Sandstone, gray, round 5 Chert, round Tr. Andesite, dark, round Tr. Largest pebble, 11 by 7 by 5 inches.	5	Quartzite, gray, round 75 Quartzite, red, round 25 Sandstone, gray, round Tr. Andesite, dark, round Tr. Largest pebble, 8 by 6 by 4 inches.	20	Quartzite, gray, round 60 Quartzite, red, round 30 Chert 10	10	Quartzite, gray, round 70 Quartzite, red, round 20 Chert, gray, round 5 Sandstone, gray, round Tr. Andesite, decomposed, round Tr. Largest pebble, 8 by 6 by 5 inches.	3	Quartzite, gray, round 95 Quartzite, red, round Tr. Sandstone, white, round 5
2-4	15	Quartzite, gray, round 60 Quartzite, red, round 35 Sandstone, gray, round 2 Chert, round Tr. Chert breccia, round Tr.	15	Quartzite, gray, round 65 Quartzite, red, round 25 Chert, black, round 5 Chert, gray, round 5	30	Quartzite, gray, round 50 Quartzite, red, round 30 Chert, black, round 10 Chert, light brown, round 10 Chert breccia, round Tr.	30	Quartzite, gray, round 70 Quartzite, red, round 20 Chert, gray, round 10 Chert breccia Tr.	12	Quartzite, gray, round 70 Quartzite, red, round 20 Chert, decomposed, round 10
1-2	25	Quartzite, gray, round 50 Quartzite, red, round 40 Sandstone, gray, round 5 Chert, gray, round 5	20	Quartzite, gray, round 70 Quartzite, red, round 20 Chert, black, round 5 Chert, gray, round 5 Andesite, round Tr.	10	Quartzite, gray, round 30 Quartzite, red, round 60 Chert 5 Chert breccia 5	20	Quartzite, gray, round 60 Quartzite, red, round 25 Chert, black, round 5 Chert, gray, round 10	15	Quartzite, gray, round 60 Quartzite, red, round 25 Chert, round 15
½-1	20	Quartzite, gray, round 65 Quartzite, red, round 25 Chert, gray, subangular 10	15	Quartzite, gray, round 70 Quartzite, red, round 20 Chert, round 10	3	Quartzite, gray, round 40 Quartzite, red, round 50 Chert 5 Chert breccia 5	5	Quartzite, gray, round 60 Quartzite, red, round 25 Chert, black 10 Chert, gray 5	25	Quartzite, gray, round 45 Quartzite, red, round 45 Chert, round 10
¼-½	Trace	Quartzite Chert.	5	Quartzite 90 Chert 10	2	Quartzite, gray 40 Quartzite, red 55 Chert 5	Trace	Quartzite 40 Chert 60	15	Quartzite, gray, round 45 Quartzite, red, round 45 Chert, round 10
<¼	30	Not determined	40	Not determined	30	Not determined	35	Not determined	30	Chert. Quartz.

Composition of second conglomerate of Fort Union formation

[Grass Creek Basin quadrangle]

Range in size (inches)	11. SW. ¼ sec. 25, T. 46 N., R. 99 W.; 5-foot zone 360 feet above base of formation		12. NE. ¼ sec. 8, T. 45 N., R. 98 W.; 12-foot zone 360 feet above base of formation		13. NW. ¼ sec. 18, T. 45 N., R. 97 W.; 12-foot zone 360 feet above base of formation		14. SE. ¼ sec. 34, T. 47 N., R. 98 W.; 5-foot zone 680 feet above base of formation	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
4-8	Trace	Quartzite, gray, round 95 Chert, gray, round 5 Largest pebble, 4 by 3 by 2 inches.	2	Quartzite, gray, round 70 Quartzite, red, round 10 Sandstone, red and gray, round 10 Chert, gray, round 10 Clay balls Tr.	Trace	Quartzite, gray, round 95 Quartzite, red, round 5	Trace	Largest pebble, 5 by 3 by 2 inches.
2-4	10	Quartzite, gray, round 70 Quartzite, red, round 10 Chert, gray, round 20	8	Quartzite, gray, round 50 Quartzite, red, round 10 Sandstone, red, round 10 Chert, black and gray, round 25 Sandstone, gray, round 5	25	Quartzite, gray, round 85 Quartzite, red, round 10 Chert, white, round 5	2	Quartzite, red, round 25 Quartzite, gray, round 35 Chert, gray, round 20 Chert, black, round 15 Silicified wood, subangular 5
1-2	15	Quartzite, gray, round 50 Quartzite, red, round 20 Chert, gray, subangular 30	15	Quartzite, gray, round 50 Quartzite, red, round 50 Sandstone, red, round Tr. Chert, black and gray, round 35 Sandstone, gray, round Tr.	35	Quartzite, gray, round 80 Quartzite, red, round 10 Chert, red, round 10	8	Quartzite, red, round 15 Quartzite, red, round 15 Chert, white, round 35 Chert, black, round 30 Silicified wood, subangular 5
½-1	30	Quartzite, gray, round 35 Quartzite, red, round 15 Chert, gray, subangular 50	25	Quartzite, gray, round 20 Quartzite, red, round Tr. Chert, round 70 Sandstone Tr.	20	Quartzite, gray, round 70 Quartzite, red, round 10 Chert, subangular 20 Sandstone, round Tr.	20	Quartzite, red, round 10 Quartzite, gray, round 10 Chert, gray, white, subangular 55 Chert, black, subangular 20 Silicified wood, subangular 5

¼-½	20	Quartzite. Chert.	25	Quartzite 20 Chert 80	15	Quartzite, gray, round 30 Quartzite, red, round 5 Chert, subangular 65	15	Quartzite, red and gray, round 8 Chert, red and gray, subangular 50 Chert, black, subangular 40 Silicified wood, subangular 2
<¼	25	Not determined	25	Not determined	10	Chert, subangular 80 Quartz, subangular 20	55	Chert, subangular 75 Quartz, subangular 25

Composition of fifth conglomerate of Fort Union formation

Range in size (inches)	Meeteetse quadrangle						Grass Creek Basin quadrangle	
	15. NE. ¼ sec. 11, T. 49 N.; R. 100 W.; 18-inch zone, 1,800 feet above base of formation		16. NE. ¼ sec. 8, T. 48 N.; R. 99 W.; 6-foot zone, 1,860 feet above base of formation		17. SE. ¼ sec. 9, T. 48 N., R. 99 W. (east of quadrangle); 30-foot zone, 1,850 feet above base of formation		18. SE. ¼ sec. 8, T. 46 N., R. 97 W.; 30-foot zone, 2,060 feet above base of formation	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
4-8			2	Quartzite, gray, round 70 Quartzite, red, round 10 Chert, round 10 Sandstone, round 10 Largest pebble, 8 by 7 by 5 inches.	2	Quartzite, gray, round 50 Quartzite, red, round 5 Chert, round 20 Sandstone, round 20 Silicified wood, round 5 Largest pebble, 9 by 6 by 5 inches.	Trace	Largest pebble, 5 by 3 by 2 inches.
2-4	2	Sandstone, round 25 Chert, black, round 75	5	Quartzite, gray, round 60 Quartzite, red, round 5 Chert, subangular 25 Sandstone, round 10	10	Quartzite, gray, round 60 Quartzite, red, round 10 Chert, subangular 30	10	Quartzite, red and gray, round 75 Chert, gray and black, round 25 Silicified wood, round Tr.
1-2	5	Quartzite, gray, round 10 Chert, subangular 50 Sandstone, subangular 30 Limestone, round 5 Quartz, round 5	15	Quartzite, gray, round 30 Chert, subangular 60 Sandstone, round 10 Shale, flat Tr.	25	Quartzite, gray, round 50 Quartzite, red, round 5 Chert, subangular 35 Sandstone, round 10 Granite, pink, round Tr.	30	Quartzite, red and gray, round 55 Chert, gray and black, round 45 Quartz, vein, round Tr. Silicified wood, round Tr.
½-1	15	Chert, subangular 60 Quartzite 35 Agate 5	40	Quartzite, gray, round 25 Chert, subangular 75	25	Quartzite, gray, round 30 Quartzite, red, round 5 Chert, black, subangular 65	30	Quartzite, red and gray, round 30 Chert, gray and black, subangular 70
¼-½	25	Chert 75 Quartz 25	25	Quartzite 10 Chert 90	15	Quartzite, round 10 Chert, subangular 80 Quartz, vein, round 10	10	Quartzite, round 10 Chert, subangular 90 Quartz, vein, subangular Tr.
>¼	53	Not determined	13	Not determined	23	Chert Quartz.	20	Chert. Quartz. Clay.

The general character of the Fort Union formation persists throughout the region under consideration, but in some respects there are striking local differences. In contrast with the sandstone beds of the Lance formation those of the Fort Union are generally thin bedded. A striking exception to this tendency is observed in the northeastern part of the Grass Basin quadrangle, where the basal sandstone is a single massive bed that commonly ranges from 80 to 120 feet in thickness and attains a maximum of 230 feet. The sandstone beds are uniformly light colored but range from light gray and white in the northern part of the area to light buff and white in the southeastern part. A large part of the shale is light gray, but locally there are beds of drab, olive-brown, and red. The lowest red clay in the section measured at the head of Fifteenmile Creek is 1,250 feet above the base, but on the south slope of Ilo Ridge there is a bed 306 feet above the base. The lowest bed of red clay in the Shoshone River section is 3,920 feet above the base. These as well as other relations of the beds of red clay indicate that the color was not an original property of the sediment but was caused by certain conditions under which the beds were laid down, and these conditions were not widespread during the early stages of deposition of the formation.

The beds of conglomerate in the Fort Union show a great range in areal extent and in size of material. The zones from 1,800 to 2,060 feet above the base may be parts of a single layer, and if they are, this layer would be 30 miles long in a southeast direction. None of the other zones appears to persist for more than 10 miles. There are four or possibly five separate zones of conglomerate in the 3,140 feet exposed in the Grass Creek Basin quadrangle, where the formation appears to overlie the Lance beds conformably, but about 15 miles to the northwest there is only one such zone, and on Shoshone River, 50 miles farther northwest, where no unconformity has been recognized at the base, there is one thick zone at the base and two others at 3,875 and 4,425 feet above the base. Conglomerates are apparently lacking in the lower 600 feet of beds in the region of unconformity. These relations indicate that the region around the Oregon Basin domes was gently upfolded near the end of the Lance epoch and that while streams both northwest and southeast of the upfolded area were receiving great quantities of coarse and fine sediments, this area was undergoing erosion. When finally uplift ceased and erosion removed the part above the surface, fine sediments only were deposited unconformably on the Meeteetse and Lance beds.

In the only part of the region where there is any evidence as to the attitude of the basal zone of conglomerate southwest and northeast of Grass Creek Basin, the longer axis of this zone appears to lie in a northwesterly direction. On the other hand, in this locality the longer axes of the individual lenses that make up the zone appear to lie in a northeasterly direction. These relations would be found where a group of streams flowing northeastward over an alluvial plain had deposited their débris in lenticular zones broadly parallel to a more remote shore line trending northwest.

The material that makes up the conglomerates indicates their source, as well as that of the other sediments in the formation. The fossils that have been found in the chert pebbles show clearly that they were derived in part, at least, from beds that range from Mississippian to Permian in age. On the other hand, the quartzite resembles more than anything else on record the material that is found here and there in Algonkian sediments. The nearest generally western source of this quartzite as well as the few granite and vein quartz pebbles lies in the Wind River and Gros Ventre mountains,[15] about 60 miles to the southwest.

Similar material may have been exposed at the surface during Fort Union time in the region west and northwest of the Wind River Mountains that is now covered with Tertiary lava flows and related igneous rocks. The silicified wood pebbles are undoubtedly derived from areas of the Meeteetse formation exposed farther west. The few pebbles of fine-grained igneous rocks are interesting, but it has not been possible to identify a possible source of them. They appear to be extrusive rocks, and if they are, they would indicate a period of volcanism earlier than that during which the lavas of Yellowstone Park and Idaho were poured out. The pebbles of coal resemble and may be fragments eroded from beds in the Meeteetse formation in a region southwest of that in which they are now found.

The formation has yielded numerous fossil plants but thus far no invertebrate or vertebrate animal remains. There appear to be no well-defined fossiliferous zones, although fossils are more abundant near the base, in the vicinity of coal beds. Several of the best collections have been derived from the shale that overlies the Black Diamond and Gwynn coal beds.

Fossil plants from the Fort Union formation

[Determined by F. H. Knowlton]

Oregon Basin quadrangle

6167. NE. ¼ sec. 24, T. 50 N., R. 100 W.; about 600 feet above base of formation. A single dicotyledonous leaf without margin. Age unidentifiable from this species, though apparently Tertiary.

6171. North center sec. 24, T. 50 N., R. 100 W.; about 500 feet above base of formation. *Cornus newberryi?* Hollick, *Fagus?* sp., *Populus amblyrhyncha?* Ward, *Quercus* sp. Age Fort Union.

[15] St. John, Orestes, Report of the geological field work of the Teton division: U. S. Geol. and Geog. Survey Terr., Eleventh Ann. Rept., pp. 320-508, 1879. Endlich, F. M., Report on the geology of the Sweetwater district: Idem, pp. 3-158.

6172. NW. ¼ sec. 13, T. 50 N., R. 100 W.; about 150 feet above base of formation. Fragments of several dicotyledons but nothing determinable.

6173. E. ½ sec. 31, T. 50 N., R. 99 W.; 1,200 feet above base. *Celastrus ferrugineus?* Ward, *Equisetum* sp., *Populus grewiopsis?* Ward, *Sequoia nordenskioldi* Heer, *Taxodium* sp. Age Fort Union.

6175. SE. ¼ sec. 27, T. 50 N., R. 100 W.; 150 feet above base. A large *Platanus*, probably *P. raynoldsii* Newberry, but the identification is uncertain, as there is no margin. No determination of age possible, though apparently it is Fort Union.

6361. SW. ¼ sec. 24, T. 50 N., R. 100 W.; 100 feet above base. *Populus cuneata* Newberry, fragments without margin of one or two other dicotyledons. The *Populus* is a Fort Union species.

Meeteetse quadrangle

6181 (also Woodruff 30). Roof of Black Diamond mine, SE. ¼ sec. 21, T. 49 N., R. 100 W.; 120 feet above base. *Dryopteris* n. sp., fine and new; *Ficus* sp., lauraceous leaf, new; *Sapindus grandifolius* Ward; *Sequoia langsdorfii*, or near it. Age probably Fort Union, but material not sufficient to be certain.

Grass Creek Basin quadrangle

6365. NW. ¼ sec. 27, T. 46 N., R. 99 W.; roof of coal bed 50 feet above basal conglomerate. *Monimiopsis fraterna* Saporta, *Platanus* sp., *Populus amblyrhyncha* Ward, *Populus daphnogenoides* Ward, *Taxodium occidentalis* Newberry. Age Fort Union.

6369. E. ¼ sec. 5, T. 45 N., R. 98 W.; 20 feet above basal conglomerate. *Platanus raynoldsii* Newberry, *Viburnum* sp. Age Fort Union.

6370. SE. ¼ sec. 9, T. 45 N., R. 98 W.; shale over basal conglomerate. *Carpites* sp., *Celastrus ferrugineus?* Ward, *Hedera* sp., *Platanus haydenii* Newberry, *Platanus* sp. Age Fort Union.

6668. NW. ¼ sec. 28, T. 46 N., R. 97 W.; 200 feet above base. *Platanus* sp., *Populus amblyrhyncha* Ward, *Salvinia* sp. (probably new), *Viburnum tilioides* Ward, *Viburnum* sp.? Age Fort Union.

26 (Woodruff). 2 miles north of Ilo. *Berchemia multinervis?* Al. Braun, *Celastrus* sp. (probably new), *Ficus* (type of *F. planicostata* Lesquereux), *Ginkgo adiantoides* Heer, *Magnolia tenuinervis?* Lesquereux, *Platanus nobilis?* Newberry, *Populus amblyrhyncha* Ward, *Quercus* sp., *Viburnum newberryanum* Ward, *Viburnum antiguum?* (Newberry) Hollick. Age Fort Union.

6666 (Woodruff). Gwynn's prospect, SW. ¼ sec. 5, T. 45 N., R. 97 W.; 175 feet above base. *Celastrus ferrugineus* Ward, *Celastrus taurinensis* Ward, *Celastrus pterospermoides* Newberry, *Celastrus* sp., *Corylus americana* Walter, *Diospyros* sp.?, *Juglans* sp. (probably new), *Onoclea sensibilis fossilis* Newberry, *Paliurus pulcherrimus* Ward. *Paliurus* sp. (new?), *Platanus haydenii* Newberry, *Platanus raynoldsii* Newberry, *Populus arctica* Heer of Lesquereux, *Populus amblyrhyncha* Ward, *Populus daphnogenoides* Ward, *Populus cuneata* Newberry, *Populus* n. sp., *Protophyllocladus* n. sp. (fine), *Sapindus affinis* Newberry, *Sapindus grandifolius* Ward, *Sequoia nordenskioldi* Heer, *Sequoia* sp.

Oregon Basin quadrangle.—Exposures of the Fort Union formation in the Oregon Basin quadrangle are confined to three irregular areas. The smallest, which covers scarcely a quarter of a square mile, lies in sec. 27, T. 50 N., R. 101 W., near the southwest corner of the quadrangle. Another lies near the northern border, and the largest lies adjacent to the Cottonwood syncline, on the southern border. Between these last two areas the formation is concealed by the overlapping Wasatch formation. In the northern area the beds are poorly exposed, for only a few ledges of sandstone and conglomerate crop out above the wash. Exposures are better in the southern areas, though south of Meeteetse Rim the beds dip in the same direction as the slope of the surface and the exposed sections are therefore thin, but several good sections are shown in fair detail along the north side of the Rim.

Early in the progress of this investigation an angular unconformity was discovered in secs. 13, 14, and 24, T. 50 N., R. 100 W., which, as further study seems to prove, lies at the base of the Fort Union formation. Unconformable relations were observed in three areas and will be described in detail. In an area of badlands at the head of a ravine in the SW. ¼ NW. ¼ sec. 24 a group of gray and drab sands and sandy clays characteristic of the Lance formation trend N. 45° E. and dip 20° SE. The only fossils collected from these beds were a few aquatic plants, of which *Trapa microphylla* was the most abundant (collections 6174, 6360).

According to F. H. Knowlton, one collection appears to be characteristic of the Judith River formation (middle formation of the Montana group) and the other of the Fort Union formation (lower Eocene). About 500 feet northeast of these exposures a low ridge that extends northward is made up wholly of beds of white sandstone that trend N. 5° W. and dip 19° E. Although these particular beds have not yielded any fossil plants, they are distinctly unlike the underlying sediments and resemble characteristic Fort Union material in this general region. The relations of the two groups of beds leave no doubt that a pronounced unconformity separates them.

Half a mile farther north, near the southwest corner of sec. 13, T. 50 N., R. 100 W., there are fair exposures of the beds on the north side of a ravine that drains west. The lowest beds consist largely of massive buff sandstone from which concretions weather out in persistent zones. Although the strike of these beds can be determined only approximately, the dip is clearly 22° E. About 500 feet to the east the dip of several conspicuous ledges of white to yellowish thin-bedded sandstone is 9° E. Closer examination shows that the change from the steeper to the flatter dip is abrupt and not gradual. If these exposures were isolated, they would be suggestive but not conclusive evidence of an unconformity.

Farther north, in the NE. ¼ sec. 14, T. 50 N., R. 100 W., a ravine that drains northward has carved out a badland area in which the bedrock exposures are very good (Pl. XIII). The west slope of a low ridge shows the alternating gray and buff sand, brown shale, and coal characteristic of the upper part of the Meeteetse formation. (See Pls. XI and XIII.)

These beds strike N. 15° E. and dip 23° SE. If the hillside is viewed from the southwest, it is apparent that thick beds of brown shale and coal are cut off in their northward extension by the bed of pale-yellowish sandstone that forms the crest of the ridge. In a distance of 2,000 feet north from the head of the ravine about 160 feet of beds are cut off by the overlying sandstone. East of the ridge the strike of the overlying beds is readily determined to be N. 10° W., and the dip 9° E. Farther north the beds converge, and the unconformity can be recognized only by the absence of the beds that normally make up the upper 500 feet of the Meeteetse formation and the entire Lance formation.

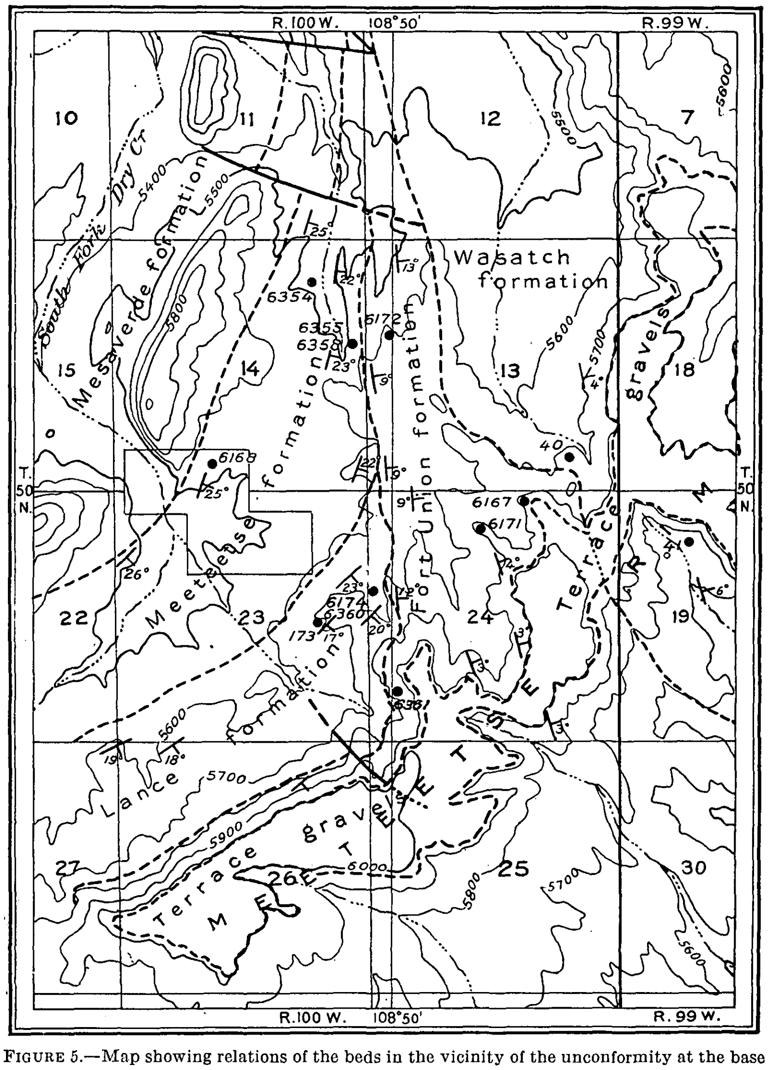


FIGURE 5.—Map showing relations of the beds in the vicinity of the unconformity at the base of the Fort Union formation

The significance of the exposures in these three localities is apparent when it is observed that the beds considered to mark the base of the Fort Union formation at the southern locality can be traced with fair assurance to the uppermost beds at the northern locality. There are about 1,500 feet of beds lacking at the northern locality which are present at the southern, about 2 miles distant. The unconformity undoubtedly continues northward, because in the center of sec. 2, T. 50 N., R. 100 W., the base of the Fort Union formation rests on beds in the middle of the Meeteetse formation, and about 1,800 feet of beds are missing. Farther north beds of the Wasatch formation overlap the unconformity, and nothing can be determined about it.

Figure 5 has been prepared to show the detailed structural relations on which the interpretation of the unconformity is based and the source of fossil collections. Unfortunately, the collections are not large and some of the material is fragmentary, so that the age relations of the beds are not closely determined. Consideration of this material in connection with that collected farther south leaves little doubt that the unconformity separates an underlying group of beds that yield considerable reptilian remains and are properly correlated with the Lance formation of eastern Wyoming and an overlying group of beds that are free from reptilian remains but carry abundant fossil plants that warrant their correlation with the Fort Union formation. (See discussion of correlation, p. 61.)

Curiously, the basal beds of the Fort Union formation do not contain any conglomerate or coarse sediments in the region of the unconformity, but as they are traced westward and then southward beyond Greybull River, zones of fine gravel appear sporadically, and in the region south of Gooseberry Creek such zones are a conspicuous feature of the beds. Chert pebbles that rarely exceed an inch in diameter are distributed in lenses 3 to 12 inches thick near the base of the formation along the new Cody-Meeteetse road in sec. 28, T. 50 N., R. 100 W.; in the small remnant of Fort Union beds in sec. 27, T. 50 N., R. 101 W.; in the SE. ¼ sec. 36, T. 50 N., R. 101 W.; and in the NW. ¼ sec. 6, T. 49 N., R. 100 W. In the last two localities subangular pebbles of silicified wood as much as 2 inches long are common.

A particularly interesting zone of conglomerate crops out for a distance of 1,500 feet along a low ridge in the SW. ¼ sec. 10, T. 52 N., R. 100 W. On account of its resemblance to the gravel zones that lie at the base of the Fort Union on Shoshone River,[16] it is there considered to mark the base of the formation also. The southwest slope of the ridge shows two lenses of conglomerate, 3 and 10 feet thick, separated by thin-bedded sandstone that trends N. 10° W. and dips 32° NE. The northeast slope is strewn with the gravel

[16] Hewett, D. F., The Shoshone River section, Wyo.: U. S. Geol. Survey Bull. 541, pp. 59-61, 1914.

set free by weathering. The composition of the upper conglomerate zone is shown in the table on page 31, No. 1. By close examination numerous silicified fossils were found in the gravel in a sufficiently good state of preservation to permit identification. They have been examined by G. H. Girty, of the United States Geological Survey, who has submitted the following statement concerning them:

I find that the chert pebbles contain a large and striking species of *Spiriferina* which can be no other than *S. pulchra*. The range of this species is so limited that it is possible to state almost positively that the Phosphoria formation furnished part of these pebbles. There are also two smaller species of *Spiriferina*, *Hustedia meekana*, which in this region is known only in the Phosphoria formation, and a number of Bryozoa that have been more or less provisionally referred to the genera *Stenopora*, *Batostomella*, *Lioclema*, and *Polypora*. Bryozoa of similar type, possibly representing the same species, are abundant in the Phosphoria formation (*Spiriferina pulchra* zone). There is also a fragment of a pelecypod (*Pseudomonotis?*) which would not be alien to the same fauna. It seems probable, therefore, that the bulk of these pebbles were derived from the Phosphoria formation, which is of Permian age.

I find a few forms, however, which at present are not known in the Phosphoria fauna. These are a zaphrentoid coral, a *Fusulina*, and a *Hustedia*, which can probably be identified with *H. mormoni*. Somewhat provisionally, therefore, it seems best to infer that these pebbles represent a different horizon, one of Pennsylvanian age. They are, furthermore, composed of a somewhat different and darker chert than is common in the pebbles from the Phosphoria formation, but some of the latter show no material difference in this respect.

These determinations leave no doubt that the chert conglomerate at this locality was derived largely from beds of Pennsylvanian and Permian age.

In the vicinity of South Fork of Dry Creek the basal beds of the formation are a group of indurated light-gray to white sandstones that range from 3 to 20 feet in thickness and weather as a series of benches along the north slope of Meeteetse Rim. They contrast with the underlying Lance beds, which are largely buff to yellowish, massive, and feebly indurated.

The determination of the top of the Fort Union formation is relatively simple in parts of the quadrangle but is attended with some uncertainty elsewhere. Locally there is good evidence of a pronounced unconformity at the base of the Wasatch formation; elsewhere an unconformity probably exists but the exposures are poor. In general the evidence is best in the southern part of the quadrangle; east of Oregon Basin the position of the boundary is obscure. It is clear that the character of the basal beds of the Wasatch formation is different in the different parts of the quadrangle. In a belt 6 or 8 miles long east of Oregon Basin the Fort Union formation is completely overlapped by the Wasatch formation.

The maximum thickness of the Fort Union formation in this quadrangle is about 1,300 feet, but the character of only the lower 400 feet is well shown. Only 200 feet of beds are present in sec. 27, T. 50 N., R. 101 W.

No detailed sections of the formation in this quadrangle have been prepared. It shows characteristically numerous beds of light-gray to yellowish-white indurated sandstone, largely from 5 to 20 feet thick, alternating with laminated gray and brown shale. About 100 feet above the base, north of Meeteetse Rim, there is a persistent zone of brown shale which locally contains one or more layers of coal about 1 inch thick. No other coal beds were found in the formation in this quadrangle, so that this zone may represent the horizon of the Black Diamond bed near Meeteetse. A characteristic feature of the formation that is also found farther south is the presence of many irregular slabs several inches thick of heavily iron-stained sandstone. Many of these slabs contain excellent imprints of fossil leaves. The surface in small badlands is here and there thickly strewn with such slabs; where they are encountered in place, they uniformly lie on the top of beds of sandstone under beds of shale. Rounded concretions, large or small, such as are characteristic of the Lance and parts of the Meeteetse formation are practically absent. The only conglomerate zones are those which occur in the basal 100 feet of the formation.

Meeteetse quadrangle.—The Fort Union formation underlies a large area on both sides of Greybull River northeast of Meeteetse. Its contact with the Lance formation is locally concealed by the Wasatch formation east of Meeteetse, but farther east the formation is well exposed in the Hole in the Ground.

The larger surface features of the northern part of the Meeteetse quadrangle are dominated by the remnants of the high terrace known as Meeteetse Rim. Where the terrace has been worn away there appears to be no great difference between the surface forms carved in beds of the Lance formation and those in the Fort Union formation. The beds of both formations dip at low angles, 3° to 6°, and over large areas both are worn to smooth slopes, which are largely covered with grass and sagebrush. The areas underlain by the Fort Union formation appear to show more badlands, in or near which there are bare low conical hills made up of numerous steplike ledges of outcropping sandstone. The lower valleys of Cottonwood Creek and Long Hollow are carved in Fort Union beds. By contrast with the valleys that follow the Meeteetse formation, these are wider and contain many minor ridges and isolated hills or buttes.

Southeast of Meeteetse, where the Lance beds dip steeply and are highly indurated, the Fort Union beds are deeply eroded, and although the drainage lines in general follow the strike of the beds the pattern is irregular.

The base of the Fort Union formation is traced from the region to the north, where it is unconformable on the Lance formation, for there is no evidence of unconformity in the Meeteetse quadrangle and farther south. The zones of chert conglomerate that occur in the basal sandstone north of Meeteetse Rim are also found here and there in this quadrangle—in the NW. ¼ sec. 8, T. 49 N., R. 100 W. (No. 2, p. 31), and the SW. ¼ sec. 21, T. 49 N., R. 100 W. (No. 3, p. 31). The exposures leave little doubt, however, that conglomerate is absent from the basal beds over considerable distances. The basal sandstone is commonly a massive bed 20 to 50 feet thick and is uniformly light colored, generally light buff to nearly white.

The upper limit of the Fort Union is the basal sandstone, generally conglomeratic, of the Wasatch formation. This sandstone is unconformable with the Fort Union, for it may be traced from the northeast corner of T. 48 N., R. 100 W., where it overlaps the base of the Fort Union formation, both northward and eastward to points where the Fort Union is about 2,000 feet thick. Here and there the surface of unconformity is readily recognizable (see Pl. X, *B*, of Fisher's report [17]), but elsewhere, as in the trough of the Cottonwood syncline in the southeast corner of T. 49 N., R. 100 W., where the beds above and below are nearly horizontal, it can be traced only by traversing certain beds near the base. In the region north of the Hole in the Ground the boundary was determined only approximately, being inferred by estimating the slope to the northeast of the surface of unconformity.

The characteristic features of the formation in this quadrangle are the succession of beds of light-colored to white sandstone, largely 5 to 20 feet thick, interlayered with thin beds of gray shale. At the head of Fifteenmile Creek, east of the Hole in the Ground, in the east half of T. 48 N., R. 99 E., where a section of 1,970 feet was measured and examined in detail (Pl. XIV) the lower 850 feet consist largely of white gritty sandstone in beds 5 to 25 feet thick. Here and there lenses 4 to 20 inches thick contain a large proportion of grains about a quarter of an inch in diameter. These as well as most of the finer materials are chert grains that range in color from white through gray to black. The interbedded material is gray to brown shale, locally containing thin layers of coal. The upper part, 1,125 feet thick, contains much less sand and more clay and sandy clay, the color of which commonly ranges from drab to olive-green. The lowest red clay is found about 1,250 feet above the base, and the lowest conglomerate 1,860 feet above the base (No. 15, p. 33). This conglomerate zone occurs near the top of a conical hill in the NE. ¼ sec. 11, T. 49 N., R. 100 W. In the section measured at the head of Fifteenmile Creek the sandstone beds of the lower 850 feet are rather persistent, and many of them are capped by a layer of flat concretions of iron hydrate. These concretions weather out as dark slabs, 1 to 4 inches thick, which are strewn over the adjacent slopes. The sandstones of the upper part of the formation are much less persistent and do not contain concretions. Thin zones of carbonaceous shale are found near the top as well as near the base.

In 1907 Loomis [18] described the beds that yield vertebrate fossils of Wasatch age near Tatman Mountain. He presents stratigraphic details and a cross section along "the Owl Creek Mountains near Meeteetse, Wyo., across Buffalo Basin, 17 miles to the top of Tatman Mountain." A comparison of the major stratigraphic features as well as the dips shown in this section with those of the section measured by the writer in secs. 21, 22, and 28, T. 48 N., R. 99 W. (Pl. XIV), shows that the lower 1,296 feet of Loomis's section comprises beds of the Fort Union formation, and the lowest stratum is approximately 600 feet above the base recognized in this report.

Only one coal bed more than several inches thick is known to occur in the formation in this quadrangle. This is the bed explored at the Black Diamond mine. (See p. 106.)

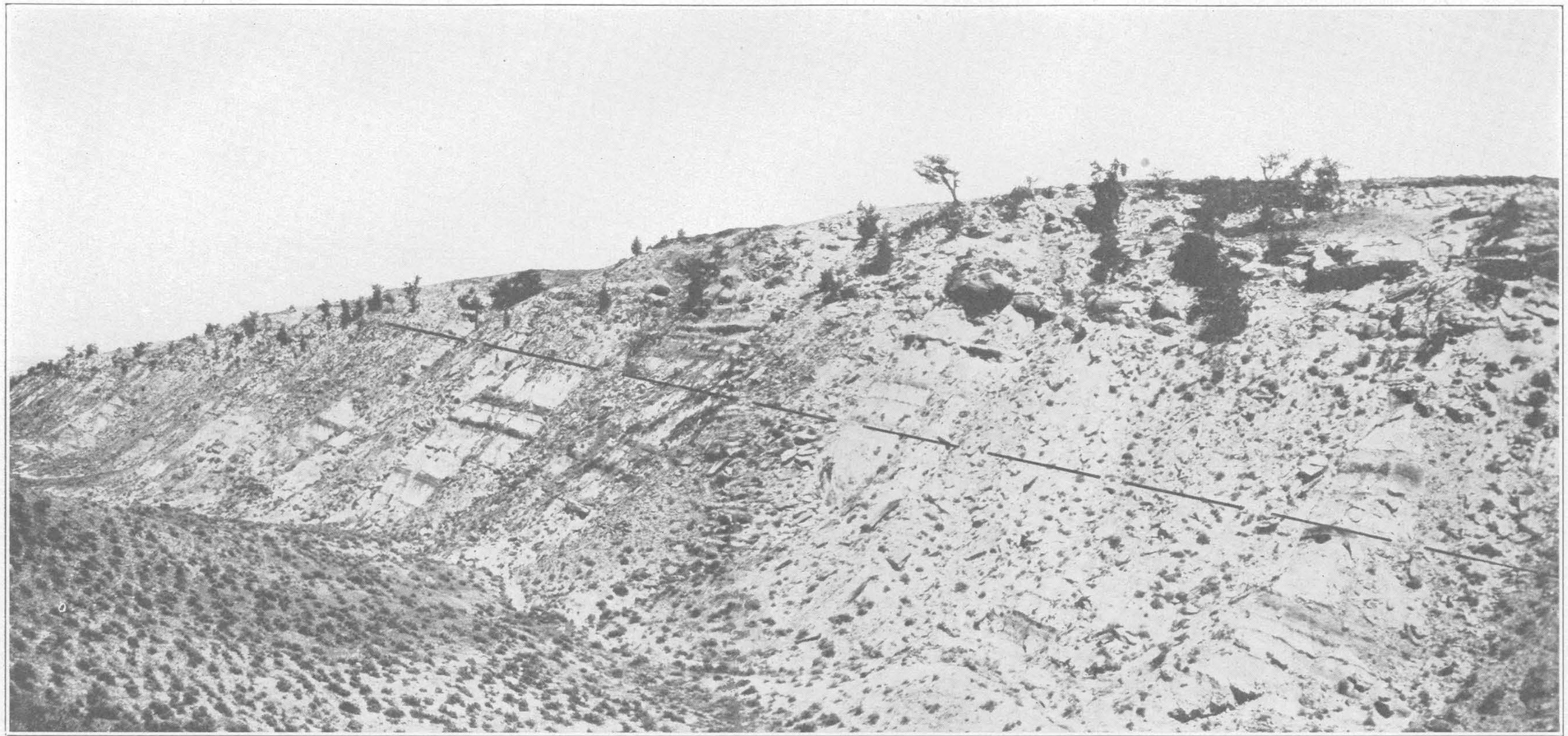
Grass Creek Basin quadrangle.—The Fort Union formation in the Grass Creek Basin quadrangle is both of scientific interest and of economic importance. It contains several thick beds of coal, also at three horizons beds of conglomerate that determine some of the conspicuous surface features. The formation crops out in three separate areas—one in the northeast corner, another in Ilo Ridge, and a third, irregular area southwest of Grass Creek. The beds are uncommonly well exposed in the last two areas, and several thick sections have been measured in detail. A large part of the northeastern area coincides with broad smooth valleys where only hard beds crop out.

Here, as in the Meeteetse quadrangle, no unconformity appears to separate the Lance and Fort Union formations. The base has not been traced continuously from the Meeteetse quadrangle, but the bed chosen has lithologic features that correspond to those at similar horizons farther northeast. This bed is a conglomeratic sandstone 36 to 230 feet thick, which generally crops out conspicuously and may be readily traced throughout the area. In the area southwest of Grass Creek the basal bed is a rather persistent conglomerate that ranges from 40 to 60 feet in thickness and is made up of uncommonly large cobbles, mostly quartzite. (See Pls. XII, *C*, *D*; XV, *A*, *B*.) Estimates of the composition are shown in the tables on pages 31–32.

In several parts of the area the outcrop of the basal bed does not contain a single pebble for a distance of about 500 feet; elsewhere it contains several separate lenses 4 to 6 feet thick, but over a much larger area

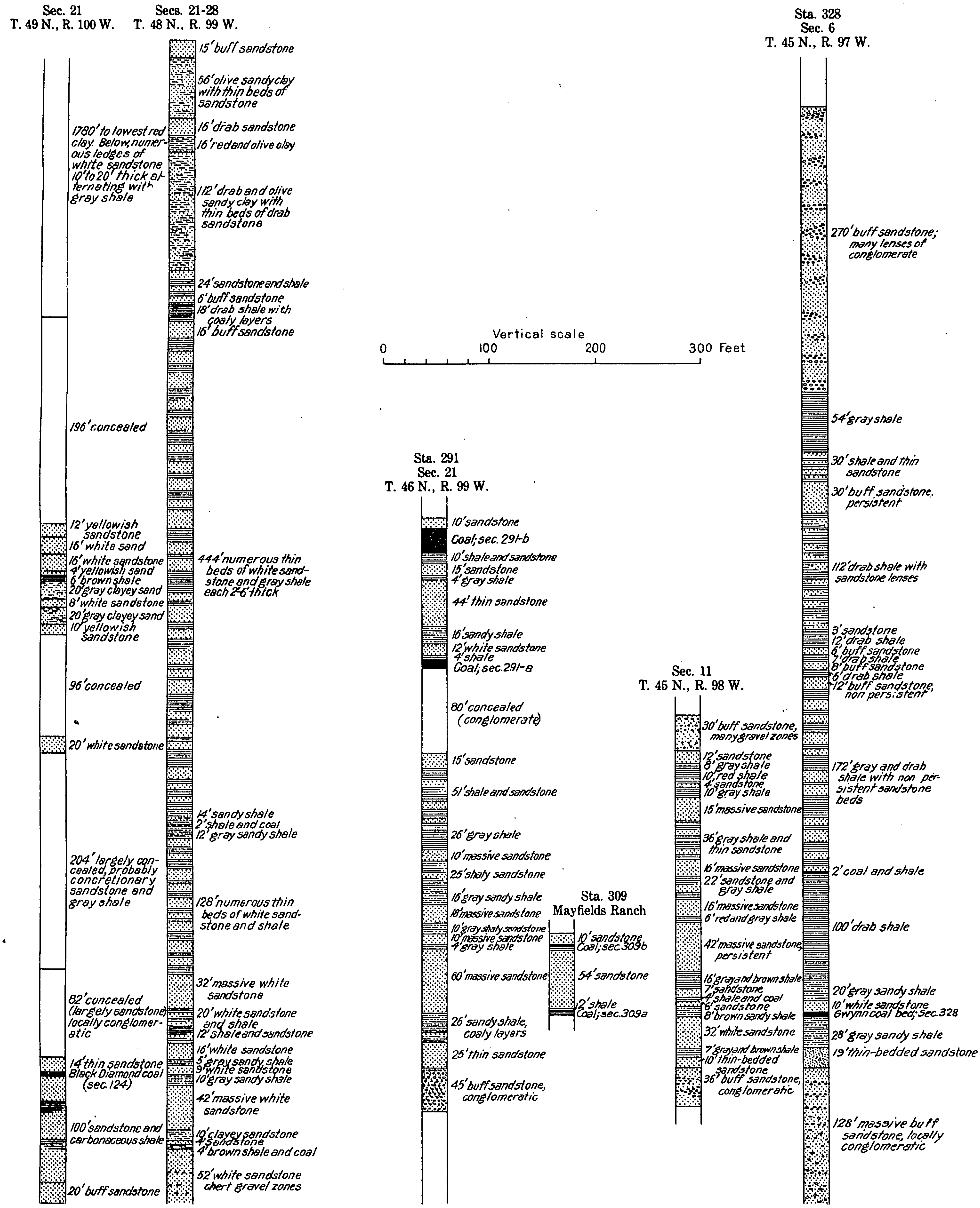
[17] Fisher, C. A., Geology and water resources of the Bighorn Basin, Wyo.: U. S. Geol. Survey Prof. Paper 53, 1906.

[18] Loomis, F. B., Origin of the Wasatch deposits: Am. Jour. Sci., 4th ser., vol. 23, pp. 356-364, 1907.



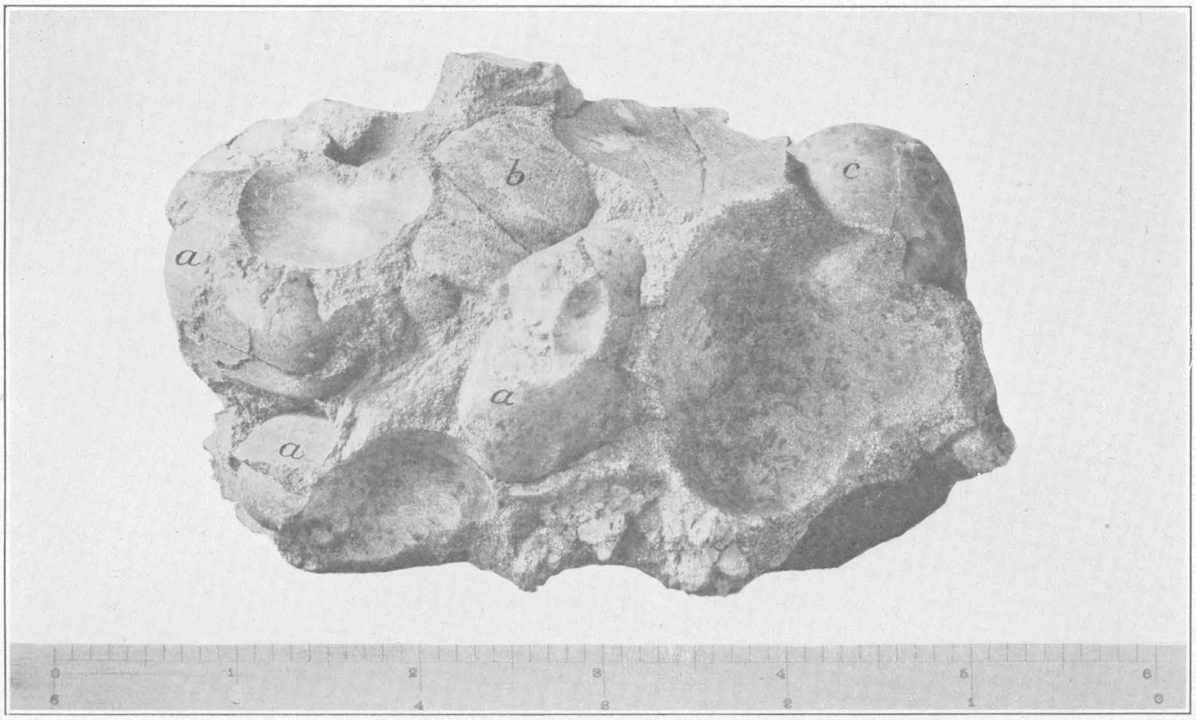
UNCONFORMITY BETWEEN MEETEETSE FORMATION AND FORT UNION FORMATION IN THE NE. ¼ SEC. 14, T. 50 N., R. 100 W.

The crest of the ridge is formed by the basal sandstone of the Fort Union, and the underlying beds are the upper part of the Meeteetse. At this point 1,300 feet of the Lance formation and several hundred feet of the Meeteetse formation have been eroded. The heavy line is drawn on a bed of brown shale in the Meeteetse formation



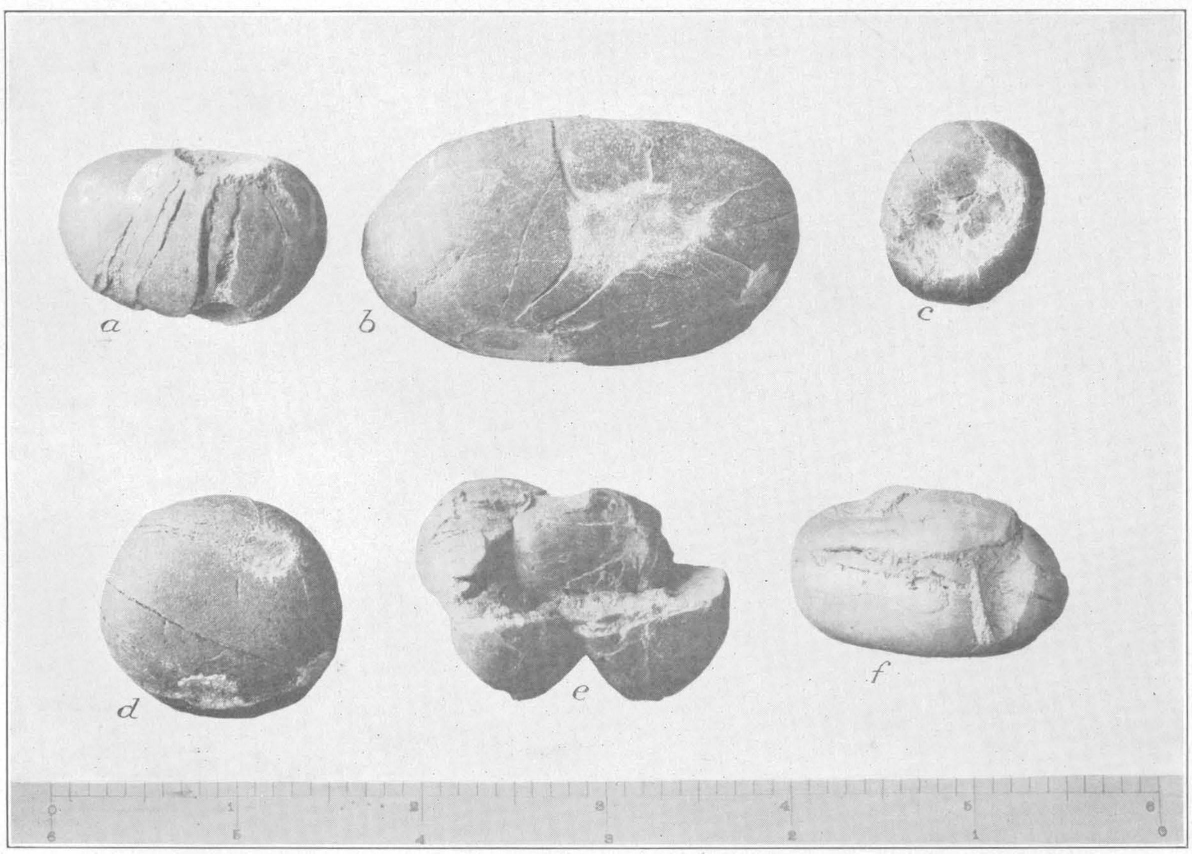
DETAILED AND GENERALIZED SECTIONS OF THE FORT UNION FORMATION, MEETEETSE AND GRASS CREEK BASIN QUADRANGLES, WYOMING

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



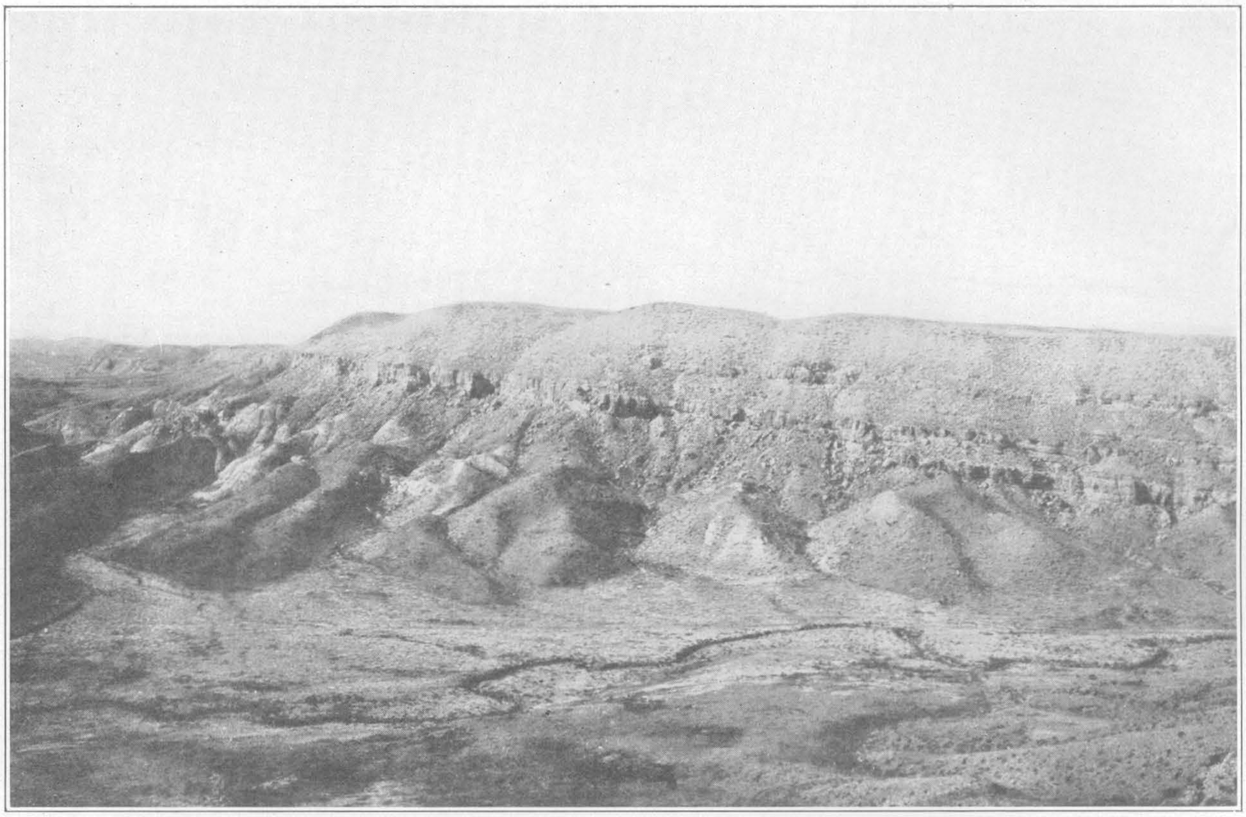
A. SPECIMEN OF BASAL CONGLOMERATE OF FORT UNION FORMATION, SE. ¼ NW. ¼ SEC. 22, T. 46 N., R. 99 W.

