# Reconnaissance Geology of Hiland-Clarkson Hill Area, Natrona County Wyoming

GEOLOGICAL SURVEY BULLETIN 1107-G

*Prepared on behalf of the U.S. Atomic Energy Commission*

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*By* ERNEST I. RICH

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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[Plates are in pocket]



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By Ernest I. Rich


## ABSTRACT

The Hiland-Clarkson Hill area lies in the eastern third of the Wind River structural basin and includes about 860 square miles of the west-central part of Natrona County, Wyo. The city of Casper, Wyo., is about 20 miles east of the area.

Rocks ranging in age from Precambrian to Recent crop out along the margins of the basin, and rocks of early Eocene age fill the central part of the basin and lap uncomformably onto older rocks. Strata of Oligocene and Miocene age are exposed south of the basin-margin and lap northward onto older rocks. This report, however, is concerned only with the rock formations of Late Cretaceous and Tertiary age.

The Upper Cretaceous series is represented by the Frontier, Cody, Mesaverde, Lewis, Meeteetse, and Lance formations, in ascending order. The aggregate thickness of these formations is about 9,500 feet, and the rocks are of marine, brackish-water, and nonmarine origin. The Frontier formation and Cody shale represent deposition in an offshore marine environment and consist of about 5,800 feet of dark-gray shale and lenticular sandstone beds. The basal member of the Mesaverde formation, the Parkman sandstone, consists of massive to bedded sandstone about 100 feet thick and represents deposition in a nearshore marine environment. It is probably a regressive sandstone deposited near the shoreline of the eastward-retreating Late Cretaceous sea. The unnamed middle member of the Mesaverde formation is gradational with the underlying Parkman sandstone member. It ranges in thickness from 400 to 800 feet and represents deposition in an environment of coastal swamps and flood plains landward from the retreating shoreline. The Teapot sandstone, the upper member of the Mesaverde formation, is a relatively thin layer of sandstone, 50 to 125 feet thick. The lithologic character and areal and stratigraphic distribution of the Teapot sandstone is inconsistent with the normal pattern of regressive and transgressive deposition suggested by the overlying and underlying rocks; hence it represents a sudden change in sedimentation, perhaps as a result of a rather sharp orogenic pulse in the source area. The Lewis shale, which can be divided into upper and lower tongues, has an aggregate thickness of about 500 feet and the tongues represent a fairly rapid transgression of the

Late Cretaceous sea. The Meeteetse formation, about 800 feet thick, is the nonmarine equivalent of the Lewis shale, and it intertongues eastward with the Lewis shale. The Lance formation, the uppermost formation of Late Cretaceous age, is about 1,700 feet thick and represents deposition in a flood plain, or locally marine to brackish-water, environment.

The Tertiary rocks include, in ascending order, the Fort Union formation of Paleocene age, the Wind River formation of early Eocene age, the White River formation of early Oligocene age, and an unnamed sequence of early and middle Miocene age. These formations are about 5,000 feet thick and are wholly of continental origin.

The Fort Union formation, as much as 2,700 feet thick, probably represents filling of a shallow basin formed at the close of Late Cretaceous time. The basin was deepened and deformed during a phase of the Laramide orogeny at the end of Paleocene time, and strata of the Wind River formation, consisting of sediments derived from the surrounding highlands, filled the central part of the basin. These strata make up the lower fine-grained facies of the Wind River formation and range in thickness from 300 to about 4,000 feet. Near the end of early Eocene time coarse-grained and conglomeratic arkosic sandstone, probably derived from the Granite Mountains about 10 miles south of the mapped area, was deposited along the southern margin of the basin. These strata make up the upper coarse-grained facies of the Wind River formation and are as much as 1,000 feet thick. No rocks of middle and late Eocene age were recognized in the mapped area. Strata of the White River formation unconformably overlie the upper coarse-grained facies of the Wind River formation and older rocks. The White River consists of 12 to 50 feet of granite-boulder conglomerate overlain by about 800 feet of tuffaceous siltstone, sandstone, and relatively pure tuff. The source area for the sediments making up the White River formation was probably the Absaroka Range. At the close of Oligocene time, the rocks were gently folded and deeply eroded. Rocks of early and middle Miocene age fill channels cut into the White River formation. The lower and middle Miocene rocks consist predominantly of tuffaceous sandstone with intercalated sandstone and siltstone lenses. These rocks are about 1,500 feet thick and represent deposition on a broad flood plain. They are the youngest Tertiary rocks exposed in the Hiland-Clarkson Hill area.

The principal structural feature of the area is the northwestward-plunging asymmetrical syncline that forms the southeastern end of the Wind River Basin. The northeastern limb of this syncline has been modified by folding and faulting contemporaneous with, and subsequent to, the deposition of the Tertiary rocks. The southern limb of the syncline has been modified by the North Granite Mountain fault zone, which, in the subsurface, has a displacement of 4,000 to 5,000 feet. The faulting probably took place during middle and late Eocene time. Post-Miocene movement along this fault zone has displaced the Eocene and younger strata only about 175 feet.

Areas of anomalous radioactivity occur in the Wind River and White River formations. Small amounts of uranium have been found in two places within the Hiland-Clarkson Hill area—one near the town of Hiland and the other in the White River formation near Clarkson Hill in the southeastern part of the area. In general, the percent of uranium found in rock samples collected from the areas of anomalously high radioactivity is less than the equivalent uranium. A few water samples contain more uranium than average and those with the highest amount, exclusive of those from the mineralized areas, are at or near the structurally low synclinal axis of the Wind River Basin.

Accumulations of oil and gas may occur in updip stratigraphic traps in the zone of intertonguing between the Cody and Mesaverde formations.

Coal beds are exposed in the Hiland-Clarkson Hill area, but none of the beds are being mined commercially.

Sandstone deposits containing titanium-bearing minerals crop out near Clarkson Hill and Pine Mountain.

## INTRODUCTION

### LOCATION AND EXTENT OF AREA

The Hiland-Clarkson Hill area is near the geographic center of Wyoming in west- and south-central Natrona County. It is a narrow, irregular-shaped area trending about N. 45° W. and covers about 860 square miles in the eastern third of the Wind River structural basin (fig. 78). It is bounded on the southwest by the Rattlesnake Hills anticline, on the northeast by the Powder River lineament, and

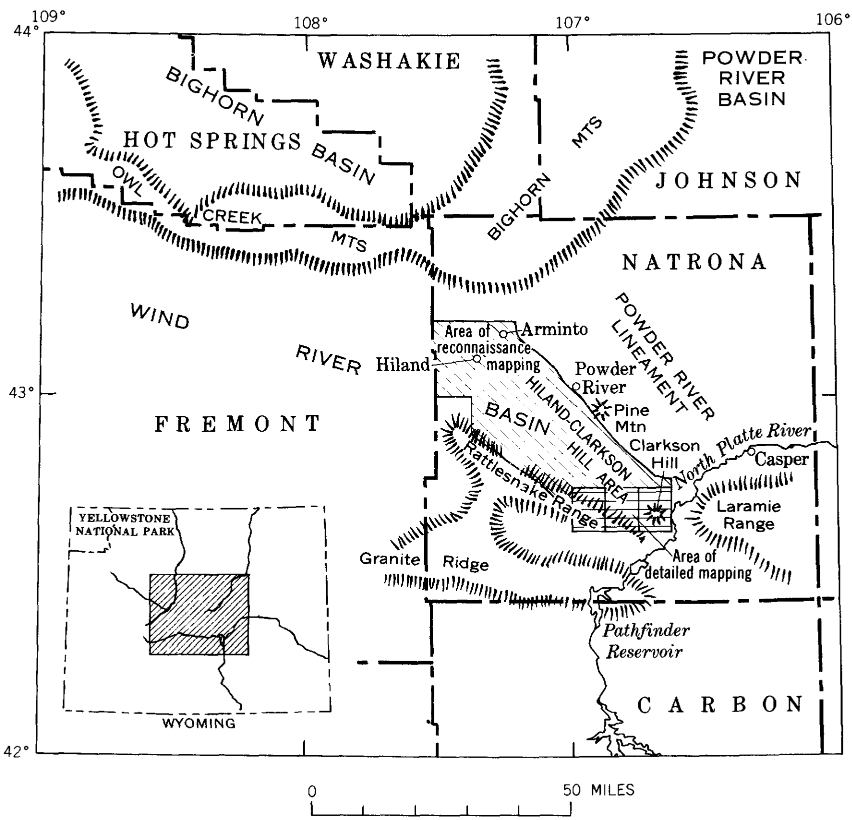


FIGURE 78.—Index map of central Wyoming showing location of Hiland-Clarkson Hill area with relation to major physiographic features.

on the east by the North Platte River. The Fremont-Natrona County boundary was selected arbitrarily as the western limit. The area takes its name from the Hiland post office near the western boundary and from Clarkson Hill, a high mesa, along the eastern edge of the area.

## PURPOSE AND SCOPE OF REPORT

The objectives of this study are to present basic data for use in exploration for uranium. The data include thicknesses, lateral variations, and relative ages of the various stratigraphic units, present structural configuration, and the tectonic and sedimentational history of the area. Special attention is given to recording and interpreting the stratigraphic and structural data of the Tertiary rocks as a basis for appraising the potential uranium of the area and for comparing the geologic conditions that may have influenced uranium deposition in this part of the Wind River Basin with those in the productive Gas Hills area, which adjoins the Hiland-Clarkson Hill area to the west.

## PRESENT INVESTIGATION

This report is based on fieldwork done during the summers of 1955 and 1956 and 2 weeks in 1957. The first field season was spent in reconnaissance mapping to determine the general geologic relations of the various rock units and to outline, for more detailed study, those areas most favorable for the accumulation of uranium. As a result of the findings during the first field season, the Clarkson Hill, Benton Basin NE, and the McCleary Reservoir 7½-minute topographic maps in the southeastern part of the basin were considered most significant and were mapped in more detail. The areas of reconnaissance and detailed mapping are shown on figure 78.

The reconnaissance map (pl. 6) was compiled on aerial photographs at a scale of 1:20,000, and the data were transferred by use of a vertical sketchmaster to a base map of Natrona County, Wyo., prepared by the Wyoming Highway Department. The detailed mapping was done on U.S. Geological Survey 7½-minute topographic maps at a scale of 1:24,000 (pl. 7). Stratigraphic sections of major units were measured by planetable and alidade; smaller units were measured by compass and tape.

## PREVIOUS INVESTIGATION

No comprehensive report on the geology of the Hiland-Clarkson Hill area has been published; however, the geology of the area has been included in published reports and geologic maps of much larger areas in central Wyoming. In 1859 and 1860, Hayden (1869) made a reconnaissance study of a large part of Wyoming, and in the report he very briefly described the geography and tectonic history of the region surrounding the Hiland-Clarkson Hill area. Knight (1895) prepared for the U.S. Geological Survey a summary of the coal fields of Wyoming, in which the coal-bearing strata along the northeastern flank of the Rattlesnake Hills anticline were described. In a report on the artesian basins of Wyoming, Knight (1900) first recognized the fault system within the Hiland-Clarkson Hill area. Later (Knight and Slosson, 1901) he prepared a report concerning the oil potential along the southern margin of the Wind River Basin and included a generalized description of some of the Upper Cretaceous units. Darton (1908) prepared his studies of the Paleozoic and Mesozoic rocks of central Wyoming, of which the Hiland-Clarkson Hill area was a small part. Woodruff and Winchester (1912) made a detailed study of the Cretaceous and Tertiary coal resources of the Wind River structural basin. Hares (1916) prepared a brief report on the anticlines in central Wyoming and examined several localities within the area of this report; Hare (1946) also prepared his reconnaissance geologic map of the southeastern end of the Wind River structural basin. A geologic map of Natrona County, Wyo. (Weitz and others, 1954), and the geologic map of Wyoming (Love and others, 1955) are the most recent maps showing the geology of the area. Tourtelot (1953, 1957) gave comprehensive accounts of the Tertiary geology in the Badwater area that adjoins the Hiland-Clarkson Hill area on the north; Zeller and others (1956) prepared a preliminary map of the Gas Hills uranium-producing area (pl. 6), which is contiguous on the west with the area covered by this report.

In addition to the reports listed above and those cited in the list of references, several graduate students from the University of Wyoming have prepared theses on small areas within and adjacent to the Hiland-Clarkson Hill area. The authors and the titles of their theses are:

Berry, R. M., 1950, Tertiary stratigraphy of the Bates Hole-Alcova region, central Wyoming.

Bogrett, J. W., 1951, Geology of the northwestern end of the Rattlesnake Hills, Natrona County, Wyoming.

Faulkner, G. L., Geology of the Bessemer Mountain-Oil Mountain area, Natrona County, Wyoming.

Larsen, J. H., 1951, Ground water conditions of a part of the Kendrick project, Natrona County, Wyoming.

Rachou, J. F., 1951, Tertiary stratigraphy of the Rattlesnake Hills, central Wyoming.

Roehler, H., 1957, Geology of the Bates Hole region, Wyoming.

Willis, J. G., 1955, Geology of the Pine Mountain area, Natrona County, Wyoming.

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## ACKNOWLEDGMENTS

The project was directed by E. J. McKay of the U.S. Geological Survey for the first 2 months of 1955 and by the writer for the succeeding 2 months of 1955 and for the field season of 1956 and 1957. In 1955 Ernest Espenshade assisted in the mapping of the Tertiary rocks in the western part of the area. W. K. Clark collaborated with the writer during the 1956 field season in mapping and in measuring several stratigraphic sections of Upper Cretaceous and Tertiary rocks in the southeastern part of the area. All phases of the investigation were supervised by J. D. Love and W. R. Keefer, whose cooperation and suggestions greatly facilitated the preparation of this report.

Most identifications and age determinations of fossils were made by paleontologists of the U.S. Geological Survey. The Late Cretaceous invertebrate marine fossils were identified by W. A. Cobban. C. L. Gazin of the U.S. National Museum identified the Paléocene and Eocene vertebrate fossils, and G. E. Lewis of the U.S. Geological Survey identified the Oligocene and Miocene vertebrates. Plant spore and pollen from the Oligocene rocks were identified by Estella Leopold. Radiometric, chemical, and mineralogic determinations were made by personnel of the U.S. Geological Survey laboratories.

The work upon which this report is based was done by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

## GEOGRAPHY

### DRAINAGE AND TOPOGRAPHY

The Hiland-Clarkson Hill area includes parts of the Wind River, Powder River, and North Platte River drainage systems, all in the Missouri River watershed. In the mapped area (pl. 6), Alkali and Poison Creeks flow westward, join the Wind River near the town of Shoshoni, and then flow into the Missouri River by way of the Bighorn and Yellowstone Rivers. The central part of the area is drained by the South Fork of the Powder River, which flows northeastward into the Powder River and the Yellowstone River. In the eastern and southern parts of the area, the Rattlesnake Hills separate the northward-flowing tributaries of the North Platte River from the southward-flowing tributaries of the Sweetwater River. The Sweetwater River joins the North Platte River at the Pathfinder Reservoir, about 10 miles south of the mapped area. The North Platte River, which flows northward along the eastern edge of the mapped area, flows eastward near Casper, Wyo. and eventually reaches the Missouri by way of the Platte River.

The North Platte River is the only perennial stream in the area partly because its flow is regulated by the several reservoirs along its course. Poison Spider Creek, T. 33 N., Rs. 83–86 W., and the South Fork of Casper Creek, Tps. 33 and 34 N., Rs. 84 and 85 W. (pl. 6), which head in the Rattlesnake Hills, contain water throughout much of the year but may become dry during midsummer. Henderson Creek, T. 31 N., R. 85 W. (pl. 7), a relatively short southward-flowing tributary of the Sweetwater River, is fed by several springs along its course; hence this stream flows throughout the early part of the summer. All the remaining streams and their tributaries flow only after rains or during the spring runoff period. Earth dams have been built along many of these streams to store water for cattle during the summer months.

Several springs and seeps occur along the surface trace of some of the larger faults; however, the accumulative flow of these springs is not sufficient to maintain a constant flow of water in any streams.

The maximum relief in the mapped area is about 2,140 feet. The altitude ranges from about 5,200 feet above sea level along the North Platte River to about 7,340 feet on top of Horse Heaven, T. 32 N., R. 85 W. (pl. 7), a high mesa at the eastern end of the Rattlesnake Hills. The topographically lower part of the Wind River Basin ranges in altitude from about 5,640 feet near Poison Spider Creek to about 6,420 feet near Hiland. The crest of the Rattlesnake Hills drainage divide within the Hiland-Clarkson Hill area rises from an altitude of 6,600 feet in the southeast to 7,340 feet near Horse Heaven. Westward from Horse Heaven and outside of the mapped area, the Rattlesnake Hills rise to a maximum altitude of about 9,300 feet.

In addition to forming a drainage divide, the Rattlesnake Hills mark a boundary between two distinct types of topography. To the north, the Wind River Basin is etched out of tilted or horizontal Tertiary rocks, whereas the Sweetwater plateau, which lies to the south, is relatively flat and undissected. When viewed from a distance, the land surface in the Wind River Basin appears to be a relatively smooth plane that dips away from the margins toward the central part of the basin; however, this plane is deeply dissected and locally has extensive badland topography. Conspicuous examples of the badland topography can be seen at Hells Half Acre, T. 35 N., R. 86 W., and near the head of Coyote Creek, Tps. 33 and 34 N., R. 86 W.

The drainage divide between the Wind River and the Powder River is a broad northward-trending arch, locally called the Hiland arch. The divide is not conspicuous inasmuch as the land surface slopes away from the divide at a very low angle; the average slope is about 35 feet per mile.

## CLIMATE AND VEGETATION

Although the climate of most of the area is arid, the crest and slopes of the Rattlesnake Hills are semiarid. The lower parts of the basin receive an average annual rainfall of about 10 inches; the gaging stations of the U.S. Weather Bureau, located in or near the Hiland-Clarkson Hill area, record an average annual precipitation ranging from 6.8 inches at Arminto to 14.15 inches at Casper, Wyo. More than half the annual precipitation falls during the months of April, May, June, and July. The precipitation is inadequate for farming, and cultivation of crops is successful only where additional water is supplied by irrigation.

There are no temperature-recording stations within the Hiland-Clarkson area; however, the average temperature at Casper is 48° F and at the Pathfinder Reservoir, about 10 miles south of the area, it is 45.6° F. The average monthly temperatures range from a low of 23.2° F during January at the Pathfinder Reservoir to a high of 72.1° F during July at Casper.

Vegetation in the basin area consists mainly of sagebrush, pricklypear, rabbitbrush, and some grass and weeds. Precipitation is somewhat greater in the Rattlesnake Hills, and grasses are more abundant. There are few trees in the topographically lower parts of the basin. Scrub firs and piñon trees grow at the higher altitudes along the Rattlesnake Hills drainage divide.

## TRANSPORTATION AND SETTLEMENT

U.S. Highway 20 and the Chicago, Burlington and Quincy Railroad cross the northwestern part of the area. Many improved and unimproved roads leading away from U.S. Highway 20 make most of the western part of the area readily accessible by automobile. An oiled road from Casper, Wyo., to the Poison Spider and Grieve oil fields provides all-weather access to the central part of the area, and Wyoming State Route 220, just east of the mapped area, provides easy access to the southern and eastern parts.

There are no incorporated towns within the mapped area. Arminto, the largest settlement, is located on the railroad and serves as headquarters for railroad repair crews and as a shipping point for the local ranches. The town of Powder River, near the intersection of U.S. Highway 20 and the South Fork of the Powder River serves as a trading center. Other points of settlement are the Waltman and Hiland post office which provide limited services for local ranchers. At the time of this investigation, there were about 7 inhabited ranches in the area.

## STRATIGRAPHY

### GENERAL FEATURES

The exposed rocks in the southeastern part of the Wind River Basin range in age from Precambrian to Miocene. The Precambrian to Paleocene rock units crop out along the margins of the Wind River structural basin, and the rocks of early Eocene age fill the central part of the basin and lap unconformably onto the Paleocene and older rocks along the margin. No rocks of middle or late Eocene age are thought to be present within the mapped area; however, these rocks are exposed in considerable thickness along Beaver Divide, about 20 miles west of the Hiland-Clarkson Hill area (Van Houten, 1954) and in the Badwater area, adjacent on the north. Rocks of Oligocene and Miocene ages are exposed in the southern part of the area.

The Upper Cretaceous and Tertiary formations were the only rocks studied during the present investigation. The Upper Cretaceous formations are, in ascending order, the Frontier formation, Cody shale, Mesaverde formation, Lewis shale, Meeteetse formation, and the Lance formation. The Frontier, Cody, and Lewis formations are predominantly of marine origin and consist of interbedded shale and sandstone; the Mesaverde, Meeteetse, and Lance formations are predominantly of near-shore and coastal-swamp origin and consist of sandstone, carbonaceous shale, and coal. The aggregate thickness of the Upper Cretaceous rocks is about 9,500 feet. The Tertiary formations include the Fort Union, Wind River, and White River formations of Paleocene, early Eocene, and early Oligocene ages, respectively, and unnamed rocks of early and middle Miocene age. The Tertiary rocks are entirely of continental origin and consist of fluvial conglomerate, sandstone, siltstone, claystone, and tuffaceous sandstone and siltstone. The maximum thickness of these formations is about 5,000 feet. A generalized graphic section of rocks that crop out in the Hiland-Clarkson Hill area is shown in plate 8. The relation of the Upper Cretaceous rock units to the standard reference section for the western interior of the United States is shown in figure 79.

### CRETACEOUS SYSTEM

#### FRONTIER FORMATION

The Frontier formation, the lowermost unit of Late Cretaceous age in the Wind River Basin, is a sequence of sandstone and shale that conformably overlies the Mowry shale of Early Cretaceous age and underlies the Cody shale. As originally defined by Knight (1902, p. 721) from exposures in southwestern Wyoming, the Frontier consists of coal-bearing sandstone and shale at the base and top with an inter-

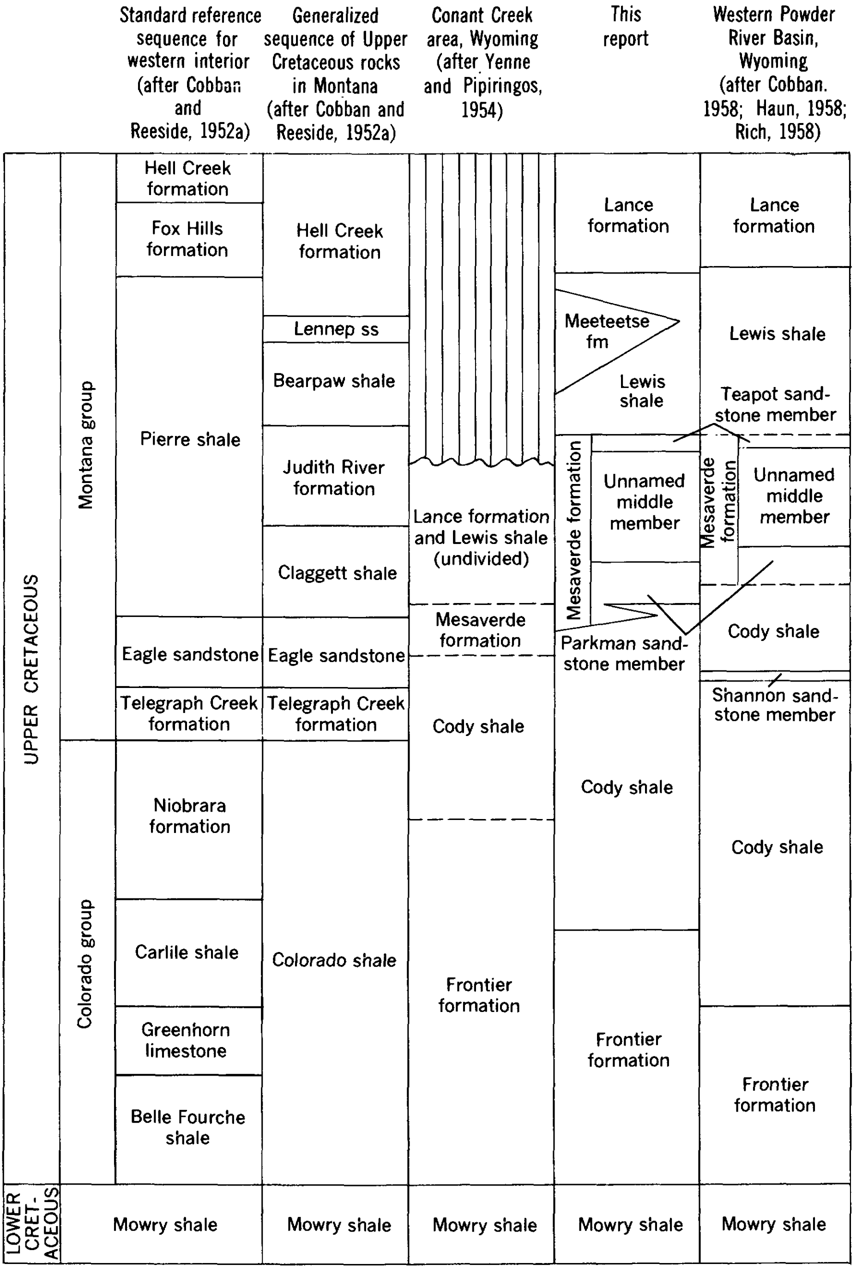


FIGURE 79.—Diagram showing the relation of Upper Cretaceous rocks in the Hiland-Clarkson Hill area to the standard reference sequence for the western interior and to a generalized Montana sequence.

vening marine sandstone and shale unit; however, eastward from the type locality the formation becomes dominantly marine rocks, with fewer and thinner sandstone beds. Later workers have assigned the name Frontier to stratigraphically equivalent beds in the Bighorn Basin (Washburn, 1908; Hintze, 1915; Lupton, 1916; Masters, 1952), the Powder River Basin (Wegemann, 1911; Thom and Spieker, 1932; Towse, 1952; Haun, 1958; and Hose, 1955), and the southeastern part of the Wind River Basin (Cobban and Reeside, 1952b; Hares, 1916, 1946; Thompson and others, 1949; Towse, 1952). In the Powder River Basin some of the prominent sandstone beds have been named, such as the "First, Second, and Third Wall Creek Sands" (Towse, 1952, p. 1965), but the correlation of these sandstone units within the Powder River Basin as well as into adjacent basins is uncertain (Haun, 1958, p. 84), although Towse (1952, fig. 16) considers the upper sandstone bed of the Frontier formation in the Wind River Basin to be equivalent to the "First Wall Creek sand" in the Powder River Basin.

Although the Frontier formation forms a wide, nearly continuous outcrop belt along the Powder River lineament, only the upper few feet of the formation is exposed within the boundaries of the Hiland-Clarkson Hill area (secs. 11 and 14, T. 32 N., R. 81 W.). At this locality the upper sandstone crops out as a resistant ridge encircling the Iron Creek anticline (pl. 6).

