Stratigraphy and Geologic History of the Uppermost Cretaceous, Paleocene, and Lower Eocene Rocks in the Wind River Basin, Wyoming

GEOLOGICAL SURVEY PROFESSIONAL PAPER 495-A

Prepared in cooperation with the Geological Survey of Wyoming and the Department of Geology of the University of Wyoming as part of a program of the Department of the Interior for development of the Missouri River basin

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By WILLIAM R. KEEFER

GEOLOGY OF THE WIND RIVER BASIN, CENTRAL WYOMING

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By William R. Keefer

ABSTRACT

The Wind River Basin, which covers 8,500 square miles in central Wyoming, is one of the major sedimentary and structural basins formed in the Rocky Mountain region during Laramide deformation. Wide belts of folded and faulted Paleozoic and Mesozoic rocks completely encircle the basin, including the Granite Mountains on the south, the Wind River Range on the west, the Washakie Range, Owl Creek and southern Bighorn Mountains on the north, and the Casper Arch on the east. The basin floor has marked structural asymmetry; the structurally deepest parts are along the north and east margins. During latest Cretaceous, Paleocene, and early Eocene times this extensive trough area was the site of accumulation of a continuous sequence of fluviatile, lacustrine, and possibly marine sediments which attain a maximum thickness of nearly 20,000 feet.

The stratigraphic units include the Lewis Shale and Meeteetse and Lance Formations of Late Cretaceous age, the Fort Union Formation of Paleocene age, and the Indian Meadows and Wind River Formations of early Eocene age. The Wind River Formation is the surface rock over much of the basin area, whereas the other formations crop out only in a few places around the edges of the basin. Many wells drilled for oil and gas in the middle of the basin penetrate all or parts of the formations. In general, the individual stratigraphic units are thin and unconformable in surface sections along the basin margins, but they are conformable and much thicker short distances downdip from the outcrops.

The Meeteetse Formation and Lewis Shale are for the most part stratigraphic equivalents. The Meeteetse is a nonmarine sequence of very carbonaceous strata in the central and western parts of the basin. The formation has an average thickness of about 800 feet, but thins toward the eastern edge of the basin where it is overlain and underlain by 200- to 300-foot tongues of marine shale and sandstone of the Lewis Shale. Strata of the Meeteetse Formation were deposited in widespread swamps, broad flood plains, lagoons, and deltas during the brief invasions and final retreat of the Lewis Sea across central Wyoming.

The Lance Formation of latest Cretaceous age consists of interbedded sandstone, shale, claystone, carbonaceous shale, and thin beds of coal. Conglomerate and conglomeratic sandstone crop out in the southern and north-central parts of the basin. Thicknesses range from a few hundred feet in most marginal areas to more than 5,500 feet in the deep trough areas. Deposition during Lance time took place in broad river floor plains, swamps, and probably lakes. Rising highlands along the south and northwest edges of the basin contributed coarse clastic debris, and in those places the Lance is locally unconformable on the Meeteetse and older formations.

The Fort Union Formation includes all the rocks of Paleocene age in the Wind River Basin, and throughout most of the region it can be divided into two general lithologic units: a lower unit of sandstone, conglomerate, shale, and carbonaceous shale deposited in a fluviatile environment, and an upper unit of very fine grained clastic strata deposited in and adjacent to an extensive body of water, referred to as Waltman Lake. The formation has a probable maximum thickness of 8,000 feet in the deep trough areas of the basin.

The upper part of the Fort Union Formation consists of two members, one representing deposition in the marginal areas of Waltman Lake during its maximum expansion and subsequent retreat, and the other representing contemporaneuos deposition in the offshore areas. The marginal unit, referred to as the Shotgun Member, is characterized by dull-gray and tan claystone, siltstone, and shale and minor amounts of sandstone, carbonaceous shale, and coal. The offshore unit, referred to as the Waltman Shale Member, is homogeneous dark-brown to black silty micaceous shale. The Waltman is the most easily recognized unit in the entire uppermost Cretaceous, Paleocene, and lower Eocene sequence in the Wind River Basin. It has a maximum thickness of 3,000 feet in the northeastern part of the basin, but thins to extinction a few miles downdip from the exposures of Paleocene rocks along the south and west margins. The Shotgun Member thickens correspondingly, but in sections near the south and west margins it grades into coarse-grained sandstone and conglomerate, similar to strata in the lower part of the Fort Union Formation, and also loses its identity.

Paleontologic data indicate a middle to late Paleocene or possibly earliest Eocene age for the Shotgun Member and middle to late Paleocene for the Waltman Shale Member of the Fort Union Formation. Remains of marine-type sharks and hystrichosphaerids in these strata, and glauconite formed in place, suggest that Waltman Lake may have been connected to a body of marine water, possibly the Cannonball Sea which extended from the Gulf of Mexico to South and North Dakota during Paleocene time. Tectonic movements around all sides of the Wind River Basin except the east exerted a significant influence on the pattern of sedimentation throughout the epoch.

The lower Eocene sequence, represented by the Wind River and Indian Meadows Formations, includes a maximum of 9,000 feet of strata in the structurally deepest parts of the Wind River Basin. The two units can be separated in some places along the

north and east margins of the basin, but not in the central part. The Wind River Formation probably comprises all the lower Eocene rocks in outcrops along the south and west edges of the basin. The lower Eocene rocks were deposited in extensive alluvial fans around the periphery of the basin during periods of active uplift and erosion of the bordering mountain ranges; contemporaneous deposition in the interior regions of the basin was in lakes and across broad flood plains. The deep trough area of the basin may have been occupied by a vestige of Waltman Lake during earliest Eocene time.

The Indian Meadows Formation of earliest Eocene age (Gray Bull of Wood and others, 1941) consists chiefly of varicolored red, purple, gray, and white claystone, siltstone, sandstone, and conglomerate. Maximum thickness is 4,000–5,000 feet. Locally the conglomerate beds are very coarse, with boulders several feet across. In places the formation contains large detached blocks of resistant Paleozoic rocks, some of which are ancient landslides from the fronts of rising mountain ranges.

The Wind River Formation of late early Eocene age (Lysite and Lost Cabin) also consists chiefly of brightly variegated strata. The Lysite and Lost Cabin Members can be distinguished on the basis of fossil mammals only in their type areas along the northeast margin of the basin. However, there also seems to be an angular discordance which coincides locally with a change in lithology between the two members in this region, and these criteria are used to distinguish the Lysite and Lost Cabin in outcrops along the east edge of the basin.

The uppermost Cretaceous, Paleocene, and lower Eocene rocks record a history of extensive crustal movement in the Wind River Basin and adjacent uplifts during the Laramide. This history is summarized as follows:

1. *Late Cretaceous.*—Downwarping of the basin floor along its north edge probably began as early as Meeteetse and Lewis time, and became more pronounced in latest Cretaceous time. Upwarping of the Granite Mountains and Washakie Range along the south and northwest margins of the basin, respectively, took place at the beginning of deposition of the Lance Formation.

2. *Paleocene.*—The Wind River Range began to rise along the west side of the basin, and broad shallow folds developed in the Owl Creek Mountains along the north side. Subsidence of the basin floor and uplift of the Granite Mountains and Washakie Range continued.

3. *Early Eocene.*—In earliest Eocene time folding and uplift of the mountain ranges were accelerated, and reverse faulting took place along the northwest edge of the basin. Following the deposition of the Indian Meadows Formation, the Owl Creek Mountains and Casper Arch were uplifted along extensive reverse faults. Folding was renewed in some areas during and at the end of early Eocene time. The basin floor also continued to sink throughout this period.

Downwarping played a dominant role in the structural evolution of the basin. Subsidence began in Late Cretaceous time, in the earliest stage of the orogeny, and continued until the end of deposition of the Wind River Formation. Along the north and east edges of the basin, where deformation was most intense (maximum structural displacement about 35,000 ft), the actual movement that can be attributed to subsidence is equal to, or exceeds, the amount of uplift of the adjacent Owl Creek Mountains and Casper Arch in most places.

Commercial quantities of petroleum have been discovered in several horizons within the uppermost Cretaceous, Paleocene, and lower Eocene rocks. Factors favoring the generation and accumulation of oil and gas in these strata include (1) an abundance of reservoir and source rocks; (2) abrupt facies changes from shale to sandstone in the marginal (updip) areas of the basin; (3) presence of unconformities between successive stratigraphic units; and (4) anticlinal folding in both the marginal and interior regions of the basin. The highly organic shale and claystone of the Waltman Shale Member of the Fort Union Formation are probably the source of much of the oil and gas in the lower Tertiary rocks of the basin.

Coal and lignite beds are present in all the formations except the Lewis Shale. The thickest and most extensive coal is in the Meeteetse Formation; beds in the other formations are generally thin and discontinuous. Large deposits of uranium occur in the Wind River Formation in the Gas Hills area along the south edge of the basin.

INTRODUCTION

The Wind River Basin in central Wyoming (fig. 1) contains sequences of uppermost Cretaceous, Paleocene, and lower Eocene rocks that are among the thickest and most complete in the Rocky Mountain region. The stratigraphic, structural, and paleontological data now available on these strata from nearly all parts of the basin afford an opportunity to study the character of sedimentation and its relation to the various kinds of crustal movements in a major intermontane basin during Laramide deformation. A better understanding of the major aspects of basin evolution and mountainbuilding throughout the Rocky Mountains should thus be gained.

ACKNOWLEDGMENTS

An investigation of this scope was made possible only through the efforts and cooperation of many geologists and paleontologists, all of whom are cited in appropriate places in the report. The author acknowledges particularly the valuable contributions of J. D. Love, which resulted not only from his own field studies in many parts of the region but also from his continuing interest and helpful advice and criticism on all phases of this basinwide study, including the preparation of this report. R. L. Koogle and J. A. Van Lieu assisted in the fieldwork during the summers of 1959 and 1960, respectively. Chemical and petrologic studies of Paleocene rocks by H. A. Tourtelot, and his interpretations of the resulting data, greatly facilitated the work. P. O. McGrew, S. H. Knight, and D. L. Blackstone, Jr., Department of Geology, University of Wyoming, provided much useful information regarding regional aspects of the stratigraphy, structure, and paleontology of lower Tertiary rocks throughout Wyoming. The assistance of the following persons in various stages of the author's field and office work is also gratefully acknowledged: T. W. Bibb, J. F. Bookout, P. E. Flanagan, G. D. Mathews, P. R. May, H. C. Mosher, C. A. Mueller, R. M. Normark, D. W. Paape, J. W. Strickland, and J. J. Thuis.

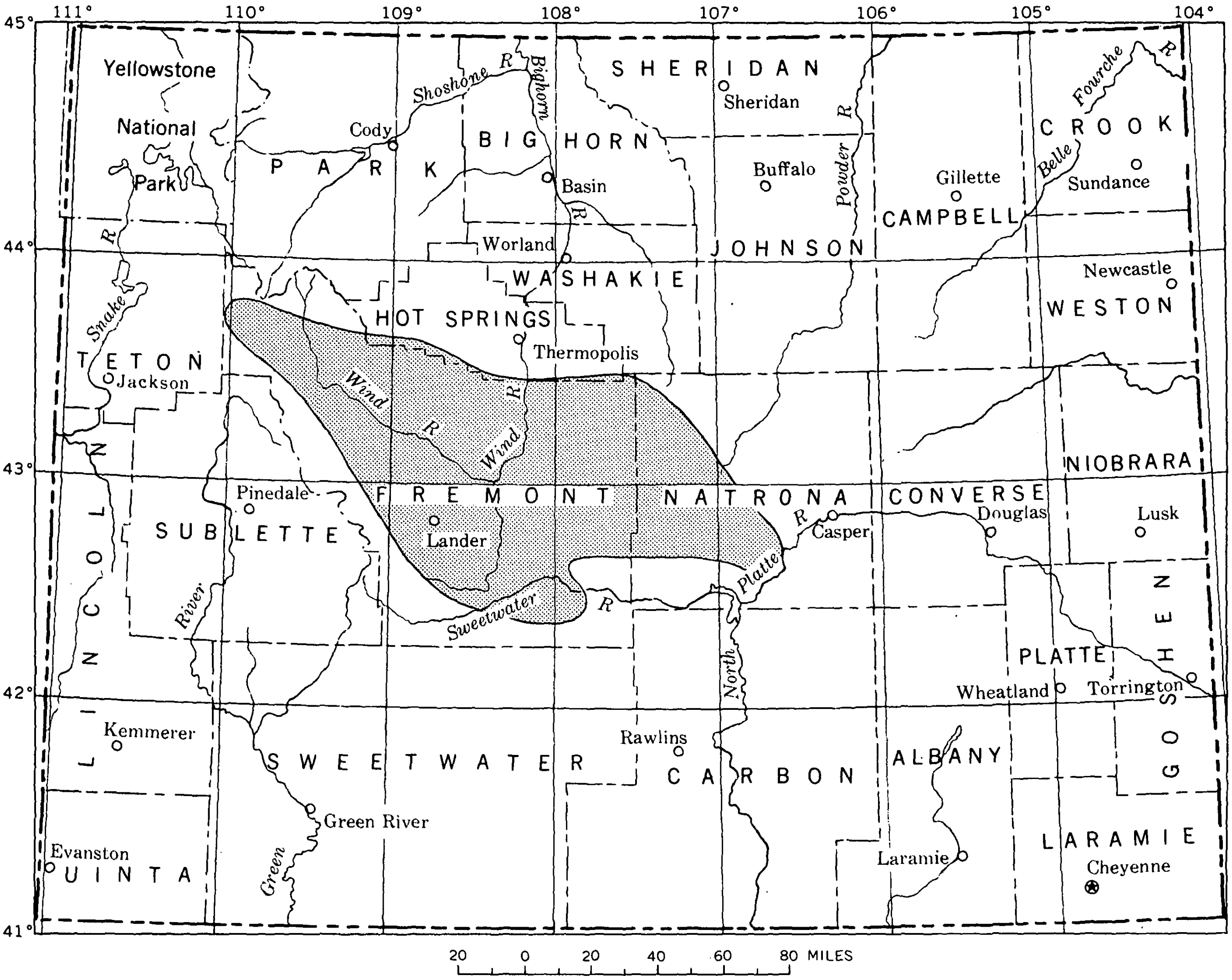


FIGURE 1.—Index map of Wyoming showing area of Wind River structural basin.

This report was prepared with the cooperation of the Geological Survey of Wyoming and the Department of Geology of the University of Wyoming as part of a program of the Department of the Interior for the development of the Missouri River basin.

HISTORY OF INVESTIGATIONS

The general geologic features of the Wind River Basin were first described by geologists accompanying the exploratory expeditions of the U.S. Army before 1875. The first colored geologic map of the Tertiary and older rocks of the basin accompanied a report of investigation by F. V. Hayden for the years 1859–60 (Hayden, 1869), and a second map by T. B. Comstock (in Jones, 1874) differentiated the rocks in the west half of the basin. Early note was taken particularly of the flat-lying red- and gray-banded Tertiary rocks which are extensively exposed across the basin floor; in 1861 these rocks were formally referred to as the "Wind River deposits" by Meek and Hayden (1861, p. 434). Additional descriptions of these strata were published by Comstock (in Jones, 1874, p. 128–129) in annual reports of the U.S. Geological and Geographical Survey of the Territories (for example, St. John, 1883, p. 255–263), and by Darton (1906a, p. 24–25; 1906b, p. 70). It was not until 1910, however, that sufficient stratigraphic and paleontologic data had been obtained to definitely assign an early Eocene age to the rocks that are now defined as the Wind River Formation (Granger, 1910, p. 247).

Rocks of latest Cretaceous and earliest Tertiary ages were recognized by pioneer investigators in many parts of the Rocky Mountains and adjacent Great Plains. The controversies that arose over the systemic boundary within the Laramie beds are well known (Knowlton, 1922, p. 1–81). Hayden (1869) showed the general distribution of these strata, which he had termed the Fort Union or Great Lignite group, in central Wyoming and adjacent areas. Eldridge (1894, p. 24–25, pl. 1) published a brief description of the uppermost Cretaceous and early Tertiary rocks, which he referred to as Laramie, and showed some of the major outcrop areas on his geologic map. Darton (1906a, p. 24) also gave brief descriptions from exposures in the north-central part of the basin, including some of the coal beds, in his study of the Owl Creek Mountains. Other early investigations dealt primarily with the occurrence and potential economic value of the coal beds; the first significant study of the coal in the Wind River Basin was that published by Woodruff and Winchester (1912).

In the early 1940's a systematic program of detailed geologic mapping and stratigraphic studies in the Wind River Basin was begun by the U.S. Geological Survey. The program was stimulated by extensive development of oil and gas fields and reclamation areas in the middle and late 1940's and by the discovery of uranium, oil and gas in Tertiary rocks during the 1950's. Many individuals have been associated with this basinwide study, and their work has led to the publication of many geologic reports; some of the areas of study are shown on figure 2. The primary purpose of the present report is to compile and synthesize all the data that were obtained on the uppermost Cretaceous, Paleocene, and lower Eocene rocks during these investigations. Additional fossil collections, detailed lithologic descriptions, and other essential data were obtained by the writer at many key localities around the margins of the basin during several weeks of fieldwork in the summers of 1959–61. This was supplemented by the microscopic examination of samples and cores from about 20 wells, representing nearly 200,000 feet of drilling, and the study of electric and lithologic logs of numerous other wells.

GEOGRAPHY

The Wind River Basin occupies 8,500 square miles in central Wyoming (fig. 1). It includes most of Fremont County and the western part of Natrona County. The basin is 180 miles long from northwest to southeast and is 75 miles wide. A major part of the structural basin is a topographic depression bordered by mountains on all sides except the east (fig. 3). The most prominent of these mountains is the Wind River Range whose rugged peaks attain altitudes of 13,000 feet or more along the west margin of the basin. To the north the Absaroka Range, Washakie Range, Owl Creek Mountains, and Bighorn Mountains form a nearly continuous mountain barrier for about 100 miles. The south edge of the topographic basin is marked by the Beaver

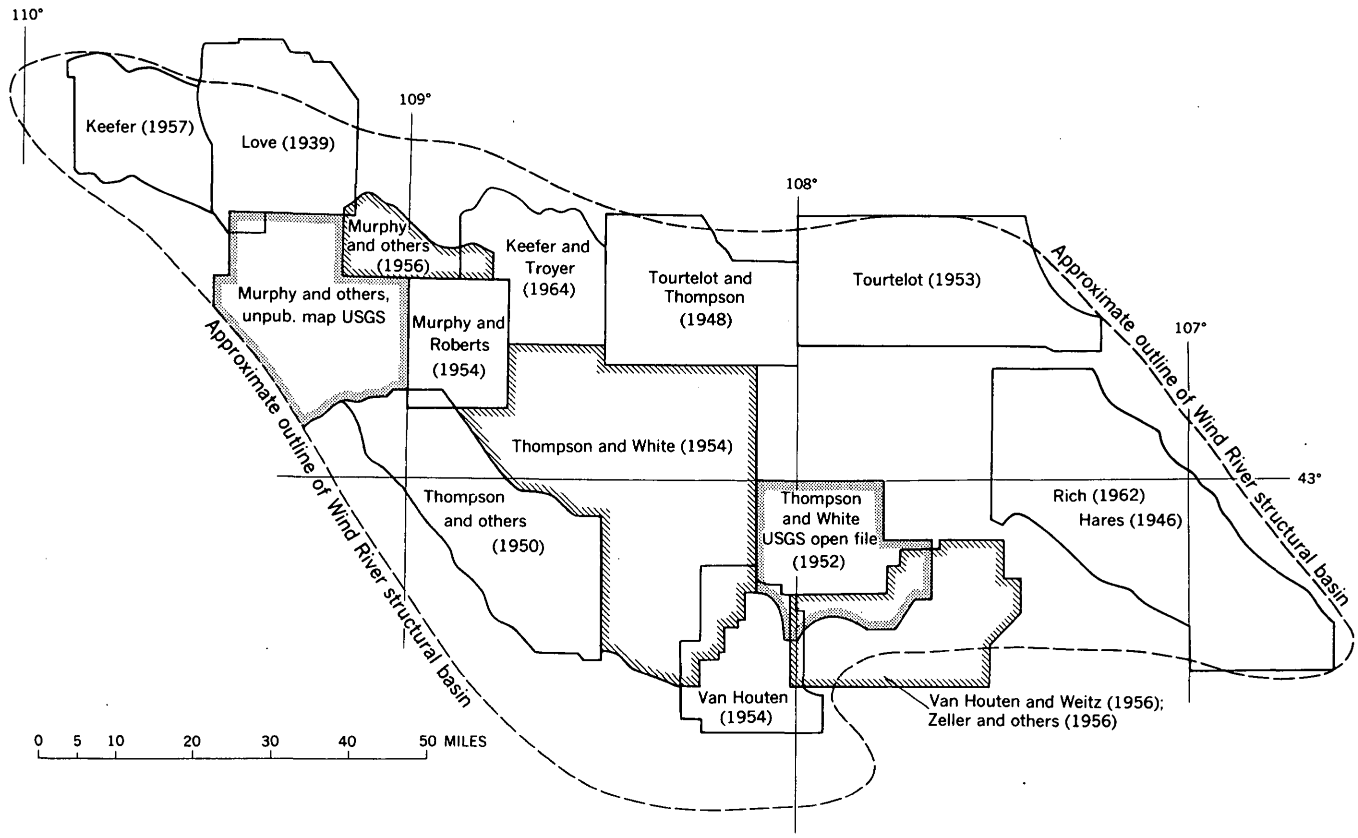


Figure 2.—Principal sources of geologic mapping data used in this report.

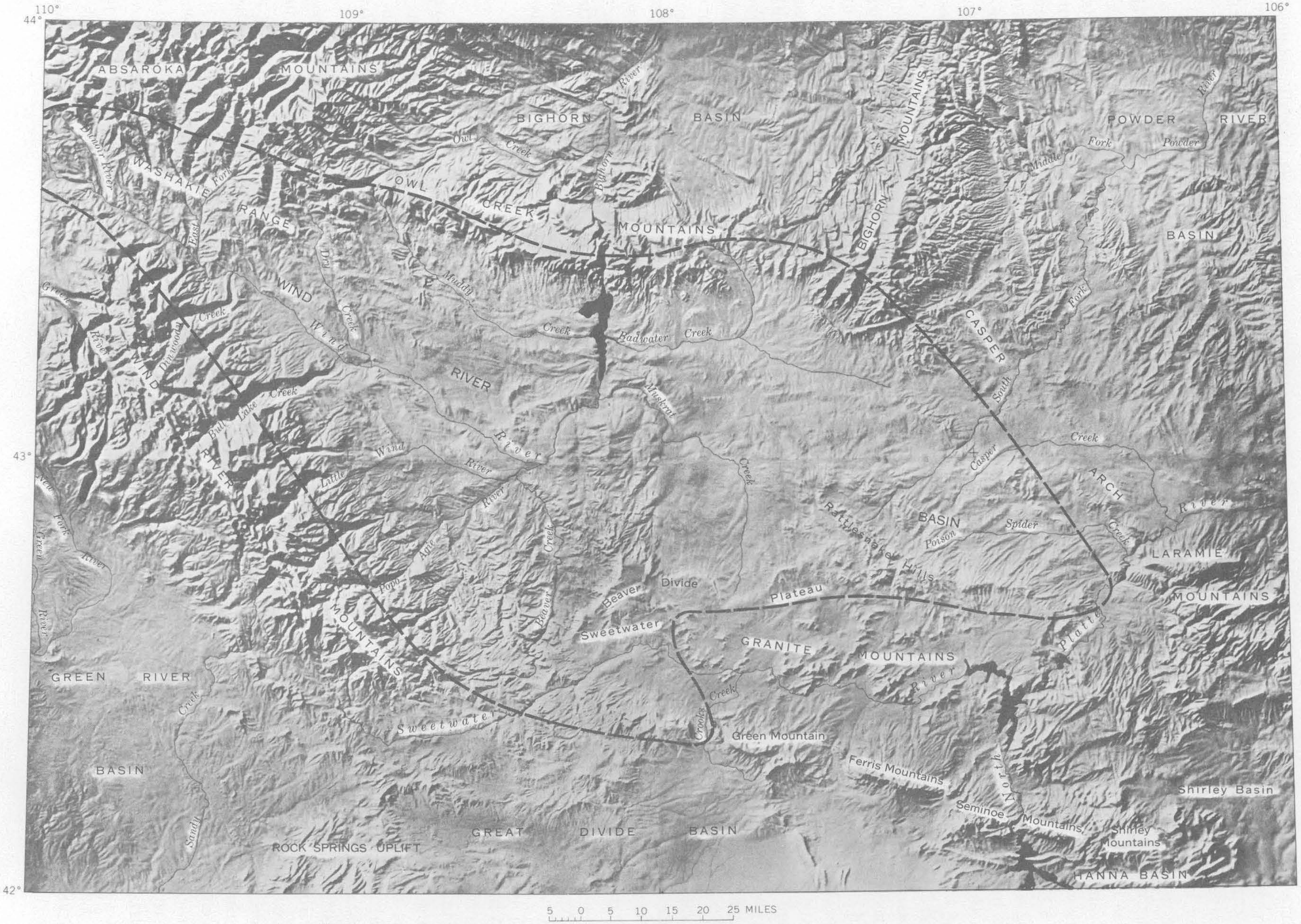


FIGURE 3.—Major physiographic and structural features in central Wyoming. Dashed line indicates approximate outline of Wind River structural basin.

Divide—an erosional escarpment 500–1,000 feet high which extends eastward from the Wind River Range for 50 miles—by the Rattlesnake Hills, and by another erosional escarpment in the extreme southeast corner. The south margin of the structural basin, as developed in the lower Eocene and older rocks, however, is the north flank of the Granite Mountains. Thus, the structural basin includes part of the upland region commonly known as the Sweetwater Plateau which lies south of the Beaver Divide (fig. 3). The east edge of the basin coincides with the west flank of a major, but not deeply eroded, structural upwarp known as the Casper Arch. This region is characterized by low hills and ridges which in most places do not form a topographic barrier between the Wind River Basin and the Powder River Basin to the east; in fact, the entire southeast arm of the Wind River Basin drains eastward into the Powder River Basin.

The basin floor is a region of low relief; only a few scattered buttes and mesas rise as much as 500 feet above the general landscape. Terrace and pediment surfaces form extensive tableland areas, but locally there are prominent badlands in the soft Tertiary sediments. In the northwestern part the altitude of the basin floor is about 7,000 feet above sea level, whereas farther to the east and southeast in the central part the average altitude is 5,000–5,500 feet. The major part of the basin area is drained by the Wind River and its tributaries. The southeastern part, however, is drained by tributaries of the Powder and North Platte Rivers, and the region south of Beaver Divide is drained by the Sweetwater River (fig. 3).

GEOLOGIC SETTING

The Wind River Basin is one of many structural and sedimentary basins formed in the Rocky Mountain region during Laramide deformation. It is surrounded by folded and faulted Paleozoic and Mesozoic strata which form the flanks of the adjacent mountain ranges and anticlinal uplifts. Along the south and west margins these strata dip toward the center of the basin at an average of 10°–20°, whereas along the north and east margins the dips are commonly vertical to overturned. The basin floor thus is markedly asymmetrical; the structurally deepest parts are close to the Owl Creek Mountains on the north and to the Casper Arch on the east.

The center is covered by nearly flat-lying lower Eocene rocks which overlap all older strata. The lower Eocene sequence is a part of the basin fill that accumulated during Laramide deformation and is now being stripped away by erosion.

Until Late Cretaceous time, the present site of the Wind River Basin was part of the foreland or stable shelf region which lay to the east of the main Cordilleran geosyncline. Rocks representing all systems, except possibly the Silurian, were deposited during transgressions and regressions of epicontinental seas across this region, but the stratigraphic sequence is thin and discontinuous as compared to the thick geosynclinal accumulations farther west in Idaho.

Beginning in Late Cretaceous time, the main sites of sedimentary accumulation shifted eastward because of uplift west of the present Idaho-Wyoming boundary. The last major episode of marine deposition in central Wyoming is marked by the Cody Shale of late Colorado (Niobrara) and early Montana (Telegraph Creek, Eagle and Claggett) ages. The basal sandstone of the Mesaverde Formation was deposited during the eastward regression of the Cody sea. Minor readvances of the sea occurred, as represented by thin tongues of marine shale in the basal part of the Mesaverde Formation in the central and eastern parts of the basin; but during most of the deposition of the Mesaverde, the basin area was an emergent surface of low relief characterized by broad flood plains, coastal swamps, deltas, and lagoons. Except for brief marine invasions during deposition of the Lewis Shale, conditions generally similar to those during deposition of the Mesaverde prevailed throughout the rest of Late Cretaceous time. However, during the latest part of the period there was local tectonic activity that represented the initial phases of the Laramide orogeny in central Wyoming, and these movements exerted an increasing degree of influence on the pattern of sedimentation during all early Tertiary time.

The complex sedimentary and structural history which followed the deposition of the Mesaverde Formation is the major theme of this report.

STRATIGRAPHY

The sedimentary sequence here described includes the Lewis Shale and Meeteetse and Lance Formations of Late Cretaceous age, the Fort Union Formation of Paleocene age, and the Indian Meadows and Wind River Formations of early Eocene age. The Wind River Formation lies at the surface throughout much of the basin area, whereas the other formations crop out only here and there along the basin margins (pl. 1). They are widespread in the subsurface, however, and have been penetrated by numerous deep wells in the central part of the basin. In the northwestern part, west of Steamboat Butte and Pilot Butte anticlines (locs. 36 and 37, pl. 1), meager subsurface data suggest that the lower Eocene rocks rest directly on the Mesaverde or older formations with no intervening uppermost Cretaceous or Paleocene strata, except possible remnants of the Meeteetse Formation in some of the deeper synclinal troughs.

The formations within the uppermost Cretaceous, Paleocene, and lower Eocene sequence are thin and unconformable in most surface sections, but are much thicker and virtually conformable only short distances downdip from the outcrops. Abrupt changes in lithology within individual formations are also common near the basin margin. Regional correlations are, therefore, difficult to establish.

In the central and northeastern parts of the Wind River Basin, the thick homogeneous black Waltman Shale Member of the Fort Union Formation is easily recognized in well cuttings and on electric logs (figs. 14, 15; pl. 3), and affords an excellent datum for correlation of the Paleocene rocks. Other stratigraphic units in the structurally deeper parts of the basin are more difficult to define, on the other hand, because lithologic changes are generally very gradual through the contact zones as the result of almost continuous deposition during all Late Cretaceous, Paleocene, and early Eocene times. In some wells the formation contacts are best defined on electric logs, but, owing to the similarities in electrical properties shown by many units, correlations based solely on electric logs are apt to be misleading unless supplemented by a general knowledge of the lithologies penetrated. Correlations based particularly on gross lithologic aspects, structural relations, and similar environments of deposition can be made with some degree of assurance over relatively wide areas.

Plate 2 shows the author's interpretation of the regional stratigraphic relations of the uppermost Cretaceous, Paleocene, and lower Eocene rocks in the Wind River Basin. The sections used in the construction of the fence diagram are listed in table 1, and significant fossil collections are listed in tables 2 and 3.

TABLE 1.—*List of geologic sections used in construction of fence diagram, plate 2*

Geologic section No. (pls. 1, 2)	Locality name	Location			Depth of well (feet)	Formations studied	Source of information
		Section	Township	Range			
1	Bench Creek	{12, 13, 24 6, 7.	42 N. 42 N.	108 W. 107 W.		Wind River	Measured by W. R. Keefer.
2	East Fork Wind River.	14, 15, 22	6 N.	6 W.		Wind River (in part), Indian Meadows.	Measured by J. D. Love.
3	Phillips Petroleum Co., Austral 1.	SW¼NE¼ 7	3 N.	1 W.	11, 370	Wind River	Sample study by W. R. Keefer.
4	Ethete	22	1 N.	1 E.		Wind River and Fort Union.	Measured by K. A. Yenne and W. R. Keefer.
5	Hudson	3, 4	33 N.	98 W.		Fort Union (in part)	Measured by R. M. Thompson and J. L. Weitz.
6	Stanolind Oil & Gas Co. Johnson 1.	SE¼SE¼ 3	33 N.	96 W.	8, 920	Wind River and Fort Union.	Sample study by J. D. Love.
7	Alkali Butte	16, 20, 21, 28, 29, 32, 33.	1 S.	6 E.		Wind River (in part), Fort Union, Lance.	Measured by K. A. Yenne and G. N. Pipiringos, modified by W. R. Keefer.
8	Conant Creek	28, 32, 33	34 N.	93 W.		Fort Union (in part), Lance.	Measured by K. A. Yenne and G. N. Pipiringos.
9	Castle Gardens	{5, 9, 10, 16 32, 33.	34 N. 35 N.	90 W. 90 W.		Wind River (in part), Fort Union, Lance, Meeteetse.	Measured by K. A. Yenne, J. L. Weitz, and J. Belshe.
10	Rattlesnake Hills	{3, 4, 9 26, 34, 35.	34 N. 35 N.	88 W. 88 W.		do	Measured by W. R. Keefer and E. I. Rich.
11	Cities Service Oil Co. Govt. C–1.	NW¼SW¼ 12	32 N.	85 W.	11, 281	Wind River, Fort Union, Lance, Meeteetse, Lewis	Sample study by W. R. Keefer.
12	Casper Canal	9, 10, 15	31 N.	82 W.		Fort Union (in part), Lance, Meeteetse, Lewis.	Measured by E. I. Rich.
13	Shotgun Butte	17, 20, 21, 26, 27, 28, 35.	6 N.	1 E.		Indian Meadows, Fort Union, Lance, Meeteetse.	Measured by W. R. Keefer and M. L. Troyer.

TABLE 1.—*List of geologic sections used in construction of fence diagram, plate 2*—Continued

Geologic section No. (pls. 1, 2)	Locality name	Location			Depth of well (feet)	Formations studied	Source of information
		Section	Township	Range			
14	Phillips Petroleum Co. Boysen 1.	SE¼SE¼ 27	5 N.	5 E.	15, 050	Wind River, Indian Meadows, Fort Union, Lance (in part).	Sample study by W. R. Keefer.
15	Shell Oil Co. Howard Ranch 23–15.	NE¼SW¼ 15	39 N.	93 W.	11, 474	do	Do.
16	Sinclair-Wyoming Oil Co. Lysite 1.	NE¼NW¼ 35	39 N.	91 W.	12, 588	do	Do.
17	Pure Oil Co. Badwater 1.	NE¼NW¼ 26	39 N.	89 W.	17, 030	do	Do.
18	Waltman	4, 5, 8	36 N.	86 W.		Wind River (in part), Fort Union, Lance, Meeteetse, Lewis.	Measured by W. R. Keefer and R. L. Koogle.
19	British-American Oil Producing Co. J. B. Eccles 1.	SE¼SE¼ 31	35 N.	84 W.	10, 810	Wind River, Indian Meadows, Fort Union (in part).	Sample study by W. R. Keefer.
20	Pure Oil Co. West Poison Spider 1.	11	33 N.	84 W.	14, 305	Wind River, Indian Meadows, Fort Union, Lance, Meeteetse, Lewis.	Do.
21	Gulf Oil Corp. Mae Rhodes 1.	NW¼NW¼ 3	3 N.	2 E.	11, 000	do	Do.
22	Phillips Petroleum Co. Missouri 1.	NW¼SE¼ 8	2 N.	4 E.	10, 500	Wind River, Indian Meadows, Fort Union, Lance, Meeteetse (in part).	Well log study by W. R. Keefer.
23	Superior Oil Co. Fuller Reservoir 1–26.	NW¼SE¼ 26	36 N.	94 W.	9, 149	Wind River, Fort Union, Lance, Meeteetse.	Sample study by W. R. Keefer.
24	Humble Oil & Refining Co. Gov't.-Walker 1.	NE¼NW¼ 33	37 N.	92 W.	7, 242	Wind River, Indian Meadows, Fort Union (in part).	Well log study by W. R. Keefer.
25	Continental Oil Co. Squaw Buttes 28–1.	NW¼NW¼ 28	36 N.	90 W.	6, 956	Wind River, Indian Meadows, Fort Union, Lance (in part).	Sample study by W. R. Keefer.
26	California Co. Cooper Reservoir 2.	SE¼SW¼ 34	36 N.	87 W.	8, 631	do	Do.
27	Continental Oil Co. Moneta Hills 11–1.	NE¼SE¼ 11	37 N.	91 W.	5, 594	Wind River, Indian Meadows, Fort Union (in part).	Do.
28	California Co. Madden 1.	NE¼SW¼ 8	38 N.	89 W.	12, 505	Wind River, Fort Union, Lance (in part).	Do.

UPPER CRETACEOUS SERIES

ROCKS UNDERLYING THE MEETEETSE FORMATION AND LEWIS SHALE

The Mesaverde Formation, largely a nonmarine sequence of sandstone, shale, carbonaceous shale, and coal, underlies the Meeteetse Formation and Lewis Shale throughout the Wind River Basin. In extensive areas the upper part of the Mesaverde is characterized by massive white to light-gray sandstone which commonly forms prominent ridges. This sandstone sequence, referred to as the white sandstone member in the north-central part of the basin and the Teapot Sandstone Member in the southeastern part (Keefer and Rich, 1957, p. 73), contrasts sharply in both lithology and topographic expression with the nonresistant rocks of the overlying Meeteetse Formation and Lewis Shale. Where the sandstone is absent or poorly developed, however, the contract, particularly between the Mesaverde and Meeteetse Formations, is not so easily recognized.

MEETEETSE FORMATION AND LEWIS SHALE

DEFINITION

The stratigraphic interval between the Mesaverde and Lance Formations consists of nonmarine rocks in the central and western parts of the Wind River Basin and of interbedded marine and nonmarine rocks in the eastern part. The nonmarine strata are referred to the Meeteetse Formation (Hewett, 1914, p. 102), the type section of which is in the Bighorn Basin to the north. The marine strata, on the other hand, are placed in the Lewis Shale, a name used by Cross and Spencer (1899, p. 5) for the sequence of sandy shale and claystone of marine origin overlying the Mesaverde Formation in southwestern Colorado.

DISTRIBUTION

Figure 4 shows the distribution of the Meeteetse Formation and Lewis Shale in the Wind River Basin. Exposures are present along the south and east edges of the basin and in the Shotgun Butte area in the north-

TABLE 2.—*Fossil collections in the Wind River Basin*

[Stratigraphic positions shown on pl. 2]

Collection on pl. 2	USGS locality No.	Location: Section	Location: Township	Location: Range	Formation	Fossil type	Species	Age assignment	Identified by (or published reference)
1A		N ½ 29	42 N	107 W	Wind River	Vertebrate	*Lambdotherium* sp., *Esthonyx* sp., *Ectocian* sp., *Phenacodus* sp., *Diacodexis* sp., *Hyracotherium* cf. *H. vasacciense*.	Early Eocene (Lost Cabin).	Keefer (1957, p. 190).
1B		NE¼ 10	42 N	108 W	do	Plant	*Equisetum* sp., *Allantodiopsis erosa*, *Woodwardia* sp., *Lygodium* sp., *Thuja* sp., *Metasequoia occidentalis*, *Sparganium antiquum*, *Pterocarya* sp., *Ailanthus* sp., *Mimosites* sp., *Cercidiphyllum* sp., *Platanus* sp., *Liquidambar callarche*, *Cinnamomum* sp.	Early to middle Eocene.	Do.
1C		SE¼ 5	42 N	107 W	do	Vertebrate	*Hyracotherium* cf. *H. vasacciense*, *Lambdotherium* cf. *L. popoagicum*.	Early Eocene (Lost Cabin).	Do.
2A					Indian Meadows	do	*Oxyaena gulo*, *Haplomylus speirianus*, *Hyopsodus simplex*, *H. latidens*, *Hyracotherium* sp., *H. etsagicus*, *Esthonyx bisulcatus*, *Coryphodon* cf. *C. elephantopus*, *Coryphodon* sp., *Phenacodus* sp.	Early Eocene (Gray Bull of Wood and others 1941).	Love (1939, p. 62–63).
2B					Wind River	do	*Phenacodus* cf. *P. wortmani*, *Heptodon* cf. *H. ventorum*, *Viverravus* cf. *V. dawkinsianus*, *Diacodexis* cf. *D. chacensis*, cf. *Diacodexis* sp., *Hyopsodus* cf. *H. mentalis*, *Hyopsodus* sp., *Hyracotherium* sp., *Coryphodon* sp., *Didelphos* sp.	Early Eocene.	Love (1939, p. 65).
4A		SE¼ 22	1 N	1 E	Fort Union	Plant	*Sabalites* sp., *Quercus* sp., *Fagus* sp., *Carya antiquorum* Newberry, *Cercidiphyllum arcticum* (Heer) Brown, *Celastrus ferruginea* Ward, *Sassafras* sp., *Viburnum antiquum* (Newberry) Hollick, *Ginkgo adiantoides* (Unger) Heer, *Carpanus* sp., *Platanus raynoldsi* Newberry, *Ulmus* sp., *Carpites* sp., *Betula* sp., *Rhamnus goldianus* Lesquereux.	Paleocene.	Thompson and White (1954).
6A		(Southeastern part of township).	33 N	96 W	Wind River	Vertebrate	*Hyopsodus* sp., *Didymictis? altidens*, *Microsyops* sp., *Hyracotherium craspedotus*, *Hyracotherum? venticolus*, *Heptodon calciculus*, *H. ventorum*, *Lambdotherium popoagicum*, *Coryphodon* sp.	Early Eocene (Lost Cabin).	Sinclair and Granger (1911, p. 91).
7A	D1434	SW¼ 28	1 S	6 E	Lance	Plant	*Sequoia reichenbachi* (Geinitz) Heer	Late Cretaceous.	Thompson and White (1954).
						Spore and pollen	See collection D1434, table 3	Cretaceous	E. B. Leopold (1962);[1] G. O. W. Kremp (1960).[1]
7B		NE¼ 29	1 S	6 E	Fort Union	Plant	*Cercidiphyllum arcticum* (Heer) Brown, *Sparganium antiquum* (Newberry) Berry, *Platanus raynoldsi* Newberry.	Paleocene.	Yenne and Pipiringos (1954).
7C		SE¼ 20; Center 21	1 S	6 E	do	do	*Ginkgo adiantoides* (Unger) Heer, *Metasequoia* sp., *Sparganium antiquum* (Newberry) Berry, *Lemna scutata* Dawson, *Platanus raynoldsi* Newberry, *P. haydeni* Newberry, *Aralia notata* Lesquereux, *Cercidiphyllum arcticum* (Heer) Brown, *Alnus* sp. *Ulmus* sp.	Late Paleocene.	Yenne and Pipiringos (1954); J. A. Wolfe (1961).[1]
8A	D1486A–C	SE¼ 32	34 N	93 W	Lance	Spore and pollen	See collection D1486A–C, table 3	Cretaceous	E. B. Leopold (1962);[1] G. O. W. Kremp (1960).[1]
8B	21540	SE¼ 32	34 N	93 W	do	Plant	*Dryophyllum subfalcatum* Lesquereux	Late cretaceous	Yenne and Pipiringos (1954).
						Invertebrate	*Unio* sp., *Viviparus* cf. *V. retusus* (Meek and Hayden), *Viviparus* sp., *Campeloma vetula* (Meek and Hayden), *Lioplacodes* sp., *Hydrobia* cf. *H. subconica* (Meek and Hayden), *Goniobasis* cf. *G. sublaevis* (Meek and Hayden), *Goniobasis* cf. *G. tenuicarinata* (Meek and Hayden), *Physa* sp.		
8C	D1487	NW¼ 33	34 N	93 W	Fort Union	Plant	*Ginkgo adiantoides* (Unger) Heer; *Cercidiphyllum arcticum* (Heer) Brown.	Paleocene	Do.
						Spore and pollen	See collection D1487A–C, table 3		G. O. W. Kremp (1960).[1]
9A	D1501C	SW¼ 10	34 N	90 W	Lance	Plant	*Anemia* sp., *Platanus* sp., *Cercidiphyllum ellipticum* (Newberry) Brown, *Viburnum marginatum* Lesquereux.	Probable Late Cretaceous.	R. W. Brown (1950).[1]
						Spore and pollen	See collection D1501C, table 3	Cretaceous	E. B. Leopold (1962);[1] G. O. W. Kremp (1960).[1]
9B	D1489A	NW¼ 5	34 N	90 W	Fort Union	do	See collection D1489A, table 3		G. O. W. Kremp (1960).[1]
9C		SE¼ 36; SE¼ 31	35 N; 35 N	91 W; 90 W	do	Plant	*Onoclea* sp., *Glyptostrobus dakotensis* Brown, *Carya antiquorum* Newberry, *Cercidiphyllum arcticum* (Heer) Brown, *Carpites verrucosus* Lesquereux.	Paleocene	R. W. Brown (1950).[1]
10A	D1503B	S½ 34	35 N	88 W	do	Spore and pollen	See collection D1503B, table 3		G. O. W. Kremp (1960).[1]
10B		SW¼ 21	35 N	88 W	do	Plant	*Glyptostrobus* sp., *Metasequoia glyptostroboides* Hu and Cheng, *Platanus haydeni* Newberry.	Paleocene	J. A. Wolfe (1961).[1]

See footnotes at end of table.

