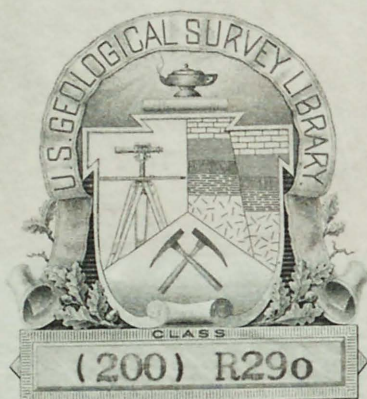


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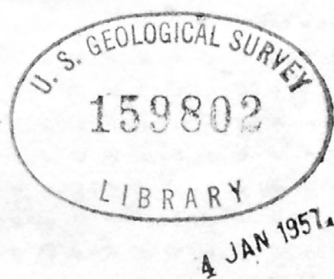


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GEOLOGY OF THE DU NOIR AREA,
FREMONT COUNTY, WYOMING

by

William R. Keefer

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ABSTRACT

The Du Noir area includes about 250 square miles in the northwestern part of the Wind River Basin, Fremont County, Wyoming. It is bounded on the south by the Wind River and Warm Spring Creek, which flow along the northeast flank of the Wind River Mountains, and on the north by the steep scarps of the southern margin of the Absaroka Mountains. Rugged mountainous terrain dominates both the southwest and northern portions of the mapped area while badland topography and deeply dissected upland surfaces characterize the central part. One of the most significant physiographic and structural features of the region is a belt of folded and faulted Paleozoic and Mesozoic rocks, referred to as the Washakie Range, which lies along the southern margin of the Absaroka Mountains. These highlands, attaining elevations of as much as 10,000 feet, were buried by Tertiary volcanic debris and subsequently partly exhumed as the Wind River Basin was reexcavated by Wind River and its tributaries.

The sedimentary rocks exposed in the Du Noir area are more than 12,500 feet thick and range in age from Cambrian to Recent. All systems, with the exception of the Silurian, are represented. Precambrian granite and granite gneiss are present in both the Wind River and Washakie Ranges.

The Cambrian system is represented by the Flathead sandstone, Gros Ventre shale, and Gallatin limestone. The remaining Paleozoic formations, named in ascending order, are the Bighorn dolomite of Ordovician age, Darby formation of Devonian age, Madison limestone of Mississippian age, Amsden formation and Tensleep sandstone of Pennsylvanian age, and Phosphoria formation of Permian age. With a few exceptions, the thicknesses and lithologies of the formations do not vary greatly within the mapped area. Erosional unconformities are present at several horizons, the most conspicuous occurring between the Darwin sandstone member of the Amsden formation and the Madison limestone. This unconformity is considered by the writer to mark the Pennsylvanian-Mississippian boundary in this area.

Mesozoic strata have only limited exposures. Triassic rocks are represented by the Dinwoody and Chugwater formations, Jurassic rocks by the Nugget sandstone, Gypsum Spring formation, "lower Sundance," "upper Sundance," and Morrison formation, and Cretaceous rocks by the Cloverly formation, Thermopolis shale, Mowry shale, Frontier formation, and Cody shale. No consistent basis for subdivision of the Morrison and Cloverly formations, which span the Jurassic-Cretaceous boundary, was found in the area and they have been mapped as a single unit. The Lower Jurassic Nugget sandstone thins markedly from a maximum of about 120 feet to a wedge-edge and in places the Gypsum Spring formation rests directly upon the Chugwater formation. The Cody shale has only limited exposures because of overlapping Tertiary rocks and structural complications. Younger Upper Cretaceous rocks, commonly found in adjacent regions, are not present.

Tertiary strata, which cover a large portion of the Du Noir area, have been divided into 5 units: The Fort Union(?) formation of Paleocene(?) age, Indian Meadows and Wind River formation of lower Eocene age, Tepee Trail formation of upper Eocene age, and Wiggins formation of Oligocene(?) age. The presence of middle Eocene rocks has not been confirmed but rocks of this age could be present. In some areas the lower Eocene rocks have been mapped as a single unit and designated as Wind River and Indian Meadows formations, undivided. Mountainward facies of the Eocene rocks, consisting mostly of coarse arkose, are present on the northeast flank of the Wind River Mountains and have been mapped as Eocene rocks, undivided. Conglomerates containing Mesozoic rock fragments along the southwest flank of the Dubois anticlinal complex are believed to represent the Fort Union formation in this area. The lower Eocene strata are characterized by brightly variegated fine-grained claystones and siltstones and massive conglomerates with Paleozoic and Precambrian rock fragments. A thick drab-colored tuffaceous sandstone unit near the middle of the Wind River formation marks the first appearance of conspicuous amounts of volcanic debris in the Tertiary sequence. Younger beds contain progressively more pyroclastic material, and the upper part of the Tepee Trail formation and the Wiggins formation are predominantly coarse volcanic conglomerates.

Seven different kinds of Quaternary deposits are distinguished, including glacial moraines, landslide debris, terrace gravels, colluvium, lag gravels, travertine, and alluvium. A study of the terraces, 7 levels in all, and the glacial deposits indicates a complex glacial and erosional history for the northwestern part of the Wind River Basin.

The Du Noir area includes three major structural provinces, all formed during the Laramide Revolution: the northeast flank of the Wind River Mountains on the south, an intervening synclinal basin thought to be a northwestern extension of the Wind River Basin, and the Washakie Range on the north. No structure is apparent in the Tertiary volcanic rocks along the southern margin of the Absaroka Mountains. The trend of the Laramide structural features is approximately N. 45° W. The most intense folding and faulting occurred along the south edge of the Washakie Range and in the northern portion of the synclinal basin. Asymmetric anticlinal folds have their steep flanks on the southwest and, with one exception, the movement of the overriding blocks of thrust or high-angle reverse faults has been relatively southwestward. Large-scale normal faulting is present near the top of Spring Mountain and the adjacent parts of Horse Creek Basin.

The first evidences of Laramide folding occurred prior to the deposition of the Fort Union(?) formation, the conglomerates of which were most probably derived during the initial stages of folding of the Dubois anticlinal complex. The Wind River and Washakie Ranges were folded to mountainous proportions and subsequently deeply eroded prior to the deposition of the lower Eocene Indian Meadows formation. Both of these ranges have undergone little deformation since that time. Intense deformation occurred in the center of the synclinal basin, however, during lower Eocene time. This deformation was manifested by large-scale thrusting and by renewed folding and faulting of the Dubois anticlinal complex. Erosional unconformities are present at the top of the Wind River formation and at the top of the Tepee Trail formation.

The best opportunities for oil and gas production are in the northern part of the synclinal basin and along the south flank of the Washakie Range where most of the surface rocks are post-Paleozoic and where the greatest amount of folding occurred. One producing well and one dry hole have been drilled on the Dubois anticlinal complex. This structure yielded 21,741 barrels of 20° API gravity crude oil during the period 1946 through 1953. The anticlinal structures are largely obscured by Tertiary or Quaternary rocks so that a complete appraisal of potential oil traps is not possible from surface data alone. Some areas are deemed favorable for seismic exploration.

Several thin coal and lignite beds are present near the base of the Frontier formation and in some zones in the Wind River formation and Eocene rocks, undivided. Surface exposures of coal are very limited and only a few seams are of sufficient thickness to be of economic importance. Although small amounts of coal have been mined in the area in the past, no mining operations are being carried on at the present time. Bentonites, ranging in thickness from a few inches to as much as 14 feet, are common in the Mowry and Frontier formations, but none have been exploited and their quality is not known. Abandoned gold placer mines are present along Warm Spring Creek.

GEOLOGY OF THE DU NOIR AREA

INTRODUCTION

Location and Extent of the Area

The Du Noir area includes approximately 250 square miles in the northwestern part of the Wind River Basin, Fremont County, Wyoming (fig. 1). The mapped area is bounded on the south by the Wind River and Warm Spring Creek and on the west by the range line between R. 108 and 109 W. The northern edge lies along the southern margin of the Absaroka Mountains. The eastern boundary is the Wiggins Fork River except in the southeast corner of the area, where mapping was terminated along the range line between R. 105 and 106 W.

Purpose and Scope of the Report

Geologic investigations in the region were undertaken by the U. S. Geological Survey as part of its program of geologic mapping in the Wind River Basin with the primary objective of evaluating the oil and gas and coal possibilities of the area. The detailed stratigraphic studies and structure mapping provide useful data in the interpretation of the geologic history of the basin and have a direct bearing on the oil and gas possibilities of the region. In addition, the study of the complex Quaternary deposits and their related physiographic features provide basic data for the interpretation of the glacial and erosional history of much of the western part of the Wind River Basin.

Fig. 1 Index Map of Wyoming Showing Location of Mapped Area

Previous Investigations and Publications

Early geologic investigations in this area and adjoining regions were carried out by various expeditions of the U. S. Army, the work of which resulted in reconnaissance topographic and geologic maps and reports. F. V. Hayden accompanied the expedition in charge of Capt. W. F. Reynolds in 1859 and gave an account of some of the geologic features in the region. T. B. Comstock, who accompanied the expedition of Capt. W. A. Jones in 1873, published a geologic map and brief summary of the general geology of central and northwestern Wyoming. Although maps of the routes followed by this expedition do not show that it visited the upper parts of the Du Noir River and Horse Creek valleys, outcrops of Jurassic, Triassic, and Carboniferous rocks are shown on the geologic map as occurring in these areas.

The earliest significant geologic work in the Du Noir area was done by O. H. St. John who, in 1877 and 1878, was engaged in reconnaissance geologic investigations of a large part of west central Wyoming as part of the program of the U. S. Geological and Geographical Survey of the Territories under the direction of F. V. Hayden. St. John (1883, p. 228-270) presented a rather accurate and comprehensive account of the geologic features along the Wind River southeastward from Togwotee Pass through the southern part of the Du Noir area. His report includes descriptions of Tertiary sediments and Quaternary deposits which are present along the river as well as a section of Paleozoic rocks in Warm Spring Creek canyon. Although only the southern part of the area was visited by St. John, his generalized geologic map covers the entire area. From 1883 to the present time no detailed or reconnaissance geologic map of the Du Noir area has been published except that which was compiled by the author and which appears on the present geologic map of Wyoming (Love, et al., 1955).

Eldridge (1894, p. 62) published some coal analyses of samples described as coming from the vicinity of Warm Spring Creek. During the years 1910 to 1913 Blackwelder (1915) carried out regional geologic investigations in west central Wyoming and described glacial deposits and related features around the mouth of the Du Noir River. Miller (1936) published a section of Cambrian rocks measured along Warm Spring Creek. Love (1939) published a detailed geologic map and comprehensive report of the region which adjoins the Du Noir area on the east. This publication contains a complete bibliography of the geologic work that had been done in this part of the Wind River Basin up to that time. Miner and Delo (1943) studied glacial features in the Du Noir Valley.

Recent publications include many by the U. S. Geological Survey in its program of geologic mapping and regional stratigraphic studies in the Wind River Basin and adjacent areas to the west along the northwest flank of the Wind River Mountains and Jackson Hole. The areas covered by recently published geologic maps are shown on Plate 1. In addition to these maps there are several U. S. Geological Survey Oil and Gas Preliminary charts and other reports primarily concerned with the Mesozoic stratigraphy of the basin. Geological Survey of Wyoming Bulletin No. 38 (Love, et al., 1947) contains a detailed section of the Mesozoic rocks exposed along Horse Creek, and the author has freely drawn information from this bulletin for the lithologic descriptions of these formations.

Field Work

The field work on which this report is based was done during the summers of 1951 and 1952 and June, 1953. The field mapping was on aerial photographs at a scale of 1:20,000. As no adequate base map was available for the area one was constructed from aerial photographs by the spider templet (Floore Radial Intersector) system of radial triangulation. A polyconic projection at a scale of 1:31,680 (2 inches to the mile) served as the base on which the control points were plotted. Primary control was furnished by triangulation stations Kent, Round, Warm Spring Lookout, Dubois, and Wind River. Data were transferred from the aerial photographs to the base map by use of a radial planimetric (Kail) plotter.

Most of the General Land Office surveys in the Du Noir area were made in 1891 and 1892. Since that time some resurveys of previously established section lines and additional surveys of areas not covered originally have been made. Most of the section corners are marked by rocks near which have been placed small cairns, while some of the more recently established corners are marked by capped iron posts. The north central portion of the area remains unsurveyed. Many corners were located in the field and these formed the basis for the construction of the General Land Office grid on the base map. In areas where no corners were recovered, data from the township plats were used to complete the grid. In addition to section corners, quarter corners that were located in the field are also indicated on the base map, since the irregular topography and large number of forested slopes made it difficult to locate specific section corners in certain parts of the area.

The Younts Peak (30-minute) quadrangle, in which the entire Du Noir area is located, was published in 1907. This map constitutes the only topography available in the area. Both U. S. Coast and Geodetic and U. S. Geological Survey bench marks are present along the Wind River. Additional lines of U. S. Geological Survey bench marks were established along the Union Trail, which is closely approximated by the present Du Noir Tie Camp road, and along the road that leads northeast out of Dubois to Little Alkali Creek and the Wiggins Fork River. Other bench marks are located sporadically throughout the area, but mostly at remote points not readily accessible for use as control points. Elevations for structure contour data were obtained with aneroid barometer. In some parts of the area lines of elevations were projected many miles from bench marks. The Younts Peak topographic map was used to construct the profiles for the structure sections.

Stratigraphic sections were measured by plane table and alidade, by 100-foot tape and Brunton traverse, and by a combination of the two methods. An aneroid barometer was used to measure the thickness of some of the Tertiary formations.

Acknowledgments

The investigation was carried out under the supervision of J. D. Love, whose guidance during all phases of the work was of invaluable assistance. The helpful suggestions and criticisms of Professors D. L. Blackstone, Jr., and S. H. Knight, Department of Geology, University of Wyoming, are also gratefully acknowledged. The writer was capably assisted in the field during the summer of 1951 by R. J. Burnside and during the summer of 1952 by W. H. Curry, III. Helpful assistance was received from the following U. S. Geological Survey paleontologists: R. W. Brown, who has collected and studied fossil plants and leaves from the Tertiary rocks of the area from time to time since 1941; J. B. Reeside, Jr., and W. A. Cobban, who visited the party during the first season and collected Upper Cretaceous invertebrates; M. J. Hough, who spent a few days collecting vertebrate fossils during both summers; J. E. Smedley and Helen Duncan, who identified invertebrate fossils from the Madison and Amsden formations; and Josiah Bridge, who identified collections from the Leigh dolomite (Ordovician). C. L. Gazin, of the U. S. National Museum, kindly identified many of the vertebrate collections. Professor P. O. McGrew, University of Wyoming, offered many helpful suggestions concerning the stratigraphy and paleontology of the Tertiary rocks in the area.

GEOGRAPHY

Surface Features

The Du Noir area lies in the northwestern end of the Wind River Basin, a structural and topographic basin which broadens southward and eastward to form one of the major intermontane basins of Wyoming. Within the mapped area the basin proper is restricted to a northwest-trending synclinal valley only a few miles wide; the southern edge is approximately delineated by the Wind River while the northern edge is not well defined and merges with the upland surface that lies along the southern margin of the Absaroka Mountains.

Regions of rugged mountainous terrain are present south of the Wind River and along the northern part of the mapped area. South of the Wind River the northeast flank of the Wind River Mountains rises in moderately steep dip slopes through which streams have cut deep canyons. The highest point in the southern part of the area is Warm Spring Mountain with an elevation of 9,500 feet, about 2,300 feet above the adjacent Wind River Valley floor. Warm Spring Creek, which follows a narrow strike valley along most of its course, has incised a precipitous canyon nearly 1,000 feet deep in its lower reaches.

The Wind River Valley, the term herein used to designate only the valley floor upon which the river flows and the adjacent slopes, descends from an elevation of 7,500 feet at the western edge of the mapped area to 6,700 feet at the southeastern edge or at an average rate of about 40 feet per mile. Downstream from the narrow steep-walled canyon at Stony Point the valley is bounded on the north for the most part by broad alluvial plains and on the south by abrupt slopes that descend from terraces that were developed on the northeast flank of the Wind River Mountains. Upstream from Stony Point the valley is formed by a very broad flat alluvial plain developed at the confluence of the Wind and Du Noir Rivers. Near the western edge of the area the valley of Wind River contains much glacial debris through which the river has cut a narrow channel.

North of the Wind River ~~a series of~~ ^{are} badlands ~~is~~ developed in nearly flat-lying Tertiary strata. These badlands constitute a zone 4 to 6 miles wide extending from the southeastern corner of the area northwestward to the Du Noir River. The general surface of the badlands rises in elevation northward and, in the central portion of the area, culminates in Ramshorn Peak. The relatively low-lying section along the western edge of the map is characterized by irregular hummocky glaciated topography.

North of a line trending west and northwest from the mouth of Little Alkali Creek to the junction of the East and West Forks of the Du Noir River is an area of rugged mountainous terrain which rises to elevations of 9,500 to 10,000 feet along the base of the steep scarps of the Absaroka Mountains. This belt of irregular terrain is a zone of folded and faulted Paleozoic and Mesozoic rocks which was buried by volcanic debris and subsequently partly exhumed. The zone extends both northwest and southeast of the mapped area along the southern margin of the Absaroka Mountains and has been referred to as the Washakie Range by Love (1939) who presented a detailed account of the geologic and geographic features of the range in areas to the southeast and the relationship of this structure to other mountain ranges in the region.

The scarp marking the southern border of the Absaroka Mountains is a sheer wall of flat-lying Tertiary pyroclastic rocks nearly 1,000 feet high which dominates the landscape in the extreme northwest corner of the Wind River Basin. The range is a plateau remnant, about 11,500 feet in elevation, which at one time probably extended across the Wind River Basin but has since receded to its present position as the basin was reexcavated by Wind River. The plateau surface is broken by isolated peaks and rounded hills that reach elevations of 12,000 feet or more. Continental Divide is located about 3 miles northwest of the northwestern corner of the mapped area. In this general locality, too, is the divide between the Wind River and Shoshone River drainages. Because of active erosion by the major streams the southern margin of the Absaroka Mountains is very irregular, with prominent ridges along the interstream divides, such as Du Noir Butte, the Ramshorn, and Elkhorn Ridge, extending several miles southward from the general mass of the range. The most conspicuous of these narrow precipitous ridges is the Ramshorn which culminates in Ramshorn Peak, a sharp angular pinnacle 11,625 feet in elevation, forming the most prominent peak in the entire area.

The Du Noir River, the main tributary of the Wind River within the mapped area, flows through a broad flat-floored valley that is from one-half to three-quarters of a mile wide and approximately 8 miles long. The valley is a striking physiographic feature in an otherwise rugged and irregular terrain. East and West Forks, which join to form the Du Noir River at the upper end of the valley, flow through canyons along most of their courses as do other tributaries to the river. Horse Creek, which enters the Wind River at the town of Dubois, is also characterized for the most part by a broad flat valley in its lower reaches and by canyons toward its headwaters. The Wiggins Fork River, along the northeastern edge of the mapped area, is bounded by precipitous canyons along most of its course.

Drainage and Water Supply

The entire area is drained by the Wind River, which heads about 12 miles west of the mapped area in the vicinity of Togwotee Pass, and its tributaries. The main tributaries include the Du Noir River, Warm Spring Creek, Horse Creek, and the Wiggins Fork River, a tributary of the North Fork which enters the Wind River 3 miles southeast of the area.

The only gaging station of the U. S. Geological Survey on the Wind River within the mapped area is located near Stony Point, about $1\frac{1}{2}$ miles downstream from the confluence of the Wind and Du Noir Rivers. The discharge of the Wind River at this point during the water year 1948-1949 varied from a minimum of 46 second-feet per day for the period March 26-30 to a maximum of 802 second-feet on June 13, and from a mean of 51.3 second-feet during March to a mean of 543 second-feet during June (Paulsen, 1951, p. 208). The mean annual discharge for the calendar years 1946-1948 was 64,443 second-feet.

All of the main tributary streams are perennial and head in high mountainous areas where they are charged the year around by melt water. Smaller streams that flow throughout the year include Bench Creek, Crooked Creek, and Long Creek. Many tributaries of these streams are fed by springs. In the badland areas most of the streams are intermittent and flow only during the spring runoff and after rains. Flash-floods are likely to occur in their channels during heavy rainstorms, at which times they become heavily laden with silt from the soft underlying Tertiary strata.

Because ^{much} of the area is traversed by perennial streams the need for other water supplies for stock and irrigation purposes is not acute. Water for irrigation is derived mainly by diverting water from the main streams into irrigation ditches which extend along the edges of the valleys. Trail Lake, located in sec. 34, T. 44 N., R. 108 W., is utilized as a reservoir from which water is used to irrigate meadows on the upland surface northeast of Pickett's ranch. Since the mountainous areas contain numerous small streams, springs, and ponds the water supply for summer grazing generally presents few problems. Much of this water is also excellent for domestic use.

Water for domestic use for the ranches located in the valleys is derived mainly from wells, and in some cases from springs. Wells, particularly those located on the valley floors, are usually shallow and bottom in alluvial gravels. Some, however, are deep enough to penetrate the underlying Tertiary sandstone.

Climate and Vegetation

The climate of the Du Noir area is semiarid to arid. Records of the U. S. Weather Bureau at Dubois show the average annual precipitation for the period 1907-1952 to be 9.29 inches. Nearly half of the precipitation comes during the months of April, May, June, and July. Little data are available for the mountain areas but the precipitation in those regions is considerably greater as evidenced by the thick growth of trees and other vegetation. The amount of moisture in the valley portions is not sufficient for agricultural purposes, and farming is successful only where additional water is supplied by irrigation.

The mean annual temperature, compiled from climatic data of Dubois, is 39.7°F. for the period 1907-1952. Daily and seasonal variations are great. The average length of the growing season is about 88 days with the average date of the last killing frost in the spring as June 11 and the average date of the first killing frost in the autumn as September 7. The average annual snowfall for the period 1906-1948 was 39.2 inches at Dubois, but is considerably greater in the mountains.

The records of the U. S. Weather Bureau at Dubois are given in Table 1.

Since the average annual precipitation is less than 10 inches in the basin the native vegetation is sparse and consists mainly of grasses and sagebrush. Some willows and pines occur along the streams. The mountain areas, which receive much more moisture, contain thick dense pine forests and plentiful grass, flowers, and other types of vegetation. The principal varieties of grasses are wheat, sedge, fescue, mountain and nodding brome, mountain timothy, big blue grass, juncus, and wild rye. Larkspur, lupine, and Astragalus are also present. In the mountain areas the forests consist mainly of lodge-pole pine, sugar pine, spruce, and Douglas fir. Aspens are also common; cottonwood and dogwood trees are found along streams at lower elevations. Through irrigation, extensive hay meadows have been developed by ranchers along the main valleys. Besides the raising of hay, mainly alfalfa, brome, and meadow fescue for winter feed purposes, small grains, such as oats, barley, and intermediate wheat are also cultivated.

Transportation and Settlement

Dubois, with a population of 279 according to the 1950 census, is the only town in the area. It is located on U. S. Highway 287 which parallels the Wind River through the southern part of the area. The highway affords the best avenue of travel into the area. The nearest railroads are at Lander and Riverton, Wyoming, both about 80 miles to the southeast.

Table 1. Average Monthly and Annual Precipitation and Temperature at Dubois*
(Compiled from U. S. Weather Bureau Records)

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|-------------------------------|------|------|------|------|------|------|------|------|-------|------|------|------|--------|
| Precipitation (inches) | .47 | .41 | .54 | 1.04 | 1.38 | 1.23 | .87 | .83 | 1.01 | .81 | .37 | .33 | 9.29 |
| Temperature (° Fahrenheit) | 20.9 | 23.3 | 28.9 | 38.2 | 45.7 | 53.8 | 60.3 | 58.6 | 50.8 | 42.0 | 31.2 | 23.6 | 39.7 |

*Incomplete records for period 1907-1952.

Improved roads extend along the main valleys and lead to ranches in those areas. A graded road extends southward from Highway 287 to the former site of the Du Noir Tie Camp on Warm Spring Creek. Only the roads that lie at lower elevations are suitable for year around travel; roads at higher elevations are commonly blocked by snow. Recent. All systems, with the exception of the Silurian, are represented. Precambrian rocks are exposed in both the southwestern and northeastern parts of the area. The lithology and thickness of the formations are shown on figure 2 and their distribution on Plate 2, streams where irrigation water and bottom land are available for the raising of hay. Summer grazing areas are situated in the mountains on ~~government-owned~~ ^{federal} lands. Several ranches maintain permanent camps as bases for summer activities in the mountains. Because of the proximity to extensive primitive mountain areas and the accompanying big-game hunting and fishing, guest-ranching has become an important occupation. The extensive forests in the northern portion of the mapped area and along Warm Spring Creek have been the site of logging operations for many years. This industry accounted for much of the early settlement of the region. The lumber has been used largely for the production of railroad ties. Because of the necessity of good roads for heavy logging equipment many remote localities have been made accessible for automotive travel.



In pocket

Figure 2. Generalized columnar section of *consolidated* rocks in the Du Noir area.

LEGEND

1. Lower Eocene
2. Cody shale
3. Frontier formation
4. Mowry shale
5. Thermopolis shale
6. Morrison & Cloverly fms., undivided.
7. "Upper Sundance"
8. "Lower Sundance"
9. Gypsum Springs fm.
10. Nugget sandstone
11. Chugwater formation
12. Dinwoody formation
13. Phosphoria formation
14. Tensleep sandstone
15. Amsden formation
- 15a. Darwin ss. member
16. Madison limestone
17. Darby formation
18. Bighorn dolomite
19. Gallatin limestone
20. Gros Ventre shale
21. Flathead sandstone

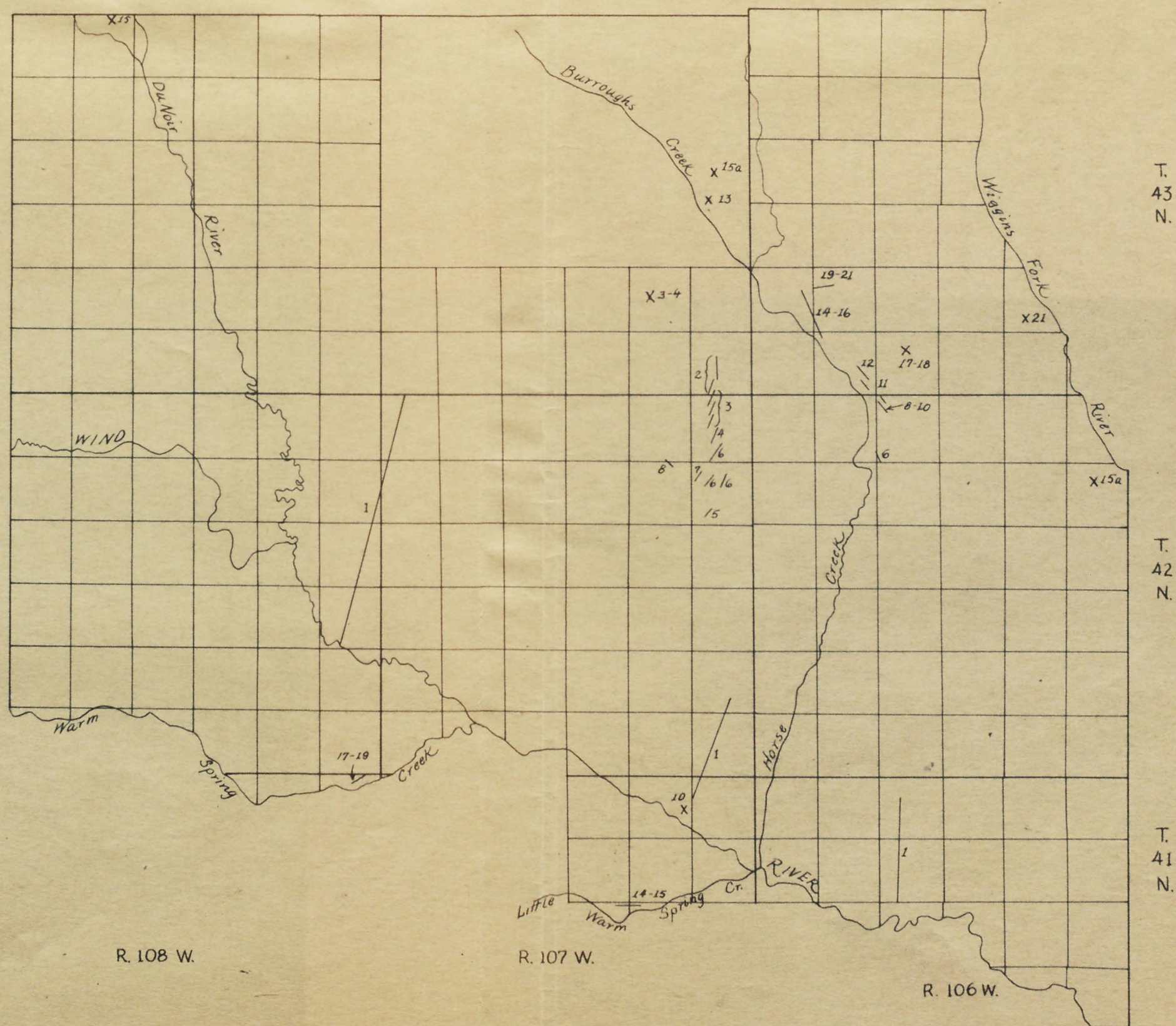


Figure 3. INDEX MAP SHOWING LOCATION OF MEASURED SECTIONS

Complete sections of Paleozoic rocks are exposed on the northeast flank of the Wind River Mountains and at the western end of Spring Mountain. These two sections, which lie only about 10 miles apart, are excellent tie-points for correlation and study of the Paleozoic sequence since the outcrop belts diverge basinward along the Owl Creek Mountains on the north and the Wind River Mountains on the west. The Mesozoic rocks are well exposed along Horse Creek and Little Horse Creek; some of the older Mesozoic formations are exposed along the Wind River near Dubois. These occurrences constitute the northwestern-most exposures of Mesozoic rocks in the Wind River Basin and therefore offer the best opportunities for correlation with similar stratigraphic units in regions to the west. Inasmuch as a detailed study of the Mesozoic ~~section~~^{rocks} had been made by the U. S. Geological Survey in the Horse Creek area (Love, et al., 1947) the author has freely drawn from this information for the stratigraphic discussions of those formations. Tertiary strata, which form an uninterrupted sequence about 5,000 feet thick in the central portion of the mapped area, cover a large part of the area. A variety of Quaternary deposits, including glacial moraines, landslides, terrace gravels, and alluvium, have been differentiated.

Precambrian Rocks

Precambrian rocks crop out along Warm Spring Mountain and in many places in the northeast portion of the mapped area where they form the core of a large anticlinal structure. Detailed studies of the Precambrian rocks were not attempted. Gray and pink coarsely crystalline granite and granite gneiss are the predominant rock types. They consist mainly of quartz, feldspar, and mica. Many of the rocks are schistose, with an abundance of biotite and appreciable amounts of pink garnet. Some of the gneissic granites are cut by thin pegmatite dikes and quartz veins.

The unconformity between Precambrian and Cambrian rocks is not readily observed as the contact is commonly obscured by talus from the overlying Flathead sandstone cliffs and by dense forest cover in many parts of the area. It is thought that the contact is relatively even and that local relief along the contact is not pronounced, although the thickness of the Flathead sandstone varies about 50 feet within the area. Regionally, however, the thickness of the Flathead sandstone varies greatly, and this variation is thought by Miller (1936, p. 118) to reflect the relief of the Precambrian peneplain. In some places the contact is not sharp, with the coarse Flathead arkoses grading downward through a weathered zone into unweathered granite.

Cambrian system

The Flathead sandstone crops out along Warm Spring Creek and

Flathead sandstone

The name "Flathead formation" was originally proposed by Peale (1893, p. 20-22) from exposures in southwestern Montana to include a basal quartzite or sandstone, termed the Flathead quartzite, and an upper green shale sequence designated the Flathead shales. In the Gros Ventre Mountains Blackwelder (1918, p. 417) included the shales in the lower part of the Gros Ventre shale and restricted the term Flathead to the basal sandstone. The Flathead sandstone (Flathead quartzite of many writers) is now generally accepted in this restricted sense and has been recognized over wide areas in western and central Wyoming. In the Wind River Canyon, Miller (1936, p. 124) included both the Flathead sandstone and the Gros Ventre shale in the Depass formation, because there the contact between the two was found to be gradational. Tourtelot and Thompson (1948), however, separated the two formations in that area and present a brief summary of the problems involved in the Cambrian nomenclature. The name Depass has not been generally accepted in central Wyoming. rubble of large sandstone blocks which have slid down the slopes; many such slopes are devoid of all vegetation except grass and are conspicuous in an otherwise heavily forested area (figure 4).



Figure 4. Flathead sandstone (Gf) and Gros
Ventre shale (Gg/) along Warm Spring Creek
in SW $\frac{1}{4}$ sec. 30, T. 42 N., R. 108 W. Dip
slope of Flathead sandstone in foreground.

Miller (1936), who made a paleontologic and stratigraphic study of the Cambrian rocks in northwestern Wyoming, concludes ^{from} ~~that~~ paleontologic evidence ~~indicates~~ that the Flathead sandstone is largely, if not wholly, Middle Cambrian in age. The contact between the Flathead sandstone and the overlying Gros Ventre shale is marked by a change from quartzitic and, in part, shaly sandstone below to soft micaceous shaly sandstone above. The lithologic change is not pronounced, however, and in places it is more or less gradational. The contact is also marked by a topographic change from Cliffs below to weathered slopes above.

Gros Ventre shale

The Gros Ventre shale was named by Blackwelder (1918) from exposures on Doubletop Peak in the Gros Ventre Mountains, approximately 25 miles southwest of the mapped area. The sequence probably includes the lateral equivalents of the Flathead shales and the lower part of the Gallatin formation of Peale (1893, p. 20-25) in southwest Montana. At the type section the Gros Ventre shale is 769 feet thick and can be divided into three distinctive lithologic units: a lower shale unit, a middle limestone unit called the Death Canyon limestone by Miller (1936), and a thick upper shale and limestone unit. These units are readily distinguishable throughout the mapped area. The formation crops out along Warm Spring Creek and in many places in the northeastern part of the area. Outcrops of the shale units commonly are grass covered slopes and good exposures are rare; in contrast the Death Canyon limestone member forms vertical cliffs and constitutes one of the most conspicuous units in the Cambrian sequence of this region (figure 4).

Because of poor exposures no detailed measured section of the Gros Ventre shale was obtained in the mapped area. A generalized section was measured on the northwest end of Spring Mountain, where it is 503 feet thick. The section on Warm Spring Creek in the extreme southwestern corner of the area is 747 feet thick (Miller, 1936, p. 132). In areas to the east Love (1939, p. 132) reported thicknesses ranging from 550 to 700 feet.

The lower unit has a uniform thickness of about 110 feet throughout the mapped area. It consists of greenish-gray, tan, and pink shaly micaceous very fine-grained sandstone that is highly glauconitic in most places. The basal part contains some beds similar to those in the upper part of the Flathead sandstone so that the contact in places is gradational. The Death Canyon member, which ranges in thickness from 140 to 219 feet, is characterized by gray thin-bedded crystalline cliff-forming limestone that is commonly mottled tan by the inclusion of granular tan irregular masses.

The upper unit is 421 feet thick on Warm Spring Creek (Miller, 1936, p. 132) and only 254 feet at the Spring Mountain locality. The sequence is composed mostly of soft greenish gray micaceous shale with varying amounts of thin-bedded gray limestone which increase in abundance toward the top. The limestone commonly contains beds of flat-pebble conglomerate. Best exposures of the shale can be seen in the road cuts along the switch-backs that descend into Warm Spring Canyon southwest of Harrison's ranch.

No fossils were found in the formation by the author, but a few trilobites and brachiopods have been reported from the Warm Spring Creek section (Miller, 1936, p. 132) and adjoining areas to the east (Love, 1939, p. 16). The fauna indicates a Middle Cambrian age, which agrees with that assigned by Blackwelder (1918) to the type section.

The contact between the Gros Ventre shale and the overlying Gallatin limestone is marked by a sharp topographic break and by a change from predominantly shale lithology below to predominantly limestone above. Wherever the contact was observed it appeared to be conformable, but the variation in thickness of the upper shale unit may be indicative of a disconformity between the two formations. A disconformity was noted by Miller (1936, p. 122) in the Teton Mountains and Blackwelder (1918) at the type section in the Gros Ventre Mountains. Inasmuch as the Death Canyon limestone also thins considerably northeastward from Warm Spring Creek the thinning of both of the upper units may be due largely to nondeposition.

Gallatin limestone

The Gallatin limestone, the youngest Cambrian formation in the area, was named and described by Peale (1893, p. 22-23) from exposures in southwestern Montana. At the type section it included in its lower part limestone and shale of Middle Cambrian age, which probably constitute the upper part of the Gros Ventre shale as that formation was defined by Blackwelder (1918), and limestone of Late Cambrian age in its upper part. Inasmuch as the Gallatin limestone, in its restricted sense, contains only strata of Late Cambrian age and is therefore not completely representative of the type Gallatin, Deiss (1938, p. 1104) applied the term Boysen formation for the Upper Cambrian rocks in Wind River Canyon. That name, although extended into the Gros Ventre Mountains by Foster (1947, p. 1547), has not gained wide acceptance.

