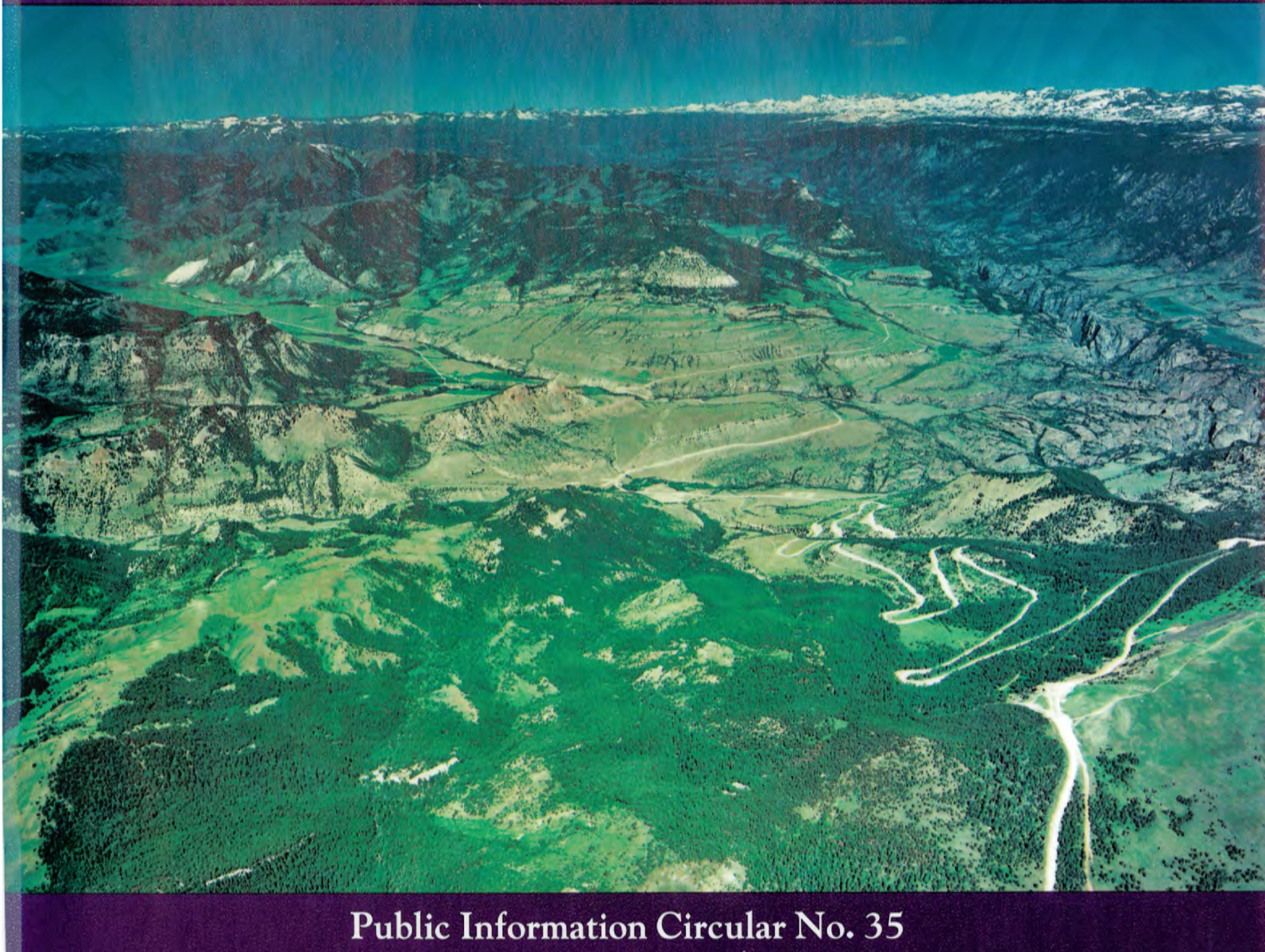
WYOMING STATE GEOLOGICAL SURVEY
Gary B. Glass, State Geologist

A self-guided geologic tour of the Chief Joseph Scenic Highway and surrounding area, northwestern Wyoming

by
H.P. Heasler, C. Jaworowski, R.W. Jones, R.H. De Bruin, and A.J. Ver Ploeg



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Front Cover: Air oblique view to northwest showing Chief Joseph Scenic Highway. Dead Indian Hill in lower right, Dillworth Bench in upper right, Sunlight Basin is the green valley in the upper left, Clarks Fork Canyon in the top right, Beartooth Mountains are snow-capped peaks on right horizon, and the Absaroka Range (including Pilot and Index Peaks) is represented by the snow-capped peaks left of center on horizon. The tan hill in the upper center of photograph shows evidence of glacial erosion and deposition. For details, see panorama photograph (**Figure 28**, pages 53-54) and **Areas of Interest** (pages 22-27). (July, 1971 photograph by Wyoming Department of Transportation, Photogrammetry and Survey Program.)

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A SELF-GUIDED GEOLOGIC TOUR OF THE CHIEF JOSEPH HIGHWAY AND SURROUNDING AREA, NORTHWESTERN WYOMING

by

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Photographs for this publication are credited to the individual or organization who supplied them, along with an approximate date of the photograph. The photographers are given in each photograph by the following initials: A.D., Al Deiss; D.D., Dennis Davis; H.P.H., Henry P. Heasler; R.W.J., Richard W. Jones; C.J., Cheryl Jaworowski; M.G.H., Michael G. Hager; and WDOT, Wyoming Department of Transportation, Geology Program.

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Foreword

The view from the top of Dead Indian Hill on the Chief Joseph Scenic Highway has been called . . . *one of the most spectacular views in Wyoming* (Boberg, 1975, p. 273); *This is one of the great visual and geologic panoramas of the West* . . . (Parsons, 1978, p. 125). Given the majesty of the Grand Tetons and the spectacular scenery of Yellowstone, these statements should prepare the traveler for what may be the most spectacular highway in Wyoming. We hope that this guide adds to your enjoyment and understanding of this spectacular region.

Introduction

This publication covers the Chief Joseph Scenic Highway (Wyoming State Highway 296) and surrounding area and is divided into two parts: Part I, a discussion of the general geology and cultural history plus a description of selected areas of interest, and Part II, road logs of the scenic highway and other highways in the area. The general geology section provides information about the unique geology described in the road logs. The cultural history section summarizes the human occupation of the region and the creation of Shoshone National Forest. Areas of interest (**Figures 1** and **2**) are described to assist the reader in identifying and studying specific features without consulting the individual road log segments. The road log segments (Part II) that do cover these areas of interest contain some cross-references to the discussion in Part I.

The geologic tours in Part II (see **back cover**) describe: a part of Wyoming State Highway 120 from Cody to the Chief Joseph Scenic Highway (State Highway 296) (**Segment 1**, pages 30-33), Wyoming State Highway 120 from the scenic highway turnoff to the junction of Park County Road 1AB (**Segment 2**, pages 34-37), Park County Road 1AB to the end of Park County Road 8VC in Clarks Fork Canyon (**Segment 3**, pages 38-45), the Chief Joseph Scenic Highway (**Segment 4**, pages 46-64), and U.S. Highway 14/16/20 from Cody to Buffalo Bill State Park (**Segment 5**, pages 66-72).

The geologic discussions, road logs, and areas of interest assume the reader understands basic geology and general principles of mineralogy, stratigraphy, geomorphology, and structural geology. Numerous materials are available to assist the beginner, including basic geology textbooks, field guides, and other books and publications. Some suggested publications that may help the reader are listed on the inside back cover of this publication.

The region encompassed by this publication contains several national forests and wilderness areas, a state and a national park, and a wild and scenic river. Because much of the area is mountainous and many roads are narrow and steep, travelers in the area should be prepared for hazardous conditions and inclement weather at any time and should be aware that much of the area is very sparsely populated. When in doubt about the weather or road conditions, don't take unnecessary chances–seek the advice of the locals that are familiar with the area.

Frontispiece. Chief Joseph, Nez Perce. Photograph courtesy of and used with permission of the American Heritage Center, University of Wyoming.

Part I. Geology, mineral resources, cultural history, and areas of interest of the Chief Joseph Scenic Highway and surrounding area

Introduction

From its beginnings as a wagon road to the present paved highway, the Chief Joseph Scenic Highway has enabled earth scientists to investigate the unique geology of Sunlight Basin and the Clarks Fork valley. The earliest geologists and pioneers in Sunlight Basin traveled over Dead Indian Hill (elevation of pass 8071 feet) and down to Dead Indian Creek (elevation 5800 feet) via a straight wagon road. The first upgrade on the road was in 1909. From 1910 until the late 1920s, geologists and others traveled this dirt road over Dead Indian Hill to reach the Sunlight and Clarks Fork valleys and the mining community of Cooke City. In discussing the access to the sulfur deposits of Sunlight Basin, Hewett (1911) wrote:

> *The district is accessible by a fair wagon road from Cody, by which the distance is 52 miles. A weekly stage service is operated between Cody and Painter, which is 12 miles east of the sulphur deposits. Transportation into or away from the basin is greatly hindered by a steep hill between Dead Indian Creek and Pat O'Hara Creek, over which the ascent amounts to approximately 2,000 feet in less than 2 miles. Though it is possible to construct a road with a lower gradient, the present road is the only means of access.*

In the 1930s, glacial geologists, structural geologists, and others gained access to the area down an improved Dead Indian dirt road with a series of switchbacks. Throughout the 1960s, 1970s, and 1980s improvements to the road made travel easier during the winter and springtime.

The area around Chief Joseph Scenic Highway contain a wide variety of landforms and topography that varies from low basinal areas (elevations around 5000 feet) to high mountain peaks (elevations over 13,000 feet) considerably above timberline (**Figure 1**). To show the relation of elevation and topography to the geology, **Figure 2** is a general geologic map of the same area as shown in **Figure 1**.

On the geologic map of northwestern Wyoming, rocks and sediments are divided into 10 groups by age (**Figure 3**). The ancient rocks of the Beartooth Plateau represent a very early part of the Precambrian eon (from about 4.0 billion to 2.7 billion years ago) (Frost and Frost, 1993). Little evidence of life on Earth is preserved in these ancient rocks. Fossils are better preserved and more easily found in rocks of the Phanerozoic eon (570 million years ago to the present). Fossils found in these Phanerozoic rocks help us understand paleoenvironments and paleogeography and aid the subdivision of Phanerozoic time into the Paleozoic Era (570-240 Ma=Mega annum or millions of years before present), Mesozoic Era (240-66 Ma), and Cenozoic Era (66 Ma to the present). The eras are subdivided into numerous periods (Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, Permian, Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary), and epochs (Paleocene 66-58 Ma, Eocene 58-38 Ma, Oligocene 38-24 Ma, Miocene 24-5 Ma, Pliocene 5-1.65 Ma, Pleistocene 1.65 Ma to 10,000 years before present (y.b.p.), and Holocene 10,000 y.b.p. to present). The rocks which were deposited during these time intervals are subdivided into Erathems, Systems, and Series (**Figure 4**). In this part of Wyoming, Silurian, Oligocene, Miocene, and Pliocene rocks are not present.

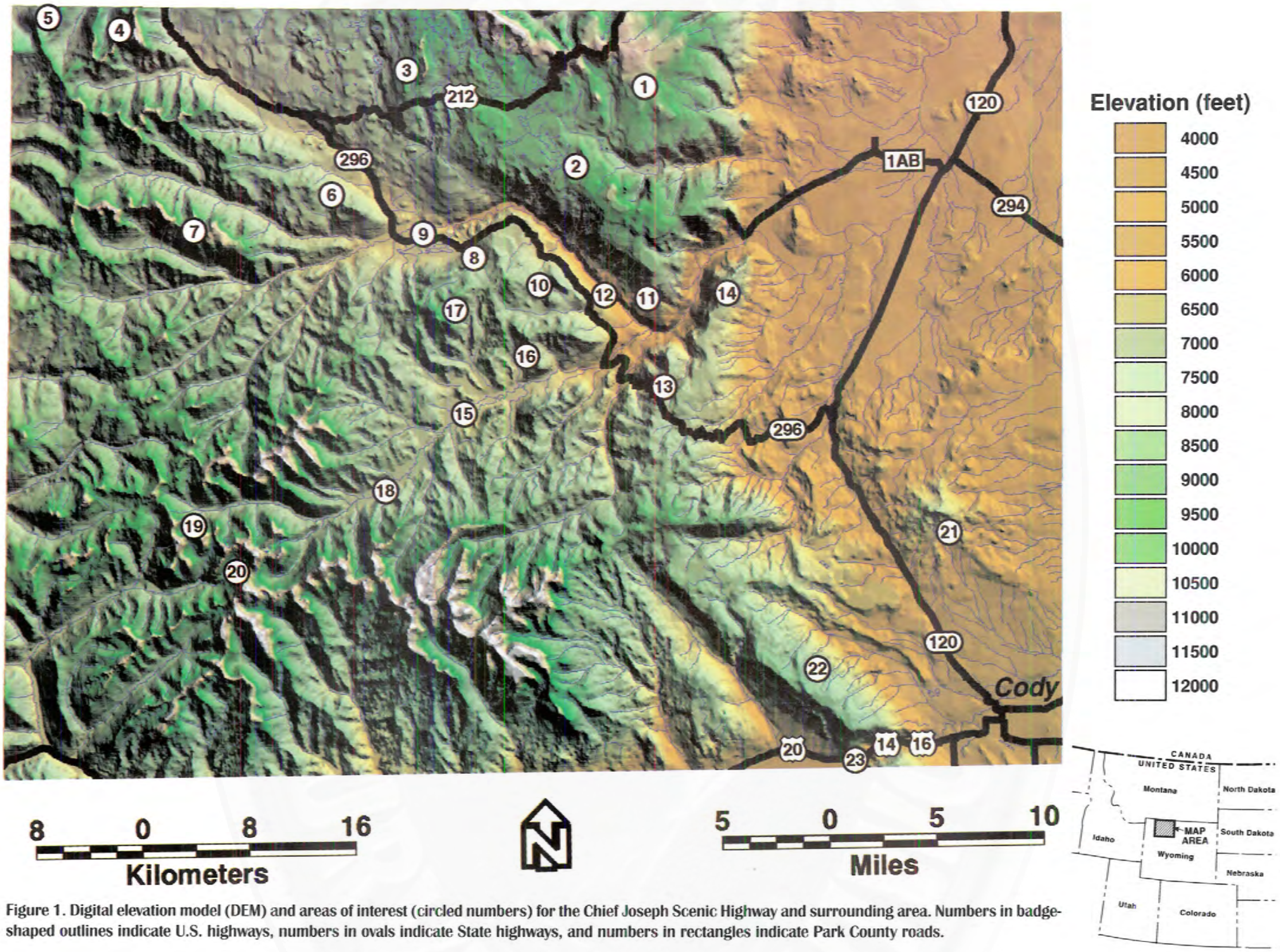


Figure 1. Digital elevation model (DEM) and areas of interest (circled numbers) for the Chief Joseph Scenic Highway and surrounding area. Numbers in badge-shaped outlines indicate U.S. highways, numbers in ovals indicate State highways, and numbers in rectangles indicate Park County roads.

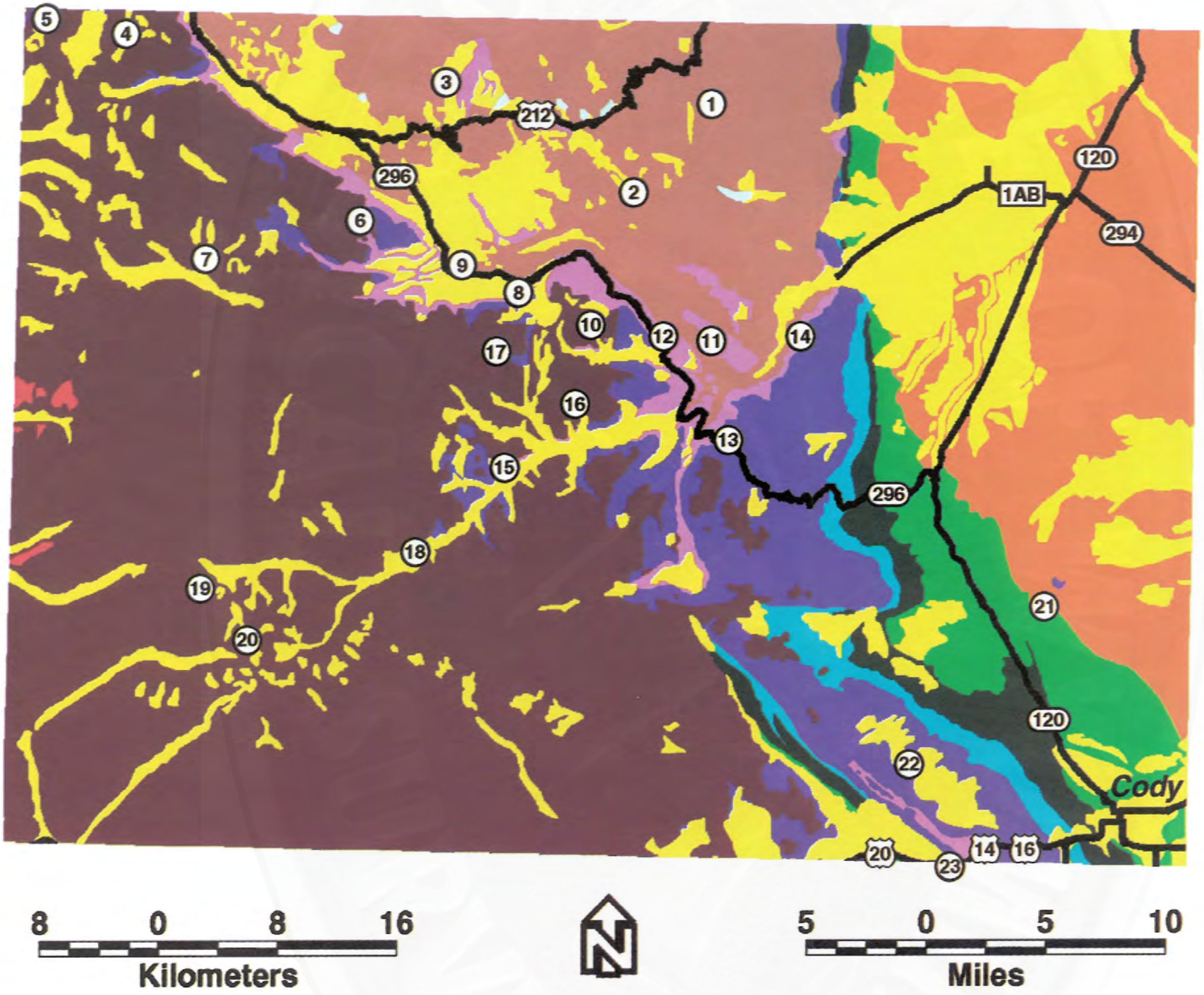


Figure 2. Generalized geologic map and areas of interest (circled numbers) for the Chief Joseph Scenic Highway and surrounding area. Roads are delineated as in **Figure 1**. See **Figure 3**, page 7, for explanation.

Geologic History

General geologic history and stratigraphy of the northwestern Bighorn Basin

The northwestern Bighorn Basin has had an extensive and interesting geologic history. A sedimentary section with an aggregate thickness of 33,000 feet, ranging from Cambrian to recent in age, is identified in the basin and on its margins. A significant portion of that section is represented in the northwestern portion of the basin (**Figure 4**). The geologic history of the Bighorn Basin and specifically the northwestern portion of the basin is outlined below.

Precambrian rocks, exposed in the core of the Beartooth Mountains and in Shoshone and Clarks Fork Canyons, are composed of what are now folded and highly metamorphosed sedimentary rocks of great thickness. These rocks have been intruded by large bodies of granite and other igneous rocks. The Precambrian period of time, which is poorly documented from a geological standpoint, covered hundreds of millions of years. In the later part of the Precambrian, ancient mountains were eroded away, and by the beginning of Paleozoic time, the land surface was reduced to a relatively flat erosional plane.

The Cambrian sea entered Wyoming from the west and in it were deposited sandstones, shales, and some limestone which make up the Flathead, Wolsey, Meagher, Park, Pilgrim, and Snowy Range Formations. By the end of Cambrian time, the seas had completely withdrawn and Wyoming remained emergent through much of Ordovician time. Late in Ordovician time, the State, and specifically the Bighorn Basin, was again submerged, and the Bighorn Dolomite was deposited in this sea. In the Bighorn Mountains to the east, this formation contains the earliest record of fish remains in the State, which are the oldest vertebrate fossils known in geological history.

The seas may have covered northwestern Wyoming during the Silurian Period, but if so, these sediments must have been completely eroded away before late Devonian time, since these rocks have not been recognized here. Late in Devonian time, a sea covered northwestern Wyoming and in it were deposited gray dolomite, gray to orange siltstone, and some black shale of the Beartooth Butte, Jefferson, and Three Forks Formations.

Early in Mississippian time, most of the State was covered by a sea in which was deposited the characteristic blue-gray Madison Limestone. During Late Mississippian time, the seas withdrew, leading to erosion of the upper Madison Limestone. This erosion created the cavernous upper surface upon which Upper Mississippian-age sandstones in the lower part of the Amsden Formation (Darwin Sandstone) were deposited.

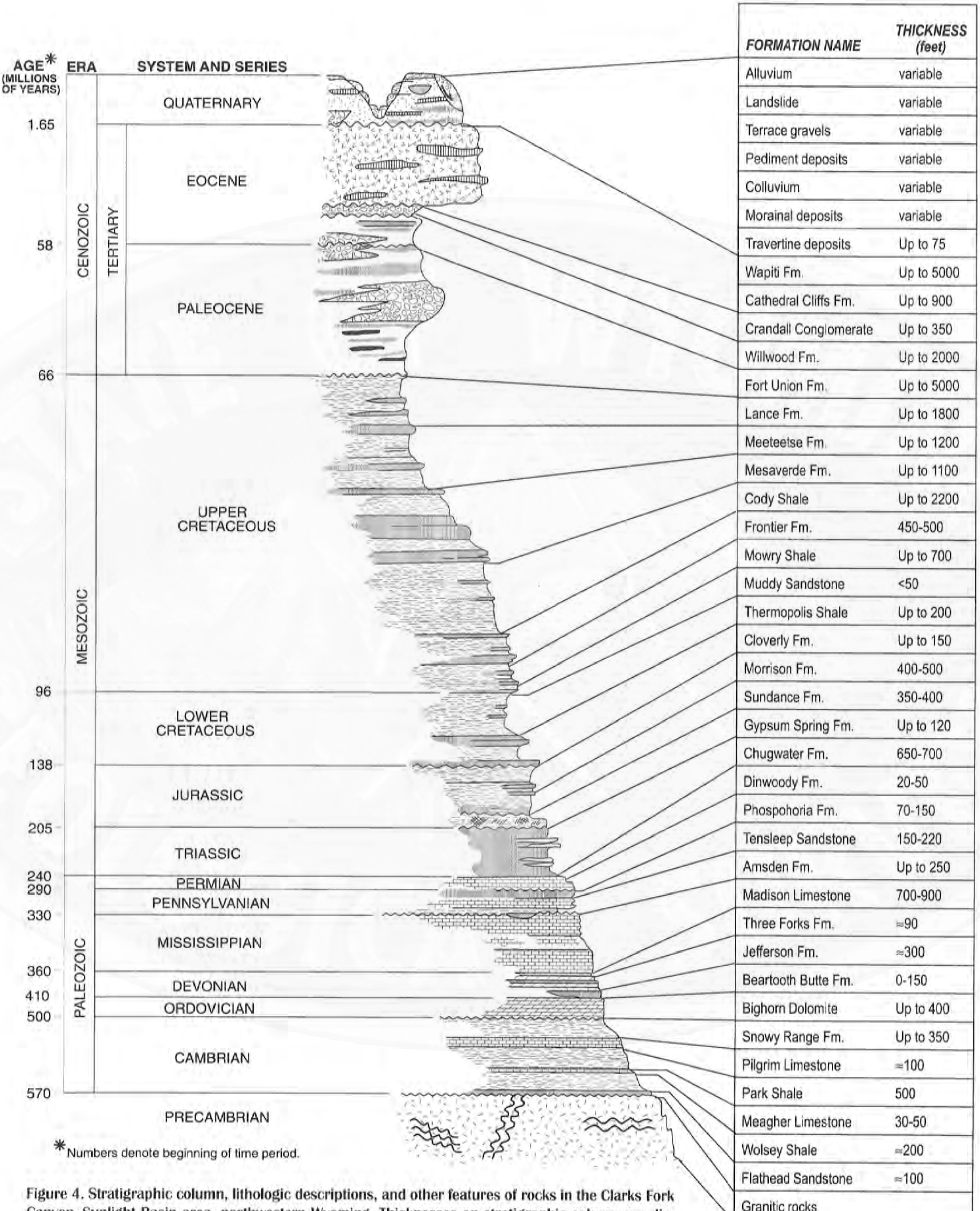
During the first half of the Pennsylvanian Period, a fluctuation of the sea across the area allowed deposition of marine red shale, cherty limestone, and sandstone. During the last half of Pennsylvanian and earliest Permian time the tan, crossbedded, massive sandstones of the Tensleep Sandstone were deposited in a shallow marine to terrestrial environment. This portion of northwestern Wyoming now was emergent. During Middle Permian time, the Phosphoria sea entered Wyoming from the west and dolomite, chert, limestone, sandstone, and phosphate rock were deposited in it. A deeper marine depositional environment existed to the west and a very shallow, oxidizing marine environment existed to the east.

No folding of the rocks occurred at the end of the Paleozoic era in this area, since Mesozoic rocks rest directly upon Paleozoic rocks with no angular discordance. The Triassic sea invaded Wyoming from the west and marine siltstone, gypsum, and dolomite were laid down. With the termination of normal marine conditions, the red shales and fine-grained sandstones of the Chugwater Formation were laid down in a dominantly shallow sea and tidal plain depositional environment.

During Jurassic time, gypsum, sandstone, limestone, and variegated shales were deposited under a wide variety of marine and continental conditions. The Jurassic Period opened with a very low-lying, restricted depositional environment, with the red shales, gypsum, and limestone of the Gypsum Spring Formation being deposited. This was followed by more extensive marine deposition of the olive green shales, sandstones, and limestones of the Sundance sea. The Jurassic ended with retreat of the seas due to uplift of

Ages (millions of years)		
1.65-Present	🟨	**Quaternary rocks** and unconsolidated alluvial, colluvial, glacial, lacustrine, landslide, gravel, fan, and loess deposits.
1.65-Present	🟥	**Quaternary rhyolite and basalt flows.**
55-38	🟫	**Tertiary intrusive igneous rocks and the Absaroka Volcanic Supergroup:** Rocks include volcanic conglomerates, tuffs, andesite lava flows, dark-brown breccia, trachyandesite, and dacitic volcaniclastic rocks.
66-38	🟧	**Tertiary sedimentary rocks:** includes variegated claystones, shales, sandstones, and conglomerates of the Wilwood Formation; and shales, sandstones, and coals of the Fort Union Formation.
96-66	🟩	**Upper Cretaceous rocks:** includes sandstones, shales, and coal of the Mesaverde Formation; sandstone, drab-green shale, and thin conglomerates of the Lance Formation; sandstone, bentonitic claystone, tuff, and coal of the Meeteetse Formation; shales and siltstones of the Cody Shale.
138-96	⬛	**Lower and other Cretaceous rocks:** includes sandstones, shales, coals, and lignites of the Frontier Formation; black shales of the Thermopolis Shale; sandstone, bentonitic claystone, and chert-pebble conglomerates of the Clovery Formation; and fossiliferous shales of the Mowry Formation.
240-138	🟦	**Triassic and Jurassic rocks:** includes gypsum, halite, red siltstones and shales of the Goose Egg and Chugwater Formations; dolomitic siltstone of the Dinwoody Formation; dull-variegated claystone, limestone, and siltstone of the Morrison Formation; glaconitic sandstone and shales of the Sundance Formation; red shale, dolomite, and gypsum of the Gypsum Spring Formation.
410-240	🟦	**Devonian, Mississippian, Pennsylvanian, and Permian rocks:** includes red siltstones, limy sandstone, and limestone of the Beartooth Butte Formation; dolomitic siltstone, shale, fetid brown dolomite of the Three Forks and Jefferson formations; blue-gray, massive limestone of the Madison Group; red and green dolomitic shale, siltstone, and sandstone of the Amsden Formation; white to gray sandstone with thin beds of limestone and dolomite within the Tensleep Sandstone; and brown sandstone, dolomite, cherty phosphatic and glaconitic dolomite, and shales of the Phosphoria Formation.
570-435	🟪	**Cambrian and Ordovician rocks:** includes the dull, red-quartzitic sandstone of the Flathead Sandstone; the green micaceous shales of the Wolsey Shale; the blue-gray and yellow limestones of the Meagher Limestone, the green, micaeous Park Shale, the green, micaeous shales and blue-gray limestones of the Gallatin Group, and the light-gray, massive siliceous dolomite known as the Bighorn Dolomite.
3900-2700	🟥	**Early Archaen rocks:** includes granitic gneiss, migmatite, quartzite, iron-formation, amphibolite, and metasedimentary rocks.

Figure 3. Explanation for generalized geologic map and ages of rock units (see **Figure 2**).



FORMATION NAME	*THICKNESS (feet)*
Alluvium	variable
Landslide	variable
Terrace gravels	variable
Pediment deposits	variable
Colluvium	variable
Morainal deposits	variable
Travertine deposits	Up to 75
Wapiti Fm.	Up to 5000
Cathedral Cliffs Fm.	Up to 900
Crandall Conglomerate	Up to 350
Willwood Fm.	Up to 2000
Fort Union Fm.	Up to 5000
Lance Fm.	Up to 1800
Meeteetse Fm.	Up to 1200
Mesaverde Fm.	Up to 1100
Cody Shale	Up to 2200
Frontier Fm.	450-500
Mowry Shale	Up to 700
Muddy Sandstone	<50
Thermopolis Shale	Up to 200
Cloverly Fm.	Up to 150
Morrison Fm.	400-500
Sundance Fm.	350-400
Gypsum Spring Fm.	Up to 120
Chugwater Fm.	650-700
Dinwoody Fm.	20-50
Phospohoria Fm.	70-150
Tensleep Sandstone	150-220
Amsden Fm.	Up to 250
Madison Limestone	700-900
Three Forks Fm.	≈90
Jefferson Fm.	≈300
Beartooth Butte Fm.	0-150
Bighorn Dolomite	Up to 400
Snowy Range Fm.	Up to 350
Pilgrim Limestone	≈100
Park Shale	500
Meagher Limestone	30-50
Wolsey Shale	≈200
Flathead Sandstone	≈100
Granitic rocks	

*Numbers denote beginning of time period.