The Frontier was not studied in detail by the writer, and the position of the top of the Frontier shown on plate 6 is taken from Hares' (1946) map of the southeastern part of the Wind River Basin. In exposures about 2 miles northwest of the Iron Creek anticline the Frontier is about 850 feet thick and consists of a 5-foot bentonite bed at the base, overlain by about 270 feet of dark-gray to black shale containing several ironstone concretionary beds and some thin bentonite beds. Above the shale unit is a sequence of alternating sandstone and shale about 510 feet thick, capped by about 60 feet of gray to grayish-brown fine- to medium-grained resistant sandstone. This sandstone is conformably overlain by the Cody shale.

In a regional study of the Frontier formation Cobban and Reeside (1952b, p. 68–69) show that the upper sandstone beds in the Frontier formation are progressively older from west to east across Wyoming. They range in age from early Niobrara at the type locality in southwestern Wyoming to late Carlile in the eastern part of the Wind River Basin. Along the western edge of the Powder River Basin, about 20 miles northeast of the Hiland-Clarkson Hill area, the upper part of the Frontier formation is of Greenhorn age (Hose, 1955, p. 60).

Although the exposures of the Frontier formation within the Hiland-Clarkson Hill area are too few to make generalizations concerning the environment of deposition of the formation, it is thought to have been deposited in a shallow sea (Cobban, 1957, p. 70; Haun, 1958, p. 88; Towse, 1952, p. 2001). In general, the change westward from dominantly marine rocks to interbedded marine sandstone and nonmarine sandstone, shale, and coal suggests that at least the upper part of the Frontier formation was deposited along the oscillating shoreline of a westward-transgressing sea.

### CODY SHALE

The Cody shale, which conformably overlies the Frontier formation and underlies the Mesaverde formation, was first named by Lupton (1916, p. 171) from exposures near the town of Cody, Wyo., in the Bighorn Basin. The name has been extended into the western and central parts of the Wind River Basin by Love and others (1947) and Thompson and others (1949). In the Powder River Basin, about 20 miles east of the Hiland-Clarkson Hill area, Cobban and Reeside (1952b, p. 1959, fig. 4) and Heisey (1954, p. 47) divided the stratigraphic interval between the Frontier formation and the Mesaverde formation into the Carlile shale, Niobrara formation, and the Steele shale, in ascending order. This division into formational units is not used in this report because of the apparent lack of a lithologic break within the sequence.

The Cody shale is continuously exposed from near the town of Arminto southeastward to the North Platte River and along the northeastern flank of the Rattlesnake Hills anticline; however, the only exposures within the boundaries of the Hiland-Clarkson Hill area are in Tps. 31 and 32 N., R. 82 W. The lower part of the Cody shale is poorly exposed and forms broad, flat valleys in contrast with the upper part which contain some ledged sandstone beds that form low discontinuous ridges.

The Cody shale is about 4,800 feet thick in the eastern part of the Hiland-Clarkson Hill area, and data from oil wells drilled in the Hiland-Clarkson Hill area indicate that it ranges in thickness from 4,500 feet in the Grieve oil field (T. 32 N., R. 85 W.) to 5,060 feet in the West Poison Spider oil field (T. 33 N., R. 84 W.).

The lithology of the Cody shale was not studied in detail, but in general it is characterized by soft gray to black fissile shale that becomes progressively more silty and sandy toward the top. The shale is commonly bentonitic and limy and is locally fossiliferous. Several of the sandstone beds in the upper part crop out as resistant ledges and attempts have been made to correlate them with the

Shannon and "Sussex" sandstone members of the Steele shale of the Powder River Basin (Heisey, 1954, p. 47; Parker, 1958, p. 90); however, accurate correlations have not been established.

The Cody shale throughout much of the western and central parts of the Wind River Basin ranges in age from early Niobrara into Eagle with all of the intermediate stages represented (Yenne and Pipiringos, 1954). However, in the southeastern part of the basin, a collection of marine invertebrate fossils, from about 50 feet below the top of the Cody shale in the NW¼ sec. 27, T. 32 N., R. 85 W., about 1 mile west of the Grieve oil field, contained *Baculites obtusus* Meek which is Claggett in age. The collection, identified by W. A. Cobban (written communication, 1957) include the following species:

*USGS Mesozoic locality D1167*

Pelecypods:
- *Pteria* cf. *P. linguaeformis* (Evans and Shumard)
- *Ostrea* cf. *O. russelli* Landes
- *Crenella elegantula* Meek and Hayden
- *Ethmocardium* sp.

Gastropods: *Anisomyon* aff. *A. subovatus* (Meek and Hayden)
Cephalopods (Ammonites): *Baculites obtusus*

In the Powder River Basin, about 20 miles east of the Hiland-Clarkson Hill area, Wegmann (1911, p. 53) records a similar species of *Baculite* from about 100 feet below the top of what is herein referred to as the Cody shale.

The paleontological evidence suggests that the upper limit of the Cody shale is progressively younger from west to east across the Wind River Basin in contrast to the lower limit, which is progressively older from west to east. This relation is shown on figure 79.

Although the Cody shale as a whole represents deposition in an offshore marine environment, the progressive increase upward in the grain size of the sediments comprising the upper part of the formation indicates a progressive change in the factors controlling the transportation, sorting, and deposition of the sediment. The presence of fissile shale in the lower part of the Cody suggests slow deposition of mud in relatively deep quiet water; whereas the presence of interbedded sandstone and siltstone in the upper part suggests deposition of less sorted sediment in more shallow and more turbulent water, perhaps at or near the effective wave base. Although this change in the environment of deposition may have marked the beginning of the regression of the Late Cretaceous sea, it is not known whether the change was due to a rise of the bordering landmass, lowering of sea level, or change in the rate of deposition in a stable trough.

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The contact between the Cody shale and the overlying Mesaverde formation is generally placed between sediments deposited in offshore marine environments and those deposited in near-shore and continental environments, respectively. However, because of the oscillatory nature of the shoreline during the regression of the Late Cretaceous sea, intertonguing of the two formations is common.

### MESAVERDE FORMATION

Throughout much of central and southern Wyoming the strata directly overlying the Cody shale, or its equivalent, and underlying the Lewis shale or Meeteetse formation are referred to the Mesaverde formation (Cobban and Reeside, 1952b). In the Hiland-Clarkson Hill area the Mesaverde formation has been divided into three members consisting, from base to top, of the Parkman sandstone member, an unnamed middle member, and the Teapot sandstone member. The Parkman sandstone was originally defined by Darton (1906, p. 59) near Parkman, Wyo., to include all the sandy strata correlative with what is herein referred to as the Mesaverde formation. In a report on the Salt Creek oil field, however, Wegemann (1911, p. 47) considered the Parkman sandstone to be a member of the Pierre formation of the Montana group. In 1918 Wegemann (1918, p. 20–21) revised the stratigraphic nomenclature in the Salt Creek oil field and divided the Montana group into the Steele shale, Mesaverde formation, and Lewis shale, in ascending order. With regard to the Mesaverde formation, he stated:

> Above the * * * [Steele shale] * * * lies a series of sandstone, coal and shale, about 845 feet thick which represents in whole or in part the Mesaverde formation of Colorado and southern Wyoming and to which that name is here applied.
>
> The Mesaverde may be divided into three members—the Parkman sandstone at the base, the Teapot sandstone at the top, and an intervening unnamed member of sandstone and shale.

Hares (1916 and 1946) extended the names Parkman sandstone and Teapot sandstone into the southeastern part of the Wind River Basin, where he applied them to similar units separated by a thick sequence of nonmarine beds. The writer (1958, p. 2427) considers these nonmarine beds between the Parkman sandstone and Teapot sandstone members to be temporal and nonmarine equivalents of the unnamed member of Wegemann.

#### PARKMAN SANDSTONE MEMBER

The Parkman sandstone member of the Mesaverde formation crops out in a narrow belt along the northeastern margin of the Wind River Basin. It is exposed within the mapped area only in Tps. 31

and 32 N., R. 82 W., where it forms an outcrop band around the southeastern end of the Wind River Basin. It commonly crops out as a low ridge between the Cody shale and the overlying unnamed middle member of the Mesaverde formation.

The contact between the Parkman sandstone and the underlying Cody shale is gradational and is placed at the base of the first persistent sandstone overlying the Cody shale. Because of poor exposures and because the rocks grade from predominantly shale and sandy shale below to predominantly sandstone above, the contact must locally be placed arbitrarily within the transition zone.

The Parkman sandstone member consists of light-gray to grayish-orange fine- to medium-grained massive to bedded marine sandstone, containing discontinuous shale lenses, 1 to 2 feet thick, in the lower third of the unit. The grains in a disaggregated sample are angular to subangular and moderately well sorted. The grains are, for the most part, cloudy and clear quartz and feldspar, but the sample also includes a moderate amount of black mica and an unidentified dark mineral. Lenses of brown titaniferous sandstone are present in the upper part of the Parkman in sec. 20, T. 31 N., R. 82 W. (J. F. Murphy, written communication, 1959).

Lithologic descriptions of measured stratigraphic sections of the Parkman sandstone member are given with the discussion of the Teapot sandstone member.

The Parkman is 100 feet thick along the Casper Canal (sec. 16, T. 31 N., R. 82 W.), 87 feet thick near Meadow Creek (sec. 31, T. 33 N., R. 82 W.), and 48 feet thick near Aspirin Creek (sec. 5, T. 34 N., R. 88 W.). In subsurface studies of the Cities Service Oil Co. well, Government C–1 (sec. 12, T. 32 N., R. 85 W.), the Cody shale is overlain by about 160 feet of medium-grained poorly sorted sandstone containing siltstone and shale beds in the upper and lower 10 to 20 feet. Overlying this sandstone unit is 250 to 260 feet of alternating gray shale and glauconitic sandstone, which in turn is overlain by 60 feet of fine- to medium-grained calcareous sandstone containing some carbonaceous shale in the upper 20 feet. The gray shale and glauconitic sandstone sequence of this section is interpreted as a westward-thinning tongue of the Cody shale that splits the Parkman sandstone member into an upper and a lower tongue (pl. 9). The tongue of Cody shale is more sandy and more difficult to recognize west of the Cities Service Oil Co. well, but its wedge edge may extend as far west as Aspirin Creek. It increases in thickness eastward to about 350 feet in the Tidewater Associated well, Poison Spring 1 (sec. 31, T. 33 N., R. 84 W.), and merges with the main body of the Cody shale near the Casper Canal. The lower tongue of the Parkman sandstone member thins eastward and pinches out between Poison Spring Creek and the Casper Canal. The tongue of the Cody shale was found in the Pure Oil Co. wells, Government 5, in the West Poison Spider oil field, and Waltman 1, near Arminto.

The upper boundary of the Parkman is marked by a change from nearshore marine sandstone below to nonmarine sandstone and shale above. The change is gradual, and the contact between the Parkman sandstone member and the unnamed middle member of the Mesaverde formation is drawn at the top of the highest persistent marine sandstone bed in the transition zone.

The Parkman for the most part, represents a regressive sandstone deposited near the shore of the eastward-retreating Late Cretaceous sea. The westward-thinning tongue of Cody shale in the central part of the area reflects deposition during a minor readvance of the sea during this general regression.

Marine invertebrate fossils collected from the Parkman may indicate an age equivalent to that of the Claggett shale of Montana. A collection from about 40 feet above the base of the Parkman sandstone member at the Casper Canal was identified by W. A. Cobban (written communication, 1957) and includes the following forms:

*USGS Mesozoic localities D1168 and D1169 (SE¼ sec. 16, T. 31 N., R. 82 W.)*

Echinoid: *Hardouinia* sp.

Pelecypods:
- *Nucula* sp.
- *Inoceramus* sp.
- *Inoceramus subcompressus* Meek and Hayden
- *Crenella* sp.
- *Protodonax* cf. *P. altantis* (Stephenson)
- *Ethmocardium whitei* Dall

Yenne and Pipiringos (1954) report marine invertebrate fossils of late Eagle or possibly Claggett age near Conant Creek, about 35 miles west of the mapped area, and of Eagle age from the Alkali Butte area, about 12 miles west of Conant Creek. Cobban (1958, p. 117) indicates a probable Judith River age for the Parkman sandstone member in the southwestern part of the Powder River Basin, about 25 miles east of the Hiland-Clarkson Hill area. The paleontologic evidence, therefore, seems to corroborate the evidence of physical stratigraphy that the basal part of the Mesaverde formation is progressively younger from west to east across the Wind River Basin (fig. 79).

#### UNNAMED MIDDLE MEMBER

As originally used by Wegemann in the Powder River Basin (1918, p. 20–21), the unnamed member of the Mesaverde formation is a sequence of marine shale and sandstone overlying the Parkman sandstone member and underlying the Teapot sandstone member. In the southeastern part of the Wind River Basin, the same stratigraphic interval is represented by nonmarine sandstone, siltstone, and carbonaceous shale, which the writer (1958, p. 2427) considers to be the continental equivalent of the marine unnamed member of Wegeman. Because correlations outside of the mapped area are uncertain, this nonmarine sequence is not given a formal stratigraphic name but is referred to in this report as the unnamed middle member of the Mesaverde formation.

Although the unnamed middle member of the Mesaverde formation is well exposed along the margins of the Wind River Basin, it was mapped only in Tps. 31 and 32, R. 82 W. The best exposures are along the banks of the Casper Canal in sec. 16, T. 31 N., R. 82 W. In other places the strata are soft and easily eroded so that the formation generally underlies conspicuous strike valleys.

The lithologic character of the basal beds of the unnamed middle member varies from place to place, but the strata are everywhere of nonmarine origin. At the Casper Canal the underlying Parkman sandstone grades upward into dark-gray carbonaceous shale, whereas near Aspirin Creek the lower part of the unnamed middle member consists of alternate beds of gray shale and yellowish-gray sandstone. The contact between the Parkman sandstone and the unnamed middle member is therefore drawn, as near as possible, at the base of the lowest nonmarine beds in the Upper Cretaceous sequence.

The unnamed middle member is a variable sequence of yellowish-gray sandstone, gray siltstone, carbonaceous shale, and coal. No individual bed can be traced laterally for more than a few hundred feet. Sandstone beds are more numerous in the upper half of the unit, and in some places individual sandstone beds may be as much as 40 feet thick, but laterally they wedge out into shale and siltstone. Shale beds range in thickness from 1 to 30 feet, but most of them are less than 10 feet. They commonly grade into siltstone and thin-bedded sandstone at the base and top. Beds of coal, from less than 1 foot to as much as 7 feet thick, are present at many horizons, but they are more common in the lower 150 feet.

Stratigraphic sections of the unnamed middle member were measured in several places, and the descriptions of these sections are given with the discussion of the Teapot sandstone.

In surface exposures the unnamed middle member increases in thickness westward from about 450 feet near the Casper Canal to about 750 feet on Aspirin Creek (sec. 5, T. 34 N., R. 88 W.). In the subsurface it ranges in thickness from about 450 feet in the Tidewater Associated well, Poison Spring 1, (sec. 31, T. 33 N., R. 84 W.), to about

480 feet in the Pure Oil Co. well, Waltman 1, near Arminto (sec. 29, T. 37 N., R. 86 W.).

The contact between the unnamed middle member and the overlying Teapot sandstone member is characterized in surface exposures by a change from alternate gray shale and yellowish-gray sandstone below to light-gray and white massive to crossbedded well-indurated sandstone above. In most areas; however, the basal part of the Teapot sandstone may contain thin beds of gray sandy shale, about 20 feet thick, so that it is difficult to locate the contact accurately.

The unnamed middle member of the Mesaverde formation represents the first period of nonmarine deposition during the Late Cretaceous in the Hiland-Clarkson Hill area. The interbedded coal, sandstone, and carbonaceous shale in the lower part of the unnamed middle member suggest deposition in coastal swamps, lagoons, and estuaries in contrast to the nearshore marine environment that characterized the underlying Parkman sandstone. The general increase in the abundance of sandstone as well as the decrease in carbonaceous material, upward through the sequence probably records a gradual change from an environment of widespread swamps to one of more broad and extensive flood plains during the time of deposition of the unnamed middle member.

No identifiable fossils have been collected from the unnamed middle member, although many of the shale and coal beds contain fragments of fossil leaves. On the basis of stratigraphic succession and approximate correlations of the strata into the western part of the Powder River Basin and southern part of the Bighorn Basin, the unnamed middle member is probably of early Judith River age in the Hiland-Clarkson Hill area.

### TEAPOT SANDSTONE MEMBER

The Teapot sandstone member crops out as a conspicuous white ridge that can be traced continuously along the northeastern and southwestern margins of the Wind River Basin; however, it was mapped only in Tps. 31 and 32 N., R. 82 W. It is more resistant to erosion than are the overlying and underlying units, so it generally forms a prominent hogback, whose dip slope is commonly pine-covered.

The basal bed of the Teapot sandstone member is light-gray to white sandstone containing thin discontinuous layers of carbonaceous shale and, very locally, thin coal beds. It is apparently conformable with the underlying unnamed middle member, but because of the nature of the bedding above and below the contact local disconformities may be present.

The Teapot sandstone member is light-gray to white fine- to medium-grained massive to crossbedded sandstone that is of nonmarine origin. Light-gray moderately well sorted angular to subangular quartz grains are the chief constituent; however, considerable amounts of unidentified black and pink grains and small fragments of carbonaceous material are scattered throughout the sequence. Nearly all exposures include a 5- to 10-foot layer of dark carbonaceous shale or coaly shale in the middle or lower third of the unit.

The following sections include the descriptions of the three members of the Mesaverde formation; the suggested correlation of these sections with those of drilled wells are shown on plate 9.

*Section of Mesaverde formation, Casper Canal, secs. 15 and 16, T. 31N., R. 82 W.*

| | *Feet* |
|---|---|
| Lower tongue of Lewis shale: Shale and sandstone, interbeded, light-gray to black, slightly carbonaceous | 20 |
| Apparent conformity at contact. | |
| Teapot sandstone member of Mesaverde formation: | |
| Sandstone, light-gray to white, fine- to medium-grained, massive to crossbedded; contains chips of gray shale, as much as 2 in. in diameter, throughout and stringers of carbonaceous shale in upper 5 ft.; resistant | 24 |
| Shale, pale-brown, carbonaceous | 23 |
| Sandstone, same as above | 18 |
| Total thickness of Teapot sandstone member | 65 |
| Conformity at contact. | |
| Unnamed middle member of Mesaverde formation: | |
| Shale, light- to dark-gray; weathers light gray; carbonaceous, sandy in upper 10 ft; contains fragments of fossil leaves | 49 |
| Covered; probably alternates with sandy shale and sandstone | 38 |
| Sandstone, light-gray to yellowish-gray, fine-grained, thin-bedded to crossbedded; platy in lower 20 ft, concretionary in upper 4 ft; contains 2- to 5-ft layer carbonaceous shale 20 ft from base | 29 |
| Concealed; probably gray sandy shale | 9 |
| Shale, gray to dark-gray, carbonaceous, sandy in upper 7 ft | 17 |
| Sandstone, yellowish-gray, fine-grained, platy; alternates with gray to dark-gray carbonaceous shale | 28 |
| Sandstone, yellowish-gray, fine- to medium-grained, massive, crossbedded; contains gray sandy shale layers in basal 5 ft; weathers into large concretionary masses as much as 10 ft in diameter; resistant | 50 |
| Sandstone, yellowish-gray, fine- to medium-grained, thin- to thick-bedded; alternates with gray to dark-gray carbonaceous shale; 0.2 ft coal 15 ft from top | 100 |
| Sandstone, light-gray to yellowish-gray, fine- to medium-grained, crossbedded, resistant | 18 |
| Shale, dark-gray to brownish-gray, carbonaceous | 36 |

*Section of Mesaverde formation, Casper Canal, secs. 15 and 16, T. 31 N., R. 82 W.*—Continued

| | Feet |
|---|---|
| Unnamed middle member of Mesaverde formation—Continued | |
| Sandstone, gray to yellowish-gray, fine- to medium-grained, crossbedded to massive | 6 |
| Shale, gray to brownish-gray, carbonaceous; contains thin sandstone beds in basal 10 ft | 65 |
| Sandstone, light-gray to yellowish-gray, fine- to medium-grained, crossbedded to massive, resistant | 11 |
| Shale, light-gray to black, carbonaceous; contains fragments of fossil wood, and coal | 7 |
| Total thickness of unnamed middle member | 453 |
| Conformity at contact. | |
| Parkman sandstone member of Mesaverde formation: | |
| Sandstone, grayish-orange to yellowish-gray, fine- to medium-grained, crossbedded to massive; discontinuous olive-gray shale in lower 6 ft; resistant iron-stained layer 20 ft from base; fossiliferous zone, 10 ft thick, 30 ft from base, contains Claggett fauna (USGS Mesozoic loc. D1168 and D1169): *Hardouinia* sp., *Nucula* sp., *Inoceramus* sp., *I. subcompressus* Meek and Hayden, *Crenella* sp., *Protodonax* cf. *P. atlantis* (Stephenson), and *Ethmocardium whitei* Dall | 100 |
| Total thickness of Mesaverde formation | 618 |
| Gradational contact. | |
| Cody shale: Shale, olive-gray; contains discontinuous resistant sandstone beds in upper 30 ft | 74 |

*Section of Mesaverde formation, 3 miles east of Meadow Creek, secs. 30 and 31, T. 33 N., R. 82*

| | Feet |
|---|---|
| Lower tongue of Lewis shale: Shale, gray, sandy, grades upward into sandstone | 200 |
| Apparent conformity at contact. | |
| Teapot sandstone member of Mesaverde formation: Sandstone, light-gray to white, fine- to medium-grained, crossbedded to massive; friable in lower 15 ft, well indurated and resistant in remainder of unit; forms hogback | 116 |
| Concealed contact, probable conformity at contact. | |
| Unnamed middle member of Mesaverde formation: | |
| Concealed; probably gray shale | 30 |
| Sandstone, light-gray, fine- to medium-grained, shaly; contains carbonaceous shale layers in basal 3 ft | 69 |
| Shale, dark-brown, carbonaceous | 1 |
| Sandstone, white to light-gray, fine- to medium-grained; contains layer of gray sandy shale | 31 |
| Concealed; probably alternates with shale and sandstone | 93 |
| Shale, light-gray to gray, sandy | 8 |

*Section of Mesaverde formation, 3 miles east of Meadow Creek, secs. 30 and 31, T. 33 N., R. 82 W.*—Continued

| | Feet |
|---|---|
| Unnamed middle member of Mesaverde formation—Continued | |
| Concealed | 82 |
| Sandstone, yellowish-gray, fine- to medium-grained, crosbedded, resistant; weathers pale brown; forms strike ridge | 30 |
| Concealed; probably alternates with yellowish-gray sandstone and carbonaceous shale | 212 |
| Sandstone, pale-brown, fine- to medium-grained, thin-bedded to crossbedded; poorly exposed | 4 |
| Concealed | 8 |
| Sandstone, same as above | 3 |
| Concealed; probably dark-gray carbonaceous shale | 20 |
| Sandstone, light-gray to dusky-yellow, fine- to medium-grained platy | 3 |
| Total thickness of unnamed middle member | 593 |
| Conformity at contact. | |
| Parkman sandstone member of Mesaverde formation: | |
| Sandstone, light-moderate-olive- to pale-brown, fine- to medium-grained; thin-bedded in basas 4 ft, massive in upper 15 ft; contains poorly preserved casts of *Halymenites;* resistant, concretionary | 19 |
| Shale, light-gray to yellowish-gray, sandy | 7 |
| Sandstone, light-gray to dusky-yellow, fine- grained, crossbedded to massive; thinly laminated in basal 2 ft; contains poorly preserved fossils, probably pelecypods | 12 |
| Shale, yellowish-gray, sandy; alternates with yellowish-gray fine-grained thinly laminated sandstone | 13 |
| Sandstone, light-moderate-olive-brown, fine-grained, crossbedded to massive; concretionary; resistant; forms low ridge | 37 |
| Total thickness of Parkman sandstone member | 88 |
| Total thickness Mesaverde formation | 797 |
| Gradational with underlying Cody shale. No apparent disconformity at contact. | |

*Section of Mesaverde formation, 1 mile west of Aspirin Creek, sec. 5, T. 34 N., R. 88 W.*

| | Feet |
|---|---|
| Meeteetse formation: Shale, dusky-brown, carbonaceous | 56 |
| No apparent discordance at contact. | |
| Teapot sandstone member of Mesaverde formation: Sandstone, white to light-gray, medium-grained, crossbedded to massive; oil-stained near top; resistant; forms hogback; basal 15 ft partly concealed | 43 |

*Section of Mesaverde formation, 1 mile west of Aspirin Creek, sec. 5, T. 34 N., R. 88 W.*—Continued

| | Feet |
|---|---|
| Apparent conformity at contact. | |
| Unnamed middle member of Mesaverde formation: | |
| Shale, light-gray, sandy; 4 ft iron-stained lenticular sandstone, 27 ft above base | 107 |
| Sandstone, light-gray to yellowish-gray, medium-grained, thin-bedded; contains fossil bone fragment, 2 ft long, 3 in. in diameter | 3 |
| Shale, dark-gray at base, light-gray at top, carbonaceous | 57 |
| Sandstone, yellowish-gray, fine- to medium-grained, massive to crossbedded; 2 ft layer of carbonaceous shale 10 ft from base increases in thickness westward; resistant in upper 2 ft | 66 |
| Sandstone, yellowish-gray, fine- to medium-grained, thin-bedded; alternates with light-gray carbonaceous shale | 247 |
| Concealed; probably alternates with sandstone and shale | 63 |
| Sandstone, yellowish-gray, very fine to fine-grained, thin-bedded; weathers platy; resistant; concretionary in upper 10 ft | 37 |
| Sandstone, yellowish-gray, thin-bedded; alternates with light-gray shale | 49 |
| Sandstone, grayish-orange to yellowish-gray, fine-grained; thin-bedded at base; crossbedded at top; wedges out 300 ft west of section; appears to thicken eastward | 11 |
| Sandstone, yellowish-gray, thin-bedded; alternates with light-gray shale | 74 |
| Concealed | 73 |
| Sandstone, yellowish-gray, fine- to medium-grained, thin-bedded; resistant | 12 |
| Shale, dark-gray, carbonaceous; alternates with pale-yellowish-brown fine- to medium-grained crossbedded sandstone; in beds 1 to 2 ft thick | 33 |
| Total thickness of unnamed middle member | 834 |
| No apparent discordance at contact. | |
| Parkman sandstone member of Mesaverde formation: Sandstone, yellowish-gray, fine- to medium-grained, crossbedded to massive, friable; weathers into hummocky topography | 48 |
| Total thickness of Mesaverde formation | 925 |
| Gradational into underlying Cody shale. No apparent disconformity at base. | |

Surface measurements of the Teapot sandstone member range in thickness from 65 feet at the Casper Canal to about 115 feet near Meadow Creek to 43 feet near Aspirin Creek. In the subsurface, the Teapot is about 90 feet thick in the Tidewater Associated well, Poison Spider 1, and about 75 feet thick in the Cities Service Oil Co. well, Government 1–C. The variation in thickness does not seem to be of regional significance, but may instead indicate local relief on the surface on which the Teapot sandstone was deposited.