The Gallatin limestone is a resistant sequence that forms conspicuous cliffs above the Gros Ventre shale slopes. In Warm Spring Canyon it constitutes the lowermost series of ledges in the precipitous canyon wall (figure 5). The formation is also present and well exposed in the northeastern portion of the area. On Warm Spring Creek it is 365 feet thick. The Du Noir member, which forms the basal unit, was named by Miller (1936, p. 125) and the type section is about 2 miles west of the Du Noir Tie Camp, in the southwest corner of the area.

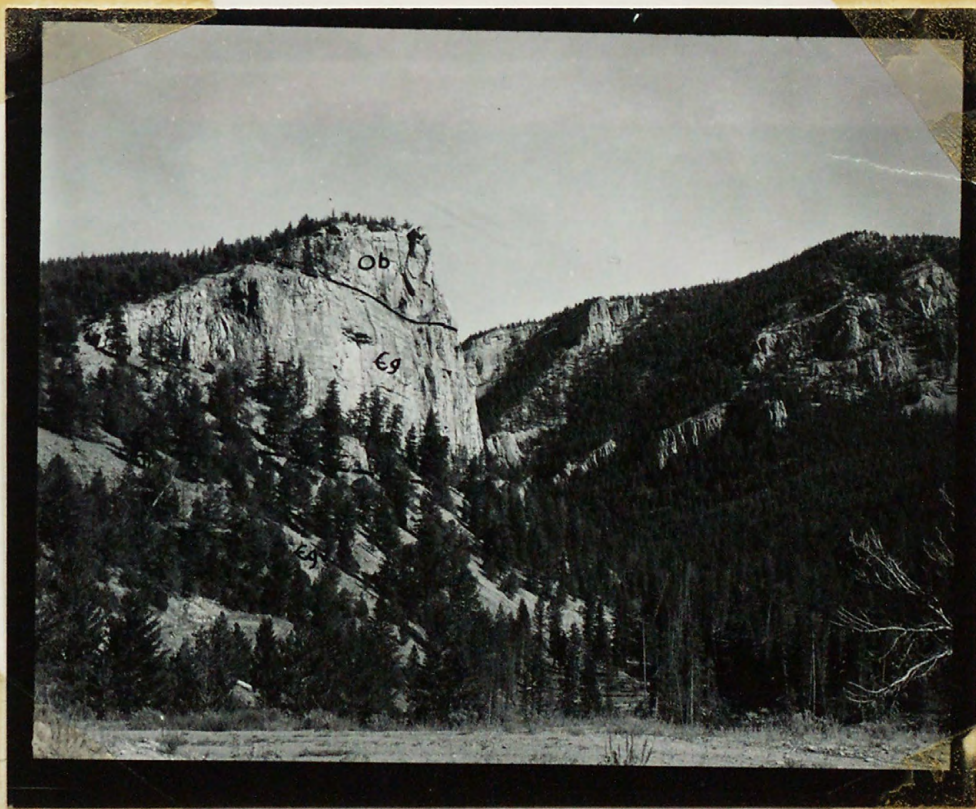


Figure 5. Gallatin limestone (Gg) and Bighorn dolomite (Ob) on north side of Warm Spring Canyon, N $\frac{1}{2}$ sec. 1, T. 41 N., R. 108 W.

In Warm Spring Canyon the Du Noir limestone member is an easily recognizable 48-foot cliff-forming unit of gray thin-bedded highly glauconitic and oolitic limestone with some flat pebble conglomerates. The overlying unit, which is 54 feet thick and generally poorly exposed because of talus cover, consists mainly of soft greenish gray shale with a minor amount of thin-bedded gray limestone. The uppermost sequence which forms the main mass of the formation is a hard resistant series of gray thin-bedded to massive limestones. Some of the exposed surfaces weather with a rough pitted surface similar to the overlying Bighorn dolomite. The upper part of the unit is commonly mottled with tan small irregular granular limestone masses. The formation in many places contains caverns filled with red earthy deposits which, where exposed on the sides of cliffs, contribute much red staining to the outcrops. Because of this, the outcrops, when viewed from a distance, appear to contain a large amount of red material. The caverns may have been developed and filled during short periods of erosion in Late Cambrian time and as such may represent local disconformities within the formation. On the other hand they may have been formed and filled at a much later date.

Section of Gallatin limestone measured on north wall of Warm Spring

Canyon in sec. 1, T. 41 N., R. 108 W.

| | Feet |
|---|------------|
| Bighorn dolomite. | |
| Gallatin limestone: | |
| Limestone, white to gray and tan mottled, thin-bedded glauconitic(?); sporadic brachiopod fragments. | 49 |
| Limestone, gray, thin-bedded, cherty at top; abundant trilobite fragments at top. | 36 |
| Limestone, gray to buff, massive to thin-bedded; cavernous with caverns containing red earthy material which stains cliff red. | 97 |
| Limestone, gray, thin-bedded, conglomeratic in part with granule size fragments of glauconite(?). | 81 |
| Largely covered interval; underlain mostly by soft greenish gray shale and gray limestone. | 54 |
| <u>Du Noir limestone member.</u> Limestone, gray, thin-bedded, highly glauconitic, oolitic; some flat-pebble conglomerates; sporadic brachiopod fragments at top; forms cliff. | 48 |
| | <u>365</u> |
| Gros Ventre shale. | |

Only unidentifiable trilobite and brachiopod fragments were found in the Gallatin limestone. However, in his studies of the Cambrian sequence of this region Miller (1936, p. 140-141) collected fossils from many faunal zones in the Gallatin limestone and correlated them with zones in the type St. Croixan (Upper Cambrian) of the upper Mississippi Valley.

The contact between the Gallatin limestone and the overlying Bighorn dolomite is not sharp in the section measured in Warm Spring Canyon, but is marked only by a gradual change from gray limestone below to buff granular limestone and dolomite above. The contact is likewise difficult to determine in the cliff faces along the canyon. In many places throughout the area, however, a sharp topographic change delineates the contact as the more easily eroded thin-bedded limestone forms slopes beneath the very resistant massive Bighorn dolomite. Love (1939, p. 19) states that the Bighorn dolomite rests with slight disconformity on the Gallatin limestone. In some areas Miller (1936) found an erosional disconformity at the top of the Cambrian while in others the contact appeared to be conformable. Miller (1936, p. 131) noted the presence of 100 feet of beds at the top of the Gallatin limestone on Warm Spring Mountain that were absent about 3 miles to the west. Since the Gallatin limestone is Upper Cambrian and the lower part of the Bighorn dolomite is considered to be of Middle or Late Ordovician age (Thomas, 1948, p. 80) this break represents considerable time.

Ordovician system

Bighorn dolomite

Along the flank of the Wind River Mountains the Bighorn dolomite, which was named and described by Darton (1904, p. 394-396) from exposures in the Bighorn Mountains, is divisible into three lithologic units: a basal lenticular sandstone called the Lander sandstone member by A. K. Miller (1930, p. 196), an unnamed middle massive dolomite member, and an upper thin-bedded dolomite member called the Leigh dolomite by Blackwelder (1918). Within the mapped area only the upper two dolomite members are believed to be present, although, owing to its lenticular nature and thinness, the Lander sandstone may be present in areas where the basal part of the formation is concealed. A 1-foot bed of coarse-grained sandstone at the base of the Bighorn dolomite was observed by the writer along Torrey Creek near the Trail Lake Ranch, approximately 5 miles south of the Fish Ranch. Love (1939, p. 18) reported the Lander sandstone to be present in several places in areas to the east, with thicknesses averaging about 7 feet.

The Bighorn dolomite forms massive cliffs throughout most of its area of outcrop (figure 5). It is 254 feet thick in Warm Spring Canyon and 296 feet on top of Spring Mountain in the N $\frac{1}{2}$ sec. 33, T. 43 N., R. 106 W. The lower massive member varies from 170 to 249 feet in thickness and is composed of buff very resistant massive granular dolomite which weathers with a characteristic rough pitted surface. The lower part of the member is quite limy and commonly more gray in color but still retains its granular nature. The Leigh dolomite member at the top, 47 to 84 feet thick, consists of gray to pink platy dense porcellainous dolomite, the lower part of which weathers chalky white and constitutes a conspicuous unit that generally forms reentrants along the cliff faces. The upper part of the member is similar to the massive dolomite in the lower part of the formation. The variation in thickness of both members is most probably due to the unconformities at the top and bottom of the formation.

Section of Bighorn dolomite measured on north wall of Warm Spring

Canyon in sec. 1, T. 41 N., R. 108 W.

| | <u>Feet</u> |
|--|-------------|
| Darby formation. | |
| Bighorn dolomite: | |
| Leigh dolomite member: | |
| Dolomite, light buff and pink, granular to crystalline, thin-bedded; upper part earthy and contains layers of calcite crystals as much as 1 inch thick and cavities as much as 1 foot in diameter filled with calcite crystals; upper part brecciated. | 38 |
| Dolomite, gray and pink, massive, crystalline, dense. | 9 |
| Dolomite, white and light gray, pinkish at top, weathers chalky white, dense, porcelain-like, thin-bedded; contains brachiopods and molds of small gastropods. | 34 |
| Dolomite, mottled pink and white; contains cavities filled with calcite crystals. | 3 |
| | <u>84</u> |
| Lower part of Bighorn dolomite: | |
| Dolomite, buff, massive, granular, sugary, fetid in part; contains geodes as much as 1 inch in diameter filled with calcite crystals; weathers with characteristic rough-pitted surface. | 101 |
| Limestone, or dolomite, buff, granular, in beds 1 to 4 feet thick, blocky, sugary texture in part; some surfaces contain characteristic pitted weathering; crinoid stems 15 feet below top. | 69 |
| | <u>170</u> |
| Total thickness Bighorn dolomite. | <u>254</u> |
| Gallatin limestone. | |

The problems involved in the age and correlation of the Bighorn dolomite, which have long been controversial, have been summarized by Thomas (1952, p. 35; 1948, p. 83) and Love (1939, p. 20). Until 1930 the lower part of the formation was thought to be Middle Ordovician (Mohawkian-Trenton) in age and the upper part to be late Upper Ordovician (Richmond) in age. A. K. Miller (1930, 1932) found in the Lander sandstone near Lander, Wyoming, a large fauna, chiefly cephalopods, which consisted of both Mohawk and Richmond species. He (Miller, 1932, p. 203, 209) concluded that the appearance of Richmond fossils in this case was sufficient to fix the age of the lower part of the formation as very Late Ordovician. More recent investigations of North American Ordovician cephalopods by Flower (1946, 1952) have shown that Bighorn-type forms occur in New York and Ontario in beds of definite late Trenton age. Thomas (1952, p. 35) summarizes "The Bighorn may be correlated with certainty with strata of similar age through wide areas in northern North America, but the determination of the age of these units in terms of standard Ordovician time remains a problem."

A few horn corals were the only fossils observed in the massive dolomite member within the mapped area, but the Leigh dolomite contains crinoid stems, small brachiopods, gastropods, and ostracodes. A collection obtained from the Leigh dolomite along the Wiggins Fork River in SE $\frac{1}{4}$ sec. 3, T. 43 N., R. 106 W. contained an abundance of crinoid stems and small poorly preserved brachiopods tentatively identified as Catazyga? sp. Josiah Bridge states (memorandum to W. R. Keefer, June 12, 1953) that species of Catazyga are common in both uppermost Ordovician and lowermost Silurian horizons, but that no exact stratigraphic determination could be made because specific identification was impossible.

he further states, however, that the material is similar lithologically to collections made by R. K. Hose in the Bighorn Mountains, which are late Ordovician in age. Thus it appears that at least the upper part of the Bighorn dolomite is Upper Ordovician in age.

There is an erosional unconformity, marked by earthy beds with layers and cavities filled with calcite crystals, at the top of the Bighorn dolomite. In Warm Spring Canyon the contact appears to have as much as 20 feet of relief locally and at one place in the canyon wall a large mass of breccia was observed at the upper contact which is thought to be a sink hole deposit that was developed in the Bighorn beds prior to the deposition of the Darby formation. The contact is also marked by a conspicuous topographic break.

Devonian system

Darby formation

The Darby formation was named by Blackwelder (1918) from exposures on the west slope of the Teton Mountains and includes all of the strata of Devonian age in that area. The formation has been traced eastward into the Gros Ventre, Wind River, and Owl Creek Ranges. At most places in the mapped area the Darby formation is poorly exposed, commonly forming topographic saddles or benches between the resistant beds of the overlying Madison limestone and the underlying Bighorn dolomite. However, along the north side of Warm Spring Canyon it is well exposed and constitutes a very distinctive unit. Most of the formation is also well exposed in a large excavation just south of the Horse Creek road in the SW $\frac{1}{4}$ sec. 19, T. 43 N., R. 106 W., where material was removed for surfacing roads in the vicinity. Other exposures were observed in the core of the Du Noir anticline along the East Fork of the Du Noir River, and at the eastern end of Spring Mountain in Wiggins Fork Canyon.

The formation is 193 feet thick in Warm Spring Canyon and 209 feet thick on Spring Mountain. It consists mainly of buff, gray, and brown dolomites and greenish gray and red siltstone and shale. The most characteristic beds of the sequence are the dark brown hard fetid dolomites which are readily distinguished from the Bighorn dolomite and the Madison limestone, although some of the lower limestones of the Madison limestone are superficially similar. On Spring Mountain it contains some thin beds of red, tan, and gray fine-grained soft porous thin-bedded sandstone. Near the top of the formation in Warm Spring Canyon is a white to pink granular limestone bed containing an abundance of limy oolites and large frosted sand grains. Also at this locality, about 35 feet above the base, are lenses of coarse-grained sandstone and granule conglomerate containing fragments of limestone in a limy matrix; these appear to be of local extent only and probably indicate local disconformities within the formation. The base of the Darby formation is very irregular due to the erosional unconformity on the top of the Bighorn dolomite.

Section of Darby formation measured on north wall of Warm Spring

Canyon in sec. 1, T. 41 N., R. 108 W.

| | Feet |
|---|------|
| Madison limestone. | |
| Darby formation: | |
| Poorly exposed; underlain mostly by interbedded shale, siltstone, and limestone; varicolored white, pink, brown, gray, greenish gray, and red. | 59 |
| Limestone and dolomite interbedded, white and pink; geodes at base. | 10 |
| Siltstone, mottled red and green, shaly, sandy in part, slightly dolomitic. | 5 |
| Limestone, mottled pink and white, thin-bedded and slabby, extremely granular and appears oolitic in part with fine grains of calcite and large frosted sand grains. | 4 |
| Dolomite, dark gray, brown, and pink, crystalline, massive to thin-bedded, hard, fetid; minor amount of green and red siltstone. | 18 |
| Siltstone, red and greenish gray, shaly. | 1 |
| Dolomite, brown, granular to crystalline, massive to thin-bedded, fetid. | 24 |
| Siltstone, greenish gray and red, thin-bedded; minor amount of red shale and hard brown dolomite; poorly exposed. | 31 |
| Dolomite or limestone, buff, gray, and brown, granular to crystalline, platy, hard; rings when struck. | 2 |
| Dolomite, light gray, dense, hackly and splintery; locally contains lenses or coarse sandstone and granule conglomerate with fragments of calcite in a limy matrix. | 4 |
| Dolomite, light gray and brown, finely-granular, thin-bedded, hard, ledgy; upper 3 feet fetid and contains geodes as much as 4 inches in diameter filled with calcite crystals. | 15 |
| Dolomite, dark gray to dark brown, crystalline, massive to thick-bedded, fetid. | 12 |
| Dolomite, buff and green, shaly in part, soft, sandy. | 2 |
| Dolomite, brown, thin-bedded; base very irregular. | 6 |
| Bighorn dolomite. | 193 |

No fossils were found in the Darby formation of the mapped area and few have been found in adjacent regions. Recent studies of Devonian rocks near the north end of the Bighorn Mountains, north-central Wyoming, have been made by Blackstone and McGrew (1954). There the sequence is characterized by a basal conglomeratic channel deposit containing Early Devonian fossils and an upper 250-foot unit of dolomite, limestone, and siltstone with frosted sand grains containing fossils of Middle to Late Devonian age. Blackstone and McGrew (1954) correlated the lower channel deposit with the Beartooth Butte formation and the upper part with the Jefferson limestone and Three Forks shale of northwestern Wyoming. Correlation of the Darby formation at the northwest end of the Wind River Mountains with the Devonian sequence at the north end of the Bighorn Mountains is uncertain; the Darby formation may be equivalent to only the upper part of the Devonian section in the latter region. In western Wyoming the formation is considered to be Late Devonian in age and is correlated with the upper part of the Jefferson limestone of Idaho (Cooper, et al., 1942).

The contact between the Darby formation and the overlying Madison limestone is marked by a sharp topographic break and by a change from red shale and siltstone and brown dolomite below to predominantly gray crystalline limestone above. No evidence of an unconformity between the two formations was seen in the mapped area, but Love (1939, p. 22) noticed a sharp erosional unconformity in Wiggins Fork Canyon. Blackwelder (1918) reported at least local erosional unconformities at the type section in the Teton Mountains to the west.

Carboniferous systems

Mississippian system

Madison limestone

The Madison limestone forms extensive outcrops along the northeast flank of the Wind River Mountains, on Spring Mountain, and on the high ridge north of the Horse Creek Ranger station. It also forms the bulk of rocks exposed in the Du Noir anticline in the northwestern part of the area. The formation is 740 feet thick on the west end of Spring Mountain near Livingston's Ranch, but the thickness is probably variable because of a pronounced unconformity at the top. There is a regional thickening westward, however, and in the Gros Ventre Mountains the Mississippian limestones total 930 feet in thickness (Love, et al., 1951a).

No detailed section of the Madison limestone was measured, but the lithology is quite uniform throughout. It consists mainly of resistant bluish gray to gray massive to thin-bedded crystalline limestone. The limestone is commonly mottled tan because of inclusions of tan granular material similar to those in both the Gallatin limestone and the Death Canyon member of the Gros Ventre shale. At most localities the basal part of the formation contains thin beds of buff granular dolomitic limestone similar to some of the strata in the upper part of the Darby formation. The lower beds also contain masses of breccia consisting of angular limestone fragments in a red earthy matrix. Weathering and erosion of these causes conspicuous red staining on many outcrops. Massive to bedded chert layers as much as 15 feet thick are present at several localities on the northeast flank of the Wind River Mountains. Caverns are commonly developed in the limestone, especially in the more granular beds. In some places near or at the top of the Madison limestone, a zone, estimated to be 100 feet thick, of red shale and thin-bedded tan to yellowish dolomite and limestone resembles beds in the upper part of the Amsden formation. About 2 miles north of the Horse Creek Ranger station this zone is overlain by about 20 feet of Madison-type limestone. The sequence was not observed along the northeast flank of the Wind River Mountains, but is thought to be present in places in the northwestern part of the Du Noir area.

The Madison limestone, named by Peale (1893, p. 32) from the Madison Range in north-central Montana, is considered to be of Early Mississippian age (Weller, et al., 1948). There is evidence to indicate, however, that the formation, as it is defined in this report, also includes strata of later Mississippian age which probably are equivalent to some parts of the Middle and Upper Mississippian Brazer limestone of northeastern Utah, southeastern Idaho, and western Wyoming (Williams and Yolton, 1945). A Late Mississippian fauna from the upper part of the Madison limestone along Bull Lake Creek, approximately 40 miles southeast of the Du Noir area, was described by Branson and Greger (1918) and, because of both faunal and lithologic distinction, these strata were subsequently named the Sacajawea formation (Branson, 1937). Love (1939) also reported Late Mississippian fossils from this sequence.

The following collection, identified by J. E. Smedley, was obtained approximately 100 feet below the top of the Madison limestone at the Spring Mountain locality: Spirifer striatus var. madisonensis (of Girty, 1899), Spirifer sp. undet. aff. S. Missouriensis Swallow, Spirifer cf. S. increbescens Hall, Spirifer sp., Composita sp. indet. Smedley concludes (written communication) that the absence of Spirifer centronatus Winchell, particularly from a fauna composed largely of spirifers, is rather unusual and that it may represent a facies of the Madison that is a little younger than the typical Madison limestone. The collection also contained crinoid columnals, fenestellid bryozoans, and corals. Although the specimens were too fragmentary and poorly preserved for specific determination, Helen Duncan (written communication) concludes that the coral faunule is not one that would be considered typical Madison, at least not typical of the lower part of the formation where the characteristic Madison fauna is best developed.

Thus it appears likely that Mississippian strata younger than true Madison are present in this region, but as yet insufficient lithologic and faunal data are available to warrant separation of the sequence into two formations in the Du Noir area. The term Sacajawea formation has not gained wide acceptance.

One of the most pronounced erosional unconformities in the Paleozoic sequence of this region occurs between the Madison limestone and the overlying Darwin sandstone member of the Amsden formation. The Darwin sandstone was apparently deposited on a karst topography developed on the top of the Madison limestone that may have as much as 135 feet of relief (fig. 6) in a distance of 3 miles. Many dip slopes formed on the top of the limestone were observed to contain cracks and joints filled with red sandstone in areas where the main mass of the Darwin sandstone has been stripped away by erosion.

Pennsylvanian system

Amsden formation

The Amsden formation was named and described by Darton (1904, p. 396-397) from exposures in the Bighorn Mountains and included the strata lying between the Madison limestone and the massive crossbedded Tensleep sandstone. Two distinct lithologic units, the Darwin sandstone member at the base and an upper predominantly shale and dolomite sequence are readily recognized throughout the mapped area. With the exception of the Darwin sandstone, which forms cliffs in most places, the formation is generally poorly exposed due to the weak nature of most of the strata and to talus cover from the overlying Tensleep sandstone cliffs. The upper part of the formation characteristically produces red and yellowish soils which are generally sufficient for recognition of the sequence.

The formation is 291 feet thick near Livingston's Ranch in the SW $\frac{1}{4}$ sec. 29, R. 43 N., R. 106 W. and 309 feet thick along Esmond Creek near its junction with the West Fork of the Du Noir River in the NE $\frac{1}{4}$ sec. 5, T. 43 N., R. 108 W. At these two localities the exposures are poor and detailed lithologies could not be obtained. A detailed section was measured on the north side of Little Warm Spring Creek which lies outside the mapped area about 2 miles southwest of Dubois in the NE $\frac{1}{4}$ sec. 15, T. 41 N., R. 107 W. Here the formation is 356 feet thick.

Section of Amsden formation measured on the north side of Little
Warm Spring Creek in secs. 14, 15, T. 41 N., R. 107 W., about
2 miles southwest of Dubois

| | Feet |
|---|------|
| Tensleep sandstone. | |
| Amsden formation: | |
| Dolomite, gray to pink, fine-grained; 6 inches gray chert at top. | 2 |
| Shale, grayish green; some thin partings of dolomite. | 2 |
| Sandstone, buff, brown, and gray, hard, quartzitic. | 2 |
| Dolomite, brown, granular. | 2 |
| Shale, green. | 1 |
| Sandstone, buff, fine-grained, thick-bedded, hard, limy; sporadic black chert grains. | 5 |
| Dolomite, brown to tan, thin-bedded; some dark chert layers and nodules; upper 1-foot mostly quartz which appears to have replaced the dolomite. | 4 |
| Shale, gray green, fissile. | 2 |
| Dolomite, brown and gray, platy to blocky. | 4 |
| Sandstone, gray to white, very fine-grained, limy, very hard and quartzitic in part. | 4 |
| Dolomite, brown, blocky. | 1 |
| Shale, green. | 1 |
| Sandstone, gray to white, very fine-grained, limy, friable to quartzitic; slight disconformity at base. | 2 |
| Dolomite, brown to gray, thin-bedded to massive, dense. | 4 |
| Sandstone, gray and brown, hard, quartzitic; thin beds of green shale at top and 2 feet below top. | 4 |
| Shale, gray, fissile. | 1 |
| Breccia; mostly limy sandstone with green shale pellets in lower 6 inches; angular fragments of sandstone and cherty limestone as much as 2 inches in diameter in upper part. | 3 |

| | Feet |
|---|------|
| Limestone, gray and buff, hard, crystalline; many calcite veinlets. | 3 |
| Shale, pale green and maroon, fissile. | 2 |
| Sandstone, white and light red, very fine-grained, thin-bedded; geodes as much as 1 foot in diameter filled with calcite crystals present near the top; local discontinuity 3 feet above the base overlain by 1 foot of red sandstone that contains cross-bedded laminae of white coarse sand grains. | 7 |
| Dolomite, pink to red, fine-grained, irregularly bedded; thin bed of green fissile shale at top. | 2 |
| Shale, red, blocky to fissile. | 1 |
| Dolomite, white, granular, hard. | 2 |
| Shale, purple, some tan laminae, fissile; some thin beds of purple dolomite. | 11 |
| Dolomite, purplish red and green, thin-bedded, sandy in part. | 4 |
| Dolomite, variegated red, brown, reddish brown, gray, and greenish gray, in beds as much as 3 feet thick, cherty near base; crinoid columnals 3 feet below top. | 7 |
| Siltstone, gray to green. | 1 |
| Shale, tan, red, and green, fissile in part; silty in part. | 1 |
| Dolomite, brown, reddish brown, and buff, sublithographic, massive to thin-bedded and shaly, cherty in lower 3 feet; some beds ring when struck. | 7 |
| Poorly exposed; underlain mostly by greenish gray fissile shale. | 3 |
| Dolomite, gray to reddish, massive to thin-bedded, dense, hard, slightly limonitic; some thin beds of green shale in middle. | 18 |
| Poorly exposed; sporadic outcrops of hard dolomite, yellow silty shale, and green fissile shale. | 20 |
| Dolomite, light brown, buff, and pink, thin-bedded to shaly. | 2 |

| | |
|--|------------|
| Shale, green and grayish green, fissile; minor amount of dolomite. | Feet 1 |
| Sandstone, white, very fine-grained, irregularly bedded, moderately soft and porous. | 2 |
| Dolomite, buff to brown, massive, to irregularly bedded, dense, hard; masses of black chert as much as 1 foot in diameter occur locally at the base; thin bed of white clean sandstone 4 feet above base. | 9 |
| Dolomite, buff and pink, dense, massive, hard; contains vugs as much as 1½ inch in diameter filled with calcite crystals; some calcite veinlets. | 5 |
| Covered. Lateral exposures indicate that unit is mostly underlain by soft red shale. | 34 |
| <u>Darwin sandstone member.</u> Sandstone, red in basal 10 feet, white and reddish in remainder, weathers gray for the most part, fine- to medium-grained, massively to thinly crossbedded, moderately porous and friable, soft to hard, limy, limonitic in part; some green grains; some pink grains that may be feldspar; grains mostly rounded; forms conspicuous cliff; base very irregular and disconformable on Madison limestone. | 170 |
| | <u>356</u> |
| Madison limestone. | |

The Darwin sandstone member at the base of the formation was named by Blackwelder (1918) from exposures on Darwin Peak in the Gros Ventre Mountains, approximately 25 miles southwest of the mapped area. The average thickness throughout west-central Wyoming is about 75 feet. Throughout a large part of the Du Noir area the unit forms one of the most prominent sandstones in the Paleozoic sequence. The sandstone is red, gray, and white, fine- to medium-grained, commonly crossbedded to massive, and moderately porous and friable. Most of the grains are rounded and consist of quartz with a minor amount of pink and green grains, some of which are feldspars. In gross aspect the Darwin sandstone is strikingly similar to the overlying Tensleep sandstone. It varies considerably in thickness, from 29 feet on the east end of Spring Mountain, N $\frac{1}{2}$ sec. 12, T. 42 N., R. 106 W., to 170 feet at the Little Warm Spring Creek locality (fig. 6). Within the mapped area this thickness variation was found to have no uniform trend (fig. 6), except for a slight regional thinning toward the southeastern part of the Wind River Mountains. The very irregular erosion surface that was developed on top of the Madison limestone prior to the deposition of the Darwin sandstone is thought to account for the extremely localized character of this thickness variation.

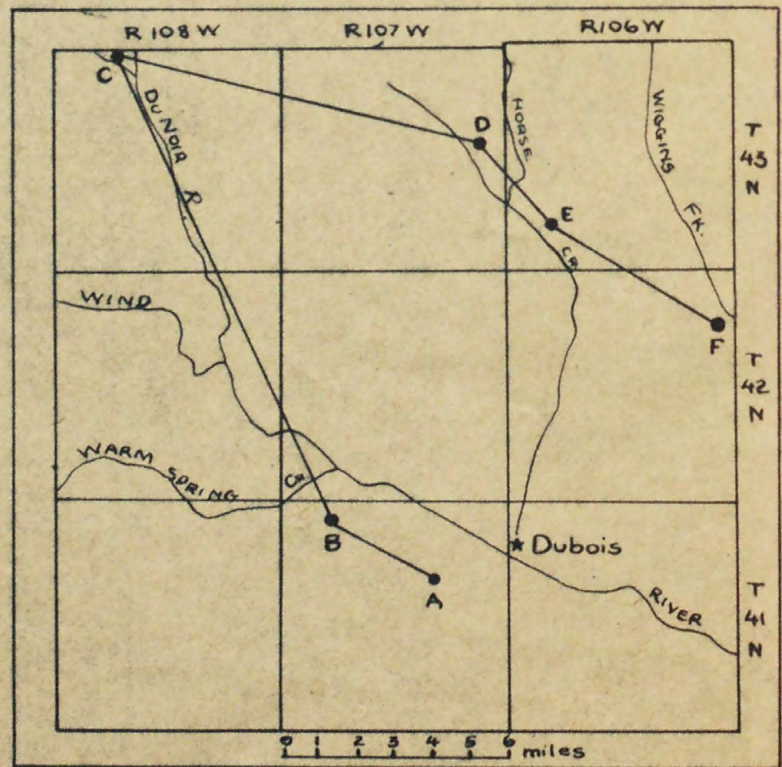
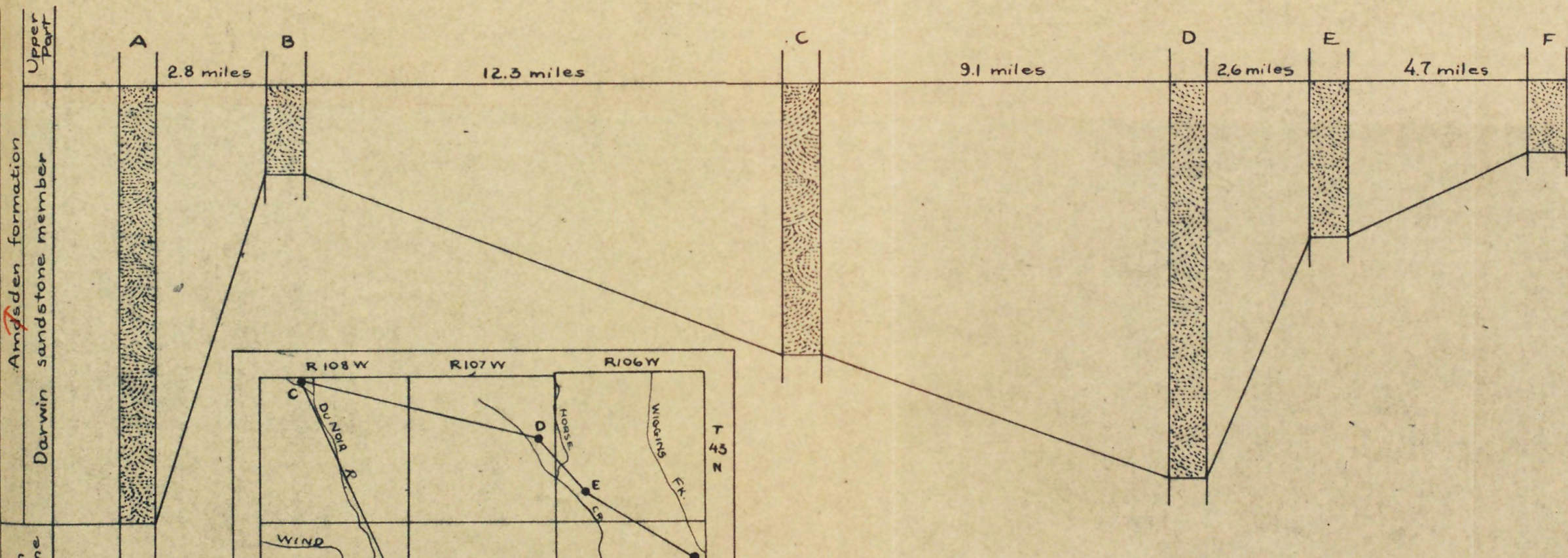
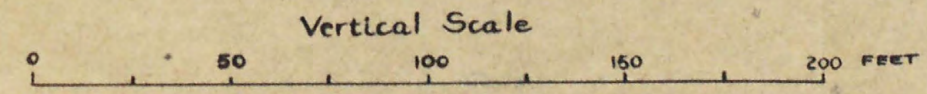


Figure 6.
 DIAGRAM SHOWING THICKNESS VARIATION OF DARWIN SANDSTONE MEMBER



The upper part of the Amsden formation is a variable sequence of dolomite, shale, quartzitic sandstone, and limestone and ranges in thickness from 186 to about 300 feet. Most common colors are red, green, and buff. Overlying the Darwin sandstone in most places is a sequence of poorly exposed red shale, averaging about 40 feet in thickness, which forms a conspicuous red zone along the weathered slopes. Hematite-nodule beds are commonly present in the red shale. Thin sandstone beds occur mostly in the upper part of the formation and are typically fine-grained, hard, and quartzitic. The dolomite and limestone are massive to thin-bedded and generally cherty. Shale is soft and fissile to blocky. Local inconspicuous disconformities occur within the sequence. The formation is only sparsely fossiliferous ; crinoid stems and small brachiopods, Composita sp., were the only fossils observed.

For many years the age of the lower part of the Amsden formation and the position of the Mississippian-Pennsylvanian boundary have been the subjects of much controversy in this and adjacent areas. Branson and Greger (1918) described a Ste. Genevieve fauna (Late Mississippian age) from red ferruginous shale and purple limestone about 60 feet above the base of what they considered to be the Amsden formation near Lander, Wyoming. Because the section was poorly exposed near Lander they cited the Bull Lake section (Sacajawea formation) of gray limestone containing a Ste. Genevieve fauna, as a lateral equivalent. This sequence is overlain by the Darwin sandstone member at the Bull Lake locality, but at the Lander locality the Darwin is very poorly developed or entirely absent and cannot be recognized with certainty. Morey (1935, p. 474) studied the ostracodes of the Lander section and confirmed the Ste. Genevieve age. From more recent studies (Shaw and Bell, 1955) it is now apparent that two faunal sequences, one of Mississippian age and one of Pennsylvanian age, occur in red strata overlying typical Madison limestone in the Lander area. The older fauna is like that of the Sacajawea formation at Bull Lake. C. C. Branson (1937, p. 651-652) assigned a few feet of limestone lying above the Sacajawea formation and below the Darwin sandstone member to the lower Amsden formation (pl. 3) of possible Chester age. The whole of the Amsden formation as it is defined in this report he then referred to as the Upper Amsden formation. In subsequent papers C. C. Branson (1939, p. 1209-1211) and Branson and Branson (1941, p. 132) abandoned the name Amsden formation and included both the Amsden formation and Tensleep sandstone, as defined in this report, in the Tensleep formation (pl. 3). This usage, however, has not been followed by subsequent workers.

In the northwestern part of the Wind River Basin the Amsden formation is now generally restricted to those strata which lie between the base of the Darwin sandstone member and the base of the overlying Tensleep sandstone. No fossils have been reported from the Darwin sandstone member, but several localities have yielded faunas from beds lying above the Darwin. Burk (1954) concludes, after studying many of these faunas from the region, that the Amsden formation, as thus defined, should be referred to the Pennsylvanian. Scott (1948, p. 38) also places the entire formation in the Pennsylvanian on both faunal and physical evidence. Inasmuch as the most pronounced erosional unconformity within the controversial sequence in the Du Noir area lies at the base of the Darwin sandstone it seems most likely that the Mississippian-Pennsylvanian boundary falls at this horizon.

The boundary between the Darwin sandstone member and the upper part of the Amsden formation is rarely well exposed, and no evidence of a physical break was observed where the contact was mapped. At some localities shaly beds have been reported in the upper part of the Darwin, suggesting that the boundary is gradational. The contact between the Amsden formation and the overlying Tensleep sandstone is likewise ill defined and is found to be gradational in adjacent areas (Love, et al., 1951a; Scott, 1948). The gradational nature of this boundary, as well as the one at the top of the Darwin sandstone, probably accounts for the conspicuous thickness variation of the upper part of the Amsden formation. Within the mapped area the upper boundary of the Amsden formation is generally obscured by talus, but it is well exposed on Little Warm Spring Creek and shows a conspicuous change from thin-bedded dolomite, shale, and sandstone below to massive sandstone above. No physical break in sedimentation is in evidence. The boundary is also marked by a conspicuous topographic change from weathered slopes below to nearly vertical cliffs above.

Tensleep sandstone

The Tensleep sandstone was defined by Darton (1904, p. 397) as the thick sandstone overlying the Amsden formation in the Bighorn Mountains. It is well exposed at many localities in the mapped area and forms massive cliffs throughout most of its area of outcrop. The formation is 213 feet thick at the Little Warm Spring Creek locality, but thickens to 245 feet near Livingston's Ranch on the west end of Spring Mountain. It consists of buff, cream-colored, and white, fine-grained moderately friable and porous crossbedded sandstone. Some beds are hard and slightly quartzitic. Thin irregular beds of chert are present. Many of the outcrops weather brown and rusty brown and, viewed from a distance, some cliffs appear to be nearly black. Coarse talus generally accumulates at the base of the cliffs and obscures the lower part of the formation as well as much of the underlying Amsden formation.