Figure 4. Stratigraphic column, lithologic descriptions, and other features of rocks in the Clarks Fork Canyon–Sunlight Basin area, northwestern Wyoming. Thicknesses on stratigraphic column are diagrammatic. Modified from Foose and others, 1986, from an illustration by D.U. Wise, 1982.

DESCRIPTION	***DEPOSITIONAL ENVIRONMENT***	***FOSSILS***
Unconsolidated deposits of silt, sand, gravel, and cobbles along stream valley near present stream level.	Present terrestrial	
Heterogeneous deposits of rock debris.	Present terrestrial	
Unconsolidated deposits of gravel, sand, cobbles, and silt; includes up to five levels.	Present terrestrial	
Smooth gently sloping erosional surfaces cut on bedrock, only a thin veneer of surficial material.	Present terrestrial	
Heterogeneous deposits of rock detritus and soil material on relatively steep slopes.	Present terrestrial	
Heterogeneous glacial deposits, mostly terminal moraine, some lateral moraine; mostly Wisconsin age.	Glacial and interglacial	Large Ice-Age mammals
Travertine-calcium carbonate precipitate associated with hot springs.	Present terrestrial	
Dark colored breccias, tuffs, volcanic sediments, and lava flows.	Volcanic activity/terrestrial	
Light colored tuff, volcanic sediments, conglomerate, and breccia.	Volcanic activity/terrestrial	
Channel deposit of well-cemented coarse conglomerate; rounded cobbles from Paleozoic rocks.	Terrestrial/fluvial	
Varicolored claystone, sandstone, and shale; some thin coal beds; thick conglomerate at base.	Uplift completed/fluvial	Mammals, petrified wood, plants, etc.
Thin light colored sandstone interbedded with tan shale; some coals; conglomeratic near Beartooths.	Mtn. uplift/fluvial	Mammals, petrified wood, plants, etc.
Drab gray shale, sandstone, some lignites and bentonites.	Mtn. uplift/fluvial/minor marine	Dinosaurs, mammals, plants, etc.
Gray to white sandstone, brown shale, and bentonitic clay.	Marine/minor fluvial	Plants
Upper part interbedded buff sandstone and gray shale, lower massive buff sandstone, thin coals.	Fluvial/lagoonal/marine	Plants
Upper sandy shale and thin laminated buff sandstone and lower dark gray thin bedded shale.	Marine	Oyster shells, cephalopods, etc.
Thick lenticular gray sandstone interbedded with gray to black shale and bentonite beds.	Shoreline/marine	Rare ammonites, cephalopod
Gray, brown and black shale, partially siliceous, with numerous bentonite beds and abundant fish scales.	Marine	Fish scales
Thin white sandstone and silty zone between the Mowry and Thermopolis.	Shoreline	
Soft black shale with numerous bentonite beds.	Marine	Fish teeth
Rust-colored silty zone and light gray sandstone over variegated shales; basal chert conglomerate.	Fluvial/lacustine	Dinosaurs, plants, "gastroliths"
Variegated claystone and gray silty sandstone. Famous as source for dinosaur bones in Bighorn Basin.	Fluvial/lacustine	Dinosaurs
Olive green to gray shale, greenish gray glauconitic limy sandstone, and thin fossiliferous limestone.	Marine	Belemnites, oyster shells
Red to gray shale, fossiliferous limestone, and gypsum beds-up to 50-foot gypsum bed near base.	Shallow marine	
Red siltstone, shale, and fine grained sandstone; gypsiferous.	Shallow marine	Rare reptiles, ammonites
Tan to gray and red siltstone, gypsum, and dolomite.	Shallow marine	Oyster shells
Gray thin bedded siliceous limestone, nodular chert, and tan and gray shale.	Marine	Rare reptiles, pelecypods
Light gray, crossbedded, massive sandstone: thin beds of limestone and dolomite in lower portion.	Shallow marine/eolian	Foraminifera, amphibian tracks
Red shale, some limestone and dolomite beds; chert and hematite nodules common; sandstone at base.	Marine and shoreline	Brachiopods
Blue-gray massive limestone; cavernous in upper portion; lower portion fossiliferous; cliff former.	Marine	Brachiopods, corals
Greenish gray to dark gray dolomitic siltstone; black shale, and silty dolomite.	Marine	Brachiopods, corals
Brown dolomite; light gray to tan limestone; and yellowish-orange dolomite and siltstone in upper portion.	Marine	Brachiopods, fish fragments, corals
Red calcareous siltstone and silty limestone; siltstone and limestone conglomerate-local channel deposits.	Fluvial	Plants and fish
Gray, massive, cliff-forming dolomite and dolomitic limestone; locally fossiliferous.	Marine	Corals, brachiopods, sponges, etc.
Thin gray limestone and dolomite toward top; gray-green shale and greenish flat pebble conglomerate.	Marine	Trilobites, brachiopods, worms
Massive gray oolitic limestone; prominent ledge former.	Marine	Brachiopods
Green to purple shale; limestone flat pebble conglomerate.	Marine	Trilobites and worms
Gray thin bedded nodular limestone interbedded with green shale; minor ledge former.	Marine	Brachiopods, trilobites
Gray, green, and purple, papery shales.	Marine	Trilobites
Thin tan quartzitic sandstone.	Marine	Worm tubes
Pink granite gneiss and granite; amphibolites.	Crustal growth	Algae

the area immediately to the west. At this time, deposition of the fluvial and lacustrine sediments of the Morrison Formation occurred. The well-known Jurassic dinosaurs also flourished at this time.

In the Cretaceous, a large inland sea covering much of the interior of North America oscillated back and forth across Wyoming and in it were deposited the shales, sandstones, and conglomerates of the Cloverly, Thermopolis, Muddy, Mowry, Frontier, Cody, Mesaverde, and Meeteetse Formations. Volcanic ash beds (from volcanic activity to the west) were deposited in the marine shales, altering over time to the clay minerals now comprising the rock bentonite. Coal was deposited in swamps on the coastal plains. During Late Cretaceous time, a period of intense crustal disturbance began and the seas made a final retreat eastward during the time of Lance Formation deposition. Laramide uplift initiated the dominantly fluvial sandstone and shale deposition characteristic of the Lance.

By early Cenozoic, the mountains and basins of northwestern Wyoming were well outlined (**Figure 5**). As the mountains continued to grow, they were subject to erosion and the resultant fluvial sandstones and shales of the Tertiary Willwood and Fort Union Formations were deposited in the basin and on the basin margin. Deposition continued through the Eocene and Miocene, filling the basin and covering the present-day mountains. Concurrently to the west in the greater Yellowstone area, extensive volcanism produced the Eocene-aged Absaroka volcanics which included the Cathedral Cliffs and Wapiti Formations. Intermittent volcanism has continued until recent times. In Pliocene time, large-scale regional erosion of the basin occurred, removing most of the basin fill since Eocene, uncovering buried features, and leaving the basin with essentially its present appearance. In Pleistocene time, an ice sheet covered the adjacent mountains and valley glaciers filled the valleys to create the landforms that we see today.

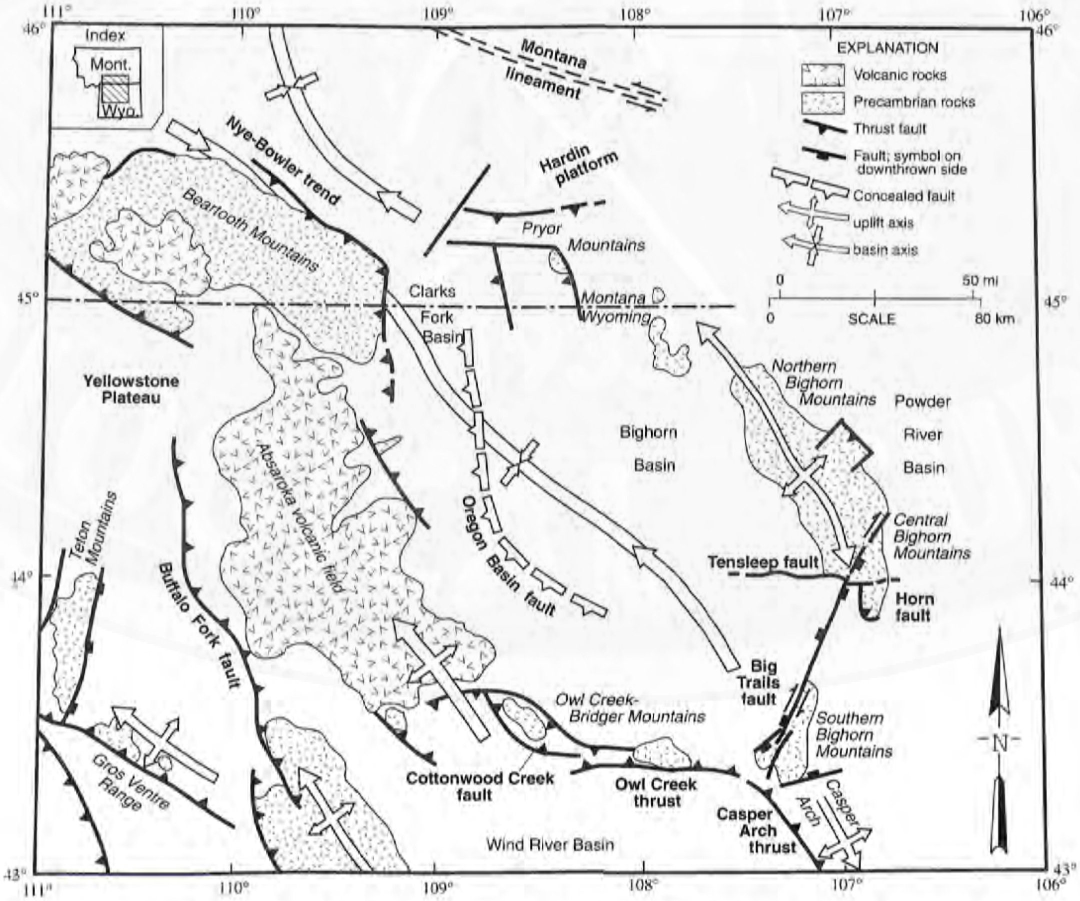


Figure 5. General tectonic and index map of central and northern Wyoming and southern Montana. Modified from Blackstone (1990).

The Heart Mountain detachment fault

Introduction

Heart Mountain north of Cody (**Area of Interest AI-21, Figures 1** and 2; and photograph, **Segment 1,** page 32) is an unusual feature in the Bighorn Basin. At Heart Mountain, older rocks (500-320 Ma) overlie younger rocks (approximately 60-50 Ma) and the principle of superposition (that younger rocks generally overlie older rocks) appears invalid. Geologists have written about Heart Mountain since the early 1900s and the scientific debate about the origin of this feature continues.

Early ideas

Geology and the road over Dead Indian Hill were still in their infancies when Cassius A. Fischer (1906) published on the geology and water resources of the Bighorn Basin. He thought that the 360-320 Ma Madison Limestone blocks at the top of Heart Mountain were caused by a circular fault. He writes that:

> *. . . the underground structural relations of Heart Mountain are somewhat obscure, but the uplift is probably due to a circular fault, which raised the Madison Limestone several thousand feet above its original position.*

Development of better roads with access to mountainous areas west of Heart Mountain assisted the development of geologic thought. In 1909, the wagon road over Dead Indian Hill was upgraded, giving geologists after Fischer better access to the valleys of the Sunlight and the Clarks Fork of the Yellowstone River. Approximately 10 years after Fischer, Dake studied the geology along the South Fork of the Shoshone, Sunlight Creek, and the Clarks Fork. In 1918, Dake concluded that the many faults he observed within the area were part of a great overthrust.

Beginning of modern thought

Two geologists, Walter H. Bucher and William G. Pierce, began studying the Heart Mountain problem in the 1930s. No doubt, they traveled down the switchbacks along the improved 1930s Dead Indian Road to study the relationships between the 600-300 Ma Paleozoic limestones and shales and the 53-38 Ma Absaroka volcanic rocks within the valleys of Sunlight Creek and the Clarks Fork River. The geologic investigations of both men were interrupted by World War II. Walter H. Bucher published his idea about how Heart Mountain came to be in 1947:

> *. . . wedge-shaped slices of limestone, some several square miles in area, broke loose, sheared off the base of the Bighorn Limestone and across higher beds, landed on the temporarily steepening slope and slid downward under the action of gravity, probably aided by frequent earthquake shocks that preceded the outbreak of volcanic activity.*

William G. Pierce was assigned to work in northwestern Wyoming for the U.S. Geological Survey in 1935 and published his first paper on the Heart Mountain and South Fork thrusts in 1941. In 1957 and for the next thirty years, he published numerous papers, maps, and reports documenting his observations and ideas.

Pierce (1957) described the unusual Heart Mountain detachment thrust as

> *. . . sheets of sedimentary rocks which have broken loose along a basal shearing plane, have moved long distances by gravitational gliding, and have been deformed independently from the rocks below the fault plane.*

The idea of a rootless thrust was similar to Bucher's, but Pierce had accumulated geologic evidence to support a unique, and catastrophic 45-Ma event that moved Paleozoic limestones up to 30 miles from their source. More than 50 remnants of the Heart Mountain detachment fault form the landscape from Cooke City, Montana to McCulloch Peaks in the Bighorn Basin (**Figure 6**).

In Pierce's numerous publications on the Heart Mountain detachment fault, he documented some aspects of this unique geologic event: (1) a north-south trending breakaway fault near the northeast entrance of Yellowstone Park; (2) a nearly horizontal "bedding plane" fault, 35 miles long and 15 miles wide; (3) a transgressive fault; (4) a nearly horizontal fault across

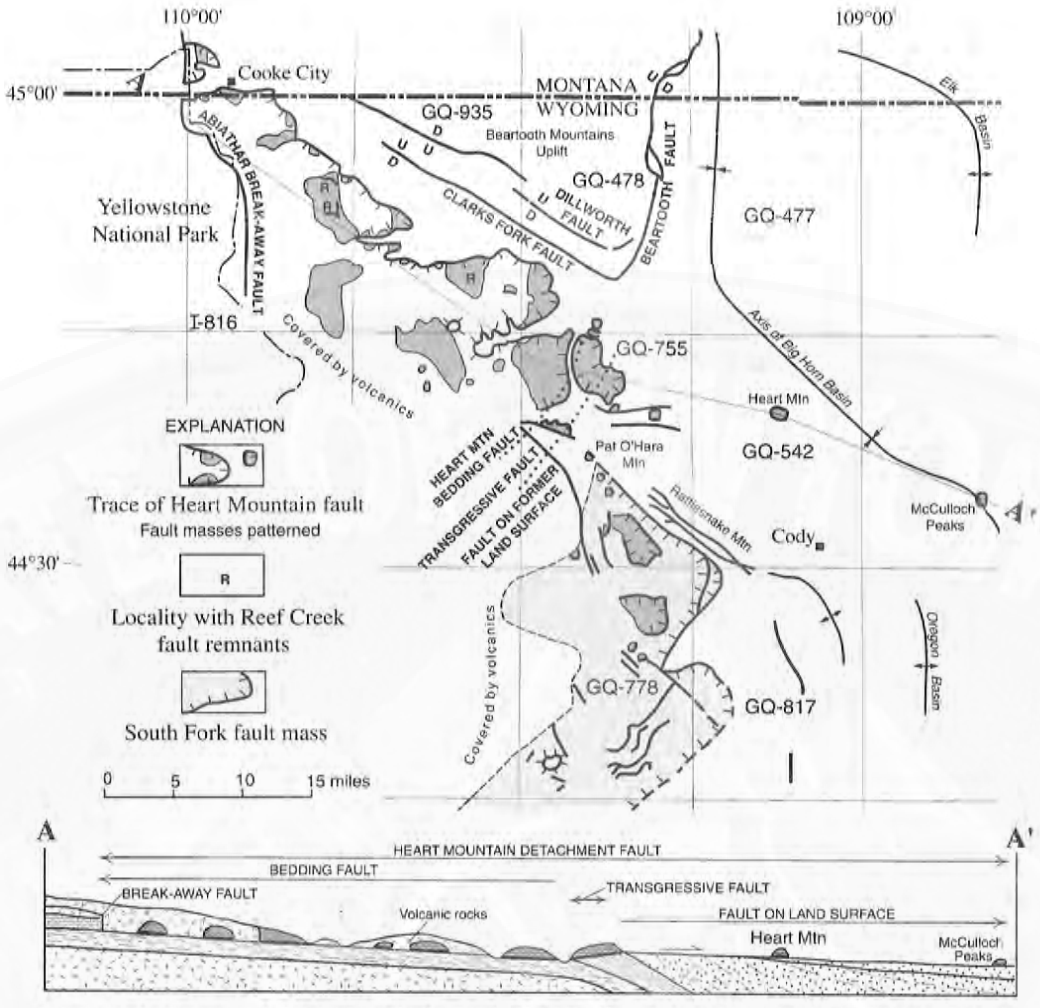


Figure 6. Index map of detachment faults, including the Heart Mountain detachment fault, in northwestern Wyoming. Geologic maps (U.S. Geological Survey GQ and I designations) of the area are indicated. Modified from Pierce and Nelson, 1978.

the former land surface; (5) a carbonate fault breccia; (6) an old stream deposit affected by the Heart Mountain detachment fault; and (7) volcanic rocks which help to date this catastrophic event.

The scientific debate

In contrast to Pierce's view that Wapiti volcanic rocks covered the plane of tectonic denudation, Thomas Hauge (1982) began mapping the younger Wapiti volcanic rocks as fault-emplaced. Hauge (1993) reinterpreted the upper plate of the Heart Mountain detachment as a continuous extensional allocthon which was emplaced noncatastrophically. The crux of the argument is the stratigraphic relationship between the Cathedral Cliffs, Lamar River, and Wapiti volcanic rocks of the Absaroka Volcanic Supergroup. Hauge argues that the Wapiti rocks were coeval with extension of the Heart Mountain allocthon. Pierce mapped the Wapiti rocks in depositional contact with the many detached blocks of the Heart Mountain detachment fault.

The basic argument over depositional versus fault-emplaced contacts, catastrophic tectonic denudation versus a non-catastrophic, extending allocthon, and the use of the terms Wapiti and Cathedral Cliffs still remains. So, the problem of how the Paleozoic limestones were moved across such a large area for long distances still attracts scientists from all over the world. One can observe the faults and rocks in the area that have inspired intensive study and stirred the controversy. After almost 100 years of study, the mechanism for the emplacement of the Heart Mountain detachment fault still remains controversial.

Absaroka volcanics

Approximately 53-38 Ma, volcanic activity covered portions of northwestern Wyoming (Sundell, 1993). Andesitic Absaroka volcanism began shortly after the Laramide Orogeny and was coeval with the subduction of the East Pacific Plate beneath North America. In the western U.S., other centers of Eocene volcanic activity were closer to this zone of subduction than the Absaroka Volcanic Province, which was greater than 1,000 miles (1,610 kilometers) from the west coast. Fossil plants and leaves preserved in these middle Tertiary (Eocene) rocks indicate that the climate was similar to present-day southeast Asia.

Absaroka volcanic rocks include andesites, basalts, trachyandesites, dacites, and rhyolites. The majority of Absaroka volcanic rocks are reworked into volcanic sandstones, siltstones, claystones, conglomerates, and breccias. Extensive reworking of volcanic rocks, large-scale mass movements, and cross-cutting relationships make Absaroka volcanic stratigraphy very complex.

The Sunlight Group of the Absaroka Volcanic Supergroup predominates in the area of the field guide. It contains more mafic rocks than the older Washburn Group or the younger Thorofare Creek Group. Examination of the Eocene Absaroka volcanic rocks reveals two depositional environments: a vent facies and an alluvial facies. Vent facies are composed of volcanic breccias and lava flows. The lava flows of the Wapiti Formation and the Trout Peak Trachyandesite (members of the Sunlight Group) show Hawaiian-type vent facies, lava flows, and large lava lakes (Nelson and Pierce, 1968). Dikes are common near centers of volcanic activity. One center of volcanic activity was Hurricane Mesa; another center of Eocene volcanic activity occurred in the headwaters of Sunlight Creek. These centers of Absaroka volcanism developed after the Heart Mountain detachment fault (Nelson and Pierce, 1983). Mineralized and metamorphosed rocks are found in the vicinity of these ancient, eroded volcanoes.

The Cathedral Cliffs and Lamar River Formations are alluvial facies of the Washburn Group. These volcaniclastic rocks are lithified stream deposits, mud flows, and volcanic rocks from the slopes of andesitic volcanoes. An accessible example of Absaroka volcaniclastic rocks is found by hiking the Specimen Ridge trail in Yellowstone National Park. Ancient trees engulfed by volcaniclastic deposits are preserved and easily seen. Other examples of volcaniclastic rocks can be seen in the Shoshone National Forest surrounding Yellowstone National Park.

The Absaroka volcanic rocks play a role in our understanding of the timing and mechanism of the Heart Mountain detachment fault. Older Absaroka volcanic rocks (Cathedral Cliff Formation, approximately 52 Ma) were moved across the Eocene landscape along with the Paleozoic limestones. Younger Absaroka volcanic rocks (Wapiti Formation, approximately 50 Ma) either flowed over many of the fragments of the Heart Mountain detachment fault (Pierce, 1957, 1987) or were involved in Heart Mountain faulting (Hauge, 1993). The stratigraphic and field relationships of these two Absaroka volcanic rocks are at the center of the Heart Mountain detachment fault scientific debate.

Yellowstone volcanism

The late Cenozoic, silicic volcanism (2.2 Ma to 70,000 y.b.p.) of the Yellowstone region is related to the southwest movement (4.5 cm/year) of the North American plate over a mantle plume known as the North American Hot Spot. The position of this "hot spot" appears to have moved from southwest to northeast across the North American plate over geologic time, but in fact it is the North American plate that has moved over the "hot spot" attached to the mantle. The "hot spot" is presently located under Yellowstone National Park in northwestern Wyoming and southwestern Montana.

The track of the middle Miocene to late Pliocene-Pleistocene movement of North America over this mantle plume is the Snake River Plain of Idaho. According to Smith and Braille (1993), the 16 Ma trace of the Yellowstone hotspot (the Snake River Plain) is surrounded by earthquakes, normal faulting, and a "bow wave" of high topography. Along the

800-kilometer-long and 80-kilometer-wide Snake River Plain, the elevation changes from greater than 3000 meters in northwestern Wyoming to 1200 meters in southwestern Idaho. During the middle Miocene, the "hot spot" was centered near the border of southwestern Idaho and northern Nevada. Smith and Braille (1993) argue that the high topography of the Yellowstone Plateau relates to a significant positive anomaly (+10 to 12 meters) in the North American geoid. Other geophysical evidence (such as P-wave delays) is consistent with partial melting and hydrothermal fluids in the lithosphere underneath Yellowstone. Surface expressions of the hot spot include geysers, other hydrothermal features found in Yellowstone, and heat flow values of 2,000 mW/m2 (Morgan and others, 1977).

Measurements of magnetic polarity and recent geochronologic work with 40Ar/39 Ar has refined the timing of Yellowstone's major eruptive cycles (Obradovich, 1992). The first of three major Yellowstone rhyolitic eruptions spanned 400,000 years and ranged from 2.2 to 1.8 Ma. The main phase eruptive event resulted in the 172-meter-thick Huckleberry Ridge Tuff. This tuff (dated at 2.09-2.11 Ma) is composed of a 2-meter-thick airfall deposit and three welded tuffs (members A, B, and C). The Huckleberry Ridge Tuff was preceded by the flows of the Junction Butte Basalt in northeastern Yellowstone National Park. These basalt flows are exposed along the Yellowstone River and on Mt. Everts. The last units of this First Volcanic Cycle were the basalts and sediments of the Narrows.

During the Second Volcanic Cycle, a smaller, main eruptive phase resulted in the Mesa Falls Tuff (1.3 Ma). The center of this eruption is the Island Park area of eastern Idaho. In contrast to the First Volcanic Cycle, the pre- and post-collapse volcanism of the Second Volcanic Cycle lasted only 50,000 years.

The pre-collapse volcanism (Mount Jackson Rhyolite flows) of the Third Volcanic Cycle began shortly after the post-collapse phase of the Second Volcanic Cycle. However, the locus of eruption shifted northeastward from the Island Park area to the Yellowstone Plateau. The main eruptive phase of the Third Volcanic Cycle is known as the Lava Creek Tuff. The 300-meter-thick Lava Creek Tuff (0.65 Ma) consists of two units: Lava Creek A and Lava Creek B. The eruption of the Lava Creek Tuff led to a collapse and the formation of the present Yellowstone caldera, which now contains Yellowstone Lake. Resurgent doming (Sour Creek Dome) possibly occurred less than 10,000 years after the eruption of the Lava Creek Tuff. The post-collapse phase of the Third Volcanic Cycle involved the eruption of the Plateau Rhyolites. Volcanism occurred intermittently until 70-80,000 y.b.p.

It is not known whether the Third Volcanic Cycle is complete. From 1923 to 1984, the Yellowstone caldera deformed or rose as much as 1 meter; this was followed by subsidence of approximately 12 centimeters from 1985 to 1991. This "slow breathing" of the Yellowstone caldera indicates its eruptive potential.

One of youngest volcanic ashes from the Yellowstone area was found near the old bridge across Sunlight Creek (Cheryl Jaworowski, Henry Heasler, and Ken Pierce, 1987; personal communication). This volcanic ash, known as the Tuff of Bluff Point (150,000 y.b.p.), probably was associated with the formation of the West Thumb of Yellowstone Lake. The volcanic ash rested on Cambrian bedrock and was overlain by glacial till. The roadcut was reclaimed when the new bridge across Sunlight Creek was built. The late Cenozoic volcanic eruptions of Yellowstone assist in dating Quaternary glacial, fluvial, and lacustrine sediments throughout Wyoming and the western United States.

Glacial history of Sunlight Basin and the Clarks Fork River

During the last glacial maximum (18,000-20,000 y.b.p.), ice flowed from the high elevation and relatively flat landscape of the Beartooth Plateau. Ice tongues from the Beartooth Ice Cap filled the valley of the Clarks Fork River. Although ice usually flows downstream, there is evidence that ice pushed upstream along Sunlight, Dead Indian, Elk, and Russell Creeks. The ice in these valleys impeded water flow and the water accumulated, forming glacial lakes (**Figure 7**).

Evidence of the area's glacial history is recorded by the presence of granitic boulders from the Beartooth Plateau, U-shaped valleys, glacial deposits, glacial pol-

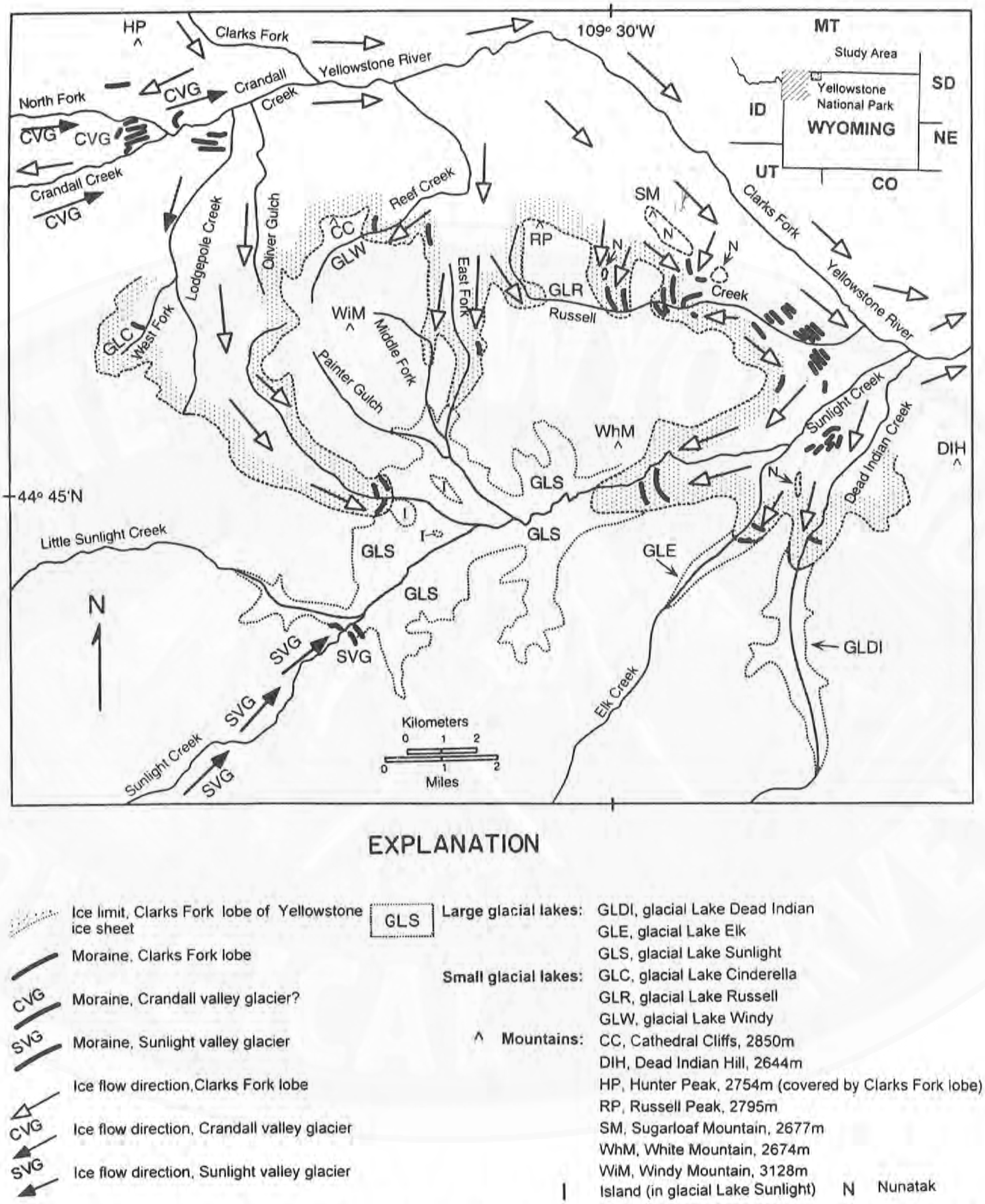


Figure 7. Glacial geologic map of the Sunlight-Clarks Fork region. (From Carson and others, 1996.) Note the north to south movement of Beartooth ice across the Crandall-Sunlight divide and up Sunlight, Dead Indian, and Elk Creeks. Ice did not cover the topography completely; some hills such as Steamboat, a nunatak, were above the ice. Glacial lakes Sunlight, Dead Indian, and Elk were the largest glacial lakes. Ice-rafted boulders of granitic rocks can be found around the margin of glacial lakes Sunlight and Dead Indian. At different times, ice flowed both up and down Crandall Creek.

ish, glacial striations, mud deposited in lakes, and catastrophic flood deposits. Ice moving over the landscape either eroded rocks or deposited sediments, causing a streamlined or scoured appearance to the landscape (see **Front Cover** and **Segment 4,** pages 53-54 and 60).

