Traveler's Guide
to the

GEOLOGY
OF
WYOMING

second edition

by D.L. Blackstone, Jr.

Geological Survey of Wyoming
Bulletin 67
Gary B. Glass, State Geologist
Laramie, Wyoming

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Front cover: Hikers in the lower left part of the photograph are dwarfed by a thick sequence of volcanic rocks exposed in the southern part of the Absaroka Range. This area is located near Brooks Lake campground, east of Togwotee Pass and north of U.S. Highway 26/287 between Dubois and Jackson. For more detailed discussion of this area, see page 83 of this publication. (Photograph by Richard W. Jones)

Back cover: Selected sites described in this bulletin. Sites are located on a computer-generated physiographic base map created by Lawrence M. Ostresh. Printed with permission of the University of Wyoming Department of Geography and Recreation.

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THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

BULLETIN 67

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Laramie, Wyoming
1988

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Foreword

Since publication of the first edition of the *Traveler 's guide to the geology of Wyoming* in 1971, over 10,000 copies of this popular bulletin have been purchased by laymen and geologists alike. No other Survey publication has enjoyed such enduring and successful life on our sales shelves. In 1986, however, the thought crossed our minds that a revision of this booklet was in order, not because the geology had changed, but because our knowledge of some things had improved.

With a little arm twisting, Dr. D.L. Blackstone, Jr., now a Professor Emeritus of Geology at the University of Wyoming with 40 years of geologic experience under his belt, was persuaded to create a second version of his best seller. The second edition is filled with new illustrations and discussions of geologic features and phenomena. Readers still holding their copies of the first version will find this sequel a valuable complement to the original version.

The Geological Survey of Wyoming is again pleased to present a popular treatise on the geology of Wyoming that you, as a traveler, may use to become better acquainted with the fascinating geologic history of the Cowboy State.

Gary B . Glass
State Geologist

Acknowledgments

The revision of the *Traveler's guide to the geology of Wyoming* would not have been possible without the aid provided by the staff of the Geological Survey of Wyoming. Gary B. Glass and the geologic staff reviewed the manuscript and W. Dan Hausel, Ray E. Harris, and Richard W. Jones contributed sections of the text in their areas of special interest and expertise. Phyllis Ranz redrafted all diagrams to achieve a uniformity of presentation. The careful editing of the manuscript by Sheila Roberts and her assistant Michelle Richardson greatly improved the product. The writer acknowledges the contributions of these individuals and thanks them for their cooperation. The writing in general is the responsibility of the author.

D.L. Blackstone, Jr.

Introduction

The landscape of Wyoming was created and is being modified by a wide variety of physical processes acting upon variable bedrock. The evolution of the present landscape began over three billion years ago, with formation of the oldest dated rocks in Wyoming. The early crust, now exposed in the cores of some Wyoming mountain ranges, was later deformed in a series of events that culminated in intrusion of large bodies of igneous material, now granite, about 1.4 billion years ago. The major intervals during which these early events took place are the Archean (oldest) and the Proterozoic (youngest) (see **Geologic time scale, inside back cover**).

A long period of erosion erased most of the evidence of geological events that occurred in Wyoming between 1.4 and 0.6 billion years ago and ultimately reduced much of the Rocky Mountain region to an almost featureless plain extending northeastward into Canada. About 600 million years ago, the western margin of the area began to subside and marine waters transgressed inland across the surface. For about the next 500 million years, subsidence continued intermittently and sediments accumulated beneath the marine waters to a thickness of over 10,000 feet. The marine rocks, which formed from the sediments, thin eastward from Idaho and Utah into Wyoming. Finally, crustal movement elevated and deformed these rocks, so that the processes of erosion could carve them into the landforms and scenic wonders we see today.

Brief summary descriptions of Wyoming's geography, geology, mineral resources, and scenic highlights are presented here in the hope that the travelers' understanding, appreciation, and enjoyment of the State will be enhanced.

Where is Wyoming?

The answer to the question, "Where is Wyoming?" is multifaceted. The nearly rectangular, 97,914-square-mile area that comprises Wyoming lies west of the 100th Meridian, which Major John Wesley Powell designated the beginning of the arid west (**Figure 1**). This places the State in the western half of the United States, primarily in what is often popularly referred to as the Rocky Mountains. This popular designation of Wyoming's location, however, is not technically correct since only a part of Wyoming lies within the Rocky Mountains.

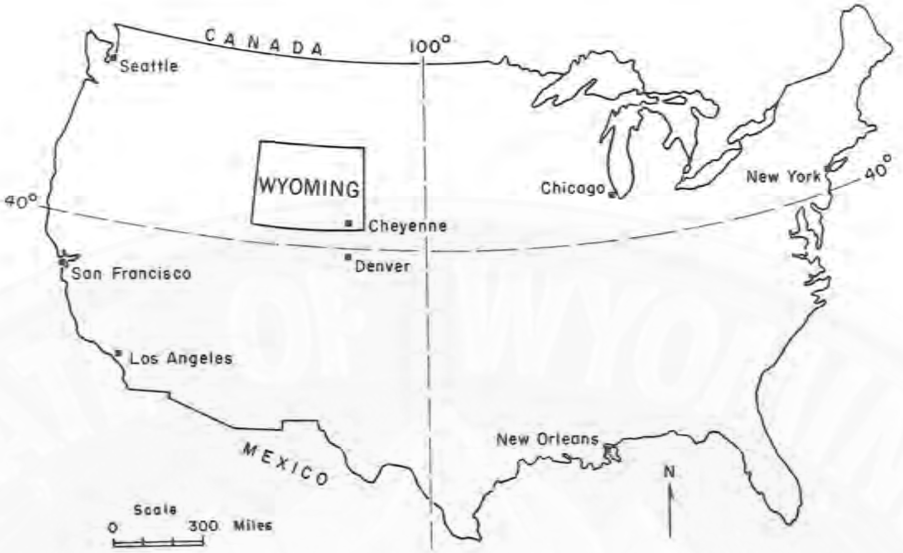


Figure 1. Position of Wyoming in the conterminous United States.

All of Wyoming is over 3,000 feet above sea level. The highest point is the summit of Gannett Peak (13,804 feet) in the Wind River Range and the lowest point (3,180 feet) is in the channel of the Belle Fourche River in northeast Wyoming (Figure 2). In general, the elevations are higher in the western part of the State, but locally there are marked differences in relief. A physiographic map (Figure 3) provides a general view of Wyoming's topographic variety. This map emphasizes the difference between the higher, rougher topography of the mountains and the lower, smoother basin areas (see also outside back cover).

Wyoming sits astride the Continental Divide, or backbone of the continent. Surrounding the Continental Divide, is the mountainous terrain called the Rocky Mountains, a part of the vast system of ranges that stretches from the plains to the Great Basin.

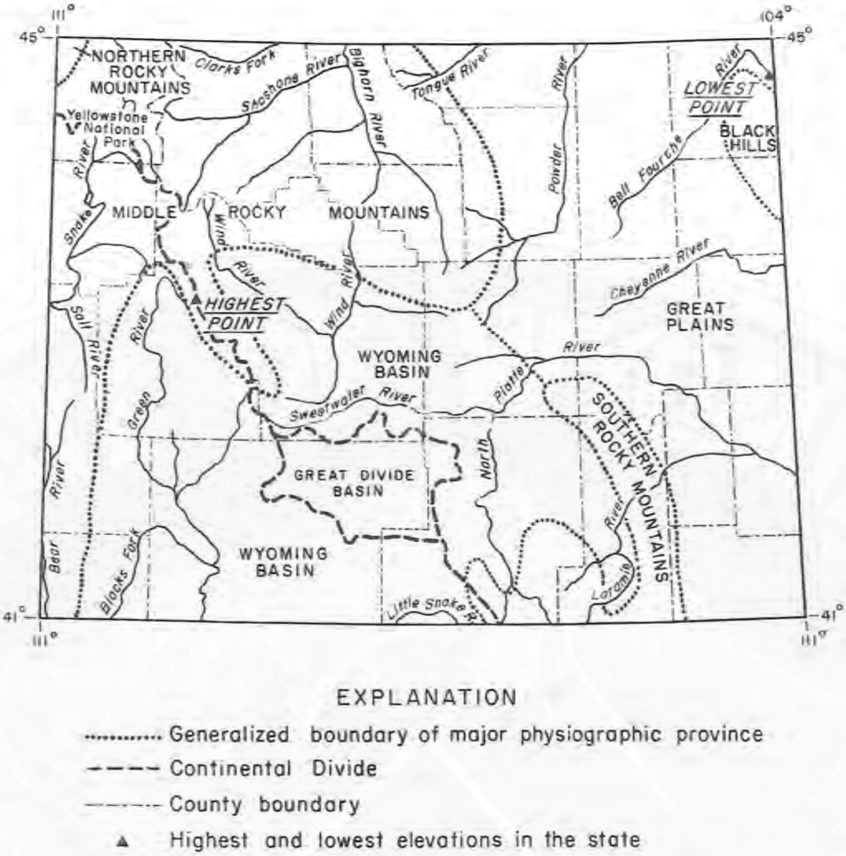


Figure 2. Physiographic provinces of Wyoming. Major drainages, the Continental Divide, and the highest and lowest points in the State are shown.