The Tensleep sandstone is generally unfossiliferous. However, a few fossil fragments, chiefly brachiopods, were found in the lower part of the formation on Little Warm Spring Creek. Fusulinids have been found in the formation in other areas and indicate a Pennsylvanian age (Thomas, 1948, p. 88).

The boundary between the Tensleep sandstone and the overlying Phosphoria formation is marked by only a slight erosional unconformity, although regionally this break is quite pronounced. Blackwelder (1911, unpublished field notes, U. S. Geological Survey) reported as much as 37 feet of the Tensleep sandstone locally cut out by pre-Phosphoria erosion in the vicinity of Dinwoody Lakes, approximately 12 miles southeast of the Du Noir area. Within the mapped area the basal beds of the Phosphoria formation are conglomeratic and are overlain by a distinctive series of interbedded chert, limestone, and siltstone which contrast sharply with the massive to coarsely bedded Tensleep sandstone. The contact is best exposed in the cliff at Stony Point (fig. 7).

Permian system

Phosphoria formation

Originally the term Embar formation, proposed by Darton (1906, p. 35) for exposures on the north flank of the Owl Creek Mountains, was used to include all strata occurring between the Tensleep sandstone and the Chugwater redbeds. In 1912 Richards and Mansfield (1912, p. 683-689) applied the name Phosphoria formation to include the lower part of these strata in southeastern Idaho and the name has since been used for the lower part of the Embar formation in central and western Wyoming. Blackwelder (1918) proposed the term Dinwoody formation for the upper part of the Embar formation in Dinwoody Canyon approximately 12 miles southeast of the mapped area. These names are now in general usage in this region. The Phosphoria formation produces oil and gas in many areas in Wyoming and constitutes the producing horizon in the Sinclair-Wyoming Oil Company Dubois Unit No. 1 well on the Dubois anticline.

The Phosphoria formation crops out along the Wind River Mountains, around the Du Noir anticline, on the west end of Spring Mountain, and along the east side of Burroughs Creek. The best exposures are found along Burroughs Creek about a mile north of the Horse Creek Ranger Station. At this locality the strata on the west side of a thrust fault are overturned and dip eastward into the hill at an angle of about 40 degrees. The formation here is 261 feet thick.

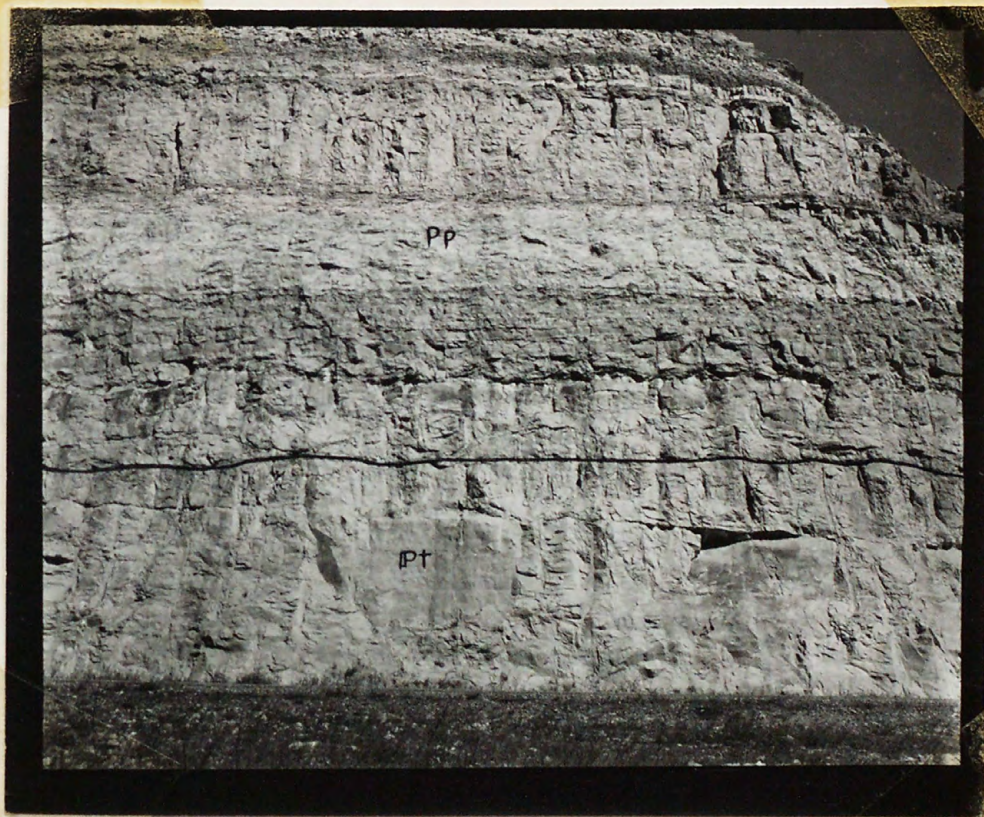


Figure 7. Contact between Phosphoria formation (Pp) and Tensleep sandstone (IPt) at Stony Point.

The Phosphoria formation consists chiefly of interbedded dolomite, chert, limestone, siltstone, and sandstone with a few thin beds of phosphate rock. A minor amount of shale is present. The color is predominantly tan, gray, and buff. The more phosphatic beds are dark gray to brown and black. The basal bed, about 5 to 15 feet thick, is commonly conglomeratic with angular fragments as much as $\frac{1}{2}$ inch in diameter of white and gray siltstone, sandstone, and crystalline quartz, and black rounded chert pebbles and granules. At Stony Point the basal beds contain some pebbles as large as 2 inches in diameter. The matrix of the conglomerate varies from a dense pink and gray sandy limestone to a tan and pink coarse-grained sandstone with an abundance of dark grains. The conglomerate is distinctive and thus forms a valuable criterion for determining the base of the formation. Chert occurs in thin beds and as tubular twisted masses in thick-bedded limestone and dolomite; these latter beds form very prominent units and are the most characteristic lithologic feature of the formation. A bed of black oolitic phosphate rock, 1.2 feet thick, is present approximately 160 feet above the base and other beds from 160 to 200 feet above the base are phosphatic to some extent. Many fossils are also phosphatic.

Section of the Phosphoria formation measured on the east side of
Burroughs Creek, SW $\frac{1}{4}$ sec. 13, T. 43 N., R. 107 W. (unsurveyed)

| | Feet |
|---|------|
| Chugwater formation. | |
| Phosphoria formation: | |
| Dolomite, tan, massive; contains geodes as much as 3 inches in diameter filled with calcite crystals; forms ledge. | 10 |
| Sandstone, gray to tan, very fine-grained, limy, geodes. | 4 |
| Dolomite or limestone, tan, granular, massive to thin-bedded, cherty in part; geodes. | 9 |
| Limestone, gray and tan, massive to thin-bedded, cherty, geodes in part, silty; abundant bryozoans and brachiopods. | 22 |
| Shale, gray, soft. | 1 |
| Limestone, gray, tan, and black, platy, fossiliferous. | 3 |
| Limestone and chert interbedded, dark gray to black, phosphatic(?) | 10 |
| Limestone, dark grayish brown, irregularly bedded, highly fossiliferous. | 4 |
| Limestone and chert, dark gray, brown, and black, massive, phosphatic(?) in part; chert occurs as tubular twisted masses. | 8 |
| Siltstone, dark brown and black, massive, limy. | 4 |
| Limestone and chert, dark gray and brown; contains characteristic tubular twisted masses. | 6 |
| Dolomite and chert, dark gray, irregularly bedded. | 20 |
| Phosphate, rock, black, oolitic, slightly limy. | 1 |
| Sandstone, tan to brown, very fine-grained; abundant large brachiopods. | 5 |
| Siltstone, gray and buff, massive to thin-bedded, limy; highly fossiliferous. | 23 |
| Limestone, dark gray to black, hard, dense, fossiliferous. | 2 |
| Limestone and siltstone interbedded, tan, thin-bedded. | 6 |

| | |
|---|------------|
| Limestone, tan, thin-bedded, crystalline, hard cherty; fossiliferous. | Feet 8 |
| Dolomite, white to cream-colored, thin-bedded, cherty in part. | 10 |
| Chert, white and pink. | 1 |
| Siltstone, tan, shaly at base, cherty at top. | 9 |
| Dolomite, tan and pink, cherty. | 2 |
| Siltstone, tan, shaly, highly limy. | 11 |
| Siltstone, tan and pink, massive to thin-bedded, sandy, limy cherty, geodes in part; fossiliferous. | 6 |
| Sandstone, pink, very fine-grained, massive, soft, porous, friable. | 2 |
| Chert, white, dark gray, and black. | 1 |
| Siltstone, pink, slightly limy. | 1 |
| Sandstone, white, uniformly very fine-grained, massive; nearly a pure quartz sandstone. | 16 |
| Chert, gray, irregularly bedded. | 2 |
| Siltstone, limestone, and chert interbedded, pink and gray, brecciated in part. | 3 |
| Siltstone, pink, highly limy; some thin beds of chert. | 19 |
| Chert, white and bluish gray, irregularly bedded; some limy layers. | 9 |
| Siltstone, pink and gray, cherty, porous. | 2 |
| Chert, white and bluish gray; some limy layers. | 3 |
| Siltstone, pink to brown, sandy, slightly limy, contains some red grains. | 4 |
| Limestone and siltstone interbedded, pink, tan, and gray, slabby, thin-bedded; basal beds contain limy pebbles and are quite conglomeratic. | 14 |
| | <u>261</u> |
| Tensleep sandstone. | |

The Phosphoria formation is abundantly fossiliferous with a predominance of brachiopods and bryozoans. Beds consisting almost entirely of large specimens of a single fossil species are locally developed. Most notable are bellerophon gastropods and productid brachiopods, both of which are as much as 3 inches in width. Orbiculoidea fragments are common near the base. Shark teeth are also present at some localities. The fauna was not collected extensively or studied by the author, but in most respects it resembles the fauna collected from adjacent areas and to which a Middle Permian age is generally assigned. The exact time span of the formation, however, has not been determined since the faunal assemblage is a provincial one and is not well represented in the classic Permian section of west Texas (Thomas, 1948, p. 90).

The contact between the Phosphoria formation and the overlying Dinwoody formation, which marks the boundary between the Paleozoic and Mesozoic eras, appears to be conformable throughout the mapped area. Regionally, however, the Dinwoody formation overlaps the Phosphoria formation progressively from west to east (Newell and Kummel, 1942, p. 945). Lithologically, the boundary is marked by a change from hard ledgy cherty limestone and dolomite below to thin-bedded gray siltstone and sandstone above.

Triassic system

Dinwoody formation

The Dinwoody formation is rarely well exposed and crops out only along Horse Creek north of the EA Ranch and at some places along Burroughs Creek. A section was measured in the SE $\frac{1}{4}$ sec. 32, T. 43 N., R. 106 W., approximately 1 $\frac{1}{2}$ miles north of the EA Ranch by Love, et al. (1947, p. 10). At this locality the formation is 154 feet thick and is characterized by yellowish, pink, tan, and brown thin-bedded very fine-grained sandstone and siltstone. The beds are commonly dolomitic and limy, and some are shaly. An examination of cores and well samples of the Stanolind Oil and Gas Company Dubois No. 2 dry hole on the Dubois anticline shows the formation to contain much grayish-green shale with an abundance of cubic pyrite crystals. The sequence is easily weathered and consequently forms soil covered slopes in most places.

Section of Dinwoody formation in sec. 32, T. 43 N., R. 106 W.

(Measured by Love, et al., 1947, p. 10)

| | Feet |
|--|------------|
| Chugwater formation. | |
| Dinwoody formation: | |
| Sandstone, brown, very limy, thick to thin-bedded, ripple-marked; fine rounded grains; upper 20 feet is a slabby siltstone containing <u>Lingula</u> . | 66 |
| Sandstone, brown, fine-grained, very limy, thin-bedded, slabby, hard to soft, containing <u>Lingula</u> . | 58 |
| Covered interval. Probably all fine-grained sandstone. | 8 |
| Sandstone, pink, fine-grained, slabby. | 15 |
| Sandstone, pink, coarse-grained, very limy; subangular grains; numerous calcite vugs. | 5 |
| Sandstone, yellowish, very fine-grained, limy, slabby, brecciated. | 2 |
| | <u>154</u> |
| Phosphoria formation. | |

The Dinwoody formation contains an abundance of Lingula and poorly preserved pelecypods. Newell and Kummel (1942, p. 942-945) who made a regional stratigraphic and faunal study of the Lower Triassic rocks in western Wyoming and southeastern Idaho, recognized two faunal zones in the formation, a lower Lingula zone and an upper Claraia zone with molds of several kinds of pelecypods of which species Claraia are the most distinctive. The formation is considered to be Early Triassic in age.

The contact between the Dinwoody formation and the overlying Chugwater formation is commonly marked by a change from grayish-green and tan dolomitic siltstone below to red non-dolomitic siltstone and shale above. The contact, however, is gradational and at some localities it has been found that the color change is independent of the bedding. Love, et al. (1945c), following a regional study of the two formations in the Wind River Basin, state that strata both above and below the contact are commonly superficially similar in appearance and lithology, but that the beds above are usually softer, less dolomitic, and more shaly.

Chugwater formation

The Chugwater formation includes the thick prominent series of redbeds which lies between the Dinwoody formation and the Nugget sandstone. It is one of the most easily recognized units of the sedimentary succession in this part of Wyoming because of its thickness and bright red color. The name, proposed by Darton (1904, p. 397) and applied by him to all of the redbeds between the Tensleep sandstone and the Sundance formation from the Bighorn Mountains southward to Colorado, has undergone extensive redefinition. As originally described it included strata that were later separated off as the Embar formation by Darton (1906, p. 35) in the Owl Creek and Bighorn Mountains and which in turn were further subdivided, as previously discussed, into the Phosphoria and Dinwoody formations. Love (1939, p. 42) included in the Chugwater formation all of the strata lying between the Dinwoody formation and the Sundance formation, but has since (Love, et al., 1945c) restricted its usage to those beds lying below the Nugget sandstone and above the Dinwoody formation.

Throughout most of the southern and western parts of the Wind River Basin the Chugwater formation, ranging in thickness from 1,000 to 1,250 feet, is divisible into three distinctive members (Love, et al., 1945c): the Red Peak, the Alcova limestone, and the Popo Agie members. These divisions can be distinguished and mapped as separate units only where the Alcova limestone is present. This member is not present in the northwestern part of the Wind River Basin, including the Du Noir area, but has been recognized as far west as Lower Slide Lake on the Gros Ventre River (Love, et al., 1951a). In the area of this report and adjacent areas to the east there is locally developed between the Popo Agie and Red Peak members, a 200- to 300-foot unit of sandstone that was named the Crow Mountain sandstone member by Love(1939, p. 44). Much interest has centered on the latter unit since the recent discovery of oil in it by the Skelly Oil Company No. 1 Tribal, SWSWSW sec. 36, T. 6 N., R. 3 W. (Wind River Meridian), at Northwest Sheldon Dome, approximately 24 miles east of the Du Noir area.

Within the mapped area a section of the Chugwater formation was measured (Love, et al., 1947, p. 9-10) along the east side of Horse Creek about one mile north of the EA Ranch. At this locality it is, for the most part, well exposed and aggregates a thickness of 1,293 feet. The lower 766 feet constitutes the Red Peak member and is characterized by bright red shaly siltstone with a very minor amount of sandstone. The overlying 300 feet, which is the Crow Mountain member, consists chiefly of buff and orange, shaly and silty in part, massive to slabby fine-grained sandstone. The upper 227 feet

comprises the Popo Agie member and is a variable sequence of ocher-colored claystone, red, green, and purple shale and siltstone, and limestone pellet conglomerate. Many of the beds contain conspicuous amounts of pinhead-sized growths of white analcime. The presence of analcime in the Popo Agie member has recently been recognized (Keller, 1952, p. 70-82) as a distinctive sedimentary feature of these strata and is thought to be a valuable aid in regional correlation. The lower part of the Popo Agie member is not well exposed along Horse Creek but forms conspicuous outcrops on the south side of the Wind River at Dubois and at many places along U. S. Highway 287 southeast of Dubois.

Section of Chugwater formation in secs. 32 and 33, T. 43 N., R. 106 W.

and sec. 4, T. 42 N., R. 106 W.

(Measured by Love, et al., 1947, p. 9-10)

| | Feet |
|---|------|
| Nugget sandstone. | |
| Chugwater formation: | |
| Popo Agie member: | |
| Shale, red and green, soft, limy. | 1 |
| Claystone, ocher, soft, silty, blocky. | 82 |
| Covered interval. | 144 |
| Crow Mountain sandstone member: | |
| Sandstone; buff in upper part; red and silty in lower part; numerous shaly beds near top. | 300 |
| Red Peak member: | |
| Siltstone, red, soft to hard; numerous red shale partings. | 292 |
| Sandstone, white, fine-grained, soft, clean; rounded grains; forms prominent white zone marker bed. | 6 |
| Siltstone, red, hard to soft; numerous red shale partings; a few thin white siltstones in upper 70 feet. | 246 |
| Siltstone, red, shaly; locally gray and red in lower 20 feet; increasingly silty near top; partly covered. | 222 |
| | 1293 |
| Dinwoody formation. | |

The precise age and correlation of the various members of the Chugwater formation in central Wyoming with Triassic rocks in other areas is still in doubt. The Red Peak member, though devoid of fossils, overlies the Dinwoody formation of known Early Triassic age and is correlated by Newell and Kummel (1942, p. 949) with the Woodside formation of western Wyoming and southeastern Idaho which is overlain by the Lower Triassic thick marine Thaynes limestone in those regions. The Red Peak member probably also contains equivalents of at least a part of the Thaynes limestone. Present evidence thus indicates that the lower part of the Chugwater formation is Early Triassic in age. Both marine vertebrates and invertebrates are sparsely present in the Alcova limestone but there is no general agreement regarding the age of the fauna, which has variously been ascribed to the Early, Middle, and Late Triassic. Love, et al. (1945c) state that the fauna has little present significance, but is more like known Early Triassic assemblages. They further conclude that, since there is no significant physical evidence either at the base or at the top of the Alcova limestone, it seems better to assign it arbitrarily to the Lower Triassic. Newell and Kummel (1942, p. 949) correlate both the Alcova limestone and the Crow Mountain member with the Thaynes limestone thus considering those two units to be Early Triassic in age. Marine reptiles and a few pelecypods and plant remains have been collected from the Popo Agie member. The vertebrates have been assigned to the Middle Triassic by some investigators and to the Late Triassic by others. Colbert, who collected vertebrate fossils from the Popo Agie member southeast of Dubois in 1953 is of the opinion that the member is of Late Triassic age (personal communication to J. F. Murphy, 1953).

The contact between the Chugwater formation and the overlying Nugget sandstone is marked by a sharp lithologic change from red and green shale and ocher-colored claystone below to gray and orange sandstone above. There is a regional unconformity between the two formations, but it is not readily apparent in localized exposures. In some parts of the mapped area the Nugget sandstone is absent and the Chugwater formation is overlain directly by the Gypsum Spring formation.

Jurassic system

Nugget sandstone

According to present definition in the western part of the Wind River Basin and adjacent regions the Nugget sandstone occupies the stratigraphic position between the Popo Agie member of the Chugwater formation and the Gypsum Spring formation. Its original definition in southwestern Wyoming (Veatch, 1907, p. 56) included all of the strata lying between the Thaynes limestone (lower Triassic) and the Twin Creek limestone (Middle and Upper Jurassic). In the type area near Nugget, Wyoming, the formation included a lower red shale member and an upper sandstone member considered to be wholly or in part of Triassic age. The lower red shale unit, possibly the stratigraphic equivalent of the Popo Agie member, was designated the Ankara shale and the Nugget sandstone was restricted to the upper sandstone unit by Boutwell (1912, p. 58) in the Park City mining district, Utah. The Nugget sandstone was used in this restricted sense by Mansfield (1927, p. 96) in southeastern Idaho.

The Nugget sandstone is present throughout the central and western parts of the Wind River Basin. At some localities in the southern part of the basin where the overlying Gypsum Spring formation is not present it is difficult to determine whether the basal sandstone of the Jurassic system is the Nugget sandstone or a sandstone in the basal part of the "lower Sundance." In adjacent areas to the east of the Du Noir area, where the Nugget sandstone is very poorly developed or entirely absent, its stratigraphic interval was included in the Chugwater formation by Love (1939, p. 43). The name Wyopo formation was applied by Branson and Branson (1941, p. 136) to the Nugget strata near Lander, Wyoming, but that term has not been generally accepted.

Within the mapped area the Nugget sandstone ranges in thickness from a wedge-edge to at least 120 feet, reaching its greatest development in exposures near Dubois (fig. 8). The formation has a marked northward thinning from Dubois, being 65 feet thick in the Sinclair-Wyoming Oil Company Dubois No. 1 well, only 31 feet (Love, et al., 1947, p. 9) along Horse Creek about 1 mile north of the EA Ranch, and entirely absent about 1/2 mile northwest of the Horse Creek Ranger Station. The sandstone is gray, white, and orange, fine- to medium-grained, massively crossbedded to thin-bedded and slabby. Large rounded frosted grains are common. A few green shaly beds are present. The unit, where well developed, forms conspicuous cliffs above the red and ocher-colored slopes of the Chugwater formation.



Figure 8. Outcrop of Nugget sandstone
(Jn) west of Dubois in E₁ sec. 2, T. 41 N.,
R. 107 W. (T_{pc}, Chugwater formation).

Section of Nugget sandstone in sec. 4, T. 42 N., R. 106 W.

(Measured by Love, et al., 1947, p. 9)

| | Feet |
|---|----------|
| Gypsum Spring formation. | |
| Nugget sandstone: | |
| Sandstone, red, massive to thin-bedded, fine- to medium-grained. | 15 |
| Sandstone, red, massive, fine- to medium-grained; rounded frosted grains; a few green shale fragments near top. | 5 |
| Sandstone, white, fine-grained, rounded grains, thin-bedded, limy. | 11 |
| | <hr/> 31 |
| Chugwater formation. | |

The Nugget sandstone is unfossiliferous and has in the past been assigned to both the Triassic and Jurassic systems. It is now considered to be Early Jurassic in age (Imlay, 1950, table 1).

The contact between the Nugget sandstone and the overlying Gypsum Spring formation is marked by a sharp lithologic change from sandstone below to red shale and dolomitic limestone above. Evidence of an unconformity, other than the sharp lithologic change, was not observed in the mapped area. Present data, however, indicate that the northward thinning and disappearance of the Nugget sandstone is caused largely by a regional unconformity between the Nugget sandstone and the overlying Gypsum Spring formation. Love (1948, p. 101) states:

"Studies of electric log data from the northwestern part of the Wind River Basin indicate that successively older beds are cut from south to north by the unconformity at the top of the Nugget sandstone and that the lowest bed forms the wedge-edge along the northern margin of the basin."

Regionally the thinning of the Nugget sandstone is very gradual but in areas immediately adjacent to the wedge-edge the thinning is abnormally abrupt as is demonstrated in the Du Noir locality and also in the area between the Gros Ventre River and Ditch Creek in Jackson Hole (Love, et al., 1951a). The position of the wedge-edge indicates gentle uplift of the region along the northern margin of the Wind River Basin and in the area extending westward from Togwotee Pass to Ditch Creek and erosion prior to the deposition of the Gypsum Spring formation.

Gypsum Spring formation

The Gypsum Spring formation was named and described by Love (1939, p. 45) from exposures on Red Creek, about 15 miles east of the mapped area, and was originally designated the topmost member of the Chugwater formation. Following recognition of its Middle Jurassic age and more detailed stratigraphic studies the unit was later classed as a formation (Love, et al., 1945b). In the Du Noir area the Gypsum Spring formation crops out in the vicinity of Dubois, along Horse Creek north of the EA Ranch, and at one locality northwest of the Horse Creek Ranger Station.

A detailed section was measured in the NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 4, T. 42 N., R. 106 W. along the east side of Horse Creek where the formation is 109 feet thick (Love, et al., 1947, p. 9). In the Sinclair-Wyoming Oil Company Dubois Unit No. 1 well it is 140 feet thick. The Gypsum Spring formation is a variable sequence of thin bedded red shale and gray to gray-green dolomitic limestone and dolomite. The limestone and dolomite are commonly dense and very finely crystalline and form ledges in otherwise smooth soft shale slopes. The most prominent bed in surface outcrop is a 20-foot earthy limestone breccia near the base. In the Sinclair well on the Dubois anticline the formation contains anhydrite throughout but most abundantly near the base, and the thickness is correspondingly greater.

Section of Gypsum Spring formation in sec. 4, T. 42 N., R. 106 W.

(Measured by Love, et al., 1947, p. 9)

| | Feet |
|---|------|
| "Lower Sundance". | |
| Gypsum Spring formation: | |
| Limestone, earthy; obscure fossil fragments. | 1 |
| Shale, red. | 1 |
| Limestone, green, silty, soft; poorly exposed. | 2 |
| Limestone, green to tan, dolomitic, moderately fossiliferous. | 2 |
| Shale, red, with thin green siltstone 2 feet above base. | 10 |
| Dolomite, white to grayish green, slabby, moderately pure. | 6 |
| Shale, red, soft; silty in lower 2 feet. | 10 |
| Limestone, bluish gray, brecciated; locally dolomitic and slabby in upper part; probably a residual breccia from which gypsum has been leached. | 2 |
| Shale, red, soft, with thin green shale at top. | 14 |
| Covered interval. Apparently mostly red shale. | 34 |
| Limestone breccia, dolomitic, with cavities filled with gypsum crystals. Apparently this is a residual breccia resulting from leaching out of the main gypsum bed in the Gypsum Spring formation. Thickness maps indicate that probably at least 100 feet of gypsum has been leached out of this section, most of it probably from this unit. | 19 |
| Shale, red, fine-grained; dolomite nodules near top; a thin purple shale at top. | 8 |
| | 109+ |
| Nugget sandstone. | |

At the type section on Red Creek the basal part of the Gypsum Spring formation contains a massive cliff-forming gypsum sequence, 127 feet thick, with a minor amount of red shale and limestone, but no limestone breccia. The occurrence of evaporites at the base of the formation is sporadic in surface outcrops but regional studies in the western part of the Wind River Basin (Love, et al., 1945b) indicate that the conspicuous anhydrite sequence is consistently present in the subsurface. Because of the subsurface persistence of the ^{Calcium}sulfate beds, their general absence in surface outcrops is believed to be due mainly to near-surface leaching by water. No studies were made to determine the physical or chemical means by which the leaching may have occurred. In areas where the gypsum is not present in surface exposures its stratigraphic position is generally occupied by a resistant brecciated limestone sequence which is thought to be the residuum after the leaching of the gypsum. The total thickness of the formation at these outcrops is considerably reduced from the expected thickness in the area. Burma and Anderson (1939), from studies of the formation near Lander, Wyoming, attempted to relate the amount of gypsum remaining to diastrophism and concluded that in areas of intense deformation the Gypsum Spring formation was likely to contain less gypsum because of the flowage of the gypsum into areas of relatively little deformation. Love, et al. (1945b), however, report that there is little evidence of flowage of gypsum even where it has been subjected to intense deformation.

A few fossil fragments are present in some of the limestone beds of the Gypsum Spring formation on Horse Creek. In some areas it is abundantly fossiliferous with a varied fauna of Middle Jurassic age. The formation has been traced westward into Jackson Hole (Love, et al., 1951a) and is correlated with the redbed sequence in the lower part of the Twin Creek formation in western Wyoming and southeastern Idaho. It is not present in the southern part of the Wind River Basin.

At the type section of the Gypsum Spring formation the basal bed of the overlying "lower Sundance" is conglomeratic, with an abundance of limestone fragments and chert pebbles, and the contact is consequently easily recognized. The conglomeratic beds are not present in the Du Noir area, however, and the contact is more difficult to determine. Regionally the contact is described (Love, et al., 1951b) as being between ". . .very finely crystalline slabby limestone, earthy gray weathered-looking dolomites, red shales, or gypsums below and oolitic fossiliferous limestones with chert pebbles, or gray fossiliferous marls above." The contact in the Du Noir area generally falls in a variable sequence of thin bedded limestone and shale, and is placed at the base of the lowest highly fossiliferous oolitic limestone in the sequence, below which the shales are generally red and the overlying shales are gray and gray-green.

"Lower Sundance"

The Sundance formation was named and defined by Darton (1899, p. 383-386) from exposures near the town of Sundance in the Black Hills. Since that time the formation, which included the rocks between the Spearfish formation (Triassic redbeds) and the Morrison formation has undergone extensive redefinition in that area. Imlay (1947) separated the sequence into the Nugget(?) sandstone, Gypsum Spring formation, and Sundance formation, and differentiated five members within the Sundance formation. The name has been accepted widely throughout the State of Wyoming. In the northwestern part of the Wind River Basin it is applied to the sequence of rocks overlying the Gypsum Spring formation and underlying the Cloverly and Morrison formations, undivided. In this region the Sundance strata are provincially divided into two sequences, "lower Sundance," and "upper Sundance" (Love, et al., 1945b). Peterson (1954, p. 465 ff.) has proposed that the Sundance formation in the Powder River Basin be raised to group rank and that the two units of formational rank within the Sundance be called Rierdon and Swift formations, following Montana terminology.

A section of the "lower Sundance" was obtained in the NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 4, T. 42 N., R. 106 W., along the east side of Horse Creek north of the EA Ranch (Love, et al., 1947, p. 9). The lower part is exposed also in the hill which rises abruptly on the north edge of Dubois and at a few places northwest of the Horse Creek Ranger Station, while the upper part is exposed on the west end of the Dubois anticlinal complex in the vicinity of the Sinclair-Wyoming Oil Company Dubois Unit No. 1 well. At the Horse Creek locality, where parts of the formation are poorly exposed, it is 305 feet thick. The lower part is characterized by an alternating succession of hard gray and bluish gray oolitic limestone, and soft green and gray, locally red shale and siltstone. The upper 250 feet is a gray-green soft fissile non-glaucconitic shale sequence containing abundant specimens of Gryphaea nebrascensis that weather out in profusion on the slopes. This prominent shale zone can be recognized over wide areas in west-central Wyoming. The limestone of the "lower Sundance" is coarsely crystalline in contrast to the finely crystalline carbonates of the Gypsum Spring formation.

Section of "lower Sundance" in sec. 4, T. 42 N., R. 106 W.

(Measured by Love, et al., 1947, p. 9)

| | Feet |
|--|-----------|
| Upper Sundance. | |
| Lower Sundance: | |
| Shale, gray green, sandy in upper 10 feet; containing abundant <u>Gryphaea nebrascensis</u> , and <u>Pentacrinus</u> sp. | 95 |
| Covered interval. | 180 |
| Limestone, bluish gray, hard, very oolitic, fossiliferous. | 8 |
| Shale, greenish to red, limy. | 1 |
| Limestone, gray, hard, fine-grained. | 2 |
| Siltstone, green to gray, limy at top. | 3 |
| Limestone, bluish gray, hard, oolitic, fossiliferous. | 2 |
| Shale, green, laminated. | 2 |
| Limestone, bluish gray, very oolitic, very fossiliferous. | 2 |
| Partially covered interval; probably limestone in lower 4 feet and green shale in upper 2 feet. | 6 |
| Limestone, bluish gray, oolitic, hard; highly fossiliferous, containing <u>Pentacrinus</u> sp., and bryozoans. | 4 |
| | <hr/> 305 |
| Gypsum Spring formation. | |

The "lower Sundance" contains abundant fossils of Late Jurassic age and is correlated with the upper part of the Twin Creek limestone and the Preuss sandstone of southeastern Idaho (Imlay, 1947, Table 1). The contact between the "lower" and "upper" Sundance is placed at the base of the lowermost glauconitic bed, commonly a coarse-grained conglomeratic limestone, in the sequence.

"Upper Sundance"

The "upper Sundance" is the glauconitic upper part of the Sundance strata in the Wind River Basin. In the mapped area it crops out on the Dubois anticline and in the vicinity of the EA Ranch. A detailed section of the formation was measured and described on the west side of Little Horse Creek opposite the Sinclair-Wyoming Oil Company Dubois Unit No. 1 well, NE $\frac{1}{4}$ sec. 11, T. 42 N., R. 107 W., where it is 130 feet thick (Love, et al., 1947, p. 8). The formation consists chiefly of green to gray-green fine- to coarse-grained slabby and thin-bedded highly glauconitic sandstone and greensand. The lower 30 feet contains some 3- to 5-foot beds of ledgy gray conglomeratic limestone with pebbles as much as $\frac{1}{2}$ inch in diameter and abundant coarse sand grains. The limestones are in part highly fossiliferous and some may be classed as coquinas. The sandstone and greensand are moderately soft, porous, and friable, depending on the amount of calcareous cement present. The formation is ledgy and the soft sandstone weathers to slopes.

Section of "Upper Sundance" in sec. 11, T. 42 N., R. 107 W.

(Measured by Love, et al., 1947, p. 8)

| | Feet |
|--|------------|
| Morrison formation. | |
| "Upper Sundance": | |
| Sandstone, grayish green, limy, medium-grained, soft to hard, slabby, with some pink grains and a moderate amount of emerald-green glauconite in rounded grains. | 20 |
| Sandstone, grayish green, very limy, hard, coarse-grained, glauconitic. Upper 2 feet is a sandy limestone with sporadic small limestone pebbles. | 10 |
| Sandstone or greensand, green, coarse-grained, highly glauconitic; abundant dark greenish gray shale in upper part. | 10 |
| Sandstone, grayish green, glauconitic, coarse-grained, slabby. | 2 |
| Greensand, green, medium-grained; a thin sandy limestone 40 feet above base. | 57 |
| Limestone, gray, hard, glauconitic, highly fossiliferous. | 4 |
| Greensand, green, fine-grained, limy. | 5 |
| Limestone, gray, very conglomeratic and fossiliferous. Pebbles as much as $\frac{1}{2}$ inch in diameter in upper part. | 3 |
| Greensand, green; very glauconitic in upper half; shaly near base; partly covered. | 14 |
| Limestone, gray, very conglomeratic; some pink and pale green rounded grains; slightly oolitic near top. | 5 |
| | <u>130</u> |
| "Lower Sundance". | |

The "upper Sundance" is of Late Jurassic age. The contact between it and the overlying Cloverly-Morrison sequence is marked by a change from glauconitic sediments below to nonglauconitic beds above. The overlying Cloverly-Morrison rocks are commonly red in contrast to the gray-green colors below.

Nonmarine Upper Jurassic and Lower Cretaceous rocks

Cloverly and Morrison formations, undivided

The Morrison formation was first named and defined by Eldridge (Emmons, et al., 1896, p. 60-62) from exposures near the town of Morrison, Colorado. The name had already been used by Cross (1894, p. 2). The formation included a series of green, drab, or gray marls, sandstone, and limestone with abundant dinosaur remains and was overlain disconformably by the basal conglomeratic bed of the Dakota sandstone (Cretaceous) and underlain disconformably by a "...brown and pink sandstone closing the Trias." The type section has been revised at various times, most recently by Waldschmidt and Leroy (1944) who divided the sequence into several units and included the brown and pink sandstone mentioned above as the basal Morrison sandstone. This sandstone may possibly contain some equivalents of the Sundance formation. The name Morrison has gained wide acceptance throughout a large part of Wyoming and the Rocky Mountains.

The Cloverly formation was first described by Darton (1904, p. 398-399) from Cloverly, a former post office on the east side of the Bighorn Basin, Wyoming, to include a basal, locally conglomeratic sandstone and an upper shale sequence. Darton correlated the basal sandstone with the Lakota sandstone and the overlying shale with the Fuson shale of the Black Hills. Later Darton (1906, p. 50) referred to the Cloverly formation as being representative of the Dakota sandstone.

Regional studies of the Cloverly and Morrison formations have been made in the Wind River Basin (Love, et al., 1945a) but no consistent basis for subdivision was found. Conglomeratic beds, some of which are probably equivalent to the basal beds of the Cloverly formation as it is defined in other regions, occur locally within the sequence. Where present at the base, they provide a mappable contact in some areas in the basin, but in other areas, including the Du Noir area, where no conglomerates are present, the two formations are mapped together as a single unit. Throughout the basin, however, a quartz crystal sandstone zone occurs 100 to 200 feet above the top of the "upper Sundance" and may mark the base of the Cloverly formation. More data are needed, however, before the true relationships of the Morrison and Cloverly sequences in this region are known.

In the Du Noir area the Cloverly and Morrison formations, undivided, are underlain by the "upper Sundance" and overlain by the Thermopolis shale. A composite section of the sequence was measured on the Dubois anticline and in the vicinity of the EA Ranch, the total thickness being 539 feet (Love, et al., 1947, p. 7-8). It can be divided into three more or less distinctive lithologic units. The lower 186 feet is characterized by variegated red, purple, gray, blue, and green claystone, shale, and siltstone, interbedded with gray to white silty fine- to coarse-grained lenticular sandstone that locally becomes yellowish buff due to the presence of ferruginous material. The conspicuous claystone beds commonly contain layers of hard limestone nodules. Highly polished pebbles as much as 2 inches in diameter, chiefly of chert, occur throughout and are thought by some geologists to be gastroliths. A few dinosaur bones were observed. The overlying 193 feet is also characterized chiefly by variegated claystone and gray to white sandstone, but the sandstone is sparkly and clean. The basal sandstone of this sequence is locally conglomeratic and may represent the base of the Cloverly formation. The upper 60 feet of claystone in the middle unit is sometimes referred to as the "lilac zone" because of its distinctive color. Because of the predominance of soft plastic claystone in both the lower and middle units they are readily susceptible to landsliding and many local slumps have occurred in them, particularly on the Dubois anticline and in the vicinity of the EA Ranch.

