Over 10,000 feet of marine and nonmarine Late Cretaceous sedimentary rocks are exposed within a 110 square mile area in northeastern Teton County, Wyoming. An additional 1400 feet of nonmarine Paleocene and Miocene rocks overlie these. Landslide deposits and Pleistocene glacial moraine cover over one-half of the area.

The Late Cretaceous Cody Shale and Bacon Ridge Sandstone, which are the oldest rocks exposed, represent the last marine invasion of the region. The overlying Late Cretaceous nonmarine rocks consist of the Coaly Sequence, Lenticular Sandstone and Shale Sequence, Mesaverde Formation, and Harebell Formation. These formations are composed largely of poorly sorted quartz arenites with intercalated mudstones, claystones, shales, and coals. A few quartzite conglomerate lenses are present near the top of the sequence.
These rocks, which contain numerous quartz, chert, and metaquartzite grains, were derived from Precambrian metamorphic and Paleozoic sedimentary rocks exposed to the west and northwest. The sediments were carried into the area by streams and were deposited on a broad coastal plain similar to the modern Texas Gulf Coast. Many of the fine-grained sediments were deposited in swamps and small freshwater lakes.

Near the end of Cretaceous time, a large area of Precambrian Beltian quartzite was exposed in central Montana. Powerful streams carried large volumes of coarse sediments into the area mapped forming the Paleocene Pinyon Conglomerate. Basalt and andesite were extruded locally during the Miocene. Morainal deposits from two Pleistocene glacial stages are recognized.

Two periods of Laramide deformation are represented by broad asymmetric folds. The Spread Creek anticline, a large doubly plunging fold, was formed near the end of Cretaceous time. Three adjacent folds to the northeast are post-Paleocene in age. Several high-angle faults are present.

Structural and stratigraphic conditions appear to be favorable for the formation and accumulation of oil and gas. However, five dry oil and gas test holes have been drilled. The possibilities of finding commercial production are not encouraging. The area has also been prospected for coal and alluvial gold.
GEOLOGY OF THE WHETSTONE ANTICLINE AREA, TETON COUNTY, WYOMING

by

David Ray Hill

A THESIS

submitted to

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in partial fulfillment of the requirements for the degree of

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Date thesis is presented April 24, 1965

Typed by Barbara Glenn
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<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Location and Accessibility</td>
<td>1</td>
</tr>
<tr>
<td>Purpose and Method of Investigation</td>
<td>3</td>
</tr>
<tr>
<td>Previous Work</td>
<td>4</td>
</tr>
<tr>
<td>Relief</td>
<td>5</td>
</tr>
<tr>
<td>Drainage</td>
<td>5</td>
</tr>
<tr>
<td>Climate</td>
<td>8</td>
</tr>
<tr>
<td>Vegetation</td>
<td>8</td>
</tr>
<tr>
<td>Stratigraphy</td>
<td>10</td>
</tr>
<tr>
<td>Regional Stratigraphy</td>
<td>10</td>
</tr>
<tr>
<td>Thesis Area Stratigraphy</td>
<td>12</td>
</tr>
<tr>
<td>Subsurface Stratigraphy</td>
<td>12</td>
</tr>
<tr>
<td>Paleozoic Rocks</td>
<td>14</td>
</tr>
<tr>
<td>Mesozoic Rocks</td>
<td>14</td>
</tr>
<tr>
<td>Surface Stratigraphy</td>
<td>15</td>
</tr>
<tr>
<td>Cody Shale</td>
<td>16</td>
</tr>
<tr>
<td>Bacon Ridge Sandstone</td>
<td>20</td>
</tr>
<tr>
<td>Coaly Sequence</td>
<td>30</td>
</tr>
<tr>
<td>Lenticular Sandstone and Shale Sequence</td>
<td>35</td>
</tr>
<tr>
<td>Mesaverde Formation</td>
<td>42</td>
</tr>
<tr>
<td>Harebell Formation</td>
<td>48</td>
</tr>
<tr>
<td>Pinyon Conglomerate</td>
<td>58</td>
</tr>
<tr>
<td>Colter Formation</td>
<td>71</td>
</tr>
<tr>
<td>Unconsolidated Sediments</td>
<td>73</td>
</tr>
<tr>
<td>Structural Geology</td>
<td>79</td>
</tr>
<tr>
<td>Regional Tectonic Setting</td>
<td>79</td>
</tr>
<tr>
<td>Whetstone Anticline Area Structure</td>
<td>81</td>
</tr>
<tr>
<td>Folds</td>
<td>82</td>
</tr>
<tr>
<td>Spread Creek Anticline</td>
<td>82</td>
</tr>
<tr>
<td>Whetstone Anticline</td>
<td>84</td>
</tr>
<tr>
<td>Lava Creek Syncline</td>
<td>84</td>
</tr>
<tr>
<td>Box Creek Syncline</td>
<td>85</td>
</tr>
<tr>
<td>Faults</td>
<td>86</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>88</td>
</tr>
<tr>
<td>Nonglacial Features</td>
<td>88</td>
</tr>
<tr>
<td>Stream Erosion</td>
<td>88</td>
</tr>
<tr>
<td>Terraces</td>
<td>89</td>
</tr>
<tr>
<td>Erosion Surfaces</td>
<td>90</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Landslides</td>
<td>92</td>
</tr>
<tr>
<td>Glacial Features</td>
<td>95</td>
</tr>
<tr>
<td>Historical Geology</td>
<td>99</td>
</tr>
<tr>
<td>Economic Geology</td>
<td>103</td>
</tr>
<tr>
<td>Oil and Gas</td>
<td>103</td>
</tr>
<tr>
<td>Evidence for Oil and Gas</td>
<td>103</td>
</tr>
<tr>
<td>Possible Reservoir Rocks</td>
<td>105</td>
</tr>
<tr>
<td>Structural and Stratigraphic Traps</td>
<td>106</td>
</tr>
<tr>
<td>Oil and Gas Possibilities</td>
<td>107</td>
</tr>
<tr>
<td>Gold</td>
<td>108</td>
</tr>
<tr>
<td>Coal</td>
<td>110</td>
</tr>
<tr>
<td>Bibliography</td>
<td>112</td>
</tr>
<tr>
<td>Appendix</td>
<td>116</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>View north across Pacific Creek</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>View west from Baldy Mountain</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Buffalo Fork Valley</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>Outcrop of Bacon Ridge Sandstone along Leidy Creek</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>Outcrop of Bacon Ridge Sandstone along Lava Creek</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>Ripple-mark casts from a mudstone bed in the Bacon Ridge Sandstone</td>
<td>27</td>
</tr>
<tr>
<td>7</td>
<td>Mudcracks on a mudstone bed in the Bacon Ridge Sandstone</td>
<td>27</td>
</tr>
<tr>
<td>8</td>
<td>Outcrop of the Coaly Sequence along Lava Creek</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>Outcrop of the Lenticular Sandstone and Shale Sequence along Spread Creek</td>
<td>36</td>
</tr>
<tr>
<td>10</td>
<td>Thick sandstone lenses in the Lenticular Sandstone and Shale Sequence along Spread Creek</td>
<td>36</td>
</tr>
<tr>
<td>11</td>
<td>Outcrop of the Mesaverde Formation along the South Fork of Spread Creek</td>
<td>43</td>
</tr>
<tr>
<td>12</td>
<td>Outcrop of the Harebell Formation north of Pacific Creek</td>
<td>50</td>
</tr>
<tr>
<td>13</td>
<td>Harebell sandstone and siltstone beds along the North Fork of Spread Creek</td>
<td>50</td>
</tr>
<tr>
<td>14</td>
<td>Conglomerate and sandstone lenses in the Harebell Formation two miles west of Gravel Mountain</td>
<td>55</td>
</tr>
<tr>
<td>Figure</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>98</td>
<td></td>
</tr>
</tbody>
</table>

## LIST OF PLATES

<table>
<thead>
<tr>
<th>Plate</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>111</td>
</tr>
<tr>
<td>Table</td>
<td>Description</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Correlation chart.</td>
</tr>
<tr>
<td>2</td>
<td>Stratigraphic units exposed in the Whetstone anticline area</td>
</tr>
<tr>
<td>3</td>
<td>Modal analysis of Bacon Ridge Sandstone samples</td>
</tr>
<tr>
<td>4</td>
<td>Modal analysis of Lenticular Sandstone and Shale Sequence samples</td>
</tr>
<tr>
<td>5</td>
<td>Modal analysis of Mesaverde Formation samples</td>
</tr>
<tr>
<td>6</td>
<td>Modal analysis of sandstone samples from the Harebell Formation</td>
</tr>
<tr>
<td>7</td>
<td>Pebble counts of Pinyon Conglomerate roundstones</td>
</tr>
<tr>
<td>8</td>
<td>Modal analysis of two sandstone samples from the Pinyon Conglomerate</td>
</tr>
<tr>
<td>9</td>
<td>Erosion surfaces and glacial stages in western Wyoming</td>
</tr>
<tr>
<td>10</td>
<td>Hydrocarbon analysis of gas samples collected from a gas seep near Halfmoon Lake</td>
</tr>
<tr>
<td>11</td>
<td>Summary of oil and gas test holes in the thesis area</td>
</tr>
</tbody>
</table>
GEOLOGY OF THE WHETSTONE ANTICLINE AREA, TETON COUNTY, WYOMING

INTRODUCTION

Location and Accessibility

The Whetstone anticline area is located in northeastern Teton County, Wyoming (Plate 1). The 110-square-mile area mapped includes parts of Townships 44, 45, and 46 North; Ranges 112 and 113 West in the northwest one-fourth of the Mt Leidy Quadrangle. Most of the area lies within the Teton National Forest, but the northern one-third is in the Teton Wilderness Area. Grand Teton National Park and Jackson Hole are immediately to the west and Yellowstone National Park is about 15 miles to the north. Jackson, Wyoming, 35 miles to the southwest, is the nearest town. However, food and gasoline may be purchased at the Hatchet Motel which is located in the Buffalo Fork Valley.

Access is provided for the central part of the area by U. S. Highway 26-287 which parallels the Buffalo Fork River. One good gravel road extends south from the paved highway to Spread Creek, and another gravel road extends to the north along Pacific Creek. Jeep trails are numerous south of the Buffalo Fork River, but only foot trails are present to the north in the Teton Wilderness Area where motor vehicles are not permitted. No point in the area is
PLATE I. Map of Wyoming showing location of thesis area.
more than six miles from a good road, but thick vegetation and locally high relief make travel difficult.

**Purpose and Method of Investigation**

The primary purpose of this study was to map the surface geology of the Whetstone anticline area in greater detail than was done during any of the previous investigations. One of the principal objectives was to determine the extent of the Whetstone anticline and its relationship to adjacent folds.

Field work was begun on June 24, 1963, and completed September 3, 1963, in a total of ten weeks. The surface geology was plotted on aerial photographs in the field. No stratigraphic sections were measured because of the lack of good outcrops and the rapid lateral variations in lithology. Formation thicknesses were computed from outcrop widths and electric well logs. Several samples of natural gas were collected for hydrocarbon analysis.

Since no accurate base map exists for the area, a planimetric map was prepared from existing topographic maps and aerial photographs. Twenty-seven thin sections were prepared from selected samples and were studied microscopically. Modal analyses were performed by the point-count method, counting 100 to 150 points per thin section. All sandstones were classified by Gilbert's classification (33, p. 289-297).
Previous Work

The first geologic references to the thesis area appeared in 1873 when Bradley (3, p. 261-262) discussed briefly some of the rocks along the Buffalo Fork River. St. John (27, 28) made the first geologic reconnaissance of the area and adjacent parts of western Wyoming in 1877 and 1878 while with the Hayden Surveys. Weed (7, p. 184-188) studied some of the area north of Pacific Creek during his study of Yellowstone National Park. In 1915, Blackwelder (2) described the physiography and glacial deposits of the Whetstone anticline area and adjacent parts of northwestern Wyoming.

Stratigraphic studies including parts of the area have been published by Love (11, 19) and Foster (5). Several square miles of the area studied, south of Spread Creek, have been mapped by Love et al. (18). Geologic reconnaissance maps by Love (20) and Bengtson (1) cover the area. Horberg et al. (9) have described Pleistocene erosion surfaces north of the Buffalo Fork River.

The general geology, structure, and stratigraphy of parts of the Jackson Hole region have been described by the following: Horberg et al. (8), Nelson and Church (24), Love (11, 12, 16), Love et al. (17), and Wanless et al. (32). An excellent bibliography of geologic studies in the region is included in G. S. A. Memoir 63 by Wanless et al. (32).
Relief

Elevations in the area range from a minimum of about 6775 feet, where Lava Creek enters the Buffalo Fork River, to a maximum of 9645 feet on Gravel Mountain. Consequently, the maximum topographic relief is approximately 2870 feet. The relief is greatest in the mountainous northern (Figure 1) and southern parts of the area and is least in the glaciated area (Figure 2) between Spread Creek and the Buffalo Fork River.

Drainage

The thesis area is drained by three major streams which flow west into Jackson Hole and the Snake River. Pacific Creek with its major tributaries, Whetstone and Mink Creeks, drains the northern part of the area. The central part is drained by the Buffalo Fork River (Figure 3) and its main tributaries, Box Creek, Blackrock Creek, and Lava Creek. Spread Creek and its tributary streams drain the southern part. These streams are all permanent. However, in the mountainous parts of the area there are numerous minor intermittent streams.

Stream gradients range from about 400 feet per mile on Whetstone Creek, one-fourth mile above its mouth, to about ten feet per mile along the Buffalo Fork River near Halfmoon Lake.
FIGURE 1. View north across Pacific Creek along the axis of the Whetstone anticline. Whetstone Mountain in right distance.

FIGURE 2. View west from Baldy Mountain showing the valley of Spread Creek and adjacent glaciated topography. Jackson Hole and Teton Range in the distance.
FIGURE 3. Buffalo Fork Valley. View southeast from Davis Hill.
Climate

The nearest United States Weather Bureau station is at Moran, Wyoming, seven miles to the west. Most of the Whetstone anticline area has a climate similar to that at Moran except that the higher elevations have lower average temperatures and higher precipitation.

The mean annual temperature at Moran, based on the period 1931-1960, is 34.7°F. (31). January is the coldest month, with a mean temperature of 10.6°F., and July is the warmest month, with a mean temperature of 57.9°F. Maximum summer temperatures rarely exceed 85°F. and nights are pleasantly cool--frost is not uncommon. Winter temperatures remain below freezing for long periods of time and minimum temperatures of -50°F. have been recorded.

December is the wettest month with an average of 2.36 inches of precipitation and July the driest with 0.97 inches. The mean annual precipitation is 21.30 inches. Most of the winter precipitation is in the form of snow since the average annual snowfall exceeds 120 inches. Much of the summer precipitation comes via thunderstorms.