TABLE 2.—*Fossil collections in the Wind River Basin*—Continued

Collection on pl. 2	USGS locality No.	Location			Formation	Fossil type	Species	Age assignment	Identified by (or published reference)
		Section	Township	Range					
12A	Mesozoic D1170.	SW¼ 15	31 N.	82 W.	Lewis Shale (lower tongue).	Invertebrate	*Inoceramus* cf. *I. barabini* Morton, *Inoceramus* (*Endocostea*) sp., *Pteria* n. sp., *Baculites eliasi* Cobban, *Acanthoscaphites* sp.	Late Cretaceous (late Bearpaw).	Rich (1962).
12B	Mesozoic D1171.	CW½ 15	31 N.	82 W.	Lewis Shale (upper tongue).	do	*Glycimeris wyomingensis* (Meek), *Anomia* sp., *Ethmocardium* sp., *Turritella* sp., *Baculites* cf. *B. clinolobatus* Elias.	Late Cretaceous (Lennep or Fox Hills).	Do.
13A		W½ 17	6 N.	1 E.	Meeteetse	Vertebrate	Fragments of dinosaur bones	Cretaceous	Keefer and Troyer, 1956.
13B	D1476E	SE¼ 20	6 N.	1 E.	Lance	Spore and pollen	See collection D1476E, table 3	do	E. B. Leopold (1959).[1]
13C		SW¼ 21	6 N.	1 E.	Fort Union (lower part).	Plant	*Aralia notata* Lesquereux, *Platanus raynoldsi* Newberry, *Cercidiphyllum arcticum* (Heer) Brown, *Persea* sp.	Paleocene	Keefer and Troyer (1956).
13D		NW¼ 26	6 N.	1 E.	Fort Union (Shotgun Member).	do	*Castanea* sp., *Metaseguoia* sp. *Ulmus* sp., *Platanus* sp.	Probable late Paleocene.	Do.
		E½ 27	6 N.	1 E.		Vertebrate	*Phenacodus primaevus*, *Plesiadapis* cf. *P. cookei*	Late Paleocene or earliest Eocene.	Do.
	D1640	SW¼ 36	6 N.	1 E.		Spore and pollen	See collection D1640, table 3	Eocene(?)	E. B. Leopold (1962).[1]
13E		SE¼ 26	6 N.	1 E.	Indian Meadows	Vertebrate	*Phenacodus* sp., *Ectocion* sp., *Hyracotherium* sp., Creodont (mesonychid?).	Early Eocene (Gray Bull of Wood and others, 1941).	Keefer and Troyer (1956).
14A	D1519B	SE¼ 27	5 N.	5 E.	Fort Union	Spore and pollen	See collection D1519B, table 3		G. O. W. Kremp (1960).[1]
18A	Mesozoic D1173.	NE¼ 10	36 N.	86 W.	Lewis Shale (lower tongue).	Invertebrate	*Inoceramus* sp., *Pteria subgibbosa* (Meek and Hayden), *Pteria* (*Oxytoma*) *nebrascana* (Evans and Shumard), *Modiolus meeki* (Evans and Shumard), *Polinices* sp., *Acanthoscaphites* sp., *Baculites eliasi* Cobban.	Late Cretaceous (late Bearpaw).	Rich (1962).
18B	D1827A–B	NW¼ 8	36 N.	86 W.	Lance	Spore and pollen	See collection D1827A–B, table 3	Early Paleocene	E. B. Leopold (1962).[1]
18C		Center 8	36 N.	86 W.	Fort Union (lower part).	Plant	*Carya antiquorum*	Paleocene	J. A. Wolfe (1961).[1]
18D	D1483A–B	NE¼ 17	36 N.	86 W.	Fort Union (Waltman Shale Member).	Spore and pollen	See collection D1483A–B, table 3		G. O. W. Kremp (1960).[1]
26A	D1507A	SW¼ 34	36 N.	87 W.	Fort Union	do	See collection D1507A, table 3		Do.
28A	D1508B–E	SW¼ 8	38 N.	89 W.	do	do	See collection D1508B–E, table 3		Do.
F		S½ 32	42 N.	106 W.	Wind River	Vertebrate	*Hyracotherium* cf. *H. vasacciense*	Early Eocene (Lost Cabin).	Keefer (1957, p. 191).
G		NW¼ 12	41 N.	106 W.	do	do	*Viverravus* cf. *V. dawkinsianus*, *Heptodon* cf. *H. calciculus* *Lambdotherium* cf. *L. progressum*, *Hyracotherium* sp.	Early Eocene (Lost Cabin).	Love (1939, p. 65–66).
H		SE¼ 32	6 N.	5 W.	Indian Meadows	do	*Hyracotherium* sp., *Hyopsodus* cf. *H. simplex* (Loomis) *Haplomylus speirianus* (Cope), cf. *Pelycodus trigonodus* Matthew and Granger, *Diacodexis* cf. *D. metsiacus* (Cope), cf. *Ectocion* sp., cf. *Coryphodon* sp., *Viverravus*, near *V. acutus* Matthew and Granger, cf. *Didymictus* sp.	Early Eocene (Gray Bull of Wood and others, 1941).	C.L. Gazin (1956).[1]
	21005	NE¼ 3	5 N.	5 W.		Invertebrate	*Physa* cf. *P. bridgerensis* Meek, *Physa* cf. *P. pleromatis* White, *Anisus* sp., *Drepanotrema*? sp.	Early Eocene	D.W. Taylor (1962).[1]
I		NE¼ 32	6 N.	5 W.	Wind River	Vertebrate	*Hyracotherium* sp., *Haplomylus* sp. or small *Hyopsodus* sp.	do	C. L. Gazin (1956).[1]
		SE¼ 23					*Lambdotherium popoagicum* (Cope)	Early Eocene (Lost Cabin).	
J		NE¼ 22	4 N.	3 W.	do	Plant	*Sparganium antiquum* (Newberry) Berry, *Juglans* sp., *Platanus raynoldsi*, Newberry, *Aralia wyomingensis* Knowlton and Cockerell.	Possible middle Eocene	Murphy and others (1956).
		SE¼ 22				Vertebrate	*Eotitanops* sp	Early Eocene (Lost Cabin).	R. L. Hay.[2]
K		26 and 35	5 N.	1 E.	do	do	*Ectocion* sp., *Phenacodus* sp., *Hyracotherium* cf. *H. boreale*, *Pelycodus*? sp., *Hyopsodus* sp., *Hyopsodus* cf. *H. mentalis*, *Cynodontomys* sp., *Heptodon brownorum*, *Lambdotherium popoagicum*, *Crocodilus* sp.	do	Keefer and Troyer (1956)
L		SE¼ 30	6 N.	3 E.	Fort Union (Shotgun Member).	do	*Ptilodus* cf. *P. montanus* Douglass, *Mimetodon* cf. *M. douglassi* (Simpson), *Ectypodus*? cf. *E. silberlingi* Simpson, ?*Anconodon gidleyi* (Simpson), *Eucosmodon*? sp., *Catopsalis* cf. *C. fissidens* Cope, *Peradectes*? sp., *Gelastops* sp., *Diacodon*? sp., possibly *Aphronorous* sp., *Pentacodon* sp., possibly *Zanycteris* sp., Plesiadapid cf. *Pronothodectes* sp., *Claenodon* cf. *C. ferox* (Cope) *Tricentes* near *T. subtrigonus* (Cope), *Periptychus* cf. *P. carinidens* Cope, *Anisonchus* near *Ausectorius* (Cope), *Promioclaenus* sp., *Litomylus*? sp., *Gidleyina* sp. *Pantolambda* cf. *P. cavirictus* Cope.	Middle or early late Paleocene (Torrejon or early Tiffany of Wood and others, 1941.	Keefer (1961).
						do	*Corax pristodontus* or *Galeocerdo* sp., Sand shark or mackerel shark.		
M	D1482D–E	NE¼ 31	6 N.	3 E.	do	Spore and pollen	See collection D1482D–E, table 3	Eocene?	E. B. Leopold (1962).[1]

N		SW¼ 6 NE¼ 12	2 S. 2 S.	6 E. 5 E.	Wind River	Vertebrate	*Phenacodus* sp., *Hyracotherium* sp.	Early Eocene	Thompson and White, 1954.
P		Center 17	34 N.	92 W.	Fort Union	Plant	*Cercidiphyllum ellipticum, Carya antiquorum, Sequoia* sp., *Platanus raynoldsi, Platanus haydeni.*	Paleocene	R. W. Brown.[3]
	D1511A-B	SW¼ 31	34 N.	92 W.		Spore and pollen	See collection D1511A-B, table 3.	Paleocene	E. B. Leopold (1962);[1] G. O. W. Kremp (1960).[1]
Q		SE¼ 28	34 N.	91 W.	Lance	Plant	*Equisetum* sp., *Metasequoia cuneata* (Newberry) Chaney *Fokienia* n. sp., *Vitis stantoni* (Knowlton) Brown, *Grewiopsis saportana* Lesquereux.	Late Cretaceous	J. A. Wolfe (1960).[1]
	D1641	Center 22	34 N.	91 W.		Spore and pollen	See collection D-1641, table 3.	Cretaceous	E. B. Leopold (1962).[1]
R		NW¼ 19	39 N.	89 W.	Wind River (Lysite Member).	Vertebrate	*Hyopsodus* sp., *Hyracotherium* cf. *H. borealis, Hyracotherium* cf. *H. craspedotum, Glyptosaurus* sp.	Early Eocene	Tourtelot, (1953).
S		SE¼ 11 NE¼ 22	38 N.	89 W.	Wind River (Lost Cabin Member).	do.	*Hyopsodus mentalis, Hyrachyus*? sp., *Coryphodon* sp., *Notharctus venticolus, Notharctus* sp., *Hyracotherium* sp., *Heptodon* sp., *Phenacodus primaevus, Phenacodus* sp., *Didymictis protenus, Allognathosuchus* sp., *Viverravus* cf. *V. actus, Paramys* sp., *Stylinodon*? sp. or *Ectoganus* sp., *Lepisosteus* sp.	Early Eocene	Do.
T		S½ 25 SW¼ 31	37 N. 37 N.	87 W. 86 W.	Wind River (Lysite Member).	do.	*Phenacodus wortmani, Hyracotherium* sp., cf. *Diacodexis* sp., *Absarokius abbotti, Heptodon* cf. *H. ventorum, Esthonyx* cf. *E. bisulcatus, Oxyrhina* sp.	Early Eocene	C. L. Gazin (1961);[1] F. C. Whitmore (1961).[1]
U		NW¼ 14	36 N.	87 W.	Wind River	do.	*Lambdotherium popoagicum*	Early Eocene (Lost Cabin).	Rich (1962).

[1] Written communication.
[2] Unpub. Ph. D. dissertation, Princeton Univ., Princeton, N. J.
[3] Oral communication.

central part. Meeteetse and Lewis strata have been penetrated by wells in the shallower parts of the basin, but no well in the central and northeastern parts has been drilled to sufficient depths to penetrate these formations. Subsurface data are lacking in critical areas west of Steamboat Butte anticline (loc. 36, pl. 1); it is not known, therefore, whether Meeteetse strata are present in the northwestern part of the basin.

TABLE 3.—*Collections of spore and pollen in Wind River Basin; a selected list of genera of limited stratigraphic range*

[Identified by E. B. Leopold and G. O. W. Kremp, U.S. Geological Survey; see table 2 and pl. 2 for geographic and stratigraphic positions]

Genera	Collection No. in table 2 and pl. 2															
	13B	M	18D	7A	8A	8C	9B	9A	10A	26A	28A	P	14A	13D	Q	18B
	USGS paleobotanic locality No.															
	D1476E	D1482D-E	D1483A-B	D1484	D1486A-C	D1487A-C	D1489A	D1501C	D1503B	D1507A	D1508B-E	D1511A-B	D1519B	D1640	D1641	D1827A-B
Eocene and younger:																
Platycarya		X												?		
Tilia														?		
Paleocene and younger:																
Caryapollenites		X	X			X					X	X	X			?
Pistillipollenites		X								X		X				
Cretaceous and early Paleocene:																
Classopollis			X	X	X		X	X	X							X
Cicatricosisporites	X			X											X	
Wodehousia								X								
Cretaceous:																
Appendicisporites	X															
Aquilapollenites				X				X							X	
Proteacidites	X				X			X							X	
Hemitelia															X	

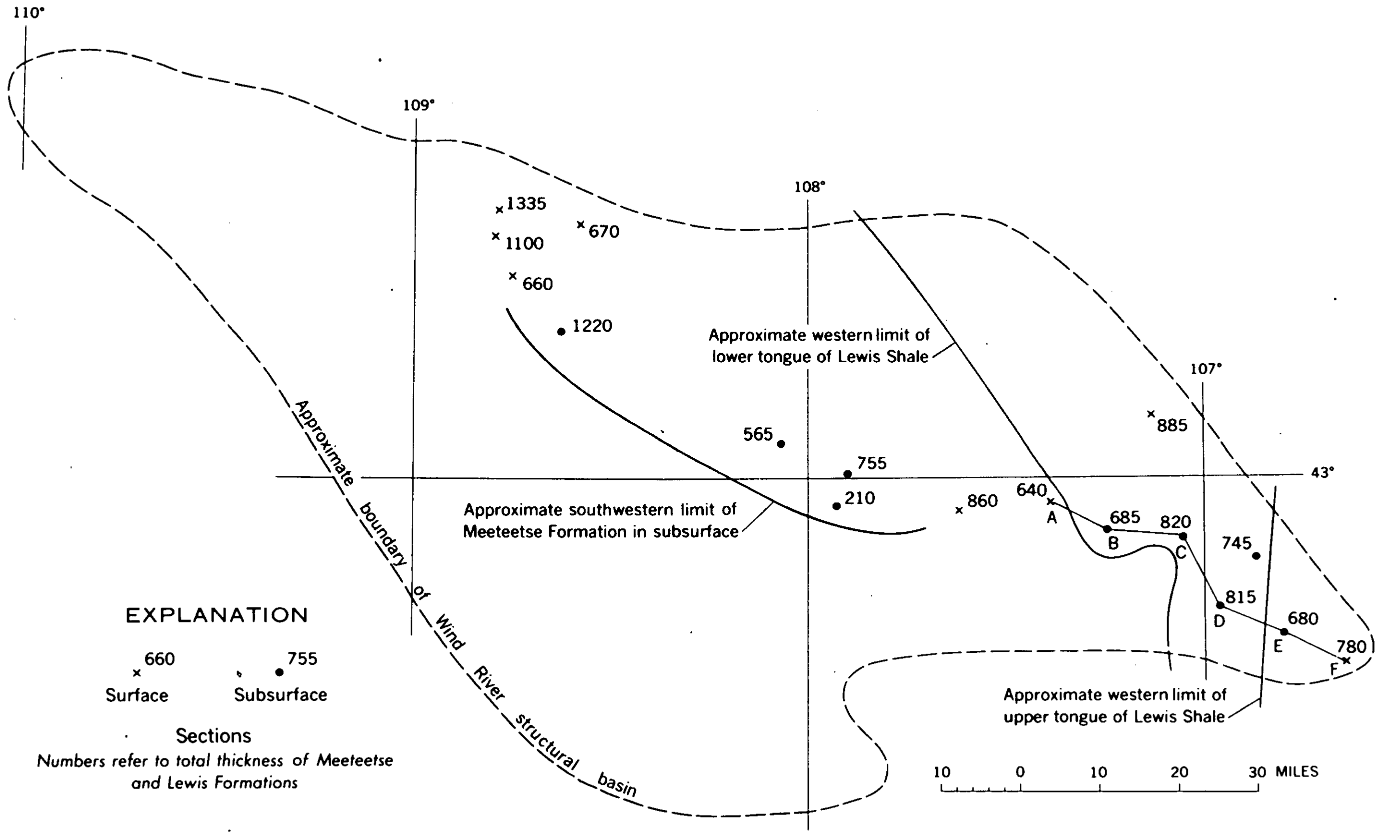


FIGURE 4.—Sketch map of Wind River Basin showing thicknesses and distribution of Meeteetse Formation and Lewis Shale. Adapted in part from Rich (1958). Correlation diagram through points *A–F* shown on figure 6.

LITHOLOGY AND THICKNESS

The general appearance and lithology of the Meeteetse Formation and Lewis Shale differ markedly from that of the underlying Mesaverde Formation and the overlying Lance Formation. The strata are nonresistant for the most part, and form conspicuous strike valleys that extend for several miles with few outcrops.

In the Shotgun Butte area the Meeteetse Formation is 660–1,335 feet thick, and can be divided into a lower unit of interbedded sandstone, siltstone, shale, carbonaceous shale, and coal, and an upper unit consisting largely of lenticular sandstone. The lower unit is 650–1,080 feet thick and, where well exposed, presents a gray, black, yellow, and brown banded appearance that is unique among Upper Cretaceous rocks in the basin (fig. 5). One of the most distinguishing features is the profusion of spherical cannonball-like calcareous sandstone concretions, as much as 3 feet in diameter, which weather out on some of the smooth rounded outcrops. The sandstone in the concretions is coarse grained and contains abundant grains of brownish-red biotite. Some beds are highly bentonitic and weather tan or yellow. Coal beds are present throughout the lower part of the Meeteetse Formation and several are of minable thickness. The thickest bed observed, 16.5 feet thick including 7 feet of relatively clean coal at the base, is at the Welton mine in sec. 20, T. 6 N., R. 1 E. (loc. 39, pl. 1).

The lenticular sandstone unit that forms the upper part of the Meeteetse Formation in the Shotgun Butte area ranges in thickness from 0 to about 320 feet. Individual sandstone beds are locally as much as 120 feet thick. A few thin beds of gray shale are interbedded with the sandstone, but little coal is present.

The lithology, banded appearance, and nonresistance of the bulk of the Meeteetse Formation in the Shotgun Butte area also characterize the formation in most exposures in the southern and eastern parts of the Wind River Basin. Thicknesses range from about 390 feet in the Casper Canal section, where the Meeteetse is underlain and overlain by marine tongues of the Lewis Shale (section F, fig. 6), to 860 feet in the Castle Gardens section (loc. 9, pls. 1, 2), where no Lewis Shale is present.

The alternation of thin beds of sharply contrasting lithologies probably produces the distinctly uneven and jagged resistivity curves on electric logs which are associated with the Meeteetse interval in many subsurface sections (see sections B and C, fig. 6). In well cuttings a diagnostic feature is the abundance of coal and other carbonaceous material as compared with that in both the overlying Lance Formation and the underlying Mesaverde Formation.

765-797 O—65——2

The Lewis Shale in the Wind River Basin consists of an upper and lower tongue, each consisting of interbedded gray, olive-gray, and buff shale and fine- to medium-grained sandstone. The lower tongue, which ranges in thickness from 0 to 390 feet, directly overlies the Mesaverde Formation and extends west in the basin almost to the measured section at the north end of the Rattlesnake Hills (loc. 10, pls. 1, 2). The upper tongue, separated from the lower tongue by an eastward projecting tongue of the Meeteetse Formation, is about 200 feet thick in the Casper Canal section and 120 feet thick in the Tidewater Associated Oil Co. Poison Spring 1 (sections *E* and *F*, fig. 6), but it does not extend as far west as the Cities Service Oil Co. Govt. C–1 (section *D*, fig. 6). In the True Oil Co. Sun Ranch 1 (section *C*, fig. 6), the stratigraphic interval occupied by the lower tongue of the Lewis Shale farther east contains lithologies representing both the Lewis Shale and the Meeteetse Formation, indicating a near-shore condition.

Written descriptions of the Meeteetse Formation and Lewis Shale at the Shotgun Butte and Casper Canal localities have been given by Keefer and Troyer (1964, p. 65–68, 77–80, 106–108) and Rich (1962, p. 473–478), respectively. The section measured at Castle Gardens is given as stratigraphic section 1 of this report.

CONTACT WITH THE LANCE FORMATION

The Meeteetse Formation seems to be absent in the belt of outcrops extending eastward from Alkali Butte to Muskrat Creek, and beds believed to represent the Lance Formation rest directly on the Mesaverde Formation (fig. 7).

In the Shotgun Butte area, the Lance Formation is conformable on the Meeteetse Formation in the section directly west of the butte (loc. 39, pl. 1), but to the south toward Little Dome anticline (locs. 39 and 40, pl. 1), the Lance bevels down to the lower part of the Meeteetse Formation (Keefer, 1960, p. B233–B234; Keefer and Troyer, 1964). These unconformities extend only short distances into the subsurface, however, for the Meeteetse Formation seems to be fully represented in wells that have been drilled only a few miles downdip from the outcrops (for example, locs. 21, 23, 49, and 50, pl. 1); elsewhere in the Wind River Basin the Meeteetse and Lance Formations are apparently conformable. Although individual beds of similar lithology are present in both formations in most places, the basal beds of the Lance are predominantly massive sandstone as compared to the thin-bedded sandstone, shale, and coal in the Meeteetse Formation. This lithologic difference is well defined on some electric logs (fig. 6). Where the Lance Formation directly overlies the Lewis Shale, the contact is easily recognized in both surface and subsurface sections.

FIGURE 5.—Outcrop of Meeteetse Formation south of Shotgun Butte, sec. 16, T. 5 N., R. 1 E. Note banded appearance.

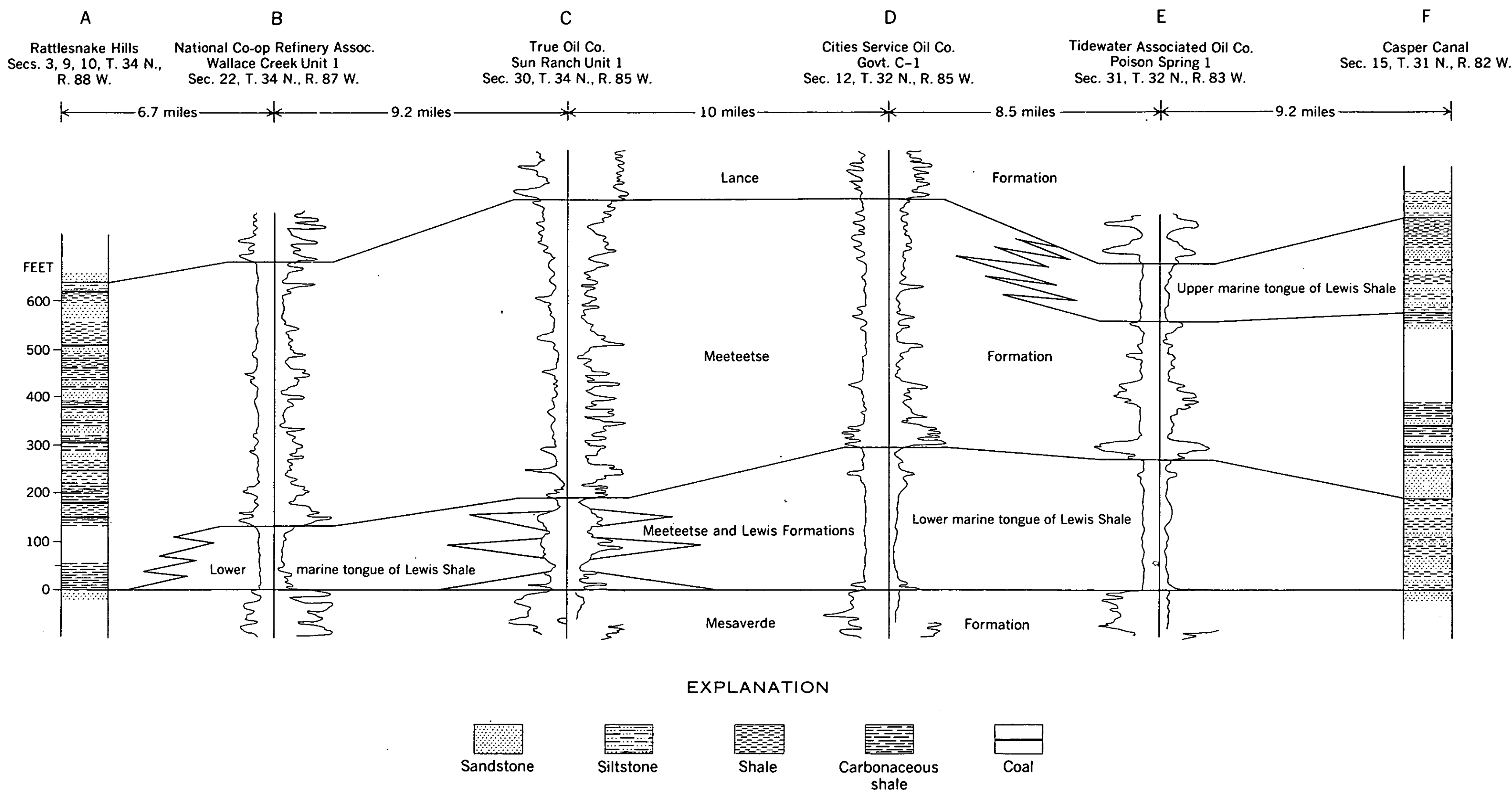


FIGURE 6.—Correlation of Meeteetse Formation and Lewis Shale, southeastern Wind River Basin. In part after Rich (1958); line of section shown on figure 4. For each well, resistivity log on right, self-potential log on left.

FIGURE 7.—Unconformity between Lance (Kl) and Mesaverde (Kmv) Formations along east flank of Alkali Butte anticline, sec. 4, T. 2 S., R. 6 E.

CONDITIONS OF DEPOSITION

The Meeteetse Formation was deposited in widespread swamps, broad flood plains, and lagoons that lay along the west edge of the Late Cretaceous sea. The thin tongues of marine shale and sandstone of the Lewis Shale represent minor readvances of the sea into the eastern part of the Wind River Basin. There is little evidence of local tectonic activity during the deposition of the Meeteetse and Lewis, except possibly a little downfolding of the major trough area along the present north margin of the basin (fig. 6; Keefer, 1960, p. B233).

AGE AND CORRELATION

Marine invertebrate fossils were collected from both the upper and lower tongues of the Lewis Shale in the eastern part of the Wind River Basin by Rich (1962, p. 474–478). The fossils from the lower tongue (colln. 12A and 18A, table 2) are equivalent in age to the upper part of the Pierre Shale; those from the upper tongue (colln. 12B, table 2) are equivalent to the Fox Hills Sandstone in the northeastern part of the Powder River Basin, Wyo. (fig. 8).

Plant remains, including *Sequoia reichenbachi*, fragments of large dinosaur bones (colln. 13A, table 2), and spore and pollen of Late Cretaceous age were collected from the Meeteetse Formation at a few localities; these fossils, however, do not define the specific time zones represented. Inasmuch as strata of the Meeteetse Formation intertongue with the Lewis Shale in the eastern part of the basin, the Meeteetse there is also inferred to be largely correlative with the upper part of the Pierre Shale and the Fox Hills Sandstone in eastern Wyoming. Because individual stratigraphic units in the Upper Cretaceous sequence over much of the Rocky Mountain region tend to transgress time—older to the west, younger to the east (Weimer, 1960)—strata assigned to the Meeteetse Formation may be somewhat older in the western part of the Wind River Basin than in the eastern part.

Figure 8 also shows equivalent rocks in other basins adjacent to the Wind River Basin. Cobban and Reeside (1952) correlated the Lewis and Meeteetse Formations with the American and European standard sections.

LANCE FORMATION

DEFINITION

The name "Lance Creek beds" was introduced by Hatcher (1903, p. 369) for the uppermost Cretaceous strata overlying the Fox Hills Sandstone along Lance Creek in the southeastern part of the Powder River Basin, Wyo. The name was modified to Lance Formation by Stanton (1910), and this name subsequently has been used to designate rocks of latest Cretaceous age in many other parts of Wyoming (fig. 8), including the Wind River Basin, even though the character of the rocks varies greatly from place to place.

DISTRIBUTION

The Lance Formation crops out extensively along the south and east margins of the Wind River Basin. It is absent along the west margin of the basin, but occurs in limited outcrops in the Shotgun Butte area. The formation is also widespread in the subsurface where it has been wholly or partly penetrated by many wells.

LITHOLOGY AND THICKNESS

The Lance Formation is a sequence of interbedded white, gray, and buff, fine- to coarse-grained, in part conglomeratic sandstone; gray to black shale and claystone; and brown to black carbonaceous shale and coal. Thicknesses range from zero to several hundred feet along the south and west margins of the basin, but increase to a maximum of more than 5,000 feet in the north and eastern parts (fig. 9). The thickest surface section observed, 5,130 feet, is northeast of Waltman (loc. 18, pls. 1, 2). The formation probably is about 6,000 feet thick to the north and west. The writer believes, for example, that the Pure Oil Co. Badwater 1 and 2–A (locs. 17 and 68, pl. 1) bottomed within the Lance Formation at depths of 17,030 and 16,500 feet, respectively, after penetrating more than 5,500 feet of Lance strata.

In areas where the Lance Formation is thickest, sandstone generally predominates in the lower part and shale and claystone in the upper part. In the thicker surface sections, such as at the north end of the Rattlesnake Hills, along the Casper Canal, and at Waltman (locs. 10, 12, and 18, pls. 1, 2), the upper shale and claystone commonly have a definite banded appearance, although the individual bands are generally thicker and duller looking than those in the underlying Meeteetse Formation (fig. 10). Many of the shale and claystone beds are bentonitic, and characteristically weather to smooth rounded hills and slopes which are strewn with large selenite crystals.

In the Shotgun Butte area, where the Lance Formation has a maximum thickness of 1,150 feet (loc. 39, pl. 1), the lower part consists of white to light-gray and buff sandstone with thin irregular beds and lenses of conglomerate. The conglomerate contains granule-sized fragments and scattered pebbles of chert, siliceous shale, and porcelanite. The upper part of the Lance Formation in the Shotgun Butte area is predominantly shale and claystone similar to that in thicker sections elsewhere in the basin.

Series		Tertiary[1] provincial ages	Cretaceous reference sequence[2]	Wind River Basin (this report)	Great Divide Basin[3] East	Great Divide Basin[3] Southwest	Green River Basin (southeast)[4]	Hoback Basin[5]	Jackson Hole[7]	Bighorn Basin[8]	Powder River Basin (western)[10]	Powder River Basin (northeast)[12]	Hanna Basin[14]
Eocene	Middle	Bridgerian		Aycross Formation	Bridger Formation	Bridger Formation	Bridger Formation	Absent	Middle Eocene rocks	Middle Eocene rocks	Absent	Absent	Absent
Eocene	Lower (Wasatchian)	Lostcabinian		Wind River Formation: Lost Cabin Member	Battle Spring Formation	Green River Formation / Wasatch Formation	Green River Formation / Wasatch Formation	Pass Peak Formation	Wind River and Indian Meadows Formations, undivided	Tatman Formation; Willwood Formation: Lost Cabin equivalents	Wasatch Formation: Lost Cabin equivalents[11]	Wasatch Formation	Wind River(?) Formation
Eocene	Lower (Wasatchian)	Lysitean		Wind River Formation: Lysite Member	Battle Spring Formation	Wasatch Formation	Wasatch Formation	Pass Peak Formation	Wind River and Indian Meadows Formations, undivided	Willwood Formation: Lysite equivalents	Wasatch Formation: (No Lysite rocks present)	Wasatch Formation	Wind River(?) Formation
Eocene	Lower (Wasatchian)	Graybullian		Indian Meadows Formation	Battle Spring Formation	Wasatch Formation	Wasatch Formation	Indian Meadows equivalents[6]	Wind River and Indian Meadows Formations, undivided	Willwood Formation: Gray Bull beds	Wasatch Formation: Moncrief Member; Kingsbury Cgl Mbr	Wasatch Formation	Hanna Formation
Paleocene		Clarkforkian		Fort Union Formation: Shotgun Member	Fort Union Formation	Fort Union Formation	Fort Union Formation	Hoback Formation	Greenish-gray and brown sandstone and claystone sequence	Fort Union Formation[9]	Fort Union Formation	Fort Union Formation: Tongue River Member	Ferris Formation
Paleocene		Tiffanian		Fort Union Formation: Shotgun Member; Waltman Shale Mbr	Fort Union Formation	Fort Union Formation	Fort Union Formation	Hoback Formation	Greenish-gray and brown sandstone and claystone sequence	Fort Union Formation[9]	Fort Union Formation	Fort Union Formation: Tongue River Member; Lebo Shale Member	Ferris Formation
Paleocene		Torrejonian		Fort Union Formation: Lower part	Fort Union Formation	Fort Union Formation	Fort Union Formation	Hoback Formation	Pinyon Conglomerate	Fort Union Formation[9]	Fort Union Formation	Fort Union Formation: Lebo Shale Member	Ferris Formation
Paleocene		Dragonian		Fort Union Formation: Lower part	Fort Union Formation	Fort Union Formation	Fort Union Formation	Hoback Formation (?)	Pinyon Conglomerate	Fort Union Formation[9]	Fort Union Formation	Fort Union Formation: Tullock Member	Ferris Formation
Paleocene		Puercan		Fort Union Formation: Lower part	Fort Union Formation	Fort Union Formation	Fort Union Formation		Pinyon Conglomerate	Fort Union Formation[9]	Fort Union Formation	Fort Union Formation: Tullock Member	Ferris Formation
Upper Cretaceous			Hell Creek Formation; Montana Group: Fox Hills Sandstone	Lance Formation	Lance Formation	Lance Formation	Lance Formation	Not known	Harebell Formation	Lance Formation	Lance Formation	Lance Formation[13]	Medicine Bow Formation
Upper Cretaceous			Montana Group: Pierre Shale	Meeteetse Formation / Lewis Shale	Lewis Shale	Lewis Shale	Lewis Shale	Not known	Meeteetse Formation	Meeteetse Formation	Bearpaw Shale	Fox Hills Sandstone; Pierre Shale	Lewis Shale
Upper Cretaceous			Montana Group: Pierre Shale	Mesaverde Formation	Mesaverde Formation	Mesaverde Formation	Mesaverde Group: Almond Formation	Not known	Mesaverde Formation	Mesaverde Formation	Parkman Sandstone	Pierre Shale	Mesaverde Formation

[1] Used by vertebrate paleontologists (Wood and others, 1941), and have not been adopted by the U.S. Geological Survey.
[2] Cobban and Reeside (1952); reference section is in South Dakota.
[3] Pipiringos (1961); Cobban and Reeside (1952).
[4] Bradley (1926); Cobban and Reeside (1952).
[5] Dorr (1958).
[6] J. D. Love (oral commun., 1961).
[7] Love (1956).
[8] Hewett (1926); Van Houten (1944); Hay (1956).
[9] Referred to by some workers as Polecat Bench Formation of Jepsen (1940) in north-central Bighorn Basin.
[10] Hose (1955); Mapel (1959).
[11] Lost Cabin strata present locally at Pumpkin Buttes (J. D. Love, oral commun., 1961).
[12] Mapel and others (1959).
[13] Also referred to as Hell Creek Formation by some workers.
[14] Knight (1951); Dobbin and others (1929).

FIGURE 8.—Nomenclature and correlation of uppermost Cretaceous, Paleocene, and lower Eocene rocks in the Wind River Basin and adjacent regions in Wyoming.

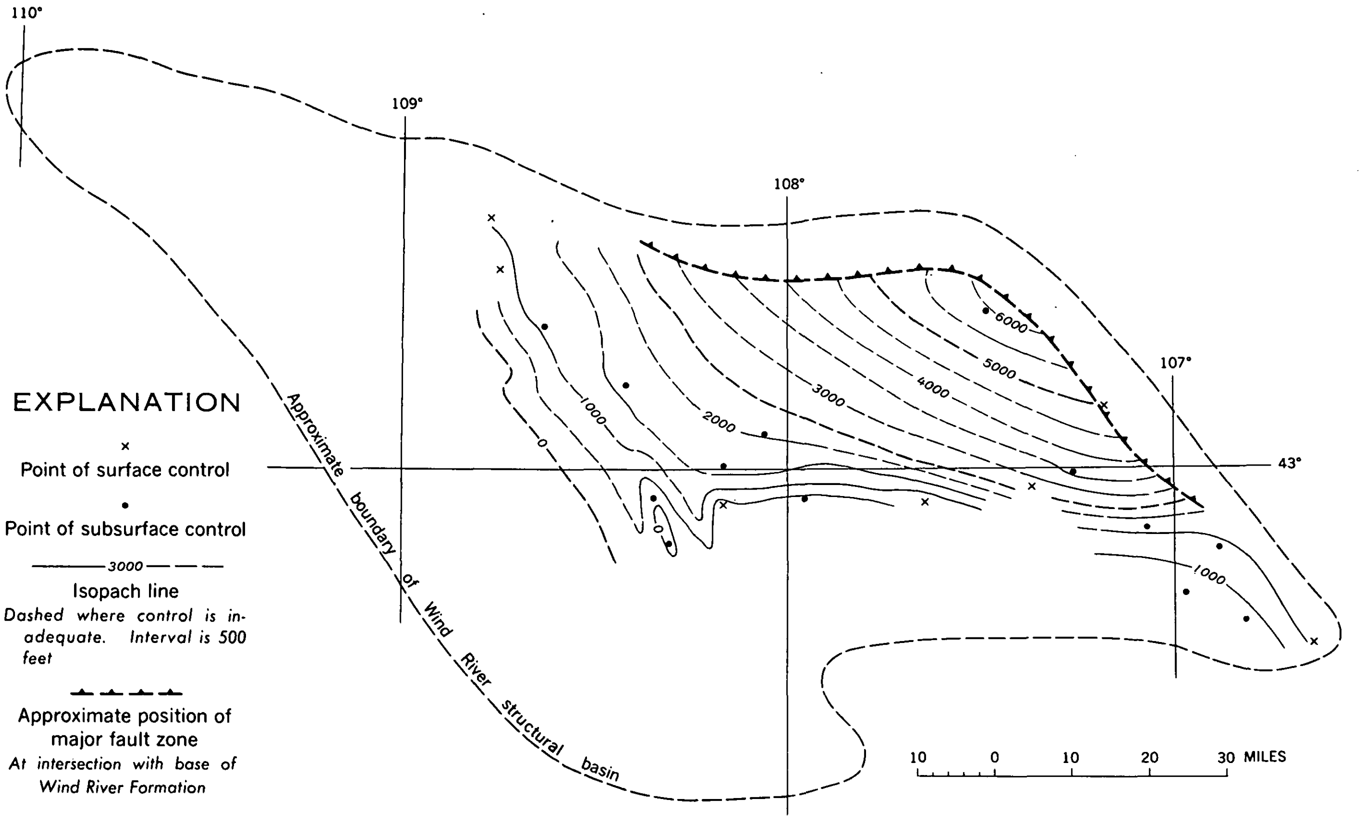


FIGURE 9.—Isopach map of Lance Formation.