> *One of the major divisions of the United States is the great barrier of mountains between the Great Plains on the east and the Colorado Plateau, Great Basin, and Columbia Plateau on the west. The entire area is called the Rocky Mountain System. It is not all mountains, but its mountainous and non-mountainous parts are so related that, even in their descriptions and much more in their history, it is necessary to consider them parts of a larger whole.* (Fenneman, 1931, p. 92.)

The Rocky Mountains are further subdivided into groups of ranges — the Southern Rocky Mountains, the Middle Rocky Mountains, and the Northern Rocky Mountains — and between the first two of these lies the Wyoming basin (Figure 2).

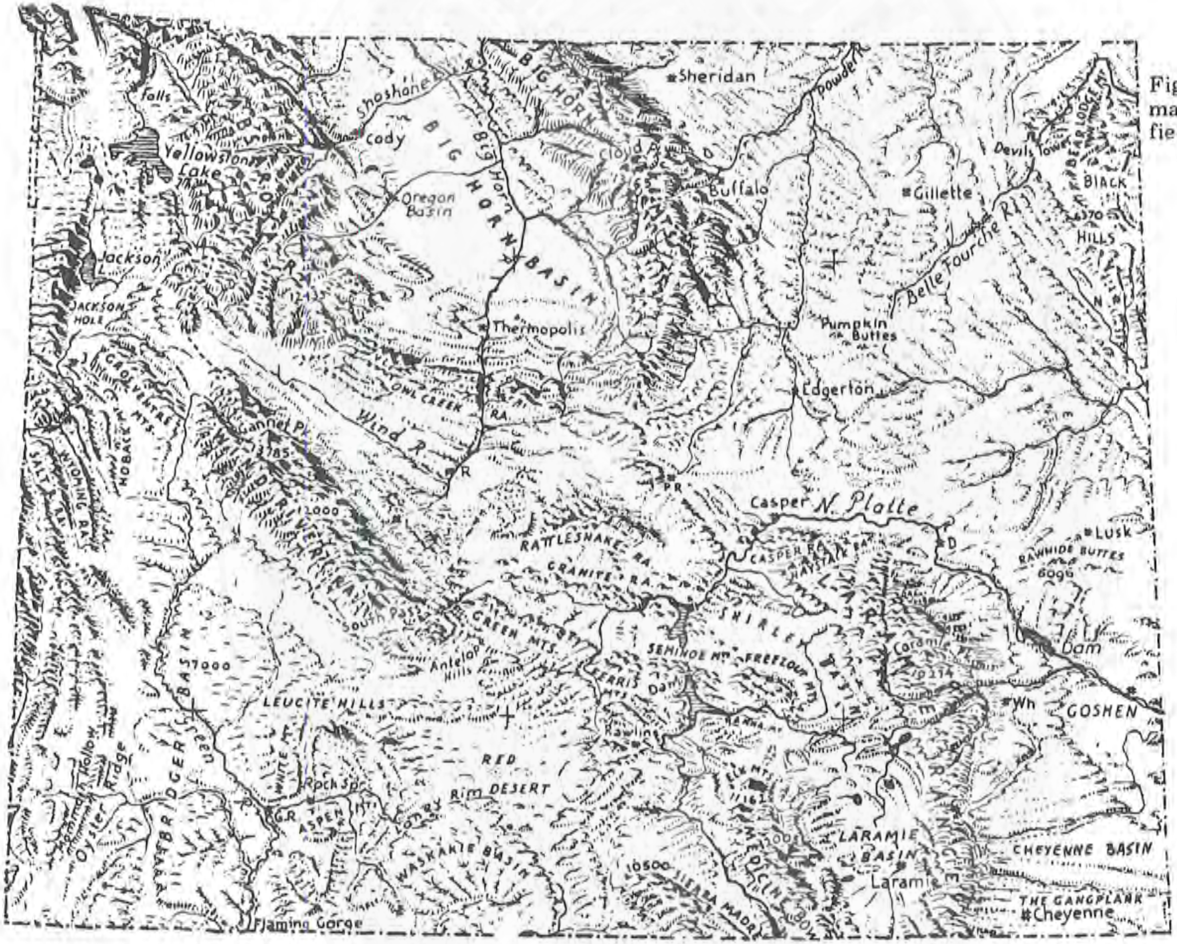


Figure 3. Physiographic map of Wyoming, (modified from Raisz, 1957).

East of the Rocky Mountains are the seemingly endless prairies of the Great Plains, of which Mark Twain said in *Roughing it* (1891, p. 6-7):

> *We were spinning along through Kansas and in the course of an hour and a half we were fairly abroad on the Great Plains. Just here the land was rolling—a grand sweep of regular elevations and depressions as far as the eye could reach — like the stately heave and swell of the ocean's bosom after a storm.*
>
> *. . . But presently this sea upon dry ground was to lose its "rolling" character and stretch away for seven hundred miles as level as a floor.*

Major Physiographic Provinces

The boundaries of Wyoming, its geographic coordinates, and the boundaries of the physiographic provinces in which it lies are shown on **Figure 2**. The landscape and the underlying geology in each of the provinces is different. In this section, each province is briefly described.

Black Hills

The highest parts of the Black Hills are in the adjacent state of South Dakota; only the northwestern segment, including the Bear Lodge Mountains and Mineral Hill, continues northwestward into Wyoming. The Wyoming Black Hills are of low relief and are composed of sedimentary, igneous, and minor metamorphic rocks uplifted on a major structural arch.

Great Plains

The name Great Plains has long been in use for a broad belt of highlands that slope gradually eastward from the Rocky Mountains to the central lowland. In popular usage the limits of this belt are not defined, nor are the essential characteristics by which it is distinguished from the lowlands on the east. The eastern boundary of the Great Plains has been chosen by some geologists on the basis of elevation. One choice is the 1,500-foot contour line, the other the 2,000-foot contour. Both trend in a generally north-south direction, and there is no marked sharp change in slope that is readily observable. The elevation increases slowly to the west to approximately 5,000 feet along the eastern slope of the Rocky Mountains.

The term Great Plains has commonly been associated in the popular mind with a monotony of landscape and also with short grass, which has in a rough way distinguished the Great Plains from the prairie or long-grass country to the east.

Mean annual precipitation on the Great Plains ranges from about 20 inches on the eastern side to 15 inches or less on the western side.

Southern Rocky Mountains

The Southern Rocky Mountains lie largely south of Wyoming in Colorado and New Mexico, and consist of elevated bands of ancient Precambrian basement rocks, flanked on the margins by tilted successions of younger sedimentary rocks. The Southern Rocky Mountains extend into Wyoming in three prongs — the Laramie Mountains, the Medicine Bow Mountains, and the Sierra Madre.

Wyoming Basin

The Wyoming Basin is really a group of large and small uplifts and intermontane basins that lie between the Southern and Middle Rocky Mountains. The northeastern boundary is indistinct because the topography of the basins merges eastward into the Great Plains without great change in character. The Laramie Mountains form the southeastern boundary. The large uplifts lack the continuity expressed in the surrounding provinces; traveling west from Rawlins on Interstate Highway 80, one may not realize how mountainous Wyoming really is.

Middle Rocky Mountains

The province is shaped like the letter C, open to the southeast and enclosing the Wyoming basin in its central area (Figure 2). The mountain uplifts that make up the Middle Rocky Mountains are mainly linear in map form, with a single range likely to be a single fault block or fold. A diversity of features exists in the province, ranging from the north-south trending Overthrust Belt mountains of western Wyoming to the pile of volcanic materials known as the Absaroka Plateau in northwest Wyoming.