Vegetation

The natural vegetation of the area is diverse and abundant. In fact, the abundance of vegetative cover is a great hindrance to
geologic field work. The forests, which cover most of the area, are largely lodgepole pine but Douglas fir, alpine fir, Engelmann spruce, limber pine, and whitebark pine are represented. Aspen, cottonwood, willow, and alder grow in profusion along the streams and in the landslide areas. The timber of the region has a greater scenic than commercial value since only a few of the lodgepole pine, Douglas fir, and Engelmann spruce grow large enough for lumber.

Open meadows covered by native grasses, flowering plants, and low shrubs are numerous, especially above 7500 feet elevation. During the summer, these meadows are taken over by seasonal blooms of blue lupine, larkspur, scarlet gilia, mules ear, balsam root, and Indian paintbrush. The unforested areas at lower elevations support thick growths of native grasses, sagebrush, rabbit brush, and other small shrubs.

Some agriculture is practiced in the Buffalo Fork Valley where alfalfa and native grasses are grown for hay. Most of the thesis area is a summer range for the cattle and horses from the six ranches located in the Buffalo Fork Valley. The many dude ranches in the area owe their existence to the scenic beauty and abundant wildlife of the region.
STRATIGRAPHY

The rocks of the Jackson Hole region range in age from Precambrian to Quaternary. The following section contains a short summary of the rocks exposed in the region.

Regional Stratigraphy

Precambrian gneiss and schist are well exposed 20 to 30 miles from the thesis area, in the cores of the Gros Ventre, Wind River, and Teton Ranges. Several relatively small outcrops of these rocks lie along the Buffalo Fork River six miles east of the area studied. Nearly all of the Precambrian rocks are intricately folded and faulted; they also contain many intrusive bodies ranging from acidic to ultrabasic in composition.

Marine Paleozoic rocks crop out on the flanks of the Gros Ventre, Wind River, and Teton Ranges. Sandstone, limestone, dolomite, and shale are the dominant rock types. Paleozoic limestones and sandstones are exposed several miles east of the thesis area near Togwotee Pass. Wanless et al. (32) have discussed the Paleozoic and Mesozoic rocks of most of the region. The total thickness of Paleozoic rocks north of the Gros Ventre River ranges from 3000 to 4000 feet, but these rocks become progressively thicker to the south and southwest.
Over 15,000 feet of Mesozoic strata overlie the Paleozoic rocks immediately east of Jackson Hole. The lower one-half of the section consists of marine and nonmarine sandstone, shale, claystone, limestone, and gypsum, whereas the remainder contains continental sandstone, claystone, shale, and coal.

Outcrops of Mesozoic rocks are widespread along the Hoback, Gros Ventre, and Buffalo Fork Rivers, but are present as far north as southern Yellowstone National Park. Spectacular exposures of Triassic, Jurassic, and Cretaceous strata lie along the Gros Ventre River from Lower Slide Lake east to Bacon Ridge. These rocks are also well exposed between the Gros Ventre River and the Buffalo Fork River.

A thick sequence of Tertiary sedimentary and volcanic rocks overlies the older rocks of the region. The Paleocene Pinyon Conglomerate, which consists of over 1000 feet of conglomerate, caps most of the high mountain peaks immediately east of Jackson Hole. A thick sequence of Late Tertiary nonmarine sedimentary rocks is exposed on the east and northeast borders of Jackson Hole. Farther north and northeast, on the Yellowstone Plateau, a thick sequence of nearly horizontal Tertiary volcanics lies at the surface.

Quaternary glacial moraine, landslide debris, and alluvial deposits cover much of the region. Glacial moraine is abundant, particularly at higher elevations. Numerous landslides occur along
the east and northeast sides of Jackson Hole from Yellowstone National Park south to the Gros Ventre Range. Alluvial sand and gravel deposits blanket the floors of nearly all the major stream valleys and Jackson Hole.

**Thesis Area Stratigraphy**

Rocks ranging in age from Late Cretaceous to Middle Miocene are exposed within the Whetstone anticline area. Since five oil and gas test holes have been drilled in the area, some of the subsurface stratigraphy is also known. The thicknesses and general lithologies of the subsurface formations were determined from electric and stratigraphic well logs. The relationship of these rocks to others occurring in the central Rocky Mountain region is shown in Table 1. In the following sections, a summary of the known subsurface stratigraphy will be presented, followed by detailed descriptions of the exposed units.

**Subsurface Stratigraphy**

Over 6000 feet of Paleozoic and Mesozoic sedimentary rocks, not exposed in the thesis area, have been penetrated by oil and gas test holes. This sequence, especially the pre-Cretaceous strata, becomes progressively thicker to the south and southwest. It is noteworthy that the Jurassic (?) Nugget Sandstone is missing in the
<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Correlation Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Southwestern</td>
</tr>
<tr>
<td></td>
<td>Wyoming</td>
</tr>
<tr>
<td>PLIOCENE</td>
<td></td>
</tr>
<tr>
<td>MIOCENE</td>
<td></td>
</tr>
<tr>
<td>Oligocene</td>
<td></td>
</tr>
<tr>
<td>EOCENE</td>
<td></td>
</tr>
<tr>
<td>Paleogene</td>
<td></td>
</tr>
<tr>
<td>TERTIARY</td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td></td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td></td>
</tr>
<tr>
<td>Jurassic</td>
<td></td>
</tr>
<tr>
<td>Triassic</td>
<td></td>
</tr>
<tr>
<td>Permian</td>
<td></td>
</tr>
<tr>
<td>Pennsylvanian</td>
<td></td>
</tr>
<tr>
<td>Mississippian</td>
<td></td>
</tr>
<tr>
<td>Devonian</td>
<td></td>
</tr>
<tr>
<td>Silurian</td>
<td></td>
</tr>
<tr>
<td>Ordovician</td>
<td></td>
</tr>
<tr>
<td>Cambrian</td>
<td></td>
</tr>
<tr>
<td>Precambrian</td>
<td></td>
</tr>
</tbody>
</table>

Compiled by D. Hill from various sources.
thesis area but is present less than 15 miles to the south.

**Paleozoic Rocks**

The two deepest test holes, the British-American et al. Spread Creek no. 1 Unit and the Texaco, Inc. Spread Creek no. 1 Unit (Plate 3), bottomed in the Pennsylvanian Tensleep Sandstone. This formation consists of hard, fractured, gray quartzitic sandstone with a few thin dolomite beds. The overlying Phosphoria Formation is composed of thin sandstone, siltstone, dolomite, chert, and phosphate beds.

Less than 500 feet of Paleozoic marine strata were encountered in the oil and gas test holes. If the thicknesses of Paleozoic rocks beneath the thesis area are comparable to those in nearby outcrops, less than 3000 feet of Paleozoic sedimentary rocks underlie the area.

**Mesozoic Rocks**

Over 1700 feet of Triassic sandstone, siltstone, shale, and gypsum of the Dinwoody and Chugwater Formations were encountered in the Texaco and British-American test holes. An additional 700 feet of the overlying Jurassic Gypsum Spring and Sundance Formations are present. The Jurassic rocks are composed of marine and nonmarine shale, sandstone, gypsum, and limestone.
The overlying Jurassic-Cretaceous Morrison Formation, which is made up of about 350 feet of sandstone and shale, was identified in the two deep test holes and in the Travis-True Oil Buffalo Creek no. 1 Unit test. Early Cretaceous formations present include the Cloverly Formation, Muddy Sandstone, and Mowry Shale. Marine shale and sandstone are the two dominant rock types represented.

All of the oil and gas test holes penetrated the Late Cretaceous Frontier Formation and Cody Shale. The Frontier Formation is made up of many thin- to thick-bedded sandstones with subordinate siltstones, claystones, coals, and shales. Gray shale and claystone are the most abundant rock types in the Cody Shale, but there are a few thin gray sandstone beds in the upper one-half of the formation. Cretaceous formations younger than the Cody Shale were penetrated in most of the tests. Their characteristics will be discussed in the following sections.

Surface Stratigraphy

About 10,000 feet of Late Cretaceous sedimentary rocks are exposed in the Whetstone anticline area. This sequence is divided into six formations: the Cody Shale, Bacon Ridge Sandstone, Coaly Sequence, Lenticular Sandstone and Shale Sequence, Mesaverde Formation, and Harebell Formation.
An additional 1400 feet of Tertiary rocks overlie the Cretaceous strata. The Tertiary rocks are divided into two formations: the Pinyon Conglomerate and the Colter Formation.

The areal distribution of these units in the thesis area is shown on Plate 3. A summary of the stratigraphic units and their characteristics is presented in Table 2. The following sections contain descriptions of these rock units in stratigraphic sequence.

**Cody Shale**

The oldest rock unit exposed in the area mapped is the Late Cretaceous Cody Shale. It was named by Lupton (21, p. 171-173) for over 3000 feet of soft gray shale and thin drab-gray sandstone beds exposed along the Shoshone River near Cody, Wyoming. Several fossiliferous sandstone beds occur near the base and the top of the formation in the type area.

In the thesis area, the base of the Cody Shale is not exposed but the underlying Frontier Formation has been identified from well cuttings and electric logs. The base of the Cody Shale is arbitrarily picked at the zone where thick shaly sandstone beds of the Frontier Formation grade upward into a thick sequence of blue-gray sandy shale and claystone. The contact with the overlying Bacon Ridge Sandstone is arbitrarily placed at the base of a thick light-gray sandstone sequence.
### Table 2. Stratigraphic Units Exposed in the Whetstone Anticline Area.

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Thickness (feet)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td>Alluvium and Landslide deposits</td>
<td>?</td>
<td>Unconsolidated and poorly sorted silt, sand, gravel and boulders.</td>
</tr>
<tr>
<td></td>
<td>(Unconformity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Bull Lake Moraine (?) Buffalo drift</td>
<td>100 (?)</td>
<td>Poorly sorted sand, gravel, and boulders.</td>
</tr>
<tr>
<td></td>
<td>(Unconformity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miocene</td>
<td>Colter Formation</td>
<td>100 (?)</td>
<td>Basalt and andesite flows.</td>
</tr>
<tr>
<td></td>
<td>(Unconformity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paleocene</td>
<td>Pinyon Conglomerate</td>
<td>1000-1200</td>
<td>Light-brown quartzite conglomerate with thin sandstone lenses.</td>
</tr>
<tr>
<td></td>
<td>(Disconformity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>Harebell Formation</td>
<td>3500-4000+</td>
<td>Olive-drab sandstone, claystone, shale, and conglomerate.</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>(Unconformity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>Mesaverde Formation</td>
<td>0-600 (?)</td>
<td>Thick white nonmarine sandstone beds.</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>(?)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>Lenticular Sandstone and Shale Sequence</td>
<td>1000-2000</td>
<td>Gray channel sandstones with intercalated soft shale and claystone.</td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>Coaly Sequence</td>
<td>1000-1200</td>
<td>Thin-bedded sandstones, claystones, shales, and coals.</td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>Bacon Ridge Sandstone</td>
<td>900-1200</td>
<td>Thick to thin-bedded fossiliferous sandstone with mudstone and coal.</td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>Cody Shale</td>
<td>1800-2000</td>
<td>Soft blue-gray claystone and shale with thin glauconitic sandstones.</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>(Base not exposed)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Distribution and Topographic Expression. Extensive outcrops of Cody Shale lie south of the area studied along the Gros Ventre River. Other outcrops occur to the east near Togwotee Pass and to the north near the southern boundary of Yellowstone National Park. The upper one-third of the formation is exposed within the thesis area along Leidy Creek, three miles east of Mt Leidy, at the highest structural elevation on the Spread Creek anticline.

The Cody Shale is poorly exposed along Leidy Creek; in fact, only two small outcrops were observed. The soft shales and claystones of the formation are easily eroded and are usually valley formers. Thus, the narrow valley of Leidy Creek is wider where it is underlain by Cody Shale.

Thickness. In the Jackson Hole region, the thickness of the Cody Shale ranges from 1370 to 2200 feet. Within the area mapped, thicknesses ranging from 1800 to 2000 feet were computed from electric logs.

Lithology. Most of the Cody Shale consists of gray to blue-gray claystone, siltstone, and shale. Gray glauconitic sandstone beds up to 75 feet thick are present throughout the formation, but are more numerous in the upper one-half of the Cody Shale.

The outcrops of Cody Shale along Leidy Creek are composed
of soft blue-gray shale and sandy claystone weathered to a light-gray to light blue-gray color. No sandstone beds are exposed, but a few weathered fragments of gray to tan sandstone lie on the surface. Hard glauconitic sandstone beds up to 75 feet thick have been penetrated in nearby oil and gas test holes.

**Age.** Love (13, p. 80) states that the Cody Shale of the Jackson Hole region contains Late Cretaceous fossils which are typical Middle Niobrara, and equivalent in age to the lower part of the Smoky Hill chalk member of the Niobrara Formation of Kansas. Generally, the Cody Shale contains abundant micro- and megafossils, but the lack of outcrops in the thesis area hinders the search for fossils. However, several poorly preserved pelecypod shells were found in the outcrops along Leidy Creek.

According to Love (13, p. 80) the Cody Shale in the Jackson Hole region is equivalent to about the lower one-half of the formation at the type area. It is also correlative with parts of the Hilliard Shale, Mancos Shale, Baxter Shale, Steele Shale, Pierre Shale, and Carlile Shale of the central Rocky Mountain region.

**Source Rocks and Depositional Environment.** Deposition of the Cody Shale, as indicated by the lithology and fossils, occurred in a marine environment. The glauconite in many of the sandstone beds suggests that the sediments were deposited at a shallow to
moderate depth in a nearly normal marine environment. The number of sandstone beds increases toward the top of the formation and there is a transition to the shallow-marine deposits of the Bacon Ridge Sandstone. This suggests that the upper Cody sediments were deposited in a shallow marine environment.

Since samples from the formation were not studied microscopically, possible source rocks cannot be suggested. However, the source area was probably to the west since a large Late Cretaceous sea covered much of the Rocky Mountain region east of the thesis area during Cody time.

**Bacon Ridge Sandstone**

The Cody Shale is conformably overlain by the Late Cretaceous Bacon Ridge Sandstone, which was named and described by Love et al. (17, p. 2) from exposures at Bacon Ridge 20 miles southeast of the thesis area. The formation consists of thick basal sandstone beds overlain by thinner intercalated sandstone, mudstone, claystone, carbonaceous shale, and coal beds.

A persistent zone, about 25 feet thick, of thin coal beds, carbonaceous shale, bentonite, porcellanite, and thin-sandstone beds, called the "pearl-gray marker zone" by Love (17, p. 5), occurs about 75 feet above the base at the type area on Bacon Ridge. This zone rises in the stratigraphic section to the northwest and along Leidy Creek is about 500 feet above the base. However, the "pearl-gray marker zone" is usually poorly exposed and difficult
to recognize north of the Gros Ventre River.

No evidence of unconformities exists at the base or top of the formation. The contacts are conformable and gradational.