In the vicinity of Castle Gardens (loc. 9, pls. 1, 2; fig. 11) the Lance is chiefly white to light-gray massive crossbedded sandstone containing thin beds of carbonaceous shale. Correlations are more uncertain farther west, but in outcrops extending from Muskrat Creek westward to Alkali Butte, the formation is believed to be represented by a heterogeneous unit of white to gray sandstone, carbonaceous shale that weathers dark bluish gray, and thin reddish-brown ironstone beds. The ironstone beds locally contain siliceous shale fragments, rounded polished chert pebbles, and abundant fresh water mollusks (colln. 8B, table 2). The sequence seems to be bounded both at the top and bottom by unconformities; intraformational unconformities may also occur locally. Paleontologic data indicate that most of this unit is Late Cretaceous in age.

Written descriptions of the Lance Formation have been published for the Shotgun Butte area by Keefer and Troyer (1964, p. 64, 75–77) and for the southeastern part of the basin by Rich (1962, p. 480–481). Sections for the Castle Gardens and Conant Creek areas are given as stratigraphic sections 1 and 2 of this report.

CONTACT WITH FORT UNION FORMATION

The Lance Formation is overlain with erosional and (or) angular unconformity by the Fort Union Formation of Paleocene age in nearly all exposures of these rocks around the margins of the Wind River Basin. In most places the angular discordance is slight and not easily detected, although at some localities, such as the north end of the Rattlesnake Hills (loc. 10, pls. 1, 2), the discordance is as much as 8°. The unconformities seem to extend only short distances into the subsurface, however, and the two formations are conformable in the major basin trough area where deposition was virtually continuous from Late Cretaceous into Paleocene time. The surface sections at Waltman (fig. 10) and Shotgun Butte (locs. 18 and 13, pls. 1, 2) represent two such conformable sequences.

In most outcrops the contact is marked by a lithologic change from dull-gray and tan, banded soft shale, claystone, and sandstone below to white sandstone and siltstone interbedded with thin conspicuous ledgy red-brown ironstone beds above (fig. 10). The color contrast is especially well exhibited in the exposures at Shotgun Butte, at the north end of the Rattlesnake Hills, and at Waltman (locs. 39, 10, and 18, pl. 1).

The Lance interval on electric logs generally is characterized by a sharp and well-defined alternation of high and low resistivity and self-potential peaks corresponding to the sequence of interbedded shale, claystone, and sandstone in the upper part of the formation.

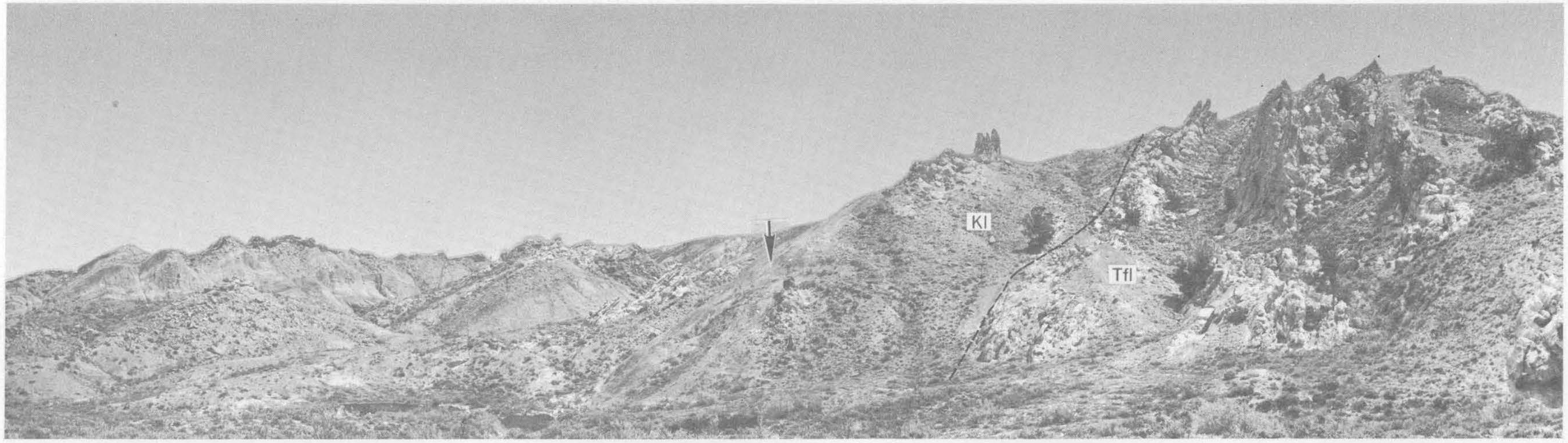


FIGURE 10.—Exposure of upper part of Lance Formation (Kl) and lower part of Fort Union Formation (Tfl) in overturned sequence northeast of Waltman, sec. 8, T. 36 N., R. 86 W. Contact is transitional and is drawn between predominantly shaly strata below and predominantly sandy strata above. Arrow indicates horizon of fossil collection 18B, tables 2 and 3.

FIGURE 11.—Part of Lance Formation, locally referred to as Castle Gardens sandstone, at Castle Gardens, secs. 9 and 10, T. 34 N., R. 90 W. The locality is famous for Indian pictographs.

In contrast, the basal strata of the Fort Union Formation, predominantly sandstone, commonly produce a more expanded series of resistivity and self-potential curves on electric logs (pl. 3).

CONDITIONS OF DEPOSITION

In contrast to the depositional history of earlier Cretaceous time, the sedimentary pattern during the deposition of the Lance Formation was significantly influenced by local tectonic movements representing the start of basin growth. Probably the most prominent feature was an extensive downwarp along the present north margin of the Wind River Basin. As much as 6,000 feet of fine-grained clastic strata accumulated in this area during Lance time (fig. 9). Although most of these strata seem to have been deposited in broad river flood plains and in swamps, some of the thick noncarbonaceous gray shale and claystone beds in the upper part of the formation may have originated in large lakes. E. B. Leopold (written commun., 1963) reported that spore and pollen assemblages in the uppermost beds of the Lance Formation near Shotgun Butte are indicative of fresh-water and brackish-water environments.

During the same time, rising highlands in the regions now occupied by the Granite Mountains and the Washakie Range contributed coarse clastic debris that was deposited along the southwest (Alkali Butte-Conant Creek area) and northwest (Shotgun Butte area) margins of the basin. From the available evidence, on the other hand, it seems probable that little or no arching took place along the present trends of the Wind River Range, Owl Creek Mountains, and the Casper Arch during Lance time.

AGE AND CORRELATION

Fossil leaves, spores and pollen of Late Cretaceous age, and fragments of dinosaur bones were collected from the Lance Formation at many localities in the Wind River Basin (tables 2, 3). The paleontologic data indicate that the contact between the Lance and overlying Fort Union Formation selected on the basis of physical evidence (for example, lithology, unconformities, and color contrasts, as previously described) coincides closely with the Cretaceous-Paleocene boundary in most of the surface sections studied. One exception is at the Waltman locality (loc. 18, pls. 1, 2) where the upper few feet of beds placed in the Lance Formation on field evidence contain a spore and pollen assemblage of earliest Paleocene age (colln. 18B, tables 2, 3). This is the thickest surface section in the basin, and the strata are transitional through the contact zone. There is a lithologic change from predominantly gray and tan shale, claystone, and sandstone below to predominantly white sandstone above, and this change was considered to mark the formation contact (fig. 10). Detailed stratigraphic and paleontologic studies in this area may locate the Cretaceous-Paleocene boundary more closely. No paleontologic data were obtained from subsurface sections; the contacts seem to be transitional in most of these sections and probably do not everywhere coincide precisely with the systemic boundary.

Correlation of the Lance Formation with equivalent rocks in adjacent parts of Wyoming is shown on figure 8. Correlations with the standard American and European sections are shown by Cobban and Reeside (1952).

PALEOCENE SERIES

FORT UNION FORMATION

DEFINITION

Meek and Hayden (1861, p. 433) first used the term "Fort Union group" (and the synonymous term "Great Lignite group") in descriptions of the thick series of claystone and sandstone containing abundant lignite beds near Fort Union, N. Dak. Rocks now assigned to both the Cretaceous and Tertiary were included, and much controversy arose over their exact correlation throughout the western Great Plains and Rocky Mountain regions. Weed (1896), working in south-central Montana, was one of the first to restrict the Fort Union to the Tertiary (Eocene). Brown (1938) satisfactorily demonstrated that the disputed lignite-bearing strata overlying the Hell Creek Formation and underlying the Wasatch Formation in western North Dakota and eastern Montana "constitute a recognizable, measurable, and mappable unit, carrying a distinctive flora and fauna differing significantly from those of the Hell Creek and Wasatch." He (p. 422) further proposed that the age of these rocks (now referred to the Fort Union Formation) be designated as Paleocene.

In the Wind River Basin the Fort Union Formation includes all rocks of Paleocene age and regionally can be divided into two general lithologic sequences: a lower part of interbedded sandstone, conglomerate, shale, and carbonaceous shale deposited in a fluviatile environment; and an upper part of very fine grained clastic strata deposited in and adjacent to an extensive body of water.[1] This upper part contains two distinct rock types deposited contemporaneously in the marginal and offshore areas of the lake. The marginal unit, characterized by gray and tan shale, siltstone, claystone, and sandstone, has been named the Shotgun Member; the offshore unit, consisting of homogeneous dark-brown

[1] As is described more fully in a following section, evidence is inconclusive as to whether this body of water was marine or lacustrine. For convenience of discussion, however, it is here referred to as Waltman Lake.

to black silty micaceous shale, has been named the Waltman Shale Member (Keefer, 1961).

DISTRIBUTION

The Fort Union Formation crops out in a narrow discontinuous belt along the east, south, and west margins of the Wind River Basin (pl. 1). Along the north margin there are extensive exposures in the Shotgun Butte area and small outcrops along the south side of Badwater Creek (loc. 66, pl. 1), but elsewhere the formation is overlapped by lower Eocene rocks. A thin sequence of conglomerate on the south side of the Dubois anticline (locs. 32 and 33, pl. 1), in the northwest corner of the basin, may also represent the Fort Union Formation. Many wells penetrate the formation in the central part.

The Waltman Shale Member of the Fort Union Formation is thickest along the north margin of the basin, thins progressively southward, and wedges out within a few miles downdip from exposures of Paleocene rocks along the south margin (fig. 14; pl. 3). The Shotgun Member thickens correspondingly, but in sections near the south margin it grades into coarse-grained sandstone and conglomerate similar to strata in the lower part of the Fort Union Formation and loses its identity. It is not feasible, therefore, to divide the Paleocene sequence into individual members in the surface sections and nearby subsurface sections between Alkali Butte and the north end of the Rattlesnake Hills (locs. 7 and 10, pls. 1, 2). The same is true for the southeastern part of the basin. However, in the Shotgun Butte area, the Shotgun Member is easily distinguished from the lower part of the formation, though the Waltman Shale Member is absent.

THICKNESS

The thickness of the Fort Union Formation varies considerably along the basin margins largely because of erosion. Along the west and south sides the thickness ranges from 200 to 1,000 feet; to the north and east toward the major basin trough it increases appreciably and in some places may be as much as 8,000 feet (fig. 12). The Shotgun Butte and Waltman surface sections (locs. 13 and 18, pls. 1, 2), with thicknesses of 3,925 and 2,970 feet, respectively, are in the main trough area.

LOWER PART OF FORT UNION FORMATION

The lower part of the Fort Union Formation is characterized by white to gray fine- to coarse-grained massive to crossbedded sandstone, interbedded with dark-gray to black shale, claystone, siltstone, and brown carbonaceous shale. Some of the uppermost sandstone beds are highly glauconitic. Abundant thin brown-weathering ironstone beds are present in most places, and lenticular coal beds occur locally. The sequence commonly forms resistant ridges in outcrops (fig. 13), and on electric logs it produces a more expanded series of resistivity and self-potential curves than the overlying or underlying strata (pl. 3). Thicknesses range from 575 to 1,500 feet in the line of wells extending eastward from the Superior Oil Co. Fuller Reservoir 1–26 to the California Co. Cooper Reservoir 2 (loc. 23 and 26, pls. 1, 2). Along the north margin of the basin, in the major trough area, maximum thicknesses are more than 3,500 feet.

In the Shotgun Butte area, as well as in some sections near the south edge of the basin, the lower part of the Fort Union Formation locally contains much coarse-grained sandstone and conglomerate. These beds have abundant chert, quartz, porcelanite, and siliceous shale fragments ranging in size from coarse sand grains to cobbles as much as 6 inches across. A typical section containing conglomerate beds near Shotgun Butte has been described by Keefer and Troyer (1964, p. 72–75).

In the north and northeastern parts of the basin, the lower part of the Fort Union Formation predominantly consists of fine-grained sandstone, siltstone, shale, and claystone. Studies of cuttings and cores from the Phillips Petroleum Co. Boysen 1, Shell Oil Co. Howard Ranch 23–15, Sinclair-Wyoming Oil Co. Lysite 1, Pure Oil Co. Badwater 1, and California Oil Co. Madden 1 (locs. 14–17 and 28, pls. 1, 2) indicate that very little coarse clastic debris is present in the sequence in these regions despite their proximity to the Owl Creek Mountains. A typical section was penetrated by the California Co. Madden 1, and is given as stratigraphic section 3 of this report.

In the surface section near Waltman (loc. 18, pls. 1, 2), the lower part of the Fort Union Formation is 2,325 feet thick and consists chiefly of white fine- to coarse-grained sandstone with numerous thin brown ironstone beds at the base (fig. 10) and of interbedded very fine grained sandstone and siltstone at the top. The thick siltstone units characteristically weather into conspicuous white castlelike spires and walls.

The contact between the lower part of the Fort Union Formation and the overlying Waltman Shale Member is sharp and well defined on electric logs (fig. 15; pl. 3). Lithologically, however, most subsurface sections show a thin transitional zone of interbedded sandstone, black micaceous shale, carbonaceous shale, and thin coal beds at the top of the lower part that represents deposits laid down during the beginning episodes of the development of Waltman Lake.

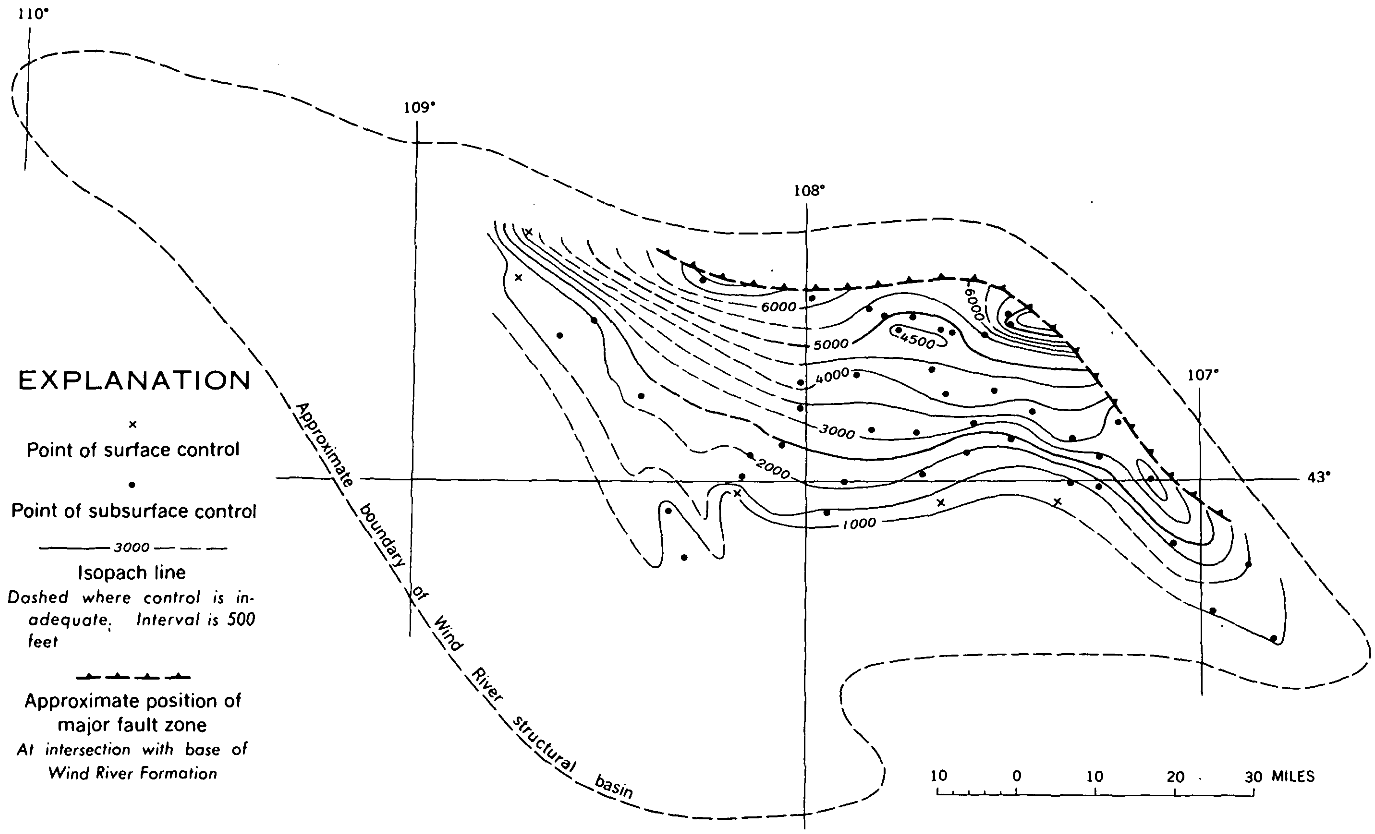


FIGURE 12.—Isopach map of Fort Union Formation.

WALTMAN SHALE MEMBER

The Waltman Shale Member of the Fort Union Formation was named from exposures about 2¼ miles northeast of Waltman in the NE¼ sec. 17, T. 36 N., R. 86 W. (Keefer, 1961, p. 1315–1319). These outcrops, which are part of the sequence of vertical to overturned beds along the west flank of the Casper Arch (pl. 1; fig. 23), extend southeastward for 5 miles (fig. 13). At the type section (loc. 18, pl. 1; loc. 1, fig. 23) the member is 643 feet thick and is characterized by chocolate-brown and gray silty and shaly claystone with a few thin beds of ledge-forming sandstone. One of the most characteristic features of the claystone is an abundance of uniformly disseminated minute white mica flakes. The member is overlain with angular discordance by the Wind River Formation of early Eocene age; its base is also in contact locally with Wind River strata along normal faults of small displacement (Keefer, 1961, p. 1317).

Southeast of the type section the sandstone beds are progressively thicker and more prominent, so that at the southeast end of the outcrop belt, in secs. 24 and 25, T. 36 N., R. 86 W. (fig. 23), the member contains several sandstone units that are 25–30 feet thick. Some of this sandstone is conglomeratic, having abundant pebbles of black chert and scattered cobbles of white Precambrian granite as much as 6 inches across in a coarse-grained arkosic sandstone matrix. The southernmost outcrop of the shale observed by the writer is about 1½ miles south of Hells Half Acre in secs. 7 and 18, T. 35 N., R. 85 W. (fig. 23). There the shale unit is only about 50 feet thick and is both underlain and overlain by coarse-grained arkosic conglomeratic sandstone.

In all other exposures of Paleocene rocks around the margins of the Wind River Basin, the Waltman Shale Member is absent; either it has been truncated by overlying lower Eocene strata, or it has changed laterally into a different lithologic facies. Possibly some thin beds of the shale extend into outcrops in a few places along the south margin of the basin, but if so, they have not been recognized.

The Waltman Shale Member of the Fort Union Formation is widespread in the subsurface of the Wind River Basin, underlying more than a thousand square miles. Thicknesses range from zero in wells near the south and west margins of the basin to more than 3,000 feet in wells near the north margin (fig. 14). In both lithologic and electric log characteristics, the member is the most easily recognized unit in the entire Tertiary sequence of this region. The dark-brown to black color

FIGURE 13.—Exposure of Waltman Shale Member of Fort Union Formation 3.5 miles southeast of type section in sec. 23, T. 36 N., R. 86 W. Ridges in background are formed by sandstone in lower part of Fort Union Formation.

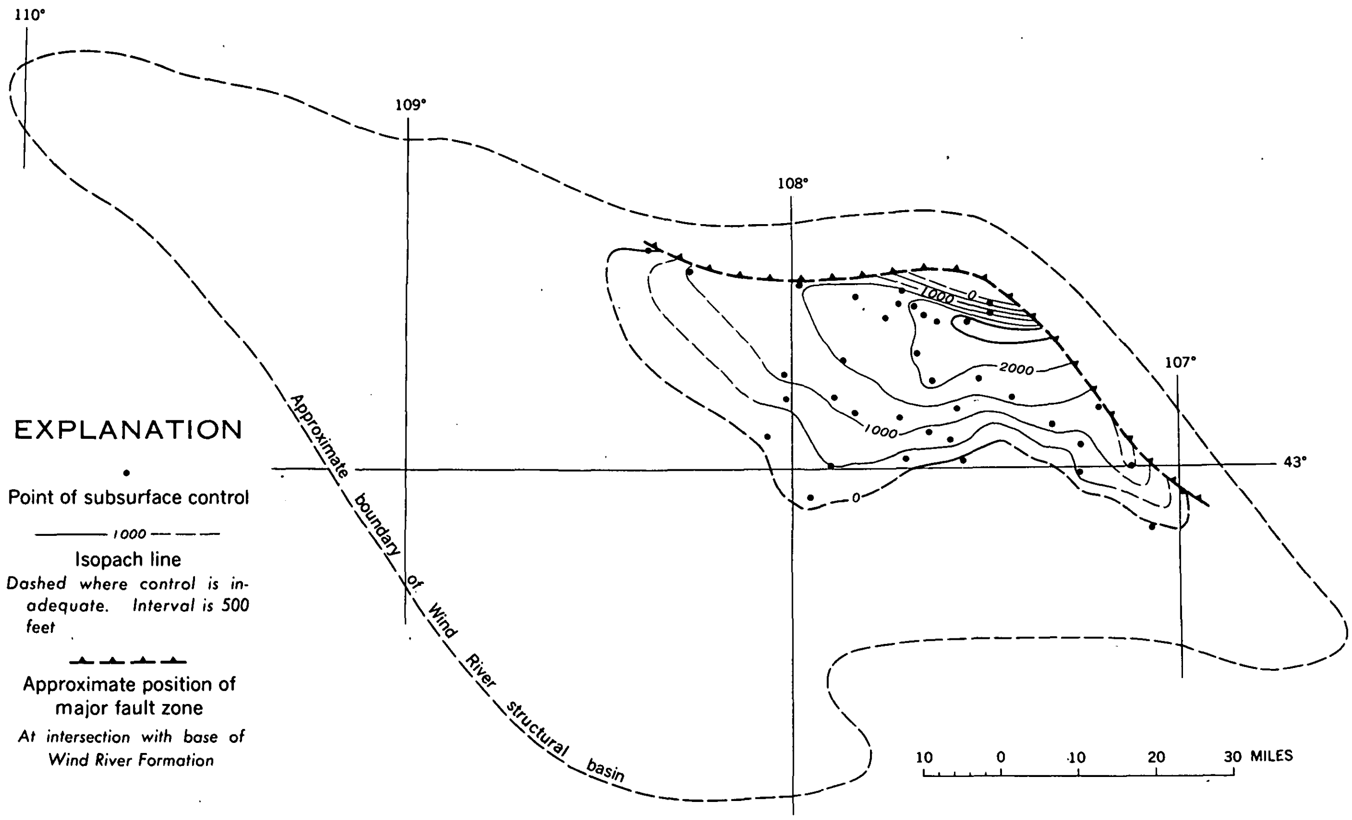


FIGURE 14.—Isopach map of Waltman Shale Member of Fort Union Formation.

and its almost lustrous uniformly silty and micaceous character are particularly diagnostic features of the shale in well cuttings. The shale is generally fissile in the subsurface, although in several cores examined, the shale broke into small blocky fragments as does the rock in exposures near Waltman. On electric logs the member is characterized by low self-potential and resistivity curves in contrast to more expanded curves for both the underlying and overlying strata (fig. 15; pl. 3). Individual units, as shown on figure 15, are easily identified in sections that are several miles apart. The cause for the characteristic marker peaks is not readily apparent from sample studies, but they may reflect slight but significant changes in the matrices of seemingly uniform rocks.

Several samples of cores and cuttings have been analyzed chemically and studied in thin section. These samples, however, represent such a small part of the member as a whole, both vertically and horizontally, that the analytical results may not be significant. Chemical analyses of three shale samples from the Waltman Shale Member are given in table 4. The distribution of certain elements in the shale, as derived from semiquantitative spectrographic analyses of 11 samples from widely scattered localities, is presented on figure 16.

TABLE 4.—*Chemical analyses, in percent, of shale from Waltman Shale and Cannonball Members of Fort Union Formation and average composition of selected samples from the Pierre Shale and Green River Formation*

	Waltman Shale Member [1]			Cannonball Member [5]	Pierre Shale [6]	Green River Formation [7]
	USGS Laboratory No.					
	H3650 [2]	H3651 [3]	H3652 [4]			
SiO_2	74.84	58.43	58.17	60.72	57.02	30.8
Al_2O_3	12.58	15.67	16.56	14.89	15.30	6.5
Fe_2O_3	1.35	1.53	1.42	2.55	3.56	2.0
FeO [8]	.27	3.34	3.90	2.03	1.43	.94
MgO	.72	1.54	1.64	2.60	2.09	6.6
CaO	.25	1.64	.89	1.57	2.90	20.5
Na_2O	.27	.90	.62	1.84	.94	2.6
K_2O	2.19	2.55	2.72	2.39	2.20	2.1
H_2O+ [8]	3.66	5.91	6.09	2.89	4.78	[9] 5.3
H_2O-	1.80	1.71	1.50	2.66	4.28	-------
TiO_2	.57	.62	.67	.67	.57	.26
P_2O_5	.03	.42	.35	.18	.14	4.5
MnO	.01	.08	.07	.03	.14	.11
CO_2	.02	2.44	2.37	.79	1.92	15.6
Total	98.56	96.78	96.97	95.81	97.27	97.81

[1] V. C. Smith, analyst.
[2] Type area of Waltman Shale Member, outcrops in sec. 27, T. 36 N., R. 86 W.
[3] Humble Oil & Refining Co. Govt.-Witt 1, sec. 24, T. 36 N., R. 88 W., depth 4,000–4,300 ft (loc. 75, pl. 1).
[4] Same well as above, depth 5,000–5,300 ft.
[5] Shale from the type area of the Cannonball Member of Fort Union Formation, ½ mile west of Mandan, N. Dak. (outcrop in T. 139 N., R. 81 W.; sample furnished by P. O. McGrew).
[6] Average composition of 69 samples of bentonite, shale, claystone, and marlstone from the Pierre Shale in South Dakota and adjacent parts of North Dakota, Nebraska, Wyoming, and Montana; H. A. Tourtelot, written commun., 1961.
[7] Average composition of 26 samples of shale and siltstone from Green River Formation, Green River Basin, Wyo.; analyses furnished by J. D. Love, U.S. Geological Survey. Samples are from phosphate-rich zones; hence they have higher than average P_2O_5 content.
[8] Because of the presence of oil and organic matter, values given for H_2O+ and FeO from Waltman Shale Member samples may be in error.
[9] Combined H_2O content.

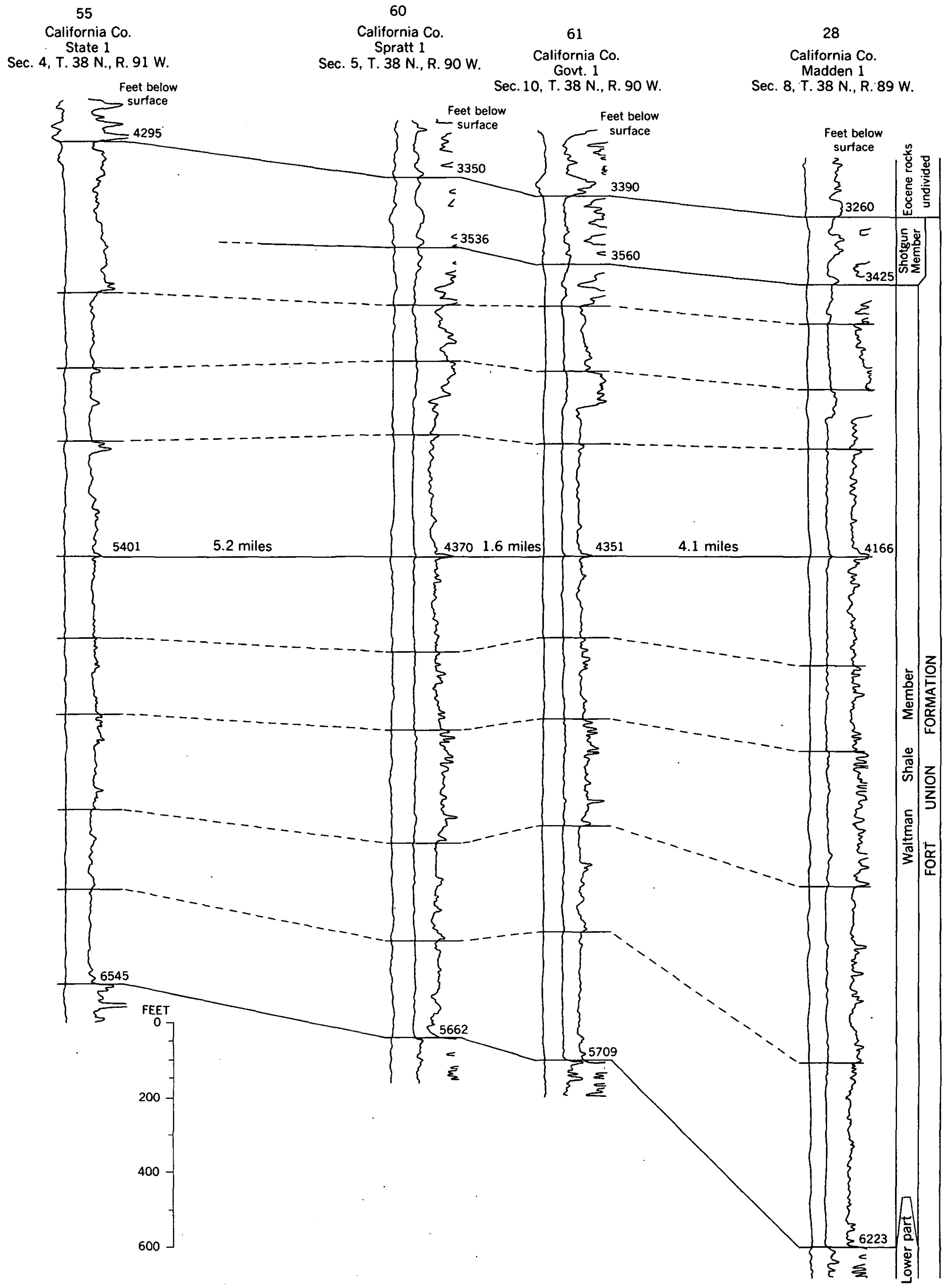
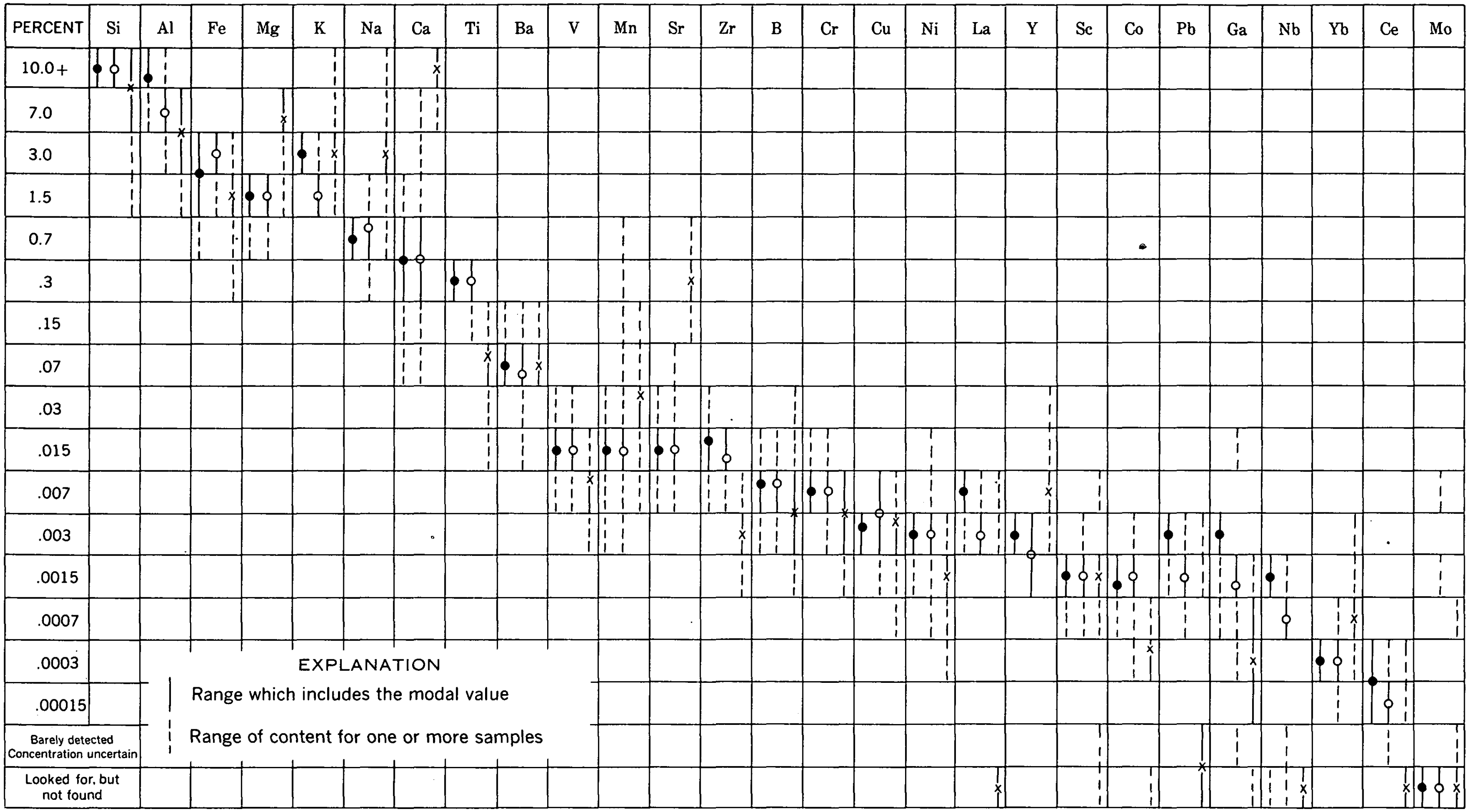


FIGURE 15.—Characteristic electric logs of Waltman Shale Member of Fort Union Formation and associated strata. Resistivity log on right, self-potential log on left. Locality numbers shown on plate 1.



Figures shown are approximate midpoints of arbitrary ranges of content; the ranges are bounded by multiples of the progression 1.0, 2.1, 4.6, and 10; at least 60 percent of the results are expected to be in the correct range.

● Modal value from group of 11 samples of the Waltman Shale Member of the Fort Union Formation, Wind River Basin, Wyo.; analyses by N. M. Conklin and P. R. Barnett, U.S. Geological Survey.

○ Modal value from group of 67 samples of Pierre Shale and equivalent rocks, and some older Cretaceous shales of marine origin, from Wyoming, Nebraska, South Dakota, North Dakota, and Montana; from Tourtelot, 1963, p. 48.

× Modal value from group of 22 samples of shale and siltstone from Green River Formation, Green River Basin, Wyo.; data furnished by J. D. Love, U.S. Geological Survey.

Symbol representing modal value displaced toward adjacent range if that range contains half as many samples as modal range.

FIGURE 16.—Distribution of elements in Waltman Shale Member of Fort Union Formation, Pierre Shale, and Green River Formation as shown by semiquantitative spectrographic analyses.

Thin-section studies by H. A. Tourtelot (written commun., 1960) show that the shale commonly contains quartz, feldspar, pyrite, glauconite, and mica. Calcite and dolomite are present only in minor amounts, as indicated by the low percentages of CaO, MgO, and CO_2 in table 4. Clay comprises 50–60 percent of most samples; X-ray analyses of the total clay fractions from five samples are given in table 5. The analytical results indicate that the clay fractions of samples from the upper part of the Waltman Shale Member contain appreciable amounts (20–30 percent) of montmorillonite, whereas those from the lower part contain no montmorillonite. This difference may reflect a significant change between the types of sediment that were being carried into Waltman Lake during deposition of the lower and upper parts of the member; however, the available data are as yet too meager for reliable conclusions.

The glauconite apparently was derived both from preexisting rocks and from alteration in place of iron-rich minerals (H. A. Tourtelot, written commun., 1960). Many of the grains which are inferred to have been altered in place have one or more straight edges that may be original crystal boundaries or cleavage faces. Some grains show relicts of internal cleavage that have no relation to the aggregate extinction characteristics of glauconite. Interstitial clay is partly altered to green material that could be either glauconite or chlorite.

TABLE 5.—*X-ray analyses of clay from the Waltman Shale Member of the Fort Union Formation*

[Analyses by H. A. Tourtelot, U.S. Geological Survey]

Locality No. (pl. 1)	Location of sample	Total clay fraction in bulk rock sample	Clay minerals (percent of total clay fraction)				
			Montmorillonite	Mixed-layer	Illite	Chlorite	Kaolinite
18	Waltman surface section (type area).[1]	50	30	30	10	------	30
75	Humble Oil & Refining Co. Govt-Witt 1. Depth 4,000–4,300 ft.[1]	65	20	40	25	5	10
75	Same well as above. Depth 5,000–5,300 ft.[2]	60	------	50	30	------	20
28	California Co. Madden 1. Depth 5,200–5,500 ft.[2]	60	------	40	30	5	25
15	Shell Oil Co. Howard Ranch 23–15. Depth 5,200–5,700 ft.[2]	Total clay fraction and mineral composition similar to samples from loc. 28 and depth 5,000–5,300 ft at loc. 75.					

[1] Sample from upper part of Waltman Shale Member.
[2] Sample from lower part of Waltman Shale Member.

The shale also contains appreciable amounts of organic material. One of the most distinctive features of the rock, particularly in beds near the base and top of the Waltman Shale Member, is scattered threadlike laminae of black shiny coal. The organic content of 4 shale samples, analyzed by J. W. Smith, U.S. Bureau of Mines, ranges from 2.5 to 6.5 percent. Upon retorting, about 25 percent of the organic matter is recoverable as oil, which is a yield of 2.5–4 gallons per ton of the original raw shale. The remaining 75 percent of the organic matter is in the form of minute, thoroughly disseminated particles of coal. The carbon-hydrogen ratio of the organic material (ranging from 11 : 1 to 15 : 1) is similar to that of coal, which begins at a ratio of about 12 : 1 (J. W. Smith, written commun., 1961). Samples of the coal interbedded with shale and sandstone just below the base of the Waltman Shale Member in the Continental Oil Co. Squaw Buttes 1–2 (loc. 65, pl. 1) are of high subbituminous or low bituminous rank (J. M. Schopf, written commun., 1960).

The shale ranges from light chocolate brown and gray in outcrops to dark brown and black in subsurface sections; these color differences may be caused by weathering. The shale is highly organic, and upon weathering, chemical and (or) physical changes probably occur in some of the organic constituents.

The contact between the Waltman Shale Member and the overlying Shotgun Member is transitional, and thin beds of black shale alternate with fine-grained sandstone, carbonaceous shale, and coal. The contact is generally placed at the top of the main shale mass, although on this basis some sandstone beds are inevitably included in the Waltman Shale Member and black shale beds in the Shotgun Member. The transitional contact is likewise apparent on many electric logs (fig. 15; pl. 3).

SHOTGUN MEMBER

The Shotgun Member of the Fort Union Formation was named from exposures in the vicinity of Shotgun Butte (loc. 13, pl. 1), a prominent topographic feature in the SE cor. T. 6 N., R. 1 E., in the north-central part of the Wind River Basin (Keefer, 1961, p. 1311; fig. 25). The outcrop belt completely encircles the butte and extends south about 6 miles toward Little Dome anticline (loc. 40, pl. 1). The member is also well exposed near Twin Buttes, about 8 miles east of Shotgun Butte in the southwestern part of T. 6 N., R. 3 E. (loc. 45, pl. 1).

The Shotgun Member in the type area is remarkably evenbedded soft claystone, siltstone, shale, and sandstone. In the section at Armstrong mine (loc. 40, pl. 1) the upper part contains some thick conglomerate beds. The rocks are mostly gray, olive green, buff, brown, and tan, but a few zones are pale red and purple. Several thin brown carbonaceous shale beds crop out as conspicuous dark bands on the normally light-colored slopes, and thin beds of resistant sandstone and siltstone locally form ledges in otherwise deeply weathered and dissected outcrops.

The thickest exposure (2,830 ft) of the member directly west of Shotgun Butte (loc. 13, pl. 1) was designated as the type section (Keefer, 1961). Written descriptions at various localities in the Shotgun Butte area have been published by Keefer and Troyer (1964, p. 61–63, 72, 105, 115–117).

The only other known exposures of the Shotgun Member in the Wind River Basin are in an isolated outcrop on the south side of Badwater Creek near the center of T. 39 N., R. 89 W. (loc. 66, pl. 1; fig. 22). These strata were described by Tourtelot (1953). The exposed part of the member on Badwater Creek is 1,600 feet thick, overlain with angular unconformity by conglomerate of late early Eocene age, and faulted at the base against rocks of late Eocene age (cross section *C–C′*, fig. 24).