Northern Rocky Mountains

The extreme southern tip of this province extends into Wyoming in the northwest corner of the State. The mountains are long, linear, and arranged in a belt that continues northward across Montana and Idaho and into Canada.

Wyoming geography

Rivers

Since the backbone of the continent extends across Wyoming, it is logical that the headwaters of some major rivers are in the State (Figure 2). The major eastward drainage from the flank of the Rocky Mountains is the Missouri River, made famous by Lewis and Clark's epical journey to the Pacific (1804 to 1806). Two of the three tributaries (the Madison and Gallatin Rivers), which join at Three Forks, Montana to form the Missouri, begin in Wyoming. Both originate in Yellowstone National Park. The Yellowstone River and its principal tributaries — Clarks Fork, Wind River-Bighorn River, and Powder River — all originate in Wyoming and flow to the north. The Belle Fourche and the Cheyenne Rivers, which drain northeastern Wyoming, exit the State into South Dakota.

Another major drainage system is the North Platte River, which originates in the North Park region of Colorado and swings in a U-shaped loop through the southeast quarter of the State. The Laramie River is a major tributary. The water of this system is stored in a series of reservoirs that are used for irrigation. The impoundments (beginning at the upstream end) are Seminoe, Kortes, Pathfinder, Alcova, Glendo, and Guernsey Reservoirs.

The Sweetwater River, a major tributary of the North Platte, begins in the southern end of the Wind River Range and flows eastward across central Wyoming. The valley of this river is a famous part of the main route of emigration to Utah, Oregon, and California in the mid 1800s. In this valley are such pioneer landmarks as Independence Rock, Split Rock, Devil's Gate, and Sweetwater Crossing.

The Green River rises in the northern Wind River Range and flows south across the Uinta Mountains to join the Colorado River. The Blacks Fork, a tributary to the Green River, originates in the Uinta Mountains south of Evanston, loops through the Bridger Basin, and joins the Green River near Flaming Gorge Reservoir.

The Pacific Ocean receives the waters of the Snake River, a major tributary of the Columbia River, which heads south out of Yellowstone National Park and flows westward into Idaho. Several impoundments including Jackson Lake and Palisades Reservoir store waters of this drainage for irrigation projects in Idaho.

A smaller river, the Bear, flows northward out of the southwest corner of Wyoming, and its water finally empties into the Great Salt Lake, to end its journey without reaching the ocean.

There exists then, in Wyoming, a triple divide with water flowing ultimately to the Gulf of Mexico, the Gulf of California, and the Pacific Ocean. In fact, at Two Ocean Pass south of Yellowstone National Park, water from a single small pond that has two outlets departs for two oceans — the Atlantic and the Pacific.

Plains

The term plains is usually associated with a landscape of low relief, broad valleys, and low rolling hills; well-developed soil cover; grassland-type vegetation; and a monotonous repetition of scene. This is the typical landscape of the prairie wheat-farming areas of western Kansas, Nebraska, eastern Colorado, or some of the prairie provinces of Canada. States east of Wyoming receive greater annual precipitation, and therefore have thicker grass cover than the high dry plains of Wyoming.

In Wyoming, the high plains are developed for the most part on a series of essentially flat-lying rocks of Cenozoic and Mesozoic age, much of which originated as debris ejected from volcanoes far to the west. This debris was carried eastward by a complex of rivers. Later, when the area was uplifted, streams cut deeply into these rocks and developed broad-floored valleys with wide, extensive interstream divides and occasional scarps with small buttes along the margins.

A typical high plains landscape is seen along Interstate Highway 80 from near Pine Bluffs toward the Laramie Mountains. The surface of the plains rises steadily in elevation from Pine Bluffs westward, coinciding with the eastern flank of the Laramie Mountains and forming the famous Gangplank, over which the highway and the railroad find an easy crossing of the first mountain barrier as these transportation routes enter the Rocky Mountains. So smooth is this transition that the traveler arrives at the summit of the Laramie Range without any sense of crossing a mountain range.

The high plains surface is also well developed in the vicinity of Lusk, Wyoming, where it grades imperceptibly eastward into the Nebraska sand hills country. The high plains surface once extended much farther to the north, but the headwater erosion of the Cheyenne River's tributaries created a scarp. The scarp, known as the Pine Ridge escarpment, called the Hat Creek Breaks in Wyoming, extends eastward for over a hundred miles into Nebraska. Erosion is slowly removing the Cenozoic rocks and in the process creating a strip of badlands topography along the escarpment.

Mountains

In the clear air of Wyoming it is possible to see great distances, and in that view there is almost always a mountain. The clear air makes the distances deceptive, and what appears to be just a little way down the road turns out to be a half day's drive away.

Mountains rise to considerably higher elevations than the surrounding landscape. How was this difference in elevation developed? In many places, there has been uplift of large segments of the Earth's crust, which formed folds, wrinkles, and blocks bounded by fractures. Elsewhere, high piles of volcanic flows and ash, such as Mount Washburn in Yellowstone National Park, are certainly also mountains. Other mountainous features exist where whole areas have been uplifted *en masse* and then deeply eroded. Figure 4 is a generalized geologic structure map of Wyoming that shows the major mountain ranges and basins.

The landscape is continually being modified by the actions of wind, running water, moving ice, freezing and thawing, gravity, and chemical reactions, which are actively altering major blocks of rocks, albeit imperceptibly. These processes are analogous to the work of a sculptor, and the product, the current landscape, is younger than the material from which it is carved.

A question frequently asked of geologists is, "How old are the mountains?" We might say they are as old as the oldest rocks exposed in them. The oldest rocks in the core of Wyoming's mountains are at least 3.4 billion years old. In a different view, we might consider the time that has elapsed since the rocks were elevated so that the present landforms could develop. Many mountainous regions in Wyoming were elevated about 60 million years ago. The uplift is quite young by geologic standards.

Black Hills

The highest part of the Black Hills is in South Dakota, culminating in Harney Peak near Custer. The Black Hills provide a fine example of an erosionally dissected domal uplift with a core of crystalline Precambrian rocks encircled by hogbacks of sedimentary rocks. The western flank of the uplift is in Wyoming, easily seen where U.S. Highway 16 parallels hogback ridges between Newcastle and Moorcroft. Several intrusive rock bodies cut through the sedimentary rocks and create small, local domal uplifts such as Sundance and Inyan Kara Mountains. The most spectacular igneous rock body is Devils Tower, a prominent column of jointed phonolite northwest of Sundance, Wyoming. Devils Tower is a favorite site for mountain-climbing enthusiasts.