**Distribution and Topographic Expression.** Outcrops of Bacon Ridge Sandstone are common between the Gros Ventre River and the Buffalo Fork River. Isolated outcrops are present as far north as Yellowstone Lake. In the Whetstone anticline area, the formation is exposed along the crest of the Spread Creek anticline from Leidy Creek (Figure 4) north to Lava Creek; however, much of this area is covered by glacial moraine and Quaternary alluvium. Therefore, the total outcrop area is less than four square miles.

The thick sandstone beds at the base of the formation form cliffs 15 to 30 feet high. These cliffs are best seen near the axis of the Spread Creek anticline where it crosses Leidy Creek, Spread Creek, and Lava Creek (Figure 5). The remainder of the formation is generally poorly exposed and underlies low rounded hills. Deeply weathered outcrops are usually covered by a light-gray soil containing fossil mollusk shell fragments.

**Thickness.** In the Jackson Hole region, the Bacon Ridge Sandstone ranges from 900 to 1250 feet in thickness. The formation is over 900 feet thick in the British-American, et al. Spread Creek no. 1 Unit oil and gas test hole on Spread Creek.
FIGURE 4. Poorly exposed outcrop of Bacon Ridge Sandstone on the north side of Leidy Creek.

FIGURE 5. Smoothly rounded outcrop and honeycombed weathering of Bacon Ridge Sandstone on east side of Lava Creek.
Thicknesses of surface sections range from about 980 feet on Leidy Creek to 1200 feet on Lava Creek; however, some of the variation in thickness is due to the varying interpretations of the arbitrary boundaries at the base and top of the formation.

The basal sandstone beds have a total thickness ranging from 50 to 75 feet in the thesis area. The thickness increases from south to north. Love (13, p. 80) has measured 480 feet of the basal sandstone unit in southern Yellowstone National Park.

**Lithology.** The Bacon Ridge Sandstone contains many thin-to thick-bedded sandstones, mudstones, shales, and coals. Marine fossils are abundant throughout the formation. Most of the sandstone beds are less than three feet thick, except near the base where they are up to 30 feet thick.

Thick lenticular sandstone bodies 5 to 30 feet thick and several hundred feet in length characterize the basal part of the Bacon Ridge Sandstone. These gray to tan sandstones weather to a light-gray color. They form rounded honeycombed cliffs up to 30 feet high. Fossil pelecypod shells are abundant, especially in the finer-grained beds. Cross-lamination is common.

The sandstones are fine to medium grained, well sorted, and porous. Grains of quartz, dark rock fragments, and biotite are visible in the hand specimen. Microscopically, they are
composed of well-sorted angular to subrounded grains of quartz, chert, and metaquartzite. Detrital carbonate, in sparry hematite-rimmed fragments, is a common constituent. Biotite, muscovite, chalcedony, microcline, zircon, garnet, tourmaline, magnetite, sphene, and green hornblende are minor constituents. Modal analyses of two thin sections from these sandstones are shown in Table 3.

**TABLE 3. Modal analysis of Bacon Ridge Sandstone samples.**

<table>
<thead>
<tr>
<th></th>
<th>DRH 28(^1)</th>
<th>DRH 59(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>48</td>
<td>52</td>
</tr>
<tr>
<td>Chert</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>Metaquartzite</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Detrital carbonate</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Rock fragments</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Biotite</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>K-feldspar</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Carbonate cement</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Matrix</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Sample locations:

\(^1\) Along Lava Creek, 200 yards north of U. S. Highway 26-287 bridge.

\(^2\) Along Leidy Creek, at base of the formation.
Quartz is common as colorless grains which are generally strained and contain regular or irregular inclusions. The chert grains are usually dark-gray in color. The grains listed as rock fragments in Table 3 and elsewhere in this report are largely siltstone and mudstone. A few mica schist fragments are present. In fact, it is the dark chert and other dark rock fragments, not magnetite, which give the sandstones a "salt and pepper" appearance. The metaquartzite grains are polygranular and have serrated boundaries between the components of the grains. The feldspar grains, which are largely plagioclase, are only slightly altered.

The sandstones are poorly cemented by calcite and hematite. The porous and friable nature of these sandstones in outcrops is probably due to the leaching out of detrital and authigenic carbonate, since the well logs usually indicate a much lower porosity at depth. A small amount of clay occurs in some of the sandstones. Hematite, sericite, and chlorite are the most common authigenic minerals.

Using Gilbert's classification (33, p. 289-297), the samples studied would be classified as quartz arenites because of the high percentages of quartz, chert, and metaquartzite. Feldspars, matrix, and rock fragments are minor constituents.

Thin beds of mudstone, claystone, shale, and coal are abundant throughout the formation. These fine-grained rocks have a
gray to black color which weathers blue gray to tan. They are thin bedded; beds rarely exceed one foot in thickness. Asymmetric ripple marks (Figure 6) and mudcracks (Figure 7) are common. Some beds contain abundant fossil pelecypod and gastropod shells which locally form coquina beds up to six inches thick.

Sandstone beds become thinner and fewer in number toward the top of the Bacon Ridge Sandstone. The sandstone beds above the thick basal sandstones range from six inches to three feet in thickness. They are usually hard and calcareous with a gray to tan color. Cross-lamination and blocky jointing are common.

Love's "pearl-gray marker zone" is poorly exposed along Leidy Creek where it consists of thin coal, carbonaceous shale, bentonite (?), and sandstone beds. The zone was not found north of Leidy Creek.

Coal beds are present throughout the formation but the thickest and best quality coals lie near the base. Thin coal beds, less than six inches thick, are exposed along Leidy Creek. They become thicker and more numerous to the north on Spread Creek and Lava Creek where they were mined in the early 1900's. The coal beds along Spread Creek are usually less than six inches thick, but one coal bed seven feet thick has been reported (13, p. 80).

The thickest coal bed observed by the writer was a three-foot thick bed of bituminous coal exposed in the bed of Lava Creek,
FIGURE 6. Ripple-mark casts from a mudstone bed in the Bacon Ridge Sandstone near Davis Hill.

FIGURE 7. Mudcracks on a mudstone bed in the Bacon Ridge Sandstone along Lava Creek.
one-fourth mile north of the U. S. Highway 26-287 bridge over Lava Creek. Nearly all of the coal is low-grade lignite or coaly shale.

**Age.** Marine mollusk fossils are abundant throughout the Bacon Ridge Sandstone. However, most of them are poorly preserved and fragmental. The best fossil localities in the thesis area are near the U. S. Highway 26-287 bridge over Lava Creek and near the caved portals of coal mines in the vicinity. The following pelecypod genera were collected and identified by the writer: *Ostrea, Cardium, Unio, Anomia, Volsella, Arca, Pedalion, Pecten,* and *Pinna.* Numerous other unidentified genera and species of pelecypods and gastropods are present. Fossil lists for these localities have been published by Love et al. (19) and Foster (5, p. 1586-1587). The consider the fossils to be of Middle Niobrara age.

Poorly preserved *Ostrea* and other pelecypod shell fragments were collected from the Bacon Ridge Sandstone on Spread Creek and Leidy Creek. *Ostrea* is the most abundant genus found at these localities. *Inoceramus* shell prisms occur in some of the basal sandstones on Spread Creek.

The formation is correlative with the upper Cody Shale of north-central Wyoming and upper part of the Hilliard Shale of southwestern Wyoming.
Source Rocks and Depositional Environment. The abundant quartz, chert, carbonate, and sedimentary rock fragments in the Bacon Ridge Sandstone suggest that sedimentary rocks were the dominant source rocks. The rounded grains of tourmaline and zircon also indicate a sedimentary rock source. Paleozoic limestones, cherts, and sandstones probably contributed most of these fragments. It is also possible that some of the grains are reworked Early Mesozoic sedimentary rocks which were originally derived from Paleozoic rocks.

Pryor (25, p. 45) suggests that most of the chert fragments found in the Late Cretaceous rocks of western Wyoming were derived from the Rex chert member of the Phosphoria Formation and from cherts in the Madison Group. The writer agrees with Pryor's conclusion.

Metamorphic source rocks for the Bacon Ridge sandstones are indicated by the metaquartzite, schist, and garnet grains in the sandstones. Igneous rocks were minor source rocks and contributed small amounts of quartz, biotite, plagioclase, microcline, and magnetite.

Since a large sea covered most of the Rocky Mountain region east of Idaho during the Late Cretaceous, the sources of the Bacon Ridge sediments were probably to the west and northwest in eastern Idaho and western Montana. A western source is also
suggested by the mineralogy of the sediments. Broad outcrops of Paleozoic sandstones and carbonates were eroded during Bacon Ridge time and the detritus was carried east by numerous streams.

At the beginning of Bacon Ridge time, a discontinuous blanket of beach sand was deposited as the Late Cretaceous sea regressed to the east. Much of the material carried into the area from the west was deposited in estuaries, lagoons, and swamps which occurred along the eastern edge of a broad coastal plain. Some of the sediments were cleaned and sorted by wave action and deposited as offshore bars and as sand spits. Many coal swamps existed in the thesis area and are now represented by the numerous coal beds in the Bacon Ridge Sandstone. During Bacon Ridge time, the area was located in a region very similar to the present-day Gulf Coast of Texas.

**Coaly Sequence**

The Late Cretaceous Coaly Sequence, which conformably overlies the Bacon Ridge Sandstone, was named by Love et al. (17, p. 17-39) for exposures along the Gros Ventre River. It consists of thin gray and brown lenticular sandstones, siltstones, carbonaceous shales, and coals. Coal beds are thicker and more numerous toward the base of the formation.

The base and top of the Coaly Sequence are arbitrarily
picked. At the base, the contact with the underlying Bacon Ridge Sandstone is picked at the top of the highest sandstone bed containing marine fossils.

**Distribution and Topographic Expression.** Outcrops of the Coaly Sequence occur along the Gros Ventre River and north through the Whetstone anticline area to southern Yellowstone National Park. In the thesis area the formation is poorly exposed along the east flank of the Spread Creek anticline. The best exposures lie along Leidy Creek and Lava Creek. The Coaly Sequence and the underlying Bacon Ridge Sandstone form low rolling hills between Leidy Creek and Lava Creek.

**Thickness.** Along the Gros Ventre River the Coaly Sequence is about 1000 feet thick. In the thesis area, it is about 1000 feet thick near Leidy Creek and about 1200 feet thick along Lava Creek.

**Lithology.** Thin beds of sandstone, siltstone, mudstone, claystone, shale, and coal make up the formation (Figure 8). Sandstone and mudstone are the most common rock types.

The sandstone beds are typically thin bedded and lenticular. These lenses are generally only several feet thick and less than 100 feet long. Weathered surfaces are light gray to tan, whereas
FIGURE 8. Outcrop of thin-bedded coal, mudstone, and sandstone of the Coaly Sequence along Lava Creek, one mile south of Davis Hill.
fresh surfaces are usually darker in color. Most of the sandstone beds are fine grained, hard, and calcareous with platy parting parallel to the bedding. Asymmetric ripple marks are common on the fine-grained beds. Cross-lamination and small cut-and-fill structures are also present. The sandstones are nearly identical in composition to the underlying Bacon Ridge sandstones, but contain no marine fossils.

Blue-gray to olive claystone, mudstone, and shale beds constitute about 50 percent of the rocks in the formation. They have a gray to tan color on weathered surfaces. Many of the mudstone and shale beds are carbonaceous, especially so near the base of the Coaly Sequence. Asymmetric ripple marks and mudcracks are common.

Most of the coal beds are less than six inches thick, but beds up to 12 inches thick were observed. The coal is of poor quality ranging from coaly shale to low-grade lignite. Individual coal beds become thinner and fewer in number toward the top of the formation.

Several thin lenses of gray freshwater limestone were observed in the area. They are less than two feet thick and pinch out laterally within a few feet. These limestones or marlstones locally contain well-preserved leaves (13, p. 81), but none were found in the thesis area.
Age. The Late Cretaceous age of the Coaly Sequence has been based on stratigraphic position and fossil leaves. The writer found no fossils other than poorly preserved plant fragments in the formation. Love (13, p. 81) believes that the Coaly Sequence merges into the upper part of the marine Cody Shale to the east in the Wind River and Bighorn Basins. However, this correlation must be made on stratigraphic position. Thus, the Coaly Sequence is correlative with the upper part of the Cody Shale or the basal part of the Mesaverde Formation of north-central Wyoming.

Source Rocks and Depositional Environment. The source rocks for the Coaly Sequence were nearly identical to those of the underlying Bacon Ridge Sandstone. The Late Cretaceous shoreline was shifting to the east of the thesis area as the Coaly Sequence sediments were being deposited. As a result, no marine fossils have been found in the formation.

The sediments were deposited on a low, broad coastal plain by numerous streams flowing from the source area to the west. Many swamps, ponds, and small lakes existed on this coastal plain. The abundance of coal and fine-grained sedimentary rocks in the Coaly Sequence suggests that none of the streams were fast moving.
Lenticular Sandstone and Shale Sequence

The Late Cretaceous Lenticular Sandstone and Shale Sequence overlies the Coaly Sequence in the thesis area. The contact is conformable and gradational. Love (17, p. 14-28) named the formation for thick channel deposits of sandstone separated by soft mudstone and shale lenses along the Gros Ventre River near Bacon Ridge.

The base of the formation is arbitrarily placed where coal-bearing mudstone and shale grade upward into thick lenticular sandstones with mudstones and shales which contain relatively little coal. North of the Buffalo Fork River, an unconformity exists at the top of the formation, but to the south it is conformably overlain by the Late Cretaceous Mesaverde Formation.

Distribution and Topographic Expression. Extensive exposures are present along the Gros Ventre River and extend north into the Whetstone anticline area. Within the thesis area, the formation is well exposed on the east flank of the Spread Creek anticline along Lava Creek, Spread Creek (Figure 9), and the South Fork of Spread Creek. The formation plunges beneath Tertiary rocks north of Davis Hill.

The sandstone lenses form rounded cliffs up to 100 feet high which lense out laterally in a few hundred feet. These cliffs are
FIGURE 9. Rounded and honeycombed outcrop of the Lenticular Sandstone and Shale Sequence on the north side of Spread Creek.

FIGURE 10. Thick sandstone lenses in the Lenticular Sandstone and Shale Sequence on the north side of Spread Creek.
usually lens shaped (Figure 10) and are separated by smooth gray slopes underlain by soft shale and mudstone. Many of the cliffs contain small weathered cavities up to 18 inches in diameter. Davis Hill is held up by thick resistant sandstone lenses of the Lenticular Sandstone and Shale Sequence, but the formation generally forms low rounded hills.

**Thickness.** In the southeastern part of the Jackson Hole region, the formation is 2300 to 2400 feet thick. The formation is 2200 feet thick along the South Fork of Spread Creek, but is only 1000 feet thick to the north on Davis Hill. This change in thickness is probably due to Late Cretaceous erosion north of the Buffalo Fork River since the Mesaverde Formation, which ordinarily overlaps the Lenticular Sandstone and Shale Sequence, is completely missing north of the river.

**Lithology.** Thick sandstone lenses separated by soft siltstone, mudstone, claystone, and shale lenses characterize the Lenticular Sandstone and Shale Sequence.