The upper 160 feet, commonly referred to as the "Rusty beds" member of the Cloverly formation, offers sharp contrast to the underlying units and was consequently mapped as an individual unit. It is comprised of resistant gray, olive drab, brown, and black fine-grained thin-bedded to platy sandstone and siltstone interbedded with a minor amount of black fissile shale. Bedding surfaces have abundant fucoidal markings. The basal bed is commonly a gray and white massive to slabby hard sandstone 5 to 10 feet in thickness which forms a conspicuous ledge. The name "Rusty beds" was originated by Washburne (1908, p. 350) to apply to the lowermost bed of the Colorado formation in the Bighorn Basin and refers to the distinctive rusty brown weathering color of most of the outcrops. The relationship between the "Rusty beds" in the Bighorn Basin to the "Rusty beds" in the Wind River Basin are not adequately known.

Composite section of Cloverly and Morrison formations, undivided,
in secs. 1 and 12, T. 42 N., R. 107 W., and sec. 4, T. 42 N., R. 106 W.

(Measured by Love, et al., 1947, p. 7-8)

Feet

Thermopolis shale.

Cloverly and Morrison formations, undivided:

"Rusty beds" member of Cloverly formation:

| | |
|--|-----|
| Sandstone, gray, weathering rusty brown, fine-grained, hard, thin-bedded, highly fucoidal; interbedded with thin black shale. At a point 35 feet above the base there are 6 feet of black laminated shale overlain by 6 inches of sandstone, then 6 feet of black laminated shale. | 57 |
| Siltstone, black, hard, shaly from 5 to 8 feet above base; minor amounts of interbedded sandstones. | 20 |
| Sandstone, gray, weathering rusty; thin-bedded in lower part; slightly shaly near top. | 10 |
| Shale, brown to black; thin interbedded sandstone and siltstone. | 10 |
| Sandstone, gray, weathering brown, fine-grained, hard, thick-bedded. | 5 |
| Partly covered interval. Some exposures of sandstone, gray, weathering rusty, thin-bedded, fine-grained, highly fucoidal; interbedded with minor amounts of dark gray shale. | 30 |
| Covered interval. | 28 |
| Lower part of Cloverly and Morrison formations, undivided. | |
| Claystone, variegated, gray, light red, with lilac zone in upper 60 feet. Partly covered. | 155 |
| Sandstone, gray, medium-grained, sparkly, clean; numerous pink minerals. | 10 |
| Claystone, variegated, gray, red, and purple; largely covered. | 20 |
| Sandstone, gray, coarse-grained, sparkly, clean; numerous pink minerals. A quarter of a mile east along strike this unit contains chert pebble conglomerates. | 8 |

| | |
|---|------------|
| Claystone, red and purple, lavender in upper 3 ft. | Feet 16 |
| Sandstone, dark gray, with prominent yellowish layers, soft, silty and clayey; contains numerous polished pebbles. | 6 |
| Shale, dark gray, laminated; a thin sandstone in middle. | 4 |
| Sandstone, white, medium-grained, limy; sparse pink grains. | 1 |
| Siltstone and sandstone, grayish green to dark gray, shaly, hard; contains dinosaur bones. | 13 |
| Sandstone, gray, lenticular; contains variegated claystone lenses and dinosaur bones. Sandstone is soft in lower part, hard in upper part. | 24 |
| Claystone, red, blocky; numerous sandstone lenses, more abundant near top. | 7 |
| Sandstone, greenish gray, lenticular, fine-grained, variegated claystone lenses. | 11 |
| Claystone, variegated red, blue, green, and gray, silty; contains numerous thin hard sandstone lenses, layers of limestone nodules, and a few polished pebbles. | 92 |
| Sandstone, greenish gray; very lenticular; limy, medium- to coarse-grained. | 4 |
| Claystone, red, sandy, hard. | 3 |
| Siltstone, red, hard, with some claystone and sandstone near top. | 5 |
| | <hr/> 539 |
| "Upper Sundance." | |

The Morrison and Cloverly formations are continental in origin; the former is Late Jurassic and the latter Early Cretaceous in age. In central Wyoming the sequence locally contains abundant fresh water mollusks, ostracodes, and charaphyte oogonia in addition to dinosaur remains. The Morrison formation has yielded dinosaurs of Upper Jurassic age, most notably from Como Bluff in southeastern Wyoming. Fresh water mollusks of Early Cretaceous age have been found in both the "Rusty beds" and the variegated claystone zone directly beneath the "Rusty beds" at some localities in the Wind River Basin (Love, et al., 1945a) and from fresh water limestones in the above mentioned variegated beds on Bacon Ridge to the west (Love, et al., 1951a). In the western part of the Wind River Basin microfossils, ostracodes and charaphyte oogonia, have proved to be the most useful criteria for distinguishing Upper Jurassic from Lower Cretaceous beds (Peck, 1937, 1941; Peck and Reker, 1948). Peck (personal communication) has identified microfossils from red zones just above the top of the "upper Sundance" on the Dubois anticline as being Late Jurassic in age.

The contact between the "Rusty beds" and the overlying Thermopolis shale is rarely well exposed. It is marked by a change from olive drab and gray-green thin-bedded sandstone interbedded with a minor amount of black shale below to predominantly black laminated shale above. The lower part of the Thermopolis shale, however, may in places contain thin stringers of sandstone similar to that in the "Rusty beds." The contact is usually also marked by a conspicuous topographic change from ledges below to weathered slopes above.

Cretaceous system

Thermopolis shale

The Thermopolis shale was named and described by Lupton (1916, p. 168) from exposures in the Bighorn Basin near Thermopolis, Wyoming, where it is about 700 feet thick and consists predominantly of shale with a number of lenticular sandstone beds, the most persistent being the Muddy sandstone occurring from 210 to 330 feet above the base. The shale is underlain by the Cloverly formation (Greybull sandstone member) and overlain by the Mowry shale. In the Du Noir area and throughout much of the Wind River Basin the Thermopolis shale consists of three members, an upper and lower black shale member separated by a middle sandstone member referred to as the Muddy sandstone. The contact between the upper black shale member and the overlying Mowry shale is everywhere difficult to determine due to lithologic similarities, gradational nature and general poor exposures. For these reasons the upper member is combined with the Mowry shale for stratigraphic discussion and geologic mapping purposes, and will not be treated in this report as a part of the Thermopolis shale even though it is most probably correlative with the upper part of the formation at the type section. The Muddy sandstone was mapped as a separate unit.

Within the mapped area the Thermopolis shale crops out on the complexly folded southwest flank of the Dubois anticlinal complex and forms limited exposures in the vicinity of the EA Ranch and just east of the Stanolind Oil and Gas Company Dubois Unit No. 2 well. A composite section was measured on the flanks of the Dubois anticline (Love, et al., 1947, p. 7). The lower black shale member is 136 feet thick and consists of black soft laminated shales with numerous ferruginous and dahlite concretions. The concretions, where exposed, readily weather to small angular fragments which are scattered over the shale slopes. The Muddy sandstone member, here considered as the upper member of the Thermopolis shale for discussion and geologic mapping purposes, is 34 feet thick and consists chiefly of gray, brown-weathering, medium- to coarse-grained thin-bedded sandstone with a minor amount of black to brown sandy shale. Much of the sandstone is highly fucoidal and resembles that of the "Rusty beds" of the Cloverly formation to some extent. The upper 2-foot sandstone is commonly conglomeratic with small rounded pebbles and granules, and some black grains that may be phosphatic. A few fish teeth are also present in this bed. The Muddy sandstone usually forms ledges while the underlying shale forms soft smooth slopes.

Composite section of Thermopolis shale in secs. 1 & 12, T. 42 N., R. 107 W.

(Measured by Love, et al., 1947, p. 7)

Feet

Mowry shale:

Thermopolis shale:

Muddy sandstone member:

Sandstone, gray, weathering brown, coarse-grained,
conglomeratic; contains small pebbles and black grains
that may be phosphatic; a few fish teeth present. 2

Shale, black to brown, sandy. 4

Sandstone, gray, weathering brown, medium-grained,
fucoidal. 3

Sandstone, gray, weathering brown, thin-bedded; black
silty shale partings. 11

Sandstone, gray, weathering brown, moderately thin-
bedded, crossbedded, fucoidal, medium-grained,
with numerous dark minerals, non-calcareous. 14

Lower black shale member.

Shale, black, soft, laminated; numerous ferruginous con-
cretions, and dahlite concretions. 136

170

"Rusty beds" member of Cloverly formation.

No fossils, except fish teeth, were found in the formation. Until recently the base of the Muddy sandstone was believed to mark the base of the Upper Cretaceous in central Wyoming (Love, et al., 1945a). It has now been established, however, that the Mowry shale is of Early Cretaceous age (Cobban and Reeside, 1951); thus the Thermopolis shale is both underlain and overlain by strata of known Early Cretaceous age.

Mowry shale

The term "Mowrie beds" was applied by Darton (1904, p. 394-401) on the east side of the Bighorn Mountains northwest of Buffalo, Wyoming, to include about 150 feet of hard light gray shale and thin-bedded sandstone with abundant fish scales, lying within the Benton formation. The Mowry shale, now considered as a formation, is widespread throughout Wyoming.

In the Wind River Basin the Mowry shale is overlain by the Frontier formation and underlain by the Muddy sandstone member of the Thermopolis shale and in its lower part most probably contains equivalents of the upper part of the Thermopolis shale as that formation is defined in the Bighorn Basin. In the Du Noir area the Mowry shale crops out on the flanks of the Dubois anticline and is overturned northwest of the EA Ranch. A complete section was measured on the east side of the Little Horse Creek road in sec. 1, T. 42 N., R. 107 W. by Love, et al., (1947, p. 6-7). At this locality it is 717 feet thick. The formation consists predominantly of shale with thin beds of bentonite and sandstone. In the lower part the shale is soft, black, and finely laminated while in the upper part it is mostly gray, brown, and black, hard, siliceous, blocky and distinctive silver gray weathering. The middle one-third of the formation is poorly exposed at the locality where the section was measured, and contains the transitional zone between black shale below and siliceous shale above. In this interval is the contact between the Mowry shale and Thermopolis shale as these formations are defined in other areas. Bentonite beds, ranging from a few inches to as much as 8 feet in thickness, occur throughout the formation. Most are impure and contain thin black shale partings. Sandstone is generally confined to the upper part of the formation and is characteristically gray-green fine- to medium-grained, silty, siliceous, and hard. Beds are 2 to 4 feet thick and commonly have a "salt and pepper" appearance due to the abundance of dark grains. Fish scales occur abundantly in the siliceous shale and form one of the most distinguishing features of the formation. A few fish teeth are also present. The weathered

slopes of the Mowry shale are characteristically gray and dark gray banded because of the alternation of black shale and light-colored bentonite and siliceous shale (figure 9). The siliceous beds usually form ledges.

Section of Mowry shale in sec. 1, T. 42 N., R. 107 W.

(Measured by Love, et al., 1947, p. 6-7)

| | Feet |
|--|------|
| Frontier formation. | |
| Mowry shale: | |
| Shale, black, laminated; thin yellowish gray siltstone, and fine-grained sandstone partings. | 27 |
| Sandstone, green, fine to medium-grained, slabby, hard, with silty and shaly partings. | 3 |
| Bentonite, pale yellowish green, with a few black shale partings. | 3 |
| Shale, black, laminated, slightly carbonaceous; thin bentonite beds near base. | 31 |
| Sandstone, dull green, fine to medium-grained, slabby, hard, silty at base; some shale partings. | 20 |
| Bentonite, shaly. | 4 |
| Shale, yellowish brown to silvery gray, hard. | 5 |
| Bentonite, pale yellow. | 2 |
| Shale, yellowish brown to silvery gray, hard, containing sparse poor pelecypod casts and molds. | 2 |
| Bentonite with interbedded black shale. | 4 |
| Shale, dark gray, weathering silver gray, siliceous, hard, splintery, containing fish scales. | 24 |
| Sandstone, dull greenish gray to buff; silty layers; numerous dark grains; numerous fish scales and teeth. | 4 |
| Bentonite, pale yellow; a thin black shale at top. | 2 |
| Sandstone, dull greenish gray to buff; silty layers; numerous dark grains and fucoidal markings. | 2 |
| Shale, black, bentonitic, with 0.5 feet of bentonite at base and a thin greenish gray sandstone in middle. | 5 |
| Sandstone, dull greenish gray to buff; silty layers; numerous dark grains; fish teeth and scales. | 2 |

| | Feet |
|--|------------|
| Shale, black to brown, weathering gray, hard, silty, with a few poorly preserved lucinoid type pelecypods. A shaly white bentonite 0.5 feet thick is present 15 feet above base, and 90 feet above base are several thin bentonites, above which the shale is harder and more siliceous. | 108 |
| Covered interval. | 245 |
| Shale, black, soft, laminated; thin bentonite layers throughout sequence but less abundant in upper part. | 113 |
| Bentonite, yellow, hard, with coarser tuffaceous material. | 6 |
| Shale, black, soft, with numerous soft yellow bentonite beds. | 73 |
| Shale, black, bentonitic, with a few ironstone concretions. | 12 |
| Bentonite, gray; thin hard white tuffaceous beds in upper part and black shales in lower part. A few bone fragments present. | 8 |
| Shale, black, bentonitic; a thin yellowish green bentonite 2 feet above base. | 12 |
| | <u>717</u> |
| Muddy sandstone member of Thermopolis shale. | |



Figure 9. Frontier formation (Kf) and Mowry shale (Kmr) on east side of Little Horse Creek road, NW $\frac{1}{4}$ sec. 1., T. 42 N., R. 107W.

No fossils of value in dating the formation were found in the Du Noir area. Thin-shelled pelecypods and a few flattened ammonites have been collected at some localities in the Wind River Basin (Thompson, et al., 1949). Recent paleontologic studies of ammonites occurring in the Mowry shale and its equivalents at many widely scattered areas in Colorado, Wyoming, and Montana by Cobban and Reeside (1951, p. 1892) have proved a Early Cretaceous age for the formation.

The contact between the Mowry shale and the overlying Frontier formation, which coincides with the boundary between the Lower and Upper Cretaceous in this region, is marked by a change from black shale below to tan, gray, and yellowish sandstone above.

Frontier formation

The Frontier formation was named and described by Knight (1902, p. 721) from exposures near the town of Kemmerer in southwestern Wyoming. A comprehensive historical treatment of its application throughout Wyoming and adjacent states is presented by Cobban and Reeside (1952). A detailed surface and subsurface study of the formation in the Wind River Basin has been published (Thompson, et al., 1949). Within the basin the Frontier formation is predominantly a sandstone and shale sequence overlain by the Cody shale and underlain by the Mowry shale. It is an important oil and gas producing sequence in many fields in Wyoming.

In the Du Noir area the Frontier formation crops out along Little Horse Creek and at some places northwest of the EA Ranch. A well exposed section was measured in sec. 1., T. 42 N., R. 107 W., and sec. 36, T. 43 N., R. 107 W. where it is 752 feet thick (Love, et al., 1947, p. 4-6). The formation consists chiefly of an alternating succession of sandstone and shale with minor amounts of bentonite, tuff, carbonaceous shale, lignite, and coal. The sandstone beds, which range from a few inches to as much as 65 feet in thickness, are white, gray, tan to yellowish, and brown, fine- to coarse-grained, and commonly crossbedded. Some are hard and tuffaceous, while others are soft and moderately porous and friable. Most contain abundant dark minerals and some near the top are glauconitic. The shale is generally black and finely laminated with minor amounts of bentonite and carbonaceous material. Bentonite occurs mainly in the lower half of the formation as beds as much as 14 feet thick. It is generally sandy and shaly, although a few beds appear to be pure. Coal and lignite beds which are also confined chiefly to the lower part, are rarely more than 3 feet thick but have been mined for local use. The coal is, for the most part, of subbituminous grade and none is being mined at the present time in the area. The sandstone at the top of the formation in some localities contains shale with numerous black and brown well rounded flat chert pebbles; these pebbles, however, also occur in the basal beds of the Cody shale. The sandstone ^{in the} formation is quite resistant and forms ledges.

Section of Frontier formation in sec. 1, T. 42 N., R. 107 W.

(Measured by Love, et al., 1947, p. 4-6)

| | Feet |
|---|------|
| Cody shale. | |
| Frontier formation: | |
| Covered interval forming dip slope and supporting a heavy growth of trees. One-quarter mile east along strike this zone consists of sandstone containing abundant pelecypods and gastropods overlain by brownish gray shale containing numerous flat black chert pebbles. Niobrara fauna (USGS Loc. 19534): <u>Ostrea anomioides</u> Meek, <u>Camptonectes</u> n. sp., <u>Tellina?</u> cf. <u>T. subalata</u> Meek, <u>Cardium curtum</u> Meek and Hayden. | 20 |
| Sandstone, gray to brown, medium-grained, limy, hard, petroliferous. A highly limy zone 5 feet thick near the center of the unit and one 10 feet thick near the top contain an abundant and well-preserved fauna of pelecypods, bizarre gastropods, echinoids, and ammonites. Niobrara fauna (USGS Loc. 19537): <u>Inoceramus deformis</u> Meek, <u>Ostrea anomioides</u> Meek, <u>Exogyra</u> sp., <u>Camptonectes</u> n. sp., <u>Cardium curtum</u> Meek and Hayden, <u>Cardium pauperculum</u> Meek, <u>Tellina</u> n. sp., <u>Cymbophora</u> cf. <u>C. arenaria</u> Meek, <u>Gyrodes</u> sp., <u>Pugnellus fusiformis</u> Meek, <u>Pyropsis?</u> n. sp., <u>Volutoderma</u> sp., <u>Placentoceras planum</u> Hyatt, gastropods, several undetermined new forms. | 30 |
| Partly covered interval. A few gray sandstone ledges visible. | 40 |
| Shale, black to brown, laminated. | 15 |
| Sandstone, gray; hard, fine-grained, limy near top. Abundant pelecypods present. Poorly exposed. Niobrara fauna (USGS Loc. 19538): <u>Ostrea sannionis</u> White. | 20 |
| Shale, black to brown; sandy in lower part. | 6 |
| Partly covered interval. A few gray glauconitic sandstone ledges visible. | 20 |
| Sandstone, light gray to yellowish gray, highly glauconitic, limy, crossbedded, very fossiliferous with abundant pelecypods and a few ammonites. Niobrara fauna (USGS Loc. 19535): " <u>Gervillia</u> " <u>propleura</u> Meek, <u>Pteria gastroides</u> Meek, <u>Inoceramus</u> sp., <u>Cardium pauperculum</u> Meek. | 11 |

| | |
|---|------------|
| Sandstone, gray, fine-grained, soft, very shaly. | Feet 16 |
| Shale, brownish gray, sandy. | 1 |
| Sandstone, gray, medium-grained, limy; abundant rounded grains of glauconite. | 6 |
| Shale, black, laminated; yellowish fine-grained slightly carbonaceous sandstones in upper 5 feet. | 25 |
| Sandstone, gray, fine-grained, limy, crossbedded, soft in lower half. | 6 |
| Shale, brown, sandy, soft, with a carbonaceous layer near middle. | 5 |
| Sandstone, yellowish brown, fine-grained, limy, hard, slightly carbonaceous. | 11 |
| Covered interval. Lower part probably dark gray carbonaceous shale and upper part probably black fissile shale. | 44 |
| Lignite, black to brown, shaly. | 1 |
| Sandstone, yellowish brown, medium-grained, cross-bedded, limy, locally with ironstone concretions. | 6 |
| Shale, black, laminated. | 6 |
| Sandstone, yellowish brown, medium-grained, cross-bedded, limy, locally with ironstone concretions. | 9 |
| Shale, black, laminated; 0.2 feet of greenish yellow bentonite at top. | 1 |
| Sandstone, yellowish brown, fine-grained, limy, slabby, finely crossbedded. | 4 |
| Shale, black in lower part; brownish near top; laminated; moderately sandy near middle. | 16 |
| Sandstone, yellowish gray, medium to fine-grained, inter-laminated black shale near middle. | 65 |
| Shale, black, laminated in lower 40 feet; abundant secondary gypsum. | 45 |
| Sandstone, yellowish gray to white, coarse-grained, soft. | 4 |

| | Feet |
|--|------|
| Shale, dark gray, sandy, with thin lignite beds. | 2 |
| Sandstone, yellowish gray, fine-grained, soft in lower part; coarser and somewhat shaly near top. | 9 |
| Shale, black, laminated. | 4 |
| Sandstone, yellowish gray, fine-grained, soft. | 1 |
| Shale, black, laminated, poorly exposed. | 20 |
| Bentonite, yellow; abundant secondary gypsum. | 5 |
| Shale, black, laminated. | 2 |
| Sandstone, yellowish gray, soft, fine-grained, bentonitic. | 3 |
| Shale, greenish gray; soft and bentonitic in lower 3 feet, then 2 inches of soft yellowish gray sandstone overlain by black laminated shale, sandy near top. | 5 |
| Lignite in lower half; carbonaceous gray siltstone in upper half. | 1 |
| Shale, black and very lignitic near base; gray and silty in middle and upper parts. | 7 |
| Bentonite, gray, sandy. | 10 |
| Sandstone, brownish gray, very coarse-grained, very limy; soft in lower 10 feet; abundant dark minerals. | 27 |
| Shale, carbonaceous, with thin coal layers. | 2 |
| Bentonite, white, with coarser tuff beds. | 12 |
| Coal. This bed has been mined for local use. | 3 |
| Shale, black to brown, very sandy. | 4 |
| Sandstone, white to yellowish, crossbedded, fine to medium-grained, nodular; with numerous dark minerals; with thin carbonaceous shale beds. | 10 |
| Shale, black, fine-grained, soft; bentonitic in lower half; slightly sandy, brown, hard, silty in upper half; thin bentonite at top. | 15 |
| Sandstone, gray to yellowish, soft; carbonaceous and bentonitic near base; abundant dark minerals. | 11 |

| | Feet |
|--|------|
| Shale, black, laminated. | 2 |
| Coal, black, soft. | 1 |
| Sandstone, brownish gray, fine-grained, silty to shaly, soft. | 3 |
| Shale, brown to black; bentonitic in lower 5 feet. | 15 |
| Sandstone, gray to brown, weathering black, hard, crossbedded, slightly limy; numerous dark minerals. | 2 |
| Shale, black, laminated, very bentonitic. Abundance of bentonite makes weathered slopes appear white. | 11 |
| Lignite and carbonaceous shale; sandstone lenses in middle of unit; more nearly pure lignite near base and top. | 6 |
| Bentonite, yellow; shaly in lower part. | 6 |
| Tuff or very fine-grained tuffaceous sandstone, gray, with interbedded bentonite. | 3 |
| Bentonite, gray. | 9 |
| Bentonite, gray; a highly carbonaceous brown tuff 1.5 feet thick, poorly preserved plant remains in lower part. | 14 |
| Tuff, brown, highly carbonaceous; abundant poorly preserved plant remains. | 1 |
| Bentonite, white to yellowish, interbedded with coarser bentonitic tuffs containing plant remains. | 7 |
| Shale, black, bentonitic, with thin ironstone zone at top. | 3 |
| Sandstone, dark gray, very coarse-grained, angular, very hard, tuffaceous, with abundant dark minerals and glassy fragments resembling shards. | 2 |
| Bentonite, gray, very impure, with a thin coarse-grained sandstone containing wood and bone fragments at base of unit. | 3 |
| Lignite, and dark gray carbonaceous shale. | 3 |

| | Feet |
|---|------------|
| Sandstone, gray, coarse-grained, angular; soft in lower part; hard in upper 15 feet; cliff-forming; a few thin carbonaceous shale partings; abundant dark minerals. | 18 |
| Lignite, black, interbedded with black carbonaceous shale. | 2 |
| Bentonite, gray. | 2 |
| Sandstone, white, with thin shale partings and thin ferruginous sandstone containing shard-like fragments. | 2 |
| Shale, black, hard, bentonitic. | 8 |
| Sandstone, gray to yellowish, coarse to medium-grained, hard, lenticular; numerous thin shale partings; abundant dark minerals. | 16 |
| Shale, black to brown, laminated. | 7 |
| Sandstone, white to yellow, coarse-grained, crossbedded, cliff-forming; sandy gray shale partings. | 10 |
| Sandstone, gray, medium-grained, moderately soft; numerous black shale partings. | 8 |
| Sandstone, tan to yellowish, fine-grained, moderately hard; numerous dark minerals, and numerous brown glossy fish scales. | 2 |
| | <u>752</u> |
| Mowry shale. | |

The sandstones in the upper part of the Frontier formation, particularly those at the top, are locally very fossiliferous. The uppermost sandstone contains a varied fauna of pelecypods, gastropods, echinoids, and ammonites of early Niobrara age (W. A. Cobban, personal communication, 1951). The lower part of the formation, however, is probably of Carlile age.

There is a sharp lithologic break between the Frontier formation and the overlying Cody shale with a change from resistant sandstone below to soft black shale above. There is also a conspicuous topographic change, with the upper Frontier sandstone usually forming a dip slope.

Cody shale

The Cody shale, which was named and described by Lupton (1916, p. 171) from the town of Cody in the western part of the Bighorn Basin, is widely distributed throughout central Wyoming where it consists of about 4,000 feet of marine shale and sandstone. It is underlain by the Frontier formation and generally overlain by the Mesaverde formation. In the Du Noir area, however, due to overlapping Tertiary rocks only the lower 3,000 feet of the formation is exposed at the surface; no younger Upper Cretaceous rocks are present. A broad poorly exposed outcrop belt extends southeastward from the upper end of Little Horse Creek valley to the vicinity of the EA Ranch. The upper part of the formation is further cut out by faulting along the north side of this outcrop belt.

The best exposures are present on the east side of the Little Horse Creek road in sec. 36, T. 43 N., R. 107 W. (figure 10). A section was measured at this locality by Love, et al., (1947, p. 3-4) who reported 3,000 feet of Cody strata present but only the lower 1,500 feet sufficiently well exposed to be described in detail. The upper half of the formation is mostly obscured by debris from the overlying Tertiary conglomerate. The lowermost 1,080 feet consist chiefly of brownish gray soft laminated shale with a few thin sandy zones. The overlying 429 feet consist mainly of shale but also contain an increasing proportion of greenish gray medium- to coarse-grained cross-bedded to slabby sandstone. The uppermost 1,500 feet, of which the lithology is imperfectly known, probably contain shale and sandstone in about equal amounts. Several ledgy sandstone beds can be observed in the slopes; some of these sandstones are highly glauconitic. The basal bed of the formation on the west side of Little Horse Creek in the S $\frac{1}{2}$ sec. 26, T. 43 N., R. 107 W. is a shale zone which contains abundant well rounded flat chert pebbles that weather out in profusion on the slopes.



Figure 10. Cody shale (Kc) overlain unconformably by Wind River formation (Twdr) on east side of Little Horse Creek road, sec. 36, T. 43 N., R. 107 W.

Section of Cody shale in sec. 36, T. 43 N., R. 107 W.

(Measured by Love, et al., 1947, p. 3-4)

| | Feet |
|--|--------------|
| Wind River formation (lower Eocene). | |
| Cody shale: | |
| Shale, gray, soft, poorly exposed. Top of shale is obscured by landslide debris. No sandstone of the Mesaverde formation was found in the area, and the Cody shale is apparently overlain by Eocene rocks. | 1500+ |
| Sandstone, greenish gray, medium-grained, soft, crossbedded; abundant dark minerals; interbedded with equal amounts of gray shale. | 43 |
| Sandstone, greenish gray, medium-grained, limy, hard, crossbedded, with numerous dark minerals. | 2 |
| Shale, dark gray, laminated, with a few thin layers of greenish gray sandstone. | 102 |
| Sandstone, greenish gray, coarse-grained, slabby; interbedded dark gray shale. | 28 |
| Sandstone, greenish gray, coarse-grained, angular; numerous dark minerals, crossbedded; some shale partings. | 65 |
| Sandstone, greenish gray, coarse-grained, angular; ledgy near base; shaly in upper part; poorly preserved pelecypods in basal 2 feet. Niobrara(?) fauna (USGS Loc. 19539): <u>Inoceramus</u> sp., <u>Cymbophora</u> sp., <u>Ostrea</u> sp. | 15 |
| Shale, brownish gray, laminated; sandy in lower 50 feet; 6-inch sandstone, fine to medium-grained, carbonaceous, with sparse pelecypods, 50 feet above base. | 172 |
| Sandstone, light greenish gray, coarse-grained, angular, limy; numerous dark minerals. | 2 |
| Shale, brownish gray, laminated, soft; some sandy zones. | 1080 |
| | <u>3009+</u> |
| Frontier formation. | |

The Cody shale is sporadically fossiliferous. In 1949 J. D. Love, accompanied by the writer, collected the following fossils, which were identified by W. A. Cobban, approximately 1,500 feet above the base of the formation: Inoceramus stantoni Sokolow, Baculites asper Morton, Baculites codyensis Reeside, Baculites? n. sp., and Scaphites vermiformis Meek and Hayden var. binneyi Reeside. This assemblage is of late middle Niobrara age. W. A. Cobban and J. B. Reeside visited the section in the summer of 1951 and collected fossils of an earlier Niobrara age in the lower part of the formation. No fossils were collected from the uppermost 1,500 feet of the Cody shale, but regional relationships in the Wind River Basin (Yenne and Phipps, 1954) suggest that the age probably ranges from late Niobrara (uppermost Colorado) into possibly Telegraph Creek and Eagle ages (lower Montana). In the Jackson Hole region to the west the uppermost marine Cretaceous strata are of middle Niobrara age (Love, et al., 1951b), thus indicating that the withdrawal of the Cretaceous seas was from west to east.

The top of the Cody shale within the mapped area is everywhere delimited by overlapping Tertiary strata or structural features.

Tertiary system

Paleocene(~~X~~) series

Fort Union(?) formation

The presence of Paleocene rocks in the Du Noir area has not been fully substantiated. The rocks here referred to the Fort Union(?) formation crop out only locally in the Dubois anticlinal complex and have been strongly folded and faulted (figure 11). They occur associated with Cretaceous rocks and nowhere can their relationships with other Tertiary rocks be observed. The total thickness of the sequence is not known, but as much as 50 feet is exposed west of Little Horse Creek. The Fort Union(?) formation is largely conglomeratic and made up entirely of Mesozoic rock fragments. Angular light-colored Mowry shale chips form the most conspicuous element in the conglomerate. Fragments of "upper Sundance" limestone and sandstone and Cloverly and Morrison sandstone and siltstone are also present. Red and gray siltstone and claystone is present in some places.

No fossils were found in the Fort Union(?) formation but the presence of Mesozoic rock fragments, complete absence of Paleozoic rocks, and the structural relationships of the formation suggest that this series of conglomerate siltstone, and claystone are older than those of known lower Eocene age. The Fort Union(?) strata were most probably deposited during the initial stages of folding of the anticline.



Figure 11. Fort Union(?) formation (Tfu) and Mowry shale (Kmr) strongly folded and faulted at southeastern end of Dubois anticlinal complex, NE $\frac{1}{4}$ sec. 13, T. 42 N., R. 107 W. (T on overriding block of thrust fault; Twdr, Wind River formation.)

Eocene series

Indian Meadows formation

The name Indian Meadows formation was applied by Love (1939, p. 58) to a series of interbedded red clay, shale, sandstone, and conglomerate nearly 1,000 feet thick which lie along the east side of the North Fork River, approximately 4 miles east of the southeast edge of the Du Noir area. The massive conglomerate beds, containing fragments of granite; Paleozoic limestone, dolomite, and chert; and conspicuous algal-ball limestone beds, were considered to be distinguishing lithologic features of the formation. Vertebrate fossils at the type section indicate a lowermost Eocene age, equivalent to that of the Gray Bull faunal zone in the Bighorn Basin. The close resemblance between the fine-grained strata of the Indian Meadows formation and those of the overlying Wind River formation, however, makes it impossible to differentiate the two formations in areas where they occur in juxtaposition except where there are fossils or mappable unconformities. No fossils were found in the strata assigned to the Indian Meadows formation in the Du Noir area; they have been so designated because of their conglomeratic character, similarities to the type section, and structural relationships. In the southeast portion of the mapped area where both the Indian Meadows and Wind River formations are believed to be present, they have been mapped as Wind River and Indian Meadows formations, undivided.

The Indian Meadows formation crops out along the West Fork of the Du Noir River, on the south flank of Spring Mountain, and along the Wiggins Fork River. It is probably also present on the north side of the Wind River and on the north side of the Wind Ridge fault, but at these localities cannot be distinguished from the Wind River formation (fig. 12). At the localities where the formation can be observed in contact with the underlying Paleozoic and Mesozoic rocks there is a pronounced angular unconformity of as much as 60 degrees. This is best seen along the east side of Horse Creek north of the EA Ranch (fig. 13). The thickness varies greatly from one place to another and no detailed section of the formation was measured. The maximum thickness is unknown because on the south edge of Spring Mountain the lower part is delimited by faulting and the upper part is poorly exposed, and because in the southeast portion of the mapped area the total stratigraphic interval represented by the formation could not be determined. The massive conglomerate beds attain an aggregate thickness of as much as 150 to 200 feet near the EA Ranch and along the West Fork of the Du Noir River, but the thickness diminishes rapidly northward to a wedge-edge as the formation laps up against the highlands along the south flank of the Washakie Range.



Figure 12. Outcrop of lower Eocene rocks along north side of Wind River southeast of Dubois. Wind River flows along base of cliffs.



Figure 13. Angular unconformity between Indian Meadows formation (Tim) and Chugwater formation (Tc). On east side of Horse Creek, near junction of secs. 32 and 33, T. 43 N., R. 106 W., and secs. 4 and 5, T. 42 N., R. 106 W. Top of Spring Mountain on skyline at left.

The strata assigned definitely to the Indian Meadows formation consist chiefly of red crudely stratified to massive conglomerate overlain in some places, as on the south flank of Spring Mountain, by variegated fine-grained sandstone, siltstone, claystone, and shale. The conglomerate beds are hard and indurated and form massive cliffs throughout most of their area of outcrop. They consist chiefly of subrounded boulders and cobbles of Paleozoic sandstone, limestone, dolomite, and chert as much as 6 feet in diameter in a matrix of red and gray limy coarse-grained sandstone. No Precambrian rock fragments are present in the exposures along the West Fork of the Du Noir River and on the south flank of Spring Mountain and no volcanic material was observed. The lowermost Eocene rocks along the north side of the Wind River and on the north side of the Wind Ridge fault, which probably belong to the Indian Meadows formation, consist of 10- to 20-foot beds of conglomerate interbedded with variegated fine-grained strata. These conglomerates are not as coarse as those that lie adjacent to the folded Paleozoic highlands to the north, and the boulders are not more than 2 feet in diameter. These conglomerates also contain fragments of deeply weathered granite, gneiss, and schist. At some localities along the north side of the Wind River these strata contain algal-ball limestone beds which are characteristic of the formation at the type section. Similar beds were observed at one locality on the south edge of Spring Mountain. These beds are gray and appear to be very conglomeratic, but consist almost entirely of rounded masses of limestone as much as 2 inches in diameter. The

limestone is arranged in concentric layers around a nucleus. A detailed study of these was not made by the writer, but Love (1939, p. 60) reported that the nuclei were commonly Goniobasis sp. (gastropod), clay balls, chert, limestone, arkose, shale, sandstone, and granite fragments.

The Indian Meadows strata probably formed during the active erosional period which followed the folding of the Washakie and Wind River Ranges. The red color, which characterizes much of the formation, is very similar to that of the Triassic Chugwater formation. Where the conglomerates are in direct contact with the Chugwater formation, as in the locality north of the EA Ranch, the colors are identical. The Indian Meadows formation lies horizontally upon the upturned edges of folded and eroded Paleozoic rocks along the West Fork of the Du Noir River and on both Paleozoic and Mesozoic rocks along the south flank of Spring Mountain. The formation has been involved in later thrust faulting in the southeast portion of the mapped area.

Wind River formation

The term Wind River formation is used throughout the Wind River Basin to include all of the strata of lower Eocene age with the exception of the Indian Meadows formation. A historical summary of its definition and application has been presented by Tourtelot (1948, p. 114). In the northeastern part of the basin the Wind River formation is separated into two distinct lithologic and faunal units; the Lysite member at the base and the Lost Cabin member at the top (Tourtelot, 1948, p. 114-119). Faunally, the two members are differentiated by the presence or absence of Lambdotherium, which occurs only in the Lost Cabin member. Lambdotherium-bearing strata are present in the Du Noir area, but the presence of Lysite strata has not been substantiated.