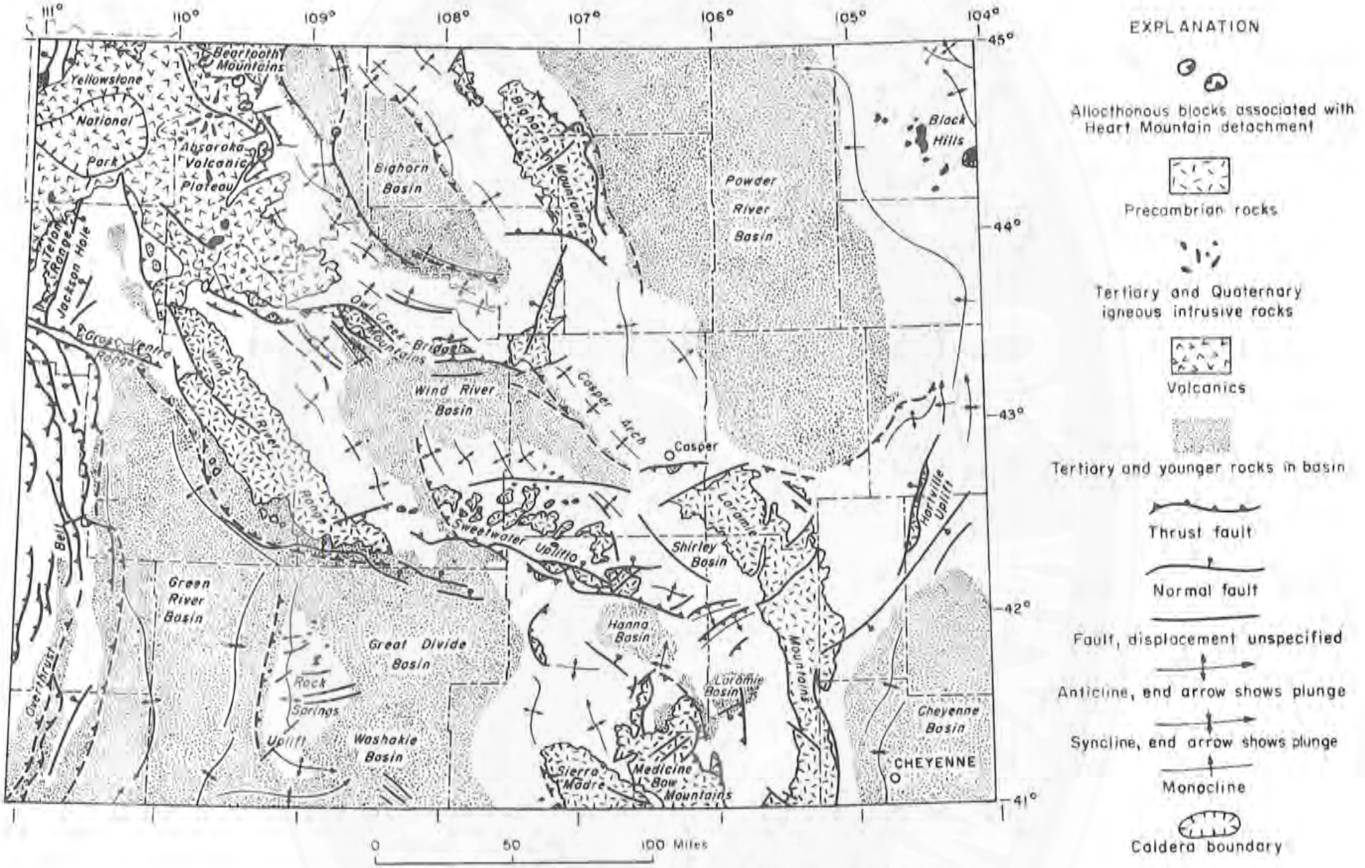


Figure 4. Major structural elements in Wyoming.

Laramie Mountains

The mountain masses of the Southern Rocky Mountains divide into three prongs just south of the Colorado-Wyoming boundary. These three prongs are the Laramie Mountains, the Medicine Bow Mountains, and the Sierra Madre in Wyoming.

Some confusion in nomenclature exists in early accounts of exploration in the State. The mountains now named the Laramie Mountains were referred to by many trappers, military men, and emigrants as the black hills because of their dark profile when viewed from the east near old Fort Laramie (Figure 5). Actually, the Laramie Mountains are the northern continuation of the Front Range of Colorado.

Figure 5. Laramie Peak, northern Laramie Mountains, viewed from the eastern plains. (Photograph by Ray E. Harris.)

Near the State Line between Wyoming and Colorado, the Laramie Mountains have been reduced to low relief. The mountains are rugged to the north, climaxed by Laramie Peak (elevation 10,274 feet), a famous landmark well known to emigrants moving westward along the Oregon Trail. The basic geologic structure of the range is of a large asymmetric arch. Precambrian rocks are exposed in its core, which is flanked by sedimentary strata.

Crossing the Laramie Mountains between Cheyenne and Laramie, Interstate 80 traverses a rolling upland of low relief at about 8,000 feet called the Sherman surface. (The feature derived its name from an old railroad station on the original route of the Union Pacific

Railroad.) Erosion during Tertiary time left a few higher granite boulder knobs such as the spectacular area at Vedauwoo.

The highest elevation on Interstate 80 is 8,640 feet, reached at Happy Jack Recreation Area in the Laramie Mountains. The highway, which was originally designated the Lincoln Highway in the national system, is memorialized by a large bust of Abraham Lincoln (the work of Robert I. Russin, Professor Emeritus of Art at the University of Wyoming) overlooking the rest area and the summit. From the summit, the road descends through Telephone Canyon down the west flank of the Laramie Mountains to the city of Laramie. Roadcuts in the canyon expose colorful sandstone and limestone of the Pennsylvanian-Permian Casper Formation.

Medicine Bow Mountains

The Medicine Bow Mountains are separated from the Laramie Range by a structural basin underlying the Laramie plains. The mountains are characterized by a rather broad, rolling upland surface approximately 9,000 feet above sea level, above which rise two areas of higher relief. The highest part of the Medicine Bow Mountains, the Snowy Range (**Figure 6**), is composed of a thick sequence of metasedimentary rock, including quartzite, that culminates in Medicine Bow Peak at 12,006 feet.

Figure 6. Looking north at the high Precambrian quartzite ridge of the Snowy Range in the Medicine Bow Mountains. (Photograph by D.L. Blackstone, Jr.)

The uplift contains an excellent record of Precambrian Archean and Proterozoic history in the western United States. A thick series of metasedimentary rocks is in fault contact along a major shear zone or suture with a younger sequence of metamorphic rocks. Stromatolites occur within 1.7-billion-year old metasedimentary rocks. Stromatolites are fossil remains of blue green algae, among the oldest forms of life known. They resemble giant cabbage heads and can be seen along the road to Lewis Lake en route to the Sugarloaf Recreation Area (Figure 7).

Sierra Madre

A topographic feature often has two or more names, depending upon who saw it and from what view. Sierra Madre is the name applied in Wyoming to a section of mountainous terrain that is continuous with a mountain mass in Colorado, known there as the Park Range.

Geologically, the Sierra Madre is quite similar to the Medicine Bow Mountains but lacks the broad upland surface of the latter. Within this mountain mass was located one of the early large-scale mining ventures of Wyoming — the Ferris-Haggarty copper mine in the Grand Encampment district.

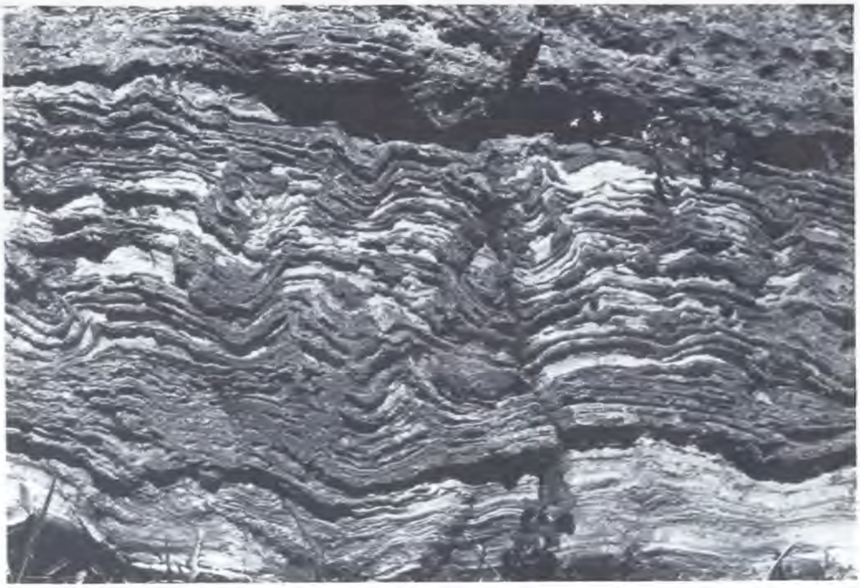


Figure 7. Stromatolites in the Medicine Bow Mountains. (Photograph by Sheila Roberts.)

The crest of the Sierra Madre is the Continental Divide. Drainages on its west flank are tributary to the Colorado River by way of the Little Snake River; drainages on the east flank are tributary to the North Platte River.

Bighorn Mountains

A more or less continuous chain of mountains sweeps in a great arc (concave to the west) from southern Montana, around the Bighorn Basin, and then northwestward toward Yellowstone National Park. The highest and most rugged part of this arc lies west of the town of Buffalo, Wyoming, where the Bighorn Mountain front rises abruptly above the Powder River Basin on the east and culminates in the spectacular summit of Cloud Peak (elevation 13,166 feet).

The structurally deepest part of the Powder River Basin lies close to the eastern Bighorn Mountain front in the area of the foothills. The difference in elevation between the top of the crystalline Precambrian basement at the deepest point in the Powder River Basin and the crest of the mountains is about 30,000 feet (5.7 miles), demonstrating the magnitude of the crustal displacement.

The Bighorn Mountains are traversed by two very scenic highways, U.S. 16 and 14/14A (Plate 1A).