The sandstone lenses are up to 75 feet thick and 2000 feet long, but are generally about 10 to 20 feet thick and pinch out laterally within several hundred feet. They are usually cross-laminated and have a platy parting parallel to the bedding. These gray and tan sandstone beds are weathered light gray to tan. They are fine
to medium grained, friable, and contain hard calcareous lenses up
to three feet thick and 15 to 20 feet in length.

The calcareous lenses have a blocky jointing and form re-
sistant ridges on the outcrops. These resistant calcareous lenses
locally cap small hoodoos of friable sandstone. They weather to a
darker brown or tan color than the enclosing sandstone.

Light-gray marcasite concretions up to ten inches in diame-
ter are abundant in the sandstone lenses. Generally, they are one-
half to three-fourths of an inch in diameter. They weather to a
yellow-brown color and thus give the outcrop a rusty spotted ap-
pearance. The honeycombed nature of the outcrops is mostly due
to the more rapid weathering and removal of these concretions.

In the hand specimen, grains of quartz, dark rock frag-
ments, and biotite are visible. The sandstones are fine to medium
grained, not well sorted, and are locally porous. Microscopically,
they are very similar to the Bacon Ridge sandstones. Modal anal-
yses of several samples of sandstone from the Lenticular Sand-
stone and Shale Sequence are shown in Table 4.

Angular to subrounded grains of quartz, chert, sedimen-
tary rocks, and metaquartzite are the most common detrital min-
eral constituents. Detrital carbonate grains comprise about six
percent of the total detrital grains. Only trace amounts of plagio-
cline are present. Magnetite, microcline, zircon, biotite,
muscovite, and organic matter are minor constituents.

TABLE 4. Modal analysis of Lenticular Sandstone and Shale Sequence samples.

<table>
<thead>
<tr>
<th></th>
<th>DRH 20&lt;sup&gt;1&lt;/sup&gt;</th>
<th>DRH 33&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>33</td>
<td>35</td>
</tr>
<tr>
<td>Chert</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Metaquartzite</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Rock fragments</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Detrital carbonate</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Organic matter</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Carbonate cement</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>Clay</td>
<td>6</td>
<td>11</td>
</tr>
</tbody>
</table>

Sample locations:
<sup>1</sup> Along Grouse Creek, one mile southeast of the South Fork of Spread Creek.
<sup>2</sup> Along Lava Creek, at the southeast base of Davis Hill.

The sandstones are well cemented by calcite and lesser amounts of very fine-grained clay. Many of the detrital grains appear to be floating in the calcite cement. This suggests that these grains were once supported by a clay matrix or other detrital grains which have since been replaced by calcite. Much of the calcite cement in these nonmarine sandstones probably came from the recrystallization of detrital carbonate grains. Minor amounts of
authigenic hematite, sericite, and chlorite are present.

The samples studied are quartz arenites and quartz wackes. The apparent textural maturity of some of these sandstones is due to the dominant quartzose source rocks.

Light-gray to black mudstone, claystone, and shale lenses and beds are poorly exposed. The lenses are usually less than ten feet thick and individual beds are less than one foot thick. The lenses pinch out laterally within a few tens of feet. Asymmetric ripple marks commonly occur on bedding surfaces. Thin discontinuous coal beds less than six inches thick and carbonized wood fragments are associated with the fine-grained sedimentary rocks. Poorly preserved wood fragments and leaf fossils occur throughout the formation.

Age. The Late Cretaceous age of the formation is based on plant fossils, nonmarine mollusk fossils, and stratigraphic position (13, p. 81). In the area of study, numerous plant fragments were found in the Lenticular Sandstone and Shale Sequence, but none were well preserved.

Love (13, p. 81) believes that the formation merges into the upper Cody Shale to the east. If this is true, the rocks correlative with the Lenticular Sandstone and Shale Sequence become marine to the east of the thesis area. It is also possible that they are
correlative with the lower part of the Mesaverde Formation in the Wind River Basin.

Source Rocks and Depositional Environment. The source rocks for the detrital grains making up the Lenticular Sandstone and Shale Sequence were nearly identical to those of the Bacon Ridge Sandstone and the Coaly Sequence. Sedimentary rocks, especially chert, limestone, and sandstone, were the dominant source rocks. The low percentage of feldspar, biotite, and other typical igneous rock minerals in the sandstones suggests that very few igneous rocks were exposed in the source area. Metamorphic quartzite and schist were also source rocks.

The Whetstone anticline area was located on a broad, low coastal plain when the Lenticular Sandstone and Shale Sequence was deposited. The Late Cretaceous shoreline was 50 to 100 miles to the east and a region of moderate to high relief lay to the west. Large streams carried sediments into the area from the source areas to the west. The deposits from some of these large streams are represented by the thick channel sandstones found in the Lenticular Sandstone and Shale Sequence. The numerous marcasite concretions in the formation suggest that reducing conditions existed in parts of the area. Since sandstones are much more abundant in the formation than in the underlying Coaly Sequence, most of the
streams were more competent. Fewer sediments were being de-
posited in swamps and similar environments at this time.

Mesaverde Formation

Over 600 feet of nonmarine white sandstone overlies the
Lenticular Sandstone and Shale Sequence in the area studied. These
white sandstone beds, which were formerly called the White Sand-
stone Sequence, were described by Love et al. (17, p. 13-27) for
exposures along the Gros Ventre River. They have since been cor-
related with the Late Cretaceous Mesaverde Formation of central
Wyoming and Colorado.

The contact with the underlying Lenticular Sandstone and
Shale Sequence is conformable and gradational. The base of the
Mesaverde Formation is arbitrarily picked at the base of a thick
sequence of light-gray to white sandstone beds.

Distribution and Topographic Expression. Outcrops of the
Mesaverde Formation are present near the Gros Ventre River and
north along the Spread Creek anticline to the Buffalo Fork River.
No outcrops have been found north of the Buffalo Fork Valley. In
the thesis area the formation is well exposed along the South Fork
of Spread Creek (Figure 11) and immediately south of the Hatchet
Motel.
FIGURE 11. Outcrop of white sandstone in the Mesaverde Formation along the South Fork of Spread Creek.
Mesaverde Sandstone beds form extensive white cliffs. A light-gray to white soil covers the formation where it is poorly exposed. Large angular blocks of white sandstone occur in the soil near the outcrops.

**Thickness.** The Mesaverde Formation is about 900 feet thick in the Jackson Hole region. In the Spread Creek Canyon, several miles west of the thesis area, it is 920 feet thick (13, p. 81). Approximately 600 feet of the formation are exposed near the Hatchet Motel, but several miles to the north it is completely absent. Apparently the Mesaverde Formation was eroded, north of the Buffalo Fork River, prior to the deposition of the overlying Late Cretaceous Harebell Formation.

**Lithology.** The Mesaverde Formation is made up of persistent sandstone beds 5 to 30 feet thick separated by thinner beds of gray shale and siltstone. A few coal beds less than six inches thick are present.

The sandstone beds, which are gray to blue gray on fresh surfaces and light gray to white on weathered surfaces, are generally medium to coarse grained, friable, and poorly sorted. Individual beds are poorly graded and are usually 15 to 20 feet thick. They have a platy to blocky jointing pattern. The sandstones are cross-laminated and small cut-and-fill structures up to five feet in length
are common. A few marcasite concretions weathered to a yellow-brown color are present.

In the hand specimen, the sandstones are friable and contain visible grains of quartz, dark rock fragments, magnetite, and pink garnet (?). Under the microscope they are very similar to the other Late Cretaceous sandstones of the area. Modal analyses of two Mesaverde sandstone samples are shown in Table 5. Sample number 45 was collected 15 miles south of the thesis area. The other sample came from a sandstone bed 15 feet thick located near the junction of the North and South Forks of Spread Creek.

**TABLE 5. Modal analysis of Mesaverde Formation samples.**

<table>
<thead>
<tr>
<th></th>
<th>DRH 45</th>
<th>DRH 61</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>37</td>
<td>70</td>
</tr>
<tr>
<td>Chert</td>
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<td>Metaquartzite</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Rock fragments</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Detrital carbonate</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Carbonate cement</td>
<td>29</td>
<td>7</td>
</tr>
<tr>
<td>Clay</td>
<td>3</td>
<td>-</td>
</tr>
</tbody>
</table>

The mineralogy of the Mesaverde sandstones is nearly identical to that of the sandstones in the underlying Lenticular Sandstone
and Shale Sequence. Quartz, chert, metaquartzite, and sedimentary rock fragments are the most common detrital minerals. Most of the sandstones contain some detrital carbonate. Minor amounts of plagioclase, biotite, magnetite, microcline, garnet, green hornblende, schist, and sphene are present.

Most of the sandstones are poorly cemented by calcite. Very few Mesaverde sandstones from the thesis area are as calcareous as sample number 45 which contains 29 percent carbonate. Many of the sandstones contain up to ten percent clay matrix. The clay, which is probably montmorillonite, occurs as very fine-grained yellow to yellow-brown material between the detrital grains. Small amounts of authigenic sericite, hematite, and chlorite are present.

All of the samples studied are classified as quartz arenites. They contain large amounts of quartz, chert, and metaquartzite with minor amounts of montmorillonite (?).

Light-gray siltstones and shales are very poorly exposed at the base of several Mesaverde sandstone cliffs. The individual beds are less than six inches thick and locally contain abundant plant material. Thin zones of coaly shale are also present.

Age. The Late Cretaceous age of the Mesaverde Formation is based on nonmarine mollusk fossils and plant fossils (13, p. 81).
Fossils are not abundant in the formation. Only a few poorly preserved leaves and plant fragments were found in the thesis area.

Love (13, p. 81) believes that the Mesaverde Formation is correlative with at least part of the Mesaverde Formation of the Wind River and Bighorn Basins to the east.

**Source Rocks and Depositional Environment.** Paleozoic and Mesozoic sandstones, cherts, and limestones were the principal source rocks. Igneous and metamorphic rocks were of less importance in the source area. These source rocks, which were located west of the thesis area, were nearly identical in composition to those which supplied debris to the other Late Cretaceous rocks now exposed in the thesis area. However, the thick and extensive sandstone beds of the Mesaverde Formation represent a change in conditions at the source areas.

These persistent and thick sandstone beds suggest that the source area was uplifted at the beginning of Mesaverde time. Thus, thick blankets of sand were rapidly deposited by streams charged with sediments from the newly uplifted source areas. This uplift to the west probably represents the first pulse of the Laramide revolution. The Mesaverde Formation was deposited on a broad coastal plain of low to moderate relief. Therefore, the depositional environment was very similar to that of the Lenticular Sandstone and
Harebell Formation

The Late Cretaceous Harebell Formation was named by Love (14, p. 1900-1904) for over 5000 feet of sandstone, siltstone, claystone, shale, and conglomerate exposed near Harebell Creek, 12 miles east of the south entrance to Yellowstone National Park.

Unconformities are present at the base and top of the formation but are rarely exposed. The Harebell Formation unconformably overlies the Mesaverde Formation south of the Buffalo Fork River. North of the river, where the Mesaverde Formation is absent, it lies unconformably on the Lenticular Sandstone and Shale Sequence.

Distribution and Topographic Expression. Broad outcrops of the Harebell Formation occur between the Gros Ventre River and southern Yellowstone National Park. The best and most extensive exposures are located between the Buffalo Fork River and Yellowstone National Park.

In the area studied, the formation is exposed along the east flank of the Spread Creek anticline and in the core of the Whetstone anticline. The best outcrops lie along the North Fork of Spread Creek, Blackrock Creek, Lava Creek, and Pacific Creek.
The Harebell Formation is generally poorly exposed, but some of the more resistant calcareous sandstone beds form low cliffs up to 20 feet high (Figure 12). Many landslides occur in the formation north of Spread Creek. The rocks are best exposed in landslide scars and on steep slopes held up by resistant sandstone and conglomerate beds in the overlying Pinyon Conglomerate.

**Thickness.** North of Mt Leidy, the Harebell Formation ranges in thickness from 3500 to 5000 feet with the greatest thicknesses to the north near Yellowstone National Park. South of Mt Leidy, near the Gros Ventre River, the formation is only about 50 feet thick.

Formation thicknesses, computed from surface sections within the Whetstone anticline area, range from about 3500 feet on the North Fork of Spread Creek to over 4000 feet on Pacific Creek. The Harebell Formation is about 4000 feet thick along the Buffalo Fork River and Blackrock Creek.

**Lithology.** The Harebell Formation, in the thesis area, consists of thin to thick beds of sandstone, conglomerate, siltstone, mudstone, claystone, shale, and coal (Figure 13). Olive-drab sandstone beds are very common in the lower one-half of the formation and numerous quartzite conglomerate lenses occur in the upper one-half.

FIGURE 13. Northeast-dipping Harebell sandstone and siltstone beds on the north side of the North Fork of Spread Creek.
Gray to tan sandstone, weathered to an olive-drab to khaki color, is the most common rock type in the formation. The sandstone beds are usually five to ten feet in thickness but locally attain 20 feet. Generally, they pinch out laterally within several hundred feet, but locally extend several thousand feet. Cross-laminations are common in the sandstone beds. Groove casts, asymmetric ripple marks, and streaks of heavy minerals are present on some of the bedding-plane surfaces. Platy parting parallel to the bedding or the cross-lamination is very common. Joints at right angles to the bedding are less common and are usually confined to calcareous beds.

The sandstones are fine to coarse grained, poorly sorted, and poorly graded. Angular to subrounded grains of quartz, feldspar, biotite, rock fragments, and magnetite are visible in the hand specimen. Some of the beds contain hard calcareous zones up to two feet thick and 25 to 30 feet in length. These calcareous zones form knobs and ridges on the weathered outcrop since most of the sandstones are soft and easily eroded.

Microscopically, the sandstones contain angular to subrounded grains of quartz, chert, metaquartzite, plagioclase, and rock fragments. Biotite, microcline, magnetite, zircon, sphene, green hornblende, epidote, garnet, rutile, apatite, and organic matter are minor detrital constituents. The results of point counts
on four samples of Harebell sandstone are shown in Table 6.

TABLE 6. Modal analysis of sandstone samples from the Harebell Formation.

<table>
<thead>
<tr>
<th></th>
<th>DRH 4&lt;sup&gt;1&lt;/sup&gt;</th>
<th>DRH 27&lt;sup&gt;2&lt;/sup&gt;</th>
<th>DRH 40&lt;sup&gt;3&lt;/sup&gt;</th>
<th>DRH 58&lt;sup&gt;4&lt;/sup&gt;</th>
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</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>34</td>
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</tr>
<tr>
<td>Chert</td>
<td>4</td>
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<td>36</td>
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<tr>
<td>Metaquartzite</td>
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<td>10</td>
</tr>
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<td>6</td>
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<td>Detrital carbonate</td>
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<td>-</td>
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<td>3</td>
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<td>Biotite</td>
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</tr>
<tr>
<td>Clay</td>
<td>12</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Sample locations:
1. One mile north of end of gravel road along Pacific Creek.
2. On the west flank of the Whetstone anticline, one-half mile south of Pacific Creek.
3. Along a small stream, one and one-half miles south of Gravel Mountain.
4. Along the North Fork of Spread Creek, one and one-half miles southeast of Baldy Mountain.