The upper contact of the Teapot sandstone grades upward from massive white resistant sandstone into dark-gray carbonaceous shale through a zone, about 20 feet thick, of alternate white sandstone and gray sandy shale; however, because the upper massive sandstone bed of the Teapot sandstone member is easily recognized at the surface as well as on electric logs, the contact was drawn at the top of this sandstone bed.

The environment in which the Teapot sandstone member was deposited cannot be ascertained from exposures in the Hiland-Clarkson Hill area. The Teapot sandstone apparently was deposited as a thin layer of sand across the mapped area and into the adjacent Powder River Basin, but its areal distribution and stratigraphic relations are inconsistent with those normally expected under regressive and transgressive conditions. Although the Teapot is generally considered to be of nonmarine origin it is between marine beds in the Powder River Basin, between nonmarine beds near Aspirin Creek, and at the Casper Canal it is overlain by marine strata of the Lewis shale and is underlain by nonmarine strata. The name Teapot sandstone is not recognized west of the mapped area, but Troyer and Keefer (1955) described a white sandstone unit at the top of the Mesaverde formation in the northwestern part of the Wind River Basin that is similar in lithologic character and stratigraphic position to the Teapot sandstone. Eastward from the margin of the Wind River Basin, the Teapot sandstone member may grade into marine littoral deposits as suggested by Partridge (1957, p. 880). Therefore, the Teapot sandstone may represent the influx of debris, derived from the erosion of a rapidly elevated landmass that lay far to the west of the Hiland-Clarkson Hill area.

Fossils have not been collected from the Teapot sandstone member. In the eastern part of the mapped area, the unit is overlain by rocks containing a marine faunal assemblage characteristic of the Bearpaw shale of Montana and is underlain by rocks of probable early Judith River age. It is possibly of late Judith River age.

### LEWIS SHALE AND MEETEETSE FORMATION

The Lewis shale was first named by Cross (1899) from exposures in southwestern Colorado. Hares (1916, table facing p. 239) was the first to use the name in the Wind River Basin of Wyoming; however, his paper is a much condensed account of the geology and does not make clear how widely the name was intended to apply nor the rock types to be included. Later, the name Lewis shale was restricted to marine strata overlying the Mesaverde formation and underlying the Lance formation (Cobban and Reeside, 1952a).

The Meeteetse formation, which is considered to be the nonmarine equivalent of the Lewis Shale (Cobban and Reeside, 1952a), was first described by Hewett (1914, p. 102) from exposures south of Cody, Wyo., along the southern margin of the Bighorn Basin. Troyer and Keefer (1955) and Love (Love and others 1951) applied the name to similar strata in the northwestern part of the Wind River Basin. Keefer and Rich (1957, p. 74) extended the name Meeteetse as used by Troyer and Keefer eastward into the area covered by this report.

Only the Meeteetse formation is present along the western margin of the Hiland-Clarkson Hill area, but the Meeteetse interfingers with the Lewis shale toward the east; a tongue of the Meeteetse formation extends as far east as the North Platte River.

The Lewis shale and the Meeteetse formation were mapped only in Tps. 31 and 32 N., R. 82 W., where they are exposed along a narrow outcrop band extending from the southeastern corner of sec. 8, T. 32 N., R. 82 W., southeastward to the North Platte River. They are covered by Quaternary sand and gravel near the river; but they can be traced by means of isolated outcrops westward along the southern flank of the Wind River Basin from the central part of sec. 14, T. 31 N., R. 82 W., to the western edge of sec. 18, T. 31 N., R. 82 W. From there to the vicinity of the Grieve oil field, the Lewis and Meeteetse formations are overlapped by Tertiary strata. West of the Grieve oil field on the southern edge of the basin and Iron Creek on the northern edge, they are discontinuously exposed, but were not mapped by the writer. In the unmapped area they are grouped with the overlying Lance formation; the position of the base of the Lewis or Meeteetse and the top of the Lance on pl. 6 is taken from the geologic map of Natrona County, Wyo. (Weitz and others 1954). Stratigraphic sections of these strata were measured by the writer and correlations into the unmapped area are shown on plate 9.

The strata of the Lewis and Meeteetse are soft and easily eroded; so they generally underlie strike valleys. Locally, as near Iron Creek and along the Casper Canal, they form a gentle debris-covered slope below the somewhat more resistant Lance formation.

### LEWIS SHALE

The Lewis shale is separated into an upper tongue and a lower tongue by an eastward projecting tongue of the Meeteetse formation. The base of the lower tongue of the Lewis shale is generally well exposed, and the contact with the underlying Teapot sandstone is marked by a change from white sandstone below to dark-gray and olive-gray shale and thin-bedded sandstone above. No discordance between the basal beds of the Lewis and the Teapot sandstone member was detected. In each of the measured sections, the Teapot sandstone is overlain by 20 to 50 feet of carbonaceous shale and thin lenticular white sandstone, which suggests that the Teapot sandstone may grade upward into the lower tongue of the Lewis shale. However, because the upper massive sandstone bed of the Teapot sandstone is easily recognized in surface exposures, as well as in electric logs, and is a fairly continuous unit throughout the area, the top of this sandstone bed is used to mark the contact between the Lewis shale and the Teapot sandstone.

The lower tongue of the Lewis shale is characterized by soft, light-olive-gray shale with thinly intercalated yellowish-gray concretionary sandstone beds. The sandstone beds are commonly fossiliferous.

The stratigraphic sections of the lower tongue of the Lewis shale in the Hiland-Clarkson Hill area are included with the discussion of the Meeteetse formation.

The lower tongue of the Lewis shale thins westward. In the section measured along the Casper Canal, the beds assigned to the lower tongue of the Lewis shale are about 190 feet thick. At Meadow Creek (sec. 31, T. 33 N., R. 82 W.), Dobbin and Reeside (1929, p. 20–21) measured 300 feet, which agrees closely with 304 feet measured by the writer at Iron Creek. In drilled wells in the Grieve and Wallace Creek oil fields, along the flank of the Rattlesnake Hills anticline, the lower tongue is about 280 and 110 feet thick, respectively. It thins westward from the Wallace Creek field and wedges out or grades into nonmarine rocks near Aspirin Creek, sec. 4, T. 34 N., R. 88 W. (pl. 9). The thicknesses measured at Iron Creek and the Casper Canal may also indicate a thinning toward the southeast.

The upper contact of the lower tongue of the Lewis shale is poorly exposed throughout most of the mapped area. However, in those places where the contact is exposed, as along the Casper Canal and Iron Creek, the upper beds of the lower tongue of the Lewis shale grade upward, through an interval of 10 to 30 feet, into light-gray to gray friable sandstone of the eastward-projecting tongue of the Meeteetse formation. The contact can be placed only arbitrarily within this gradational zone.

An upper tongue of the Lewis shale overlies the eastward-projecting tongue of the Meeteetse in the eastern part of the Hiland-Clarkson Hill area. The upper tongue of the Lewis apparently has a very small westward extent, as it can be traced in surface outcrops only about 5 miles west of Meadow Creek.

The basal beds of the upper tongue of the Lewis shale are poorly exposed. However, the contact is marked by a change from gray and dark-gray carbonaceous shale and sandstone upward to light olive-gray to light-gray shale and thin-bedded lenticular sandstone. No discordance was found at the contact.

The upper tongue of the Lewis shale is characterized by light-olive-gray shale and sandstone; the shale is darker gray and more carbonaceous toward the top. Stratigraphic sections of this unit are included with the discussion of the Meeteetse formation.

The upper tongue of the Lewis shale is about 200 feet thick along the Casper Canal, and Dobbin and Reeside (1929, p. 20–21) measured 250 feet at Meadow Creek. Westward from Meadow Creek, the tongue could be traced only about 5 miles along the outcrop, where the unit is obscured by a thick soil cover. Sample studies of the Pure Oil Co. well, Government 5, and the Cities Service Oil Co. well, Government C–1, indicate that the Lewis and Meeteetse interval above the lower tongue of the Lewis shale consists of alternating shale, coal, and sandstone, not unlike the Meeteetse formation. On the basis of these data, the upper tongue of the Lewis shale is thought to wedge out between Meadow Creek and the Cities Service Oil Co. well on the southern edge of the Wind River Basin and between Meadow Creek and the Pure Oil Co. well on the northern edge of the basin (pl. 9).

In the eastern part of the Hiland-Clarkson Hill area, the upper tongue of the Lewis shale is overlain by nonmarine strata of the Lance formation, and the contact between the two units is drawn at the top of the highest marine strata. The transition zone from marine to nonmarine strata is about 50 feet thick and is characterized by an increase upward in poorly bedded carbonaceous shale and thin to thick sandstone with an accompanying decrease in light-olive-gray, thinly bedded shale and sandstone. About 3 miles west of Iron Creek, a thin limy siltstone, about 2 feet thick, is the highest stratum containing marine fossils and this bed can be traced in surface outcrop into the mapped area. It was used where possible to mark the contact between the Lewis shale and the Lance formation.

The abundance of sandy shale and sandstone in the Lewis shale suggests deposition in shallow water, probably not far from shore. The fauna also indicates a shallow-water environment; many of the fossil concentrations are comprised of broken shells, probably the result of wave action along the shore. The *Turritella* from the upper tongue of the Lewis shale suggests a depth of water less than 40 fathoms (W. A. Cobban, written communication, 1957).

The fauna collected from the lower tongue of the Lewis shale is similar to a zone in the upper Bearpaw shale of Montana, whereas the fauna from the upper tongue suggests an age equivalent to the Fox Hills sandstone of Montana (W. A. Cobban, written communication, 1957). Northeast of the Hiland-Clarkson Hill area, the tongues of the Lewis shale apparently merge and correlate with the main body of the Lewis shale in the Powder River Basin and, still farther east, with the upper part of the Pierre shale. Westward, the tongues of the Lewis shale wedge out or grade into nonmarine strata of the Meeteetse formation.

### MEETEETSE FORMATION

The Meeteetse formation was mapped only in the eastern part of the Hiland-Clarkson Hill area, where it is overlain and underlain by tongues of the Lewis shale. In the western part of the area, the Meeteetse is not mapped separately but is grouped with the Lewis and Lance formations. It is shown on plate 6 as Lewis, Meeteetse, and Lance formations undifferentiated. Correlations presented here are based on sections measured in both the mapped and unmapped areas.

In the mapped area, the Meeteetse formation overlies and underlies tongues of the Lewis shale; westward, the tongues of the Lewis shale wedge out, and the Meeteetse formation conformably overlies the Teapot sandstone member of the Mesaverde formation and underlies the Lance formation.

The basal beds of the Meeteetse formation consist of thin to thick beds of light-gray friable sandstone and dark-gray carbonaceous shale. In some exposures the sandstone beds are soft and friable, whereas in others they are relatively well indurated.

The formation is characterized by a succession of alternating sandstone, siltstone, shale, tuffaceous siltstone or mudstone, carbonaceous shale, and lenticular coal beds. Where the exposures are good, the unit has a gray, black, yellowish-gray, and brown banded appearance that is unlike any other Upper Cretaceous formation in the area. Locally, as at Meadow Creek and Aspirin Creek, some of the lower sandstone beds weather into "cannonball" concretionary masses.

The following stratigraphic sections are representative of the Lewis and Meeteetse formations in the Hiland-Clarkson Hill area.

*Section of Lewis shale and Meeteetse formation, Casper Canal, sec. 15, T. 31 N., R. 82 W.*

| | *Feet* |
|---|---|
| Lance formation: | |
| Shale, light-olive-gray to dark-gray; carbonaceous in upper 10 ft; intercalated with gray to olive-gray lenticular sandstone | 56 |
| Conformable contact. | |
| Upper tongue of Lewis shale: | |
| Siltstone, light-gray, calcareous; weathers yellowish gray; breaks into irregular pieces | 1 |
| Shale, gray to dark-gray; contains thin (1 to 2 ft) beds of sandstone in lower 20 ft; carbonaceous in upper 20 ft | 60 |
| Sandstone, white to yellowish-gray, fine- to medium-grained, massive to crossbedded; contains widely spaced, thin (0.1 to 0.3 ft) carbonaceous shale bands in upper 8 ft | 27 |

*Section of Lewis shale and Meeteetse formation, Casper Canal, sec. 15, T. 31 N., R. 82 W.*—Continued

| | Feet |
|---|---|
| Upper tongue of Lewis Shale—Continued | |
| Shale, light-gray to light-olive-gray; alternates with light-olive-gray fine-grained lenticular sandstone; sandy in basal 2 ft and upper 10 ft | 96 |
| Sandstone, olive-gray, fine-grained; fossiliferous; (USGS Mesozoic locality D1171): *Glycimeris wyomingensis* (Meek), *Anomia* sp., *Ethmocardium* sp., *Turritella* sp., *Baculites* cf. *B. clinolobatus* Elias | 2 |
| Shale, gray to dark-gray; grades into dark-gray to black carbonaceous shale | 12 |
| Total thickness of upper tongue of Lewis shale | 198 |
| Gradational contact. | |
| Meeteetse formation: | |
| Shale, gray to dark-gray, carbonaceous; weathers reddish brown in lower part | 19 |
| Coal, black, vitreous | 1 |
| Sandstone, light-gray, fine- to medium-grained, thin-bedded | 14 |
| Concealed; probably alternates with carbonaceous shale and sandstone | 159 |
| Shale, dark-gray, carbonaceous; sandy in basal 2 ft; contains abundant fossil plant fragments | 31 |
| Sandstone, light-gray to white, fine-grained, poorly bedded; contains thin (0.1 to 0.3 ft) carbonaceous shale layers 1 and 5 ft above base | 6 |
| Shale, gray; weathers reddish brown; contains 4-ft sandstone layer 5 ft above base; abundant fossil wood fragments throughout | 13 |
| Coal | 1 |
| Shale, light-gray to dark-gray, carbonaceous; contains gray fine-grained sandstone in beds 1 to 4 ft thick | 28 |
| Coal | 1 |
| Shale, light-gray to dark-gray, carbonaceous | 27 |
| Sandstone, light-gray to white, very fine to fine-grained, poorly bedded | 3 |
| Shale, dark-gray; weathers reddish brown; contains thin laminae of sandstone | 7 |
| Sandstone, light-gray to white, fine-grained; weathers light gray; bedding obscure; shaly toward top; forms miniature badlands topography | 81 |
| Total thickness of Meeteetse formation | 392 |
| No evidence of discordance at contact. | |
| Lower tongue of Lewis shale: | |
| Sandstone, light-olive-gray, fine-grained; weathers grayish olive | 3 |
| Shale, olive-gray, thin-bedded; sandy in upper 10 ft | 46 |
| Concealed; probably shale and thin-bedded sandstone | 38 |
| Shale, pale-olive, poorly laminated; contains thin beds of sandy shale in upper 15 ft | 43 |

*Section of Lewis shale and Meeteetse formation, Casper Canal, sec. 15, T. 31 N., R. 82 W.*—Continued

| | Feet |
|---|---|
| Lower tongue of Lewis shale—Continued | |
| Sandstone, light-olive-gray, fine-grained; weathers pale olive; fossiliferous, upper Bearpaw fauna (USGS Mesozoic locality D1170): *Inoceramus* cf. *I. barabini* Morton, *I.* (*Endocostea*) sp., *Pteria* n. sp., *Baculites eliasi* Cobban, *Acanthoscaphites* sp | 23 |
| Shale, light-olive-gray; weathers olive gray; contains sandy siltstone 6 ft above base | 19 |
| Shale, light-gray to dark-gray, slightly carbonaceous; alternates with light-gray fine-grained lenticular sandstone | 20 |
| Total thickness of lower tongue of Lewis shale | 191 |
| Total thickness of Lewis shale and Meeteetse formation | 781 |

Apparent conformity.

Teapot sandstone member: Sandstone, light-gray to white; forms resistant ridge.

*Section of lower tongue of Lewis formation, ½ mile northwest of Iron Creek, secs. 5 and 8, T. 32 N., R. 82 W.*

| | Feet |
|---|---|
| Tongue of Meeteetse formation: | |
| Sandstone, light-yellowish-gray, massive, medium-grained, friable; weathers light gray; shaly in lower part | 49 |
| Apparently conformable at contact. | |
| Lower tongue of Lewis shale: | |
| Sandstone, light-gray to light-olive-gray, fine- to medium-grained; thinly bedded at base, massive at top | 36 |
| Sandstone, olive-gray, fine- to medium-grained; weathers light olive-gray; abundant dark mineral grains; limy spherical concretions as much as 3 ft in diameter; abundantly fossiliferous, fossils mostly in concretions, upper Bearpaw fauna (USGS Mesozoic loc. D1175): *Tancredia americana* Meek and Hayden, *Protocardia rara* (Evans and Shumard), *Baculites eliasi* Cobban | 57 |
| Shale, light-olive-gray; alternates with light-olive-gray fine- to medium-grained sandstone; concretionary; fossiliferous, fossils in concretions, upper Bearpaw fauna (USGS Mesozoic loc. D1174): *Protocardia rara* (Evans and Shumard), *Baculites eliasi* Cobban | 23 |
| Shale, olive-gray, sandy; contains discontinuous lenses of limy sandstone | 64 |
| Sandstone, light-olive-gray, fine- to medium-grained, poorly sorted; rusty-brown concretionary masses in upper 5 ft | 17 |
| Concealed; probably shale and thin-bedded sandstone | 57 |
| Partly concealed; mostly light-gray to dark-gray carbonaceous shale with thin sandstone beds | 20 |
| Partly covered; alternates with dark-gray carbonaceous shale and sandstone in basal 4 ft, probably alternates with shale and sandstone above | 30 |
| Total thickness of lower tongue of Lewis shale | 304 |

Apparent conformity.

Teapot sandstone member: Sandstone, white to light-gray, forms resistant ridge.

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The following is part of a section measured by Dobbin and Reeside (1929, p. 20–21) and is reproduced here to show the general lithology and thickness of the Meeteetse fromation.

*Section of Meeteetse formation, 2 miles southeast of Meadow Creek, sec. 31, T. 33 N., R. 82 W.*

Upper tongue of Lewis shale:
Shale, brown, sandy; grades upward into fossiliferous concretionary sandstone.
Apparent conformity at contact.

| Meeteetse formation: | *Feet* |
|---|---|
| Shale, gray, sandy | 40 |
| Lignite and brown carbonaceous shale | 3 |
| Sandstone, gray, fairly hard; contains much carbonaceous debris | 5 |
| Shale, gray, sandy | 10 |
| Coal | 1 |
| Shale, grayish-white, sandy; contains thin lenses of yellow concretionary sandstone | 90 |
| Sandstone, gray, platy, concretionary | 1 |
| Shale, gray and brown, sandy, soft | 80 |
| Shale, gray, and carbonaceous shale, sandy shale, and concretionary sandstone | 70 |
| Sandstone, brown, hard; makes small ridge | 3 |
| Shale, gray, carbonaceous | 25 |
| Sandstone, soft, carbonaceous; contains several hard layers | 6 |
| Shale, some sandy and some carbonaceous | 1 |
| Sandstone, gray, carbonaceous | 8 |
| Sandstone, white; contains many gray cannonball concretions as much as 3 ft in diameter | 62 |
| Shale, brown, sandy; occupies a low valley | 66 |
| Total thickness of Meeteetse formation | 471 |

No discordance at contact.
Lower tongue of Lewis shale: Sandstone, gray and brown, fossiliferous; contains many large concretions.

*Section of Meeteetse formation, ½ mile northwest of Aspirin Creek, sec. 4, T. 34 N., R. 88 W.*

Lance formation:
Sandstone, dusky-yellow, fine- to medium-grained, friable, poorly bedded; forms large cannonball concretions; contains 2 ft. carbonaceous shale at base.
No apparent discordance at contact.

| Meeteetse formation: | |
|---|---|
| Siltstone, light-gray, tuffaceous, poorly bedded; contains fractured masses of gypsum at top | 9 |
| Coal and carbonaceous shale | 1 |
| Shale, light-gray, tuffaceous; 0.5-ft sandstone ledge at top | 26 |

*Section of Meeteetse formation, ½ mile northwest of Aspirin Creek, sec. 4, T. 34 N., R. 88 W.*—Continued

| | Feet |
|---|---|
| Meeteetse formation—Continued | |
| Sandstone, white, fine- to medium-grained, crossbedded; 2-ft resistant ledge at base and top; weathers reddish brown; upper 4 ft bentonitic | 39 |
| Shale, light-gray to brownish-gray; contains irregularly spaced lenticular sandstone and coal | 128 |
| Sandstone, light-yellowish-gray, coarse- to very coarse-grained, poorly bedded | 6 |
| Shale, dark-gray to brownish-gray, carbonaceous | 4 |
| Sandstone, gray; shaly at top; contains iron-stained streaks near base | 17 |
| Shale, dark-gray, carbonaceous | 2 |
| Mudstone, greenish-gray, tuffaceous | 12 |
| Coal | 1 |
| Shale, dark-gray, carbonaceous; contains fossil tree trunk 3 ft in diameter and 3 to 5 ft long at base | 12 |
| Sandstone, light-gray to white, fine- to medium-grained; forms cannonball concretions | 4 |
| Sandstone, silty, very dark brown to black; iron-stained on weathered surface | 1 |
| Shale, silty, gray, carbonaceous | 11 |
| Sandstone, light-gray, medium- to coarse-grained, crossbedded, lenticular; poorly defined base and top; forms disk-shaped concretions as much as 4 ft in diameter | 3 |
| Shale, gray to dark-gray; becomes sandy toward top; contains 2 ft coaly shale 8 ft above base | 22 |
| Shale, dark-gray, carbonaceous; alternates with brownish-gray sandstone | 8 |
| Shale, gray to brownish-gray, carbonaceous | 12 |
| Coal and coaly shale | 2 |
| Shale, gray to brownish-gray, carbonaceous | 3 |
| Sandstone, gray, medium- to coarse-grained, platy | 6 |
| Shale, gray to dark-gray, carbonaceous | 17 |
| Sandstone, light-gray, fine- to medium-grained, platy; weathers dark brown | 5 |
| Shale, light-gray, carbonaceous; weathers brownish gray; contains coaly streaks and abundant fossil plant fragments | 130 |
| Coal and coaly shale, poorly exposed; shows on surface as dark streak | 2 |
| Shale, sandy, gray, carbonaceous | 30 |
| Concealed; probably gray sandy shale | 65 |
| Shale, dusky-brown; carbonaceous | 56 |
| Total thickness of Meeteetse formation | 634 |

No discordance at contact.

Teapot sandstone member of Mesaverde formation: Sandstone, light-gray to white, massive, crossbedded, resistant; forms high ridge.

*Section of lower tongue of Lewis shale, Lox section, 7½ miles southeast of Arminto, Wyo., NE¼ sec. 10, T. 36 N., R. 86 W.*

| | Feet |
|---|---|
| Meeteetse formation: Shale, dark-gray, carbonaceous; contains thin sandstone lenses | 10 |
| Apparently conformable and gradational at contact. | |
| Lower tongue of Lewis shale: | |
| Shale, light-gray to light olive-gray; contains thin (1 to 2 ft) beds of sandstone; grades upward into carbonaceous shale | 75 |
| Sandstone, olive-gray, crossbedded, resistant; weathers moderate yellowish brown | 4 |
| Shale, light-gray to light olive-gray; contains intercalated thin (2 to 3 ft) beds of resistant sandstone | 29 |
| Sandstone, light olive-gray, fine- to medium-grained, massive to bedded, resistant, concretionary; contains poorly preserved casts or fossils | 21 |
| Sandstone, light-yellowish-gray, fine- to medium-grained, massive to bedded, fossiliferous, weathers light brown; contains upper Bearpaw fauna (USGS Mesozoic loc. D1173): *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 | 6 |
| Shale, light-gray to dark-gray, carbonaceous; intercalated thin (1 to 2 ft) beds of gray, fine- to medium-grained sandstone; fossil tree limbs and trunks in lower 10 ft | 20 |
| Concealed; probably sandy shale and thin-bedded sandstone | 30 |
| Total thickness of lower tongue of Lewis shale | 244 |
| Apparent conformity at contact. | |
| Teapot sandstone member: | |
| Sandstone, light-gray to white, forms resistant ridge. | |

The Meeteetse formation has a maximum thickness in the western part of the area of about 635 feet; eastward, it decreases in thickness to about 470 feet near Meadow Creek and about 390 feet at the Casper Canal (pl. 9). It probably wedges out east of the Casper Canal.

In the western part of the mapped area, where the Meeteetse formation is overlain by the Lance formation, the contact between the two formations is conformable and, in good exposures, is marked by a change from the underlying light-gray and dark-gray carbonaceous and tuffaceous siltstone, shale, and sandstone to the overlying yellowish-brown to dark-brown thinly bedded sandstone and grayish-brown carbonaceous shale. Most commonly, however, the contact is concealed in debris-covered slopes or in low soil-filled valleys so that it can be located only approximately.

The Meeteetse formation and the Lewis shale apparently were deposited contemporaneously; the Meeteetse formation represents deposition in a nonmarine environment, and the Lewis shale represents deposition in a marine environment. The intertonguing of the two formations further suggests that deposition took place along a fluctuating shoreline so that the environments of deposition advanced and retreated with the changes in sea level. The Meeteetse was probably deposited in coastal swamp and flood-plain environments.

The Meeteetse formation probably ranges from Bearpaw to Fox Hills in age, although no fossils, other than poorly preserved wood and carbonized plant material, were found in the mapped area. The Meeteetse formation is presumed to have approximately the same age span as the Lewis shale inasmuch as it intertongues with the Lewis shale and, in areas where the Lewis shale is absent, it occupies a similar stratigraphic interval.

### LANCE FORMATION

The Lance formation was named by Hatcher (1903, p. 369) from exposures in the southeastern part of the Powder River Basin, Wyo. In the type area, the Lance is separated from the Pierre shale by about 500 feet of the Fox Hills sandstone; however, the lithologic equivalent of the Fox Hills sandstone is not present in the Hiland-Clarkson Hill area, and the Lance formation rests on the Lewis shale or Meeteetse formation. Although the name Lance formation is used in this report, the rocks referred to this formation may not everywhere represent the same time interval nor correlate exactly with the type Lance in eastern Wyoming.

The Lance formation is intermittently exposed along the northeastern margin of the Wind River Basin, from near Arminto to the North Platte River. Just west of the North Platte River, the dip of the strata flattens and the Lance formation crops out in a broad well-exposed band around the southeastern end of the Wind River Basin. The exposures of the Lance formation from the North Platte River westward along the southern margin of the basin are poor. In the western half of sec. 16 and the eastern half of sec. 17, T. 31 N., R. 82 W., the upper part of the formation is overlapped by Eocene rocks; farther west it is completely covered by Oligocene and younger rocks. The Lance is exposed along the flank of the Rattlesnake Hills anticline from the Grieve oil field to the western edge of the mapped area. It was mapped in detail only in Tps. 31 and 32 N., R. 82 W. (pl. 7), and is included in the Lewis, Meeteetse, and Lance formations undifferentiated in the remainder of the Hiland-Clarkson area (pl. 6).