Owl Creek and Bridger Mountains

At the southern sweep of the arc, a low range of mountains extends westward from the southern Bighorn Mountains to the area near Dubois. The Wind River flows north through the mountains in a magnificent canyon, the walls of which tower over 3,000 feet above the river bed and expose a spectacular cross section of the geology of a mountain range.

The Wind River Canyon divides the mountain mass into two geographic entities. The region east of the canyon is the Bridger Range and that to the west is the Owl Creek Mountains. The Wind River Canyon is so deep and precipitous that it was impossible in early days to use it as a water-level access route to the Bighorn Basin to the north. As a result, the early wagon roads crossed the Bridger Range over Bridger Pass at the head of Bridger Creek, and over DePass at the head of Birdseye Creek near Copper Mountain. The passes over the Owl Creek Mountains were Mexican Pass at the head of Mexican Draw, and Merrit Pass north of Bargee. Construction of the railroad through the canyon was instrumental in settlement and development of the Bighorn Basin. The railroad paved the way for the present highway through the canyon. Today, U.S. Highway 20 (Wyoming 789) traverses the canyon itself.

The Bridger Range and Owl Creek Mountains consist of several northwest-trending segments bounded by reverse faults. The southern margin is bounded by a major low-angle thrust fault that dips northward beneath the mountains. One of the deepest wells drilled in Wyoming (24,877 feet) is located in the Madden gas field 30 miles southeast of the canyon mouth.

Wind River Range

The Wind River Range is the largest discrete mountain mass in Wyoming and also has the highest summit peaks, such as Gannett Peak (13,804 feet), Fremont Peak (13,745 feet), and Wind River Peak (13,192 feet). Trending N40°W from South Pass City on the south to Fish Lake Mountain on the north, the range is a major barrier between western and central Wyoming. On the east, the mountain mass has an east-sloping flank of sedimentary rocks, exposed in a series of hogbacks. Glaciated peaks mark the central region and permanent ice fields lie in the higher valley heads (Figure 8). On the west side of the range, there is a broad bench-like platform at about 9,400 feet above sea level, dotted by a myriad of glacial lakes. At the base of the western flank, long deep lakes such as Fremont and New Fork occupy valleys in which glacial ice once flowed down from the higher regions onto the basin floor.

A survey by the Consortium for Continental Reflection Profiling (COCORP) used reflection seismology across the southern Wind River Range along Wyoming State Highway 28 to provide new data concerning crustal structure. The data revealed that the thrust fault along the western boundary of the range dips to the east at an angle of 30° and extends to a depth of approximately 18.7 miles (30 kilometers) (Smithson and others, 1979).

Gros Ventre Mountains

Offset a little to the northwest and across the Green River drainage from the Wind River Range are the Gros Ventre Mountains, from which the river of the same name flows northward into Jackson Hole. The peaks are sharp and rugged and largely carved from layered sedimentary rocks of Paleozoic and Mesozoic age. A major crustal fracture, the Cache Creek fault, inclines northward under the mountain mass (Plate 1B). The fault can be seen at Granite Creek near Jackson.

Figure 8. Peaks in the Precambrian core of the Wind River Range, upper North Fork Bull Lake Creek, with Mount Warren, Turret Peak, and Sunbeam Peak (from left to right) on the skyline. Dismembered blocks of high-grade metamorphosed sediments in this valley may contain evidence for the oldest crust in North America (Aleinkoff and others, 1987; Ron Frost, personal communication, 1987). (Photograph by Ron Frost.)

Teton Range

A medium sized, but unique, mountain range rises with spectacular grandeur from the floor of Jackson Hole (Plate 2A). The Teton Range block may have attained its present position by rotation on an east-dipping normal fault that reaches the surface to the west of the mountain mass. The fault at the eastern face of the range dips steeply to the east, and on this fault the floor of Jackson Hole has subsided about 15,000 feet. The rotation of the Teton Range and Jackson Hole upon these east-dipping faults has caused the strata in both instances to dip to the west. The rugged mountain peaks have been carved from the elevated segment of the crust, with matterhorns and U-shaped valleys characterizing the landforms.

The Tetons are extremely young in a geologic sense, having attained much of their height (Grand Teton elevation is 13,770 feet) within the last ten million years. This places them among the youngest ranges in the Rocky Mountains. Several minor earth tremors within historic time in Jackson Hole attest to the fact that these mountains are young and still growing.

Beartooth Mountains

The highest point in this range (also the highest point in Montana) is Granite Peak (12,799 feet), but other rugged peaks are seen rising above the Beartooth plateau in Wyoming. The south flank of the range slopes gently down into the valley of Clarks Fork River, beyond which is the vast extent of volcanic rocks comprising most of the Absaroka Mountains. Beartooth Butte, an erosional remnant of Paleozoic rocks, stands as a reminder of the sedimentary rock cover that once extended across the mountains (Plate 2B). There are many lakes on the plateau. The drive across the Beartooth Mountains from the northeast corner of Yellowstone National Park via the Cooke City-Red Lodge Highway (U.S. Highway 212) is perhaps the most scenic trip in the State.

Mountains of the Wyoming-Idaho border

Long linear mountain ridges, separated by equally linear valleys, characterize much of the region west of the Green River Basin and across the Wyoming border into Idaho. The structural style of these mountains is quite different from that of the uplifts in central Wyoming. Here the mountains are remnants of large folds, which have been forcibly pushed eastward upon fault planes that dip westward under the mountains at low angles. These faults, on which the lateral movement is measurable in miles, are called thrust faults, and this belt of mountains is known among geologists as the Overthrust Belt (Figure 9).

Figure 9. View northwest toward Mount McDougal at the head of Blind Bull Creek, Lincoln County, Wyoming. Blind Bull Creek drains west into Greys River. Light colored Cretaceous marine shales (dipping west) are overlain by coal-bearing nonmarine rocks. The Cretaceous strata are overridden by Mississippian Madison Limestone in the Darby thrust plate that moved from left to right. (Photograph by D.L. Blackstone, Jr.)

South of Jackson and the Snake River canyon, the linear ranges from northeast to southwest are the Hoback Range, the Wyoming Range, and the Salt River Range. The latter two are separated by the valley of Greys River. These ranges continue southward to about La Barge Creek, beyond which the mountain ranges have new names. The Wyoming Range continues southward as Commissary Ridge, and the Salt River Range continues as the Tunp Range, separated by the Hams Fork valley. A fourth range, between Afton and Cokeville, Wyoming, is the Sublette Range. It lies between Bear River and the Smiths Fork of the same drainage. These mountain ranges and major structures appear on a map of the Overthrust Belt by Blackstone and DeBruin (1987). West of the Salt River Range is Star Valley a major agricultural area. This valley is drained by the north-flowing Salt River. West of Star Valley are more linear ranges in eastern Idaho.

In the vicinity of Kemmerer, a low ridge facing the Green River Basin is known as Oyster Ridge (**Figure 3**) because of the abundance of fossil oyster shells in some of the sandstone ledges. Between Oyster Ridge and the Tunp Range lies Fossil syncline, containing fossil fish-bearing beds of the Green River Formation.

A major oil province, estimated to have reserves of at least 600 million barrels of oil, was discovered in the Overthrust Belt in 1975. Oil seeps were known in this region since the emigrant migration to the Great Salt Lake valley, and the tar-like residues were used to grease the wheels of wagons on the trail. Two such oil seeps south of Evanston, Brigham Young oil spring and Carter oil spring, are still active.

Granite Mountains

In 1847, the "Year of Decision" as described by the historian DeVoto (1943), about 50,000 emigrants toiled westward up the valley of the Sweetwater River after fording the North Platte near Casper and passing through Emigrant Gap and over the heights beyond. Along the Sweetwater River are some famous landmarks of the Oregon Trail – Independence Rock, Devils Gate, Split Rock, Sweetwater Crossing, and others. A number of these landmarks are composed of massive pink granite, which crops out in bald stark knobs that stand above the light colored, flat-lying sediments. The landscape is reminiscent of central Africa and parts of Australia.

The area of the Granite Mountains is unique because it was once much higher but is now structurally lower. During Eocene time, the mountains were the source of the giant boulders now found in and on top of Green and Crooks Mountains south of the Sweetwater River. Later, a period of crustal extension caused the crest of the mountains to subside about two thousand feet into a trough bounded by east-west trending normal faults.