The Shotgun Member is widespread in the subsurface of the Wind River Basin, where it forms the series of sandstone, shale, and carbonaceous beds overlying the Waltman Shale Member (pl. 3) that were deposited during the withdrawal of Waltman Lake. Thicknesses range from 0 to as much as 1,100 feet in wells along the south margin of the basin and from 150 feet to more than 2,200 feet in wells along the north margin. Considerable local variation in the thickness is the result of erosion of the crests of rising anticlines during the close of Paleocene and the beginning of Eocene deposition.

In subsurface sections along the north margin of the Wind River Basin, the lithology of the Shotgun Member is similar to that in the type area and at the Badwater Creek locality. To the south, however, the member becomes progressively coarser grained and more conglomeratic, and contains abundant arkosic material. Thus, it is difficult to distinguish from the lower part of the Fort Union Formation where the intervening Waltman Shale Member is absent (pl. 3).

In some places the facies change from shale and claystone of the Waltman Shale Member to sandstone and siltstone of the Shotgun Member is relatively abrupt. One of the best examples is near the Continental Oil Co. Squaw Buttes 28–1 (loc. 25, pls. 1, 2), where the upper part of the Fort Union Formation is about 1,250 feet thick and consists of individual units of black silty micaceous shale, as much as 60 feet thick, interbedded with about equal amounts of white to gray fine- to coarse-grained sandstone, which is in part conglomeratic. This suggests that the ancient shoreline oscillated in this area, resulting in alternating offshore and fluviatile deposits. Two or three miles farther south the shale tongues are absent.

Another example of abrupt facies change within the upper part of the Fort Union Formation was observed in the sections penetrated by the California Co. Madden 1, and Pure Oil Co. Badwater 1 and 2–A (loc. 28, 17, and 68, pl. 1). As shown on plate 3, the Waltman Shale Member, which is about 2,600 feet thick in the Madden well, grades laterally into the sandstone, siltstone, and carbonaceous shale of the Shotgun Member in the Badwater 1. The distance between the 2 wells is about 4 miles.

FORT UNION FORMATION (UNDIVIDED) IN WESTERN AND SOUTHERN WIND RIVER BASIN

Because the Waltman Shale Member is absent, the Fort Union Formation is not readily divisible into individual members in the western, southern, and southeastern parts of the Wind River Basin (pl. 2). In these regions the formation is largely a series of interbedded white, gray, tan, buff, and brown sandstone, conglomerate, shale, and siltstone. Thicknesses range from 210 feet in the Ethete section to about 1,000 feet at the north end of Alkali Butte anticline (locs. 4 and 7, pls. 1, 2).

In the line of sections extending eastward from Alkali Butte to the north end of the Rattlesnake Hills (loc. 10, pls. 1, 2), conglomerate beds in the lower part of the formation consist almost entirely of fragments of quartzite, chert, and siliceous shale in a nonarkosic sandstone matrix; but there is a gradual change upward through arkosic sandstone into conglomerate containing abundant Precambrian granite cobbles in the upper part. This transition is well shown in both the Alkali Butte and Castle Gardens sections. Along the west margin of the basin, on the other hand, all the conglomerate is arkosic and contains granite cobbles.

Descriptions illustrating the lithology of the Fort Union Formation (undivided) along the west and south margins of the Wind River Basin are given in stratigraphic sections 4, 5, and 6 of this report. A generalized description of the exposures at the north end of the Rattlesnake Hills was given by Rich (1962, p. 484).

In the Alkali Butte area (loc. 7, pls. 1, 2) the arkosic sandstone and granite-cobble conglomerate forming the upper part of the Fort Union Formation rests with angular unconformity on the lower part of the formation (Keefer, 1960, p. B235). The extent of this unconformity is not known, but it seems to continue only a short distance downdip. The thin sequence of Paleocene beds cropping out along the west margin of the basin (for example, at the Ethete section) is arkosic, which may indicate that only the upper part of the Fort Union Formation is preserved and that older Paleocene rocks have been beveled. However, sufficient data were not obtained for more precise correlations with various members of the Fort Union in adjacent subsurface sections.

765–797 O—65——3

CONTACT WITH LOWER EOCENE ROCKS

The contact relations between the Fort Union Formation and the overlying lower Eocene rocks, represented by the Indian Meadows and Wind River Formations, vary considerably from place to place in the Wind River Basin. In most outcrops the contact is easily recognized because of angular unconformity (figs. 17–19) and a change from bright-red, purple, and gray strata above to dull-colored strata below. The contact is difficult to determine in many subsurface sections, however, because the rock units are thick and conformable, lithologic changes are more gradual through the contact zone, and paleontologic data are very meager.

Throughout much of the basin, the contact between the Paleocene and Eocene rocks in the subsurface has been placed at the top of well-bedded sandstone, black silty shale, carbonaceous shale, and coal which characterize the Shotgun Member of the Fort Union Formation. In places where the basal Eocene rocks are gray, gray green, and pale green and grade into the dark-gray and black strata of the Shotgun Member, however, the location of the contact is uncertain. On some electric logs the sandy beds assigned to the basal Eocene show more expanded resistivity and self-potential curves than the underlying strata, and the contact is selected on this basis (fig. 15; pl. 3). In other logs, however, there are no conspicuous differences among the curves. In the southeastern part of the basin, the contact between the Fort Union Formation and the overlying lower Eocene sequence is placed at the base of a thick series of coarse arkosic sandstone. In other parts of the basin, abundant arkose is present in the upper part of the Fort Union Formation as well as in the basal Eocene strata. Generally, the sandstone in the lower Eocene rocks is coarse grained and unconsolidated in well cuttings, whereas the sandstone in the underlying Fort Union Formation is fine grained, better consolidated, and contains flakes of white mica and an abundance of green mineral grains, some of which are glauconite.

CONDITIONS OF DEPOSITION

The tectonic movements which began in latest Cretaceous time in the Wind River Basin continued through the Paleocene Epoch and continued to influence the pattern of sedimentation. Locally derived coarse clastic debris was spread basinward by streams which flowed across broad shelves flanking the rising highlands along the south and west margins of the basin. Concomitant downwarping along the present northeast margin of the basin resulted in the accumulation of a thick sequence of fine-grained fluviatile sediments in the major basin trough area during early Paleocene time and of several thousand feet of lacustrine or marine deposits in middle and late Paleocene time.

The shoreline of Waltman Lake migrated from east to west across the Wind River Basin, and apparently the water body extended eastward, and perhaps northeastward, beyond the present limits of the basin. The lake formed rapidly, particularly in the major trough area, but it subsided slowly as it filled with fine-grained detritus contributed by the surrounding highlands at a rate commensurate with the rate of sinking. Sedimentation took place largely under quiet-water conditions, and this environment prevailed for a long time. By the end of Paleocene time the lake had largely disappeared, although vestiges probably remained in the central part of the basin (fig. 33).

ABSENCE OF CARBONATE ROCKS

During Paleocene time thick sequences of carbonate rocks, especially those in the Madison Limestone (Mississippian), Bighorn Dolomite (Ordovician), and Gallatin Limestone (Cambrian), were eroded from the slopes of the rising mountain masses along the south, west, and northwest edges of the Wind River Basin. (See section, "Summary of geologic history and paleogeography.") Despite this, carbonate rocks of any kind are rare in the Paleocene sediments in the basin. It is assumed that nearly all the carbonate rocks were destroyed by chemical weathering during erosion and that only a residue of chert and other siliceous rocks was preserved during transport and redeposited along with the coarser grained sediments of the Fort Union Formation, even though deposition must have been rather rapid in some places. Furthermore, little calcareous material was precipitated during deposition of the Waltman Shale Member, and the environment in Waltman Lake was apparently unfavorable for the existence or preservation of remains of mollusks and other lime-secreting organisms.

In the Hoback Basin and Jackson Hole regions, 50–75 miles to the west, the Paleocene sequences also consist chiefly of fluviatile and lacustrine deposits containing abundant carbonaceous material. There, however, the strata include thin beds of very limy claystone and shale with limestone nodules and abundant mollusks, and the conglomerates are composed in part of limestone and dolomite fragments (Dorr, 1956, p. 102–105; Love, 1956, p. 84–85). Carbonate rocks and mollusks are also present in the next younger Indian Meadows and Wind River Formations (early Eocene) in the Wind River Basin.

This difference in depositional conditions with respect to calcium carbonate has not been studied in detail, and

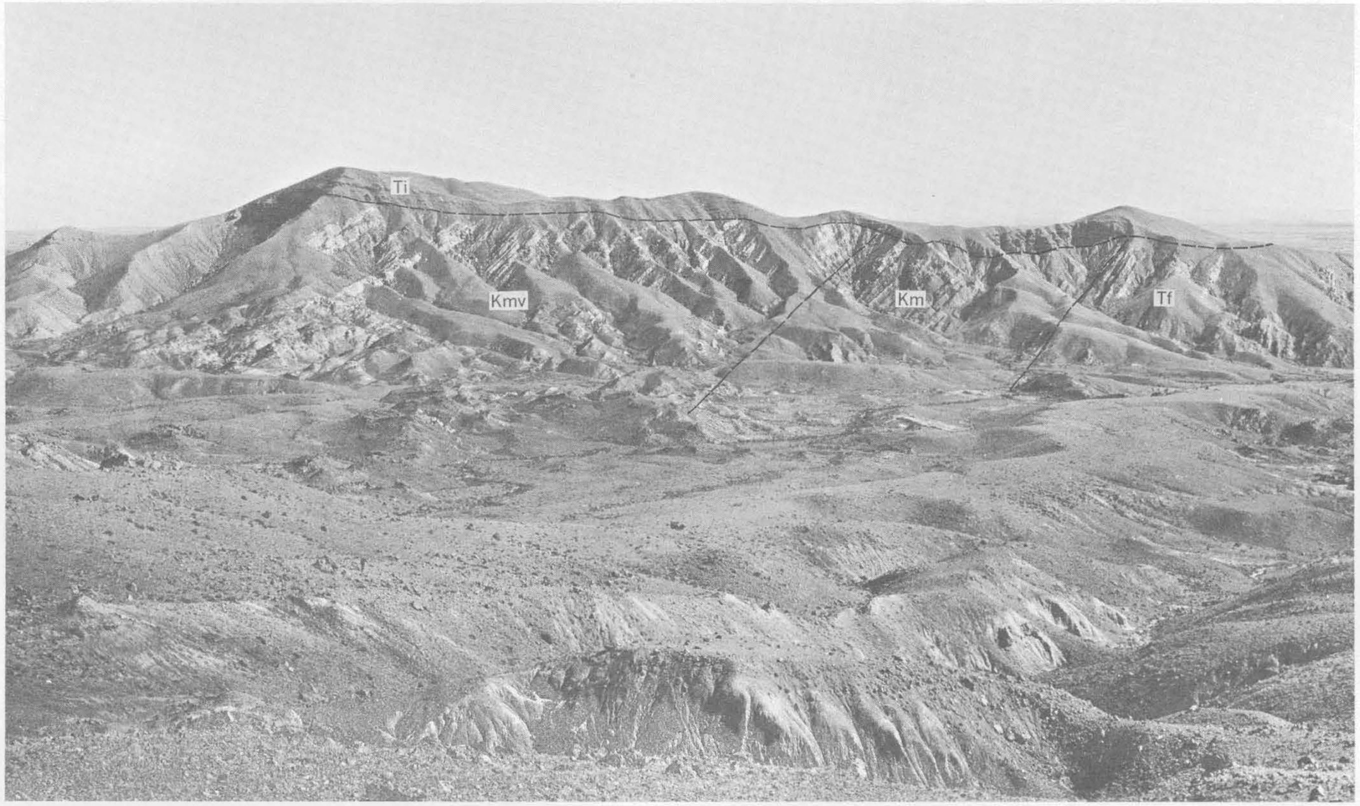


FIGURE 17.—Unconformity between Indian Meadows Formation (Ti) and overturned strata of Mesaverde (Kmv), Meeteetse (Km), and Fort Union (Tf) Formations at Twin Buttes, sec. 33, T. 6 N., R. 3 E. and sec. 4, T. 5 N., R. 3 E.

no satisfactory explanation can be made on the basis of available data. The most obvious difference in environment between Paleocene and Eocene times in the Wind River Basin, and between this basin and adjacent regions to the west during the Paleocene Epoch, was the presence of Waltman Lake. The environmental conditions that were associated with this large body of water must have had a profound influence on the associated sediments and invertebrate faunas in and around the lake. Perhaps one of the chief contributing factors to the absence of carbonates, at least in the Waltman Shale Member, was the abundance of decaying plant remains which mantled large areas of the lake floor. During decomposition, concentrations of carbon dioxide, hydrogen sulfide, and organic acids would increase, and the pH of the water would be lowered. Consequently, much of the introduced calcareous material would be dissolved. Another factor influencing carbonate deposition is the probability of at least limited circulation between the lake water and waters from an open sea, which could reduce the concentration of carbonate-forming components in the lake (see below). These and other aspects of the lake and its environment require additional investigation.

MARINE VERSUS LACUSTRINE ORIGIN FOR THE WALTMAN SHALE MEMBER

It has been generally assumed that marine sedimentation in Wyoming ceased in Late Cretaceous time, and that those Tertiary sediments which were deposited in bodies of standing water are lake sediments. Most features of the Waltman Shale Member of the Fort Union Formation could indicate deposition in either a marine or lacustrine environment. However, certain evidence favors a marine origin (Keefer, 1961, p. 1321–1322). This includes (1) the presence of marine-type shark remains in equivalent strata of the Shotgun Member near Twin Buttes (loc. 45, pl. 1), only a few miles landward (west) from the shoreline of Waltman Lake; (2) the presence of microfossils (Hystrichosphaerida)

FIGURE 18.—Unconformity between Lysite Member of Wind River Formation (Twl) and nearly vertical strata of Lance (Kl) and Fort Union (Tf) Formations at Hells Half Acre, sec. 36, T. 36 N., R. 86 W.

which, so far as is known, are restricted to strata deposited in marine or brackish waters (Wilson and Hoffmeister, 1955); and (3) the widespread occurrence of glauconite, some of which formed in place (normally considered to be indicative of marine conditions), in the shale and associated sandstone beds.

The shark fauna at Twin Buttes (colln. L, table 2) probably is especially significant. It includes an abundance of two or more distinct types of sharks which, as far as is known of their past distribution as well as the distribution of related living forms, were exclusively marine in habitat (D. H. Dunkle, written commun., 1959). Although sharks now inhabit certain rivers and lakes in various parts of the world, only one species is known to have adapted itself permanently to fresh-water conditions (Bigelow and Schroeder, 1948, p. 341, 381). Furthermore, the rivers and lakes currently inhabited by sharks either are near the open ocean, or were once part of the open ocean.

The nearest known occurrence of marine strata of Paleocene age is the Cannonball Member at the base of the Fort Union Formation in North and South Dakota. The Cannonball is considered to be Paleocene, but, except for the area of outcrop shown on figure 20, very little is known about the movements, extent, and duration of the sea in which it was deposited. The close affinities between the Foraminifera of the Cannonball Member and the Foraminifera of the Midway Group of the Gulf Coast region (Fox and Ross, 1942), however, have prompted general acceptance of the theory that the Cannonball sea originated in the Gulf Coast region and spread northward across the Great Plains at least as far as the Canadian border (fig. 20) during early Paleocene time. The western edge of the main body of water was probably somewhere in western Nebraska and western South Dakota, and complete withdrawal may not have taken place until the late Paleocene. Any arm of the open sea that connected central Wyoming and the region to the east during middle and late Paleocene time would therefore seem to have been in the southern part of the Powder River Basin of eastern Wyoming, where the Paleocene section thickens rapidly southward, at least as far as the line where appreciable pre-Eocene beveling begins. Furthermore, the northern part of the Casper Arch, which lies between the Wind River and Powder River Basins (fig. 3), did not begin to rise until after Paleocene time; so there was no obstruction to the movement of water across this entire region.

Evidence for an extensive open-sea connection between central Wyoming and the Great Plains region to the east, however, has not been reported from the Paleocene rocks of the intervening Powder River Basin. In a brief summary of the Fort Union strata in that basin, Brown (1958) noted that the rocks are mainly nonmarine, and were deposited on flood plains and in estuaries, sloughs, and swamps not much above sea level but in some places considerably inland from the open sea to the east and northeast. Thus, the conclusion is that Waltman Lake was an isolated body of water that had been linked to an open sea by rivers or narrow estuaries to provide access for migrating sharks. The low salinity of the lake waters, as indicated by the absence of evaporites in the Waltman Shale Member, also suggests that the lake basin drained to the sea. If the presence of glauconite in the Waltman strata can be considered a specific indicator of marine conditions, however, then there might have been at least a small flow of marine waters into central Wyoming through westward-projecting estuaries.

AGE AND CORRELATION

Paleontologic evidence, based on studies of fossil vertebrates, leaves, spores and pollen collected from many localities throughout the Wind River Basin (tables 2, 3), suggests that the thicker sections of the Fort Union Formation may contain rocks representative of each subdivision of Paleocene time. Fossil mammals, leaves, and spores and pollen from the Shotgun Butte area (colln. 13D, L, and M, tables 2, 3) indicate that the Shotgun Member ranges in age from late middle or early late Paleocene (Torrejonian or Tiffanian of Wood and others, 1941) at the base to latest Paleocene or earliest Eocene at the top. Spore and pollen assemblages from the Waltman Shale Member in other parts of the basin indicate a similar age range. From these ages it is inferred that the thick sequence of strata forming the lower part of the Fort Union Formation may range from early to middle Paleocene (Puercan and Dragonian of Wood and others, 1941), although the fossils reported—largely plants— are not diagnostic as to the Paleocene provincial ages that are represented.

An interesting collection of seeds and fruits that are rarely preserved as fossils was obtained from sandstone and ironstone beds in the Fort Union Formation at the north end of Sand Draw anticline (loc. 47, pl. 1). The following forms were identified by J. A. Wolfe (written commun., 1961):

Juglans? sp.
Pterocarya (*Cycloptera*) sp.
Pterocarya (*Diptera?*) sp., aff. *Bowerbankella* sp.
Magnolia? sp.
Palaeophytocrene sp.
Nyssa sp.
Langtonia sp.

FIGURE 19.—Unconformity between Wind River (Tw) and Fort Union (Tf) Formations north of Castle Gardens, sec. 33, T. 35 N., R. 90 W.

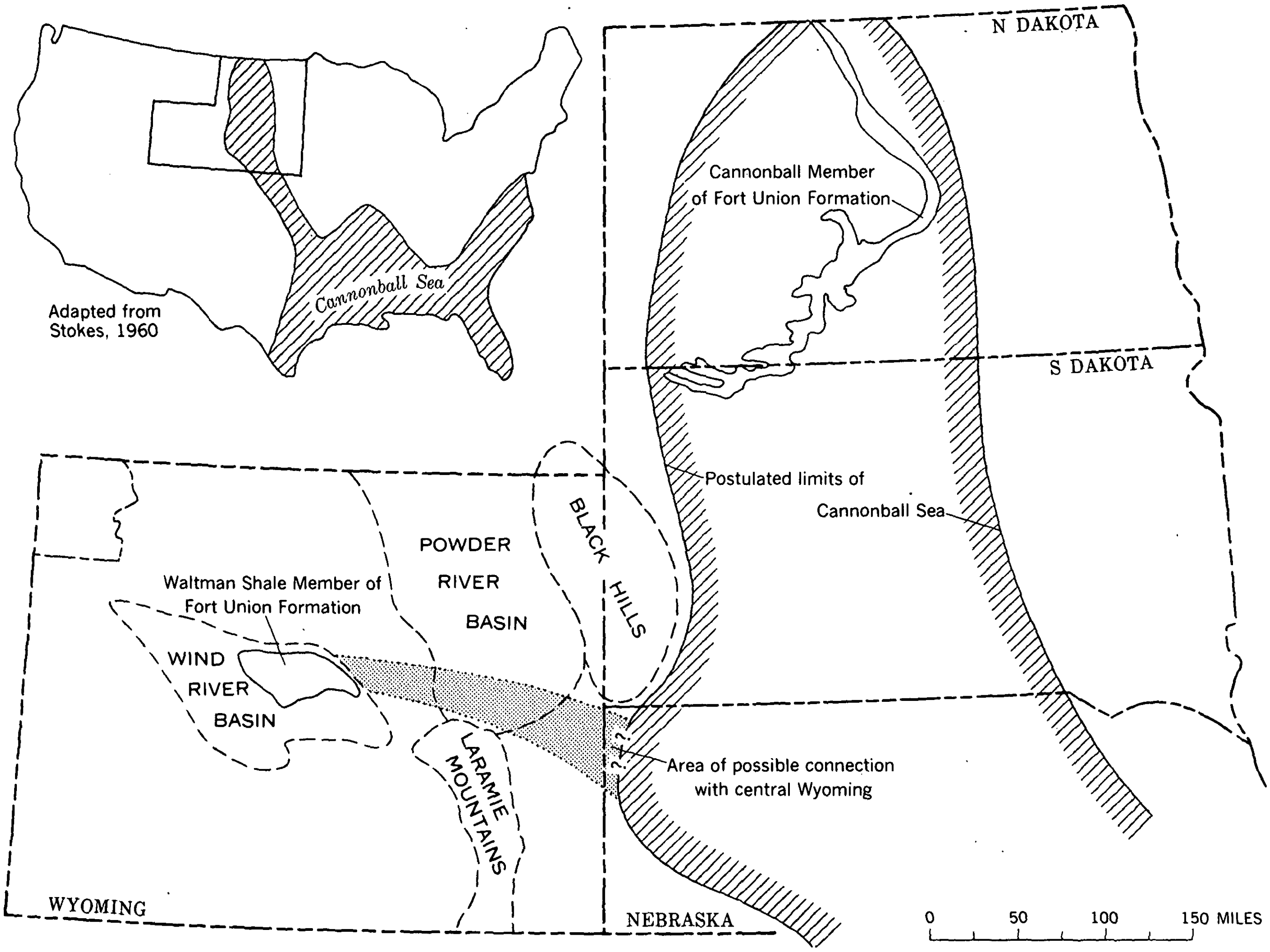


FIGURE 20.—An interpretation of geography during Paleocene time in parts of Wyoming and adjacent States. Distribution of Cannonball Member of Fort Union Formation based on Hansen, 1956, and Lloyd and Hares, 1915.

In addition to the large variety of fossil mammals at the Twin Buttes locality (colln. L, table 2; loc. 45, pl. 1), the fauna also contains abundant teeth of marine-type sharks. Included are two types of teeth, one representing either a species of sand shark or mackerel shark, and the other representing either the mackerel shark *Corax pristodontus* or the tiger shark *Galeocerdo* (D. H. Dunkle, written commun., 1959). The geologic range of these sharks is from Late Cretaceous to late Tertiary or Recent; their significance was discussed in the preceding section of this report.

Correlation of the Fort Union Formation in the Wind River Basin with equivalent rocks in adjacent regions is shown on figure 8. Diagnostic mammalian faunas have been reported from the Paleocene rocks particularly in the Bighorn, Hoback, and Green River Basins, and also from the Bison Basin area at the southeast end of the Wind River Range (Gazin, 1961, p. 47–51). In these occurrences, as in the Wind River Basin, rocks representing the Tiffanian (and (or) Torrejonian) of Wood and others (1941) seem to be the most fossiliferous of all the Paleocene.

LOWER EOCENE ROCKS

INDIAN MEADOWS FORMATION

DEFINITION

The name Indian Meadows Formation was applied by Love (1939, p. 58–59) to rocks of earliest Eocene age along the east side of the East Fork Wind River in the northwestern part of the Wind River Basin (fig. 21). Love included about 900 feet of strata in the type section, which extends from near the center of sec. 22 to the center of sec. 14, T. 6 N., R. 6 W. On the basis of vertebrate fossils in the lower part of the formation, he (Love, 1939, p. 63) concluded that the Indian Meadows was correlative in time with the beds of Gray Bull age of Wood and others (1941) (earliest Eocene) in the lower part of the Willwood Formation in the Bighorn Basin (Granger, 1914, p. 202–205; Van Houten, 1945, p. 426–428).

Later work in the type area by J. F. Murphy (written commun., 1962) has shown, however, that there is a distinct lithologic and faunal break approximately in the middle of the sequence originally assigned to the Indian Meadows Formation. The lower half contains the earliest Eocene (Gray Bull) fauna discussed by Love, whereas the upper half contains fossils of later early Eocene age (Lysite and (or) Lost Cabin) and thus correlates with the Wind River Formation. Regarding lithology, Murphy stated that the sandstone and conglomerate in the Indian Meadows includes both Paleozoic and Precambrian rock types, whereas the coarse fraction in the Wind River is almost exclusively from Precambrian rocks. Also, the fine-grained sediments of the Indian Meadows are largely brick red, whereas those of the Wind River are reddish pink, owing to color dilution by arkosic grit.

Accordingly, the Indian Meadows Formation, as used in this report, is restricted to the lower unit of earliest Eocene age, and its type section is confined to the northeast quarter of sec. 22, T. 6 N., R. 6 W. (fig. 21); the upper unit is assigned to the Wind River Formation. Although the two formations appear to be conformable at this locality, about 1 mile south, across a major reverse fault, the Wind River Formation rests unconformably on Lower Cretaceous rocks (fig. 21).

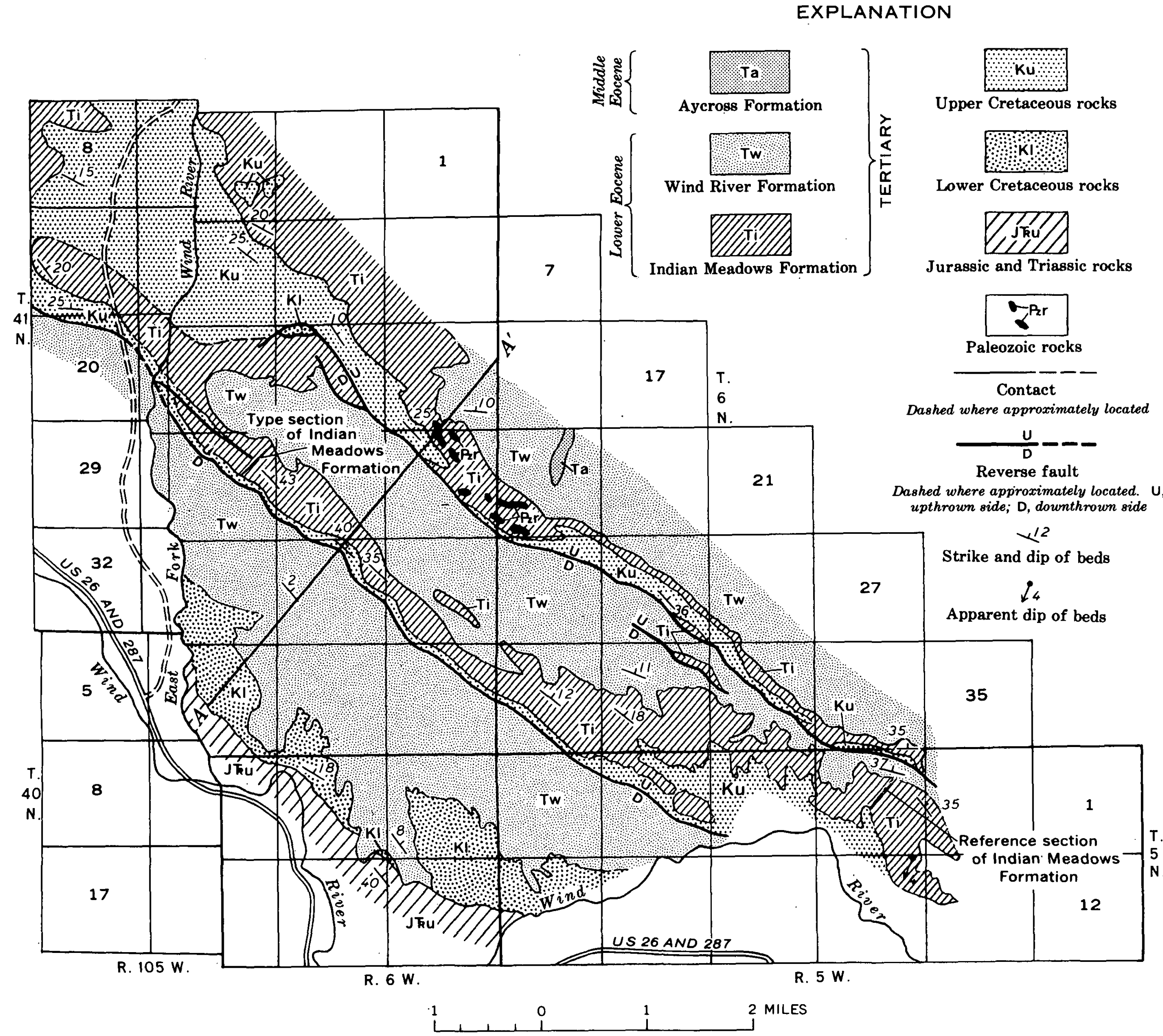


FIGURE 21.—Generalized geology in type area of Indian Meadows Formation. Based on J. D. Love (1939) and J. F. Murphy (unpub. map). Structure section along line *A–A'* shown on figure 24.

DISTRIBUTION

The Indian Meadows Formation crops out extensively northwest of the type section, although in some places it cannot be differentiated from the Wind River Formation (Keefer, 1957, p. 187–188). The formation can be traced for about 6 miles along the strike southeast of the type section (fig. 21), but there it also merges with, and becomes indistinguishable from, the basin facies of the Wind River (J. F. Murphy, written commun., 1962).

Elsewhere in the basin, rocks believed to correlate with the Indian Meadows Formation are exposed only in the Shotgun Butte area (Keefer and Troyer, 1956), in a small area at the west end of Cedar Ridge (fig. 22), in a few buttes about 1½ miles northeast of the town of Arminto (fig. 23), and at the base of Clarkson Hill in the extreme southeastern part of the basin (Rich, 1962, p. 487–488; loc. 81, pl. 1). Except at Shotgun Butte, where earliest Eocene vertebrate fossils have been found, these correlations are based solely on the physical stratigraphic and structural relations with the enclosing rocks at the locality indicated. So far as is known, rocks equivalent to the Indian Meadows are not exposed along the west and south margins of the Wind River Basin.

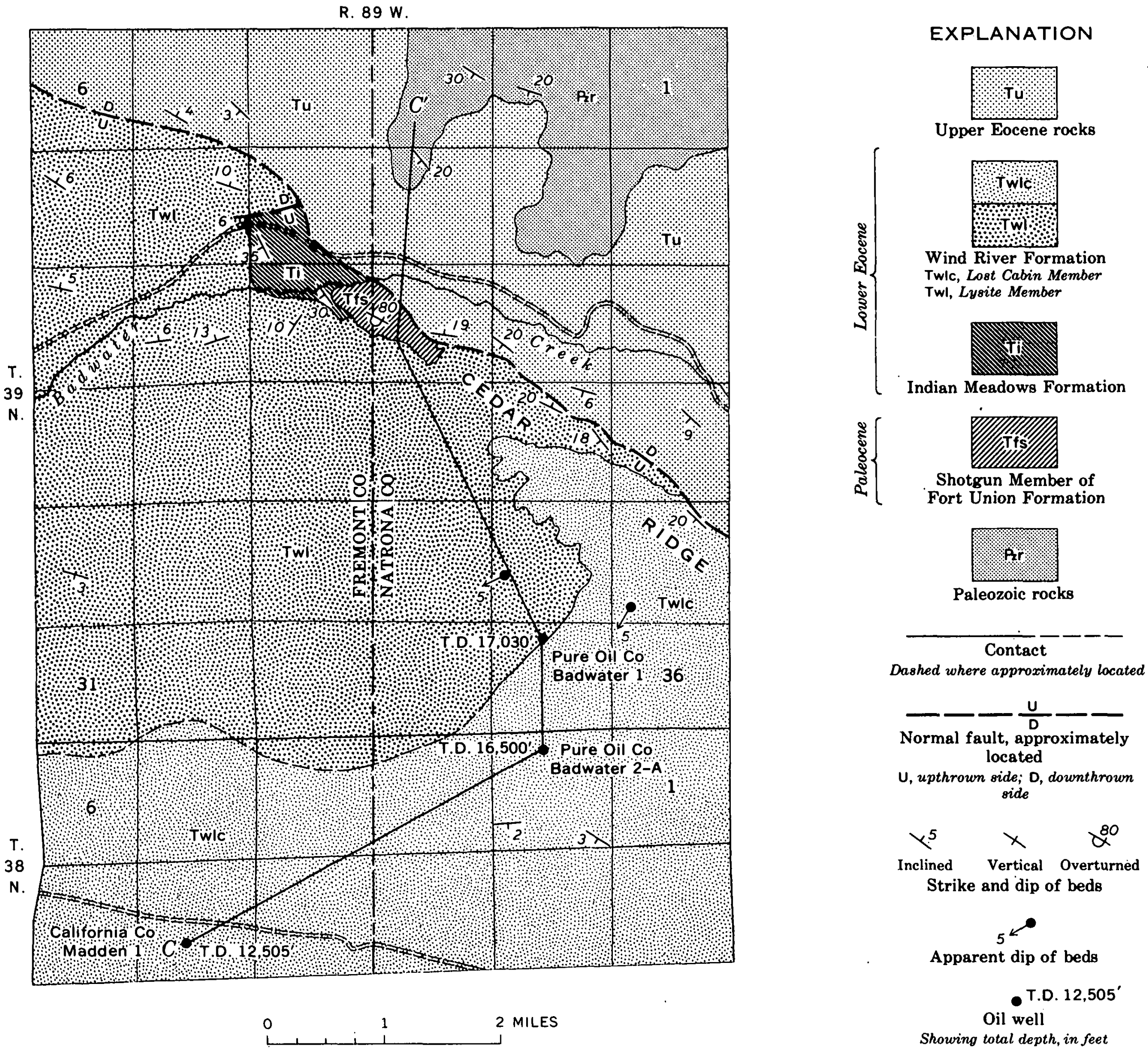


FIGURE 22.—Generalized geology of the Badwater Creek area. Based on Tourtelot (1953). Structure section along line C–C' shown on figure 24.

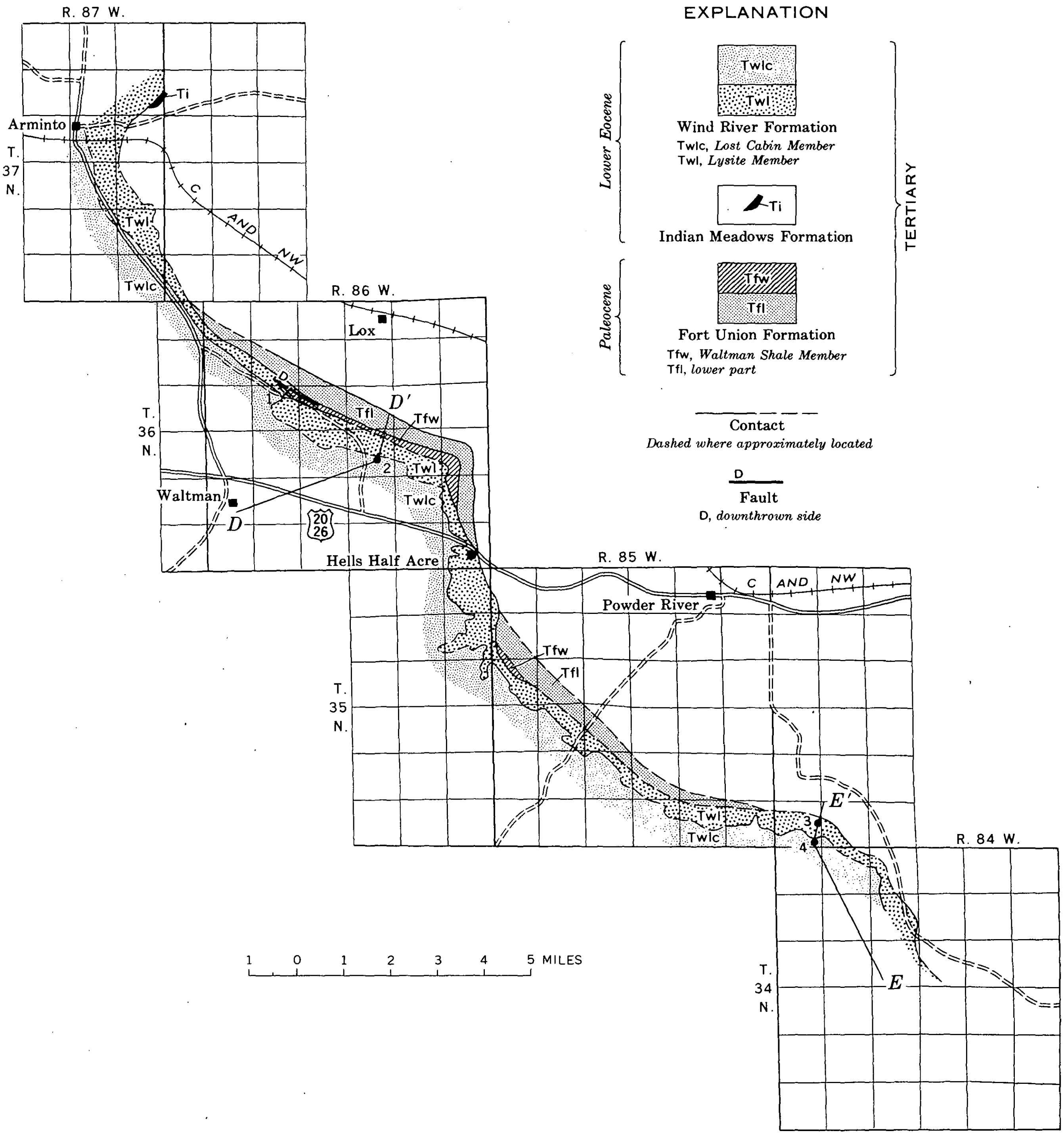


FIGURE 23.—Outcrops of Paleocene and lower Eocene rocks, along west flank of Casper Arch. In part based on Rich (1962) and Hares (1946). Numbered localities are: 1, type section, Waltman Shale Member of Fort Union Formation; 2, Continental Oil Co. Hells Half Acre 1; 3, British-American Oil Producing Co. Downer 1; 4, British-American Oil Production Co. Eccles 1. Structure sections along lines *D–D′* and *E–E′* shown on figure 24.

The extent of the Indian Meadows Formation in the subsurface is not known. Because the major basin trough was subsiding through all of latest Cretaceous and early Tertiary times, it seems likely that strata equivalent to the Indian Meadows are an indistinguishable part of a continuous depositional sequence of lower Eocene rocks in the deep trough areas. This interpretation is shown on structure sections drawn through selected wells along the north and east margins of the Wind River Basin (sections *C–C′*, *D–D′*, and *E–E′*, fig.

24). The stratigraphic sections penetrated by these wells, as determined from well cuttings, and the regional geologic structure require the presence of a thick sequence of strata younger than the Fort Union Formation but older than the major reverse faulting in the Owl Creek Mountains and Casper Arch. These strata are thus older than the major movements of Laramide deformation in this region and are also older than the comparatively undeformed beds of the overlying Wind River Formation.

LITHOLOGY AND THICKNESS

In its type area along the East Fork Wind River (fig. 21), the Indian Meadows Formation is composed of variegated brick-red, purple, gray, and white claystone, siltstone, sandstone, and conglomerate and thin beds of gray algal-ball limestone. The conglomerate consists chiefly of rounded pebbles and cobbles of granite of Precambrian age, and limestone, dolomite, sandstone, quartzite, and chert of Paleozoic age. Large podlike masses (maximum length more than one-quarter of a mile) of resistant Paleozoic rocks are incorporated within the variegated sequence in some places. The formation, which generally weathers to prominent badlands, is highly folded and faulted (cross section *A–A′*, fig 24). Lithologic descriptions obtained from exposures about 6 miles southeast along strike from the type section are given in stratigraphic section 7 of this report.

Northwest of the type area, along the south flank of the Washakie Range (loc. 34 and vicinity, pl. 1), the Indian Meadows Formation consists of 150–200 feet of red massive cliff-forming conglomerate with cobbles and boulders as much as 6 feet long of Paleozoic sandstone, limestone, dolomite, and chert. The formation may also be represented in the basal part of the lower Eocene sequence in the spectacular red-banded cliffs and badlands along the main channel of Wind River; but in these exposures the strata contain fragments of Precambrian granite, gneiss, and schist, and cannot be distinguished lithologically from the overlying Wind River Formation (Keefer, 1957, p. 187–188). Paleontologic evidence (colln. F and G, table 2) indicates that earliest Eocene strata do not extend as far northwest along the river as the town of Dubois.

One of the thickest and best exposed sections of the Indian Meadows within the Wind River Basin is at Shotgun Butte (fig. 25; Keefer and Troyer, 1964, p. 71–72). This prominent topographic feature, in the SE cor. T. 6 N., R. 1 E. (loc. 13, pl. 1), rises 500 feet above the general landscape and is composed entirely of the bright-red, gray, and tan banded rocks of the Indian Meadows Formation. These strata have been preserved from erosion by being downfolded in a large syncline (cross section *B–B′*, fig. 24).

Near Twin Buttes, 8 miles east of Shotgun Butte (near locs. 44 and 45, pl. 1), the Indian Meadows Formation consists of thin conglomerate beds that cap hills and slopes (fig. 17). The conglomerate is similar to that in the upper part of the formation at Shotgun Butte and likewise is distinguished by the absence of Precambrian rock fragments. The relative abundance of such fragments in the overlying Wind River Formation provides a useful criterion for separating the two formations in the Shotgun Butte area.