Shows crushed pebbles in matrix of sand. *a*, Quartzite; *b*, sandstone; *c*, chert. Each of the pebbles shows percussion markings



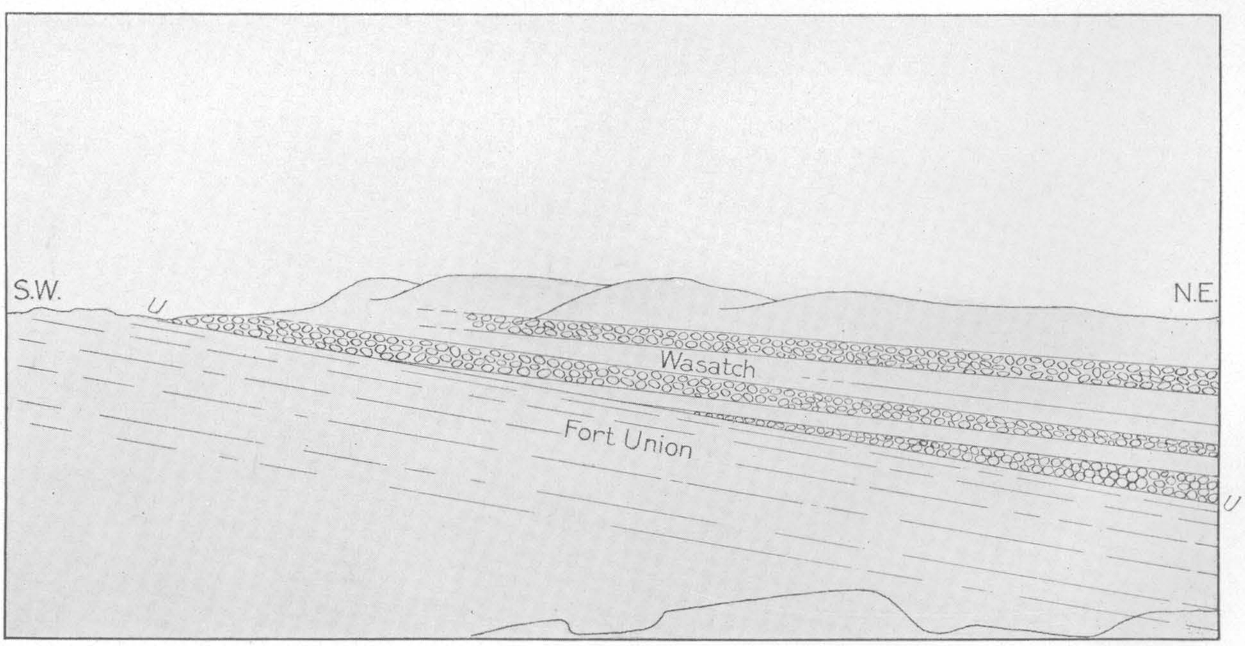
B. CRUSHED PEBBLES FROM BASAL CONGLOMERATE OF FORT UNION FORMATION, SW. ¼ SEC. 16, T. 46 N., R. 99 W.

The pebbles show percussion marks and cracks from having been crushed during the folding of the beds. *a*, *c*, *e*, Reddish quartzite; *b*, *d*, black chert; *f*, gray chert



A. BEDS OF THE UPPER PART OF THE FORT UNION FORMATION AND LOWER PART OF THE WASATCH FORMATION EXPOSED IN THE RAVINE THAT CUTS THROUGH BLUE RIDGE IN SEC. 5, T. 46 N., R. 97 W.

The conspicuous bed near the middle of the section is the massive conglomerate that forms the base of the Wasatch in this region



B. SKETCH OF BEDS ILLUSTRATED IN *A*, TO SHOW RELATION OF BASAL CONGLOMERATE ZONES TO SURFACE OF UNCONFORMITY (*U*) AT BASE OF WASATCH FORMATION the bed is made up largely of pebbles that range from 1 to 8 inches in diameter. On the other hand, on Ilo Ridge the basal bed contains pebbles at only one locality (No. 10, p. 32) and near by is a massive buff sandstone that attains a maximum thickness of 128 feet. In the region north of Gwynn's ranch only one pebble 2 inches in maximum dimension was found in a distance of 8 miles, and the basal bed is massive buff sandstone that ranges in thickness from 80 feet at the southeast end of the belt to 230 feet near the northwest end. In this area the upper third of the sandstone contains thin lenses of iron concretions as well as lenses of chert pebbles none of which are more than half an inch in diameter. This material shows torrential cross-bedding. Throughout the distance in which it crops out the basal sandstone resists erosion and therefore forms either a conspicuous bench near the top of a steep slope or a persistent ridge.

The upper limit of the Fort Union is the basal bed of the Wasatch formation—in the region northeast of Grass Creek, a bed of coarse conglomerate composed of reworked Fort Union pebbles, not distinctly unconformable; in the region southwest of Grass Creek a bed of pebble-bearing sandstone, in some exposures conspicuously unconformable on the Fort Union as well as older rocks. Within the limits stated the maximum thickness of Fort Union beds exposed in this quadrangle is 3,140 feet northeast of Grass Creek; only 1,030 feet is exposed at Ilo Ridge, and only 750 feet farther west.

In addition to the basal bed there are conglomerates at higher horizons in each of the areas. A bed of sandstone 30 to 50 feet thick, the base of which is about 360 feet above the base of the formation, crops out here and there along the southwest slope of Ilo Ridge and up Spring Gulch (Nos. 11, 12, 13, p. 32). A third zone about 270 feet thick and 760 feet above the base crops out in a rough area northeast of Ilo Ridge, where about one-fifth of the thickness is made up of lenses of pebbles from 1 to 8 feet thick. The pebbles attain a maximum size of 2 by 4 by 5 inches and include chert, quartzite, and coal. There are also numerous mud balls as much as 15 inches in diameter. This zone may correspond with that which is nearly 100 feet thick in the SE. ¼ sec. 34, T. 47 N., R. 98 W., but its base is about 680 feet above the base of the formation (No. 14, p. 32). A fourth zone about 60 feet thick lies 340 feet higher, or 1,120 feet above the base of the formation. It crops out conspicuously in the SE. ¼ sec. 2, T. 46 N., R. 98 W., but disappears farther south. A fifth zone that crops out continuously for 5 miles in the northeast corner of the quadrangle is 30 feet thick in the SE. ¼ sec. 8, T. 46 N., R. 97 W., where it is estimated to be 2,060 feet above the base of the formation. The position of this zone corresponds approximately with that at the head of Fifteenmile Creek, which is about 15 miles farther northwest.

The pebbles of the conglomerates present a wide range in shape, which appears to depend upon the kind of material of which they are composed, as well as other features, such as size. The largest pebbles are gray and red quartzite, and the ratio of the three diameters of those whose largest dimension exceeds 2 inches is commonly 3 to 2 to 1. On the other hand, the smaller quartzite pebbles are nearly spherical. Some coarse chert pebbles are slightly flattened, but those less than an inch in diameter are commonly subangular. The pieces of silicified wood are long or flat and subangular.

Some of the chert pebbles that are found in the beds of conglomerate contain fossils, and several collections have been submitted to G. H. Girty, who has made the following report:

178. From third conglomerate, in the SE. ¼ sec. 34, T. 47 N., R. 98 W. *Rhombopora*, crinoid fragments, and numerous small undetermined gastropods.

185. From basal conglomerate, in the NE. ¼ sec. 5, T. 45 N., R. 98 W. Crinoid segments, *Fenestella* sp., *Productus* sp.

191. From basal conglomerate, in the SE. ¼ sec. 9, T. 45 N., R. 98 W. *Fenestella* sp., crinoid segments, *Stenopora?* sp.

195. From second conglomerate, in the SE. ¼ sec. 25, T. 46 N., R. 99 W. *Fenestella* sp., indications of molluscan shells.

It is often difficult to give specific identification to fossils preserved as imperfectly and as fragmentarily as these, and I have been unsuccessful in the present instance. Also when it comes to determining the geologic age we are met by the difficulty that no two pebbles may have had their source at the same horizon. Thus, the pebble in lot 178, which contains only small gastropods, differs rather conspicuously from anything else in the collection, as does also the pebble from lot 191, which contains cylindrical Bryozoa, probably belonging to the genus *Stenopora*.

It is safe to say, however, that all the pebbles, with the possible exception of the one with the small gastropods, came from Paleozoic horizons. It is noteworthy also that these pebbles contained a very different fauna from those found under similar circumstances in the SW. ¼ sec. 10, T. 52 N., R. 100 W. (See pp. 36-37.) Those contained the diagnostic species *Spiriferina pulchra* and other forms that are entirely lacking in the present collection, which appears therefore to represent a different and, I suspect, an older fauna. The material constituting lot 185 is apparently Carboniferous, and I do not doubt that the other pebbles are of that age also, though the evidence is lacking to prove this. These pebbles, furthermore, do not show the characteristic fauna of the Madison limestone and one of them contains a type apparently not belonging in the Madison fauna (the dendroid *Stenopora*). By exclusion, therefore, and on the assumption that they have come from about the same horizon, so that the evidence furnished by one answers for all, these pebbles probably came from rocks younger than the Madison and older than the Phosphoria formation—I suspect from some horizon in the Pennsylvanian.

One feature of the pebbles of the Fort Union was useful in determining the base of the Wasatch formation in this part of the region. Many of the Fort Union pebbles, especially those which range from 1 to

2 inches in maximum dimension, show percussion marks from which numerous cracks radiate (Pl. XV, *B*). The cracked pebbles are more abundant where the beds have been steeply folded, but percussion marks are common even where the beds have a flat dip. Where, as on Blue Ridge, there is no unconformity between the Fort Union and Wasatch beds and they closely resemble one another, the base of the Wasatch is drawn at the lowest conglomerate bed that contains reworked pebbles.

The remaining beds of the formation (see Pl. XIV) are massive and thin-bedded buff to white sandstone, gray, drab, and red shale, and coal. The thick, massive sandstone beds form more persistent outcrops than the thin beds. The lowest red shale in the formation is 306 feet above the base in sec. 11, T. 45 N., R. 98 W. Flat concretions of iron hydrate are not as common as those which are spherical, and these are conspicuous only in the basal sandstone north of Gwynn's ranch.

Coal beds are present at two horizons near the base of the formation and two 450 to 550 feet above the base. All four horizons are not represented in any one section, however. They are discussed on pp. 100-101.

WASATCH FORMATION

General features.—The work of Fisher and other earlier investigators has shown that beds of the Wasatch and younger formations cover a large area in the center of the Big Horn Basin and that a belt of similar beds locally underlies the volcanic rocks that make up the mountains west of the basin. In an earlier paper [19] the present writer has referred to the latter as the "border Wasatch." The beds that once connected the two areas are largely eroded, so that it is possible only to speculate concerning their relation. The three quadrangles under consideration cover the region between the two areas, so that any data which they yield should serve to interpret this relation as far as possible. The Oregon Basin quadrangle covers a part of the basin area; the other two quadrangles cover areas that are successively nearer to as well as a part of the "border Wasatch."

A review of the nature of the beds that make up the formations as well as of the surface upon which they were laid down shows that conditions have not been the same throughout the three quadrangles. The data from these quadrangles and similar data from the upper valleys of Wood and Greybull rivers indicate that the Wasatch beds were deposited on a nearly plane surface, which probably sloped gently to the northeast in and adjacent to the belt that borders the present mountain front. Where the surface was cut across the upper Mesaverde and younger rocks it was nearly a plane, but the lower massive sandstones of the Mesaverde formation resisted erosion and formed low hills possibly 100 or even 200 feet higher than the near-by stream channels. In the areas farther northeast, near the center of the Big Horn Basin, the relief of the surface was probably less, although in some places there were undoubtedly hills 50 or 100 feet higher than the streams, as in the region northwest of Sleeper's ranch.

Within this surface of low relief there were undoubtedly several large streams that rose in a mountainous area farther southwest and flowed generally northeastward toward the center of the Big Horn Basin. There were also probably smaller tributaries of irregular pattern.

This surface has been warped locally since the Wasatch beds were laid down, but the nature and amount of the warping can not be accurately determined. It is clear from the distribution of coarse and fine sediment that an area in secs. 3, 4, and 10, T. 44 N., R. 99 W., which once stood relatively high, has been warped downward, apparently along the axis of the Wagonhound syncline. On the other hand, the residual deposits which mark a channel that trends northeastward across Buffalo Basin indicate that its gradient has not been changed since the beds were laid down. It should be noted at this place, although the significance is discussed under "Structure" (p. 68), that the steepest dips measured on beds of the Wasatch formation are found in a belt which is arc-shaped, is concave to the northeast, and is generally parallel to the border of the basin area of the formation.

Several generalizations may be made concerning the size of the sediments that make up the Wasatch formation. Beds of conglomerate and coarse sandstone are uncommonly abundant in the formation but are present in more exposures near the mountains than elsewhere. On the other hand, there are more beds of conglomerate and the beds are thickest in the region east of Greybull River from Meeteetse to Sleeper's ranch. When all the sedimentary and stratigraphic features of the formation in this region are considered, it is very apparent that the coarse material represents an alluvial fan spread out on the the border of an extensive alluvial plain at the point of emergence of one of the major rivers that supplied the sediments. The fan is roughly triangular and is 5 or 6 miles wide at the base and 8 or 10 miles long, with the apex at the mouth of the ancient river. In the adjacent region on the northwest, in Tps. 50 and 51 N., R. 99 W., there appear to have been no major rivers during Wasatch time, for the beds of conglomerate are thin and discontinuous and finer sediments predominate even near the base of the formation.

No other river channels that compare with this have been recognized in the entire region. Smaller channels

[19] Hewett, D. F., The Heart Mountain overthrust: Jour. Geology, vol. 28, pp. 536-557, 1920

undoubtedly existed in the western part of the Grass Creek Basin quadrangle, but their courses can not be clearly identified. The conglomerate that is continuous from Blue Ridge 12 miles northwest to Fifteenmile Creek may have merged into this alluvial fan but probably was made up largely of local Fort Union pebbles spread out by many small streams.

The varieties of rock in the Wasatch conglomerates correspond so closely with those of the underlying Fort Union beds that, considered with the percussion marks which they bear, there can be no doubt that the one is largely derived from the other. The additional varieties in the Wasatch, granite and limestone, indicate that the streams were also bringing down new material. The fossils that have been recognized in Wasatch limestone pebbles indicate that part of the sediments were derived from older and more deeply buried beds than those which supplied the Fort Union chert pebbles, but too much importance should not be attached to the few species that have been found.

The cross section of basal Wasatch beds shown in the ravine in sec. 5, T. 46 N., R. 97 W., presents features that resemble those shown east of Greybull River in secs. 28 and 33, T. 50 N., R. 99 W. (Pl. XVI), and that are important in an interpretation of the relative age of the parts of the Wasatch formation. In this locality, vertical cross sections roughly at right angles to the strike of the beds show (1) that although locally the beds of conglomerate rest on the surface of unconformity, broadly they have a slightly lower inclination; (2) that the individual beds of conglomerate disappear within short distances down the dip and are replaced by thicker lenses of sand; (3) that hence, in the cross section, the beds diverge rather than continue parallel; and (4) that the successively higher beds of conglomerate extend farther southwest (upstream) than older underlying beds. (See Pl. XVI, *B*.)

The stratigraphic evidence confirms the interpretation by Sinclair and Granger [20] of the major relations of the faunal zones of the Wasatch formation, based on paleontologic studies. They state:

> Although the Eocene beds have been uptilted about the southwest margin of the basin, dipping in general, with the exception of minor flexures, toward Tatman Mountain, we have not been able to find any exposures of the Knight formation (the lowest faunal zone) in this area, the Wind River horizon (Lysite and Lost Cabin) (higher faunal zones) apparently overlapping unconformably on the Fort Union and entirely concealing the Knight.

If this interpretation is correct the "border Wasatch" was not deposited at the same time as the basal beds of the Wasatch (Knight) in the center of the Big Horn Basin but much later, possibly as late as the "Tatman formation" of Sinclair and Granger, which they regard as possibly equivalent to the Bridger formation. The "border Wasatch" closely resembles the "Tatman formation" in lithologic features and in yielding no fossils.

[20] Sinclair, W. J., and Granger, Walter, Notes on the Tertiary deposits of the Bighorn Basin: Am. Mus. Nat. Hist. Bull., vol. 31, p. 61, fig. 2, 1912.

In the areas of the Wasatch formation nearest the center of the Big Horn Basin many varieties of vertebrate fossils have been found. In addition to the collections listed below, beds near the base of the formation in sec. 14, T. 51 N., R. 100 W., have yielded a large number of fossil plants, which F. H. Knowlton considers characteristic Fort Union species. The significance of these collections is discussed on pages 61–62. Another collection of fossil plants (6371) was obtained from beds of the "border Wasatch."

Vertebrate fossils from the Wasatch formation

[Determined by J. W. Gidley]

Oregon Basin quadrangle

40. SE. ¼ sec. 13, T. 50 N., R. 100 W.; 150 feet above base of formation. *Coryphodon* sp., a premolar, canine, and several fragments; *Eohippus?*, distal end of radius; *Sinopa multicuspis* Cope, portion of left lower jaw with broken teeth. Age Wasatch.

41. NW. ¼ sec. 19, T. 50 N., R. 99 W.; 200 feet above base. *Coryphodon* sp., fragments of tooth and vertebrae; crocodilian, two portions of vertebrae. Age Wasatch.

42. NW. ¼ sec. 9, T. 50 N., R. 99 W.; 1,000 feet above base. *Coryphodon lobatus?* Cope, fragments of lower molars. Age Wasatch.

52. West center sec. 27, T. 50 N., R. 99 W.; 400 feet above base. Anaptomorphid, n. gen. and sp.?, near *Hemiacodon*, portion of lower jaw containing molars 1 and 2; *Microsus* (or n. gen.) n. sp.; portion of left lower jaw containing two molars; *Pelycodus frugivorus* Cope; fragment containing two upper molars; fragment of left lower jaw containing last two molars. Age Wasatch.

55. NE. ¼ SE. ¼ sec. 24, T. 52 N., R. 100 W., and SW. ¼ sec. 19, T. 52 N., R. 99 W.; 600 feet above base. *Coryphodon*, sp. undet., portion of incisor; *Crocodylus*, fragment of dentary; *Eohippus angustidens?* Cope, portion of left lower jaw containing last molar; *Eohippus index* Cope (or n. sp.), portion of left lower jaw containing three teeth and fangs of premolars 2 and 3; *Oxyaena lupina?* Cope, left upper canine and portion of canine; *Phenacodus* n. sp., portion of left lower jaw containing last two molars. Age Wasatch.

170. SE. ¼ sec. 36, T. 51 N., R. 100 W.; 100 feet above base. *Coryphodon* sp., fragments of teeth. Age Wasatch.

171. NW. ¼ sec. 23, T. 51 N., R. 100 W.; basal conglomerate. Creodont, phalanx (toe bone), genus and species indeterminable. Age probably Wasatch.

Fossil plants from the Wasatch formation

[Determined by F. H. Knowlton]

Oregon Basin quadrangle

6177. South center sec. 11, T. 51 N., R. 100 W.; 200 feet above base. *Populus cuneata?* Newberry, *Taxodium occidentalis* Newberry. Fort Union flora.

6359. Center sec. 14, T. 51 N., R. 100 W.; 150 feet above base. *Glyptostrobus europaeus* (Brongniart) Heer, *Leguminosites* sp., *Populus newberryi* Cockerell, *Populus craspedodroma* Ward, *Taxodium occidentalis* Newberry, small dicotyledon, apparently new. Fort Union flora.

6371. SE. ¼ sec. 33, T. 47 N., R. 101 W.; *Aralia notata* Lesquereux, *Monimiopsis?* sp., *Platanus basilobata* Ward. Fort Union flora.

Composition of gravel zones in the Wasatch formation

Range in size (inches)	Oregon Basin quadrangle				Meeteetse quadrangle			
	1. SE. ¼ sec. 35, T. 51 N., R. 100 W.; 8-foot zone at or near base		2. SE. ¼ sec. 18, T. 50 N., R. 99 W.; zone of gravel 250 feet above base		3. SE. ¼ sec. 5, T. 49 N., R. 99 W.; part of 52-foot zone 160 feet above base		4. SE. ¼ sec. 18, T. 49 N., R. 99 W.; 7-foot zone near base	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
4–8	------	------	------	------	20	Quartzite, gray, round ---- 60 Sandstone, yellow, subangular -- 20 Hard shale ---- 10 Silicified igneous rock ---- 10	20	Quartzite, round ---- 100
2–4	------	------	------	------	25	Quartzite, round ---- 40 Sandstone, round ---- 25 Chert, subangular ---- 20 Limestone, round ---- 15	30	Quartzite, round ---- 80 Chert, round ---- 20
1–2	10	Sandstone ---- 50 Limestone, cream, round --- 30 Chalcedony ---- 20 Silicified wood, angular ---- Tr.	10	Sandstone ---- 40 Quartzite ---- 30 Chert ---- 25 Chalcedony ---- 5	------	(Included with 2–4 inches) ----	15	Quartzite, round ---- 60 Chert, subangular ---- 30 Chalcedony, subangular -- 10
½–1	15	Quartzite ---- 30 Chert, round to angular ---- 40 Chalcedony ---- 10 Silicified wood, angular ---- 10 Limestone, round ---- 10	10	Sandstone ---- 40 Quartzite ---- 20 Chert ---- 35 Chalcedony ---- 5	10	Quartzite ---- 40 Sandstone ---- 25 Chert ---- 20 Limestone ---- 15	------	(Included with 1–2 inches.)
¼–½	15	Quartzite ---- 20 Chert, subangular ---- 70 Chalcedony ---- 10	15	Quartzite ---- 10 Chert ---- 70 Chalcedony ---- 20	------	(Included with ½–1 inch) ----	10	Quartzite ---- 20 Chert ---- 80
<¼	60	Chert ---- Quartzite. Quartz.	65	Not determined ----	45	Chert ---- 90 Quartz ---- 10	25	Not determined.

Range in size (inches)	Meeteetse quadrangle				Grass Creek Basin quadrangle			
	5. SE. ¼ sec. 12, T. 48 N., R. 100 W.; 6-foot zone near base		6. Southeast corner sec. 23, T. 47 N., R. 101 W.; zone near base		7. NW. ¼ sec. 22, T. 44 N., R. 99 W.; 3-foot zone near base		8. T. 46 N., R. 97 W.; 20-foot zone near base	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
4–8	50	Quartzite, gray, round 95 Limestone, round 3 Granite, round 2	15	Quartzite, round 95 Chert, round 5 Granite, gray, round Tr.	------	------	10	Quartzite, white, round 70 Quartzite, red, round 25 Chert, round Tr. Sandstone, round Tr. Largest pebble 10 by 8 by 6 inches.
2–4	20	Quartzite, gray, round 80 Granite, white, round 10 Chert, round 10	25	Quartzite, round 50 Chert, round 5 Granite, round 10 Limestone, cream-colored, flat 30 Sandstone, flat 5	1	Granite, white, round 40 Silicified shale, flat 40 Schist, white, round 10 Chert, round 10	15	Quartzite, gray, round 60 Quartzite, red, round 35 Chert, round 5
1–2	10	Quartzite, gray, round 60 Granite, round 10 Limestone, round 10 Chert, round 10 Sandstone, round 10	35	Quartzite 20 Chert 25 Granite 10 Limestone, cream-colored, flat 25 Sandstone 20	2	Pegmatite, round 20 Silicified shale, round 20 Quartz, vein, round 30 Chert, brown, black, angular 30	25	Quartzite, round 70 Chert, round 25 Granite, round Tr. Silicified wood, subangular Tr.
½–1	------	(Included with 1–2 inches)	------	(Included with 1–2 inches)	5	Feldspar, subangular 10 Shale, subangular 20 Quartz, vein, round 40 Chert, subangular 30	25	Quartzite, round 40 Chert, subangular 60 Silicified wood, subangular Tr.
¼–½	5	Quartzite 20 Chert 80	25	Chert 60 Limestone 20 Quartz 10 Sandstone 10	2	Feldspar, round 10 Quartz, vein, round 40 Chert, subangular 50	10	Quartzite 15 Quartz 5 Chert 80
<¼	15	Chert Quartz. Clay.	------	(Included with ¼–½ inch)	90	Feldspar 10 Quartz, vein 60 Chert 20 Clay 10	15	Quartz. Chert.

Oregon Basin quadrangle.—The Wasatch formation underlies a larger area in the Oregon Basin quadrangle than any other formation, and both the area and the thickness of the beds are greater than in the Meeteetse and Grass Creek Basin quadrangles.

Beds of the formation underlie nearly the entire eastern third of the quadrangle. There are numerous small badland areas in the northeast corner, north of the abandoned Wiley canal, where many sections 20 to 100 feet thick are well exposed. In the region between the Wiley canal and Dry Creek the only exposures are found in the low hills along the western boundary of the formation. In the region between Dry Creek and Greybull River there are many good exposures of sections 50 to 250 feet thick, especially along the upper parts of ravines that rise near Meeteetse Rim.

The base of the formation is traced northward from two localities in the southeast corner of the quadrangle, where the basal beds rest unconformably upon the Fort Union formation. The best evidence of unconformable relations is found along the east side of the deep ravine in secs. 5 and 8, T. 49 N., R. 99 W. (Pl. XVII). Here the lower beds are alternating thin white and buff sandstones and gray shale, locally carbonaceous, that represent the upper part of the Fort Union formation. They trend northeast and dip about 2° SE. The base of the Wasatch formation is the base of a dark zone that is the lowest bed of conglomerate. A detailed section of the lower 212 feet of the Wasatch formation measured at the head of the ravine on the right is presented in Plate XVIII. These beds trend north and strike 2° E. In the distance in the view shown in Plate XVII, about 250 feet of Fort Union beds are cut out by the surface of unconformity, which here is nearly a plane, gently inclined eastward. The unconformity is readily traceable northeastward into sec. 33, T. 50 N., R. 99 W., where it passes under the alluvial valley of Greybull River.

The second locality at which the base of the Wasatch is clearly identified is in the SE. ¼ sec. 13, T. 50 N., R. 100 W., where conditions are somewhat different. Beds of the Fort Union formation, 400 to 600 feet above the base, are well exposed on the northwest side of Meeteetse Rim in sec. 24, T. 50 N., R. 100 W. (fig. 5). They include white and buff sandstones and gray shale, which yield Fort Union plants. They trend N. 10° W. and dip 3°–4° E. The low conical hill on the line between secs. 24 and 13 is made up of these beds, but the low ridge that extends northward from the hill is made up of beds of red and drab sandy clay which also trend north and dip east but which yield mammalian remains characteristic of the Wasatch formation. The exposures are very good and leave no doubt that the Wasatch beds, largely clay free from sand and conglomerate, abut against a steep slope carved out of Fort Union material. The surface of unconformity is therefore not a plane but an irregular surface of fair relief. Between this locality and the first the contact of the two groups of beds can not be traced accurately but is drawn at the western limit of red clay.

From the second locality northward the base of the Wasatch is drawn at a zone of pebbles among which limestone is conspicuous (No. 1, p. 42), but the exposures are poor and unsatisfactory. In the NW. ¼ sec. 23, T. 51 N., R. 100 W., a similar zone of pebbles yielded a single bone, which has been determined to be of Wasatch age (collection 171). From this point northward to the edge of the quadrangle the position of the base of the formation can be indicated only approximately. It is estimated that the maximum thickness of beds of this formation in this quadrangle is about 1,200 feet. None of the higher groups of beds recognized farther south are present here.

The beds that make up the formation differ greatly from the lowest to the highest zones and in the several areas throughout the quadrangle. East of the Sleeper ranch the basal beds are alternating zones of coarse sand and conglomerate. The lowest conglomerate is thin, and as far as a horizon 300 feet above the base the successively higher beds are thicker and the cobbles are coarser. On the other hand, farther north, in the area covered by Figure 5, there is only a thin zone of small pebbles at the base, and most of the material in the overlying 300 feet is fine sand and clay. In this area there are zones of conglomerate 300 to 500 feet above the base, but few of them exceed 6 inches in thickness, and the coarsest pebbles are 3 inches in diameter. It appears that in the area where the surface of unconformity has the highest relief the sediments are finer.

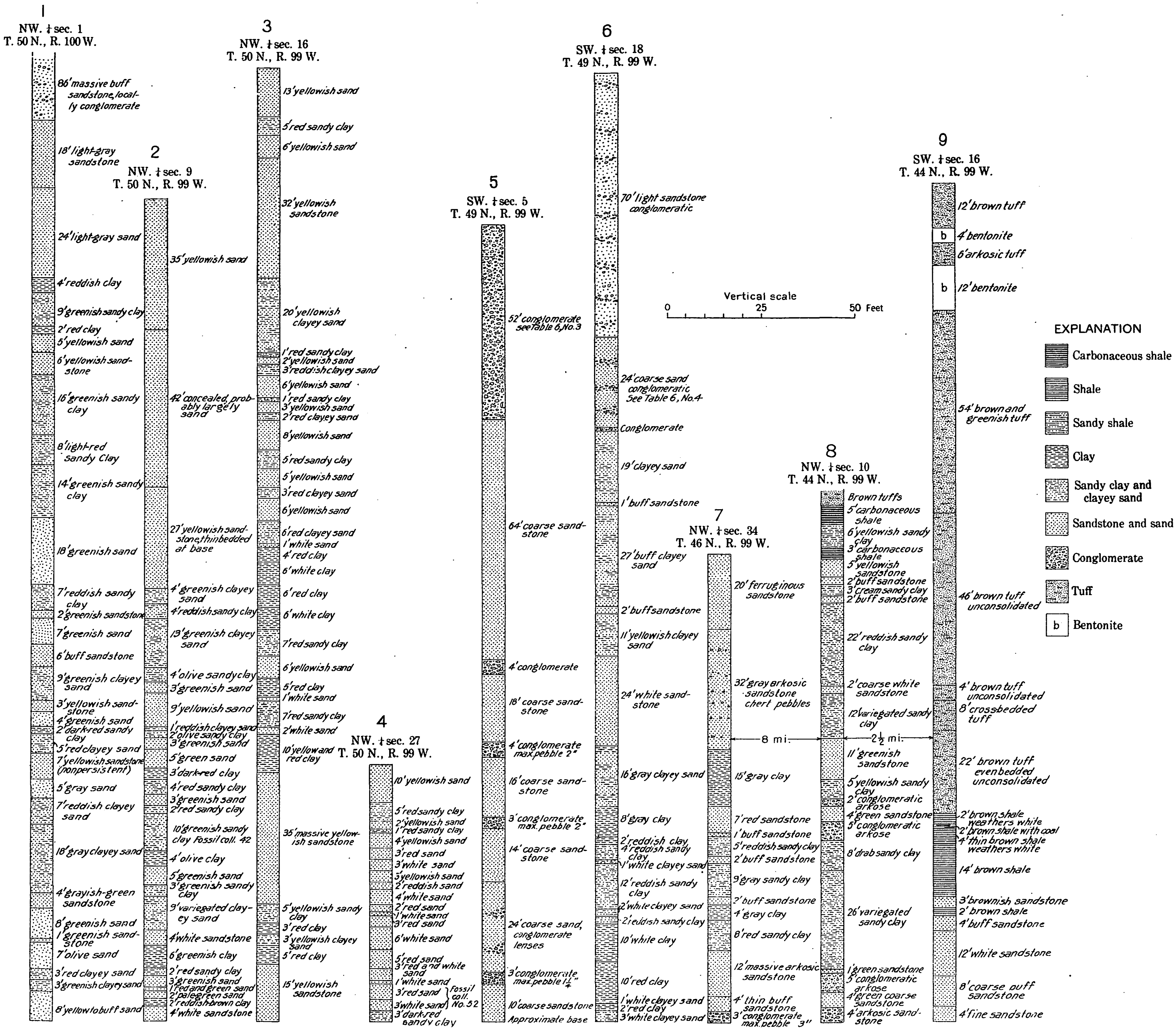
In contrast with the sediments of the Lance and Fort Union formations, those of the Wasatch have a greater range in size and mineralogy, and the beds are thinner, are less persistent, and show a wider range in induration. A conspicuous feature is the presence of many beds of red or variegated red and greenish clay which alternate with greenish clay and yellowish sandstone.

A review of the exposures within a 3-mile radius of the Sleeper ranch indicates that the zones of conglomerate that are so conspicuous in the lower 200 feet of the formation southeast of that place do not persist more than 1 mile northeastward, but that their place in the section is taken first by coarse sand, then fine sand, and finally, farther northeast, by clay. Conclusions concerning the significance of these relations are presented on pages 61-62.

The composition of two conglomerate zones in this quadrangle is presented in the table on page 42 (Nos. 1–2). With the exception of limestone, which appears to be characteristic, the remaining material represents

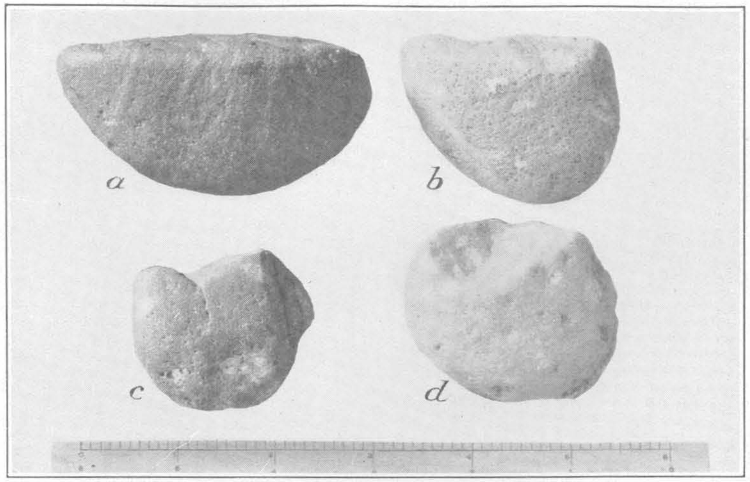
UNCONFORMITY BETWEEN BEDS OF THE UPPER PART OF THE FORT UNION FORMATION AND THE WASATCH FORMATION IN SEC. 5, T. 49 N., R. 99 W.

Looking northeast. The position of the unconformity is shown by the heavy lines at the sides



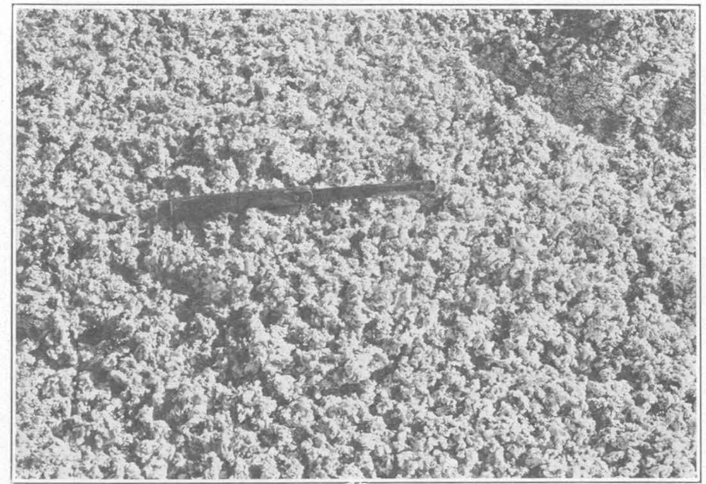
STRATIGRAPHIC SECTIONS OF THE WASATCH FORMATION, OREGON BASIN, MEETEETSE, AND GRASS CREEK BASIN QUADRANGLES, WYOMING

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



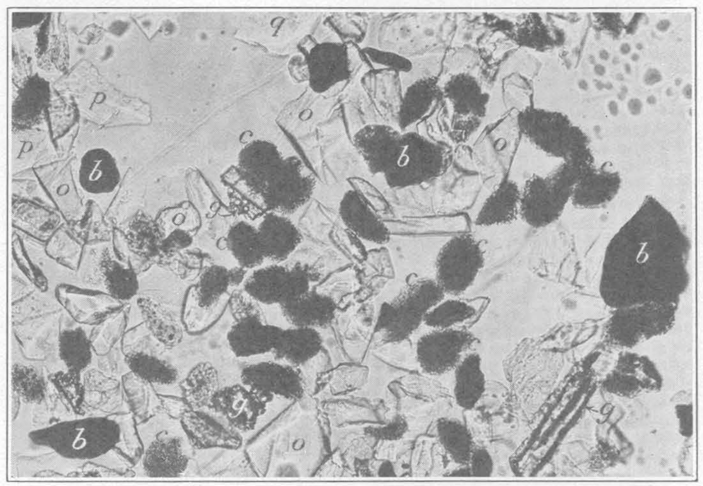
A. QUARTZITE PEBBLES FROM THE BASAL ZONE OF THE WASATCH FORMATION

a, *b*, *c* from SE. ¼ sec. 11, T. 48 N., R. 100 W.; *d* from SE. ¼ sec. 36, T. 47 N., R. 98 W.



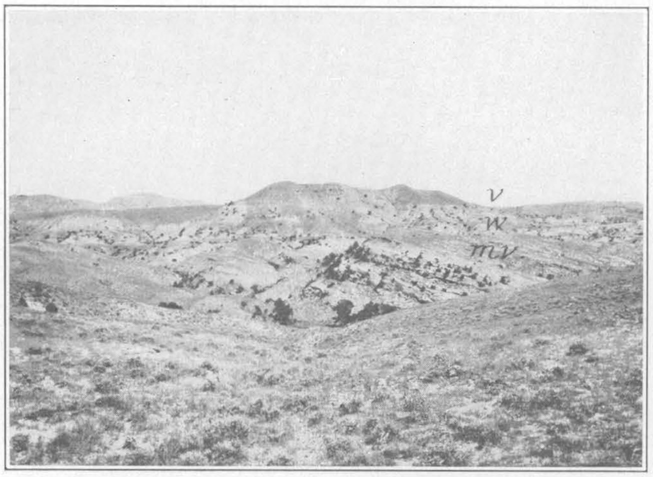
B. SCORIA-LIKE OUTCROP OF A BED OF BENTONITE IN SEC. 30, T. 22 N., R. 75 W.

Scale indicated by foot rule. Photograph by C. E. Siebenthal



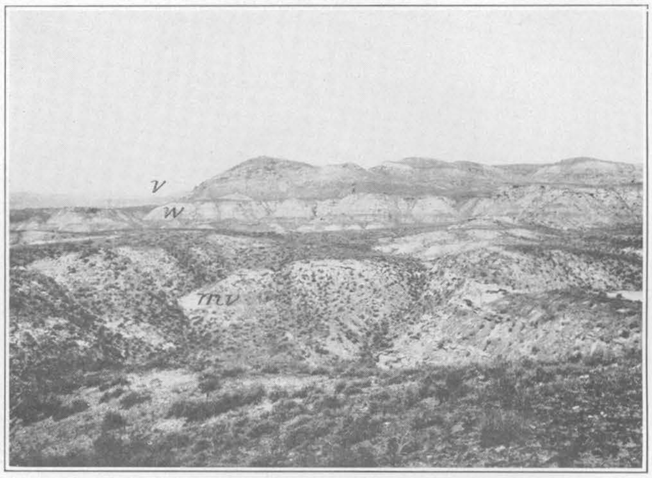
C. PHOTOMICROGRAPH OF A "VERY FINE SAND" PORTION FROM A BED OF BENTONITE NEAR THE TOP OF THE THERMOPOLIS SHALE, SHOSHONE RIVER

b, Black plates, biotite; *c*, dark granular masses, clay aggregates; *g*, irregular vesicular grains, glass; *o*, angular grains with high relief, orthoclase; *p*, angular grains with low relief, plagioclase; *q*, angular grains with moderate relief, quartz. The grains are immersed in an oil which has an index of refraction of 1.55. They range in size from 0.05 to 0.1 millimeter



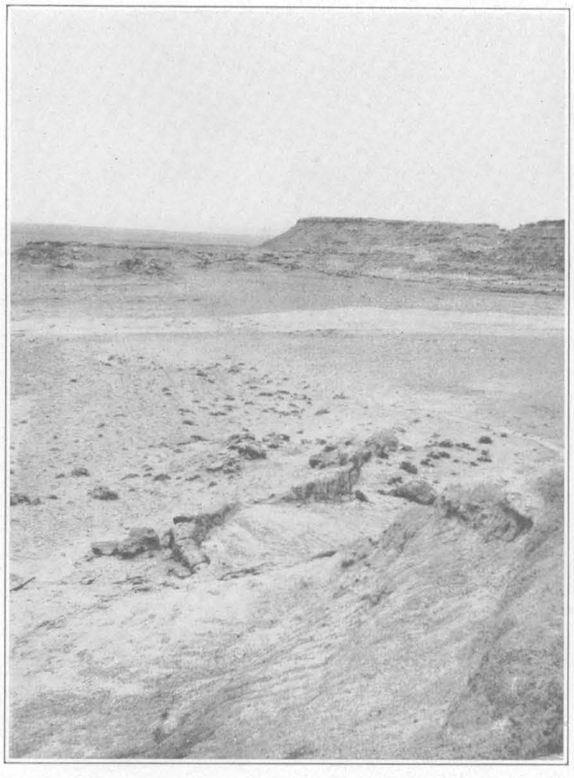
A. SANDSTONES IN THE UPPER PART OF THE MESAVERDE FORMATION (*mv*) UNCONFORMABLY OVERLAIN BY BEDS OF THE WASATCH FORMATION (*w*) AND VOLCANIC TUFF (*v*) NEAR THE HEAD OF PROSPECT CREEK, SEC. 33, T. 45 N., R. 99 W.

Looking north

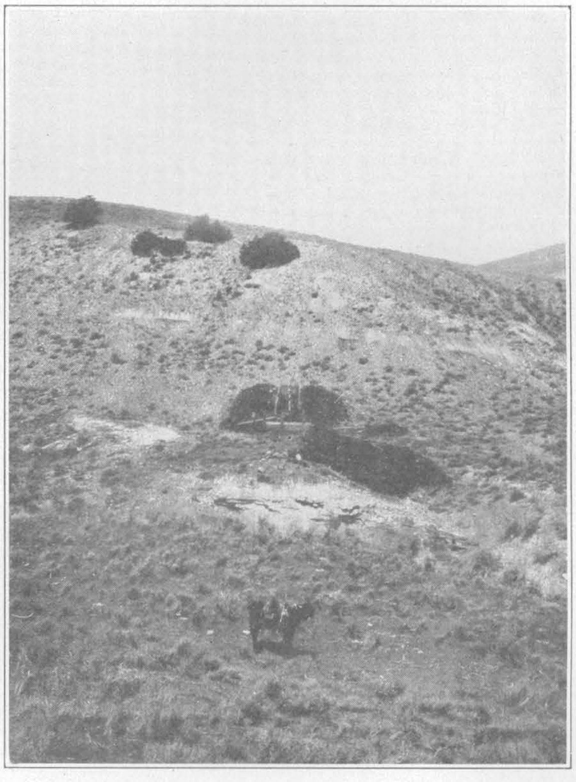


B. SANDSTONES OF THE MESAVERDE FORMATION (*mv*) UNCONFORMABLY OVERLAIN BY BEDS OF THE WASATCH FORMATION (*w*) AND VOLCANIC TUFF (*v*) ALONG VALLEY OF COTTONWOOD CREEK 1 MILE NORTHWEST OF THE PUNTENEY RANCH, IN SEC. 16, T. 44 N., R. 99 W.

Looking northwest



C. VERTICAL SANDSTONE DIKE IN BEDS OF THE WASATCH FORMATION, SEC. 8, T. 52 N., R. 99 W.



D. PROSPECT ON THE MAYFIELD BED OF COAL OF THE FORT UNION FORMATION, COAL MINE DRAW, SEC. 26, T. 46 N., R. 99 W.

The bed is 30 feet thick at this locality, but only the lower 6 feet is mined an average assortment of the varieties found in the conglomerate zones near the base of the Fort Union formation. On the other hand, granite pebbles, which are common in the southern quadrangles, were not noted in this area.

The badlands of this quadrangle offer the best opportunity in the entire region for the examination of the distribution and relations of the beds of red and variegated clay. These beds are rarely more than 8 feet thick and commonly are only 3 or 4 feet; they are interbedded with beds of fine to coarse sand and light colored clay of about the same thickness. No definite succession of beds is invariably present; the most common is (1) gray or buff sand or sandstone, (2) red clay or sandy clay, (3) gray or greenish clay or sandy clay. From this it would appear that the red clay was generally laid down first after a layer of coarser material. There is good evidence that beds of red clay were being deposited in sec. 1, T. 50 N., R. 100 W., at the same time that beds of coarse sand and conglomerate were being laid down in sec. 5, T. 50 N., R. 99 W. It is thus apparent that the color is related to local conditions of deposition and is not inherent in the material that was being supplied.

In the parts of the region where the beds of red clay are most abundant and displayed to the best advantage, in Tps. 51 and 52 N., R. 99 W., they can be traced with assurance for several miles at least, but no satisfactory idea of the shape of the lenses has been obtained. Their extent appears to correspond with that of the gray and greenish clay that overlies them. The beds of finer sediment have a wider extent than the coarser.

In the NE. ¼ SE. ¼ sec. 8, T. 52 N., R. 99 W., a sandstone dike crops out in a badland area (Pl. XX, *C*). The dike is from 1 to 3 feet wide and stands from 2 to 4 feet above the adjacent surface, and the outcrop is continuous for 100 feet. The dike appears to be vertical and trends N. 45° W. Examination of the hand specimens and of a thin section under the microscope shows that it is made up of grains of quartz, orthoclase (microperthitic), and a little chloritized biotite. The grains are subangular to angular and are exceptionally uniform in size, ranging from 0.1 to 0.2 millimeter in diameter. The cementing material is calcite.

The uniformity in the size of grain and the general resemblance to sediment that makes up some of the Wasatch beds indicate that the dike consists of material from a deeper bed that has been forced upward into a fissure, possibly at the time of some earth disturbance that took place shortly after the beds were laid down. If the material that forms the dike had fallen from the surface into an open fissure, it would probably contain a mixture of coarse and fine sediments.

Meeteetse quadrangle.—Wasatch beds are found in two parts of the Meeteetse quadrangle. The largest area lies in the northeast corner and is continuous with the large area in the Oregon Basin quadrangle. In addition, there is a group of three separate small areas on the crests of several hills at the head of Iron Creek, near the southwest corner. Still farther southwest, in T. 46 N., R. 101 W., the beds underlie a large area adjacent to the mountains. The exposures of the beds are generally fair, and there are numerous localities along the steep bluffs east of Greybull River where they may be measured in detail. (See Pl. XVIII.)

There is no difficulty in tracing the unconformity at the base of the Wasatch beds from the region east of Sleeper's ranch southward along Greybull River and east to the Hole in the Ground, although here and there its exact position is obscure. A detailed section in sec. 18, T. 49 N., R. 99 W., has been prepared to show the change in the character of the beds in the transition from the underlying Fort Union to the Wasatch formation (Pl. XVIII). The unconformity is particularly well shown in sec. 12, T. 48 N., R. 100 W.,[21] but it can be traced only with difficulty northward from the Hole in the Ground down the west side of the valley of Fifteenmile Creek, as the dip and lithologic features of the upper part of the underlying Fort Union beds closely resemble those of the Wasatch formation. In this area the position of the surface of unconformity is inferred from its apparent slope farther south.

The small areas of Wasatch beds at the head of Iron Creek throw light on the surface features of the region at the time the beds were deposited as well as on the subsequent earth movements. Although these small areas occupy the crests of hills, there are other hills near by that rise as high or higher but are made up of older beds, generally resistant Mesaverde sandstone. The relations indicate that the Wasatch beds in these localities are remnants of material laid down in a river channel that followed a sinuous course through low rounded hills. By constructing a profile along this channel it has been found that the average gradient along the part of the channel trending N. 47° E. to sec. 8, T. 47 N., R. 100 W., a distance of 6½ miles, is 60 feet to the mile. For the next stretch, trending N. 25° E. to sec. 11, T. 48 N., R. 100 W., a distance of 6¼ miles, the average gradient is 25 feet to the mile. Finally, for the third stretch, trending N. 40° E. to sec. 29, T. 49 N., R. 99 W., a distance of 4 miles, the average gradient is 175 feet to the mile. The possibility of regional uplift or depression being disregarded, it appears that the gradient of the channel within the second stretch has not been changed

[21] Fisher, C. A., Geology and water resources of the Bighorn Basin, Wyo.: U. S. Geol. Survey Prof. Paper 53, pl. 10, *B*, 1906.

since the beds were laid down, and further that the channel within the third stretch has possibly been locally inclined gently toward the northeast. The material in each of these remnants is essentially of the same character, consisting of sand and conglomerate, the pebbles of which attain a maximum diameter of 8 inches (No. 4, p. 42; Nos. 5 and 6, p. 43). Some red and greenish clays are locally present above the basal conglomerate.

Columnar sections 6 and 7, Plate XVIII, show the character of the beds that make up the formation east of Greybull River. The exposed sections consist largely of zones of coarse sand and conglomerate, the thicknesses of which show a considerable range. Here, as in areas farther north, most of the pebbles are clearly the common assortment of the varieties found in the Fort Union formation. Not only do many pebbles still show the percussion marks produced when the Fort Union and older beds were folded, but here and there pebbles may be found which by their form show that they have been broken, retransported, and laid down in their present locations. Two assortments of such pebbles are shown in Plate XIX.

In addition to the common Fort Union varieties, pebbles of red granite and cream-colored limestone are rather common. A collection of limestone pebbles from a zone about 100 feet above the base of the formation in the SE. ¼ SW. ¼ sec. 5, T. 49 N., R. 99 W., have been submitted to G. H. Girty, of the United States Geological Survey, for identification. He reports as follows:

The limestone pebbles are fossiliferous, but the fossils are fewer and less satisfactory than those collected from the Fort Union beds. I find a *Zaphrentis* (*Menophyllum?*); a *Spirifer*, apparently of the *centronatus* or *rockymontanus* type; and an abundance of small crinoid stems. From the character of the fossils and also of the rock which contains them, I think it probable that the mother rock was the Madison limestone (lower Mississippian), but I would hardly venture a definite statement from the evidence at hand.

Grass Creek Basin quadrangle.—Beds of the Wasatch formation are found in two parts of the Grass Creek Basin quadrangle. A small area lies in the northeast corner, and numerous small isolated areas lie along the western border. The northeastern area is not large and the exposures are very good (Pl. XVI). The exposures along the western border are generally poor, but those near the head of Wagonhound Creek are uncommonly good (Pl. XX, *A*, *B*).

The bed of conglomerate that is mapped as the base of the formation in the northeastern area is a conspicuous feature of the region all the way from the valley of Fifteenmile Creek to Blue Ridge, which is 12 miles farther southeast. Although the observations of strike and dip on this bed of conglomerate correspond closely with those made on the underlying Fort Union beds, the significance of the conglomerate is shown by the two facts that it contains reworked Fort Union pebbles (Pl. XIX) and that it may be traced into an area where it is unconformable on the Fort Union beds. The maximum thickness of Wasatch beds in this locality is about 500 feet.

The several detached remnants of Wasatch beds on the western border of the quadrangle have generally similar lithologic features and rest unconformably on the underlying formations, which range from the Mesaverde to the Fort Union. The surface on which the beds were laid down is almost a plane and nearly horizontal, although it is broken by two faults near the head of Little Prospect Creek. These faults limit a long, narrow block that has been dropped about 360 feet with respect to the adjacent beds, at the west edge of the quadrangle. Along a cross section drawn due north near the west edge of the quadrangle the altitude of the surface of unconformity decreases from 6,000 feet near Cottonwood Creek to 5,900 feet, then rises uniformly to nearly 6,800 feet in a distance of 7 miles, and then decreases in 3 miles more to 6,600 feet. In the small areas where contours may be drawn upon this surface they trend generally northwest. Along a cross section drawn N. 53° E. across Grass Creek Basin the surface is first inclined gently northeast and then dips more steeply near the trough of the Grass Creek syncline. If the surface is projected across Grass Creek Basin, there are several parts of the high ridge northeast of the basin that rise above it before, near Gooseberry Creek, it again dips steeply at about 8°.

In the western border region where the surface of unconformity is cut across rocks of the Meeteetse, Lance, and Fort Union formations it is nearly a plane, and the beds that project above the extension of this plane are generally the lower sandstones of the Mesaverde formation. So far as there is any evidence, the depressions in this surface coincide closely with more pronounced troughs in the older beds, such as the Cottonwood and West Ilo synclines.

The upper limit of the Wasatch beds in this quadrangle is the lowest bed of the great mass of volcanic tuff that covers a large area on the west side of the Big Horn Basin. Where the exposures are good the surface between the Wasatch sediments and the tuffs is readily recognizable.

The beds that make up the Wasatch formation in this area are conglomerate, sandstone, and clay that show a wide range in color. Although the individual beds appear to be highly lenticular the thickness of the aggregate is rather uniform over the entire area. The minimum thickness of 107 feet is found in sec. 3, T. 44 N., R. 99 W., and from this point the thickness increases southwestward to 164 feet in sec. 16, T. 44 N., R. 99 W., and northward to 300 feet in sec. 16, T. 45 N., R. 99 W. In other words, the formation is thinnest where the altitude of the base is lowest and thickest where it is highest.