The Wind River formation is the most widespread lithologic unit in the Du Noir area and crops out extensively in the southern and central portions of the mapped area. Vertebrate fossil evidence indicates that all of the lower Eocene rocks west of Horse Creek belong in the formation. Wind River strata probably comprise the bulk of the lower Eocene rocks east of Horse Creek, but, as previously discussed, could not be differentiated from the finer-grained facies of the Indian Meadows formation. The thickness of the Wind River formation varies considerably from one locality to another because of pronounced unconformities both at the base (where not in contact with the Indian Meadows formation) and at the top. The thickest section is present in the central part of the area, where the formation crops out in an uninterrupted sequence from the Wind River north to the upper end of Little Horse Creek valley.

Five units were recognized within the formation: a lower variegated sequence, a greenish gray and drab tuffaceous sequence, a middle variegated sequence, a conglomerate sequence, and an upper variegated sequence. The lower three units are the most widespread and are best exposed along Bench Creek where they are 1,618 feet thick. The units could not be mapped, however, because of the gradational nature of their contacts. A series of generalized sections, presented on figure 14 and figure ¹⁵ ~~14a~~, shows the writer's interpretation of the relationships between the different facies of the Wind River formation and the approximate positions of fossil collections.

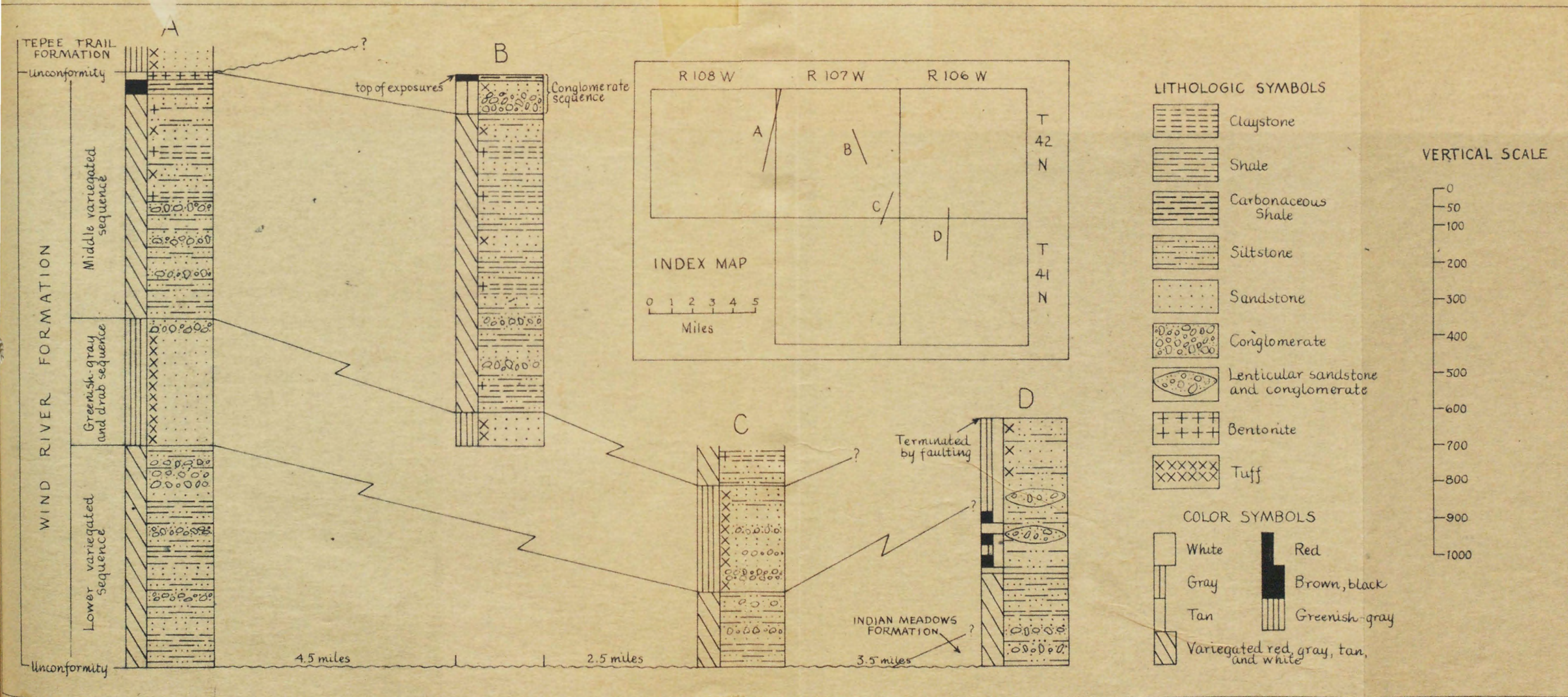


Figure 14. CHART SHOWING LATERAL VARIATION OF THE WIND RIVER FORMATION

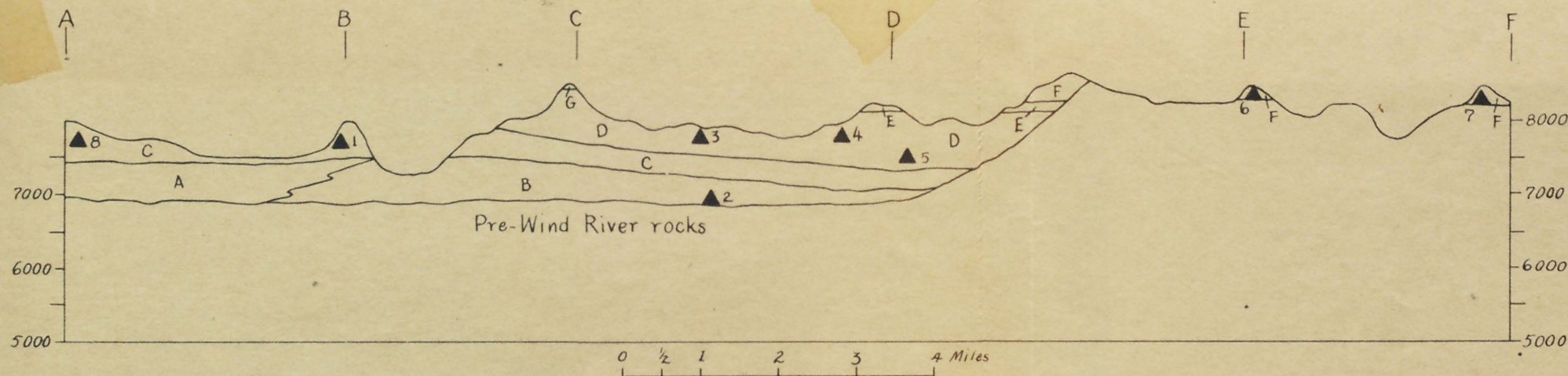


FIGURE 15

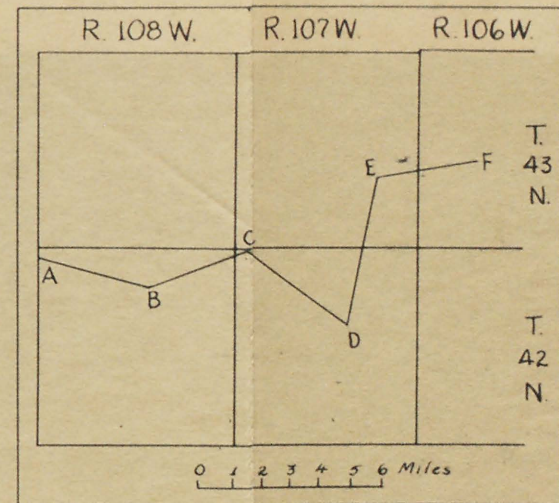
DIAGRAMMATIC CROSS SECTION SHOWING APPARENT RELATIONS OF FACIES OF WIND RIVER FORMATION

LEGEND

- A Eocene rocks, undivided
 - B Lower variegated sequence
 - C Greenish gray and drab tuffaceous sequence
 - D Middle variegated sequence
 - E Conglomerate sequence
 - F Upper variegated sequence
 - G Tepee Trail formation
 - ▲⁵ Approximate horizon of fossil collection
- } Wind River formation

FOSSIL COLLECTIONS

1. NE $\frac{1}{4}$ sec. 10, T. 42 N., R. 108 W.
Lambdotherium, *Esthenyx*, *Ectocian*,
Phenacodus, *Diacodexis*,
Hyracotherium cf. vasaccense
Age: Lost Cabin
2. N $\frac{1}{2}$ sec. 9, T. 42 N., R. 107 W.
Lambdotherium, *Heptodon*,
Cynodontomys. Age: Lost Cabin
3. SE $\frac{1}{4}$ sec. 5, T. 42 N., R. 107 W.
Hyracotherium cf. vasaccense,
Lambdotherium cf. popoagicum
Age: Lost Cabin
4. SW $\frac{1}{4}$ sec. 10, T. 42 N., R. 107 W.
Lambdotherium, *Heptodon*,
Cynodontomys. Age: Lost Cabin
5. SW $\frac{1}{4}$ sec. 14, T. 42 N., R. 107 W.
Phenacodus cf. wortmani
Age: Wasatchian
6. SE $\frac{1}{4}$ sec. 23, T. 43 N., R. 107 W.
Didymictis altidens
Age: Lost Cabin
7. NW $\frac{1}{4}$ sec. 29, T. 43 N., R. 106 W.
Paramys Age: Eocene
8. Approximate location of fossil leaf collection by Erling Dorf, and reported by him to have affinities with late Eocene to early Oligocene floras. (Dorf, 1953)



The lower variegated sequence along Bench Creek is at least 554 feet thick, with the base concealed. Westward the thickness decreases to a wedge-edge west of the mouth of the Du Noir River, where it apparently intertongues with arkosic facies of Eocene rocks, undivided (figure 15). Eastward the thickness varies considerably because of the pronounced basal unconformity. The lower variegated sequence, which forms conspicuous badlands, consists chiefly of red siltstone and shale, soft to hard buff fine-grained shaly sandstone, and white to buff cobble and pebble conglomerate. The conglomerate beds contain rounded fragments as much as 6 inches in diameter of Paleozoic rocks with a subordinate amount of Precambrian granite. Many of the shale and siltstone beds in the upper part are bentonitic and plastic. Just east of Stony Point, in the SW $\frac{1}{4}$ sec. 19, T. 42 N., R. 107 W., the basal beds are chiefly tan and white arkose interbedded with minor amounts of gray and tan siltstone and brown carbonaceous shale with black coaly partings. The arkose is composed of coarse-grained to granule-sized angular fragments of quartz and feldspar with some dark grains in a fine-grained limy matrix. In a distance of a few hundred yards east of this locality the tan and gray beds grade into redbeds. It is interesting to note that this pronounced color change coincides closely with the base of the Chugwater redbeds as the trend of that formation is projected northwestward across the Wind River from Harrison's Ranch, suggesting that much of the red sediment in the lower part of the Wind River formation was derived from the Chugwater formation.

The contact between the lower variegated sequence and the overlying greenish gray and drab sequence is gradational. The interfingering between the two units can best be seen in the high hill on the east side of Bench Creek, NE $\frac{1}{4}$ sec. 13, T. 42 N., R. 107 W. East of Horse Creek are some lenticular conglomeratic sandstone beds, which occur both in the upper part of the lower variegated sequence and the lower part of the greenish gray and drab sequence making the contact between the two units difficult to determine. These sandstones may be channel deposits.

Vertebrate fossils were found at several localities in the lower variegated sequence. A Lost Cabin age for the basal part of the unit west of Horse Creek is indicated by a collection containing Lambdotherium (coll. 2, fig. 15) obtained in the N $\frac{1}{2}$ sec. 29, T. 42 N., R. 107 W. North of the 2N Ranch, S $\frac{1}{2}$ sec. 32, T. 41 N., R. 106 W., a lower jaw of Hyracotherium cf. vasacciense of possible Lost Cabin age was collected from the base of the lower variegated sequence, suggesting that the Indian Meadows formation is not represented at the base of the lower Eocene this far westward. The following fossils were collected from the top of the sequence in the SW $\frac{1}{4}$ sec. 30, T. 42 N., R. 106 W., opposite the entrance to the Rocking Chair Ranch: lower jaw close to Paramys buccatus Cope, maxilla with three teeth of Hyracotherium cf. index (Cope), and upper and lower jaws of Hyopsodus, close to H. wortmani Osborn. The latter suggests a Lost Cabin age as does Hyracotherium cf. index (Cope), which is found associated with Lambdotherium in the Green River Basin although it has been recorded from Gray Bull (lowermost Eocene) faunas in the Bighorn Basin as well.

The greenish gray and drab tuffaceous sequence is well exposed in the high bluff on the north side of U. S. Highway 287 east of the Long Creek Inn and along both Bench and Long Creeks. It is 390 feet thick along Bench Creek, but thins eastward to 290 feet north of Dubois in the SE $\frac{1}{4}$ sec. 25, T. 42 N., R. 107 W. (fig. 15). Its stratigraphic thickness on the east side of Horse Creek (section D, fig. 14) could not be specifically determined because the upper part of the section is cut by faulting and the lower contact is not well defined. The unit consists chiefly of greenish gray, gray, and olive drab soft porous friable tuffaceous fine- to coarse-grained sandstone with minor amounts of shale, carbonaceous shale, and conglomerate. A thin section study indicates that the sandstone contains much clayey material in addition to distinct grains of quartz, plagioclase, and biotite. Both the biotite, which occurs as euhedral hexagonal flakes readily observed in a hand specimen, and the feldspar are probably of volcanic origin but the quartz appears to have been derived largely from non-volcanic sources. At the locality north of Dubois (section C, fig. 14; fig. 16) the unit contains some hard limy highly tuffaceous "cannonball" concretions as much as 4 feet in diameter. The conglomerate beds are 20 to 30 feet thick, commonly lenticular, and contain roundstones of Precambrian quartzite, granite, and schist, and Paleozoic limestone, sandstone, and chert as much as 6 inches in diameter as well as sporadic pebbles of volcanic rocks. The presence of quartzite fragments, some of which have pressure scars, is particularly significant because they have not been observed in any other Tertiary conglomerate on the north side of the Wind River. They occur in Eocene strata in some places south of the river, however. As far as is known this is



Figure 16. Exposures of a portion of the Wind River formation in SE $\frac{1}{4}$ sec. 25, T. 42 N., R. 107 W. (A, lower variegated sequence; B, greenish gray and drab sequence; C, middle variegated sequence). Top of butte covered by a veneer of coarse gravels, representative of the Black Rock cycle of erosion.

also the lowest stratigraphic occurrence of volcanic pebbles in the Eocene rocks of the Du Noir area. Thin sections of these rocks were not obtained. Thin beds of carbonaceous shale and gray shale are present in the sequence at some localities, most notably along the north side of U. S. Highway 287 west of the Long Creek Ranch. The contact between the greenish gray and drab sequence and the middle variegated sequence is not well exposed and their relationships are not readily observed. It appears, however, that the contact is gradational and similar to that at the base of the greenish gray and drab sequence.

Only one unidentifiable tooth fragment was found in the greenish gray and drab sequence. There is, however, an abundance of well preserved plant remains at many localities. A large and varied collection of fossil leaves (coll. 1, fig. 15) was obtained in the NE $\frac{1}{4}$ sec. 10, T. 42 N., R. 108 W. Some of the forms were identified by R. W. Brown as follows: Equisetum sp., Allantodiopsis erosa (Lesquereux) Knowlton and Maxon, Woodwardia sp., Lygodium sp., Thuja sp., Metasequoia occidentalis (Newberry) Chaney, Sparganium antiquum (Newberry) Berry, Pterocarya sp., Ailanthus sp., Mimosites sp., Cercidiphyllum sp., Platanus sp., Liquidambar callarche Cockerell, and Cinnamomum sp. According to Brown (oral communication, 1954) this flora is similar in many respects to that found near the middle of the Green River formation of early to middle Eocene age in northwestern Colorado and southwestern Wyoming. However, a plant collection (coll. 8, fig. 15) from approximately the same horizon by Dorf (1953) was interpreted by him to have close affinities with late Eocene to early Oligocene floras of the Pacific Coast region. This latter view is not compatible with the fossil vertebrate evidence which indicates a Lost Cabin age for strata lying both above and below the greenish gray and drab sequence (fig. 15).

The middle variegated sequence is best exposed in the high bluff along the north side of Tappan Creek westward from Warnock's Ranch, and at White Pass. At the Bench Creek locality, where it is overlain by the Tepee Trail formation, the unit is 674 feet thick, but thickens eastward to a maximum of about 800 feet (section B, fig. 14) in secs. 14, 15, and 23, T. 42 N., R. 107 W. Its total thickness east of Horse Creek could not be determined because of structural complications.

The sequence is characterized by bright red, purple, and gray bentonitic claystone and siltstone and white to gray tuffaceous sandstone and siltstone. The individual color bands are generally thicker and the claystones and siltstones more bentonitic than those in the lower variegated sequence. The lower 300 feet commonly contains 10- to 15-foot beds of sandstone and massive conglomerate with pebbles and cobbles of Paleozoic chert, limestone, and sandstone. The tuffaceous sandstone contains much biotite and is generally silty. In the high hill on the north side of White Pass the top 148 feet of the middle variegated sequence contains a 37-foot bed of brown carbonaceous shale with thin coal partings overlain by 11 feet of white bentonite and bentonitic claystone (section A, fig. 14). This highly bentonitic zone can be traced northeastward from White Pass for about 3 miles along the contact between the Wind River and Tepee Trail formations. The middle variegated sequence has been highly folded along the south flank of the Dubois anticlinal complex. Vertebrate fossils collected from about the middle of the unit at various localities along the north side of Tappan Creek indicate a Lost Cabin age (colls. 3, 4, and 5, fig. 15).

In the central portion of the mapped area, capping the high bluff on the north side of Tappan Creek and overlying the middle variegated sequence, is a 100-foot conglomerate, sandstone, and carbonaceous shale unit (section B, Fig. 14). The lower 40 feet is a tan massive conglomerate with rounded to subrounded fragments as much as 6 feet in diameter. Rock types represented include limestone from the Madison, Gallatin, and Gros Ventre formations, sandstone and quartzite from the Tensleep and Flathead sandstones, dolomites from the Darby and Bighorn formations, and Precambrian granite, gneiss, and schist. The matrix is coarse-grained and limy, with most of the grains angular. The overlying 40 feet consists mainly of tan fine- to coarse-grained limy sandstone with conspicuous grains of biotite and with minor amounts of gray claystone and brown carbonaceous shale. The upper 20 feet is brown carbonaceous shale with numerous black coal partings.

The conglomeratic sequence is also present on top of the Dubois anticlinal complex where it lies horizontally upon the folded Mesozoic rocks (fig. 17). These conglomerates can be distinguished from those in the Indian Meadows formation, which crop out farther east along Horse Creek, by their color and Precambrian rock content. Although the conglomeratic sequence lies conformably upon the middle variegated sequence along the north side of Tappan Creek, there is an unconformable relationship between the two in the vicinity of the Dubois anticlinal complex where the middle variegated sequence is involved in the folding and the conglomeratic sequence appears to be little disturbed. No fossils were collected from the latter unit.



Figure 17. Angular unconformity between the conglomeratic sequence of the Wind River formation (Twdr) and Mowry (Kmr) and Frontier (Kf) formations on Dubois anticlinal complex in C, sec. 1, T. 42 N., R. 107 W.

The uppermost beds assigned to the Wind River formation occur in isolated outcrops at the upper end of Little Horse Creek Valley and at the northwest end of Horse Creek Basin. These strata, constituting the upper variegated sequence, consists chiefly of gray, greenish gray, and pale red highly tuffaceous and bentonitic shale, claystone, siltstone and fine-grained sandstone. A large amount of landsliding has occurred in these beds at the upper end of Little Horse Creek Valley. The thickness varies considerably; it is at least 100 feet in the NW $\frac{1}{4}$ sec. 20, T. 43 N., R. 106 W., where the sequence is overlain by the Wiggins formation. A few vertebrate teeth were collected from the upper variegated sequence (colls. 6 and 7, fig. 15). These include Paramys and Didymictis altidens. C. L. Gazin of the U. S. National Museum concludes that the latter is a Lost Cabin species.

In areas to the east the lower Eocene rocks are overlain by the middle Eocene Aycross formation (Love, 1939, p. 66-73) which is characterized by variegated clays, shales, sandstones, conglomerates, and volcanic rocks. This formation has not been specifically recognized in the Du Noir area because all of the uppermost variegated Tertiary strata appear to be ^{of} lower Eocene age and have therefore been assigned to the Wind River formation. The possibility exists, however, that the two upper units of the formation in the Du Noir area may be lateral equivalents of some parts of the Aycross formation. This interpretation is suggested by the unconformable relationship between the conglomeratic sequence and the middle variegated sequence on the Dubois anticlinal complex; this unconformity may correlate with that noted by Love (1939, p. 70) at the base of the Aycross formation in areas to the east. As will be discussed later, some parts of the Aycross formation may also be represented in the basal portion of the Tepee Trail formation, as the latter formation is defined in this report.

Tepee Trail formation

The Tepee Trail formation was named and described by Love (1939, p. 73) from exposures along the East Fork River about 12 miles east of the Du Noir area. There the strata ~~are highly volcanic,~~ ^{consist largely of debris, are} generally well bedded, green or brown, and contain textures ranging from coarse angular breccias to finely laminated shale and tuff beds. The volcanic rocks are chiefly basic and typically are biotite-augite andesites and hypersthene-augite andesites. Fragmentary fossil evidence at the type section and its vicinity indicates an upper Eocene age. Either angular or erosional unconformities are present both at the top and base of the formation (Love, 1939, p. 74).

Because the Tepee Trail formation in the Du Noir area is apparently everywhere underlain directly by the lower Eocene Wind River formation, without any recognizable Aycross strata between them, it is possible that the basal part of the Tepee Trail formation, as it is defined in this report, may contain equivalents of the Aycross formation. This conclusion is further strengthened by the fact that the lower part of the Tepee Trail formation in the Du Noir area contains hornblende- and biotite-rich volcanic rocks similar to those described by Love (1939, p. 67, 77) as being characteristic of the Aycross formation, whereas the rocks in the upper part, which contain conspicuous amounts of pyroxene, are more like those of the Tepee Trail volcanics at the type section. Inasmuch as all of the strata lying between the Wind River and Wiggins formations are green and brown in color, with none of the brightly variegated beds characteristic of the Aycross formation, the entire sequence is designated as the Tepee Trail formation in the mapped area.

The Teepee Trail formation crops out in a wide belt which extends westward from Burroughs Creek to at least as far as the western edge of the mapped area. Bright green tuffaceous sandstone in the vicinity of BM 8818, near the top of Spring Mountain, are included in the formation. As far as could be determined it is not present around the base of Elkhorn Ridge between Horse Creek and the Wiggins Fork River, although here some of the coarse basal conglomerate of the Wiggins formation is similar in color to the Teepee Trail strata. In general the formation is poorly exposed, due mainly to the large amount of forest cover and to talus debris from the overlying Wiggins formation. However, some parts of the sequence are well exposed at the upper ends of Little Horse Creek and Sixmile Creek drainages, where conspicuous cliffs occur at the heads of large slump areas. No detailed measured section of the formation was obtained in the mapped area. The thickness varies greatly from one locality to another; it is about 575 feet thick on the west side of Du Noir Butte, where the basal bed is in sharp contact with the Madison limestone but where its upper contact with the Wiggins formation could only be approximately located. In the central part of the area the thickness is probably as much as 1,500 feet.

The Tepee Trail formation is a very distinctive unit because of its predominant bright green color; it may include shades of olive drab, grayish green and brown. The sequence consists chiefly of interbedded sandstone, conglomerate, shale, and tuff, with more or less well-defined bedding which indicates that most, if not all, of the strata are water-laid. The conglomerate is composed mainly of angular to subrounded fragments of volcanic rocks in a tuff or tuffaceous sandstone matrix. Most of the sandstone is highly tuffaceous, with both crystal and lithic fragments. The brown shale commonly contains abundant leaves and fresh water invertebrates.

Everywhere that the basal strata were observed they consist of grayish green fine-grained well bedded tuffaceous sandstone. The rocks contain a high percentage of quartz in addition to angular grains of plagioclase feldspar, biotite, hornblende, and magnetite. A few pyroxene crystals may be present and fragments of volcanic rocks are common. The microcrystalline groundmass is probably mostly clay, but may also include some glassy material. Detailed studies of the feldspars were not made, but the plagioclase appears to range from andesine to labradorite; thus the tuffs are both andesitic and basaltic. Because no quartz was found in any of the volcanic rocks studied from this area, it is concluded that the quartz in the sedimentary rocks was derived from a non-volcanic source; the other constituents were derived in large part from volcanic sources.

The Tepee Trail strata become progressively coarser and more conglomeratic toward the top. The basal beds directly overlying the Madison limestone on the southwest edge of Du Noir Butte in the extreme northwest corner of the mapped area contain cobbles of volcanic rocks as much as 6 inches in diameter in a fine-grained tuff matrix. These beds, although forming the base of the formation at this locality, probably belong to the upper part of the sequence inasmuch as they lie at a higher elevation than the occurrences on Long Creek and at White Pass. Similar conglomerate is present in the upper part of the formation at the south end of the Ramshorn in the central part of the mapped area.

The volcanic rocks in the upper part of the Tepee Trail formation are mostly bright green to dark green, the color being due mainly to the conspicuous amount of chlorite(?) present. Much of the material is highly altered, as indicated both by the large amount of chlorite(?) and by the altered condition, probably kaolinization, of much of the plagioclase. Volcanic pebbles in the conglomerate are invariably porphyritic, and generally contain a higher percentage of augite and less hornblende and biotite than the tuffs and lithic fragments near the base of the formation. Some olivine may also be present. Some of the volcanic pebbles are red; these contain an abundance of red brown hornblende and probably hematite in the groundmass. The plagioclase phenocrysts, where not considerably altered, exhibit excellent zoning and range from andesine to labradorite. Both basalt and andesite are thus represented. In contrast to the lowermost beds of the formation, no quartz grains were observed in the upper coarse conglomerate.

Fossil leaves were collected from the Tepee Trail formation at several localities in the Sixmile Creek drainage. The following specimens were identified by R. W. Brown: Lygodium kaulfussi Heer, Salvinia preauriculata Berry, Sparganium antiquum (Newberry) Berry, Potamogeton sp., Carya sp., Zizyphus, Equisetum sp., Lemna scutata Dawson, Salix cockerelli Brown, Populus ? sp., Platanus sp., and Cercidiphyllum ? sp. According to Brown (written communication, 1952) this assemblage is of middle to late Eocene age. As mentioned previously, Love (1939, p. 78) assigned a late Eocene age to the sequence at the type section.

The Tepee Trail formation rests with a pronounced angular and erosional unconformity on the Paleozoic rocks along the north flank of the Du Noir anticline. Everywhere that the formation was observed in contact with the Wind River formation conformable relationships appear to exist. Inasmuch as the two upper units of the Wind River formation are not present at White Pass and in adjacent areas to the west, a period of erosion prior to the deposition of the Tepee Trail strata is suggested.

The contact between the Tepee Trail formation and the overlying Wiggins formation is nearly everywhere concealed by the dense forest around the southern margin of the Absaroka Mountains. This contact, inferred throughout, was determined from isolated outcrops in which the predominantly green strata of the Tepee Trail formation are overlain by the light-colored strata of the Wiggins formation. No Tepee Trail rocks were recognized east of Burroughs Creek, and the Wiggins formation rests upon rocks ranging in age from Precambrian to lower Eocene. This relationship is due either to non-deposition of Tepee Trail strata or to deposition followed by complete erosion before deposition of the overlying Wiggins formation. Probably both interpretations are possibilities. Tepee Trail strata lap up on the Paleozoic highlands of the Washakie Range and may not have been deposited on all surfaces at higher elevations. On the other hand, this formation occurs at higher altitudes than that of Horse Creek Basin, where Wiggins strata rest on the upper part of the Wind River formation, suggesting that Tepee Trail rocks were once present in Horse Creek Basin but were eroded away before deposition of the Wiggins formation.

Eocene rocks, undivided

Eocene rocks, undivided, crop out in extensive areas on the northeast flank of the Wind River Mountains. These rocks, whose constituents were apparently derived from the higher parts of the Wind River Range to the west, were deposited over a surface of considerable relief that was developed prior to Eocene time and represent mountainward facies of the various Eocene formations that occur on the north side of the Wind River (figure 18). Because of the lack of fossil evidence and the lithologic dissimilarity between these strata and the other Eocene rocks in the region, the sequence was not referred to a specific formation. The thickness of the Eocene rocks, undivided, was not determined; it varies greatly in short distances. Where the pre-existing surface was relatively high the deposit is only a veneer, whereas ⁱⁿ pre-existing valleys it is much thicker. The maximum thickness is developed in secs. 21 and 22, T. 42 N., R. 108 W., where the rocks form a high rounded hill which rises more than 200 feet above the pass through which the Du Noir Tie Camp road enters Warm Spring Creek Valley. Apparently much of the debris that was deposited on the mountain flank was transported eastward from the higher parts of the Wind River Range through this pass. The lowermost exposures are found on the north side of Crooked Creek west of its mouth, and along the north side of the Wind River in the E₂¹ sec. 15, T. 42 N., R. 108 W. The strata are nearly flat-lying, but there is a slight regional dip northeastward into the basin which may, in part, be a reflection of depositional dip.



Figure 18. Eocene rocks, undivided (Teu) in south side of Wind River, NW $\frac{1}{4}$ sec. 25, T. 42 N., R. 108 W. (Pp, Phosphoria formation; IPT, Tensleep sandstone.)

The sequence consists chiefly of white to tan arkose and sandstone containing angular fragments of quartz and feldspar as much as $\frac{1}{4}$ inch long and some dark grains. The beds are commonly limy. At several localities thin beds of carbonaceous shale with lignite and coal partings and tan siltstone and shale are interbedded with coarser-grained strata. Coal beds, as much as 2 feet thick, are present in the NW $\frac{1}{4}$ sec. 25, T. 42 N., R. 108 W., and have been mined in the past. A notable feature of the Eocene rocks, undivided, is the almost complete absence of red beds that are so prominent in the Tertiary sequence on the north side of the Wind River. Some red strata mapped as Eocene rocks, undivided, occur in an isolated outcrop on the steep dip slope of the Tensleep sandstone in the C sec. 23, T. 42 N., R. 108 W.

The arkose beds are well exposed on the south side of Hat Butte. There they contain much volcanic material similar to that in both the lower part of the Tepee Trail formation and the middle drab sequence of the Wind River formation. Forming the prominent rim at the top of the butte is a 20-foot bed of brown slabby to crossbedded tuffaceous sandstone and conglomerate that is arkosic in part and contains fragments of chert and quartzite as much as 3 inches in diameter, in addition to smaller fragments of volcanic rocks. The principal constituents of the tuffaceous matrix include quartz, green-brown biotite, hornblende, plagioclase, and magnetite. One volcanic pebble contained an abundance of hornblende. The beds on top of the butte are finer-grained and contain fragments of leaves and other organic material.

The relationships of the Eocene rocks, undivided, to the thick sections of Eocene formations on the north side of the Wind River are not fully understood. The beds along the north side of Crooked Creek appear to underlie the middle drab sequence of the Wind River formation. The arkose at the base of that formation east of Stony Point are quite similar to those in the Eocene rocks, undivided; both sequences also contain carbonaceous shale. The conglomerate with quartzite and volcanic pebbles near the top of Hat Butte is similar to the conglomerate which occurs at the base of the Tepee Trail formation along Long Creek, although the latter contains no quartzites, and also to the conglomerate near the top of the middle drab sequence of the Wind River formation on the east side of Bench Creek, in the SE $\frac{1}{4}$ sec. 12, T. 42 N., R. 108 W., which contains both quartzite and volcanic fragments. The middle drab sequence of the Wind River formation also contains carbonaceous shale. It seems best, therefore, to correlate the major part of the Eocene rocks, undivided, with the Wind River formation. The rocks with abundant volcanic pebbles may be equivalent to some part of the Tepee Trail formation, and the basal strata may represent some part of the Indian Meadows formation.

Oligocene(?) series

Wiggins formation

The Wiggins formation includes the youngest Tertiary rocks in the Du Noir area and forms the spectacular scarps which outline the southern margin of the Absaroka Mountains (figure 19). The unit, named by Love (1939, p. 79) from the Wiggins Fork River, is assigned an Oligocene age on the basis of vertebrate fossils.

In the Du Noir area the Wiggins formation is more than 1,000 feet thick and is composed of flat-lying massive volcanic conglomerates and breccia with volcanic rock fragments as much as 3 feet in diameter, interbedded with fine-grained tuffs. The volcanic rock is usually dark while the matrix is mainly pink, gray, and white and contrasts sharply with the underlying dark green strata of the Tepee Trail formation. The tuff is generally of lighter color than the conglomerate so that the alternation of tuff and conglomerate produces the pronounced stratified appearance of the sequence. No flows were observed in the Du Noir area, but Love (1939, p. 80) noted some flows near the top of the formation in areas to the east.

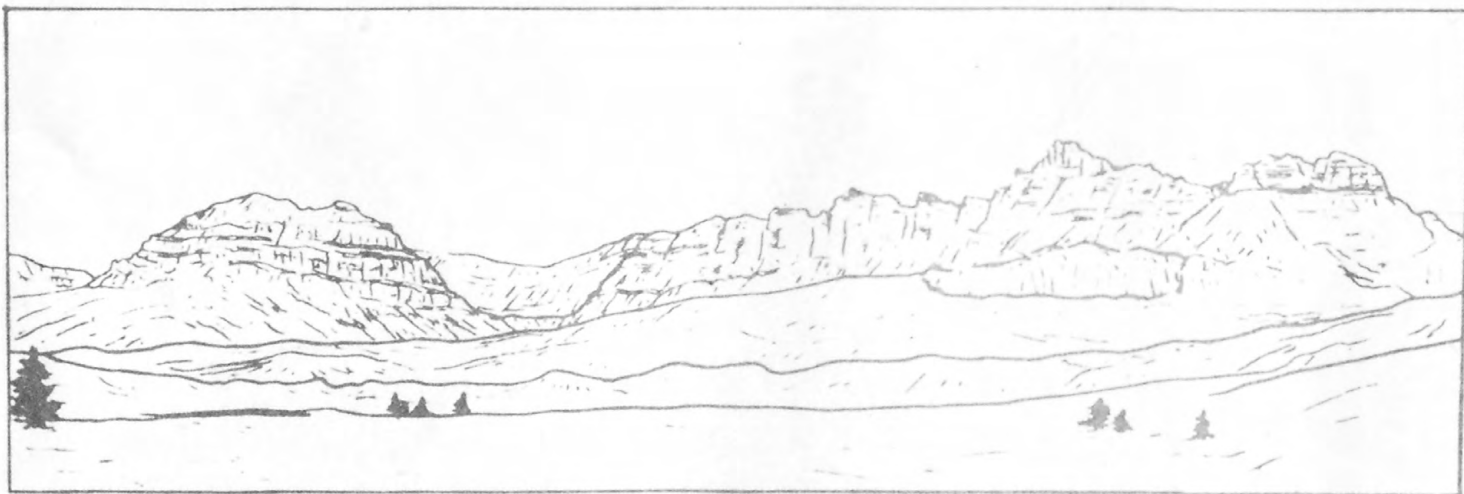


Figure 18. The Ramshorn as viewed from the SW $\frac{1}{4}$ sec. 24, T. 43 N., R. 108 W. Ramshorn Peak is highest point on skyline near right side of sketch. Wiggins formation forms massive cliffs while Tepee Trail sediments form rounded hills beneath. (Sketch from a photograph by J. Witt, U. S. Geological Survey).

A detailed stratigraphic section of the Wiggins formation was not measured. Thin sections of representative volcanic pebbles and tuff from different horizons were examined. The volcanic rocks are predominantly rich in pyroxenes, both augite and hypersthene, and contain little or no hornblende and biotite, with the exception of the red pebbles which have an abundance of red brown hornblende. Plagioclase phenocrysts average about $Ab_{45}An_{55}$. Olivine is common and magnetite is invariably present. An appreciable amount of what may be a feldspathoid mineral was observed in one pebble. The groundmass of most thin sections is microcrystalline and probably contains some glass. The tuff contains both lithic and crystal fragments and those near the base have a small amount of quartz which was probably derived from nonvolcanic sources.

The volcanic rocks described above differ from those noted by Love (1939, p. 81) to be characteristic of the type section a few miles to the east. There the rocks are commonly rich in biotite and hornblende, and the plagioclase is andesine in about 80 percent of the cases. Sufficient data were not obtained in the present study to offer a suitable explanation for this variance in composition of the rocks between the Du Noir area and the type section. The source of much of the volcanic material in the Wiggins formation is presumably from the large volcanic centers described by Hague, et al. (1899) along the eastern border of Yellowstone National Park, but some of it has been furnished by smaller localized vents such as those observed by Love (1939, p. 82) in adjacent areas to the east. How great an influence was exerted by local vents along the north edge of the Du Noir area is not known. Although none were observed in that region by the writer, they could lie buried under the main mass of volcanic detritus. If in the same period of time one vent furnished a different rock type from another vent, then the local variation could be explained. But this phenomenon would not be expected as it would be more likely that all of the vents would have more nearly the same magmatic source at a given time.

Quaternary system

General Statement

Several kinds of Quaternary deposits, including moraines, landslide debris, lag and terrace gravel, colluvium, travertine, and alluvium, are present in the Du Noir area. A detailed study of many of these deposits and their related physiographic features was made to furnish an aid to the interpretation of the Quaternary history of other parts of the Wind River Basin. Further, since in this region the Wind River and Absaroka Mountains are in close proximity, an excellent opportunity is afforded for correlation of the glacial and erosional cycles of the two ranges. Although many of the deposits are composed of similar materials there are sufficient differences in occurrence and terrain to distinguish one source from another in most cases.