In general, the mineralogy of the Harebell sandstones is very similar to that of the other Late Cretaceous sandstones of the
area. However, some of the sandstones in the Harebell Formation contain large numbers of angular zoned plagioclase grains. These sandstones also contain numerous magnetite, sphene, green hornblende, and biotite grains. They generally have a clay matrix and contain only small amounts of carbonates. Sample number 4, shown on Table 6, is typical of these arkosic wackes. These sandstones are much lighter in color than the typical Harebell sandstone and are usually associated with landsliding because of their high clay content.

The rock fragments, other than chert, in the Harebell sandstones are mostly fine-grained sedimentary rocks, but a few grains of basic volcanic rock are present. Thin beds, less than two inches thick, of heavy minerals occur locally in the sandstones. They are composed of about 80 percent magnetite with subordinate amounts of quartz, chert, zircon, garnet, sphene, and rutile. The Harebell sandstones usually contain more magnetite, biotite, and plagioclase than the other Late Cretaceous rocks of the thesis area.

Several of the samples studied contained up to 50 percent montmorillonite (?) with abundant biotite and long angular grains of quartz. The presence of very angular detrital grains, abundant biotite, and the clay matrix suggests that these sandstones are tuffaceous. However, no glass shards were observed. The glass shards, if they were present, have probably decomposed.
The sandstones are usually cemented by sparry and fine-grained calcite. Detrital carbonate is generally present in the rocks cemented by calcite. Many of the sandstones, especially those containing substantial amounts of plagioclase, have a fine-grained clay matrix. The clay is usually yellow-brown nontronite (?) or some other variety of montmorillonite. Some bentonite may occur in the tuffaceous (?) sandstones of the formation. Minor amounts of authigenic hematite, sericite, and chlorite are present.

Many thin beds of claystone, mudstone, shale, and coal occur in the Harebell Formation. They are gray, blue-gray, green, or black on fresh surfaces. The weathered surfaces are blue-gray to light-brown in color. The beds are normally less than two feet thick and pinch out laterally within a few feet. All of the coal beds observed are less than one foot thick. Asymmetric ripple marks and cross-laminations are common.

These fine-grained sedimentary rocks are usually calcareous and locally contain gray calcareous concretions up to two feet in diameter. Claystone is the most common rock type. The claystone and shale beds contain abundant plant fossils and a few fossil nonmarine gastropod shells.

Light-brown conglomerate lenses, identical in composition to those of the overlying Pinyon Conglomerate, become more numerous toward the top of the Harebell Formation (Figure 14). The
FIGURE 14. Conglomerate and sandstone lenses exposed near the top of the Harebell Formation two miles west of Gravel Mountain. Light-gray beds in photograph are sandstone.
lenses are up to 20 feet thick and pinch out laterally within several hundred feet. They are composed of well-rounded quartzite and chert pebbles and cobbles in a medium- to coarse-grained sandstone matrix.

Microscopic examination of the matrix indicates abundant quartz, chert, metaquartzite, and rock fragments. Minor amounts of magnetite, microcline, biotite, garnet, zircon, epidote, and green hornblende are present. These detrital grains are cemented by calcite and clay.

Age. The Harebell Formation is Late Cretaceous in age. This age is based on plant fossils and freshwater invertebrates which occur throughout the formation. Love (13, p. 83) has discussed the basis for the assignment of a Late Cretaceous age to the formation.

Numerous and well-preserved leaf fossils are present in the claystones and mudstones of the Harebell Formation. However, the writer did not attempt to identify the leaf fossils. Poorly preserved nonmarine gastropod and ostracod (?) shells were collected from calcareous concretions in the Harebell Formation, one and one-half miles west of Gravel Mountain. Similar fossils were found in a thin shaly sandstone bed along Blackrock Creek, two miles east of the Hatchet Motel.
The Harebell Formation is correlative with the Lance Formation of central Wyoming. It is probably correlative with the lower part of the Evanston Formation south of the Jackson Hole region.

**Source Rocks and Depositional Environment.** Most of the rocks in the source area were sedimentary or metamorphic as evidenced by the abundant quartz, chert, metaquartzite, and sedimentary rock fragments in the Harebell Formation. However, several of the Harebell samples studied contained large amounts of fresh zoned, oligoclase and andesine with many grains of sphene and green hornblende. These mineral grains suggest that intermediate igneous rocks were locally important source rocks. Most of the Harebell sandstones contain some basic volcanic rock fragments and abundant magnetite. Therefore, basic volcanic rocks were present in the source area.

The abundant biotite, montmorillonite, and angular quartz grains in some of the sandstones suggests that volcanic ash was locally deposited in the thesis area. The source of this ash is not known.

Harebell sediments were deposited in an area of low relief by numerous streams running east and southeast from the source area. Swamps and small lakes were present in the area studied.
Thin coal beds formed in some of the swampy areas where plant material accumulated in large quantities. The plant fossils in the formation suggest that the climate was temperate or subtropical and that vegetation was profuse.

Near the end of Harebell time, a large area of Precambrian (?) or Cambrian quartzite was exposed to erosion in central or southwestern Montana. As a result, large amounts of quartzite gravel and coarse sand were carried into the thesis area by several large streams. To the south of the area, similar deposits were being formed by debris from sources to the south and southwest. These coarse-grained deposits are preserved as conglomerate lenses in the upper part of the Harebell Formation.

Pinyon Conglomerate

The Paleocene Pinyon Conglomerate overlies the Harebell Formation in the Whetstone anticline area. Weed (6) first described the Pinyon Conglomerate for a thick sequence of conglomerate and sandstone exposed on Pinyon Peak five miles north of the thesis area. At the type locality, the formation consists of a poorly exposed basal coal member overlain by a thick sequence of quartzite conglomerate containing thin lenticular sandstone beds.

An angular unconformity exists between the Harebell Formation and the basal coal member on Pinyon Peak. Two miles
north of Mt Leidy an angular unconformity of over 80 degrees occurs between the Pinyon Conglomerate and the underlying Mesa- verde Formation. However, neither the unconformity nor the basal coal member were observed in the area studied. Thus, the base of the Pinyon Conglomerate is arbitrarily picked at the zone where lenticular quartzite conglomerate becomes the dominant rock type.

**Distribution and Topographic Expression.** The Pinyon Conglomerate crops out in the mountains east and northeast of Jackson Hole. It is well exposed along the Gros Ventre River and on the higher mountain peaks to the north. The sandstone and conglomerate lenses in the formation are very resistant to erosion and as a result cap Mt Leidy, Mt Randolph, Gravel Mountain, Whetstone Mountain, and other high points in the thesis area.

Conglomerate hoodoos capped by calcareous sandstone are common on and around Gravel Mountain and Whetstone Mountain (Figure 15). Spectacular cliffs of Pinyon Conglomerate, such as those shown in Figure 16, occur on Whetstone Mountain and Gravel Mountain. However, the formation generally underlies steep gravel-covered mountain slopes.

**Thickness.** About 600 feet of the formation are exposed on Pinyon Peak. In the thesis area the top of the formation is nowhere exposed. The maximum thickness is on Gravel Mountain.
FIGURE 15. Hoodoos of Pinyon Conglomerate on the south side of Whetstone Mountain.

FIGURE 16. View of the west face of Gravel Mountain where over 1200 feet of Pinyon Conglomerate are exposed.
where over 1200 feet of Pinyon Conglomerate are exposed.

**Lithology.** On Pinyon Peak the formation consists of a thin basal coal and shale zone overlain by a thick sequence of light-brown pebble and cobble conglomerate with a minor gray to light-brown sandstone lenses. Farther south, near Mt Leidy, a thin coal and shale sequence at the base of the Pinyon Conglomerate has been described (13, p. 84).

The basal coal member, which is composed of coaly shale, coal beds, claystone, and thin lenticular sandstone beds, was not observed in the thesis area. Since the base of the Pinyon Conglomerate is poorly exposed, the coal member may be present. However, it is more likely that the coal member present on Pinyon Peak and near Mt Leidy has graded into the overlying conglomerate member in the area studied.

Several hundred feet of fossiliferous sandstone, siltstone, mudstone, claystone, shale, and coal are exposed at the base of the Pinyon Conglomerate near the mouth of Whetstone Creek (Figure 17). Since numerous plant fossils of Paleocene age (13, p. 84) have been found in these rocks, they are included in the Pinyon Conglomerate. These rocks may be correlative with the basal coal member exposed to the north on Pinyon Peak.

Similar rocks containing well-preserved leaf fossils are
FIGURE 17. Siltstone, shale, and fine-grained sandstone exposed on Whetstone Creek. These rocks may be correlative with the basal coal member of the Pinyon Conglomerate.

FIGURE 18. Typical poorly sorted Pinyon Conglomerate exposed two miles south of Whetstone Mountain.
exposed on the south side of Pacific Creek, two miles southwest of Whetstone Creek, and also underlie Pinyon Conglomerate. These fine-grained sedimentary rocks are not present at the base of the Pinyon Conglomerate elsewhere in the area mapped. This suggests that they were deposited locally in swamps and small lakes.

The conglomerate in the Pinyon Conglomerate is composed of poorly sorted pebbles and cobbles in a fine- to coarse-grained sandstone matrix (Figure 18). Roundstones from the formation are composed of quartzite, chert, and metavolcanic rocks. The conglomerates are poorly graded and cross-bedded. Many of the foreset beds, such as those shown in Figure 19, dip to the south or southeast and thus indicate deposition by currents flowing from the north or northwest.

About ten percent of the roundstones are cobble- or boulder-sized. Most of the roundstones smaller than cobbles are in the medium to coarse pebble size range. Boulders up to 12 inches in diameter were observed in the conglomerates.

Pebble counts, shown in Table 7, indicate that quartzite is the dominant rock type making up about 80 to 95 percent of the total roundstones. Most of the quartzite is gray, tan, or purple, but white, green, pink, and brown quartzite are also present. Metavolcanic roundstones usually comprise five to ten percent of the total roundstones, and chert up to six percent of the total. The
FIGURE 19. Outcrop of Pinyon Conglomerate along Lava Creek showing foreset beds.

FIGURE 20. Well-rounded and "pressure-marked" cobbles of quartzite from the Pinyon Conglomerate one mile west of Turpin Meadow.
metavolcanic and chert fragments are dark-gray to black in color. Pebbles of weathered acidic volcanic rocks occur infrequently in the conglomerate. One pebble count west of Turpin Meadow indicated an unusually high percentage of metavolcanic (16 percent) and chert (14 percent) roundstones.

TABLE 7. Pebble counts of Pinyon Conglomerate roundstones.

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<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tr>
<td>Quartzite</td>
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<td>89</td>
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<td>81</td>
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<tr>
<td>Metavolcanics</td>
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<td>10</td>
<td>11</td>
<td>12</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>Chert</td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Location of pebble counts:
1. South slope of Whetstone Mountain.
2. One-fourth mile southwest of mouth of Whetstone Creek.
3. One-fourth mile northeast of mouth of Whetstone Creek.
4. West flank of Whetstone anticline, one-fourth mile south of Pacific Creek.
5. Three miles northwest of Gravel Mountain.
6. Along Lava Creek, two miles east of Davis Hill.
7. One mile west of Turpin Meadow.
8. Two miles east of Hatchet Motel on Rosies Ridge.

All of the roundstones are subrounded to well-rounded and most have a slight polish. Many of the pebbles and cobbles are elongate, but no study was made to determine preferred orientations. Dents, scars, and radial fractures occur on the surfaces of many roundstones where adjacent pebbles and cobbles have been in
contact (Figure 20). In fact, many of the clasts are highly frac-
tured and crushed. These "pressure marks" and fractures were
formed by compaction and tectonic movements in the sediments af-
ter deposition.

Tanner (29, p. 637-641) has described the same surface
features on quartzite and limestone roundstones in the pebble con-
gglomerates of the Paleocene Beaverhead Formation of southwestern
Montana. He attributes the "pressure marks" and fractures to de-
formation caused by lateral motion on a large fault in the area.

The matrix of the conglomerate is a light-brown, fine- to
coarse-grained sandstone, which comprises 25 to 35 percent of the
conglomerate. The mineralogy of the matrix is identical to that of
the sandstones in the sandstone lenses of the formation.

Light-gray to brown sandstone lenses make up about ten per-
cent of the total formation. The lenses are up to 15 feet thick and
grade laterally into conglomerate within a few tens of feet. They
are fine to medium grained and poorly sorted. Cross-laminae sets
up to two feet in length are common. Carbonized wood fragments
and thin lignite seams, less than six inches thick, are locally pre-
sent.

Microscopically, the Pinyon sandstones are composed
largely of angular to subrounded grains of detrital quartz, chert,
metaquartzite, and rock fragments. Two thin sections of Pinyon
sandstone were studied. A modal analysis for each is shown in Table 8. Both of the samples are quartz arenites, using Gilbert's classification (33, p. 289-297).

**TABLE 8. Modal analysis of two sandstone samples from the Pinyon Conglomerate.**

<table>
<thead>
<tr>
<th></th>
<th>DRH 24</th>
<th>DRH 65</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quartz</strong></td>
<td>45</td>
<td>42</td>
</tr>
<tr>
<td><strong>Chert</strong></td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td><strong>Metaquartzite</strong></td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td><strong>Rock fragments</strong></td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td><strong>Plagioclase</strong></td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td><strong>Organic matter</strong></td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td><strong>Heavy minerals</strong></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Carbonate cement</strong></td>
<td>26</td>
<td>21</td>
</tr>
<tr>
<td><strong>Clay</strong></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Chlorite</strong></td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

Sample locations:
1 Two miles northwest of Gravel Mountain.
2 Along Whetstone Creek, one and one-half miles east of Whetstone Mountain.

Most of the rock fragments are mudstone or siltstone, but a few grains of mica schist and basalt (?) are present. Colorless to pink garnet, in very angular grains, is the most common heavy
mineral. Angular grains of light-brown sphene are also quite common. Other heavy minerals present include zircon, magnetite, and epidote.

Nearly all of the sandstones are well cemented by calcite and thus have a low porosity. In fact, some of the quartz grains are embayed and partially replaced by calcite. Argillaceous material is present in the sandstones, but is usually a minor constituent. Small amounts of authigenic hematite, chlorite, and sericite are also present.

The Pinyon sandstones are very similar in composition to the underlying Harebell sandstones. Both contain basic volcanic rock fragments and a larger percentage of heavy minerals than the other Late Cretaceous sandstones of the area.

Age. The Pinyon Conglomerate was originally assigned an Eocene age by Weed (6), but later studies have indicated a Paleocene age. The Paleocene age is based on plant and nonmarine invertebrate fossils and correlation with nearby formations, such as the Hoback Formation, which contain Paleocene vertebrate fossils.