The general lithologic features of the formation along the western border of the quadrangle are shown in sections 7, 8, and 9, Plate XVIII. The basal bed is commonly a conglomerate several feet thick, in which the largest pebbles rarely exceed 3 inches in diameter. Here and there conglomerate is present higher in the section. In some places, as in sec. 10, T. 44 N., R. 99 W., the basal bed is carbonaceous shale with thin lenses of coal. Farther north, in secs. 16 and 21, T. 45 N., R. 99 W., the basal bed is a pale-reddish sandstone that is more highly indurated than those commonly met in the Wasatch formation. In that area conglomerate is sparingly present. On the other hand, one or more beds of red sandy clay that rarely exceed 10 feet in thickness are present at almost every locality.

No fossils have been found in any of the exposures along the western border of the quadrangle.

QUATERNARY SYSTEM

TERRACE DEPOSITS

Terraces of four ages occur in these quadrangles. They are described on pages 5–7. The deposits on the youngest or Greybull terrace are considered to be of late Pleistocene age, those on the Sunshine terrace early Pleistocene, those on Meeteetse Rim Miocene or Pliocene, and those on the oldest or Cottonwood terrace possibly Miocene. The deposits on Meeteetse Rim are correlated by Alden with the Flaxville gravel of Montana, which is either late Miocene or early Pliocene.

ALLUVIUM

Valley and flood-plain deposits of sand and gravel of Pleistocene and Recent age occur along the streams of these quadrangles.

VOLCANIC ROCKS

Oregon Basin quadrangle.—There are no volcanic rocks in place in the Oregon Basin quadrangle. In the SW. ¼ NE. ¼ sec. 9, T. 50 N., R. 101 W., scarcely 500 feet west of the west border of the quadrangle, a flat-topped hill that rises to an altitude of 6,890 feet is capped by a sheet of augite andesite. The exposures are not good enough to determine its thickness accurately, for except here and there the surface is covered with soil and grass; the thickness is estimated at 20 feet. There are a sufficient number of bare surfaces, 6 by 6 feet, to warrant the assumption that this rock is in place.

In hand specimens the rock is nearly black, and except for a few blades of striated feldspar and grains of augite it is very fine grained. A thin section of the rock shows a few large crystals of labradorite feldspar, augite, and magnetite, which are embedded in a very fine grained groundmass composed of the same minerals. No glass is present.

The rock is undoubtedly the easternmost remnant of one of the surface flows which, with a great thickness of breccias, make up the Absaroka Mountains. Carter Mountain, 7 miles to the west, consists of such flows and breccias. In this locality no layer of Wasatch sediments underlies the volcanic material, which rests on beds of the Lance formation.

Meeteetse quadrangle.—No volcanic rocks crop out in the Meeteetse quadrangle, but in the SE. ¼ sec. 33 and the SW. ¼ sec. 34, T. 47 N., R. 100 W., about half a mile south of the south border, fine-grained light-colored tuffs overlie the Wasatch beds that fill an ancient river channel. These tuffs were the source of a collection of fossil plants (No. 6371) described on page 41.

Grass Creek Basin quadrangle.—Along the western border of the Grass Creek Basin quadrangle there are four small areas and one large area within which volcanic tuff conformably overlies the "border Wasatch" beds.

The largest area lies in secs. 4, 9, 10, and 16, T. 44 N., R. 99 W., where a total thickness of 600 feet of tuff is locally present. A typical example of the relations of the volcanic material to the "border Wasatch" beds is shown in section 9, Plate XVIII. Practically throughout this area the "border Wasatch" beds contain paper-thin brown shale that weathers white. The first layer of tuff is commonly pale greenish gray and also very thin bedded. Within 20 to 50 feet above the base the tuff is coarser and of brown color. Although in a broad sense the bedding trends west and dips gently north, in detail the material is highly cross-bedded. The highest hill in the area, in the SE. ¼ sec. 9, T. 44 N., R. 99 W., is made up of highly cross-bedded brown tuff, the individual fragments of which rarely exceed a quarter of an inch in diameter and are commonly rounded. So far as the bedding can be interpreted it appears that successively higher beds dip more steeply until the maximum of 35° is reached. The strike of the layers of tuff in this hill and the hills half a mile to the west is roughly parallel to an arc of which the center appears to be near Crater Sink, in sec. 16, T. 44 N., R. 99 W.

Crater Sink is a flat circular area about 250 feet in diameter which lies about 10 feet lower than the adjacent surface. In wet weather it is covered with water, but in dry weather the ground is soft and porous and supports much more grass than the surrounding hills. Unlike many small intermittent lakes in the region, which are caused by local damming along drainage lines, it does not contain any alkali efflorescence. The surface features of the sink, considered with the tuff, suggest that it was once the throat of a cinder cone, the source of a part of the near-by tuff, and that the top of the cone has been blown away by an explosion.

The mass of tuff in sec. 9, T. 45 N., R. 99 W., presents somewhat different features. The basal tuff rests conformably on the underlying "border Wasatch" sandstone and green and red clay. Fine greenish tuff predominates near the base, but the successively higher material is coarser, so that 300 to 400 feet above the base zones of well-rounded pebbles of dark-reddish and greenish andesite are present. The bedding is very irregular. Some layers of homogeneous tuff about 30 feet thick strike northwest and dip 20° SW., but in detail they are highly cross-bedded. Such layers are locally interrupted by vertical masses of homogeneous fine tuff which appear to be filled crevices. In general, the tuff in this locality is more highly indurated than that farther south, and here and there irregular bodies of fine tuff are highly silicified. Although the mineralogy of the tuff has not been closely studied, there is reason for believing that it closely resembles that of the coarse pebbles and therefore that the tuff is of andesitic character.

EXAMINATION OF THE SEDIMENTS

A number of specimens of the sedimentary rocks have been collected, disintegrated, sized, and examined under the microscope in the hope that the data thus obtained, taken in connection with those collected in the field, would throw additional light on the character, source, and manner of deposition of the sediments. Early in the progress of the field work it became apparent that close laboratory study of several varieties of the sediments, such as bentonite, might yield critical information concerning their origin, and it was planned to collect representative material. However, as the principal purpose of the work was to study the mineral resources of the region, and as the stratigraphic section is thick and contains many diverse rocks, only a relatively small number of specimens could be examined.

Only 24 specimens have been examined in detail, although many more were collected and have been useful for reference. Of the specimens examined, 7 were bentonite, 10 sandstone, 1 sand, 1 clayey sand, 2 sandy clay, and 3 clay. The source of the specimens was as follows: Thermopolis shale, 4 bentonite; Frontier formation, 1 bentonite; Cody shale, 1 sandstone; Mesaverde formation, 1 sandstone; Meeteetse formation, 1 sandstone, 1 sand, 1 clayey sand, 1 sandy clay, and 2 bentonite; Lance formation, 1 sandstone; Fort Union formation, 4 sandstone, 1 sandy clay, and 1 clay; Wasatch formation, 2 sandstone and 2 clay.

Samples that ranged from half a pound to 2 pounds in weight were selected in the field. The samples for sizing and mineral determination commonly ranged from 10 to 20 grams; those of bentonite weighed only 5 grams. After preliminary experiments to determine the best method, the samples were disintegrated, and the material in suspension was submitted to the laboratory of the United States Bureau of Soils, for separation into sizes. The method[22] provides for the separation of the grains coarser than 0.05 millimeter by settling for the appropriate period, and of the finer sizes by decanting. The silt is separated from the clay by centrifuging for a certain period and, after decanting the suspended silt, evaporating the excess water. The clay is also recovered by evaporating the excess water on a steam bath. The coarser sizes, free from silt and clay, are dried and sized.

Most of the samples, especially the bentonites and clays, were disintegrated in a satisfactory manner, but several of the sandstones from the Meeteetse and Fort Union formations were disintegrated rather imperfectly. The liquid used for disintegrating each sample is shown in the tables.

The minerals present in the several sizes of grains separated from each sample were determined by the immersion method.[23] A small portion of each size was placed in a drop of oil of known index of refraction, covered with a thin cover glass, and examined under the petrographic microscope. The purpose of the examination was to determine the kind, shape, and proportion of the minerals that made up a large part of the total, and not to make the special effort commonly necessary to determine accurately the uncommon or minor minerals that might be present. The list of minerals for each size is therefore smaller than is frequently reported in such examinations. The estimates of the proportion of each mineral present were made by counting the number of grains first in one and then in another field of vision. By repeated trials it was found that the proportions of the most abundant minerals rarely deviated more than 25 per cent from those indicated by the first count. The attempt to estimate the composition of the silt was not satisfactory, as although the minerals present could be determined, it was a laborious operation to estimate their proportions. The clay portions were not examined under the microscope.

The results of this work throw considerable light on the nature of the bentonite and indicate the source of a part of the sediments that make up several formations. These results are presented elsewhere in this report in statements concerning bentonite and the mineralogic features of the several formations and are summarized in the following tables:

[22] Briggs, L. J., Martin, F. O., and Pearce, J. R., The centrifugal method of mechanical soil analysis: U. S. Dept. Agr. Bur. Soils Bull. 24, 1904.

[23] McCaughey, W. J., and Fry, W. H., Microscopic determination of soil-forming minerals: U. S. Dept. Agr. Bur. Soils Bull. 91, pp. 43-45, 1913.

Mineralogic analyses of bentonite from Shoshone River section

[Disintegrated in water]

Range in size	Thermopolis shale								Frontier fortification	
	1. 4-inch bed 527 feet above base		2. 4-inch bed 527 feet above base		3. Base of 4-foot bed 575 feet above base		4. Top of 4-foot bed 575 feet above base		5. 8-foot bed 401 feet above base	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
Fine gravel (1 to 2 mm.).										
Coarse sand (0.5 to 1 mm.).										
Medium sand (0.25 to 0.5 mm.).	0.2	Biotite, fresh 5 Orthoclase, angular 40 Albite, angular 10 Quartz, angular 45	0.2	Not determined						
Fine sand (0.1 to 0.25 mm.).	9.1	Biotite, plates 5 Orthoclase, angular 40 Albite, angular 40 Quartz, angular 15	8.1	Not determined	1.5	Biotite, plates 20 Orthoclase, angular 25 Andesine, angular 38 Quartz, angular 5 Glass, angular 2 Clay aggregates 10	0.6	Biotite, plates 20 Orthoclase, angular 15 Andesine, angular 5 Quartz, angular 30 Glass, angular Tr. Clay aggregates 30	3.6	Biotite, plates Tr. Orthoclase, angular 60 Andesine, angular 37 Quartz, angular ? Opal, angular 3 Glass ?
Very fine sand (0.05 to 0.1 mm.).	11.2	Biotite, plates 2 Orthoclase, angular 35 Albite, angular 60 Quartz, angular 3 Apatite, crystals Tr.	11.9	Not determined	7.5	Biotite, plates 10 Orthoclase, angular 35 Andesine, angular 20 Quartz, angular 2 Glass, angular 8 Clay aggregates 25	4.7	Biotite, plates 5 Orthoclase, angular 10 Andesine, angular 5 Quartz, angular 20 Glass, angular 10 Clay aggregates 50	4.0	Biotite, plates Tr. Orthoclase, angular 50 Andesine, angular 45 Quartz, angular ? Opal, angular 5
Silt (0.005 to 0.05 mm.).	6.7	Not determined	6.0	Not determined	29.2	Biotite Orthoclase Andesine Quartz Glass	41.7	Biotite, plates 10 Orthoclase, angular 10 Andesine, angular 5 Quartz, angular 15 Glass, angular 60	12.2	Biotite, plates 5 Orthoclase, angular 5 Andesine, angular 5 Opal, angular 5 Clay aggregates 80
Clay (less than 0.005 mm.).	72.8	Not determined	73.8	Not determined	61.8	Not determined	53.		80.2	

Mineralogic analyses of sediments from Oregon Basin and Meeteetse quadrangles and vicinity

Range in size	Cody shale, Oregon Basin quadrangle		Mesaverde formation, Oregon Basin quadrangle		Meeteetse formation, Oregon Basin quadrangle					
	6. Sandstone, 1,500 feet above base, SE. ¼ sec. 3, T. 50 N., R. 100 W. Disintegrated in cold dilute acid; cement, calcite		7. Sandstone, 80 feet above base, SW. ¼ sec. 34, T. 51 N., R. 101 W. Disintegrated in cold dilute acid; cement, largely calcite		8. Sand, 250 feet above base, SE. ¼ sec. 11, T. 50 N., R. 100 W. Disintegrated in water		9. Sandstone, 450 feet above base, NW. ¼ sec. 23, T. 51 N., R. 100 W. Disintegrated by boiling in caustic potash solution; imperfect separation		10. Bentonite, 450 feet above base, NW. ¼ sec. 23, T. 51 N., R. 100 W. Disintegrated in water	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
Fine gravel 1-2 mm.).	------	------	0.17	Aggregate of smaller grains	------	------	0.43	Aggregate of smaller grains	------	------
Coarse sand (0.5 to 1 mm.).	0.97	Aggregate of smaller grains	1.97	Aggregate of smaller grains	0.1	Quartz, subangular 60 Chert, aggregate 40 Biotite Tr.	7.09	Aggregate of smaller grains	0.2	Biotite 70 Clay aggregates 30
Medium sand (0.25 to 0.5 mm.).	1.07	Aggregate of smaller grains	1.83	Quartz, subangular 40 Chert, subangular 60	.6	Quartz, subangular 60 Chert, subangular 39 Orthoclase, angular 1	6.86	Quartz subangular 60 Chert, subangular 35 Undetermined 5	.2	Biotite 90 Clay aggregates 10 Andesine, angular Tr.
Fine sand (0.1 to 0.25 mm.).	73.13	Quartz, angular 85 Orthoclase, subangular 4 Plagioclase 1 Clay aggregate 10	72.14	Quartz, subangular 70 Chert, subangular 28 Orthoclase, subangular 1 Undetermined 1	77.5	Quartz, subangular 60 Chert, subangular 35 Orthoclase, angular 3 Plagioclase, angular Tr. Biotite Tr. Undetermined 2	62.07	Quartz, subangular 65 Chert, round 15 Orthoclase, subangular 10 Plagioclase, angular 5 Biotite Tr. Undetermined 5	4.2	Biotite 85 Clay aggregates 5 Andesine angular 10
Very fine sand (0.05 to 0.1 mm.).	20.88	Quartz, angular 90 Orthoclase, angular 2 Plagioclase, angular Tr. Clay aggregates 8	15.66	Quartz, angular 65 Chert, subangular 30 Orthoclase, angular 4 Undetermined 1	9.9	Quartz, subangular 50 Chert, subangular 37 Orthoclase, subangular 8 Plagioclase, angular 1 Biotite 3 Undetermined 1	9.73	Quartz, angular 70 Chert, round 10 Orthoclase, subangular 10 Plagioclase, subangular 5 Biotite 1 Undetermined 4	1.7	Biotite 50 Andesine, angular 50 Orthoclase, angular Tr. Zircon, crystals Tr.
Silt (0.005 to 0.05 mm.).	3.95	Not determined	8.23	Quartz 60 Clay, etc 40	4.1	Quartz Biotite	13.82	Quartz, feldspar, biotite 30 Clay, etc 70	6.4	Biotite 50 Andesine, angular 50 Glass Tr.
Clay (less than 0.005 mm.).	------	Included with silt	------	Included with silt	7.8	Not determined	------	Included with silt	87.3	Not determined.

Range in size	Meeteetse formation, Meeteetse quadrangle						Lance formation, Meeteetse quadrangle		Fort Union formation, Oregon Basin quadrangle	
	11. Clayey sand, 760 feet above base, NE. ¼ sec. 10, T. 48 N., R. 100 W. Disintegrated slowly in ammonia and water		12. Bentonite, 800 feet above base, NE. ¼ sec. 10, T. 48 N., R. 100 W. Disintegrated in water		13. Sandy clay, 825 feet above base, NE. ¼ sec. 10, T. 48 N., R. 100 W. Disintegrated in water		14. Sandstone, 800 feet above base, SW. ¼ sec. 20, T. 48 N., R. 99 W. Disintegrated in dilute acid; cement, calcite		15. Sandstone, 600 feet above base, NE. ¼ sec. 24, T. 50 N., R. 100 W. Disintegrated in dilute acid; cement, calcite	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
Fine gravel (1–2 mm.).										
Coarse sand (0.5–1 mm.).							0.95	Quartz, round 30 Chert 60 Orthoclase, angular 5 Andesine, angular 3 Muscovite, plates 2	0.58	Aggregates of smaller grains.
Medium sand (0.25–0.5 mm.).					0.1	Aggregates of smaller grains 100	5.70	Quartz, subangular 45 Chert 50 Microcline, angular 5 Chlorite, angular Tr.	.87	Quartz, subangular 70 Quartz, aggregates 30 Orthoclase, subangular Tr.
Fine sand (0.1–0.25 mm.).	4.7	Quartz, subangular 50 Orthoclase, subangular 27 Plagioclase Tr. Biotite, plates 3 Chert 20	4.1	Quartz, round 5 Orthoclase, angular Tr. Andesine, angular 50 Biotite, plates 40 Zircon, crystals Tr.	.3	Quartz, round 2 Orthoclase, subangular 3 Biotite, plates 1 Iron concretions 94	79.65	Quartz, subangular 45 Chert 50 Microcline, angular 5 Chlorite, angular Tr.	70.73	Quartz, subangular 85 Chert 10 Orthoclase, subangular 5
Very fine sand (0.05–0.1 mm.).	42.6	Quartz, subangular 45 Orthoclase, angular 15 Andesine, angular 10 Biotite, plates Tr. Zircon, crystals Tr. Chert 30	7.2	Quartz, round 5 Orthoclase, angular 3 Andesine, angular 60 Biotite, plates 30 Apatite, crystals 2 Zircon, crystals Tr.	19.9	Quartz, subangular 50 Orthoclase, angular 5 Andesine, angular 20 Biotite, plates 5 Chert 20 Apatite, crystals Tr.	6.32	Quartz, subangular 45 Chert 50 Microcline, angular 5 Andesine, angular Tr. Chlorite, angular Tr.	22.66	Quartz, subangular 85 Chert 10 Orthoclase, subangular 5
Silt (0.005–0.05 mm.).	38.1	Quartz Orthoclase Andesine Biotite, plates	10.4	Andesine, angular 75 Biotite, plates 20 Apatite, crystals 3 Zircon, crystals 2	58.9	Quartz, angular 50 Andesine, angular 25 Biotite, plates 5 Chert 20	7.38	Quartz, etc. 30 Clay 70	5.13	Quartz, etc. 5 Clay 95
Clay (less than 0.005).	14.6	Not determined	78.3	Not determined	20.8	Not determined		Included with silt		Included with silt.

Mineralogic analyses of sediments from Oregon Basin and Meeteetse quadrangles and vicinity—Continued

Range in size	Fort Union formation, east of Meeteetse quadrangle (sec. 22, T. 48 N., R. 99 W.)									
	16. Olive brown sandy clay, 940 feet above base. Disintegrated in water and ammonia; very imperfect separation		17. Variegated red clay, 1,230 feet above base. Disintegrated in water and ammonia, then acid; some carbonate present		18. Sandstone, 1,325 feet above base. Disintegrated in water, then strong acid; some carbonate present		19. Olive brown sandstone, 1,705 feet above base. Disintegrated in dilute potassium hydrate solution; no carbonate present		20. White sandstone, 1,860 feet above base. Disintegrated in dilute acid; some carbonate present	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
Fine gravel (1–2 mm.).			0.9	Aggregates of smaller grains 100	0.11	Aggregates of smaller grains 50 Muscovite 50	0.3	Chert aggregates 100	8.9	Chert aggregates 75 Quartz, round 25
Coarse sand (0.5–1 mm.).	0.4	Aggregates of smaller grains 95 Muscovite 2 Biotite 3	7.4	Aggregates of smaller grains 100 Muscovite Tr.	4.53	Quartz, subangular 50 Chert 45 Microcline, subangular 5 Plagioclase, subangular Tr. Opal, round Tr.	8.2	Quartz, round 70 Chert 20 Microcline, angular 10	10.9	Quartz, subangular 40 Chert 50 Aggregates of smaller grains 10
Medium sand (0.25–0.5 mm.).	.5	Aggregates of smaller grains 95 Muscovite 2 Biotite 3	5.0	Aggregates of smaller grains 100 Muscovite Tr.	10.55	Quartz, subangular 50 Chert 30 Microcline, subangular 15 Plagioclase, subangular Tr. Opal, round 5 Muscovite Tr.	17.8	Quartz, round 70 Chert 15 Microcline, subangular 10 Igneous rock ? 5	8.1	Quartz, subangular 70 Chert 30
Fine sand (0.1–0.25 mm.).	10.3	Quartz, subangular 25 Chert 20 Orthoclase, subangular 3 Plagioclase, subangular 5 Biotite 2 Green aggregates ? 45	17.0	Aggregates of smaller grains 100 Muscovite Tr.	66.60	Quartz, subangular 50 Chert 30 Microcline, subangular 15 Plagioclase, subangular Tr. Opal, round 5 Muscovite Tr.	57.5	Quartz, round 80 Chert 10 Microcline, subangular 5 Igneous rock, subangular 5 Zircon, crystals Tr.	40.8	Quartz, subangular 85 Chert 10 Microcline, angular 4 Plagioclase, angular 1
Very fine sand (0.05–0.1 mm.).	33.5	Quartz, subangular 70 Chert 10 Orthoclase, subangular Tr. Plagioclase, subangular 5 Biotite Tr. Hornblende, subangular Tr. Green aggregates 15	6.9	Aggregates of smaller grains 98 Quartz 2 Orthoclase Tr.	10.42	Quartz, subangular 50 Chert 25 Microcline, subangular 15 Plagioclase, subangular 5 Opal Tr. Garnet 5	6.5	Quartz, subangular 85 Chert Tr. Microcline, angular 10 Igneous rock, angular 5 Zircon Tr.	17.9	Quartz, subangular 85 Chert 10 Microcline, angular 5 Plagioclase, angular Tr. Zircon, crystal Tr.
Silt (0.005–0.05 mm.).	38.0	Quartz, etc 95 Biotite Tr. Hornblende Tr. Aggregates 5	35.1	Quartz, angular 40 Aggregates of smaller grains 60	7.79	Quartz, etc 20 Clay 80	9.7	Quartz, etc 10 Clay 90	13.4	Quartz, etc 20 Clay 80
Clay (less than 0.005 mm.).	17.3	Not determined	27.7	Not determined		Included with silt		Included with silt		Included with silt.

Range in size	Wasatch formation, Oregon Basin quadrangle							
	21. Sandstone, 810 feet above base, SE. ¼ sec. 14, T. 51 N., R. 100 W. Disintegrated in dilute acid; cement, calcite		22. Sandstone, 480 feet above base, NW. ¼ sec. 1, T. 50 N., R. 100 W. Disintegrated in dilute acid; cement, calcite		23. Red clay, 250 feet above base, NW. ¼ sec. 19, T. 50 N., R. 99 W. Disintegrated in dilute ammonia water		24. Greenish clay, 260 feet above base, NW. ¼ sec. 19, T. 50 N., R. 99 W. Disintegrated in dilute ammonia water	
	Per cent	Material	Per cent	Material	Per cent	Material	Per cent	Material
Fine gravel (1 to 2 mm.)	0.85	Chert, round 90 Quartz, angular 5 Microcline, angular 5	----		----		0.1	Clay concretions 70 Manganese oxide 30
Coarse sand (0.5 to 1 mm.)	38.87	Chert, subangular 40 Quartz, subangular 50 Microcline, subangular 10	0.3	Quartz, subangular 100 Chalcedony, subangular Tr. Biotite Tr.	0.1	Clay concretions 100	.2	Clay concretions 60 Manganese oxide 40
Medium sand (0.25 to 0.5 mm.)	21.69	Chert, subangular 5 Quartz, subangular 75 Microcline, subangular 20	.5	Aggregates of smaller grains 70 Quartz, subangular 25 Chert 3 Microcline 2	.1	Quartz, angular 10 Clay concretions 90	.2	Clay concretions 55 Biotite, plates 5 Manganese oxide 40
Fine sand (0.1 to 0.25 mm.)	25.22	Chert, subangular 10 Quartz, subangular 75 Microcline, subangular 15 Garnet Tr.	20.5	Quartz, subangular 84 Chert, subangular 5 Microcline, angular 10 Plagioclase, angular 1	.8	Quartz, subangular 48 Chert, round 10 Orthoclase, angular 2 Plagioclase, angular Tr. Clay concretions 40	.9	Quartz, angular 24 Orthoclase, angular 71 Clay concretions 0 Manganese oxide 5
Very fine sand (0.05 to 0.1 mm.)	3.48	Chert, subangular 10 Quartz, subangular 65 Microcline, subangular 25	31.8	Quartz, angular 80 Chert, subangular 15 Microcline, angular 5 Plagioclase, angular Tr. Zircon, crystals Tr.	13.8	Quartz, angular 93 Chert, round 5 Orthoclase, angular 1 Plagioclase, angular 1	18.1	Quartz, subangular 80 Orthoclase, subangular 5 Plagioclase, subangular 5 Biotite 5 Manganese oxide 5
Silt (0.005 to 0.05 mm.)	9.89	Quartz, etc. 10 Clay 90	46.9	Quartz, etc. 40 Microcline, angular Tr. Clay, etc. 60	33.0	Quartz, angular 99 Orthoclase, angular 1	48.0	Quartz, angular 95 Orthoclase, angular 2 Plagioclase 3
Clay (less than 0.005 mm.)	----	Included with silt	----	Included with silt	52.2	Not determined	32.5	Not determined.

The Thermopolis shale is made up of light and dark gray shale, fine sandstone, and bentonite. An examination of the Shoshone River section, which is exposed in great detail, indicates that one-seventh of the entire thickness, 650 feet, is bentonite. The appearance of the Muddy sand where it crops out on Shoshone River indicates that the sizes of grains resemble closely those of the sandstone in the Cody shale (No. 6, p. 50), although the underlying sand contains a few chert pebbles as much as half an inch in diameter.

No samples of sediments from the Mowry shale have been examined in detail, but a typical specimen of gray laminated Mowry shale was crushed to a powder and examined under the microscope. In addition to quartz the powder contains many grains of a vesicular amorphous material that is probably volcanic glass. From this test it would appear that the Mowry shale probably contains considerable volcanic glass. Two thick beds of bentonite in this formation crop out along Shoshone River, and each of the logs of wells farther south reports beds of the material. The sandstone of the Mowry resembles that collected in the Cody shale (No. 6, p. 50).

Only one sample of bentonite from the Frontier formation has been examined in detail. The section exposed on the northeast flank of the Cottonwood anticline contains several beds of platy gray shale which closely resembles the Mowry shale and undoubtedly contains volcanic glass. Several of the sandstone beds of the Frontier contain coarser material than the sandstone of the Cody shale (No. 6, p. 50) and appear to range from that to the coarsest Fort Union sand (No. 20, p. 52). Zones of chert gravel in which the pebbles attain a maximum diameter of 2 inches are persistently present in the beds near the base. Quartz pebbles are conspicuously absent.

Except for the identification of glauconite along Shoshone River the fine material of the Cody shale has not been closely examined. The sample of sandstone (No. 6, p. 50) is typical of considerable material in the upper third of the formation throughout the region. In view of the abundance of chert gravel in the underlying formations and the persistent presence of chert in the higher formations, it is surprising that none was found in this sample. By contrast with that in the bentonite of the lower formations, the orthoclase in the sample is much decomposed and iron stained. It was undoubtedly altered by weathering before deposition.

The single sample of sandstone (No. 7, p. 50) from the Mesaverde formation is probably typical in mineralogy and size relations of a large part of the sandstones of the entire formation. Although the Mesaverde contains numerous thin zones of clay balls, the only coarser material is the thin zone of chert gravel locally present in the Oregon Basin quadrangle. Chert, which is absent in the sandstone of the Cody shale, is an abundant constituent of the Mesaverde and is present in every sample of the higher sandstones. The orthoclase, like that in the Cody sandstone, shows decomposition.

Of the six samples from the Meeteetse formation, two are bentonite and the other four appear to cover the range in sizes of the sediments that make up the formation. Chert is persistently present and is rather more abundant in the coarse than in the fine material. The sand portions contain much more orthoclase than those from lower and older sandstones, and it is generally more abundant in the finer sizes. A part of the orthoclase is fresh, and a part is slightly decomposed. Plagioclase, which is lacking in the older formations except in the bentonite, is present in the sands. The persistent association of fresh orthoclase, plagioclase, biotite, and zircon in the sand portion of sandstones and clayey sands suggests that the sediments are derived from two sources, one being the same as that which yielded the sandstone from the Cody shale and the other having the elements of bentonite and probably being volcanic in origin. The general lack of induration of the beds that make up the Meeteetse formation is probably due to the heterogeneous character of the sediments, for clean sandstone and shale make up a small part of the total thickness.

Although sandstone makes up a large part of the total thickness of the Lance formation, and the single sample examined appears to represent the average in sizes of grains, the mineralogy may not be representative. It is of interest, however, in that microcline, which was not found in the older sediments, forms an appreciable part of the sand portions. Also, chert exceeds quartz in the sands, and chlorite, not accompanied by biotite, is present.

The six samples from the Fort Union formation more nearly cover the variety of the sediments than any other group. In contrast with the samples from the underlying sediments, they were most difficult to disintegrate. Chert is persistently present but does not exceed quartz in any sample. Orthoclase is present in the sands, but in the samples taken from the upper half of the formation it is the microcline variety which is associated solely with granitic rocks. The evidence from the fine sediments agrees with that from the conglomerates, for granitic pebbles are almost unknown near the base of the Fort Union, are present in small quantity in the higher conglomerates, and are common in the Wasatch formation. The green aggregates in one sample (No. 16, p. 52) appear to be small grains of quartz or chert cemented by a chloritic material.

The sands of the Wasatch sediments contain considerable chert, which locally exceeds quartz, and show a rather high percentage of fresh angular microcline. The examination of the red and green clays shows a curious difference that may aid in understanding the significance of the color of the fine sediments of the formation. Neither specimen was easily disintegrated, and in each sand portion there were many little hard composite grains or concretions. Those from the red clay were reddish iron oxide with clay, whereas those from the green clay were black manganese oxide almost free from iron. No complete analyses that might show the amount and degree of oxidation of the iron present are available. Commonly the difference in color of such clays is supposed to be due to the difference in the degree of oxidation of the iron present. Sinclair and Granger [24] showed that although some red clays contain about 1.5 per cent more ferric oxide than some blue clays, both varieties contain from 2.77 to 7.91 per cent of ferric oxide and less than 0.58 per cent of ferrous oxide. It seems probable that the manganese content should receive consideration, for it is known that in making brick a clay that normally burns to a bright red can be burned to yellowish gray by adding a small proportion of manganese oxide.

Before summarizing the results of the study of the sediments, the purpose of the inquiry should be stated. The examination of a large region in south-central Montana, 100 to 200 miles northwest of the area under consideration, has shown the presence of a large body of volcanic material known as the Livingston formation. Stone and Calvert [25] have shown that this formation is the local equivalent of the Claggett, Judith River, Bearpaw, Lennep, and Lance formations and the lower part of the Fort Union formation of central Montana. It is therefore roughly equivalent to beds that range from the lower part of the Mesaverde to the lower part of the Fort Union in the Big Horn Basin. It was the purpose of this examination, therefore, to determine whether volcanic material is present in the section, and to gather any other information that might be disclosed concerning the source of the sediments and the conditions under which material was delivered to the streams.

1. The inquiry shows that bentonite, a volcanic product, is abundant in the Thermopolis, Mowry, Frontier, and Meeteetse formations, although it forms a smaller part of the total thickness than the volcanic materials in south-central Montana. The first three formations are much older than the Livingston formation. There can be no doubt that volcanoes were active in a land area west of the Big Horn Basin at the time these beds were laid down.

2. The results, considered with the record of composition of the conglomerates, indicate that in addition to volcanic material the coarser sediments that make up the Thermopolis, Mowry, Frontier, Cody, Mesaverde, Meeteetse, Lance, and Fort Union (lower part) formations were derived from two sources—(*a*) areas of cherty limestones and probably quartzose sediments; (*b*) areas of granitic rocks. During the entire period of deposition of these formations climatic conditions appear to have favored the thorough weathering and decay of these rocks, for very little feldspar and no limestone reached the areas of deposition. The quantity of material and the sizes of grains varied from time to time, depending upon several factors other than climate.

3. The deposition of the upper part of the Fort Union formation corresponded with distinct changes in the mineralogic character of the sediments. Much more feldspar from areas of granitic rocks and some fresh limestone reached the zones of deposition. If any volcanic material was added to the sediments of this region during Fort Union and early Wasatch time, it has not been detected.

BENTONITE

Bentonite is a clay with some uncommon properties that has been recognized in several parts of Wyoming as well as adjacent States. A summary of its properties and mode of occurrence is given by Fisher,[26] and it has also been described by Siebenthal,[27] Wherry,[28] the writer,[29] and others. From existing records as well as the unpublished work of several members of the United States Geological Survey it appears highly probable that the material is rather widespread, especially in the Rocky Mountain region.

Physical properties.—When freshly exposed pure bentonite is a white to pale-yellow clay practically free from grit. In color and texture it resembles the common grades of castile soap. It shows no stratification but breaks with a conchoidal fracture. Every stage from the pure material to that which contains a large proportion of gritty constituents may be found near the pure beds. With exposure the pure material loses water and becomes lighter in color and harder, and many cracks develop. Natural exposures by alternate wetting and drying present a curious scoria-like appearance (Pl. XIX, *B*), but when such surfaces are wet, the material becomes very plastic.

Stratigraphic relations.—Until recently it was thought that beds of bentonite were confined to the Benton shale, of the Cretaceous system, and its equivalents, but now it is known to occur at several horizons in the

[24] Sinclair, W. J., and Granger, Walter, Eocene and Oligocene of the Wind River and Big Horn basins: Am. Mus. Nat. Hist. Bull., vol. 30, pp. 114–117, 1911.

[25] Stone, R. W., and Calvert, W. R., Stratigraphic relations of the Livingston formation, Montana: Econ. Geology, vol. 5, pp. 551–557, 652–669, 741–764, 1910.

[26] Fisher, C. A., Bentonite deposits in Wyoming: U. S. Geol. Survey Bull. 260, pp. 559–563, 1905.

[27] Siebenthal, C. E., Bentonite of the Laramie Basin: U. S. Geol. Survey Bull. 285, pp. 445–447, 1906. Darton, N. H., and Siebenthal, C. E., Geology and mineral resources of Laramie Basin, Wyo.; U. S. Geol. Survey Bull. 364, pp. 58–60, 1909.

[28] Wherry, E. T., Clay derived from volcanic dust in the Pierre in South Dakota: Washington Acad. Sci. Jour., vol. 7, pp. 576–583, 1917.

[29] Hewett, D. F., The origin of bentonite and the geologic range of related materials in Big Horn Basin, Wyo.: Washington Acad. Sci. Jour., vol. 7, p. 196, 1917. Wherry, E. T., Clay derived from volcanic dust in the Pierre of South Dakota: Idem, pp 576–583.

Cretaceous and Tertiary rocks of the Rocky Mountain region and more widely as well.

During the progress of this work on the west side of the Big Horn Basin beds of bentonite were recognized in the Thermopolis, Mowry, Frontier, and Meeteetse formations and in the tuffs that overlie the "border Wasatch" near Cottonwood Creek (fig. 6). Although the largest number of beds have been found in the Thermopolis shale, 32 beds from that formation ranging from 1 inch to 5 feet in thickness being recorded on Shoshone River, the thickest beds occur in the Frontier formation. These formations, with the intervening Mowry shale, are roughly the equivalent of the Benton shale of the plains of Montana, Wyoming, and Colorado. Beds of bentonite as much as 3 feet thick are also present in the Meeteetse formation (fig. 6). Thus bentonite is found in beds of marine as well as continental origin. The persistence of the bentonite beds in this area is discussed on page 14.

In detail, most of the beds of bentonite are sharply separable from the sediments that underlie them, whether they are sandstone or shale. The upper part of each bed of bentonite, on the other hand, shows a gradual transition to the overlying sediment (fig. 6). In order to determine the extent to which the beds are homogeneous, samples were taken from several parts of the outcrop of a thin bed (Nos. 1 and 2, p. 49) and from the bottom and top of a 4-foot bed (Nos. 3 and 4, p. 49). The proportions of the several sizes of sand in the first pair of samples indicate that the thin bed is practically homogeneous, but even though the proportions in the second pair are slightly different, the difference is probably too slight to be significant.

Minerals present.—The analyses in the table on page 49 show that a few minerals make up a large part of the sand in bentonite, but the proportions differ considerably between one sample and another and between the different sizes. Orthoclase, the potash feldspar, is commonly the most abundant mineral and is present as fresh angular fragments, here and there bounded by cleavage planes. Andesine, a soda-lime feldspar, is also abundant and is present as fresh angular grains. Albite has been recognized in one sample. Neither of the feldspars appears to show the slightest trace of decomposition. Biotite is also characteristic, and the grains are commonly dark olive-green to brownish modified hexagonal plates. A few grains show a border of discoloration that may indicate decomposition. Quartz is commonly present but generally in smaller proportion than either of the feldspars. The grains are characteristically angular and free from gas inclusions. An amorphous clear glass is present in several specimens of impure bentonite but has not been definitely recognized in the purest material. The glass is colorless and vesicular, has an index of refraction of about 1.48, and is therefore rhyolitic or dacitic. Some grains partly inclose fragments of feldspar; in others round vesicles are filled with an undetermined birefringent mineral. Zircon in minute perfectly terminated crystals is a constant accessory, and crystals of apatite are present in some specimens. Many of the sand portions of disintegrated specimens of bentonite contain rounded aggregates of clay particles.

Comparison of the coarse particles in bentonite with those of similar sizes in clays and sands from near-by beds, as shown in the tables on pages 49–53, as well as in many sediments from other regions, reveals striking differences. In marine sediments plagioclase feldspars are uncommon, and only rarely do the proportions of feldspar exceed those of quartz. Furthermore, the feldspar grains from most such sediments show a decomposed border, whereas those from bentonite are quite clear and unaltered. These differences must be accounted for in any satisfactory explanation of the origin of bentonite.

Analyses.—Both Fisher and Siebenthal, as well as others, record analyses of bentonite from Wyoming. Several new analyses of bentonite, made in the chemical laboratory of the United States Geological Survey, are presented in the accompanying table, as well as the range in the ingredients shown by previously published analyses of 11 samples of bentonite and 5 samples of pumice. By contrast with many clays that possess similar physical properties the ratio of silica to alumina in bentonite is very high, but there is nothing uncommon among the other ingredients.

Analyses of bentonite and pumice

	Bentonite				Pumice	
	1	2	3	4	5	6
SiO_2	65.63	54.31	58.25	66.5	56.57	79.49
Al_2O_3	13.40	20.22	12.63	24.7	11.60	17.99
Fe_2O_3	} 2.55	{ 1.88	} 2.40	3.7	{ .32	5.84
FeO		.19			.0	1.99
MgO	2.17	.98	1.0	4.14	.0	.77
CaO	.85	.94	.5	4.12	1.63	5.11
Na_2O	.69	2.35	-------	-------	3.09	4.74
K_2O	.27	.21	-------	-------	1.52	4.80
H_2O+	} 14.33	{ 13.18	} 5.0	16.36	{ .15	5.98
H_2O-		5.46			-------	-------

1. Uppermost bed of Frontier formation, Shoshone River, Wyo. Sample No. 5, p. 49, collected by D. F. Hewett. Analysis by United States Geological Survey.
2. Bed in Graneros shale, sec. 30, T. 47 N., R. 63 W., Wyo. Collected by F. W. Mondell. Analysis by United States Geological Survey.
3, 4. Minimum and maximum percentages of elements in 11 samples of bentonite, assembled by C. E. Siebenthal, U. S. Geol. Survey Bull. 285, p. 446, 1906.
5, 6. Minimum and maximum percentages of elements in 5 samples of pumice, assembled by H. S. Washington, U. S. Geol. Survey Prof. Paper 14, 1903.

Origin.—Any satisfactory explanation of the origin of bentonite should consistently account for the peculiarities in chemical and mineralogic composition, stratigraphic relations, and regional distribution. The high ratio of silica to alumina suggests that it is derived from one or more substances with a similar composition, such as the feldspars, zeolites, or highly siliceous glasses. Each of these except the zeolites is actually present. It seems strange, however, if the alteration

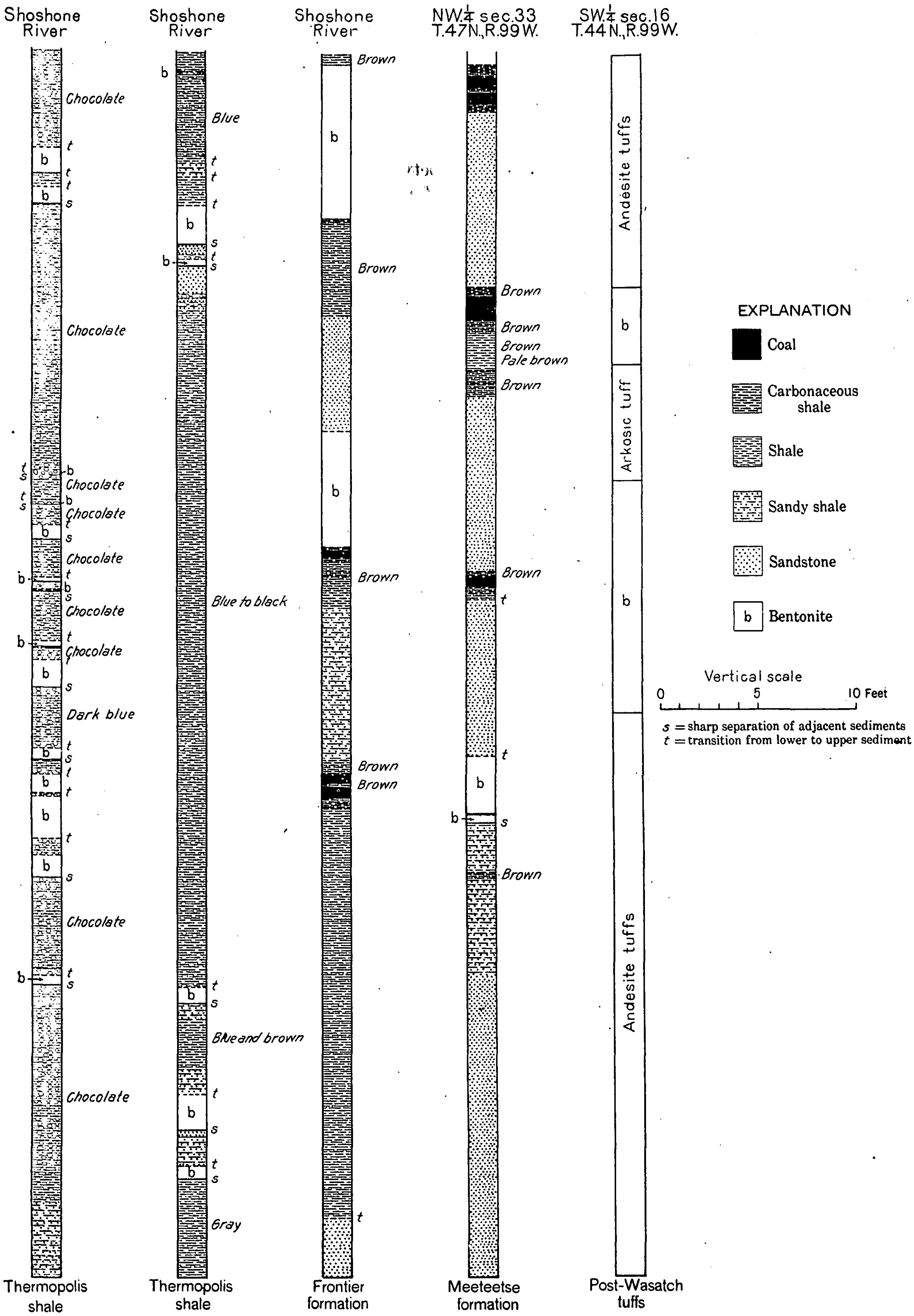


FIGURE 6.—Detailed stratigraphic sections showing relations of beds of bentonite to adjacent rocks

took place after the sediment was buried, that neither the feldspars nor the glass shows stages of alteration. Evidence from other regions indicates that glass fragments have survived, practically unaltered, from early Cretaceous and Tertiary time to the present. The persistent presence of fresh feldspar and absence of altered feldspar indicate that these minerals were not the source of bentonite.

The sharp separation of the base of nearly all the beds of bentonite from the underlying material shows that they mark a distinct interruption in the deposition of the normal clay and sand. The widespread occurrence of the beds in a thin zone of sediments near the base of the Cretaceous deposits indicates that the material was almost simultaneously delivered to the channels that supplied sediment to a large region.

Without entering further at this place into a discussion of the problem or of the earlier explanations that have been offered to account for the origin of the bentonite the writer suggests the following as being most consistent with its composition and relations. Bentonite is doubtless in large measure the alteration product of a volcanic glass but in part may be derived from some mineral that was crystallized in the glass. The alteration probably took place soon after the explosions, when the vapors condensed and gathered mineral particles into drops and produced mud showers. Some mineral particles were blown beyond the region of condensing gases and remained fresh and unaltered. The alteration of most of the material was probably completed when the beds were laid down and covered with overlying sediments.[30]

The identification of bentonite as an altered volcanic glass and its recognition in beds of the Colorado and Montana groups over a large area confirm the following statement by Pirsson:[31]

> As petrographic studies are progressively made of the later bedded rocks of the region of the American Cordillera, it is certain that vast amounts of tuffaceous sediments will be found in them.

The volcanoes that were the source of the glass which was altered to bentonite were probably situated in the region west of Wyoming, very likely in central Idaho. The presence of numerous beds of bentonite near the base of the Cretaceous section shows that volcanoes were active in the western United States much earlier than is commonly suspected.

CORRELATION OF FORMATIONS

It is one of the aims in the study of the stratified rocks of a region to determine as far as possible the relations of the beds to those in near-by regions, particularly to determine which beds in each region were deposited at the same time. Such determinations depend largely on the identification and interpretation of the relations of the fossil plants or vertebrate and invertebrate animals that may be found in the beds. The studies are also aided by evidence of erosion or absence of persistent beds between other groups of beds, as well as other evidence of a regional character. However, it is only rarely, if ever, possible to determine that a single thin bed of sandstone or shale in one locality was deposited at practically the same time as a similar bed in another locality near by. Sediments of one variety or another are being laid down almost continuously in every persistent body of water, but during any particular brief period the sediments at one place undoubtedly differ appreciably from those at other places in mineralogic character, relations of size of grain, and thickness of the layers. In groups of beds 5,000 to 10,000 feet thick, made up largely of sandstone and shale, such as those comprised in the Upper Cretaceous series of western Wyoming, it is generally necessary to rest content with the recognition in different localities of groups of marine beds 200 to 500 feet thick or continental deposits 500 to 2,000 feet thick that were practically contemporaneous.

The beds that make up the Cretaceous section have been studied closely in many parts of Montana, Wyoming, and Utah and in southeastern Idaho, as well as in the adjacent group of States farther east. Although these studies have continued since 1860, it may be stated broadly that only during the last 30 years have the sections been examined in sufficient detail and enough fossils collected to permit the reliable correlation of groups of marine beds 500 feet thick in one region with those in other regions several hundred miles away. The problem of correlating the nonmarine or continental beds of the Upper Cretaceous section is even more difficult, and the relations of several groups of beds 2,000 to 5,000 feet thick in a number of localities are still obscure.

In the attempt to interpret the relations of the Cretaceous beds in these quadrangles to those in near-by regions, it has seemed best to place most confidence on the detailed studies made during the last ten years in the region within 250 miles of Cody, Wyo. Plate XXI has been prepared to make the relations of the beds clear. The same vertical scale is used throughout, and the spacing is proportional to the distance between the areas where the sections have been studied. The two groups of sections shown lie along straight lines, one of which makes nearly a right angle with the other. One group extends from Shoshone River[32] near Cody, on the

[30] Since the completion of the work upon which this interpretation was based the writer's attention has been called to a similar suggestion by Prof. J. E. Todd (Condra, G. A., Geology and water resources of a portion of the Missouri River valley, in northeastern Nebraska: U. S. Geol. Survey Water-Supply Paper 215, p. 13, 1908).

[31] Pirsson, L. V., The microscopical characters of volcanic tuff: Am. Jour. Sci., 4th ser., vol. 40, p. 204, 1915.

[32] Hewett, D. F., The Shoshone River section, Wyo.: U. S. Geol. Survey Bull. 541, pp. 89-113, 1914.

west, S. 60° E. 156 miles to Salt Creek [33] and 84 miles farther to Lance Creek.[34] The other group extends from Judith, Mont.,[35] S. 5° E. 434 miles to Baxter Basin, Wyo.,[36] and passes through Lake Basin, Mont.,[37] Elk Basin, Wyo.,[38] Cody, Wyo., and Maverick Springs, Wyo.[39]

The beds included range from the Thermopolis shale, near the base of the Upper Cretaceous section, the lowest exposed on the surface in these quadrangles, to those of the Lance formation, of late Cretaceous or early Tertiary age but at present classified as Tertiary (?) by the United States Geological Survey. These beds fall readily into five groups whose limits are chosen on the basis of the conditions under which they were laid down.

The three lowest formations of the Shoshone River section, the Thermopolis, Mowry, and Frontier, are included in the first group. They contain only a small number of fossils, which include a few plants, a turtle, a few crocodile teeth, and a single marine shell. The leaves (from the Frontier formation) are reported to belong to the flora of the Dakota sandstone. The character of the sediments, however, warrants their approximate correlation with beds in sections farther north, east, and south. Although the thin coal beds in the Frontier formation on Shoshone River indicate the continental origin of at least part of the formation, coal beds appear to be absent east of the Big Horn Mountains, and farther east only marine beds were laid down. North and west of Cody most of the information concerning the beds in the position of this group has been obtained from wells, and it is insufficient to determine whether they are largely or wholly marine.

The second group of beds includes only the Cody shale on the west side of the Big Horn Basin. The lower 600 feet contains numerous marine fossils, some of which are known to occur in a similar group of beds over a wide area in eastern and southern Wyoming. These fossils appear to furnish the best criterion for comparing the stratigraphic sections of all the areas in Wyoming and Montana. With them as a basis, a line has been drawn through both groups of sections which probably indicates a zone of beds that was laid down almost contemporaneously in the entire region. The identification of this zone of contemporaneous beds in the Cody, Colorado, and Steele shales confirms the correlation of the underlying group—the Frontier formation, Mowry shale, and Thermopolis shale. The sections show that although the lithologic character and thickness of this first group change greatly in passing from west to east, they show little change in passing from north to south. The overlying group of marine shales and thin sandstones represented in the Shoshone River section by the Cody shale tends to show the same relations. In that part of the section the thickness of shale increases greatly from Cody eastward but only slightly from Cody southward. The size of the area occupied by the marine shale indicates that the Cretaceous sea had its maximum extent in this part of the United States during the deposition of this shale.

The marine shale is succeeded throughout western Wyoming and Montana by the third group, which near Cody includes the Mesaverde formation, made up largely of sandstone but containing shale and thick coal beds. In the earlier studies in this region, begun in west-central Montana, correlations of the beds were based on the assumption that the lowest coal beds were laid down contemporaneously. Thus the basal beds now called Mesaverde were formerly correlated with the Eagle sandstone of central Montana. Later, however, fossils collected, first by Hintze [40] and later by Hares,[41] indicated that species characteristic of the Eagle sandstone were present in the marine Cody shale from 300 to 500 feet below the base of the Mesaverde formation. This discovery is confirmed by the relations of the coal beds of this formation in the quadrangles here considered, for it is now known that they do not form a persistent zone at one horizon but are overlapping lenses which are higher in the section in successive areas toward the east. Although, therefore, the coal-bearing formation that overlies the marine Cody shale is now known widely in Wyoming as the Mesaverde, it is apparent that the basal beds of this formation were not deposited simultaneously over the area in which they are now found. It is probable that the lowest bed of the Parkman sandstone, which forms the base of the Mesaverde formation in the Salt Creek region, Wyo., is somewhat younger than the base of the Mesaverde near Cody. Fisher's work,[42] as well as that done more recently by Bowen and Hancock, tends to show that the Mesaverde formation near Cody may include beds whose age is similar to that of the largely marine Claggett formation of central Montana. The collections of leaves from these quadrangles are not large and with one exception are reported as characteristic of the Judith River formation, a part of which is correlated with a part of the Mesaverde. One collection consisted of two species identified as belonging to the Eagle flora.

[33] Wegemann, C. H., The Salt Creek oil field, Wyo.: U. S. Geol. Survey Bull. 670, pp. 12-24, 1917.

[34] Hancock, E. T., The Lance Creek oil and gas field, Wyo.: U. S. Geol. Survey Bull. 716, pp. 100-107, 1921.