In the eastern part of the area, the basal beds of the Lance formation overlie the upper tongue of the Lewis shale; in the western part of the area, the basal beds lie directly on the Meeteetse formation. The beds are apparently conformable with the underlying formations. Local disconformities may be present between the Meeteetse and Lance, but none were observed by the writer.

The Lance formation consists of interbedded sandstone and shale. The lower 150 feet of the formation is gray to dark-gray shale with intercalated fine-grained crossbedded sandstone. In sec. 6, T. 32 N., R. 82 W., the lower 5 to 10 feet is made up of lenticular deposits of fragmental oyster shells imbedded in a fine- to medium-grained calcareous sandstone. Above the basal 150 feet is a series of yellowish-gray crossbedded sandstone, gray carbonaceous shale, and thin coal beds that are cyclically repeated through an interval of about 860 feet. Each cycle is 25 to 60 feet thick and consists of fine- to medium-grained light-gray to yellowish-gray platy sandstone at the base grading upward into gray to olive-gray sandy shale which, in turn, grades upward into gray carbonaceous shale. The gray carbonaceous shale is overlain by a 1- to 5-foot bed of coaly shale or coal, and locally, the upper limit of the cycle is marked by a ½- to 1-foot bed of gray to brown calcareous silty mudstone. The thickness of each of the units within the cycle varies from place to place and individual units can be traced laterally only a few hundred feet. The upper part of the Lance formation is predominantly dark-gray carbonaceous shale with lenticular gray to yellowish-gray crossbedded sandstone beds. Some of the sandstone beds are as much as 40 feet thick, but most of them are only about 10 feet thick.

The following stratigraphic section, measured in the vicinity of the Casper Canal, is representative of the Lance formation in the Hiland-Clarkson Hill area.

*Section of Lance formation, Casper Canal, secs. 9, 10, and 15, T. 31 N., R. 82 W.*

Fort Union formation:

Sandstone, white, fine- to medium-grained; contains considerable mica and highly weathered feldspar, platy at base.

Erosional unconformity at contact.

Lance formation:

| | *Feet* |
|---|---|
| Shale, gray; carbonaceous in upper 15 ft, 1-ft rusty-brown shale at top, sandy at base | 76 |
| Concealed; probably gray shale | 82 |
| Shale, gray, carbonaceous; 1-ft dusky-brown calcareous siltstone at top; weathers black | 5 |
| Concealed; probably gray shale | 15 |
| Shale, gray, carbonaceous | 4 |
| Sandstone, yellowish-gray, fine-grained, crossbedded, concretionary, resistant | 10 |
| Concealed; probably gray shale and sandy shale | 39 |
| Shale, gray and dark-gray; alternates with thin discontinuous sandstone lenses; fish scales and horny scales, probably from a crocodile-like animal, 300 ft east of measured section | 80 |
| Sandstone, yellowish-gray, fine- to medium-grained; grades upward into shale | 8 |

*Section of Lance formation, Casper Canal, secs. 9, 10, and 15, T. 31 N., R. 82 W.*—Continued

| Lance formation—Continued | *Feet* |
|---|---|
| Shale, yellowish-gray, sandy | 10 |
| Shale, gray, carbonaceous | 34 |
| Partly concealed; basal part probably sandstone or sandy shale, remainder gray shale | 53 |
| Sandstone, yellowish-gray, medium-grained, well sorted, crossbedded; channel containing rectangular blocks of concretionary sandstone in middle third of unit; channel truncates crossbedding | 27 |
| Concealed; probably sandstone | 20 |
| Sandstone, light-greenish-gray, fine-grained, poorly bedded; contains thin beds of medium-gray shale; fractured, iron-stained along fractures | 35 |
| Concealed; probably alternate gray shale and sandstone | 69 |
| Sandstone, yellowish-gray, very fine grained, massive to poorly bedded; contains carbonaceous wood fragments | 10 |
| Shale, light-greenish-gray to medium-gray, sandy; contains thin lenses of siltstone; abundant fossil wood | 25 |
| Sandstone, gray to yellowish-gray, fine- to medium-grained, crossbedded; shaly at top | 21 |
| Shale, dark-gray, carbonaceous | 1 |
| Sandstone, gray to yellowish-gray, fine-grained, massive to crossbedded; contains poorly preserved skull and bone fragments of horned dinosaur at base, exposed in east bank of irrigation canal in NE¼NW¼ sec. 10 | 21 |
| Shale, dark-gray, carbonaceous | 5 |
| Concealed; gray shale in upper 6 ft | 20 |
| Shale, dark-gray, carbonaceous; sandy in upper 4 ft; light-gray and sandy in lower part | 34 |
| Sandstone, gray to yellowish-gray, fine-grained, crossbedded | 10 |
| Shale, dark-gray, carbonaceous; contains bone fragments at top | 4 |
| Shale, olive-gray; grades upward into dark-gray carbonaceous shale | 8 |
| Concealed; probably yellowish-gray sandstone | 20 |
| Sandstone, shale, and coal alternate: cyclic repetition of beds, each cycle consisting of 2 to 6 ft of yellowish-gray to gray fine- to to medium-grained massive to platy sandstone at the base, grading upward into 10 to 30 ft of olive-gray to dark-gray sandy shale, which in turn grades into 10 to 20 ft of dark-gray carbonaceous shale containing abundant fossil wood, into 1 to 2 ft of coal, lignite, or coaly shale; each complete cycle 25 to 60 ft thick | 863 |
| Sandstone, light-gray to yellowish-gray, fine- to medium-grained, crossbedded; contains thin beds (0.1 to 0.2 ft thick) of carbonaceous shale along bedding planes; considerable carbonaceous wood fragments; lower 23 ft weathers with boxworklike markings on exposed surfaces | 88 |
| Coal | 2 |
| Shale, light-olive-gray to dark-gray; carbonaceous in upper 10 ft; intercalated with gray and olive-gray lenticular sandstone | 56 |
| Total thickness of Lance formation | 1,755 |

Apparent conformity.

Upper tongue of Lewis shale: Siltstone, light-gray, calcareous.

The thickness of the Lance formation in the central part of the Wind River Basin may be greater than the exposed thickness along the margin, but no subsurface data are available from the southeastern end of the basin to verify this statement. The thickness ranges from 1,755 feet at the Casper Canal to about 1,775 feet in a well in the Grieve oil field to 2,670 feet near Aspirin Creek (Keefer and Rich, 1957, p. 75). Although stratigraphic correlation in this part of the section is difficult, the upper and lower contacts in the Aspirin Creek area seem to be consistent with those in adjacent areas to the east. The increase in thickness may be attributed in part to the unconformable relation of the Lance and the overlying formations; however, it more probably is due to a local downwarping at the north end of the Rattlesnake Hills during Lance time, which resulted in a thicker accumulation of sediments.

The contact between the Lance formation and the overlying Fort Union formation of Paleocene age is unconformable. Near Austin Creek (secs. 34 and 35, T. 35 N., R. 88 W.) the Fort Union overlies the Lance with an angular discordance of 5° to 10°. A slight angular discordance was observed at the contact in the vicinity of Arminto and also in widely separated localities along the northeastern margin of the Wind River Basin. In the southeastern part of the area, the contact is marked by an erosional unconformity.

Rocks assigned to the Lance formation are of fresh-water origin or, very locally, of brackish-water origin and represent sediments deposited after the final withdrawal to the east of the Late Cretaceous sea. The upward change in the strata of the Lance formation from dark-gray shale and sandstone at the base to cyclically repeated sandstone, shale, and coal, to thick gray carbonaceous shale and lenticular sandstone at the top, is the result of a gradual change from nearshore to coastal-swamp to flood-plain environments, respectively.

Paleontologic data are too incomplete to indicate the exact time units that are represented. Stratigraphic relations within the mapped area suggest that the Lance is equivalent, in part, to the upper part of the Fox Hills sandstone, the Lance formation of the type area, and the Hell Creek formation of the standard reference section (fig. 79) (Cobban and Reeside, 1952a).

## TERTIARY SYSTEM

### FORT UNION FORMATION

The Fort Union formation of Paleocene age which was named and described by Meek and Hayden (1862, p. 433) from exposures in North Dakota, is widely distributed throughout much of North Dakota, Montana, and Wyoming. It underlies rocks of early Eocene age and overlies rocks of Late Cretaceous age. The Fort Union was variously assigned to either the Late Cretaceous or early Eocene ages until 1938, at which time R. W. Brown (1938, p. 422) indicated that the fauna and flora of the Fort Union formation were significantly different from those in the overlying and underlying formations and he considered the Fort Union formation to be of Paleocene age. This age assignment is now used throughout central Wyoming.

The Paleocene rocks in the Hiland-Clarkson Hill area were called Fort Union by Woodruff and Winchester (1912, p. 527) and by Hares (1916, 1946). This identification apparently was based upon lithologic characteristics and stratigraphic position above the Cretaceous rocks.

The Fort Union formation, like the underlying Upper Cretaceous rocks, crops out only along the margins of the southeastern end of the Wind River Basin. It is discontinuously exposed along the northeastern edge of the basin from about 3 miles southeast of Arminto to 2 miles west of the North Platte River. Near Pine Mountain (T. 34 N., R. 84 W.), Willow Creek (T. 32 N., R. 82 W.), and along the southern margin of the basin, from the North Platte River to the Grieve oil field, it is completely overlapped by the Wind River formation and younger Tertiary rocks. Along the flank of the Rattlesnake Hills anticline, from the Grieve oil field to the western boundary of the mapped area, however, it is continuously and well exposed. The Fort Union was mapped in detail only in the southeastern part of the area; the location of the contact of the Lance and Fort Union (pl. 6) in the western part of the area is from the geologic map of Natrona County (Weitz and others, 1954).

Because the Fort Union formation consists of interbedded resistant and nonresistant strata and is steeply dipping, it crops out as a series of alternating ridges and valleys. In areas where the dip of the formation is less steep, it is eroded into badlands.

The lithologic character of the basal beds of the Fort Union formation is not everywhere the same. Near Austin Creek a conspicuous zone, about 10 feet thick, of reddish-brown to gray interbedded fine-grained sandstone and shale unconformably overlies the Lance formation; whereas near the North Platte River (sec. 9, T. 31 N., R. 82 W.) the basal beds consist of yellowish-gray fine- to medium-grained massive sandstone about 15 feet thick. Near Iron Creek (sec. 17, T. 32 N., R. 82 W.) the strata at the base of the Fort Union formation are a series of yellowish-gray to buff lenticular concretionary sandstone and dark-gray carbonaceous shale and siltstone beds.

The Fort Union formation generally contains many thin discontinuous layers of dark-brown ferruginous sandstone and thin to thick

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beds of gray to white siltstone, sandy siltstone, and sandstone. Some sandstone and conglomerate beds contain reworked fragments of older strata. In gross appearance these features distinguish the Fort Union from the underlying Lance formation and from the overlying Wind River formation. Locally, however, the lithologic character of the Fort Union and the Wind River formations is similar and other criteria, such as angular or erosional unconformity, must be used to distinguish the two.

Everywhere the top of the Fort Union formation is an erosional surface. Accordingly, it is impossible to determine the maximum original thickness of the formation. The Fort Union formation was not measured within the eastern part of the mapped area; but a reconnaissance stratigraphic section of the exposed strata near Austin Creek, made by W. R. Keefer, R. J. Burnside, and Dee Beardsley, is reproduced here.

*Generalized stratigraphic section of Fort Union formation, Austin Creek, secs. 34 and 35, T. 35 N., R. 88 W.*

| | Feet |
|---|---|
| Wind River formation. | |
| Angular unconformity at contact. | |
| Fort Union formation: | |
| Shale and siltstone, brown, carbonaceous; contains some thin beds of sandstone, shale, and arkose; many ironstone concretions in upper part | 448 |
| Arkose, brown to buff; contains angular to subangular grains of quartz and feldspar; some pebbles of chert and siliceous shale or porcellanite; calcareous matrix | 10 |
| Shale and siltstone; basal 100 to 200 ft is bluish gray and forms distinctive sequence, rest of unit brown and carbonaceous; contains many thin beds of brown ferruginous sandstone and buff and white sandstone | 657 |
| Conspicuous zone of reddish-brown fine-grained sandstone, shale, and siltstone | 10 |
| Total thickness of Fort Union formation | 1,125 |
| Angular unconformity at contact. | |
| Lance formation. | |

Exposures of the Fort Union formation vary markedly in thickness from place to place because of the unconformity at the base and top of the formation, but in the Hiland-Clarkson Hill area the range is from 1,125 feet at Austin Creek to 65 feet near the North Platte River. Tourtelot (1953) reports about 2,800 feet of Fort Union strata in the vicinity of Arminto. Thickness in the subsurface ranges from about 1,570 feet in the Grieve oil field to about 2,700 feet in the West Poison Spider oil field.

The unconformity between the strata of the Lance formation and those of the Fort Union formation, although locally marked by only slight angular discordance, suggests moderate downwarping of the central part of the Wind River Basin relative to the margins. Although the strata are characteristic of flood-plain deposition, as is the upper part of the Lance formation, the source area for the sediments making up the Fort Union formation was in large part the relatively higher marginal area. The chert pebbles, typical of the Cloverly formation of Early Cretaceous age, and fragments of siliceous shale or porcellanite, typical of the Mowry shale of late Early Cretaceous age, suggest that rocks at least as old as Early Cretaceous were being eroded in the marginal areas by mid-Paleocene time. The presence of the arkosic sandstone further suggests that, locally at least, granite rocks were exposed to erosion.

The Paleocene age assigned to the Fort Union formation in this report is in conformity with the age assigned to the formation in other areas in central Wyoming rather than on specific paleontologic data from within the mapped area. Along the northern margin of the Wind River Basin, the Fort Union formation has been tentatively correlated with fossil-bearing rocks of Paleocene age in the Badwater area (Tourtelot, 1953). The maps of Hares (1946) and Love and others (1955) show that the Fort Union formation is present in the Dutton basin, about 6 miles west of the Hiland-Clarkson Hill area, but the easternmost exposure of fossil-bearing rocks of Paleocene age are near Conant Creek along the southern margin of the Wind River Basin. At this place Yenne and Pipiringos (1954) have collected and identified several species of fossil plants. They assign the rocks containing these fossils to the Fort Union formation and describe the strata as lenticular beds of conglomerate, sandstone, carbonaceous shale, siltstone, and claystone with a few coal beds. Some of the conglomerate beds contain pebbles of igneous and metamorphic rock and abundant chert pebbles and fragments of siliceous shale. These lithologic characteristics are similar to those of the Fort Union formation in this report. In the Powder River Basin, Hose (1955, p. 66–67) and Brown (1958, p. 111–113) have identified fossil plants of Paleocene age from rocks that overlie Cretaceous and underlie Eocene strata, and assigned these rocks to the Fort Union formation. Thus on the basis of stratigraphic position and lithologic similarity. the Fort Union formation in the Hiland-Clarkson Hill area is assigned a Paleocene age.

Two small bone fragments and a part of a crocodile tooth were collected from the upper part of the Fort Union formation in sec. 18, T. 32 N., R. 82 W., but the material was too fragmentary for specific identification. Fossil leaves were also collected, but they too were nondiagnostic.

### WIND RIVER FORMATION

The first use of the name Wind River was apparently by Hayden (1861), who referred the strata overlying the Fort Union formation to the deposits in the Wind River Valley. In Hayden's report of 1869, he refers to the "Wind River deposits" and also used the word "formation" in connection with these strata. Since that time the Wind River has been considered by most authors to be a formation. No type area, other than the Wind River Basin, was designated by Hayden.

In the Badwater area, adjacent to the Hiland-Clarkson Hill area on the north, Sinclair and Granger (1911, p. 104–105) divided the Wind River formation of early Eocene age into faunally and lithologically separable members, the Lysite and Lost Cabin members, in ascending order. Wood and others (1941, p. 7) and Tourtelot (1948, p. 114–120; 1953; 1957, p. 4–5) followed this nomenclature. However, in the Gas Hills area, which is contiguous with the Hiland-Clarkson Hill area on the west, Zeller and others (1956) divided the Wind River formation into a lower fine-grained facies and an upper coarse-grained facies. The lower fine-grained facies of Zeller may be lithologically and temporally equivalent to the Lysite and Lost Cabin members in the Badwater area. The upper coarse-grained facies of Zeller is limited in distribution to a relatively narrow outcrop band along the southern margin of the Wind River Basin and apparently has no lithologic or genetic equivalent in the Badwater area. Because the strata assigned to the Wind River formation in the area covered by this report are more similar to those in the Gas Hills than they are to those in the Badwater area, the nomenclature used by Zeller and others (1956) will be followed.

Near the eastern edge of the mapped area, at the base of Clarkson Hill, a conglomeratic sandstone unit unconformably overlies the Fort Union and Lance formations and is unconformably overlain by strata of the Wind River formation. Because this conglomeratic sandstone unit has a small areal distribution and has no lithologic equivalent in the adjoining areas, it is included in the Wind River formation and is referred to as the conglomeratic sandstone unit in this report.

The Wind River formation of early Eocene age is the most widespread lithologic unit in the Hiland-Clarkson Hill area. It crops out extensively in the central part of the Wind River Basin and underlies most of the area shown on the geologic maps (pls. 6, 7). The conglomeratic sandstone unit is exposed only in Clarkson Hill. The lower fine-grained facies is exposed from the western boundary of the area as far east as Poison Spider Creek, T. 33 N., Rs. 83–85 W.; eastward from Poison Spider Creek the upper coarse-grained facies is exposed.

The lower fine-grained facies is poorly indurated and easily eroded so that it forms hummocky and badlands topography, whereas the upper coarse-grained facies is more resistant and forms relatively high grass-covered ridges.

### CONGLOMERATIC SANDSTONE UNITS

Near the base of Clarkson Hill (secs. 4, 9, 16, and 17, T. 31 N., R. 82 W.) in the southeastern end of the Wind River Basin the Lance and Fort Union formations are separated from the Eocene strata by a conglomeratic sandstone unit. This unit is not exposed elsewhere in the Hiland-Clarkson Hill area and its stratigraphic and age relations to the overlying and underlying rocks are uncertain. Because of the small exposure and the uncertainty of correlation of the unit with other strata in the Hiland-Clarkson Hill area, this conglomeratic sandstone unit is included with the Wind River formation.

The unit is composed of very coarse angular poorly sorted grains of clear and milky quartz and white feldspar in a white to yellowish-gray clay matrix. Pebbles and cobbles as much as 10 inches in diameter occur in discontinuous layers in the upper 50 feet. Small pods, ranging from a fraction to 1 foot in diameter, and layers of gray carbonaceous siltstone and claystone, as much as 5 feet thick, are scattered throughout the sequence. Some of these carbonaceous siltstone pods and layers are radioactive.

The thickness of the unit ranges from 0 in sec. 4, T. 31 N., R. 82 W., to a maximum of about 120 feet in sec. 9, T. 31 N., R. 82 W. The following stratigraphic section is representative of the conglomeratic sandstone unit.

*Stratigraphic section of conglomeratic sandstone unit of Wind River formation, Clarkson Hill, sec. 17, T. 31 N., R. 82 W.*

| | |
|---|---|
| Wind River formation: | |
| Siltstone, variegated red and gray. | |
| Angular unconformity at contact. | |
| Conglomeratic sandstone unit: | *Feet* |
| Sandstone, white to very pale orange, conglomeratic, arkosic, poorly bedded | 51 |
| Conglomerate; granite cobbles as much as 10 in. in diameter in coarse-grained arkosic matrix | 3 |
| Sandstone, pale-greenish-yellow, conglomeratic, arkosic, poorly bedded; contains fragments of quartz and feldspar as much as 3 mm in diameter, and pods and thin layers of carbonaceous siltstone | 37 |
| Sandstone, light-brownish-gray, very fine grained; alternates with thin layers of carbonaceous siltstone; siltstone contains carbonaceous wood as much as 4 in. long; radioactive, 0.019 percent U and 0.070 percent eU | 4 |

*Stratigraphic section of conglomeratic sandstone unit of Wind River formation, Clarkson Hill, sec. 17, T. 31 N., R. 82 W.*—Continued

| | Feet |
|---|---|
| Conglomeratic sandstone unit—Continued | |
| Sandstone, white to pinkish-gray, coarse-grained to conglomeratic, arkosic, massive to poorly bedded; contains shale fragments of Lance formation in lower 3 ft and finely disseminated carbonaceous woody fragments and pods of carbonaceous shale | 19 |
| Total thickness of conglomeratic sandstone unit | 114 |
| Angular unconformity at contact. | |
| Lance formation: | |
| Shale, gray, carbonaceous, sandy. | |

The conglomeratic sandstone unit seems to bear the same stratigraphic relation to the remainder of the Wind River formation as does the Lysite member of early Eocene age in the Badwater area along the north-central margin of the basin (Tourtelot, 1948, p. 115). As such the conglomeratic sandstone unit may represent the initial flood of material washed into the basin from a newly formed mountain area. Since this sequence has a very limited areal distribution and has a high content of arkosic material, it is believed to represent local deposition along a stream, whose headwaters were actively cutting into Precambrian granite along the southern margin of the basin.

No fossils were found in the conglomeratic sandstone unit; however, the Fort Union is the youngest formation underlying the sequence, and beds containing early Eocene fossils are the oldest beds overlying it. This suggests an earliest Eocene age for this unit. Hence it may correspond in age to the Indian Meadows formation of Love (1939, p. 58–63) in the northwestern part of the Wind River Basin.

#### LOWER FINE-GRAINED FACIES

Two units were recognized within the lower fine-grained facies of the Wind River formation: a lower variegated sequence and an upper drab greenish-gray sequence. The units were not mapped separately, however, because no persistent horizon could be found to separate the two.

The contact between the Fort Union formation and the variegated sequence is marked by an angular unconformity. The angularity ranges from 5° to 45° and, generally, is greater along the northeastern margin of the basin. Along the flanks of the Rattlesnake Hills anticline, the angularity rarely exceeds 5°; whereas along the northeastern margin of the basin, it ranges from about 10° near Meadow Creek (sec. 35, T. 33 N., R. 83 W.) to about 45° near Hells Half Acre (sec. 36, T. 36 N., R. 86 W.). The unconformity is well exposed at Hells Half Acre (fig. 80).

The basal 1 to 3 feet of the variegated sequence is nearly everywhere a medium-grained to conglomeratic yellowish-gray sandstone. In a few places along the flank of the Rattlesnake Hills anticline, this sandstone contains fragments of sandstone and shale probably derived from Mesozoic rocks. Overlying this basal sandstone and making up the remainder of the variegated sequence is 250 to 800 feet of poorly bedded red, purplish-red, greenish-gray to gray siltstone interbedded with lenticular light-gray to yellowish-gray channel-filling sandstone. The variegated siltstone beds are abundant throughout the area of exposure, but individual color bands are discontinuous and can be traced along strike no more than a few hundred feet. In the northwestern part of the mapped area, the sandstone beds are composed of white to gray quartz grains with abundant small fragments and pebbles of Mesozoic and Paleozoic rocks, but they become progressively more arkosic toward the east. Near Poison Spider Creek (T. 33 N., R. 85 W.), the sandstone beds are composed of fine to coarse grains of quartz and feldspar and abundant small rounded pebbles of granite and a few fragments of Mesozoic and Paleozoic rocks. In general, the variegated sequence is more coarse grained, less brightly colored, and more arkosic in the eastern part of the mapped area.


FIGURE 80.—Unconformity between Fort Union formation (Tfu) and the lower fine-grained facies of the Wind River formation (Twl) at Hells Half Acre, Wyo. View southeastward.

The variegated sequence grades upward into the drab greenish-gray siltstone sequence. No individual bed, or group of beds, could be found that might serve to mark the contact between the two units. A carbonaceous zone, 1 to 5 feet thick, composed of alternating carbonaceous shale and thin coal beds is exposed on Coyote Creek and locally forms a marker bed along the contact zone, but it could be traced only a short distance along the strike of the beds. In the western part of the area, the lithologic character of the coarse-grained strata changes upward from white and gray sandstone containing fragments of Mesozoic and Paleozoic rocks to yellowish-gray arkosic sandstone containing few Mesozoic and Paleozoic rock fragments. This change might be used to mark the top of the variegated sequence in the western part of the area; but, as stated above, the sandstone beds within the variegated sequence are progressively more arkosic toward the east so that the vertical change in lithologic character is of little value in determining an accurate contact. The upward change in the siltstone beds from variegated red, purple, and gray to drab greenish gray seems to be the only persistent feature throughout the area, but even this change does not everywhere occur at the same stratigraphic horizon.

The drab greenish-gray sequence of the lower fine-grained facies of the Wind River formation is composed of intercalated siltstone, claystone, and lenticular arkosic sandstone beds. The physical characteristics of the siltstone and claystone beds are similar to the underlying variegated beds except that the color banding is absent. The sandstone beds are tan to yellowish brown, fine to coarse grained, and well to poorly sorted. They contain abundant carbonaceous fragments and thin layers of carbonaceous siltstone, some of which are radioactive northwest of the town of Hiland.

The maximum original thickness of the entire lower fine-grained facies of the Wind River formation is not known because, in areas where the facies can be observed, it rests with angular unconformity on older rocks and its upper limit forms the present erosion surface. The following measured stratigraphic section is given here to show the general lithologic character of the rocks.