Absaroka Range

The region along the headwaters of the Yellowstone, Shoshone, Greybull, and Wood Rivers in northwest Wyoming is perhaps the least known and certainly the least appreciated mountain area in the State. This broad rolling upland above timberline, at about 10,000 to 12,000 feet above sea level, is reminiscent of the moors of Scotland. Looking across a landscape of bogs, small lakes, and numerous small streams, there is no sense of height and few peaks. Only when one looks down into a major valley does the great vertical relief become apparent, and only then can the mountainous character of the terrain be appreciated (**Figure 10**).

The summit of the Absaroka Range is essentially a plateau coinciding with the top of a vast pile of nearly horizontal sheets of rock derived from volcanic vents probably only a short distance away. Once the pile of volcanic debris had accumulated, the region was subjected to the ever-present forces of erosion, which cut deep valleys. The Absarokas are the remnants of erosion and are a classic example of this type of mountain development.

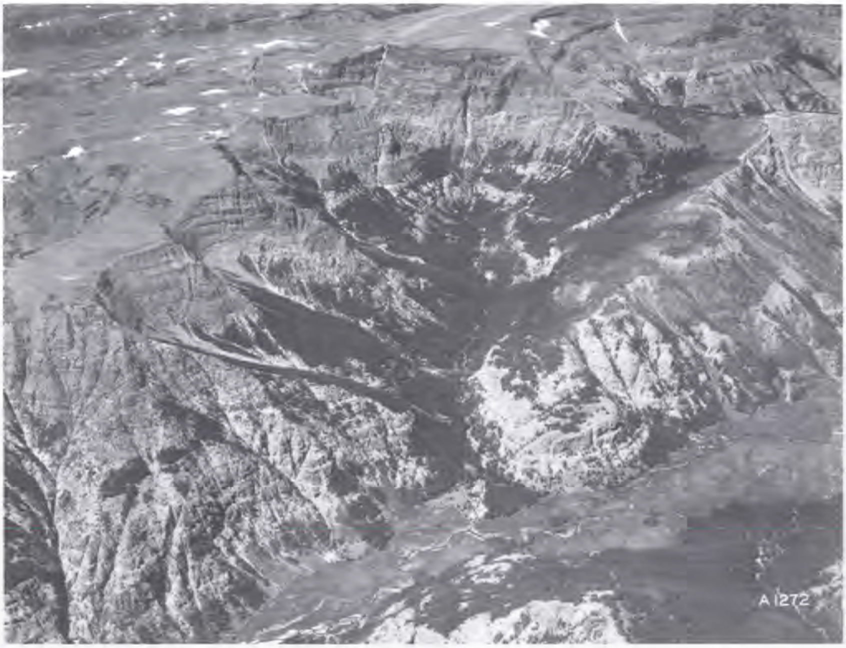


Figure 10. Absaroka Range. Air-oblique view northwest across the South Fork of the Shoshone River (elevation 8,200 feet) up the valley of Bliss Creek to the Buffalo Plateau (elevation 10,600 feet). All rocks are Wiggins Formation of Middle and Late Eocene age, chiefly water-laid andesitic volcanic conglomerates. The age of the Buffalo Plateau surface is thought to be Late Cenozoic. (Photograph by H.M. Cowling, 1936, J.D. Love collection.)

A series of igneous instrusions cut across the Absaroka volcanics along a northwest-trending line, roughly along the crest of the range. A striking example is the Washakie Needles in the southern Absarokas near the headwaters of the South Fork of Owl Creek.

In the past few years, researchers have discovered large-scale gravity movement (landsliding) that occurred in part during the period of major volcanic activity. Such activity created the Castle Rock chaos, where 50 cubic miles of material gradually moved or slid eastward away from a volcanic center located near the headwaters of the present North Fork of Owl Creek (Sundell, 1982). Volcanic debris around major volcanic vents is notoriously unstable. During Pleistocene time, the eastern margin of the Absaroka Range developed many large landslides in the area between Owl Creek and the Wood River (Bown, 1982).

Washakie Range

One mountain range in Wyoming is only partially visible. West of the Owl Creek Mountains, a series of topographic eminences including Black Mountain and Crow Mountain are separated from the western part of the main range by a broad syncline. These isolated mountains are the exposed southern segment of a feature named the Washakie Range. Most of the mountains are buried beneath the great pile of flat-lying rocks of volcanic derivation that make up the Absaroka Plateau. The full extent of the Washakie Range is not known, but it may extend as far north as the South Fork of the Shoshone River.

Basins

The scenery in the basins of Wyoming is generally regarded as less inspiring than the mountains, and the long, rather monotonous vistas of low buttes and mesas and sparse vegetation may seem to some like a lost world. A trip across one of the basins during the heat of the day in August can be a less than exciting experience, but if the same trip is made in early morning or in very late evening, the landscape has a different appearance, accentuated by low-level lighting, and it can be very beautiful.

From a geologic perspective, however, basins can be much more stimulating than some of the uplifts, and they are just as profound in terms of the movements of the Earth's crust. In fact, the amount of downfolding of the crust in the basins usually exceeds the uplift of the adjacent mountains if sea level is used as a datum. The basins are surface topographic depressions, but at the same time they are compound synclines in which the layered sedimentary rocks dip toward the lowest point (trough). Many of the critical aspects of these downwarps are hidden from the eye because they lie at great depths.

In terms of economics and natural resources, Wyoming could not prosper without the raw materials found in the rocks of these basins. Along the basin margins, the sedimentary strata often crop out in hogbacks, exposing limestone, gypsum, bentonite, phosphate rock, and building stone. Farther out in the basins are uranium deposits and some of the great coal fields of Wyoming. The rock units that extend under the basins at depth act as reservoirs for oil and gas accumulations. Products such as trona and oil shale are found in the central part of one of the basins (the Green River Basin). Artesian water conditions prevail in all basins.

Despite the rather limited vegetative cover, the wide lonesome stretches of Wyoming's basins provide a large amount of pasture that is utilized by sheep, cattle, horses, and wildlife, particularly in the winter months, when snow melt provides water for the animals.

Great Divide Basin

Some precipitation falling along the Continental Divide never flows out of Wyoming and is removed from the State only by evaporation. A basin on top of the continent, approximately 3,900 square miles in extent, contains shallow lakes that have no outlet. The Continental Divide splits near South Pass, with one part trending south-southeast and the other east. The split divide encloses an area of interior drainage, the Great Divide Basin (Figure 2). It becomes a single divide again at historic Bridger Pass, approximately 20 miles southwest of Rawlins.

Because of this bifurcation, Interstate 80 crosses the Continental Divide twice between Rawlins and Rock Springs. The first crossing is approximately 5.5 miles west of Rawlins, near the railroad siding of Hadsell. Unfortunately, the Continental Divide turnout and marker three miles west of Creston Junction are not on the divide. At the time the transcontinental highway was designated as the Lincoln Highway, someone improperly reported the location of the divide and it was marked and put into guidebooks. The current official Wyoming State Highway Commission map properly locates the divide. West of Hadsell, the highway crosses the Great Divide Basin. It reaches the second limb of the Continental Divide between Tipton and Table Rock. The Great Divide Basin is characterized by ephemeral streams, permanent and playa lakes, and scrub vegetation used largely for winter pasture. Because of the red and purple colored rocks and soil in the area, this basin is often called the Red Desert.

Powder River Basin

A very wide and moderately deep basin, which takes its name from Powder River, *a mile wide and an inch deep*, lies between the Black Hills and the Bighorn Mountains. Over broad areas, the Tertiary surface rocks contain extensive low-sulfur coal deposits that are surface mined near Gillette and Wright. In many places, natural burning of thick coals initiated by lightning strikes, grass fires, and spontaneous combustion baked the rocks overlying the coal beds in a manner similar to the action of a brick kiln. The resulting red "clinker" is resistant to erosion and caps buttes and mesas over a large area of the basin.

Along the margins of the Powder River Basin, there are oil fields such as Salt Creek, Teapot Dome, Big Muddy, and Lance Creek developed over anticlines. Beneath the ground surface, oil was trapped in porous rocks at the tops of the folds. These fields were discovered years ago and are declining in production. Exploration during the last fifteen years has concentrated on the deeper parts of the basin in search for stratigraphic traps, many at depths in excess of 12,000 feet. The oil in these reservoirs is trapped by barriers within the rocks themselves, not by folding.

Wyoming's largest uranium mine was located in the southern Powder River Basin district northeast of Glenrock. In the central part of the basin, surrounding the Pumpkin Buttes, uranium was produced from many small mines. It was here that uranium ore in commercial quantities was first discovered in Wyoming in 1952.