[35] Bowen, C. F., The stratigraphy of the Montana group: U. S. Geol. Survey Prof. Paper 90, pp. 96-103, 1915.

[36] Schultz, A. R., Oil possibilities in and around Baxter Basin, Wyo.: U. S. Geol Survey Bull. 702, pp. 24-36, 1920.

[37] Hancock, E. T., Geology, oil and gas prospects of the Lake Basin field, Wyo. U. S. Geol. Survey Bull. 691, pp. 111-121, 1919.

[38] Hares, C. J., The Elk Basin oil field, Mont.-Wyo. (manuscript report).

[39] Collier, A. J., Anticlines near Maverick Springs, Fremont County, Wyo.: U. S. Geol. Survey Bull. 711, pp. 152-160, 1920.

[40] Hintze, F. F., jr., Basin and Greybull oil and gas fields, Wyo.: Wyoming State Geologist's Office Bull. 10, pp. 27-30, 1915.

[41] Hares, C. J., The Elk Basin oil field, Mont.-Wyo. (manuscript report).

[42] Fisher, C. A., Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana: Econ. Geology, vol. 3, p. 87, 1908.

Only when the next higher group of beds is studied—those which include the Bearpaw shale of central Montana, the Meeteetse formation of the Big Horn Basin, and the Lewis shale of central Wyoming—is the full significance of the Mesaverde formation in northwestern Wyoming understood. The Bearpaw shale contains an abundant marine fauna, and it has been mapped over a large area in central and western Montana as far south as Elk Basin, Wyo. Throughout this region it overlies beds of the Judith River formation, which contains meager plant remains and a few bones of terrestrial animals. Bowen has shown that the Judith River formation thins eastward and that in eastern Montana its place in the stratigraphic section is taken by marine shales that form a part of the Pierre shale. Similarly, in southern and eastern Wyoming the Mesaverde formation is overlain by the Lewis shale. According to Bowen[43] the Lewis thins westward and disappears in western Wyoming. It would appear that even in the lack of exhaustive comparisons of the marine fauna of the Bearpaw shale and Lewis shale the conclusion is warranted that there was a period in late Montana time when a sea encircled the entire northwest quarter of Wyoming, where marine shales are replaced by continental deposits. Such a conclusion indicates that the Meeteetse formation contains beds which were being deposited simultaneously with the Bearpaw shale. Although the collections of plant remains from the Meeteetse formation are not large, they have almost uniformly been identified as Judith River or Belly River species, thus indicating that the Mesaverde flora persisted under similar conditions while the Meeteetse formation was being deposited. The Meeteetse formation has not yielded vertebrate or invertebrate fossils, however.

The foregoing discussion, considered with the sections of Plate XXI, is sufficient to show that although a sea covered all of Wyoming and central and eastern Montana during late Colorado time, it was withdrawn from all except eastern Wyoming and eastern Montana during part of Montana time. This withdrawal may have been due either to a regional uplift in the area where the nonmarine beds are found or to a cessation of sinking coincident with a great increase in the supply of the coarse material of which the beds are made up, or to both causes. As no widespread unconformity has been found in the Montana section, it appears to the writer that the second cause must have been more effective than the first. However that may be, it is apparent that subsequently renewed sinking permitted the sea again to cover most of Montana and most of Wyoming except the northwest quarter.

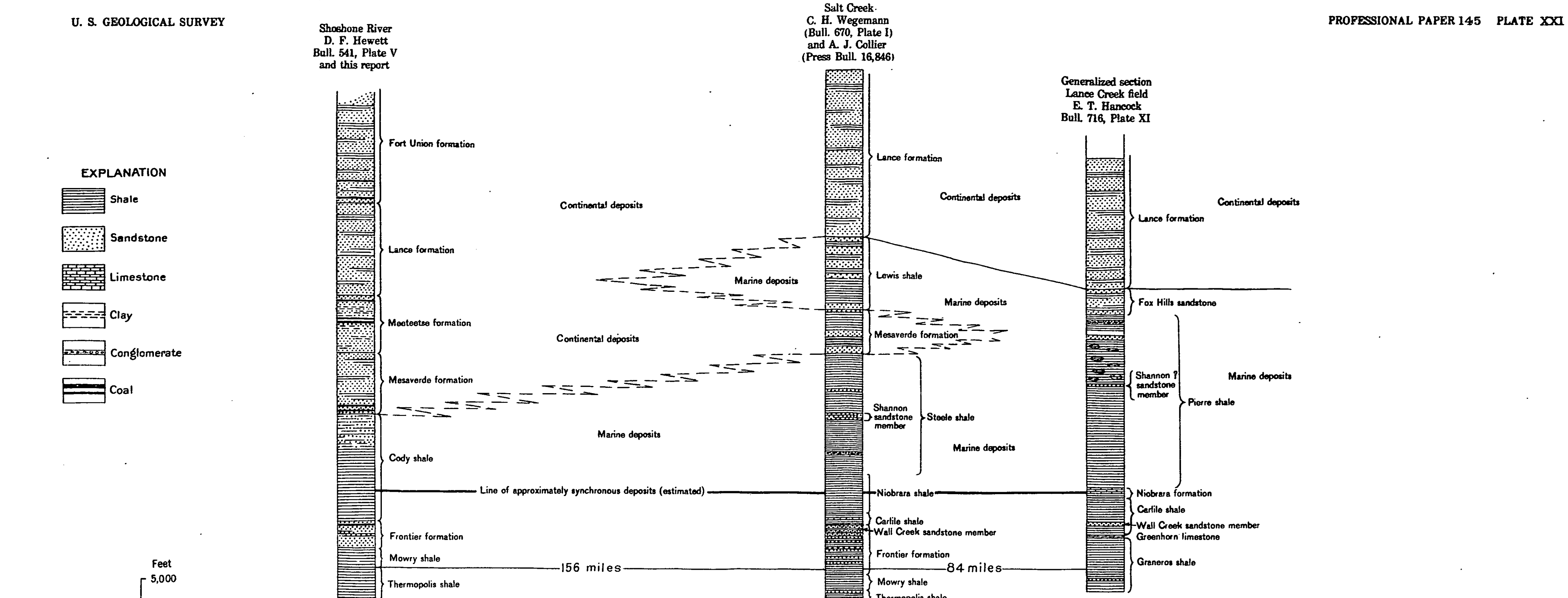
The shape and extent of the great sheet of continental deposits of which the Mesaverde and Meeteetse formations were a part suggest that one of the principal sources of the sediment which was contributed to the Upper Cretaceous sea was a group of rivers that rose in Idaho or farther west and flowed eastward, collecting sediment throughout eastern Idaho and spreading it out in a great delta or flood plain in northwestern Wyoming. Several of the principal coal beds of the Mesaverde formation are long, narrow lenses whose largest dimensions trend north, probably parallel to the average trend of the shore line of the ancient sea.

The basis for identifying the Lance formation, which makes up the next group of beds in the stratigraphic section, is afforded by the vertebrate fossils which it contains. All the material from the Big Horn Basin is fragmentary, but it appears to be sufficient to correlate the beds with those of the Lance formation near Lance Creek, in eastern Wyoming. Until recently the available information concerning the fossils present in the Lance formation and the nature and extent of the sediments, including the coal beds, justified the assumption that it was a sheet of river or flood-plain sediments spread out rather uniformly over most of Wyoming and Montana, as well as North and South Dakota, and that the underlying Bearpaw shale marked the last marine advance into the Great Plains region. In 1911, however, the discovery of the Cannonball marine member near the top of the Lance formation[44] showed that the sea again advanced over part of western North and South Dakota and possibly eastern Montana. In the Big Horn Basin the Lance formation has not yielded many of the invertebrate fossils and plants that are characteristic of it in the large area farther east and north.

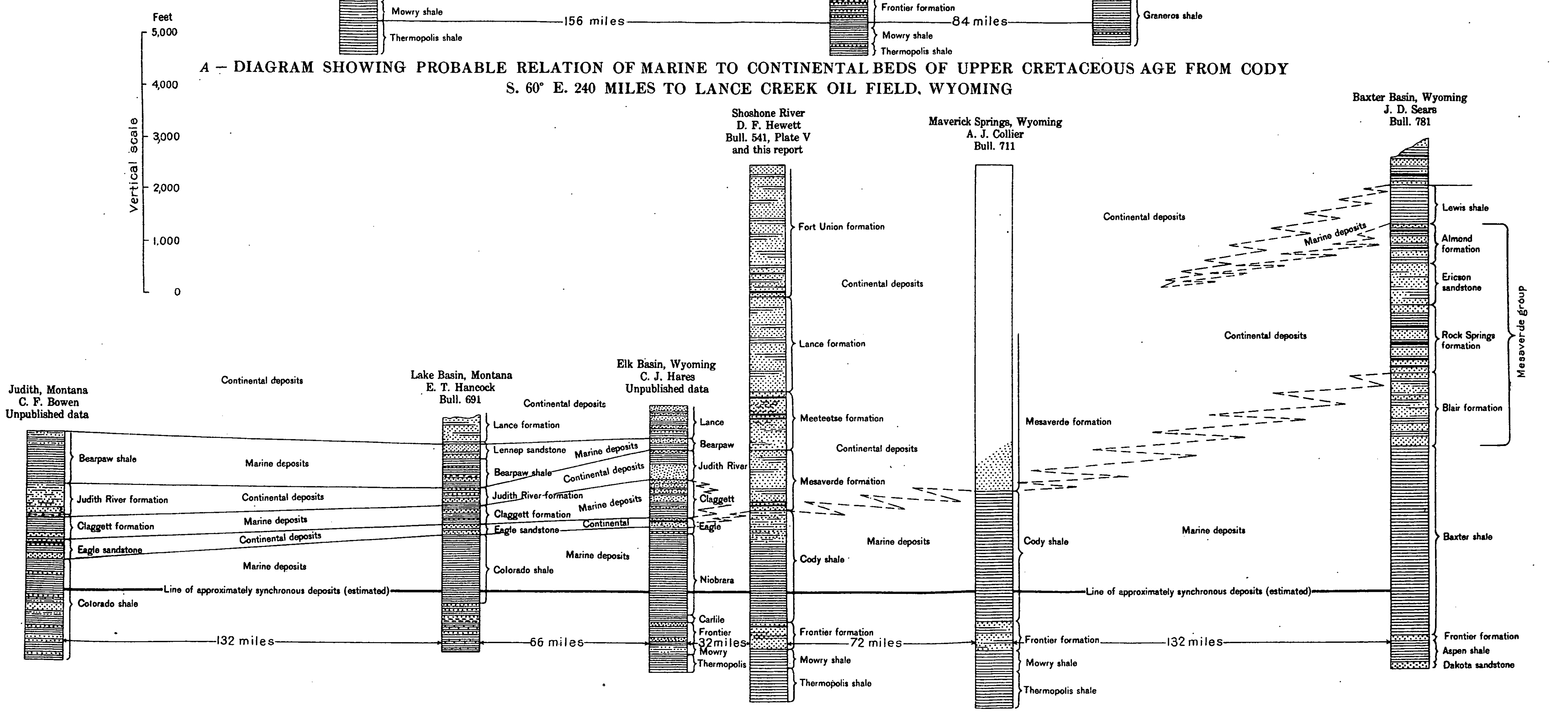
The unconformity between the Lance and Fort Union formations is not widespread, but the thickness of beds removed locally is so large that it must be recognized as an important stratigraphic and structural feature. Unconformities between beds identified as parts of the Lance and Fort Union formations are reported in several parts of Wyoming and Montana. Some mark only a slight amount of erosion, but a few mark the erosion of great thicknesses of beds. None of these surfaces of erosion appear to be traceable over a great extent of territory. The condition in these quadrangles, where the unconformity is traceable for only 5 miles out of about 75 for which the beds are in contact, appears to be characteristic. The regional significance of the unconformity is fortified by the presence in Fort Union beds of fossil wood and coal derived from the lower formations. The structural relations of the unconformity in the Big Horn Basin show clearly that the folding of the beds, which became highly pronounced after the Fort

[43] Bowen, C. F., Stratigraphy of the Hanna Basin, Wyo.: U. S. Geol. Survey Prof. Paper 108, p. 234, 1918.

[44] Lloyd, E. R., and Hares, C. J., The Cannonball marine member of the Lance formation and its bearing on the Lance-Laramie problem: Jour. Geology, vol. 23, pp. 523-547, 1915. Winchester, D. E., and others, The lignite field of northwestern South Dakota: U. S. Geol. Survey Bull. 627, pp. 22-26, 1916.



A — DIAGRAM SHOWING PROBABLE RELATION OF MARINE TO CONTINENTAL BEDS OF UPPER CRETACEOUS AGE FROM CODY S. 60° E. 240 MILES TO LANCE CREEK OIL FIELD, WYOMING



B — DIAGRAM SHOWING RELATION OF MARINE TO CONTINENTAL DEPOSITS OF UPPER CRETACEOUS AGE FROM JUDITH, MONTANA, S. 5° E. 434 MILES TO BAXTER BASIN, WYOMING

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

Union beds were laid down, was begun in this region before the lowest beds of that formation were deposited. Unfortunately the unconformity can not be used as a trustworthy basis for correlation.

The correlation of the Fort Union formation in these quadrangles with beds of similar age in Montana, eastern Wyoming, and the Dakotas is based on stratigraphic position and lithologic character, together with the fossil plants which the beds contain. None of the invertebrate fossils that are characteristic of the beds farther north and east appear to be present in this region. This raises the question, also brought up in connection with the Wasatch formation, Do not local conditions of deposition determine whether remains of plants only or of invertebrate or vertebrate animals will be buried with the beds? Fortunately, only two collections of leaves from beds below those here mapped as the Fort Union formation have been considered as belonging to it, whereas all those from the formation as mapped have been considered characteristic of it elsewhere. On the other hand, a problem is raised by the identification of several collections of leaves from the overlying Wasatch formation as belonging to the Fort Union flora. In other parts of Wyoming Fort Union plants are found associated with Wasatch vertebrates and the Wasatch formation is not known to have a distinctive flora.

The unconformity between beds of the Fort Union and Wasatch formations resembles that between the Lance and Fort Union in that although pronounced in part of the area studied it can not be detected structurally in other parts, especially in several areas nearest the center of the Big Horn Basin. In general the recognition of Wasatch beds is based upon the identification of characteristic vertebrate fossils. On this basis the beds have been identified over a large area of western Wyoming, eastern Utah, and eastern Idaho. It is interesting that until 1915,[45] when vertebrate fossils characteristic of the Wasatch formation were found in the Powder River basin, east of the Big Horn Mountains, the presence of an equivalent of the Wasatch formation in the Great Plains province was suspected only by a few. The Eocene deposits of eastern Wyoming, eastern Montana, and the Dakotas have long been included in the Fort Union formation on the basis of the fossil plants which they contain.

The relations of the Fort Union and Wasatch deposits in Wyoming and Montana have been made more clear by the careful studies of the vertebrate fossils by Sinclair and Granger,[46] who divide the Wasatch formation into five faunal zones including their "Clark Fork beds," which yield a fauna transitional from Fort Union to Wasatch fauna. They find that the second of their five Wasatch zones, their "Sand Coulee beds," occupies an area in the northwest corner of the Big Horn Basin adjacent to the area within which the "Clark Fork beds" occur, and that the successively younger faunal zones (their "Greybull beds," "Lysite formation," and "Lost Cabin formation") are best developed in localities successively southeast of that occupied by the older beds. In other words, the base of the Wasatch formation, beginning in the northwestern part of Big Horn Basin, is first the "Clark Fork beds," then the "Sand Coulee beds," then the "Greybull beds," then the "Lysite beds," and, in the southwestern part of the Big Horn Basin, the "Lost Cabin beds." This interpretation is based on the distribution of certain vertebrate fossils, and if any fossil plants are present in the beds they have not been considered.

These conclusions by Sinclair and Granger permit an interpretation of the relations of the beds mapped as the Wasatch formation in these quadrangles that is probably substantially correct, even though according to Sinclair[47] the vertebrate fossil collections from this area do not contain diagnostic species. It would appear that the beds that are mapped in these quadrangles as the Fort Union formation are part of an extensive sheet of continental deposits spread out over northern Wyoming, eastern Montana, and the Dakotas. After 3,000 to 5,000 feet of beds had been laid down along the western border of the Big Horn Basin there was uplift along the present mountain front, and the beds were greatly folded. Vigorous erosion took place in these quadrangles, and the site of deposition of the coarser sediments shifted northeastward to southern Montana and farther east, and the "Clark Fork beds" were laid down. Apparently the site of deposition of the sediments then gradually shifted southwestward again or moved headward along the streams, so that the "Sand Coulee," "Greybull," "Lysite," and "Lost Cabin beds" were laid down successively. The manner in which the successively higher beds in the Wasatch formation east of Meeteetse and along Blue Ridge overlap the underlying beds tends to confirm the broader interpretation suggested by the vertebrate fossils. It will now be apparent that even if the site of deposition of coarser sediments shifted southwestward during Wasatch time, some of the fine sediment would have been likely to move downstream and be deposited in the Great Plains region in beds that are the equivalent of the Wasatch beds of the Big Horn Basin.

According to this interpretation the "border Wasatch" in these three quadrangles is not the

[45] Wegemann, C. H., Wasatch fossils in so-called Fort Union beds of the Powder River basin, Wyo.: U. S. Geol. Survey Prof. Paper 108, p. 59, 1918.

[46] Sinclair, W. J., and Granger, Walter, Eocene and Oligocene of the Wind River and Big Horn basins: Am. Mus. Nat. Hist. Bull. 30, pp. 83-117, 1911; Notes on the Tertiary deposits of the Big Horn Basin: Am. Mus. Nat. Hist. Bull. 31, pp 57-67, 1912. Granger, Walter, On the names of the lower Eocene faunal horizons of Wyoming and New Mexico: Am. Mus. Nat. Hist. Bull. 33, pp. 201-207, 1914.

[47] Personal communications.

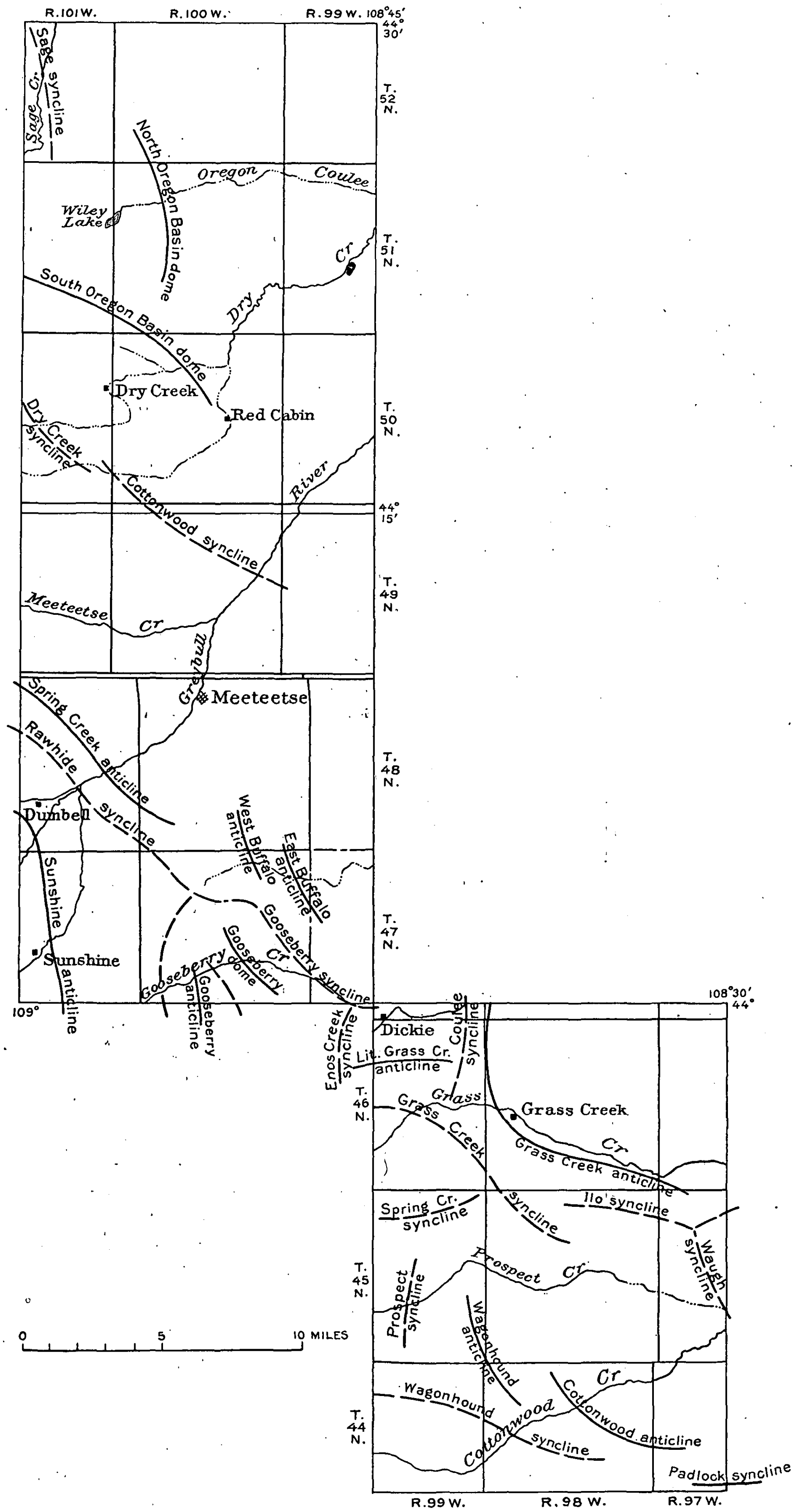


FIGURE 7.—Map showing the names and location of the anticlines in the Oregon Basin, Meeteetse, and Grass Creek Basin quadrangles

equivalent of the beds at the base of the Wasatch formation in the northern part of the Big Horn Basin but the equivalent of beds high in the section in the central part of the basin, possibly those near the top of McCulloch Peak correlated with the Bridger formation.[48]

Even though the bedded tuffs in the southwest corner of the Grass Creek Basin quadrangle rest conformably upon the underlying "border Wasatch" beds, their age would be obscure if studies in the region west of Cody had not shown critical evidence of their relations. The work of Dake,[49] supplemented by that of the writer,[50] indicates that these tuffs are the equivalent of the early acid breccia of the Yellowstone Park region,[51] of Eocene age, and yet neither the oldest nor the youngest Eocene in the area.

Except for those brief periods when the thin layers of gravel have been deposited on terraces, erosion has been steadily at work in this region since the tuffs were laid down.

STRUCTURE

Studies of the structure of bedded rocks are concerned with the attitude of the beds and the breaks or faults that have taken place since they were laid down. They determine measurements of thickness of the beds, as well as the probable positions of buried beds, and in connection with the observations on surfaces of unconformity they permit interpretations of the local movements of the earth's crust throughout geologic time.

On the basis of structure as well as that of surface forms the Big Horn Basin may be roughly separated into two parts—the central part, in which the beds on the surface are nearly horizontal, and the border belt, in which there are numerous folds. Most of the area of these three quadrangles lies in the border belt, but

[48] Hewett, D. F., The Heart Mountain overthrust: Jour. Geology, vol. 28, pp. 549–550, 1920.

[49] Dake, C. L., The Hart Mountain overthrust and associated structures in Park County, Wyo.: Jour. Geology, vol. 26, pp. 45–55, 1918.

[50] Hewett, D. F., op. cit.

[51] Hague, Arnold, U. S. Geol. Survey Geol. Atlas, Absaroka folio (No. 52), 1899.

a portion covers the flat beds of the central part. The dividing line between the two parts may be placed at the southwestern edge of the large area of Wasatch and younger beds that lie in the center of the Big Horn Basin. An examination of Figure 7 shows that there are two well-defined and nearly parallel groups of folds in the Big Horn Basin, one on either side of a central trough. The structural significance of these two belts is considered on page 68.

DEFINITIONS

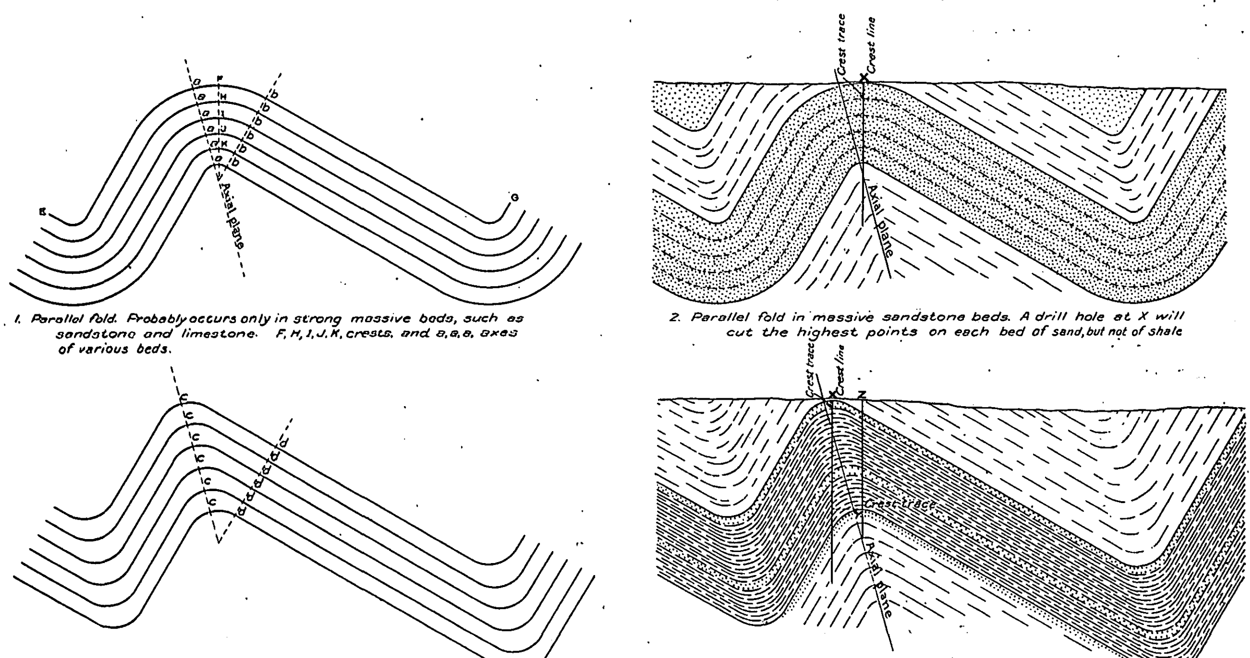
In general, the term "anticline" is applied to an upfold in bedded rocks and the related term "syncline" to a downfold. Horizontal folds that are beveled by a surface which is approximately horizontal show nearly parallel outcrops of the beds of rock. In an anticline the oldest beds—those that were originally the most deeply buried—lie in the middle and are bordered on both sides by belts of younger rocks—the oldest nearest the middle—which dip outward from the central older rocks. In a syncline the youngest rocks form the middle belt and are bordered by belts of older rocks, which dip inward toward the central younger rocks. Some anticlines and synclines show on the surface as exceptionally regular parallel belts of rock beds 50 to 100 miles long. Most folds, however, are shorter, and the outcrops of the beds that form them appear at the surface as roughly parallel elliptical belts. Where these belts are nearly circular or slightly elliptical and the rocks dip away from the center the fold is called a dome.

Parallel folds[52] are those in which the thickness of the large rock units is practically the same throughout the fold. They are probably found only among the strongest and most massive groups of beds such as thick sandstones and limestones. (See sections 1 and 2, fig. 8.)

Similar folds are those in which the beds are appreciably thicker on the crests and troughs than on the limbs. They appear to be found only among the weak and thin beds such as shale and thin sandstone. (See sections 3 and 4, fig. 8.)

The axial plane of a fold is the plane or surface that bisects the angle between the limbs.[53]

The axis is the line marking the intersection of the axial plane or surface of a fold with any particular bed.



1. Parallel fold. Probably occurs only in strong massive beds, such as sandstone and limestone. F, H, I, J, K, crests, and a, a, a, axes of various beds.

2. Parallel fold in massive sandstone beds. A drill hole at X will cut the highest points on each bed of sand, but not of shale

3. Similar fold. Thin beds of weak rocks, such as shale and thin sandstone, tend to assume this form.

4. Similar fold in shale and thin sandstone. A drill hole at X will fall to the left of the crest line of the bed at Y. In order to strike this point, the well should be drilled at Z

FIGURE 8.—Cross sections of inclined folds of two types, showing the relations of wells drilled at the crests of folds

The crest trace is that line on the surface of a folded bed which passes through the highest points of all vertical sections that cut it at right angles to its trend.

The crest line is that line on the surface of the ground which separates opposed dips.

STRUCTURE CONTOURS

Although descriptions of structure are necessary, structure contours on specially chosen beds set forth many details in the most precise manner. In the preliminary report on this region[54] a general statement

[52] Van Hise, C. R., Principles of North American pre-Cambrian geology: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 1, pp. 599-600, 1896

[53] Willis, Bailey, The mechanics of Appalachian structure: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, p. 220, 1892.

[54] Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 656, 1917.

of the significance and method of interpreting structure contours was supplemented by structure contour maps of each of the anticlines and domes. Some contours were drawn on the top of the Greybull sand of the Cloverly formation, others on the top of the Torchlight (?) sand of the Frontier formation, and still others on the most continuous coal zone near the base of the Mesaverde formation. In consideration of the use to which the structure contours might be put, it has seemed best in this report to draw them at two horizons. One set of contours are drawn on the most persistent coal zone near the base of the Mesaverde formation, where it is buried beneath the surface, and the other set on the top of the Torchlight (?) sand where the overlying coal is removed by erosion. The contours on the coal zone are based entirely on surface data, the altitude and dip of the outcrop and the thicknesses of the overlying formations as estimated from surface dips. The contours on the Torchlight (?) sand are largely based on the records of drill holes but here and there on the altitude of higher outcropping beds.

FOLDS AND FAULTS

Inasmuch as rather detailed descriptions of the features of each anticline and dome are presented in connection with the discussion of the occurrence of oil and gas, only brief statements that bear largely on regional relations will be given at this place.

The largest upfold in the three quadrangles coincides with Oregon Basin and includes two distinct domes, the north and south Oregon Basin domes. Sandstones of the Frontier formation are brought to the surface on both and, if restored, would attain altitudes of 5,450 feet on the north dome and 5,775 feet on the south dome. Although the escarpment of Mesaverde sandstone indicates a single fold that trends due north, the local outcrops of lower beds around the crests of the domes show clearly that they trend northwest and are therefore nearly parallel with others farther south. They are separated by a flexure which is related to the large fault in sec. 2, T. 50 N., R. 100 W. The north dome does not affect the surface rocks a few miles north of the quadrangles. On the other hand, the crest line of the south dome appears to be continuous westward with that of a sharp anticline that culminates on the north in Rattlesnake Mountain.

The Oregon Basin domes show more faults than any other folds in the region. All but several scattered faults may be considered in three groups, of which two are on the east limbs of the folds and the third on the southwest limb of the south dome. The first two groups limit a block of Mesaverde sandstone about 7 miles long, which has moved westward or downward relatively, about a mile beyond the adjacent outcrops north and south of the faults. The faults of the northern group trend generally southwest, and all except one minor break dip southeast. The principal movement has taken place along one crushed zone about 600 feet wide, which on Plate I has been generalized as four separate breaks. It is well marked on the surface by shear zones in the coal-bearing beds near the base of the Mesaverde. It is probably continuous with the fault that breaks the crest of the north dome.

Of the group of four faults southeast of the south dome three have small displacements, but the fourth and northernmost drops the top of the Mesaverde formation about 1,250 feet stratigraphically. It is marked by a prominent cliff cut across massive sandstones near the middle of the Mesaverde formation. The fault zone is not more than a foot thick, and the northward-facing wall contains striae and furrows that pitch 75° NW. The wall is heavily iron stained. (See Pl. VII, *A*.)

The largest fault of the group of five that lies south of the south dome is the easternmost and has a stratigraphic displacement of about 400 feet. The effect of the other four faults of this group is to drop inward toward the crest of the dome a small wedge-shaped block of Mesaverde formation.

The Oregon Basin domes are separated from the Spring Creek anticline on the south by a well-defined trough, the Cottonwood syncline. It rises out of the main trough of the Big Horn Basin on the east and disappears several miles west of the Oregon Basin quadrangle. It is not a simple fold but is made up of two troughs which are offset nearly half a mile in sec. 25, T. 50 N., R. 101 W. Several careful measurements show that the maximum thickness of the Meeteetse formation in this region, 1,240 feet, is found in the north half of T. 50 N., R. 101 W., and that of the Lance formation, 1,300 feet, is found several miles to the east, in the west half of T. 50 N., R. 100 W. Both maximum measurements lie on the northeast side of the Cottonwood syncline, whereas the thickness as measured in the southwest quarter of T. 49 N., R. 100 W., is 810 feet for the Meeteetse formation and 910 feet for the Lance formation. As there is no evidence of faulting to account for the extreme thicknesses, they are considered correct and demand the assumption that the trace of the trough on the buried Mesaverde coal zone is about a mile east of the trough line shown on the surface. This relation is shown by structure contours on Plate I.

Another unusual feature of this trough is shown in sec. 26, T. 50 N., R. 101 W. Here there is a well-defined local anticline in the general position of the trough line (Pl. XII, *A*). The anticline is about 400 feet wide, and its crest is about 50 feet above the local troughs near by. The formation of such anticlines indicates that in the folding less work was required to lift the beds over the arch than to push them outward up the sides of the trough by slipping on the bedding.

As the beds are not massive and resistant, the conclusion is drawn that the thickness of beds over the arch at the time of folding was not great, possibly less than 2,500 feet.

The Spring Creek anticline, which lies southwest of the Cottonwood syncline, begins on Iron Creek and rises gradually toward the northwest. Reconnaissance examinations by C. T. Lupton and the writer indicate that it is not a closed anticline but continues to rise as far as the mountain front, where it passes under horizontal volcanic rocks. The maximum dip along the northeast limb is 8°, although there is a persistent flexure 6 miles northeast of the crest along which the basal Fort Union beds attain a dip of 18°. The maximum dip along the southwest limb is 32° and is found in beds of the Mesaverde formation. No faults were found on either limb of this anticline.

The outcrop of the Mesaverde formation around Little Buffalo Basin indicates a single anticline, but a few outcrops of the Cody shale and the records of drill holes prove the presence of two small anticlines. The uppermost sandstone of the Frontier formation rises to an altitude of 4,750 feet on the east anticline and to 4,700 feet on the west anticline. The maximum dip on the northeast limb is 34° and is found in basal beds of the Fort Union formation; that on the southwest limb is 36° and is found in beds of the Mesaverde formation. The exposures along the Mesaverde escarpment are sufficiently good to show clearly that faults are absent.

The Rawhide syncline lies southwest of the Spring Creek anticline and the Little Buffalo anticlines. The trough descends to a low point where it crosses Greybull River, rises southeastward to the divide west of Iron Creek, and descends sharply at the head of Iron Creek, where it is occupied by a triangular block of Lance sandstones (Pl. X, *D*). From this point it rises to a low saddle that separates it from the Gooseberry syncline farther southeast. The Renner syncline enters the Meeteetse quadrangle from the south and descends sharply to meet the lowest point on the Rawhide syncline. A similar syncline descending from the south meets the Gooseberry syncline in sec. 32, T. 47 N., R. 99 W.

The beds rise westward from the Rawhide and Renner synclines to the Sunshine anticline, which is marked by uniformly steep outcrops and is the narrowest fold in the region. If the uppermost Frontier sandstone were restored over the crest, it would attain an altitude of 7,550 feet, the highest in these quadrangles. The crest of the South Sunshine anticline, which is exposed several miles south of the Meeteetse quadrangle, lies west of that of the Sunshine anticline. No faults are exposed on the Sunshine anticline, but much of the area near the crest is concealed by terrace gravel and river alluvium. West of the Sunshine anticline the beds dip toward the Sunshine syncline.[55] On account of the difference in the dip on the limbs of the anticline—22° on the east and 46° on the west—the axial plane is inclined eastward and the crest line on the restored uppermost Frontier sandstone is about 400 feet west of the crest trace on the buried Greybull sand.

Between the Renner syncline on the west and the Gooseberry syncline on the east there are two small folds—the Gooseberry anticline, which coincides with the basin near Renner's ranch, and the Gooseberry dome, farther east, which has no conspicuous surface features. The uppermost Frontier sandstone rises to an altitude of 4,100 feet on the dome and 4,300 feet on the anticline. Almost the entire area of the dome is in the Meeteetse quadrangle, but the anticline extends several miles south of the border. No faults have been observed in the rocks that mark either fold.

The Grass Creek anticline is unusual in that it has two and possibly three fairly well defined crests along a continuous arc-shaped crest line of small radius. The maximum dip on the basinward limb (32°) is found near the north end in beds of the Meeteetse formation. On the southwest limb the maximum dip (60°) is found in beds of the Fort Union formation. There is one small fault near the north end, but at the east end there is a group of faults in outcropping beds that range from the Cody shale to the Fort Union formation. These faults dip 60°–80° N., and the stratigraphic displacements range from 10 to 170 feet. They appear to be parts of a related system.

The Little Grass Creek dome is nearly circular in outline and is separated from the Grass Creek anticline by a sharp but nonpersistent syncline. The dome merges westward into a distinct local anticline.

The area between the Grass Creek anticline on the north and the Cottonwood and Wagonhound anticlines on the south includes the persistent Grass Creek syncline and the related minor Spring Creek and Prospect synclines, as well as the Ilo syncline and the related Waugh syncline. Well-defined anticlines appear to rise west of the first group, but only the Enos Creek anticline has been studied, and its exact relation to the synclines is not known. Farther south the Fort Union and older rocks are obscured by the cover of Wasatch beds and overlying tuffs. Interesting features of this part of the region are the two eastward-trending faults that limit a dropped block of Wasatch beds and volcanic tuffs. The faults converge downward and disappear on the east near the mouth of Spring Gulch. The maximum displacement of the base of the Wasatch beds along the western border of the Grass Creek Basin quadrangle is 360 feet. In age these faults are assuredly post-Bridger or middle and

[55] Woodruff, E. G., Coal fields of the southwest side of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 341, p. 213, 1909.

upper(?) Eocene and therefore much younger than all the other faults of the border belt.

The trough line of the Ilo syncline is distinctly offset from that of the Grass Creek syncline farther west and extends eastward about 3 miles beyond the edge of the Grass Creek Basin quadrangle. It is joined from the south by the Waugh syncline, which begins about 2 miles southeast of the border of the quadrangle. The Waugh anticline lies east of the Waugh syncline.

The Cottonwood anticline brings to the surface the oldest beds that crop out in these quadrangles, those of the Thermopolis shale. If the uppermost Frontier sandstone were restored over the crest it would attain an altitude of 6,450 feet. The maximum dip on the basinward limb is 15° and is found in beds of the Mesaverde formation; the maximum on the mountainward limb is 75° and is found in beds of the Frontier formation. The difference in the dip of the limbs is the largest encountered in these quadrangles. From cross sections it would appear that the crest line as shown on the surface in beds of Thermopolis shale is 700 feet southwest of the crest trace on the Cloverly formation and about 1,500 feet southwest of that on the top of the Embar formation.

Two groups of faults are mapped on the Cottonwood anticline. Two faults in sec. 20, T. 44 N., R. 97 W., lie at right angles to the trend of the crest and have a stratigraphic displacement of about 150 feet. The faults of the other group are disposed radially around the west end of the anticline, and their displacement ranges from 16 to 160 feet. For more than a mile in secs. 23 and 24, T. 44 N., R. 98 W., the steeper southwest limb of the anticline is broken by many small faults that trend north to N. 10° E. and have a displacement of 10 to 25 feet. The beds trend nearly west, but as each successively western block is thrown north 10 to 25 feet, the average strike of the beds ranges from N. 80° W. to N. 60° W. None of the faults are shown on Plate III.

The Wagonhound anticline appears to be simple in form, and its central portion is unfaulted. As it is indicated by only a few outcrops of the Cody shale, and as most of the area eastward to the crest of the Cottonwood anticline is covered by terrace gravel, its relation to that fold is only conjectured. The drill holes on the crest indicate that the uppermost Frontier sandstone attains an altitude of 5,100 feet. The outcrop of basal Mesaverde sandstones shows three faults, of which the largest has a stratigraphic displacement of 210 feet.

The Wagonhound syncline, which lies southwest of the Wagonhound and Cottonwood anticlines, pitches west under the cover of Wasatch beds and volcanic tuffs. From it the beds rise gradually to the Embar anticline, south of the border of the Grass Creek Basin quadrangle. The Padlock syncline is offset north from the eastward continuation of the crest line of the Wagonhound syncline and continues only a few miles east of the southeast corner of the quadrangle.

MINOR FLEXURES

Throughout most of the area of these quadrangles the beds are so folded that the outcrops and structure contours on the beds follow broad, gentle curves, unbroken by abrupt changes in direction. Here and there, however, in at least three localities, the most massive and resistant beds are so flexed on the limbs of major anticlines that the strike of the beds changes abruptly. In sec. 25, T. 52 N., R. 101 W., and sec. 8, T. 47 N., R. 101 W., the massive basal sandstones of the Mesaverde formation are so sharply flexed that the radius of curvature of the outer limiting surface is from 500 to 800 feet. A similar flexure is found in the same beds in sec. 35, T. 48 N., R. 101 W. Such flexures show that the most massive beds locally accommodate themselves to the stresses of folding by slipping between the beds, rather than by internal deformation. It may be a coincidence, but it is worthy of note that there are no thick coal beds near these flexures. It is possible that the coal beds were made thinner by the slipping of overlying beds of massive sandstone upon those which underlay the coal.

THICKENING AND THINNING OF FORMATIONS

In the descriptions of the formations the range in thickness in each quadrangle has been stated. At this place will be set forth the extent to which some of the variations in thickness may be attributed to flow of material during folding, rather than to original differences in the thickness of sediments laid down.

The measurements of thickness of every formation exposed in these quadrangles show an appreciable range. The range is least for the Mesaverde formation and the combined Frontier, Mowry, and Thermopolis formations, and greatest for the Cody shale and Lance formation. The maximum measurement of aggregate thickness of the Frontier, Mowry, and Thermopolis, 1,520 feet on Shoshone River, is 20 per cent more than the minimum, 1,262 feet in State Land well No. 1 in Grass Creek Basin. A still smaller measurement of 1,174 feet was made by Woodruff along Big Horn River at Thermopolis. The data are not as abundant as might be wished, but indicate that the original thickness of the three formations decreased steadily toward the south and southeast. The maximum thickness of the Mesaverde formation, 1,450 feet in sec. 35, T. 46 N., R. 98 W., Grass Creek Basin, is 30 per cent more than the most reliable minimum measurement, 1,050 feet in sec. 24, T. 45 N., R. 99 W., south of Prospect Creek. The range in thickness for the Meeteetse formation is from 750 feet in sec. 13, T. 45 N., R. 99 W., on Prospect Creek, to 1,240 feet in sec. 11, T. 50 N., R. 101 W., along upper Dry Creek.

On the other hand, the maximum measurement of the Lance formation, 1,360 feet along the northeast limb of the Cottonwood syncline, is 97 per cent larger than the minimum, 695 feet in sec. 11, T. 45 N., R. 98 W., north of Prospect Creek. Conclusions drawn from variations in the thickness of the Lance formation should take into consideration the existence of a local unconformity east of Oregon Basin and the possibility that others are present under the conglomerate at the base of the Fort Union formation.

The maximum and minimum thicknesses of each of the formations discussed above are not found close together. For the Mesaverde formation the extremes were measured on the steep limb and flat limb of the same fold at points that were 8 miles apart. The extreme measurements of the other formations were much more remote. An examination of the conditions under which the measurements of these formations were made indicates that a large part of the difference between maximum and minimum measurements is due to tendencies toward thickening or thinning in certain regional directions, to errors in the choice of a limiting bed, and in less degree to errors in measurement, rather than to local migrations of material during folding. Thus it appears that the thickness of the combined Frontier, Mowry, and Thermopolis formations and of the Meeteetse formation decreases steadily southward and southeastward from Shoshone River toward Big Horn River. The variations in the measurements of the Mesaverde formation appear to be largely due to local errors in the choice of limiting beds, rather than to any regional cause, for most of the measurements throughout the three quadrangles do not deviate more than 100 feet from 1,250 feet.

The measurements of the Cody shale show a wide range that appears to demand other explanations. As it is the thickest formation below the Fort Union and as the exposures between limiting outcrops of Frontier and Mesaverde sandstones are generally poor, there are probably some appreciable errors in most of the measurements. After allowance has been made for probable errors, however, there remain some differences between measurements at points near together that can be explained only by assuming that the formation has been made much thicker on one limb of a fold than on the other during the process of folding. On the limbs of all the anticlines except three the measurements do not depart more than 200 feet from 2,300 feet. This is true of the Shoshone anticline, the Oregon Basin domes, the Spring Creek anticline, the Little Buffalo anticlines, the Gooseberry dome and anticline, and the Wagonhound anticline. This group of folds characteristically shows generally lower dips on the limbs and less difference between the maximum dips on opposed limbs than the remaining folds. On the other hand, the measurements on the Sunshine anticline range from 2,500 feet on the flat eastern limb to 3,400 feet on the steep western limb, 2 miles distant; on the Grass Creek anticline they range from 2,450 feet on the flat northeastern limb to 1,800 feet on the steep southwestern limb, 2 miles distant; and on the Cottonwood anticline they range from 2,400 (?) feet on the flat northern limb to 1,900 feet on the steep southern limb, 4 miles distant. The great differences in thickness shown by these pairs of measurements, made only a few miles apart, must have arisen during folding and indicate thickening on one limb or thinning on the other, or possibly both. Curiously, the differences on the three folds are not consistent. In the Grass Creek and Cottonwood anticlines the flat basinward component of the fold is thicker than the steep mountainward component, but in the Sunshine anticline these conditions are reversed. If the Sunshine fold were like the other two, the conclusion would be justified that under the local conditions of folding, soft rocks such as shale are forced from the steep limbs of anticlines downward to adjacent synclines or upward to adjacent anticlines. Unfortunately the evidence indicates that the causes of localization of flowage are complex. The data leave no doubt, however, that flowage has taken place.

AGE RELATIONS OF FAULTS AND FOLDS

The faults may be classified into three groups on the basis of their areal relation or lack of relation to anticlinal crests, or into two groups on the basis of their age. The first three groups are as follows:

1. One group of faults trend roughly at right angles to the anticlinal crest lines and generally crop out in beds of the Mesaverde formation. They are best shown by the two sets of faults on the east side of Oregon Basin. These faults limit a large segment along the limb of an anticline which appears to have been pushed inward with respect to near-by segments. One fault appears to extend across the crest of the north Oregon Basin dome. The age of this group of faults is fixed by the areal relations of the beds in the northeast quarter of T. 50 N., R. 100 W., where the largest fault of the group, as well as of the entire region, offsets the Fort Union formation but does not offset the overlying Wasatch beds. These faults were clearly formed during or soon after the folding. Two similar faults lie along the east end of the Cottonwood anticline.

2. A second group of faults radiate outward from the crests of anticlines. They are found near Elk Butte and along the southwest border of Oregon Basin, around Grass Creek Basin, and around the Wagonhound and Cottonwood anticlines. The dis-

placement along these faults rarely exceeds 150 feet. They appear to represent the minor adjustments in the more resistant rocks produced by local flowage of the weaker rocks, such as shale, during or shortly after the folding. There is no field evidence by which the age of this group of faults may be definitely fixed, although their relations and distribution indicate that they are of the same age as the first group.

3. The third group of faults appear to have no areal or genetic relation to the folding of the region and are much later in age than the first two groups. This group includes the two faults near the head of Spring Gulch, in the north half of T. 45 N., R. 99 W., which limit a long, narrow wedge of Wasatch beds and overlying volcanic tuffs. The relations show clearly that they are much younger than the first group and probably than the second group.

In view of the number of faults around Oregon Basin, Grass Creek Basin, the Wagonhound anticline, and the Cottonwood anticline, it is surprising to find no faults around Spring Creek Basin and Little Buffalo Basin.

The interpretation of the age of the folding should consider evidence of several kinds—character of the sediments, age and extent of unconformities, regional relations and degree of folding, and areal relations of faults. Unless it is stated otherwise, the following discussion applies only to the formations of the Big Horn Basin. Some of the formations, such as the Fort Union, are represented in large areas north and east of the Big Horn Basin, but the precise correlation of the beds that make them up involves elements of speculation that are not raised at this place.

The only conspicuous changes in the character of the sediments that bear upon folding are those which are noticed in passing from the Lance to the Fort Union formation and from the Fort Union to the Wasatch. Even though the unconformity at the base of the Fort Union is not widespread, the base is widely marked by one or more zones of gravel or conglomerate that undoubtedly indicate elevation of the region farther southwest. These gravel zones contain numerous partly rounded pebbles of the fossil wood that is common in the Meeteetse formation and a few pebbles of coal from the same formation. There can be no doubt that beds of the Meeteetse formation were uplifted and probably folded a short distance southwest of these quadrangles, while the basal beds of the Fort Union were being laid down within them. This statement also holds for the southeastern part of the Grass Creek Basin quadrangle, where no unconformity is noticeable at the base of the Fort Union. It looks as if there were widespread uplift and probably folding along the present site of the Absaroka Range when there was only local folding in the border belt of the Big Horn Basin. Where the unconformity at the base of the Fort Union is best shown these beds dip 9° E. and the underlying Lance beds dip 22° E. The relations indicate that the Lance beds dipped about 13° before the Fort Union beds were laid down.

A great thickness of the Fort Union formation is involved in the folds of the border belt, and most of the folding was accomplished before the basal Wasatch beds were laid down farther northeast. The coarse material near the base of the Wasatch, as well as above it, is largely that which was laid down in the basal Fort Union beds, although some new material is present. Zones of such coarse material dip as much as 16° toward the Big Horn Basin east of Oregon Basin and 10° northeast of Grass Creek, showing that along the basinward limbs of basinward anticlines folding continued while Fort Union beds were being eroded a short distance to the southwest. The base of the Wasatch formation is most highly unconformable on underlying beds in the same region that the base of the Fort Union is unconformable on older beds, showing that the local uplift in the region of Oregon Basin before the basal Fort Union beds were laid down continued into Wasatch time or was renewed after the basal Wasatch beds were laid down.

From the regional studies of the fauna by Sinclair and Granger, as well as from local exposures, especially northeast of Meeteetse, it seems clear that the beds at the base of the Wasatch in the border belt are younger than the basal beds of the central and northern parts of the Big Horn Basin. The local areal relations of the "border Wasatch," 125 to 250 feet thick, indicate that it is the equivalent of beds high in the Eocene section in the center of the Big Horn Basin, probably the "Tatman Mountain beds," which are regarded by Sinclair and Granger as of later Eocene (possibly Bridger) age. It is necessary to conclude, therefore, that folding along the axes of the folds of the border belt ceased between the deposition of the basal Wasatch and that of the uppermost Wasatch beds.

These observations lead to the conclusion that some of the basinward anticlines of the border belt were formed appreciably later than those nearer the mountains and probably also later than those large anticlines which coincide with the mountains, such as the Bridger and Owl Creek mountains. The unconformity at the base of the Fort Union east of Oregon Basin, however, leaves no doubt that the folding of the two domes that underlie it was begun early in Eocene time and continued until late Eocene time. It then appears that although there may have been a tendency toward progressive development of folds from the principal anticlines that outline the Big Horn Basin inward toward the center of the depression, there also were local exceptions to this rule.

The present form of the surface of low relief upon which the "border Wasatch" was laid down, considered with the character of the sediments spread upon it, indicates that an area between Wood River and Owl Creek was warped upward with reference to the surrounding region to a maximum of about 1,200 feet after the andesitic tuffs of that region were deposited, probably in middle Eocene time. The faults at the head of Little Prospect Creek accompanied or were later than this warping but were clearly much later than the early faults near the crests of anticlines.

These quadrangles contain no evidence of the Heart Mountain overthrust [56] recognized by Dake after the writer's areal work in the quadrangles was completed. The relations of this extraordinary structural feature to the folding, faulting, and sedimentation of the Big Horn Basin were clarified by the recognition on McCulloch Peak of remnants of the thrust block resting on beds forming the top of the Wasatch formation in the Big Horn Basin. The thrust fault appears to have been the culmination of the long series of Tertiary deformation of the west side of the basin. There is no evidence to show whether it preceded or followed the warping and normal faulting along Little Prospect Creek; it is assumed to have preceded these events.

[56] Dake, C. L., The Hart Mountain overthrust: Jour. Geology, vol. 25, pp. 44-55, 1918.

CORRELATION

The following table sets forth the succession of structural events and deposition of sediments in the two belts partly covered by these quadrangles, as well as the mountainous belt lying farther west.