*Stratigraphic section of lower fine-grained facies of the Wind River formation, Wallace Creek, sec. 36, T. 35 N., R. 87 W.*

| | |
|---|---|
| Present erosion surface. | |
| Upper drab greenish-gray sequence: | |
| | *Feet* |
| Sandstone, dark-yellowish-orange, coarse-grained to conglomerate, arkosic; weathers dark brown; resistant | 4 |
| Siltstone, greenish-gray, sandy | 43 |

*Stratigraphic section of lower fine-grained facies of the Wind River formation, Wallace Creek, sec. 36, T. 35 N., R. 87 W.*—Continued

| | Feet |
|---|---|
| Upper drab greenish-gray sequence—Continued | |
| Sandstone, yellowish-gray, medium- to coarse-grained, crossbedded; base channeled into underlying siltstone | 6 |
| Siltstone, light-olive-gray to pale-olive; sandy in basal 2 ft | 17 |
| Sandstone, pale-orange; coarse-grained to conglomeratic, arkosic, friable; weathers dark yellowish orange; calcareous in upper 2 ft; forms ledge | 18 |
| Partly concealed; contains light olive-gray siltstone at top | 76 |
| Sandstone, yellowish-gray, crossbedded, arkosic, resistant; conglomeratic at base, medium-grained at top; forms ledge | 13 |
| Partly concealed; probably greenish-gray siltstone | 11 |
| Sandstone, yellowish-gray, fine- to medium-grained, well-sorted; lenticular, wedges out about 100 ft east and west of measured section | 6 |
| Claystone, greenish-gray, nonresistant | 19 |
| Sandstone, dark-yellowish-orange, coarse-grained to conglomeratic, arkosic, resistant, crossbedded; weathers dark brown; channeled into underlying unit | 12 |
| Siltstone, greenish-gray, sandy | 3 |
| Sandstone, yellowish-gray, arkosic, crossbedded, friable; coarse-grained at base, conglomeratic at top; contains pods, as much as 1 ft in diameter, of greenish-gray siltstone and claystone at base | 6 |
| Total thickness of upper drab greenish-gray sequence | 234 |
| Approximate contact. | |
| Variegated sequence: | |
| Siltstone, light-gray to pale-purple; contains 1- to 2-ft yellowish-gray medium-grained lenticular sandstone bed 20 ft above base | 76 |
| Claystone, mottled red and gray; contains pods of siltstone | 3 |
| Siltstone, light-gray | 16 |
| Claystone, reddish-purple and pale-purple; alternates with greenish-gray siltstone | 11 |
| Siltstone, grayish-pink; weathers to hues of red and purple | 57 |
| Siltstone, light-gray to greenish-gray; sandy at top | 13 |
| Siltstone, gray to brownish-gray; contains layers of ferruginous sandstone 6 in. to 1 ft thick near base; 1 ft white fine- to medium-grained lenticular sandstone, containing grains of reddish siliceous sandstone, 30 ft above base | 69 |
| Siltstone, light-gray to brownish-gray; and white to light-gray, medium-grained, friable sandstone; predominantly sandstone | 29 |
| Total thickness of variegated sequence | 274 |
| Total thickness of lower fine-grained facies | 508 |
| Angular unconformity of about 5° at contact. | |
| Fort Union formation: | |
| Sandstone, grayish-orange, medium- to coarse-grained; conglomeratic at top; contains fragments of brownish quartz | 3 |

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The lower fine-grained facies appears to thicken basinward from the margins and its exposed thickness ranges from 0 along the margins of the basin to about 800 feet along the South Fork of Powder River. About 4,600 feet of rock lithologically similar to the lower fine-grained facies described in this report have been reported in the West Poison Spider oil field (Beasley, 1954, p. 66). Although these figures may reflect to some degree the differences in original thickness, the variation is in large part due to the beveling of the upper strata by Recent erosion. No strata assigned to the lower fine-grained facies was found in wells drilled south of the Rattlesnake Hills drainage divide.

The angular unconformity between the strata of the lower fine-grained facies and the Fort Union formation suggests that the downfolding of the Wind River structural basin took place before the deposition of the lower fine-grained facies and, furthermore, that the northeastern margin of the basin was more intensely folded and faulted than was the southwestern margin. The major structural features of the southeastern end of the Wind River Basin may have been formed at this time.

The strata of the lower fine-grained facies of the Wind River formation were probably deposited on a flood plain in a nearly closed basin. In the western two-thirds of the Hiland-Clarkson Hill area the sedimentary structures in the channel-filling sandstone beds of the variegated sequence, such as crossbedding, pebble alinement, and elongation of calcareously cemented lenses, indicate that the streams that brought sediment into the area flowed about normal to the margins of the basin; whereas those in the drab greenish-gray sequence indicate that the streams were flowing from west to east or northeast. The change in drainage pattern may indicate that the first major eastward drainage outlet for the Wind River Basin was formed at this time.

The Mesozoic and Paleozoic rock fragments and arkosic sandstone suggest that, during the deposition of the lower fine-grained facies, progressively older sedimentary rocks in the source area were subjected to erosion and that exposed areas of Precambrian granite supplied the bulk of sediment toward the end of the depositional period. The reddish color in the lower variegated sequence and its absence in the drab greenish-gray sequence may reflect differences in the kind and amount of iron in the original sediment or a difference in the environment at the place of deposition. Van Houten (1948, p. 2120–

2122) suggests that the differences in coloring of the rocks, here included in the lower fine-grained facies, may have been controlled by paleoclimatic conditions in the source area as well as in the area of deposition.

Collections of vertebrate fossils from the upper 100 to 200 feet of the variegated sequence in the extreme northwestern part of the mapped area indicate that these strata are probably equivalent to the Lost Cabin member of the Wind River formation in the Badwater area. The assemblage of fossils, which was collected in sec. 27, T. 37 N., R. 88 W., about 3 miles northwest of Hiland, was identified by C. L. Gazin and includes the following:

*Lambdotherium popoagicum* Cope
*Hyracotherium* sp.
*Hyopsodus wortmani* Osborn
*Hyopsodus mentalis* Cope
*Cynodontomys* sp.
cf. *Notharctus nunienus* (Cope)
cf. *Palaeictops* sp.
cf. *Didelphodus* sp.
Fossil remains of crocodile.

Other collections of vertebrate fossils from near Pine Mountain (NW¼ sec. 5, T. 35 N., R. 84 W.) contain genera similar to those near Hiland; these indicate early Eocene age but are not diagnostic as to stage. Fragments of teeth belonging to *Coryphodon* sp. were collected near Wallace Creek (sec. 2, T. 34 N., R. 87 W.) and near Poison Spider Creek (sec. 24, T. 33 N., R. 85 W.). These collections also indicate an early Eocene age. Fossils were not found in the drab greenish-gray unit. The rocks assigned to the variegated sequence of the lower fine-grained facies may be stratigraphically equivalent to the Lost Cabin member of the Wind River formation in the Badwater area; however, the extension of this correlation east and south of Waltman is doubtful. Along the southern margin of the Wind River Basin and in the eastern part of the mapped area only an early Eocene age can be assigned.

### UPPER COARSE-GRAINED FACIES

The upper coarse-grained facies of the Wind River formation is exposed only north of the Rattlesnake Hills drainage divide in the eastern third of the mapped area. This facies rests with erosional unconformity on the lower fine-grained facies, and near Poison Spider

Creek it fills channels cut into the upper surface of the lower fine-grained facies.

The upper coarse-grained facies is composed of medium- to coarse-grained light-yellow-gray arkosic sandstone and granite pebble to cobble conglomerate with minor amounts of lenticular siltstone, claystone, and carbonaceous shale. In good exposures, the lower third of the unit consists of medium- to coarse-grained, poorly sorted arkosic sandstone containing lenticular conglomerate and siltstone layers, whereas the upper two-thirds is predominantly arkosic pebble to cobble conglomerate containing lenticular sandstone and siltstone beds.

Most of the beds are poorly consolidated, and abrupt vertical and lateral changes in lithologic character are common. None of the beds can be traced laterally for more than a few hundred feet. Bedding is obscure, although crossbedding can be seen in a few of the sandstone beds. Some of the sandstone beds are calcareous and weather into elongated cylinders or "cannonball" concretions. Some of the conglomerate beds, particularly in the lower part, are iron stained. The siltstone and claystone layers are dark gray to black and contain abundant carbonaceous woody material. A carbonized log about 2 feet in diameter and 4 feet in length was found in the SE¼ sec. 19, T. 32 N., R. 84 W. Nearly all the carbonaceous siltstone layers have somewhat higher-than-background radioactivity.

Most boulders and cobbles are subrounded to subangular light-gray to white granite. Disaggregated white fragments of feldspar are particularly abundant; subrounded pebbles and cobbles of dark-gray to light-brown quartzite and dark-gray to black chert are common; fragments of Paleozoic and Mesozoic rocks are rare or absent.

No detailed stratigraphic sections of the upper coarse-grained facies of the Wind River formation were measured by the writer, but a generalized section measured in the vicinity of Burnt Wagon Draw is reproduced here to show the lithologic character of the unit. A detailed section would be useful for stratigraphic correlation in only a very small area because the beds are lenticular and the lithologic character changes abruptly in very short distances. Correlations based on gross lithologic aspect can therefore be made on a large scale and with greater accuracy.

*Generalized stratigraphic section of upper coarse-grained facies of Wind River formation, Burnt Wagon Draw, secs. 26 and 34, T. 34 N., R. 84 W., and secs. 4, 9, and 16, T. 33 N., R. 84 W.*

| | Feet |
|---|---|
| Top of section, erosion surface of Recent age. | |
| Upper coarse-grained facies: | |
| Sandstone and conglomerate, yellowish-gray to dark-yellowish-orange, arkosic, poorly indurated; contains lenticular pods of carbonaceous siltstone; conglomerate contains pebbles and cobbles of granite as much as 15 in. in diameter in upper 100 ft | 500 |
| Conglomerate, dark-reddish-brown, iron-stained, resistant, well-indurated; contains pebbles and cobbles of rounded to angular chert, quartz, quartzite, and granite in coarse-grained poorly sorted arkosic sandstone matrix; forms ridge | 50 |
| Sandstone and conglomerate, yellowish-gray to dark-yellowish orange, lenticular, poorly indurated; contains lenticular layers of carbonaceous siltstone; locally, calcareous sandstone beds, weather into loglike concretions | 170 |
| Conglomerate, yellowish-gray, lenticular; contains pebbles of granite as much as 3 in. in diameter, and large disaggregated white feldspar fragments | 20 |
| Sandstone, yellowish-gray to dark-yellowish-orange, medium- to coarse-grained, arkosic; contains poorly sorted, discontinuous lenses of pebble conglomerate in upper part | 110 |
| Total thickness of upper coarse-grained facies | 850 |
| Erosional unconformity at contact. | |
| Drab greenish-gray unit of lower fine-grained facies: Siltstone, greenish-gray to gray; contains intercalated fine- to medium-grained lenticular arkosic sandstone. | |

For the most part the coarse-grained facies was truncated by erosion to form the present surface; however, in T. 31 N., R. 82 W., it is unconformably overlain by the basal conglomerate of the White River formation. There, the contact is marked by an angular unconformity of about 30° and by a change upward from coarse-grained arkosic sandstone to a coarse boulder and cobble conglomerate.

Because the base and top of the upper coarse-grained facies are defined by either ancient or present erosional surfaces, the original thickness is unknown. Its thickness ranges from 0 along the northeastern margin of the Wind River Basin to about 50 feet along the eastern margin, and to a maximum of about 900 feet in the Cities Service Oil Co. well in T. 32 N., R. 85 W., along the southern margin. No strata assigned to the upper coarse-grained facies of the Wind River formation were found in wells drilled south of the Rattlesnake Hills drainage divide.

The wide range in grain size, the subrounded or subangular character of the larger fragments, the arkosic composition, the somewhat limited distribution, and the wedging out of the strata northward and eastward are compatible with the conclusion that the upper coarse-grained facies was derived from an elevated granite mass south of the Hiland-Clarkson Hill area. The most probable source for the sediments is the Granite Mountains about 10 miles south of the mapped area, although some sediments may have been derived from local sources along the margin of the basin.

No fossils were found in the upper coarse-grained facies, and the age of the unit can be determined only from its relations with adjacent rock units. In the Gas Hills area, a similar facies is gradationally overlain by pyroclastic rocks of middle and late Eocene age and underlain by rocks of early Eocene age; this facies is considered to be of early Eocene age (Van Houten, 1955, p. 6–10; Zeller and others, 1956). In the Hiland-Clarkson Hill area no pyroclastic rocks, which are typical of middle and late Eocene age, were observed by the writer, and the upper coarse-grained facies is unconformably overlain by rocks of Oligocene age and underlain by rocks of early Eocene age. Thus the upper coarse-grained facies may range in age from early Eocene to early Oligocene. However, because the strata here assigned to the upper coarse-grained facies are lithologically and stratigraphically similar to the upper coarse-grained facies in the Gas Hills area, they also are considered to be of early Eocene age.

### WHITE RIVER FORMATION

From a study of the Tertiary rocks of the high-plains areas of Wyoming, Nebraska, and South Dakota, Meek and Hayden (1861) defined the strata overlying the rocks of Eocene age and named them the White River group. The White River group was further divided by Darton (1899, p. 736) into the Chadron and Brule formations, in ascending order. Darton (1908, p. 463) extended the White River nomenclature into the area of this report and assigned the exposed Oligocene rocks to the Chadron formation. In the Beaver Divide area the Oligocene rocks have been variously called the White River group, White River formation, Chadron, Chadron and lower Brule, Brule, or Oreodon beds (Wood, 1948, p. 39); however, as a result of recent stratigraphic studies in that area, Van Houten (1954) assigned these rocks to the White River formation of Granger (1910). The Oligocene rocks in the Hiland-Clarkson Hill area are here referred to as the White River formation.

The White River formation is exposed along the northern slope of the Rattlesnake Hills drainage divide from Clarkson Hill to the head of Meadow Creek (sec. 33, T. 33 N., R. 84 W.), and along the southern slope of the Rattlesnake Hills drainage divide from the head of Meadow Creek to the western edge of the mapped area. The northern limit of the exposure is defined, in general, by the eastward-trending North Granite Mountain fault zone (Carey, 1954, p. 33); however, in T. 32 N., R. 83 W., scattered remnants of the basal conglomerate of the White River formation are preserved on the tops of some of the higher ridges north of the fault. From Clarkson Hill southwestward to the southern boundary of the mapped area, the formation is undisturbed by faulting and the entire unit is well exposed in an eastward-facing cliff. In nearly all exposures, the White River formation is soft and easily eroded so that it weathers into badlands or into steep slopes underlying the more resistant Miocene rocks.

Near Clarkson Hill the basal strata of the White River formation are unconformable with the underlying formations. South of the North Granite Mountain fault zone in secs. 18, 23, 24, and 26, T. 31 N., R. 82 W., the basal conglomerate of the White River rests on the eroded edges of Upper Cretaceous and older rocks. The Upper Cretaceous rocks strike northwest and dip about 45° NE, whereas the strata of the White River formation generally strike northeast and dip 1° to 3° W. North of the fault zone in secs. 8 and 17, T. 31 N., R. 82 W., the basal beds of the White River rest unconformably on the Wind River formation. In this area, the strata of the White River formation dip as much as 24° SW. and the strata of the Wind River formation dip 1° to 5° N. West of Clarkson Hill, on the southwest side of the fault, the basal beds of the White River formation are downfaulted or they may be covered by Recent alluvium. In the isolated outcrops north of the fault and west of Meadow Creek on the Rattlesnake Hills drainage divide, an erosional unconformity separates the basal conglomerate of the White River formation from the upper coarse-grained facies of the Wind River formation.

The lower 12 to 50 feet of the White River formation is a massive to poorly bedded conglomerate containing granite boulders as much as 20 feet in diameter, rounded pebbles and cobbles of Paleozoic sandstone, brownish-gray quartzite, basic igneous rock, and pale-green Precambrian quartzite; the matrix consists of coarse-grained arkosic sandstone. In the vicinity of Clarkson Hill the basal conglomerate contains abundant pebbles and cobbles of Paleozoic sandstone; however, the amount of Paleozoic sandstone in the boulder-conglomerate decreases westward and is absent in the westernmost outcrops. Conversely, angular fragments of brownish-gray quartzite, as much as 3 feet in diameter, are abundant in the westernmost exposures, decrease in amount eastward, and are rare or absent in the east. Boulders of granite and cobbles of pale-green Precambrian quartzite are present in all exposures.

The rest of the White River formation is characterized by light-gray, pinkish-gray, tan, and white tuffaceous siltstone and claystone interbedded with light- to dark-gray tuff and conglomeratic sandstone. The individual beds are lenticular and can be traced only short distances along the strike. The upper 50 to 100 feet is predominantly white to light-gray tuff interbedded with pinkish-gray tuffaceous siltstone. The tuff beds are lenticular and range in thickness from 0 to about 20 feet.

The conglomerate beds consist of angular to subrounded fragments, as much as 2 inches in diameter, of granite, dark intrusive igneous rocks, and some dark-green to black metamorphic rock in a tuffaceous siltstone, or locally arkosic sandstone, matrix. None of these rock types seem to have been derived from the middle and upper Eocene volcanic rocks in the Rattlesnake Hills; they are mineralogically similar to the Precambrian rocks exposed in parts of the Rattlesnake Hills and in areas south and southwest of the mapped area.

Many of the conglomerate beds contain pale-brown to medium-dark-gray pebbles of chert or chalcedony that are coated with a dull white porcelainlike material. The white coating is probably the result of leaching or hydration of the silica within the pebble itself or of the siliceous cement surrounding the pebble. Although chert pebbles are common in both the White River formation and the overlying Miocene rocks, the white coating seems to be found only on the pebbles in the White River formation.

Carbonaceous layers are scarce in the White River formation; however, a radioactive carbonaceous zone about 20 feet thick and about 1,000 feet long was found approximately 300 feet above the base of the White River formation in sec. 4, T. 31 N., R. 83 W. It consists of two lenticular beds of carbonaceous sandy siltstone separated by a thin coarse-grained sandstone. The carbonaceous zone is overlain and underlain by white poorly indurated sandstone. Disseminated grains of meta-autunite and (or) uranocircite have been identified from the lower bed.

Thin mudstone dikes—1 to 2 inches thick, 100 feet long, and extending to a depth of as much as 150 feet—are common in the upper part of the White River formation. These dikes have no consistent orientation. The contact between the dikes and the adjacent rock is sharp and there is no apparent displacement of the bedding planes. The origin of these dikes is not known.

The following section is representative of the White River formation in the Hiland-Clarkson Hill area.

*Section of White River formation, 1 mile north of Lone Tree Gulch, sec, 13, 22 to 24, T. 31 N., R. 83 W.*

Lower and middle Miocene rocks:
Siltstone, light-brown and pale-olive-gray, tuffaceous.
Erosional unconformity at contact.
White River formation:

| | Feet |
|---|---|
| Siltstone, medium-light-gray to pinkish-gray, tuffaceous; sandy in part: contains 1- to 3-in. layers of dense mudstone | 94 |
| Tuff, white to light-gray; powdery on weathered surface; resistant | 6 |
| Siltstone, light-gray, tuffaceous; contains thin resistant mudstone layers | 48 |
| Sandstone, white, medium-grained, poorly sorted, tuffaceous; contains unidentifiable fossil bone fragments | 4 |
| Siltstone, light-gray, tuffaceous: contains lenticular conglomeratic sandstone and thin resistant mudstone: mudstone dikes common | 145 |
| Conglomerate, light- to medium-gray, tuffaceous and sandy matrix: contains many white-coated chert pebbles and angular fragments of white feldspar and rounded quartz grains | 10 |
| Siltstone, light-gray, tuffaceous: sandy in upper 3 ft | 57 |
| Tuff, light- to medium-gray; contains many minute dark mica flakes | 8 |
| Siltstone, light-gray, tuffaceous, sandy | 59 |
| Tuff, white to light-gray, sandy | 6 |
| Siltstone, medium-gray, tuffaceous; contains thin lenticular pods of white coarse-grained sandstone | 20 |
| Conglomerate, yellowish-gray; fine- to medium-grained tuffaceous crossbedded sandstone matrix; concretionary, resistant | 15 |
| Tuff, white to light-gray, sandy | 6 |
| Siltstone, light-greenish-gray, tuffaceous | 100 |
| Sandstone, light-gray, conglomeratic; alternates with pale-olive tuffaceous sandy siltstone | 10 |
| Sandstone, yellowish-gray, medium- to coarse-grained, crossbedded, calcereous; contains scattered black chert pebbles as much as 4 in. in diameter and thin layers of pea-size pebbles along bedding planes; wedges out laterally | 20 |
| Siltstone, pale-olive, tuffaceous; faint reddish streak 2 ft thick, 12 ft above base, is highest red zone in section | 34 |
| Sandstone, light-gray, coarse-grained to conglomeratic; fragments of feldspar and quartz, few scattered pebbles | 2 |
| Siltstone, pale-olive, tuffaceous in lower and upper 10 ft; pale reddish-brown silty mudstone which contains unidentifiable fossil bone fragments | 42 |
| Sandstone, yellowish-gray, very coarse grained to conglomeratic, crossbedded, calcareous, resistant; contains pebbles of granite and chert as much as 1 in. in diameter | 6 |
| Siltstone, pale-olive, tuffaceous, sandy | 32 |
| Sandstone, pale-yellowish-orange, medium- to coarse-grained, arkosic, resistant | 2 |

*Section of White River formation, 1 mile north of Lone Tree Gulch, sec. 13, 22 to 24, T. 31 N., R. 83 W.*—Continued

| | Feet |
|---|---|
| White River formation—Continued | |
| Siltstone, pale-reddish-brown and pale-olive; alternates in bands 3 to 5 ft thick; fossiliferous, contains *Hyracondon* sp., *Mesohippus* sp., *Leptomeryx* sp., *Agriochoerus* sp. | 38 |
| Sandstone, yellowish-gray, fine- to medium-grained, crossbedded, resistant; silty in lower 6 ft; 2-ft pebble zone at base contains white-coated chert, granite, and Cretaceous sandstone | 34 |
| Siltstone, pale-olive, tuffaceous; sandy in upper 8 ft | 24 |
| Mudstone, pale-reddish-brown, tuffaceous, sandy | 2 |
| Sandstone, yellowish-gray to pale-olive, fine- to coarse-grained, crossbedded; conglomeratic at base; base irregular | 7 |
| Conglomerate, dark-yellowish-orange; contains rounded boulders of granite as much as 3 ft in diameter and cobbles and pebbles of brown quartzite; coarse-grained arkosic sandstone matrix; poorly sized and sorted, poorly bedded | 12 |
| Total thickness of White River formation | 843 |
| Angular unconformity at contact. | |
| Parkman sandstone member of Mesaverde formation. | |

The maximum original thickness of the White River formation cannot be determined because it is unconformably overlain by younger Tertiary rocks. The exposed thickness ranges from a maximum of 843 feet near Lone Tree Gulch to about 350 feet in sec. 26, T. 32 N., R. 84 W. South of the mapped area the White River formation thins to a wedge edge and is absent south of sec. 4, T. 30 N., R. 83 W. In the subsurface it ranges in thickness from about 865 feet in the Chicago Corp. well, Tysor Government 1C (sec. 13, T. 31 N., R. 84 W.), to about 580 feet in the Chicago Corp. well, Tysor Government 2C (sec. 2, T. 31 N., R. 84 W.), to about 370 feet in the True Oil Co. well, Ritter 1 (sec. 32, T. 32 N., R. 84 W.).

Rocks of Miocene age rest with erosional unconformity on the White River formation. In T. 32 N., R. 83 W., the Miocene rocks fill a channel, 350 to 400 feet deep and about 2½ miles wide, cut into strata of the White River formation. About 2 miles south of the mapped area in sec. 4, T. 30 N., R. 83 W., the White River formation was removed by post-early Oligocene erosion, and strata of Miocene age rest unconformably on Lower Cretaceous and older rocks. The structural relation between the White River formation and the Miocene rocks suggests that the White River formation was folded into a northeast-trending syncline and was deeply eroded before the deposition of the Miocene rocks. West of Meadow Creek, the Miocene rocks lap northward onto the White River formation and the angularity between the two formations ranges from 5° to 10°.

The basal conglomerate of the White River formation, like the upper coarse-grained facies of the Wind River formation, is considered to be an orogenic conglomerate derived from a sharply elevated landmass south or southwest of the Hiland-Clarkson Hill area. Unlike the upper coarse-grained facies of the Wind River formation, the composition and thickness of the basal conglomerate of the White River formation varies along the strike. These variations, the wide range in size of the rock fragments, and lack of bedding, suggest that the gradient of the streams along which the White River conglomerate was deposited was relatively steep and that the headwaters of these streams were actively eroding different rock types in different parts of the source area. The large granite boulders contained in the conglomerate further suggest that the material was not transported far.

The rest of the White River formation was apparently deposited on a flood plain that received frequent and prolonged showers of ash. Some of the ash reached the area directly as pyroclastic debris, but much of it was washed in from the uplands. Wood (1949) and Van Houten (1954) suggested that volcanic vents in the Yellowstone-Absaroka region, about 180 miles northwest of the mapped area, contributed a substanial part of the volcanic debris.

The White River formation in the Hiland-Clarkson Hill area is of early Oligocene (Chadron) age. Vertebrate fossils were collected from about 20 feet above the base to within 100 feet of the top of the formation. The fossil material includes many individual teeth, jaws, and disarticulated bone fragments. The collections, identified by G. E. Lewis (written communication, 1957), include the following forms:

*Sec 18, T. 31 N., 82 W., and secs. 13, 21, to 24, T. 31 N., R. 83 W. (from 50 to 600 ft above the base)*

*Hyracodon* sp.
*Mesohippus* sp.
*Leptomeryx* sp.
*Agriochoerus* sp.
?*Merycoidodon* sp.
*Perchoerus* sp.
Brontothere cf. *Allops* sp.
*Brontotherium* sp.

*Sec. 4, T. 31 N., R. 83 W., and sec. 33, T. 32 N., R. 8 W. (from 100 to 400 ft above the base)*

?*Pseudocynodictis* sp.
*Mesohippus* sp.
?*Brontotherium* sp.
*Brontotherium medium* (Marsh)
*Trigonias* sp.
*Archaeotherium mortoni* Leidy
?*Aepinacodon* sp.
*Leptomeryx* sp.

*Sec. 6, T. 31 N., R. 83 W., and sec. 31, T. 32 N., R. 83 W. (from 50 to 100 ft above the base)*

*Mesohippus* sp.
?*Leptomeryx* sp.
*Hyracodon* sp.

*Sec. 26, T. 32 N., R. 84 W. (from 20 to 30 ft above base)*

*Mesohippus* sp.

In addition to the vertebrate fossils listed above, samples from the carbonaceous zone in sec. 4, T. 31 N., R. 83 W. (USGS Paleobot. loc. D1230), about 300 feet above the base of the White River formation, were analyzed for pollen and spores by Estella B. Leopold (written communication, 1957). Listed below are the plant forms identified and the approximate percentage of each:

| *Plant forms* | *Percent of total pollen* |
|---|---|
| *Zelkova* sp | 45 |
| *Sarcobatus* cf. *vermiculatus* | 20 |
| *Salix* sp | 15 |
| *Carya* sp | 5 |
| *Fraxinus* cf. *nigra* | 5 |
| *Pinus* sp | 5 |
| Miscellaneous forms, each less than 1 percent of total pollen: | |
| *Picea* sp | |
| *Ephedra* cf. *nevadensis* | |
| *Carpinus* sp | |
| *Juglans* sp | |
| *Ptelea* cf. *baldwinii* | |
| Gramineae | 5 |
| *Potamogeton* sp | |
| *Euphorbia* sp | |
| *Tsuga* | |
| *Cardiospermum* cf. *corindum* | |
| *Selaginella* cf. *densa* | |
| *Quercus* | |

Of this collection Leopold states (written communication, 1958):

> Among these are warm temperaturue woody genera now living in relatively humid environments including * * * *Zelkova*, which now is restricted to Formosa and warm temperate parts of China, walnut, linden, ash, hornbeam, and hickory. Chaparral or desert shrub elements * * * include greasewood, *Ephedra*, and *Ptelea*. *Salix* (willow), *Potamogeton* (pondweed), and dinoflagellate algae suggest a shoreline environment. The assemblage suggests that these environments existed at or near the locality.