Granitic rocks from the Beartooth Plateau

Hewett's (1911) study of the region's glacial history concluded that a broad, rounded moraine dammed Sunlight Creek and formed a lake. In 1919, Dake found granitic rocks in moraines in the valleys of Dead Indian, Elk, Sunlight, and Russell Creeks. This was a puzzle because the hillsides of those creeks were made of limestones, shales, and volcanic rocks. The only source for the granitic rocks found in these moraines was the Beartooth Plateau. Parsons (1939b) found granitic boulders and cobbles along Lodgepole and Trail Creeks. Evidently, ice from the Beartooth Plateau moved from north to south across stream divides between the valleys of Clarks Fork River and Sunlight Creek (**Figure 7**).

Glacial till and U-shaped valleys

About midway down Dead Indian Hill at about 7200 feet elevation, Paleozoic rocks are covered by Pinedale age (30,000-20,000 y.b.p.) glacial till. Glacial till (a mix of fine sediments and boulders) covers older rocks from Dead Indian Hill to the junction of State Highway 296 and U.S. Highway 212.

Looking toward the Beartooth Plateau from the top of Dead Indian Hill, U-shaped valleys hang above the present-day valley of the Clarks Fork River (see **Segment 4**, pages 58 and 61). These U-shaped valleys were carved as glaciers flowed from the Beartooth Plateau into the Clarks Fork valley. Other U-shaped valleys are visible along the Chief Joseph Scenic Highway.

Glacial polish, glacial striations, and chattermarks

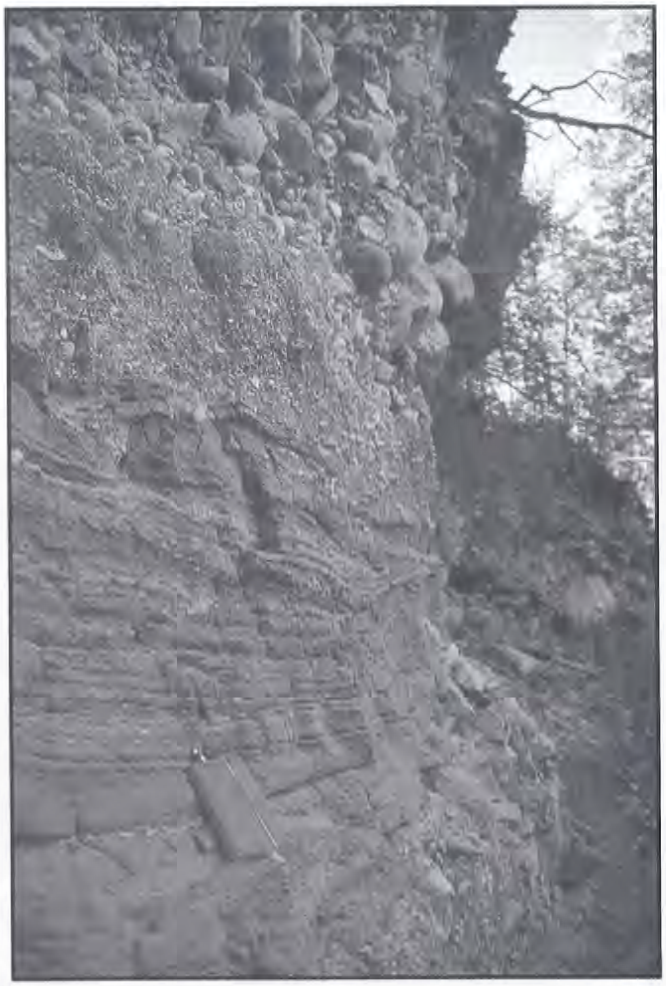
Not far from the bridge over Sunlight Creek, the outcrops of Cambrian Flathead Sandstone, in places, feel smooth and are polished. Water and grit flowing under glacial ice polished the Flathead Sandstone. Over 10,000 years have passed since the glaciers left the area and some glacial polish remains. In addition to the Flathead Sandstone, glacial polish still can be seen on granitic rocks and rarely on volcanic rocks. Glacial striations and chattermarks also occur on the polished surfaces of the Flathead Sandstone. Glacial striations and chattermarks are formed when rocks on the bottom of a glacier are moved across the ground. Glacial striations are elongated, linear features on polished rock; chattermarks are crescentic cracks on the surface of polished rock. The direction of ice movement can be determined from striations and chattermarks.

Glacial muds

Recently, thinly-bedded lake deposits were found along Dead Indian Creek and in Sunlight Basin. Along Dead Indian Creek, the thinly-layered beds of clay and silt resemble varves (the result of the yearly cycle of sedimentation brought about by the freezing and thawing of a glacial lake). In Sunlight Basin, the brown clay and silt are not thinly-bedded or laminated; however, there are faceted, polished, rounded, and striated cobbles of Paleozoic limestones, Flathead Sandstone, Beartooth granite, and volcanic rocks in the brown clay. The faceting, polishing, and striations on the rocks indicate that they were dropped from icebergs in a glacial lake in Sunlight Basin. Lack of laminations in the muds indicate that the lake drained quickly or that the muds were near the shore.

Catastrophic flood deposits

Evidence that glacial lake Dead Indian drained quickly was found near a terminal or end moraine along Dead Indian Creek (Placzek and Sneeringer, 1995). A catastrophic flood deposit consisting of clay, silt, sand, limestone pebbles, cobbles, and boulders (up to 2 meters in diameter) was deposited downstream from the terminal moraine (**Figure 8**). The flood deposit consists of a lower crossbedded unit, a boulder-rich unit, and a travertine cap (not related to the flood). The open framework within the lower crossbedded unit indicates high flow of this debris/water mixture. These catastrophic flood deposits may relate to other flood deposits near the mouth of Clarks Fork Canyon.



Another piece of the glacial history lies near the mouth of the Clarks Fork Canyon. Piles of granitic boulders and dirt (glacial moraines) can be seen along Park County Roads 1AB and 8VC (See **Segment 3**, pages 38-45). Boulders of granite range from 1 to 11 feet in diameter (Ballard, 1976) and were pushed here by ice descending the Clarks Fork valley. Granitic boulders and cobbles were spread beyond the glacial moraines by catastrophic floodwaters from the glacial lakes in Sunlight Basin or along Dead Indian Creek. Floodwaters from glacial lakes probably rushed down the Clarks Fork more than once. The presence of weathered and "fresh" rocks near the mouth of the Clarks Fork Canyon is the best evidence that glaciers piled up rocks and debris during the Bull Lake glaciation (approximately 140,000 y.b.p.) and the Pinedale glacial maximum (18,000-20,000 y.b.p.).

Figure 8. Catastrophic flood deposit along Dead Indian Creek. Field notebook for scale resting on the lower crossbedded unit. A boulder-rich unit overlies the crossbedded unit. Travertine caps and helps preserve this flood deposit. (Photograph by C.J., 1995.)

Mineral resources

Oil and gas resources of the Bighorn Basin

The Bighorn Basin of northwestern Wyoming is bordered on the west by the Beartooth Mountains and the Absaroka Volcanic Plateau, on the south by the Owl Creek Mountains, and on the east by the Bighorn and Pryor Mountains (**Figures 5** and **9**). The Bighorn Basin extends into south-central Montana where the Nye-Bowler lineament separates the Bighorn Basin from the Crazy Mountains Basin of Montana. This Laramide foreland basin is about 120 miles long and 75 miles wide and is asymmetric with its steepest side on the west. The axis of the basin trends northwest-southeast. Paleozoic, Mesozoic, and Cenozoic rocks are present in the basin and have a total thickness that exceeds 24,000 feet in the deepest part of the basin.

Nearly all of the 2.4 billion barrels of oil and 1.5 trillion cubic feet of gas produced in the Bighorn Basin has come from sandstone and carbonate reservoirs associated with large anticlines around the margins of the basin (**Figure 10**). Most of these structures are related to reverse or thrust faults. Eight fields in the basin (Elk Basin, Oregon Basin, Hamilton Dome, Frannie, Grass Creek, Little Buffalo Basin, Byron, and Garland) (**Figure 9**) have each produced a minimum of 100 million barrels of oil. Seven of these fields were discovered between 1906 and 1918. Elk Basin, which extends into Montana, is the largest field in terms of past production. The Wyoming portion of the field has produced nearly 450 million barrels of oil and 360 billion cubic feet of gas (Wyoming Oil and Gas

Conservation Commission, 1995). Most oil production in the basin has come from reservoirs in the Paleozoic Phosphoria Formation, Tensleep Sandstone, and Madison Limestone. Most gas production is associated or dissolved with the oil production, but some Cretaceous reservoirs produce some nonassociated gas.

The structural traps in the Bighorn Basin are often enhanced by porosity and permeability changes in the reservoirs. Many reservoirs have tilted gas/water or oil/water contacts due to hydrodynamic flow from structurally higher exposures of the reservoir rock on the basin margins. In addition to the structural accumulations of oil, Cottonwood Creek Field was drilled on the basis of a carbonate stratigraphic play (Pedry, 1975). Cottonwood Creek was discovered in 1953 and has produced nearly 60 million barrels of oil and 45 billion cubic feet of gas. The Phosphoria Formation is the likely source for most of the oil that has been produced in the Bighorn Basin.

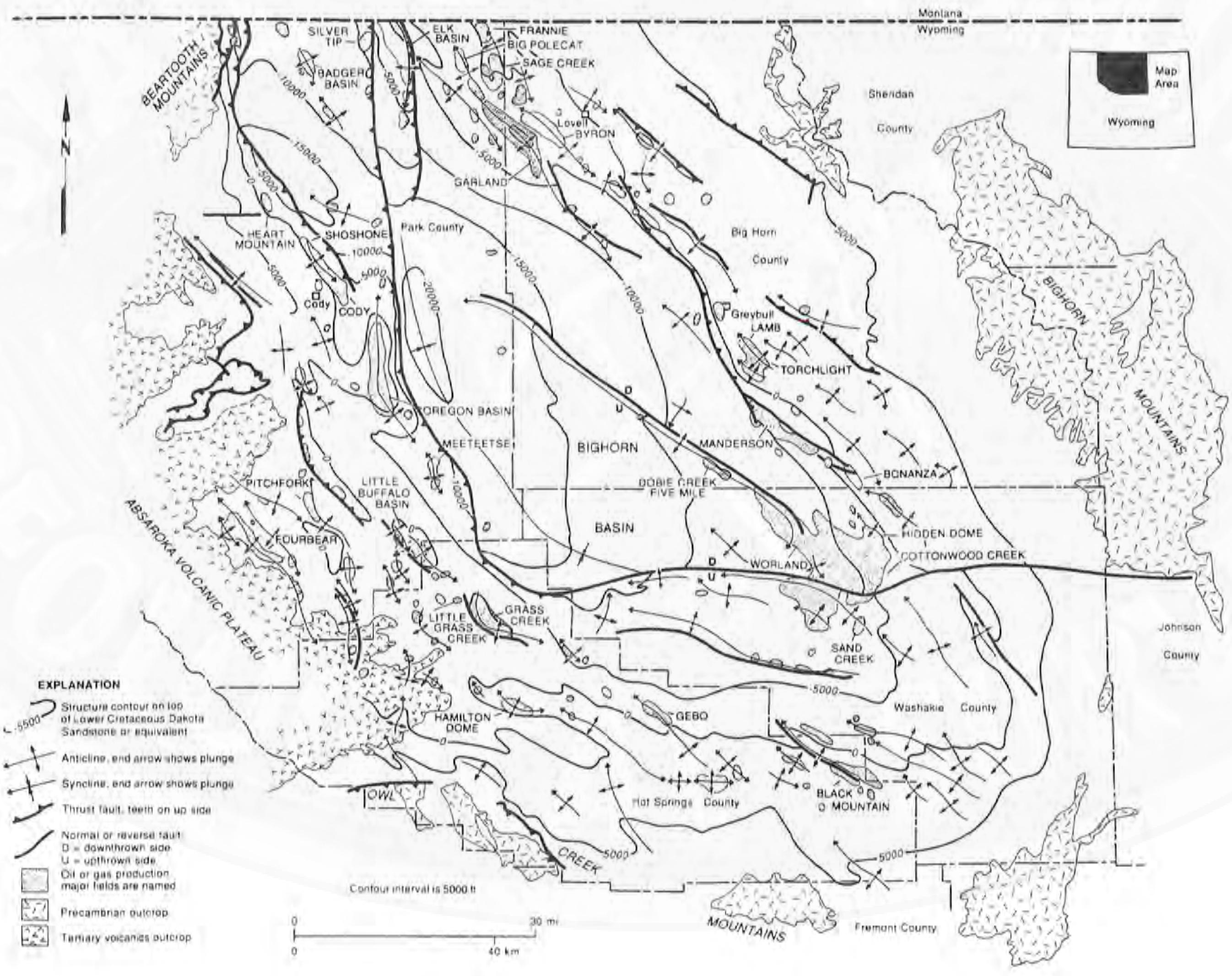


Figure 9. Structure map of the Bighorn Basin contoured on top of the Lower Cretaceous Dakota Sandstone (or equivalents) showing major structural and tectonic features. Adapted from Mullen and Barlow and Haun, Inc., 1993.

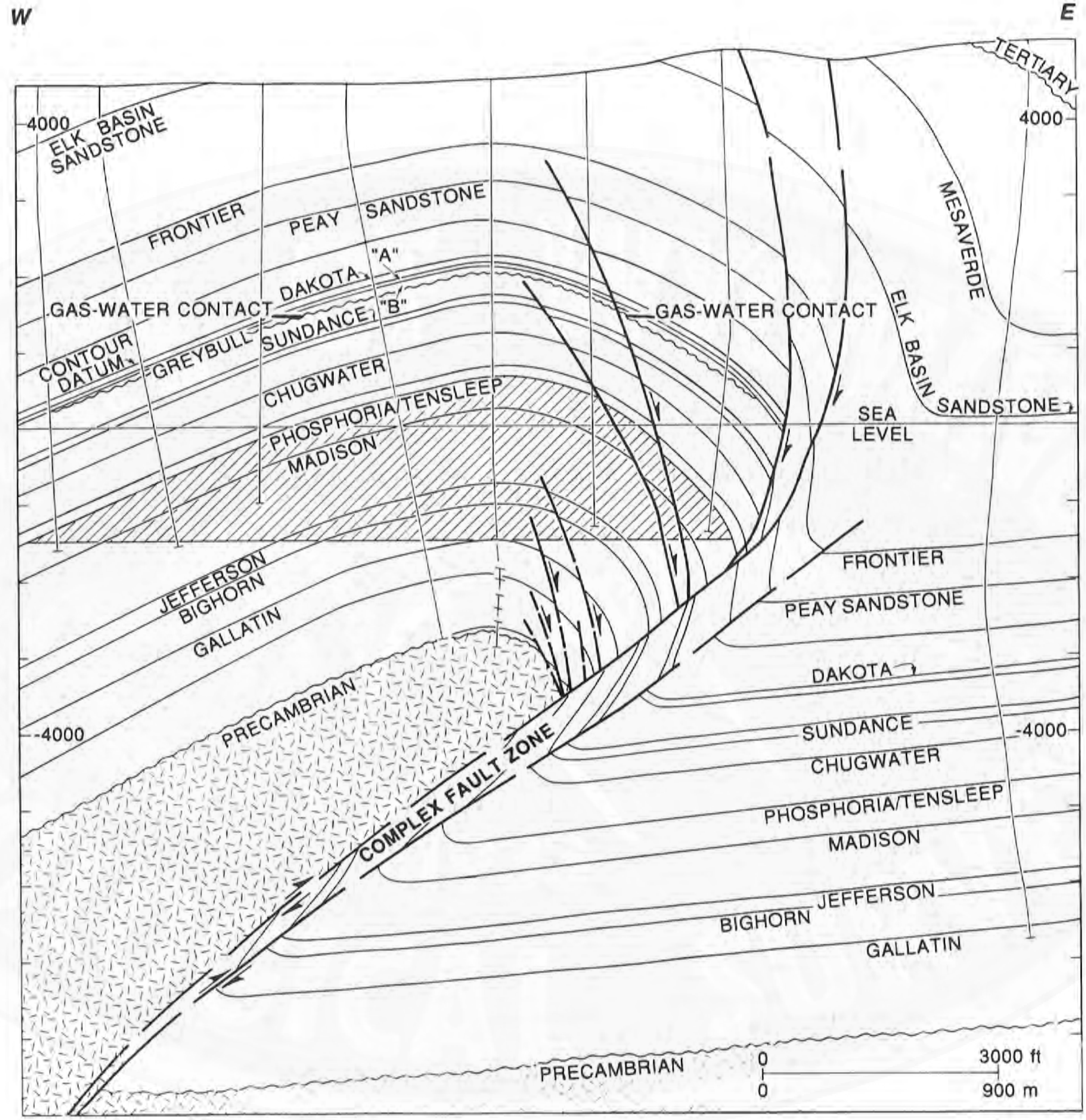


Figure 10. West to east cross section through Elk Basin field. This is a good example of the type of structure in many fields in the Bighorn Basin where oil and gas are trapped in anticlines. Hatchured area is a Paleozoic common-pool oil accumulation that also contains associated gas. There is also a shallower, Cretaceous nonassociated gas reservoir shown (adapted from Stone, 1983).

Gold and copper resources of the northwestern Bighorn Basin

by W. Dan Hausel

Some significant copper-silver-gold mineralization has been recognized in the Sunlight district in the northeastern Absaroka Mountains. Nearby, placer gold is found along the Clarks Fork River, and some placer and paleoplacer gold occurs in modern streams and Tertiary conglomeratic units near Heart Mountain along the western margin of the Bighorn Basin.

Clarks Fork gold placers

Gold placers have been known in the Clarks Fork of the Yellowstone River for many decades. Available reports indicate some of these pacers were dredged for gold in the 1930s. A small amount of gold was mined from the Dietrick placer on the Clarks Fork in 1931, and some additional gold was recovered from the Clarks Fork placers in 1933 (Hausel, 1989). Placer gold was also reported in Crandall Creek (which drains into the Clarks Fork River) along the edge of the Beartooth and Absaroka Mountains (Avon Brock, personal communication, 1986). The source of gold is unknown, although the precious metal was possibly derived from veins of disseminated deposits within the Absaroka volcanics.

Sand Coulee gold placer

East of the Absaroka Mountains, placer gold is found in stream sediments and gravels in the Sand Coulee drainage northeast of Heart Mountain. The gold occurs as fine flakes and pinpoint-size specs (Jerry Ward, personal communication, 1987).

The source of the Sand Coulee gold is probably from early Tertiary conglomerates found in the area. The Big Sand Coulee drains across the Willwood (Eocene) and Fort Union (Paleocene) Formations which consist of claystones, shales, sandstones, and conglomerates. Both formations have auriferous conglomeratic lenses (Antweiler and Love, 1967: Love and Christiansen, 1985).

Sunlight Basin copper-silver porphyry

The Absaroka volcanic plateau along the margin of the Bighorn Basin hosts several mineralized intrusive complexes (Hausel, 1982). These complexes exhibit stockwork, disseminated, and vein mineralization and hydrothermal alteration mineral assemblages characteristic of porphyry copper deposits mined elsewhere in the world, which typically contain very large, low-grade metal resources.

One of these complexes occurs in the Sunlight district in the Sunlight Basin. The district has yielded significant and widespread copper-gold-silver-zinc-lead anomalies, as well as a minor amount of gold-copper-silver ore that was mined in 1903 (Bergendahl, 1975).

Industrial minerals and uranium along the Chief Joseph Scenic Highway

by Ray E. Harris

Significant amounts of white bedded gypsum occur adjacent to the Dead Indian Hill segment of the highway in the Gypsum Spring Formation and to a lesser degree in the underlying upper Chugwater Formation. The limestones in the Madison Limestone in the area are chemical grade (>95% calcium carbonate).

Uranium occurrences and radioactivity anomalies are present at the unconformable contact of Precambrian rocks and the Cambrian Flathead Sandstone along Sunlight Creek near where the highway crosses the creek (Harris, 1983). There are also scattered thorium-rich fossil placer deposits in the Cambrian Flathead Sandstone in the same area.

Cultural history

The natural resources (animals, rocks, vegetation, and water) of the Shoshone National Forest and surrounding areas attracted Native Americans, fur trappers, miners, and homesteaders. Archaeologists have found sites of human occupation in the region along Dead Indian Creek and in Sunlight Basin. The Dead Indian Creek site was occupied by people of the McKean culture, approximately 4400 to 3800 y.b.p. (Frison, 1978). From 8000 to 4000 y.b.p., a drier climate (the Altithermal) forced Native Americans to utilize the mountainous areas more than the basins (Reider, 1990). These McKean people camped here during the winter and hunted mule deer and mountain sheep. Later (approximately 1500 to 500 y.b.p.), Native Americans camped and hunted at the Dead Indian site and another site (the Bugas-Holding site) in Sunlight Basin (Frison, 1978; Huckleberry, 1985).

Other sites documenting Native American use and movement in northwestern Wyoming occur along the North Fork of the Shoshone River (Mummy Cave), in the Pryor Mountains, in Yellowstone National Park, and in the Bighorn Basin (Horner, Hanson, and Colby sites). The Mummy Cave (9230-7970 y.b.p.), Horner (approximately 9000-8000 y.b.p.), Hanson (approximately 10,000 y.b.p.), and Colby (11,500-11,000 y.b.p.) sites document Native American usage of the region during a climate that was changing from a moist late Pleistocene climate to the drier climate of the Altithermal (Frison, 1978; Reider, 1990). The Colby mammoth site documents Native American hunting of extinct fauna such as *Bison* (bison), *Mammuthus columbi* (mammoths), *Camelops* (American camel), and *Equus* (extinct Mexican ass), and still surviving species such as *Lepus linnaeus* (rabbit) and *Antilocapra americana* (pronghorn) by people of the Clovis culture (Frison, 1986).

Since prehistoric times, the Clarks Fork of the Yellowstone River has been an east-west travel route. Before the Native Americans acquired horses, humans may have found their way on foot down the Clarks Fork Canyon. But with the advent of horses, changes in lifestyle, and more goods to transport, the canyon route was impassable.

The Dead Indian Hill route may have been in use as early as 1700 A.D. The Bannock, Nez Perce and Shoshone tribes were among those who traveled the trail to reach buffalo hunting grounds and to trade with the plains tribes. When the first trappers, traders, and prospectors arrived, they found the trail well established. Mountain man John Colter traveled through the Clarks Fork area in 1807 after leaving the Lewis and Clark Expedition. Colter was the first white man to report the thermal features of what is now Yellowstone National Park. Trappers frequented the Clarks Fork country, Sunlight Basin, and Crandall areas. Early-day journals and other sources indicate there was abundant wildlife in the area including wolves, grizzly bears, elk, bighorn sheep and a variety of smaller animals.

In 1869, gold was discovered along the upper Clarks Fork River and a mining camp (later to become Cooke City) was established. At times, miners used a trail from the Bighorn Basin, over Dead Indian Pass, and up the Clarks Fork River. Settlers usually traded in Cooke City or Livingston, Montana. In 1884, the first ranch was established in Sunlight Basin. In the 1890s, Mormon communities in the Bighorn Basin competed with the Montana communities for trade with the settlers. A route from the Bighorn Basin over Dead Indian Hill became used for trade.

The Beartooth Expedition of 1882, led by General Phillip H. Sheridan, accomplished the first organized crossing of the Beartooth Plateau. Two earlier U.S. Army detachments tried to cross the Beartooths. Captain W.P. Clark's reconnaissance group of 1878 and the Montana-Wyoming boundary survey party of 1880 were both unsuccessful. Sheridan's expedition party left from Green River, Wyoming, and traveled through Yellowstone National Park, Cooke City, Montana, and proceeded down the banks of the upper Clarks Fork River. The party camped on the river beneath Pilot and Index peaks before ascending the southwestern flanks of the Beartooths, camping below Beartooth Butte, and descending down a narrow divide between Rock Creek and Line Creek. The expedition ended in Billings, Montana, where the members boarded a train for Chicago. After the expedition, Sheridan recommended that Yellowstone National Park be extended 40 miles east and 10 miles south to take in the Beartooth Mountains. Although the Park was not extended, Sheridan's proposal led to the establishment of forest reserves that included the Beartooth Mountains nine years later.

In 1887, Chief Joseph led his band of Nez Perce over what is now the Nez Perce National Historic (Nee-Me-Poo) Trail as they were pursued by General O.O. Howard and the U.S. Cavalry. The Nez Perce were trying to reach safety in Canada, the "Grandmother Country," to avoid being forced onto a reservation. They were stopped short of the Canadian border by Colonel Nelson Miles and his cavalry.

There are different accounts about how Dead Indian Hill got its name. One account is that when Chief Joseph's band was fleeing the cavalry, an old warrior died and they perched his body on top of the hill to make it look like he was a scout. This deceived the cavalry into thinking the Nez Perce had taken that higher route when they had actually taken a lower route. Archaeologists and historians are still debating this, however.

Some believe that a more plausible account for naming Dead Indian Hill happened a year later when the Bannock Indians also were fleeing the U.S. Cavalry. According to this account, near present day Clark, Wyoming, just after the Battle of the Big Hole, in Montana, Crow scouts working for the Cavalry captured a wounded Bannock warrior and tortured him to death on top of Dead Indian Hill.

The Shoshone National Forest, America's first national forest

On March 30, 1891, President Benjamin Harrison created the Yellowstone Park Timberland Reserve that comprised much of what is now the Shoshone National Forest. This first forest reserve, the beginnings of the National Forest System, was an attempt to protect timberlands from destruction and abuse by variety of parties, including early-day sheep men who were burning tracts of timber to create more grazing areas.

Today the Shoshone National Forest has some 2.4 million acres. More than half of the forest, nearly 1.4 million acres, is designated wilderness in all or parts of five different wilderness areas. It also includes parts of the Absaroka, Beartooth and Wind River mountain ranges. Flowing through the spectacular Clarks Fork Canyon is the Clarks Fork River, Wyoming's only wild and scenic river. Elevations in the forest range from 4600 feet at the mouth of Clarks Fork Canyon to 13,804 feet on Gannett Peak, Wyoming's highest point, in the Wind River Range.

Areas of interest

These brief descriptions summarize some of the more interesting geologic and natural features in the area. Most of the descriptions have been adapted or modified from Wilson (1963). Refer to **Figures 1** and 2 for locations of these Areas of Interest (AIs).

1. Beartooth Plateau.

The Beartooth Plateau (**Frontispiece**, page 34, and **Segment 4**, pages 53-54) is a high, rolling erosional surface that exposes mainly Precambrian granites and metamorphic rocks and a few remnants of lower Paleozoic rocks. Many Pleistocene glacial cirques and U-shaped valleys occur here, and these are often occupied by lakes and perennial snow and ice fields.

2. Sawtooth fen-palsa.

(Written by Hollis Marriott, Wyoming Nature Conservancy.) On the Beartooth Plateau below Sawtooth Mountain lies an unusual bog, the Sawtooth Fen-Palsa. This is a peat bog containing relic permafrost. The frozen soil most likely formed during the colder times of the last glacial episode. The overlying peat layer provided enough insulation to keep the ice from thawing as the climate warmed during post-Pleistocene times.

The term "fen-palsa" refers to the two major zones found in the bog. The interior of the bog consists of a raised zone of peat underlain with permafrost–a palsa.

Ice occurs at depths of 15 to 18 inches. There is very little vegetation on the palsa, aside from moss hummocks and scattered grasses. Thermokarst features are well-developed, including crack polygons and depression pools formed by repeated freezing and thawing. In some areas, the frost cracks have filled with soil (wind deposited?) and are vegetated with grass, making the polygonal patterns quite striking.

Surrounding the palsa is a fen–a nutrient-poor wetland–that is dominated by sedges (grass-like plants). Farther out from the palsa, the fen gives way to wet meadow. This type of wetlands complex is very common in northern Canada, but rare to the south. The Sawtooth bog is the only fen-palsa known from the contiguous United States.

3. Beartooth and Clay Buttes.

These buttes are remnants of lower Paleozoic sedimentary rocks resting on Precambrian rocks. The oldest known land fossils as well as ancient fish remains occur in the Early Devonian age Beartooth Butte Formation at Beartooth Butte. Clay Butte has a fire lookout station operated by the U.S. Forest Service. A spectacular view of the surrounding area can be seen from the top of Clay Butte via a relatively accessible gravel road.

4. Pilot and Index Peaks

Pilot Peak (11,708 feet) to the south is a sharp glaciated horn (see **Segment 4**, page 64) that has been eroded from the flat-lying flows of the Trout Peak Trachyandesite. Index Peak (11,319 feet) to the north is composed of the Wapiti Formation. Pilot Peak was first climbed in 1939.

5. Cooke City (New World) mining district.

This district became active in the early 1870s, and some mining activities have continued intermittently until the present time. The mineralization is composed of iron-copper-gold veins and lead-silver veins. Although most of the mineralization occurs in the Gallatin National Forest of Montana, some of the lead-silver mines (particularly on Republic Mountain) extend into the Shoshone National Forest in Wyoming. Plans for a large gold mine in this area were recently abandoned, however, because of its proximity to Yellowstone National Park and the Clarks Fork Wild and Scenic River.

6. Hunter Peak area.

Southeastward from its junction with the Beartooth Highway (U.S. 212), the Chief Joseph Scenic Highway (Wyoming 296) for the next seven miles follows along the side of the Clarks Fork valley, just below the Cambrian Pilgrim Limestone. Precambrian granite gneisses are exposed in Clarks Fork canyon and on the north side of the valley. The Pilgrim crops out as a continuous shelf along the south side of the valley. The dark brown-colored Wapiti Formation unconformably overlies the Paleozoic formations. Since the Wapiti Formation may lie on rocks as stratigraphically high as the Mississippian Madison Limestone or may lie on rocks as stratigraphically low as the Cambrian Pilgrim Limestone, the pre-volcanic relief (erosional surface) on which the Wapiti was deposited was about 1500 feet.