Preliminary correlation of Tertiary deformation and sedimentation in Big Horn Basin

Geologic age		Absaroka-Owl Creek mountain front		Big Horn Basin			
				Border belt		Central part	
		Deposition or erosion	Deformation	Deposition or erosion	Deformation	Deposition or erosion	Deformation
Miocene.	Upper.	Early basic breccias (widespread).		Basic tuff (?) (local).		(?)	
	Lower.	Erosion.		Erosion (?).		Erosion (?).	
Oligocene.		Erosion.		Erosion.		Erosion (?).	
Eocene.	Upper.	Erosion.	Uplift (?). Normal faults (local).	Erosion.	Uplift. Normal faults (local).	Erosion (?).	(?)
		–Unconformity (?) —	–Heart Mountain–overthrust.	–Unconformity (?) —	–Heart Mountain–overthrust.	–(?) —	–Heart Mountain–overthrust.
	Middle.	Early acid breccia (local).		Andesitic tuffs (local).		Andesitic tuffs (?) (local).	
		–Conformity —		–Conformity —		–(?) —	
	Lower.	"Border Wasatch" (local). Erosion.		"Border Wasatch" (local). Erosion.		"Tatman Mountain beds." [a] "Lost Cabin beds." "Lysite beds." "Gray Bull beds." "Sand Coulee beds."	Local depression.
		–Unconformity —		–Unconformity —		–Unconformity (?) — "Clark Fork beds." [b]	
	Basal Eocene ("Paleocene").		Extensive normal faults, large folds, widespread uplift.		Local normal faults, small folds, local uplift.		Depression.
		Fort Union (?).	Sinking (?).	Fort Union formation.	Widespread sinking.	Fort Union formation.	Widespread sinking.
		–Local unconformity–	Local warping.	–Local unconformity–	Local warping.	–(?) —	(?)
Tertiary (?) [c]		Lance formation (?).	Sinking (?).	Lance formation.	Sinking.	Lance formation.	Sinking.

[a] Possibly younger than lower Eocene.
[b] Younger than Fort Union and included with overlying zones in the Wasatch.
[c] The Lance formation is here classified as Tertiary (?) to conform with the usage of the U. S. Geological Survey, although the local evidence indicates conformability with the underlying Cretaceous beds.

OIL AND GAS

NORTH AND SOUTH OREGON BASIN DOMES

Surface features.—Oregon Basin is the largest depression on the west side of the Big Horn Basin, being about 6 miles wide and 11 miles long. It is unlike most of the other basins in that it is less regular in outline and presents many diverse surface forms. It is limited by impressive escarpments of Mesaverde sandstones on the north and south, but these are locally absent on the east and west sides. The floor of the basin, especially the southern part, contains numerous ridges, some of which are flat topped and covered with gravel. The crest of the South dome almost coincides with the position of Elk Butte, a high flat-topped hill which is a remnant of the Rim terrace. On the other hand, the North dome coincides closely with a nearly flat featureless area, of which a part is depressed about 100 feet below the surrounding ridges, so that it has no outlet.

All the streams of the basin are intermittent, and their pattern is very irregular. None of the water is fit for domestic use. Water supplies at the few permanent settlements are derived from wells, cisterns, and the unused parts of coal mines. Recently water from one of the wells on the north dome has been used largely in one camp.

The basin may be entered by roads from the east, south, and west, and they are more numerous than the topographic map shows. Although a small area near the Wiley ranch is cultivated by the use of water drawn from the North Fork of Shoshone River, the basin presents in general a desolate picture. Herds of sheep graze over the surface during the fall, but the number of permanent residents rarely exceeds 5.

Stratigraphy.—The lowest beds exposed at the surface on the north and south domes include those from 100 to 120 feet below the top of the Frontier formation. The Cody shale underlies a large area in the basin, but good exposures are widely scattered. The most reliable estimate of its thickness is that of 2,300 feet, made southwest of Elk Butte. The Mesaverde formation forms the escarpment that encircles the basin.

Of the eight wells that have been drilled in the basin, five yield sections as deep as the Cloverly formation, and one, the Pauline, penetrated 490 feet of the Morrison formation.

Structure.—The structure of these domes is represented on Plate I, by structure contours based on the data from outcrops and wells. The contours on the uppermost sandstone of the Frontier formation are probably nearly correct for areas several square miles in extent near the crests of the domes but are more speculative for the outer zone.

The position and displacement of most of the faults in the Frontier and Mesaverde sandstones were determined from direct observations. Of the two faults near the crest of the South dome, the western one has a displacement of about 25 feet, with the north side relatively raised, and the eastern one has a displacement of 12 feet, with the west side raised. On the other hand, the position assigned to the fault that crosses the north dome is approximate only, and the displacement was inferred from the structure contours.

Many faults exist in the massive Mesaverde sandstones that form the escarpment. From such study as it has been possible to give to these faults, it seems highly improbable that even the one with the greatest displacement, 1,250 feet, persists downward far enough to break the Frontier sandstones along the direct extension of its plane. It would appear rather that the Frontier sandstones are broken and slightly offset at several places and that the structure contours should indicate a sharp flexure.

Although the region east of the Oregon Basin quadrangle has not been studied in detail, there is basis for believing that the Cretaceous beds rise continuously, without reversal of dip, from the middle trough of the Big Horn Basin. The maximum dip of 50° along the east flank occurs in beds of the Meeteetse formation. On the west side of the south dome the maximum dip of 34° occurs in the Mesaverde sandstones as they descend toward the Cottonwood and Dry Creek synclines. The available observations of dip indicate that the south dome merges westward into a distinct anticline. West of the north dome the beds dip abruptly to the Sage Creek syncline.

Exploration.—The south dome was the first to be explored. A shallow well (No. 1, Pl. I) was drilled in SW. ¼ sec. 4, T. 50 N., R. 100 W. early in 1912 but the first deep exploration was the McMahan well (No. 2, Pl. I) sunk during July and August, 1912. The first deep well to be drilled on the north dome was the Pauline well (No. 3, Pl. I). To date three deep wells have been sunk on each of the domes, in addition to several shallow wells. Summaries of the logs of nine of the wells are presented herewith.

Summary of wells on south Oregon Basin dome

No. 2. McMahan well, NW. ¼ SW. ¼ sec. 32, T. 51 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co., July 15 to August 24, 1912]

	Thickness	Depth
	Feet	*Feet*
Soil and wash	60	60
Frontier formation:		
Shale	221	281
Sand	39	320
Shale	50	370
Sand	10	380
Mowry and Thermopolis shales:		
Shale and sandy shale	105	485
Bentonite	20	505
Shale	41	546
Sand; water	39	585
Shale	20	605
Sand; water	40	645
Lime, gray	10	655
Sand, dark; water	4	659
Shale, dark	336	995
Lime, broken	10	1,005
Sand and lime	4	1,009
Sand; gas (Muddy sand?)	6	1,015
Shale	215	1,230
Sand	2	1,232
Sand and shale, broken	43	1,275
Cloverly formation: Sand; gas	46	1,321

No. 8. Hallene well,[a] SW. ¼ SW. ¼ sec. 29, T. 51 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co., October 6, 1913, to April 25, 1914]

	Thickness	Depth
Frontier formation:	*Feet*	*Feet*
Clay	12	12
Sand	8	20
Shale, dark	65	85
Sand	55	90
Shale, dark	55	145
Sand	5	150
Shale, light and dark	90	240
Sand, broken	15	255
Shale, light	15	270
Sand, coarse	15	285
Shale, light	5	290
Sand, fine and coarse; oil colors	15	305
Shale, light	25	330
Sand, coarse	20	350
Shale, light and black	20	370
Limestone; water	10	380
Sand, dark, coarse	20	400
Sand and shale	15	415
Sand	5	420
Mowry and Thermopolis shales:		
Shale, light, dark, and black	170	590
Sand, coarse	10	600
Shale, black	20	670
Sand, black	10	680
Bentonite	5	685
Shale, dark	40	725
Bentonite	10	735
Shale, dark	15	750
Sand	10	760
Shale, light and black	370	1,130
Sand, shale (Muddy sand?)	7	1,137
Shale, black	223	1,360
Cloverly formation:		
Mixed shale and sand; gas	65	1,425
Sand	30	1,455
Morrison formation:		
Mud, red	78	1,533
Sand shell	2	1,535
Shale, red	25	1,560
Lime shell and shale; water	60	1,620

[a] Ziegler, Victor, The Oregon Basin oil and gas field, Park County, Wyo.: Wyoming Geologist's Office Bull. 15, p. 237, 1917.

Summary of wells on south Oregon Basin dome—Contd.

No. 4. SE. ¼ SW. ¼ sec. 32, T. 51 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co. to depth of 688 feet; passed through Frontier formation and entered Mowry shale]

No. 7. Jack well, SE. ¼ NW. ¼ sec. 30, T. 51 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co., July 20 to October 7, 1914, to depth of 1,826 feet. A bed of sand 66 feet deep at the bottom is probably the Cloverly formation. Water was struck at several horizons but no oil or gas]

No. 6. NE. ¼ SE. ¼ sec. 20, T. 57 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co. to a depth of 669 feet. A bed of sand 20 feet thick at this depth is probably that at the top of the Frontier formation]

Summary of wells on north Oregon Basin dome

No. 3. Pauline well, NE. ¼ SE. ¼ sec. 5, T. 51 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co., October, 1912, to January, 1913]

	Thickness	Depth
	Feet	*Feet*
Soil	49	49
Shale, black and sandy	121	170
Frontier formation:		
Sand	5	175
Shale, light	65	240
Sand; some oil and gas	20	260
Shale, brown and sandy	120	380
Sand	20	400
Shale, sandy	20	420
Sand; gas	27	447
Shale, with lime and sand	51	498
Sand; gas at 510 feet, show of oil at 530 feet	42	540
Slate	13	553
Sand	27	580
Shale with sand	18	598
Sand	13	611
Mowry shale:		
Bentonite	4	615
Shale, black and brown	80	695
Sand, black; water	10	705
Shale, black and light	10	715
Sand	27	742
Shale	16	758
Sand, dark	10	768
Shale	36	804
Sand, black	5	809
Shale, hard, brown	77	886
Sand	5	891
Thermopolis shale:		
Shale	439	1,330
Sand (Muddy sand?)	44	1,374
Shale	151	1,525
Cloverly formation:		
Sand; water, show of oil	145	1,670
Morrison formation:		
Lime, red	40	1,710
Sand; water, show of oil and gas	76	1,786
Shale, green, with sand	4	1,790
Rock, red	40	1,830
Sand, broken	17	1,847
Rock, red	53	1,900
Shale	15	1,915
Sand	7	1,922
Shale	70	1,992
Sand	6	1,998
Shale, gray; water	162	2,160

No. 5. NW. ¼ SW. ¼ sec. 5, T. 51 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co. in 1913 to depth of 415 feet. The bottom of the well is on beds of the Frontier formation. The well is now capped, but when opened it yields a large flow of wet gas]

Summary of wells on north Oregon Basin dome—Continued

No. 9 (new No. 5), SE. ¼ NW. ¼ sec. 5, T. 51 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co., June 14 to December 3, 1916]

	Thickness	Depth
	Feet	*Feet*
Frontier formation:		
Sandstone and dark shale	50	50
Sand, greenish	20	70
Shale, sandy	45	115
Sand, water	10	125
Shale, sandy	38	163
Sand, white; show of oil and gas	22	185
Sand, muddy	23	258
Shale, dark	29	237
Sand, gray; water	24	261
Shale, dark	16	277
Sand, water	8	285
Bentonite	3	288
Gravelly formation, green	2	290
Sand, show of gas	5	295
Shale, dark, sandy; water	75	370
Sand, dark; oil and gas	4	374
Mowry and Thermopolis shales:		
Shale, light and dark	41	415
Sand and hard lime	4	419
Shale and bentonite	14	433
Sand and hard lime	3	436
Shale, sandy, and dark lime	146	582
Bentonite	3	585
Shale, sandy	36	621
Sand, hard, black	9	630
Shale and lime; show of oil	147	777
Sand, black	20	797
Shale, dark	110	907
Sand, muddy	10	917
Shale, dark	122	1, 039
Sand, shale, and shale sand	47	1, 086
Shale, blue (Muddy sand); show of gas	164	1, 250
Cloverly formation:		
Sand, broken, white	40	1, 290
Sand; much gas at 1,300–1,335 feet	50	1, 340
Morrison formation:		
Shale, red, sandy	17	1, 357
Sand, hard, black; show of oil and gas	4	1, 361
Shale, red, gray, and white	117	1, 478
Sand, hard, red	2	1, 480
Shale and lime, hard, red, sandy	39	1, 519
Sand, white and purple	21	1, 540

No. 10. NW. ¼ sec. 32, T. 52 N., R. 100 W.

[Drilled by Enalpac Oil & Gas Co. Record not available. Reported to have been drilled to a depth of 1,600 feet, or to the Cloverly formation. Water with considerable sodium carbonate but fit for domestic use now flows from the top of the casing at the rate of 15 gallons a minute. Gas and drops of yellow oil rise to the surface of the water.]

Occurrence of oil and gas.—Although traces of oil and gas have been found in several sands of the Frontier formation and Mowry shale near the crests of both domes, the most productive formation is the Cloverly. One well on the north dome and two on the south dome have yielded gas under pressure estimated at 500 to 800 pounds to the square inch. Considerable gas was encountered in the Muddy sand in the No. 9 (new No. 5) and McMahan wells, and small quantities in the Morrison formation. The areas on these domes that may yield oil or gas have not been definitely established, but it appears that the areas within which the Cloverly formation may yield gas have been indicated approximately. Although the absence of commercial quantities of oil in the Cretaceous beds is not yet proved, the areas that may yield oil from that source are insignificant. There seems to be on the south dome a nearly circular area a mile in diameter within which gas will be found under fair pressure, even though the McMahan well is reported to have discharged for more than a year uncontrolled. This area appears to be outlined by the 5,600-foot contour on Frontier sandstone.

The north dome is broken by a northeast fault having a displacement of about 300 feet, which seems to separate an area north of it that contains gas from an area south of it that appears to be barren. A small amount of oil may be present on the dome, but at present it would appear to be negligible. The area within which gas may be found on this dome is probably rudely semicircular and about a mile in diameter.

The deeper formations that may contain oil or gas on these domes include the Morrison, Chugwater, and Embar. The sands in the Chugwater and Embar that are productive on the Cottonwood anticline lie approximately 1,200 and 2,000 feet below the top of the Cloverly formation. Until further exploration to these deep sands on the Oregon Basin domes indicates that factors controlling the distribution of oil and gas are unfavorable to the occurrence of these substances in the sands on these domes they must be regarded as possible sources of production.

EAST BUFFALO AND WEST BUFFALO ANTICLINES

Surface features.—The crests of the East Buffalo and West Buffalo anticlines coincide with one of the most impressive surface basins on the west side of the Big Horn Basin. Little Buffalo Basin is an elliptical flat area, 4 miles wide and 7 miles long, almost encircled by a rugged escarpment 400 to 700 feet high. Only a few trails cross the escarpment, and the only means of access by wagons or automobiles are roads that enter by the deep notches cut by Little Buffalo Creek at the west and east sides of the basin. The basin is mostly flat and smooth, but a few flat-topped ridges, probably corresponding to the Sunshine terrace, rise about 100 feet above the general level. Little Buffalo Creek and its tributary ravines are sunk 25 to 50 feet below this level.

Although parts of Little Buffalo Creek carry a small flow of alkaline water most of the year, water for domestic uses must be brought from Gooseberry Creek or Greybull River. The basin is devoid of all vegetation except sagebrush and a sparse growth of grass, which serves as pasturage for a few herds of sheep during the fall.

Stratigraphy.—The beds exposed at the surface in Little Buffalo Basin include the massive sandstones near the base of the Mesaverde formation and the upper 1,200 feet of the Cody shale. The exposures in the central part of the basin, however, are uncommonly poor, and thus it is difficult to construct a structure contour map of this area. The upper 600 feet of the Cody shale appears in a number of outcrops in the eastern half of the basin. Estimates of the thickness of the Cody shale indicate that it is approximately 2,550 feet.

Structure.—The meager exposures of thin beds of sandstone in the shale near the center of the basin, supplemented by the data from wells, constitute the basis for the structure contours drawn on the top of the Frontier formation. Although these contours probably represent the general form of the anticlines, further exploration may show local departures from this form. The dip of the Mesaverde beds ranges from 12° to 18° along the northeast flank of the folds, where they rise out of the trough of the Big Horn Basin. The surface outcrops indicate two anticlines, of which the eastern is the longer, separated by a low syncline. The beds on the southwest flank of the East Buffalo anticline dip toward the Gooseberry syncline, whereas those on the southwest flank of the West Buffalo anticline dip toward the eastern extension of the Rawhide syncline.

The anticlines are particularly interesting on account of their relation to the middle trough of the Big Horn Basin and the apparent absence of faulting around the Mesaverde escarpment and near the crest.

Exploration.—Prior to October, 1919, eight wells had been drilled on these anticlines but the records of only five are available. A summary of the record of drilling as well as the available logs is given below:

Summary of wells on East Buffalo and West Buffalo anticlines

No. 1. SW. ¼ SW. ¼ sec. 35, T. 48 N., R. 100 W.

[Drilled by Midwest Refining Co., August and September, 1914. In lowest sand, at 1,655 to 1,702 feet, encountered considerable gas, which has since been capped and used locally for drilling other wells. Log reported by Hintze]

	Thickness	Depth
	Feet	*Feet*
Surface wash: Clay, red	30	30
Cody shale:		
Shale, blue	473	503
Sand, green	6	509
Shale, blue	5	514
Sand, dry	6	520
Shale, sandy	350	870
Shale, blue	306	1, 176
Shales	24	1, 200
Shale, blue	152	1, 382
Frontier formation:		
Sand; water at 1,412 feet	62	1, 444
Shale, brown	15	1, 459
Sand	20	1, 479
Shale, white	67	1, 546
Sand	10	1, 556
Shale, brown	44	1, 600
Sand	36	1, 636
Shale, brown	19	1, 655
Sand; gas at 1,702 feet	47	1, 702

Summary of wells on East Buffalo and West Buffalo anticlines—Continued

No. 2. SW. ¼ SW. ¼ sec. 36, T. 48 N., R. 100 W.

[Drilled by W. L. Valentine, July to September, 1914. It is reported that the Ohio Oil Co. now controls the tract on which the well is located. The owners withhold publication of the well log, but it is reported that considerable gas was encountered in sands near the base of the Frontier formation at depths ranging from 1,576 to 1,681 feet]

No. 3. SE. ¼ NW. ¼ sec. 2, T. 47 N., R. 100 W.

[Drilled by Ohio Oil Co., July to November, 1914]

	Thickness	Depth
	Feet	*Feet*
Sand and soil	20	20
Soil and gravel	20	40
Cody shale:		
Shale, black and brown	440	480
Sand, greenish	25	505
Shale, brown, sandy, with shells	715	1, 220
Sand, black	15	1, 235
Shale, black and brown	230	1, 465
Frontier formation:		
Sand; hole filled with water	10	1, 475
Sand; no water	20	1, 495
Sand; water	15	1, 510
Sand; no water	30	1, 540
Shale, dark	148	1, 688
Sand	14	1, 702
Shale	28	1, 730
Sand; gas	32	1, 762
Shale and sand	5	1, 767
Sand; much gas	25	1, 792

No. 4. NE. ¼ SW. ¼ sec. 36, T. 48 N., R. 100 W.

[Drilled by Ohio Oil Co., August, 1916, to June, 1918. It is reported that considerable gas was produced from the sand at 1,810 feet, but this is at present sealed]

	Thickness	Depth
Cody shale:	*Feet*	*Feet*
Shale and shells	825	825
Shale, brown	30	855
Shale, sandy	100	955
Shale and shells	465	1, 420
Shale, muddy	20	1, 440
Shale	35	1, 475
Frontier formation:		
Sand, soft	35	1, 520
Shale	210	1, 720
Sand; gas	90	1, 810
Shale, black, with sand	42	1, 852

No. 5. NW. ¼ NE. ¼ sec. 7, T. 47 N., R. 99 W.

[Drilled by Producers Oil Co.; reported to be a shallow well]

No. 6. NE. ¼ SE. ¼ sec. 7, T. 47 N., R. 99 W.

[Drilled by Producers Oil Co., 1916. Log not available. Reported to have attained depth of about 2,300 feet without striking oil or gas]

Summary of wells on East Buffalo and West Buffalo anticlines—Continued

No. 7. NW. ¼ NE. ¼ sec. 10, T. 47 N., R. 100 W.

[Drilled by Midwest Refining Co., June to December, 1917. The casing has been sealed, but gas and a little water leak through outside the casing]

	Thickness	Depth
	Feet	*Feet*
Cody shale:		
Shale, brown, gray, and white	790	790
Sand, gray	30	820
Shale, brown, black, and gray	894	1, 714
Slate and lime	144	1, 858
Frontier formation:		
Sand; gas	24	1, 882
Lime	4	1, 886
Sand; gas	8	1, 894
Lime	10	1, 904
Slate	18	1, 922
Sand; gas	33	1, 955
Lime	10	1, 965
Sand	16	1, 981
Slate	8	1, 989
Sand, dry	28	2, 017
Slate and lime	21	2, 038
Sand; some gas	15	2, 053
Shale and shells	162	2, 215
Sand; water	25	2, 240
Shells	8	2, 248
Sand	9	2, 257
Shale and shells	128	2, 385

No. 8. NE. ¼ NW. ¼ sec. 10, T. 47 N., R. 100 W.

[No record. Well yields several gallons of soft water a minute, and gas bubbles freely at the surface. Well is not capped]

Occurrence of oil and gas.—Graphic comparison of the logs of five of these wells shows that the sections of the Frontier formation are highly similar although only one well, No. 7, appears to have passed completely through the formation. The upper sandstone appears to carry only water in the central area (wells Nos. 1, 2, 3, and 4), but the sands 250 to 300 feet lower uniformly carry gas under considerable pressure. Curiously these conditions are reversed in well No. 7, for gas is reported there in the uppermost sandstone and water in the lower. No appreciable quantity of oil has yet been encountered in these fields. From existing data it would appear that the lower sandstones are likely to yield gas on both anticlines from the area within the 4,300-foot contour drawn on the top of the uppermost sandstone.

Outlook.—Explorations to date appear to have rather adequately demonstrated that there is little prospect of obtaining oil in commercial quantities from the Frontier sandstones in these fields, although those in the lower part of the formation contain considerable gas. According to reports a little gasoline can be condensed from the gas, but it appears to be much drier than that from the same horizon in Grass Creek Basin or Oregon Basin. The evidence of well No. 7 indicates there is not a complete gravitative adjustment of gas and water in the sands. Under such circumstances there is a remote chance that small pools of oil may yet be found.

There still remains, however, the possibility that oil may be found in beds below the frontier formation. In the highest part of the East Buffalo anticline, the Greybull horizon would be found at a depth of 2,475 feet, the Chugwater oil-bearing zone at 3,565 feet, and the oil sand in the Embar formation at 4,465 feet. Efforts to discover oil in these lower formations should be made only after its presence in them has been determined in several other anticlines that bear the same relation to the major trough of the Big Horn Basin as these anticlines.

SPRING CREEK ANTICLINE

Surface features.—The Spring Creek anticline extends from Greybull River in T. 48 N., R. 101 W., northwestward for a number of miles. A part of it was examined by Lupton,[57] but the northwestern limit has not been determined. It coincides with Spring Creek Basin, which is marked by a steep escarpment of Mesaverde sandstone. The basin may be entered by fair roads from upper Meeteetse Creek on the north or along Spring Creek from the east, but the best approach lies along a new road from F. A. Whitney's ranch on Greybull River.

The surface of Spring Creek Basin is uncommonly smooth and unbroken, although the southern part is locally deeply trenched by narrow ravines that drain northward to Spring Creek. The smooth floor of the basin appears to have been established when the Greybull or valley-floor terrace was being cut. Several round hills and smooth ridges rise as much as 100 feet above the floor and are covered with a layer of gravel 3 feet thick. These hills are probably residuals of a terrace that was once more extensive, corresponding to the Sunshine terrace.

Stratigraphy.—The floor of Spring Creek Basin is cut in the upper part of the Cody shale, a few exposures of which are to be found in the ravines. The upper 250 feet of the Cody shale is uncommonly well exposed under the massive basal Mesaverde sandstones in several steep escarpments along the southeast end of the basin. The thickness of the Cody shale on the southwest side of Spring Creek Basin is estimated to be 2,250 feet. According to Lupton, beds of the Mowry shale and Frontier formation crop out around the crest of the anticline west of the border of the Meeteetse quadrangle.

Structure.—Spring Creek anticline is one of the simplest folds on the west side of the Big Horn Basin. The northeast flank is made up of the beds that rise gently from the Cottonwood syncline. The dip of the beds is less than 5° for 3 miles southwest of the syncline, increases abruptly to 18° near the Black Diamond mine, and ranges from 6° to 11° for 6 miles

[57] Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 656, p. 174, 1917.

farther, to the crest of the anticline. There is a possibility that the abrupt increase and decrease in dip mark the approximate position of the crest of a buried anticline, roughly parallel with that of the Spring Creek anticline. Southwest of the crest the dip attains the maximum of 32° in the basal sandstones of the Mesaverde formation and then decreases abruptly to the trough of the Rawhide syncline.

It has not yet been determined whether the contours on the upper sandstone of the Frontier formation close around the crest of the anticline or whether they are open to the northwest. No faults have been noted in any part of the anticline, but there are numerous joints in the rocks around the southeast end, especially in secs. 2 and 3, T. 48 N., R. 101 W, where the lower Mesaverde sandstones are broken into many diamond-shaped blocks of great range in size.

Exploration.—The principal exploration on the Spring Creek anticline consists of the well drilled by the Peerless Oil Co. in sec. 4, T. 48 N., R. 101 W., in 1915. A copy of the log is reproduced herewith.

Log of well drilled by Peerless Oil Co. in sec. 4, T. 48 N., R. 101 W.

	Thickness	Depth
	Feet	*Feet*
Soil	10	10
Shale, dark	790	800
Greenish sand; trace of gas	10	810
Shale, blue	850	1, 660
Frontier formation:		
Sandstone; water	12	1, 672
Shale, brown	86	1, 758
Sandstone; water	18	1, 776
Shale, brown, sandy	114	1, 890
Sandstone; water	15	1, 905
Shale	15	1, 920
Sandstone; water, 11 gallons a minute	35	1, 955
Shale	35	1, 990
Sandstone, dry	20	2, 010
Shale, sandy	20	2, 030
Sandstone, dry	45	2, 075
Shale	70	2, 145
Sandstone; water, 25 gallons a minute	125	2, 270
Shale; top shows a little oil	40	2, 310

The 610 feet of beds penetrated from 1,660 to 2,270 feet appear to represent the Frontier formation, so that the well was stopped in Mowry shale. In October, 1916, the water that flowed from the top of the casing at the rate of several gallons a minute was distinctly soft and free from sulphurous and other gases.

During 1918 and 1919 the Midnight Oil Co. drilled five holes in an area 100 feet square in the NE. ¼ sec. 5, T. 48 N., R. 101 W. The first well drilled attained a depth of 1,200 feet without striking the uppermost sandstone of the Frontier formation. The succeeding holes were 600, 500, 80, and 260 feet deep. It was the aim in each hole to drill to the Frontier sandstones, but the holes became crooked and had to be abandoned. Water flowed into the first hole at 710 feet but had to be continually added to each of the other holes during drilling.

Outlook.—The chance of discovering oil or gas on the Spring Creek anticline will be largely determined by the form of the highest part of the crest. If the structure contours near the crest close in the region west of the Meeteetse quandrangle, there is a possibility that the beds of the Chugwater or Embar formation may contain oil or gas. The relation of the fold to the trough of the Big Horn Basin indicates that beds of the Frontier, Mowry, and Thermopolis formations probably do not contain oil or gas. The Peerless well gives adequate evidence that the part of the anticline in the Meeteetse quadrangle is not likely to contain oil or gas. Any further drilling on the fold should be preceded by exhaustive study of the structure of the beds in the vicinity of upper Spring Creek.

SUNSHINE ANTICLINE [58]

Surface features.—The surface features in the vicinity of the Sunshine anticline differ greatly from those near similar folds in this region. Although a high, rugged escarpment of the Mesaverde sandstones lies parallel with the fold east of Wood River for a distance of 7 miles, it is completely eroded for 2 miles near the junction of Wood and Greybull rivers and then continues for 4 miles farther north of the Greybull. The Mesaverde rocks are largely eroded west of Wood River, and only a triangular block several miles wide remains northwest of Sunshine post office. The Sunshine anticline is one of the few folds in the Big Horn Basin that is crossed by large perennial streams, and the outstanding local features are the wide, flat valleys that follow the rivers and the high terraces that lie adjacent to the valleys. One remnant of the Sunshine terrace lies north of the valley and is more than 3 miles long and three-quarters of a mile wide; smaller remnants lie southeast of the river. There is also a large remnant of the Rim terrace west of Wood River and north of Sunshine. The remnants of terraces are much smaller along the Greybull Valley.

Nearly half the valley of Wood River is devoted to agriculture, and a large area has recently been brought under cultivation along the valley of Sunshine Creek by the use of water drawn from Wood River.

Stratigraphy.—The massive sandstones near the base of the Mesaverde formation crop out prominently near the top of the escarpment east of Wood River and north of Greybull River. The Cody shale underlies two wide belts, one on each side of the anticline, but except along the intermittent streams

[58] Moody, C. L., and Taliaferro, N. L., Anticlines near Sunshine, Park County, Wyo.: California Univ. Dept. Geology Bull., vol. 10, pp. 445–459, 1918.

tributary to Gooseberry Creek on the south exposures are poor. The sheets of gravel completely obscure outcrops of the shale on the high terraces, and by shedding waste down the adjacent slopes conceal outcrops there also. Measurements of the thickness of the Cody shale range from 2,500 feet east of Sunshine post office to 3,400 feet northwest of it. The greater thickness is undoubtedly only local, being due to thickening during folding, and does not represent a variation during the deposition of the beds.

The complete section of the Frontier formation is well exposed in secs. 15 and 16, T. 47 N., R. 101 W., on each side of Wood River, where measurements of the thickness show 493 and 528 feet (sections 6 and 7, Pl. VI). The principal sandstones in both sections can be satisfactorily correlated, but they show a great range in thickness.[59]

Beds of the Mowry shale crop out prominently on both sides of the anticline north of Wood River and locally south of the river. The dip of the beds and the recorded thickness of the Mowry shale in this region indicate that the Thermopolis shale should crop out along the crest of the anticline, but it has not been identified. In the highest part of the anticline, in the SW. ¼ sec. 22, T. 47 N., R. 101 W., the Greybull sand would probably be struck at a depth of 800 feet.

Less than half a mile south of the border of the Meeteetse quadrangle the Frontier sandstones pass under an area of Wasatch deposits.

Structure.—The Sunshine anticline is a rather simple narrow fold which is one of a well-defined chain that trends generally northwest in this region. On the south there are two small anticlines,[60] whose crests trend northwest but are offset successively westward from that of the Sunshine anticline. The Pitchfork anticline,[61] several miles northwest of Greybull River, bears a similar relation. This group of anticlines is limited on the east by an irregular group of synclines, which includes the Rawhide and Renner.

The form of the anticline is well indicated by the outcrops of the uppermost Frontier sandstone, which is well exposed except on the slopes adjacent to Sunshine Creek. The range in dip of this sandstone is 22° to 38° along the east flank and 30° to 46° along the west flank. No evidence of faults in this bed has been observed.

Exploration.—A single well has been drilled on the Sunshine anticline in the SE. ¼ sec. 33, T. 48 N., R. 101 W. It was drilled by the Twin Falls Oil & Development Co., of Twin Falls, Idaho, during the period from October, 1918 to September, 1919. The log as submitted by Mr. E. S. Stevens is given below.

[59] Hintze, F. F., jr., The Little Buffalo Basin oil and gas field: Wyoming State Geologist's Office Bull. 11, pt. 1, p. 75, 1915.

[60] Moody, C. L., and Taliaferro, N. L., op. cit., pp. 456–457.

[61] Hewett, D. F., and Lupton, C. T., op. cit., pp. 171–173.

Log of well of Twin Falls Oil & Development Co. in the SE. ¼ sec. 33, T. 48 N., R. 101 W.

	Thickness	Depth
	Feet	*Feet*
Clay	60	60
Shale, black	134	194
Shale, hard lime	3	197
Sand, gray; water (top of Frontier formation?)	60	257
Shale, white	190	447
Sand, gray	37	484
Shale, black	100	584
Sand, white; water, caused hole to cave	22	606
Shale, black	79	685
Sand, gray	15	700
Shale, white	50	750
Shale, black	90	840
Sand, gray	56	896
Sand, muddy	114	1, 010
Lime, gray	15	1, 025
Clay, white	20	1, 045
Shale, black	75	1, 120
Sand, white	10	1, 130
Shale, black	178	1, 308
Sand	37	1, 345
Shale, black	5	1, 350
Lime, blue	5	1, 355
Sand, gray	10	1, 365
Shale, black	11	1, 376
Shale, lime	3	1, 379
Shale, blue	4	1, 383
"Shell," lime	2	1, 385
Shale, black	13	1, 398
Lime, gray	6	1, 404
Shale, gray	216	1, 620
Lime, hard	2	1, 622
Shale, black	478	2, 100
Shale, gray, streaks of sand; show of oil	140	2, 240
Shale, black	90	2, 330
Sand, gray; show of oil	2	2, 332
Shale, black	101	2, 433

In several respects this is an extraordinary record. The group of sandstones struck at 197 to 1,365 feet have several characteristics of the Frontier formation, and the underlying gray and black shales resemble the Mowry and Thermopolis shales. If the sand struck at 197 feet is considered the top of the Frontier formation and the thicknesses of the underlying formations are normal the red shale of the Morrison formation should have been struck at about 1,850 feet. As neither red shale nor sandstone resembling the Cloverly formation was struck, it must be concluded either that the entire section is uncommonly thick or that the beds have a high dip where they are penetrated. If the latter explanation is correct, as seems most probable, the beds must dip from 30° to 45°, and the bottom of the hole is in the shale near the base of the Thermopolis shale.

The structure of the beds near the well can not be determined from surface outcrops. The structure contours in this vicinity have been drawn on the assumption that the sandstone at 197 feet is the top of the Frontier formation, dipping gently northwest from the crest of the anticline. The structure of the Mesaverde coal beds where they cross Wood River, considered with the attitude and position of the Frontier sandstones along the anticline, indicate the possibility that there may be a local sharp anticline between the Sunshine anticline and the Mesaverde formation where it crosses Wood River. If this is true, the well may be on a steep western flank of the local anticline.

Outlook.—As the Frontier formation and Mowry shale crop out along Wood River, the prospect for the discovery of commercial quantities of oil and gas in these formations on the Sunshine anticline is not encouraging. On the other hand, beds of the Chugwater and Embar formations, which are buried at a depth of 1,700 to 2,400 feet in the NW. ¼ sec. 22, T. 47 N., R. 101 W., on the south side of Wood River, offer a fair prospect for successful drilling. As the Sunshine anticline is a narrow unsymmetrical fold, with the steeper dips west of the crest, and as the difference in thickness of the Frontier formation on the two sides is slight, it appears that the axial plane of the fold dips east. Wells should therefore be placed 300 to 500 feet east of the crest line in order to penetrate the highest part of the crest in Chugwater and Embar beds.

GOOSEBERRY DOME AND ANTICLINE

Two small folds, a dome and an anticline, cross Gooseberry Creek in T. 47 N., R. 100 W. The anticline coincides with a flat basin about 1 mile in diameter, and a large area north of the creek is under cultivation. The basin is almost surrounded by high, rugged escarpments, made up of the outcropping massive ledges of sandstones of the lower Mesaverde formation. The crest of the dome, however, is not so deeply dissected, and the lower sandstones of the Mesaverde lie low on a group of rugged ridges that partly surround it (Pl. VII, *C*). The basins are accessible by roads along Gooseberry Creek or by trails through several ravines from the north.

Estimates of the thickness of the Cody shale on the Gooseberry anticline, based upon surface outcrops and the data from the well on the anticline, indicate that it is about 2,550 feet. In the absence of any drilling on the dome, the thickness of the shale there is assumed to be the same.

The beds of Mesaverde sandstone descend abruptly from the Little Buffalo Basin anticline to the Gooseberry syncline, from which they rise gently at dips that range from 7° to 11° to the crest of the dome. A well-defined trough separates the dome and anticline, and beyond it the beds rise at 12° to 16° to the crest of the anticline. The dip of the beds increases abruptly to the maximum of 27° from the crest of the anticline to the trough of the Renner syncline. The southward extension of the anticline is locally covered by beds of the Wasatch formation and has not been explored in detail. The highest part of the crest is apparently in the Meeteetse quadrangle.

A single well has been drilled near the crest of the anticline, but the dome is not yet explored. The following data concerning this well were submitted by Mr. Russell Kimball, of Cody. The well was drilled in the SE. ¼ SE. ¼ sec. 29 to a depth of 2,550 feet from September, 1915, to June, 1916. The log of this well shows the first sand (Torchlight?) dry at 1,725 to 1,740 feet and other sands at 2,002 to 2,032 and 2,070 to 2,110 feet. It is reported that a flow of fresh water was struck at 2,032 feet and that the water rose to the surface. A smaller flow of brackish water, which also rose to the surface, was struck at 2,070 feet. It is reported that when drilling in the lowest sand the bit became covered with a dark asphaltic material, but none of the common evidences of oil were observed. The casing was placed to 2,272 feet.

It is apparent that if the first sand struck at 1,725 feet is regarded as the top of the Frontier formation, the well penetrated the entire formation but did not reach the Muddy sand in the Thermopolis shale. As this well was placed close to the crest line of the anticline and neither oil nor gas in appreciable quantity was struck, there is little prospect that other wells on this fold will find economically important quantities of these substances in the beds of the Cretaceous section. On the other hand, the possibility of finding oil and gas in the Chugwater and Embar beds can not be determined in advance of drilling. The area that might serve as the collecting ground of this anticline is much smaller than that of the Cottonwood anticline, so that the prospect for production from these formations is less favorable here. At the crest of the anticline the productive bed in the Chugwater is about 4,200 feet below the surface and that in the Embar 5,100 feet.

The Gooseberry dome is similar to the anticline but is less pronounced and has a smaller collecting ground. The outlook for discovering more than traces of oil and gas in beds of the Cretaceous section on this dome is not good. Also, even though these substances may be found in the deeper beds, it seems improbable that any production that is likely to be obtained would repay the cost of exploration.

GRASS CREEK OIL FIELD

DEVELOPMENT

The first explorations for oil in the Grass Creek field were made late in the summer of 1913, but as only light portable rigs were used none of the holes were drilled deep enough to strike any of the productive sands. The efforts attracted attention locally, however, and early in 1914 several groups had brought in drilling outfits and were ready to drill. Oil was first struck by the W. L. Valentine interests in June, 1914, at well No. 1, on Washakie No. 11 tract. Additional wells were drilled during the summer and fall, and according to Hintze, 23 wells were completed by January 1, 1915. As there were no facilities for shipping the oil, the wells were capped until the completion in July, 1915, of a 6-inch pipe line from Grass Creek to Chatham, on the Chicago, Burlington & Quincy Railroad. Development continued rapidly on the patented lands south of Grass Creek during 1915, so that on August 1, when C. T. Lupton visited the field, 55 wells had been completed. Explorations north of Grass Creek were hindered by the withdrawal from entry of the unpatented land on May 6, 1914, and May 27, 1915.

The writer visited the field in October, 1916, and located 193 wells, of which 129 were producing oil. Most of the remaining 64 were border wells, which either struck water or found too little oil to warrant pumping. The peak of production was reached in March, 1918, when 292,887 barrels was produced from 240 wells. When the field was revisited in September, 1919, there were 332 wells. Since that time the principal work has included the deepening of a number of wells so that they now pump from the entire Frontier section, the completion of all wells justified under local conditions, and the drilling of several wells to zones as deep as the Morrison formation. Since the summer of 1919 production has declined rather rapidly.

SURFACE FEATURES

The Grass Creek anticline coincides with a conspicuous basin of low relief, almost surrounded by a rugged escarpment made up of Mesaverde sandstones. Roads enter the basin from the four points of the compass through notches cut in the escarpment. Two of these notches, at the west and east ends of the basin, are occupied by Grass Creek. The northern notch is the outlet for Canyon Coulee, and that on the south border has been cut by the stream in Spring Gulch. There is also a gap in the western border where the Mesaverde sandstones have been removed from the syncline that separates the Grass Creek anticline from the Little Grass Creek dome. Plate XXIV, *A*, shows the general features of the basin and the escarpment that limits it on the northeast.

Grass Creek cuts the basin into two almost equal parts, which are rather unlike. The part that lies south of the creek is a smooth, gently sloping surface in which all outcrops of the underlying Cody shale are concealed by a layer of alluvium 10 to 60 feet thick. Before the explorations for oil were made, several hundred acres was cultivated on the Quintin Littlejohn and William Littlejohn ranches by water drawn from Grass Creek in ditches. The part of the basin that lies north of Grass Creek has a sparse cover of soil and contains numerous outcrops of the sandy layers of the Cody shale. This area is trenched by many shallow ravines, which are tributary to Canyon Coulee. The long, narrow ridge in the center of the basin is all that remains of an extensive gravel-covered terrace, which is correlated with the Sunshine terrace, in the Wood River valley. The terrace is covered by a layer of gravel and boulders 8 to 10 feet thick. Most of the boulders range from 3 to 8 inches in diameter, but 200 feet southeast of the northwest corner of sec. 20, there is a boulder of dark andesite 2½ by 3 by 4½ feet, the largest found on this terrace in the region.

Grass Creek is a perennial stream, although before 1914 most of the water was diverted into ditches for use in irrigating tracts in the basin during the summer. The water was not of desirable quality for domestic supplies, but suitable water was derived from shallow wells sunk within a hundred feet of the stream channel. With the development of the oil field the surface water has become fouled through leakage of oil from the wells. Most of the present supply of the camp is derived from four shallow wells in the SW. ¼ sec. 20 T. 46 N., R. 98 W. These wells were driven to depths that range from 42 to 64 feet and obtain water of fair quality from a buried zone of gravel. The pumps are operated by power plants near by, and the combined yield of the four wells is about 100 barrels a day. An 80-foot well adjacent to S. L. Wiley well No. 4 is reported to yield the best water in camp.

STRATIGRAPHY

The lowest rocks exposed at the surface of the Grass Creek anticline are in the Cody shale about 300 feet above the base. Here and there in ravines north of Grass Creek are outcrops of gray and olive-green shale and thin-bedded gray sandy shale, which are locally stained brownish or yellowish by iron oxides derived from the weathering of disseminated pyrite. The thin sandstone and sandy shale that make up the upper 600 feet of the Cody shale are very well exposed in secs. 8 and 17, T. 46 N., R. 98 W. Measurements across the northeastern limb of the anticline indicate that the thickness of the Cody shale is 2,450 feet.

The thickness of the Frontier formation in wells near the crest of the anticline ranges from 380 to 470 feet. Graphic sections of this formation are shown on Plates VI and XXIII, *A* and *B*. Of the total number of wells in the field, about 332 in October, 1919, only a few passed completely through the Frontier section and only two entered the Morrison formation. Most of the wells drilled for oil up to 1919 penetrated only the upper 250 feet of the Frontier formation. Plate XXIII, *A*, *B*, shows the correlation of the sands of the Frontier formation, the distribution of gas, oil, and water in the beds, and the general form of the anticline. It displays clearly several characteristics of the Frontier formation in this field. First, the uppermost bed of sandstone is probably the most persistent bed in the field and rather commonly contains water, though rarely enough to rise more than a few feet in the hole. Second, the uppermost sandstone is underlain by 80 to 100 feet of shale, which is rarely interrupted by a bed of sandstone. Third, the oil-bearing sandstones form an underlying zone that has been proved to have a minimum thickness of 100 feet and, to judge from sporadic records of the entire Frontier, is probably more nearly 200 feet thick.[62] Fourth, the individual sands are not highly persistent. It is even doubtful whether any single bed of sand persists throughout the field. From available records it is not clear whether, as one bed pinches in a general eastward direction, another bed begins at the same stratigraphic position or slightly higher or lower. What is known about the persistence of the base of the Mesaverde formation suggests the probability that in a general eastward direction each new bed in the Frontier formation lies at a successively higher position.

From the well records it is impossible to determine the line or zone that limits the Mowry and Thermopolis shales. The combined thickness of these formations in three wells ranges from 839 to 881 feet. The Muddy sand appears to be uncommonly persistent, however, and ranges in thickness from 35 to 60 feet. The top of the Cloverly formation is considered to be the top of the first sandstone under the Muddy sand, but the base is obscure in the few holes that have been drilled. The underlying Morrison formation is characterized by red shale. The oil-bearing sand in the Chugwater formation under the Cottonwood anticline is about 1,090 feet below the top of the Cloverly, and that in the Embar about 816 feet lower. The minimum depth of these sands below the surface under the Grass Creek anticline is 2,760 and 3,576 feet, respectively.

STRUCTURE

Maps showing the structure of the Grass Creek anticline by contours on the top of the uppermost Frontier sandstone, based on well records, have been prepared by Hintze in 1914, by Estabrook in 1922 for the papers already cited, and by the present writer (Pl. XXII). These maps differ slightly in detail, but agree closely in the form of the anticline, altitude of the crest, and slope of the limbs. Neither of the earlier reports shows the structure of the southeast end of the field. These maps show clearly that there are three and possibly four distinct local high areas along the general crest line of the Grass Creek anticline. The crest on the top of the uppermost Frontier sandstone attains an altitude of about 4,000 feet under the Mayfield tract, in the S. ½ sec. 27, T. 46 N., R. 98 W.; 4,700 feet under the Q. Littlejohn tract, in the E. ½ sec. 29, T. 46 N., R. 98 W.; and 5,350 feet under the Meeteetse No. 15 tract, in the SW. ¼ sec. 18, T. 46 N., R. 98 W. Another crest may occur under the Findley tract, in the NW. ¼ sec. 33, T. 46 N., R. 98 W.

The contours show that the beds on the basinward limb dip rather uniformly at 11½° E. There has been little exploration on the mountainward limb, and the steepest dip on this limb indicated in the wells is 29° for 500 feet on the Happy Thought lease, in the NE. ¼ sec. 30, T. 46 N., R. 98 W. Within 1,000 feet to the southwest beds on the surface attain a dip of 40° SW. Well records indicate that the Frontier sandstones are badly broken on the steep southwest limb.

If any faults cross the field, they are not apparent from available well records. In the earlier report on the field[63] a fault was inferred from well records in the SE. ¼ sec. 19, but this interpretation was probably not correct.

OIL

Grass Creek pool.—There is no record that any surface indications of oil were found in the Grass Creek field. No seepages are known, and there are no fissures filled with ozokerite, such as those found in the Salt Creek and other Wyoming fields during recent years.

The earliest development of the pool, in 1914, took place in sec. 18, T. 46 N., R. 98 W., near the highest part of the crest, but as that part of the field was under litigation arising out of the public-land withdrawal of May 6, 1914, it was temporarily abandoned. During 1915 and 1916 the patented tracts of the southeastern part of the field, including the Ridgely and Orchard leases, the Mill Iron Cattle Co. ground, and the ranches of Q. and W. Littlejohn, were almost completely drilled.

During 1917 and 1918, after litigation was over, the tracts north of Grass Creek were drilled, and by October, 1919, almost all the wells in the field had been put down. These wells appear to have determined rather closely the original extent of the pool in the Frontier sands. The area of the pool as shown on Plate XXII is about 1,600 acres. In several parts of the field a sufficient number of wells have been drilled to show that the outer limit of the oil zone in Frontier sands is very clearly marked. In these areas, notably on the Orchard, W. Littlejohn, and Lucky Buck No. 1 tracts and at the northwest end of the field, the distance between wells yielding only water and wells yielding largely oil ranges from 200 to 400 feet. The line on Plate XXII dividing wells originally yielding considerable oil from those yielding only water is made up of smooth, gentle curves, sharp irregularities being distinctly lacking.

[62] Estabrook, E. L., Production problems in the Grass Creek oil field: Mining and Metallurgy, No. 182, pp. 65-66, 1922.

[63] Hewett, D. F., and Lupton, C. T., op. cit., p. 153.

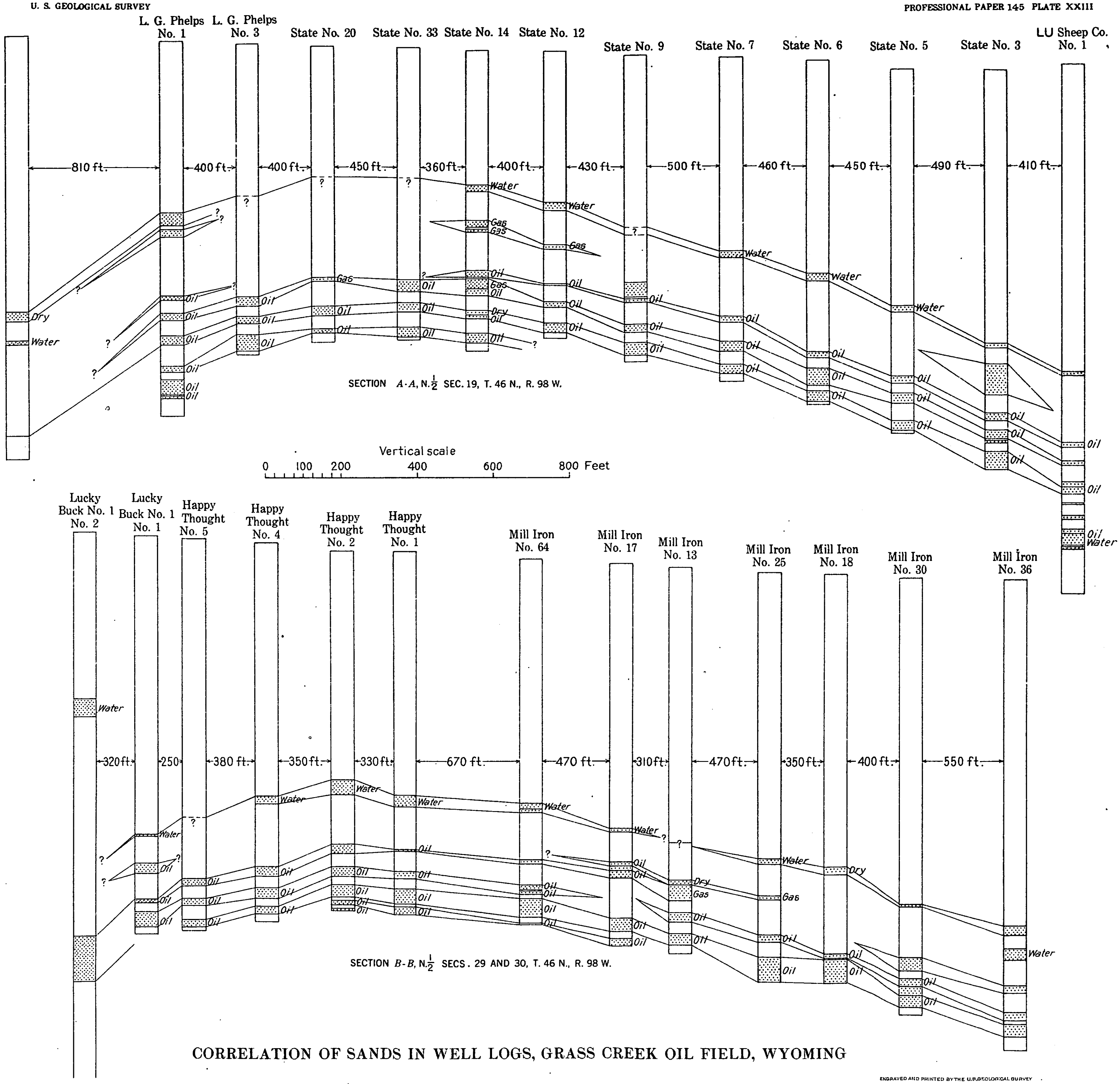
STRUCTURE CONTOUR MAP OF

GRASS CREEK OIL FIELD, HOT SPRINGS COUNTY, WYOMING

0 ¼ ½ 1 2 Miles

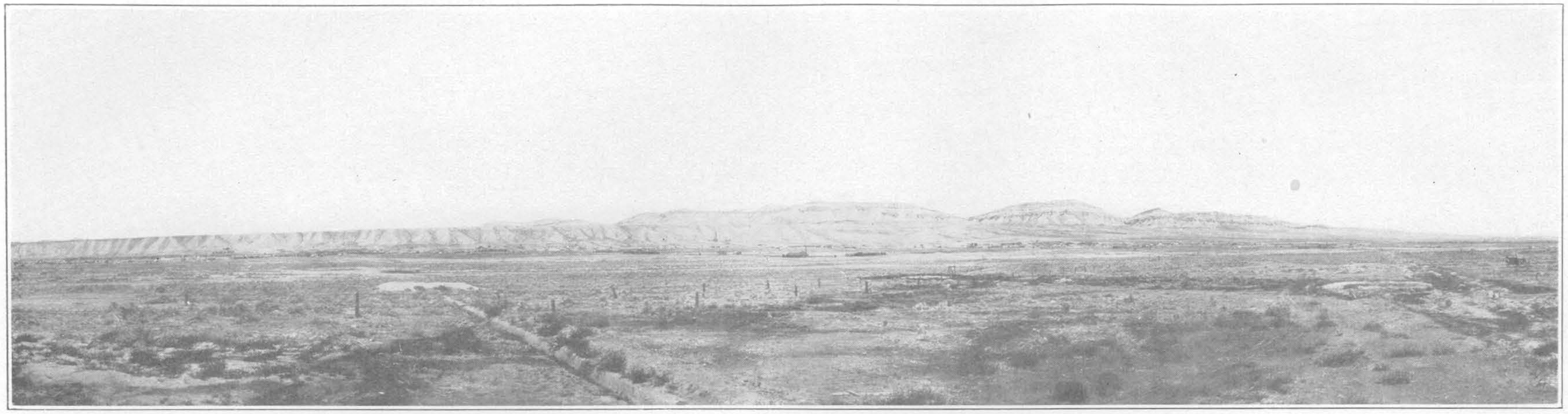
1925

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



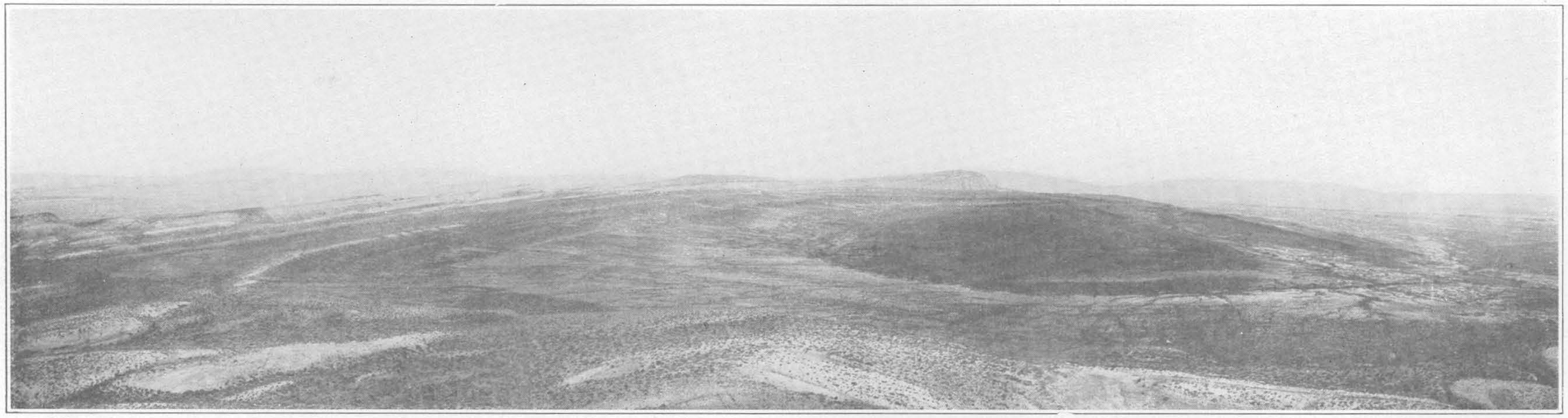
CORRELATION OF SANDS IN WELL LOGS, GRASS CREEK OIL FIELD, WYOMING

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY



A. PANORAMIC VIEW OF GRASS CREEK OIL FIELD

Bluffs in distance underlain by sandstone of Mesaverde formation; material in foreground is wash covering Cody shale. Photograph by R. Lindstad



B. COTTONWOOD OIL FIELD (HAMILTON DOME) FROM THE WEST

The ridges that encircle the basin are underlain by Frontier and Mowry sandstones. The area in the foreground is underlain by the Thermopolis shale

Methods of drilling and production.—The exploratory work in 1913 was done by portable rigs, but in all the development of the pool during 1914 standard rigs were used. When permanent camps were established and the roads were improved heavy portable rigs of the Star, National, and St. Louis types were brought in and have been used to complete the exploration. In accordance with the preponderant Wyoming practice, the plans provide for drilling nine wells in each 40-acre tract, so that the wells are commonly 400 feet apart, one well for each 4.5 acres.