Bighorn Basin

A native of Wyoming speaks of having been *up in the basin country*, meaning that he had visited the intermontane depression lying west of the Bighorn Mountains and extending to the east-facing scarp of the Absaroka Range. Almost elliptical in shape, the basin is rimmed on all but the north end by mountains. Major deformation of the rocks created many large folds on the flanks of the basin, such as Big and Little Sheep Mountains north of Greybull, Oregon Basin south of Cody, and Thermopolis anticline near Thermopolis. The central portion of the basin has widespread rugged badlands carved in red and purplish claystone of the Eocene Willwood Formation, from which famous collections of vertebrate fossils have been taken (**Plate 3A**).

The basin is drained by the Bighorn River, named by Lewis and Clark in 1804 when they passed the mouth of the river (in Montana) on their way back from the Pacific. The river leaves the basin through a great canyon across the north end of the Bighorn Mountains, now partially filled by water impounded behind the Yellowtail Dam in Montana. Early trappers visiting the headwaters of the river, south and west of the Bighorn Basin, called it by a different name, so south of Thermopolis, the river bears the name Wind River (**see Figure 2**).

North of Powell, there is a 700-foot-high, gravel-capped surface called Polecat Bench. This bench was once the valley floor of the ancestral Shoshone River, which exited from the basin to the Yellowstone River by way of the deep, (now dry) canyon called Pryor Gap. Headward erosion by a tributary of the Bighorn River captured the ancestral river and diverted the flow into the channel now occupied by the Shoshone River between Cody and Lovell.

Wind River Basin

Almost exactly in the center of Wyoming, there is a rhomb-shaped topographic depression known as the Wind River Basin. Nothing about the area is simple. The mountains both to the north and south of the basin trend northwest-southeast, whereas the basin is bowed down along an east-west axis. The deepest part of the trough is in the north, immediately adjacent to the Owl Creek Mountains.

The western boundary of the basin is the east-dipping flank of the Wind River Range, characterized by northwest-trending hogbacks of sedimentary rocks. Most of the southern boundary is a north-facing escarpment, Beaver Rim (**Figure 11**), an erosional feature analogous to the Pine Ridge escarpment in eastern Wyoming and Nebraska.

Figure 11. Beaver Rim, at the southern boundary of the Wind River Basin. View is to the east from U.S. Highway 287. Relatively flat-lying Tertiary rocks in the cliff overlie more steeply dipping Cretaceous shales in the foreground. (Photograph by Sheila Roberts.)

The Casper arch, a broad upfold of sedimentary rock, forms the eastern boundary. The topographic relief is low, but the rocks are greatly elevated relative to the Powder River and Wind River Basins on opposite sides of it. Exploratory drilling revealed that the west side of the arch is actually in the hanging wall of a thrust fault with low dip to the east. There is in excess of five miles of westward movement on the hanging wall of the fault, and production of oil and gas has been established in the footwall.

The basin is bounded on the north by the geologically complex, discontinuous Owl Creek-Bridger Mountain uplift, a cross section of which can be seen in Wind River Canyon.

Within the Wind River Basin is the oldest producing oil field in Wyoming. Oil was discovered at Dallas Dome, located about six miles southeast of Lander, in 1884. The first large-scale uranium mine in Wyoming (1957) is located in the Gas Hills at the eastern end of this basin.

Cheyenne-Denver Basin

The surface rocks in southeastern Wyoming east of the Laramie Range are nearly horizontal strata of Late Tertiary age, which lie unconformably on rocks of Paleozoic and Mesozoic age downfolded into a large trough. The trough extends southward from Cheyenne to Colorado Springs, Colorado. The axis of the trough lies a few miles east of the mountain front and the deepest part of the basin is located very near Denver, Colorado.

Laramie-Hanna Basins

Between the Laramie Mountains and the Medicine Bow Mountains is a complexly downfolded area, the trend of which roughly parallels the sweeping arc of U.S. Highway 30 and the Union Pacific Railroad from Laramie to Rawlins. The area is comprised of the Laramie Basin (with its subsidiary Cooper Lake Basin) and the Hanna Basin (with its subsidiary Carbon Basin). The basins, which are shallowest to the south, reach a maximum depth in the northern part of the Hanna Basin north of the coal mining community of Hanna. The Hanna Basin is quite small as intermontane depressions go — only about 35 miles by 20 miles — but it is unique because of the great depth to which the sedimentary rocks are depressed. The floor (older crystalline basement) beneath the sedimentary rocks lies about 30,000 feet below sea level.

The basins contain a thick sequence (up to 23,000 feet) of Upper Cretaceous and Tertiary clastic sedimentary rocks derived in part from adjacent uplands. The Hanna and Ferris Formations contain thick coal seams. Coal was originally mined underground at old Carbon and later at Hanna and was used to fuel steam locomotives on the Union Pacific Railroad; now coal is extracted by underground and surface mining methods and is used as fuel in electric-generating plants.

Basins of southwestern Wyoming

There is a broad uniformity in the geology of a large triangular area in southwestern Wyoming, with its apex near Bondurant and its base along the Colorado-Utah and Wyoming border. The area is bounded on the west by the linear ranges that make up the Overthrust Belt; the northeastern margin is flanked by the Gros Ventre and Wind River Ranges and the Sweetwater uplift; and the eastern margin is bounded by the Rawlins uplift and the Sierra Madre.

The triangular area is divided into two parts by a large, elliptical anticlinal fold centered east of Rock Springs and named after the town. East of the Rock Springs uplift is a compound depression — the northern part is called the Red Desert or Great Divide Basin and the southern part is the Washakie Basin. The structural separation of the two basins is an arch that parallels Interstate 80 and passes through Wamsutter. North and west of the Rock Springs uplift is a very large structural depression, the Green River Basin, named for the river that drains the entire area.

Early in the exploration of the region, it was recognized that there were both fluvial (river) and lacustrine (lake) deposits cropping out over large areas of southwestern Wyoming. These sedimentary rocks were designated the Green River Formation because exposures of the rocks are excellent near the town of Green River. During the Eocene Epoch, very large lakes existed in this corner of Wyoming, as well as in Colorado and Utah. The lakes were fresh at the times of maximum extent, but the water level fluctuated greatly, resulting in periods when the lakes were shallow and extremely saline, allowing the precipitation of salts by evaporation. In and adjacent to these lakes, a remarkable sequence of intertonguing fluvial and lacustrine sediments were deposited, including conglomerate, limestone, siltstone, oil shale, and muddy limestone, which contain fossil fish. All these rock types are now well displayed in the badlands that form the characteristic topography of the basins. Trona and halite occur in large quantities in the central part of the Green River Basin and have been identified in the Washakie Basin. These deposits are not exposed at the surface.

The Green River lacustrine sediments contain a few thin layers in which fossil fish are abundant. West of Kemmerer, an area containing these fossil fish beds has been set aside as Fossil Butte National Monument, where one can see the beds in place and view an exhibit of fossil fish.

Jackson Hole

The small basin in northwest Wyoming lying at the foot of the Teton Range is very young (Plate 2A). It was created by crustal subsidence beginning in Late Miocene time, 8 million years ago, and continuing to the present. The downwarping was accompanied by volcanic activity that created tuffaceous sediments such as those seen at Signal Mountain. The basin was a hideout for an early-day group of individuals described as "the wild bunch". Now the area is very popular with geologists, skiers, hikers, fishermen, and hunters because it offers a wide range of recreational opportunities. A part of the basin near Jackson was designated a National Elk Refuge in 1912 and another part of it is located in Grand Teton National Park.

Landscape styles in Wyoming

The present landscape of Wyoming is the ever-changing product of a long series of events extending back in geologic time almost to the inception of the earth as a planet. Major events in the Earth's history are recorded in the rocks, and hence in some fashion influence the landforms of the present. Wyoming's crust, about 22 miles (35 kilometers) thick and composed of dense, crystalline, igneous and metamorphic rocks, subsided relative to sea level for a long period of time. Several thousand feet of sedimentary rock accumulated beneath the oceanic waters or along the shoreline areas of ancient Wyoming. In a period of strong crustal movement termed the Laramide orogeny, which began in Late Cretaceous time, the essentially flat-lying sedimentary rocks were uplifted, folded, and fractured, creating much of the present geologic structure and outlining the present mountains and basins. The episode of mountain building elevated the rocks above sea level and, together with further elevation in Late Tertiary time, provided the necessary gradients whereby the streams could dissect the rocks into the existing landforms.