Along Badwater Creek at the northwest end of Cedar Ridge, secs. 9 and 16, T. 39 N., R. 89 W. (fig. 22), Tourtelot (1946) described a series of varicolored siltstone, sandstone, conglomerate, and algal-ball limestone which he referred to as "beds of early Wasatchian age" and tentatively correlated them with the Indian Meadows Formation. Later, he (Tourtelot, 1948, 1953) included them in the Lysite Member of the Wind River Formation. Additional surface and subsurface studies in the region by the author and J. D. Love, however, indicate that the sequence is overlain unconformably by the Lysite Member. The basal part is terminated in most places against the Cedar Ridge fault (fig. 22), but in a very small area on the south side of Badwater Creek it directly overlies the Shotgun Member of the Fort Union Formation with an angular discordance of about 70°. Although no fossils have yet been found, these strata are here assigned to the Indian Meadows Formation.

Maximum thickness of the Indian Meadows Formation in the Badwater Creek area is about 2,500 feet in surface exposures, but may increase to as much as 4,000 or even 5,000 feet in nearby subsurface sections (cross section *C–C′*, fig. 24). The conglomerate beds consist mostly of boulders of sandstone, siliceous shale, and chert as much as 4 feet across; but they contain few or none of the limestone and dolomite fragments that are common in the overlying Lysite Member of the Wind River Formation.

Rocks believed to be equivalent to the Indian Meadows Formation are present in small exposures 1½–2 miles northeast of the town of Arminto (fig. 23). These rocks, which are about 50 feet thick, are a series of conglomerate beds containing sandstone, siliceous shale, and chert cobbles that unconformably overlie the Upper Cretaceous Cody Shale and underlie varicolored shales of the Wind River Formation.

The basal Eocene sequence in exposures at Clarkson Hill in the extreme southeast corner of the Wind River Basin (loc. 81, pl. 1) is characterized by arkosic sand-

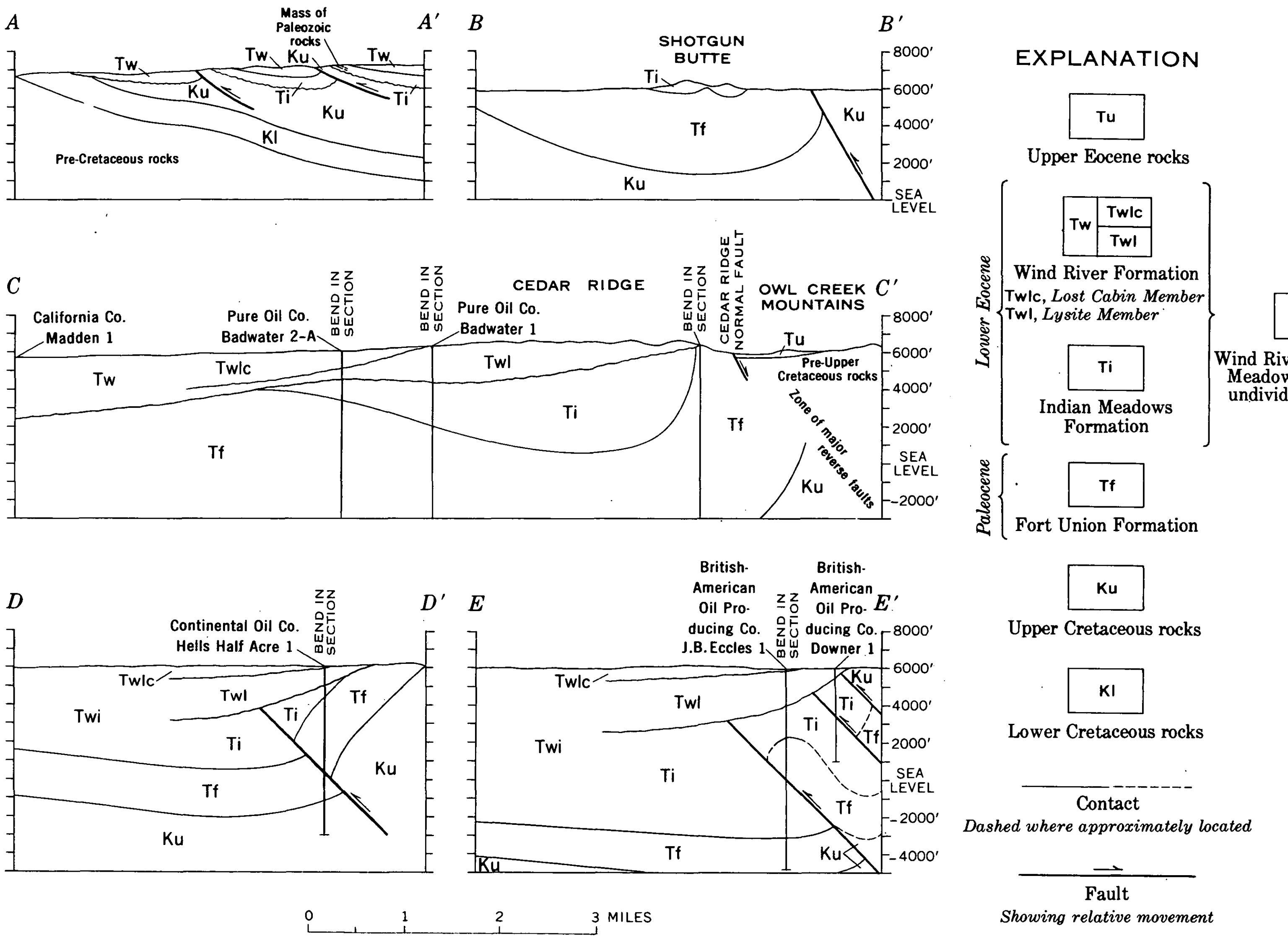


Figure 24.—Sections showing stratigraphic and structural relations of Paleocene and lower Eocene rocks in parts of the Wind River Basin. Lines of sections shown on plate 1 (*B–B′*) and figure 21 (*A–A′*), 22 (*C–C′*), and 23 (*D–D′* and *E–E′*).

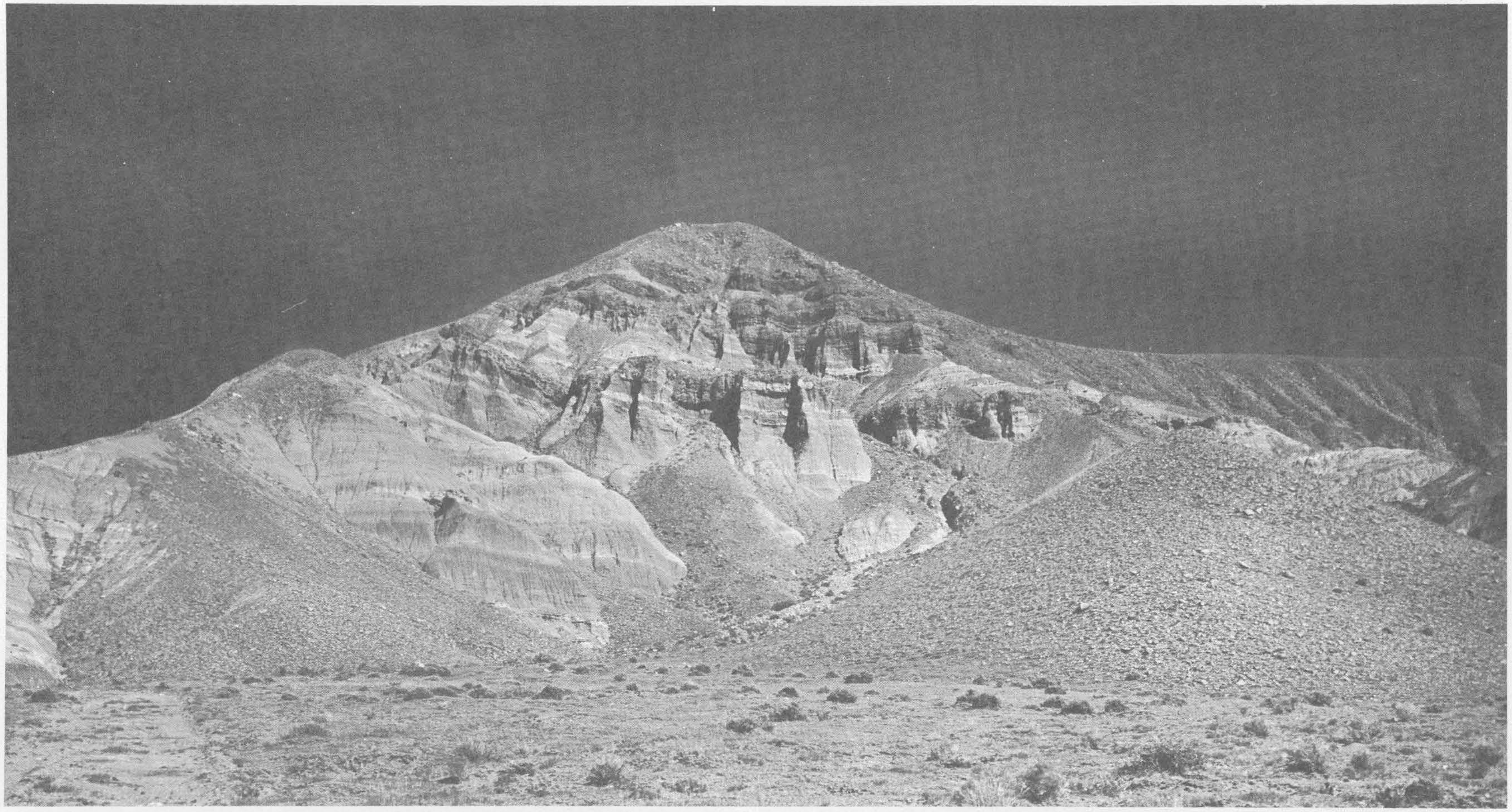


FIGURE 25.—Indian Meadows Formation on west side of Shotgun Butte, secs. 26 and 35, T. 6 N., R. 1 E. Coarse conglomerate forms ledges near top of butte, and fine-grained variegated strata are at base of butte; difference in altitude between top and base of butte is 500 feet.

stone and conglomerate with thin interbeds of carbonaceous siltstone and claystone. Rich (1962, p. 487–488) referred to these strata as the "conglomeratic sandstone unit" of the Wind River Formation, but he tentatively concluded that they may correspond in age to the Indian Meadows Formation because they are overlain unconformably by beds of known early Eocene age and underlain unconformably by beds of Paleocene and Late Cretaceous age.

In most subsurface sections the interval of the Indian Meadows Formation can be determined only generally because of lithologic similarities with the younger lower Eocene rocks, and, in some wells, with the underlying Fort Union Formation as well. The probable stratigraphic and structural position of the Indian Meadows Formation in a few selected areas is shown on figure 24. Its position is particularly well shown in the Badwater area where surface and subsurface data are adequate and can be closely integrated (pl. 3; fig. 22; cross section *C–C′*, fig. 24). Projection of stratigraphic units into the subsurface from the exposures along Cedar Ridge, and correlation of units in the California Co. Madden 1 and the Pure Oil Co. Badwater 1 and 2–A, indicate that 4,000–5,000 feet of strata are present above the top of the Fort Union Formation and below the Wind River Formation. In the Pure Oil Co. Badwater 1 these rocks occupy the interval 1,897–4,350 feet, and are characterized by red, gray, and gray-green siltstone and fine-grained sandstone which in places contains some very coarse chert grains. Carbonaceous shale and coaly beds occur in the lower 400 feet. In contrast, the overlying Lysite Member of the Wind River Formation is predominantly coarse-grained sandstone with abundant fragments of limestone and dolomite. A similar succession is also present in the Pure Oil Co. Badwater 2–A where the Indian Meadows Formation occupies the depth interval 1,555–2,620 feet. About 3 miles to the south, however, in the California Co. Madden 1, the basal beds of the Wind River Formation apparently rest directly on the Fort Union Formation, and the intervening strata of the Indian Meadows Formation have been removed by pre-Wind River erosion (pl. 3; cross section *C–C′*, fig. 24).

Correlations of lower Eocene rocks in subsurface sections along the east margin of the Wind River Basin are not so apparent, but they are probably comparable to those in the Badwater area. Several hundred to several thousand feet of unidentified strata overlying the Fort Union Formation have been overridden by westward-moving reverse fault blocks along the west flank of the Casper Arch and are overlain unconformably by the Wind River Formation (cross sections *D–D′* and *E–E′*, fig. 24). These strata include coarse-grained arkosic sandstone similar to that described by Rich (1962) in the basal Eocene rocks at Clarkson Hill (loc. 81, pl. 1), which he tentatively concluded may correspond in age to the Indian Meadows Formation. In the vicinity of British-American Oil Producing Co. J. B. Eccles 1 (cross section *E–E′*, fig. 24), these strata have a probable maximum thickness of 6,000 feet or more, but because of faulting, a total of only about 2,930 feet (interval 6,060–8,990 ft) was penetrated in the well itself. The arkosic material is mostly white feldspar that is relatively unaltered near the top of the interval, but is progressively more altered toward the base. The interbedded shale, claystone, and siltstone is variegated red and purple in some places but gray, gray green, and black in others.

ANCIENT LANDSLIDES IN THE INDIAN MEADOWS FORMATION

Large masses of resistant Paleozoic rocks, several miles from their nearest mountain source, are incorporated within the Indian Meadows Formation in the northern and northwestern parts of the Wind River Basin. The largest are in the type area (Love, 1939, p. 60–62) and near Twin Buttes (near loc. 45, pl. 1) in the Shotgun Butte area (Keefer and Troyer, 1964, p. 36–37). The detached masses are mostly Gallatin Limestone of Late Cambrian age, Bighorn Dolomite of Ordovician age, Madison Limestone of Mississippian age, Tensleep Sandstone of Pennsylvanian age, and rocks of the Phosphoria Formation of Permian age; each mass is composed of rocks from only one or two of these formations. Relatively undisturbed bedding is exhibited in some of the blocks; but generally the strata are highly distorted and brecciated, which suggests that they once had been an accumulation of very coarse rubble which was later compacted and cemented into coherent blocks. All the masses seem to have been emplaced contemporaneously with extensive uplift and reverse faulting along the flanks of the adjacent mountain ranges.

The question arises as to whether the detached blocks were emplaced by faulting or by gravity sliding. The ultimate interpretation depends in large part on the angle of dip of associated reverse faults. If these faults are low-angle overthrusts, direct tectonic emplacement of the detached masses may be inferred; but if the faults are high-angle, then origin by gravity sliding seems to be the more logical interpretation.

At the Twin Buttes locality, masses of Bighorn Dolomite and Madison Limestone as much as 1,000 feet long in the basal part of the Indian Meadows Formation were probably emplaced by gravity sliding (Keefer and Troyer, 1964, p. 37; fig. 26). The nearest source of the Ordovician and Mississippian strata is about 2 miles to the north, in a segment of the Owl Creek Mountains which was uplifted at the beginning of Eocene time along the steep north-dipping Cottonwood Creek reverse fault. The most plausible explanation, as shown on figure 26, is that the blocks of Paleozoic rocks were parts of large landslides that sloughed off the front of the rising fault blocks during the period of active erosion accompanying the uplift. Cambrian shale probably provided a ready glide plane for the slides in the mountains, and soft shale in the Upper Cretaceous and Paleocene strata may have further facilitated sliding as the masses moved onto the basin floor. Although the actual glide plane is conjectural, it probably was inclined at about 5° (fig. 26).

The detached masses in the type area of the Indian Meadows Formation along the East Fork Wind River are not so readily explained. There, the major reverse faults are buried by relatively undeformed Tertiary strata, and the nearest source for the Paleozoic rocks is 5–6 miles distant (Love, 1939). These masses may have had a history similar to those at Twin Buttes; or they may have been subject to a more complex series of movements, such as those described by Pierce (1957) for the origin of large detachment blocks in the Heart Mountain area along the northwest margin of the Bighorn Basin.

CONTACT WITH THE WIND RIVER FORMATION

The Indian Meadows Formation is overlain unconformably by the Wind River Formation in most outcrops along the margin of the Wind River Basin where the two units occur in juxtaposition. The unconformity can be projected downdip from the outcrops, but it probably does not extend for more than a few miles toward the interior of the basin. In some places, the composition of the conglomerate beds in the Indian Meadows Formation is distinctly different from that of the beds in the Wind River Formation, as is indicated by the following observations:

1. Along the south flank of the Washakie Range, in the extreme northwestern part of the Wind River Basin (loc. 34, pl. 1), the Indian Meadows Formation contains only Paleozoic rock fragments, whereas the overlying Wind River Formation is very arkosic, indicating sources in Precambrian terrane.
2. In the type area, the conglomerate in the Indian Meadows contains both Paleozoic and Precambrian rock types, whereas the coarse fraction in the Wind River is almost exclusively from Precambrian rocks. Algal-ball limestone beds are present in both units, but are generally more abundant in the Indian Meadows.
3. In the Shotgun Butte area the conglomerate in the Indian Meadows Formation is nonarkosic, but that of the Wind River Formation is very arkosic.
4. In the Badwater area, the conglomerate beds assigned to the Indian Meadows Formation are characterized by fragments of sandstone, chert, and siliceous shale, whereas those in the overlying Lysite Member of the Wind River Formation contain conspicuous quantities of limestone and dolomite.
5. Along most of the east margin of the Wind River Basin, and in the southeast corner, the entire lower Eocene sequence is arkosic and cannot be subdivided on the basis of composition of the conglomerates. It should be noted, however, that the arkosic material in beds assigned to the Indian Meadows Formation as seen in well cuttings consists predominantly of white feldspar grains, whereas that in the Wind River Formation contains many pink grains.

The Indian Meadows and Wind River Formations can be distinguished, according to the general criteria given above, in a few of the subsurface sections along the north and east margins of the Wind River Basin. In most sections, however, there is no reliable basis for subdivision, and except for those wells located only a few miles downdip from the outcrops, no attempt was made to differentiate the lower Eocene sequence in subsurface sections throughout the remainder of the Wind River Basin. Electric log characteristics of strata in the deep trough area show no special diagnostic features in the strata presumed to be the downdip equivalent of the Indian Meadows Formation. The sections of lower Eocene rocks penetrated by wells in the other parts of the basin are treated in the discussion of the Wind River Formation.

CONDITIONS OF DEPOSITION

Strata of the Indian Meadows Formation were deposited during the period of active erosion which followed the pronounced uplift of the mountain masses bordering the Wind River Basin at the beginning of Eocene time. The coarse conglomerate originated as a series of extensive alluvial fans and stream-channel deposits along the south flanks of the Washakie Range and Owl Creek Mountains. Powerful streams, with headwaters in the ancestral Granite Mountains to the south, flowed northeastward across the southeastern part of the basin and probably across the present site of the Casper Arch into the southern part of the Powder River Basin. Thick sequences of coarse arkosic sand and gravel derived from the central core of the Granite Mountains, alternating with finer grained silt and clay,

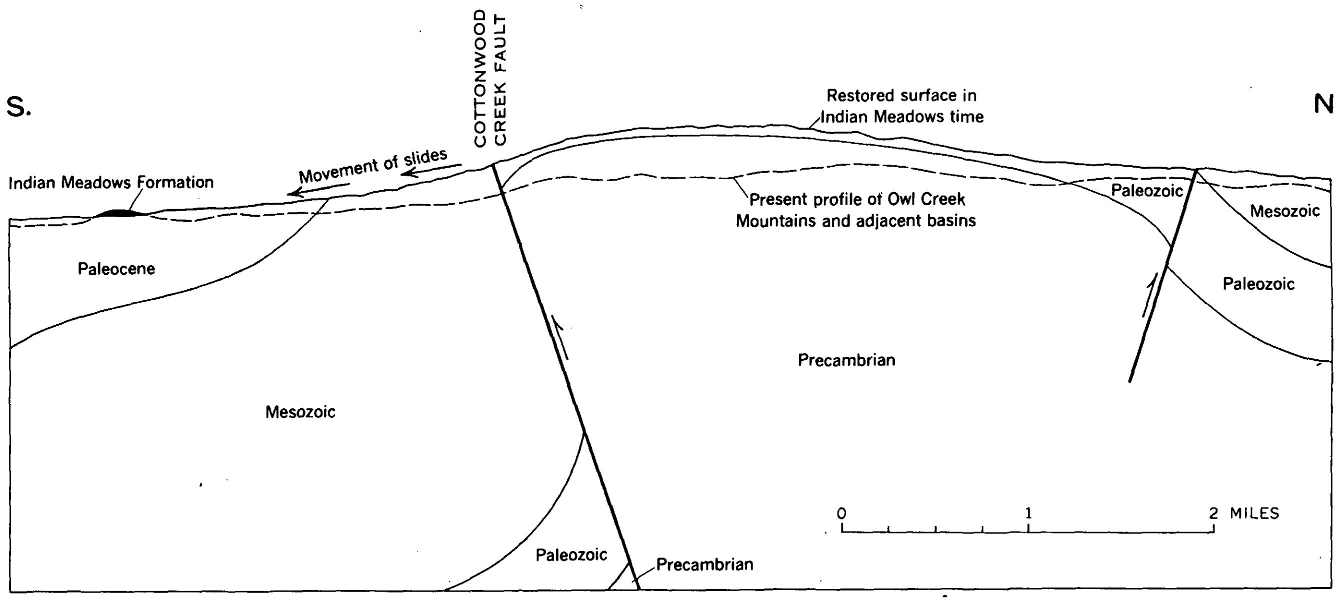


FIGURE 26.—An interpretation of the origin of detached masses of Paleozoic rocks in the Indian Meadows Formation near Twin Buttes, secs. 31 and 32, T. 6 N., R. 3 E. Geology is generalized; in part based on Keefer and Troyer (1964); line of section shown on plate 1.

were deposited across broad flood plains. The major basin trough along the north margin of the basin continued to subside, and several thousand feet of fine-grained clastic debris accumulated in it. As is discussed more fully below, it seems possible that lakes occupied parts of the trough almost continuously through Indian Meadows time.

AGE AND CORRELATION

Collections of fossil mammals in the type area (colln. 2A and H, table 2) and in the Shotgun Butte area (colln. 13E, table 2) indicate that the Indian Meadows Formation is earliest Eocene in age and correlative with the beds of Gray Bull age in the lower part of the Willwood Formation in the Bighorn Basin. Equivalent strata are present in nearly all the other sedimentary basins of Wyoming, but they have not been generally distinguished as formations (fig. 8).

WIND RIVER FORMATION

DEFINITION

Meek and Hayden (1861, p. 434) first used the term "Wind River deposits" in describing the prominent series of beds between the "true lignite beds of the Tertiary" (Fort Union or "Great Lignite group") below and the "White River Tertiary deposits" above in central Wyoming and adjacent regions. Frequent mention of these deposits (also as "Wind River group") was made by Hayden in his later reports on the geology of various parts of Wyoming. St. John (1883, p. 228–269), during his reconnaissance studies in the northwestern part of the Wind River Basin, apparently was the first to employ the term "Wind River Formation." No type section has ever been designated.

Granger (1910, p. 241–246) recognized two lithologically and faunally distinct units within the Wind River Formation in the northeastern part of the basin, and Sinclair and Granger (1911, p. 104) named the Lost Cabin and Lysite as formations of the Wind River. The faunal distinction was based largely on the presence of the genus *Lambdotherium* in the Lost Cabin beds and on its absence in the Lysite beds. Subsequent workers described the Lysite and Lost Cabin as members of the Wind River Formation (Wood and others, 1941; Tourtelot, 1948, p. 114).

DISTRIBUTION

The Wind River Formation has the most widespread outcrops of any stratigraphic unit in the Wind River Basin; it is the surface rock in nearly 4,000 square miles of the central part of the basin. Division of the formation into the Lysite and Lost Cabin Members, however, has been made only along the east and northeast margins of the basin.

LITHOLOGY AND THICKNESS

Because the Wind River Formation originated during the active erosional period that followed the uplift of the mountain ranges along the margins of the Wind River Basin, its thickness and lithology vary considerably from place to place. In general, however, two facies predominate—a coarse boulder facies representing deposition along the mountain slopes and a fine-grained commonly brightly varicolored facies representing deposition farther out in the basin. As might be expected under these conditions, there is a complete gradation of the two facies in areas which overlap both the mountain and basin structural provinces. Depending on the transport power of the ancient streams, the coarse facies may extend several miles into the basin, or it may be confined to the relatively narrow mountain slopes.

The thickness of the Wind River Formation ranges from a wedge-edge at the basin margins to several thousand feet in the major trough area. As mentioned previously, it is difficult to distinguish the Wind River Formation from the Indian Meadows Formation in most subsurface sections, so that individual formation thicknesses can be determined only in a general way. Although the Wind River is the surface formation throughout most of the basin, it is rarely well exposed, because the strata are flat lying and easily weathered; the basin floor has low relief and in many places is covered by sand and gravel. In a few localities, however, the combination of topographic relief and structural conditions is such that several hundred feet of beds are exposed almost continuously. A few areas representing different parts of the basin are described below to illustrate the significant stratigraphic features of the Wind River Formation.

NORTHWESTERN WIND RIVER BASIN

Some of the thickest and best exposures of the Wind River Formation occur near Dubois in the northwestern part of the Wind River Basin. The basinward facies, consisting chiefly of brightly varicolored beds, are continuously exposed in badlands that extend north from the main channel of Wind River (loc. 31, pl. 1) for 8 miles to the upper reaches of Little Horse Creek (loc. 30, pl. 1). The strata have a composite thickness of more than 1,800 feet, and have been divided into 5 distinct units (Keefer, 1957, p. 188–193), which are summarized as follows:

1. Upper variegated sequence (>100 ft)—gray, greenish-gray, and light-red highly tuffaceous and bentonitic shale, claystone, siltstone, and fine-grained sandstone; contains *Didymictus altidens* of late early Eocene (Lost Cabin) age; overlain unconformably by upper Eocene or Oligocene rocks.
2. Conglomerate sequence (100 ft)—lower 40 feet is tan massive conglomerate containing fragments of Precambrian and Paleozoic rocks as much as 6 feet long; overlying 40 feet is tan fine- to coarse-grained tuffaceous sandstone and minor amounts of gray claystone and brown carbonaceous shale; upper 20 feet is chiefly brown carbonaceous shale with abundant black coal partings; unit unconformably overlies next older beds in some places.
3. Middle variegated sequence (675–800 ft)—bright red, purple, and gray bentonitic claystone and siltstone, and white to gray tuffaceous sandstone and siltstone; lower half contains 10- to 15-foot beds of massive conglomeratic sandstone with abundant pebbles and cobbles of Paleozoic limestone, chert, and sandstone; at White Pass (loc. 29, pl. 1) the upper 48 feet contains a 37-foot bed of brown carbonaceous shale with coal partings overlain by 11 feet of white bentonite and bentonitic claystone; fossil vertebrates (colln. 1C, table 2) indicate a late early Eocene (Lost Cabin) age.
4. Tuffaceous sandstone sequence (290–390 ft)—greenish-gray and gray soft tuffaceous fine- to coarse-grained sandstone and minor amounts of shale, carbonaceous shale, and conglomerate; sandstone contains abundant grains of biotite and plagioclase feldspar; conglomerate beds are 20–30 feet thick and contain well-rounded pebbles and cobbles of Precambrian quartzite, granite, and schist; Paleozoic limestone, sandstone, and chert; and Tertiary volcanic rocks; fossile leaves (colln. 1B, table 2) indicate an early to middle Eocene age. This is the only zone of Precambrian quartzite cobbles and also the lowest stratigraphic occurrence of lithic fragments of Tertiary volcanic rocks observed in the Wind River Formation in the northwestern part of the basin.
5. Lower variegated sequence (555 ft)—red siltstone and shale, buff fine-grained shaly sandstone, and white to buff cobble-and-pebble conglomerate; conglomerate contains Precambrian granite and Paleozoic rock fragments as much as 6 inches long; shale and siltstone are bentonitic in upper part; forms conspicuous badlands; fossil vertebrates (colln. 1A, F, and G, table 2) indicate a late early Eocene (Lost Cabin) age. This sequence grades westward into the coarse arkosic sandstone of the mountainward facies and rests with pronounced angular discordance on underlying Paleozoic and Mesozoic rocks.

South of the Wind River, along the slopes of the Wind River Range, the mountainward facies of the Wind River Formation consists of white to tan arkosic sandstone containing abundant coarse angular grains of quartz and feldspar. In some places siltstone, shale, and carbonaceous shale with coal partings are interbedded with the sandstone. Southeast of Dubois, in Torrey, Dinwoody, and Bull Lake Canyons, this facies contains boulders as much as 10 feet across, chiefly of Precambrian granite (fig. 27).

CROWHEART BUTTE AREA

In the Crowheart Butte area (loc. 35, pl. 1), the Wind River Formation commonly consists of a basal conglomeratic sequence, a middle variegated sequence, and an upper tuffaceous sandstone sequence (Murphy and others, 1956). The basal conglomerate, 50–200 feet thick, is composed predominantly of Precambrian granite and metamorphic rock fragments in some places and of Paleozoic or Mesozoic rocks in others. Boulders in some deposits are as much as 10 feet long. The middle variegated sequence is largely red, gray, and gray-green siltstone interbedded with coarse-grained sandstone and pebble conglomerate. This sequence has a

765-797 O—65——4

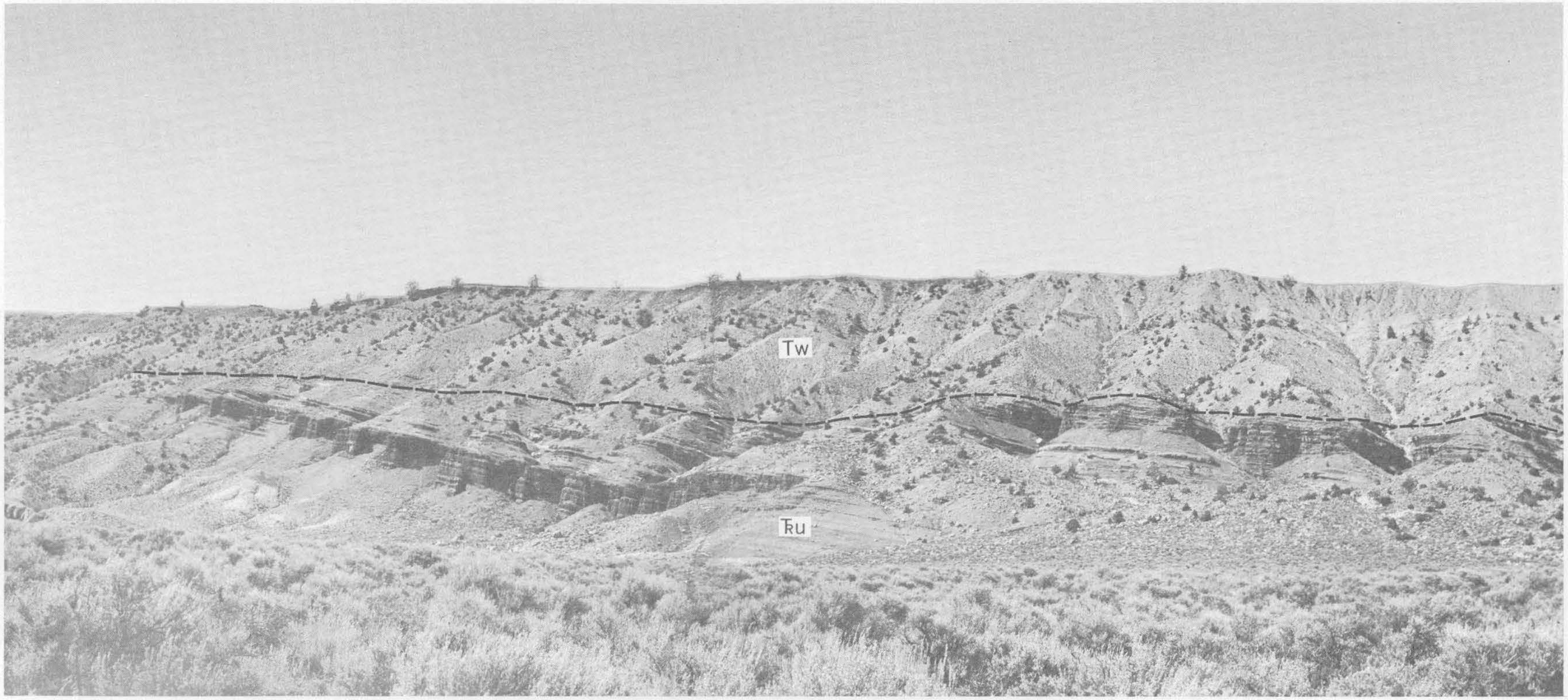


FIGURE 27.—Wind River Formation (Tw) overlapping Triassic rocks (T̄Ru) along north wall of Dinwoody Canyon, sec. 31, T. 5 N., R. 5 W., and sec. 36, T. 5 N., R. 6 W. Deposits near top of ridge partly glacial in origin.

probable maximum thickness of about 2,000 feet. The upper part of the Wind River Formation in this area is buff coarse-grained tuffaceous sandstone and tuff, about 250 feet thick, with a 30- to 40-foot conglomerate at the base containing abundant well-rounded pebbles and cobbles of Precambrian quartzite and some Tertiary volcanic rocks. This conglomerate is similar to that in the tuffaceous sequence in the northwestern part of the Wind River Basin (see preceding description), and may be correlative with it.

Crowheart Butte, because of its topographic position contains the youngest Tertiary strata in this part of the basin. Although most of the butte is formed by the Wind River Formation, there is some question whether the uppermost tuff and tuffaceous sandstone beds also belong in the Wind River Formation, or are part of the next younger Aycross Formation. Hay (1956, p. 1894–1895) and J. F. Murphy (unpub. map, U.S. Geol. Survey) considered all the beds to be part of the Wind River Formation. J. D. Love (oral commun., 1961), on the other hand, recognized an erosional unconformity with considerable local relief about 50 feet stratigraphically below the top of the butte. The strata above the unconformity contain much more volcanic debris than those below it. Love considered this unconformity to mark the Wind River-Aycross contact, and so mapped it on the geologic map of Wyoming (Love and others, 1955).

Fossil vertebrates indicate a late early Eocene (Lost Cabin) age for most of the Wind River Formation in the Crowheart Butte area. Fossil leaves (colln. J, table 2) from near the top of the tuffaceous sequence, but below the unconformity described above, have a middle Eocene aspect (Murphy and others, 1956).

SOUTHWESTERN WIND RIVER BASIN

Along the northeast flank of the Wind River Range (for example, Table Mountain, loc. 43, pl. 1) the strata are predominantly boulder conglomerate interbedded with coarse arkosic sandstone (Thompson and others, 1950). Individual boulders are as much as 15 feet across at the western edge of the exposures, but the maximum size diminishes rapidly eastward (basinward). The fragments are mostly of Precambrian igneous and metamorphic rocks, some of which are soft and deeply weathered; but resistant Paleozoic rock fragments are abundant in places. Maximum preserved thickness of this mountainward facies is about 200 feet.

East of the mountains and foothills, the Wind River Formation generally consists of a basal arkosic sandstone and conglomerate overlain by a prominent series of badland-forming red, purple, gray, and white claystone and siltstone with lenses of tan to brown coarse-grained arkosic sandstone (Thompson and others, 1950). Maximum thickness is about 2,000 feet. Some of the varicolored strata, especially in the upper part of the formation, are highly bentonitic and weather into smooth rounded hills and slopes. Conspicuous in this sequence are zones of white to gray resistant tuff which form excellent marker beds in several areas. One of the tuff zones, about 1,000 feet stratigraphically above the base of the Wind River Formation (referred to as the Hudson tuff zone by Thompson and White, 1954), is about 20 feet thick, and extends in surface exposures east and southeast of the town of Hudson for a distance of about 9 miles. Tuff also crops out prominently around the edges of Riverton Dome, Beaver Creek, Alkali Butte, and Sand Draw anticlines (Thompson and White, 1954). Sinclair and Granger (1911, p. 93–94) gave detailed descriptions of these rocks, including a chemical analysis; they observed, from thin-section studies, that the chief constituents are glass shards, orthoclase, plagioclase, biotite, hornblende, and a black opaque mineral, probably iron oxide. The tuff is also slightly radioactive (J. D. Love, oral commun., 1962).

Lambdotherium-bearing beds occur both above and below the tuff in the Beaver Creek area (colln. 6A, table 2), indicating a late early Eocene (Lost Cabin) age for at least the upper part of the Wind River Formation in that region. However, 1,000 feet or more of Wind River strata underlie the lowest known occurrence of *Lambdotherium*, so that the lower part of the formation may contain beds equivalent to the Lysite Member.

SHOTGUN BUTTE AREA

Some of the best localities at which to study the stratigraphic and structural relations of the Wind River Formation are in the Shotgun Butte area (Troyer and Keefer, 1955; Keefer and Troyer, 1956; 1964, p. 38–39). The thickest section, about 1,000 feet, is exposed west of the northwest end of Muddy Ridge (loc. 41, pl. 1). The strata at that locality are typical of the basin facies; they consist of interbedded bright-red, purple, gray, and white claystone, shale, sandstone, and conglomerate. Conglomerate beds are generally most abundant in the basal part of the formation, and are composed chiefly of fragments of Paleozoic rock and of Precambrian granite ranging in length from ¼ to 2 inches. In at least one place (loc. 42, pl. 1) the conglomerate consists entirely of well-rounded Precambrian quartzite cobbles similar to those described in the Crowheart Butte area and in the northwestern part of the basin. Fossils diagnostic of the Lost Cabin Member of the Wind River Formation have been found in the

Shotgun Butte area (colln. K, table 2), but none that are restricted to the Lysite Member.

NORTHEASTERN WIND RIVER BASIN

The type areas for the Lysite and Lost Cabin Members of the Wind River Formation are in the northeastern part of the Wind River Basin. The lithologic and faunal differences between these two units were first recognized and described by Granger (1910, p. 241–246), and new formation names—later changed to member rank—were applied a year later by Sinclair and Granger (1911, p. 104–105). Generalized descriptions were given by these early workers, but specific type sections were not selected. The type area of the Lysite is on Lysite and Cottonwood Creeks, north of the town of Lost Cabin (primarily in the west half of T. 39 N., R. 90 W.); the type area of the Lost Cabin Member is east of Lost Cabin along Alkali Creek and on the drainage divide between Alkali and Poison Creeks (northeastern part of T. 38 N., R. 89 W.). Additional stratigraphic and paleontologic data have been supplied by Tourtelot (1946; 1948, p. 114–119; 1953) and Van Houten (1945, p. 428–430). Part of their exposures near the type areas is mapped on figure 22.

The Lysite Member of the Wind River Formation is yellow to brown sandstone and conglomerate interbedded with red, gray, and greenish-gray sandy claystone and siltstone; a partial section is given in stratigraphic section 8 of this report. At some localities, particularly near the mountains, Lysite strata are predominantly conglomeratic. At the west end of Cedar Ridge (loc. 66, pl. 1; fig. 22), for example, the basal 560 feet consists almost entirely of very coarse conglomerate, with some boulders as much as 20 feet long (Tourtelot, 1946). Nearly all the resistant rock types of the Paleozoic sequence that crop out in the nearby Owl Creek and Bighorn Mountains are represented, but one of the most distinguishing features is the almost complete absence of Precambrian rock types.

The maximum thickness of the Lysite Member in outcrops on the south side of Cedar Ridge (cross section *C–C′*, fig. 24) appears to be about 2,000 feet. In the Stuarco Oil Co. Govt. 1 (loc. 58, pl. 1) nearly 3,000 feet of strata were assigned to the member on the basis of sample studies.

The Lost Cabin Member of the Wind River Formation consists of gray, yellow, and brown sandstone with locally prominent beds of conglomerate alternating with violet, red, purple, gray, and green sandy claystone and clayey sandstone (Tourtelot, 1946; see stratigraphic sections 9 and 10, this report). The conglomerate beds, most abundant closest to the mountains, are composed chiefly of Precambrian igneous and metamorphic rocks with some fragments of Cambrian sandstone; largest boulders are about 6 feet across. Maximum thickness of the member may be as much as 2,000 feet.

On of the chief differences between the two members of the Wind River Formation in their type areas is the composition of the conglomerates. The Lost Cabin Member contains abundant Precambrian rock fragments, whereas the Lysite Member contains few, if any. This distinction is useful in local geologic mapping in the northeastern part of the basin (Tourtelot, 1946, 1953), and the same criterion has been used by the writer in distinguishing the Lysite and Lost Cabin Members in wells drilled a few miles downdip from the outcrops. Although correlations are very uncertain in these subsurface sections, a distinction can be made, on the basis of sample studies, between highly arkosic strata above (considered to be indicative of the Lost Cabin Member) and strata which contain an abundance of limestone, dolomite, and chert fragments below (considered to be indicative of the Lysite Member). In the Pure Oil Co. Badwater 2–A (pl. 3), for example, the lithologic change takes place at a depth of about 1,000 feet; if the correlations shown are correct, then an unconformity between the Lysite and Lost Cabin Members is indicated, at least across the crest of the large Lost Cabin anticline (cross section *C–C′*, fig. 24). Tourtelot (1946), on the other hand, did not recognize an unconformity in surface exposures and described the contact as being transitional through a zone about 100 feet thick.

Large and varied vertebrate faunas have been collected from the Lysite and Lost Cabin Members in the northeastern part of the Wind River Basin (Van Houten, 1945, p. 428–430; Tourtelot, 1948, p. 114–119). The most reliable criterion for separating the two faunas is the presence or absence of *Lambdotherium*, although each member also contains other relatively diagnostic species of fossil mammals. *Lambdotherium* is restricted to the Lost Cabin Member, and its presence has provided a valuable means for distinguishing strata of latest early Eocene age throughout much of the Wind River Basin, as well as adjacent regions. Paleontologic definition of the Lysite Member, on the other hand, is not so precise. The absence of *Lambdotherium* is not in itself indicative, unless the rocks in question have enough other faunal elements to warrant correlation with the Lysite. This is true for the type area of the Lysite Member but not for most other areas in the Wind River Basin.