Well-preserved leaf fossils were found by the writer in the claystones and shales at the base of the formation on Whetstone Creek. Love (13, p. 84) states that plant fossils identified as _Celastrus ferruginea_ and _Metasequoia sp._ were found at this
locality. No fossils were found elsewhere in the formation.

The Pinyon Conglomerate is probably correlative with the Hoback Formation of southeastern Jackson Hole and the Fort Union Formation of central and eastern Wyoming. The Beaverhead Conglomerate of southwestern Montana may also be correlative. All of these Paleocene rocks, except the Fort Union Formation, were rapidly deposited in restricted basins.

Source Rocks and Depositional Environment. The origin of the voluminous deposits of Pinyon Conglomerate in the Jackson Hole region has puzzled geologists for many years. Love (11) suggests that they were deposited by powerful rivers carrying debris from a source area in Montana where Precambrian rocks of the Belt Series were exposed. Eardley (4, p. 323) believes the source was in central Montana where Beltian rocks are now exposed.

Most of the quartzite and metavolcanic roundstones in the formation are probably from the Precambrian Belt Series. However, some of the light-colored quartzite fragments may be Paleozoic quartzites, such as those in the Cambrian Flathead Formation. The chert roundstones are probably of Paleozoic age. Since none of the roundstones were studied petrographically, their exact origin can only be postulated.

If we assume that most of the roundstones are Beltian
quartzite, an extensive Late Cretaceous and Paleocene source area must be found. The only extensive modern exposures of the Belt Series, capable of supplying a large volume of quartzite debris, are in southwestern and central Montana, 150 to 200 miles north of the thesis area. However, large exposures of quartzite could have been present immediately north or northwest of the area studied during the Late Cretaceous. This region is blanketed by extensive Tertiary lavas; therefore, little is known about the underlying rocks. A northern source is indicated by foreset beds (Figure 19) found by the writer and Love (13, p. 82) in the Pinyon Conglomerate. If our present knowledge is correct, none of the mountain ranges now surrounding the Jackson Hole region were eroded to Precambrian rocks during the Late Cretaceous or the Paleocene.

The writer believes that the major source of Pinyon debris was in central Montana with minor amounts coming from an uplifted area to the west. South of the area mapped, the Pinyon Conglomerate contains numerous limestone, chert, and sandstone roundstones derived from Paleozoic and Mesozoic rocks located to the south and southwest.

Coarse debris was carried into the thesis area during Pinyon time by large high-gradient streams and was deposited as large gravel fans. These streams must have been very powerful since the probable source area was far to the north and
roundstones up to three feet in diameter (13, p. 84) have been found in the conglomerate.

These coarse sediments were deposited in a Late Cretaceous and Paleocene basin which was formed, in part, by post-Harebell folding along what is now the eastern margin of Jackson Hole. While these anticlines, including the Spread Creek anticline, were being formed, Harebell conglomerates were being deposited in an adjacent basin to the east. Deposition continued as the Spread Creek anticline was eroded. During Pinyon time, the basin was filled and much of the region was covered by a thick blanket of gravel.

It is of interest to consider the character of the unconsolidated sediments now covering the floor of Jackson Hole west of the area mapped. These sediments consist largely of quartzite gravel deposited by the Snake River and its tributaries. Some debris was also carried in by Pleistocene glaciers. Thus, a present-day example of a basin receiving coarse sediments similar to the one which existed during Late Harebell and Pinyon times is present.

Colter Formation

The Middle Miocene Colter Formation was named by Love (14, p. 1904-1907) for over 7000 feet of sandstone, claystone, and waterlaid pyroclastics near Pilgrim Creek and Colter Bay
northwest of the area studied. Andesite and basalt flows and intrusions are locally present in the formation.

**Distribution and Topographic Expression.** Widespread outcrops of the formation lie immediately west and northwest of the thesis area on the east side of Jackson Hole. In the Whetstone anticline area, Colter Formation lava flows crop out one-half mile west of Davis Hill and one mile to the north across Pacific Creek.

The lava flows form low hills covered by a red soil. The rocks are very poorly exposed, but locally form small cliffs five to ten feet high.

**Thickness.** In the type area, the Colter Formation is about 7000 feet thick. Less than 150 feet of the formation are exposed in the area studied.

**Lithology.** The Colter Formation consists largely of sandstone, claystone, and waterlaid tuff beds. However, none of these sedimentary rocks occur in the area of study—only basic volcanics are present.

Dark-gray to black porphyritic andesites and basalts of the Colter Formation crop out in the thesis area. They are weathered to a brick-red to purple-gray color. The flows are poorly exposed; therefore, flow thicknesses cannot be determined. These rocks
are usually vesicular, scoriaceous, or brecciated. Many of the cavities and fractures contain secondary calcite, chalcedony, and zeolites.

A thin section from a basalt lava flow located on the western boundary of the area, one-half mile north of Pacific Creek was studied. It contained numerous augite phenocrysts in a groundmass of bytownite and labradorite laths. Some magnetite and interstitial black glass is also present in the groundmass.

Age. These basalt and andesite flows are considered to be correlative with the Colter Formation since they lie unconformably on the Harebell Formation and probably intertongue with the Colter Formation to the west.

Vertebrate fossils of Middle Miocene age have been found in the Colter Formation several miles west of the area mapped (13, p. 88). None were found in the thesis area.

Unconsolidated Sediments

Much of the thesis area is covered by deposits of unconsolidated sediments. Pleistocene glacial deposits, Quaternary alluvium, and Quaternary landslide deposits occur in the area.

Glacial Deposits. Pleistocene glacial deposits cover over 45 square miles in the Whetstone anticline area. At least three
distinct glacial stages are represented by these deposits. These three stages were first described by Blackwelder (2, p. 321-333) in his classic work on the geology of northwestern Wyoming. He named them, in chronological order, the Buffalo, Bull Lake, and Pinedale stages.

Small isolated patches of weathered Buffalo Drift are present north of the Buffalo Fork River at elevations above 7500 feet. Only resistant rock fragments, largely quartzite, occur in the Buffalo Drift. Therefore, it is frequently difficult to distinguish highly weathered Buffalo drift from weathered Pinyon Conglomerate. In fact, the smooth rounded pebbles and cobbles lying on weathered outcrops of Pinyon Conglomerate have been called Buffalo drift by some geologists.

The Buffalo drift was deposited by a huge ice sheet which flowed south and west into the Jackson Hole region from the B eartooth Mountains of Montana, and the Absaroka and Wind River Mountains of Wyoming. Montagne and Love (23) have described some of the glacial erosion features and the possible extent of the Buffalo ice sheet. The Buffalo ice advance is considered to be pre-Wisconsin in age (2, p. 329).

Most of the glacial moraine in the area was probably deposited during the Bull Lake glacial stage. The Bull Lake glaciers were generally restricted to individual valleys. Erratic boulders
of limestone, gneiss, schist, and volcanic breccia are numerous along the Buffalo Fork Valley and in the hills to the south (Figure 21). Many of these boulders have been polished, scratched, or grooved by glacial action.

Since the erratic boulders increase in size and number to the east, the glacial ice probably flowed to the west. This is further substantiated by the rock types in the moraine. Since there are outcrops of Precambrian metamorphics, Paleozoic limestones, and Tertiary volcanic breccia 10 to 15 miles east of the thesis area and not immediately to the north, south, or west, it is probable that the erratic boulders originated to the east. Therefore, the widespread glacial deposits along the Buffalo Fork Valley and on Baldy Mountain were no doubt deposited by a local piedmont ice sheet extending down the valleys of the Buffalo Fork River, Blackrock Creek, and the North Fork of Spread Creek. This ice advance was post-Buffalo and probably occurred during Black-welder's Bull Lake glacial stage.

Some local Pinedale glaciation may have taken place in the higher valleys of the thesis area. The huge gneiss and volcanic breccia boulders, up to 15 feet in diameter, along the North Fork of Spread Creek may have been carried in by Pinedale glaciers. Elsewhere in the thesis area little evidence for Pinedale glaciation exists.
FIGURE 21. Large glacial boulder of volcanic breccia on Rosies Ridge.
Valley Fill and Terrace Deposits. Unconsolidated gravel, sand, and silt are present along the permanent and intermittent streams in the area studied. The depth of these deposits is not known.

Quartzite, derived from the Pinyon Conglomerate, is the dominant rock type in the stream gravels. In fact, the gravel along Pacific Creek is composed of over 90 percent quartzite. Stream gravels south of Pacific Creek contain appreciable amounts of gneiss, schist, limestone, and volcanic breccia. Some of the smaller streams are choked by boulders from the glacial moraine. Along Blackrock Creek and the North Fork of Spread Creek, there are boulders of volcanic breccia and gneiss up to 15 feet in diameter.

The fine-grained alluvial sediments were not examined. Some gold is present in the sands along Pacific Creek. The gold deposits will be discussed in a later chapter.

The terrace gravels contain poorly sorted sediments similar to those found in the present stream channels. Quartzite is the dominant rock type. These deposits were not studied in detail.

Landslide Deposits. Unconsolidated and very-poorly sorted deposits of landslide debris cover over 17 square miles in the studied area. These deposits contain angular boulders and huge blocks of sandstone and conglomerate mixed with fine-grained rock
fragments. Most of the landslide debris is composed of material from the Harebell Formation and the Pinyon Conglomerate.

All of the landslide deposits north of the Buffalo Fork River and east of Davis Hill are made up of debris from the Harebell Formation and the Pinyon Conglomerate. The small slides along Lava Creek, southwest of Davis Hill, are composed of fragments from the Bacon Ridge Sandstone, Coaly Sequence, and Lenticular Sandstone and Shale Sequence.

South of the Buffalo Fork Valley, most of the small landslide deposits contain fragments of pre-Harebell rocks. However, the large landslides on Baldy Mountain and along Blackrock Creek are composed of debris from the Pinyon Conglomerate and Harebell Formation. The slides along Spread Creek contain rock fragments from the Lenticular Sandstone and Shale Sequence and the Mesaverde Formation. Fragments from the Mesaverde Formation and the Harebell Formation occur in the slide near the Hatchet Motel.
Western Wyoming is in a structural transition zone between the highly deformed, thick geosynclinal sedimentary rocks of eastern Idaho and the less-deformed and thinner shelf sequence to the east. The Whetstone anticline area lies near the western edge of the Paleozoic and Early Mesozoic stable platform.

Regional Tectonic Setting

Thrust faults, reverse faults, and overturned folds yielding to the east are characteristic structural features of the geosynclinal area. Broad asymmetric folds and high-angle reverse and normal faults characterize the structure of the western margin of the stable shelf. The shelf folds, which are usually asymmetric to the southwest, were probably formed by folding and faulting in the Precambrian basement rocks. The Teton and Hoback normal faults may be surface expressions of deep-seated faulting. Some of these structural features are shown on Plate 2.

The Gros Ventre, Wind River, and Teton Ranges are large tilted uplifts on the western margin of the stable shelf. Many folds, which are asymmetric to the southwest and trending N. 20°W. to N. 60°W., are superimposed on these uplifts. Precambrian basement rocks are exposed in the central parts of each of these ranges.
TECTONIC MAP OF NORTHERN TETON COUNTY, WYOMING
The Hoback and Snake River Ranges, southwest of the thesis area, are composed of intensely folded and faulted geosynclinal sedimentary rocks. Most of the fold axes and faults strike to the northwest, parallel to the regional structural trend.

Three major periods of deformation have taken place in the region: one during the Precambrian, another during the Late Cretaceous and Early Tertiary Laramide revolution, and the last during the Late Tertiary. Horberg (8, p. 183-185) has outlined the sequence of deformation in the region.

Precambrian folds and faults are exposed in the cores of the Gros Ventre, Wind River, and Teton Ranges. However, most of the folding and thrust faulting in western Wyoming took place during the Laramide revolution. Late Tertiary faulting, especially on the Teton and Hoback normal faults, represents the latest period of deformation.

**Whetstone Anticline Area Structure**

Broad asymmetric folds are the dominant structures of the Whetstone anticline area. High-angle faults are subordinate structures. Most of these folds and faults were formed during the Laramide revolution, probably in response to folding and faulting in the underlying Precambrian basement rocks. These structures generally parallel the northwest-southeast structural alignment of the
region. However, several post-Harebell high-angle faults in the area strike to the northeast.

Folds

Two large anticlines and two synclines are present in the thesis area (Plate 3). These are, from southwest to northeast: the Spread Creek anticline, Lava Creek syncline, Whetstone anticline, and Box Creek syncline. They were formed during two distinct stages of the Laramide revolution.

Spread Creek Anticline

The Spread Creek anticline is a large asymmetric, doubly plunging anticline over 19 miles in length, and extends across the southwestern part of the area mapped. Synclines flank the structure on the southwest and northeast. The arcuate axis of the anticline strikes N. 25°W. to N. 30°W. north of Spread Creek, and N. 45°W. to N. 50°W. south of Spread Creek. Near Lava Creek, the Spread Creek anticline plunges to the northwest beneath Tertiary sedimentary and volcanic rocks. Southeast of Mt Leidy, near the South Fork of Spread Creek, it plunges to the southeast. The highest structural elevation on the fold occurs three miles east of Mt Leidy, along Leidy Creek, where the Late Cretaceous Cody Shale is exposed.
The asymmetry of this anticline is very evident. On the steep southwest flank of the fold, dips up to 90° have been recorded; whereas, none of the dips on the northeast flank exceed 30°. A complete stratigraphic section from the Cody Shale through the Harebell Formation is exposed on the flanks of the Spread Creek anticline.

The anticline was folded after deposition of the Mesaverde Formation and before deposition of the Pinyon Conglomerate since nearly horizontal beds of Pinyon Conglomerate lie on eroded and steeply dipping beds of Mesaverde sandstone near Mt Leidy. Love (18) believes the age of folding to be post-Cretaceous and pre-Pinyon. The angular unconformity between the Pinyon Conglomerate and the older Cretaceous rocks on Mt Leidy is not present within the thesis area.

Five dry oil and gas test holes have been drilled on the northeast flank of the Spread Creek anticline. One of these tests, by Stanolind Oil and Gas Company, encountered a thrust fault at a depth of 6400 feet. This fault probably is the subsurface extension of the Spread Creek thrust, which is exposed several miles west of the area studied.
**Whetstone Anticline**

The Whetstone anticline is a broad slightly asymmetric fold lying in the north-central part of the area studied. It is located approximately four miles northeast of the Spread Creek anticline. South of Lava Creek, the Whetstone anticline dies out into the homoclinal northeast flank of the Spread Creek anticline. The fold extends for about nine miles through the thesis area and northwest toward Yellowstone National Park. The strike of the axis ranges from N. 30°W. near Lava Creek to N. 15°W. north of Pacific Creek. Dips along the anticline become steeper to the north, ranging from less than ten degrees near Lava Creek to over 20 degrees near Whetstone Mountain.