Under the prevailing drilling practice 10-inch pipe is used to a depth of about 60 feet. If water is met in the surface wash, which is rarely more than 50 feet thick, 8¼-inch pipe is placed below the water-bearing zone. From a depth of about 60 feet to the bottom of the hole 6⅝-inch pipe is placed. After the well is completed a line of 2-inch tubing is suspended from the casing head to a point 20 feet above the bottom. Ball valves are placed at the lower end of the tubing and at a point 20 feet higher. The pumping jack is of the Oklahoma pattern, made of steel; pump rods have joints every 20 feet. The pay sands are shot with 60 to 250 quarts of nitroglycerine when the well is completed. It is obvious that the oil from the well comes from all the sands penetrated by the drill.

The oil is first pumped to small tanks near the pumping plants. From the wells in the Canyon Coulee drainage basin it is drawn periodically to the storage tank of the Illinois Pipe Line Co. in sec. 7, T. 46 N., R. 98 W. From those in the Grass Creek drainage basin it is drawn to a large storage tank in the lower end of Grass Creek Basin and thence into a 6-inch pipe which delivers it at Chatham or Greybull, 25 and 79 miles distant, respectively.

Source of the oil.—Until 1920, when one well, the L. U. Sheep Co. No. 13, in the NW. ¼ NW. ¼ sec. 19, T. 46 N., R. 98 W., struck heavy oil in a sand high in the Morrison formation, all the oil produced in the Grass Creek field was derived from sands near the middle of the Frontier formation. During 1915 and 1916 much gas was also obtained from the Muddy sand in State Land well No. 1, in the NE. NW. ¼ sec. 19. Until early in 1920 it was assumed that the lower sandstones of the Frontier were water-bearing, and only a few holes penetrated them. According to Estabrook explorations in 1920 on some of the central tracts showed that these sands contained oil, and many wells were deepened to tap them, with the result that the yield under pumping was increased temporarily 250 per cent.

Plate XXIII, *A*, *B*, shows the distribution of oil and water in the sands struck in two groups of wells. The notation along each log indicates the original conditions shortly after each well was drilled.

Relations of gas, oil, and water.—There is probably no important question about an oil field that is more obscure than the relation of the gas, oil, and water as they lie in the buried beds of sand and shale. Not only is a great mass of accurate quantitative data for a large part of the field necessary, but such data should be collected periodically throughout the development and decline of the field and should be carefully studied in the light of the stratigraphy and structure as interpreted from accurate well logs.

The nature of the writer's latest work in the region (October, 1919) did not permit him to collect personally many of the essential quantitative data. Most of the well logs were available, and in large part they are fairly detailed and probably accurate. Records of the production of oil and water are available for only a few separate wells, although the weekly or monthly production of oil from each lease over the entire period of operation is known. In order to get impressions of the water problem, the writer interviewed the man in charge of each pumping plant concerning the duration of pumping, the ratio of water to oil from each well, and the frequency with which each well was cleaned.

An attempt to draw significant conclusions from the data thus obtained leaves much to be desired. In 1919 very few wells yielded oil only, and they are distributed rather irregularly throughout the field. The largest group is on Meeteetse No. 15 tract, near the crest of the anticline, although several on the Ridgely tract still yielded only oil after four years of pumping. Several such wells lie on the northeast limb and southeast end of the anticline, although many higher wells yielded mixed water and oil. Wells Nos. 4 and 13 on the Littlejohn tract, in the NE. ¼ SW. ¼ sec. 28, yielded only oil, although wells near by as high on the anticline yielded considerable water. In general, the wells that yielded more than 4 parts of oil to 1 of water are on the higher part of the anticline, and those that yielded more than 4 parts of water to 1 of oil are near the border of the pool. A few wells here and there, however, such as State tract Nos. 10 and 13, in the SE. ¼ NE. ¼ sec. 19, located well up on the anticline, yielded more water than oil, even though neighboring wells lower down yielded only oil.

Study of the areal distribution of wells that yielded widely differing proportions of oil and water, after several years of pumping, leads to the conclusion that some sands are much more persistent or uniformly pervious than others and that in persistent or pervious sands border water is readily drawn into open channels. On the other hand, some sands must be much less persistent or pervious or draw oil from near-by lower zones, so that they yield a greater proportion of oil for a longer period.

A significant feature of the pool is the tendency for a well under pumping to yield less and less of both liquids, oil and water, until it must be abandoned.

In general, a border well is abandoned when it begins to yield only water. There are several wells, however, high on the anticline, such as State Land No. 1, in the NE. ¼ NW. ¼ sec. 19, that have continued to yield less and less of both liquids even after long lapses between pumping periods and finally have failed to yield either oil or water. In such circumstances the casing has been pulled and the hole filled with cement. Such failures may be due to the deposition of minerals or paraffin in the pores of the sand. On the other hand, such wells are not always those which give most trouble from deposition of sand and paraffin in the casing. There seems to be no consistent relation between the ratio of oil and water in a well and the tendency to deposit paraffin. Some wells must be cleaned every three days; most of them may be pumped satisfactorily when cleaned only once in every two to four months.

By way of summary, it may be said that after five years of pumping only a few border wells have ceased to yield enough oil to justify pumping. Although the ratio of water to oil has increased most in the border wells, especially at the southeast end of the field, the ratio has also steadily increased in most of the wells near the crest. As wells on the crest originally yielded oil alone, it is very clear that the water table, which broadly underlies the oil, is not rising uniformly around the border of the pool so as to exclude oil completely from the border wells, but that channels of circulation have developed which permit water to be drawn from areas beyond the border of the pool to wells high on the anticline. Where wells on the crest have gone dry, the pores of the sands near by have probably been completely sealed with paraffin.

No wells drilled in the Frontier sands yield gas alone, although one well, State Lease No. 1, in the NE. ¼ NW. ¼ sec. 19, drilled to the Muddy sand in 1915, yielded a large flow of gas until 1919. Practically all wells in the Frontier sands, however, yield some gas with the oil. The gas from some leases is used directly at the pumping plants, but that from others is taken off at the casing heads and delivered to the compressor plant of the Ohio Oil Co. in the W. ½ sec. 20. In October, 1919, about 1,000,000 cubic feet of gas, or two-thirds of the total output, was received daily at this plant and yielded under compression about 3,000 gallons of high-test gasoline.

Yield of the wells.—In the early days of the development of the pool it was not uncommon for wells to yield a flow of oil for several days after having been drilled through the productive sands and shot with 60 to 250 quarts of nitroglycerine. Oil flowed from one well in the SW. ¼ SE. ¼ sec. 29 for three weeks after it was shot. In this early period the initial daily yield commonly ranged from 150 to 400 barrels, but succeeding days showed lower yield.

Rather complete records of the yield of each lease have been submitted by the operators, but permission to publish has been withheld, and only general conclusions may be stated. The yield per well per day shows a wide range throughout the field and naturally has rather steadily declined on each lease since the early stages of development. Some conclusions that seem obvious concerning yield must be modified when proper consideration is given to relative periods of maximum exploration and to the increased yield when wells were drilled to deeper sands. The best leases show a decline from 60 barrels per well per day during the early period of exploration to 20 or 25 barrels at the end of three years. The poorer leases began with an initial daily average yield of 20 to 25 barrels per well and after three years were yielding from 5 to 10 barrels. In a broad way, the highest initial yields have come from leases on the east limb of the anticline, although several leases on the southwest limb containing only a few wells have also shown high initial yields. Leases on which the initial yield is high show more rapid decline than those on which it is low. The lowest initial yields come from leases some distance down on the southeast end of the anticline. In general, the initial and final daily yields are highest where the number of wells per 40-acre tract is lowest.

Figure 9 shows the differences in character of the production curves in the several parts of the field. The curves are generalized graphs that show the monthly production of six leases during periods that range from four to seven years. The production has been adjusted to 80-acre tracts, but no allowance has been made for slight differences in the number of wells on the adjusted tracts. The curves show that tracts covering the east limb of the anticline maintain their rate of production better than tracts on the crest, which in turn maintain their rates better than those on the southwest limb. The curves show clearly that all except a few tracts in favorable locations approach the same rate of production after about three years. None of these curves take into account the increased production from several tracts in the field resulting from deeper drilling in the Frontier sands.

Mayfield pool.—In the southeast end of Grass Creek Basin, in the SE. ¼ sec. 27, five wells have yielded a small but steady flow of oil for several years. The area is rather well defined on the east and south but only broadly defined on the west and north. Four wells were drilled here between November, 1915, and October, 1916; a fifth was drilled in March, 1919; and one of the original four was abandoned later in 1919. This area is known as the Mayfield pool, from the name of the owner of the tract, I. V. Mayfield.

Information concerning the wells has been obtained from C. W. Ford, of Thermopolis. The total depth ranges from 1,580 to 1,640 feet, but as complete logs are not available the exact depths to the top of the Frontier formation are not known. Well No. 2 is reported to be the best well. For the first 60 days it yielded about 30 barrels a day, and in 1919 it was yielding 10 barrels. It has never been shot with nitroglycerine. Enough gas is obtained from the casing head to supply the pumping plant and local domestic needs.

The total production of the pool up to January 1, 1919, is estimated at 15,000 barrels, of which about 8,000 barrels has been sold and the rest used at the pumping plant. In October, 1919, about 25 barrels was being used daily under a boiler to supply power for drilling and cleaning wells. Recent surplus output has been sold to the Northwest Refining Co. at Cowley.

Past and future production.—The records of production in the Grass Creek field are detailed and complete. As practically all the wells have been pumped throughout their history and adequate preparation to conserve oil was made in advance of drilling, very little oil has been lost. Both of the producing companies, the Midwest Refining Co. and the Ohio Oil Co., have delivered all the oil not burned under boilers to the Illinois Pipe Line Co., which has delivered it to the railroad cars and refinery at Greybull. Both companies have courteously submitted complete records of production by leases, but unfortunately, as the Ohio Oil Co. records production on a weekly basis and the Midwest Co. on a monthly basis, the records can not readily be merged for study.

The annual production of the field since the pipe line was completed in July, 1915, is recorded below.

Oil produced in the Grass Creek field, 1915–1922, in barrels

1915	99,000
1916	1,370,000
1917	2,756,000
1918	2,951,000
1919	2,049,000
1920	1,573,000
1921	1,435,000
1922	1,784,000
1923	1,589,000
1924	1,113,000
	15,619,000

In addition to this production of crude oil, gasoline has been produced since 1918 by compressing the casing-head gas. In 1919 a plant in the NW. ¼ NW. ¼ sec. 20, T. 46 N., R. 98 W., was treating approximately 7,000,000 cubic feet of gas weekly, from which about 20,000 gallons of gasoline was produced. This indicates a recovery of 3.5 gallons per 1,000 cubic feet of gas. About two-thirds of the gas of the district is treated in this plant.

Of the several methods of estimating the future production of oil fields, that based upon the average yield per well per unit of time has been chosen for the Grass Creek field. The available data consist of figures showing the yield of leases that have furnished about two-thirds of the total production. Until 1920 the entire output of the district was obtained from the upper half of the Frontier formation, but since

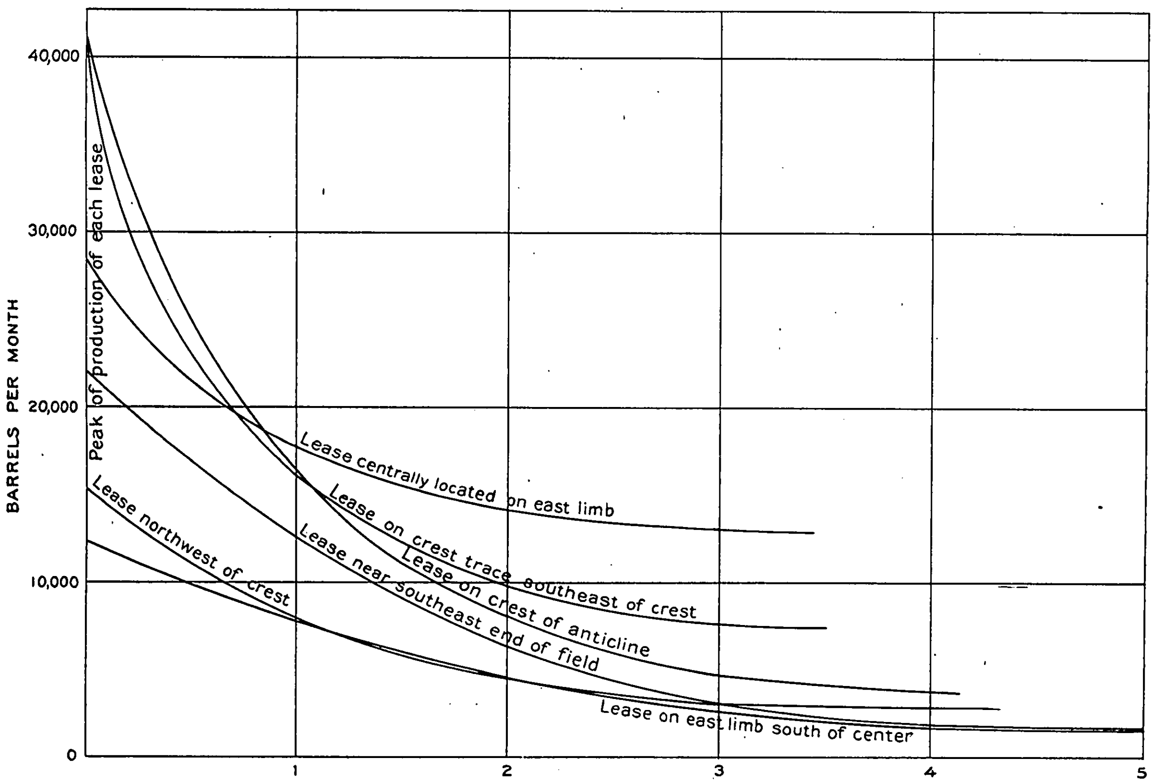


FIGURE 9.—Production of different leases in the Grass Creek field

then many wells have been deepened so as to yield oil from the lower half of the Frontier, and a few have been continued as far as sands in the Morrison and Embar formations. Records are not available by which to estimate the contribution of these lower sands nor the extent to which they may be expected to contribute in the future. The data of production since 1920 represent the composite contribution from all sands.

Curves have been prepared that show the average weekly production per well, based upon quarterly, semiannual, and annual production. The curve based upon average quarterly production has been extended into the future in such a way as to try to take account of the influence of the drilling into deep sands. The quarters chosen begin with the months of December, March, June, and September, rather than the customary quarters of the calendar year, in order to bring out the effect of the three severest winter months, December, January, and February. As the local high points commonly fall in the period June to December, the curve shows that the weather conditions have an important effect on current production in this latitude.

By extrapolating the curve of future production to 1940, when, it is estimated, the average weekly production per well will have fallen to 10 barrels, it is determined that the total production to that year will be about 22,000,000 barrels, or about 6,500,000 barrels more than the total produced before 1925.

LITTLE GRASS CREEK DOME

The Little Grass Creek dome coincides with a nearly circular basin slightly more than a mile in diameter in secs. 2, 3, 10, and 11, T. 46 N., R. 99 W. The basin is cut in the upper part of the Cody shale and is nearly surrounded by an escarpment of lower sandstones of the Mesaverde formation. Most of the basin is drained eastward by Canon Coulee into the northwest end of Grass Creek Basin; a small part is drained northward to Gooseberry Creek. Coal beds near the base of the Mesaverde formation crop out almost entirely around the basin, and prospects have been opened at three places. The upper part of the Cody shale is made up of the characteristic thin sandstones, which crop out widely.

In its broader aspect, the dome is a part of the Grass Creek anticline, from which it is separated only by a shallow but abrupt syncline. If contours are drawn on the lowest coal bed of the Mesaverde formation, only those representing the upper 500 feet of the dome close around it. Probably on successively lower horizons, the dome is less distinctly marked. Only one small fault was noted around the border.

In 1919 two wells had been drilled near the crest of the dome, the earlier by the Great Dome Oil Co. in the E. ½ sec. 10 and the later by the Mexico Wyoming Oil Co. near the center of sec. 11, T. 46 N., R. 99 W. The log of the earlier well, drilled in 1916, was not obtained, although it was locally reported to be 2,100 feet deep and to have encountered water in the Frontier formation but little if any oil or gas. The later well, which was 2,580 feet deep in October, 1919, reported sands at 350, 764, and 1,710 feet, but the depth of the top of the Frontier formation is not recorded. At the time of visit a large flow of water, probably derived from the Frontier formation, issued from the top outside of the casing. A show of oil and gas is reported at 1,710 feet. Later it was reported that considerable gas was struck at a lower horizon, possibly the Muddy sand.

The wells that have been drilled demonstrate that no oil or gas will be found in the Frontier formation on this dome. If there is gas in a lower sand, oil may yet be found in an outer zone on the same sand. There seems to be slight chance that the quantity will be large, however.

WAGONHOUND ANTICLINE

Surface features.—The crest of the Wagonhound anticline lies in sec. 6, T. 44 N., R. 98 W., about 6 miles west of the highest part of the Cottonwood anticline. Unlike that anticline, the Wagonhound fold has no unusual surface features that distinguish it from near-by areas along Cottonwood Creek. The anticline is fairly indicated by outcrops of the sandy layers of Cody shale, which are found here and there in shallow ravines cut below a barren plain. Wagonhound Bench covers a large area and conceals the outcrops that would show the relation of this anticline to the Cottonwood anticline. The plain is limited on the southwest and north by the escarpment of Mesaverde sandstones.

Cottonwood Creek carries water on the surface from the region near the anticline westward toward its head. Wagonhound Spring yields a small flow of alkaline water, which, although unfit for drinking, has been used in boilers.

Stratigraphy.—The lowest beds that crop out on the crest of the anticline are those about 400 feet above the base of the Cody shale. The thickness of the shale southwest of the crest is 2,300 feet. The latest well that was sunk prior to 1919 (No. 4, Pl. III) was 1,720 feet deep and passed through the Frontier, Mowry, Thermopolis, and Cloverly formations.

Structure.—The crest of the anticline is rather definitely indicated by outcropping thin layers of sandstone. Contours on the upper sandstone of the Frontier formation are based upon these outcrops and the positions indicated in the three wells that have been drilled to it. No faults have been recognized near the crest, but as there are two near by in the Mesaverde escarpment, others are probably present in the buried Frontier sandstones.

As shown by the structure contours, the anticline is rather simple in form and has a well-defined crest line which trends northwest and is roughly parallel to that of the Cottonwood anticline although offset from it. The crest plunges northwestward toward an area of complicated structure at the head of Prospect Creek.

Exploration.—Prior to October, 1919, four wells had been drilled on the Wagonhound anticline. The first three were drilled during the winter of 1915–16 by a company of which C. S. Sollars was the local manager. The depths of these wells are reported to be 1,833, 1,300, and 680 feet. The log of the first well, the only one available, is presented herewith.

Log of well No. 1, Wagonhound anticline, NE. ¼ sec. 36, T. 45 N., R. 99 W.

	Thickness	Depth
	Feet	*Feet*
Cody shale:		
Shale, gray and brown	1, 505	1, 505
Frontier formation:		
Sandstone, dark	23	1, 528
Shale	18	1, 546
Sandstone; a little gas at 1,562 feet	60	1, 606
Shale, black	64	1, 670
Sandstone, coarse, with water	20	1, 690
Shale, black; a little oil and gas	35	1, 725
Sandstone with shale	5	1, 730
Sandstone, gray; water	24	1, 754
Shale, gray	5	1, 759
Sandstone	16	1, 775
Shale, with bentonite	12	1, 787
Sandstone, oil	8	1, 795
Shale, with bentonite	7	1, 802
Sandstone, water	12	1, 814
Shale, with bentonite	7	1, 821
"Lime" rock	2	1, 823
Sandstone, oil	10	1, 833

During 1919 the Midwest Refining Co. drilled a fourth well, of which the log is as follows:

Log of well of Midwest Refining Co. on Wagonhound anticline

	Thickness	Depth
	Feet	*Feet*
Cody shale:		
Shale, black	418	418
Frontier formation:		
Sand	12	430
Lime shell and black shale	40	470
Shale	15	485
Sand; traces of oil, gas, and water	60	545
Shale	5	550
Sand; water	32	582
Sand	13	595
Shale, brown and gray	30	625
Sand	35	660
Shale, sandy	15	675
Sand	25	700
"Granite" (?)	20	720
Sand	25	745
Shale, sandy	25	770
Sand	35	805
"Granite" (?)	10	815
Sand	25	840
Mowry and Thermopolis shales:		
Shale, sandy, brown	85	925
Shale, sandy, gray	45	970
Shale	35	1, 005
"Granite" (?)	15	1, 020

Log of well of Midwest Refining Co. on Wagonhound anticline—Continued

	Thickness	Depth
Mowry and Thermopolis shales—Contd.	*Feet*	*Feet*
Shale, sandy	40	1, 060
Shale	14	1, 074
"Granite" (?)	21	1, 095
Shale	365	1, 460
Sand; water (Muddy sand ?)	50	1, 510
Shale, brown	96	1, 606
Sand	8	1, 618
Shale, sandy	5	1, 623
Shale, brown	47	1, 670
Cloverly formation:		
Sand	15	1, 685
Shale, sandy	10	1, 695
Lime, sandy	25	1, 720
Sand	20	1, 740

The log of this well shows that the section closely resembles in thicknesses and lithology the sections of the same formations recorded in the deep wells of Grass Creek. The term "granite" was undoubtedly used incorrectly by the driller.

Outlook.—Although these wells are drilled on the crest of the anticline, none of the beds as deep as the Cloverly formation yielded more than traces of oil and gas. The work that has been done shows clearly that those beds are not oil and gas bearing in this anticline. The Muddy sand, which contains gas at Grass Creek and the Oregon Basin South dome, contains water here. It must be admitted, however, until more information is available concerning the distribution of oil and gas in the Morrison, Chugwater, and Embar formations, that those substances may be present in these beds on the Wagonhound anticline.

COTTONWOOD ANTICLINE

Surface features.—The Cottonwood anticline,[64] or Hamilton dome, as it has been called recently, is conspicuously marked by a series of low concentric ridges near Cottonwood Creek in T. 44 N., R. 98 W., 20 miles west of Thermopolis (Pl. XXIV, *B*). These ridges rise several hundred feet above a broad plain, which is 4 to 5 miles wide where it is crossed by Cottonwood Creek. The plain ends abruptly on the north and west and locally on the south and east against a steep, rugged escarpment 400 to 600 feet high made up of sandstones of the Mesaverde formation. The ridges consist of the sandstones of the Frontier formation, and the successive outcrops form uncommonly perfect ellipses whose axes are parallel to the crest of the anticline. In the center an elliptical flat basin coincides with the outcrop of the Thermopolis shale.

The region is practically devoid of all vegetation except a sparse growth of dwarfed sagebrush and grass.

[64] Collier, A. J., Oil in the Warm Springs and Hamilton domes, near Thermopolis, Wyo.: U. S. Geol. Survey Bull. 711, pp. 61–73, 1920.

A few pines dot the ridges here and there. Cottonwood Creek carries water on the surface most of the year. The region may be reached by fair roads from the valley of Owl Creek on the south, from the east, and from Grass Creek on the north.

Stratigraphy.—The lowest beds exposed on the crest of the anticline are the shales near the top of the Thermopolis formation. The Mowry and Frontier formations crop out, and the beds of the Frontier have been measured in detail (Pl. VI, No. 14). The broad plain that surrounds the ridges is cut in the Cody shale, the lower 300 feet of which is fairly well exposed on a low hill in sec. 18, T. 44 N., R. 97 W.

The thickness of the Cody shale has been measured at several localities near the anticline and appears to range from 1,900 feet on the steep south limb to 2,950 feet on the flat north limb. As these measurements depart appreciably from the average of several made near by, it seems highly probable that the shale along the south limb has flowed during compression and that a structural terrace exists along the north limb. Beds of the Cloverly, Morrison, Sundance, Chugwater, and Embar formations have been penetrated by the drill in several wells on the anticline.

Structure.—The anticline is separated from the middle trough of the Big Horn Basin by a group of anticlines that include the Grass Creek and Waugh anticlines and by a complicated group of synclines that include the Waugh, Ilo, and Grass Creek synclines. The dip of the beds as they rise from the Ilo and Waugh synclines is exceptionally uniform at 10° to 15°. The escarpment of Mesaverde sandstones on the north dips uniformly 11°–12° NE., and this conforms closely with the dip of the outcropping Frontier sandstones. On the south side of the anticline these sandstones dip steeply to the Wagonhound syncline on the west and the Padlock syncline on the east, locally attaining angles of 72°. South of the Wagonhound syncline the beds rise again to a group of anticlines south of Owl Creek. The structure contours on the uppermost sandstone of the Frontier are based largely on the surface outcrops of that bed.

Four faults, roughly radial in arrangement, lie around the west end of the anticline, but on the east there are two parallel faults that are normal to the crest line. The south limb, especially in sec. 24, T. 44 N., R. 98 W., is broken into a number of segments by a number of roughly parallel faults that trend N. 10° W. to N. 10° E. and dip steeply west. The effect of each of these faults is to throw the western segment north a small distance, nowhere more than 25 feet. The plotted boundary of the Frontier formation follows the average direction of all the segments rather than the varying directions of the separate segments. It seems highly probable that similar faults break the thin sandstones as deep as those in the Chugwater formation, if not deeper.

Exploration.—Three wells were drilled on this anticline before oil was encountered. By October, 1919, three more had been drilled and the rigs of two more were completed. The first two wells were scarcely 50 feet apart, in the NW. ¼ SE. ¼ sec. 14, T. 44 N., R. 98 W. The record of the first is not available. The second well (No. 1, Pl. III) had attained a depth of 850 feet in September, 1913. It started in the Thermopolis shale, and the bottom at 850 feet was in the Chugwater formation. No oil or gas and only a little water was obtained from it. Another well (No. 2, Pl. III) was drilled in 1916, but the depth and log are not known.

The first successful well (No. 3, Pl. III) was begun in May, 1918, by the Petroleum Producers Corporation, of Seattle, Wash., and by October had reached a depth of 1,420 feet, where heavy oil was struck in the Chugwater formation. It was pumped intermittently from October, 1918, to August, 1919, yielding from 20 to 30 barrels of oil a day. The well was then drilled deeper in the hope of striking the Embar oil sand. It was 2,215 feet deep on September 22, 1919. A partial log of this well [65] is given herewith:

Log of Petroleum Producers Corporation well No. 1, in the SW. ¼ SW. ¼ sec. 13, T. 44 N., R. 98 W.

	Thickness	Depth
	Feet	*Feet*
Thermopolis shale:		
Limestone, sandy, broken	25	25
Shale, blue	10	35
Lime, sandy	15	50
Mud, blue	50	100
Slate, black	25	125
Mud, blue	35	160
Lime, soft	10	170
Shale, black	35	205
Shale, light, sandy	50	255
Cloverly formation:		
Sand, dry	40	295
Rock, red	20	315
Clay, sandy	20	335
Morrison formation:		
Clay, yellow	20	355
Slate, gray	30	385
Clay, all colors	55	440
Sandstone	5	445
Rock, red	40	485
Rock, white sand	40	525
Talc	65	590
Sundance formation:		
Talc	55	645
Shale	15	660
Talc	70	730
Sand	5	735
Shell, hard	10	745
Shale, blue	80	825
Lime, sandy	5	830
Lime, hard	35	865
Talc	35	900
"Sundance beds"	30	930
Chugwater formation:		
Red beds	340	1, 270
Shale, gray; gas	10	1, 280
Red beds	65	1, 345
Shale, gray; show of oil	30	1, 375
Sand, oil	45	1, 420

Petroleum Producers well No. 2 (No. 4, Pl. III), in the NE. ¼ SE. ¼ sec. 14, T. 44 N., R. 98 W., was spudded November 15, 1918, but was drilled only 30

[65] Collier, A. J., op. cit., pl. 8, p. 66.

feet that winter. Drilling was begun again August 4, 1919, and on September 24 had penetrated the oil sand in the Chugwater formation at a depth of 1,520 feet. A sample of the oil was collected by the writer (No. 8, p. 88).

Petroleum Producers well No. 3 (No. 5, Pl. III), in the NE. ¼ NW. ¼ sec. 24, T. 44 N., R. 98 W., was spudded February 21, 1919. Oil was struck in the Chugwater sand April 10 and rose 400 feet in the well. Sinking was continued, and on July 4 oil was struck in a sand of the Embar formation at a depth of 2,292 feet. The well was pumped from six to ten hours daily from July 4 to September 24, 1919, with an estimated maximum yield of 156 barrels in 24 hours and an estimated total yield of 4,000 barrels. A sample of the oil drawn from the line to the tank has been analyzed, with the results given in No. 7, page 88. A copy of the log submitted by the manager, E. C. Johnson, is presented below:

Log of Petroleum Producers Corporation well No. 3, in the NE. ¼ NW. ¼ sec. 24, T. 44 N., R. 98 W.

	Thickness	Depth
	Feet	*Feet*
Thermopolis shale:		
Slate, gray and blue	220	220
Shale, gray and blue	120	340
Cloverly formation(?):		
Shale, dark gray	30	370
Shale, red	25	395
Morrison formation:		
Shale, pink	95	490
Shale, gray, sandy	25	515
Shale, pink	40	555
Sand, coarse and fine, gray	95	650
Sundance formation:		
Shale, gray	5	655
Sand, gray	10	665
Shale, gray, sandy	125	790
Sand, gray, hard	15	805
Shale, blue; show of oil, gas, and water	85	890
Sand, gray	5	895
Lime, hard	20	915
Sand, light	5	920
Talc	60	980
Chugwater formation:		
Shale, pink	40	1,020
Red beds	120	1,140
Shale, pink	111	1,251
Red beds	132	1,383
Shale, gray	37	1,420
Sand, gray; oil	51	1,471
Red beds	104	1,575
Sand; oil	10	1,585
Red beds	105	1,690
Shale, red, sandy	5	1,695
Sand, gray; oil	25	1,720
Red beds	95	1,815
Sand; show of oil	5	1,820
Red beds	70	1,890
Sand, hard, red	5	1,895
Sand and shale, gray	5	1,900
Red beds	30	1,930
Sand; oil	42	1,972
Red beds	10	1,982
Sand, gray	33	2,015
Red beds	90	2,105
Shale, sandy, gray	15	2,120
Red beds	125	2,245
Embar formation:		
Sand and lime	47	2,292
Sand, soft, gray; oil	5	2,297
Sand, hard, brown	25	2,322

In September, 1919, the other two wells (Nos. 6 and 7, Pl. III) had attained a depth of only 20 feet.

Occurrence of oil and gas.—The well records do not show a sand that can be correlated with the Muddy sand, and the Cloverly formation, buried at a depth of only 275 feet, is barren of oil and gas. The trace of oil and gas recorded in the Sundance formation is interesting as the first recorded in this formation in Wyoming. It was apparently too slight to warrant attaching great importance to it at this time.

The occurrence of commercially important quantities of petroleum in beds of the Chugwater formation is highly interesting. Lupton [66] records a seepage of heavy oil on the outcrop of Chugwater beds near the crest of the Red Spring anticline, in the NW. ¼ sec. 29, T. 43 N., R. 93 W., and Collier [67] states that traces of oil were reported at several horizons in the Chugwater formation in a well in sec. 23, T. 6 N., R. 2 W. Wind River meridian. Woodruff [68] says that wells in the Lander field have found local reservoirs of oil in the Chugwater beds. The yield of these beds on the Cottonwood anticline, however, appears to be greater than in any other locality.

Oil has been found in beds of the Embar group in the Warm Springs, Maverick Springs, and Lander fields and on Bolton Creek, Natrona County. Analyses of these oils show that the oil from the Cottonwood anticline is lighter and yields a higher proportion of light distillates than the others.

The extent of the pools on the Cottonwood anticline had not been determined in 1919. At that time no well in the Chugwater and Embar formations had yielded water.

ANALYSES

Analyses of oil.—The table on page 88 presents analyses of eight samples of crude oil, five from wells in the Grass Creek field and three from the Cottonwood field. All except three of these samples were collected by the writer. C. T. Lupton collected the samples from L. G. Phelp's well No. 1 and Washakie No. 13 lease well No. 1, and A. J. Collier [69] collected the sample from Petroleum Producers Corporation well No. 1 in 1918. The exact conditions under which these three samples were collected are not known. Of the remaining five, all except that from Petroleum Producers Corporation well No. 3 were collected from the casing heads at the wells. Although one sample was collected from Q. Littlejohn well No. 4 in 1916, it was considered desirable to take a second sample in 1919. The slight differences between the analyses of these two samples appear to be but little more than those which might be expected from duplicate analyses of the same sample.

[66] Hewett, D. F., and Lupton, C. T., op. cit., p. 135.

[67] Collier, A. J., Anticlines near Maverick Springs, Wyo.: U. S. Geol. Survey Bull. 711, p. 165, 1920.

[68] Woodruff, E. G., The Lander oil field, Wyo.: U. S. Geol. Survey Bull. 452 p. 27, 1911.

[69] Collier, A. J., Oil in the Warm Springs and Hamilton domes, near Thermopolis, Wyo.: U. S. Geol. Survey Bull. 711, pp. 61-73, 1920.

Analyses of oils from Grass Creek and Cottonwood anticlines

	Grass Creek					Cottonwood		
	1	2	3	4	5	6	7	8
Laboratory No.	(?)	(?)	00463	(?)	00464	00373	00466	00465
Amount distilled (cubic centimeters)	100	100	300	(?)	300	200	300	300
First drop of distillate appeared (° C.)	28	[a] 80	26	32	23	60	25	24
Air distillation, with fractionating column:								
Pressure (millimeters)	----	----	747	----	746.8	(?)	739	741.6
Fractions, by volume (per cent)—								
To 50° C.			4.3	2.0	2.6	0.0	2.1	1.0
50°–75° C.			4.3	3.5	3.8	.7	1.9	.6
75°–100° C.	35	[a] 22	8.2	6.5	9.0	.5	.9	1.3
100°–125° C.			8.4	9.5	8.5	1.6	2.6	1.9
125°–150° C.			7.1	9.0	7.6	3.7	3.2	3.3
150°–175° C.			7.1	6.0	6.6	2.3	3.9	2.2
175°–200° C.			4.8	5.5	5.1	4.3	3.5	2.3
200°–225° C.	32	42	5.6	6.0	6.1	3.9	3.7	3.5
225°–250° C.			5.8	5.5	6.0	6.7	4.8	4.3
250°–275° C.			5.6	6.5	6.2	5.0	4.8	6.6
275°–300° C.			6.9	5.5	6.1	----	6.9	17.4
Residue	33	36	31.9	34.5	32.4	71.3	61.7	55.6
Vacuum distillation, without fractionating column (pressure, 40 millimeters):								
150°–175° C.	----	----	----	----	.1	2.0	.6	.9
175°–200° C.	----	----	.03	----	1.4	6.5	1.3	.5
200°–225° C.	----	----	4.3	----	4.0	12.0	4.3	.9
225°–250° C.	----	----	5.1	----	5.0	19.0	5.2	3.0
250°–275° C.	----	----	4.0	----	4.1	([b])	6.6	6.4
275°–300° C.	----	----	4.3	----	1.9	----	3.6	3.4
Specific gravity:								
Crude	0.7984	[a] 0.8187	0.805	0.7977	0.805	0.917	0.895	0.934
Equivalent on Baumé scale (°)	45.3	41.0	44.0	45.5	44.0	22.6	26.6	19.0
To 50° C.			0.635		0.640	----	0.665	
50°–75° C.			.680		.662			0.715
75°–100° C.	0.7290	0.7530	.724	0.7275	.728	0.710	.725	
100°–125° C.			.749		.750			
125°–150° C.			.770		.768	.752	.751	.751
150°–175° C.			.783		.785	.765	.770	.782
175°–200° C.			.797		.795	.791	.790	.798
200°–225° C.	.8150	.8175	.807	.8120	.809	.808	.800	.815
225°–250° C.			.820		.822	.828	.821	.831
250°–275° C.			.838		.837	.840	.839	.848
275°–300° C.			.840		.843	----	.858	.858
Sulphur (per cent)	0.10	----	0.12	----	0.085	----	1.32	2.56
Water	----	----	None.	----	None.	----	None.	None.

[a] Specimen weathered.

[b] Cracked at about 260° in vacuum.

1. L. G. Phelps No. 1, 670–930 feet (Frontier). Sample collected July, 1915.
2. Washakie No. 1, 1,060–1,135 feet (Frontier). Sample collected July, 1915.
3. D. A. Ehrlich No. 22, 678–830 feet (Frontier). Sample collected Sept. 30, 1919.
4, 5. Q. Littlejohn No. 4, 1,081–1,280 feet (Frontier). Samples collected, No. 4, Oct. 17, 1916; No. 5, Sept. 30, 1919.
6. Petroleum Producers Corporation No. 1, 1,375–1,420 feet (Chugwater). Sample collected Sept. 23, 1919.
7. Petroleum Producers Corporation No. 3, 2,292–2,297 feet (Embar). Sample collected Sept. 23, 1919.
8. Petroleum Producers Corporation No. 2, 1,520 feet (Chugwater). Sample collected Sept. 23, 1919.

The characteristic feature of the oil from the Frontier formation at Grass Creek is the high yield in gasoline, which ranges from 30 to 35 per cent. In this feature the oil closely resembles that from the Lance Creek field, but the yield is much higher than that from the oils of Salt Creek and most of the other Wyoming fields.

Analyses of water.—During the progress of the field work three samples of water were collected from wells that were being pumped in the Grass Creek field, and these have been analyzed in the laboratory of the United States Geological Survey, with the results presented in the following table. Samples Nos. 1 and 2 were collected from the northeast or basinward side of the anticline, and No. 3 from the southwest or mountainward side of the anticline. These three analyses closely resemble one another; the principal differences in composition concern the ratio of carbonate to bicarbonate radicle, and this may be explained by the method of analysis or the time elapsing between collection and analysis.

The analyses resemble those of samples Nos. 2 and 7 collected by Wegemann [70] from the Shannon and Wall Creek sands, respectively, in the Salt Creek field. They are uncommonly interesting because the content of chloride and sulphate radicles is low.

Analyses of oil-field waters from Grass Creek field

	1	2	3
Properties: [a]	*Per cent*	*Per cent*	*Per cent*
Primary salinity	12.8	8.6	16.3
Secondary salinity	----------	----------	----------
Primary alkalinity	86.7	91.5	82.5
Secondary alkalinity	0.5	0.9	1.2
	100	100	100
Constituents:	*Parts per million*	*Parts per million*	*Parts per million*
Sodium	1,012	1,105.1	1,237.2
Potassium	Trace.	2.7	2.7
Alkalies	1,012	1,107.8	1,239.9
Calcium	4.3	5.2	7.6
Magnesium	Trace.	1.7	3.6
Alkaline earths	4.3	6.9	11.2
Iron, alumina	Trace.	3.4	1.5
Sum of bases	1,016.3	1,118.1	1,252.6
Sulphate	79	2.7	13
Chloride	143	134.0	304.7
Strong acids	222	136.7	317.7
Carbonate	144	1,354.4	1,362.3
Bicarbonate	1,903	1,298.0	1,238.0
Weak acids	2,047	2,652.4	2,600.3
Sum of acids	2,269	2,789.1	2,918.0
Silica	22	12	16.4
Total solids	3,307.3	3,919.2	4,187.0

[a] Reacting values of acids and bases do not balance; it is assumed that errors have been made in the determinations of carbonate and bicarbonate.

[70] Wegemann, C. H., The Salt Creek oil field, Wyo.: U. S. Geol. Survey Bull. 670, pp. 42-44, 1917.

Analyses of oil-field waters from Grass Creek field—Continued

	1	2	3
Reacting values: [a]	*Parts per million*	*Parts per million*	*Parts per million*
Alkalies:			
Sodium	44.022	48.071	53.818
Potassium	----------	.059	.059
Alkaline earths:			
Calcium	.214	.259	.379
Magnesium	----------	.159	.296
Total bases	44.236	48.548	54.552
Strong acids:			
Sulphate	1.643	.056	.270
Chloride	4.032	3.778	8.592
Weak acids:			
Carbonate	4.795	45.101	45.364
Bicarbonate	31.209	21.287	20.303
Total acids	41.679	70.222	74.529

[a] Reacting values of acids and bases do not balance; it is assumed that errors have been made in the determinations of carbonate and bicarbonate.

1. Meeteetse 17 No. 9, 978-1,100 feet (upper 200 feet of Frontier). Sample collected Oct. 17, 1916.
2. Orchard No. 9, 997-1,075 feet (upper 200 feet of Frontier). Sample collected Sept. 14, 1919.
3. Happy Thought No. 3, 870-987 feet (upper 200 feet of Frontier). Sample collected Sept. 30, 1919.

OCCURRENCE OF OIL AND GAS

Within the 661 square miles covered by the three quadrangles considered in this report there are 12 well-defined anticlinal folds. All but one of these, the Gooseberry dome, have been explored by the drill, with the result that two of them, the Grass Creek and Cottonwood anticlines have become productive oil fields, and four more, the Oregon Basin domes and the Buffalo anticlines, have yielded considerable gas. Except on the Cottonwood anticline, where the Frontier formation is exposed by erosion and the oil occurs in the Chugwater and Embar formations, all the oil or gas has been yielded by sands of the Frontier. Deep drilling at Grass Creek has proved that oil is present also in the Morrison formation.

In the preliminary report on the occurrence of oil in this region [71] a summary of the results of exploration of 24 of the 50 anticlines south of the latitude of Cody was presented. It was pointed out then (1916) that every upfold which had yielded more than traces of oil or gas lay adjacent to the middle trough of the Big Horn Basin and that every tested upfold which was separated from the middle trough by other folds had either yielded water with the merest traces of oil and gas or was barren of oil and gas. It was therefore concluded that basinward upfolds offered the best chances for exploration.

Although data that would permit an exhaustive reconsideration of the relations of oil and gas to basinward and mountainward upfolds are not available, sufficient is now known to show that no simple statement can be made. There appear to be exceptions to all general statements concerning the production of the sands and the areal relations of the folds. In these quadrangles all the basinward upfolds have

[71] Hewett, D. F., and Lupton, C. T., op. cit., pp. 43-45.

yielded considerable gas or oil from the Frontier sands. On the other hand, if the entire southwest side of the Big Horn Basin is considered, there are two exceptions to the statement that the Frontier sands do not yield appreciable oil or gas in mountainward upfolds—the Enos Creek anticline, where considerable gas is found in a lower sand of the Frontier, and the Kirby Creek anticline, where considerable oil also is found in a lower Frontier sand. Furthermore, recent exploration has shown that oil and gas are widely distributed in sands below the Frontier formation without regard to the areal relations of the folds. Thus, the Morrison formation yields oil under the Grass Creek anticline, and the Chugwater formation yields considerable gas in the Little Grass Creek dome and the mountainward Wagonhound and Cottonwood anticlines. The Embar also yields oil on the mountainward Cottonwood and Warm Springs anticlines.[72]

One tentative conclusion may be drawn from the results of drilling on the southwest side of the Big Horn Basin to date—namely, that oil and gas tend to accumulate in Chugwater and Embar sands under more upfolds, regardless of their areal relations, than in Frontier, Mowry, Thermopolis, and Cloverly sands. It is worth while, therefore, to consider exploration for oil and gas in these deep sands under upfolds where the higher sands have been proved to be dry. Thus far, however, the pools in the deep sands have been found to have smaller areal extent than those in the higher sands, and the thickness of the productive sands is much less. Moreover, as the deep sands lie 2,000 to 3,000 feet deeper than the top of the Frontier formation, their exploration is much more expensive.

Only in the Grass Creek field has there been sufficient exploration to indicate precisely the shape of the pools and their relation to the anticlinal crest. It is clear that the principal pool in this field extends 500 feet lower on the southeast end of the anticline than on the northwest end, and 200 to 300 feet lower on the basinward side than on the mountainward side. Although the Greybull pool, on the northeast side of the Big Horn Basin, is much smaller and less definitely proved, it is clear that there also the oil extends 1,000 to 1,500 feet lower on the basinward side than on the mountainward side. Reference is made to this similarity in considering the part that movement of water may have played in concentrating the oil in anticlines (p. 92).

Faults are present on the surface near the crest of each upfold that bears oil or gas on the west side of the basin, except the Little Buffalo anticlines. Only on the Oregon Basin North dome, however, is it clear that a fault has played an important part in localizing the oil. In that field the oil occurs only on the north side of a fault, in the block that was dropped relatively. Although undoubtedly there are many small faults on the crest of the Cottonwood anticline, they do not appear to affect the distribution of oil near the crest.

[72] Collier, A. J., op. cit.

ACCUMULATION OF OIL AND GAS

In the attempt to understand the causes of the accumulation of oil in pools, many kinds of data deserve consideration. First of all, many local data are needed by which to interpret the present lithologic, stratigraphic, and structural conditions in the area, the properties of the oil, gas, and water, their present distribution in the beds and their behavior when the beds are penetrated by drills and thereafter under pumping. Inasmuch as most geologists agree that oil, gas, and water have migrated during the process of accumulation, similar data are also needed from near-by regions if they are obtainable. Events that have an important bearing on the stratigraphic problem and structural history may not have left an adequate local record. Although the writer is particularly familar with the three quadrangles under consideration, and much is on record concerning the geology and occurrence of oil and water in the Big Horn Basin, there is need for much more information before a comprehensive explanation of the process of accumulation can be confidently offered.

In order to consider the problem of migration of oil and water in the Frontier formation, the relations and continuity of the sandstone layers should be reviewed. The available data indicate that the sands are not persistent over large areas comparable to the present Big Horn Basin, although the formation retains its character over a larger area. It seems doubtful whether any layer of sandstone persists 20 miles, and many probably do not persist 10 miles. If this is true, it is hard to imagine that in this region water or oil has circulated freely for such greater distances at any time. Furthermore, the beds of sand are separated here and there by beds of bentonite probably as persistent as those of sand. These beds would certainly hinder widespread movement through the beds laterally or transversely. Of the wells drilled into these beds that do not yield oil, only a few yield a continuous flow of water, and the rate of flow is small. Thus, these sands yield a small flow from the well in sec. 4, T. 48 N., R. 101 W., in Spring Creek Basin; well No. 8, in sec. 10, T. 47 N., R. 100 W., in Little Buffalo Basin; and the well on the Enos Creek anticline, in sec. 25, T. 46 N., R. 100 W. In a greater number of wells more widely distributed, however, water was either negligible or rose only a short distance in the well. By contrast, the Muddy sand and Cloverly sandstone (Greybull sand) yield water freely over a large area and are therefore probably continuous throughout the basin. In the opinion of the writer, the behavior of the water in the Frontier sandstones confirms the impression, obtained from study of the outcrop, that the beds are lenticular and do not offer opportunity for free flow over areas as large as the Big Horn Basin.

Several features of the region indicate that all the folds were not formed at the same time but that they were progressively formed from the mountainward areas inward toward the center of the Big Horn Basin. During the folding tremendous compressive forces would affect all the rocks in the basin and tend to force liquids to higher zones. Furthermore, it seems certain that the central part of the Big Horn Basin sank after the belt of folds had been formed. If this sinking was due to the load of Wasatch sediments spread in Eocene time, it would probably tend to consolidate further the more deeply buried sediments. The first stage of folding would probably not give any particular fold an advantage over another as a favorable collecting area for oil and water, but the later sinking of the center of the basin would tend to force oil and water to the border group of anticlines. This would offer an explanation of the apparent advantage of basinward anticlines, at least so far as the Frontier formation is concerned.

The faults of this region are not extensive nor of great throw but are largely localized near crests of folds. They appear to have locally controlled the movement of oil but at no place to have played a part in determining whether a fold received oil or gas. The faults near the crests of the Oregon Basin domes and Cottonwood anticline have not permitted gas and oil near by to escape.

The oil, gas, and water are found near the crests of upfolds in the beds, much as is demanded by the simplest conception of the anticlinal theory. In the strictest sense the pools of oil are not symmetrically disposed on the crests but extend lower on the basinward sides than on the mountainward sides. In other words, there is not complete hydrostatic adjustment between the two liquids, even though the concentrated bodies of the lighter liquid lie above those of the heavier. Over a large part of the principal pool, however, the oil and water appear to be rather intimately mixed. After long-continued pumping, the border wells tend to yield decreasing quantities of oil and increasing quantities of water, but here and there, at existing rates of pumping, wells in several parts of that field are readily exhausted of both liquids temporarily. These data, however, probably indicate local differences in the porosity of the sands.