EASTERN AND SOUTHEASTERN WIND RIVER BASIN

In the eastern and southeastern parts of the basin, the Wind River Formation consists of basal varicolored strata overlain, in places unconformably, by greenish-gray and tan sandstone. The sandstone unit has been traced into the type area of the Lost Cabin Member, and the varicolored unit is considered to be the Lysite Member. The upper unit contains *Lambdotherium*, but paleontologic evidence that the lower unit is of Lysite age is inconclusive. The Lysite and Lost Cabin Members, as here designated in the southeastern part of the Wind River Basin, correlate wholly or partly with the upper greenish-gray and tan sequence and the lower variegated sequence, respectively, of the lower fine-grained facies of the Wind River Formation of Rich (1962, p. 488–493).

Strata assigned to the Lysite Member are red, purple, gray, greenish-gray, and white siltstone and claystone interbedded with white, gray, and buff lenticular sandstone, in part arkosic. Thicknesses range from a maximum of about 1,000 feet in surface sections to 3,000 feet or more in the subsurface (cross sections *D–D′* and *E–E′*, fig. 24). The unit is well exposed for 11 miles in a series of bluffs including, and extending northwest from, the spectacular badlands at Hells Half Acre to Arminto (figs. 23, 28). Good exposures are also present in places along the east flank of the Rattlesnake Hills (Rich, 1962, p. 490–491).

The basal beds of the Lysite Member are conglomeratic in most places and generally consist of rock fragments from both Paleozoic and Mesozoic formations. Along the east edge of the badlands at Hells Half Acre, the lower few feet is highly ferruginous arkosic sandstone with abundant coarse angular grains and small pebbles of quartz, feldspar, and chert. In the vicinity of the Continental Oil Co. Hells Half Acre 1 (loc. 79, pl. 1) the most conspicuous rock in the basal conglomerate is black to dark-brown petrified wood in rounded fragments as much as 3 feet long. Boulders and cobbles of Paleozoic and Mesozoic rocks are also present at that locality. Farther south, near West Poison Spider oil field (near loc. 20, pl. 1), the conglomerate contains boulders of virtually unweathered Precambrian granite. In general, conglomerate beds are not so prominent in the basal part of the member along the east flank of the Rattlesnake Hills.

In all surface exposures around the southeastern part of the Wind River Basin, the Lysite Member overlies older strata with conspicuous angular discordance. One of the best exposures of the unconformity is at the east rim of Hells Half Acre, where the Lysite strata dip 20°–30° westward and the underlying Fort Union and Lance strata dip from 45° westward to nearly vertical (fig. 18). The relatively steep dips in the Lysite indicate that it was also involved in the folding of the Casper Arch. In a few places, as at locality 18 (pl. 1) and in the vicinity of West Poison Spider oil field, Lysite strata are cut by normal faults.

The only fossil vertebrates collected from strata assigned to the Lysite Member in this part of the basin are from 2 to 3 miles northwest of locality 18 (pl. 1). This assemblage (colln. T, table 2), however, indicates only that the age is early Eocene, although the absence of *Lambdotherium* might possibly indicate a temporal equivalence to the Lysite Member as it is defined in the type area farther northwest.

The Lost Cabin Member of the Wind River Formation in the southeastern Wind River Basin is characterized by gray, greenish-gray, yellowish-gray, and tan arkosic sandstone and siltstone. The sandstone is commonly conglomeratic and contains abundant boulders and cobbles of granite, quartz, and chert. Maximum thickness of the member in this part of the basin is probably about 1,000 feet, but only a few tens of feet is exposed at any one place because of recent erosion. Fossil vertebrates collected by Rich (1962, p. 493) include—

Lambdotherium popoagicum Cope
Hyracotherium sp.
Hyopsodus wortmani Osborn
Hyopsodus mentalis Cope
Cynodontomys sp.
cf. *Notharctus nunienus* (Cope)
cf. *Palaeictops* sp.
cf. *Didelphodus* sp. (colln. U, table 2 and loc. 73, pl. 1)

In some places in the eastern and southeastern parts of the basin there is a conspicuous angular unconformity between the Lysite and Lost Cabin Members. Such a relation is well shown along the west rim of Hells Half Acre where 20–30 feet of the dull-colored gently dipping beds of Lost Cabin forms the upper part of the rim bevel across the more steeply dipping red-banded strata of the Lysite Member (fig. 28). Similar relations are also present at the north end of the Rattlesnake Hills (loc. 74, pl. 1), but farther southeast (loc. 78, pl. 1) the two members are apparently conformable (Rich, 1962, p. 490–491).

SOUTHERN WIND RIVER BASIN

In the outcrop belt extending westward from the Rattlesnake Hills to Alkali Butte (locs. 74 and 7, pl. 1), the Wind River Formation generally consists of a thin series of coarse-grained sandstone and conglomerate at the base overlain by varicolored siltstone and claystone interbedded with white, gray, and tan lenticular sandstone. Some of the best exposures are in the vicinity of Castle Gardens (loc. 62, pl. 1) and at Double Butte (near loc. 49, pl. 1). Maximum thickness in surface sections is about 1,000 feet. The sandstone and conglomerate series is arkosic nearly everywhere, and in

FIGURE 28.—Prominent badlands in variegated strata of Lysite Member of Wind River Formation at Hells Half Acre, sec. 36, T. 36 N., R. 86 W. Arkosic sandstone of Lost Cabin Member (Twlc) of Wind River Formation forms dark band at top of rim and unconformably overlies Lysite Member.

some places the conglomerate contains boulders and cobbles of granite as much as 1 foot long. Other common constituents are chert, quartzite, and siliceous shale. In many outcrops the basal beds are saturated with oil.

The Wind River strata in this region are virtually undeformed, with basinward (north) dips not exceeding 5° in most places, and overlap all older rocks with conspicuous angular and erosional unconformity. Slight angular and erosional unconformities may also be present within the formation itself, for in some places the basal beds seem to be overlapped by the younger beds. Because of generally poor exposures, however, the extent of these unconformities was not determined.

The stratigraphic and structural relations suggest that the bulk of the Wind River Formation along the south margin belongs to the Lost Cabin Member. Some of the basal conglomerate, however, particularly where overlain unconformably by younger beds, may be equivalent to the Lysite Member. *Heptodon* sp. and *Hyracotherium* sp. were collected (loc. 57, pl. 1) from about 3,000 feet above the base of the formation, but these species indicate only that the strata are early Eocene and younger than Gray Bull of Wood and others (1941).

GAS HILLS AREA

The Wind River Formation covers an extensive area in Tps. 32 and 33 N., and Rs. 88 to 93 W., which is south of the main basin area along the north side of the Beaver Divide escarpment (Van Houten and Weitz, 1956). The Gas Hills uranium district, where uranium ores are mined from sandstone within the Wind River Formation, occupies about 40 square miles in the eastern part of this outcrop area (Zeller and others, 1956; Zeller, 1957). The formation was deposited on a surface of considerable relief cut in the Paleozoic and Mesozoic rocks; no uppermost Cretaceous or Paleocene rocks are present.

The Wind River Formation in this region was divided into two units by Zeller and others (1956). The lower unit ranges in thickness from 0 to 130 feet and consists of grayish-green to light-gray siltstone and claystone and some gray very fine grained sandstone. A minor amount of red banding is present locally. The unit contains a few thin lenticular carbonaceous siltstone beds; toward the base, the siltstone and sandstone are commonly stained with oil. The upper part of the formation, 300–800 feet thick, is predominantly yellowish-gray, dusky-yellow, in part reddish-brown, medium-grained to very coarse grained and granular cross-bedded arkosic sandstone with some intercalated mudstone, carbonaceous shale, and siltstone. Conglomerate beds 10–15 feet thick are common in places, and contain boulders and cobbles of granite as much as 2 feet long.

Lithologic descriptions of the Wind River Formation in the Gas Hills area are given in stratigraphic sections 11 and 12 of this report.

The lower part of the Wind River Formation in the Gas Hills area has yielded no fossils. It is believed to be largely representative of the Lost Cabin Member, but the basal part may be equivalent to the Lysite. The uppermost part of the formation, as mapped by Van Houten and Weitz (1956) and by Zeller and others (1956), contains poorly preserved leaves. The following forms were collected in sec. 27, T. 33 N., R. 89 W. (loc. 72, pl. 1):

Zizyphus cinnamomoides
Zelkova nervosa
Quercus castaneopsis
Sparganium antiquum
Leguminosites sp.
Aralia sp.
Ulmus sp.

Although this flora has some middle Eocene aspects, Van Houten (1955, p. 6) suggested that it may be transitional between early and middle Eocene floras, and that all the Wind River strata in this region could therefore be of early Eocene age. On the other hand, from studies in the Sweetwater Plateau region to the south and west, Love (oral commun., 1962) tentatively considered the plant-bearing beds to form part of a transitional sequence which is better assigned to the next overlying unit of middle and upper Eocene rocks rather than to the Wind River Formation. Although correlations are as yet uncertain, the questionable strata at locality 72 (pl. 1) may be equivalent to the so-called transitional beds mapped by Van Houten (1954) as part of the middle and upper Eocene sequence farther west along the Beaver Divide escarpment (see discussion below).

LOWER EOCENE ROCKS IN CENTRAL PART OF WIND RIVER BASIN

The Lost Cabin Member of the Wind River Formation forms the surface rock throughout the central Wind River Basin. In most wells, however, as has been discussed, there are no criteria either on the basis of sample or electric-log studies for separating the Wind River Formation into its individual members, or from the Indian Meadows Formation. The lower Eocene rocks are therefore treated as a unit.

The thickness of the lower Eocene sequence increases appreciably toward the major basin trough area (fig. 29). Maximum thickness may exceed 9,000 feet in the north-central and southeastern parts of the basin, as is indicated by sample studies of the Phillips Petroleum Co. Boysen 1 and the British-American Oil Producing Co. J. B. Eccles 1 (locs. 14 and 19, pls. 1, 2). As might be expected, the isopach map of the lower Eocene rocks (fig. 29) reflects the structural configuration of the basin floor in many places.

The lower Eocene rocks also become finer grained toward the center of the basin, and the interformational and intraformational unconformities disappear. Most sections are characterized by varicolored red, gray, and gray-green claystone and siltstone interbedded with white to gray fine- to medium-grained sandstone. In some places the upper several hundred feet is predominantly buff to gray sandstone—similar to the surface rock over much of the central basin area—that grades downward into the varicolored strata. In the southern part, such as at the sites of the Superior Oil Co. Fuller Reservoir 1–26 and the Continental Oil Co. Squaw Buttes 28–1 (locs. 23 and 25, pls. 1, 2), beds of medium- to coarse-grained arkosic sandstone extend many miles northward into the central part of the basin.

At Continental Oil Co. Moneta Hills 11–1 (loc. 27, pls. 1–3), according to the author's interpretation, the lower part of the lower Eocene sequence is predominantly gray to black carbonaceous shale and claystone, and contains abundant ostracodes in some beds (stratigraphic section 13, this report). These rocks grade downward into strata of the Fort Union Formation. These relations suggest that the lower Eocene strata representing Indian Meadows and perhaps part of Lysite time in this area were deposited in, or adjacent to, a body of water, possibly a relict of the Paleocene Waltman Lake (fig. 33).

OTHER STRATA ASSIGNED TO WIND RIVER FORMATION

In the southeast corner of the Wind River Basin, Rich (1962, p. 493–496) described arkosic sandstone and conglomerate which overlies all older Wind River strata with erosional unconformity and which, in turn, is overlain with angular unconformity by the Oligocene White River Formation. The chief difference between this conglomerate unit and the conglomerates in underlying lower Eocene strata (see discussion under "Eastern and southeastern Wind River Basin") is the greater abundance of arkosic material—mostly boulders and cobbles of light-gray to white granite and coarse angular fragments of feldspar—and the paucity of Paleozoic and Mesozoic rock types (Rich, 1962, p. 495).

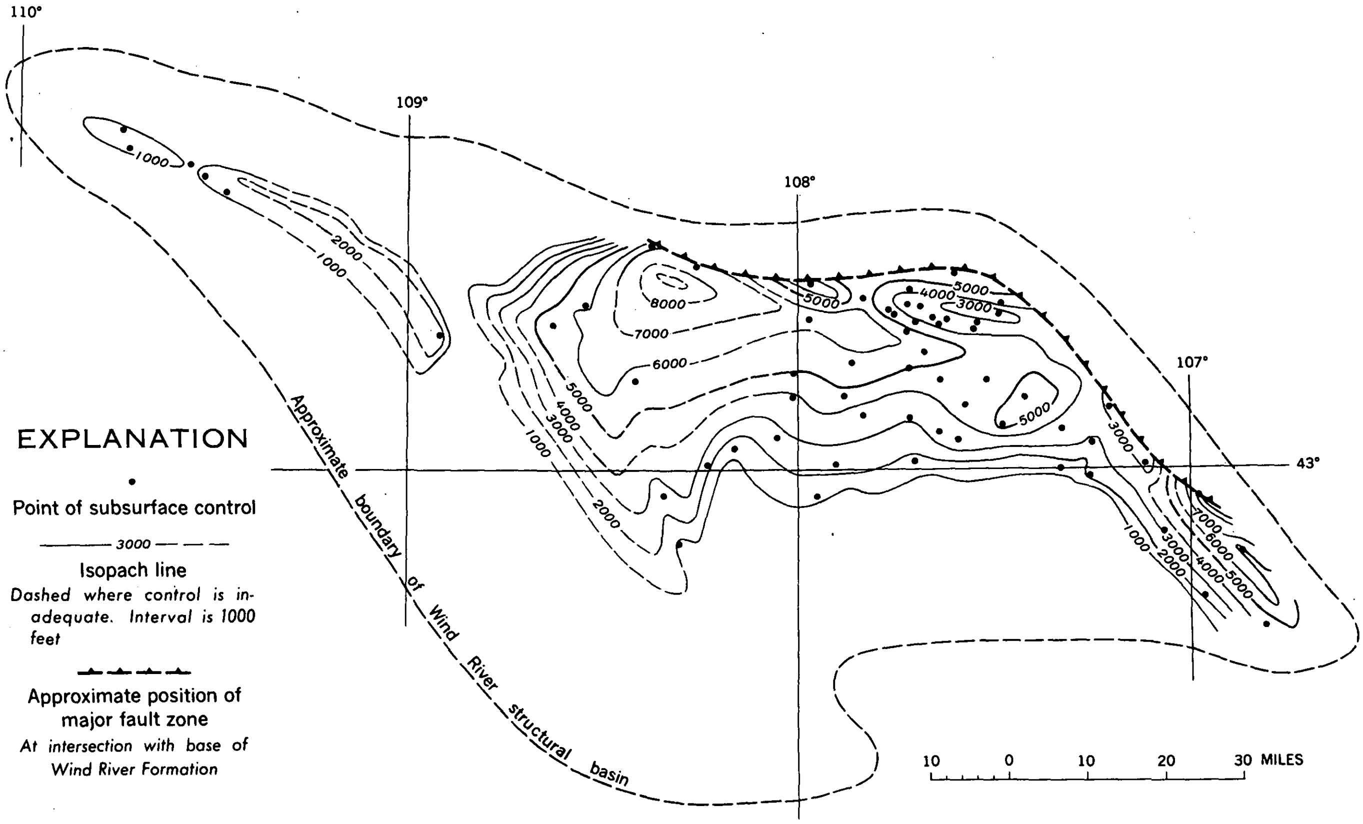


FIGURE 29.—Generalized isopach map of lower Eocene rocks.

Although these rocks have yielded no fossils, they are overlain by Oligocene rocks and underlain by Eocene rocks, so that they could range from lower Eocene to lower Oligocene. Rich (1962, p. 496) concluded that the conglomerate beds are best assigned to the lower Eocene. The most compelling evidence is that middle and upper Eocene and lower Oligocene rocks in nearby areas contain abundant volcanic debris (Van Houten, 1955), whereas the conglomerate sequence contains none. These conglomerates may therefore represent a part of late early Eocene time younger than the Lost Cabin Member of the Wind River Formation in areas farther to the north.

The original distribution of the conglomerates is not known. They may have been restricted to the present outcrop area in the southeastern corner of the basin (Rich, 1962), or they may have been spread farther out into the basin and subsequently eroded.

In a narrow strip along the north side of the Beaver Divide escarpment, Van Houten (1954) described a zone of variable thickness (as much as 185 ft), without red layers, which is transitional between the typical varicolored strata of the Wind River Formation below and the predominantly greenish-yellow and yellowish-gray sandstone and siltstone of middle and late Eocene age above. For convenience in geologic mapping, the top of the Wind River Formation was arbitrarily placed at the base of these "transition beds" (Van Houten, 1954), but it is yet to be determined that this surface coincides with the early Eocene and middle Eocene time boundary (see discussion of Wind River Formation in Gas Hills area, p. A51).

Coarse arkosic sandstone and conglomerate containing pebbles and cobbles of volcanic rocks are exposed in a prominent ridge that projects northward from the main part of Beaver Divide along the east edge of the Gas Hills area (near loc. 71, pl. 1). They seem to overlie all older rocks, including known Wind River strata, with angular unconformity. The age of these rocks is not known, but Van Houten and Weitz (1956) have considered them to be intermediate between that of the Wind River Formation below and the middle and upper Eocene beds above. The ridge may represent an eastward extension of the "transition beds" just described.

CONTACT WITH YOUNGER ROCKS

The Wind River Formation is overlain by younger Tertiary rocks in a few places around the margins of the Wind River Basin (pl. 1). Along the south margin, as discussed in the preceding paragraphs, the formation is conformably overlain by a transition zone of uncertain age which, in turn, grades upward into strata of known middle Eocene age. In the southeastern part of the basin the conglomerate sequence that is tentatively assigned to the upper part of the Wind River Formation is overlain with conspicuous angular discordance by the White River Formation of Oligocene age (Rich, 1962, p. 496); no intervening middle and upper Eocene rocks have been recognized with certainty, although remnants may be present locally. At the northeast edge of the basin, upper (and possibly middle) Eocene rocks are faulted down against the Wind River Formation (fig. 22; Tourtelot, 1953; Tourtelot and Thompson, 1948); therefore depositional contact relations cannot be observed. In the northwestern part of the basin the Wind River Formation is overlain directly by middle and upper Eocene strata throughout a considerable length of outcrop (Keefer, 1957). The contact there is marked by an angular and erosional unconformity, although in some places the degree of discordance is slight.

The Wind River Formation and younger rocks differ chiefly in the relative amount and composition of incorporated volcanic debris. Volcanic material in the Wind River Formation is generally limited to tuffaceous and bentonitic strata in the upper part and scattered volcanic pebbles in a few places. In contrast, middle and upper Eocene rocks are commonly highly tuffaceous throughout, and contain abundant volcanic boulders and cobbles which reflect the widespread eruptions in the volcanic fields of the Absaroka Range and Rattlesnake Hills at the close of early Eocene time (see Sinclair and Granger, 1911; Van Houten, 1955; Hay, 1956; Tourtelot, 1957).

CONDITIONS OF DEPOSITION

Conditions similar to those that existed during the time of Indian Meadows deposition also prevailed during the deposition of the Wind River Formation. Coarse bouldery debris stripped from the flanks of the uplifted mountain ranges was deposited in fans and stream channels, along the mountain slopes and foothills; in some places the coarse detritus was spread many miles into the basin proper. By the end of early Eocene time the granitic cores of all the bordering ranges had been deeply eroded, except for the Casper Arch (fig. 3) that had been warped up at the beginning of Wind River time. Extensive flood plains and broad stream channels characterized the interior of the basin. The major trough area continued to sink throughout all early Eocene time, and lakes and swamps developed in the larger lowland regions.

The origin of the characteristic red banding in lower Eocene rocks has been the subject of much debate. In some localities it can be satisfactorily demonstrated that red layers are composed of debris eroded from the thick

Triassic Chugwater Formation and other red formations exposed along the basin margins and redeposited in adjacent lowlands. However, this process does not account for all the red strata in the lower Eocene sequence. Van Houten (1948) concluded that the source of much of the red-banded Tertiary deposits in intermontane basins was from mantles of red soil developed under a warm humid climate in the broad upland regions surrounding the basins. Streams carried the red sediment onto the basin floors and redeposited it in layers. He (Van Houten, 1948, p. 2120–2121) also presented evidence that the intercalated green and greenish-gray siltstone resulted from the reduction of the original iron-oxide pigment by decaying plant remains during periods of heavy vegetation.

AGE AND CORRELATION

The Lysite and Lost Cabin Members of the Wind River Formation are early Eocene as indicated by numerous collections of fossil vertebrates (see table 2). Fresh-water mollusks of Eocene age are also present (table 6). In a few localities fossil plants similar to those in the Green River Formation to the southwest, and generally considered to be indicative of middle Eocene age, have been collected from the Wind River Formation (for example, colln. 1B and J, table 2). Van Houten (1955, p. 6) suggested that the transition from typical early Eocene floras to middle Eocene floras may have occurred in the Wind River Basin before the end of early Eocene time. Most of these floral comparisons, however, were made at a time when the Green River Formation was regarded as wholly middle Eocene. Several workers (Bradley, 1959; McGrew and Roehler, 1960; Pipiringos, 1961) have since shown that the lower part of that formation is early Eocene, or transitional between early and middle Eocene.

Strata equivalent to the Wind River Formation are widespread in nearly all the intermontane basins of Wyoming. Correlative units are shown on figure 8.

YOUNGER TERTIARY ROCKS

No Tertiary rocks younger than the Wind River Formation crop out in the central part of the Wind River Basin, except possibly the uppermost beds on Crowheart Butte (loc. 35, pl. 1), which may be middle Eocene. Upper and possibly middle Eocene rocks crop out extensively along the northeast margin of the basin, however, and these, as well as thick sequences of Oligocene rocks, are also widespread in the Absaroka Range at the northwest margin and in the Beaver Divide area along the south margin. Miocene and Pliocene strata underlie extensive areas in the Sweetwater Plateau and Granite Mountains regions farther to the south.

TABLE 6.—*Molluscan faunas in the Wind River Formation*

[Identifications by D. W. Taylor, U.S. Geological Survey]

U.S. Geological Survey Cenozoic locality No.	Location			Collector	Genera and species															
					Fresh-water clams		Fresh-water snails								Land snails					
	Section	Township	Range		*Pisidium*	Unionidae indet.	*Valvata*	*Bellamya* n. sp.	*Elimia* n. sp.	Ancylidae?	*Physa* cf. *P. bridgerensis* Meek	*Physa* cf. *P. pleromatis* White	*Planorbina pseudoammonius* (Schlotheim)?	*Drepanotrema*?	Succineidae	"*Macrocyclis*" *spatiosa* Meek and Hayden	*Oreoconus* n. sp.	*Discus*	Polygyridae	*Glyptérpes veternus* (Meek and Hayden)
20301	33	40 N.	94 W.	H. A. Tourtelot	----	----	----	×	×	----	----	----	----	----	----	×	----	----	----	----
20303	7	4 N.	4 E.	R. M. Thompson	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----
20933	29?	39 N.	90 W.	H. A. Tourtelot	----	×	----	----	----	----	----	----	----	----	----	×	----	----	----	----
20934	8	39 N.	89 W.	do	----	×	----	×	×	----	----	----	----	----	----	×	----	----	----	----
20935	16	39 N.	89 W.	do	----	×	----	×	×	----	----	----	----	----	----	----	----	----	----	----
20937	25	39 N.	90 W.	do	----	×	----	×	----	----	----	----	----	----	----	----	----	----	----	----
20938	6	3 N.	1 W.	J. F. Murphy	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	×
20940	28	38 N.	87 W.	H. A. Tourtelot	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
20941	19	39 N.	89 W.	do	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----
22218	11	38 N.	89 W.	do	----	----	----	----	----	----	----	----	----	----	----	×	----	----	----	----
22219	11	38 N.	89 W.	do	----	----	----	----	----	----	----	----	----	----	----	----	----	----	×	?
22220	11	39 N.	89 W.	do	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	?
22221	5	4 N.	6 E.	T. E. White	----	----	----	----	----	----	----	----	----	----	----	----	×	----	----	----
22222	11	4 N.	5 E.	do	----	----	----	----	----	----	----	----	----	----	----	----	----	×	×	----
22223	29	5 N.	6 E.	do	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	----
22224	30	38 N.	94 W.	do	----	----	----	----	----	----	----	----	----	----	----	×	----	----	----	----
22684	22	43 N.	108 W.	R. M. Thompson	×	×	×	----	----	×	----	×	×	×	×	----	----	----	----	----
22685	22	43 N.	108 W.	O. M. Delo	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----
22686	34	43 N.	108 W.	do	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	----

SUMMARY OF GEOLOGIC HISTORY AND PALEOGEOGRAPHY

The sedimentary and structural history and the geography of the Wind River Basin during latest Cretaceous, Paleocene, and early Eocene times are portrayed in five diagrams (figs. 30–34). Although information is still inadequate for parts of the basin, the stratigraphic and structural data presented in the foregoing pages permit reconstruction of the major physiographic and tectonic features during successive stages of basin evolution. The diagrams are adapted in part from a series of maps prepared by J. F. Murphy and J. D. Love (unpub. recs., U.S. Geol. Survey; see also Murphy and Love, 1958; Love, 1954a).

The landscape in central Wyoming at the time of maximum westward advance of the Lewis Sea is reconstructed on figure 30. The land must have been characterized by extensive nearly featureless plains over which a relatively uniform sheet of highly carbonaceous sediment, the Meeteetse Formation, was deposited. The surface probably sloped gently eastward and broad deltas extended many miles into the sea. Except for local minor warping, no tectonic activity is recorded in the strata of the Lewis and Meeteetse Formations. Uplifts apparently existed in eastern Idaho, a few hundred miles to the west, and these furnished fine-grained clastic debris to the eastward-flowing rivers. Volcanic ash, probably derived from centers west or northwest of the Yellowstone region, was also deposited across central Wyoming.

At the beginning of deposition of the Lance Formation, broad upwarps began to form in the present areas of the Granite Mountains along the south edge of the basin and along the Washakie Range at the northwest edge. By the end of Lance time these upwarps had become relatively well-defined and in some places had been eroded into the Lower Cretaceous rocks (fig. 31). There is no definite evidence, however, for uplift of the Wind River Range at this time. The basin trough sank markedly during deposition of the Lance Formation, and lakes may have formed. Major exterior drainage was eastward, although some areas in the southwestern part may have been drained by southward- and southwestward-flowing streams.

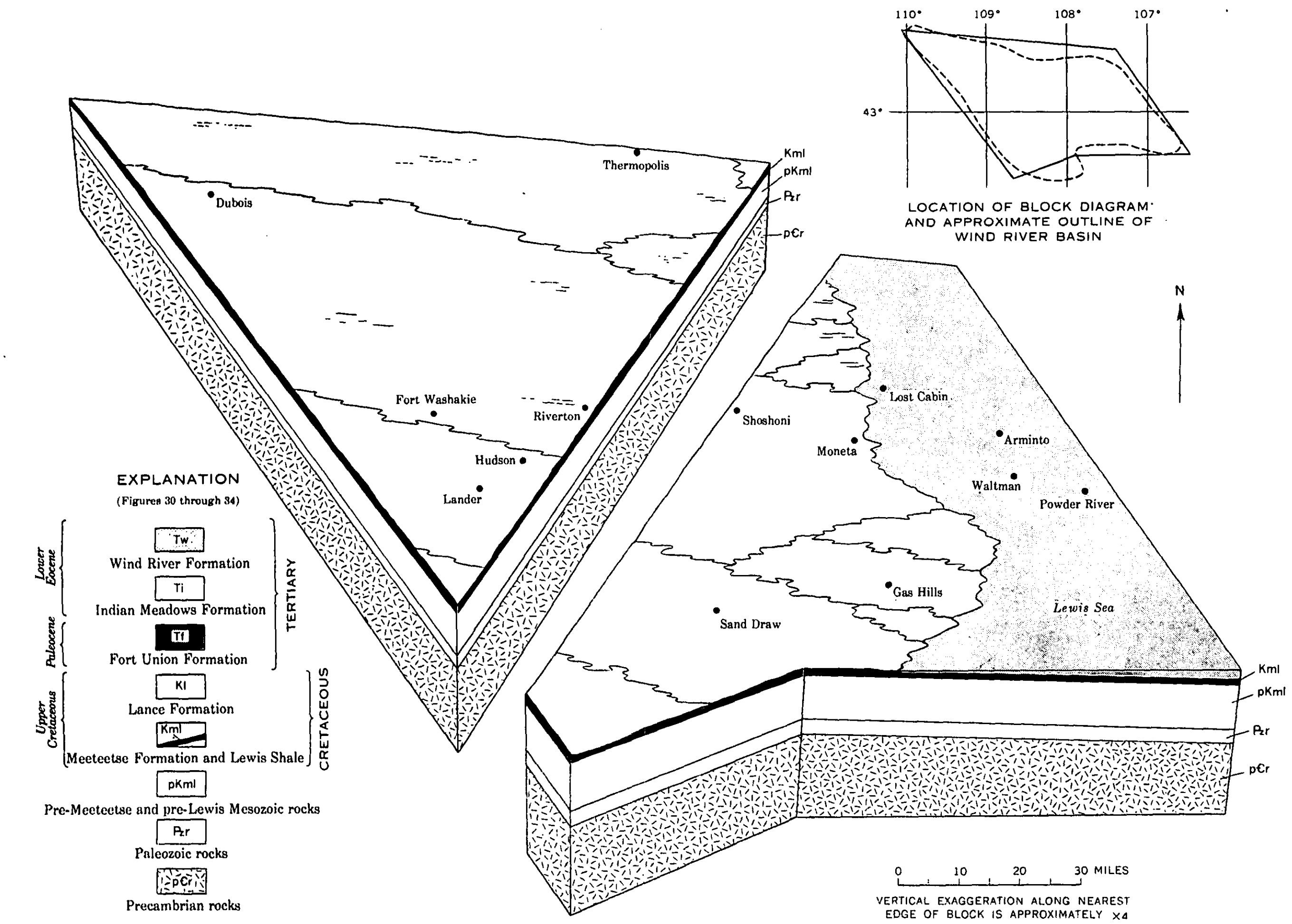


FIGURE 30.—Wind River Basin at maximum westward advance of Lewis Sea.

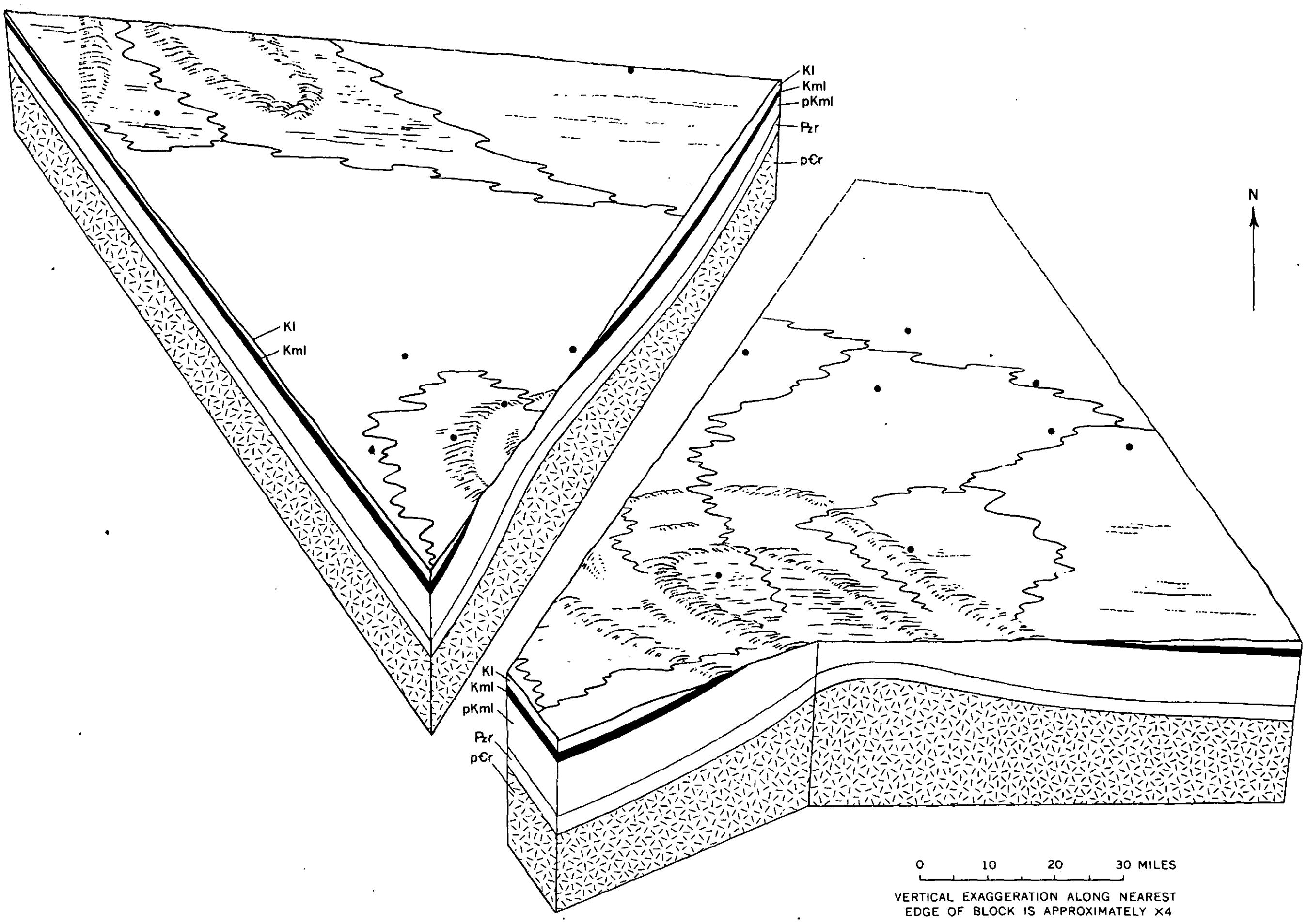


FIGURE 31.—Wind River Basin near end of Lance deposition. See figure 30 for explanation.

The Wind River Range began to rise along the west side of the basin probably at the beginning of Paleocene time. Broad low northwest-trending folds also formed at this time at the present site of the Owl Creek Mountains along the north side. The Granite Mountains and the Washakie Range continued to rise, and folding took place in some of the marginal areas of the basin proper. By middle to late Paleocene time the Precambrian crystalline cores of the Wind River Range and Granite Mountains had been breached locally, but in the Washakie Range and Owl Creek Mountains dissection had probably not yet reached the Paleozoic rocks in most places. Although locally derived material accumulated along the mountain slopes, deposition during the Paleocene Epoch was confined largely to the central downwarped part of the basin. The landscape during the maximum expansion of Waltman Lake is reconstructed on figure 32. This water body extended eastward beyond the present limits of the basin for an unknown distance.

In earliest Eocene time, during deposition of the Indian Meadows Formation, folding and uplift of the mountain masses became more prominent, marginal folds were greatly accentuated, and large-scale reverse faulting took place in the northwestern part of the basin. Very coarse clastic debris accumulated in extensive alluvial fans in front of the rising highlands to the north and northeast. In the southeastern part of the basin a broad fan was spread eastward and northeastward into the present site of the Powder River Basin. This huge deltalike deposit, which is now the Indian Meadows Formation, may have formed a drainage barrier between the two basins and blocked the eastern side of Waltman Lake. The lithology of the basal Eocene rocks in the central part of the basin indicates that this lake may have persisted in at least restricted form during Indian Meadows time, and perhaps part of Lysite time as well. Thick deposits accumulated in the central part of the basin, which continued to subside throughout the period, and also in a narrow synclinal area in the northwestern part of the basin (fig. 33).

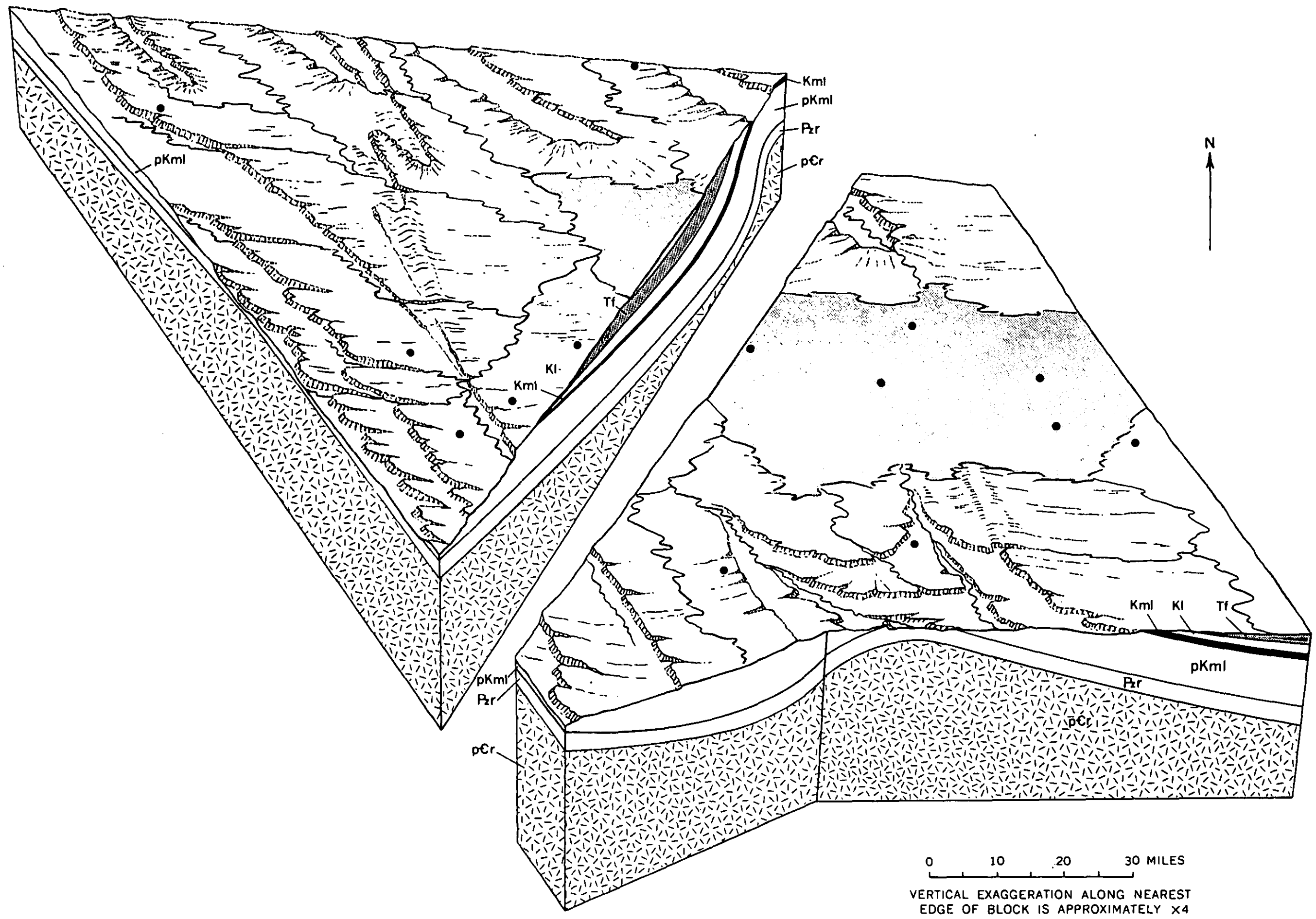


FIGURE 32.—Wind River Basin during deposition of Waltman Shale Member of Fort Union Formation. See figure 30 for explanation.

After the deposition of the Indian Meadows Formation, the central and eastern parts of the Owl Creek Mountains and the Casper Arch were uplifted along extensive reverse faults. Large areas of Precambrian rocks in both the Wind River Range and Granite Mountains, as well as small areas in the Washakie Range, Owl Creek, and Bighorn Mountains, were exposed to erosion, and the smaller folds along the basin margins were deeply dissected. All streams that formerly had flowed out of the basin probably were blocked, and for a brief time interior drainage prevailed. Lakes probably occupied the central part of the basin during earliest Wind River time. A reconstruction of this landscape is shown on figure 33. In many places the terrain was similar to that of today.

Extensive lowering of the highlands surrounding the Wind River Basin continued throughout Wind River time. The highland debris was spread basinward on all sides and was supplemented during the latter part of early Eocene time by volcanic debris from the Absaroka-Yellowstone region. By the end of early Eocene time the accumulated sediment lapped high onto the mountain flanks and probably buried the Casper Arch, as well as parts of the Washakie Range and Owl Creek Mountains (fig. 34). Exterior drainage toward the east had been reestablished. The major basin trough areas continued to sink, but by the end of early Eocene time, or shortly thereafter, the downwarping movements had nearly ceased.

Renewed folding and faulting of existing structural features, such as the Casper Arch, took place during and at the end of Wind River deposition. New folds and reverse faults were established in some areas, but with few exceptions these were relatively minor features which did not significantly modify the earlier structural trends.