Rocks of the Harebell Formation and Pinyon Conglomerate are exposed along the Whetstone anticline. No angular unconformity exists between the Harebell Formation and the Pinyon Conglomerate on the anticline. Since the Pinyon Conglomerate is involved in the folding, the Whetstone anticline was formed during post-Pinyon times. Thus, the adjacent Spread Creek anticline, which is pre-Pinyon in age, was folded before the Whetstone anticline.

**Lava Creek Syncline**

A shallow syncline lies between the Spread Creek and Whetstone anticlines north of Lava Creek. The Lava Creek syncline,
which is about four miles in length, dies out to the southwest into the northeast flank of the Spread Creek anticline. To the north it is covered by Quaternary alluvium and probably dies out into the west flank of the Whetstone anticline. The axis of the syncline strikes about N. 35°W. Beds of the Harebell Formation and Pinyon Conglomerate are exposed along the structure.

The Lava Creek syncline was formed by the folding of the Spread Creek anticline to the west during pre-Pinyon times and by the post-Pinyon folding of the Whetstone anticline to the east. Therefore, the syncline is post-Pinyon in age.

**Box Creek Syncline**

The Box Creek syncline lies southeast and parallel to the Whetstone anticline. It extends for about four miles along the eastern edge of the area studied. The syncline was mapped only at Turpin Meadow, but Bengtson (1) has indicated that it extends many miles to the northwest and southeast. At Turpin Meadow the fold is very asymmetric with 30 to 45 degree dips on the east flank and 10 to 15 degree dips on the west flank.

Rocks of the Pinyon Conglomerate and the Harebell Formation crop out along the Box Creek syncline. The time of folding is post-Pinyon since the Pinyon Conglomerate is involved in the folding. Thus, the Whetstone anticline and Box Creek syncline were formed after the Spread Creek anticline.
Faults

Four probable faults were mapped in the Whetstone anticline area (Plate 3). Two of these, striking to the northwest, roughly parallel the strike of the regional structure, and two cut across the regional strike. Faulting is indicated by changes in topography, offsets of outcrop patterns, and lineations on aerial photographs. However, fault gouge, slickensides, and other fault features are rarely seen because of the poor exposures. Thus, it is not possible to determine the exact displacement and lateral extent of these faults.

Two miles southwest of Gravel Mountain near Lava Creek, beds of the Harebell Formation have been faulted up against the Pinyon Conglomerate. This fault strikes N. 15°W. and can be traced for about one mile. It is probably a high-angle reverse (?) fault formed during or after folding of the Whetstone anticline. Since the rocks on the east side of the fault have moved up relative to those on the west side, and several known thrust faults occur six to eight miles to the east, this fault is probably a reverse fault.

Another fault trending N. 25°W. parallels the Box Creek syncline one-half mile west of Box Creek. This fault also involves the Harebell Formation and Pinyon Conglomerate, but exposures are very poor in this area. The fault was probably formed during folding of the Box Creek syncline or in response to post-Pinyon
thrusting which occurred east of the thesis area.

One fault, striking N. 40°E. lies near the Hatchet Motel. Another, striking N. 60°E. is present one mile south of Spread Creek. Both of these faults are very-poorly exposed, but can be traced for several miles on the aerial photographs. They are post-Mesaverde in age since both displace beds of the Mesaverde Formation.

Several minor faults are exposed in the roadcuts along U. S. Highway 26-287, one mile east of the Hatchet Motel. These faults strike to the northeast and are probably formed by landsliding on Rosies Ridge. Many small faults and joints are present in the area mapped, but were not studied in detail. Other major faults are no doubt present in the area but the lack of good exposures because of thick vegetation, extensive glacial moraine, and abundant landslide debris makes their detection difficult.
GEOMORPHOLOGY

Many glacial and nonglacial geomorphic features occur in the Whetstone anticline area. Running water is the most important agent of erosion today, whereas glaciers were the primary agents during the Pleistocene.

Nonglacial Features

Stream Erosion

The thesis area is highly dissected by stream erosion north of the Buffalo Fork River, but is less dissected south of the river. Thus, the area is largely mountainous and is in the late youth to early maturity stage of stream erosion. Most of the stream divides are narrow and relief is moderate to high. Locally, large cliffs of conglomerate over 1000 feet high are present.

Several large alluvial fans of gravel have been formed two miles south of Gravel Mountain by small intermittent streams flowing south from the mountain. These fans are about one-half mile wide and are very evident on aerial photographs. They are practically devoid of vegetation.

Most of the streams in the area mapped flow to the west or southwest and thus cut across the northwest-trending regional structure. Since they flow across the structure, they are probably
superposed streams which once flowed on nearly horizontal Tertiary rocks, similar to many of the other streams of central and western Wyoming (30, p. 119). This is particularly true of the Buffalo Fork River which was probably in existence during the Late Tertiary as a tributary of the ancient Snake River.

Stream meanders are numerous along the Buffalo Fork River, and several oxbow lakes, such as Halfmoon Lake, have been developed. Meander scars in the Buffalo Fork Valley and along Pacific Creek are easily recognizable on the aerial photographs of the area.

Terraces

Alluvial terraces are common along all the major streams in the thesis area; however, they are locally difficult to distinguish because of recent erosion and landsliding.

One well-developed terrace, 15 to 20 feet above stream level, is preserved along Pacific Creek. Remnants of several lower terraces are also present. Two small but distinct alluvial terraces occur along Lava Creek two miles east of Davis Hill. One terrace is about four feet above stream level and the other eight to ten feet above stream level. The Lava Creek terraces die out upstream and were probably formed after the removal of landslide dams along the stream.
No distinct terraces were observed along the Buffalo Fork River in the area studied, but several are present downstream, west of the mouth of Lava Creek. Numerous terrace remnants are preserved along Spread Creek. One terrace 50 to 75 feet above stream level is well preserved, especially near the British-American, et al. oil and gas test hole (Plate 3). At least three terraces are developed along the South Fork of Spread Creek south of the mouth of Leidy Creek.

Alluvial terraces may be attributed to at least three causes: (1) Readjustment of stream grades after the removal of channel obstructions; (2) Crustal uplifts; (3) Climatic variations. Most of the terraces of the area were probably formed during Late Pleistocene climatic fluctuations when large amounts of sediment were deposited by glacial meltwater and were later incised by streams. Some of the small terraces may have been formed by removal of landslide dams on the streams.

Erosion Surfaces

Several Pliocene and Pleistocene erosion surfaces exist in northwestern Wyoming. Blackwelder (2, p. 310-321) named them the Fremont Peneplain, Union Pass Surface, Black Rock Surface, and Circle Terraces. These erosion surfaces and their relation to Pleistocene glacial stages are shown in Table 9.

<table>
<thead>
<tr>
<th>Age</th>
<th>Erosion Cycle</th>
<th>Erosion Surface</th>
<th>Glacial Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td></td>
<td></td>
<td>Pinedale</td>
</tr>
<tr>
<td>Lenore</td>
<td>(small terraces)</td>
<td></td>
<td>Bull Lake</td>
</tr>
<tr>
<td>Circle</td>
<td>Circle Terraces</td>
<td></td>
<td>Buffalo</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Black Rock Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Rock</td>
<td>Black Rock Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Union Pass</td>
<td>Union Pass Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pliocene</td>
<td>Fremont</td>
<td>Fremont Peneplain</td>
<td></td>
</tr>
</tbody>
</table>

Remnants of mature valley floors of Pleistocene age, the Black Rock surface, are numerous in the thesis area. The type area is at Blackrock Meadows (Blackrock was spelled as two words in 1915) five miles east of the area studied. Horberg (9, p. 507-509) has described this erosion surface north of the Buffalo Fork River. The Black Rock surfaces lie 500 to 1000 feet above the present streams at elevations ranging from 7300 to 9000 feet. They are usually covered by Buffalo glacial drift. Black Rock surfaces are preserved along Box Creek, around the south side of Mt. Randolph, and northwest across Pacific Creek. They are not as evident south of the Buffalo Fork River.

A large rock-cut terrace covered by alluvium lies along the South Fork of Spread Creek 100 feet above the stream. This
terrace probably corresponds to Blackwelder's Circle Terraces. The Circle Terraces, which were formed prior to the Bull Lake glacial stage, are 100 to 200 feet above the present stream levels. Many of the smaller alluvial terraces along Spread Creek and Pacific Creek were possibly formed during Blackwelder's Lenore erosion cycle, since the Lenore terraces are 10 to 50 feet above modern stream levels.

Landslides

The Jackson Hole region is noted for its numerous and locally large landslides. Landslides are particularly abundant along the Gros Ventre River 15 to 20 miles south of the thesis area. The most famous of these, the Lower Gros Ventre slide, occurred in June 1925 when over 50,000,000 cubic yards of rock descended 2000 feet into the Gros Ventre Valley. Keefer (10) has discussed this and other slides along the Gros Ventre River.

Landslides are not confined to the Gros Ventre Valley; they are plentiful in the Whetstone anticline area. At least 25 distinct landslide areas (Plate 3), covering over 17 square miles are present in the thesis area. The two largest slide areas, each covering about three square miles, lie between Pacific Creek and Whetstone Mountain. There are other major slide areas on the west slope of Gravel Mountain, south slope of Mt Randolph, and northeast slope
of Baldy Mountain. Many smaller slides exist along the larger creeks in the area.

The landslides are characterized by hummocky topography with numerous closed depressions containing ponds and swamps. Generally, they are covered by a thick growth of aspen, cottonwood, and underbrush. Some of the trees growing on these slides are tilted because of recent movement in the slides. Landslide scars, cracks, and slump blocks are very common at the heads of these slides, particularly in the major slide areas. These characteristics are readily recognizable on the aerial photographs of the area.

Nearly all of the slides in the thesis area would be classified as earthflows by Sharpe's classification (26, p. 50-55). Slumps are present, but are always found at the heads of earthflows. This is especially true in the large landslide areas immediately north of Pacific Creek where large slump blocks, several acres in extent, lie above large earthflows. Locally, small mudflows have formed on the earthflows because of excess water saturation.

Most of the slides involve the Late Cretaceous Harebell Formation or masses of the overlying Paleocene Pinyon Conglomerate sliding on the Harebell. The abundant claystones and argillaceous sandstones in the Harebell Formation become extremely plastic when wet. Most of the slides along Pacific, Lava, and Blackrock Creeks are confined to the Harebell Formation, whereas the large
slide areas west of Gravel Mountain and southeast of Whetstone Mountain involve Pinyon Conglomerate. Several small landslide areas also occur in other Late Cretaceous sandstones and shales on Lava Creek and Spread Creek.

Some of the major factors that influence landsliding in sedimentary rocks are composition, structure, relief, and climate. Each of these factors is of importance in the thesis area. However, it is believed that composition is the major factor inasmuch as most of the slides are restricted to plastic beds in the Late Cretaceous shales and sandstones. High relief is important in slides involving the Pinyon Conglomerate, which caps the higher mountains of the area. Landslides are common on the steep slopes north of the Buffalo Fork Valley. The landsliding is controlled slightly by structure.

The present and past climates of the region are also a major factor. Some of the landslides probably date back to the Late Pleistocene when the melting of glacial ice and saturation of valley slopes by glacial melt water left many unstable valley slopes. The present-day spring thaw and resultant heavy runoff also contributes to slope instability during the late spring and early summer months of each year.

The landslides of the Whetstone anticline area have little economic effect because of the low population density and the few
roads. Several small landslides have displaced or covered U. S. Highway 26-287 along the south slope of Rosies Ridge. One of these slides partially blocked the highway for several months during the summer of 1963 (Figure 22). Other roads in the area are seldom affected by landsliding; however, several of the trails are sometimes displaced by slides.

Glacial Features

Glacial features are common in the Whetstone anticline area and in adjacent parts of northwestern Wyoming. They are very evident in Jackson Hole and the Teton Range where numerous cirques, U-shaped valleys, outwash plains, and moraines are well preserved. The glacial features of the thesis area are extensive, but not as spectacular as those in nearby Jackson Hole.

Ground moraine covers about 45 square miles of the area, but is usually deeply weathered. South of the Buffalo Fork Valley, nearly three-quarters of the area is covered by glacial moraine. North of the valley, glacial deposits do cover the southern slopes of Mt Randolph and lie around Davis Hill, but north of Lava Creek there are only small scattered patches of glacial moraine.

Because the glacial moraine is weathered, morainal features are poorly preserved. On Baldy Mountain the moraine is less weathered and hummocky morainal topography with many swamp-
and pond-filled depressions is common. Lily Lake, on the south slope of Baldy Mountain, was impounded by a Bull Lake terminal (?) moraine (Figure 23). The many adjacent ponds and swamps are probably kettle ponds and filled kettles. No glacial outwash plains were observed in the area, but glacial grooves are present in the Pinyon Conglomerate.

Several possible Buffalo stage glacial grooves cut in Pinyon Conglomerate occur three miles southwest of Gravel Mountain at an elevation of 8100 feet. These parallel grooves, 50 to 75 feet deep and 400 to 500 feet wide, are covered by a thin veneer of glacial drift containing basalt and quartzite boulders. Their north-south alignment indicates ice movement either north or south. Regional studies of these grooves and associated drift suggest that the ice movement was to the south or southwest.
FIGURE 23. View of Lily Lake and the surrounding morainal topography. Looking south from the south slope of Baldy Mountain.
During the Late Cretaceous the Whetstone anticline area was inundated by a large north-south trending sea which covered much of the Rocky Mountain and Great Plains region. The oldest rocks exposed in the thesis area represent the last extensive marine invasion of the Jackson Hole region. These rocks, which are part of the upper Cody Shale, were deposited in a shallow marine environment. During Bacon Ridge time the western shoreline of this sea extended through the area and sediments were deposited in environments similar to those found on the present day Gulf coast of Texas.

As the sea regressed to the east during Bacon Ridge time, lagoons, estuaries, and swamps were formed immediately west of the shoreline. The numerous coals and carbonaceous shales in the Bacon Ridge Sandstone and Coaly Sequence were deposited in these environments. After the Upper Cretaceous shoreline had shifted to the east of the area, a thick sequence of nonmarine sediments was deposited. The Jackson Hole region was probably a low and broad coastal plain backed by areas of high relief to the west and northwest. The Lenticular Sandstone and Shale Sequence was deposited by streams carrying debris from the elevated area to the west.

During Mesaverde time the first pulsations of the Laramide revolution caused uplift of one or more areas in eastern Idaho and
western Montana. As a result, a thick sequence of coarse white sandstone beds, nearly 1000 feet thick, was deposited in the area studied. At the end of Mesaverde time, the northern part of the area probably was uplifted and the Mesaverde Formation and part of the underlying Lenticular Sandstone and Shale Sequence were eroded. However, deposition continued in the area to the south.

Over 4000 feet of conglomerate, sandstone, claystone, and mudstone were deposited on the broad coastal plain by streams during Harebell time. Coal swamps and small lakes were present locally. Plant fossils suggest a temperate to subtropical climate. Volcanic ash, now represented by bentonite beds and tuffaceous sandstones, drifted into the area from volcanoes whose location is not known.