Hunter Peak is composed of the Bighorn, Three Forks, Jefferson, and Madison Formations that lie on the Heart Mountain detachment fault. The trace of this fault extends from just south of the Northeast Entrance to Yellowstone National Park (southwest of Silver Gate, Montana) through the Clarks Fork-Dead Indian Hill area to Heart Mountain, an airline distance of approximately 50 miles.

7. Hurricane Mesa.

Hurricane Mesa is a high, dissected plateau-like surface, that is underlain chiefly by the volcanic rocks of the Wapiti Formation. Emplaced in the center of the Mesa is a large ring dike complex of augite trachyandesite surrounding a central plug of diorite and norite (Pierce and others, 1973). This circular volcanic feature undoubtedly represents one of the source areas of the Wapiti Formation.

8. Cathedral Cliffs.

Cathedral Cliffs are precipitous north-facing cliffs that rise 2500 feet above the valley floor. The lower part of the cliffs is composed of light-colored sedimentary rocks of Cambrian, Ordovician, Devonian, and Mississippian ages. Irregularly overlying the Mississippian Madison Limestone is the Eocene volcanic Cathedral Cliffs Formation which, in turn, is unconformably overlain by the dark-colored Wapiti Formation. The Cathedral Cliffs Formation is overlain by a light-colored block of Madison Limestone which is a remnant of the Reef Creek detachment fault. The Heart Mountain fault, which is a bedding plane fault here, cuts the lower Paleozoic rocks at the base of the cliffs. The dark vertical lines in the Madison Limestone are dikes of igneous rock.

9. Swamp Lake.

(Written by Hollis Marriott, Wyoming Nature Conservancy.) Swamp Lake, also known as the Cathedral Cliffs Wetlands Complex, has been designated a Special Botanical Area in Shoshone National Forest. It contains a unique assemblage of plant species, several of which are found nowhere else in the contiguous United States. Most of these species have boreal (northern) affinities, and are thought to be relics from the Pleistocene. They are plants of colder climates that have persisted in this refugium for over 10,000 years.

Swamp Lake lies near the base of the Cathedral Cliffs visible to the south (See **Segment 4**, page 63). Extensive upwelling of groundwater occurs here, forming wetlands underlain by impervious Precambrian granitic rocks. The lake itself is about 10 acres in size, with an additional 700 acres of wetlands vegetation surrounding it. Water is supplied mainly by calcareous springs (pH 8.0-8.4), as well as by rainfall and several small streams. The wetlands are alkaline, and contain extensive marl deposits (calcareous clay).

Spruce forest borders Swamp Lake on the lower slopes below the Cathedral Cliffs. These stands are dominated by white spruce (*Picea glauca*), a boreal tree with limited distribution in Wyoming. The understory includes six plant species that are regionally rare, but occur here in abundance. The myrtle-leaf willow (*Salix myrtillifolia*) and the boreal bearberry (*Arctous rubrus*) are common in Canada but occur nowhere else in the lower 48 states.

Moving down into the wetlands, the spruce forest gives way to sedge-shrub fen (a fen is a nutrient-poor wetland). Several plant species rare in Wyoming are found here. Particularly curious is the presence of creeping juniper (*Juniperus horizontalis*) on the hummocks in this zone. Though not at all rare in Wyoming, this juniper is almost always found on dry upland sites in the State. However, in the sub-arctic it does typically occur in fens.

Inside the sedge-shrub fen vegetation zone is an area of marl flats and open water–perhaps the most unusual habitat in the wetlands. The floating, saturated marl deposits are vegetated predominantly with members of the sedge family (grass-like plants). Several of the plants found on these mats occur nowhere else in Wyoming. At least eight other plants are considered regionally rare.

10. Sugarloaf Mountain.

Sugarloaf Mountain is another exposure of the Heart Mountain detachment fault. Here, steeply dipping Bighorn Dolomite of Ordovician age rests on the flat-lying Pilgrim Limestone.

11. Dillworth fault zone.

On the north side of the Clarks Fork valley, the Precambrian rocks of the Beartooth Mountains have been elevated between 2000 to 3000 feet along the Dillworth fault zone. Several U-shaped glacial valleys have been eroded into the Precambrian rocks.

12. Antelope Mesa.

Antelope Mesa is a flat table-like butte which is capped by the Pilgrim Limestone. From Antelope Mesa to Dead Indian Creek, the Chief Joseph Scenic Highway is on Cambrian rocks. Both the Meagher and Pilgrim Limestones form prominent ledges, while above these are the "disturbed" Ordovician, Devonian, and Mississippian rocks that are involved in the Heart

Mountain detachment fault. Between Russell and Dead Indian Creeks, there are several small uranium deposits in the Cambrian Flathead Sandstone.

13. Dead Indian Hill.

From Dead Indian Creek to the top of Dead Indian Hill, the highway switchbacks cross sedimentary rocks ranging in age from Cambrian (570-500 Ma) to Pennsylvanian (330-290 Ma). The top of the hill is capped by the Pennsylvanian Tensleep Sandstone. From the top of Dead Indian Hill eastward to the Shoshone National Forest boundary, the highway progressively crosses the massive Pennsylvanian Tensleep Sandstone, limestones of the Permian (approximately 300-245 Ma) Phosphoria Formation, and red beds of the Triassic Chugwater Formation. The long dip slope east of the Forest boundary is underlain by the Phosphoria Formation.

Westward from Dead Indian Hill (see the panorama, **Segment 4**, pages 53-54) is one of the most spectacular scenic and geologic views that can be seen in any national forest. From here, one can observe Precambrian crystalline rocks from the Beartooth Plateau to Dead Indian Creek. On the south side of Clarks Fork Canyon, the Precambrian rocks are overlain by flat-lying and undeformed as well as highly faulted Paleozoic rocks. In the Sunlight Basin area, these rocks are unconformably overlain by the dark-colored volcanic rocks of the Wapiti Formation, which, in turn, have been intruded by numerous igneous dikes and plugs. The Sunlight glacier below Sunlight Peak can be seen in the distance.

14. Bald Ridge.

(Written by Hollis Marriott, Wyoming Nature Conservancy.) Bald Ridge extends south-southwest approximately six miles from Bald Peak, and forms the south wall of Clarks Fork Canyon (see oblique air photographs on the **Endpiece,** page 37, and **Frontispiece**, page 38) on the edge of the Beartooth Plateau and Absaroka Mountains. Most of the crest of the ridge is underlain by Madison Limestone, providing a large zone of habitat for at least seven plant species restricted to or found mainly on calcareous sites.

Among the species is the sweet-flowered rock-jasmine (***Androsace chamaejasme*** **ssp.** ***carinata***). This plant is widespread in northern Asia, northwest Canada and Alaska, but in the lower 48 states, it is restricted to a few widely separated locations. The other species of interest on Bald Ridge are regional to narrow endemics–species found only within a limited geographic area. Several are endemic to limestone habitat in the northern Rockies. The rarest species are the ***Shoshonea*** **(*Shoshone pulvinata*)** and the Absaroka goldenweed (***Pyrrocoma carthamoides*** var. ***subsquarrosus***). Both are endemic to northwestern Wyoming and adjacent southern Montana.

15. Sunlight Basin.

A mile-long, rather smooth terminal glacial moraine fills Sunlight Basin between White Mountain and the mouth of Elk Creek. The moraine dammed Sunlight Creek and the resultant lake formed the present flat-bottomed Sunlight Basin. This lake was short-lived, since no shoreline terrace remnants are present. Some of the pebbles in the moraine are of Precambrian rock fragments. It is likely that this moraine was deposited by a glacier moving upstream from the Clarks Fork valley since no Precambrian rocks crop out farther up Sunlight Creek.

16. White Mountain.

White Mountain, on the north side of, and at the lower east end of Sunlight Basin, was once thought to be a volcanic neck (brown-colored) that had intruded the light-colored upper Paleozoic limestones (Parsons, 1939a). Geologists now believe that White Mountain was moved to its present location by the Heart Mountain detachment fault and is not a volcanic neck (Nelson and others, 1972; Nelson, 1986). The numerous irregular dikes and spires of White Mountain are the Cathedral Cliffs Formation, one of the earliest Absaroka volcanic units. The heat from the Cathedral Cliffs lava flow caused adjacent limestone to be changed into marble, but probably before the limestones were emplaced by the Heart Mountain detachment fault.

17. Windy Mountain.

Windy Mountain is a major breccia-filled volcanic vent which has been intruded by a swarm of parallel dikes that are oriented in a north-south direction.

18. Sulfur deposits.

Several surficial sulfur deposits occur near Sulfur Camp along Sunlight Creek. Sulfur Camp is about 7 miles southwest of Sunlight Ranger Station on the road up Sunlight Creek. The two largest deposits occur on the slope northwest of Sulfur Camp and Sulfur Lake. Four other deposits, which can be seen from the road, occur on the southeastern side of Sunlight Creek. The sulfur cements surficial debris and also encrusts fractures in bleached volcanic rocks of the Wapiti Formation. The largest deposit is slightly more than two acres in size; however, most of the deposits are far less than one-half acre in size. These deposits have been known for more than 60 years and various attempts have been made to exploit them.

19. Sunlight mineralized area.

The mineralization in Sunlight occurs in the glacial cirque basins and on the ridges at the headwaters of various branches of Sunlight and Sulphur Creeks and the North Fork of the Shoshone River. These deposits are associated with an intrusive and volcanic center which consists of a small igneous stock, several plugs, hundreds of radially arranged dikes, and a few cone sheets; all intruding the Wapiti Formation. Iron, copper, lead, gold, and silver minerals occur in small irregular veins in fault zones and along dike contacts in the volcanic rocks. The mineralization was first discovered in about 1893, and numerous attempts (without success) have been made since then to develop the deposits. There are a number of underground workings in the area, but most of these are considered unsafe for entry. The total production of ore from this area probably did not exceed 40 tons.

20. Sunlight Glacier.

The Sunlight Glacier is one of a few small glaciers that exist today in the Sunlight area. It is about a mile long and about one-half mile wide and lies at the foot of Sunlight Peak in a large composite cirque basin at the head of Sulphur Creek. The other three or four glaciers in the area are small cliff glaciers plastered on the walls of northeast-facing cirques. These glaciers are remnants of the last glaciation in the Sunlight area and were responsible for the final sculpturing of the high mountain topography that can be seen today.

21. Heart Mountain.

In the Bighorn Basin north of Cody, Heart Mountain is capped by Paleozoic limestones (approximately 500-320 Ma) overlying the much younger Eocene rocks (approximately 60-50 Ma) of the Willwood Formation. This unique mountain and geological puzzle is the topographic feature for which an unusual, nearly horizontal fault, the Heart Mountain detachment fault, is named. (See the separate section on this unique geologic feature, pages 11-12.)

During World War II, the United States government decided that the security of the Pacific Coast was dependent on the transfer of Japanese to inland areas. One of ten relocation centers in the U.S. was established about 7 miles east of Heart Mountain in the Shoshone River valley. The Heart Mountain center had a population of over 10,000 in October, 1942, and still had over 8000 residents in February, 1945.

22. Rattlesnake anticline.

This structure includes the canyon of the Shoshone River, which cuts obliquely across the structure and separates Rattlesnake Mountain on the north from Cedar Mountain on the south. Blackstone (1986) stated:

> *certain areas in the foreland attract geologists like bars attract bar flies. Rattlesnake Mountain is such a place because of the excellent cross-section exposed in the Shoshone River Canyon . . .*

The structure is a northwest-southeast trending asymmetrical anticline consisting of gently-dipping (10-12°) strata on the northeast limb and steeply dipping to overturned strata on the southwest limb. The anticline is controlled by an 80°W-dipping normal fault (exposed in the core of the anticline) which parallels the west flank of the structure and by several northwest-trending, east-dipping faults of relatively small displacement on the crest of the fold (Anonymous, 1974; Blackstone, 1986).

The major fault, which offsets Precambrian basement rocks, deforms the rocks by cataclasis (deformation by fracture and rotation of mineral grains or aggregates) in a narrow shear zone (30 feet thick) in an area of pre-existing basement weakness. The sedimentary rocks stratigraphically nearest the basement fault (especially the Cambrian section) are highly extended and rotated while the sedimentary rocks higher up in the section (Ordovician through Pennsylvanian) are shortened by thrusting and/or folding (Erslev, 1990). In this area, crustal shortening is accomplished by movement of faults that offset the Precambrian basement. These faults are propagated upward into the sedimentary section with accompanying folding (Blackstone, 1986).

23. Buffalo Bill Dam and Reservoir.

This dam was built into Precambrian rocks exposed in the core of Rattlesnake Mountain in Shoshone River Canyon. Completed in 1910 as the world's highest (325 feet) and one of the world's first concrete, large-arch dams, this structure is on the National Register of Historic Places as well as a National Historic Civil Engineering Landmark. Modifications of the dam to increase water storage by raising the level of the dam 25 feet were completed in 1993 through a cooperative effort of the Federal government and the State of Wyoming. The enlarged Buffalo Bill Reservoir now is capable of holding 646, 563 acre-feet of water, which is used to irrigate over 93,000 acres of farmland in the northern Bighorn Basin. The reservoir also furnishes drinking water and industrial water for downstream users as well as power generation and recreational opportunities.

Part II. Road logs for the Cody-Sunlight Basin-Clarks Fork Canyon area, northwestern Wyoming

Introduction

This section contains primarily geologic (with some pertinent historical information) road logs for several major highways in the Cody area, including the now completed Chief Joseph Scenic Highway north of Cody. We have divided this into five logged segments (**Figure 11**) which can be used by travelers going in either direction on the route. We have tried to avoid using left and right as well as clock directions (e.g., ahead at 10:00 o'clock) and instead have specified an approximate compass direction. Recommended stops are placed throughout the guide, as are some of the points of interest discussed in Part I. Because this guide provides flexibility in the number of stops that one can take, we have not estimated travel times for the segments.

We have freely used information contained in many previous road logs and field guides, and would like to acknowledge the work of all these previous authors. Work we have used directly is cited in the text and listed in the references at the end of this part. We especially thank the Wyoming Geological Association for granting us permission to use and modify parts of a number of their road logs.

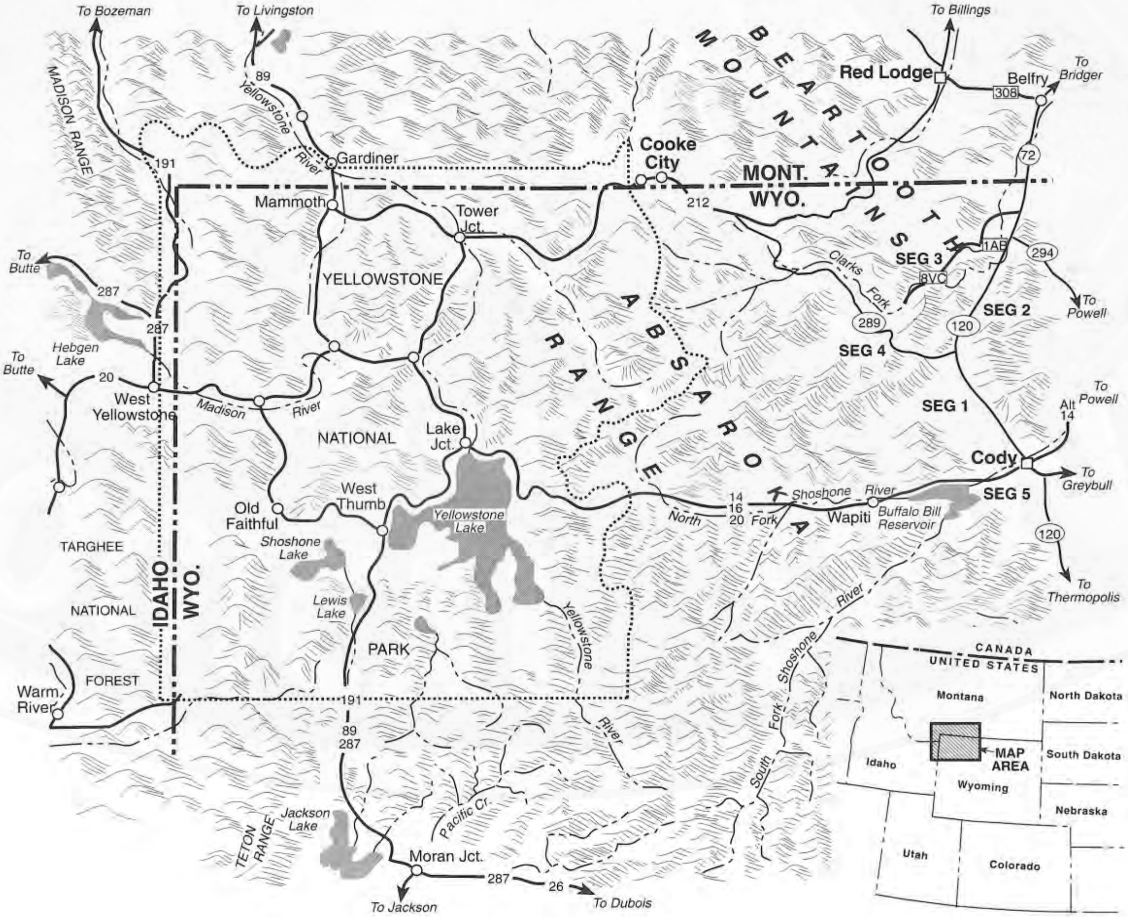


Figure 11. General location map of Chief Joseph Scenic Highway and surrounding area showing major geographic features, highways, and location of road log segments (Segment 1 - Segment 5).

Frontispiece. Air oblique view from Dead Indian Hill eastward across the Bighorn Basin. Bighorn Mountains on horizon, Heart Mountain near skyline to right of center; Road log Segments 1 and 2 traverse from right to left (south to north) between Dead Indian Hill and Heart Mountain. Note the scars from four generations of the Dead Indian Hill road (1870s, 1910s, 1930s, and 1950s). For details, see panorama on pages 53 and 54 and **Areas of Interest** (pages 22-27). (July, 1971 photograph by Wyoming Department of Transportation, Photogrammetry and Survey Program.)

Road Log Segment 1:
Cody to Chief Joseph Scenic Highway turnoff
(State Highway 120 to junction of State Highway 296)

Mileage

Cumulative from Cody	Increment	Cumulative from Hgwy 296
0.0		17.5

Parking lot at Holiday Inn, Cody, Wyoming. Proceed west one block on U.S. Highway 14 to Wyoming 120 intersection and turn north. This part of Cody is built on the Cody Terrace, 160 feet above the Shoshone River, which correlates with Pinedale-age glaciation (Moss and Bonini, 1961).

0.5 0.5 17.0

Junction Wyoming 120 and U.S. Highway 14A; turn left on Wyoming 120, known to locals as the Cody-Belfry Highway.

0.8 0.3 16.7

Now traveling on the Lower Cody terrace, about 100 feet above stream level.

0.9 0.1 16.6

Bridge over Shoshone River. Cody Shale Frontier Formation contact crosses river ¼-mile upstream. The Cody Shale and Frontier Formation are 2,000 and 475 feet thick, respectively. Celotex Corporation's gypsum plant and the abandoned Husky Oil Refinery are located downstream on north bank. This bridge was completed in 1992 and is 496 feet long and 66 feet above the river. The abutments are on experimental footings in a gravel fill (footing pressure is 1.6 tons per square foot) and are instrumented with tiltmeters and survey points for future measurements. The bridge cost $1,991,805 and replaced a bridge built in 1947.

1.5 0.6 16.0

Traveling on Cody terrace.

1.9 0.4 15.6

Traveling on Powell terrace. In this vicinity the Powell terrace averages about 290 feet above the Shoshone River. The Powell terrace correlates with the late Bull Lake Glaciation (Moss and Bonini, 1961).

3.2 1.3 14.3

Crossing Heart Mountain Canal. This is a major conduit for irrigation water in the Shoshone Reclamation District.

4.4 1.2 13.1

Good view of Heart Mountain to the northeast (**Figure 12** and **AI-21**).

4.8 0.4 12.7

Road drops down onto alluvium of Cottonwood Creek. Ridge east of Cottonwood Creek is the Cretaceous Mowry Shale. Disturbed material on the ridge is where bentonite was mined in the past.

5.6 0.8 11.9

Bridge over Cottonwood Creek.

5.7 0.1 11.8

To the west is the east flank of Cottonwood anticline. Cottonwood anticline has no oil and gas production. The deepest hole topped Madison Limestone at 2315 feet and was a dry hole. A small fault mapped here (Pierce, 1966) is shown as having right-lateral strike-slip displacement. Variegated shales, in road cut and in the sandstone ridge immediately east of the highway, are in the Jurassic Morrison and Lower Cretaceous Cloverly formations. A narrow bed of kaolinitic potter's clay occurs in these rocks on the east side of the ridge.

6.7 1.0 10.8

Recommended picture stop in afternoon. Has good lighting for view of Heart Mountain to east.

6.9 0.2 10.6

Bridge. Indian artifacts and buffalo skulls have been

Figure 12. Heart Mountain as viewed from the south near Cody. Blocks of Paleozoic limestones and dolomites rest upon a detachment plane on Eocene Willwood Formation (Twi) mudstones and siltstones. Formation symbols are: Ob, Bighorn; MDtj, Three Forks/Jefferson; Mm, Madison; Kc, Cody; and Kmv, Mesaverde. (Photograph by D.D., 1996).

Mileage

Cumulative from Cody   Increment   Cumulative from Hgwy 296

found on and in the Cottonwood Creek alluvium in this area.

7.9   1.0   9.6

Buildings east of highway were once part of a fish hatchery operated by the Wyoming Department of Game and Fish. The fresh water springs here discharge from the Mowry Shale and sandstones in the Frontier Formation along the synclinal axis between the Cottonwood and Fish Hatchery anticlines. The Fish Hatchery anticline, east of the buildings, has no oil and gas production although several holes have been drilled on the structure.

8.4   0.5   9.1

Bridge.

8.9   0.5   8.6

Heart Mountain to the north. Looking across the north plunge of Fish Hatchery anticline. Rattlesnake Mountain access road on west side; Shoshone National Forest is 12 miles distant. Ridges to the east of the road are in the Frontier Formation.

10.3   1.4   7.2

During road construction of the next four miles, the expansive type soils and shale bedrock in the road cuts were mitigated by covering the subgrade with impermeable plastic membrane. The membrane keeps surface water from infiltrating into the subgrade.

12.1   1.8   5.4

View to north from turnout. Syncline in Mesaverde Formation and Cody Shale located west of the Heart Mountain anticline. The Heart Mountain structure has cumulative production of 49,274 million cubic feet of gas and 69,697 barrels of oil from the Frontier Formation and the Cloverly Formation as of December, 1994.

13.3   1.2   4.2

Coal mine in lower Mesaverde in small draw to northeast.

14.0   0.7   3.5

Good view of Natural Corrals to the north.

14.3   0.3   3.2

For the next 2.2 miles, the highway crosses colluvial sediments that consist of collapsing soils. Collapsing soils are silts and sands that are deposited as low-density outwash. With time these soils become lightly cemented and are then strong enough when dry to support their own weight. When saturated with water, the soils collapse and compact. Highways built on these soils change the surface hydraulics. Water seeps into the dry soils, the cement dissolves, and collapse begins. These highways take on a rolling grade line with dips up to three feet deep. Mitigation is very expensive and is usually done on high-volume roads only.

Mileage

Cumulative from Cody	Increment	Cumulative from Hgwy 296
15.0	0.7	2.5

Hill of Mesaverde to north-northeast is capped by heterogeneous colluvial deposits (Pierce, 1966), some of which have a reddish color suggestive of the variegated Eocene Willwood Formation. Traveling on Cody Shale (**Figure 13**).

15.2	0.2	2.3

Two Dot Ranch on west side of road.

17.2	2.0	0.3

The Cody-Mesaverde contact can be seen along the east side of highway. For mapping purposes the contact is at the base of the lowest massive sandstone. The transitional zone in the upper part of the Cody Shale is a classic regressive sequence of alternating sandstones and shales wherein the sandstone beds increase in thickness and frequency upward to massive sandstone, which forms the top of the high ridge.

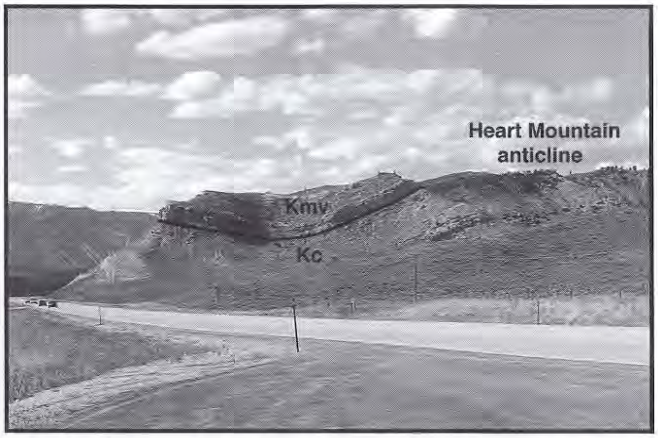
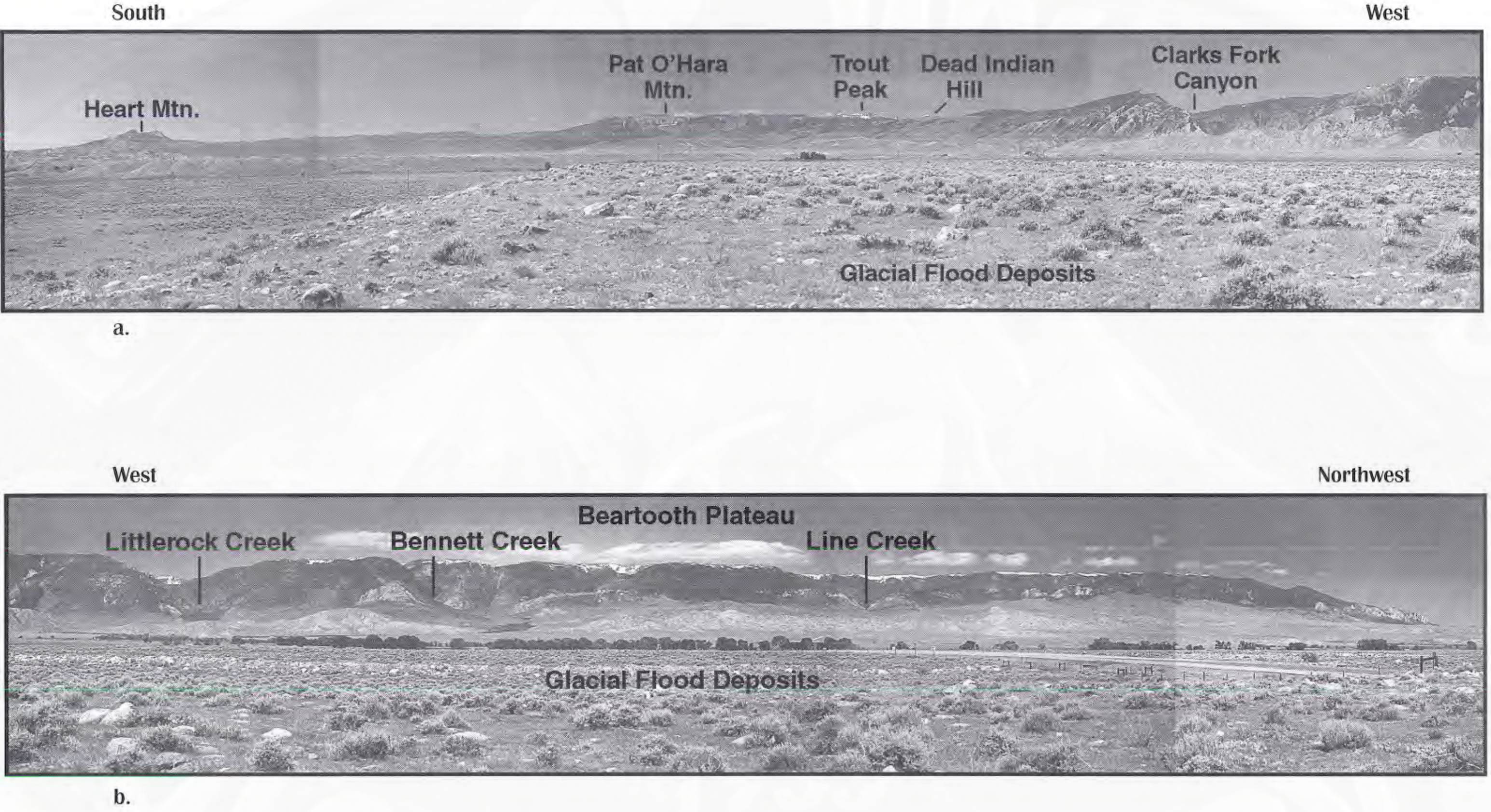


Figure 13. Small syncline in lower part of Mesaverde Formation. The Cody Shale (Kc) – Mesaverde (Kmv) contact is at the base of the lower-most sandstone visible at the base of the slope to the right. Thin coal beds in the Mesaverde Formation were once mined to the north and south of this area. (Photograph by D.D., 1996.)

17.5	0.3	0.0

End of Segment 1. Junction with Highway 296, the Chief Joseph Scenic Highway. Many people still refer to this as the Dead Indian-Sunlight Basin road.



Frontispiece. Panorama of the eastern Beartooth Mountain front and features south of Clarks Fork Canyon. Quaternary deposits such as glacial till and catastrophic flood deposits cover the ground near the mouth of Clarks Fork Canyon (upper right of photograph a). View to west from junction of State Highway 120 and Park County Road 1AB. Photograph covers field of view a) From due south on the left to west on the right and b) From west on the left to northwest on the right. (Photographs by H.P.H. and A.D., 1996)

Road Log Segment 2:
Chief Joseph Scenic Highway turnoff to Clarks Fork Canyon turnoff
(Junction State Highways 120 and 296 to junction of State Highway 120 and Park County Road 1AB)

Mileage

Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/Road 1AB
0.0		13.2

This segment begins at the junction of State Highways 120 and 296. The **Frontispiece** (page 34) shows major geographic features along the western mountain front. Proceed northward on State Highway 120. The Mesaverde Formation forms bluffs on both banks of Pat O'Hara Creek.

0.8 0.8 12.4

The Mesaverde-Meeteetse contact can be observed in a short reentrant to the east. The Meeteetse Formation is a distinctively-banded sequence of gray and white sandstones, gray and brown shales, bentonitic claystones, and thin lenticular coal beds. Uphill to the northeast the Meeteetse Formation is overlain unconformably by the Eocene Willwood Formation. To the northwest, the Willwood Formation unconformably overlies progressively older rocks, including the upper Cretaceous Meeteetse, Mesaverde, and Cody Formations. To the southeast, the Willwood overlies progressively younger rocks, including the Lance (Upper Cretaceous) and the Fort Union (Paleocene) Formations.