Basalt Lag Gravel

Extensive areas on Spring Mountain are covered by a deposit of angular boulders and cobbles here classified as basalt lag gravel (figure 20). The debris consists almost entirely of blocks of dark brown to black very hard basalt as much as 8 to 10 feet on a side and is unlike any of the debris derived from the Wiggins formation. The rock is commonly vesicular and consists mostly of small crystals of labradorite with a moderate amount of olivine and a minor amount of pyroxene. Excellent flow structure is exhibited in thin section. The basalt is not perceptibly weathered and this, in addition to the extreme angularity of the individual fragments, suggests that the rock was derived from a volcanic sequence younger than either the Tepee Trail or Wiggins formations, and that the blocks have been subjected to very little transport. Although the deposit is only a few feet thick the blocks are sufficiently numerous to conceal effectively the underlying bedrock in most places. The lag gravel is present at elevations ranging from about 8,600 feet near the top of Spring Mountain to approximately 7,500 feet along the north side of Little Alkali Creek; the occurrences at lower elevations are found only on small interstream divides. Isolated occurrences are also present on the south side of Little Alkali Creek. It is concluded that the deposit was derived from a continuous basalt layer, probably a flow which at one time covered the area, and as the easily eroded underlying bedrock was removed the basalt was broken up into large fragments which were essentially let down in place. Nowhere is the basalt preserved as true bedrock nor were any feeder dikes observed in the area covered by the lag gravels. This basalt is similar to that on Lava Mountain 6 miles west of the mapped area. The Lava Mountain basalt was described by Love (1947) as the youngest Tertiary or early Quaternary volcanic rock in the region, but older than at least some of the glaciation.



Figure 20. Angular blocks of basalt on southwest flank of Spring Mountain, NE $\frac{1}{4}$ sec. 22, T. 42 N., R. 106 W.

Moraines

Extensive deposits of glacial debris are present in both the Du Noir and upper Wind River Valleys and the Horse Creek-Wiggins Fork area. All of these deposits are believed to be composed of till; no outwash material was recognized except that which may occur in terrace deposits. The moraines have not been differentiated on the geologic map, but two or more cycles of glaciation are represented. Because complete and detailed descriptions of these deposits involve many geomorphologic considerations, they are discussed under the heading "Geomorphology."

Landslide and glacial debris, undivided

Extensive areas on both sides of the Du Noir Valley and on the east side of upper Horse Creek Valley contain deposits that exhibit characteristics of both landslide debris and glacial debris. The deposits are best developed along the Du Noir Valley, where their general upper surface slopes downward toward the valley from the glacial moraines which occupy the drainage divides. The terrain is very hummocky and irregular, with as much as 50 to 75 feet of relief in the vicinity of Dry Lakes. The deposits consist of a veneer of boulders and cobbles of Tertiary volcanic rock with a minor amount of Paleozoic rock. Some boulders are as much as 20 to 30 feet in diameter. Many small recent landslides have occurred in areas of sharp relief. The debris is underlain for the most part by the soft plastic bentonitic and tuffaceous beds of the upper variegated sequence in the Wind River formation. These beds were probably saturated by glacial melt waters and the material moved down the slopes along the Du Noir Valley as a mixture of ~~solifluction~~ ^{landslide} and glacial debris ^{by the process of solifluction}. Some of the coarser material may have originated from ground moraines deposited by the receding glaciers. The deposits on the east side of upper Horse Creek Valley are of somewhat similar occurrence, although here the landslides were motivated in large part by the steepness of the slopes which rise in elevation eastward to the nearly vertical cliffs along the west side of Elkhorn Ridge.

Landslides, undivided

Extensive landslides have occurred at many locations throughout the Du Noir area. The combination of high relief, abrupt and steep valley walls, and the soft plastic character of a large part of the Tertiary sequence is particularly favorable for large-scale mass wasting. Some of the landslides have been extensively modified by erosion but others are so recent as to be still almost devoid of vegetation. The more recent occurrences, especially mud flows, are strikingly illustrated on aerial photographs.

The word landslide is used in this report and on the geologic map as a general term to include all types of mass movements of soil and rock. However, several types of landslides were recognized in the mapped area and in the following discussions are differentiated, as completely as observations and field relationships permit, according to the rate of movement, relative amount of saturation of the bedrock by water, and the terrain involved. The terms used have been adapted and modified for the most part from Lobeck (1939, p. 92-93). Debris avalanche is the term used to designate a landslide which has had a very rapid rate of movement with relatively little water saturation of the rocks involved and which has left a conspicuous trough-like scar in its wake. Slumps are landslides which result from the slumping of extensive masses away from the outer margins of cliffs. Conspicuous vertical scars, devoid of vegetation, mark areas where slumping has occurred recently. The debris generally accumulates at the base of such scars. Some degree of saturation is usually indicated in the slumped masses, and if both the saturation and the steepness of slope are sufficiently great the debris accumulation will flow slowly valleyward as soil or rock creep. The term mud flow is used to indicate landslides with a very rapid rate of movement motivated for the most part by nearly complete water saturation of the rock involved.

The extensive deposits of Landslide and glacial debris, undivided, in areas on both sides of the Du Noir Valley have been described previously in this report as being partially landslide in origin because of the saturation of the bedrock by glacial melt water. The hummocky topography was probably developed by material moving very slowly downslope, as soil creep, toward the valley. The distance any particular mass moved, however, was probably slight but sufficient to warp the surface and produce irregular ridges and impound water in small ponds. Small recent slumps are present in some parts of these areas.

The only large scale debris avalanche in the mapped area occurs on the east side of the Du Noir River southeast of Pickett's Ranch, where it forms a conspicuous lobe extending into the valley. This slide is superimposed upon the older deposits of Landslide and glacial debris, undivided, which lie both north and south of it. The debris avalanche merges with other landslide debris which originated farther up Sixmile Creek. At the upper end of the debris avalanche, in the SE $\frac{1}{4}$ sec. 3 and NE $\frac{1}{4}$ sec. 10, T. 43 N., R. 108 W., there is a large trough-like scar from which the debris was derived (figure 21). At the northern end of the slide resistant Paleozoic rocks are inclined at about 25° southward, and furnished glide planes upon which the slide probably originated. Both Paleozoic and Tertiary strata, in addition to the deposits of landslide and glacial debris, undivided, are involved.



Figure 21. Debris avalanche in secs. 3 and 10, T. 43 N., R. 108 W. Note large scar in background, shown by dashed contact.

Large slumps characterize the extensive mass wasting in the Sixmile Creek drainage and have involved, for the most part, plastic strata in the Tepee Trail formation. Numerous large vertical scars, devoid of vegetation, mark points from which much of the slide debris was derived. The upper portions of the slides coalesce in a large swampy area of extremely irregular terrain. Although some of the movement in the accumulated debris closely approximates that in mud flows, most of the material probably moved down Sixmile Creek Valley as soil and rock creep.

Landslide debris has also accumulated in extensive areas on the west side of the upper Du Noir Valley. The southern end of this series of slides has been the most active, as is shown by the large lobe extending into the west side of the valley in the S $\frac{1}{2}$ sec. 16, T. 43 N., R. 108 W. Tuffaceous porous sandstone of the Tepee Trail formation, which forms a cliff 100 feet or more in height, is involved. The margin of the cliff is receding westward, the cliff face remaining more or less parallel to the Du Noir Valley. Great masses of rock are continually breaking away from the cliff and, as a consequence, the entire area lying between the cliff and the valley appears as a single slumped mass with highly irregular topography and innumerable small ponds and swamps. The slumping phenomenon is well demonstrated at the present time as freshly fallen masses at the base of the cliffs still have green trees and other vegetation growing on them. Most of the subsequent movement in the accumulated debris was probably by soil creep downslope toward the valley. It is difficult to classify this type of mass wasting according to the scheme used in this report, but as the material is an accumulation over a prolonged period of time of small-scale slumping, it may possibly be termed a slump.

In the northwestern part of the mapped area, north of the West Fork of the Du Noir River, a large slump involves both the Tepee Trail formation and the more resistant Madison limestone with the latter furnishing a gliding surface. Large conspicuous scars are present in the north and northwest portions of the landslide area, as well as large lakes and ponds. The hummocky topography can readily be seen along the road on the north side of the West Fork. Although small mud flows are apparent in the northern part of the slide, the movement at the lower end most probably corresponds to that of soil and rock creep.

Another relatively large landslide area occurs south of the Wind River on the west side of the Du Noir Tie Camp road. Tertiary arkose beds are involved in the slides and the glide plane was probably the northward dipping underlying Paleozoic rocks. Steep scarps rise abruptly from the southern extremities of the slides. One of the small more recent slumps in the SE $\frac{1}{4}$ sec. 15, T. 42 N., R. 108 W. has diverted the course of the Wind River so that it now flows in a northeastward direction across a wide alluvial flat instead of through the old channel which lies along the base of the steep slopes to the south.

Numerous small slumps have occurred along the west side of Little Horse Creek north of the Sinclair-Wyoming Oil Company Dubois No. 1 well. High relief, the east-west trend of the Mesozoic rocks, and the plastic nature of much of the Tertiary sequence as well as the underlying Mesozoic rocks account for most of this mass wasting. The flat meadowland near the upper end of Little Horse Creek Valley was doubtless developed because slides farther downstream blocked the drainage. The region lying north and west of this meadow is largely covered by landslide debris. This series of slides was developed in the Tepee Trail formation and in soft plastic strata of the uppermost part of the Wind River formation, which crops out extensively in the central part of the area. Prominent cliffs formed by the lower part of the Tepee Trail formation rise abruptly above the north edge of the slide area. This cliff presents an almost continuous scar from which large slumps originated. Much of the material moved valleyward as mud flows. Recurrent movements of some parts of the mass are clearly indicated by recent mud flows that are superimposed on older ones. The lowermost extremities of these flows terminate in low concentric ridges, the outlines of which are convex downslope. These ridges are composed largely of locally derived material that was pushed up in front of the moving debris.

One of the most spectacular mud flows in the region occurs north of the junction of secs. 28 and 29, T. 43 N., R. 107 W. near the center of the mapped area. This flow is confined to a narrow valley and is about three-fourths of a mile long. The debris originated in the high cliff at the upper end of the flow and moved down a slope inclined at not more than 15° in some places.

The large landslide area on the southwest side of Horse Creek near Livingston's Ranch involves mostly Mesozoic rocks, although Indian Meadows conglomerate, which crops out near the top of the ridge along the south edge of the slide, contributed some of the debris. The conspicuous red sediments in the debris were derived largely from the Triassic Chugwater formation which underlies the slide area. High relief was the primary motivating force of the slide and much of the movement was probably as soil and rock creep. In some places along the upper, or south, edge of the slide, however, small mud flows have developed in the very plastic claystone of the Cloverly and Morrison formations. Numerous small lakes and ponds are present in the hummocky terrain. Some of the material in this deposit may have originated as glacial debris, inasmuch as glacial deposits occur at the same level in adjacent localities to the northwest along Horse Creek.

One of the most extensive and clearly outlined mud flows in the mapped area descends northward from the north end of Table Mountain (figures 22 and 23). The flow originated near the top of the mountain in soft bentonitic strata of the Wind River formation. Initially the movement was most probably that of a mud flow, but subsequent movement along its northern margin appears to have been slower, more like that of soil creep. The northern edge of the slide rises about 10 feet above the smooth slopes to the north and the material advances down these slopes without any apparent disturbance of the underlying rocks.

Many of the small local slides, except those of special interest, have not been specifically mentioned in the foregoing discussion, since they are so very numerous. Most of them are slumps which occur on steep slopes along the edges of steep hills and cliffs, very similar to those that have already been described. Rock falls, a term used to designate accumulations of resistant angular boulders brought down by gravity from very precipitous cliffs, are common along the escarpments which outline the southern margin of the Absaroka Mountains, but none of these have been shown on the geologic map.

Terrace Deposits and Colluvium

Seven levels of terrace deposits, classified according to their respective heights above the present stream drainages, have been distinguished in the Du Noir area. A detailed study of these deposits reveals a complex erosional history for the northwestern part of the Wind River Basin. Inasmuch as the terraces are closely related to glacial features, the detailed descriptions and correlations of the various terraces are given under the heading "Geomorphology."

The term colluvium is used in this report to designate gravels which have been deposited on steep slopes which separate major terrace levels. The material is derived from the higher terrace deposits and moved downhill by gravity. The colluvium is commonly only a few feet thick, but sufficient to mask the underlying bedrock.

Travertine

Deposits of travertine occur near the mouth of Warm Spring Creek and in the NW $\frac{1}{4}$ sec. 23, T. 42 N., R. 108 W. The travertine is very porous and contains much silty material. In places along Warm Spring Creek much bouldery debris, with some rock fragments as much as 3 feet in diameter, are incorporated in the deposits. Numerous travertine outcrops also occur near the south (upper) edge of the conspicuous terrace which lies south of the Wind River and east of Warm Spring Creek. Sufficient data were not obtained within the mapped area to explain adequately the origin of these deposits. In some places it appears that they coincide closely with the contact between the Ten-sleep and Phosphoria formations. Their more or less linear pattern is suggestive also of fault control, but no faults are present at least west of Warm Spring Creek. That the travertine is closely associated with the development of the prominent terrace level on the south side of the Wind River is clearly evident from the fact that the gravels in the terrace contain much carbonate material which has cemented the terrace deposit into a massive conglomerate. Such an occurrence is present in the C W $\frac{1}{2}$ sec. 1., T. 41 N., R. 107 W. at the west end of the terrace upon which the Dubois airport was constructed. To the southeast J. F. Murphy (personal communication) found tuffaceous material in travertine deposits. None was observed in the mapped area, but it may be present in small amounts.

Alluvium

Alluvial deposits, which form relatively wide belts along most of the major streams, consist chiefly of gravel, sand, and silt. These belts have been extensively utilized for agricultural purposes because of the fertility of the soil and the ready supply of water for irrigation. In the Du Noir Valley large alluvial fans, consisting of coarse gravels, have spread valleyward from the mouths of Fivemile and Sixmile Creeks and the East and West Forks of the Du Noir River. For the most part, the alluvial material has been derived from slope wash of the adjacent steep valley walls; consequently most of the deposits are red because of a partial source in the lower Eocene rocks. In the Du Noir Valley, however, the soil has been extensively modified and reworked by the meandering of the Du Noir River and is commonly very dark in color because of the large amount of organic material in it. Unlike the other major streams in the area the Wiggins Fork River, bounded in most places by steep canyon walls, flows through a channel that is entirely covered by coarse boulder and cobble debris. ~~The stream is conspicuously braided and its~~ ^{the} ^{of the stream} ~~course~~ is continuously being changed by the slight shifting of gravels from one place to another within the channel.

Igneous Rocks

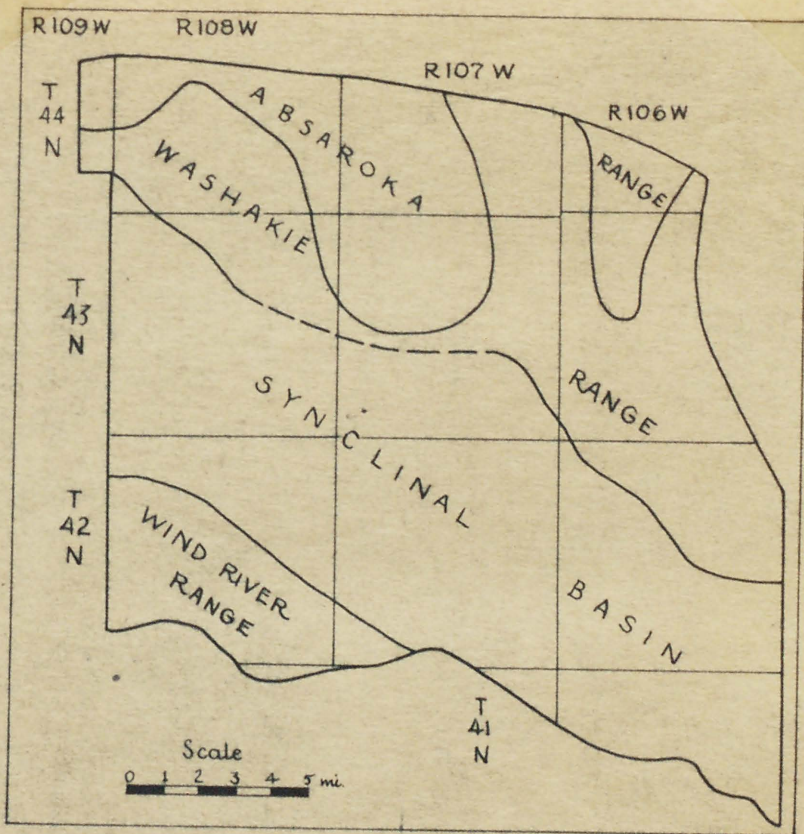
Dikes

The only dike observed in the mapped area occurs near the center of sec. 20, T. 43 N., R. 106 W., cutting vertically through strata in the uppermost part of the Wind River formation. The dike is from 1 to 3 feet thick and crops out for a distance of about 100 feet. The rock is dark green in the center, but becomes lighter colored and in places red along its outer margin. Thin sections of the rock were not studied, but it appears similar to some of the basalts studied from the Tertiary volcanic conglomerate sequence. It is slightly vesicular, suggesting that the present exposed part of the dike was near the surface at the time of the emplacement of the dike. The significance of this intrusive is not known. Perhaps it represents a small feeder dike for some of the volcanic material in the Wiggins formation and, as such, may be associated with a local vent that now lies buried under the Wiggins conglomerates of Elkhorn Ridge. On the other hand, the dike may have been emplaced later and is related to the basalt which forms the lag gravel deposit on Spring Mountain, although none of this lag gravel occurs in the vicinity.

STRUCTURE

General statement

The Du Noir area is comprised essentially of three major structural ~~provinces~~ ^{divisions}; the northeast flank of the Wind River Mountains on the south, an intervening synclinal basin thought to be a northwestern extension of the Wind River Basin, and the Washakie Range on the north (fig. 24). The relationships between the folds and faults in the mapped area to those of adjacent areas are shown on fig. 25. No structure is apparent in the Tertiary volcanic rocks along the southern margin of the Absaroka Mountains, which are an erosional remnant and will not be considered in the following discussion on the structural geology of the region.



SKETCH MAP SHOWING MAJOR STRUCTURAL DIVISIONS
Figure 24

(Fig. 25 in pocket)

The trend of the structural features throughout most of the mapped area is approximately N. 45° W., but in the western part it is more westerly. The most intense folding and faulting has occurred along the south edge of the Washakie Range and in the northern portion of the synclinal basin. Elsewhere, as along the flank of the Wind River Mountains and in the Du Noir anticline, folding has been more gentle and few faults are present. Asymmetric anticlinal folds have their steep flanks on the southwest and, with one exception, the movement of the overriding blocks of thrust or high-angle reverse faults has been relatively southwestward. The overriding block of the Wiggins Fork Trail fault in the northeast corner of the area has moved relatively northeastward. The lower Eocene rocks have been highly folded and faulted in the eastern half of the synclinal area, but no structure was observed in the Tertiary rocks in the western half. It is concluded therefore that the initial broad synclinal and anticlinal folding of the Laramide Revolution in the Du Noir area was effected prior to the deposition of the lower Eocene rocks and that the more intense deformation restricted in large part to the synclinal basin occurred during or after deposition of these rocks.

Method of Structure Contouring

Two contour horizons were selected to best portray the structure of the region; the top of the "upper Sundance" served as the horizon on the Dubois anticlinal complex and the adjacent synclinal area to the south, and the top of the Precambrian was utilized as a datum for all other regions. The structure contours have been drawn at 500-foot intervals, except for the large-scale geologic map of a portion of the Dubois anticlinal complex (pl. 4) on which the contours are drawn at 100-foot intervals. Surface elevations were obtained by aneroid barometer and because at many places lines of elevations were projected many miles from bench marks, it was difficult to maintain a high degree of accuracy for vertical control; the resulting structure contours are, therefore, only approximate.

In areas where intense deformation had occurred it was impossible to compute with any degree of accuracy elevations on the datum horizon from surface elevations and dips. The lack of subsurface data and limited exposures also contributed much to the uncertainty of structure contouring. Throughout most of the northeast portion of the mapped area lines of cross section were considered to be the best means for obtaining control points for structure contours and several sections, in addition to those that accompany this report, were constructed for this purpose. Because of asymmetry of folding only the approximate position of the traces of the axes of folds on the contour horizons are shown. In some cases the inclination of the fault planes was observed while in others the subsurface traces were subject only to the writer's interpretation. In areas of moderately gently dipping strata, with dips usually less than 30° , datum elevations were computed readily from the surface elevations, surface attitudes, and stratigraphic thicknesses. Structure contours are generally limited only to the outcrop belts of the Mesozoic and Paleozoic rocks. Where extensive overturning is present, as in the belt on the north side of the EA fault, structure contouring was not attempted. This belt served as a convenient boundary between contours drawn on the top of the Precambrian and those drawn on top of the "upper Sundance." On much of the large anticlinal uplift which forms the main part of the Washakie Range in the northeast portion of the mapped area structure contours were not made.

Wind River Mountains

The Wind River Mountains ^{are derived from} form a large anticlinal uplift that trends northwest through west central Wyoming for a distance of about 100 miles. The range is asymmetric, with the steep flank on the southwest, and large-scale thrust faulting at its northwestern end (Richmond, 1945; Baker, 1946). In contrast, moderate monoclinal dips generally prevail along the northeastern flank of the range.

In the Du Noir area the Paleozoic strata dip about 20° northeastward into the Wind River Basin. The continuity of the beds is interrupted by a normal fault which trends nearly north-south along the west edge of Warm Spring Mountain. The fault is here referred to as the Warm Spring Creek fault, from the stream upon whose south bank the fault is best exposed. The west side of the fault is downdropped, placing Flathead sandstone against Precambrian rocks along an almost vertical plane. Structure contours show that the vertical movement along the fault was between 1,500 and 1,750 feet. A small normal fault is believed to be present in the SW $\frac{1}{4}$ sec. 22, T. 42 N., R. 108 W., where an offset can be seen in light-colored beds on the hillside. At this locality, however, the exposures are poor and definite evidence for faulting is lacking. It is possible that this fault, if present, is a continuation of the Warm Spring Creek fault and the contact between the Paleozoic and Tertiary rocks on the west side of Warm Spring Mountain is a fault contact since it is along a more or less straight line between the two faulted localities. Here again, exposures are poor and the relationships cannot readily be observed. The offset in the Tertiary beds, however, is not nearly as great as the offset in the Paleozoic strata.

Synclinal basin structures

The synclinal basin which separates the Wind River Mountains from the Washakie Range is considered to be a northwestern extension of the Wind River Basin. It has been referred to as the North Fork syncline by Love (1939, p. 94-96). The entire west half of the basin is covered by Tertiary or younger rocks so that pre-lower Eocene structures in the underlying Paleozoic and Mesozoic rocks are effectively masked. With one exception, no structure, other than regional northward dips of from 2° to 4° , is apparent in the Tertiary rocks in that part of the basin and leads to the conclusions that very little post-lower Eocene deformation took place. The one exception is an 8° southward dip in the Wind River formation along the north side of Sixmile Creek (E $\frac{1}{2}$ sec. 15, T. 43 N., R. 108 W.) which may reflect renewed uplift of the Du Noir anticline. However, post-lower Eocene movement of this fold is not reflected in the Indian Meadows formation along the West Fork of the Du Noir River so that the inclination of the Wind River beds may be the result of slumping which is very prevalent in that area. Inasmuch as the lower Eocene rocks are strongly unconformable on the Paleozoic and Mesozoic rocks in the southern part of the mapped area as well as in other areas, much pre-lower Eocene deformation is indicated and the center of the basin may therefore contain broad anticlinal and synclinal folds that are not reflected in the Tertiary strata.

Outcrops of Mesozoic rocks at Dubois and along Horse Creek and Little Horse Creek provide enough data to determine the major structural elements in the central portion of the basin. In this part of the basin there are two large synclines separated by the Dubois anticlinal complex (cross section F-K, pl. 2). Sufficient data are not available to indicate the structural relief of either syncline but both are believed to be of major proportions.

The southernmost syncline, which forms approximately the south half of the basin, is hypothetically shown on cross section F-G (pl. 2). At Dubois northward dips in the Mesozoic strata range from 10° to 15° . The dips in the Mesozoic rocks along the south limb of the Dubois anticlinal complex are 35° southward, but may steepen considerably at depth producing much more asymmetry than is shown in the cross section. There is also a distinct possibility that the Wind Ridge fault may extend northwest from Horse Creek, along the south edge of the anticline, although this interpretation has likewise not been presented on the cross section. Broad flexures in the lower Eocene rocks northeast of Dubois, south of the Wind Ridge fault, leads to the conclusion that there is folding or faulting in the center of the syncline.

The Dubois anticlinal complex is so designated because it consists of several anticlines and synclines superimposed on a large anticlinal uplift. Only the eastern part of the structure is visible on the surface and the western extension is covered by Tertiary strata. The total structural relief between the crest of the fold and the troughs of the adjacent synclines could not be determined accurately; it may be as much as 4,000 to 5,000 feet. Oil is produced from the Phosphoria Unit formation in the Sinclair-Wyoming Oil Company Dubois No. 1 well which is situated on a small independent closure as shown on pl. 4. The anticlinal complex is asymmetric to the southwest and, as previously discussed, may be much more asymmetric than is shown on the accompanying cross sections, or even faulted. The small subsidiary folds plunge to the southeast, as does the structure as a whole. Data are not available to indicate whether the anticline plunges to the northwest as well. The oldest strata exposed on the anticline are in the upper part of the "lower Sundance" formation.

The southwest flank of the anticlinal complex was intensely deformed. At least 5 small folds, 3 anticlines and 2 synclines, and 3 thrust faults as well as numerous cross faults and abundant fractures are present. Plate 4 is an enlarged geologic map of this area. The southwest flanks of the anticlines are commonly overturned, but this feature may become less pronounced at depth although the beds are still vertical to overturned in the bottom of the Dubois Unit No. 1 well. The northernmost thrust faults are best exposed on the west side of Little Horse Creek whereas on the east side of the creek their traces are largely obscured by landslide debris. Both faults have little stratigraphic displacement and involve Cloverly and Morrison strata for the most part. The northern fault places both "lower" and "upper Sundance" upon Cloverly-Morrison beds in the vicinity of the Dubois Unit No. 1 well, but passes eastward into a small sharp asymmetric anticline. At the west end of the southern fault the Fort Union(?) formation appears to have been faulted over Mowry shale. Eastward this fault becomes more obscure but some evidence, such as much fracturing and cross faulting in the lower part of the "Rusty beds" suggests that it places the lower part of the Cloverly and Morrison sequence against the "Rusty beds." At the east end of this fault both the "Rusty beds" and the Thermopolis shale appear to have been down-dropped against "Rusty beds" along an almost vertical plane. This would indicate that the fault had a "scissors" movement, with the north side upthrown throughout most of its extent but downthrown at its eastern end. On the west side of Little Horse Creek the plane of the northern fault dips northward about 30°, yet no evidence was

encountered in an electric log study of the two wells to indicate that faulting had occurred so near the surface in either well. As is suggested in cross sections Q-R and S-T-U (pl. 4) the faults probably become bedding-plane faults and the amount of movement diminishes rapidly with depth. From available evidence it could not be definitely determined whether or not any faulting occurred near the bottom of the Dubois Unit No. 1 well. Only a small part of the Tensleep appears to have been encountered and the structure can be interpreted as being that of overturning rather than faulting. If faulting did occur the displacement is slight. Another thrust fault is present at the extreme southeast end of the structure where Mowry shale has been faulted upon beds of the Fort Union(?) formation, which have been sharply infolded along with the Mowry shale directly on the south side of the fault (figure 11). This fault apparently passes into an overturned syncline to the northwest, but the relationships in the Mowry shale are quite obscure. Tertiary strata are involved in this fault at its extreme eastern end. Only the larger cross faults could be shown on the geologic map; most are believed to be normal faults with only slight displacement. Many of the smaller cross faults, which are most conspicuous in the basal white sandstone of the "Rusty beds," show only lateral movement.

At least two anticlines are present on the north flank of the Dubois anticlinal complex, one along Brent Creek in sec. 26, T. 43 N., R. 107 W. (cross section C-D, pl. 2), and the other southeast of the EA Ranch in secs. 8, 9, and 16, T. 42 N., R. 106 W. (cross section L-M, pl. 2). Both are moderately symmetrical and plunge to the southeast. Structure contours on the top of the "upper Sundance" show the writer's interpretation of the relationships of these folds to the main anticlinal structure. Mowry shale is the lowest exposed formation in the fold along Brent Creek, where outcrops are exceedingly poor because of the presence of a large amount of landslide material and forest cover. Only the eastern end of the fold is exposed, so that its overall extent and value as a potential oil trap could not be determined. It trends nearly east-west and plunges about 30° eastward. Structural relief between the crest of the anticline and the trough of the adjacent syncline to the north is approximately 1,500 feet.

The structural relationships of the anticline southeast of the EA Ranch are likewise very obscure. Evidence for the fold is found in the limited exposures of the Cody shale along the east edge of Horse Creek Valley. A small outcrop of sandstone and shale, which, because of the presence of sandstone, is at least 1,200 to 1,300 feet stratigraphically above the base of the Cody shale, on the section line between secs. 8 and 9, T. 42 N., R. 106 W. has a northeastward dip of 42° . Southerly dips were obtained in the Cody shale in the vicinity of the junction of secs. 8, 9, 16 and 17. The fold, which plunges eastward, is probably cut at depth by the Little Alkali Creek fault. Its western extent could not be determined, so its true structural relationship to the main anticlinal complex is not known. The syncline adjacent to this fold on the south is well defined in the Indian Meadows conglomerate which overlies the Cody shale in that area.

East of Horse Creek the lower Eocene rocks have, in places, been highly deformed (cross section O-P, pl. 2) in front of low angle thrust faults. Although no large folds are present in the Tertiary strata, the thrust fault belt of deformation falls in direct line with the Dubois anticlinal complex. The Wind Ridge fault, mapped and described by Love (1939, p. 95-96), extends northwest from the eastern margin of the mapped area along the south edge of Table Mountain to Horse Creek. It may extend northwestward across Horse Creek and up Little Horse Creek Valley but there is no positive evidence of it doing so, unless perhaps the highly deformed character of the south flank of the Dubois anticlinal complex is considered to be related. The Wind Ridge fault plane is well exposed at many localities (figure 26). In the SW $\frac{1}{4}$ sec. 34, T. 42 N., R. 106 W. the dip of the fault plane is 23° north. Southeast of the road that leads from Dubois to Little Alkali Creek massive conglomerate in the Indian Meadows formation is thrust over soft variegated beds of the Wind River formation whereas northwest of the road fine-grained variegated beds of either the Indian Meadows or Wind River formations occupy the overriding block. This change in stratigraphic horizon is caused by progressively younger beds swinging around the northwest-plunging end of a small anticline on the north side of the fault. This fold is well developed for a mile or more on each side of the road but at its southeast end it dies out into sharp drag dips along the fault. Since the fold has little structural relief and is closely associated with drag folding it is probably confined to the overriding block.



Figure 26. Wind Ridge fault, SW $\frac{1}{4}$ sec. 34, T. 42 N., R. 106 W. Beds above fault are massive conglomerates of Indian Meadows formation; those below are soft variegated beds of Wind River formation.

The thrust fault which passes near Wind River triangulation station on the eastern edge of the area could not be traced west of Table Mountain. Along this fault Cody shale has, in places, been thrust over Indian Meadows strata.

The Little Alkali Creek fault extends northwest from the north end of Table Mountain at least as far as Horse Creek. Its presence west of Horse Creek was not definitely ascertained, nor could its trace be found east of Table Mountain. Both Cody shale and massive conglomerate beds of the Indian Meadows formation have been thrust over the upper variegated sequence of the Wind River formation. The fault relationship can best be seen from the road that leads to the EA Ranch. Dips in the lower Eocene strata in the high hill on the east side of Horse Creek Valley change abruptly from nearly horizontal to vertical. The fault plane, however, is rather obscure and its inclination was not determined. The stratigraphic displacement is not known, but it is thought to be appreciable.

The northernmost syncline of the basin, which separates the Dubois anticlinal complex from the Washakie Range, is almost completely overridden by the south flank of the range along the EA fault (section L-M-N, pl. 2) so that only the south limb of the syncline is visible. The magnitude of the syncline is indicated by the 30° to 40° north dips in the Cody shale in the vicinity of EA Mountain and the EA Ranch, but otherwise very little observable data are present with which to determine its structural relief and overall extent. In some areas, such as north of Brent Creek in the NE $\frac{1}{4}$ sec. 26, T. 43 N., R. 107 W. (cross section C-D, pl. 2), it might be possible to reconstruct the overturned north limb of the syncline without faulting it, but the amount of overturning in the strata along Burroughs Creek and the structural relationships farther southeast suggest that the entire north limb of the syncline has been extensively thrust faulted. This interpretation has been presented on all of the cross sections that were constructed across this feature.

Washakie Range

The Washakie Range has been described by Love (1939, p. 5) as being a " . . . series of faulted folds, en echelon, beginning with the eastern flank of Black Mountain, extending 70 miles northwest of the western end of the Owl Creek Mountains, and ending with the western flank of Buffalo Fork Mountain, west of Togwotee Pass." The Du Noir area includes the middle portion of the range as it is thus defined (Plate 1). This extensive anticlinal uplift, which reaches mountainous proportions with elevations of more than 10,000 feet in places, was completely buried by Tertiary pyroclastic rocks and has now been partly exhumed. As noted by Love (1939, p. 6) the flanking Paleozoic strata are at generally higher elevations than the Precambrian rocks; this is well illustrated by the Paleozoic outcrops north of Carson Lake along the north edge of the mapped area. In some regions the range is still completely buried, as beneath the Ramshorn in the north central portion of the Du Noir area. The northeast flank is nearly everywhere concealed so that very little is known of its structural characteristics. Love (1939, p. 5) expressed the opinion, and the writer concurs, that the still buried portions of the Washakie Range are not much higher, if at all, than the highest elevations attained in its presently exposed parts. Thus it is believed that in many places the central Precambrian core of the range is now visible. Where the central and southwestern parts of the Washakie Range are exposed they commonly consist of large anticlinal folds which have been extensively faulted along their southwest margins.

In the Du Noir area the Washakie Range is represented by the Du Noir anticline in the northwestern corner (cross section A-B, pl. 2) and by a broad anticlinal uplift that occupies nearly the entire northeast quarter (cross section D-E, pl. 2); these two large folds appear to be en echelon.

The Du Noir anticline extends northwest throughout the area of outcrop of the Paleozoic rocks in the northwestern part of the mapped area. The dips on the south flank are as much as 45° , but average around 25° . The north flank is more gentle, with dips generally less than 18° . The oldest formation exposed in the fold is the Darby formation, in East Fork Canyon. The axial trend describes an arcuate curve, convex to the north, and the axis plunges southward about 15° to 20° . The large bulge in the structure contours along the east side of the structure is part of a small subsidiary anticline and syncline which plunge eastward. No westward closure is apparent within the mapped area. Distinctive features are local reversals in dip on the south flank of the anticline near the mouth of the West Fork and again on the north side of the West Fork along the western margin of the mapped area. The significance of these small warps is not fully understood. It is possible that faulting accompanied the folding of the anticline and that the reversals in dip represent drag dips on the toe of a thrust plate, but because there is no positive evidence for faulting in the exposed portions of the fold, such a conclusion is not warranted. It is notable, however, that features such as these, only on a much larger scale, are present on the upper plates of the Burroughs Creek and North EA faults.

The large complex anticlinal uplift in the northeast quarter of the mapped area has an extensive core of Precambrian rocks that is flanked on the north, west, and south sides by high ridges of Paleozoic rocks that attain elevations of as much as 10,000 feet. This uplift is believed to represent a portion of the en echelon central core of the Washakie Range. Except for the west side of Wiggins Fork Canyon and the area north and west of the T-Cross Ranch the Precambrian core of the uplift is almost completely concealed by Tertiary or glacial debris.

The southwest flank of the uplift is steep and highly faulted. The EA fault, although classified as an inferred or approximate fault throughout its entire length, is believed to be the most extensive thrust fault in the entire area and the dividing line between the Washakie Range and the synclinal basin to the south. The fault is nowhere exposed, but there is abundant evidence that it exists in the approximate position shown on the geologic map. No evidence is available to indicate the amount of movement. The fault is named from the ranch across which it passes and near which the best fault relationships can be seen.

The most conclusive evidence for faulting is found just east of the EA Ranch, where sandstone and shale approximately 1,200 to 1,300 feet stratigraphically above the base of the Cody shale dip 42° N. in normal position while only one-quarter mile to the north Mowry shale beds are overturned and now dip about 70° N. The apparent displacement, measured on the base of the Frontier formation along the fault plane, may be as much as 3,500 feet at this point, as is shown on cross section M-N (pl.2). Northwest of the EA Ranch the entire sequence between the upper part of the Frontier formation and the lower part of the Cloverly and Morrison formations, undivided, is overturned. Along the south edge of this sequence Cody shale also contains northward dips, but it is concluded that these beds are in normal position like those to the northwest and that the fault lies between them and the overturned Frontier strata. Farther northwest in the vicinity of EA Mountain and in alignment with the strike of the overturned sequence, Cody shale occurs in an upright position, dipping between 32° and 40° to the north. The fault is then thought to pass under EA Mountain and to continue on to the northwest somewhere between the inverted sequence of Jurassic and Triassic rocks along the road northwest of the Horse Creek Ranger Station and the Frontier and Mowry formations in normal attitude along Brent Creek, although here, since the two exposures are more widely spaced, the evidence for the existence of a fault is not as conclusive as farther to the southeast.