No rocks of middle and late Oligocene (Brule) age were recognized in the Hiland-Clarkson Hill area, although Van Houten (1954) reports a middle Oligocene fauna from about 40 miles west of the mapped area and Berry (thesis, see p. 451 of this report) reports strata of middle and late Oligocene age about 16 miles to the southeast. In the Hiland-Clarkson Hill area the lower and middle Miocene rocks rest with erosional unconformity on the lower Oligocene rocks, so that if any rocks of middle and late Oligocene age were deposited, they were removed by post-early Oligocene to pre-early Miocene erosion.

### LOWER AND MIDDLE MIOCENE ROCKS

Rocks of early and middle Miocene age are the youngest Tertiary rocks exposed in the Hiland-Clarkson Hill area. The sequence of rock has not been given a formal stratigraphic name but is referrerd to in this report as lower and middle Miocene rocks.

In the Hiland-Clarkson Hill area, the lower and middle Miocene rocks underlie an area of about 55 square miles extending from the Rattlesnake Hills drainage divide to the southern margin of the area. The ground surface is a moderately dissected southward-dipping plain that merges southwestward with the Sweetwater Plateau. The exposures of lower and middle Miocene rocks are poor, except along Henderson Creek T. 31 N.., R. 85 W.). The lower few feet, however, are exposed in the eastward- and northward-facing slope of the Rattlesnake Hills drainage divide from sec. 27, T. 31 N., R. 83 W., to the head of Meadow Creek, sec. 33, T. 32 N., R. 84 W., and along the southern slope of the divide from Meadow Creek to the SE¼ sec. 34, T. 32 N., R. 85 W. An erosional unconformity marks the contact of the lower and middle Miocene rocks with the underlying White River formation. In the northwestern part of T. 31 N., R. 83 W., the lower and middle Miocene rocks fill a broad channel cut into the White River formation; whereas in the southern part of T. 32 N., R. 84 W., they lap northward onto the White River formation.

In general, the strata strike northwest and dip 2° to 8° SW., but like the underlying White River formation, they dip more steeply in the vicinity of the North Granite Mountain fault zone as a result of postdepositional movement along the fault.

The lower 150 to 400 feet of the lower and middle Miocene rocks is made up of alternate white lenticular conglomeratic sandstone and light-gray to pinkish-gray sandy siltstone, all tuffaceous. Individual beds can be traced no more than a few tens of feet along the strike. The conglomerate beds contain fragments of angular pink and white feldspar as much as 1 inch in diameter; angular to subrounded pebbles of granite and basic igneous rock, as much as 1 foot in diameter; and gray to white quartz in an arkosic sandstone matrix. Most of the conglomerate beds are calcareous and weather into resistant ledges or low hogbacks. The strata filling the pre-Miocene channel in T. 31 N., R. 83 W., are about 400 feet thick and consist of interbedded siltstone and conglomerate similar to the basal strata exposed elsewhere; however, they are somewhat coarser grained and more irregularly bedded.

Overlying the basal beds is a predominantly tuffaceous sandstone sequence with intercalated beds of thin to thick tuff and lenticular conglomerate. The sandstone beds are white to light gray, fine to medium grained, moderately well sorted, and massive to crossbedded. The grains are subangular; most of them are white to clear quartz, but pink grains and black mica flakes are common. The sandstone beds are as much as 150 feet thick but commonly range from 20 to 50 feet. The tuff beds are white to bluish white and range in thickness from 2 to 10 feet; the thinner beds are thinly laminated, whereas the thicker beds are poorly bedded to massive. The conglomerate lenses, 1 to 15 feet thick, are composed of arkosic sandstone in which angular fragments of chert and granite, as much as 2 inches in diameter, are imbedded. The top of this tuffaceous sandstone sequence is not exposed within the Hiland-Clarkson Hill area, but the sequence seems to grade upward into strata that are similar to the middle Miocene rocks of the Split Rock area, about 20 miles to the southwest.

No complete stratigraphic sections of the lower and middle Miocene rocks were measured; however, part of a section, measured on the western margin of the Miocene-filled channel, is given below. Although the thickness shown in this section is not representative of the lower part of the lower and middle Miocene rocks, the general lithologic character of the rocks is typical of the basal beds of the Miocene sequence throughout the area.

***Part of stratigraphic section of lower and middle Miocene rocks, near head of tributary to Poison Spring Creek, sec. 4, T. 31 N., R. 83 W.***

Top of section at top of ridge in NE¼NE¼SW¼ sec. 4, T. 31 N., R. 83 W.

Lower and middle Miocene rocks:

| | *Feet* |
|---|---|
| Concealed; probably arkosic conglomerate; upper 6 in. very coarse grained arkose | 10 |
| Siltstone, grayish-orange-pink, tuffaceous, sandy | 9 |
| Concealed; probably arkosic conglomerate | 24 |
| Sandstone, grayish-orange-pink, very fine grained to silty | 5 |
| Conglomerate, light-gray; contains granite and chert pebbles as much as 2 in. in diameter, fine- to very coarse-grained akosic calcareous matrix | 9 |
| Siltstone, grayish-orange-pink, tuffaceous | 27 |
| Conglomerate | 6 |
| Siltstone, grayish-orange-pink, tuffaceous, shaly in upper 2 ft | 23 |
| Conglomerate, light-gray, crossbedded; arkosic matrix; contains pebbles of granite, chert, and basic igneous rock as much as 6 in. in diameter; limonite-stained in upper and lower 2 in | 5 |
| Siltstone, grayish-orange-pink, tuffaceous | 9 |
| Conglomerate, light-gray; crossbedded arkosic matrix | 18 |
| Siltstone, grayish-orange-pink, tuffaceous | 3 |
| Conglomerate, light-gray, arkosic; thickens eastward, wedges out 100 ft west of line of section | 3 |
| Siltstone, pale-grayish orange-pink, tuffaceous | 19 |

*Part of stratigraphic section of lower and middle Miocene rocks, near head of tributary to Poison Spring Creek, sec. 4, T. 31 N., R. 83 W.*—Continued

| | *Feet* |
|---|---|
| Lower and middle Miocene rocks—Continued | |
| Conglomerate, light-gray, arkosic, crossbedded; contains pebbles and cobbles of granite, chert, white quartz, and basic igneous rock as much as 6 in. in diameter; limonite-staining in upper 2 ft | 12 |
| Siltstone; grayish-orange-pink at base; grades upward into pale olive gray; tuffaceous; sandy at base | 30 |
| Conglomerate, light-gray, arkosic, crossbedded; contains pebbles of granite, white quartz, chert, and basic igneous rock as much as 1 ft in diameter; resistant | 30 |
| Siltstone, light-gray, tuffaceous; grades upward into mudstone with scattered isolated sand grains | 18 |
| Conglomerate, light-gray, arkosic | 18 |
| Total thickness of lower and middle Miocene rocks | 278 |
| Contact poorly exposed, but angular unconformity at base of conglomerate about 500 ft west of line of section. | |
| White River formation. | |

The original thickness of the lower and middle Miocene rocks could not be measured in the Hiland-Clarkson Hill area because they are beveled by erosion. However, the maximum thickness of these rocks within the area, computed from the outcrop pattern (pl. 7) ranges from 1,000 to 1,500 feet. These figures are based on the assumptions that the top of the White River formation along any line of section is a planar surface and the dip of the rocks at depth is the same as those dips recorded at the surface. Both of these assumptions may be in error inasmuch as the lower contact is known to be an erosional surface and the Miocene rocks lap unconformably across the eroded surface cut on the White River formation. Therefore, any figure obtained by calculation can be only an approximation of the true thickness.

The exposed thickness of the basal beds of the lower and middle Miocene rocks ranges from 196 feet in sec. 22, T. 31 N., R. 83 W., to about 450 feet near the center of the Miocene-filled channel (secs. 3, 8, and 9, T. 31 N., R. 83 W.), to 278 feet in sec. 4, T. 31 N., R. 83 W., to about 170 feet in secs. 26 and 35, T. 32 N., R. 84 W. In the subsurface these beds range in thickness from 315 feet in the Chicago Oil Corp. well, Tysor Government 1C, sec. 13, T. 31 N., R. 83 W., to about 600 feet in the Chicago Corp. well, Tysor Government 2C, sec. 2, T. 31 N., R. 84 W.

The lower and middle Miocene rocks represent continental deposition on a pre-early Miocene erosion surface. The basal coarse-grained strata, apparently deposited along aggrading streams, fill the irregularities in the erosion surface. The upper fine-grained strata were probably deposited on a flood plain that received frequent showers of volcanic ash. The ash showers during early and middle Miocene time were probably less frequent and of shorter duration than those during Oligocene time.

In a reconnaissance study of the Split Rock area, about 20 miles southwest, Love (1952, p. 7) noted that the conglomerate lenses in the middle Miocene rocks contained rock fragments derived from adjacent Precambrian outcrops in the Granite Mountains, but that the soft tuffaceous sandstone beds were deposited against the steep faces of Precambrian knobs with no talus and little difference in grain size between the beds at the contact and those farther away. This relation suggests that the sediments making up the basal coarse-grained strata of the lower and middle Miocene rocks may have been derived from local sources, but that those of the upper fine-grained strata may have been carried by streams into the area from a source some distance to the west or southwest.

Heretofore, the Miocene rocks exposed in the Hiland-Clarkson Hill area were thought to be of middle Miocene age. In this report the range has been extended to include early Miocene time because of the discovery, within the mapped area, of a vertebrate fossil of early Miocene age. Southward the rocks grade upward into strata that are similar to the middle Miocene rocks in the Split Rock area where Schultz and Falkenbach (1940, p. 250) and McGrew (1951, p. 56) obtained large collections of middle Miocene vertebrate fossils. The vertebrate fossil of early Miocene age was found in the SW¼ sec. 12, T. 31 N., R. 85 W., and included a complete skull with articulated mandible and miscellaneous bone fragments belonging to *Merycoides cursor* Douglass. This fossil was identified by G. E. Lewis (written communication, 1957) as an early Miocene form and he states:

[This fossil] indicates a rock unit to be correlated approximately with the Gering channel sandstone of the Arikaree formation of Nebraska and with the lower Miocene rocks of Jefferson County, Montana.

## QUATERNARY SYSTEM

### TERRACE GRAVEL DEPOSITS

Gravel caps at least two terraces near the North Platte River in T. 31 N., R. 82 W. On the older terrace (pl. 7), the gravel deposits range from 5 to 20 feet in thickness and consist mainly of granitic pebbles and cobbles derived from the Granite Mountains. This gravel also contains conspicuous amounts of sandstone, siliceous shale, and limestone derived from Paleozoic and Mesozoic rocks. The younger terrace (pl. 7) is covered with deposits ranging in grain size from very coarse sand to silt, but, locally, it is capped by pebble conglomerate. The finer grained part of the gravel deposits on all the terraces ranges in size from clay to granule size. All are poorly sorted and only locally cemented. The streamward edge, or riser, of the terraces usually has a cover of colluvial material sloping toward the North Platte River. The upper surfaces are relatively flat, sloping from 1° to 5° toward the North Platte River. The older terrace is 250 to 400 feet above the river and the younger terrace is 160 to 250 feet.

#### ALLUVIUM

Although alluvium is present along the beds of most streams, it was not feasible to show it in most places on the map of the scale used. The alluvium is a mixture of clay, silt, and sand, and commonly contains much organic matter. Much of the alluvium is reworked tuffaceous material from areas underlain by Oligocene and Miocene rocks.

## STRUCTURE

### REGIONAL FEATURES

The Wind River Basin is bounded on the south by the Granite Mountains, on the north by the Owl Creek and Bighorn Mountains, and on the east by the Power River lineament (fig. 78). The axis of the basin trends about N. 45° W. in the eastern third, swings to a more east-west trend in the middle third, and then back to a northwest trend in the western third. The southern flank of the basin is modified by a series of northwestward-trending en echelon anticlinal folds; the easternmost of these anticlines, the Rattlesnake Hills anticline, forms the southern boundary of the mapped area. The northeastern boundary of the basin is limited structurally by a line of folds and faults extending from about 5 miles east of the mapped area to Arminto. This line of folds and faults, variously referred to as the Powder River lineament, the Casper arch, or the Nationa arch, forms the northeastern margin of the area covered by this report. The northern and western margins of the Wind River Basin are areas of complex folding and faulting, and although these areas are important in the regional structure, they lie outside of the mapped area and are not considered in the following discussion of the structural geology.

The trend of the major structural features throughout most of the mapped area is about N. 45° W. The most intense folding and faulting is along the Power River lineament and the Rattlesnake Hills anticline. The anticlinal folds in these areas are asymmetrical and have their steep flanks on the southwest. The trend of the North Granite Mountain fault zone deviates only slightly from the general trend of the anticlines and is, roughly parallel to the axis of the Wind River Basin. The observable displacement along the fault zone indicates that the Tertiary rocks on the northeast side are dropped relative to those on the southwest side; however, subsurface data suggest that the relative movement of the pre-Tertiary rocks along the fault zone is in the opposite direction.

The slight angular unconformity between strata of the Lance and Fort Union formations, the large angular unconformity between strata of the Fort Union and Wind River formations, and the relatively greater folding and faulting of the pre-Wind River rocks as compared with that of the Wind River and younger Tertiary rocks records in some measure the time of the Laramide orogeny in the Hiland-Clarkson Hill area. The structural deformation during this orogeny probably began near the end of, or just after, deposition of the Lance formation, and may have continued throughout Paleocene time, although no disconformities were seen within the Fort Union formation. The greatest downwarping of the southeastern end of the Wind River Basin took place at the close of Paleocene time but before the deposition of the lower fine-grained facies of the Wind River formation. Some deformation undoubtedly continued throughout early Eocene time. Deformation associated with the Laramide orogeny continued during middle and late Eocene time with faulting along the North Granite Mountain fault zone and volcanism in the vicinity of the Rattlesnake Hills. The folding in the lower Oligocene rocks and renewed movement along the North Granite Mountain fault zone during Pliocene (?) time may not be related to the same phase of the Laramide orogeny that affected the northern part of the area but rather may be the result of structural deformation centered somewhat farther south.

## METHOD OF STRUCTURE CONTOURING

The top of the Teapot sandstone member of the Mesaverde formation was selected as the datum upon which the structural configuration of the Upper Cretaceous rocks could best be depicted (pl. 7). The structure contour interval is 500 feet. Surface elevations were obtained from topographic maps and subsurface elevations were obtained from drilled wells or by extrapolation from surface data. Structure sections were used to cross-check subsurface data. Because of the lack of subsurface data and exposures, no structure contours were drawn in the central part of the area. The positions of the axial traces of the folds are based on projections of surface dips and, therefore, are only approximate. No structure contours are drawn in the area of reconnaissance mapping.

### FOLDS

The principal downfold in the Hiland-Clarkson Hill area is the northwestward-plunging synclinal depression that forms the southeastern end of the Wind River Basin. The central part of the basin is occupied by lower Eocene rocks so that pre-Eocene structural features in the underlying Mesozoic rocks are masked. However, outcrops of Mesozoic and lower Tertiary rocks along the margins of the basin provide data sufficient to determine the general structural configuration of the central part of the basin.

The Upper Cretaceous rocks dip basinward; along the northeastern flank of the syncline they dip from 36° to 78°, whereas along the southwestern flank they dip from 15° to 45°. The strata assigned to the Fort Union formation of Paleocene age also dip basinward, but the dip is much less, ranging from 10° to 43° along the northeastern flank and from 5° to 10° along the southwestern flank. The dip of the Wind River formation of early Eocene age ranges from 5° to 20° along the flanks of the basin but the formation lies almost flat near the axis of the basin. These data show that the syncline is asymmetrical.

Minor folds on the northeastern flank of the Wind River Basin syncline are exposed in T. 32 N., R. 82 W., and in T. 36 N., R. 86 W. The fold in T. 32 N., R. 82 W., is a northeastward-trending syncline that plunges southwestward. The details of the fold are obscured by alluvium; however, the field data suggest that the surface trace of the axial plane is continuous with the trace of the Bessemer Mountain normal fault, about half a mile northeast of the mapped area, and with the trend of the normal faults in the Wind River formation is secs. 19 and 20, T. 32 N., R. 82 W. Because no displacement of strata was seen in surface exposures, possibly the Bessemer Mountain fault passes southwestward into this synclinal fold: the displacement of the fault is represented in the mapped area by the northwest limb of the syncline. Movement along this structural trend after deposition of the Wind River formation may have further depressed the trough of the syncline and formed small fractures in the Wind River formation.

Similar synclinal fold is exposed in the Upper Cretaceous and Paleocene rocks in T. 36 N., R. 86 W., near Hell's Half Acre, Wyo. The surface trace of the axis of this fold trends northeastward and the axial plane plunges southwestward. No synclinal folding or faulting was seen in the overlying Eocene rocks, so that the age of the folding is probably post-Paleocene to pre-Eocene. However, post-Eocene movement along the northeastern flank of the Wind River Basin syncline may have tilted the rocks more steeply basinward.

The southeastern part of the Iron Creek anticline, exposed in secs. 11 and 14, T. 32 N., R. 82 W., is an extension of the line of folds and faults along the Powder River lineament. The surface trace of the axial plane trends northwestward. At the southeastern end of the anticline, the axis plunges about 10° SE., whereas at the northwestern end, outside of the mapped area, it plunges about 30° NW. A sandstone bed in the Frontier formation completely encircles the anticline, and the closure is estimated to be about 1,200 feet in the Lower Cretaceous rocks. A transverse fault crosses the southeastern end of the anticline.

## FAULTS

### NORTH GRANITE MOUNTAIN FAULT ZONE

The eastward-trending fault zone in the southeastern part of the mapped area (pl. 7) is continuous with the North Granite Mountain fault zone, named and described by Carey (1954, p. 33) from exposures in the Rattlesnake Hills anticline. In the Hiland-Clarkson Hill area the surface trace of the North Granite Mountain fault zone extends from Clarkson Hill, sec. 17, T. 31 N., R. 82 W., northwestward along the north side of the Rattlesnake Hills drainage divide to sec. 27, T. 32 N., R. 84 W. It could not be traced west of sec. 27, T. 32 N., R. 84 W. South of the Rattlesnake Hills drainage divide, from sec. 33, T. 32 N., R. 84 W., to the western edge of the mapped area, a zone of faults, here considered a part of the North Granite Mountain fault zone, is poorly exposed and many of the faults can be detected only as linear features on aerial photographs, and are shown as probable faults on plate 7. The fault planes dip northward at angles ranging from 60° to 85°.

The displacement of the Oligocene and Miocene rocks along the North Granite Mountain fault zone is thought to be the result of post-Miocene adjustment along a preexisting fault zone. Geophysical data indicate that the displacement of the Wind River and older formations along the fault zone may be as much as 5,000 feet with the strata on the north side of the fault dropped relative to those on the south side. On the other hand, surface data indicate that the post-Wind River strata along the fault zone are displaced about 175 feet and the strata on the south side of the fault are dropped relative to those on the north side. Thus the relative displacement of the Oligocene and Miocene rocks is in the reverse direction and of considerably less magnitude than that in the Wind River and older formations.

On the south side of Clarkson Hill, sec. 17, T. 31 N., R. 82 W., the North Granite Mountain fault zone is exposed in a shallow excavation (fig. 81). It consists of two closely spaced normal faults that

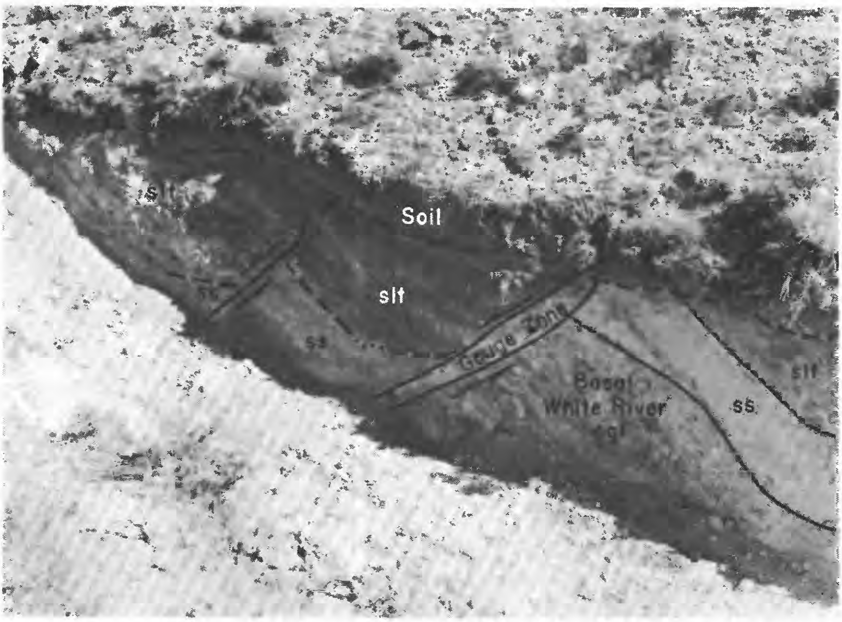


FIGURE 81.—North Granite Mountain fault zone exposed in a bulldozed pit on the south Side of Clarkson Hill. View northeastward. (ss, sandstone; cgl, conglomerate; slt, siltstone).

displace the bedding in the White River formation. The fault planes strike about N. 79° W. and dip about 45° NE. The north side of the faults is dropped and the strata are displaced about 40 feet. The faults apparently die out about half a mile east of the excavation pit; westward, the fault zone is obscured by slope debris, but its location can be indicated approximately from the attitude of the bedding on either side of the fault zone and from linear features on aerial photographs.

In sec. 3, T. 31 N., R. 83 W., the North Granite Mountain fault zone is exposed in a small tributary of Poison Spring Creek. There the fault plane strikes about N. 80° W. and dips about 78° NE. but the strata of the White River formation, on the south side of the fault, are dropped relative to the upper course-grained facies of the Wind River formation, on the north side, in reverse fault relation. The displacement along the fault is not known but is probably about 150 feet. Small reverse faults, with displacements of 5 to 10 feet each, offset the North Granite Mountain fault in sec. 34, T. 32 N., R. 83 W.

The North Granite Mountain fault zone can be traced in surface outcrop from sec. 3, T. 31 N., R. 83 W., to just east of Poison Spring

Creek. From Poison Spring Creek to the eastern part of sec. 36, T. 32 N., R. 84 W., the fault is concealed, but its location can be approximated from stratigraphic relations and from the alinement of springs, seeps, and lush vegetation. From sec. 36, T. 32 N., R. 84 W., to the head of Meadow Creek, the fault plane is exposed in the sides of small gullies; its trace can be located only approximately on the interfluve areas. In the SW¼ sec. 25, T. 32 N., R. 84 W., the fault plane strikes N. 72° W. and dips 68° NE.; the south side of the fault is down relative to the north side, so that strata of the White River are in contact with the upper course-grained facies of the Wind River formation. The stratigraphic displacement is about 175 feet; however, the actual displacement along the fault may be greater.

North of the Rattlesnake Hills drainage divide the North Granite Mountain fault zone could not be observed west of Meadow Creek. However, south of the divide from sec. 33, T. 32 N., R. 84 W., to the western edge of the mapped area (pl. 7), a zone of faults, about ½ to 1 mile wide, can be seen in surface exposures, and is here considered to be part of the North Granite Mountain fault zone. The individual faults within this fault zone strike west and northwest, dip northward, and have a maximum stratigraphic displacement of about 27 feet. The total stratigraphic displacement along the fault zone cannot be determined accurately because the original thickness of the strata is not known, but it is probably at least 100 feet in the Tertiary rocks. The strata along the south side are dropped relative to those on the north side.

A precise dating of the last episode of the fault movement cannot be made from data gathered in the mapped area; however, Knight (1900, sec. 12, p. 219) and Love (1952, p. 10) report that large-scale faulting during Pliocene(?) time dropped the central part of the Granite Mountains with respect to the Wind River Basin on the north and the Great Divide Basin on the south, and suggest that the North Granite Mountain fault zone marks the northern margin of this grabenlike depression. Thus this episode of movement along the North Granite Mountain fault zone may have occurred during Pliocene(?) time. The amount of displacement along the southern margin of the graben was greater than that along the North Granite Mountain fault zone, so that the total structural effect in the Hiland-Clarkson Hill area probably was moderate displacement along a preexisting fault and a southward tilting of the rocks south of the fault zone.

The first episode of movement along the North Granite Mountain fault zone may have taken place during middle and late Eocene time.

This episode of faulting is dated by the relations of the Wind River formation to the fault zone and to the overlying formation. Because the Granite Mountains, about 10 miles south of the mapped area, are the most probable source for the upper coarse-grained facies of the Wind River formation, this facies probably extended from near the Granite Mountains into the mapped area. South of the North Granite Mountain fault zone, however, no rocks assigned to the upper coarse-grained facies were found, either in surface exposures or in well samples, although as much as 500 feet of this unit is exposed within 2 miles north of the fault. The basal conglomerate of the White River formation rests unconformably on Cretaceous and older rocks south of the fault, whereas it rests on the upper coarse-grained facies of the Wind River formation north of the fault. Thus the displacement along the fault zone must have occurred after the deposition of the upper coarse-grained facies of the Wind River formation (early Eocene) and before the deposition of the basal conglomerate of the White River formation (early Oligocene). As a result of the fault displacement, the southern or uplifted block may have been subjected to more active erosion, so that the Wind River formation, as well as any middle and upper Eocene rocks that may have been deposited probably were removed from this block before the deposition of the White River formation.

### THRUST FAULTS

A small segment of a thrust fault was mapped in the southeastern part of the Hiland-Clarkson Hill area in the NE¼ sec. 10, T. 31 N., R. 82 W. (pl. 7). At this locality the dip of beds within the Lance formation changes progressively southwestward from 36° to about 86° near the fault. Because of the lenticularity of the beds within the Lance formation, no individual bed could be used as a plane of reference; however, the dip relation is interpreted as the result of a bedding-plane thrust or a low-angle reverse fault in which rocks on the northeast side were sharply bent and possibly thrust southwestward.

In T. 35 N., R. 85 W., well data indicate that Boone dome, and possibly Pine Mountain, are underlain by a low-angle thrust fault (Albanese, 1954, p. 69). The thrust plane was penetrated in the Cody shale at depths of 4,700 to 5,000 feet. It dips at angles of 25° to 45° NE. Directly above the fault plane the strata dip 20° to 50° NE., whereas below the fault the dips range from 60° to 85° SW. The thrust fault is not exposed at the surface.

In the vicinity of Arminto, sec. 29, T. 31 N., R. 86 W., the Pure Oil Co. well, Waltman 1, penetrated a thrust fault, about 6,570 feet below the surface. In this well the Frontier formation overlies the Lance or Fort Union formation. The fault plane appears to dip northeastward, and the rocks above the fault dip 25° to 70° SW., whereas those below the fault are nearly horizontal.

The fact that in each of the above areas the rocks involved in the thrusting are very nearly the same age and that the relative movement along the thrust fault in each of the areas is the same suggests a more or less continuous thrust sheet along the northeastern margin of the basin. Geophysical data support this interpretation.