1.6 0.8 11.6

Variegated beds in the Willwood Formation occur along east side of highway. The Willwood Formation of mostly early Eocene age and the underlying Fort Union Formation (Paleocene age) occupy the structural and depositional Clarks Fork Basin. This northern part of the Bighorn Basin extends from approximately the Shoshone River (between Cody and Lovell, Wyoming) northward to the Nye-Bowler lineament (north of the Roscoe-Red Lodge-Belfry, Montana area). According to Gingerich and others (1980), Clarks Fork Basin contains . . . *one of the most complete stratigraphic sections spanning the Paleocene-Eocene boundary in continental sediments* . . . . Since about 1880, the Bighorn and Clarks Fork Basins have become classic, world-renowned collecting areas for vertebrate paleontologists. A number of museums have extensive vertebrate fossil collections from this area.

1.9 0.3 11.3

Traveling on Chapman Bench terrace deposits, which are approximately equivalent to the Powell terrace along the Shoshone River (Pierce, 1965a). The Willwood Formation, which crops out on both sides of this bench, occupies most of the interior of the Bighorn Basin and contains all four faunal zones of the early Eocene. These faunal zones, which comprise the Wasatchian North American Land Mammal Age (NALMA), are the (oldest) Sandcouleean (named for Sand Coulee, the intermittent drainage just east of Chapman Bench), Graybullian, Lysitean, and (the youngest) Lostcabinian. In the Clarks Fork Basin, only the two oldest faunal zones are known.

All the Paleocene NALMA's as well as the latest Cretaceous NALMA, are represented in Clarks Fork Basin. These ages are, from oldest to youngest, Lancian (latest Cretaceous), Puercan, Torrejonian, and Tiffanian. The type area for the Clarkforkian NALMA, which represents the very latest Paleocene and the very youngest Eocene, is Clarks Fork Basin (Gingerich and others, 1980). Literally hundreds of fossil vertebrate localities (representing at least 70 mammalian species in the Clarkforkian alone) are known in the Clarks Fork Basin for many of the faunal zones of a land-mammal age.

3.2 1.3 10.0

Clarks Fork Canyon to the west and Beartooth uplift to the northwest. The flat surface on top of the Precambrian rocks in the Beartooth block, which may be in part the uplifted, stripped depositional contact with

Mileage		
Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/Road 1AB

Cambrian rocks or a high level erosion surface (Mears, 1993), is known as the subsummit peneplain. Badger Basin oil field, which has produced over three million barrels of oil and over 6.4 billion cubic feet of gas mainly from the Frontier Formation, is several miles beyond the small point to the north. The Pryor Mountains are on the skyline to the northeast. In the foreground, same direction, are the Badland Hills, an area which contains numerous early Eocene vertebrates in the Willwood Formation.

5.1 1.9 8.1

Pat O'Hara Creek in left foreground. A small remnant of the Chapman terrace is to the west across the creek; just beyond this and somewhat higher is Kimball Bench, an older terrace level. A remnant of an even higher, older terrace deposit occurs 3.5 miles to the southwest. This is the oldest terrace in the area (possibly older than Quaternary) and may be correlative with the extensive Polecat Bench terrace to the east.

6.3 1.2 6.9

Good exposures of Willwood Formation in low hill to the east. The prominent tree-covered feature to the southeast is Heart Mountain.

12.7 6.4 0.5

Bridge over Clarks Fork River. Approximate contact of Fort Union and Willwood Formations is buried under alluvium here. All strata from the river bend, to the east, and for several miles downstream are Fort Union Formation. The dip is three to six degrees southwest. The maximum thickness of the Fort Union is about 11,500 feet along the western margin of Clarks Fork Basin and the maximum thickness of the Willwood in the same area is about 3600 feet (Gingerich, 1983). Average thicknesses of the Fort Union and Willwood Formation in the central Bighorn Basin are 4500-5000 feet and 2300 feet, respectively. The contact between the Willwood and the underlying Fort Union Formation is generally determined by the first appearance upsection of the typical red banding in the variegated Willwood clays, sandstones, and shales. The Fort Union is generally composed of carbonaceous mudstone, shale, lenticular sandstone bodies and lignite and has a drab, somber appearance with colors being mostly shades of dark gray, olive brown, medium tan, and maroon (Hickey, 1980).

In the Clarks Fork Basin, the Fort Union Formation has been subdivided into five major lithofacies:

> *a somber member at the base and a predominantly fluvial facies forming the bulk of the sequence and constituting a sort of matrix surrounding both a predominantly lacustrine member and a coaly, paludal member which lie in the more axial parts of the basin. A conglomeratic member occurs in the upper part of the section along the overthrust margin of the Beartooth Mountains* (Hickey, 1980).

The road log for **Segments 2** and 3 will only encounter the fluvial and the conglomeratic members of the formation. The lacustrine (lake) member occurs primarily north and northeast of here and can be seen along the highway between the Wyoming-Montana state line and Belfry, Montana. The somber Lebo member at the base of the Fort Union occurs on the northeastern margin of the Clarks Fork Basin, mostly in Montana and around Elk Basin anticline. The paludal (swampy) member occurs only in the Bearcreek-Red Lodge, Montana area and contains one of the few significant coal deposits known in the Fort Union of the Bighorn Basin.

13.2 0.5 0.0

End of Segment 2. Junction with Park County Road 1AB. The panoramic photograph (**Frontispiece**, page 34) from this location identifies many geographical and geologic points of interest (also see **Areas of Interest**, pages 22-27).

Endpiece. Air oblique view to the west taken from near mouth of Clarks Fork Canyon. Clarks Fork of the Yellowstone Wild and Scenic River and Cyclone Bar in center of photograph (note bulldozer trail), Bald Ridge (with stratigraphic section from Precambrian through the Mississippian Madison Limestone) on left, and Sunlight Basin in upper right. Also see **Frontispiece** for this section (page 34) and **Areas of Interest** (pages 22-27). (July, 1971 photograph by Wyoming Department of Transportation, Photogrammetry and Survey Program.)

Frontispiece: Air oblique view (looking to the east) of Clarks Fork Canyon and Clarks Fork Wild and Scenic River. Dillworth Bench in left center and mouth of Clarks Fork Canyon in upper left of photograph, Bald Ridge immediately to right of canyon mouth, Pryor Mountains on left skyline, and Bighorn Mountains on center and right skyline. For an additional view but from the opposite direction, see the air oblique photograph at end of **Segment 2 (Endpiece**, page 37) and **Areas of Interest** (pages 22-27). (July, 1971 photograph by Wyoming Department of Transportation, Photogrammetry and Survey Program.)

Road Log Segment 3
Clarks Fork Canyon turnoff to Clarks Fork Canyon
(Junction of State Highway 120 and Park County Road 1AB to end of Park County Road 8VC)

Mileage

Cumulative from Hgwy 120/Road 1AB	Increment	Cumulative from Clarks Fork Canyon
0.0		12.1

Junction with Park County Road 1AB. Eidelweiss Bar (not of the fluvial variety!) is directly across from turnoff. Turn northwest towards Clark, Wyoming. Now traveling on undifferentiated Quaternary alluvium. The boulder field is a result of a breached morainal or glacial dam either at the mouth of the Clarks Fork Canyon or somewhere upstream. Geographic and geologic points of interest are shown on the **Frontispiece** (page 34).

0.4	0.4	11.7

Rising onto outwash terrace. To the west are the structural elements that define the northwestern margin of the Bighorn Basin. Between here and the mountain front lies the northwest-trending structural axis of the Bighorn Basin. Just north of the Montana-Wyoming state line, this axis has been overridden by eastward thrusting of the Beartooth Mountains. Structural relief on the Precambrian basement between the mountain uplift and the basin syncline is about 15,000 feet (Fisher and Gingerich, 1983).

The vertical displacement is accomplished by both basin subsidence and eastward-directed thrust faults. The Beartooth fault, which extends from Clarks Fork Canyon north to Red Lodge, Montana, places Precambrian basement against steeply-dipping to overturned Paleozoic rocks: the Madison Limestone forms hogbacks, flatirons, or palisades along the mountain front. The fault plane is nearly vertical at Clarks Fork Canyon but decreases northward to become a low angle (dip is about 12°SW) near Red Lodge, where horizontal displacement is estimated at 7.5 miles and vertical displacement is about 20,000 feet (Blackstone, 1986). East of the Beartooth front, but buried by early Tertiary rocks, is the Line Creek fault, a reverse fault that dips 45°W, and extends from about the Montana-Wyoming state line southward to about 6 miles northwest of Cody. Precambrian rocks in the hanging wall are thrust over rocks as young as the Mesaverde Formation (Late Cretaceous) rocks in the footwall and vertical separation is at least 12,000 feet (**Figure 14**) (Blackstone, 1986).

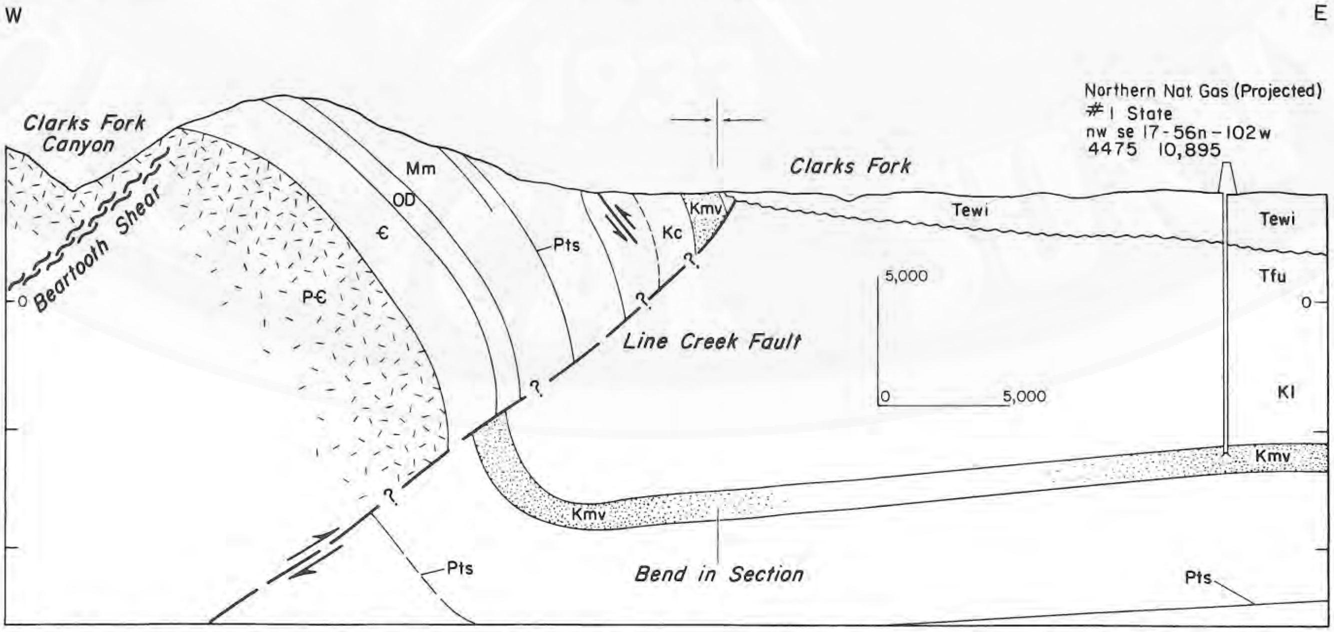


Figure 14. East-west cross section from Clarks Fork Canyon into the Bighorn Basin, showing Line Creek fault beneath early Tertiary conglomeratic units. (From cross section D-D' of Blackstone, 1986.)

Mileage

Cumulative from Hgwy 120/Road 1AB	Increment	Cumulative from Clarks Fork Canyon
2.6	2.2	9.5

Bennett Creek crossing. This creek, which was probably named for Captain Bennett, an officer killed near here (although other sources attribute the name to a pioneer rancher in the area), heads in the Beartooth Plateau and flows eastward where it eventually empties into the Clarks Fork of the Yellowstone River.

3.0 0.4 9.1

Bennett Buttes (Clark) cemetery hill. The hill is composed of synorogenic conglomerates (possibly Eocene Willwood Formation?) capped by remnants of Chapman Bench gravel. This is also near the site of the Miles Battlefield. Colonel Nelson Miles of the U.S. Cavalry, with a force of 35 soldiers and 75 Crow recruits, attacked a group of hostile Bannocks near here on a summer morning in 1878 (Brown, 1961). The Bannocks had fled their reservation in Idaho and crossed through Yellowstone National Park, following basically the same trail used by the Nez Perce in 1877. The attack was made on the Bannock camp just before dawn–with one humorous incident. When the moment arrived to signal the attack, the bugler in his excitement tripped over some sagebrush and fell on his bugle, bending it so that it was useless. The battle was relatively brief with 11 Bannocks killed and 31 captured, along with nearly 200 horses and mules. Three of Miles' men were killed, including Captain Andrew Bennett, an unnamed interpreter, and a Crow scout named Little Rock (Brown, 1961). Two nearby creeks, Bennett and Littlerock, are named for two of the casualties.

3.8 0.8 8.3

Junction. Turn southwest onto Park County Road 8VC (Clarks Fork Canyon Road). Northwest fork goes to town of Clark. Coincidentally, the Clarks Fork of the Yellowstone was named for Captain William Clark, the explorer of Lewis and Clark Expedition fame, while the town and post office of Clark was named for an early rancher in the area, Len Clark (Urbanek, 1988).

4.9 1.1 7.2

Bennett Creek crossing.

5.4 0.5 6.7

Littlerock Creek crossing. Littlerock Creek originates as an outlet for both Gardner and Christmas Lakes on the Beartooth Plateau. The creek once flowed eastward off the plateau, but a massive landslide filled the creek's canyon, forming Deep Lake behind the landslide dam. The water in the creek here originates in springs at the base of this landslide and results from seepage through the landslide debris. Large boulders south of the road are a result of the breached morainal or glacial dam, probably located near the mouth of Clarks Fork Canyon.

8.2 0.8 3.9

Suggested stop. Late Bull Lake terminal moraine on south side of road. This breached moraine extends around the west sides of high hills of steeply-dipping (17-40° E) sandstones and conglomerates north and south of the road. Patches of the moraine surrounded by alluvium have been mapped four miles south of this stop. If these morainal remnants represent the breached dam that allowed large boulders to be transported several miles eastward, the lake could have been as much as 500 feet deep and extended 8 miles upstream. A patch of morainal debris is plastered on the hillside immediately north of the road (**Figure 15**) (Rohrer and others, 1975).

The outcrop to the south is the southernmost of a discontinuous series of nine early Tertiary synorogenic deposits found along the eastern front of the Beartooth

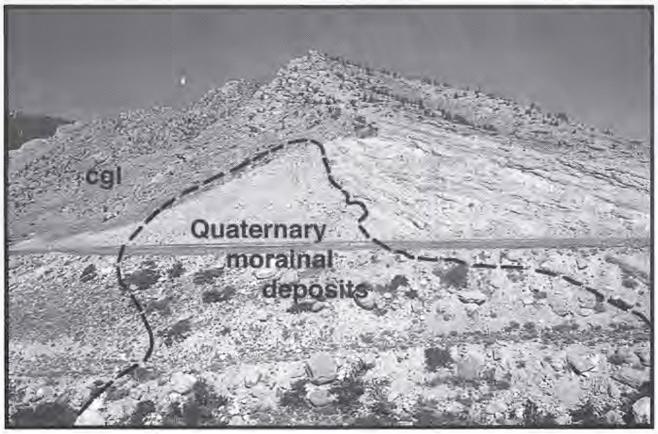


Figure 15. Morainal deposits exposed in road cut overlie eastward-dipping Paleocene and Eocene synorogenic conglomeratic units (cgl) formed during Laramide uplift of the Beartooth Mountains. (Photograph by D.D., 1996.)

Mountains from here to about 6 miles north into Montana. These deposits, which consist of conglomerates, sandstones, siltstones, mudstones, and coals, represent alluvial fan and associated floodplain and swamp deposits and give important clues to the structure and tectonic development of the Beartooth Mountains. The road log by Foose and others (1986) and an article by Dutcher and others (1986) contain excellent discussions of these deposits and form the basis for the following summary.

Using palynological, floral, and vertebrate remains, these conglomerates have been assigned to the Clarkforkian land mammal age, which spans the Paleocene-Eocene boundary. Because the faunal or floral zones, time boundaries, and lithologic boundaries are not necessarily coincident in this area, some workers have mapped these rocks as part of the Fort Union Formation; others have mapped them as part of the Willwood Formation; and still others simply call them Early Tertiary conglomerates. The entire section exposed in the outcrops north of the road is slightly over 2000 feet in thickness and consists of four units of thick, cliff-forming limestone boulder conglomerates with varying amounts of sandstone separated by three fine-grained units.

The lowermost units in the sequence generally dip steeply (60 to 70°) eastward or may even be overturned to the west. Dips decrease upsection: in this area the upper 950 feet of section dips at 22-25° east, creating an interformational unconformity. Dips also decrease basinword: steeply-dipping beds may only dip between 20° and horizontal within an east-west distance of 2 miles. For the conglomeratic deposits nearest the mountains, dips on the basinward side of the topographically highest point of each exposure are approximately 40° less than dips on the mountainward side. The strike of beds on the basinward side also appears to be more northerly.

The thick conglomerates at the base of the sequence were probably deposited as debris flows or mudflows in an alluvial fan environment very close to the rising mountain front. Finer sandstones represent fluvial channel deposits (channel lag deposits, point bars, levees, and channel fills), and the finest deposits are probably vertical accretion or overbank sediments plus coal beds (backswamp). Farthest from the alluvial fans at the basin margin are the uniformly-bedded, fine-grained, organic-rich sediments deposited in lowland areas.

In the immediate area, the lowest units in the sequence were deposited, uplifted, and tilted before upper units were deposited, and tilting of the upper units indicates that uplift continued even after they were deposited. In the outcrops south of the highway, additional uplift after deposition and lithification resulted in some low-angle gravity-slide areas in the uppermost part of the sequence.

The conglomerate sequence in the Clarks Fork Canyon area appears to be the oldest of any of the nine deposits along the eastern Beartooth front. The southernmost deposits near the canyon, which are composed primarily of limestone fragments, were stripped from Paleozoic rocks exposed on the rising mountains. The upper part of this sequence interfingers to the north with coarse deposits containing clasts of both limestone and Precambrian basement rocks. Still farther north, the conglomerates are composed primarily of crystalline Precambrian rocks plus Cretaceous porphyry rocks from an intrusive body north of Beartooth Pass. The conglomerate sequence exposed farthest north of Clarks Fork Canyon also contains, at its base, some tilted limestone conglomerates unconformably overlain by crystalline-porphyry conglomerates. Clearly the source areas for these conglomerates was dependent on both the timing and the location of the major structural elements involved in the uplift.

8.5 0.3 3.6

Recessional moraines. A dam site was once proposed for the area between these moraines and the mouth of Clarks Fork Canyon. How well a dam with abutments in morainal material would hold water is the key question for geologists (and engineers?).

10.3 1.8 1.8

View of the Mowry Shale and Frontier Formation behind residence (**Figure 16**). The Mowry consists of gray and brown shales, in part siliceous, and containing numerous bentonite beds and abundant fish scales;

about 450 feet thick. The Frontier is thick, lenticular, gray sandstone, gray and brown carbonaceous shale, and bentonite; about 450 feet thick. The formations are nearly vertical and well exposed along the ridge. W.G. Pierce has noted that the middle or upper part of the Frontier contains unusual conglomerate beds. At this locality there is a 3-foot bed of white conglomerate composed mostly of felsite porphyry pebbles. Three miles to the north there are two similar conglomerate beds. One of these beds, near the middle of the Frontier, contains black, gray, white, and mottled chert pebbles up to 3 inches across and some light-colored felsite porphyry pebbles. The other bed, about 50 feet below the top of the Frontier, is similar but contains pebbles up to 6 inches across.

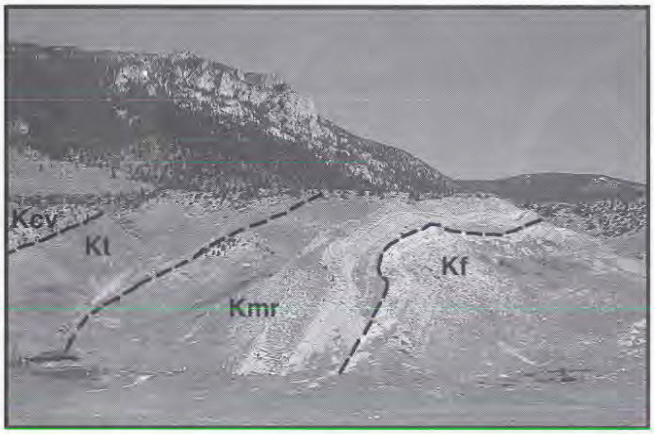


Figure 16. Steeply dipping Mowry Shale and other Lower Cretaceous rocks on east flank of Beartooth Mountains near mouth of Clarks Fork Canyon. Formation symbols are: Kf, Frontier; Kmr, Mowry; Kt, Thermopolis; and Kcv, Cloverly. (Photograph by D.D., 1996.)

10.8	0.5	1.3

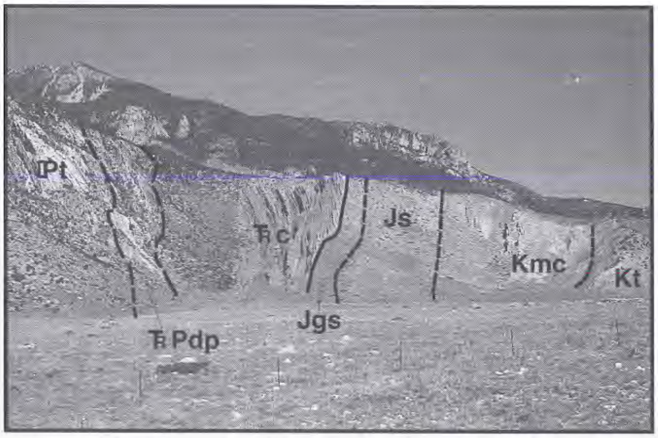


Figure 17. Steeply dipping Paleozoic and Mesozoic rocks near north side of mouth of Clarks Fork Canyon. Approximately 3000 feet of stratigraphic section is exposed here. Formation symbols are: ℙt, Tensleep; TRPdp, Dinwoody and Phosphoria; TRc, Chugwater; Jgs, Gypsum Spring; Js, Sundance; Kmc, Morrison and Cloverly; and Kt, Thermopolis. (Photograph by D.D., 1996.)

View northward of Triassic, Jurassic and Lower Cretaceous rocks (**Figure 17**). The Triassic Dinwoody Formation is not well exposed here. The Chugwater Formation is red siltstone, shale and fine-grained sandstone; 650 feet thick. Lower Jurassic rocks are absent; however the later Jurassic is represented by the Gypsum Spring, Sundance, and Morrison Formations. The Gypsum Spring Formation is red and gray shale, fossiliferous limestone, and gypsum. The white band just to the right of the Chugwater is massive gypsum in the basal part of the Gypsum Spring. The Sundance Formation is green and gray shale, glauconitic limy sandstone and fossiliferous limestone. The formation generally forms a valley with only the limestone cropping out as low ridges. Combined thickness of the Sundance and Gypsum Spring Formations is 425 to 500 feet. The Morrison Formation (uppermost Jurrasic) is variegated claystone and gray silty sandstone. The Morrison is commonly mapped with the overlying Early Cretaceous Cloverly Formation because of poor exposures. The Cloverly is gray and variegated shale, light gray sandstone, and lenticular chert conglomerate. Combined thickness of the Morrison and Cloverly is about 550 feet. The Thermopolis Shale is soft black shale with numerous bentonite beds. The Muddy Sandstone overlies the Thermopolis and is about 55 feet thick (Pierce, 1965b).

To the south is the spectacular fold at the mouth of the canyon (**Figure 18** and **Figure 19**). This northwest-trending fold consists of Paleozoic rocks folded or draped (rotated) over a faulted, unrotated basement core. The fault has about 1500 feet of throw, and the overlying sedimentary rocks, such as the Bighorn Dolomite, have been rotated about 90°. This fold is interpreted as one of several northwest-trending, early Bighorn Basin structures that has since been tilted and upturned by a slightly younger, north-south trending uplift related to the Beartooth front (Wise, 1983; Foose and others, 1986).

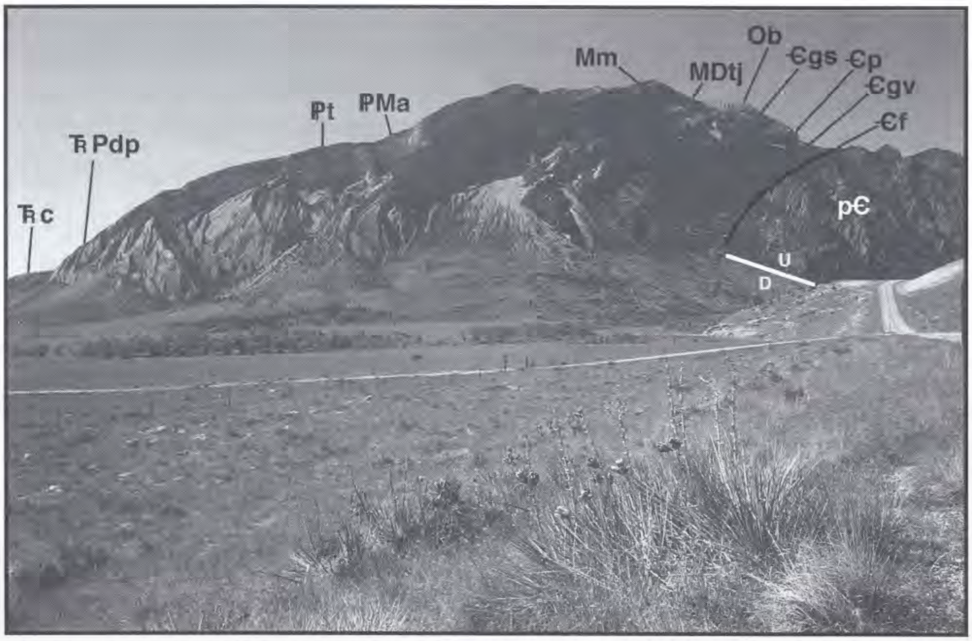


Figure 18. View to south of "canyon mouth anticline." A section of Paleozoic and younger rocks has been folded (or "draped") over an uplifted block of Precambrian granitic rocks (right center). Formation symbols are: pꞒ, Precambrian; Ꞓf, Flathead; Ꞓgv, Gros Ventre; Ꞓp, Pilgrim; Ꞓgs, Grove Creek and Snowy Range; Ob, Bighorn; MDtj, Three Forks and Jefferson; Mm, Madison; ℙMa, Amsden; ℙt, Tensleep; TRPdp, Dinwoody and Phosphoria; and TRc, Chugwater. (Photograph by D.D., 1996.)

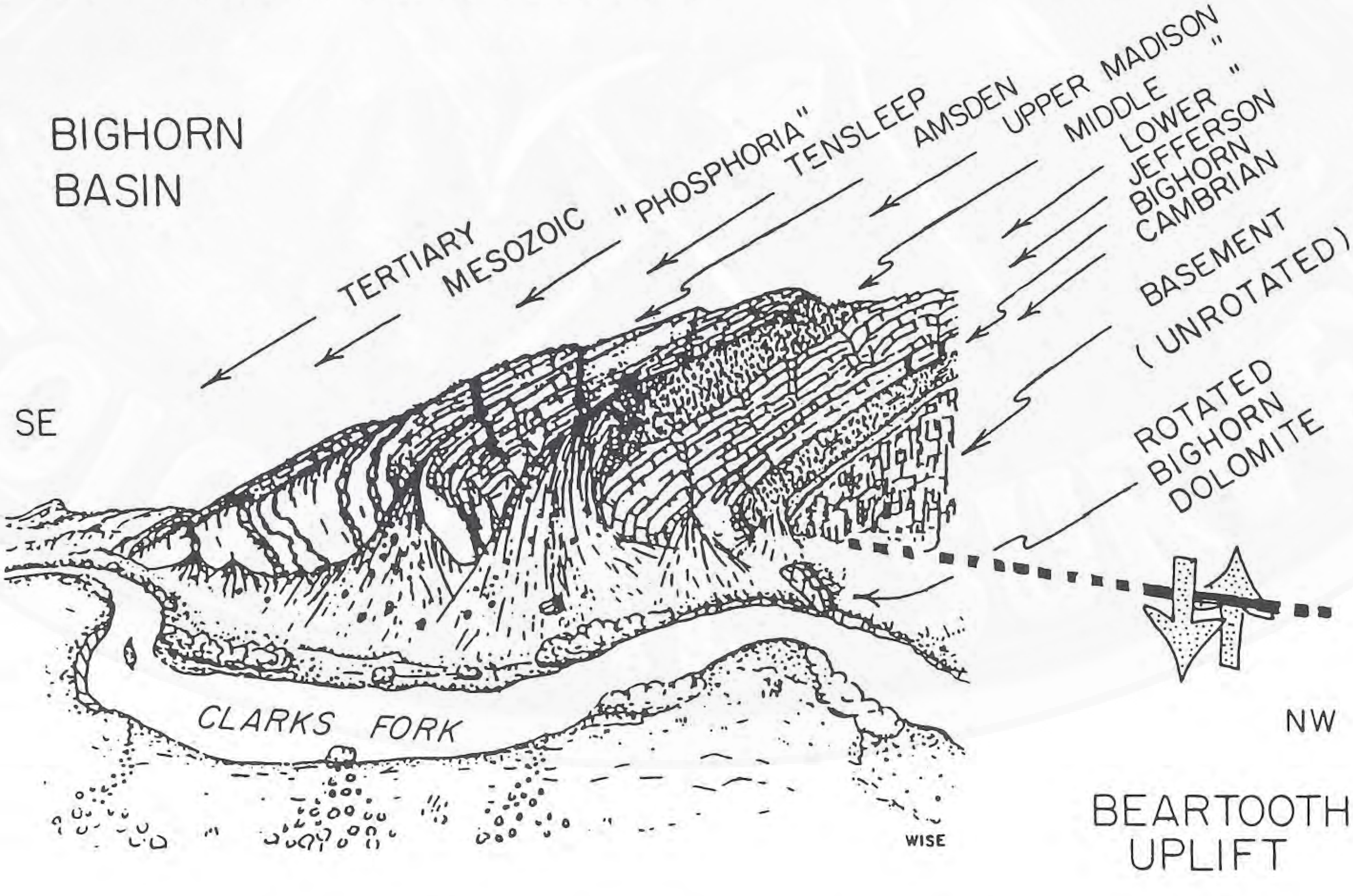


Figure 19. Geologic interpretation of "canyon mouth anticline" as viewed looking south across mouth of Clarks Fork Canyon (modified from Wise, 1983). Note: **Figure 18** is a slightly more oblique view of this structure.