Laramide deformation became more intense near the end of the Cretaceous. Large uplifts began to form to the east, north, and west of the area studied. Folding began in the western part of the thesis area at this time. One or more large streams flowing into the area from the north began to carry in large amounts of gravels, which are represented today by quartzite conglomerate lenses in the upper part of the Harebell Formation. As the western part of the area was folded, forming the Spread Creek anticline, a basin was formed to the east. The crest of the anticline was being eroded while deposition continued on the east flank of the structure.
Deposition of coarse-grained material continued into Paleocene time until several thousand feet of conglomerate had been deposited.

This thick deposit of conglomerate, known as the Pinyon Conglomerate, covered much of the area immediately east of Jackson Hole. South of the thesis area, coarse-grained sediments were carried into this Paleocene basin from the east, south, and southwest. As the source areas were eroded and the basin was filled, stream gradients became lower and finer-grained sediments were deposited. The region finally became a broad low plain of low relief after Pinyon time.

Another period of Laramide deformation occurred after deposition of the Pinyon Conglomerate. The north-central and eastern parts of the thesis area were folded, and the Lava Creek syncline, Whetstone anticline, and Box Creek syncline were formed. Several north-south trending faults in the area were also formed.

The geologic history of Eocene, Oligocene, Miocene, and Pliocene times is poorly recorded in the area mapped. Local extrusions of basalt and andesite were poured out on the surface in the northwestern part of the area during the Miocene. Thick sequences of pyroclastics and lava were formed to the north and east during Oligocene, Miocene, and Pliocene times. In the Late Tertiary, most of the Pinyon Conglomerate and younger rocks in the thesis area were eroded and carried away by the Snake River and its
Several stages of Pleistocene glaciation took place in the region. During the Buffalo stage, the area was covered by a huge ice sheet 500 to 1000 feet thick. This stage was followed by valley and local piedmont glaciation during the Bull Lake stage. A local piedmont ice sheet extended into the area from the east and deposited a blanket of morainal material south of the Buffalo Fork River. Small glaciers may have existed in the higher valleys of the area during the Late Pleistocene. Several stream terraces were developed along Spread Creek during the Bull Lake glaciation.

Post-glacial erosion and landsliding has modified the Pleistocene glacial features. Landsliding and stream erosion are still important in the area. Alluvial deposits are being formed today along the Buffalo Fork River and the smaller streams of the area studied.
Large sums of money have been spent in the Whetstone anticline area in search of oil and gas. Most of the exploration has been concentrated on the Spread Creek anticline. The area also has been prospected for coal and alluvial gold.

Oil and Gas

Stratigraphic and structural conditions in this area are apparently favorable for the formation and accumulation of petroleum and natural gas. Both source and reservoir rocks are present in the subsurface. However, five dry oil and gas test holes have been drilled on the northeast flank of the Spread Creek anticline. The locations and descriptions of these dry holes are given in the appendix.

Evidence for Oil and Gas

Numerous natural gas seeps have been discovered in the area mapped. The approximate locations of known seeps are shown on Plate 3. Many of these occur in the swampy area around Half-moon Lake near the southern edge of the Buffalo Fork Valley. The largest gas seep, which bubbles continuously in an area several feet square, emanates from the Bacon Ridge Sandstone in a swampy
area several hundred feet south of Halfmoon Lake. Two samples of gas from this seep were analyzed by Core Laboratories, Inc., under auspices of the Union Oil Company of California. The results of the hydrocarbon analysis are shown in Table 10.

**TABLE 10. Hydrocarbon analysis of gas samples collected from a gas seep near Halfmoon Lake.**

<table>
<thead>
<tr>
<th>Components</th>
<th>Sample #1</th>
<th>Sample #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>6.29&lt;sup&gt;1&lt;/sup&gt;</td>
<td>6.29</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>1.19</td>
<td>1.30</td>
</tr>
<tr>
<td>Methane</td>
<td>92.49</td>
<td>92.38</td>
</tr>
<tr>
<td>Ethane</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Others</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<sup>1</sup>Values given in Mol percentage

The high percentage of methane and nitrogen in the gas suggests that it is "swamp gas". Since the Bacon Ridge Sandstone contains many coal beds and carbonaceous shales, the gas has probably come from decayed plant material.

Other small intermittently active gas seeps were observed by the writer one and one-half miles south of Halfmoon Lake on the crest of the Spread Creek anticline, near several abandoned coal mines. These seeps are apparently coming from coaly beds in the Bacon Ridge Sandstone. Several small gas seeps are present in
beaver ponds on the North Fork of Spread Creek near the mouth of Flagstaff Creek. However, all of these are probably "swamp gas".

Love (personal communication) has seen many gas seeps emanating from the Cody Shale in beaver ponds on Leidy Creek. Since the beaver ponds are now dry, the gas seeps are not presently visible. He also observed seeps on Pacific Creek near the crest of the Whetstone anticline. Many other gas seeps are no doubt present in the area mapped, but are not in swampy or water-covered areas where they are easily detected. Most of the gas from these seeps is probably "swamp gas" from decayed plant material in the modern sediments or the Late Cretaceous rocks.

The writer did not find oil-stained rocks at any of the outcrops in the thesis area. Staining has been reported on outcrops of Frontier Sandstone and Bacon Ridge Sandstone south of the area (18).

Possible Reservoir Rocks

About 7500 feet of marine Paleozoic and Mesozoic sedimentary rocks underlie the area studied. An additional 11,000 feet of Late Cretaceous and Early Tertiary nonmarine rocks are exposed in the area.

Several of the Paleozoic formations contain possible reservoir rocks. The Ordovician Bighorn Dolomite, the Mississippian
Madison Limestone, and the Permian Phosphoria Formation are locally porous in outcrops south of the thesis area. However, the Pennsylvanian Tensleep Sandstone, which is an oil producer to the east, is a dense quartzite in the Jackson Hole region.

Cretaceous formations which contain porous sandstone beds include the Muddy Sandstone, Frontier Formation, Cody Shale, and Bacon Ridge Sandstone. Electric logs indicate that they are all less porous at depth than on outcrop. This suggests that the surface porosity is a result of weathering, particularly of the detrital carbonate found in most of these sandstones.

Source rocks for petroleum and gas, such as the Phosphoria Formation, Thermopolis Shale, Mowry Shale, and Cody Shale, are abundant in the region, especially in the Cretaceous sequence. All of the possible reservoir rocks, except the Bighorn Dolomite and the Madison Limestone, have been penetrated by oil and gas test holes in the thesis area. None have produced oil or gas.

**Structural and Stratigraphic Traps**

Two anticlines, the Whetstone and Spread Creek anticlines, lie within the Whetstone anticline area. The Whetstone anticline is a broad slightly asymmetric fold lying in the north-central part of the area. No closure was found on the structure. Since the Whetstone anticline is within the Teton Wilderness Area, permission to
drill the structure would be very difficult to obtain.

The Whetstone anticline dies out to the south into the homoclinal northeast flank of the Spread Creek anticline, a large asymmetric, doubly plunging anticline in the southwestern part of the thesis area. Several thousand feet of surface closure exist on the structure. There is a high-angle reverse fault on the oversteepened southwest flank of the fold.

Stratigraphic traps, in the form of updip pinchouts, may be present on the flanks of the two anticlines in the area. If present, they would be best developed in the lenticular sandstone beds of the Frontier Formation, Cody Shale, and basal Bacon Ridge Sandstone.

Oil and Gas Possibilities

The chances of finding commercial amounts of oil and gas in the area studied are not encouraging. Only traces of oil and gas were reported in the five oil and gas test holes drilled on the Spread Creek anticline. The structure has been fairly well tested down to the Tensleep Sandstone. The two test holes which reached the Tensleep Sandstone encountered large amounts of fresh water in the formation. This suggests that the water has entered the formation from the surface, possibly along the reverse fault zone on the southwest flank of the structure. Also, some oil and gas may have escaped when the Spread Creek anticline was eroded at the end of
Cretaceous time.

The best possibilities for oil and gas are in updip pinchouts on the northeast flank of the Spread Creek anticline. If the Whetstone anticline were not located in a wilderness area, it would warrant further study as a site of oil and gas accumulation.

**Gold**

Gold placers have been worked intermittently for over 80 years along Pacific Creek and its tributaries. Gold recovery is difficult since the gold particles are very small and are mixed with large amounts of magnetite.

The most elaborate mining project in Jackson Hole, the Whetstone mine, was located on Whetstone Creek in the northern part of the thesis area. About 1889 a Captain Harris sold stock, built a sawmill, constructed several cabins, and erected a giant sluice box on Whetstone Creek, one mile north of Pacific Creek. The sluice box, which was over 500 feet long, was built of four-inch planks bored full of two-inch holes. It was theorized that the gold would be caught in the holes. The operation was a complete failure.

The Whetstone mine was abandoned in the early 1890's. Parts of two cabins and the giant sluice box are still lying in the area. Gold is present in the gravels of Whetstone Creek, but probably not in paying quantities.
Many placer claims were staked along Whetstone and Pacific Creeks in the 1930's. Several of these claims, near the end of the gravel road along Pacific Creek, are still worked from time to time. One of the claims is controlled by Frank Allen, and about four others are worked by Bud Nelson. These claims are worked on a part-time basis and have not produced large amounts of gold. The writer panned several samples from these claims and recovered a few small flakes of gold.

The source of this gold is not known since the deposits have never been thoroughly investigated. Weed (7, p. 185) suggested that the gold comes from the matrix of the Pinyon Conglomerate, but offers no evidence. No mineral veins have been reported in the area and none were seen by the writer. An outcrop of Harebell sandstone located one mile west of the mouth of Whetstone Creek contains thin heavy mineral beds. The writer panned debris from this outcrop and recovered several small flakes of gold. No evidence of gold was found in the Pinyon Conglomerate, but the formation was not sampled in detail.

Since the gold particles are very small and no mineral veins are present in the vicinity, it is probable that the gold comes from the Pinyon Conglomerate or the Harebell Formation. If this is true, the gold probably originated to the north or northwest in Montana where many gold veins have been discovered.
Nearly all of the known gold occurrences along Pacific Creek and its tributaries are within the Teton Wilderness Area. Therefore, if commercial gold deposits were discovered, it would be impossible to develop them.

Coal

Many abandoned coal mines occur in the thesis area. These small mines were operated in thin lignite and sub-bituminous coal beds of the Bacon Ridge Sandstone. They were in operation intermittently between 1910 and 1925, during and after construction of the Bureau of Reclamation Dam at the head of Jackson Lake (Love, personal communication). The mines have been abandoned since about 1925.

Most of these abandoned coal mines are immediately north of U. S. Highway 26-287 near the Lava Creek bridge. Other abandoned mines are located one and one-half to two miles south of Half-moon Lake near the axis of the Spread Creek anticline. The general locations of these mines are shown on Plate 3.

Since most of the coal beds in the area studied are thin and low grade, coal mining will never become an important industry in the region.


APPENDIX
OIL AND GAS TESTS

Five oil and gas test holes have been drilled in the area mapped. The locations of these tests are shown on Plate 3. A summary of information from each test hole is shown in Table 11.

The first oil and gas test hole drilled in the thesis area was the Stanolind Oil and Gas Spread Creek no. 1 Unit. It was located three miles northeast of Mt Leidy and immediately east of the axis of the Spread Creek anticline. The test was drilled in 1949 to a depth of 7581 feet, and passed through a sequence of rocks from the Bacon Ridge Sandstone to the Sundance Formation. A probable reverse fault was intersected in the Sundance Formation at a depth of 6400 feet. Part of the stratigraphic section was repeated and the hole bottomed in Mowry Shale (?). Shows of oil and gas were reported from the Cloverly Sandstone, Muddy Sandstone, Mowry Shale, Frontier Formation, Cody Shale, and Bacon Ridge Sandstone.

Four core holes drilled in 1949 by Stanolind Oil and Gas, one mile south of their deep test hole, encountered small quantities of gas in the Cody Shale at a depth of 400 feet.

The George Travis-Grynburg-Government Spread Creek no. 2 Unit was drilled in 1950, one and one-half miles south of the Stanolind test. It bottomed in the Mowry Shale at a depth of 2855 feet. The Cody Shale, which is exposed at the surface, contained
<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Date</th>
<th>Total Depth</th>
<th>Spudded in</th>
<th>Bottomed in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stanolind Oil and Gas Spread Creek #1 Unit</td>
<td>NE, SE, SW, Sec. 25 T. 44N., R. 113W.</td>
<td>1949</td>
<td>7581</td>
<td>Bacon Ridge Sandstone</td>
<td>Mowry Shale</td>
</tr>
<tr>
<td>George Travis-Grynberg-Gov't Spread Creek #2 Unit</td>
<td>NW, SE, SW, Sec. 31, T. 44N., R. 112W.</td>
<td>1950</td>
<td>2855</td>
<td>Cody Shale</td>
<td>Mowry Shale</td>
</tr>
<tr>
<td>Travis-True Buffalo Creek #1 Unit</td>
<td>NE, NE, NW, Sec. 29, T. 45N., R. 112W.</td>
<td>1958</td>
<td>4367</td>
<td>Bacon Ridge Sandstone</td>
<td>Morrison Formation</td>
</tr>
<tr>
<td>British Am. Oil et al. Spread Creek #1 Unit</td>
<td>NE, NW, NW, Sec. 13, T. 44N., R. 113W.</td>
<td>1958</td>
<td>9860</td>
<td>Lenticular Sandstone and Shale Sequence</td>
<td>Tensleep Sandstone</td>
</tr>
<tr>
<td>Texaco, Inc. Spread Creek #1 Unit</td>
<td>NE, NE, Sec. 31, T. 44N., R. 112W!</td>
<td>1962</td>
<td>9585</td>
<td>Coaly Sequence</td>
<td>Tensleep Sandstone</td>
</tr>
</tbody>
</table>
several shows of gas and dead oil stains. Traces of gas were reported in the Frontier Formation.

Two oil and gas test holes were drilled on the east flank of the Spread Creek anticline in 1958. The Travis-True Buffalo Creek no. 1 Unit was drilled near Lava Creek to a depth of 4367 feet. The test spudded in Bacon Ridge Sandstone and bottomed in the Morrison Formation. No shows of oil or gas were reported.

The British-American Oil et al. Spread Creek no. 1 Unit was drilled near Spread Creek in 1958. The test penetrated a sequence of rocks from the Lenticular Sandstone and Shale Sequence through the Tensleep Sandstone. Total depth was 9860 feet. Shows of oil were reported in the Tensleep Sandstone and Phosphoria Formation. The Tensleep Sandstone is quartzitic and slightly porous because of minute fractures. Fresh water was recovered from the formation during a drill-stem test.

The latest test was drilled in 1962 by Texaco, Incorporated, about four miles southeast of the British-American test. The Texaco, Inc. Spread Creek no. 1 Unit bottomed in the Tensleep Sandstone at a depth of 9585 feet. No indications of oil or gas were reported. A drill-stem test of the Tensleep Sandstone recovered large amounts of fresh water.