Following early Eocene time the Wind River Basin was the site of virtually continuous aggradation until nearly the close of the Tertiary Period. This basin fill was predominantly volcanic in contrast to the nonvolcanic locally-derived clastic material of the older parts of the fill. Although the major mountain-building movements of the Laramide in this area were largely over by the close of early Eocene time, extensive

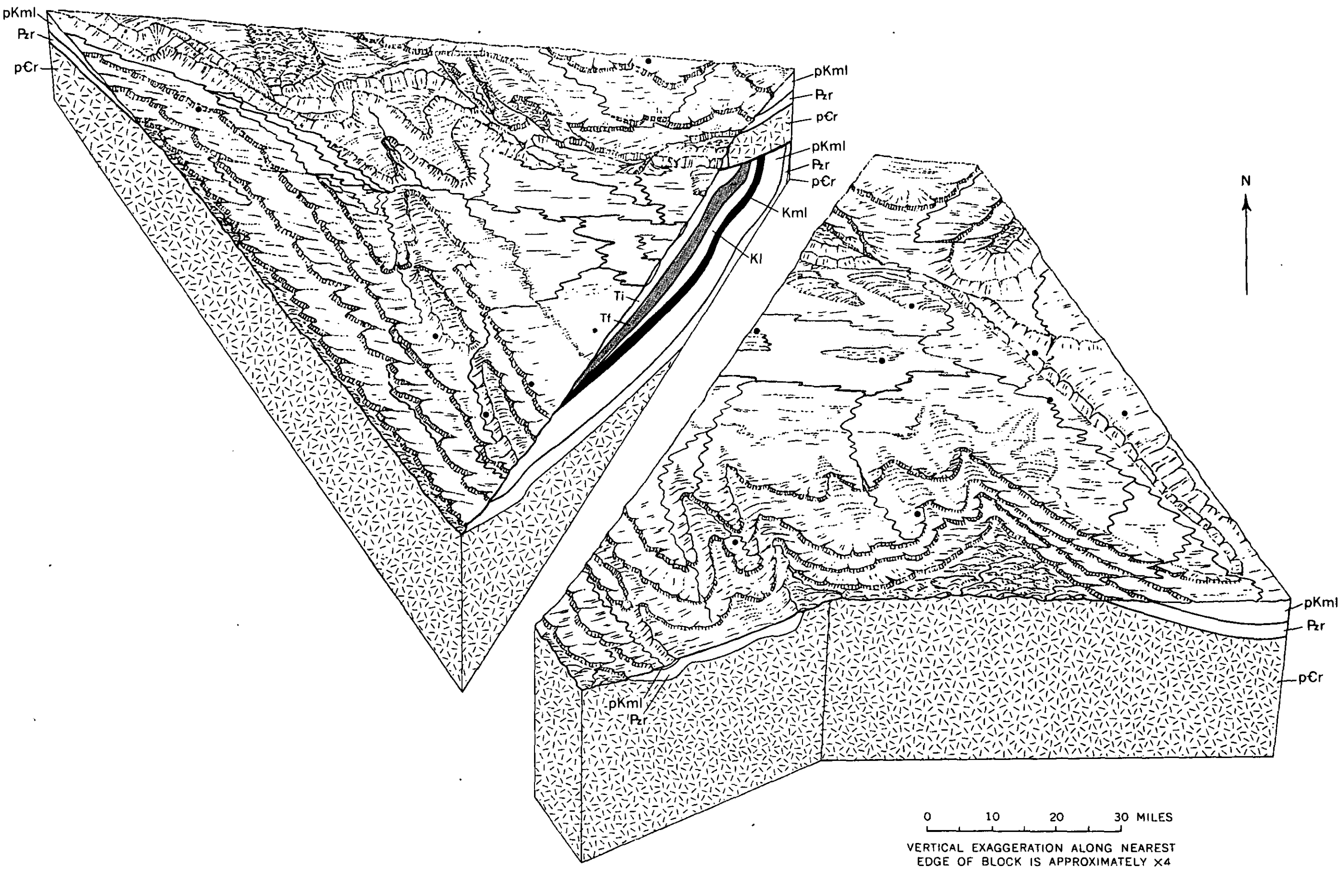


FIGURE 33.—Wind River Basin at beginning of Wind River deposition. See figure 30 for explanation.

deformation also occurred in some of the marginal areas of the basin later in the Tertiary Period.

SIGNIFICANCE OF DOWNFOLDING IN BASIN TECTONICS

The stratigraphic studies of uppermost Cretaceous, Paleocene, and lower Eocene rocks in the Wind River Basin show that downwarping played a dominant role in the structural evolution of the basin. Subsidence began in Late Cretaceous time, in the very earliest stage of the Laramide deformation in central Wyoming, and sinking was continuous until at least the close of early Eocene time. Along the north and east edges of the basin, where deformation was most intense, the actual movement that can be attributed to subsidence in many places is equal to, or exceeds, the amount of uplift of the adjacent Owl Creek Mountains and Casper Arch. Plate 4 and figure 36 illustrate some of the important relations.

The interpretations of absolute movements of adjacent crustal blocks shown on these geologic sections are based on the following premises:

1. Sea level has remained relatively constant from Late Cretaceous time to the present. Kay (1955, p. 667) states, "Most stratigraphic geologists judge that the changes in [sea] level have been of magnitude of only a few hundred feet from period to period * * *."
2. Deposition of the uppermost Cretaceous and Paleocene strata took place at or near sea level. According to Dorf (1959, p. 185–187), the flora of the Eocene rocks in this region suggests a subtropical climate; it is therefore inferred that the base level of deposition of these strata was not significantly higher (perhaps a maximum of 1,000–2,000 ft above sea level) than that which existed during Paleocene and Late Cretaceous times. The present altitude of the basin has resulted from epeirogenic uplift later in Tertiary time (Van Houten, 1961, p. 619–621; Love, 1960, p, 212).

Interpretations of various stages in the growth of the Wind River Basin are depicted on plate 4*A*–*E*. The Lewis Shale and Meeteetse Formation represent the youngest strata laid down during the preorogenic period. At this stage, as shown on plate 4*A*, the upper surface of these formations was approximately at sea level, and the upper surface of the Precambrian rocks was 12,500 feet below sea level (line *Z* on cross sections).

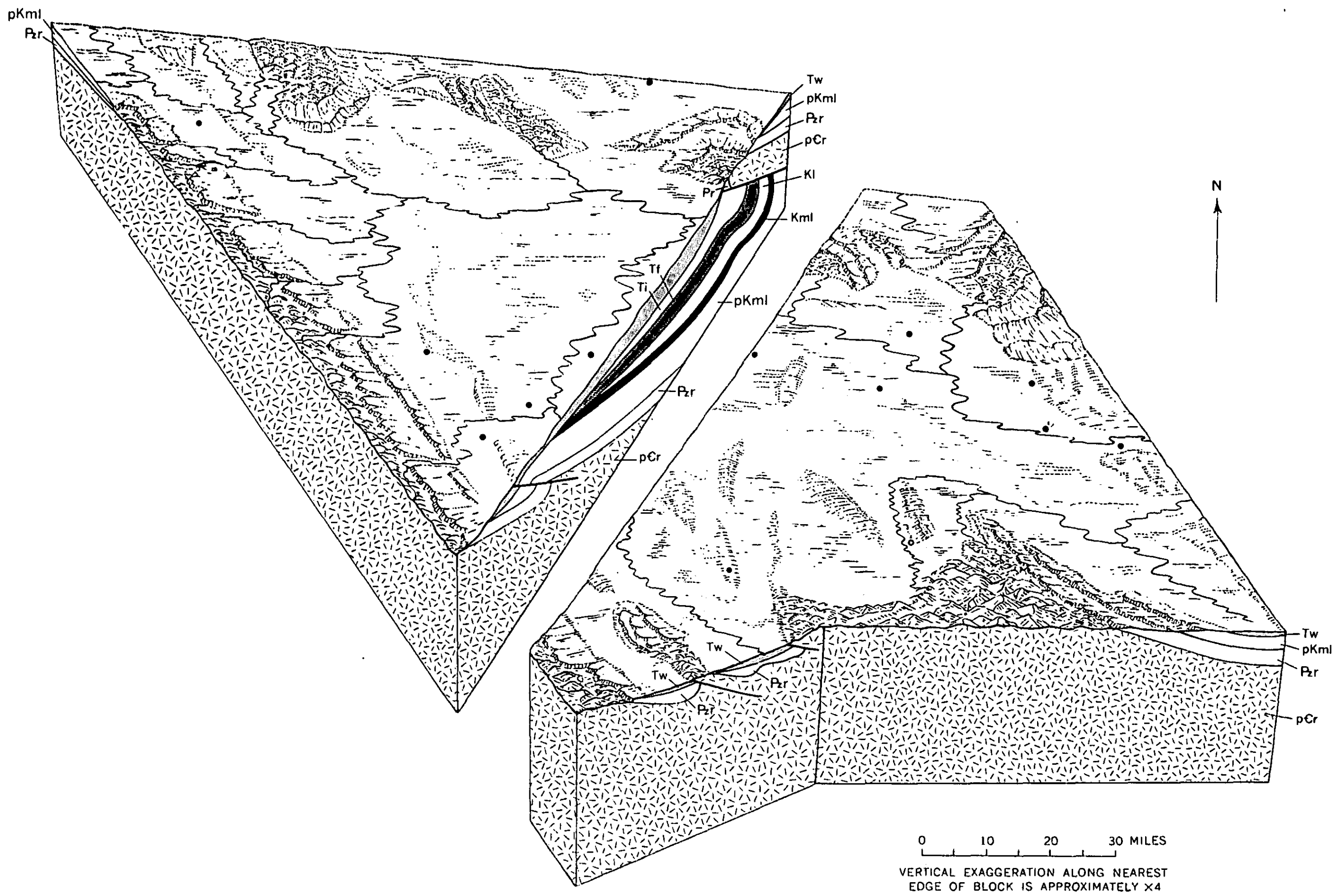


FIGURE 34.—Wind River Basin at end of Wind River deposition. See figure 30 for explanation.

Subsidence began in latest Cretaceous time, and by the end of Lance deposition about 6,000 feet of sediments had accumulated in the trough area. The surface of the Precambrian rocks was warped down a like amount beneath the trough, but the adjacent Owl Creek Mountains had probably not yet begun to rise (pl. 4*B*). Thus, downwarping was the dominant expression of the orogeny in its earliest stages along the north margin of the Wind River Basin.

Deformation of the Owl Creek Mountains began in Paleocene time, and culminated in major uplift of the range along reverse faults in early Eocene time (pl. 4*C–E*). Subsidence of the adjacent basin trough was continuous throughout this period, but the sinking had nearly ceased by the end of early Eocene time. During the orogeny, structural displacement totaled about 33,500 feet: 16,000 feet of actual subsidence and 17,500 feet of uplift (pl. 4*E*). The present structural setting (pl. 4*F*) indicates that epeirogenic uplift in late Tertiary time was about 4,000 feet, and that normal faulting lowered the Owl Creek Mountains block only a few hundred feet with respect to the basin in all post-Eocene time.

An east-west geologic section across the southeastern part of the Wind River Basin and adjacent parts of the Rattlesnake Hills and Casper Arch, as it may have been at the end of early Eocene time, is sketched in figure 36. The total offset between the basin and the Casper Arch was about 21,500 feet, of which 14,500 feet can be attributed to actual subsidence of the basin floor.

During Laramide time extensive downwarps also formed in many of the other intermontane basins of Wyoming (Love. 1960). Active subsidence of certain crustal blocks, such as the Wind River Basin, was thus an integral part of the regional mountain-building process in central Wyoming.

Two divergent views are widely held regarding crustal movement in this region (fig. 37). One interpretation, prompted by the obvious asymmetry of most basins and mountain ranges, as well as by the apparent shortening of the crust, is that deformation resulted from lateral compression, with extensive, nearly horizontal movements along low-angle reverse faults (fig. 37). The second popular interpretation is that movement between adjacent crustal blocks was largely vertical and that lateral displacement along reverse faults

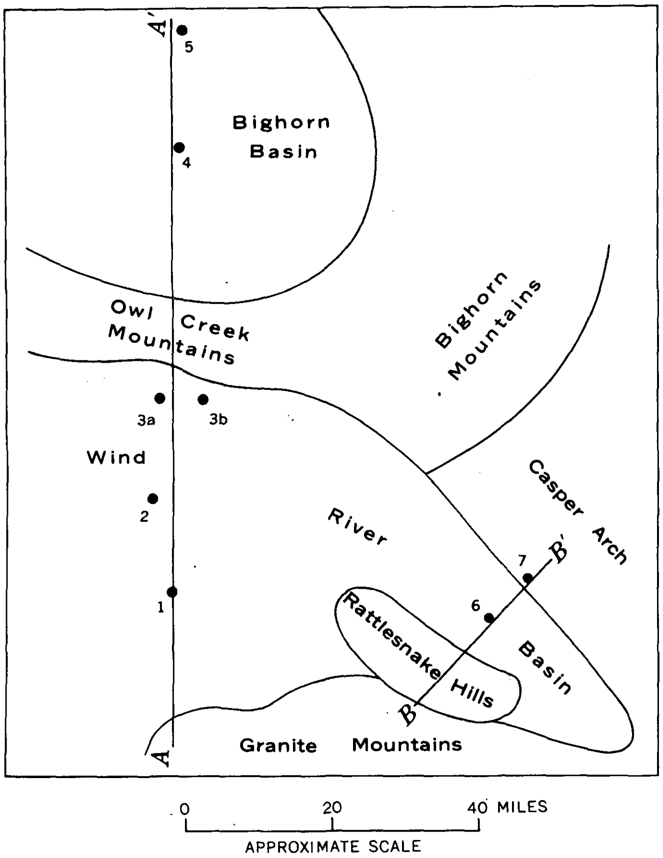


FIGURE 35.—Index map showing lines of section *A–A'*, plate 4, and section *B–B'*, figure 36.

SOURCES OF DATA

1. Seaboard Oil Co. Double Butte 1, sec. 2, T. 34 N., R. 93 W.
2. Humble Oil & Refining Co. Poison Creek 1, sec. 32, T. 37 N., R. 93 W. (projected into plane of section from well location 3.5 miles to west).
3. Shell Oil Co. Howard Ranch 23–15, sec. 15, T. 39 N., R. 93 W. (projected into plane of section from well location 1.7 miles to west); McCulloch Oil Corp. Govt. Voth 1, sec. 26, T. 39 N., R. 92 W. (projected into plane of section from well location 4.5 miles to east).
4. G and G Oil Co. Nieber Dome 1, sec. 19, T. 45 N., R. 92 W.
5. Pure Oil Co. Worland 1, sec 18, T. 48 N., R. 92 W. (projected into plane of section from well location, 1 mile to east).
6. True Oil Co. Sun Ranch 1.
7. British-American Oil Producing Co. J. B. Eccles 1.

is confined to the upper peripheral portions of the blocks (fig. 37). Which, if either, is correct depends on the configuration of the major faults at depth. Data for determining this are far too few.

Downward movements, however, were as important as upward movements in the tectonic evolution of the Wind River Basin. A comparison of total vertical movement with demonstrable, but not necessarily total, horizontal movement (pl. 4 and fig. 36) suggests strongly that the former was dominant in this region. The causes of the observed basin subsidence and mountain uplift are still unknown.

ECONOMIC GEOLOGY

OIL AND GAS

Commercial quantities of petroleum have been produced from many zones within the uppermost Cretaceous, Paleocene, and lower Eocene rocks in the structurally deeper parts of the Wind River Basin (table 7). Active oilseeps and oil-saturated sandstone are widespread along the basin margins (Tourtelot, 1953; Keefer and Rich, 1957, p. 76; Thompson and White, 1952). Favoring the generation and accumulation of oil and gas in the basin rocks are (1) abundant reservoir and source rocks, (2) abrupt facies changes from shale to sandstone in the marginal (updip) areas of the basin, (3) unconformities between successive stratigraphic units, and (4) folding in both the marginal and interior regions of the basin.

Oil and gas from the uppermost Cretaceous and lower Tertiary rocks have been found in both structural and stratigraphic traps. Along the margins of the basin, many anticlines plunge sharply basinward and are covered by the nearly flat-lying strata of the Wind River Formation. Many of these folds do not have mappable structural closure, but oil and gas traps may exist within the uppermost Cretaceous and lower Tertiary rocks where sandstone beds lens out along the flanks of the folds and where there are unconformable relations between strata across the structures (Keefer, 1960). Anticlinical folds are also present in the structurally deeper parts of the basin, and these folds have locally influenced the accumulation of hydrocarbons. Some of these folds are reflected in the isopach maps (figs. 9, 12, 14, and 29).

Conditions seem especially favorable for the stratigraphic entrapment of oil and gas in the Lance and Fort Union Formations and in the basal part of the lower Eocene section. These units contain thick sequences of shale in the central part of the basin which grade into sandstone toward the margins where updip pinchouts of strata are to be expected. The thick highly organic shale and claystone of the Waltman Shale Member of the Fort Union Formation, for example, may provide the source of much of the oil and gas in the lower Tertiary rocks. Inasmuch as the shale and claystone yield liquid hydrocarbons in laboratory distillation tests (see stratigraphic discussion of Waltman Shale Member, p. A28), it is likely that oil and gas should also be released from these rocks under the proper natural conditions and migrate into the adjacent sandstones.

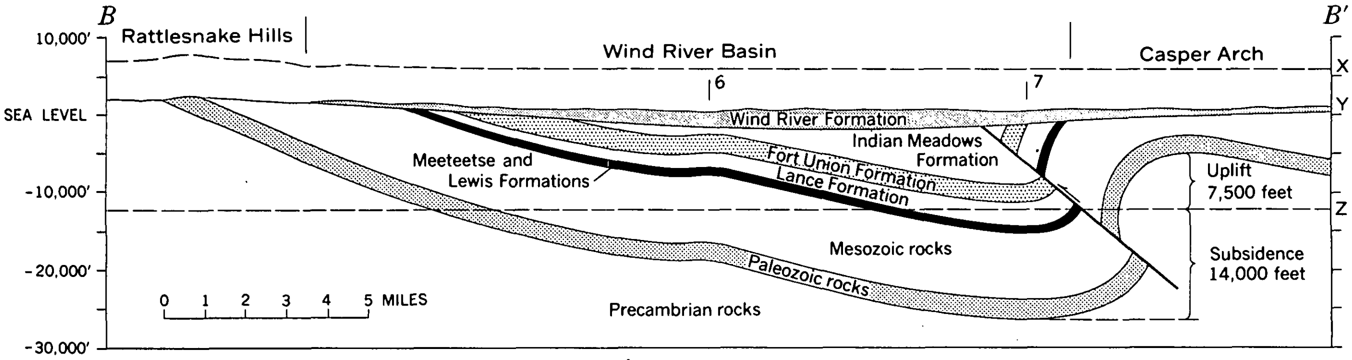


FIGURE 36.—Restored section (*B–B′*) at end of early Eocene time across southeastern part of Wind River Basin. Line of section shown on figure 35. X, present topographic profile; Y, postulated position of topographic profile at end of early Eocene time; Z, top of Precambrian rocks at beginning of deformation.

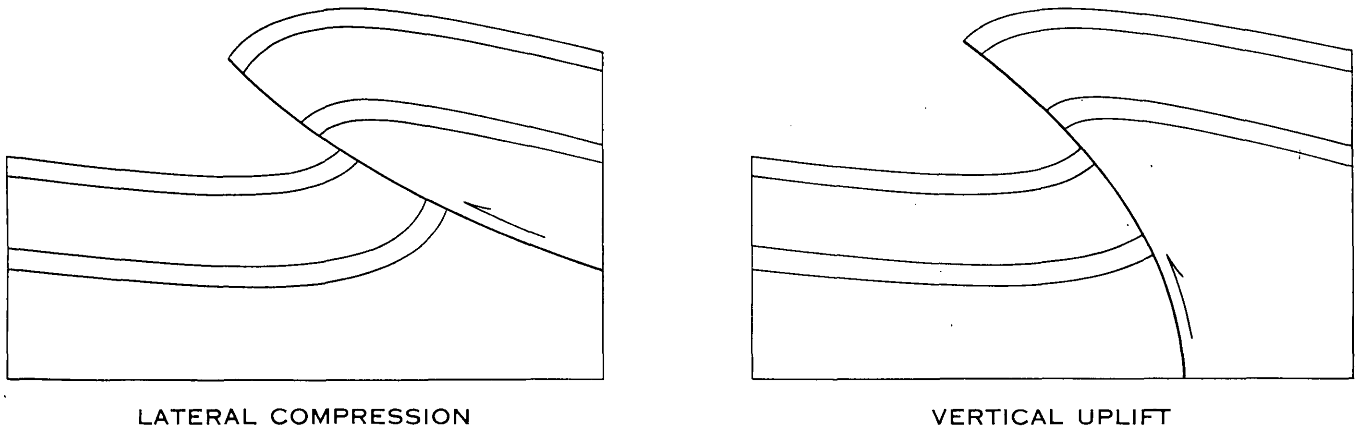


FIGURE 37.—Alternate interpretations of crustal movement in central Wyoming.

TABLE 7.—*Oil and gas discovery wells in uppermost Cretaceous, Paleocene, and lower Eocene rocks in the Wind River Basin (as of April 1, 1962)*

[MCFG, thousand cubic feet of gas per day; BO, barrels of oil per day; BC, barrels of condensate per day]

Locality No. (pl. 1)	Company	Well	Location			Total depth (feet)	Bottom formation	Producing-zone depth (feet)	Formation	Initial production[1]
			Section	Township	Range					
46	Shell Oil	Pavillion 14–12	SW¼SW¼ 12	3 N.	2 E.	6,505	Fort Union	3,838–3,858	Wind River or Indian Meadows.	1.945 MCFG
76	California	Cooper Reservoir 1	SE¼SW¼ 3	35 N.	87 W.	4,843	do	3,666–3,688	Fort Union	8,000 MCFG
65	Continental Oil	Squaw Butte Unit 1–2	NE¼SE¼ 1	36 N.	90 W.	8,648	Lance	7,268–7,291	do	2,856 MCFG
25	do	Squaw Buttes 28–1	NW¼NW¼ 28	36 N.	90 W.	6,960	do	6,338–6,354	Lance	2,200 MCFG
77	California	Waltman 1	NE¼SW¼ 31	37 N.	86 W.	11,899	Mesaverde	5,680–5,694	do	194 BO
70	Humble Oil & Refining.	Frenchie Draw 1	NE¼NE 21¼	37 N.	89 W.	10,112	Lance	9,101–9,163 9,241–9,295 9,831–9,891	do do do	4,220 MCFG 60 BC 5,055 MCFG 57 BC 5,074 MCFG, 60 BC
51	Shell Oil et al	Dinty Moore Reservoir Govt. 1.	NE¼SW¼ 3	37 N.	92 W.	10,000	do	9,138–9,144	Fort Union	2,591 MCFG, 40 BC
48	Humble Oil & Refining.	Poison Creek 1	NE¼NE¼ 32	37 N.	93 W.	9,009	do	5,418–5,432	do	2,447 MCFG, 8 BC
28	California	Madden 1	NE¼SW¼ 8	38 N.	89 W.	12,505	do	6,484–6,518 7,288–7,307	do	315 MCFG
60	do	Lost Cabin Unit Spratt 1.	SE¼SE¼ 5	38 N.	90 W.	8,990	do	8,793–8,809 8,934–8,948	Lance	8,275 MCFG
61	do	Lost Cabin Govt. 1	SW¼NW¼ 10	38 N.	90 W.	10,505	do	3,171–3,210	Wind River	256 BO
53	do	Lost Cabin Govt.—Langsdorf 1.	NW¼NE¼ 5 Lot 2	38 N.	91 W.	4,400	Wind River	4,155–4,178	do	38 BO
17	Pure Oil	Badwater 1	NE¼NW¼ 35	39 N.	89 W.	17,034	Lance	15,216–16,472	Lance	5,500 MCFG
56	Gulf Oil	Dolis Hill Unit Lysite—Federal 1.	SW¼NE¼ 23	39 N.	91 W.	7,328	Fort Union	6,780–6,827	Fort Union	21,000 MCFG
54	Sunray Midcontinent.	Lysite—Federal 1–A	NW¼SE¼ 32	39 N.	91 W.	4,749	Wind River or Indian Meadows.	4,170–4,180 4,659–4,688	Wind River or Indian Meadows.	1,000 MCFG
15	Shell Oil	Howard Ranch 23–15	NE¼SW¼ 15	39 N.	93 W.	11,474	Lance	8,318–8,952	Fort Union	2,163 MCFG

[1] Initial production data from Conservation Division, U.S. Geological Survey, Casper, Wyo., and from Petroleum Information, Inc., Denver, Colo.

765–797 O—65——5

To date, drilling to test this potential source of petroleum in some of the more favorable areas has met with varying degrees of success. Although oil and gas have been reported in nearly all wells penetrating the Fort Union Formation, not all the shows have been commercial. The following factors may be partly responsible for failure of some wells to produce:

1. Organic content of the Waltman Shale Member is in the form of minute particles of lignite and coal, and hence may not convert readily to liquid hydrocarbon in sufficient quantities for commercial production in some areas.
2. The enclosing strata, though predominantly sandstone, may not be sufficiently porous or permeable to serve as adequate reservoirs.
3. The proper combination of physical stratigraphic and structural features to ensure trapping may be rare.
4. Times of folding and of development of some structural traps may not have coincided with major times of oil migration.

Understanding the time and space relations of folding is essential to evaluating the oil and gas potential of any deformed region. Such understanding has been effectively applied by Murphy and others (1956) to two parallel series of anticlines in the northwestern part of the Wind River Basin. Circle Ridge, Maverick Spring, and Little Dome anticlines constitute one series and Dry Creek, Northwest Sheldon, and Sheldon Dome anticlines constitute the other (fig. 38). All six folds have well-defined structural closure and are eroded to rocks older than the Meeteetse Formation. These two anticlinal complexes have nearly identical patterns of oil and gas production: (1) Circle Ridge and Dry Creek (also called Rolff Lake) anticlines, at the northwest ends, are the most prolific producers; (2) Maverick Spring and Northwest Sheldon anticlines, in the middle, are only moderate producers; and (3) Little Dome and Sheldon Dome anticlines, at the southeast ends, are minor producers. To explain this pattern, Murphy and others (1956) suggested that only a single large northwest-trending anticline was formed along each alinement during the initial stage of folding in Paleocene time (fig. 38*a*), and at that time much of the available oil migrated into the highest structural positions, now occupied by Circle Ridge and Dry Creek anticlines. Renewed folding with a northeast trend at the end of early Eocene time divided each of the large ancestral folds into three small anticlines (fig. 38*b*), separated by structural sags, but at this time there was not much oil left to migrate into the Maverick Spring and Northwest Sheldon anticlines and still less into the Little Dome and Sheldon Dome anticlines. The structural history is well recorded in the Paleocene and lower Eocene rocks along the flanks of the folds.

Paape (1961, p. 193) pointed out that some anticlines along the south margin of the Wind River Basin have structural closure in strata of the Wind River Formation at the surface but no closure in the older rocks at depth. He suggested that this resulted from the following sequence of events: (1) pre-Wind River folding, with northward tilting of pre-Wind River rocks, (2) deposition of the Wind River Formation and slight northward tilting of these strata, and (3) post-Wind River tilting toward the south, enough to produce southward dips in the Wind River strata in some places but not enough to reverse the steeper north dips in the older rocks at depth.

COAL

Coal and lignite beds are present in all the formations described in this report except the Lewis Shale. The thickest and most extensive beds are in the Meeteetse Formation. In the Shotgun Butte area (loc. 39, pl. 1), for example, a single seam near the top of the Meeteetse is 16½ feet thick, and nearby there are several beds 3–5 feet thick. In general, however, most coals in the uppermost Cretaceous and lower Tertiary rocks are thin and discontinuous and have little economic value. Although a few of the thicker seams, such as those in the Meeteetse Formation in the Shotgun Butte area, have been exploited in the past, no mines are currently active in the Wind River Basin.

The coal and lignite beds have never been systematically studied. Descriptions of coal in various parts of the basin are included in papers by Woodruff and Winchester (1912), Thompson and White (1952), Keefer (1957, p. 216–217), Rich (1962), and Keefer and Troyer (1964).

URANIUM

Large deposits of uranium occur in lower Eocene rocks in the Gas Hills area. Extensive exploitation, largely by open-pit mining began in 1955; most of the mines are in T. 39 N., Rs. 89 and 90 W. The geologic setting of the deposits has been described by Love (1954b), Zeller and others (1956), Grutt (1956, p. 362–366), and Zeller (1957).

The uranium deposits in the Gas Hills area are in the upper coarse-grained facies of the Wind River Formation (see stratigraphic discussion of Wind River Formation in Gas Hills area, p. A51). The uranium-bearing minerals generally occur as interstitial fillings in irregular blanketlike bodies of sandstone. Uraninite and coffinite are the chief ore minerals in the unoxidized zones, and uranium phosphates, silicates, and hydrous

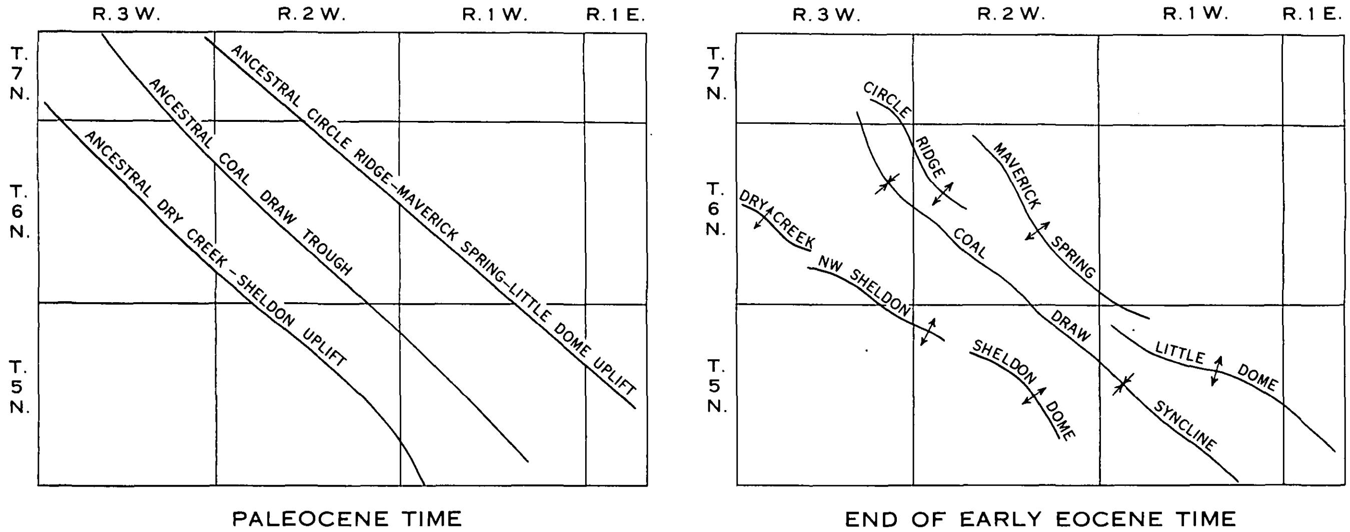


FIGURE 38.—Evolution of folds in northwestern part of Wind River Basin, based on Murphy and others (1956).

oxides in the oxidized zones (Zeller, 1957, p. 157). The contact between the oxidized and unoxidized zones is near the water table, and the main ore is just below the water table. Zeller concluded that at least some of the uranium deposits are very young (late Tertiary or Pleistocene) and are related to the movement of ground water, that the uranium was introduced by alkaline ground water rich in carbonate, and that the uranium was precipitated where these waters came in contact with reducing environments in stratigraphic and structural traps, such as were apparently present in the coarse sandstone of the Wind River Formation. Studies by Rosholt (1958, fig. 5) indicate that some of the ore was deposited 12,000–20,000 years ago. The original source of the uranium is not known. Love (1961, p. 33) suggested that some of it may have been leached from the Moonstone Formation of Pliocene age before the strata of that formation were removed by erosion from the Gas Hills area. Zeller (1957, p. 158) listed as possible sources the White River Formation of Oligocene age and the Precambrian granitic debris so abundant in the Wind River Formation.

Rich (1962) observed that many of the lower Eocene strata are radioactive in the southeastern part of the Wind River Basin, but that they contain actual uranium minerals only locally.

OTHER COMMODITIES

Deposits of sand and gravel, reworked in part from underlying strata of the Wind River Formation by stream and wind erosion, occur locally and have been used in the surfacing of roads and in the construction of canals, small dams, and other features. Bentonite and other clays occur in the Wind River Formation, as well as in the Meeteetse Formation, but their economic potential has not been studied. A deposit of titaniferous sandstone in the lower marine tongue of the Lewis Shale in outcrops along the southeast edge of the Wind River Basin (loc. 80, pl. 1) has been described by Houston and Murphy (1963, p. 101). Sandstone samples from the weathered zone have an average content of 5.2 percent titanium oxide (TiO_2) and 21.7 percent ferrous oxide (Fe_2O_3). A sample from the unweathered zone contains 7.9 percent TiO_2 and 63.7 percent Fe_2O_3.

STRATIGRAPHIC SECTIONS

1. *Section of Lance and Meeteetse Formations at Castle Gardens, secs. 5, 9, 10, and 16, T. 34 N., R. 90 W. (loc. 9, pls. 1, 2)*

[Modified from section measured by K. A. Yenne, J. L. Weitz, and John Belshe. Units 44 through 53 are locally referred to as Castle Gardens sandstone]

	Feet
Fort Union Formation:	
Siltstone, gray, shaly to blocky; spore and pollen (colln. 9B, tables 2, 3)	110
Conformable contact.	
Lance Formation:	
59. Sandstone, light-gray (weathers red brown), fine-grained, soft; ferruginous in part	7
58. Siltstone and shale, gray	13
57. Sandstone, gray (weathers red brown), fine-grained	16
56. Shale, gray; some interbedded buff to red sandstone	19
55. Sandstone, gray (weathers red brown), fine-grained	16
54. Shale, light- to dark-gray; grades into sandstone	12
53. Sandstone, light-gray to white, medium-grained, massive to crossbedded; black and pink grains common; small pellets of claystone and siltstone; forms cliff in places	78

1. *Section of Lance and Meeteetse Formations at Castle Gardens, secs. 5, 9, 10, and 16, T. 34 N., R. 90 W. (loc. 9, pls. 1, 2)*—Continued

	Feet
Lance Formation—Continued	
52. Sandstone, light-gray to white, medium- to coarse-grained, crossbedded; some lenses of claystone pellets; a few thin brown carbonaceous shale beds; fossil plants and spore and pollen assemblage of Late Cretaceous age (colln. 9A, tables 2, 3); forms cliff in places	282
51. Sandstone, light-gray to white (weathers buff in part), medium-grained, crossbedded; lenses of claystone pellets; forms cliff in places	48
50. Sandstone, gray (weathers red brown), very fine grained, ferruginous; forms ledge	3
49. Shale, dark-gray, green, and brown; carbonaceous in part with thin coal partings	15
48. Sandstone, light-gray, fine- to medium-grained; lenses of claystone pellets; forms cliff in places	27
47. Shale, dark-gray and brown; carbonaceous in part	14
46. Sandstone, light-gray to white, medium-grained; ferruginous in part; some interbedded brown carbonaceous shale	40
45. Sandstone, light-gray to white, fine- to coarse-grained, crossbedded; many zones of siltstone pellets and fragments as much as 1 ft in length	81
44. Sandstone, light-gray to white, fine-grained; crossbedded in part; ferruginous in part; some ferruginous sandstone concretions as much as 6 ft across	47
Total Lance Formation	718
Conformable contact.	
Meeteetse Formation:	
43. Coal and shale, dark-gray to black, carbonaceous	4
42. Partly covered; underlain mostly by gray and buff sandstone and shale	10
41. Coal, lignitic	2
40. Partly covered; underlain mostly by sandstone and shale	55
39. Shale, dark-gray, carbonaceous, coaly	1
38. Sandstone, gray, fine-grained	10
37. Sandstone, gray, very fine grained, calcareous, crossbedded; forms ledge	2
36. Shale, gray to green, silty; 6-in. coal bed at top; a few carbonaceous layers throughout	9
35. Sandstone, light-gray, fine-grained	30
34. Shale, gray to green, silty; minor amount of sandstone	9
33. Sandstone, buff to brown, fine-grained, calcareous, crossbedded, lenticular	2
32. Shale and siltstone, gray-green; some thin ferruginous sandstone beds	6
31. Shale, dark-gray, carbonaceous, coaly	5
30. Shale and siltstone, gray to olive-green; a few thin sandstone and carbonaceous shale beds	26
29. Covered; probably sandstone	50
28. Partly covered; sandstone, buff, coarse-grained, calcareous, crossbedded; large mica grains	39
27. Covered; probably sandstone	82

1. *Section of Lance and Meeteetse Formations at Castle Gardens, secs. 5, 9, 10, and 16, T. 34 N., R. 90 W. (loc. 9, pls. 1, 2)*—Continued

	Feet
Meeteetse Formation—Continued	
26. Siltstone, gray-green; contains some thin ferruginous sandstone lenses; 1 ft of brown carbonaceous shale in middle	10
25. Shale, dark-gray; some carbonaceous layers	7
24. Shale, gray-green	12
23. Sandstone, buff to brown, fine-grained, calcareous, crossbedded; forms ledge	1
22. Shale, gray to green; weathers buff; 6-in. coal bed near middle	10
21. Coal, lignitic	5
20. Sandstone, light-gray, fine-grained	20
19. Coal, lignitic	1
18. Shale, chocolate-brown, carbonaceous	1
17. Sandstone, gray to buff, fine-grained; some gray-green shale	16
16. Covered; underlain mostly by dull gray and buff fine-grained sandstone; 6-in. bed of lignitic coal near top	82
15. Sandstone, gray (weathers brown), fine-grained, calcareous, crossbedded	1
14. Sandstone, gray to buff, fine-grained, shaly	5
13. Coal, lignitic	1
12. Shale, chocolate-brown, carbonaceous	1
11. Shale, gray-green	10
10. Covered; probably underlain mostly by gray sandstone	224
9. Sandstone, gray, fine-grained; 2-ft lignitic coal bed 3 ft from top	21
8. Shale, chocolate-brown, carbonaceous, sandy; contains some gypsum	18
7. Shale, black to chocolate-brown, carbonaceous; 6-in. lignitic coal bed near middle	13
6. Sandstone, white to light-gray, medium-grained, crossbedded, soft; thin carbonaceous layers; forms valley	28
5. Coal, lignitic	2
4. Shale, chocolate-brown, carbonaceous, silty; contains plant fragments	1
3. Shale, dark-gray, poorly fissile	10
2. Sandstone, red-brown, fine-grained, ferruginous, gypsiferous	6
1. Shale, dark-gray, poorly fissile	12
Total Meeteetse Formation	860
Conformable contact.	
Mesaverde Formation:	
Sandstone, white to light-gray, fine- to coarse-grained, soft, carbonaceous; shale pellets and ferruginous balls 6 in. across; forms cliff	39

2. *Section of Lance Formation 1 mile east of Conant Creek, secs. 32 and 33, T. 34 N., R. 93 W. (loc. 8, pls. 1, 2)*

[Modified from section measured by G. N. Pipiringos and K. A. Yenne]

	Feet
Fort Union Formation:	
Poorly exposed; composed of white very coarse grained conglomeratic sandstone and gray to buff siltstone and shale; conglomerate contains pebbles of chert and quartz as much as ½-in. long	10+

2. *Section of Lance Formation 1 mile east of Conant Creek, secs. 32 and 33, T. 34 N., R. 93 W. (loc. 8, pls. 1, 2)*—Continued

	Feet
Angular unconformity.	
Lance Formation:	
27. Sandstone, brown, very fine grained, ferruginous, oolitic; sporadic pebbles of black and green chert; fresh water mollusks and plant remains of Late Cretaceous age (colln. 8B, table 2)	1
26. Sandstone, gray (weathers buff to yellow), very fine to medium-grained; a few thin shale partings	15
25. Shale, gray-green, fairly fissile	2
24. Sandstone, reddish-brown, very fine grained, ferruginous, oolitic; sporadic pebbles of black and green chert; fresh water gastropods; forms ledge	1
23. Sandstone, gray to brown, medium-grained, soft, porous	6
22. Sandstone, reddish-brown, very fine grained, ferruginous, oolitic; sporadic pebbles of black and green chert; sporadic fresh-water mollusks and plant remains, including *Dryophyllum subfalcatum* Lesquereux of Late Cretaceous age; forms ledge	1
21. Sandstone, gray, very fine to coarse-grained, porous, friable; scattered small pebbles of chert	2
20. Sandstone, reddish-brown and gray, very fine grained; upper 1 ft conglomeratic with smooth rounded black and green chert pebbles	4
Possible unconformity.	
19. Shale, carbonaceous	5
18. Sandstone, gray, very fine grained; forms ledge	2
17. Shale, gray to brown, carbonaceous; a few thin beds of sandstone	11
16. Sandstone, gray and brown (weathers silver gray), medium-grained, limonitic; minor amount of carbonaceous shale	5
15. Shale, gray, blocky; plant fragments	2
14. Lignite, brown and black	1
13. Sandstone, gray, medium- to coarse-grained, massive, porous	10
12. Sandstone and shale interbedded; sandstone is gray, very fine grained; shale is gray to brown, carbonaceous; a few thin coal beds	31
11. Sandstone, buff, very fine grained, shaly, 6-in. bed of ironstone at top	3
10. Shale, brown, carbonaceous; spore and pollen of Late Cretaceous age (colln. 8A, tables 2, 3)	10
9. Sandstone, buff, very fine grained; 6-in. bed of ironstone at top	4
8. Coal, black; impure in lower half	2
7. Sandstone, gray and buff, very fine grained, shaly	10
6. Shale, brown, carbonaceous; in part lignitic	5
5. Sandstone and shale interbedded: sandstone is gray and tan, very fine grained, shaly in part; shale is gray, gray-green, and brown, and carbonaceous in part	30
4. Shale, gray and brown, carbonaceous; a few thin sandstone beds	12
Lance Formation—Continued	
3. Sandstone, gray and brown, coarse-grained; abundant thin carbonaceous shale partings; forms slabby cliff	9
2. Shale, brown, carbonaceous; some interbedded sandstone	3
1. Sandstone, gray (weathers white), medium- to coarse-grained, massive, porous; contains siltstone partings as much as 6 in. thick; forms conspicuous laminated outcrop	39
Total Lance Formation	226
Unconformity.	
Mesaverde Formation:	
Sandstone, buff to brown, fine- to medium-grained, calcareous; forms broad dip slopes	2

3. *Generalized section of the lower part of the Fort Union Formation, California Co. Madden 1, sec. 8, T. 38 N., R. 89 W. (loc. 28, pls. 1, 2)*

[Sample study by W. R. Keefer]

	Depth (feet)
Fort Union Formation:	
Waltman Shale Member:	
Shale, black, silty, micaceous	3, 440–6, 020
Lower part:	
19. Sandstone, gray, fine-grained; some dark-gray to black shale	6, 020–6, 070
18. Shale and sandstone interbedded: shale is gray to black, slightly micaceous; sandstone is light gray, fine grained; minor amount of black carbonaceous shale	6, 070–6, 260
17. Sandstone, white, fine- to medium-grained	6, 260–6, 280
16. Shale and siltstone, gray to black; some fine-grained sandstone	6, 280–6, 340
15. Sandstone, gray, fine-grained; some coarse grains of quartz	6, 340–6, 360
14. Shale, siltstone, and claystone, dark-gray to black; minor amount of black carbonaceous shale and gray sandstone	6, 360–6, 470
13. Sandstone, white, fine- to coarse-grained; abundant rounded to subangular coarse quartz grains	6, 470–6, 520
12. Shale and siltstone, gray to black; minor amounts of black carbonaceous shale and gray to gray-green sandstone	6, 520–6, 740
11. Sandstone, gray, fine-grained	6, 740–6, 760
10. Shale, gray to black, silty	6, 760–6, 790
9. Sandstone, gray to gray-green, fine-grained; some interbedded black shale	6, 790–6, 860
8. Shale and siltstone, dark-gray to black, clayey in part; abundant carbonaceous material near base	6, 860–7, 080
7. Sandstone, gray to dark-gray, fine-grained; minor amout of black shale and siltstone	7, 080–7, 600

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3. *Generalized section of the lower part of the Fort Union Formation, California Co. Madden 1, sec. 8, T. 38 N., R. 89 W. (loc. 28, pls. 1, 2)*—Continued

	Depth (feet)
Fort Union Formation—Continued	
Lower part—Continued	
6. Sandstone, shale, and siltstone interbedded, gray to black; some carbonaceous shale; core sample in interval 8,110–8,130 ft contains spore and pollen assemblage (coll. 28A, tables 2, 3)	7, 600–8, 200
5. Sandstone, fine- to coarse-grained; abundant coarse grains of quartz and chert; minor amount of dark-gray to black shale and siltstone	8, 200–8, 380
4. Shale, black, clayey; minor amount of siltstone and carbonaceous shale	8, 380–8, 440
3. Sandstone, white, fine-grained	8, 440–8, 490
2. Shale, black, clayey	8, 490–8, 550
1. Sandstone, white, very fine-grained to coarse-grained; coarse angular grains of quartz, white mica, and chert; minor amount of black shale and siltstone	8, 550–8, 720
Total lower part of Fort Union Formation	2, 700
Lance Formation:	
Shale and siltstone, dark-gray; minor amount of dark-gray fine-grained sandstone.	