Mileage

Cumulative from Hgwy 120/Road 1AB	Increment	Cumulative from Clarks Fork Canyon
12.1	1.3	0.0

Recommended stop. Paved road ends; Clarks Fork Canyon turn-around. View north of lower Paleozoic formations and of the Precambrian granite and granite gneiss. The Flathead Sandstone is a hard, ledge-forming, quartzitic sandstone 100 feet thick. The overlying Gros Ventre is green micaceous shale, thin-bedded, gray limestone, and limestone-pebble conglomerate, 625 to 700 feet thick. The lowest formation of the Gallatin Group is the Pilgrim Limestone, which is massive, light-gray, mottled, oolitic limestone that forms a prominent ledge; 100 to 125 thick. The Snowy Range is a gray-green shale and greenish, flat-pebble conglomerate about 300 feet thick. Some geologists break out an uppermost Gallatin formation, the Grove Creek, which is gray, buff and orange limestone and dolomite; green shale, and gray-green limestone pebble conglomerate; 50 feet thick. The Upper Ordovician Bighorn Dolomite forms the lower massive cliff. It is gray dolomite and dolomitic limestone ranging from 400 to 475 feet thick. There is some uncertainty as to whether the Lower Devonian Beartooth Butte Formation can be seen from this vantage point. The Beartooth Butte is a stream-channel deposit of red calcareous siltstone, red and yellowish-gray silty limestone and siltstone, and siltstone and limestone conglomerate and breccia; 0 to 75 feet thick. The overlying Jefferson Formation is fetid brown dolomite and light gray and tan limestone; uppermost part is mottled yellowish-orange dolomite and yellowish-gray siltstone; about 300 feet thick. The Devonian Three Forks Formation is yellow, greenish-gray and dark gray dolomitic siltstone, black fissile shale, and silty dolomite; about 90 feet thick. For a detailed description of the Devonian rocks in this area see Sandberg (1967). A ridge of Madison Limestone is present on the north skyline **(Figure 20)**.

The original road alignment as proposed entered the Clarks Fork Canyon and climbed up the canyon walls to connect with Dead Indian Road at Sunlight Creek. Preliminary drilling on the Cyclone Bar revealed unconsolidated wind-blown sand deposits which create very unstable backslopes. Looking southwest, a faint scar is visible where a pioneer (bulldozer) trail was cut across the eolian deposits to allow access for the drill rig (see air oblique photograph, **Segment 2 Endpiece**, page 37.) Political, economic, and geotechnical difficulties associated with building the road in a steep narrow canyon caused designers to reevaluate the alignment. To allow more time to study the problems, the decision was made to begin reconstructing the highway from the Cooke City, Montana end. The final decision was to rebuild the existing alignment up and over Dead Indian Pass and to abandon the canyon alignment **(Figure 21)**.

From the Forest Service boundary to Crandall Creek (20.5 miles upstream), this section of the Clarks Fork has been designated a wild and scenic river. Access can be gained to the lower part of the canyon up-

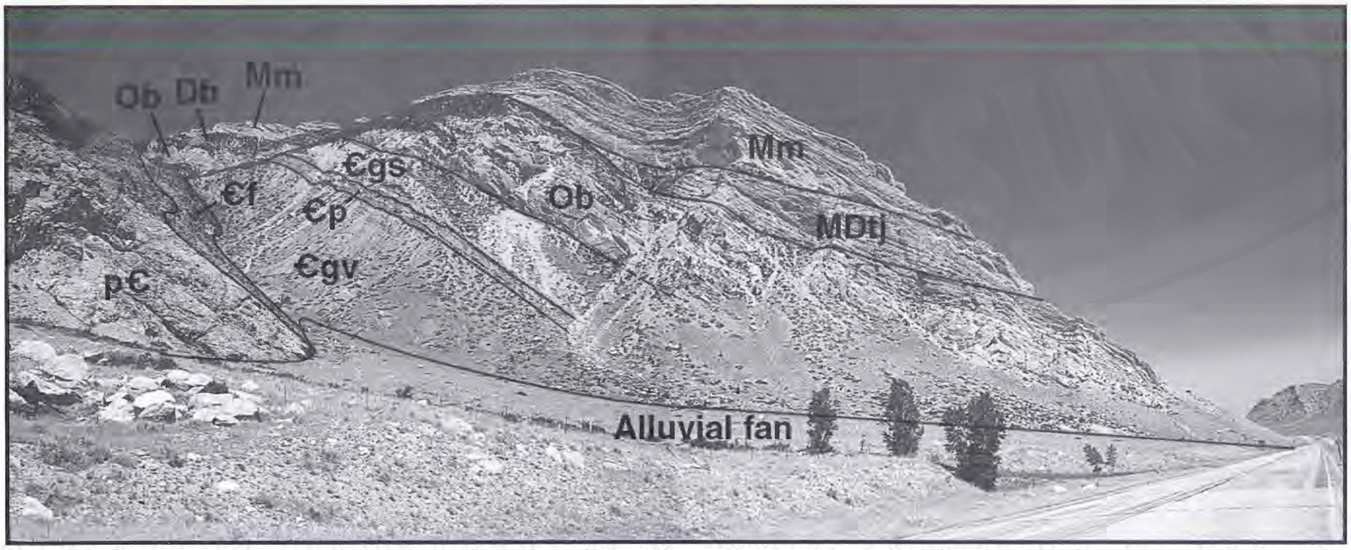
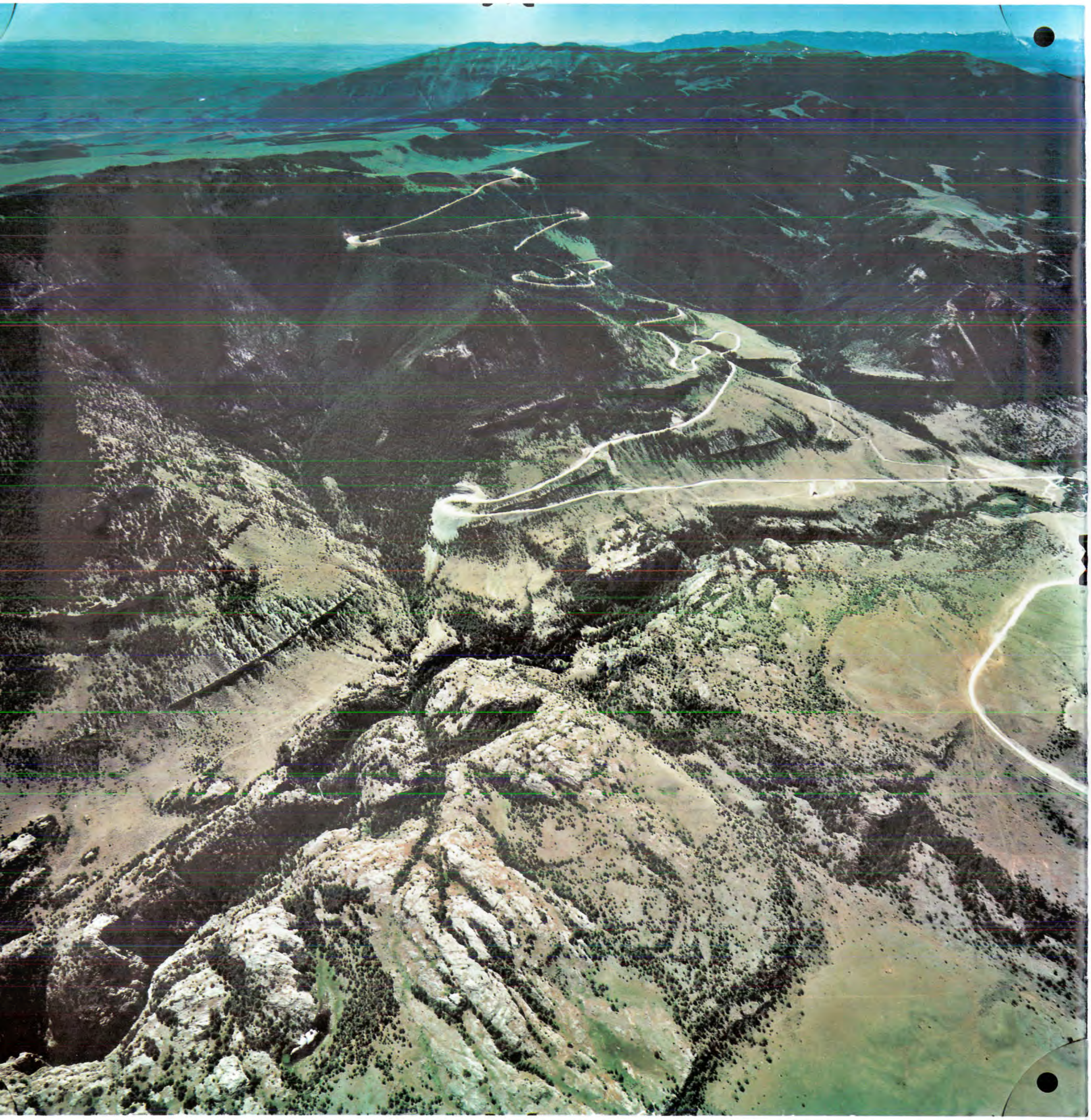


Figure 20. Panorama of the lower Paleozoic section exposed along the north side of Clarks Fork Canyon near the canyon mouth. Formation symbols are: pꞒ, Precambrian; Ꞓf, Flathead; Ꞓgv, Gros Ventre; Ꞓp, Pilgrim Limestone; Ꞓgs, Grove Creek and Snowy Range; Ob, Bighorn; MDtj, Three Forks and Jefferson; Db, Beartooth Butte; and Mm, Madison. (Photographs by H.P.H. and A.D., 1996.)

Figure 21. View southwest into canyon of Clarks Fork River from end of paved road. Exploration trail in wind-blown sand near Cyclone Bar in center of photograph. (Photograph by H.P.H., 1996.)

stream from here by a primitive "road" (high clearance, four wheel drives only). The designation, for Wyoming's first and only federally protected river, precludes dams or other development. The protected part of the river is considered unrunnable by all but the most experienced of kayakers (Dennis Davis, personal communication to Heasler, July 16, 1996).

End of Segment 3 road log.



Frontispiece. Air oblique view to southeast (from near the Dead Indian Creek-Clarks Fork River confluence) across Dead Indian Hill. Pat O'Hara Mountain on skyline in center of photograph, Carter Mountain on right skyline, and Bighorn Basin and foothills of Heart Mountain on left. For additional information, see **Areas of Interest** (pages 22-27). (July, 1971 photograph by Wyoming Department of Transportation, Photogrammetry and Survey Program.)

Road Log Segment 4:
Chief Joseph Scenic Highway turnoff to Beartooth Highway
(Junction State Highways 120 and 296 to U.S. 212)

Mileage

Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/US 212
0.0		46.9

Junction of State Highways 120 and 296. Turn west onto Highway 296. This highway segment was constructed under two projects between 1991 and 1994. They are the Two Dot section constructed between 1991 and 1992 from milepost 38 to 46 and the Forest Service section constructed between 1992 and 1994 from milepost 33 to 38. Total cost for the two sections was $8 million, or $600,000 per mile.

0.2	0.2	46.7

Climbing hill on Mesaverde Formation capped with terrace gravels. Small slide in backslope in Cody Shale. The Cody Shale is the source of many landslides along Wyoming's highways. It is very difficult to design backslopes in this formation unless they are very flat.

0.6	0.4	46.3

Now traveling on Two Dot Flats, the upper reach of the Chapman Bench terrace level. The Chapman Bench is covered with thick gravel deposits that were used for production of aggregates for all construction projects east of Dead Indian Pass.

1.3	0.7	45.6

Point of interest. View to south of landslide in Cody Shale; toward the southwest is a view of Pat O'Hara Mountain, a large east-west trending anticline. The view east is of the Mesaverde Formation, tree-covered ridge; the overlying Meeteetse, clay shales; and the variegated Willwood Formation, which is resting unconformably on the Meeteetse and on the Lance (small wedge below the triangulation station) (**Figure 22**).

2.0	0.7	44.9

Boulders along road are let down (lag) from the Heart Mountain detachment fault.

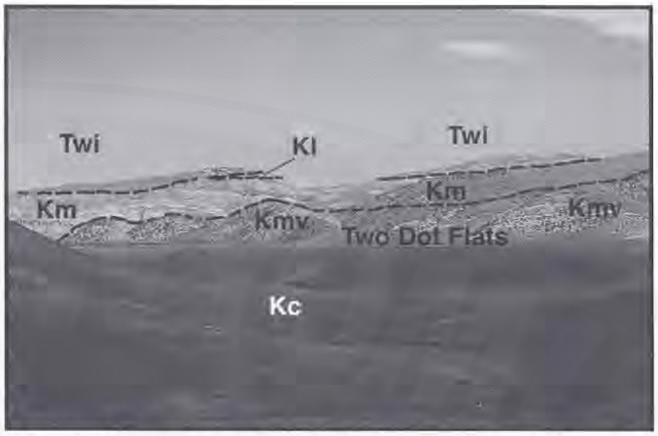


Figure 22. View to east of Cody Shale (Kc in foreground), Mesaverde (Kmv, tree-covered ridge), Meeteetse (Km, brown and gray banded rocks), Lance (Kl, brown, tree-covered ridge on left skyline), and Willwood (Twi, red and white banded rocks on right skyline) Formations. Willwood Formation unconformably overlies the Meeteetse and Lance Formations here and the Cody and Mesaverde to the north. (Photograph by H.P.H., July, 1996)

2.4	0.4	44.5

Crossing contact of Cody Shale and Frontier Formation. Blaine Creek is along north side of road; a poor exposure of the Frontier is in the hill just beyond the creek.

2.7	0.3	44.2

The road crosses a large bedding plane landslide within the Cretaceous Frontier Formation that dammed Blaine Creek and probably created a small lake. The road design across this landslide required minimal disturbance of the backslopes so as not to reactivate another slide.

2.8	0.1	44.1

The flat terrain upstream of the dam was caused by filling of the lake with soft lake deposits. All of the pipe crossings of Blaine Creek required settlement platforms to measure the settlement of the fills. Once the settlement stopped, the road was brought back up to grade and eventually paved. The original alignment crossed Blaine Creek once and followed the north side of the creek. During right-of-way negotiations, the Two

Dot Ranch required that their cattle have access to the water in Blaine Creek without having to cross the road. The new alignment winds up the valley and now crosses Blaine Creek five times.

2.9 0.1 44.0

Crossing approximate contact of Mowry and Thermopolis Shales, not well exposed here. Cliffs on skyline toward the west-southwest are Madison Limestone, Three Forks Formation, Jefferson Formation, and Bighorn Dolomite in the upper plate of the Heart Mountain fault; Chugwater red beds underlie these rocks.

3.0 0.1 43.9

Bridge.

3.5 0.5 43.4

Contact of Thermopolis Shale and Cloverly Formation; not well exposed.

3.7 0.2 43.2

Road crosses through ridge of Cloverly Formation.

4.1 0.4 42.8

Unexposed contact of Morrison and Sundance Formations. Sandstones across creek toward the south are in the basal Morrison.

4.5 0.4 42.4

Sandstones in the Sundance are exposed to north of road.

4.7 0.2 42.2

Exposures of Jurassic Sundance Formation.

5.1 0.4 41.8

Excellent exposure of contact between the Gypsum Spring and Chugwater Formations in hillside on north side of road. The thick gypsum beds in the Gypsum Spring Formation may be mined in the future by the Celotex Corporation. Gypsum removed during construction from the roadcuts was placed more than three feet from the subgrade surface due to the solubility of the gypsum.

5.7 0.6 41.2

Parking area. Chugwater and Gypsum Spring Formations. The accompanying composite graphic section was measured by W.G. Pierce in this area (**Figure 23**). Two wells drilled by the contractor to supply construction water are on the east side of the road. The wells produce 25 gallons per minute, are approximately 600 feet deep, and bottom in the Tensleep Sandstone. The wells were turned over to the Two Dot Ranch after the construction of the highway was completed. Water is now pumped to the top of the saddle north of the road and used to water livestock.

6.1 0.4 40.8

On Dinwoody Formation at crossing in draw. The Triassic Dinwoody is tan, gray, and red siltstone, gypsum, and dolomite; 20 to 50 feet thick (Pierce and Nelson, 1968).

6.7 0.6 40.2

At the next switchback, in cut bank to west, is a highly fossiliferous outcrop of the Phosphoria Formation. For the next few miles, the road traverses a 10-15° dipslope developed on the Phosphoria Formation. The U.S. Geological Survey refers to the Phosphoria as Park City Formation in this area (Pierce and Nelson, 1968; Pierce, 1965b), primarily because the formation is mostly limestone, dolomite, and nodular chert and contains little if any phosphate rock for which the Phosphoria was named.

7.1 0.4 34.8

View to the east showing the red Chugwater Formation, the white Gypsum Spring Formation, the Sundance Formation, and Heart Mountain (**Figure 24**).

7.4 0.3 39.5

View to north and east across northern part of Bighorn Basin. Pryor Mountains, Pryor Gap, and Bighorn Mountains on skyline (**Figure 25**). To the south is Pat O'Hara Mountain, an east-west trending anticlinal structure (**Figure 26**).

Figure 23. Composite section of Pennsylvanian through Lower Jurassic rocks measured by W.G. Pierce. Tensleep and Phosphoria measured at Clarks Fork Canyon; Dinwoody, Chugwater, and Gypsum Spring measured on Dead Indian Hill. (From Rohrer and others, 1975.)

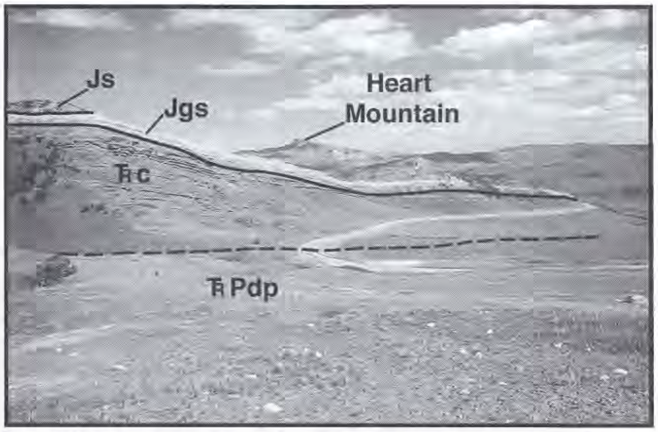


Figure 24. View to southeast from dipslope on Phosphoria/Dinwoody (₸Pdp). The red Chugwater (₸c) is 650-750 feet thick and is overlain by the white Gypsum Spring (Jgs, the white gypsum bed at the base of the formation is up to 50 feet thick) and the Sundance (Js, at the top of the exposure). Heart Mountain on the skyline in center of photograph. (Photograph by D.D., July, 1996.)

Mileage

Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/US 212
7.5	0.1	39.4

The Phosphoria Formation and Tensleep Sandstone are exposed in the canyon wall to the north. The Phosphoria is siliceous limestone and dolomite, nodular chert and tan and gray shale; 70 to 110 feet thick. The underlying Tensleep Sandstone is light-gray, well-sorted, crossbedded, massive sandstone. Thin beds of limestone and dolomite occur in the lower part of the Tensleep; 170 to 220 feet thick. The Tensleep Sandstone and Phosphoria Formation contain some of the most prolific oil reservoirs in Wyoming and together have produced nearly two billion barrels of oil in the Bighorn Basin alone. Wyoming's cumulative oil production through 1995 was over 6.3 billion barrels.

7.7	0.2	39.2

Heart Mountain on the skyline directly to east. Slightly south of east in the middle distance, are dip slopes of the Cloverly (Greybull Sandstone Member), easternmost; Sundance, middle slope; and Gypsum Spring formations, respectively.

8.0	0.3	38.9

The Dinwoody Formation is well-exposed in the road cut to the north. A short dip slope of the Dinwoody on top of the Phosphoria is immediately uphill from the roadcut. The Chugwater caps the small hill north

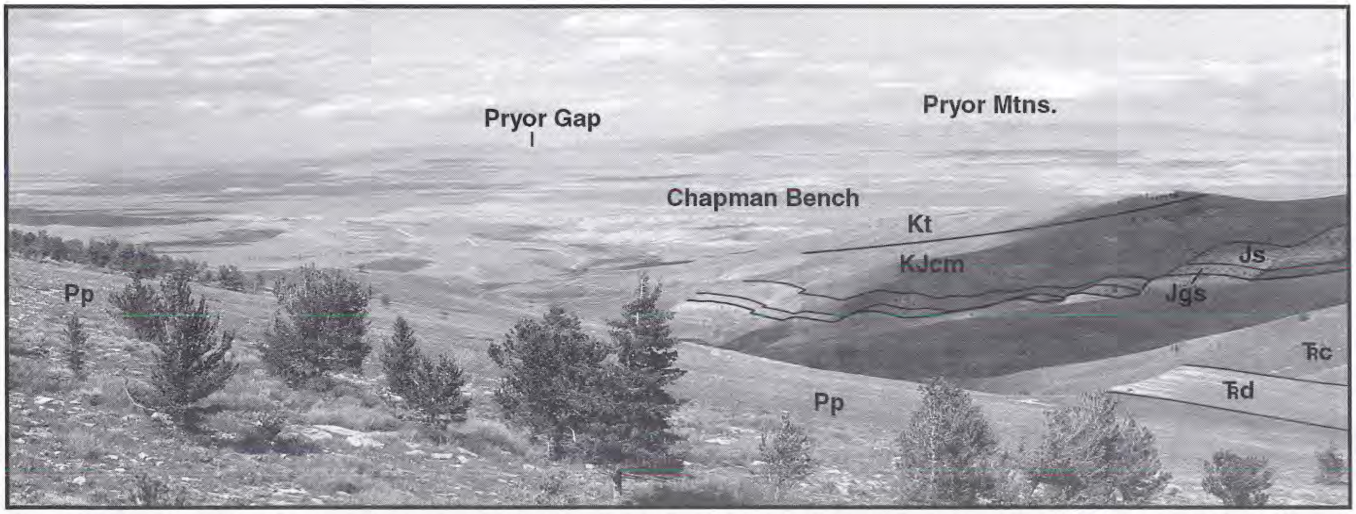


Figure 25. View to northeast across northern part of Bighorn Basin. Chapman Bench in middle distance, Pryor Mountains and Pryor Gap on skyline. Formation symbols are: Pp, Phosphoria; Ŧd, Dinwoody; Ŧc, Chugwater; Jgs, Gypsum Spring; Js, Sundance; KJcm, Morrison and Cloverly; and Kt, Thermopolis. (Photograph by D.D., July, 1996.)

of the Dinwoody exposure. Refer to the composite section (**Figure 23**) for details.

8.4 0.4 38.5

Turnout to Shoshone National Forest boundary.

9.2 0.8 37.7

Suggested stop. Turnout to scenic overview of Bighorn Basin to east.

9.5 0.3 37.4

Phosphoria Formation in road cut; poor exposure. Amethyst crystals were found during construction of the highway.

10.5 1.0 36.4

Excellent exposures for next 0.7 miles of the Phosphoria Formation and Tensleep Sandstone in canyon wall north of road along Paint Creek. The contact is at the top of the cliff. The Mississippian and Pennsylvanian Amsden Formation is partly exposed in the bottom of the canyon. The Amsden consists of red shale, dolomitic limestone, some chert and hematite nodules; siltstone or sandstone are commonly present in the lower part; 250 to 300 feet thick. It is interesting to note that Pierce and Nelson (1968) observed hematite nodules in the formation. Pisolitic and nodular hematite also have been observed in the Amsden in the Wind River Mountains and Wyoming Range.

The original proposed alignment through Paint Creek Canyon was straight and would have required retaining walls up to 50 feet high. The final alignment is curvilinear and is designed with a narrower road section and small backslope ditches. The most unstable backslopes are covered with rockfall mesh. The outside edge of the roadway is underlaid with layers of geogrid to stabilize the edge of the roadway. A 25-foot-high geogrid reinforced fill was built at the upper end of the canyon to reduce the number of trees cut in the valley (**Figure 27**).

11.2 0.7 35.7

Upon exiting the upper end of Paint Creek canyon, the road crosses a north-northwest-trending normal fault, downthrown on the west; now traveling on Chugwater Formation.

11.3 0.1 35.6

The outcrop of Phosphoria Formation south of the highway is sculptured for a natural look.

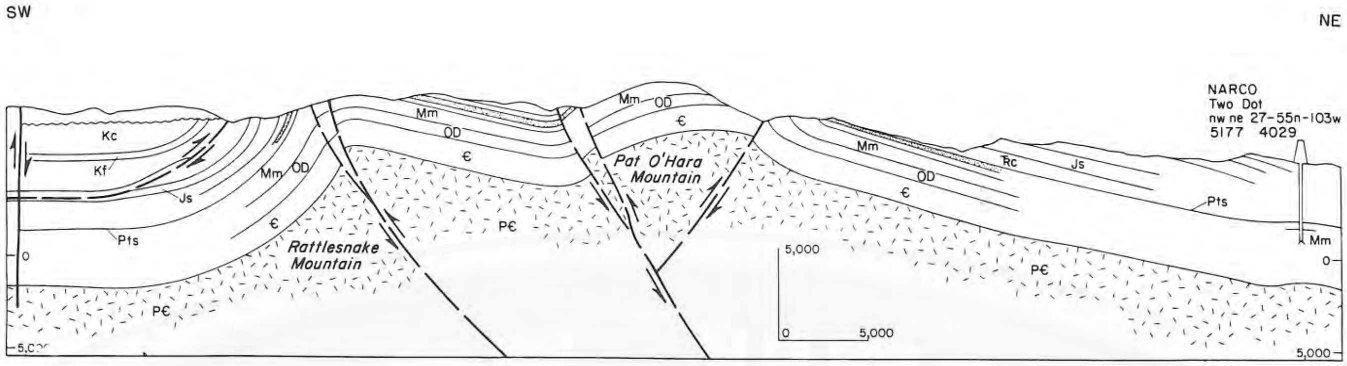


Figure 26. Southwest-northeast cross section from Rattlesnake Mountain to approximately 3 miles east of this point on the road log. (From cross section G-G' of Blackstone, 1986.)

Mileage

Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/US 212
12.9	1.6	34.0

Road crosses Heart Mountain fault. Madison Limestone in upper plate overlies Pennsylvanian through Triassic rocks.

13.6	0.7	33.3

Dead Indian Pass. Small remnants of Phosphoria Formation lie on silicified Tensleep Sandstone on top of pass. The Tensleep at the top of the pass was crushed (68,000 cubic yards) and used to top off the subgrade and to backfill behind the retaining wall.

13.8	0.2	33.1

Top of Dead Indian Hill and Sunlight Basin overlook. This is one of the most spectacular views in Wyoming. To the north and northwest is the Beartooth uplift. The Clarks Fork fault bounds the southeastern side of the uplift and the Beartooth and related faults (up to 20,000 feet of vertical displacement) bound the east side. Using Pierce's (1965b) terminology, the bedding plane phase of the Heart Mountain fault extends over many square miles to the west, from Pilot Peak to the foot of the west slope of Dead Indian Hill. The transgressive phase follows the west side of Dead Indian Hill to the summit, where it overrides the former land surface. This land surface phase occurs at Heart Mountain and McCullough Peaks. Here at the summit of Dead Indian Hill, the Phosphoria rests on silicified Tensleep Sandstone (Panorama, **Figure 28**).

Figure 27. Geogrid reinforced fill along road through Paint Creek. View is to west. Note rockfall mesh installed on unstable backslope on left side of road. (Photograph by M.G.H., 1996.)

This next part of the road log is adapted from Tucker (1982); revised and updated by H. Heasler and C. Jaworowski, October, 1995. According to Tucker (1982), the log provides:

> *. . . a general geologic description of an area of scenic beauty and unusual and well exposed geology. It is largely an up-date of a road log appearing in the Billings (Montana) Geological Society Ninth Annual Field Conference Guidebook, Beartooth Uplift and Sunlight Basin, 1958, apparently written by W.G. Pierce and others, and now out of print.*

Recommended stop **(AI-13)**. The scenic turnout and rest area is just past Dead Indian Pass (elevation 8071, as shown on the new Dead Indian Meadows 7 1/2-minute Quadrangle). Previous road logs and the earlier 15-minute quadrangle map show the elevation of the pass at 8048. Small remnants of Phosphoria Formation lie on silicified Tensleep Sandstone on top of the pass. Historical marker once located near the crest of this pass commemorates early settlers and their efforts to build this road:

> *DEAD INDIAN HILL SUMMIT*
> *Altitude 8000 feet*
>
> *This pass is the summit of Dead Indian Hill. Through this portal, great herds of wild game seasonally migrated from the mountains to the plains. This high pass was the gateway for countless Indian hunting and war parties. Through this portal, Chief Joseph, in 1877, led his Nez Perce Indians in a strategic and defensive retreat pursued by the U.S. Army soldiers. Over this one and only opening to the valleys of the west, traveled a vast army of miners to seek the wealth of Cooke City and down this steep hill the early settlers of Sunlight Basin braved dangers. The first road improvement was made possible in 1909 by dwellers of Sunlight Valley whose names are here inscribed . . ., Dedicated 1940.*

This highway segment was constructed under numerous projects between 1968 and 1995. Beginning at the junction with U.S. Highway 212 (**Figure 1**), milepost 0 to milepost 22, the roadway was built in six separate sections from 1968 to 1982 at a total cost of $6.5 million or $300,000 per mile. Between 1983 and 1985, the bridge over Sunlight Creek and a short section of roadway on both ends was constructed at a cost of $2.43 million. The remaining two sections are the Dead Indian Creek east section between milepost 22 and 26, built between 1991 and 1992, and Dead Indian Hill section between milepost 26 and 33, built between 1993 and 1995. Total cost for these last two sections was $11 million or $1 million per mile.