The movement of underground water during the early period of folding, as well as during and since the later period, up to the present time, has probably had an influence on the accumulation of oil on the crests of upfolds. There is room for a great difference of opinion, however, concerning the relative importance of the process during these periods. Daly,[73] in proposing the "diastrophic theory," considers that a considerable part of the process of accumulation takes place during the period of folding, being due to the movement of water and oil in response to the compressive forces set up at that time. On the other hand, Munn [74] and Rich [75] favor the "hydraulic theory," which is based on the idea that "moving water under either hydraulic or capillary pressure has been the direct agent of accumulation." It would appear that this agent is considered to be most effective after the rocks have been deformed. Rich[76] has urged the application of the hydraulic theory to explain conditions in the Big Horn Basin. He states:

> In a large intermont basin, like the Big Horn Basin of Wyoming, there are ideal artesian conditions. The sands of the Cretaceous are exposed at relatively high altitudes along the borders of the basin, from which they dip steeply, with here and there a reversal, into the deeper parts of the basin, 5,000 to 10,000 feet below. Conditions at most places are favorable for the intake of meteoric waters at the outcrops, and in most of the basins the outcrops on the outlet rims are some thousands of feet lower than those of the same sands on the intake rims. Under such conditions there is certainly a general and fairly rapid circulation of water through the basin.

First, it should be pointed out that the water associated with the oil at Grass Creek (p. 89), as well as that in deep wells in Little Buffalo, Spring Creek, and Oregon basins, is very unlike that found in deep oil wells elsewhere in Wyoming, as well as many other regions, and appears to be a modified surface water. It is interesting on account of its high content of sodium bicarbonate; in this respect it resembles a shallow water from the Shannon sand near the Shannon pool,[77] in the Salt Creek field. Although no special study has been made of the composition of the surface water of this region, analyses are available of Shoshone River at Cody, Wyo., Yellowstone River at Billings and Glendive, Mont., Big Horn River at Fort Custer, Mont., and North Platte River at Fort Laramie, Wyo.[78] In these waters the dissolved solids range from 153 to 403 parts per million; the ratio of lime to soda plus potash ranges from 1.5 : 1 to 1 : 1, and the ratio of bicarbonate to sulphate to chloride ranges from about 8 : 7 : 1 to 8 : 3 : 1.

By contrast, in the waters from the Grass Creek wells the ratio of lime to soda ranges from 1 : 235 to 1 : 163, and the ratio of bicarbonate to sulphate to chloride from about 1,000 : 1 : 50 to 287 : 1 : 2. From this it will be noted that the Grass Creek water resembles the surface water of the region much more closely than it resembles the brines commonly found in deeply

[73] Daly, M. R., The diastrophic theory: Am. Inst. Min. Eng. Trans., vol. 56, pp. 733-753, 1917.

[74] Munn, M. J., The anticlinal and hydraulic theories of oil and gas accumulation: Econ. Geology, vol. 4, pp. 509-529, 1909.

[75] Rich, J. L., Moving underground water as a primary cause of the migration and accumulation of oil and gas: Econ. Geology, vol. 16, pp. 347-371, 1921; Further notes on the hydraulic theory of oil migration and accumulation: Am. Assoc. Petroleum Geologists, Bull., vol. 7, pp. 213-233, 1923.

[76] Rich, J. L., Econ. Geology, vol. 16, pp. 358-362, 1921.

[77] Wegemann, C. H., op. cit., p. 42.

[78] Stabler, Herman, Some stream waters of the western United States: U. S. Geol. Survey Water-Supply Paper 274, pp. 122, 134, 135, 19, 74, 1911.

buried oil pools. It is apparent, however, that the surface water of the region would have to undergo many changes before it would resemble the Grass Creek water. It is possible to imagine that the lime of the surface water could be exchanged for soda by bringing it into contact with the bentonite present in the beds, much as is done in a recently perfected process for softening water for industrial purposes. It is not apparent, however, how the total solids could be so greatly increased and the sulphate radicle almost eliminated. The sulphate could be reduced to sulphide in contact with the oil, but it seems improbable that this process has gone on here, because the oil from the Frontier sands contains very little sulphur. The conclusion is clear that surface water has mingled with the water originally associated with the oil in the Frontier sands.

One of the fundamental requirements of the hydraulic theory of oil accumulation demands that water has moved rather freely in the oil-bearing beds from a high region of intake to a lower region of outlet.

In the Big Horn Basin, we may imagine, (1) water has remained nearly stagnant, or (2) surface water has moved freely in the beds from the higher belt of outcrops of the Frontier formation around the east, south, and west sides to the lowest point on the outcrop, where Sheep Mountain is cut by Big Horn River, roughly 2,000 feet lower, or (3) it has been taken in around the border and carried northwestward along the middle trough of the basin to a still lower region in Montana. The last assumption demands the freest movement of water and the greatest persistence of the sandstones of the Frontier formation, and the writer does not consider that it is justified. The second assumption demands that water move in the beds from the southwest side of the basin a distance of 60 miles to the northeast side at such a rate as to effect a concentration of oil under the basinward anticlines. Although surface water has undoubtedly been added to that associated with the oil in the Grass Creek pool, the available data concerning the continuity of the sands of the Frontier formation indicate that it has not circulated freely.

In any speculation concerning a great circulation of water under the Big Horn Basin, the extent of erosion since the folding that followed Fort Union time should be considered. The border belt of folds was extensively eroded after the folding, and the beds of the Frontier formation were exposed so that they could absorb water. The outcrops were probably completely covered by "border Wasatch" deposits, however, after the central part of the basin had been filled with several thousand feet of sediment. Since the outcrops were thus covered only in a few local areas southwest of the folded belt have the beds again been exposed so that they could absorb water. Thus along the southwest side of the basin west of Big Horn River the entire Frontier formation is exposed only on the Fourbear, Sunshine, Cottonwood, and Thermopolis anticlines. The upper part is locally exposed in several places. Although the period during which the Frontier formation could absorb water has therefore been brief in a geologic sense, it has been long enough to add considerable surface water to that already existing.

It may be noted that the general distribution of oil and gas on the southwest side of the Big Horn Basin is in accord with what might be expected either from the diastrophic or the hydraulic theory.

In conclusion, the writer believes that the conditions of occurrence of oil and gas in this region tend to fortify the diastrophic theory, although it is apparent that much more must be known before a conclusive opinion can be stated.

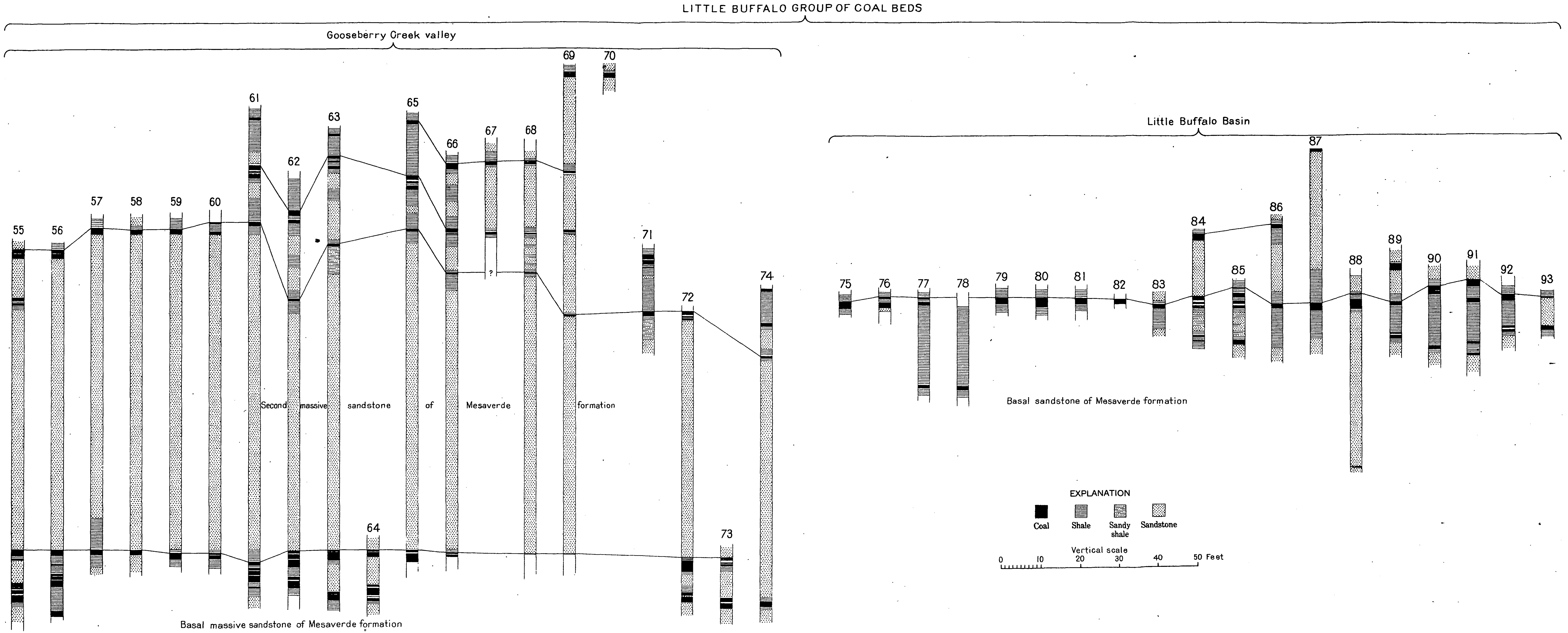
COAL

Beds of coal occur in three of the formations recognized in this region—the Mesaverde, Meeteetse, and Fort Union—and consequently outcrops are widespread. Here and there natural exposures give a fair impression of the thickness and character of the beds; elsewhere only a slight amount of digging is necessary to lay bare the entire bed. As the position and distribution of the coal beds are intimately related to several stratigraphic problems of the region, and as the coal will be an important resource some day, it seemed advisable during the progress of field work to explore by shallow grooves each of the beds in the coal-bearing part of the section at many places. This work yielded an immense amount of detailed data and showed clearly that although the number of beds is unusually large and they persist over large areas, the grade and thickness are such that they will not be exploited widely for many years. To present all the detailed records of the coal beds measured would take undue space in this report, and the conclusion has been reached that the general stratigraphic sections reproduced to scale, taken with the summarized sections on pages 94–101, give all the information needed at this time.

COAL IN THE MESAVERDE FORMATION

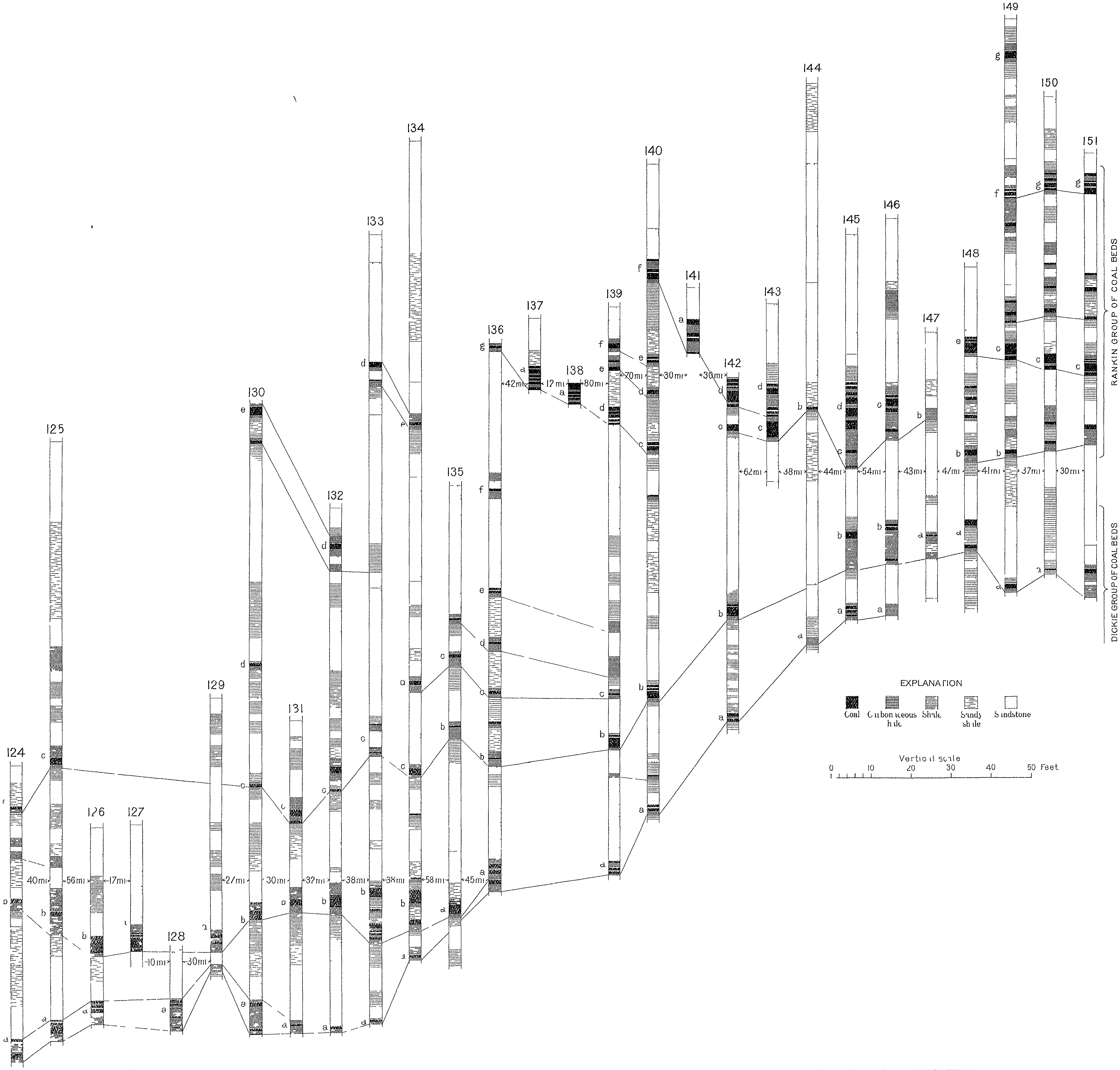
GENERAL FEATURES

By comparison with natural exposures of coal beds in general as well as of beds that occur in the higher formations in this region, the coal beds of the Mesaverde formation are well exposed. It is possible, therefore, to obtain a highly accurate idea of the nature, thickness, and extent of many beds in each part of the region. The coal beds occur in thin zones of shale and sandstone between thick beds of massive sandstone, and as they commonly dip from 10° to 50°, the rock waste is quickly stripped from the coal-bear-

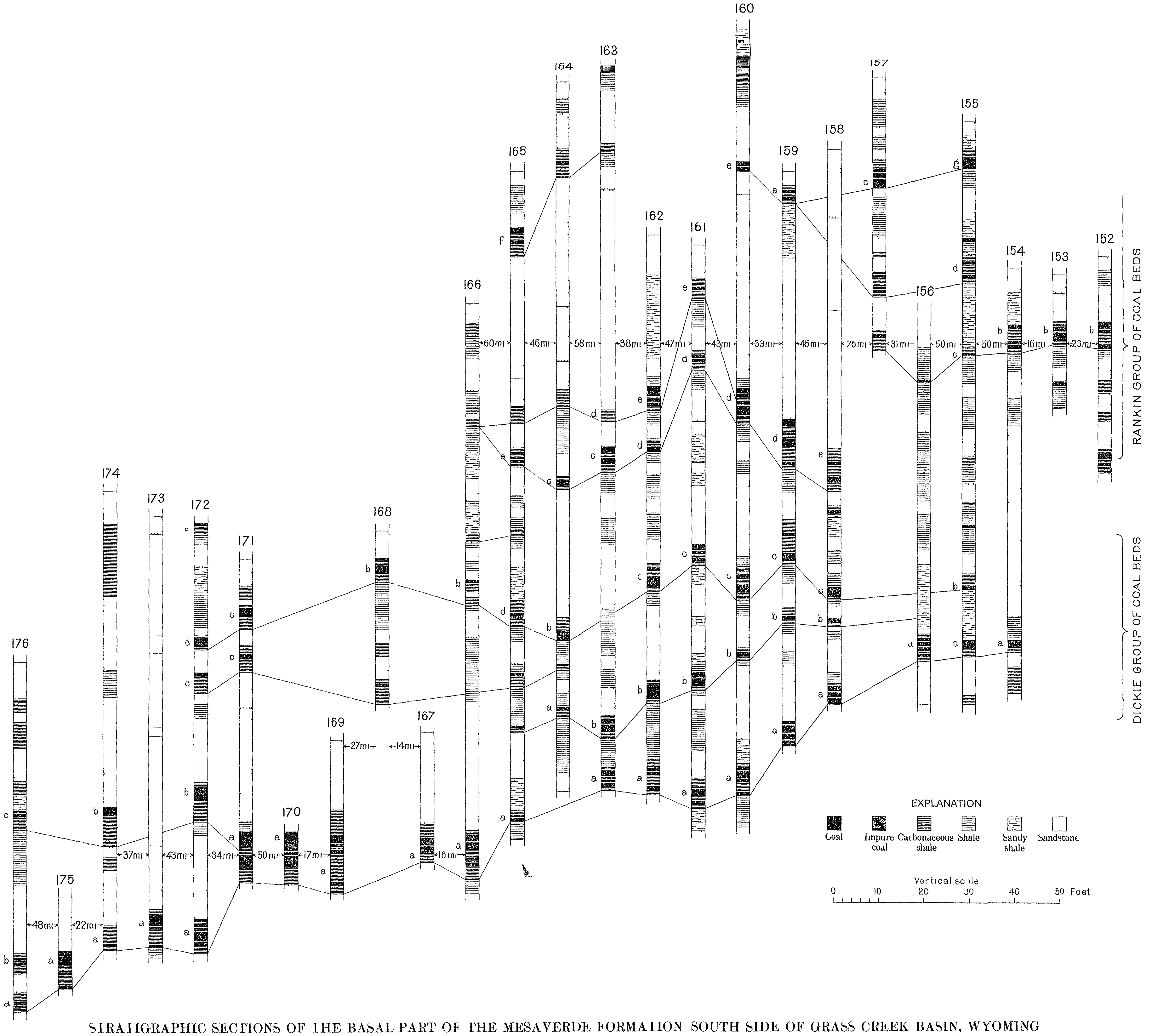


STRATIGRAPHIC SECTIONS OF THE BASAL PART OF THE MESAVERDE FORMATION, GOOSEBERRY CREEK VALLEY AND LITTLE BUFFALO BASIN, WYOMING

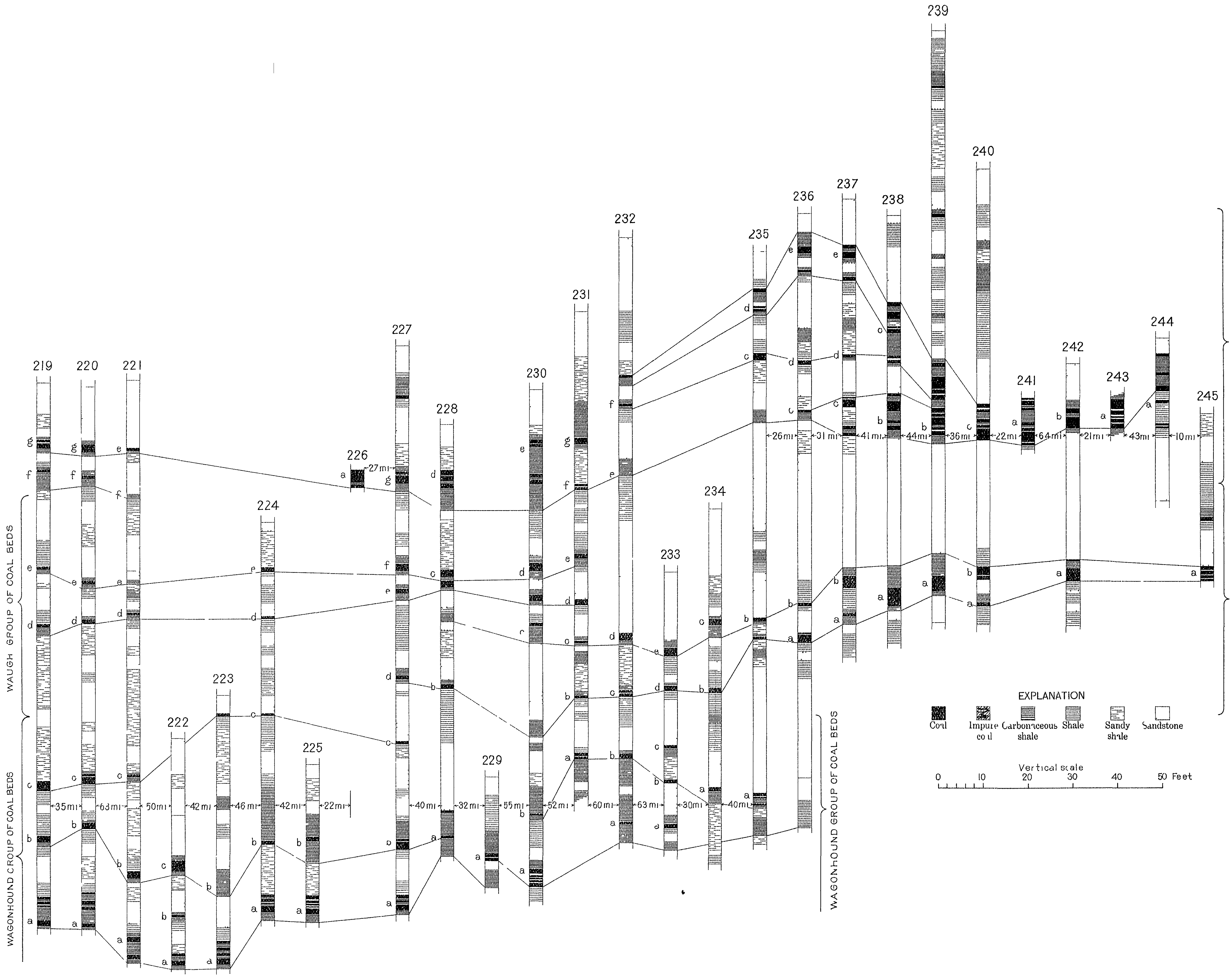
ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY



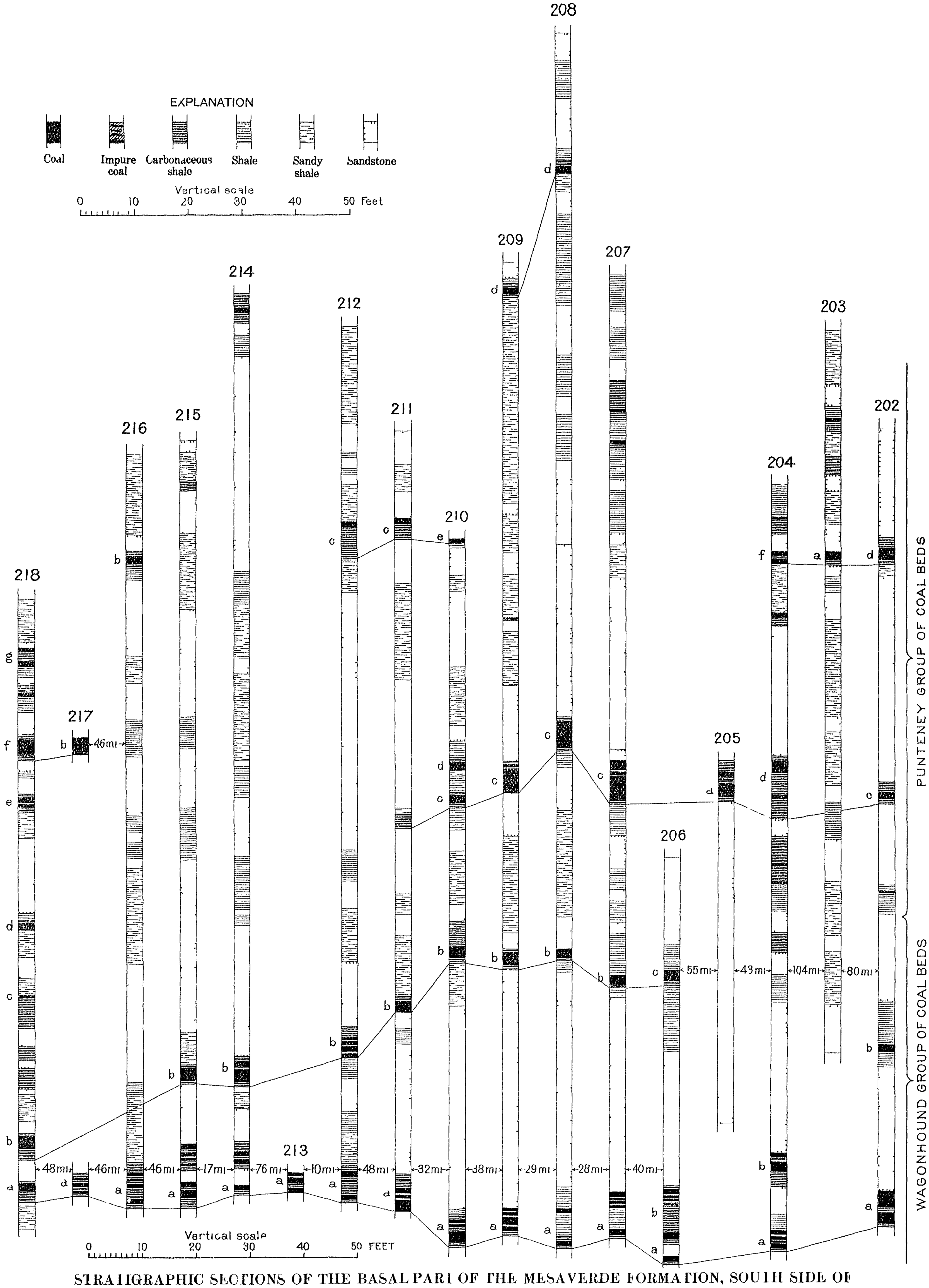
STRATIGRAPHIC SECTIONS OF THE BASAL PART OF THE MESAVERDE FORMATION, NORTH SIDE OF GRASS CREEK BASIN, WYOMING



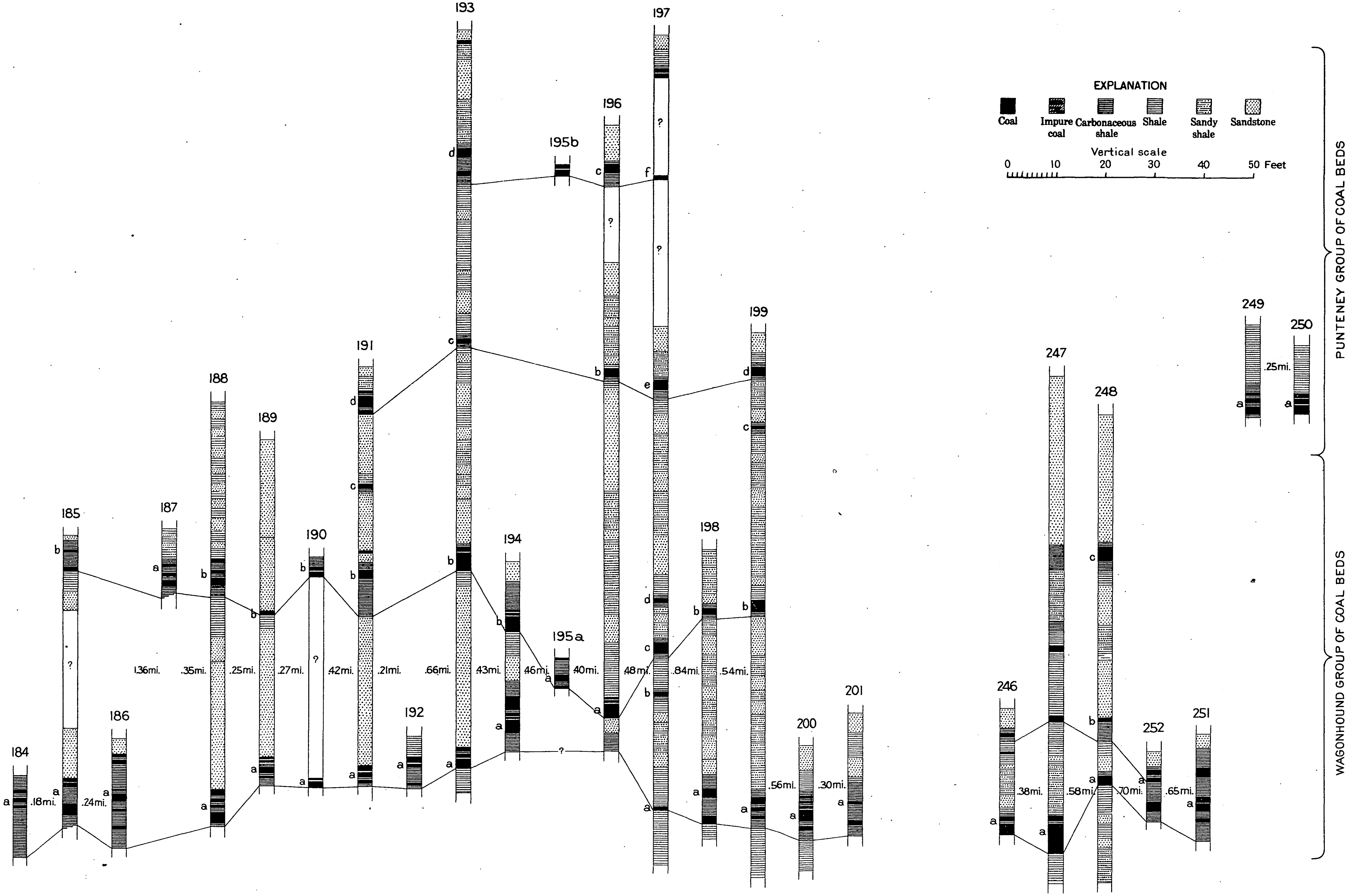
STRATIGRAPHIC SECTIONS OF THE BASAL PART OF THE MESAVERDE FORMATION SOUTH SIDE OF GRASS CREEK BASIN, WYOMING



STRATIGRAPHIC SECTIONS OF THE BASAL PART OF THE MESAVERDE FORMATION, NORTH SIDE OF COTTONWOOD BASIN, WYOMING



STRATIGRAPHIC SECTIONS OF THE BASAL PART OF THE MESAVERDE FORMATION, SOUTH SIDE OF COTTONWOOD BASIN, WYOMING



STRATIGRAPHIC SECTIONS OF THE BASAL PART OF THE MESAVERDE FORMATION, OWL CREEK ESCARPMENT, WYOMING

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

ing zone. In general, western, southern, and eastern exposures are better than northern, probably because on them the winter snows are more rapidly and more frequently melted, and the resulting water has the maximum eroding effect.

In a large part of the region the coal-bearing zone crops out on rather steep, rugged slopes of the topographic basins carved through the crests of anticlines. Generally the zone crops out from 100 to 200 feet above the flat floors of these basins and thus offers favorable conditions for exploration and mining. Here and there, however, as in the east ends of Spring Creek and Little Buffalo basins, the zone rises 300 or even 500 feet above the near-by valley floor, its position apparently depending on the size and distribution of major streams. Such portions of the outcrop are readily accessible only by tunnels from near-by ravines.

Although a few thin beds of coal are locally found in the upper part of the Mesaverde formation, the beds more than 14 inches thick and those which have been mined occur near the base of the formation. Generally there are from three to seven beds containing more than 14 inches of coal in a zone 160 to 220 feet thick that overlies the basal sandstone. This is the common condition in Spring Creek, Little Buffalo, and Grass Creek basins. Locally, however, in the northern part of Oregon Basin, in the Gooseberry Creek valley, and in the Cottonwood Creek valley, there are two coal-bearing zones, separated by a massive sandstone, the lower underlain and the upper overlain by thick massive sandstones. Where these conditions exist there is reason for believing that the areas are intermediate between those farther west, where the lower group of coal beds are most conspicuous and thickest, and those farther east, where the lower group has pinched out completely and the workable bed is in the upper part of the formation.

The grouping of stratigraphic sections in a general eastward direction, shown on Plates XXV–XXX, has been adopted after several trials to bring out the changes that appear to take place in the sections in that direction. Study of these plates shows several features of the coal beds and their distribution that are thought to have considerable significance both in the problem of local and regional distribution of coal in the Mesaverde formation as well as in an attempt to ascertain the principles that should govern the correlation of the sediments of the Upper Cretaceous epoch in Wyoming. This question is discussed further on pages 58–60.

Even though here and there sections only 1,500 to 2,000 feet apart show differences that indicate lack of persistence of coal and sandstone beds, the groups of beds may generally be traced with considerable assurance along outcrops for distances of 3 to 6 miles. Three features are brought out by the sections—(1) the shape of individual lenses, (2) the merging of several thin beds to make up one thick bed, (3) the disappearance of lenses and groups of lenses in a general eastward direction and the appearance and corresponding thickening of the overlying lenses or groups of lenses. In considering each of these features the trend of the exposures and local dip of the beds should be kept clearly in mind. The anticlines, around the flanks of which the coal is exposed, trend generally northwest, and the portion of the outcrop that trends from north to N. 60° W. is nearly three times as long as that which trends northeast. Obviously, the evidence of the features of beds along northeast axes is not nearly so good as that along northwest axes. Also the beds that dip northeast commonly range from 10° to 22°, whereas those that dip southwest range from 18° to 50°.

Among outcrops that trend north and contain coal, that along the Cody-Meeteetse road in the center of T. 52 N., R. 101 W., includes a bed which in five prospects within 2 miles ranges in thickness from 29 to 35 inches. The dip at these prospects ranges from 48° to 52° E. The escarpment along the west side of Oregon Basin dips 21°–24° W. but contains no coal beds more than 10 inches thick. That along the east side of Oregon Basin contains a bed that ranges from 38 to 43 inches in thickness within 1 mile and dips 22° E. The most persistent bed in the entire region appears to be the principal bed of the Webster coal group, which within a distance of 6 miles N. 15° W. along the east side of the Wood River valley contains from 21 to 67 inches of coal and dips 9°–20° E.

It appears probable from the similarity of the beds that this is the same as the principal bed of the Wilson coal group along Greybull River and Spring Creek, and thus it may have a minimum length of 12 miles, with the range in thickness given above. The northward-trending outcrops of Little Buffalo Basin, Grass Creek Basin, and Cottonwood Valley are short and do not yield definite evidence.

A number of coal beds occur along northwestward-trending outcrops in the southern part of the region, but only a few thin beds have been found in the northern part. Along the escarpments of Grass Creek Basin and the valleys of Cottonwood and Owl creeks, which largely range from N. 20° W. to N. 65° W., most of the lenses of coal more than 14 inches thick are from 3,000 to 7,000 feet long, although several may persist for 15,000 or even 18,000 feet. Many thinner beds appear to have generally similar lengths. The dips on the northeast flanks range from 10° to 20° and on the southwest flanks, except in the Little Grass Creek dome, from 20° to 58°. The thicker beds are found where the dips are low.

The only reliable evidence of the length of lenses along northeasterly axes is obtained from upper Gooseberry Creek. (See Pl. VIII.) Here it appears that the thickness of both beds of the Webster coal group, each of which contains more than 14 inches of coal and one as much as 46 inches, steadily decreased toward the northeast from the maximum, and the bed disappears within 15,000 feet. Similarly the thickness of the principal bed of the upper Dorr coal group decreases steadily in the same direction.

In several parts of the region two or more lenses of coal merge to form thicker beds. The best evidence of this feature is found in outcrops that trend north west in the northern escarpments of Grass Creek Basin and the Cottonwood Creek valley. (See Pls. XXVI and XXVII.) In each of these localities one section shows four or five beds 6 to 24 inches thick distributed through 35 to 45 feet of strata, and successive sections in a southeasterly direction show that these beds merge to form a single thick bed split by numerous shale partings and that still farther southeast the bed pinches out. The evidence of the merging of two thin beds in a southeasterly direction is not uncommon elsewhere.

Not only is it clear in many parts of the region that both thick and thin beds thin out and disappear along the outcrop, but zones that include several beds also disappear. The best illustration of this feature is found along Cottonwood Creek in the southeast corner of T. 45 N., R. 98 W. (See Pl. XXVIII.) The graphic sections show what may be observed clearly in the field also, that the lowest coal bed of the Wagonhound coal group which is the thickest in the area west of the Grass Creek road, gradually becomes thinner and more shaly in an easterly direction and finally disappears in section 30, T. 45 N., R. 97 W. Plate XXV illustrates the same feature in a N. 65° E. direction along upper Gooseberry Creek in T. 47 N., R. 100 W. The convergence of groups of coal beds in successive sections in a southeasterly direction is shown in the Grass Creek, Cottonwood, and Owl Creek fields.

By way of summary it may be stated that although the evidence is incomplete and locally unsatisfactory, it indicates in a general way that the longer axes of thick coal lenses trend north and the shorter axes trend east. Further, the lenses tend to merge in their eastward extensions and then disappear. The groups of coal beds also tend to converge eastward, and the basal groups tend to pinch and disappear in the same direction.

OREGON BASIN QUADRANGLE

In the Oregon Basin quadrangle coal beds of economic importance in the Mesaverde formation are confined to the 180 feet of beds that overlie the basal sandstone, but here and there thin beds of coal, rarely more than 6 inches in thickness, are present in the overlying 300 or 400 feet. Thus in section 14, T. 50 N., R. 100 W., a 4-inch bed occurs 500 feet above the basal sandstone. Within the 180-foot zone one bed more than 14 inches thick is commonly present, and locally there are four beds more than 8 inches thick, as at station 9, in the NE. ¼ sec. 11, T. 51 N., R. 101 W. On the other hand, there are large parts of the outcrop, particularly the western escarpment of Oregon Basin (4 miles long) and that which extends from Dry Creek eastward to Red Cabin, within which no bed more than 16 inches thick has been found. In those parts of the quadrangle where coal has been mined only one bed with more than 16 inches of coal appears to be present in the section.

The highly lenticular character of the coal beds is shown by sections at stations 1, 2, 3, 4, and 5, which were measured within a distance of 10,000 feet and by sections at stations 20, 21, and 22, measured within a distance of 1,300 feet.

Field study of the stratigraphic sections of the coal-bearing zone and the distribution of coal beds did not suggest any definite tendency toward thinning or convergence of the beds. Office compilation of the data from the adjoining quadrangles on the south indicates the general correlation of sections shown in Plates XXV–XXX. It can only be stated that the evidence of the Oregon Basin quadrangle is consistent with the general interpretation derived from those quadrangles that the beds tend to maintain their thickness in a general north-south direction and to merge or thin out in a general east-west direction.

Even though the exposures of the lower coal-bearing part of the Mesaverde formation are not as good in this quadrangle as they are farther south, there is sufficient evidence to warrant the conclusion that it contains fewer and less persistent beds of coal than elsewhere.

Coal sections in the Mesaverde formation, Oregon Basin quadrangle

No. on map	Section	Ft.	in.	No. on map	Section	Ft.	in.
1=2[a]	Coal	1	1	10	Coal	1	6
	Coal shale	1	1		Shale		2
	Coal	3	4		Coal		6
2=3	Coal		5	12	Coal	1	1
	Shale		3		Shale		5
	Coal		6		Coal	1	7
	Shale		5				
	Coal	1	6	13	Coal		5
					Shale		4
3=4	Coal		10		Coal		8
	Shale		5		Shale		6
	Coal		9		Coal		5
	Shale		3		Shale		6
	Coal	1	3		Coal		10
4=5	Coal		9	14	Coal	1	6
	Shale		4		Shale		5
	Coal	1	2		Coal	2	1
	Shale		3				
	Coal	1		17	Coal	1	4
5=6	Coal		9	18	Coal	1	2
	Shale		4				
	Coal		10	20=22	Coal	1	
	Shale		3		Shale		3
	Coal	1	4		Coal	2	8
					Shale		3
6=7	Coal	1	4		Coal	4	6
7	Coal		5	22	Coal		6
	Shale		5		Shale		8
	Coal		11		Coal	3	2
9	Coal		8				
	Shale		4				
	Coal	1					
	Shale	5					
	Coal	1					

[a] Equality sign indicates that the sections are considered to represent the same bed at the different localities.

MEETEETSE QUADRANGLE

Coal beds of the Mesaverde formation crop out in four isolated areas in the Meeteetse quadrangle—Spring Creek Basin, Wood River valley, Gooseberry Creek valley, and Little Buffalo Basin. In each of these areas except Little Buffalo Basin the exposures of the coal-bearing section are generally good. In Little Buffalo Basin the coal-bearing section crops out near the base of the southward-facing escarpment and consequently is heavily covered with wash. The relations of the coal beds are shown in Plate XXV.

Most of the coal beds are included in the zone which overlies the basal massive sandstone and which attains a maximum thickness of 220 feet in sec. 2, T. 48 N., R. 101 W. The highest coal bed in the section occurs 450 feet above the basal sandstone and is 14 inches thick where observed in sec. 1, T. 48 N., R. 101 W. In a large portion of the outcrop only one or two beds in this zone are more than 14 inches thick, but in a small area near the head of Gooseberry Creek (station 56) four beds, each of which exceeds this thickness, are present.

The positions of the outcrops of two groups of coal beds are indicated on the general geologic map (Pl. II). The lower or Wilson coal group, named for the Wilson mine, in sec. 13, T. 48 N., R. 101 W., where the thickest bed is mined, crops out in the escarpment that surrounds Spring Creek Basin, along the Wood River valley, and in the dissected domes along Gooseberry Creek. For a large portion of the outcrop it contains only one bed more than 14 inches thick, but along Gooseberry Creek there are two. Most of the sections are made up of a lower bench 16 to 33 inches thick and two or even three or four thinner upper benches separated by 2 to 14 inches of brown shale.

Although this group contains one or two economically important beds of coal for a distance of at least 9 miles along the outcrop that trends roughly N. 15° W. along Wood River valley, the beds thin and finally disappear within about 4 miles measured along a line extending N. 70° E. down the valley of Gooseberry Creek. Thus the total thickness of coal in the group decreases from about 73 inches in sec. 36, T. 47 N., R. 101 W., to 9 inches in the NE. ¼ sec. 21, T. 47 N., R. 100 W.; and in the SW. ¼ sec. 15, T. 47 N., R. 100 W., the coal has completely disappeared.

The upper or Buffalo group of coal beds appears to persist throughout the region, and therefore it has been used as the datum for the construction of a structure contour map. The group commonly contains two or three beds, but locally four are present. For long distances along the outcrop, however, no bed is more than 14 inches thick. The maximum thickness of coal in any outcrop is 33 inches, and where the thickness exceeds 20 inches the bed is commonly split into two or three benches. It is rather interesting that the beds of the group attain the greatest thickness in an area where the lower or Wilson group is absent. The name is given from Little Buffalo Basin, where the group is best developed. None of the beds of this group are opened by prospects or mined within the Meeteetse quadrangle.

Coal sections in the Mesaverde formation, Meeteetse quadrangle

No. on map	Section	Ft.	in.
31	Coal		8
	Shale		6
	Coal		7
32=34[a]	Coal		3
	Shale		3
	Coal	1	6
	Shale		10
	Coal	1	4
34=35	Coal		6
	Shale		3
	Coal	2	1
	Shale		4
	Coal	2	5
35	Coal		2
	Shale		2
	Coal	1	1
	Shale		4
	Coal		10
36	Coal	1	4
37	Coal	4	
	Shale		1
	Coal		2
	Shale		1
	Coal	1	2
39	Coal		6
	Shale	2	6
	Coal		6
	Shale		11
	Coal	1	2
40	Coal		4
	Shale	1	8
	Sand	3	4
	Coal		10
41	Coal	2	
42	Coal		9
	Black shale	1	3
43	Coal	1	3
	Black shale	1	6
44=46	Coal		6
	Shale		4
	Coal		10
	Shale		1
	Coal		4
	Shale		5
	Coal	2	4
45	Coal		3
	Shale	1	
	Coal		5
46=47	Coal		8
	Shale		1
	Coal		10
	Shale		3
	Sandstone	1	
	Coal		6
	Shale		5
	Coal		8
47=48	Coal		8
	Shale		7
	Coal		11
	Shale		3
	Coal		8
	Shale		7
	Coal		8
	Shale		8
	Coal	1	4
48=49	Coal		7
	Shale		2
	Coal		11
	Shale		6
	Coal	1	7
	Shale		6
	Coal	2	9
49=50	Coal	1	8
	Shale		2
	Coal	1	4
	Shale		4
	Coal	1	10
	Shale		2
	Coal		1
	Shale		2
	Coal		4
50=51	Coal	1	2
	Shale		1
	Coal		9
	Shale		2
	Coal	1	2
	Shale		1
	Coal		10
	Shale		2
	Coal	1	8
51=52	Coal		7
	Shale		6
	Coal		7
	Shale		3
	Coal	1	3
	Shale		2
	Coal	2	3
52=53	Coal		10
	Shale		3
	Coal		6
	Shale		3
	Coal	2	
	Shale		4
	Coal		5
53	Coal		3
	Shale		1
	Coal	1	6
54	Coal	2	2

[a] Equality sign indicates that the sections are considered to represent the same bed at different localities.

GRASS CREEK BASIN QUADRANGLE

Coal beds of the Mesaverde formation crop out in three isolated areas in the Grass Creek Basin quadrangle—the Grass Creek field, the Cottonwood-Owl Creek field, and the Padlock field. Small parts of the outcrop, from 1 to 2 miles in length, are obscured by wash, but the remainder in each field is exceptionally well exposed. In fact, the natural exposures in this quadrangle are so good that it seemed desirable to examine the coal sections rather closely and pursue studies of correlation of the beds and conditions of deposition not justified elsewhere. The relations of the coal beds are shown in Plates XXVI–XXX.

Most of the coal beds, including all that have any economic interest, occur in the series of shale, sandy shale, and sandstone that overlies the basal massive sandstone and is in turn generally overlain by another massive sandstone. (See Pl. XXVIII.) This series commonly ranges from 160 to 220 feet in thickness. In a few localities thin beds of coal were found higher in the formation. Thus, a 10-inch bed occurs in sec. 15, T. 46 N., R. 98 W., at a horizon 700 feet above the basal sandstone, although no other bed was found in the measures 500 feet above or below it. Also in the NW. ¼ sec. 28, T. 44 N., R. 98 W., where 910 feet of beds overlying the basal sandstone are well exposed, there are nine beds of coal in the lower 355 feet and a single lens of coal 6 inches thick 880 feet above the basal sandstone.

A comparison of the detailed stratigraphic sections of the coal-bearing portion of the Mesaverde formation in the Meeteetse and Grass Creek Basin quadrangles shows that, although fairly well defined groups of coal beds may be recognized in parts of the region, no obvious demarcation of the group exists in other parts. The separate groups may persist from one field to another, but this can not be proved. For this reason the limits of the groups are chosen arbitrarily, and local names are applied in each field.

The lowest group of coal beds in the Grass Creek field is called the Dickie coal group, from the Dickie prospect, in sec. 2, T. 47 N., R. 99 W., where one of the beds is opened (station 127, Pl. XXVI). Although it contains from three to seven beds in the western part of the field, most of these beds are less than 14 inches thick, and only a few stratigraphic sections contain more than one bed thicker than 14 inches. The maximum thickness of coal in any bed of the group is 84 inches, which was measured at a prospect in sec. 14, T. 46 N., R. 99 W. (station 170, Pl. XXVII). About 6,000 feet east of this prospect the bed contains only 10 inches of coal, and 7,500 feet farther east another bed 20 feet higher attains its maximum thickness of 42 inches. The same conditions exist on the north side of the basin. The Dickie bed, near the base of the section, contains a maximum of 50 inches of coal 1,000 feet west of the Dickie prospect, in sec. 2, T. 46 N., R. 99 W., but 5 miles farther east it has completely disappeared, and a bed 30 feet higher attains its maximum thickness of 35 inches.

The overlying group of coal beds is called the Rankin coal group, from a prospect in sec. 35, T. 46 N., R. 98 W., south of the Rankin ranch. This group appears to be completely absent in the western third of the basin escarpment, but in the eastern two-thirds it contains the thickest beds of coal found in the quadrangle. The group comprises from three to seven separate beds, but only one, formed by the merging of two or three thin beds, persistently contains more than 14 inches of coal. It shows the maximum of 117 inches of coal in sec. 21, T. 46 N., R. 98 W. (station 145, Pl. XXVI), but is split into eight benches by shale partings. It is the best example in the region of a thick bed formed by the merging of several thinner beds.

The name Wagonhound coal group is applied to the coal beds that overlie the basal massive sandstone of the Mesaverde formation in the Cottonwood and Owl Creek fields. These beds attain their maximum development in the Owl Creek escarpment, where two beds contain 73 and 44 inches of coal (sections 194a and 194b, Pl. XXX). In the western part of the Cottonwood field the group locally contains three beds, but none exceeds 30 inches in thickness. The group may be readily traced eastward until in sec. 25 T. 45 N., R. 98 W., it completely disappears between beds of massive sandstone.

The Waugh coal group, named from the Waugh ranch, in sec. 27, T. 45 N., R. 97 W., where one of the beds is opened, is sharply separable from the underlying Wagonhound group only in the region where that group thins and disappears. In the western part of the Cottonwood field it contains two or three beds, the thickest of which locally has 35 inches of coal (section 228c, Pl. XXVIII). Farther east it consists of a single bed that attains a maximum thickness of 48 inches (section 238a, Pl. XXVIII). The exposures in the southwestern part of the field are poor, but here and there a single bed with as much as 41 inches of coal may be found in the approximate position of the group. This group is probably equivalent to the Punteney coal group, which crops out along the escarpment facing Owl Creek and has been mined along Cottonwood Creek.

The Wales coal group includes the higher beds of the Mesaverde formation in the Cottonwood field. It is rather distinctly separated from the underlying group by a bed of massive sandstone, 15 to 30 feet thick. Where it is thickest it contains 118 inches of coal split into nine benches by shale partings (section 239b, Pl. XXVIII). Like the Rankin coal group, in the Grass Creek field, it attains its maximum thickness through the merging in a southeast direction of four distinct thinner beds. It does not appear to be present in the western part of the Cottonwood field. The name is taken from the Wales ranch, in sec. 5, T. 44 N., R. 97 W., north of which the thickest bed has been opened.

The Padlock field includes a rugged area about 4 miles long by 1 mile wide in the southern part of T. 44 N., R. 97 W., but less than a square mile of it is included in the Grass Creek Basin quadrangle.

Here the Mesaverde formation contains a lower group of coal beds, which crops out conspicuously along the escarpment that faces Owl Creek, and an upper group, which crops out inconspicuously in the ravines that drain northward from the escarpment. The lower group contains one or two beds, of which the lower attains a maximum thickness of 88 inches in the area where the beds lie flat along the southern escarpment (section 247a, Pl. XXX). Along the northern edge of the field, where the beds dip 46° to 50°, the beds are thinner. The upper group includes a single bed that locally contains 40 inches of coal (section 250a, Pl. XXX), but this bed has been largely eroded.

Coal sections in the Mesaverde formation, Grass Creek quadrangle

No. on map	Section	Ft.	in.
177=178[a]	Coal		6
	Bone coal		4
	Coal	2	4
	Shale		2
	Coal		1
	Shale		7
	Coal		10
178=179	Bone coal		7
	Coal	2	4
	Shale		9
	Coal		8
179=180	Coal		5
	Bone		3
	Coal	2	8
	Shale		1
	Coal		3
	Shale		4
	Coal		8
180=181	Coal	1	1
	Bone coal		3
	Coal	2	1
	Shale		1
	Coal		4
	Shale		3
	Coal		6
181=182	Coal		8
	Shale		2
	Coal	2	4
	Shale		3
	Coal		8
182=183	Coal	2	
	Shale		5
	Coal		10
183	Coal	1	9
	Shale		4
	Coal		11
246	Coal		10
	Shale		6
	Coal	2	2
247	Coal	1	
	Shale	6	4
248a	Coal	1	10
248b	Coal	2	8
249=250	Coal		5
	Shale		6
	Coal		8
	Shale		11
	Coal	1	5
250	Coal		8
	Shale		2
	Coal	1	
	Shale		4
	Coal	1	8
251=252	Coal	2	
	Shale	4	
	Coal	1	2
	Shale		1
	Coal	1	5
	Shale	1	5
	Coal		9
252	Coal		9
	Shale		7
	Coal		9
	Shale	4	
	Coal	2	

[a] Equality sign indicates that the sections are considered to represent the same bed at the different localities.

COAL IN THE MEETEETSE FORMATION

GENERAL FEATURES

The coal beds of the Meeteetse formation do not show satisfactory outcrops and therefore do not permit as reliable conclusions concerning their shape and distribution as those of the Mesaverde formation. Although individual beds may be satisfactorily correlated for distances of 3 or 4 miles in some parts of the region, commonly exposures are so isolated that no accurate correlation may be made.

Most of the good outcrops trend from S. 40° E. to due east. Practically no outcrops having a strike in the northeast quadrant can be correlated with others near by, so that nothing is known concerning the changes that take place in the beds in that general direction.

There are a sufficient number of good exposures of the upper part of the formation to justify the conclusion that it contains one or more beds of coal more than 14 inches thick throughout the region, except between upper Grass Creek and Spring Gulch in T. 46 N., R. 99 W., and T. 45 N., R. 101 W. In the northern part of the region the coal beds occur at irregular intervals throughout the upper 350 to 500 feet of the formation, but southeast of Meeteetse they appear to be localized near the base of the upper part and near the top.