### PROBABLE FAULTS

Several northwest-trending linear features, consisting of narrow zones of silicified sandstone or alinements of seeps, springs, and lush vegetation, were mapped in T. 31 N., R. 84 W. No physical evidence of faulting could be found in surface exposures; however, wells drilled in the Fish Creek oil field, secs. 8 and 9, T. 31 N., R. 84 W., penetrated a reverse fault with several hundred feet of displacement in the pre-Tertiary rocks. These linear features possibly mark the location of post-Miocene faulting along a preexisting zone of weakness. On the other hand, it is equally possible that these lineations represent points at which water, either rising along the pre-Tertiary fault or joints or fractures, reaches the surface. Although the origin of these linear features is doubtful, they are shown on plate 7 as probable faults.

Similar features interpreted as probable faults were mapped along the North Granite Mountain fault zone and in T. 33 N., R. 86 W.

## STRUCTURAL AND SEDIMENTATIONAL HISTORY

At the beginning of Late Cretaceous time, the Hiland-Clarkson Hill area was submerged beneath an epicontinental sea. Marine conditions prevailed for the most part during the deposition of the sediments now classed as the Frontier formation and Cody shale. During the latter part of the deposition of the Cody shale, the sea gradually withdrew toward the east, and the transition from marine to nonmarine conditions was gradual and fairly continuous. Minor oscillations of the strand line during this regression produced interfingering of offshore marine, littoral, and terrestrial sediments that are now represented by parts of the Mesaverde formation, Lewis shale, and Meeteetse formation. Near the end of Late Cretaceous time the epicontinental sea withdrew from the area, and the final marine deposits are probable regressive sandstone beds in the lower few feet of the Lance formation. As the withdrawal of marine waters took place, terrestrial sediments filled coastal swamps and by the end of Late Cretaceous time sediments were deposited on a broad flood plain that probably was not much above sea level. These sediments are represented by the upper part of the Lance formation.

At some time after the deposition of the Lance formation but before Paleocene time the rocks of the area were moderately downfolded. The evidence for the downfolding is a slight angular discordance between strata of the Lance formation and the Fort Union formation. Wheather or not downfolding continued into Paleocene time is not known. However, because no angular unconformities were seen within the Paleocene rocks, it is inferred that the orogeny was short-lived, and, if it continued into the Paleocene, it was not strong enough to be reflected in the sediments. The period of this deformation is thought to represent one of the initial pulsations of the Laramide orogeny and the loci of future mountain ranges and basins may have been formed at this time.

The rocks of the area were powerfully deformed at the end of the Paleocene, or during earliest Eocene time. The unconformity at the base of the Wind River formation of early Eocene age is clear evidence of this crustal deformation and suggests that the compressional forces were directed principally to the southwest. The northwestward-trending structural elements of the southeastern end of the Wind River Basin probably were formed at this time. In the Hiland-Clarkson Hill area, the northeastern and southwestern margins of the basin may have been uplifted relative to the basin syncline and were intensely folded and faulted. The thrust fault penetrated in wells near Arminto and in Boone dome and found at the surface near the North Platte River possibly was formed during this tectonic movement.

As a result of the crustal deformation, the rock units in the surrounding highlands were exposed to erosion and the resulting debris was deposited in the basin area. Near the southeastern edge of the basin, areas of Precambrian igneous rocks were exposed to erosion at the beginning of early Eocene time and the debris from these areas was deposited along streams traversing the extreme southeastern end of the Wind River Basin. These deposits are classed here as the conglomeratic sandstone unit of the Wind River formation. Along the northeastern and southern margins of the basin, however, sedimentary rocks of Mesozoic age were exposed to erosion at the beginning of early Eocene time, but successively older sedimentary rocks, and locally Precambrian crystalline rocks, were supplying the bulk of the debris to the basin throughout early Eocene time. These deposits are represented by the lower fine-grained facies of the Wind River formation.

Considerable tectonic activity probably occurred south of the Hiland-Clarkson Hill area near the end of early Eocene time, for the southern margin of the basin received a flood of coarse granitic sediment now exposed as the upper coarse-grained facies of the Wind River formation. Although there is no structural evidence for this tectonic activity in the mapped area, the coarseness and the abundance of granitic debris suggest that a fairly large mass of granite was rather quickly exposed to erosion.

After the deposition of the Wind River formation, extensive volcanic activity, accompanied by local uplift, took place along the axis of the Rattlesnake Hills anticline. Strata as much as 700 feet thick and rich in volcanic material derived from the Rattlesnake Hills volcanic field, were deposited west of the map area along the Beaver Divide (Van Houten, 1955, p. 6). These rocks are part of an unnamed sequence of middle and late Eocene age and may have been continuous with the lithologically similar middle and upper Eocene andesite-rich Aycross and Tepee Trail formations along the north-central margin of the basin (Tourtelot, 1957, p. 5–19).

The major movement on the North Granite Mountain fault zone in the southern part of the map area is believed to have taken place during middle and late Eocene time, and, as a result of the displacement along these faults, the Wind River rocks on the upthrow or southern block, as well as any middle and upper Eocene rocks that may have been deposited, were probably stripped off before the deposition of Oligocene sediments.

At or near the end of Eocene time, uplift in the Granite Mountains area led to the deposition of the basal conglomerate of the White River formation. Large granite boulders as much as 20 feet in diameter, angular and rounded cobbles and pebbles of granite, and Paleozoic rocks were washed into the area. The size of the boulders, the distribution and angularity of the rock fragments, and the lack of bedding in the conglomerate do not suggest extensive transport. In the eastern part of the Hiland-Clarkson Hill area, fragments of Paleozoic sedimentary rock are common in the conglomerate, whereas in the western part of the area brownish-gray quartzite is common and Paleozoic sedimentary rock is absent. Farther west in the Beaver Divide area, Van Houten (1954) reports that volcanic material from the Rattlesnake Hills volcanic field is common in the basal conglomerate of the White River formation. This distribution of rock types suggests that, although the areal extent of the conglomerate in an east-west direction is rather large, the material making up the conglomerate at any one place was locally derived.

After the deposition of the basal conglomerate of the White River formation, well-sorted tuffaceous and bentonitic mud was deposited in flood plains and, very locally, in lakes; and rare lenses of arkosic sand and gravel accumulated in widely separated stream channels. Frequent prolonged showers of ash, probably from volcanic vents in the Yellowstone-Absaroka region, contributed a substantial part of the sediment. Some of the ash may have reached the area directly as pyroclastic debris, whereas much of it probably was washed in from the uplands.

Probably in late Oligocene time the Sweetwater Plateau was tilted and locally folded; aggradation ceased and degradation began. By the beginning of Miocene time, most if not all the upper Oligocene sediments that may have been deposited were removed so that only the lower Oligocene sediments are preserved.

During early Miocene time, bentonitic mud interspersed with closely spaced lenses of arkosic sandstone and gravel containing considerable amounts of basic igneous rock accumulated in the larger valleys. Such valley fill is preserved in sec. 3–5, 8, and 9, T. 31 N., R. 83 W. After the valleys had been filled, tuffaceous sandstone, mudstone, and widely spaced lenses of gravel, and locally some tuff, accumulated slowly on extensive flood plains. The topographic relief was gradually reduced by erosion of the uplands and filling of the valleys so that by the end of Pliocene(?) time nearly all the mountain ranges were buried.

At some time after the deposition of Pliocene(?) sediments, the depression of the Granite Mountains area along graben faults, may have resulted in renewed movement along the North Granite Mountain fault zone and a southward tilting of the rocks south of the fault.

Subsequent to this faulting, the entire area has undergone slow degradation and the topographic relief as seen today is the result of post-Pliocene(?) to Recent erosion.

## ECONOMIC GEOLOGY

### URANIUM OCCURRENCES

#### METHODS OF RADIOACTIVITY INVESTIGATIONS

Many of the Tertiarty strata in the southeastern part of the Wind River Basin are radioactive, but only a minor amount of uranium mineralization was found.

Radioactivity data were obtained by use of a portable scintillation counter, analyses in the laboratory of rock and water samples collected at the outcrop, and an airborne radioactivity survey made by the U.S. Geological Survey, in a north-south strip about 9 miles wide between long 106°45′ W. and 106°55′ W. and lat 42°45′ N. and 43°00′ N.

Radioactivity anomalies detected during the airborne survey were checked on the ground with portable scintillation counters and samples were collected for laboratory analysis. Radiometric traverses were made with the portable scintillation counter from a slowly moving automobile or while walking along the outcrop. In some areas, as for example on top of Clarkson Hill, many closely spaced shallow bulldozed pits were examined, and rock samples were collected from those pits that showed abnormally high readings on the scintillation counter. Samples of the water from flowing creeks, springs, seeps, and wells were collected and were analyzed for uranium content.

Radioactivity anomalies occur in the Wind River and White River formations in association with carbonaceous sandstone and siltstone beds. Although the anomalies are more numerous in the upper coarse-grained facies of the Wind River formation, anomalous radioactivity was found also in the lower fine-grained facies and in the lower part of the White River formation. Locally, as in sec. 20, T. 31 N., R. 82 W., and sec. 36, T. 34 N., R. 84 W., radioactivity anomalies were found in titaniferous sandstone lenses in the Parkman sandstone member of the Mesaverde formation; the radioactivity there is thought to be due to uraniferous zircon and opaque oxides as well as minor thorium minerals (J. F. Murphy, written communication, 1959).

## DESCRIPTION OF URANIUM-BEARING AREAS

For purposes of detailed descriptions of the radioactivity, the Hiland-Clarkson Hill area is divided into three parts on the basis of the rock formations in which the radioactivity anomalies occur, on the similarity of geologic structure, or on a combination of these two. The westernmost part, the Hiland area, extends eastward from the edge of the mapped area to Poison Spider Creek (T. 33 N., Rs. 84 and 85 W.) and includes all of the occurrences in the lower fine-grained facies of the Wind River formation. The middle part extends eastward from Poison Spider Creek to Willow Creek (Tps. 31 and 32 N., Rs. 82 and 83 W.). In this area, all the uranium occurrences are in the upper coarse-grained facies of the Wind River formation or the lower part of the White River formation in association with the North Granite Mountain fault zone. The easternmost part, the Clarkson Hill area, extends from Willow Creek to the eastern edge of the mapped area and includes all those uranium occurrences that are found in the conglomeratic sandstone unit at the base of the Wind River formation.

### HILAND AREA

About 2.5 miles northwest of the town of Hiland (sec. 26 and 27, T. 37 N., R. 88 W.), uranium occurs in a lenticular arkosic sandstone channel at the base of the upper drab sequence of the lower fine-grained facies of the Wind River formation. This lens is about 2,400 feet long in an east-northeastward direction and 300 feet wide. The uranium is associated with carbonaceous material and friable sandstone in a zone 10 feet wide, 1 to 5 feet thick, and 2,000 feet long. A generalized cross section through the channel and a detailed map of the location of the samples are shown in figure 82. Analyses of the samples are in table 1.

The carbonaceous zone, about 1.5 feet thick, is composed of lenses and pods of dark-gray to black siltstone and shale containing coalified wood. Fine-grained yellowish-gray to brown poorly indurated arkosic sandstone overlying the carbonaceous zone contains disseminated coaly fragments and is highly calcareous in the upper part. A channel sample from the carbonaceous zone at sample locality 5 (fig. 83) contains 0.58 percent uranium and 0.44 percent equivalent

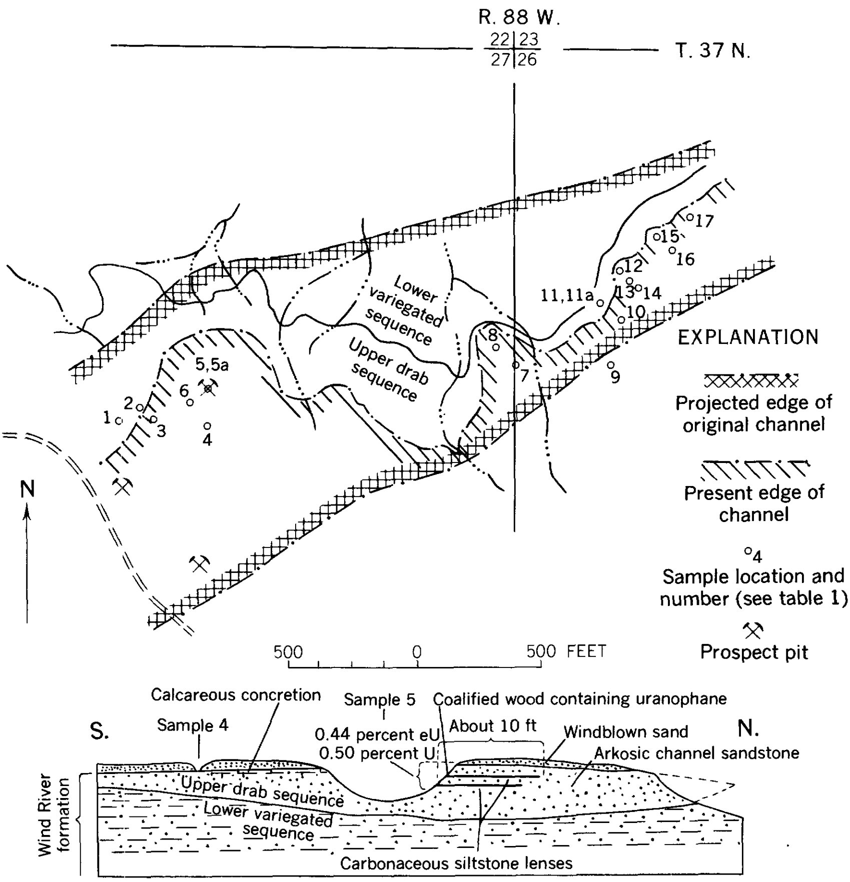


FIGURE 82.—Geologic map and diagrammatic section of Hiland channel deposit.

TABLE 1.—*Analyses of rock samples from Hiland channel deposit*

[Analysts: D. Schafer, R. Cox, J. Schuch, and R. Moore. Type of sample: C, channel sample; G, grab sample; S, selected sample]

| Sample | Sample locality (fig. 83) | Scintillation-counter reading (milliroentgen per hour) | Equivalent uranium (percent) | Uranium (percent) | Type of sample |
|---|---|---|---|---|---|
| ------------ | 1 | 0.05 | ------------ | ------------ | ---------- |
| ------------ | 2 | .05 | ------------ | ------------ | ---------- |
| 236289 | 3 | 1.00 | 0.039 | 0.031 | C |
| ------------ | 4 | .04 | ------------ | ------------ | ---------- |
| 145984 | 5 | 1.80 | .44 | .58 | C |
| [1] 145985 | 5a | 1.80 | 3.0 | 3.3 | S |
| 236291 | 6 | .70 | .058 | .020 | G |
| 292 | 7 | .03 | .001 | ------------ | G |
| 293 | 8 | 1.20 | .061 | .010 | S |
| ------------ | 9 | .029 | ------------ | ------------ | ---------- |
| 236294 | 10 | .029 | .003 | .001 | S |
| 295 | 11 | 1.05 | .028 | .020 | C |
| 145986 | 11a | 1.70 | .14 | .085 | S |
| 236296 | 12 | .12 | .008 | .014 | S |
| 297 | 13 | 1.50 | .11 | .14 | C |
| ------------ | 14 | .50 | ------------ | ------------ | ---------- |
| 236298 | 15 | .05 | .004 | .005 | S |
| 299 | 16 | .70 | .054 | .018 | S |
| 300 | 17 | .05 | .003 | .001 | S |

[1] Small sample of coalified wood containing uranophane.

uranium.[1] Uranophane [$Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$] was identified from a small chip of coalified wood taken from this same zone. No commercial quantities of uranium are exposed at the surface.

Several areas of anomalous radioactivity were detected by airborne and by portable scintillation-counter surveys within the lower fine-grained facies of the Wind River formation; however, laboratory analyses of the more highly radioactive rock samples collected from these anomalous areas show no appreciable differences in uranium content from the nonradioactive rock samples collected in the same general area. Two samples collected from a carbonaceous and coaly zone at the base of the drab greenish-gray sequence of the lower fine-grained facies in sec. 16, T. 34 N., R. 86 W., and sec. 33, T. 34 N., R. 84 W., contain 0.008 and 0.005 percent uranium and 0.007 and 0.33 percent equivalent uranium, respectively. Although these two localities show a somewhat higher uranium content than the surrounding areas, the thickness and lateral extent of the carbonaceous zone and the amount of uranium present is not significantly large.

### POISON SPIDER CREEK-WILLOW CREEK AREA

An area of anomalously high radioactivity is in the vicinity of Burnt Wagon Draw (T. 32 N., R. 84 W.); however, analyses of rock

[1] Equivalent uranium is a measure of the total amount of radioactivity emitted by a sample and is expressed as if all of the radioactivity were due solely to uranium in equilibrium with the products in its disintegration series. The radioactive substances, such as thorium, potassium ($K^{40}$), or uranium would, therefore, be included as the percent of equivalent uranium if they were present.

samples collected at the points of highest radioactivity contain a maximum of 0.058 percent uranium and 0.062 percent equivalent uranium. The higher readings on the portable scintillation counter are in the bottom of the valley, and the readings are progressively lower away from the center and upward along the valley walls. This fact and the lack of any uranium mineralization suggests that the higher radioactivity may be the result of radioactive gases, such as radon, that have collected in Burnt Wagon Draw. Water samples collected from seeps along the bottom of the valley have a maximum uranium content of 7 parts per billion.

Uranium is commonly associated with dark-brown iron-stained sandstone and conglomerate in the Gas Hills area (H. D. Zeller, written communication, 1954) and, although iron-stained sandstone and pebble conglomerate are present in Burnt Wagon Draw, they do not seem to have any direct relation to the radioactivity anomalies. Samples collected from these iron-stained sandstones do not contain a measurable amount of uranium.

In secs. 19 and 20, T. 32 N., R. 84 W., abnormal radioactivity is present in the upper coarse-grained facies of the Wind River formation in association with a light-gray carbonaceous siltstone lens. The radioactivity was found associated with large calcareous sandstone concretions and with a petrified log and chips of wood. Selected samples from the localities of higher readings have a maximum of 0.017 percent uranium and 0.053 percent equivalent uranium. Several wells have been drilled in this area; however, the results are uncertain as no fresh samples were available to the writer for analyses. The driller reported that abnormal radioactivity was detected in several of the wells by a drill-hole probe and, based on this drilling data, the overburden was stripped away from the radioactive zone (see fig. 83). No ore of commercial grade was found during the stripping operation.

Radioactivity anomalies occur in the upper coarse-grained facies of the Wind River formation in sec. 34, T. 32 N., R. 83 W. about 500 feet north of the North Granite Mountain fault zone. A 1- to 2-foot carbonaceous sandy siltstone lens is exposed in an L-shaped trench about 5 feet deep and 3 feet wide—one arm is about 10 feet long and trends northeast, and the other is about 20 feet long and trends northwest. A selected sample from this carbonaceous lens contained in maximum of 0.014 percent uranium and 0.015 percent equivalent uranium. The carbonaceous siltstone is overlain and underlain by a yellowish-gray very coarse grained calcareous arkosic sandstone. The upper sandstone is about 5 feet thick and contains very small patches of slight radioactivity.

FIGURE 83.—Upper coarse-grained facies of the Wind River formation in strip pit at the head of Burnt Wagon Draw. Height of outcrop is about 10 feet.

In sec. 4, T. 31 N., R. 83 W., uranium occurs in a carbonaceous siltstone lens in the lower part of the White River formation. The lens crops out near the head of Poison Spring Creek about 1,200 feet south of the North Granite Mountain fault zone and about 300 feet stratigraphically above the base of the White River formation. The carbonaceous zone dips 10° to 12° S. and is exposed in badlands topography. It consists of two carbonaceous siltstone beds containing finely disseminated grains of meta-autunite and (or) uranocircite, separated by a thin lenticular sandstone bed, underlain by light- to dark-gray tuffaceous siltstone and overlain by a light-gray very coarse grained tuffaceous sandstone. A section measured on the northern edge of a bulldozed pit and the location of the rock samples are shown on figure 84; analyses of the samples are shown in table 2.

About 24 exploratory holes were drilled westward from the bulldozed pit along the strike of the beds. The drilling was done by a truck-mounted pneumatic drill, and the cuttings were collected from every 2 feet of drilled depth. Although the carbonaceous zone was penetrated by the drill in each of the holes, only those cuttings having radioactivity of 2 or more times background on the portable scintil-

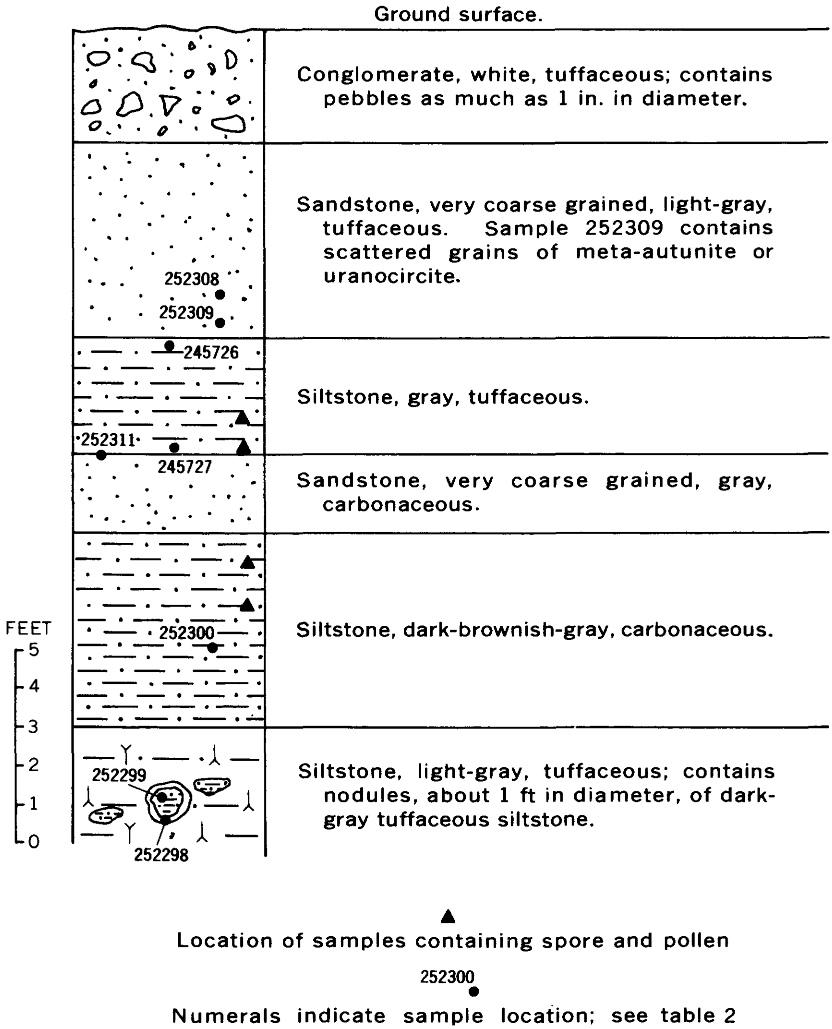


FIGURE 84.—Graphic section of the carbonaceous zone in the White River formation, NE¼ sec. 4, T. 31 N., R. 83 W.

lation counter were collected by the writer for analysis. The maximum uranium content of the samples analyzed was 0.044 percent uranium and 0.043 percent equivalent uranium.

Four of the wells drilled reached the water table. Samples of the water were collected from these wells during the drilling and the uranium content of the water ranges from 9 to 610 parts per billion, as compared to an average of 5 parts per billion for other water samples collected from the White River formation in the Hiland-Clarkson Hill area.

TABLE 2.—*Analyses of rock samples from a carbonaceous zone in the White River formation, sec. 4, T. 31 N., R. 83 W.*

[Analysts: C. G. Angelo, H. H. Lipp, and J. S. Wahlberg]

| Sample | Type of sample | Lithologic character | Equivalent uranium (percent) | Uranium (percent) |
|---|---|---|---|---|
| 245726 | 1-ft channel | 1 ft of carbonaceous siltstone and sandstone | 0.11 | 0.010 |
| 727 | Selected | Base carbonaceous siltstone | .12 | .21 |
| 245729 | Drill cutting | Carbonaceous sandstone from drill hole | .022 | .024 |
| 730 | do | do | .011 | .008 |
| 731 | do | do | .006 | .007 |
| 245734 | do | Siltstone, dark-gray, tuffaceous, from drill hole | .014 | .019 |
| 252308 | Selected | Carbonaceous woody material from conglomeratic sandstone overlying carbonaceous zone; contains scattered grains of meta-autunite or uranocircite. | .067 | .063 |
| 252311 | 1-ft channel | Carbonaceous siltstone and arkosic sandstone | .067 | .056 |
| 252298 | Selected | 1 ft of halo of olive-green tuffaceous siltstone around dark-gray siltstone pod. | .027 | .055 |
| 299 | 1-ft channel | Dark-gray siltstone pod of above | .048 | .11 |
| 300 | Selected | 1 ft of carbonaceous sandstone pod in carbonaceous siltstone. | .17 | .17 |

### CLARKSON HILL AREA

In the vicinity of Clarkson Hill, radioactivity anomalies occur in the conglomeratic sandstone unit that is here included in the Wind River formation. The radioactivity is localized in lenses or small pods of carbonaceous siltstone and shale in the arkosic sandstone. In sec. 4, T. 31 N., R. 82 W., a carbonaceous siltstone lens, which measures in outcrop about 500 feet long and 3 to 5 feet thick, is exposed in a bulldozed cut. Samples collected from this cut contain a maximum of 0.040 percent uranium and 0.037 percent equivalent uranium. In sec. 9, T. 31 N., R. 82 W., radioactive pods of carbonaceous siltstone, 1 to 3 feet in diameter, are surrounded by thin haloes of iron-stained sandstone. The radioactivity is progressively greater toward the center of the pods. The centers of the pods contain a maximum of 0.016 percent uranium and 0.018 percent equivalent uranium. A lens of carbonaceous sandy siltstone, about 10 feet below the top of the arkosic sandstone sequence, is slightly radioactive, but analyses of rock samples collected from this lens do not show an abnormal content of uranium or equivalent uranium.

In sec. 17, T. 31 N., R. 82 W., high radioactivity occurs about 35 feet above the base of the conglomeratic sandstone unit in an area about 500 feet long and 300 feet wide. The highest radioactivity is in a carbonaceous siltstone and sandstone zone about 10 feet thick. At this locality, the maximum uranium content is 0.01 percent uranium and 0.11 percent equivalent uranium. Analyses of samples collected at this locality are summarized in table 3.