Another thrust fault, more or less parallel to the EA fault, is present about half a mile north of the EA Ranch and is designated the North EA fault. The fault relationship is best seen in the SW $\frac{1}{4}$ sec. 4, T. 42 N., R. 106 W., where the "upper Sundance" on the south flank of a syncline overlies overturned beds of the Cloverly-Morrison sequence. These two formations are involved in the faulting throughout the exposed portions of the North EA fault; the stratigraphic displacement is therefore not great. Though the fault plane itself was not sufficiently well exposed to measure its inclination but it is assumed that the dip of the plane had to be somewhat less than the overturning of the strata in order to have effected that overturning. Similar reasoning also influenced, to a large extent, the reconstruction of the EA fault plane. A peculiar phenomenon associated with the North EA fault, in the vicinity of the EA Ranch, is the development of the small syncline in the overriding block directly adjacent to the fault (cross section M-N, pl. 2). Farther to the northwest, however, southward dips in the "upper Sundance" beds indicate the presence of a small anticline on the north side of the fault (cross section J-K, pl. 2) which is normal in the overriding block of a thrust fault.

The syncline and anticline mentioned above are almost entirely covered by landslide debris. ~~The syncline is clearly outlined only east of Horse Creek, while only the south flank of the small anticline is anywhere visible.~~ Both are slightly reflected in the Phosphoria formation along Horse Creek northwest of Livingston's Ranch where the beds are observed to swing abruptly from their normal northwest trend to an east-west strike for a short distance. It is interesting to note that the stream channel follows almost precisely this bend in structural trend. The beds along the north flank of the syncline rise steeply to form the south flank of the Spring Mountain, and of the main anticlinal uplift.

The Paleozoic and lower Mesozoic strata along the Burroughs Creek fault have been highly folded and faulted. Gently dipping beds of the Tensleep, Amsden, and Madison formations in a small syncline were faulted in contact with vertical to overturned beds of the same formations (cross section D-E, pl. 2). The overturning, which can be observed in strata as young as the "lower Sundance", is best exhibited in the regular succession of strata in the Phosphoria formation on the steep east wall of Burroughs Creek Canyon about a mile northwest of the Horse Creek Ranger Station, where the beds dip eastward into the hill at an angle of approximately 40° . Throughout its entire length the fault is largely concealed by forest cover. The fault relationships are best observed along the U. S. Forest Service trail that leads north from the Horse Creek Ranger Station on the east side of Burroughs Creek Canyon. It is assumed that the dip of the fault plane is less than the dip of the overturned strata, giving it an inclination of generally less than 40° . Its stratigraphic displacement is not great. In common with the North EA fault northeast of the EA Ranch, there is also a small syncline developed on the overriding block of the Burroughs Creek fault. The lower part of the Phosphoria formation is exposed in the center of the syncline, and both to the northwest and southeast the axis of the syncline is intersected by the fault. Here, also, there is no indication of a reversal that must be present to connect the west limb of the syncline with the overturned sequence on the west side of the fault. The North *Burroughs Creek* fault passes southeastward into a very sharp flexure in the upper part of the Madison limestone.

Spring Mountain is a high prominent ridge which forms a major part of the southeastern flank of the Washakie Range anticlinal uplift. The mountain has an asymmetric topographic profile, with a relatively gentle southwest flank and a steep to nearly vertical northeast flank which descends abruptly northward into Horse Creek basin, a small topographic and structural basin lying between Spring Mountain and the south end of Elkhorn Ridge. The southwest flank, although overlain in large part by Tertiary or younger rocks, appears to be little disturbed by folding or faulting, with Paleozoic and Mesozoic strata dipping southwestward about 45° . In contrast, much faulting has occurred both on the crest and along the northeast flank of the mountain, as well as on the east side of Horse Creek basin. Most of the faults are normal, with their north sides downdropped (cross section M-N, pl. 2) and are thought to be the primary cause for the topographic depression of at least the east portion of Horse Creek Basin. This system of faults suggests that extensive collapse of the center of the large anticlinal uplift followed the relaxation of the compressional forces that caused folding.

The longest of the normal faults, here referred to as the Spring Mountain fault, can be traced from the SE $\frac{1}{4}$ sec. 29, T. 43 N., R. 106 W., where the Darby and Bighorn formations are in fault contact with the Madison limestone, southeastward along the crest and northeast flank of the mountain to the east side of the Wiggins Fork River. The precipitous cliffs of Madison limestone on the northeast corner of the mountain in secs. 1, 2, 11, and 12, T. 42 N., R. 106 W., may be fault scarps. The fault relationships are best observed in secs. 33 and 34, T. 42 N., R. 106 W., southwest of BM 8885, where a repetition occurs in both the Madison and Darby formations. At its northwest end the fault appears to die out in the Madison limestone. The amount of movement increases southeastward, and at the eastern edge of the area structure contours indicate it to be more than 1,000 feet.

Just southwest of BM 8885 the Bighorn dolomite has been almost completely faulted out by a reverse fault, probably high-angle, which closely parallels the Spring Mountain fault. Highly distorted remnants of the Leigh dolomite member of the Bighorn dolomite are present in two places along the south side of the fault. In the northeast corner of sec. 33, T. 43 N., R. 106 W. dips in the Gallatin limestone, in the overriding block, are vertical to slightly overturned. The southeastern extent of this fault, which provides the only exception to the predominance of normal faulting in this part of the area, is not known, but to the northwest it is thought to extend at least as far as the center of sec. 29, where outcrops of Flathead sandstone are in close proximity to the Madison limestone (cross section J-K, pl. 2).

A normal fault of large displacement extends through the N $\frac{1}{2}$ sec. 35, T. 43 N., R. 106 W., where a repetition of Flathead sandstone and Gros Ventre shale occurs. Here the stratigraphic displacement is approximately 500 feet, but to the west in the center of the S $\frac{1}{2}$ sec. 27 the displacement reaches nearly 1,000 feet. In the S $\frac{1}{2}$ sec. 22 both the Flathead sandstone and the Gros Ventre shale have been downdropped against Precambrian rocks along another normal fault. The fault relationships are not clear because of poor exposures and the overall magnitude of the fault could not be determined. To the north another fault has produced a small offset in the Death Canyon member of the Gros Ventre shale.

A sharply folded syncline lies along the northeast edge of the mapped area. The southwest limb of the syncline, overturned in some places, is broken by the Wiggins Fork Trail fault. This fault is named after the U. S. Forest Service trail which parallels the small stream traversing the structure in the NW $\frac{1}{4}$ sec. 10 and S $\frac{1}{2}$ sec. 3, T. 43 N., R. 106 W. and along which the fault relationships are exposed. In contrast with all the other reverse faults in the mapped area, the plane of the Wiggins Fork Trail fault is inclined to the southwest; the amount of inclination was not observed, but it is believed to be high-angle (cross section D-E, pl. 2). Gallatin limestone occupies the north side of the fault throughout its extent while the Death Canyon limestone member of the Gros Ventre shale or the Flathead sandstone forms the overriding block. The amount of movement, from a maximum of nearly 1,500 feet, decreases rapidly to the northwest in the NW $\frac{1}{4}$ sec. 10 and apparently soon dies out in the soft beds in the upper part of the Gros Ventre shale. A small reverse fault, with its plane inclined to the east, occurs at the southeast end of the syncline, along the axis of the fold.

SUMMARY OF GEOLOGIC EVENTS

Paleozoic time

The Cambrian sequence in central and northwestern Wyoming represents a west to east onlap relationship, with a basal sandstone succeeded in turn by shale and limestone. Prior to Middle Cambrian time the region had been peneplained, and the surface over which the Middle Cambrian sea advanced contained only mild relief. Deposition was apparently continuous from Flathead to Gros Ventre time, with the quartzitic sandstone of the older formation grading upward into shaly sandstone. A temporary change from shale to limestone development took place during the time the Death Canyon limestone member was deposited, but throughout the remainder of Middle Cambrian time shales predominate. As the Cambrian seas spread farther eastward during Late Cambrian time limestone was deposited instead of shale. Both Miller (1936, p. 122) and Blackwelder (1918) noted a disconformity between Middle and Upper Cambrian rocks.

Although strata of Early and possibly also Middle Ordovician age are absent in the Du Noir area, there is little indication of this long hiatus between the Gallatin limestone and Bighorn dolomite. In some areas slight disconformity has been observed. Deposition during Bighorn time commenced in some places in central Wyoming with a thin sandstone, but over most of the Du Noir area this unit is apparently absent. Environmental conditions that prevailed while the thick massive lower dolomite member was deposited remained essentially unchanged over a long period in possibly Middle and Late Ordovician time as indicated by the remarkably uniform lithology of the unit. Although the dolomite in the Leigh member is platy and porcellaneous, that in the uppermost part of the formation is also massive and granular like the beds in the lower part. The whole of the Bighorn is free from clastic material.

A retreat of the Ordovician seas and a long period of erosion followed deposition of the Bighorn dolomite. The erosional unconformity between this unit and the overlying Darby formation is sharp, and locally has a contact relief of as much as 20 feet. Beds of Silurian age are not present in the area, so the interval between the two formations represents considerable time. During Devonian time dolomites and shales, as well as some coarse clastic material, was deposited. Fossils are sparse in the Darby formation so that its exact age in this region is not known. Most, if not all, of the formation in the Du Noir area is believed to be of marine origin but in other areas terrestrial plants and channel deposits are indicative of varying environments during the Devonian period in northern and northwestern Wyoming.

Early Mississippian time was marked by an extensive period of carbonate deposition. The Madison consists of several hundred feet of limestone that is remarkably uniform in lithologic character and contains an abundance of marine invertebrates. However, the upper part of the formation, possibly a lateral equivalent of some part of the Upper Mississippian Brazer limestone of southeastern Idaho, contains some clastic material. A pronounced erosional unconformity is present between the Madison limestone and the overlying Darwin sandstone member of the Amsden formation. The Darwin sandstone was apparently deposited on a karst topography developed on the top of the Madison limestone that may have as much as 135 feet of relief in a distance of 3 miles.

During the Pennsylvanian period thick sequences of sandstone, separated by a unit of interbedded shale, limestone, dolomite, and quartzitic sandstone, were deposited. Where the Darwin sandstone member is well developed it is very similar to the Tensleep sandstone. Deposition during this period was apparently continuous as evidenced by the gradational contacts of the sandstone units with the middle shale and carbonate unit; all of the strata are believed to be of marine origin.

An erosional unconformity, marked by pebbly beds at the base of the Phosphoria formation, indicates a withdrawal of the sea in Late Pennsylvanian time. The sea readvanced in Middle Permian time and the Phosphoria formation was deposited. Definite evidence of a retreat of the Paleozoic sea in Late Permian time is lacking but the apparent absence of Late Permian strata indicates a period of non-deposition and probably erosion.

The presence of lowermost Triassic fossils in the Dinwoody formation (Newell and Kummel, 1942, p. 951) is evidence of a spread of the sea at the beginning of Mesozoic time. No agreement has been reached as to whether the redbeds of the Chugwater formation are of marine or nonmarine origin, but available evidence seems to indicate a subaqueous origin. The presence of limestone and gypsum in several areas and the uniformity of the redbeds suggest subaqueous origin whereas the apparent interfingering of the redbeds with the thick marine Thaynes limestone in western Wyoming suggests, more specifically, a marine origin. Marine reptiles have been found in the Alcova limestone. Amphibians, land plants, and wood have been collected from the Popo Agie member in central Wyoming. A slight unconformity of regional extent is present at the top of the Chugwater formation (Love, 1948, p. 100) indicating uplift of the region in Late Triassic time.

The origin of the Nugget sandstone of Lower Jurassic age is conjectural. Some investigators favor a marine origin (Branson, 1927), while others favor a nonmarine origin and, more specifically, an eolian origin (Reeside, 1929; Imlay, 1947, p. 264). The thinning of the formation from 120 feet at Dubois to a wedge-edge in the vicinity of the Horse Creek Ranger Station is evidence that uplift along the north edge of the Du Noir area must have occurred during or following deposition of the Nugget sandstone. Most of the thinning is probably due to post-Nugget, pre-Gypsum Spring erosion, although a minor amount may be the result of non-deposition.

Marine waters spread over the area in Middle Jurassic time. The sea was probably shallow, and much gypsum was deposited along with the limestones and redbeds of the Gypsum Spring formation. Deepening of the sea probably occurred during Middle Jurassic time and continued on into Late Jurassic time with the deposition of shale and limestone. Oolitic limestone and, locally, red shale in the lower part of the "lower Sundance", however, indicates that the depth of the sea fluctuated. The presence of a conglomeratic limestone at the base of the "upper Sundance" suggests a disconformity. During "upper Sundance" time the seas spread again over the area and highly glauconitic sandstone was deposited.

The Jurassic sea had apparently completely withdrawn by the end of "upper Sundance" time, and continental sediments of the Cloverly and Morrison formations were deposited. The change from marine to nonmarine conditions was gradual in this area, and no sharp break is present to mark the boundary. The presence of fresh water invertebrate fossils, dinosaur remains, and chara oogonia at several localities in central Wyoming attest to a continental origin for these strata.

A readvance of the sea occurred at the end of Cloverly time and the black fissile shale of the Thermopolis shale was deposited. Although no fossils were found in the lower black shale in the Du Noir area, it is known to contain marine foraminifera in other areas. The Muddy sandstone at the top of the formation probably represents a regression of the sea near the close of Thermopolis time. Sparse oysters and other pelecypods, fish teeth, and leaves have been reported from the Muddy sandstone at various localities in the Wind River Basin (Love, 1948, p. 107). The seas were again widespread during late Lower Cretaceous time and the Mowry shale was deposited. Sparse fish scales and poorly preserved pelecypods were the only fossils observed in the Du Noir area; ammonites have been found in other places. The presence of bentonite indicates that volcanism occurred during Mowry time.

During early Upper Cretaceous time the area was alternately emergent and submergent, as evidenced by marine sandstone and shale interbedded with lignite and coal beds in the lower part of the Frontier formation. The widespread marine sedimentation represented by the Cody shale continued in the northwestern part of the Wind River Basin at least into middle and probably late Niobrara time. The Cretaceous sea, however, had started to retreat eastward from the Jackson Hole area in middle Niobrara time whereas in central Wyoming the change to nonmarine conditions took place in Eagle time. The regression was most probably caused by regional uplift in areas to the west of Jackson Hole, and marked the close of marine sedimentation in this region. Thousands of feet of continental sediments accumulated over wide areas in central Wyoming before the close of the Cretaceous period, but, if they were deposited in the Du Noir area, they were removed by erosion prior to lower Eocene time.

Because there are no Upper Cretaceous strata younger than the Cody shale in the Du Noir area, or in adjacent areas to the east, the Late Cretaceous history of the northwestern part of the Wind River Basin is not adequately known. Throughout many regions in Wyoming, however, it has been noted that the first pulsations of the Laramide Revolution occurred before the close of the Cretaceous period as evidenced by unconformities and conglomeratic beds within the Upper Cretaceous sequence. In the Jackson Hole region to the west Love, et al. (1951b) observed a conspicuous unconformity at the base of the Lance(?) formation (uppermost Cretaceous) as well as thick massive conglomerate beds within the formation.

Cenozoic time

The presence of Paleocene strata in the Du Noir area has not been definitely established, but the unit referred to in this report as the Fort Union(?) formation is provisionally assigned a Paleocene age because of its structural relationships and the nature of its conglomerate, which consists entirely of Mesozoic rock fragments and are therefore unlike any of the conglomerates of known lower Eocene age. The Fort Union(?) strata, sharply infolded and faulted with the Mowry shale (fig. 11) along the south flank of the Dubois anticlinal complex, were most probably derived during the initial stages of development of the anticline; the first evidences of Laramide folding in the Du Noir area therefore occurred prior to the deposition of these beds.

The Wind River and Washakie Ranges were folded to mountainous proportions and subsequently deeply eroded prior to the deposition of the lower Eocene Indian Meadows formation. Along the south flank of the Du Noir anticline and south face of Spring Mountain coarse conglomerate of the Indian Meadows formation lies horizontally upon steeply inclined Paleozoic and Mesozoic strata (fig. 13). At these localities the conglomerate consists entirely of Paleozoic rock fragments, but farther out in the basin, as along the north edge of the Wind Ridge fault, some extremely weathered Precambrian rocks are present in the conglomerate, indicating that at least some part of the Precambrian core of either the Washakie Range or Wind River Mountains, or both, had been exposed. Eocene rocks, undivided, were deposited over a surface of considerable relief along the north flank of the Wind River Mountains (fig. 17). These strata are nearly flat-lying, as is the Wind River formation, which attains a maximum northward dip of 4° , on the north side of the Wind River. Thus, only a minor amount of uplift of the Wind River Mountains could have occurred since early Eocene time. This is likewise true for the Washakie Range inasmuch as the original essentially horizontal position of the overlapping Indian Meadows conglomerate has been preserved to the present time. The Eocene rocks along the northeast flank of the Wind River Mountains may have been subjected to small scale normal faulting as shown by the probable fault in secs. 22 and 27, T. 42 N., R. 108 W. although the evidence for faulting here is by no means conclusive. Definite evidence of an unconformity, either angular or erosional, between the Indian Meadows and Wind River formations is lacking in

the Du Noir area but in adjacent areas to the east Love (1939, p. 58, ff.), found evidence indicating that there was folding at the end of Indian Meadows time, followed by a period of erosion.

The center of the synclinal basin, however, was intensely deformed during late early Eocene time, apparently between the time that the middle variegated sequence of the Wind River formation was deposited and prior to the deposition of the overlying massive conglomerate of the Wind River formation. This deformation was manifested by large-scale thrust faulting in the northern part of the synclinal basin and along the south flank of the Washakie Range, and by at least renewed folding and faulting of the Dubois anticlinal complex. Strata in the middle variegated sequence of the Wind River formation dip southward off the south flank of the anticline as much as 32° , essentially parallel to the underlying Mesozoic rocks, whereas the overlying conglomeratic sequence on top of the fold is nearly horizontal (fig. 17); along the north side of Tappan Creek, however, these two sequences are conformable. None of the pronounced overturning that is present in the Mesozoic rocks along the south flank of the Dubois anticlinal complex was observed in the middle variegated sequence at the southeast end of the fold, but these latter rocks were involved in the faulting. Nearly all of the thrust faults east of Horse Creek involve lower Eocene strata and the syncline lying north of the Little Alkali Creek fault is clearly reflected in the Indian Meadows formation. These strata, however, do not appear to have been affected by the North EA fault. West of Horse Creek much of the area is covered by the upper variegated sequence of the Wind River formation, which does not anywhere appear to be deformed.

The age of the normal faulting along the north edge of Spring Mountain and at the east end of Horse Creek Basin could not be definitely ascertained. No Tertiary rocks are involved in the faulting except at the extreme eastern end of the mountain where Indian Meadows conglomerate appears to have been faulted. The ages of the Burroughs Creek and the Wiggins Fork Trail faults are likewise not known. It is concluded, however, that they were probably formed sometime during the initial stages of folding of this large anticlinal uplift, which was prior to early Eocene time.

Erosional unconformities are thought to be present both at the base and at the top of the Tepee Trail formation, but there appears to be no angular discordance between this formation and either the underlying Wind River formation or the overlying Wiggins formation. In areas to the east, however, Love (1939, p. 77, 83) noted that deformation had occurred at the end of middle Eocene time and also at the close of late Eocene time.

The first noticeable evidence of Tertiary volcanism in the Du Noir area is in the tuffaceous strata of the greenish gray and drab sequence of the Wind River formation. Younger beds contain progressively more volcanic material, and the upper part of the Tepee Trail formation and in the Wiggins formation consist entirely of coarse volcanic conglomerate, interbedded with tuff. These strata are crudely stratified, and many of the boulders are rounded, suggesting that much of the volcanic debris was reworked by streams. Most of the pyroclastic material was probably derived from the large Tertiary volcanic centers situated along the eastern border of Yellowstone National Park.

The Quaternary history of the region is discussed in the following Chapter on "Geomorphology."

GEOMORPHOLOGY

General Statement

Most of the main valleys in the northwestern part of the Wind River Basin have been extensively glaciated and contain an abundance of glacial deposits. Blackwelder (1915) studied many of these deposits in the course of his investigations of the Quaternary history of west-central Wyoming. Richmond (1941, 1948) also examined glacial features in the northwestern part of the Wind River Mountains. The most recent work on the glacial and erosional features in the region has been done by J. F. Murphy (unpublished manuscript, U. S. Geological Survey) along Bull Lake Creek and adjacent drainages, approximately 35 miles southeast of Dubois. As a result of these studies the relative ages of the various erosional and glacial periods have, for the most part, been accurately determined. In those areas the morainal debris of one glacial period is, in many places, clearly superimposed on the deposits of an older glacial or erosional period. In some places, too, outwash deposits can be traced into terrace gravels. The moraines contain an abundance of large resistant granite boulders and, though weathered in varying degrees, most are still largely intact and continuous. Therefore, more or less definite criteria, such as the composition of the gravels, topography, and degree of modification by erosion and weathering, have been established by means of which the deposits of one glacial stage can be differentiated from those of another. Many of these criteria are utilized in the interpretation of the geomorphologic history of the Du Noir area.

There are several reasons, however, why the distinguishing characteristics of the different deposits in the Bull Lake region may not be applied with the same degree of assurance in the determination of the various glacial stages in the Du Noir area or in the correlation of these deposits with those farther to the southeast. The following characteristics are generally true of the glacial deposits in the Du Noir area: (1) the moraines are largely discontinuous; (2) there is no well-defined superimposition of deposits; (3) the moraines are likely to be more easily modified by erosion since they consist chiefly of volcanic conglomerate fragments which have disintegrated to form a gravel composed of much smaller rock fragments and with a large proportion of fine-grained material derived from the conglomerate matrices; (4) there is an almost complete lack of recognizable terminal moraines; (5) the rock fragments in the various moraines are not perceptibly weathered; and (6) the composition of the gravels appears to have little significance since the variations can be accounted for largely by the local differences in source rock.

Probably the most significant difference between the moraines of the two regions is the relative amounts of erosion and weathering that have taken place. Because the moraines in the Bull Lake region consist predominantly of large granite boulders they have withstood erosion to a greater degree than the moraines in the Du Noir area, where, because of the larger percentage of finer-grained debris, they have apparently been more easily modified. The almost complete absence of terminal moraines in the mapped area can be partly explained by the relatively greater amount of erosion that has taken place. Another contributing factor for the absence of such features at the lower end of the Du Noir Valley may be, however, that the erosive power of the combined drainage of the Du Noir and Wind Rivers was sufficient to erase nearly all traces of the terminal moraines, while, in comparison, the smaller streams farther to the southeast did not have the requisite erosive power. Further, when the advancing Du Noir Valley glaciers reached the Wind River at least some of the debris pushed up in front of the glacier must have been carried off immediately downstream and the terminal moraines were thus relatively reduced in size. The type of bedrock underlying the glacial deposits also has a direct influence on the ease and degree to which the moraines will be modified; in the Du Noir Valley the moraines were deposited for the most part on soft, easily eroded Tertiary sediments.

The quantitative effects that these factors may have had on the moraines in the Du Noir area relative to the same factors operating in the valleys farther to the southeast are not known. The interpretation of the glacial history in the mapped area, based of necessity on criteria established in other regions, is therefore tentative and until more data are obtained in the entire northwestern portion of the Wind River Basin more definite conclusions cannot be drawn. The same difficulties are not encountered in the classification of the terrace deposits because the various levels are more continuous and are differentiated by their relative heights above the present stream levels. The more precise determination of the erosion cycles in the Du Noir area aids to some extent the interpretation of its glacial history.

The following erosion cycles and glacial stages, listed from oldest to youngest, and their distinguishing characteristics were determined by Blackwelder (1915, p. 307-333) and have provided the basis for all subsequent studies of the Quaternary deposits in this region:

Black Rock erosion cycle. Terrace surfaces generally from 500 to 800 feet above the present stream drainages.

Two older erosion cycles, the Union Pass and Fremont cycles, were also recognized by Blackwelder (1915, p. 310-312), but they are more or less confined to the high mountain areas and are not discussed here. It may be, however, that the highest and oldest cycle, the Fremont, is represented by the plateau-like surface which now forms the general summit level of the Absaroka Mountains at elevations of approximately 11,000 feet. Although little active glaciation is going on at the present time, small permanent ice fields such as the Du Noir glacier still persist at higher elevations along the southern margin of the Absaroka Mountains. Cirques and hanging valleys high up on the cliffs of the Wiggins formation are indicative of very late stages of glaciation.

Buffalo glacial stage. Moraines exist only in the form of remnants on flat-topped divides or isolated hills. Canyons have been excavated, not only through the deposits, but 200 to 1,000 feet into the underlying bedrock. From the distribution of the deposits it is evident that the Buffalo ice covered a much larger area than the Bull Lake and Pinedale glaciers, which were mainly confined to valleys.

Circle erosion cycle. Includes terrace surfaces that are generally from 100-200 feet above present drainage levels, but some may be as much as 400 feet. Bull Lake moraines rest upon the Circle terraces, and the terrace gravels may consist largely of outwash deposits of this glacial stage.

Bull Lake glacial stage. Moraines are still largely intact, but modified by erosion to a greater degree than the Pinedale moraines. In places streams have cut rather wide flat-bottomed valleys through the terminal moraines. Large boulders are not nearly as abundant on the surface as in the Pinedale moraines.

Lenore erosion cycle. Includes the shallow inner trenches of the Wind River and its tributaries. Surfaces are generally 10 to 30 feet above present stream levels and were developed prior to the deposition of moraines of the Pinedale stage of glaciation.

Pinedale glacial stage. Morainial deposits are rough and fresh in appearance and large boulders predominate on the surface. Moraines are generally intact and continuous.

Post-glacial erosion. Includes post-glacial terracing and erosion of Recent age.

Erosion cycles

Black Rock cycle

Table Mountain, a conspicuous flat-topped prominence approximately 2 miles long and from $\frac{1}{4}$ to $\frac{3}{4}$ mile wide near the southeast corner of the area, is the highest erosion surface in the Du Noir area, with the possible exception of the Fremont cycle, and has been described by Blackwelder (1915, p. 312) and Love (1939, p. 116) as being representative of the Black Rock cycle of erosion, which preceded any known glaciation in the region. The elevation of the top of the mountain is more than 8,000 feet, approximately 1,400 feet above the adjacent Wind River Valley floor. Comparable features, such as Coulee and North Mesas (Love, 1939, p. 116) are present in adjacent areas to the east, but no other remnants are present in the Du Noir area.

The surface of Table Mountain has very little relief and slopes gently from north to south. Table Mountain is veneered with a smooth pavement of coarse cobble and boulder debris which is, for the most part, deeply weathered and overgrown with grass. The terrace deposit is best observed at the northeast corner of the mountain where landslide material has broken away to expose the gravels as well as the underlying Tertiary strata. At this locality the gravels are 30 feet thick and composed entirely of rounded to subrounded volcanic cobbles and boulders as much as 2 feet in diameter. At the south end of the mountain the upper surface more closely approximates one of true erosion, since the gravels form only a thin veneer and contain a conspicuous amount of Paleozoic rock fragments, which were probably derived in large part from the underlying folded conglomerate in the Indian Meadows formation.

Two isolated terrace surfaces, one in the SE $\frac{1}{4}$ sec. 25, T. 42 N., R. 107 W. on the north side of Tappan Creek (fig. 16) and the other near Dubois triangulation station, lie approximately 500 feet above the present drainages and are also believed to be remnants of the Black Rock cycle. However, since their heights relative to present drainage is much less than that of Table Mountain, they are not contemporaneous with the Table Mountain surface but represent a different level similar to those described by Blackwelder (1915, p. 315-316) as follows: "Between the Black Rock cycle and the next one clearly discriminated [Circle] there may well have been one or more cycles now represented by terraces visible here and there in the Wind River and Green River badlands. These are, however, but little known and appear not to have left notable marks in any but the softest strata." At the Tappan Creek locality the gravels are about 10 feet thick and consist chiefly of rounded volcanic cobbles as much as 1 foot in diameter with a very minor amount of Paleozoic rocks. No Precambrian rocks were observed. At the Dubois triangulation station locality the deposit likewise consists of chiefly volcanic rocks but, in addition, contains rounded cobbles of Precambrian quartzite. Here the volcanic rocks are, in large part, very dark-colored and dense, of a type not conspicuous in the other terrace deposit. Although the composition of the gravel varies, the two remnants are believed to be contemporaneous, but with different sources of debris, one from the Horse Creek-Tappan Creek drainage and the other from the upper Wind River drainage.

Circle cycle

The Circle cycle of erosion is represented in the Du Noir area by terrace levels that are from 100 to 300 feet above the present drainage. It is evident that two or more sub-cycles occur within the major cycle, however.

Along the Wiggins Fork River, near the mouth of Little Alkali Creek, are two distinct levels, 100 feet and 200 feet, respectively, above the present river channel (fig. 27). The type area for the Circle terraces is a few miles downstream from Little Alkali Creek along the North Fork of the Wind River where Blackwelder (1915, p. 316) described only one prominent level standing approximately 150 feet above the river. The terraces near the mouth of Alkali Creek are covered by a thin veneer of unconsolidated gravels underlain for the most part by conglomerate of the Indian Meadows formation from which most of the Paleozoic and Precambrian rock fragments in the deposits were derived. The uppermost deposit is comprised of 75 percent volcanic, 5 percent Precambrian, and 20 percent Paleozoic rock fragments. The lower terrace contains only 10 percent volcanic rocks, with the remainder equally divided between Paleozoic and Precambrian rocks. In contrast, the present river bed is almost wholly comprised of volcanic debris.



Figure 27. Terraces of the Circle cycle of erosion along west side of Wiggins Fork River near mouth of Little Alkali Creek. The two levels are approximately 100 feet apart.

On the south side of the Wind River, extending southeastward from Stony Point, the Circle cycle of erosion is represented by a well developed series of terraces which lie 150 to 250 feet above the river. Only the western end of this series is within the mapped area. All traces of the terraces have been erased from the north side of the river except for those at Stony Point and the surface upon which the Dubois airport was constructed. Although the detailed relationships between this terrace-building and the warm spring activity along the south side of the Wind River southeast of Harrison's Ranch were not worked out, it is clearly evident that the two were closely related.

Southwest of Harrison's Ranch, NW $\frac{1}{4}$ sec. 32, T. 42 N., R. 107 W., the gravel consists chiefly of Precambrian quartzites and granites with a minor amount of volcanic and Paleozoic rocks, indicating that most of the material at this point was derived from the Warm Spring Creek drainage. On the whole, however, where the deposits were not appreciably affected by debris from local tributary streams but were derived chiefly from the master stream drainage, they contain a large proportion of volcanic rocks. In a cut along the road leading from Highway 287 to the Dubois airport the gravels are nearly 90 percent volcanic with Paleozoic rocks comprising the remainder. About $\frac{1}{4}$ mile westward, at the west end of this terrace remnant and lying about 60 feet lower than the level of the airport, is a small outcrop of terrace gravel which has been cemented into a conglomerate by carbonate material that was derived from the warm spring activity farther upstream. This conglomerate, which is comprised chiefly of volcanic rocks with some Paleozoic and Precambrian rock fragments, is at the same level as those directly opposite on the south side of the river which bevel the upturned redbeds in the Chugwater formation. Further evidence of cementation of the terrace gravels by travertine is present around the mouth of Warm Spring Creek where the conspicuous travertine deposits have incorporated many pebbles and cobbles. No distinct terrace levels were observed north of Dubois along Horse Creek, but some of the gently inclined gravel-capped slopes along the east side of the creek, the lower ends of which are about 200 feet above the present valley floor, may be representative of the Circle cycle of erosion.

The broad benchland north of Stony Point is also considered to be a remnant of the Circle terrace, although it occurs approximately 300 feet above the Wind River, slightly higher than those across the river and farther downstream toward Dubois (fig. 28). Core drill data obtained from the U. S. Bureau of Reclamation indicate that the gravel underlying this surface is about 200 feet thick near the south end of the terrace. It consists of boulders and cobbles with much sand and silt. Clayey material near the base may have been reworked from the Wind River formation or may have been deposited by ponded glacial melt waters. Rounded fragments of volcanic rocks constitute about 80 percent of the debris, while Paleozoic rock fragments make up the remainder. The gradual increase in altitude of the surface northward changes to an abrupt steepening at the north end of the terrace. The slope at the north end contains volcanic cobbles as much as 40 feet above the terrace surface. Paleozoic rock fragments occur farther up the slope and are probably residual gravels derived from underlying conglomerate in the Wind River formation. Because of the thickness of this deposit at Stony Point true terrace deposits are believed to constitute only the upper few feet of the gravels with the remainder originating as glacial debris. Another terrace level, only 135 feet above the Wind River, is present at Stony Point (fig. 28). This surface contains very little detrital material and is essentially one of erosion.

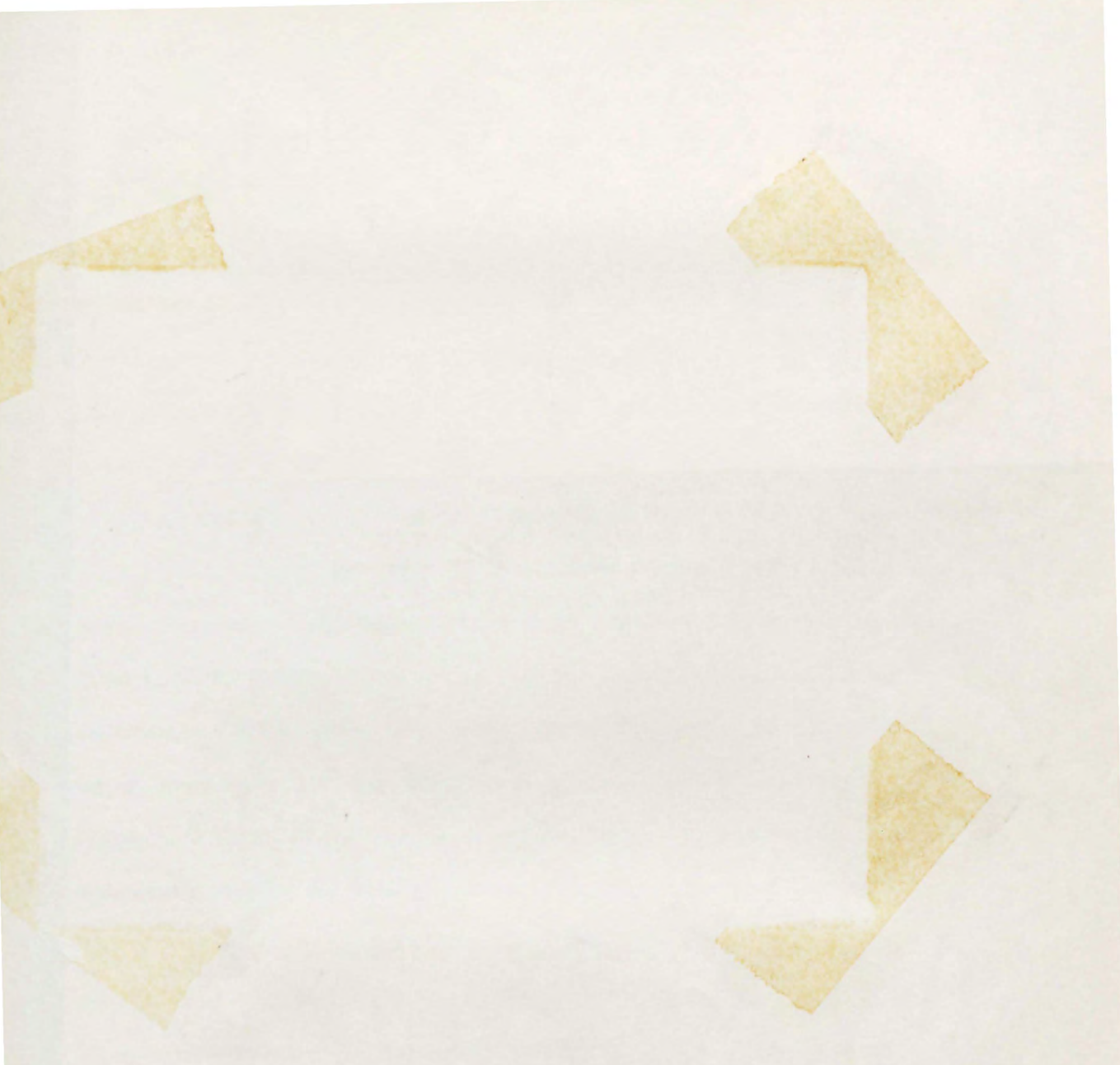


Figure 28. View looking east toward Stony Point. Wind River flows through gap near right side of picture. Terrace in foreground is representative of Lenore cycle of erosion, while those on skyline at the center and left side of photo are two different levels of the Circle cycle.