OREGON BASIN QUADRANGLE

As there has been no systematic search for coal in the Meeteetse formation in the Oregon Basin quadrangle and there are only two openings, natural exposures have yielded practically all the information that is available concerning it. The best exposures occur in badlands formed at the heads of intermittent streams, as in secs. 2, 3, 10, 11, 12, 13, T. 50 N., R. 101 W., and in sec. 14, T. 50 N., R. 100 W. Here and there good exposures of one or more beds are found along cut banks of intermittent streams, such as Sage Creek, Oregon Coulee, and Dry Creek. The information gained from the badland exposures indicates that the coal beds as well as the sediments are highly lenticular and that exposures a mile or more apart can not be correlated with assurance. Sufficient data are available, however, to suggest that the upper coal-bearing part of the formation contains one or more beds more than 14 inches thick throughout the quadrangle.

The beds show a wide range in thickness. The thickest bed so far uncovered is 42 inches thick in sec. 3, T. 50 N., R. 101 W. (section 25). The bed explored by the Eagle mine contains 54 inches of coal, but it is split into three benches by shale partings (section 24). How far these thicknesses persist is not yet known. The exceptionally good section in sec. 3, T. 50 N., R. 101 W. (fig. 3), contains six beds, each of which contains more than 14 inches of coal, and that in sec. 14, T. 50 N., R. 100 W., contains five beds (fig. 3).

Coal sections in the Meeteetse formation, Oregon Basin quadrangle

No. on map	Section	Ft.	in.
9a=24[a]	Coal	2	
	Shale		1
	Coal		9
23b	Coal	1	6
24	Coal	1	4
	Bone coal	1	
	Shale		1
	Coal	1	
	Shale		2
	Coal	2	2
27a	Coal		7
	Shale	3	8
	Coal	1	10
27b	Bone coal		5
	Shale		5
	Coal	1	2
	Clay		3
	Coal		8
	Clay		5
	Coal	1	
28a	Coal		4
	Shale		3
	Coal		9
28b	Bone coal		10
	Shale		5
	Coal	1	
	Shale		7
	Coal		7
	Shale		8
	Coal		6
29	Bone coal	1	2
	Coal	1	4
	Shale		1
	Coal		5
	Shale		7
	Coal		3

[a] Equality sign indicates that the sections are considered to represent the same bed at the different localities.

MEETEETSE QUADRANGLE

Although there is only one prospect on beds of this formation in the Meeteetse quadrangle (station 107), natural exposures are better and more numerous than farther north or south. There are good badland exposures in several localities within a belt that extends 8 miles southeast of Meeteetse, at the head of Iron Creek, in secs. 5, 7, and 9, T. 47 N., R. 100 W. and secs. 32 and 33, T. 47 N., R. 99 W. Exposures along intermittent streams are common northwest of Meeteetse.

The thickest single bed is 72 inches thick in secs. 19 and 20, T. 47 N., R. 100 W., and with the higher and lower benches this bed contains 104 inches of coal (section 121). Another bed near the top of the formation in secs. 19 and 29, T. 48 N., R. 99 W., contains a maximum of 68 inches split into three benches (station 113). This bed is fairly well proved to have a length of 3½ miles along a southeastward-trending outcrop between measurements, with a minimum of 10 inches of coal. The most completely exposed section (station 108) contains four beds each of which is more than 10 inches thick. On the other hand, a fairly well exposed section in sec. 32, T. 49 N., R. 100 W., contains only two beds more than 14 inches thick.

Coal sections in the Meeteetse formation, Meeteetse quadrangle

No. on map	Section	Ft.	in.
24	Coal		6
	Shale	1	4
	Coal		10
	Shale		1
	Coal		5
	Shale		1
	Coal	1	2
	Shale	2	4
	Coal		8
95a	Coal	2	
	Shale		2
	Coal		10
	Black shale	2	6
	Coal		7
96	Coal	1	
	Shale		1
	Coal	1	5
97a	Coal	1	6
	Shale	4	8
	Coal		11
	Shale		7
	Coal	1	6
97b	Coal		10
	Shale		2
	Sand		3
	Coal		11

Coal sections in the Meeteetse formation, Meeteetse quadrangle—Continued

No. on map	Section	Ft.	in.
98=99[a]	Coal		7
	Shale	2	1
	Coal		7
	Shale	1	
	Coal		4
99	Shale		10
	Coal		10
	Shale	1	8
	Coal		8
	Shale	1	3
	Coal		8
100	Coal	1	3
101=102	Coal	1	8
102=103b	Coal	1	1
	Shale		4
	Coal	1	1
103a=104a	Coal	1	5
103b=104b	Coal	1	
	Bone coal		4
	Coal	1	2
103c=104c	Coal	1	5
	Bone coal		6
104a=108a	Coal	1	3
104b=108b	Coal	1	1
104c=108c	Coal	1	2
105=106	Coal		2
	Shale		3
	Coal		1
	Shale		2
	Coal	1	
106=107	Bone coal		3
	Coal		2
	Shale		1
	Coal	2	4
	Shale		2
	Coal		11
107=108a	Coal	2	2
	Shale		2
	Coal	1	
	Shale		2
	Coal		6
108a	Coal	1	2
108b	Coal		10
108c=111c	Coal	2	5
	Shale		2
	Coal	1	2
	Bone coal		6
109=110	Coal		3
	Shale		4
	Coal		10
	Bone coal		9
110=111a	Coal		2
	Bone coal		4
	Shale		7
	Coal	1	6
	Shale		5
	Coal		10
	Shale		4
	Coal	1	
111a=112a	Coal	2	6
	Shale	1	
	Coal	1	
111b=112b	Coal	1	5
111c	Coal	2	2
111d=112c	Bone coal	1	6
	Coal	1	4
	Shale		4
	Coal		10
	Shale		8
	Coal		8
112a	Coal	1	6
112b	Coal	1	10
	Shale	2	
	Coal		5
112c=113	Coal		10
	Shale		6
	Coal	1	9
	Shale		4
	Coal		10
	Shale		4
	Coal		6
	Shale		1
	Coal		3
113=114	Bone coal	1	
	Coal	1	6
	Bone coal		10
	Coal	2	2
	Shale		5
	Coal	2	
114	Coal		10
	Bone coal	1	3
115	Coal	1	3
116=118	Coal	2	
	Shale		1
	Coal	1	
117	Coal	2	
118=119	Coal	1	8
	Shale		4
	Coal		6
	Shale		2
	Coal		3
	Bone coal	1	6
119=120	Coal	2	2
	Shale		3
	Coal		8
	Bone coal	1	
120	Coal	1	
	Shale		10
	Coal	1	3
121	Coal	2	4
	Clay		2
	Coal	6	
	Clay		2
	Coal		6
122=123	Coal		11
	Shale		1
	Coal		3
	Bone coal		3
	Coal		4
	Shale		1
	Coal	1	8
	Shale	1	6
	Coal		8
123	Coal	1	2
	Shale	1	6
	Coal		2
	Shale		1
	Coal		8

[a] Equality sign indicates that the sections are considered to represent the same bed at the different localities.

GRASS CREEK BASIN QUADRANGLE

The best exposures of the coal beds of the Meeteetse formation in the Grass Creek Basin quadrangle are found along Prospect Creek, although there are a few outcrops here and there along the intermittent streams northwest of Gwynn's ranch and at the head of Wagonhound Creek.

The thickest bench is 44 inches thick in sec. 32, T. 47 N., R. 98 W., but with the two overlying benches the bed contains 64 inches of coal (section 254b,

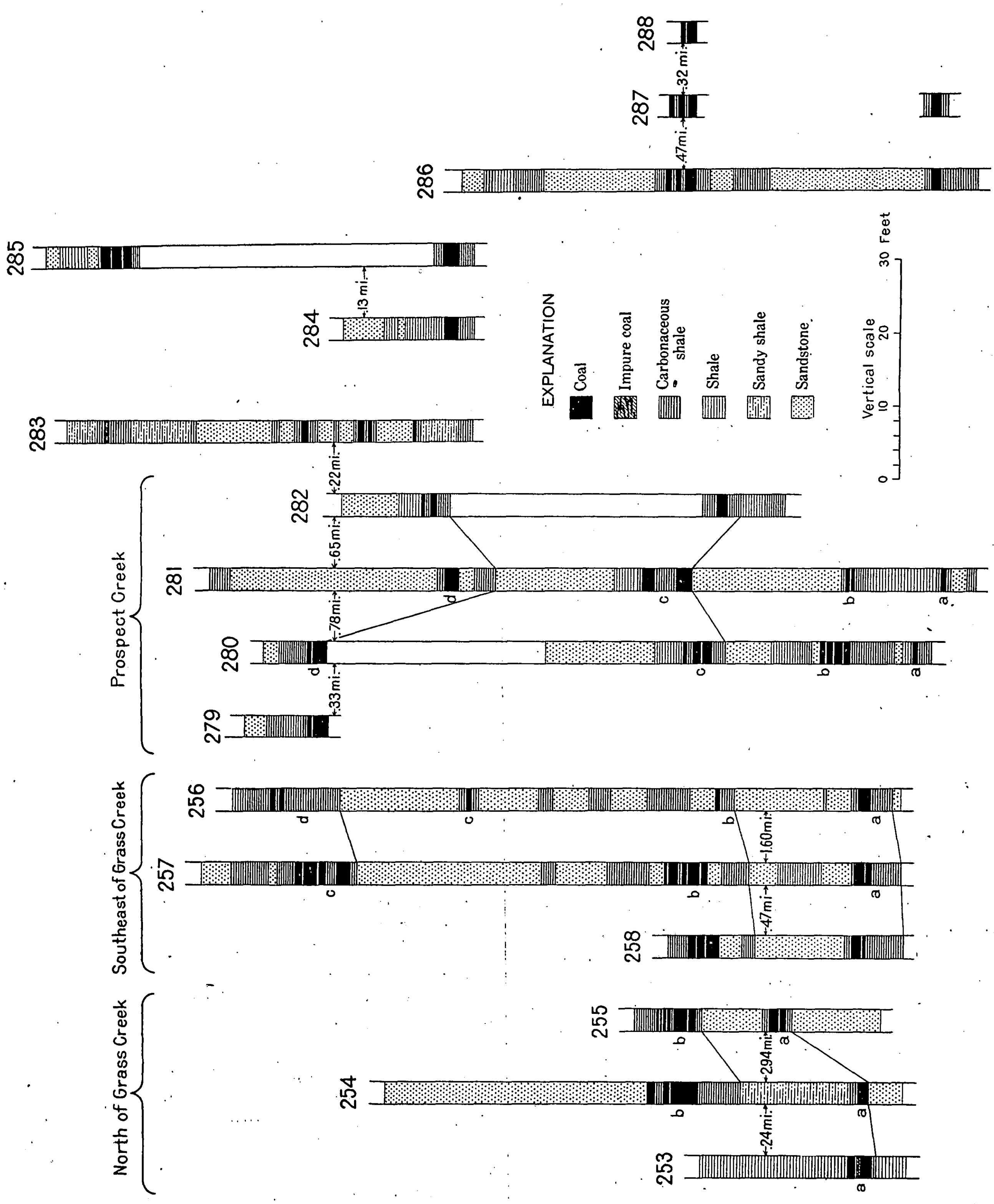


FIGURE 10.—Stratigraphic sections of the coal-bearing part of the Meeteetse formation in the Grass Creek Basin quadrangle

fig. 10). Most of the beds appear to range from 18 to 30 inches in thickness. A good exposure of the coal-bearing portion of the formation in sec. 2, T. 45 N., R. 98 W., includes three beds containing from 20 to 62 inches of coal (section 257 c, fig. 10). One bed appears to persist for at least 3 miles. Similarly good exposures of the lower part of the coal-bearing section in sec. 13, T. 45 N., R. 98 W., show three beds containing from 29 to 42 inches of coal (sections 279–282, fig. 10).

The coal-bearing part of the Meeteetse formation is well exposed in the rough region north of the upper part of Spring Gulch, but only a few beds crop out, and none are more than 14 inches thick. This is the only part of the entire region where the exposures are good in which no beds more than 14 inches thick have been found.

Farther west, along upper Prospect Creek, the upper part of the coal-bearing section is fairly well exposed. The correlation of the stratigraphic sections made in these regions is shown in Plate XXXI. These sections, considered in connection with the continuity of the basal sandstone of the Lance formation, which overlies them, indicate that beginning on the west the uppermost coal beds tend to pinch out and disappear in an eastward direction, whereas new coal beds begin 20 to 30 feet higher and, after attaining a maximum thickness, they also pinch out and disappear. These conditions appear to be the same as those shown in several localities by the coal beds of the Mesaverde formation. They raise for serious consideration the question whether over a much larger area the coal beds near the base of the Mesaverde formation and in the Meeteetse formation or its equivalents have not a similar steplike arrangement in an eastward direction. If this should be the case, as now appears probable, then the coal beds of one locality, even though they have highly similar stratigraphic relations, are younger than those farther west and older than those farther east. This matter is further discussed on page 60.

COAL IN THE FORT UNION FORMATION

GENERAL FEATURES

In any summary of the occurrence of coal in the Fort Union formation several features stand forth prominently, by contrast with the underlying coal-bearing formations. The beds of coal are rather small lenses, sporadically distributed over a large area. They are confined to the basal 600 feet in the mountainward group of outcrops and are conspicuously lacking in the basinward group of outcrops and in the region of the unconformity between the Fort Union and Lance formations. The areal distribution of the thickest beds or thickest parts of beds coincides approximately with that of beds of near-by conglomerate; the converse relation is not apparent, for there are extensive beds of conglomerate not overlain by coal beds.

OREGON BASIN QUADRANGLE

Although there are near the base of the Fort Union formation in T. 50 N., R. 100 W., several layers of brown shale which here and there contain coaly material, no beds of coal have yet been found in the formation in the Oregon Basin quadrangle.

MEETEETSE QUADRANGLE

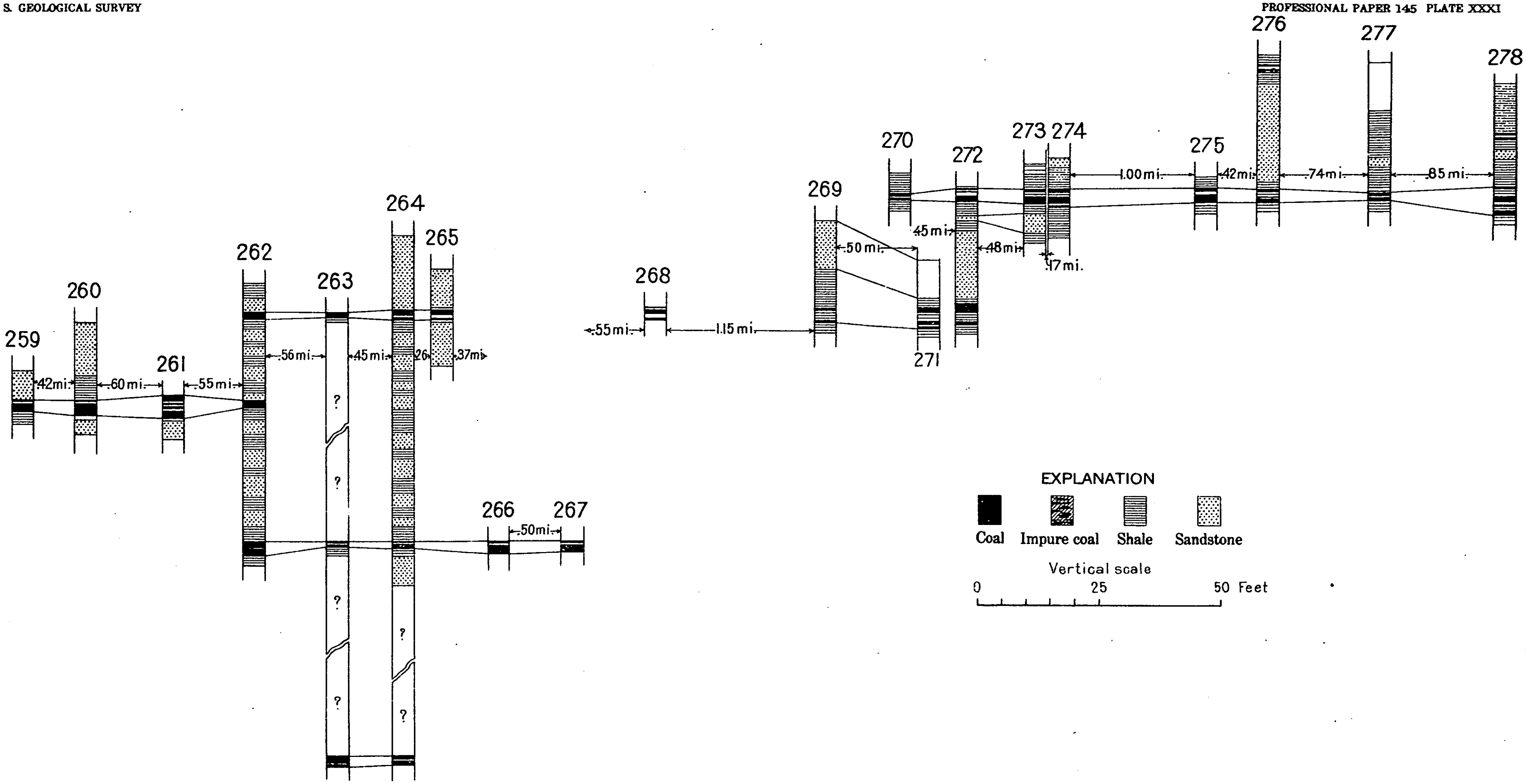
There are three openings on beds of coal in the Fort Union formation in the Meeteetse quadrangle, and from their relation to the base of the formation it is assumed that all three explore the Black Diamond bed, so called from the mine of that name in the SE. ¼ sec. 21, T. 49 N., R. 100 W. The second opening is some stripping on the west bank of Greybull River in the SE. ¼ sec. 27, T. 49 N., R. 100 W., and the third is in the adjustment strip south of sec. 36, T. 49 N., R. 100 W. At each locality the bed is about 180 feet above the base of the formation.

In sec. 24, T. 48 N., R. 99 W., just east of this quadrangle, where a detailed stratigraphic section was measured at the head of Fifteenmile Creek, there are coaly layers 840 to 920 feet above the base of the formation. This is the approximate position of the thick Mayfield bed, 12 miles to the south. In the Hole in the Ground, where exposures are uncommonly good, no persistent beds of coal are present, whereas the same part of the formation 12 miles farther south contains four thick beds.

GRASS CREEK BASIN QUADRANGLE

Although the Fort Union formation underlies a small area in the Grass Creek Basin quadrangle and only a part of this contains coal beds, several of them are uncommonly thick, and the quality of the coal is good.

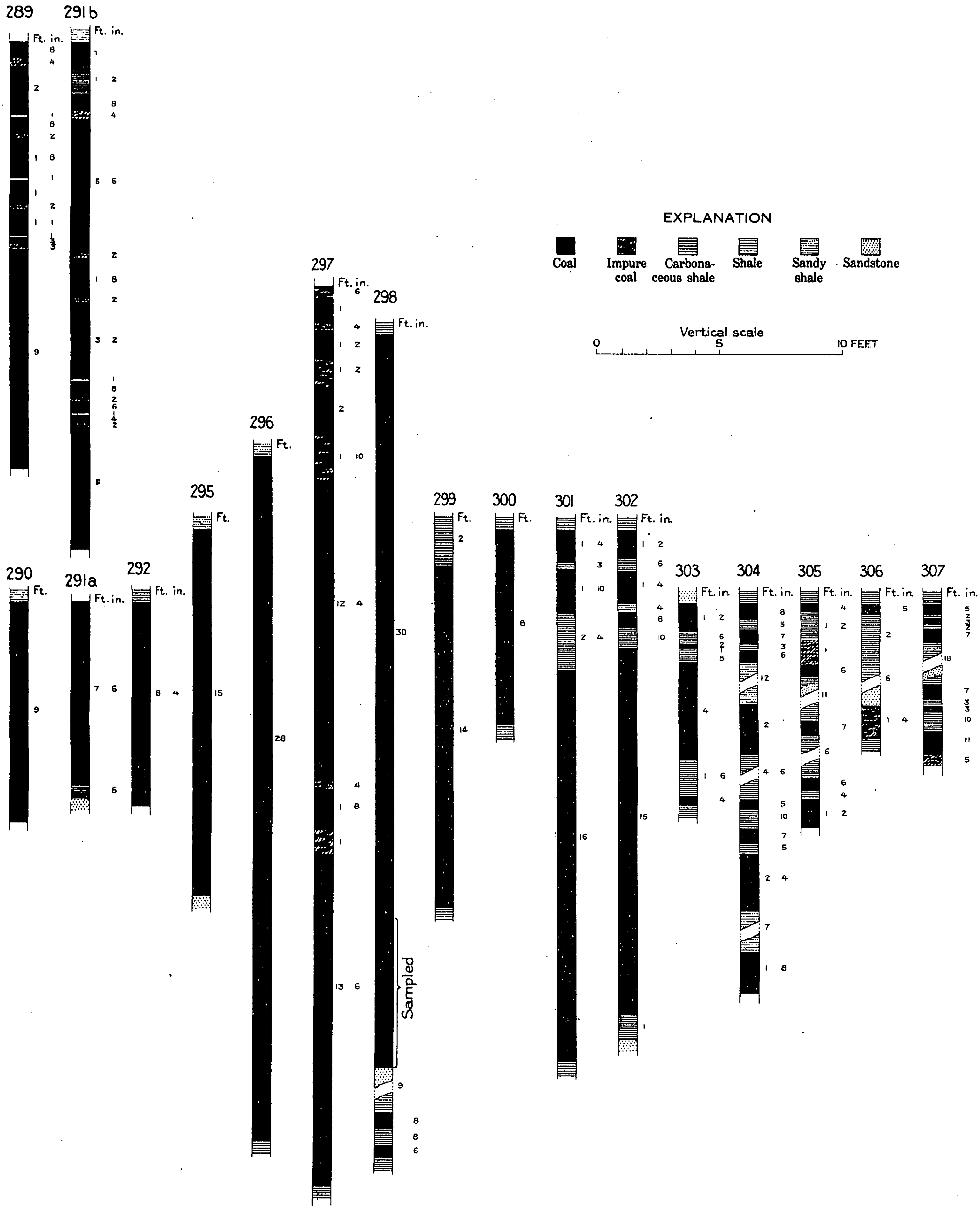
As shown on Plate XIV, beds of coal are found in two zones in the formation. The lower zone occurs near the base and commonly contains two beds more than 12 inches thick. The lowest or Gwynn bed is 40 to 50 feet above the top of the basal sandstone or conglomerate and has been traced over the entire area underlain by the formation south of Grass Creek. It is absent in the area northeast of Grass Creek. The maximum thickness of 38 inches is found in the bluffs east of Mayfield's ranch (section 308, p. 101). Although the bed has been traced over a large area, there appear to be only three separate small areas within which the bed is more than 12 inches thick. One is near Mayfield's ranch, another south of Spring Gulch, and the third on Ilo Ridge. Here and there a second bed that is not so thick lies 15 to 60 feet higher, but clearly it is not so persistent. As shown by the coal sections on page 101, the bed commonly contains one bench from 12 to 20 inches thick, and this is overlain by another thinner bench. The distribution of the measured sections does not indicate the probable original shape of the lenses of these beds. It is noteworthy, however, that, except at the east end of Ilo Ridge, the area underlain by the beds coincides generally with that within which the basal sandstone is conglomeratic. The Gwynn bed is opened by an adit from a ravine in the SW. ¼ sec. 5, T. 45 N., R. 97 W. (section 328, p. 101). The bed trends east and dips 19° S., and the adit extends 60 feet to the east. No rooms are turned off, and no coal appears to have been removed from the dump.



STRATIGRAPHIC SECTIONS OF THE COAL-BEARING PART OF MEETEETSE FORMATION, GRASS CREEK BASIN QUADRANGLE, WYOMING

Showing disappearance of some coal beds and appearance of higher coal beds in a general eastward direction

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



DETAIL OF THE COAL BEDS OF THE FORT UNION FORMATION, GRASS CREEK BASIN QUADRANGLE, WYOMING

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

The second zone is about 120 feet thick and its base is 420 feet above the base of the formation. The zone is coal bearing only in the region southwest of Grass Creek Basin, and several small residual areas are all that remain uneroded. The lowest or Mayfield bed attains a maximum thickness of 36 feet 10 inches in the NE. ¼ sec. 26, T. 46 N., R. 99 W. (station 297), and thins rapidly both westward and eastward from this locality. Within a short distance southeast of Spring Gulch the coal is replaced by shale, and the thickest bench of coal is a 42-inch bed in Gwynn's prospect, in the SE. ¼ sec. 1, T. 45 N., R. 99 W. (station 303). In the easternmost exposure, in sec. 8, T. 45 N., R. 98 W., it contains several benches of coal and bone, none more than 16 inches thick, separated by black shale. It is entirely absent in the region of Ilo Ridge and the large area northeast of Grass Creek Basin. The extent of the Mayfield bed in an east-west direction corresponds closely with that of the conglomeratic phase of the basal sandstone. If this relation has any significance the writer has been unable to interpret it. The Mayfield bed is opened by a tunnel on the northwest side of Coal Draw, in the NE. ¼ sec. 26, T. 46 N., R. 99 W., from which coal is mined for local use. The tunnel is near the base of the bed, is 6 feet high at the entrance, extends N. 55° W. for 280 feet (October 1, 1919), and is 11 feet high at the face. About 150 feet from the entrance a room is turned off to the west and extends about 100 feet. It is 20 feet wide and 10 feet high. The coal is mined during the fall and winter for local consumption.

The second bed, about 100 feet higher than the Mayfield bed, crops out in a number of places west of Coal Draw. It has been opened in the NW. ¼ sec. 4, T. 46 N., R. 99 W., where it appears to attain the maximum thickness of 20 feet 11 inches (station 291). The easternmost outcrop is in the SE. ¼ SW. ¼ sec. 23, T. 46 N., R. 99 W., but no section could be measured at this locality.

Coal sections in the Fort Union formation, Grass Creek Basin quadrangle

No. on map	Section	Ft.	in.
308=309a [a]	Coal	3	2
309a	Coal	1	10
	Shale		6
	Coal	1	9
309b	Coal	1	11
	Shale		5
	Coal		4
	Shale		3
	Bone coal		2
	Coal		5
310	Coal		10
311	Coal		2
	Shale		8
	Coal	1	2
312	Coal		1
	Shale		5
	Coal		9
313=314	Coal		3
	Shale		6
	Coal		2
	Shale		1
	Coal	1	6
314=315	Coal		4
	Shale		3
	Coal		2
	Shale		6
	Coal	1	5
315=316	Coal	1	8

[a] Equality sign indicates that the sections are considered to represent the same bed at the different localities.

Coal sections in the Fort Union formation, Grass Creek Basin quadrangle—Continued

No. on map	Section	Ft.	in.
316=317	Coal	1	6
317=318	Coal		5
	Shale		2
	Coal	1	6
318=319	Coal	1	4
319=320	Coal	1	
320	Coal		5
	Shale		1
	Coal		7
321-322	Coal		6
	Shale	1	
	Bone coal		10
322-323	Coal		4
	Shale		7
	Coal		10
	Shale	1	8
	Coal		3
323-324	Coal		3
	Shale		9
	Coal		3
	Shale		1
	Coal		9
324	Coal		3
	Shale		6
	Coal		5
	Shale		1
	Coal		8
325-326	Coal	1	
326-327	Coal	1	2
	Shale		6
	Coal	1	
327-328	Coal	1	10
	Shale		6
	Coal	1	
328-329	Coal	2	4
	Shale		5
	Bone coal	1	3
329-330	Coal		7
	Shale		5
	Coal	1	2
	Shale		5
	Coal	1	
330-331	Bone coal		5
	Shale	1	
	Coal		1
	Shale		4
	Coal	1	5
331	Coal		3
	Shale		6
	Coal	1	1

PHYSICAL PROPERTIES

Mesaverde formation.—There is little variation in the properties of the coal from the Mesaverde formation throughout the region. The color is uniformly pitch black, although the streak is dark brown. The luster on freshly broken surfaces is vitreous. Each of the beds that is opened by prospects is distinctly laminated, although here and there the thickest layers of coal are massive. Columnar jointing is common, but individual layers show conchoidal fracture.

Pyrite is commonly present, but is nowhere abundant. It occurs both as thin lenses of granular material that lie parallel to the bedding and as clean thin plates on vertical fractures. In some sections, as at the McGuffey and Dickie No. 1 mines, a distinct layer from 1 to 2 inches thick near the top of the bed contains almost as much pyrite as coal. Small round grains of reddish-brown resins can commonly be detected. Mineral charcoal is locally visible on horizontal partings.

Meeteetse formation.—The physical properties of the different coal beds in the Meeteetse formation appear to be similar throughout the region, but there are only a few openings that extend more than a few feet below the surface. The color ranges from pitch black to very dark brown, and the streak is dark brown. By contrast with the Mesaverde coal, the luster of most of the layers is rather dull and stony; commonly there is no sharp boundary between coal and bone. The beds are laminated at the Eagle mine; the jointing is almost cubic; the fracture is conchoidal. Pyrite was not noted, but may be present. Round particles of brownish resin are common, and the weathered outcrop of several beds is strewn with masses of this material as much as an inch in diameter. Mineral charcoal is present in some beds, but not in others.

Fort Union formation.—The properties of the coal beds in the Fort Union formation appear to vary slightly throughout the region. The color is commonly pitch black, and the color of the powder is also black. By contrast with the lower coals, the luster is commonly more vitreous than waxy. Like the Mesaverde coals, the beds are laminated, but individual layers are massive. The jointing ranges from columnar to cubic; the fracture is conchoidal.

Pyrite is generally absent, but at the Mayfield prospect, in Coal Draw, a few thin plates of pyrite occur on vertical fractures. Resins are uncommon, and only traces of mineral charcoal may be found.

BEHAVIOR TOWARD WEATHERING

The effect of exposure on the coal from the beds in each of the formations is similar. Lumps of coal left exposed to the weather first show surface cracks and after standing several weeks tend to crumble when handled. On the other hand, lumps of coal kept under cover do not seriously crack and crumble in several months. So far as any difference can be observed, the coal from the Fort Union beds, especially the Mayfield, is more resistant to weathering than that from the lower beds.

By contrast with eastern Wyoming, Montana, and the Dakotas, there has been in this region little natural ignition and burning of coal beds. The only locality in which there is evidence of burning is in the center of sec. 32, T. 49 N., R. 100 W., where a thin bed in the Meeteetse formation, which crops out in several small conical hills, has been completely burned.

CHEMICAL PROPERTIES

In order to determine the chemical properties of the coal samples were collected from each of the prospects in the region by the method that has been approved by the United States Geological Survey.[79] The method provides that the sample shall be cut from a groove about 2 inches wide and 1 inch deep from a clean face of coal for the entire thickness exclusive of such shale partings as would commonly be thrown out in mining. By this method about 5 pounds is cut from each foot of the bed. The cuttings are then crushed underground, so that all fragments will pass through a ½-inch screen. The fragments are then thoroughly mixed and quartered, and about 5 pounds is placed in a can, the top of which can be sealed. The analyses in the accompanying table have been made in the Pittsburgh laboratory of the United States Bureau of Mines. They represent sixteen samples, of which five were taken by E. G. Woodruff and R. L. Nelson in 1907 [80] and eleven were taken by the writer.

The table presents the analyses of ten samples of Mesaverde coal from eight prospects. Considering the extent of the territory covered and the fact that no two samples were taken from the same bed, these analyses show a notable uniformity in composition. The difference between the sample from the Berry mine and the average is probably due to weathering of that bed, for this sample was taken nearer the surface that the others. According to the classification of the United States Geological Survey the Mesaverde coals are high-rank subbituminous.

The single sample from the Meeteetse formation closely resembles the average from the Mesaverde formation. The coal is classified as high-rank subbituminous.

The table shows the analyses of five samples from three prospects on two beds in the Fort Union formation. The average closely resembles that of the Mesaverde coals, except that the sulphur content is considerably lower. The coals are classified as high-rank subbituminous.

It is an interesting fact that although the coal beds have a stratigraphic range of 3,500 feet and the beds dip from 2° to 33°, the differences in composition are slight.

[79] Campbell, M. R., Contributions to economic geology, 1907, pt. 2: U. S. Geol. Survey Bull. 341, pp. 12–13, 1909.
[80] Woodruff, E. G., op. cit., p. 217.

Analyses of coal samples from the Oregon Basin, Meeteetse, and Grass Creek Basin quadrangles

[Made by the Bureau of Mines, A. C. Fieldner, chemist in charge]

Mesaverde coal

Laboratory No.	Location No.	Source of sample: Mine	Quarter	Sec.	T.	R.	Air-drying loss	Form of analysis[a]	Proximate: Moisture	Volatile matter	Fixed carbon	Ash	Ultimate: Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Heating value: Calories	British thermal units
5767 [b]	21	Thompson	SE	34	51	101	4.60	A	15.04	31.87	38.39	14.07	0.76	5.49	52.42	0.97	25.66	5,150	9,270
								B	10.94	33.41	40.24	15.41	.80	5.22	54.95	1.01	22.61	5,398	9,717
								C		37.51	45.18	17.31	.89					6,061	10,911
								D		45.36	54.64		1.08					7,329	13,195
12883 [c]	21	Thompson, face of room 300 feet west of mouth of tunnel	SE	34	51	101	4.30	A	14.80	35.16	38.46	11.58	.68					5,285	9,513
								B	10.97	36.74	40.19	12.10	.71					5,522	9,940
								C		41.27	45.14	13.59	.80					6,203	11,165
								D		47.76	52.24		.93					7,179	12,922
5762 [b]	14	Schwoob	SE	10	51	100	5.00	A	13.43	35.16	42.86	8.55	.44	5.92	58.42	1.05	25.62	5,638	10,148
								B	8.87	37.01	45.12	9.00	.46	5.64	61.50	1.11	52.29	5,935	10,682
								C		40.61	49.51	9.88	.50					6,514	11,722
								D		45.06	54.94		.55					7,228	13,007
12884 [c]	14	Schwoob, south wall of incline 180 feet below mouth	SE	10	51	100	6.40	A	15.82	35.40	41.01	7.77	.90					5,674	10,214
								B	10.06	37.82	43.82	8.30	.96					6,062	10,912
								C		42.05	48.72	9.23	1.07					6,740	12,132
								D		46.33	53.67		1.18					7,425	13,365
12886 [c]	12	McGuffey, east wall 20 feet above third level, 70 feet east of incline.	NE	17	52	100	5.80	A	15.52	35.95	40.51	8.02	.91					5,668	10,202
								B	10.32	38.16	43.01	8.51	.97					6,017	10,831
								C		42.55	47.96	9.49	1.08					6,710	12,078
								D		47.01	52.99		1.19					7,414	13,345
12888 [c]	34	Wilson, face of room 200 feet northwest of tunnel, 400 feet from mouth.	SE	13	48	101	5.50	A	14.21	35.81	37.65	12.33	.92					5,335	9,603
								B	9.22	37.89	39.84	13.05	.97					5,645	10,161
								C		41.74	43.89	14.37	1.07					6,218	11,192
								D		48.74	51.26		1.25					7,261	13,070
5769 [b]	35	Erskine	SE	13	48	101	4.40	A	15.04	32.49	41.64	10.83	1.07	5.67	55.43	1.10	25.90	5,514	9,925
								B	11.13	33.98	43.56	11.33	1.12	5.42	57.98	1.15	23.00	5,768	10,382
								C		38.23	49.13	12.64	1.26					6,491	11,682
								D		43.76	56.24		1.44					7,431	13,372
14679 [c]	127	Dickie, east wall of incline 25 feet below mouth			46	99	0.9	A	14.75	37.77	38.08	9.40	.70					5,587	10,057
								B	13.98	38.11	38.42	9.49	.71					5,638	10,148
								C		44.30	44.67	11.03	.82					6,554	11,797
								D		49.79	50.21		.92					7,367	13,261
17709 [c]	180	Punteney, face of room 70 feet southwest of tunnel, 80 feet from mouth.	SE	24	44	99	2.0	A	13.65	35.84	41.73	8.78	.60					5,801	10,442
								B	11.93	36.55	42.57	8.95	.61					5,916	10,649
								C		41.51	48.32	10.17	.69					6,718	12,092
								D		46.21	53.79		.77					7,478	13,460
17731 [c]	196	Berry, south wall of tunnel 40 feet from mouth	SE	29	44	98	11.6	A	25.14	33.12	36.00	5.74	.98					4,179	7,522
								B	15.30	37.47	40.73	6.50	1.11					4,729	8,512
								C		44.24	48.09	7.67	1.31					5,582	10,048
								D		47.92	52.08		1.42					6,046	10,883
Average of 10 samples, Mesaverde coal							5.0	A	15.74	34.92	39.64	9.70	0.80					5,383	9,670
								B	11.27	36.71	41.75	10.26	.84					5,663	10,193
								C		41.40	47.06	11.54	.95					6,379	11,482
								D		45.79	54.21		1.06					7,216	13,088

[a] A, Composition of sample as received; B, composition of air-dried material; C, composition after moisture is eliminated; D, composition after ash and moisture are eliminated.
[b] Sample collected by R. L. Nelson.
[c] Sample collected by D. F. Hewett.

Analyses of coal samples from the Oregon Basin, Meeteetse, and Grass Creek Basin quadrangles—Continued

Meeteetse coal

Laboratory No.	Location No.	Source of sample					Air-drying loss	Form of analysis	Proximate				Ultimate					Heating value	
		Mine	Quarter	Sec.	T.	R.			Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British thermal units
12885 [c]	24	Eagle, south wall of room above lowest level, 6 feet from incline	NW	11	51	100	6.80	A	15.25	32.08	41.07	11.60	0.53					5,264	9,475
								B	9.07	34.42	44.06	12.45	.57					5,648	10,166
								C		37.85	48.46	13.69	.63					6,211	11,180
								D		43.85	56.15		.73					7,196	12,953
		Fort Union coal																	
5768 [b]	124	Black Diamond	SE	21	49	100	6.30	A	17.67	27.28	47.46	7.59	.17	5.35	57.08	0.84	28.97	5,382	9,688
								B	12.13	29.12	50.65	8.10	.18	4.96	60.92	.90	24.94	5,744	10,339
								C		33.14	57.64	9.22	.20					6,537	11,766
								D		36.51	63.49		.23					7,201	12,961
12887 [c]	124	Black Diamond, face of room 30 feet above sixth level, 200 feet west of incline.	SE	21	49	100	7.30	A	17.80	30.89	43.50	7.81	.20					5,328	9,590
								B	11.33	33.32	46.93	8.42	.22					5,748	10,346
								C		37.58	52.92	9.50	.24					6,482	11,668
								D		41.53	58.47		.27					7,163	12,893
5770 [d]	298	Mayfield			46	99	2.90	A	12.84	33.96	48.15	5.05	.39	5.92	63.68	.80	24.16	6,248	11,246
								B	10.24	34.97	49.59	5.20	.40	5.77	65.58	.83	22.22	6,435	11,582
								C		38.96	55.25	5.79	.44					7,169	12,903
								D		41.35	58.65		.47					7,609	13,696
14756 [c]	298	Mayfield, face of tunnel 30 feet from mouth			46	99	3.40	A	10.67	37.99	43.99	7.35	.35					6,151	11,072
								B	7.53	39.33	45.53	7.61	.36					6,368	11,462
								C		42.53	49.24	8.23	.39					6,885	12,395
								D		46.34	53.66		.42					7,503	13,505
17830 [c]	328	Gwynn, face of room 30 feet west of point 40 feet south of mouth			45	97	2.2	A	11.52	34.25	39.98	14.25	.45					5,547	9,985
								B	9.50	35.03	40.89	14.58	.46					5,674	10,213
								C		38.71	45.18	16.11	.51					6,269	11,284
								D		46.14	53.86		.61					7,473	13,451
Average of 5 samples, Fort Union coal							4.4	A	14.10	32.87	44.61	8.41	.31					5,731	10,316
								B	10.14	34.35	46.70	8.78	.32					5,994	10,788
								C		38.18	52.05	9.75	.35					6,668	12,007
								D		42.37	57.63		.40					7,390	13,301

[b] Sample collected by R. L. Nelson.
[c] Sample collected by D. F. Hewett.
[d] Sample collected by E. G. Woodruff

MINES AND PROSPECTS

OREGON BASIN QUADRANGLE

The McGuffey mine is in the NE. ¼ sec. 17, T. 52 N., R. 100 W. (station 12), near the base of the Mesaverde escarpment at the north edge of Oregon Basin. It was opened in 1911 by W. A. McGuffey, but after several years of operation it was closed down and dismantled. The coal-bearing portion of the Mesaverde formation is locally covered with wash, and the site of the opening was chosen after exploration. The bed strikes N. 60° W. and dips 14° NE.; it is probably one of those in the higher part of the coal-bearing section. The workings include an incline 4 by 5 feet, which was driven directly down the dip for a distance of 300 feet, and rooms turned both east and west at three levels. The rooms were driven to a maximum distance of 60 feet east and 100 feet west of the incline. Water of fair quality and sufficient for local needs stands in the bottom of the incline. The equipment included a 20-horsepower hoist, cars, and bins. Run-of-mine coal sold in 1911 at $3.50 a ton at the mine, and haulage to Cody, 15 miles distant, cost $2.35 a ton.

The Schwoob (Wiley) mine is in the SE. ¼ sec. 10, T. 51 N., R. 100 W. (station 14), at the base of the Mesaverde escarpment east of Oregon Basin. It was opened about 1902 and has been operated intermittently since that time. That part of the section which contains beds of coal is exposed in detail along the escarpment. The bed strikes N. 3° E. and dips 22° E., and it may be traced for several miles along the escarpment. It has also been opened by a prospect a mile farther south, in sec. 15. The bed resembles that at the McGuffey mine and, like it, occurs higher in the section than those explored on the west side of Oregon Basin. The workings include an incline 4 by 4 feet, which was driven directly down the dip for 200 feet, and rooms turned north and south at three levels. The rooms extend a maximum distance of 200 feet from the incline. Water hinders operations below the 200-foot level. The equipment includes a horse whim, cars, and a 5-ton bin. The product, which largely exceeds 1 inch in size, is sold for $3 a ton at the mine or $6 a ton at Cody, 17 miles distant.

The Thompson mine is in the SE. ¼ sec. 34, T. 51 N., R. 101 W. (station 21), on the west side of the mouth of a deep ravine that cuts through the entire Mesaverde formation. It was opened by Thompson Bros. about 1905, and during 1906 and 1907 between 1,500 and 2,000 tons was mined, largely for the use of the Bighorn Development Co. in constructing irrigation canals in Oregon Basin. It has been operated intermittently since 1907. In 1912 a new incline was driven east of the ravine, but the flow of water proved to be too large to be handled economically. The Mesaverde formation is exposed in detail in the ravine. The coal bed lies between beds of massive sandstone, which strike N. 70° W. and dip 32° SW. The workings include a tunnel that extends 700 feet to the northwest, the mouth of which is about 25 feet above the ravine. Rooms were turned up the dip of the beds, and near the face of the tunnel there is a connection with an old incline from the surface. The lenticular character of the bed is shown by the differences in the three sections Nos. 22, 21a, and 20, which were measured in the old incline, tunnel, and new incline, respectively, all within a distance of 1,000 feet. Horses were used for haulage, and the only other equipment included the pump and whim used in sinking the new incline. Since the failure of the Bighorn Development Co. the only market lies among the ranches near upper Sage Creek.

The Rader prospect is near the southeast corner of sec. 10, T. 52 N., R. 101 W. (station 23), near the top of a bluff that follows Sage Creek. It was opened about 1909 on a bed 700 feet above the base of the Meeteetse formation but has never yielded much coal. The beds strike N. 45° W. and dip 22° SW., but the incline has been driven at a lower angle south to southeast, for a distance estimated not to exceed 200 feet. Some coal has been mined above the incline. Although the bed contains 33 inches of coal in the workings (section 23) it is only 6 inches thick at the outcrop, 100 feet distant.

The Eagle mine is in the SW. ¼ sec. 2, T. 51 N., R. 100 W. (station 24), on a broad flat south of Oregon Coulee, east of the rim of Oregon Basin. It was opened about 1906 but has not been worked since 1910. The nearest exposures of the Meeteetse formation are along the banks of Oregon Coulee 1,000 feet to the north, but no beds of coal crop out here. The bed explored by the Eagle mine is apparently near the base of the coal-bearing part of the section and trends N. 5° E. and dips 34° E. The bed is shown in section 24, page 98. The workings include an inclined shaft, which is 60 feet deep to standing water, and from which levels extend 10 feet north and 50 feet south at a point 55 feet below the surface. Coal was hoisted to the surface by horse whim.

MEETEETSE QUADRANGLE

The Wilson (Stagg & Dodge) mine is in the SE. ¼ sec. 13, T. 48 N., R. 101 W. (station 34), on the north side of Greybull River. It was opened in 1892 and for some years was known as the Blake mine. From 1909 to 1911 it was worked by C. H. Wilson, who sold it to the present operators, Stagg & Dodge. The Erskine mine, 1,000 feet to the southeast, on the opposite side of the river, was operated for several years but finally abandoned on account of water. In this locality the coal-bearing beds strike N. 35° W. and dip 6° NE., and the coal bed is near the base of the section (section 34, p. 95). The workings include a drift 700 feet long which trends N. 25° W. and therefore descends gently in that direction. From this drift rooms are turned westward up the dip to a maximum distance of 300 feet. The area explored by the workings is about 5 acres. Hand augers are used, and the coal is shot from the solid wall without undercutting. No timber is used to support the roof. Water sometimes accumulates in the drift. The equipment includes an 85-horsepower boiler, hoist, pump, cars, and a 15-ton bin. The product is screened during loading. Two men are commonly employed. In 1911 the price was $3.50 a ton at the mine; in 1919, $4 a ton. The coal was sold in Meeteetse and to ranches in the Greybull and Wood River valleys. The annual production ranges from 1,000 to 1,500 tons.

The Spring Creek prospect is in the NW. ¼ sec. 2, T. 48 N., R. 101 W. (station 33), on the north side of Spring Creek, where the basal Mesaverde beds trend N. 35° W. and dip 9° NE. Here a drift has been driven northward about 150 feet, but little coal has been mined.

The Black Diamond mine is in the SE. ¼ sec. 21, T. 49 N., R. 100 W. (station 124), on the edge of a low hill northwest of the junction of Meeteetse Creek and Greybull River. It was opened in 1904 by Woodruff & Christopherson and has been worked intermittently every year to date. The bed explored in this mine is about 120 feet above the base of the Fort Union formation, and it has been traced half a mile northwest and a mile southeast (stations 124 and 125). It trends N. 45° W. and dips 14° NE. near the surface, but the dip increases to 18° in the bottom of the incline. The workings include an inclined shaft 4 by 6 feet, 500 feet deep, from which rooms extend northwest and southeast to distances that range from 250 to 400 feet. In the upper part of the shaft the rooms are 30 feet wide, but in the lower part they are only 20 feet wide. In mining holes are drilled by hand augers, and the coal is shot from the solid wall. Props 4 to 6 inches in diameter are used. The equipment includes a boiler and engine for hoisting the coal and for raising the water in a skip. There is a 10-ton bin, and screens for making lump and nut sizes. The following prices have been obtained: 1905, $2.25 a ton for run of mine; 1911, $3 a ton for lump and $2 for nut; 1919, $4.50 a ton for lump. The coal is marketed along the Greybull Valley and is valued highly for domestic and boiler use. The production commonly runs from 600 to 1,000 tons a year, but 2,000 tons was mined in 1905.

Beds of coal in the Meeteetse formation have been prospected along the outcrop southeast of Meeteetse, but no coal has been mined. In the NE. ¼ sec. 14, T. 48 N., R. 100 W., a tunnel extends eastward 100 feet on a bed that trends N. 35° W. and dips 18° NE. (station 107). Several shallow prospects have been made on beds of coal near the base of the Mesaverde formation in the escarpment east of Wood River and east of Renner's ranch on Gooseberry Creek.

GRASS CREEK BASIN QUADRANGLE

The Dickie prospect No. 1 was opened prior to 1907, but no additional work had been done in 1919. It is in the NW. ¼ sec. 2, T. 46 N., R. 99 W. (station 127), near the head of a small ravine, which drains northward to Gooseberry Creek. As shown in section 127, Plate XXVI, the bed explored here is the second above the base of the formation. The beds trend N. 70° W. and dip 16° NE. There are two inclines within a distance of 500 feet; the eastern one is caved and the western extends N. 30° E., a distance of 65 feet.

The Dickie prospect No. 2, like No. 1, was opened prior to 1907, and no additional work had been done in 1919. It is in the NE. ¼ sec. 14, T. 46 N., R. 99 W. (station 170), at the head of a ravine that drains eastward into Grass Creek. The beds trend N. 85° E., and dip 7° S. A tunnel has been driven 30 feet south, but no coal has been mined. (See section 170, Pl. XXVII.)

The Punteney mine is in the SE. ¼ sec. 24, T. 44 N., R. 99 W. (station 180), along the bluffs that face Cottonwood Creek. It was opened in 1923 by Vede Punteney and is worked intermittently. In this locality the beds strike N. 80° W. and dip 6° N. The coal bed lies near the top of the coal-bearing section. It is opened by two other prospects within a distance of half a mile to the west. (See sections 177, 178, 179, 180, 181, p. 97.) The workings include a tunnel that extends N. 35° W. 200 feet, from which one room is turned west at a point 80 feet from the entrance. The coal is mined for use at the ranches along Cottonwood Creek.

Berry Bros.' prospect lies in the SE. ¼ sec. 29, T. 44 N., R. 98 W. (station 196), near the head of a ravine that drains southward into Owl Creek. The beds trend N. 60° E. and dip N. 12°. The tunnel extends N. 70° E. about 60 feet, but no coal has been mined. (See section 196, Pl. XXX.)

Beds of coal in the Mesaverde formation have been opened at the following localities in the NW. ¼ sec. 35, T. 46 N., R. 98 W., in Grass Creek Basin, and in the SE. ¼ sec. 25, T. 45 N., R. 98 W., the SW. ¼ sec. 30, T. 45 N., R. 97 W., and the SW. ¼ sec. 33, T. 45 N., R. 97 W., in Cottonwood Basin, but no coal has been shipped from these openings.

The Mayfield mines Nos. 1 and 2 are in the NE. ¼ sec. 26, T. 46 N., R. 99 W. (station 298), on the east and west sides of Coalmine Draw respectively. Mine No. 1 was opened in 1906, but as it was started at the level of the ravine, there was no room for a dump, and water hindered operations. Mine No. 2 was opened 600 feet to the west in 1912 (Pl. XX, *D*). The property is now owned by Mayfield, Hillsbury & Murphy. Both openings are made on the Mayfield bed, which lies 420 feet above the base of the Fort Union formation and which attains its maximum thickness of 36 feet 800 feet east of this locality (station 298). Mine No. 1 lies in the trough of the Mayfield syncline, but mine No. 2 is southwest of the trough, where the beds are inclined at a low angle to the northeast. Mine No. 1 is an irregular tunnel or room that extends generally southward but is now caved near the mouth. Mine No. 2 starts 20 feet above the ravine, near the base of the bed, which is 30 feet thick here and trends N. 55° W. The tunnel is 6 by 6 feet at the entrance but gradually it becomes wider and higher, so that at the face, 280 feet distant, it is 11 feet high and 25 feet wide. A room is turned west at 150 feet from the entrance and extends about 100 feet farther. The bed contains an irregular layer of bone coal 3 to 4 inches thick 5 feet above the floor, but the rest of the exposed bed is clean, bright coal with persistent vertical jointing. The mine has no equipment except wooden rails, cars, and bin. Two men are generally employed during the fall and winter getting out coal for use at near-by ranches.

The Gwynn prospect is in the SE. ¼ sec. 1, T. 45 N., R. 98 W. (station 328), at the head of a ravine that drains northward to Spring Gulch. It was opened in 1912 by Ed Gwynn. The prospect explores the Mayfield bed of the Fort Union formation, but this bed is much thinner here than at the Mayfield mine, 3 miles to the northwest (section 303). The opening is nearly a mile southwest of the trough of the Mayfield syncline, and therefore the bed dips gently northeast. The prospect tunnel enters near the level of the ravine and extends first 50 feet S. 10° W., and then 30 feet S. 80° W. Only a few wagonloads of coal has been removed. The coal has well-developed vertical joints but breaks with a conchoidal fracture and is uncommonly hard. The high content of ash shown by the analysis (No. 17830, p. 104) indicates that the hardness is due to this quality.

The extent of the Mayfield bed is well shown by prospects in the south half of T. 46 N., R. 99 W., for each of the sections measured in that area represents the exposure at a prospect pit. The lower Fort Union beds are not explored in the entire region west of the Grass Creek-Cottonwood road. A tunnel has been driven eastward 60 feet from the ravine in the SW. ¼ sec. 5, T. 45 N., R. 97 W., on one of the lower Fort Union beds.

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