4. *Section of Fort Union Formation near Ethete, sec. 22, T. 1 N., R. 1 E. (loc. 4, pls. 1, 2)*

[Measured by K. A. Yenne and W. R. Keefer]

	Feet
Wind River Formation:	
Sandstone, yellow-brown conglomeratic, arkosic; fragments of siliceous shale and granite as much as 6 in. long	10+
Angular unconformity.	
Fort Union Formation:	
12. Claystone, brown, carbonaceous	1
11. Claystone, light-gray, gray-green, and buff; a few thin lenses of ferruginous sandstone and ironstone	82
10. Sandstone, light-brown, fine-grained, carbonaceous	2
9. Sandstone, white to light-gray, fine-grained	8
8. Shale, gray-green	3
7. Siltstone, light-gray to white, sandy, hard; forms ledge	26
6. Claystone, light-gray to white, sandy, hard	5
5. Claystone, light-gray; a few thin lenses of ironstone	6
4. Sandstone, red-brown, fine-grained, ferruginous	1
3. Covered; probably underlain mostly by sandstone	33
2. Shale, gray-green; thin lenses of ferruginous sandstone and ironstone; fossil plants	33
1. Sandstone, light-gray (weathers light brown), medium- to coarse-grained; crossbedded in part; nearby, unit contains rounded pebbles and cobbles of granite, sandstone, quartz, and chert as much as 6 in. long; forms cliff	9
Total Fort Union Formation	209

4. *Section of Fort Union Formation near Ethete, sec. 22, T. 1, N., R. 1 E. (loc. 4, pls. 1, 2)*—Continued

	Feet
Angular unconformity.	
Cody Shale (Upper Cretaceous):	
Siltstone and sandstone, gray-green and brown, thin-bedded	50+

5. *Section of Fort Union Formation at north end of Alkali Butte anticline, secs. 20, 28, and 29, T. 1 S., R. 6 E. (loc. 7, pls. 1, 2)*

[Modified from section measured by K. A. Yenne and G. N. Pipiringos]

	Feet
Wind River Formation:	
Sandstone and siltstone, gray, tan, and red; conglomeratic in part	50+
Angular unconformity. Discordance is slight at this locality, but along the strike, Wind River strata bevel successively older beds and rest on the lower part of the Fort Union Formation.	
Fort Union Formation:	
49. Sandstone, shale, siltstone, and conglomerate interbedded; gray, tan, yellowish-tan, and brown; sandstone is coarse grained and arkosic in part; conglomerate contains pebbles and cobbles of granite and chert; individual units not described	450
48. Conglomerate, tan to yellowish-tan, arkosic; rounded pebbles of pink to gray granite, dark-red to brown chert and quartzite, and fossil wood as much as 2 in. long	4
Apparent conformity. This horizon may mark contact between Shotgun Member and lower part of Fort Union Formation as these units are defined elsewhere. Along the flanks of this anticline arkosic beds in upper part of Fort Union Formation bevel across lower part of formation and rest on Cretaceous strata (Keefer, 1960, p. B235).	
47. Shale, gray and brown, carbonaceous in part; a few lenses of ferruginous sandstone; plant fragments in lower 2 ft	21
46. Sandstone, light-gray, fine- to medium-grained, highly crossbedded, conglomeratic; pebbles of gray quartz and chert; carbonaceous shale partings throughout	6
45. Shale and claystone, gray and brown, carbonaceous in part; fossil leaves common (colln. 7C, table 2)	8
44. Conglomerate, light-gray, buff, yellow, and brown; pebbles of gray chert, quartz and fossil wood	23
43. Shale, gray	3
42. Sandstone, buff and yellow, medium-grained	3
41. Conglomerate, light-gray, buff and yellow; pebbles of gray chert and quartz; lenses of sandstone	11
40. Shale, gray, slightly sandy	6
39. Partly covered, underlain mostly by gray sandstone	10
38. Sandstone, light-gray to buff, coarse-grained; conglomeratic in part	17
37. Conglomerate, light-gray, buff, and yellow; pebbles of gray chert and quartz; lenses of brown shale and sandstone	23

5. *Section of Fort Union Formation at north end of Alkali butte anticline, secs. 20, 28, and 29, T. 1 S., R. 6 E. (loc. 7, pls. 1, 2)*—Continued

	Feet
Fort Union Formation—Continued	
36. Sandstone, light-gray, coarse-grained, conglomeratic	7
35. Sandstone, gray and brown, fine-grained; shale partings; crystals of gypsum and stringers of a yellow earthy mineral (jarosite?) common; plant fragments	16
34. Sandstone, gray, very coarse grained, conglomeratic, calcareous; pebbles of gray quartz and black chert; lower 1 ft is quartzitic and weathers red brown	3
33. Partly covered; underlain mostly by light-gray fine- to medium-grained oil-stained (?) sandstone; scattered gray shale	53
32. Sandstone, gray, buff, and yellow, medium-grained, soft; gray shale in upper half	12
31. Sandstone, buff-yellow, coarse-grained, conglomeratic; forms steep slope	10
30. Sandstone and shale interbedded; shale is brown and micaceous; sandstone is buff and yellow, coarse grained; plant fragments	6
29. Sandstone, light-gray, buff, and yellow, coarse-grained; a few irregular beds containing chert pebbles; thin lenses of gray shale	5
28. Sandstone and shale interbedded; sandstone is light gray, weathers rust red, medium- to coarse-grained, soft, porous; shale is gray to brown, carbonaceous; plant fragments common	5
27. Sandstone, buff and yellow, conglomeratic; pebbles of black and gray chert as much as ½ in. long; highly crossbedded in part; upper 8 ft contains bands of ferruginous sandstone and a few lenses of gray shale and gypsum; forms cliff	39
26. Shale, gray, buff, and brown, gypsiferous in part; carbonaceous in upper half	14
25. Sandstone, white to gray, fine- to medium-grained, soft to hard	16
24. Shale, gray to black, fissile; light-gray medium-grained porous sandstone	6
23. Sandstone, light-gray, very coarse grained, conglomeratic	10
22. Shale, black (weathers gray), soft; carbonaceous at top; contains many layers of selenite crystals and beds of yellow-weathering sandstone	15
21. Quartzite, gray, massive; bed is highly fractured and crops out as a row of blocks rather than a ledge	2
20. Shale and claystone interbedded, gray, green, yellow, and white	19
19. Sandstone, light-gray (weathers yellow brown), medium- to coarse-grained, calcareous, hard, massive	3
18. Claystone and siltstone interbedded, green-gray and tan; weathers gray white and yellow tan	23
17. Sandstone and shale, light-gray, green, and black; sandstone is medium to coarse grained	4
16. Shale, green, yellow and gray	12
15. Siltstone, green and black, shaly	15
14. Sandstone, gray-green, fine-grained, calcareous, very clayey, hard; surface bears worm(?) trails and markings	2
13. Shale, brown to black; carbonaceous in part; obscure plant remains	6
12. Shale and claystone interbedded, green and black (weathers gray), noncalcareous; 1-ft ironstone bed near middle; forms slope	20
11. Sandstone, gray (weathers brown), fine- to medium-grained; ferruginous at base	1
10. Shale, green and black	3
9. Siltstone, light-gray; plant fragments	2
8. Shale, gray-green to black, silty in part; thin ironstone beds	14
7. Ironstone, purple to rusty-brown; fossil plants	1
6. Claystone, gray; weathers light gray	7
5. Sandstone, shaly sandstone, and sandy shale interbedded; sandstone is gray to white, fine grained, soft; shale is gray, light gray, and yellow green	40
4. Conglomerate; well-rounded pebbles of white, black, gray, and green quartzite and chert	34
3. Quartzite, gray; weathers gray brown; a few coarse quartz sand grains; forms ledge	1
2. Sandstone, siltstone, shale, and conglomerate interbedded, gray to black; sandstone is fine to coarse grained, crossbedded in part; conglomerate contains pebbles of white chert and siltstone as much as ¼ in. long; abundant fossil leaves and plants (colln. 7B, table 2)	24
1. Sandstone, light-gray (weathers rusty brown), medium- to coarse-grained; basal 1 ft is conglomeratic with subangular pebbles of white and black chert and fragments reworked from underlying strata; forms cliff	7
Total Fort Union Formation	1,042
Apparent conformity.	
Lance Formation:	
Sandstone, gray to light-gray, fine-grained; shaly in part; fossil plants, spores, and pollen of Late Cretaceous age (colln. 7A, tables 2, 3)	10+

6. *Section of Fort Union Formation near Castle Gardens, secs. 32 and 33, T. 35 N., R. 90 W., and sec. 5, T. 34 N., R. 90 W. (loc. 9, pls. 1, 2)*

[Adapted from section measured by K. A. Yenne and John Belshe]

	Feet
Wind River Formation:	
Sandstone, white to light-gray (weathers brown), very coarse grained; conglomeratic with pebbles and cobbles of chert, siliceous shale, and granite as much as 18 in. long	25+

6. *Section of Fort Union Formation near Castle Gardens, secs. 32 and 33, T. 35 N., R. 90 W., and sec. 5, T. 34 N., R. 90 W. (loc. 9, pls. 1, 2)*—Continued

	Feet
Angular unconformity.	
Fort Union Formation:	
31. Sandstone, gray and reddish-brown, fine- to coarse-grained; conglomeratic in part	9
30. Shale, gray to gray-green and brown; carbonaceous in part; thin beds of sandstone	34
29. Sandstone, light-gray to white, coarse-grained to very coarse grained; conglomeratic in part with pebbles as much as 2 in. long	58
28. Shale, gray and brown; carbonaceous in part; minor amount of gray and reddish-brown sandstone	59
27. Sandstone, gray, fine-grained	15
26. Sandstone, light-gray, fine-grained to very coarse grained; conglomeratic in part with pebbles of chert and siliceous shale as much as ½ in. long; green glauconite(?) grains	27
25. Sandstone, light-gray, coarse-grained; upper part shaly with thin beds of dark-gray and brown carbonaceous shale	25
24. Shale and sandstone interbedded, gray and buff	20
23. Poorly exposed outcrops of light-gray coarse-grained sandstone and yellowish-tan conglomerate with pebbles of chert, siliceous shale, and quartz as much as 3 in. long	154
22. Siltstone, gray and brown; carbonaceous in part; contains plant fragments	14
21. Sandstone, white to light-gray; a few lenses of reddish-brown ferruginous conglomeratic sandstone; 6 ft of gray and brown carbonaceous shale in middle	43
20. Shale and sandstone interbedded; shale is dark gray, in part carbonaceous and coaly; sandstone is light gray, fine to very coarse grained	47
19. Shale, dark-gray and brown, carbonaceous; abundant plant fragments of Paleocene age	9
18. Sandstone, gray (weathers yellowish tan), fine-grained	6
17. Shale, brown and black, carbonaceous, coaly	4
16. Sandstone, gray and buff; weathers into alternating yellowish-tan and reddish-brown beds; fine-grained, in part very coarse grained, conglomeratic, arkosic	42
15. Sandstone, gray (weathers yellowish tan), coarse-grained, conglomeratic; contains pebbles of granite, siliceous shale, and chert as much as 2 in. long	12
14. Shale, brown, carbonaceous; coaly partings	15
13. Sandstone, white, light-gray, and buff, fine- to coarse-grained; conglomeratic in part, crossbedded in part; irregular lenses of brown carbonaceous shale; glauconite(?) grains	100
12. Covered; probably underlain by sandstone	8
11. Sandstone, light-gray, fine-grained; lenses of ferruginous conglomeratic sandstone	11

6. *Section of Fort Union Formation near Castle Gardens, secs. 32 and 33, T. 35 N., R. 90 W., and sec. 5, T. 34 N., R. 90 W. (loc. 9, pls. 1, 2)*—Continued

	Feet
Fort Union Formation—Continued	
10. Sandstone, light-gray (weathers white and brown), coarse-grained; arkosic with abundant white and pink feldspar grains; a few thin carbonaceous shale beds with plant remains of Paleocene age	15
9. Covered; probably underlain by sandstone	44
8. Sandstone, gray and brown, conglomeratic, crossbedded; pebbles of chert as much as 1 in. long; glauconite(?) grains; oil stained in part	16
7. Shale, dark-gray and brown; carbonaceous in part	9
6. Sandstone, gray, medium- to coarse-grained, conglomeratic, crossbedded; pebbles of chert, siliceous shale, and quartz; upper 7 ft is brown and oil stained	33
5. Shale, gray to black; carbonaceous in part	21
4. Sandstone, gray, fine-grained; in part carbonaceous and shaly	31
3. Siltstone, gray; thin beds of black carbonaceous shale	44
2. Sandstone, gray (weathers buff to reddish brown), fine-grained	5
1. Siltstone, gray, shaly; thin bed of gray fine-grained sandstone, weathering reddish brown; spore and pollen (colln. 9B, tables 2, 3)	110
Total Fort Union Formation	1,040
Conformable contact.	
Lance Formation:	
Sandstone, light-gray, fine-grained	7

7. *Section of Indian Meadows Formation, sec. 3, T. 5 N., R. 5 W. (fig. 21)*

[Measured by J. F. Murphy]

	Feet
Wind River Formation:	
Sandstone and siltstone, gray, white, and light-red; sandstone is coarse grained to conglomeratic, thick bedded, arkosic, lenticular; fossil mammals 150 ft above base (colln. I, table 2).	
Conformable contact. Three miles west, the Wind River Formation rests directly on Cretaceous rocks with no intervening Indian Meadows.	
Indian Meadows Formation:	
10. Sandstone, light-greenish-gray, tan, rust-brown, and red, very coarse grained to conglomeratic, arkosic, soft; thin carbonaceous shale with fossil shells 4 ft above base; fossil mammals 15 and 60 ft above base (colln. H, table 2)	120
9. Claystone, red, lavender, and white, nodular; lenticular beds of conglomeratic sandstone; 2-ft bed of limestone algal balls 16 ft above base	38
8. Claystone and sandstone, red, white, and light-gray; sandstone is coarse grained to conglomeratic and highly lenticular	65

7. Section of Indian Meadows Formation, sec. 3, T. 5 N., R. 5 W. (fig. 21)—Continued

	Feet
Indian Meadows Formation—Continued	
7. Sandstone, light-tan to buff, coarse-grained to conglomeratic, thin- to medium-bedded, lenticular	27
6. Claystone and sandstone, brick-red, purple, gray, and white; sandstone is conglomeratic, lenticular and thin bedded; contains fossil mammals in a locality about 1½ miles to the northwest (colln. H, table 2)	85
5. Siltstone, light-greenish-gray to brick-red, calcareous; sandy in part	20
4. Siltstone, brick-red mottled with gray	25
3. Sandstone and conglomerate, white to gray; red in part	40
2. Shale, light-gray, tan, and rust-brown; sandy in part	14
1. Conglomerate, tan to rust-brown; contains boulders of Precambrian and Paleozoic rocks as much as 1½ ft long	11
Total Indian Meadows Formation	445

Erosional unconformity. Indian Meadows Formation rests directly on Cody Shale, several thousand feet of younger Cretaceous rocks having been removed by pre-Indian Meadows erosion.

Cody Shale (Upper Cretaceous):	
Shale, black	50+

8. Partial section of Lysite Member of Wind River Formation, sec. 29, T. 39 N., R. 90 W. (loc. 59, pl. 1)

[Measured by H. A. Tourtelot]

Top of exposures.

Wind River Formation.

	Feet
Lysite Member:	
12. Sandstone, yellowish-gray to yellowish-tan, fine-grained to very fine grained, clayey, soft	40
11. Sandstone, yellowish-tan, greenish-gray, and red, very fine grained, clayey, soft	16
10. Claystone, brick-red, sandy	5
9. Sandstone and sandy claystone, yellowish-gray to greenish-gray, soft	30
8. Claystone, brick-red, sandy	5
7. Sandstone, yellowish-tan to greenish-gray (red in part), fine-grained to very fine grained, clayey, soft	28
6. Claystone, grayish-violet to greenish-gray, sandy	6
5. Sandstone, yellowish-gray to yellowish-tan, fine-grained, clayey, soft	10
4. Claystone, brick-red, sandy	4
3. Sandstone, yellowish- to brownish-gray, fine-grained, clayey; hard coarse-grained sandstone and chert conglomerate near base	40
2. Sandstone, gray, fine-grained, clayey, soft	10
1. Sandstone, brownish- to yellowish-gray, very fine grained, clayey; many thin beds of carbonaceous shale	60
Total Lysite Member measured	254

Base of exposures.

9. Partial section of Lost Cabin Member of Wind River Formation, sec. 22, T. 38 N., R. 89 W. (loc. 69, pl. 1)

[Measured by H. A. Tourtelot]

Top of exposures.

Wind River Formation.

	Feet
Lost Cabin Member:	
6. Sandstone, yellowish-brown to light-olive-brown, medium- to coarse-grained, clayey; conglomeratic in part	20
5. Sandstone and claystone, green, greenish-gray, and reddish-purple; fish and turtle bones abundant in middle	27
4. Sandstone, greenish-gray to olive-brown; conglomeratic at base; channels into underlying strata	7
3. Sandstone and claystone, gray, violet, and orange-red; conglomeratic at base; channels into underlying strata	59
2. Claystone, violet-red to reddish-purple and brownish-red, waxy; abundant fossil vertebrates (colln. S, table 2); excellent marker bed	10
1. Sandstone, silver-gray to greenish-gray, medium-grained to very fine grained, clayey; hard calcareous sandstone lenses	50
Total Lost Cabin Member measured	173

Base of exposures.

10. Partial section of Lost Cabin Member of Wind River Formation, sec. 25, T. 39 N., R. 89 W. (loc. 67, pl. 1)

[Measured by H. A. Tourtelot]

Top of exposures.

Wind River Formation.

	Feet
Lost Cabin Member:	
11. Sandstone, yellowish- and light olive-green; mottled dark red in part; fine- to medium-grained, clayey, soft	14
10. Claystone, grayish- and violet-blue, sandy, waxy, soft; correlates with unit 2 of section 9	7
9. Conglomerate and sandstone, grayish-green; fragments of Precambrian igneous and and metamorphic rocks and of Cambrian sandstone as much as 2 ft long; basal con-contact is irregular	26
8. Claystone, reddish-purple, sandy, soft	5
7. Sandstone, greenish-gray, medium-grained, clayey; interbedded with conglomerate and purplish-red fine-grained soft clayey sandstone; channels into underlying strata	5
6. Claystone, reddish-purple, very sandy, soft	32
5. Sandstone, greenish-gray at base and purplish-red at top; medium- to coarse-grained; conglomeratic in part	3
4. Claystone, reddish-purple, sandy, soft	5
3. Sandstone, greenish-gray and purplish-red, coarse-grained; conglomeratic in part; basal contact is irregular	10
2. Claystone, reddish-purple, sandy	30

10. *Partial section of Lost Cabin Member of Wind River Formation, sec. 25, T. 39 N., R. 89 W. (loc. 67, pl. 1)*—Continued

	Feet
Wind River Formation—Continued	
Lost Cabin Member—Continued	
1. Sandstone, greenish-gray, medium- to coarse-grained, clayey; irregular masses of conglomerate and purplish-red fine-grained clayey sandstone	30
Total Lost Cabin Member measured	167

Base of exposures.

11. *Partial section of lower part of Wind River Formation, sec. 21, T. 33 N., R. 90 W. (loc. 63, pl. 1)*

[Measured by H. D. Zeller, P. E. Soister, and J. P. McDowell]

	Feet
Wind River Formation:	
Lower fine-grained facies:	
7. Claystone, pale-olive, greenish-gray, and reddish-brown	19
6. Siltstone, light-gray, sandy; minor amount of of clay and coarse-grained sandstone	43
5. Claystone, light-olive-gray, limonitic	3
4. Sandstone, light-gray (in part red), fine-grained to very fine grained, silty, massive	30
3. Sandstone, light-gray, fine-grained to very fine grained; upper 1 ft brownish-gray to brownish-black; ferruginous	6
2. Siltstone, dark-brown, carbonaceous; abundant fossil leaves	2
1. Sandstone, gray, fine-grained to very fine grained; oil-stained	10
Total Wind River Formation measured	113

12. *Partial section of upper part of Wind River Formation, sec. 32, T. 33 N., R. 90 W. (loc. 64, pl. 1)*

[Measured by P. E. Soister, R. L. Koogle, and J. P. McDowell]

	Feet
Wind River Formation:	
Upper coarse-grained facies:	
12. Sandstone, light-gray to grayish-yellow, very coarse grained to granular, arkosic; conglomeratic in part with pebbles and cobbles of light-gray granite	22
11. Shale, brownish-gray to black, carbonaceous; coaly in part	4
10. Sandstone, olive-brown to grayish-yellow, fine-grained to very coarse grained, arkosic	10
9. Siltstone, olive-brown to light-gray; clayey in part	27
8. Sandstone, dusky-yellow, fine-grained; silty in part; abundant biotite grains	3
7. Sandstone, yellow-gray, coarse-grained to very coarse grained, arkosic	12
6. Sandstone, gray, very fine-grained to fine-grained; limonitic in part	6
5. Sandstone, light-yellow to light-gray, medium- to coarse-grained, arkosic; lenses of siltstone and large concretions of hard calcareous sandstone	16

12. *Partial section of upper part of Wind River Formation, sec. 32, T. 33 N., R. 90 W. (loc. 64, pl. 1)*—Continued

	Feet
Wind River Formation—Continued	
Upper coarse-grained facies—Continued	
4. Conglomerate; cobbles and boulders of granite, quartzite, and chert	18
3. Siltstone, light greenish-gray; clayey in part	3
2. Sandstone, yellow-gray, very coarse grained, arkosic; silty in part	7
1. Siltstone, dusky-yellow to light-gray and olive-gray; clayey in part	11
Total Wind River Formation measured	139

13. *Generalized section of lower Eocene and Paleocene rocks, Continental Oil Co., Moneta Hills 11-1, sec. 11, T. 37 N., R. 91 W. (loc. 27, pl. 1)*

[Sample study by W. R. Keefer]

	Depth (feet)
Lower Eocene rocks, undivided:	
13. Sandstone, white to light-gray, fine- to coarse-grained, arkosic; coarse grains are chert, quartz, and feldspar; a few thin beds of gray to light-greenish-gray claystone and siltstone	0–560
12. Claystone and siltstone, gray to greenish-gray; carbonaceous in part; a few thin beds of fine-grained sandstone; abundant ostracodes and other shell fragments at 740 ft	560–850
11. Sandstone, white to gray, coarse-grained; abundant angular grains of quartz and feldspar	850–890
10. Claystone, shale, and siltstone, gray, dark-gray, and black; numerous thin beds of white to grayish-green fine- to coarse-grained sandstone	890–1, 360
9. Shale and claystone, gray to pale-green, red; tan mottled in part; lower 20 ft mostly medium- to coarse-grained sandstone	1, 360–1, 640
8. Claystone, shale, and siltstone, highly varicolored gray, olive-green, red, purple, and tan; scattered carbonaceous layers	1, 640–1, 970
7. Sandstone, white to light-gray, fine-grained	1, 970–2, 000
6. Claystone, siltstone, and shale, varicolored gray, olive-green, and red; carbonaceous in part; a few thin beds of fine- to medium-grained sandstone	2, 000–2, 300
5. Shale, claystone, and siltstone, gray to dark-gray and black (red in part), highly carbonaceous; a few thin beds of white to gray fine-grained sandstone; abundant ostracodes and other shell fragments at 2,520 and 3,170 ft	2, 300–3, 690
4. Shale, claystone, and siltstone, dark-gray to black; highly carbonaceous; numerous 5- to 20-ft beds of white to gray fine- to medium-grained sandstone	3, 690–4, 790

13. *Generalized section of lower Eocene and Paleocene rocks, Continental Oil Co., Moneta Hills 11-1, sec. 11, T. 37 N., R. 91 W. (loc. 27, pl. 1)*—Continued

	Depth (feet)
Lower Eocene rocks, undivided—Continued	
3. Sandstone, white, fine- to coarse-grained; sporadic green mineral grains; some dark-gray to black shale and claystone; ostracodes at 4,900 feet	4, 790–4, 940
Total lower Eocene rocks	4, 940
Gradational contact.	
Fort Union Formation:	
Shotgun Member:	
2. Shale and claystone, dark-gray to black; slightly to moderately micaceous, carbonaceous in part; some white fine- to medium-grained sandstone with abundant white mica and green mineral grains	4, 940–5, 400
Waltman Shale Member:	
1. Shale, black, silty, micaceous	5, 400–5, 945+
Bottom of well.	

LITERATURE CITED

Bigelow, H. B., and Schroeder, W. C., 1948, Sharks, pt. 3 *of* Fishes of the Western North Atlantic: Sears Found. Marine Research Mem. 1 Yale University, p. 59–576.

Bradley, W. H., 1926, Shore phases of the Green River Formation in northern Sweetwater County, Wyoming: U.S. Geol. Survey Prof. Paper 140–D, p. 121–139.

——— 1959, Revision of stratigraphic nomenclature of Green River Formation of Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 5, p. 1072–1075.

Brown, R. W., 1938, The Cretaceous-Eocene boundary in Montana and North Dakota [abs.]: Washington Acad. Sci. Jour., v. 28, no. 9, p. 421–422.

——— 1958, Fort Union Formation in the Powder River Basin, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf., Powder River Basin, Wyoming, 1958: p. 111–113.

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the western interior of the United States: Geol. Soc. America Bull., v. 63, no. 10, p. 1011–1044.

Cross, Whitman, and Spencer, A. C., 1899, Description of the La Plata quadrangle [Colorado]: U.S. Geol. Survey Geol. Atlas, Folio 60, 14 p.

Darton, N. H., 1906a, Geology of the Owl Creek Mountains: U.S. 59th Cong., 1st sess., S. Doc. 219, 48 p.

———1906b, Geology of the Bighorn Mountains: U.S. Geol. Survey Prof. Paper 51, 129 p.

Dobbin, C. E., Bowen, C. F., and Hoots, H. W., 1929, Geology and coal and oil resources of the Hanna and Carbon Basins, Carbon County, Wyoming: U.S. Geol. Survey Bull. 804, 88 p.

Dorf, Erling, 1959, Climatic changes of the past and present: Michigan Univ. Mus. Paleontology Contr., v. 13, no. 8, p. 181–210.

Dorr, J. A., Jr., 1956, Post-Cretaceous geologic history of the Hoback Basin area, central western Wyoming, *in* Wyoming Geol. Assoc. Guidebook 11th Ann. Field Conf., Jackson Hole area, 1956: p. 99–108.

——— 1958, Early Cenozoic vertebrate paleontology, sedimentation, and orogeny in central western Wyoming: Geol. Soc. America Bull., v. 69, no. 10, p. 1217–1243.

Eldridge, G. H., 1894, A geological reconnaissance in northwest Wyoming, with special reference to its economic resources: U.S. Geol. Survey Bull. 119, 72 p.

Fox, S. K., Jr., and Ross, R. J., Jr., 1942, Foraminiferal evidence for the Midway (Paleocene) age of the Cannonball formation in North Dakota: Jour. Paleontology, v. 16, no. 5, p. 660–673.

Gazin, C. L., 1961, Occurrences of Paleocene mammalia in Tertiary basins of Wyoming *in* Wyoming Geol. Assoc. Guidebook 16th Ann. Field Conf., Symposium on Late Cretaceous rocks, 1961: p. 47–52.

Granger, Walter, 1910, Tertiary faunal horizons in the Wind River Basin, Wyoming, with descriptions of new Eocene mammals: Am. Mus. Nat. History Bull., v. 28, p. 235–251.

——— 1914, On the names of lower Eocene faunal horizons of Wyoming and New Mexico: Am. Mus. Nat. History Bull., v. 33, p. 201–207.

Grutt, E. W., Jr., 1956, Uranium deposits in Tertiary sedimentary rocks in Wyoming and northern Colorado, *in* Page, L. R., Stocking, H. E., and Smith, H. B., compilers, Contributions to the geology of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 361–370.

Hansen, Miller, 1956, Geologic map of North Dakota: North Dakota Geol. Survey.

Hares, C. J., 1946, Geologic map of the southeastern part of the Wind River Basin and adjacent areas in central Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map 51.

Hatcher, J. B., 1903, Relative age of the Lance Creek (Ceratops) beds of Converse County, Wyoming, the Judith River beds of Montana and the Belly River beds of Canada: Am. Geologist, v. 31, p. 369–375.

Hay, R. L., 1956, Pitchfork formation, detrital facies of early basic breccia, Absaroka Range, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 8, p. 1863–1898.

Hayden, F. V., 1869, Geological report of the exploration of the Yellowstone and Missouri Rivers: U.S. 40th Cong., 2d sess. S. Exec. Doc. 77, 174 p.

Hewett, D. F., 1914, The Shoshone River section, Wyoming: U.S. Geol. Survey Bull. 541–C, p. 89–113.

——— 1926, Geology and oil and coal resources of the Oregon Basin, Meeteetse, and Grass Creek Basin quadrangles, Wyoming: U.S. Geol. Survey Prof. Paper 145, 111 p.

Hose, R. K., 1955, Geology of the Crazy Woman Creek area, Johnson County, Wyoming: U.S. Geol. Survey Bull. 1027–B, p. 33–118.

Houston, R. S., and Murphy, J. F., 1963, Titaniferous black sandstone deposits of Wyoming: Wyoming Geol. Survey Bull. 49, 120 p.

Jepsen, G. L., 1940, Paleocene faunas of Polecat Bench formation, Park County, Wyoming, Pt. 1: Am. Philos. Soc. Proc., v. 83, no. 2, p. 231–238.

Jones, W. A., 1874, Report upon the reconnaissance of northwestern Wyoming in 1873: U.S. 43d Cong., 1st sess. H.R. Exec. Doc. 285, 210 p.

Kay, G. M., 1955, Sediments and subsidence through time, *in* Poldervaart, Arie, ed., Crust of the earth—a symposium: Geol. Soc. America Spec. Paper 62, p. 665–684.

Keefer, W. R., 1957, Geology of the Du Noir area, Fremont County, Wyoming: U.S. Geol. Survey Prof. Paper 294–E, p. 155–221.

Keefer, W. R., 1960. Progressive growth of anticlines during Late Cretaceous and Paleocene time in central Wyoming, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400B, p. B233–B236.

——— 1961, Waltman shale and Shotgun members of Fort Union formation (Paleocene) in Wind River Basin, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 8, p. 1310–1323.

Keefer, W. R., and Rich, E. I., 1957, Stratigraphy of the Cody shale and younger Cretaceous and Paleocene rocks in the western and southern parts of the Wind River Basin, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 12th Ann. Field Conf., Southwest Wind River Basin, 1957: p. 71–78.

Keefer, W. R., and Troyer, M. L., 1956, Stratigraphy of the Upper Cretaceous and lower Tertiary rocks of the Shotgun Butte area, Fremont County, Wyoming: U. S. Geol. Survey Oil and Gas Inv. Chart OC–56.

——— 1964, Geology of the Shotgun Butte area, Fremont County, Wyoming: U.S. Geol. Survey Bull. 1157, 123 p.

Knight, S. H., 1951, The Late Cretaceous-Tertiary history of the northern portion of the Hanna Basin, Carbon County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 6th Ann. Field Conf., South-central Wyoming, 1951: p. 45–53.

Knowlton, F. H., 1922, The Laramie flora of the Denver Basin, with a review of the Laramie problem: U.S. Geol. Survey Prof. Paper 130, 175 p.

Lloyd, E. R., and Hares, C. J., 1915, The Cannonball marine member of the Lance formation of North and South Dakota and its bearing on the Lance-Laramie problem: Jour. Geology, v. 23, no. 6, p. 523–547.

Love, J. D., 1939, Geology along the southern margin of the Absaroka Range, Wyoming: Geol. Soc. America Spec. Paper 20, 134 p.

——— 1954a, Periods of folding and faulting during late Cretaceous and Tertiary time in Wyoming [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 6, p. 1311–1312.

——— 1954b, Preliminary report on uranium in the Gas Hills area, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Circ. 352, 11 p.

——— 1956, Cretaceous and Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming, *in* Wyoming Geol. Assoc., Guidebook 11th Ann. Field Conf., Jackson Hole area, Wyoming, 1956: p. 75–94.

——— 1960, Cenozoic sedimentation and crustal movement in Wyoming (Bradley volume): Am. Jour. Sci., v. 258–A, p. 204–214.

——— 1961, Split Rock formation (Miocene) and Moonstone formation (Pliocene) in central Wyoming: U.S. Geol. Survey Bull. 1121–I, 37 p.

Love, J. D., Weitz, J. L., and Hose, R. K., 1955, Geologic map of Wyoming: U.S. Geol. Survey.

McGrew, P. O., and Roehler, H. W., 1960, Correlation of Tertiary units in southwestern Wyoming, *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., Overthrust belt of southwestern Wyoming and adjacent areas, 1960: p. 156–158.

Mapel, W. J., 1959, Geology and coal resources of the Buffalo-Lake De Smet area, Johnson and Sheridan Counties, Wyoming: U.S. Geol. Survey Bull. 1078, 148 p.

Mapel, W. J., Robinson, C. S., and Theobald, P. K., Jr., 1959, Geologic and structure contour map of the northern and western flanks of the Black Hills, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Oil and Gas Inv. Map OM–191.

Meek, F. B., and Hayden, F. V., 1861, Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska Territory, with some remarks on the rocks from which they were obtained: Acad. Nat. Sci. Philadelphia Proc., v. 13, p. 415–448.

Murphy, J. F., and Love, J. D., 1958, Tectonic development of the Wind River Basin, central Wyoming [abs.], *in* Am. Assoc. Petroleum Geologists Rocky Mtn. Sec., Geol. rec., 1958: p. 126–127.

Murphy, J. F., Privrasky, N. C., and Moerlein, G. A., 1956, Geology of the Sheldon-Little Dome area, Fremont County, Wyo.: U.S. Geol. Survey Oil and Gas Inv. Map OM–181.

Murphy, J. F., and Roberts, R. W., 1954, Geology of the Steamboat Butte-Pilot Butte area, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–151.

Paape, D. W., 1961, Tectonics and its influence on Late Cretaceous and Tertiary sedimentation, Wind River Basin, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 16th Ann. Field Conf., Symposium on Late Cretaceous Rocks of Wyoming, 1961: p. 187–194.

Pierce, W. G., 1957, Heart Mountain and South Fork detachment thrusts of Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 4, p. 591–626.

Pipiringos, G. N., 1961, Uranium-bearing coal in the central part of the Great Divide Basin: U.S. Geol. Survey Bull. 1099–A, p. 1–104.

Rich, E. I., 1958, Stratigraphic relation of latest Cretaceous rocks in parts of Powder River, Wind River, and Big Horn Basins, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 10, p. 2424–2443.

——— 1962, Reconnaissance geology of Hiland-Clarkson Hill area, Natrona County, Wyoming: U.S. Geol. Survey Bull. 1107–G, p. 447–540.

Rosholt, J. N., 1958, Radioactive disequilibrium studies as an aid in understanding the natural migration of uranium and its decay products, *in* United Nations, Survey of raw materials resources: Internat. Conf. Peaceful Uses Atomic Energy, 2d, Geneva 1958, Proc., v. 2, p. 230–236.

St. John, O. H., 1883, Report on the geology of the Wind River district, *in* Hayden, F. V., 12th Ann. Report, U.S. Geol. Geog. Survey Terr., Pt. 1, 1878: p. 173–269.

Sinclair, W. J., and Granger, Walter, 1911, Eocene and Oligocene of the Wind River and Bighorn Basins: Am. Mus. Nat. History Bull., v. 30, p. 83–117.

Stanton, T. W., 1910, Fox Hills Sandstone and Lance Formation ("Ceratops beds") in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th, v. 30, p. 172–188.

Stokes, William Lee, 1960, Essentials of earth history; an introduction to historical geology: Englewood Cliffs, N.J., Prentice-Hall, Inc., 502 p.

Thompson, R. M., Troyer, M. L., White, V. L., and Pipiringos, G. N., 1950, Geology of the Lander area, central Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–112.

Thompson, R. M., and White, V. L., 1952, The coal deposits of Alkali Butte, the Big Sand Draw, and the Beaver Creek fields, Fremont County, Wyoming: U.S. Geol. Survey Circ. 152, 24 p.

——— 1954, Geology of the Riverton area, central Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–127.

Tourtelot, H. A., 1946, Tertiary stratigraphy in the northeastern part of the Wind River Basin, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Chart OC–22.

Tourtelot, H. A., 1948, Tertiary rocks in the northeastern part of the Wind River Basin, Wyo., *in* Wyoming Geol. Assoc. Guidebook 3d Ann. Field Conf., Wind River Basin, 1948: p. 112–124.

——— 1953, Geology of the Badwater area, central Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–124.

——— 1957, Geology, Part 1 *of* The geology and vertebrate paleontology of upper Eocene strata in the northeastern part of the Wind River Basin, Wyoming: Smithsonian Misc. Colln. v. 134, 27 p.

——— 1962, Preliminary investigation of the geologic setting and chemical composition of the Pierre Shale, Great Plains Region: U.S. Geol. Survey Prof. Paper 390, 74 p.

Tourtelot, H. A., and Thompson, R. M., 1948, Geology of the Boysen area, central Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–91.

Troyer, M. L., and Keefer, W. R., 1955, Geology of the Shotgun Butte area, Fremont County, Wyo.: U.S. Geol. Survey Oil and Gas Inv. Map OM–172.

Van Houten, F. B., 1944, Stratigraphy of the Willwood and Tatman formations in northwestern Wyoming: Geol. Soc. America Bull., v. 55, no. 2, p. 165–210.

——— 1945, Review of latest Paleocene and early Eocene mammalian faunas: Jour. Paleontology, v. 19, no. 2, p. 421–461.

——— 1948, Origin of red-banded early Cenozoic deposits in Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., v. 32, no. 11, p. 2083–2126.

——— 1954, Geology of the Long Creek-Beaver Divide area, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–140.

——— 1955, Volcanic-rich middle and upper Eocene sedimentary rocks northwest of Rattlesnake Hills, central Wyoming: U.S. Geol. Survey Prof. Paper 274–A, p. 1–14.

——— 1961, Maps of Cenozoic depositional provinces, western United States: Am. Jour. Sci., v. 259, no. 8, p. 612–621.

Van Houten, F. B., and Weitz, J. L., 1956, Geologic map of the eastern Beaver Divide-Gas Hills area, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–180.

Weed, W. H., 1896, The Fort Union formation: Am. Geologist, v. 18, p. 201–211.

Weimer, R. J., 1960, Upper Cretaceous stratigraphy, Rocky Mountain area: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 1–20.

Wilson, L. R., and Hoffmeister, W. S., 1955, Morphology and geology of the Hystrichosphaerida [abs.]: Jour. Paleontology, v. 29, no. 4, p. 735.

Wood, H. E., 2d, and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, no. 1, 1–48.

Woodruff, E. G., and Winchester, D. E., 1912, Coal Fields of the Wind River region, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Bull. 471–G, p. 516–564.

Yenne, K. A., and Pipiringos, G. N., 1954, Stratigraphic sections of Cody Shale and younger Cretaceous and Paleocene rocks in the Wind River Basin, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Chart OC–49.

Zeller, H. D., 1957, The Gas Hills uranium district and some probable controls for ore deposition, *in* Wyoming Geol. Assoc. Guidebook 12th Ann. Field Conf., Southwest Wind River Basin, 1957: p. 156–160.

Zeller, H. D., Soister, P. E., and Hyden, H. J., 1956, Preliminary geologic map of the Gas Hills uranium district, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Mineral Inv. Map MF–83.

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