Two distinct terraces were developed along Warm Spring Creek near the abandoned Du Noir Tie Camp. The upper level is 130 feet above the present stream channel and may represent a mountainward extension of the Circle terrace, while the lower level, 70 feet above the creek, does not apparently represent either the Circle cycle or the younger Lenore cycle. The gravels in the upper deposit consist chiefly of well rounded cobbles of Precambrian quartzite with a very minor amount of volcanic rock fragments. The deposit is best exposed along the road on the north side of Warm Spring Creek. Along the south edge of this upper terrace the gravel is 10 feet thick and is underlain by arkose and soft gray clay shale of the Eocene rocks, undivided. From here northward steep slopes descend into the Crooked Creek drainage, and the table-like surface forms the drainage divide between Crooked Creek and Warm Spring Creek in this area. The lower terrace deposits contain a conspicuous amount of granite cobbles in addition to a minor amount of Paleozoic and volcanic rock fragments. Along the north bank of the creek, SW $\frac{1}{4}$ sec. 28, T. 42 N., R. 108 W., is a small outcrop of Tertiary arkose, indicating that the entire series of terraces is underlain by Eocene rocks, undivided. According to J. D. Love (oral communication) Eocene rocks on the Continental Divide, in the vicinity of Fish Lake Mountain near the headwaters of Warm Spring Creek, contain conglomerate with fragments of both quartzite and volcanic rocks. C. L. Baker (1946, p. 581) reports quartzite boulder beds resting on Precambrian rocks $\frac{1}{4}$ miles south of the Du Noir Tie Camp. These strata would provide a ready source for the material in the terrace deposits. The two terrace levels probably represent successive stages in the downcutting of lower Warm Spring Canyon. Evidence is too fragmentary to attempt a specific correlation of these terraces with those near the mouth of Warm Spring Creek.

Lenore cycle

Remnants of the Lenore terrace occur west of Harrison's Ranch on the south side of the Wind River, both east and west of Stony Point on the north side of the river (fig. 24) and in the broad alluvial plain near the confluence of the Wind and Du Noir Rivers. These terraces range in elevation from 15 to 35 feet above the present Wind River channel. The deposits are generally finer-grained than the older Circle deposits, but as in the majority of the Circle terraces, volcanic rocks are the dominant constituents. There are two distinct levels downstream from Stony Point; the lower and most conspicuous one is 25 feet above the river and the other is 10 feet higher. The Lenore Plain is probably also represented by the relatively broad alluvial-covered surfaces extending along the north side of the Wind River from Stony Point to the southeast corner of the mapped area, but since these surfaces are covered largely by locally derived material from the easily-eroded Tertiary strata, they have been mapped as alluvium.

Post-glacial erosion

Downstream from Stony Point the Wind River has become entrenched 20 feet or more below the level of the terraces of the Lenore cycle of erosion. The present flood plains are relatively narrow. Upstream from Stony Point, however, the flood plain becomes very broad and flat and remains so throughout the Du Noir River Valley. The Wind River near the western edge of the mapped area is again confined to a relatively narrow steep-walled valley. South of the mouth of the Du Noir River the remnants of the Lenore terrace rise 10 to 15 feet above the present flood plain.

The Du Noir River Valley is unique in that it is the only one within the mapped area in which a continuous broad and flat flood plain has been developed during the post-glacial period (fig. 29). The alluvium consists chiefly of clay and silt with a large amount of organic material. Miner and Delo (1943, p. 137) concluded that the flat floor of the valley was once the bottom of a large lake, 300 feet deep, that was ponded behind glacial moraines of the Pinedale stage of glaciation which had completely blocked the mouth of the valley, and that the sediments lying in the valley originated as lake silt. The writer did not find evidence to support this conclusion; a more detailed appraisal of this possibility, however, is presented in the discussion on glaciation.

An alternative explanation for the development of the flat-floored valley, and the one favored by the writer, is that of lateral planation by the Du Noir River. The local base level of the combined drainage of the Wind and Du Noir Rivers is the narrow gap at Stony Point through which the Wind River now flows (fig. 28). The gap is cut in resistant Tensleep sandstone, and limestone and chert of the Phosphoria formation whereas the Wind River and Du Noir River Valleys upstream from Stony Point are eroded in soft Tertiary strata. The rate of downcutting of the valley is directly controlled by the rate of downcutting at Stony Point. As the Tertiary rocks are much more easily eroded, the Du Noir River has essentially reached grade and its erosive power is directed toward lateral planation of the valley. North of the Cross Ranch the river has been crowded to the west side of the valley by the large alluvial fan developed around the mouth of Sixmile Creek. Conspicuous alluvial fans are also present at the upper end of the valley near the confluence of the East and West Forks.

Perhaps a more difficult problem is to explain why, near the western edge of the mapped area, the Wind River Valley, which is also cut in Tertiary strata, is relatively narrow in comparison to the Du Noir River Valley. This part of the Wind River Valley is choked with much glacial debris and it is concluded that the erosive power of the river is directed toward downcutting of the morainal boulder debris and maintaining a relatively steep gradient.

Glacial stages

Buffalo stage

The lateral moraines which occupy the drainage divides on both sides of the Du Noir Valley (fig. 30) are similar in many respects to the deposits described by Blackwelder (1915, p. 328-333) as belonging to the Buffalo stage of glaciation. Supporting this correlation are the height of the moraines above the present stream drainage and the fact that the associated terminal moraine has been almost completely eroded away. To the writer's knowledge, however, no Buffalo moraines have previously been reported in this region.

The deposits are at elevations of 8,000 to 8,100 feet, approximately 600 to 700 feet above the present level of the Du Noir River. The best exposure of the moraine on the east side of the valley is found along Fourmile Creek above Larsen's Ranch in the SW $\frac{1}{4}$ sec. 24, T. 43 N., R. 108 W. (fig. 31). The moraines are extremely hummocky and contain numerous small ponds. They are composed of an unconsolidated mass of boulders and cobbles of Tertiary volcanic rocks and Paleozoic rocks in a matrix of finer material. No striae or polish were observed on any of the rock fragments, and most do not appear to be appreciably weathered.

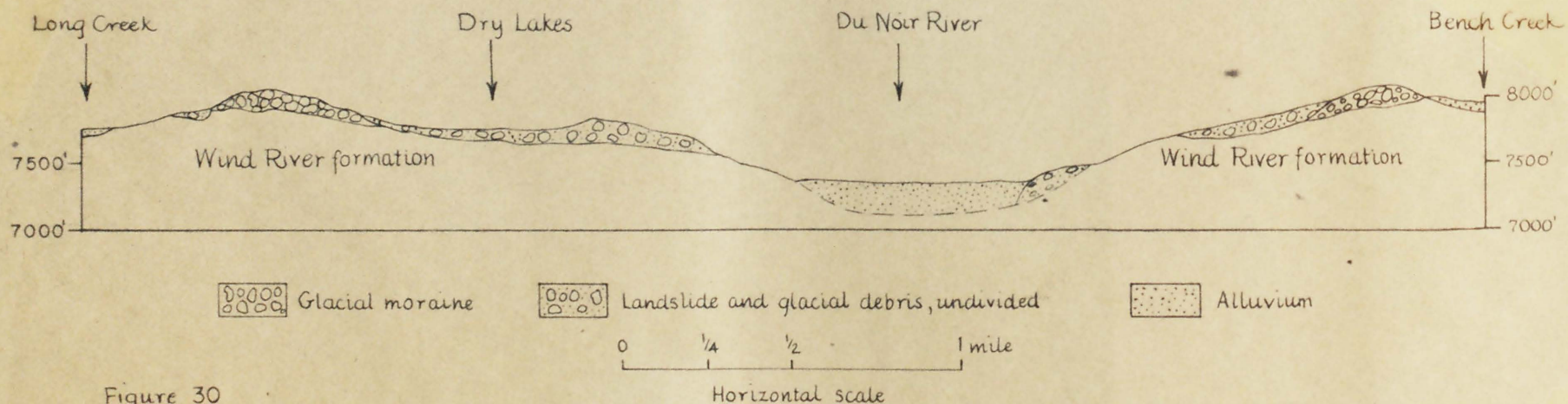


Figure 30

EAST-WEST PROFILE ACROSS DU NOIR VALLEY SHOWING RELATIONSHIPS BETWEEN GLACIAL MORAINES AND PRESENT VALLEY FLOOR



Figure 31. Lateral moraine of Buffalo stage of glaciation along Fourmile Creek, SW $\frac{1}{4}$ sec. 24, T. 43 N., R. 108 W. Ramshorn Peak in background.

The eastern end of the glacial deposit on the northeast flank of the Wind River Mountains west of Harrison's Ranch forms a high rounded hill and its westward extent is marked only by smooth boulder-strewn slopes. Tertiary volcanic boulders comprise 70 percent of the deposit, whereas Paleozoic rocks make up 25 percent and Precambrian rocks 5 percent. The presence of volcanic boulders of a type not found in place south of the Wind River indicates that much of the debris most probably was derived from the Du Noir River drainage. The deposit is slightly lower in elevation than the lateral moraines, but is still about 600 feet above the present level of the Wind River. Isolated outcrops of gravel in secs. 15 and 23, T. 42 N., R. 108 W. also contain conspicuous amounts of volcanic rocks and are thought to be morainal deposits. These deposits lying on the south side of the Wind River are believed to be remnants of a terminal moraine and to be correlative with the lateral moraines discussed above.

Extensive glaciation is also believed to have occurred during the Buffalo stage of glaciation in the Horse Creek-Wiggins Fork region. On the north flank of Spring Mountain the moraines are at elevations of as high as 8,500 feet, nearly 1,400 feet above the adjacent Wiggins Fork Valley one-half mile to the east. These are characterized by low ridges which are elongated parallel to the flank of the mountain and probably represent a large lateral moraine. The debris consists chiefly of Paleozoic cobbles and boulders with a minor amount of volcanic rocks.

The highest glacial deposit observed in the Horse Creek-Wiggins Fork area occurs near the top of the high ridge north of the Horse Creek Ranger Station at an elevation of 8,800 feet, about 1,000 feet above the present level of Horse Creek. These gravels contain Precambrian, Paleozoic, and volcanic rocks in about equal amounts. Granite boulders as much as 25 feet in diameter are present. Other prominent hills in the area, such as the one near the junction of secs. 18, 19, 29, and 30, T. 43 N., R. 106 W., also contain remnants of glacial moraines; many of these were too limited in extent to be shown on the geologic map.

Horse Creek Basin, with elevations ranging from 8,100 to 8,200 feet, has gently rolling topography with large alluvial flats separated by ridges composed of coarse boulder debris. Many small lakes occur in the basin. Near its eastern end the terrain is more hummocky and irregular, with gullies as much as 100 feet deep cut into the deposits. The terrain of the area lying between the east edge of Elkhorn Ridge and Wiggins Fork Canyon is also mildly hummocky, with a few low ridges elongated parallel to the Wiggins Fork River. Erratics of Bighorn dolomite are common in (fig. 32) this area, and many outcrops of Precambrian granite exhibit planed and faintly grooved surfaces. The deposits in Horse Creek Basin appear to have originated as a ground moraine.



Figure 32. Erratics of Bighorn dolomite
resting on the Precambrian along east
side of Charley Creek, SE $\frac{1}{4}$ sec. 9, T. 43 N.,
R. 106 W.

The general distribution of these high-level glacial deposits suggest that during the Buffalo stage large glaciers descended both the Wiggins Fork and Horse Creek Valleys and probably coalesced in Horse Creek Basin. The ice sheet had a minimum thickness of 400 feet and filled the valleys to heights ranging from 8,500 to 8,800 feet in elevation. No terminal moraines of the Buffalo glaciers were observed in either valley. The precipitous Wiggins Fork Canyon has been cut since the deposition of the moraines.

Bull Lake and Pinedale Stages

Glacial moraines younger than the Buffalo stage are present in the Du Noir area, but no definite criteria were found to enable discrimination between the two younger stages. They are therefore discussed as a single topic.

The glacial deposits which extend northwestward from Stony Point along the east side of the Du Noir Valley appear to represent a younger glacial stage than the moraines correlated with the Buffalo period (fig. 29). Although much of the debris consists of small well-rounded water worn fragments, there are sufficient numbers of large boulders to attest to its glacial origin. This occurrence has been referred to as a lateral moraine of the Bull Lake stage of glaciation by both Blackwelder (1915, p. 327) and Miner and Delo (1943, p. 134). No terminal moraines are in evidence, but the thick sequence of gravels that underlies the Circle terraces north of Stony Point may possibly represent a part of this younger series of moraines. Although Bull Lake moraines commonly rest upon the terraces of the Circle cycle of erosion, Blackwelder (1915) found that in places the two types of deposits were nearly contemporaneous, with the terrace gravels composed largely of outwash material from the glacial moraines.

The Bull Lake glacial deposits have been rather extensively modified by erosion. The downcutting by the Wind River at Stony Point is about 300 feet. The lateral moraine could be traced for only a short distance upstream along the east side of the Du Noir Valley, but because it overlies soft Tertiary strata it may have been so altered by slumping and erosion as to render it unrecognizable as a moraine. Neither were any certain traces of moraines found along the west side of the valley upstream from Spencer's Ranch, but the gravel deposits directly west of the ranch may be remnants of a Bull Lake moraine.

The glacial deposits which lie along the Wind River west of its junction with the Du Noir River, and extending to the west edge of mapped area, are still largely intact and the conspicuous hummocky topography has been preserved. For these reasons they appear to be younger than any of the glacial deposits at the lower end of the Du Noir Valley and therefore may be representative of the Pinedale glacial stage. This moraine, which forms a large lobe, is thought to have a direct influence on the course of the Wind River as it bends to the south at the Long Creek Ranch. The deposits extend from the present level of the river to about 300 feet above the river. The most conspicuous rock type observed was a dark brown to black vesicular basalt of a type not common in the volcanic rocks derived from the Du Noir River drainage, but more like those from the upper Wind River Valley in the vicinity of Lava Mountain. The relationships of this moraine to probable glacial deposits upstream on the Wind River were not studied, but it is believed to be the terminal moraine of a glacier which extended eastward only to the western edge of the Du Noir Valley.

Miner and Delo (1943, p. 134-135) reported a lateral moraine, to which they assigned a Pinedale age, approximately 50 feet above the present valley floor along the east side of the Du Noir Valley. They also mentioned glaciers as having existed in the Fourmile, Five-mile, and Sixmile Creek drainages during this period. The writer did not recognize any evidence that Pinedale glaciation occurred either in the Du Noir Valley or in its tributary streams. Miner and Delo (1943, p. 137) concluded, furthermore, that the Du Noir Valley was completely blocked by the Pinedale moraines behind which was impounded a large lake, 300 feet deep, that drained into Long Creek through the vicinity of Dry Lakes on the west side of the valley and into Bench Creek and Wagon Gulch on the east side of the valley. No evidence of channels were observed in these areas by the writer. The elevation of the Dry Lakes is between 7,700 and 7,800 feet. If a lake had maintained this level, then it would have extended up East and West Fork Canyons one-half mile or more. No evidence of lacustrine deposits was observed in those canyons, although it is conceivable that such deposits could now be completely eroded away. Terrace remnants of the Lenore cycle of erosion, presumably older than the Pinedale stage of glaciation do not appear to have been disturbed by glaciation along the Wind River west of Stony Point.

Most of the glacial deposits that lie along Horse Creek are representative of either the Pinedale or Bull Lake, or both, stages of glaciation. Some lie at or near the present stream level, but others occur as much as 300 to 400 feet above the stream.

North of Utzinger's Ranch, on the steep west slope of upper Horse Creek Valley, the glacial deposit is only a thin veneer of coarse boulder debris. Similar deposits also occur along the west side of Horse Creek below its junction with Burroughs Creek. The glacial moraine along the east side of Horse Creek, extending northwest of Livingston's Ranch, forms a high rounded hill and contains boulders as much as 6 feet in diameter.

The deposits which extend northward along Horse Creek from the vicinity of the Rocking Chair Ranch to the EA Ranch have in part been extensively eroded and modified. The topography is mildly hummocky and irregular and the general surface slopes toward the present level of the valley. The broad meadowland that extends southward from the EA Ranch for about 2 miles and through which Horse Creek now follows a meandering course was probably developed while the stream was eroding through the morainal debris at its lower end. In some parts of this locality it is difficult to distinguish glacial debris from residual gravels derived from the lower Eocene conglomerate which underlies much of the area, but in general the glacial gravels contain volcanic rock fragments and the residual gravels do not. Further, there is commonly a pronounced change in topography from the relatively smooth grassy hills underlain by lower Eocene conglomerate to the hummocky terrain of glacial debris. The most convincing evidence for the glacial origin of these gravels along Horse Creek is the moraine southeast of the EA Ranch at the upper end of Little Alkali Creek. Here the deposit forms a series of low ridges which parallel the valley slopes for a short distance and swing around convex downstream in the middle and southeasternmost portions of the moraine. Small-scale knob and kettle topography is exhibited. At its northwestern end the deposit lies approximately 200 feet above the adjacent Horse Creek Valley. The southernmost exposures of glacial debris in Horse Creek Valley are considered to be parts of a terminal moraine, which is still relatively intact. The areas that lie both southeast and west of the EA Ranch represent topographically low

localities along the edges of the valley into which glacial ice pushed and subsequently deposited its debris. Most of the isolated outcrops farther upstream are remnants of lateral moraines and those on the valley floor around Utzinger's Ranch probably originated as a ground moraine.

It could not be definitely determined whether the moraines along Horse Creek were all developed during the same glacial period. The relatively small amount of modification of some of the deposits suggests that they belong to the Pinedale stage. Supporting this interpretation is the amount of downcutting since the close of the glacial period. Horse Creek, just above its junction with Burroughs Creek, has incised a sharp channel about 40 feet deep into the underlying bedrock in post-glacial time; some of the other deposits are at present stream level.

ECONOMIC GEOLOGY

Oil and Gas

The best opportunities for successful oil and gas exploration are in structures along the northern margin of the synclinal basin and along the south flank of the Washakie Range where most of the surface rocks are post-Paleozoic, and where the greatest amount of folding has occurred. Outcrops of rocks older than Tertiary are so limited, however, that a complete and accurate appraisal of potential oil traps is not possible from surface data alone. Only small portions of the anticlinal folds are visible and their western extensions are commonly completely obscured. The upper part of the Wind River formation, which overlies much of the Dubois anticlinal complex, does not reflect the structure of the underlying rocks and the northwestern extent and character of this large fold, and its relationships to the Du Noir anticline farther to the northwest cannot be determined from the Tertiary rocks at the surface.

Two wells have been drilled in the Du Noir area, both on the Dubois anticlinal complex: The Sinclair-Wyoming Oil Company Dubois Unit No. 1, NE NE NE sec. 11, T. 42 N., R. 107 W., in 1946 and the Stanolind Oil and Gas Company Dubois Unit no. 2, SW SW SW sec. 1, T. 42 N., R. 107 W., in 1949. Only the former encountered oil in commercial quantities and has produced 21,741 barrels of crude oil with an average API gravity of 20⁰; production for 1953 totaled 935 barrels (figures supplied by the Oil and Gas Leasing Branch, U. S. Geological Survey). No other wells have been drilled in the area since 1949, but both seismic and surface explorations have been conducted periodically by various oil companies.

The Dubois anticlinal complex has at least 100 feet of closure in the vicinity of the Dubois Unit No. 1 well. This well, which is situated near the surface crest of the fold, was drilled to a total depth of 3,430 feet and produces out of nearly vertical beds of the Phosphoria formation on the steep southwest limb of the fold. The Dubois Unit No. 2 well, with a total depth of 2,721 feet, is located north of the surface crest and was in a better structural position to test adequately the Tensleep sandstone, but proved to be dry in both the Tensleep and Phosphoria formations. Cross section Q-R-S, and the structure contours on pl. 4 show the writer's interpretation of the structural position of these two wells. The major fold plunges southeastward with probably as much as 2,500 feet of closure on that end, but the total amount of closure at its western end could not be determined.

The two anticlines which lie on the north flank of the Dubois anticlinal complex are almost completely concealed and consequently very little of the nature of these folds is known. The fold southeast of the EA Ranch is probably cut at depth by the Little Alkali Creek fault and appears to have no western closure. Only the sharply plunging eastern end of the fold along Brent Creek is visible in surface exposures. This fold, which lies farther down on the north flank of the anticlinal complex, may broaden westward into a large structure. Mowry shale is the oldest formation exposed. Much subsurface and geophysical data are needed before the structure of these two anticlines can be worked out and an evaluation of their oil and gas possibilities made.

The Du Noir anticline, in the northwestern corner of the area, is breached to the Darby formation, so that the possibilities of potential oil and gas reservoirs in the underlying rocks are limited. The axis plunges southward at its southeastern end but there is no apparent westward closure within the mapped area.

The broad belt of folded Paleozoic and Mesozoic rocks, which includes the Dubois anticlinal complex and associated folds and the Du Noir anticline, must continue through the central part of the mapped area. Because several anticlines extend into this region there is a possibility of the existence of local highs along the anticlinal trends. This region is therefore thought to be promising for geophysical exploration.

Within the mapped area the Nugget sandstone thins from a maximum of 120 feet at Dubois to a wedge-edge northwest of the Horse Creek Ranger Station. The formation is 65 feet thick in the Sinclair-Wyoming Oil Company Dubois Unit No. 1 well and only 31 feet thick along Horse Creek about one mile north of the EA Ranch. The wedge-edge therefore lies somewhere along the southwest flank of the Washakie Range, where the prevailing dips are southwestward. Thus it is likely that the pinchout is up-dip in some places and that the conditions are favorable for the stratigraphic accumulation of oil and gas.

Coal

Small amounts of coal have been mined in the Du Noir area in the past, but no mining operations are being carried on at the present time. Only a very few seams are of sufficient thickness to be of economic importance and surface exposures are so limited that detailed studies of coal were not made. The only available coal analyses are those published by Eldridge (1894, p. 62) who mentioned three samples that were collected in the upper Wind River region. The ranges of these analyses are the following: moisture, 7.73 to 9.95 percent; volatile matter, 41.39 to 44.89 percent; fixed carbon, 35.45 to 41.87 percent; ash, 3.88 to 12.90 percent; and sulfur, 2.83 to 4.77 percent. No localities were given, so they cannot be related to a specific coal bed. No samples were collected for analysis in the present study.

Several thin more or less continuous coal and lignite beds occur near the base of the Frontier formation. Some of these beds have been mined periodically for local use. A shallow caved shaft is present in the NW $\frac{1}{4}$ sec. 1, T. 42 N., R. 107 W., and a few prospect pits have been dug in its vicinity. A section of the Frontier formation, measured by Love, et al. (1947, p. 4-6) along the east side of Little Horse Creek near the abandoned mine, lists 2 coal beds, one occurring 163 feet and the other 206 feet above the base. The upper bed, which has been mined, is 3 feet thick and the lower is only 1 foot. The lignites, commonly interbedded with varying amounts of carbonaceous shale, occur within the same sequence and are as much as 6 feet thick. On the north side of Brent Creek, in sec. 28, T. 43 N., R. 107 W., several thin lignite beds, in part coaly, are found in limited exposures. Northwest of the EA Ranch, CW $\frac{1}{2}$ sec. 5, T. 42 N., R. 106 W., coal has been mined in an adit which penetrates the hillside for a distance of at least 50 feet. The coal bed, which is near the base of the Frontier formation, is 3 feet thick, but exposures are too limited for a more detailed study. A few prospect pits are present in the vicinity of the shaft.

At some localities on the north flank of the Wind River Mountains the Eocene rocks, undivided, contain carbonaceous shale and thin coal beds. In the past small strip and underground mining operations have been carried on in the NW $\frac{1}{4}$ sec. 25, T. 42 N., R. 108 W. At this locality the following section was measured:

TOP

| | |
|---|-----------|
| Shale, bluish-gray and brown; black coal partings | 7 inches |
| Shale, brown, carbonaceous; black coal partings | 12 inches |
| Claystone, gray, plastic | 7 inches |
| Shale, black, lignitic | 4 inches |
| Shale, gray and brown, carbonaceous, clayey | 18 inches |
| Coal, black, nearly pure | 24 inches |
| Shale, black to brown, lignitic | 12 inches |
| Claystone, gray, plastic | 6 inches |

BASE

The 24-inch coal bed is the seam that was mined. The bed has no great lateral extent for it was deposited in a narrow valley cut in Paleozoic rocks.

Minor amounts of brown carbonaceous shale with thin black coal partings are present in the lower drab tuffaceous sandstone unit of the Wind River formation along Long Creek. A 37-foot unit of interbedded carbonaceous shale and coal occurs at the top of the formation on the north side of White Pass in the NW $\frac{1}{4}$ sec. 6, T. 42 N., R. 107 W. The coal is in very thin beds, not more than a few inches thick, and none are of sufficient thickness to be of economic importance.

Bentonite

Bentonite is common in the Mowry and Frontier formations. Some beds appear to be quite pure, but most are impure, with varying amounts of shale, sand, tuff, and organic material. Thicknesses range from a few inches to as much as 14 feet, with the thickest beds occurring in the Frontier formation. No detailed studies of these bentonites have been made in the region and no analyses are available.

A bed of white bentonite and bentonitic claystone, 11 feet thick, forms the uppermost bed of the Wind River formation near the top of the steep hill on the north side of White Pass. It occurs directly above the 37-foot unit of carbonaceous shale and coal. This highly bentonitic zone can be traced northeastward from White Pass for about 3 miles along the contact between the Wind River and Tepee Trail formations, but because of poor exposures could not be studied in detail. X-ray analyses of samples from White Pass reveal that the rock contains montmorillonite and azeolite, with moderate amounts of quartz and traces of feldspar.

Gold

Gold-bearing stream deposits are present along Warm Spring Creek west of the former site of the Du Noir Tie Camp. Little data are available concerning the operations of Clark's placer mine, now abandoned, which was located on the north side of Warm Spring Creek near the tie camp. The placer mine was mentioned by Schrader (1913, p. 136 ff.) who stated that the gold seems to be derived from prominent quartz ledges reported to crop out extensively in the granite and schist near the headwaters of the stream. Another possible source of the gold is the quartzite pebble conglomerate of the Eocene rocks, undivided, along the north side of Warm Spring Creek. Love, et al. (1951a) reported flour gold in similar conglomerate of Paleocene age along the Gros Ventre River to the west. No placer mining operations are being carried on in the region at the present time.

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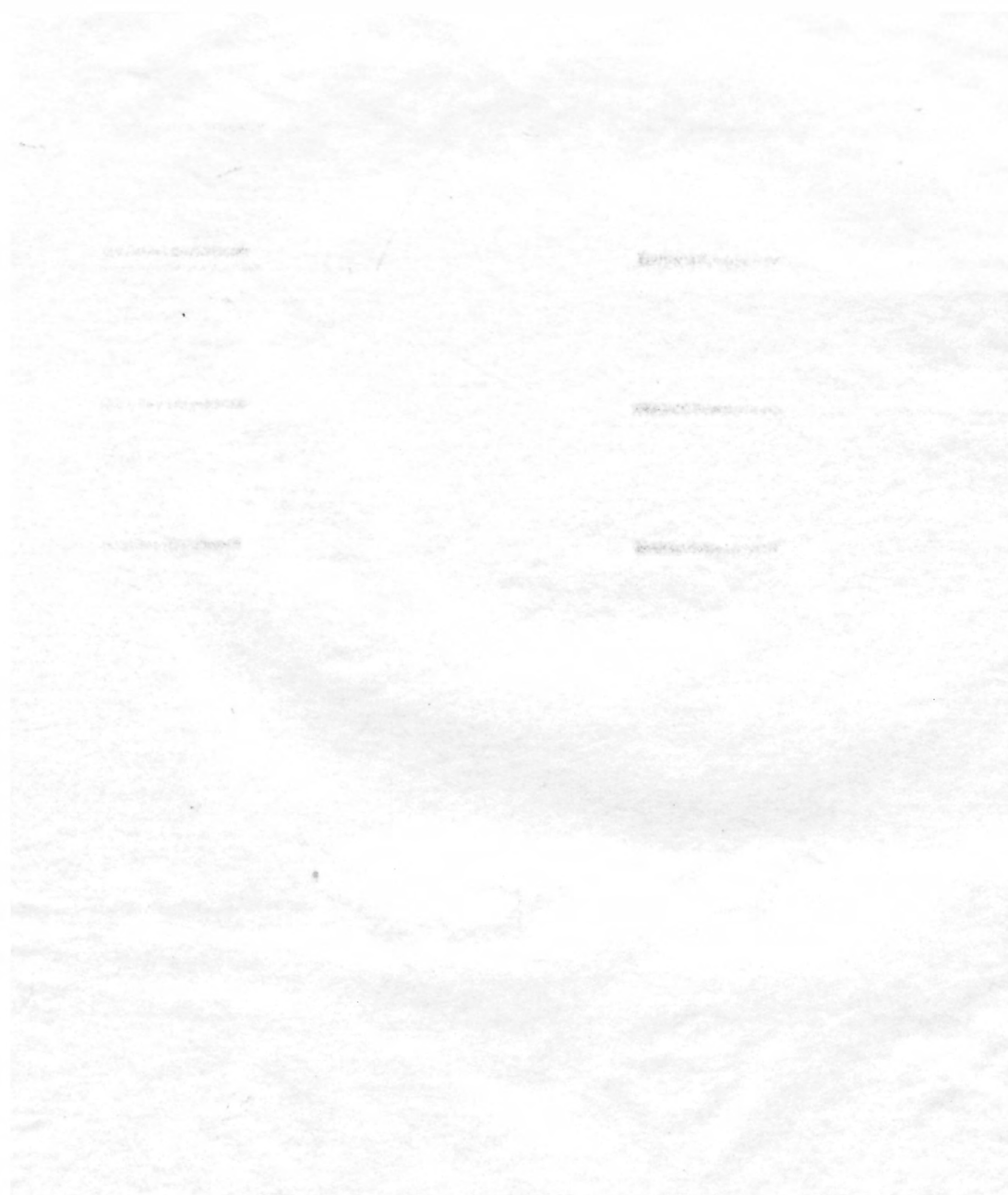


Plate 1. Index map showing major physiographic features and
/ areas of recent geologic mapping in west-central Wyoming


The image shows a geologic map and structure contour map of the Du Noir area. The map displays various geological features, including contour lines and structural sections. The map is oriented with North at the top. The title is located in the lower-left corner of the map area.

Plate 2. Geologic and structure contour
map and structure sections of the Du Noir
area.

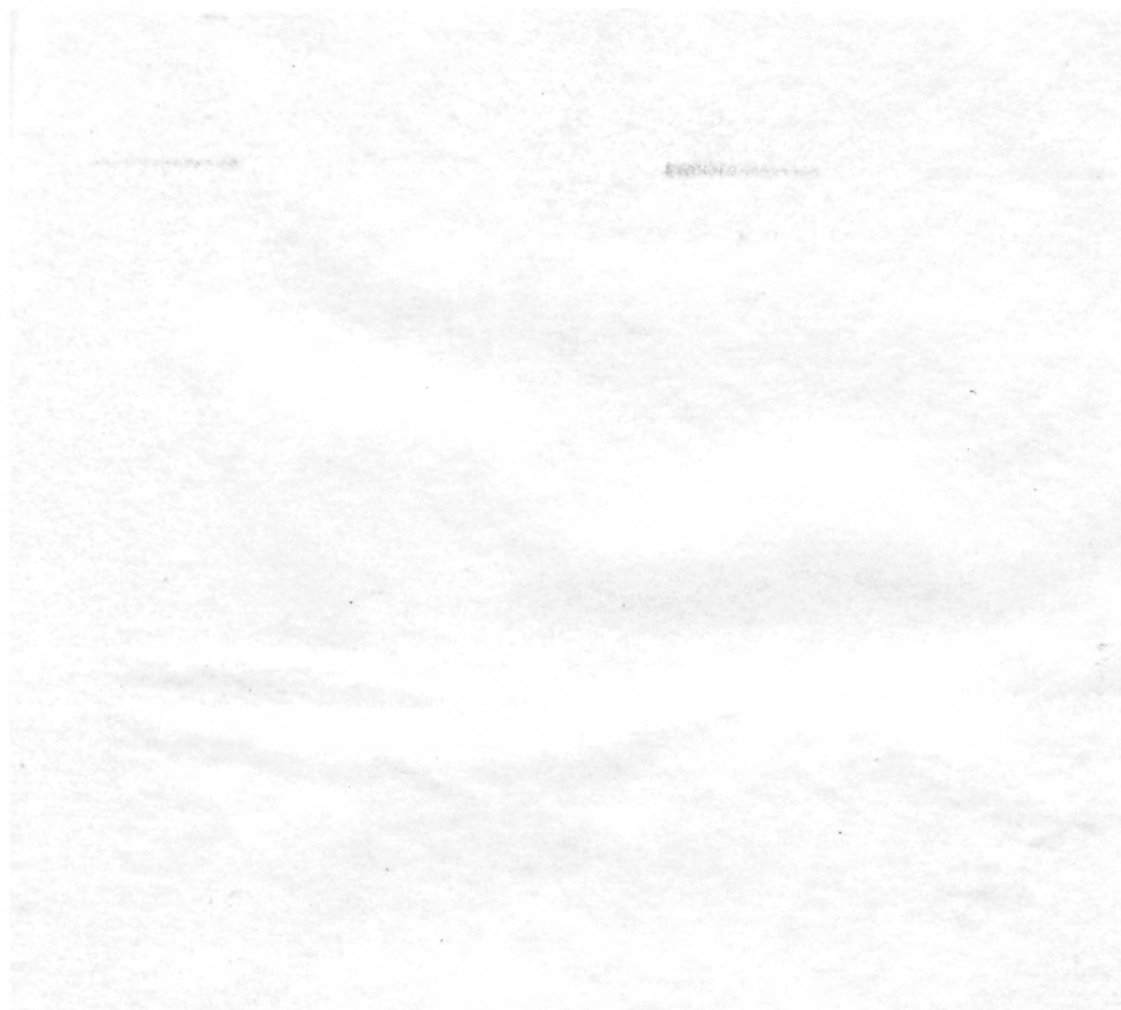
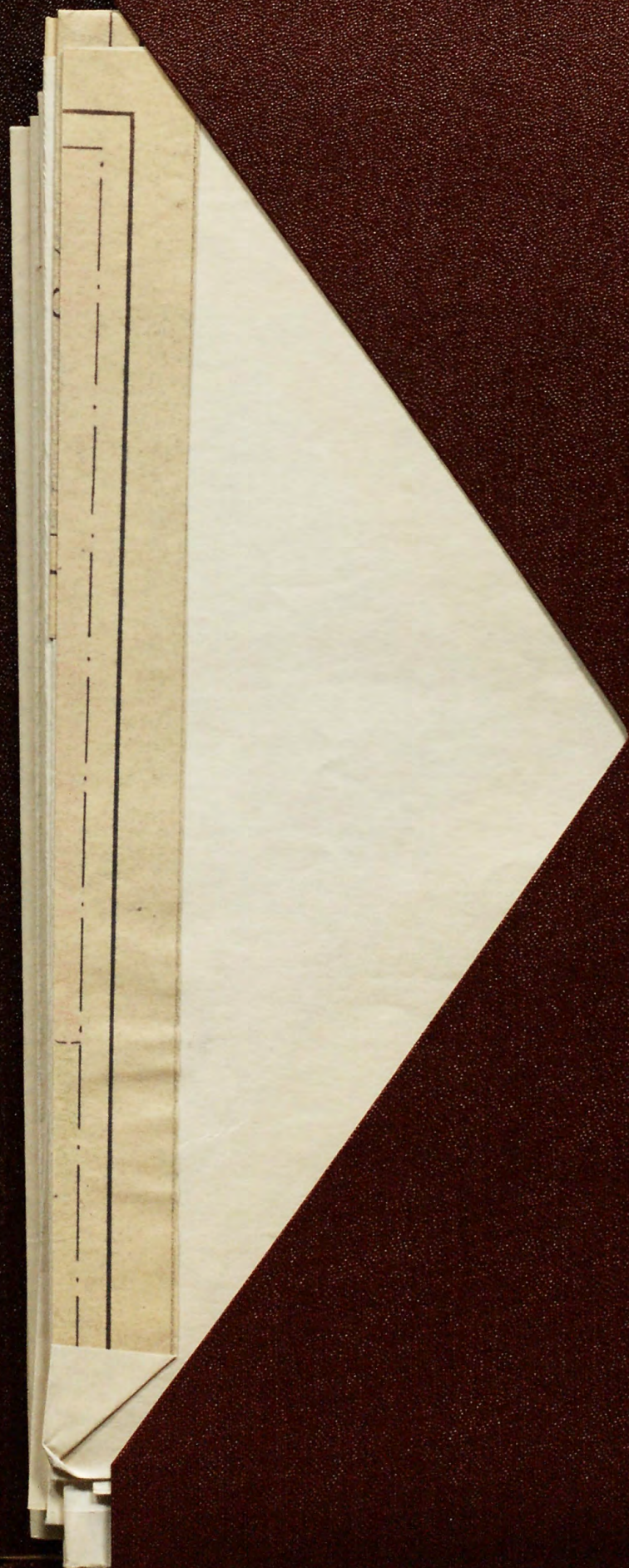


Plate 3. Correlation of carboniferous strata from Dubois southeast
along flank of Wind River Mountains



Plate 4. Geologic and structure contour map and structure sections of a part of the Dubois anticlinal complex.

Pocket contains 9 pieces



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