From the summit of Dead Indian Pass to the base of Dead Indian Hill, the roadway is supported by 19 geogrid reinforced modular block walls and several geogrid reinforced fills. The U.S. Forest Service required the rock backslopes to be sculptured and the ditch section was narrowed. In the backslope design, the walls and fills were used to minimize the amount of tree cutting and reduce the amount of scarring on the hillsides along the alignment. The color of the modular blocks was selected to match the surrounding rock and soils. Only the uppermost wall is a different color, to match the reddish stains in the Tensleep Sandstone. The bottom two walls were instrumented as part of a research project to measure settlement and deflection.

From the top of the pass to the bridge over Dead Indian Creek at the bottom of the hill, over 2000 feet of elevation are lost and seven switchbacks are negotiated.

14.0 0.2 32.9

Outcrop of limestone in the Amsden Formation to the east, below large talus slope of Tensleep Sandstone, contains intraformational chert and limestone breccia. Tensleep float is found quite some distance down the hill. Contacts with overlying Tensleep Sandstone and underlying Madison Limestone are obscure.

14.6 0.6 32.3

First switchback and Clarks Fork Canyon overlook. Roadcut here is in Mississippian Madison Limestone. The Clarks Fork Canyon is cut into Precambrian granite.

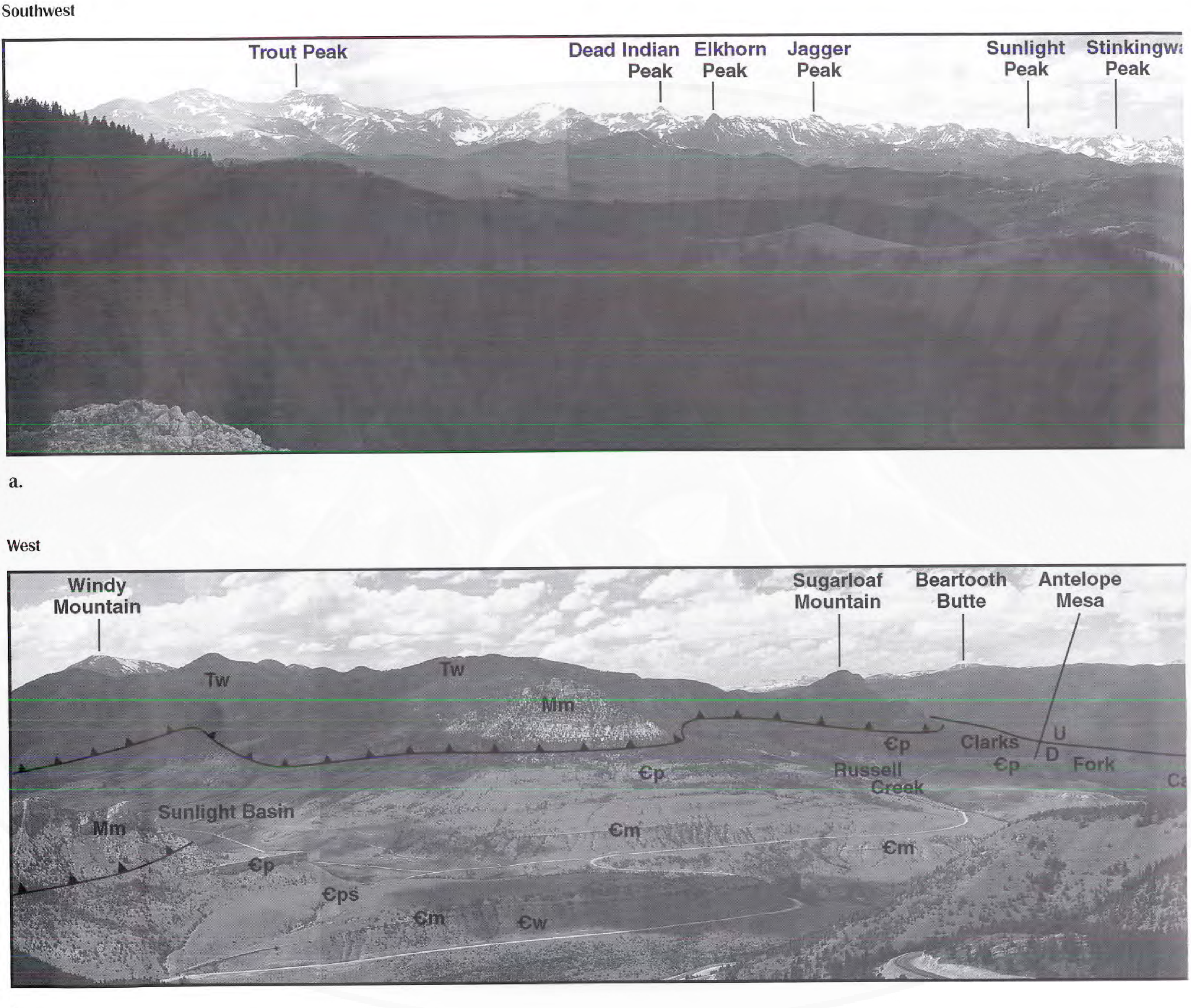
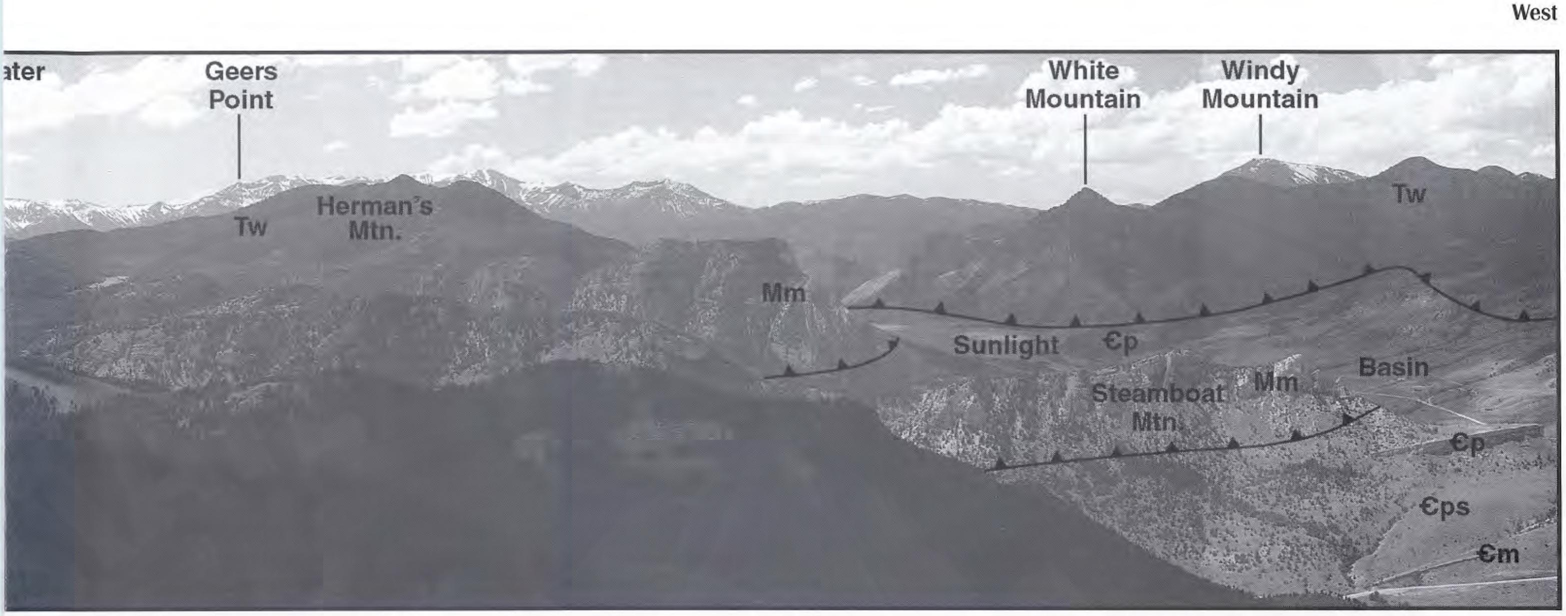
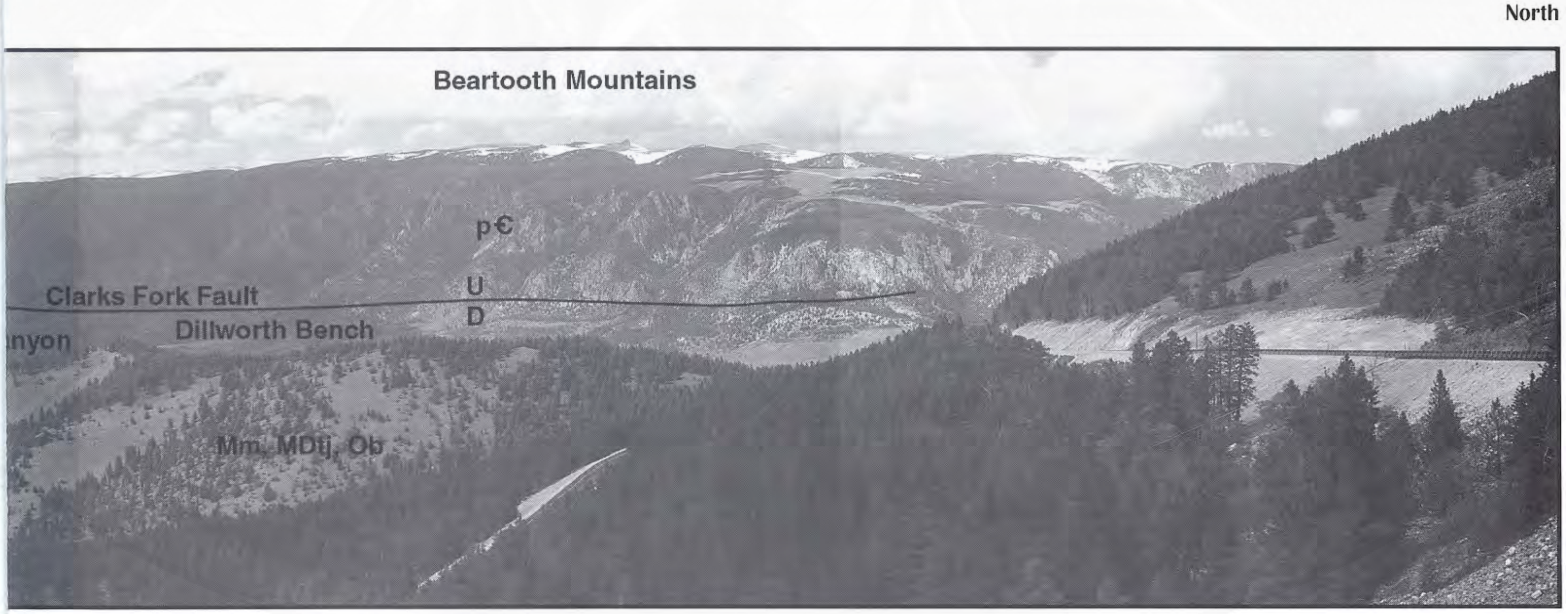


Figure 28. Panorama from top of Dead Indian Hill. View is from southwest (left) to west (right) in a. and west (left to north (right) in b. Peaks on the skyline from Trout Pe fault (sawtooth line). Beartooth Butte is a remnant of Paleozoic rocks on the Beartooth Plateau and Herman's Mountain is named for the first child born in Sunlight B The variable erosion and deposition results in streamlined or smoothed topography. Steamboat Mountain and the hill left of Sugarloaf Mountain (labeled Mm) are ex (cliff formers) and shales (slopes) that crop out along the valley walls. Formation symbols are: pЄ, Precambrian; Єw, Wolsey; Єm, Meagher; Єps, Park; Єp, Pilgri





ak to Greers Point and Windy Mountain are Absaroka volcanic rocks. Steamboat, White, and Sugarloaf Mountains were emplaced by the Heart Mountain detachment asin. As the Clarks Fork lobe of ice flowed up the valleys of Sunlight, Dead Indian, and Elk Creeks, it eroded some rocks and deposited glacial sediments in places. amples of streamlined topography. Movement of the Clarks Fork glacier (from right to left) up Sunlight Basin has erosionally highlighted the Paleozoic limestones n; Mm, Madison; MDtj, Three Forks/Jefferson; Ob, Bighorn; and Tw, Wapiti. (Photographs by H.P.H. and A.D., 1996.)

	Mileage	
Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/US 212
15.7	1.1	31.2

Second switchback contains vertical beds of purple to orange shale, and orange to tan dolomite.

16.2 0.5 30.7

The road turns northwest in poor outcrops of Three Forks (Devonian and Mississippian) and Jefferson (Devonian) Formations (**Figure 29**).

16.5 0.3 30.4

Steeply dipping Three Forks Shale (?), the same formation as at the last switchback, in the right shoulder of the road. Steeply dipping mass of limestone above the road to the right is intensely fractured Madison Limestone in a klippe above the transgressive phase of the Heart Mountain fault.

16.6 0.1 30.3

The road turns to the right around an outcrop of the Madison Limestone klippe.

16.7 0.1 30.2

Third switchback is probably in the Jefferson and Three Forks Formations.

Figure 29. View to north (before third switchback) of Three Forks and Jefferson Formations. Klippe of Madison Limestone exposed above road level in upper left part of photograph. Note retaining walls of geogrid blocks. (Photograph by WDOT, Geology Program.)

17.0 0.3 29.9

The road turns progressively to the west and south and here passes a series of small dikes and sills of basalt cutting Bighorn Dolomite.

17.4 0.4 29.5

Fourth switchback in poor outcrop of Jefferson Formation, and then the road crosses obscure contact with Bighorn Dolomite.

17.6 0.2 29.3

Gradual turn to the left in Bighorn Dolomite.

17.9 0.3 29.0

Curve past Bighorn Dolomite.

18.1 0.2 28.8

Turn and pass glacial morainal deposits approximately 1,000 feet above the present valley floor. Glacial erractics are found as high as 7200 feet.

18.4 0.3 28.5

Fifth switchback near base of Snowy Range Formation, composed of green shale and flat pebble conglomerate.

18.9 0.5 28.0

Sixth switchback in glacial till deposits.

19.2 0.3 27.7

Cross cattleguard and outcrop of Pilgrim Limestone at small fault (?). The Pilgrim nearly everywhere forms a prominent escarpment of from 50-200 feet, and is readily recognized throughout the region. Locally it is known as "the Reef."

19.5 0.3 27.4

Landslide in the Park Shale. The roadway alignment crosses a very large landslide complex twice. The design of the roadway required minimal cuts and fills and a narrow road section through the landslide deposits in order not to reactivate the slide debris. Small backslope slides were mitigated by the use of underdrains and large rocks from the Tensleep Sandstone to form toe berms.

19.7 0.2 27.2

Park Shale below Pilgrim Limestone to the southeast.

19.8 0.1 27.1

Small landslide in the Park Shale to the southeast along the roadcut.

20.1 0.3 26.8

Outcrop of Park Shale and limestone pebble conglomerate to the southeast at the seventh and last switchback. The outcrop exhibits several small chevron folds. Excellent view of the Clarks Fork Canyon to the north. In 1978, Exxon completed a uranium exploration drillhole at the switchback.

20.3 0.2 26.6

Outcrop of Meagher Limestone to the southeast, dipping more steeply at the north end due to proximity of a down-to-the-north fault.

20.4 0.1 26.5

Geogrid blocks used in highway construction (**Figure** 30 and 31).

20.6 0.2 26.3

The highway recrosses the toe of a large landslide complex. This toe area was instrumented in the 1960s with inclinometers and has been fairly stable. Local earthslides in the Park Shale and Wolsey Shale have cut into the road at several points. They are in places "stabilized" with a rip rap cover of Tensleep Sandstone. Mining claim corners seen in the area are signs of exploration for uranium in underlying Flathead Sandstone. Note strong joint pattern in the granite in the valley floor to the northwest and northeast.

20.8 0.2 26.1

View to west. Steeply dipping Madison and Bighorn Formations on Steamboat Mountain above nearly horizontal Pilgrim Limestone. They are separated by the Heart Mountain detachment fault.

Figure 30. Installation of geogrid blocks that form retaining walls upon which the highway is built. See **Figures 27** and **29** for other highway sections completed using this system. (Photograph by WDOT, Geology Program.)

Figure 31. Completed geogrid retaining wall. Pilgrim Limestone exposed in roadcut to left. (Photograph by M.G.H., 1996.)

Mileage

Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/US 212
21.7	0.9	25.2

Cross Dead Indian Creek. Forest Service campground to the north. Upstream from the bridge, a flood deposit (see **Figure** 8, page 17) is evidence of catastrophic draining of glacial lake Dead Indian.

21.8	0.1	25.1

Meagher Limestone forms prominent outcrop to the west. Flathead Sandstone crops out below the road to the east. Road is traversing Wolsey Shale.

23.1	1.3	23.8

Flathead Sandstone to the southwest. View of Sunlight Basin to the west. Sunlight Creek cuts through glacial till, Cambrian sedimentary rocks, and Precambrian granite.

23.4	0.3	23.5

Junction of Park County Road 7GQ (Sunlight Basin Road) with Chief Joseph Scenic Highway. The road leading west into Sunlight Basin can be traversed by car for approximately 15 miles, providing spectacular views of the Absaroka volcanics, Heart Mountain detachment fault, and glacial moraines. Beyond lies the Sunlight mining region, a remote silver-copper district with minor production in the past and native sulfur prospects at Lee City and Sulfur Camp (See **AIs 15-20,** pages 25-26).

23.7	0.3	23.2

Recommended stop. Turn off to overlook before crossing bridge over Sunlight Creek. Excellent exposure of Flathead Sandstone in roadcut north of overlook while approaching the bridge from the south (**Figure 32**).

23.8	0.1	23.1

Bridge over Sunlight Creek (**Figure 33**). Sunlight Creek has cut a canyon into glacial till upstream (west) from the bridge and into Precambrian rocks downstream (east) from the bridge. For the next several miles, the road is on poorly exposed Wolsey and Park Shale and Meagher Limestone, which together are equivalent to the Gros Ventre Formation.

Figure 32. Outcrop of Flathead Sandstone (Ꞓf) north of bridge over Sunlight Creek. The Flathead is about 100 feet of well-cemented brown quartzitic sandstone. Gros Ventre Shale (Ꞓgv) in slopes behind bridge, Precambrian (pꞒ) on Beartooth Plateau in distance. (Photograph by D.D., 1996.)

The Sunlight bridge was completed in 1985 at a cost of $1.3 million. The unique structure is actually three spans, two of which are buried in the canyon walls. The abutments were blasted out of the granite using presplitting techniques. The joint systems below the foundation were rock bolted. The center span is 260 feet long and the bridge is the highest in Wyoming at over 280 feet above the water. When setting one of the center steel girders, the crane cable slipped off the girder causing the crane to tip over. It almost fell into the canyon.

Figure 33. Bridge over Sunlight Creek viewed from the west. Cambrian rocks are exposed in the low tree-covered hills behind the parking area to the right; Precambrian rocks are exposed in the canyon and on either side of the bridge. (Photograph by WDOT, Geology Program, 1994.)

Mileage

Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/US 212
24.0	0.2	22.4

Road crosses fault displacing Meagher Limestone, up to west.

25.0 1.0 21.9

Excellent views of the entire Clarks Fork Valley and Sunlight Basin region. The exhumed and faulted Precambrian surface is visible to the south and southeast. To the north are the Beartooth Mountains, composed of Precambrian granite and granite gneiss, and reaching elevations of over 12,000 feet (**AI-1** and **2**). The old Morrison Ranch can be seen on a bench of Gros Ventre Formation cut off to the north by the Clarks Fork Fault. The ranch can be reached by an arduous jeep ride from the mouth of the Clarks Fork Canyon, or by airplane (**AI-11**). To the northeast is the canyon of the Clarks Fork River. On the southeast side of the canyon, the entire section from Precambrian granite through Madison Limestone is exposed along Bald Ridge. Bald Peak (elevation 8630 feet) is some 2200 feet above the mouth of the canyon (**AI-14**). To the east is Dead Indian Hill (**AI-13**). The Pilgrim Limestone forms perhaps the best outcrop, a third of the way up the slopes. Landslides in the Cambrian section can also be seen from this viewpoint (**Figure 34**). South of Dead Indian Pass are erratically dipping blocks of Paleozoic formations lying above the Heart Mountain detachment fault.

To the south is Sunlight Basin, generally surrounded by volcanic rocks of the Absaroka Volcanic Series (**AIs 15-20**). The air oblique photograph (**Figure 35**) looks south into this area.

25.6 0.6 21.3

Glacial till with erratics to the northeast.

26.5 0.9 20.4

Cross Russell Creek. East of road, Antelope Mountain is a prominent mesa supported by Pilgrim Limestone. A normal fault, up to the west, forms its western margin.

26.7 0.2 20.2

Dirt road to the east leads 100 yards to the Frank N. Hammitt Monument, memorializing a ranger with the Yellowstone National Park Forest Reserve, 1869-1903 (**AI-12**).

27.5 0.8 19.4

The new alignment along this section of highway crossed Sugar Loaf Slide on the side of Sugar Loaf Mountain. The slide was mitigated by removal of slide debris along the alignment and use of a 350-foot-long, 18-foot-high reinforced earth steel panel bin wall.

27.6 0.1 19.3

From turnout on east side of road, looking to the northeast, several glacially-carved, U-shaped valleys can be seen.

27.7 0.1 19.2

Outcrops of slumped Park Shale and Wolsey Shale on west side of road. Landslides are a characteristic problem in the Cambrian shales throughout the region.

28.6 0.9 18.3

Above road to the southwest is Sugarloaf Mountain (**AI-9**), elevation 8780 feet, an allochthonous limestone block moved horizontally by the Heart Mountain detachment fault. For the next several miles, the road traverses the Wolsey Shale, Meagher Limestone, and Park Shale.

29.4 0.8 17.5

The U-shaped valley of Canyon Creek to the north (**Figure 36**) is the dividing line between an ice sheet flowing off the Beartooth Plateau and valley glaciers flowing off the Plateau. The U-shaped valleys are evidence of valley glaciers. The smoothed topography to the west of Canyon Creek is evidence that an ice sheet from the Beartooth Mountains flowed over the terrain.

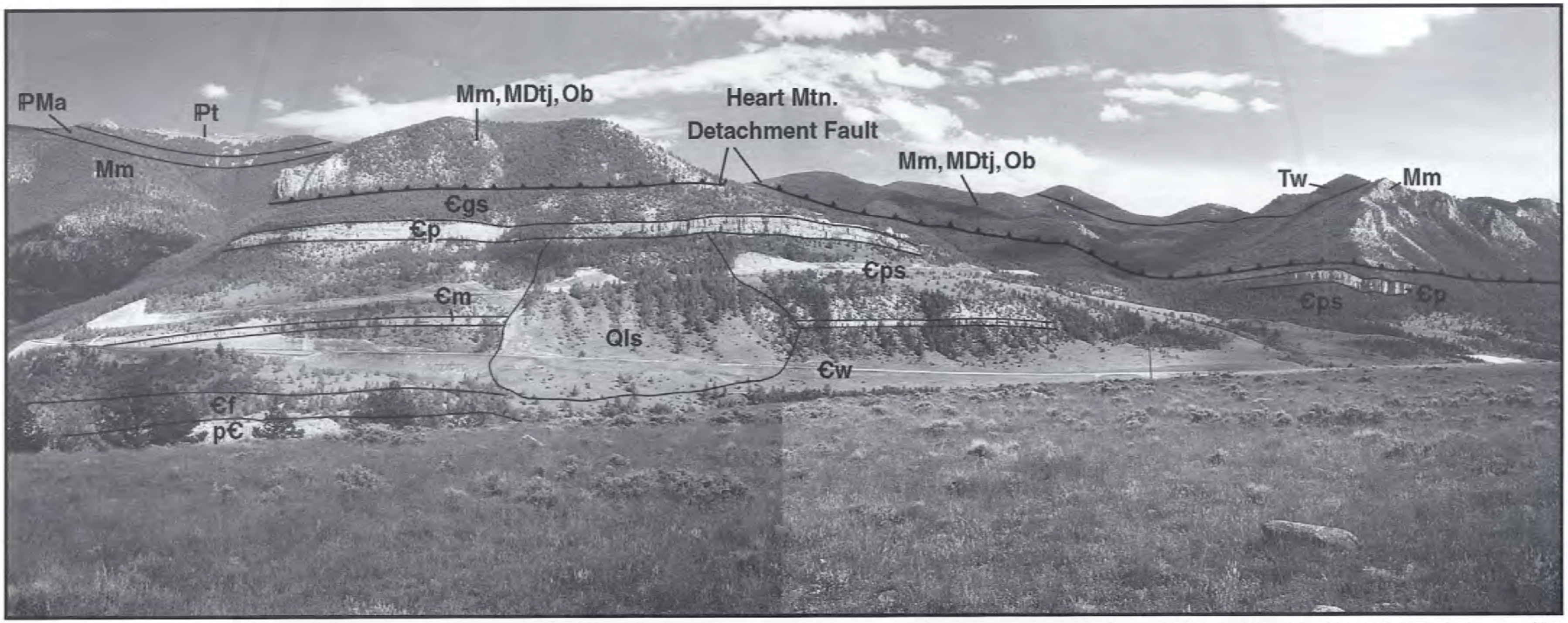


Figure 34. Panorama of Dead Indian Hill road as viewed from north of Dead Indian Creek. View to southeast. Tilted, allocthonous blocks of Madison Limestone (Mm), Bighorn Dolomite (Ob), and Three Forks-Jefferson (MDtj) in the upper plate of the Heart Mountain detachment fault overlie gently-dipping Pilgrim Limestone (Єp) and other Cambrian rocks. Additional formation symbols are: pЄ, Precambrian; Єf, Flathead; Єw, Wolsey; Єm, Meagher; Єgs, Grove Creek/Snowy Range; ℙMa, Amsden; ℙt, Tensleep; Tw, Wapiti; Qls, Quaternary landslide.

Figure 35. Air oblique photograph to south showing Clarks Fork Canyon (lower right to center left), Sunlight Basin (upper right), Steamboat (top center), and Dead Indian Hill (upper left). Chief Joseph Scenic Highway traverses the scene from Dead Indian Hill to right center of photograph near Antelope Mesa. The effects of glacial erosion and deposition have influenced most of the topographic features (such as Steamboat and Antelope Mesa) in this photograph. For additional information, see **Areas of Interest** (pages 22-27). (July, 1971 photograph by WDOT, Photogrammetry and Survey Program.)

Figure 36. U-shaped valleys in the Canyon Creek drainage along the southwestern margin of the Beartooth Plateau. Glacial ice flowed south off the plateau into the Clarks Fork drainage. (Photograph by D.D., 1996.)

Mileage		
Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/US 212
30.3	0.9(?)	16.6

Camp Creek. Road access to Reef Creek drainage.

30.7 0.4 16.2

This area is known as the Deadman Slide and is named for Deadman Creek nearby. During construction a large backslope slide developed along this section of road. It was mitigated with a toe berm which can be seen as a bench on the west side of the highway. In 1990, a slide below the road eventually caused the failure of a 300-foot section of the highway (**Figure 37**). The second Deadman Slide was rebuilt in 1992 using a geotextile wall to support the roadway (**Figure 38**). The wall is 25 feet high, but only the upper 10 feet of the wall are visible. The wrapped geotextile face is covered with shotcrete which protects it from the sunlight and weather.

30.9 0.2 16.0

To the west, the Meagher Limestone underlies both the flats in the foreground and the higher bench in the distance. They are separated by a normal fault which we cross in another 0.2 mile.

31.3 0.4 15.6

Meagher Limestone outcrop to the west.

32.7 1.4 14.2

Scenic view turnout to the north. In early summer, Canyon Creek forms an impressive cascade across the valley down the face of the Beartooth Mountains. Note several U-shaped glacial valleys.

33.3 0.6 13.6

Road crosses approximate Cambrian Flathead-Precambrian granite contact. Gneiss and granite outcrop along the road for most of the next 25 miles.

34.1 0.8 12.8

Scenic view pull-out to the right.

35.1 1.0 11.8

Cross Reef Creek. Forest Service campground to the north.

Figure 37. Highway failure caused by 1990 movement of Deadman Slide. (Photograph by M.G.H., 1990.)

Figure 38. Rebuilt highway at Deadman Slide using geotextile wall covered with shotcrete to protect it from weather. (Photograph by M.G.H., 1992.)

Mileage

Cumulative from Hgwy 120/296	Increment	Cumulative from Hgwy 120/US 212
35.2	0.1	11.7

Recent landslide in Cambrian shales to the south.

37.3	2.1	9.6

Recommended stop. Scenic view pull-out to the south. Excellent view to the south of Windy Mountain (elevation 10,262 feet) and Cathedral Cliffs (**AI-8**), a Heart Mountain fault block composed of Mississippian Madison Limestone through Ordovician Bighorn Dolomite. Here the Heart Mountain detachment fault is a bedding plane fault. The fault block is in turn partially covered by post-faulting Eocene Wapiti Formation composed of andesitic volcanic conglomerate. The Cathedral Cliffs Formation, a volcanic sandstone and tuff composed primarily of latite and andesite fragments that predate the Heart Mountain detachment fault. The entire mass is cut by numerous latite and basalt dikes.

To the north across the valley of the Clarks Fork is Table Mountain, composed of Pilgrim Limestone and Gros Ventre Formation. The updip side of the mountain is truncated by the Clarks Fork fault. Beyond Table Mountain, Beartooth Butte (elevation 10,514 feet) can be seen on the horizon (**AI-2**). This block of Cambrian rocks through Devonian carbonates is downfaulted. Clay Butte, elevation 9811, lies just southwest of Beartooth Butte and offers a spectacular view of the entire area from the fire lookout station on its summit. A relatively good gravel/dirt road can be taken to the top of Clay Butte. In the foreground to the south is Swamp Lake (see **AI-9**) for a discussion of this feature (**Figure 39**).

38.8	1.5	8.1

Crandall Ranger Station road to the west.

39.1	0.3	7.8

Cross Crandall Creek. The bridge over Crandall Creek is founded on piers **drilled** into the granite bedrock. Lawsuits were filed over the construction problems related to the foundations.

39.6	0.5	7.3

Power line crosses the road. To the west of the road is a small outcrop of Flathead Sandstone. To the north on the horizon are Clay Butte and Beartooth Butte. To the southwest is a good view of Cathedral Cliffs.