TABLE 3.—*Analyses of rock samples from vicinity of Clarkson Hill*

[Analysts: R. Moore, R. L. Wack, C. G. Angelo, H. H. Lipp, and J. S. Wahlberg. Type of sample: C, channel sample; G, grab sample; S, selected sample]

| Sample | Sample locality (pl. 7) | Scintillation counter reading (milliroentgen per hour) | Equivalent uranium (percent) | Uranium (percent) | Type of sample |
|---|---|---|---|---|---|
| 145981 | SW¼NE¼ sec. 17, T. 31 N., R. 82 W | 0.05 | 0.072 | 0.12 | S |
| 145982 | do | .1 | .010 | .017 | G |
| 236285 | do | .1 | .14 | .080 | S |
| 286 | do | .15 | .070 | .19 | C |
| 287 | do | .1 | .027 | .021 | S |
| 288 | do | .05 | .015 | .003 | C |
| 245725 | do | .5 | .11 | .010 | S |
| 252301 | SE¼SE¼ sec. 4, T. 31 N., R. 82 W | .085 | .005 | .002 | C |
| 302 | do | .12 | .007 | .003 | S |
| 303 | do | .22 | .030 | .004 | S |
| 304 | do | .26 | .037 | .040 | S |
| 305 | do | .16 | .008 | .002 | S |
| 306 | do | .25 | .038 | .035 | C |
| 307 | Sec. 9, T. 31 N. R. 82 W | .14 | .018 | .016 | S |
| 245720 | SE¼ sec. 31, T. 32 N., R. 82 W | .10 | .009 | .011 | S |
| 245721 | do | .13 | .008 | .004 | S |

## URANIUM IN GROUND WATER

As part of the investigation of uranium occurrences in the Hiland-Clarkson Hill area, 71 water samples were collected for analyses of their uranium content. The water samples were collected from seeps, springs, and wells; however, four samples of surface water were collected from reservoirs and from water that had collected in shallow prospect pits.

Pint samples of ground water were collected in polyethylene bottles, and the uranium content and acidity of the water was determined by personnel of the U.S. Geological Survey. The uranium content was determined by the fluorometric method and is expressed in parts per billion. (For a description of the fluorometric method of analyses see Denson and others, 1956, p. 794.) The acidity of the water is expressed in terms of the hydrogen-ion index or pH. The pH of a solution is equal to the negative logarithm of the hydrogen ion concentration. Pure water has a pH of 7.0. In an acid solution, the pH is smaller than 7.0; conversely, in an alkaline solution the pH is greater than 7.0.

The uranium concentration in natural waters commonly ranges from a fraction to 1 ppb (part per billion) (Ward and Marranzino, 1957, p. 182), but in water moving through ground containing some uranium minerals, the concentration may reach several thousand parts per billion. From analyses of 277 water samples collected throughout central and eastern Wyoming and western South Dakota, Denson and others (1956, p. 799) found that the uranium content of water collected from areas of Eocene and older rocks, which are void of uranium minerals, ranges from 4 to 6 ppb; whereas, the uranium content of water collected from apparent uranium-free areas of Oligocene and younger rocks ranges from 12 to 34 ppb. In contrast to the findings of Denson and others, the average uranium content in water associated with Eocene and older rocks in the Hiland-Clarkson Hill area is 8.8 ppb; whereas, for water associated with Oligocene and younger rocks the average is 5.0 ppb. None of the water samples included in the above averages for the Hiland-Clarkson Hill area were collected from known mineralized area. Samples from a known mineralized area (sec. 4, T. 31 N., R. 83 W.) in the Hiland-Clarkson Hill area, however, average 61 ppb. The analyses of the water samples collected in the Hiland-Clarkson Hill area are summarized in table 4 and on figure 85.

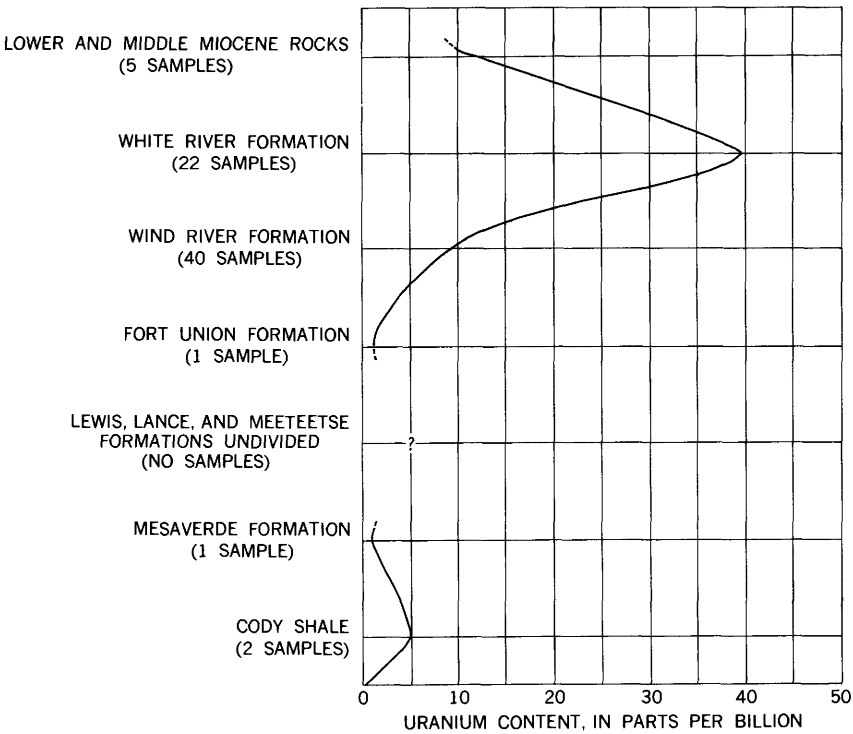


FIGURE 85.—Graph showing the average uranium content of water samples collected from different rock units in the Hiland-Clarkson Hill area.

TABLE 4.—*Analyses of water samples collected in the Hiland-Clarkson Hill area Natrona County, Wyo.*

[Analysts: E. J. Fennelly, G. T. Burrow, J. P. Schuch, J. E. Wilson, H. H. Lipp, R. Cox, and R. Daywitt]

| Sample | Sample locality (pl. 7) | | | Source of sample | Formation from which collected | Uranium content (ppb) | pH |
|---|---|---|---|---|---|---|---|
| | Sec. | T. N. | R. W. | | | | |
| 233563 | 19 | 32 | 84 | Spring | Wind River | 6 | 7.8 |
| 564 | 30 | 32 | 84 | do | do | 2 | 8.0 |
| 565 | 36 | 32 | 85 | do | White River | 3 | 7.9 |
| 566 | 23 | 32 | 85 | do | Wind River | 3 | 7.5 |
| 567 | 24 | 32 | 85 | do | do | 2 | 7.6 |
| 568 | 33 | 32 | 84 | do | White River | 1 | 7.9 |
| 569 | 36 | 32 | 84 | do | Lower and middle Miocene rocks. | <1 | 7.3 |
| 570 | 31 | 32 | 83 | do | White River | <1 | 7.3 |
| 571 | 23 | 32 | 84 | do | Wind River | 4 | 7.6 |
| 234997 | 26 | 34 | 84 | Seep | Fort Union | <1 | 7.7 |
| 998 | 22 | 34 | 84 | Spring | Wind River | 2 | 8.0 |
| 999 | 23 | 36 | 87 | do | do | 35 | 7.7 |
| 235000 | 2 | 31 | 83 | do | do | 4 | 7.3 |
| 001 | 12 | 31 | 83 | Seep | White River | 9 | 7.9 |
| 002 | 32 | 32 | 82 | Spring | Wind River | 52 | 7.7 |
| 003 | 32 | 32 | 82 | do | do | 3 | 7.5 |
| 235795 | 33 | 32 | 83 | Seep | White River | 1 | 7.7 |
| 235796 | 33 | 37 | 88 | Well | Wind River | 16 | 7.0 |
| 797 | 9 | 32 | 84 | Reservoir | do | 62 | 7.2 |
| 798 | 9 | 32 | 84 | Spring | do | 7 | 7.5 |
| 799 | 12 | 32 | 84 | do | do | 14 | 7.5 |
| 800 | 32 | 37 | 88 | Well | do | 16 | 7.8 |
| 236211 | 19 | 36 | 86 | do | do | 1 | 7.8 |
| 212 | 30 | 36 | 87 | do | do | 1 | 7.7 |
| 213 | 2 | 36 | 88 | do | do | 2 | 7.8 |
| 214 | 10 | 36 | 88 | do | do | 28 | 7.7 |
| 215 | 6 | 36 | 88 | do | do | 13 | 7.2 |
| 216 | 17 | 36 | 88 | do | do | <1 | 8.1 |
| 217 | 23 | 31 | 83 | Spring | Cody | 9 | 7.9 |
| 218 | 30 | 36 | 86 | Well | Wind River | 2 | 7.0 |
| 219 | 23 | 36 | 89 | do | do | 3 | 7.6 |
| 220 | 12 | 35 | 88 | do | do | <1 | 7.9 |
| 221 | 7 | 35 | 87 | do | do | 10 | 7.7 |
| 222 | 7 | 37 | 86 | do | do | 1 | 9.7 |
| [1] 223 | 32 | 37 | 88 | do | do | 22 | 8.0 |
| 244193 | 36 | 36 | 86 | Spring | do | <1 | 7.4 |
| 194 | 23 | 32 | 84 | do | do | 2 | 7.4 |
| 195 | 24 | 32 | 84 | do | do | <1 | 6.2 |
| 244196 | 24 | 31 | 84 | Reservoir | White River | 2 | 6.9 |
| 197 | 20 | 31 | 82 | Well | Mesaverde | <1 | 8.1 |
| 198 | 23 | 32 | 85 | Spring | Wind River | <1 | 7.2 |
| [2] 199 | 24 | 32 | 85 | do | do | 1 | 7.1 |
| 200 | 34 | 32 | 85 | do | do | 2 | 7.1 |
| 201 | 35 | 32 | 85 | do | White River | 6 | 7.1 |
| 202 | 36 | 32 | 85 | do | do | 5 | 7.1 |
| 203 | 36 | 32 | 85 | do | do | 2 | 7.1 |
| 204 | 31 | 32 | 85 | do | do | 7 | 7.2 |
| 205 | 1 | 31 | 84 | do | do | <1 | 7.1 |
| 206 | 2 | 31 | 84 | do | do | 3 | 8.0 |
| 207 | 36 | 32 | 84 | Seep | do | 1 | 7.6 |
| 246693 | 6 | 31 | 83 | do | do | <1 | 7.8 |
| 694 | 36 | 32 | 83 | Well | Wind River | 38 | 8.2 |
| 695 | 29 | 31 | 82 | do | Cody | 1 | 8.2 |
| 245684 | 6 | 30 | 83 | do | Lower and middle Miocene rocks. | 13 | 7.8 |
| 685 | 6 | 31 | 84 | Reservoir | do | 4 | 7.0 |
| 686 | 22 | 31 | 84 | do | do | 2 | 7.0 |
| 687 | 27 | 32 | 83 | Well | Wind River | <1 | 7.4 |
| 688 | 4 | 31 | 83 | Drill hole | White River | 8. | 8.4 |
| 245689 | 28 | 32 | 84 | Spring | Wind River | 3 | 7.1 |
| 690 | 4 | 31 | 83 | Drill hole | White River | 42 | 9.0 |
| 691 | 4 | 31 | 83 | do | do | 140 | 9.1 |
| 692 | 4 | 31 | 83 | do | do | 9 | 8.4 |
| 693 | 4 | 31 | 83 | do | do | 610 | 7.8 |

See footnotes at end of table.

TABLE 4.—*Analyses of water samples collected in the Hiland-Clarkson Hill area, Natrona County, Wyo.*—Continued

| Sample | Sample locality (pl. 7) | | | Source of sample | Formation from which collected | Uranium content (ppb) | pH |
|---|---|---|---|---|---|---|---|
| | Sec. | T. N. | R. W. | | | | |
| [3]HPR-56-29 | 32 | 32 | 82 | Spring | Wind River | 40 | 8.5 |
| HPR-56-30 | 2 | 31 | 83 | do | do | 3 | 8.1 |
| 56-31 | 34 | 32 | 83 | do | do | 6 | 8.2 |
| 56-32 | 29 | 32 | 82 | Seep | do | 4 | 8.6 |
| 56-33 | 31 | 32 | 84 | Well | White River | <1 | 7.7 |
| 56-34 | 20 | 32 | 82 | Spring | do | 8 | 8.0 |
| 56-35 | 29 | 32 | 82 | do | do | 14 | 8.1 |
| 56-36 | 4 | 31 | 84 | do | Lower and middle Miocene rocks. | 34 | 7.9 |

1 Same as sample 235800.
2 Same as sample 233567.
3 Same as sample 235002.

Although a comparison of the uranium content in ground water from the Hiland-Clarkson Hill area with that from other areas of Wyoming is of interest, the following conclusions can be made from a comparison of the various samples collected within the Hiland-Clarkson Hill area: Water samples collected from drilled wells in the mineralized area in the White River formation contain as much as 15 times more uranium than do those collected from other areas; similarly, the uranium concentration in samples of water collected within a radius of 2 miles of the Hiland channel deposit is 2 to 3 times greater than the average for the Wind River formation; of the samples collected from the Wind River formation, the ones containing the highest concentration of uranium are on or near the surface trace of the axial plane of the syncline that forms the southeastern end of the Wind River Basin; the water in all the samples collected is alkaline; and the uranium concentration in the water has no apparent relation to the pH of the water.

## SUMMARY OF URANIUM OCCURRENCES

Uranium minerals were found in only two places within the Hiland-Clarkson Hill area, although anomalously high radioactivity was detected in many isolated localities. In general, the percentage of uranium found in the rock samples collected from the areas of high radioactivity was less than the equivalent uranium. A few water samples contained more than an average amount of uranium, and those containing the highest concentration, exclusive of the ones from known mineralized areas, were at or near the axis of the syncline that forms the southeastern end of the Wind River Basin. These data suggest that any uranium that may have accumulated in the Hiland-Clarkson

Hill area was removed from the point of original deposition by the leaching of ground water and reconcentrated along the axis of the syncline or carried out of the mapped area. The stratigraphic and structural relations suggest that, because of the post-Miocene southward regional tilting, the flow of uranium-bearing ground water in the Oligocene and Miocene rocks south of the North Granite Mountain fault zone was reversed from a northward (basinward) to a southward (mountainward) direction. This change in direction of groundwater movement in the post-Wind River rocks may have prevented not only further trapping of uranium-bearing water in the areas where the Wind River formation is now exposed, but may also have caused leaching of previously formed uranium deposits below the unconformity at the base of the White River formation.

## OIL AND GAS

Commercial quantities of oil and gas have been produced from a series of northwestward-trending anticlines and domes along the Powder River lineament. These anticlinal structures include, from southeast to northwest, the Iron Creek, Oil Mountain, Poison Spider, South Casper Creek, and North Casper Creek anticlines; Pine Mountain and Boone domes; and Lox and Arminto anticlines. Of these only the southeastern part of the Iron Creek anticline is included in the Hiland-Clarkson Hill area. Other producing areas within the boundaries of the mapped area are the West Poison Spider oil field, T. 33 N., R. 84 W., and the Grieve oil field, T. 32 N., R. 85 W. Oil production at the West Poison Spider oil field is principally from the Mesaverde formation; however, a smaller amount of oil production was obtained from the Frontier formation and the Cody shale. Production at the Grieve oil field is from the Muddy sandstone member of the Thermopolis shale of Early Cretaceous age. A small quantity of oil has been produced at the Fish Creek oil field, T. 31 N., R. 84 W., from the Cloverly formation of Early Cretaceous age, and at the Government Bridge oil field, T. 31 N., R. 82 W., from a sandstone in the Cody shale. The production of oil at the West Poison Spider and Fish Creek oil fields is from subsurface structural traps, whereas that production at the Grieve and Government Bridge oil fields is from stratigraphic traps. Significant wells in the southeastern part of the Hiland-Clarkson Hill area are listed and described in table 5.

TABLE 5.—*Selected oil and gas wells and dry holes within area shown on plate 7*

[Remarks: P&A, plugged and abandoned; IP, initial production; MCFGPD, thousand cubic feet gas per day; BOPD, barrels oil per day]

| Operator | Location: Section (C=center) | Location: T.N. | Location: R.W. | Field | Lowest strata reached | Total depth (feet) | Date completed | Remarks |
|---|---|---|---|---|---|---|---|---|
| H. O. Batzer | C NW¼NE¼ 20 | 31 | 82 | Wildcat | Cody | 2,006 | 1956 | IP, 1275 MCFGPD. |
| Do | SE¼SW¼NE¼ 20 | 31 | 82 | do | Lakota | 5,988 | 1956 | P&A. |
| Do | NE¼SE¼NW¼ 20 | 31 | 82 | do | Cody | 2,440 | 1957 | IP, 60 BOPD. |
| Do | C NE¼SW¼ 21 | 31 | 82 | do | Lakota | 4,773 | 1957 | P&A. |
| Hancock Oil Co | C NW¼NW¼ 26 | 31 | 82 | do | Muddy | 2,700 | 1957 | P&A. |
| Earl Mallette | SW¼SW¼NE¼ 26 | 31 | 82 | do | Chugwater | 4,510 | 1955 | P&A. |
| Do | NE¼NE¼SE¼ 27 | 31 | 82 | do | Muddy | 2,633 | 1955 | P&A. |
| Chicago Corp., Republic Natural Gas | C NE¼SW¼ 17 | 31 | 83 | do | Lakota | 3,070 | 1955 | P&A. |
| Trigood Oil Co | SE¼SW¼SE¼ 23 | 31 | 83 | do | Morrison | 3,345 | 1955 | P&A. |
| Chicago Corp., Republic Natural Gas | SE¼NE¼ 28 | 31 | 83 | do | Lakota | 2,779 | 1955 | P&A. |
| Do | C SW¼SW¼ 2 | 31 | 84 | do | do | 5,590 | 1955 | P&A. |
| True Oil Co | C NW¼NE¼ 5 | 31 | 84 | do | do | 6,490 | 1958 | IP, 211 BOPD. |
| Atlantic Refining Co | SE¼SW¼SE¼ 5 | 31 | 84 | Fish Creek | Cloverly | 1,949 | 1951 | P&A. |
| Shell Oil Co | NW¼SE¼ 5 | 31 | 84 | Wildcat | Chugwater | 4,236 | 1959 | P&A. |
| Delta Drilling; Arrowhead Exploration; Argo Oil Co. | C NE¼NW¼ 6 | 31 | 84 | do | Morrison | 6,361 | 1956 | IP, 225 BOPD. |
| Atlantic Refining Co | SE¼NW¼NE¼ 8 | 31 | 84 | Fish Creek | Nugget | 1,572 | 1951 | P&A. |
| Do | SW¼NE¼NE¼ 8 | 31 | 84 | do | Sundance | 1,298 | 1951 | IP, 972 MCFGPD. |
| Do | NE¼SW¼NW¼ 9 | 31 | 84 | do | Tensleep | 2,394 | 1952 | P&A. |
| Do | SW¼SE¼SW¼ 9 | 31 | 84 | do | Cambrian (undivided). | 3,109 | 1950 | P&A. |
| S. R. McChesney | SE¼NE¼NW¼ 9 | 31 | 84 | do | Lakota | 1,391 | 1954 | IP, 13 BOPD. |
| Atlantic Refining Co | SE¼NE¼NW¼ 9 | 31 | 84 | Wildcat | do | 1,553 | 1952 | P&A. |
| Chicago Corp., Republic Natural Gas | C SW¼SE¼ 13 | 31 | 84 | do | do | 1,879 | 1955 | P&A. |
| Matt C. Jahn | SE¼SW¼NE¼ 16 | 32 | 82 | do | Cody | 600 | 1956 | P&A. |
| Shell Oil Co | SW¼NE¼SW¼ 20 | 32 | 82 | do | Lakota | 12,954 | 1958 | P&A. |
| Do | N½NE¼SE¼ 20 | 32 | 82 | do | Cody | 10,919 | 1957 | P&A. |
| Chicago Corp., Republic Natural Gas | NW¼SE¼SW¼ 23 | 32 | 82 | do | Lakota | 3,130 | 1954 | P&A. |
| True Oil Co | C SE¼SW¼ 31 | 32 | 84 | do | Muddy | 6,681 | 1957 | IP, 30 BOPD. |
| True Oil Co; R. H. Fulton | C SE¼SE¼ 32 | 32 | 84 | do | Morrison | 6,521 | 1956 | P&A. |
| True Oil Co | C SE¼SE¼ 32 | 32 | 84 | do | Lakota | 6,820 | 1958 | IP, 100–140 BOPD. |
| Forest Oil Corp | NW¼NE¼SE¼ 22 | 32 | 85 | Grieve | Muddy | 7,280 | 1956 | P&A. |
| Do | NE¼SE¼SE¼ 22 | 32 | 85 | do | do | 7,066 | 1956 | IP, 672 BOPD. |
| Do | NW¼NW¼NW¼ 26 | 32 | 85 | do | do | 7,145 | 1956 | IP, 720 BOPD, 508 MCFGPD. |
| Do | E½NW¼SW¼ 26 | 32 | 85 | do | Morrison | 7,269 | 1956 | IP, 594 BOPD. |
| Do | SE¼NE¼NE¼ 27 | 32 | 85 | do | Muddy | 6,987 | 1956 | IP, 606 BOPD. |
| Do | SW¼SW¼NW¼ 26 | 32 | 85 | do | do | 7,045 | 1956 | IP, 552 BOPD. |
| Do | NW¼SE¼SW¼ 26 | 32 | 85 | do | do | 7,055 | 1956 | IP, 540 BOPD, 435 MCFGPD. |
| Do | NE¼NE¼NW¼ 35 | 32 | 85 | do | Morrison | 6,880 | 1956 | P&A. |
| Do | NE¼SE¼ 27 | 32 | 85 | do | Cloverly | 6,786 | 1959 | IP, 7120 MCFGPD. |
| Do | NE¼SW¼ 26 | 32 | 85 | do | Muddy | 7,331 | 1959 | IP, 660 BOPD. |
| Emmett Schiek | NW¼NW¼ 36 | 32 | 85 | do | Morrison | 6,305 | 1959 | P&A. |

The Wind River formation, which overlies all the central part of the Wind River Basin, does not reflect the structure of the underlying rocks, and the extent and character of the structural features in the older rocks cannot be determined from surface exposures. However, the intensity of the folding and faulting along the northeastern margin of the basin suggests that structural traps, favorable for the accumulation of oil and gas, may exist in the Wind River and older formations the central part of the basin. This area is, therefore, thought to be promising for geophysical exploration.

The intertonguing relation of the Cody shale and the Parkman sandstone member of the Mesaverde formation suggests that the stratigraphic accumulations of oil and gas may exist in the Hiland-Clarkson Hill area. The lower tongue of the Parkman sandstone thins eastward from about 160 feet in the Cities Service Oil Co. well, Government C-1 (sec. 12, T. 32 N., R. 82 W.), to about 40 feet in the Tidewater Associated well, Poison Spring 1 (sec. 31, T. 33 N., R. 83 W.), and is absent in the measured section at the Casper Canal (sec. 15, T. 31 N., R. 82 W.). The wedge edge therefore lies somewhere between the Casper Canal and Poison Spring Creek, where the rocks in the subsurface dip northwestward around the northwest-plunging nose of the syncline. Thus, it is likely that the pinchout is updip in some places and that the conditions are favorable for the stratigraphic accumulation of oil and gas. Similarly, the westward-pointing tongue of the Cody shale thins and becomes more sandy westward from the Cities Service Oil Co. well and may pinchout in the vicinity of Aspirin Creek. The wedge edge of the Cody shale tongue may be updip in some places, and conditions may be favorable for the accumulation of oil and gas.

## COAL

Small amounts of coal have been mined in the Hiland-Clarkson Hill area in the past, but no mining operations are being carried on at present. Only a few seams are thick enough to be economically important and surface exposures are so few that detailed studies of the coal were not made.

Most of the coal beds that have been mined are in the unnamed middle member of the Mesaverde, although thin discontinuous beds of coal or carbonaceous shale with thin coal partings occur in the Meeteetse, Lance, and Fort Union formations. The beds are lenticular and can be traced only short distances in the surface outcrops. Most of the coal-bearing areas are outside the boundaries of the Hiland-Clarkson Hill area, but it is possible that some beds of coal lie in the central part of the basin under the non-coal-bearing Wind River formation.

The only known coal-bearing areas within the Hiland-Clarkson Hills area are near the North Platte River in secs. 2, 3, 14, and 15, T. 31 N., R. 82 W., and near the town of Arminto, T. 37 N., R. 87 W. Near the North Platte River nine beds of coal, ranging in thickness from 6 inches to 6 feet and aggregating about 15 feet, are exposed in the unnamed middle member of the Mesaverde formation. Some of these beds have been mined periodically for local use. A caved shaft in sec. 14, T. 31 N., R. 82 W., is probably the site of the Red Ash mine described by Woodruff and Winchester (1912, p. 562–563), and a few prospect pits have been dug in the vicinity. Near Arminto, coal beds that reach an aggregate thickness of about 17 feet are exposed in the unnamed middle member of the Mesaverde formation and extend about 1 mile along the strike.

Minor amounts of black carbonaceous shale with thin coal partings are present at the base of the drab greenish-gray sequence of the lower fine-grained facies of the Wind River formation along Coyote Creek, sec. 35, T. 35 N., R. 85 W., and near the South Fork Casper Creek, sec. 33, T. 34 N., R. 84 W. The coal is in very thin beds, not more than a few inches thick, and none are thick enough to be economically important.

## TITANIUM DEPOSITS

Lenticular deposits of sandstone rich in titanium-bearing minerals are exposed within the Hiland-Clarkson Hill area. Near Clarkson Hill (sec. 20, T. 31 N., R. 82 W.) the deposit is in the Parkman sandstone member of the Mesaverde formation, whereas the deposit near Pine Mountain (sec. 1, T. 33 N., R. 84 W., and sec. 36, T. 34 N., R. 84 W.) is in the lower tongue of the Lewis shale. These deposits were examined by J. F. Murphy of the U.S. Geological Survey during the course of fieldwork, and petrographric and heavy mineral analyses of the rock samples collected were made by R. S. Houston of the University of Wyoming. Most of the data given below were furnished by these men (written communication, 1959).

The deposit near Clarkson Hill is in the upper part of the Parkman sandstone and is about 150 feet long and 6 feet thick. The downdip dimension is not known. The deposit is distinguished at the surface by its dark-rusty-brown color. One sample of the higher grade material from this deposit contains about 35 percent heavy minerals consisting of zircon, garnet, tourmaline, rutile, augite, hornblende, oxyhornblende, biotite, chlorite, and sphene. Analyses show that the samples contains 4.8 percent $TiO_2$ and 26 percent total iron (expressed as $Fe_2O_3$). The equivalent-uranium content is 0.004 percent and the uranium content is 0.001 percent.

The deposit near Pine Mountain is in the upper part of the lower tongue of the Lewis shale. It is about 7 feet thick and is exposed for about 300 feet along the strike of the bedding. The bed dips steeply southwestward, so the downdip dimension is not known. The heavy minerals which make up about 34 percent of each of the samples analyzed, include zircon, garnet, tourmaline, epidote, sphene, spinal, staurolite, rutile, and monazite. The samples average 5.2 percent $TiO_2$ and 21.7 percent $Fe_2O_3$. The average content of equivalent uranium is 0.003 percent and that of uranium is 0.0008 percent.

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