40.6	1.0	6.3

Cross Clarks Fork of the Yellowstone River. It was down this valley that Chief Joseph led his band of Nez Perce Indians in 1877 in a futile attempt to escape the pursuing U.S. Cavalry. Various versions of the story have the party either traversing the spectacular Clarks

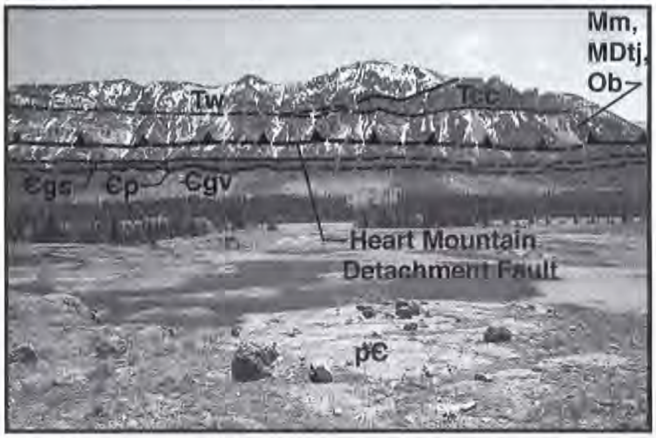


Figure 39. View to south of Swamp Lake and Cathedral Cliffs. The Heart Mountain detachment fault (here a bedding plane fault) is located just above the prominent Pilgrim Limestone. Numerous volcanic dikes cut the Heart Mountain blocks. Formation symbols are: pЄ, Precambrian; Єgv, Gros Ventre; Єp, Pilgrim; Єgs, Grove Creek/Snowy Range; Ob, Bighorn; MDtj, Three Forks/Jefferson; Mm, Madison; Tcc, Cathedral Cliffs; Tw, Wapiti. (Photograph by D.D., 1996.)

Fork Canyon, or climbing out of Sunlight Basin over Dead Indian Hill, thereby gaining several days on the less mobile cavalry. From this bridge to U.S. Highway 212 was the first paved part of the Sunlight Basin road. When it was unpaved, the road here was one of the roughest stretches of the entire Sunlight road, even including Dead Indian Hill.

41.1 0.5 5.8

Hunter Peak (elevation 9034 feet), to the south, is an allocthonous block of limestone moved horizontally by the Heart Mountain detachment fault **(AI-6)**.

42.0 0.9 4.9

Forest Service campground, Hunter Peak, to the south.

44.5 2.5 2.4

Good outcrop of Precambrian granite and gneiss on the north. The west end of the cliff has a large pegmatite vein composed of quartz and microcline feldspar.

45.7 1.2 1.2

Cross Lake Creek. Forest Service campground to north.

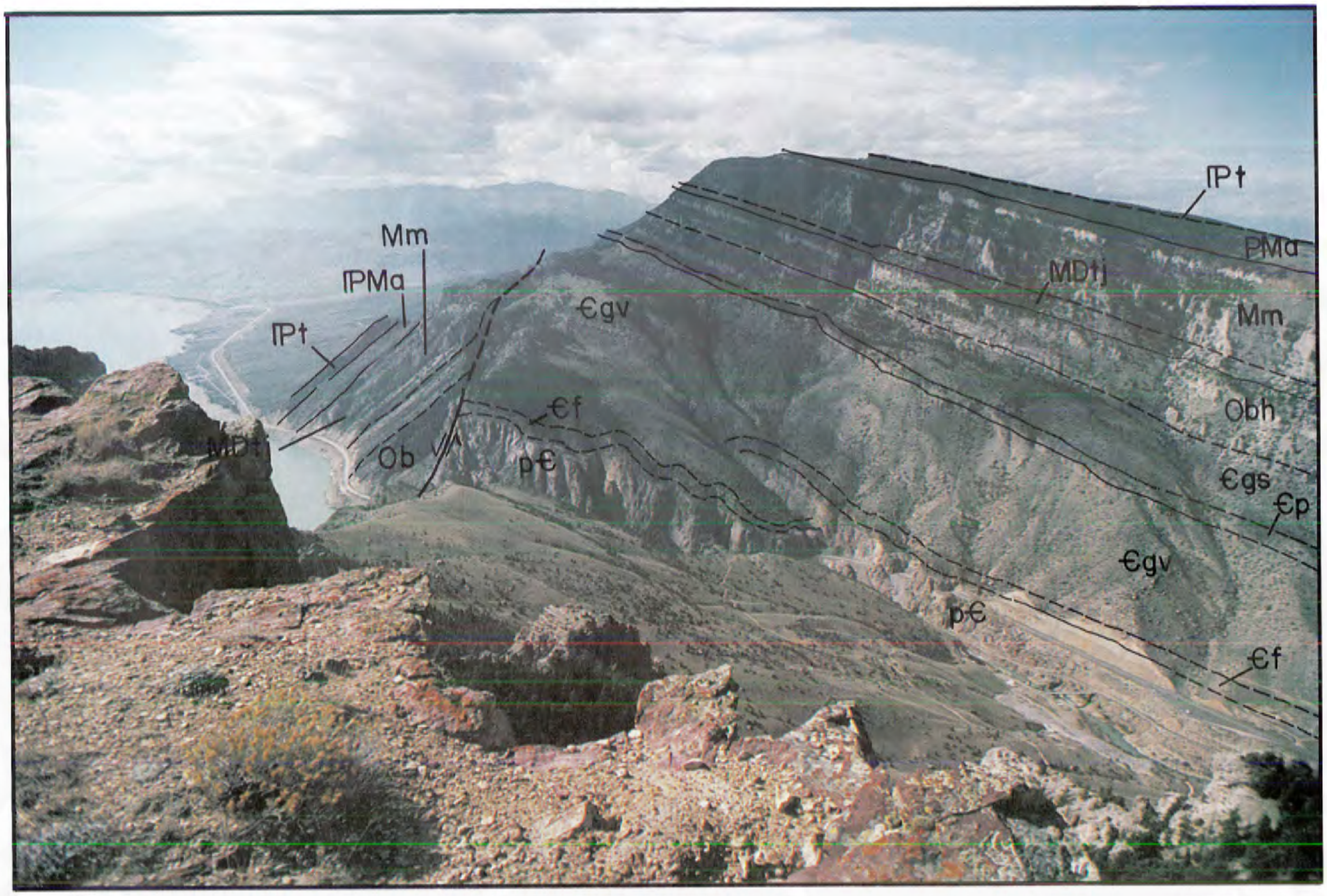
46.9 1.2 0.0

End of Segment 4 road log. Junction with U.S. Highway 212. Road to west leads to Cooke City, Montana, and provides excellent views of Pilot and Index Peaks **(Figure 40)**. To the east, the Beartooth Highway leads up and over the Beartooth Mountains to Red Lodge, Montana, providing the motorist with some of the most spectacular mountain scenery in the country. See Montana Bureau of Mines and Geology Special Publication 110, by H.L. James (1995), for a geological and historical description and road log of the Beartooth Highway.

According to Tucker (1982):

> *These peaks and the surrounding country were first seen by a white man in the winter of 1807-08 when John Colter made his famous trek eastward through the Yellowstone Park Area. Colter called them "Pilot" and "Finger" peaks, and states that "one of them derives its name from its shape, like a closed hand with the index-finger extending upward." Much confusion existed in the literature between 1872 and 1952 as to which is actually Index Peak and which is Pilot Peak. Library research forces one to conclude that Index Peak is to the north and Pilot Peak to the south.*

Figure 40. Pilot Peak, to the south (left) and Index Peak, the lower peak to the north, are 11,708 and 11,313 feet in elevation, respectively. The peaks are prominent landmarks along the Beartooth Highway. Both peaks are composed of flat-lying Eocene volcanic rocks. Pilot Peak is a glacial horn or pyramidal peak with steep sides formed by the intersecting walls of three or more cirques. (Photograph by R.W.J., 1980.)



Frontispiece. Wide angle view of the structure on the west side of Rattlesnake Mountain. View is to the northwest from the top of Cedar Mountain. Buffalo Bill Reservoir and Cody – Yellowstone road in left center of photograph. Paleozoic rocks overlying a faulted block of Precambrian basement have been folded and/or faulted; the steep west flank of the asymmetrical anticline, along with the gently-dipping east flank (to the top and right of the photograph) are well-exposed on the north side of Shoshone Canyon. Buffalo Bill Dam is hidden from view in the canyon to the right of the reservoir. Note roadcuts and the three tunnels in the lower right part of the photograph. Symbols for annotations are: pЄ, Precambrian basement; Єf, Flathead; Єgv, Gros Ventre; Єp. Pilgrim; Єgs, Grove Creek and Snowy Range; Obh, Bighorn; DMtj, Three Forks/Jefferson; Mm, Madison; ℙMa, Amsden; and ℙt, Tensleep. (Photograph by R.W.J., 1987.)

Road Log Segment 5: Cody to Buffalo Bill State Park

(Via U.S. Highway 14/16/20)

Note: this road log was adapted and modified from previous logs published by the Wyoming Geological Association, including Bullock (1975a), Bullock (1975b), and revisions to these road logs (pages 247-250 and pages 251-255 in Boberg, 1983).

Mileage		
Cumulative from Cody	Increment	Cumulative from Buffalo Bill State Park
0.0		8.4

Parking lot at Holiday Inn, Cody, Wyoming. Proceed west on U.S. Highways 14/16/20 (one block west of start, U.S. Highway 14A also joins this road and State Highway 120 continues north) through downtown Cody. The Irma Hotel, on the corner of 12th Street and Sheridan Avenue, was built by Buffalo Bill in 1902 and was named for his youngest daughter. Sheridan Avenue, the main street, was purposely built very wide—early towns were primarily built of wooden structures and when there was a fire, the entire town tended to burn, especially if there was a wind. Cody was laid out so that if there were a fire accompanied by the prevailing wind from the west, the possibility of sparks crossing the wide street was lessened and only half the town would burn down.

The central part of Cody is built on the upper Cody terrace level; a short distance south of Sheridan Avenue is the higher Powell terrace level. The lower part of town near the Shoshone River is built on the lower Cody terrace level. The Shoshone River (which has been a barrier to northward growth of the town) has cut through these terraces into Upper Cretaceous bedrock, appropriately named the Cody Shale.

0.8	0.8	7.6

Proceed westward, taking a short jog south at the Buffalo Bill Historical Center, a world-class facility for art (the Whitney Gallery of Western Art), western history (including the Buffalo Bill Museum and the Plains Indian Museum), and firearms (Winchester Arms Museum). An excellent view of the geology of the area can be seen from Buffalo Bill monument by proceeding directly west on Sheridan Avenue past West Park Hospital (to the north) and the historical center (to the south).

Looking westward toward Shoshone Canyon from the monument, Precambrian granite makes the first break from the bottom of the canyon. Madison Limestone forms the bold cliffs in the middle of the canyon slopes. Dip slopes of both Cedar (or Spirit) Mountain (south side of canyon) and Rattlesnake Mountain (**AI-22**, pages 26-27 and **Figure 1**) (north side of canyon) are maintained by limestone in the Permian Park City (or Phosphoria) Formation which forms most of the open slopes. Dark timbered belts mark areas covered with alluvial-colluvial material primarily composed of the underlying porous Tensleep Sandstone (Pennsylvanian). Erosion has removed the Triassic Dinwoody and the softer parts of the Chugwater Formations, along with the younger Mesozoic rocks. Trail Creek, near the base of the dip slope, is a consequent stream that has cut its course along the soft contact between the Chugwater red beds and the Jurassic Gypsum Spring Formation. At river bank level, several resistant sandstones in the Upper Cretaceous Frontier Formation are conspicuous ridge formers. Several younger (lower) terrace levels along the Shoshone River are also visible here.

Pat O'Hara Mountain is on the skyline to the northwest (as are the Beartooth Mountains in the far distance) and Heart Mountain is on the skyline to the north. On the skyline to the east are the McCullough Peaks, which are Eocene Willwood Formation capped with remnants of Paleozoic rocks from the Heart Mountain detachment fault.

1.6	0.8	6.8

To the north in the gully of Sulphur Creek, Cody terrace gravels unconformably overlie the eastward-dipping Muddy Sandstone (white), which is overlain by the Shell Creek Shale (exposed better downstream at next bend in creek) and underlain by the Thermopolis Shale (Eicher, 1962). The Muddy is crossbedded and contains abundant biogenic structures. Vertical height of the crossbedding and grain size of the sand decrease upward. In the general area, the Muddy is quite variable in lithology. Because it is predominantly mudstone at other localities, the sandy part here may reflect a possible origin as a tidal channel deposit (Eicher, 1962). The Thermopolis Shale is kerogenic and a possible oil-source rock.

2.6 1.0 5.8

South Fork road junction; continue to the west.

2.7 0.1 5.7

The confluence of Trail Creek with the Shoshone River occurs directly north. Triassic red beds form the Red Buttes to the west. The scarp on the east side of the stream is formed by Middle Jurassic Sundance and Gypsum Spring Formations.

3.1 0.4 5.3

Trail Town.

3.5 0.4 4.9

Directly south are old sulfur plant foundations and waste dumps from World War I mining activities. In 1906, over 850 tons of native sulfur was recovered from 2833 tons of travertine ore associated with hot spring deposits. Operations ceased in 1917 (Heasler, 1982; Breckenridge and Hinckley, 1978). Travertine deposits from the hot springs can be seen on both sides of the river (**Figure 41**).

3.7 0.2 4.7

Recommended stop. Sulfur-bearing travertine cone rises above road to the south; abandoned buildings to the north were once the Bronze Boot supper club; the original Bronze Boot night spot was located at the bottom of the Shoshone Canyon on the hot springs that issue near the level of the river. Extensive hot spring deposits (travertine) form the terrace at road level. At stream level, the Shoshone River makes a sharp turn at the contact between the Tensleep Sandstone and the Park City (Phosphoria) Formation. Extensively fractured and leached, Park City limestone is overlain by gray shaly siltstones and shales of the Dinwoody Formation. Chugwater red beds overlie the Dinwoody. Gravels of the Cody terrace unconformably overlie the eroded Chugwater.

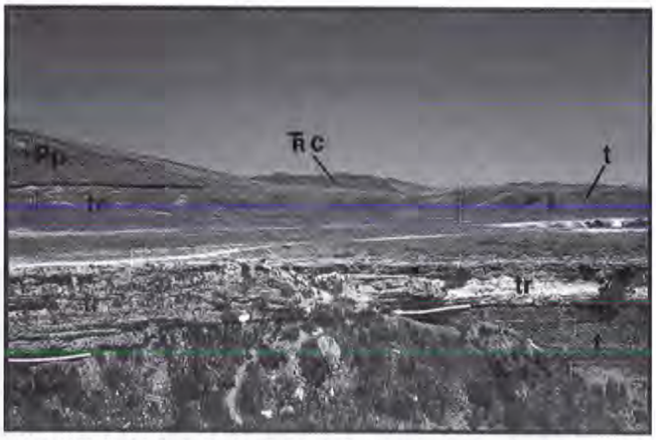


Figure 41. Travertine deposits from the DeMaris Hot Springs overlie Permian and Triassic rocks on the north side of the Shoshone River. View to the north, with Red Buttes in the middle distance and the dipslope of Phosphoria limestone on Rattlesnake Mountain to the left. The travertine was deposited on Cody terrace gravels. Symbols are tr, travertine; t, terrace deposits; Ŧc, Chugwater Formation; Pp, Phosphoria Formation. (Photograph by R.W.J., 1978.)

These gravel deposits continue southwestward along the South Fork of the Shoshone River where they merge with Pinedale-age moraines (Moss and Bonini, 1961). Mackin (1936) had interpreted the gravels as older than the moraines and deposited during an interglacial period, but Moss and Bonini (1961) concluded, on the basis of the genetic relationship of the gravels to the moraines and the great thickness of the gravels in the area, that they were outwash gravels.

Along the north side of the river are 7 major and 10 minor vents which make up the DeMaris Hot Springs. Over 1700 gallons per minute of water at 27°C to 36°C flows from them. Many of the hot springs on the terrace surface across the river have apparently dried up and become dormant since they were first described by John Colter in 1806. This area was first called Colter's Hell, and the river named Stinking Water for the sulfurous odor. The springs have been a resort since 1894 and are named for Bill DeMaris who developed them. The foundation at river level is at the contact between the Chugwater and Dinwoody and marks the largest spring and the original spa. The Cody Health Club now (1983) pumps 208 gpm at 37°C from a 41-m (135 feet) well believed from the same source as the DeMaris (Heasler, 1982). Additional hot springs activity occurs to the south along the Horse Center anticline. The source of the hot water is the upper Paleozoic carbonates which reach a depth of 5600 feet in a syncline to the west of Rattlesnake Mountain; the temperature at this depth is 50°C (Heasler, 1982; Breckenridge and Hinckley, 1978).

4.3 0.6 4.1

Sulfur diggings occur south of the highway. Directly west is Rattlesnake Mountain, capped by light-gray, siliceous limestone of the Phosphoria (Park City) Formation overlying the Pennsylvanian Tensleep Sandstone. Red shales of the Amsden Formation form the slope above the bold cliffs of the Madison Limestone.

4.5 0.2 3.9

Siphon, directly north, supplies water from Buffalo Bill Dam for the Heart Mountain canal. The siphon tunnel portal is located near the base of the Tensleep Sandstone. During construction of the tunnel, many large stalactites and stalagmites of sulfur were encountered in caves in the Madison Limestone. Several construction workers were asphyxiated when dynamite blasts ignited the sulfur (Love, 1989).

4.7 0.2 3.7

The red valley fill directly south is probably formed from slope wash derived from red shales in the Amsden Formation. Travertine deposits can be seen across the canyon to the north. Madison Limestone forms the cliffs and slopes of Cedar Mountain.

4.8 0.1 3.6

Tensleep Sandstone forms the cliffs on the skyline of Cedar Mountain to the south and Madison Limestone forms cliffs to the north and northwest.

5.0 0.2 3.4

Debris from excavation of siphon tunnel occurs to the south. Red shales of the Amsden Formation overlie the Madison to the west-northwest and the Tensleep Sandstone forms the skyline.

5.3 0.3 3.1

Old highway bridge across Shoshone River. Before the new road was built, the main road to Yellowstone National Park followed the valley of the Shoshone River at near river level through the canyon. This was a narrow, twisting road with three tunnels (sometimes allowing only one-way traffic), ending with a grade of more than 18% that took vehicles from the base of Buffalo Bill Dam to the top. During the tourist season, the Highway Department had to keep a tow truck on stand by to assist vehicles that could not negotiate the grade (Sherman, 1974a). West of the bridge, the Ordovician Bighorn Dolomite overlies the Upper Cambrian Gallatin Group, consisting of the basal Pilgrim Limestone, a 100-foot-thick, massive gray oolitic limestone that forms a prominent ledge; the Snowy Range Formation, 300 feet of gray-green shale and greenish flat pebble conglomerate; and the Grove Creek Formation, 30 to 40 feet of gray, buff, and orange limestone and dolomite, green shale, and gray-green limestone-pebble conglomerate (Pierce, 1966).

5.5 0.2 2.9

On the north side of the river, the gray, massive, cliff-forming Bighorn Dolomite overlies shales and conglomerates of the upper part of the Gallatin Group, while nearly straight ahead, the lowest prominent ledge is formed by the Pilgrim Limestone.

5.8 0.2 2.7

Bridge over the Shoshone River. The river has cut a 3000-foot-deep canyon through Rattlesnake Mountain anticline. The river's course is apparently superimposed obliquely across the anticline (Love, 1989) because it could very easily have avoided the anticline by flowing around the southern edge of Cedar Mountain. In fact, raising the level of Buffalo Bill reservoir necessitated installing retaining dikes along South Fork to keep the water from flowing around Cedar Mountain.

6.0 0.3 2.4

Directly south, the Pilgrim Limestone forms the prominent ledge.

Mileage

Cumulative from Cody	Increment	Cumulative from Buffalo Bill State Park
6.5	0.5	1.9

Middle Cambrian Flathead Sandstone along north side of highway.

6.6	0.1	1.8 1.3

Flathead Sandstone overlying Precambrian granite (**Figure 42**). The Middle Cambrian Flathead is a 120- to 150-foot-thick, reddish-brown to brown, hard, ledge-forming quartzitic sandstone. According to Sherman (1974a),

> *. . . the [Precambrian] gneissic complex traversed by the tunnels consists of three major rock types: hornblende-mica schist (oldest), granodiorite and granite pegmatite (youngest of the complex).*

6.7	0.1	1.7

East portal of Tunnel 3.

6.8	0.1	1.6

Tunnel.

6.9	0.1	1.5

Basalt dike on north side of road. Deep cleft at right is formed by erosion of the basalt dike.

Figure 42. Contact between the Precambrian granitic rocks (center of photograph) and the Cambrian Flathead Sandstone (right part of photograph) exposed in bottom of Shoshone Canyon. The Precambrian rocks can also be seen in the background. Symbols are: pЄ, Precambrian, Єf, Flathead Sandstone. (Photograph by R.W.J., 1978.)

7.0	0.1	1.4

Enter the east portal of Tunnel 1 in Precambrian granite. At 3224 feet (1 kilometer), this is the longest highway tunnel in the state.

7.6	0.6	0.8

West portal of Tunnel 1. A west-northwest-trending normal fault, upthrown on the east side, cuts across the Precambrian rocks in this vicinity (Pierce, 1966). This fault has a maximum displacement of about 2000 feet (Blackstone, 1986), and results in a 13° eastward tilting of the basement. According to Blackstone (1986), the structural relief on the west flank is approximately 8000 feet and has been accomplished predominantly by folding

7.7	0.1	0.7

Recommended stop. Turn off to Buffalo Bill Dam (**AI-23**, page 27) and visitors center. This stop is in Buffalo Bill State Park. The new visitor center was completed in 1993 as the final stage of a project to raise the level of the dam 25 feet. Buffalo Bill Dam was originally completed in 1910 to provide water for the Shoshone Reclamation Project, the first such project in the west undertaken by the U.S. Bureau of Reclamation. The 325-foot-high dam, at the time of its completion, was the tallest in the world as well as one of the first arch dams ever constructed. The reservoir provided storage of 375,900 acre-feet of water at a pool elevation of 5360 feet above sea level. The dam is a National Civil Engineering Landmark and was placed on the National Register of Historic Places in 1973. Cost of the dam at that time was about $929,000.

Modification of the dam to increase reservoir storage capacity began in 1985 and was completed in 1993. In addition to raising the dam 25 feet (and increasing storage capacity to 646,600 acre-feet), the spillway was enlarged and fitted with radial arm gates to control the spill, two dust abatement dikes and a protective dike were constructed on the reservoir, additional power-generating capacity was installed, and a new visitor's center was constructed. The project was funded through a joint venture between the Federal government and the State of Wyoming. The State contributed $52 million or about 40% of the cost of the project. Half the cost for construction of the visitor center came from local interests, which also pay the operation and maintenance costs of the center.

7.9 .02 0.5

Steeply-dipping Bighorn Dolomite is exposed in roadcuts on north side of road between west portal of tunnel and this point. The Bighorn is also exposed to the south across the reservoir (**Figure 43**). Flat-lying travertine deposits overlie the contact between Devonian and Ordovician dolomites also along the north side of highway.

8.0 0.1 0.4

Road bed is cut in Madison Limestone.

8.2 0.2 0.2

Soft Amsden shales have eroded forming the drainage between the Tensleep Sandstone and the Madison Limestone on the north side of road.

8.3 0.1 0.1

Tensleep Sandstone exposed on north side of highway.

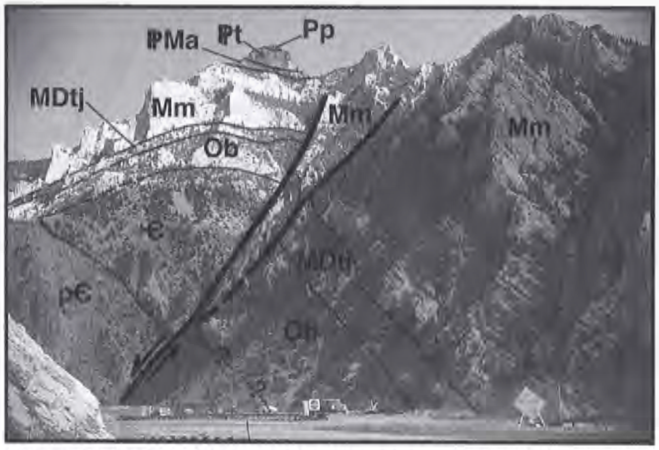


Figure 43. Steeply-dipping Ordovician and Mississippian limestones on the west flank of Cedar Mountain. View to south from Highway 14/16/20. Buffalo Bill Dam is located just off the left edge of the photograph. Most of the incompetent rocks of Cambrian age have been faulted out in this area. Formation symbols are: p€, Precambrian, €, Cambrian rocks; Ob, Bighorn; DMtj, Three Forks/Jefferson; Mm, Madison; MPa, Amsden, ℙt, Tensleep; Pp, Phosphoria. (Photograph by R.W.J., 1987.)

8.4 0.1 0.0

End of logged part of road. Observation point and turn-around. To the south is Cedar Mountain, which forms a conical southward termination of the Rattlesnake Mountain structure. On the south end of Cedar Mountain, the Tensleep Sandstone dips up to 35° south and wraps around to the west end to dip 45° to the southwest. To the west is Buffalo Bill Reservoir and State Park, formed by damming the Shoshone River downstream from the confluence of the North and South Forks of the Shoshone River (**Figure 44**). Farther west up the valley of North Fork, the highway passes over large landslide deposits overlying the Upper Cretaceous Cody Shale and Eocene Willwood Formation, which are in turn overlain by Eocene volcanic rocks that comprise the Absaroka Mountains. To the north, the steeply-dipping strata along the southwestern flank of Rattlesnake Mountain follow the general westward dip of the Precambrian-Cambrian contact into a shallow syncline, referred to by Blackstone (1986) as the Buffalo Bill syncline (**Figure 45a**). Evidence for the westward dip of the strata and the syncline is primarily from a seismic reflection profile along Highway 14/16/20 from Buffalo Bill Dam westward about 20 miles (Blackstone, 1986).

Figure 44. Wide angle view to west from top of Cedar Mountain. The valley of North Fork of the Shoshone River to the right, South Fork to the left. Sheep Mountain separates the two drainages. The upper third of Sheep Mountain is brittle cliff-forming Ordovician to Mississippian limestones and dolomites that lie on a remnant Heart Mountain detachment fault. Eocene volcanic rocks overlie these remnants on the west side of Sheep Mountain. The Heart Mountain detachment fault lies on the older South Fork detachment fault which contains Jurassic to Upper Cretaceous rocks. (Photograph by R.W.J., 1987.)

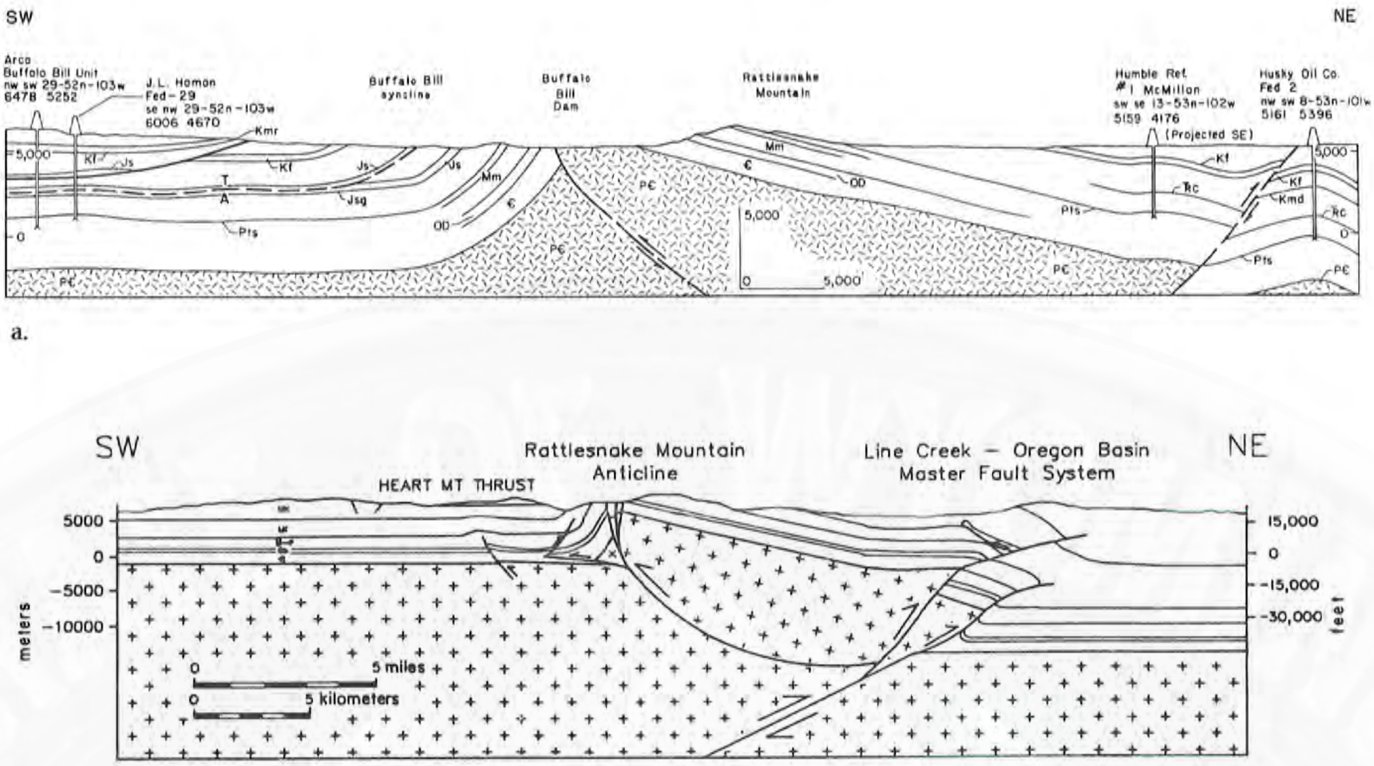


Figure 45. Cross sections through Rattlesnake Mountain. a. Interpretation from cross section R-R' of Blackstone (1986). This cross section goes through Precambrian rocks exposed in Shoshone Canyon. b. Backthrust interpretation of Erslev (1990). Cross section is about 6.5 miles northwest of Shoshone Canyon.

Blackstone (1986) reviewed the structural interpretations of Rattlesnake Mountain and concluded that the:

> *. . . anticline is an excellent example of a folded surface (the interface between the Precambrian basement and the overlying sediments) modified by east dipping reverse faults . . .*

His cross section is very similar to that shown later by Erslev (1990) (**Figure 45b**) who concluded:

> *. . . that the Rattlesnake Mountain structure is a back thrust off the blind basin boundary fault system . . . responsible for the uplift of Oregon Basin to the south and the Beartooth Mountains to the northwest.*

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