The underlying principles governing the development of the landscape were set forth by William Morris Davis (1909), dean of American geomorphologists. Davis postulated that geologic structure or spatial arrangement of the rock units is the dominant control in the evolution of landforms. He also set forth the concept that each geomorphic agent (i.e. running water, glaciation, wind, wave action) develops a characteristic set of landforms that can be readily recognized. Further, there are recognizable stages in the development of landforms that Davis termed youth, maturity, and old age. These concepts have been modified but they are still useful in describing the development of a landscape.

Erosional landforms

Erosion is the term applied to the process whereby agents such as running water, wind, waves, and ice pick up and transport rock debris. Running water is the most common agent of erosion in Wyoming, though on some days wind seems to be a close second. Erosion by running water forms an intricate network of drainage channels. The components of the channel system have a wide variety of names depending upon the location and historical background. Creeks, gullies, gulches, arroyos, canyons, coulees, draws, sags, ditches, and washes all are products of downcutting by streams that demonstrate the continual erosion of the land surface.

There are a few standard landforms that are repeated in endless variation and at many scales. Most of them are determined largely by the variation in resistance to erosion of the rock units. Basic landforms are illustrated and briefly discussed in the following section.

Simple dendritic drainage pattern

The bedrock is massive and relatively homogeneous in character and is modified by stream action. The result is a system of relatively evenly spaced streams forming a dendritic pattern (**Figure 12**). Continued erosion eventually results in a maximum of slopes. The central Laramie Range provides a good example.

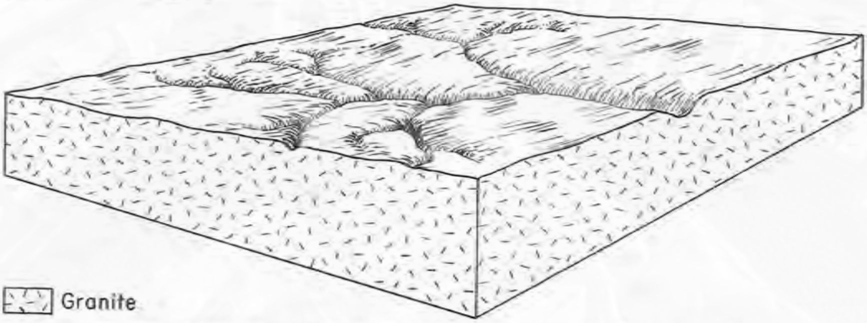


Figure 12. Dendritic (branching) drainage pattern developed on homogeneous rock (in this case, granite).

Landforms developed on flat-lying sedimentary rocks

The bedrock consists of essentially flat-lying alternating layers of shale and sandstone or other rock types of variable hardness. The major landforms are retreating escarpments forming canyon rims, with isolated outliers capped by the resistant layers standing as plateaus, buttes, or mesas (**Figure 13**). Landforms of this type are prevalent in southeastern Wyoming and in the northern Green River Basin.

Landforms developed on heterogeneous tilted sedimentary rocks

In areas underlain by tilted sedimentary rocks, stream valleys develop on the less resistant rock types such as shale, and the harder rock units are expressed as ridges. Streams cross the ridges through water gaps, and the drainage pattern is rectilinear (**Figure 14**). The major streams, which cross many ridges, follow superimposed drainage patterns that were probably established when the presently exposed rocks were buried under other sedimentary material. Excellent examples of such topographic features can be seen west of Thermopolis, at Red Grade south of Lander, and at Bessemer Bend west of Casper.

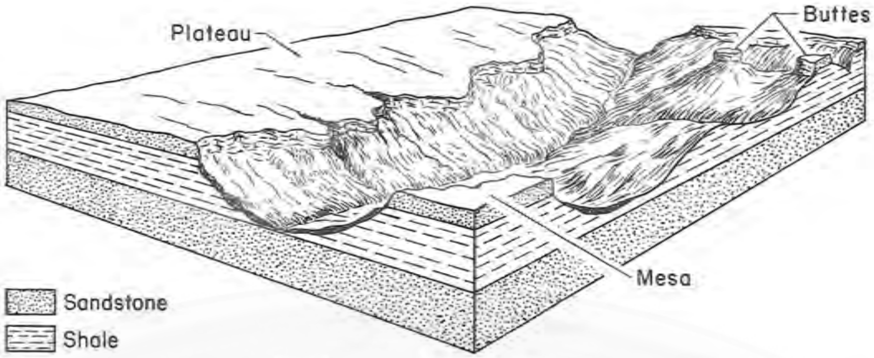


Figure 13. Landforms developed on flat-lying sedimentary rocks, for example resistant sandstone and nonresistant shale.

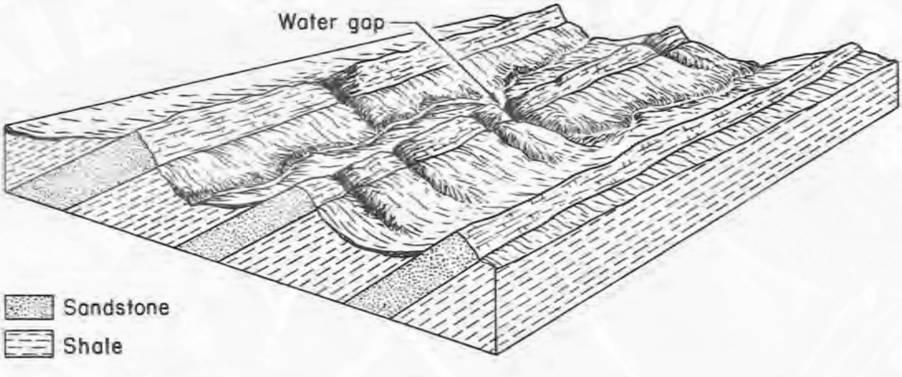


Figure 14. Hogback sandstone ridges and shale valleys developed on heterogeneous tilted sedimentary rocks.

Landforms developed on folded and faulted sedimentary rocks

If the sedimentary strata have been folded or broken by faults, complex patterns of ridges and valleys may develop. Zigzag ridges, "racetrack" valleys, and discontinuous ridges are common (Figure 15). Closed topographic basins are also possible results of this situation. Oregon Basin south of Cody and Salt Creek anticline at Midwest are examples of this type of topography.

Landforms resulting from action of glaciers

The combined actions of frost, permanent snow fields, and glaciers characterize regions of mountain glaciation. Such conditions prevail now at high elevations in Wyoming in the region of the Dinwoody and Gannett glaciers in the Wind River Range, but were much more widespread during the Pleistocene, commonly called the last ice age, which began about 1.6 million years ago.

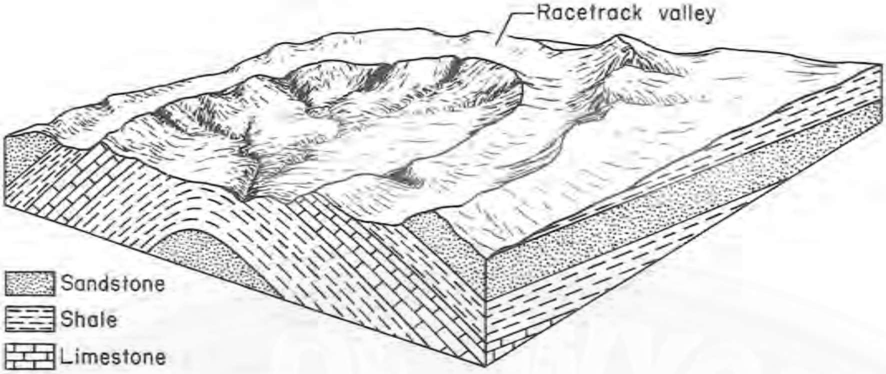


Figure 15. Landforms developed on folded sedimentary rocks.

During the Pleistocene, glacial ice and permanent snow fields occupied stream-cut valleys already in existence. The ice and rock carried by the glaciers smoothed and widened the older valleys and left valleys with U-shaped cross-sectional profiles. Sharp peaks or horns, shaped like the Matterhorn of the Alps, characterize the major divides, and great steep-walled bowls called cirques lie at the heads of the valleys. Rock-floored lakes are common. Side valleys seem to hang above the main valley, and streams cascade down from them in waterfalls (**Figure 16**).

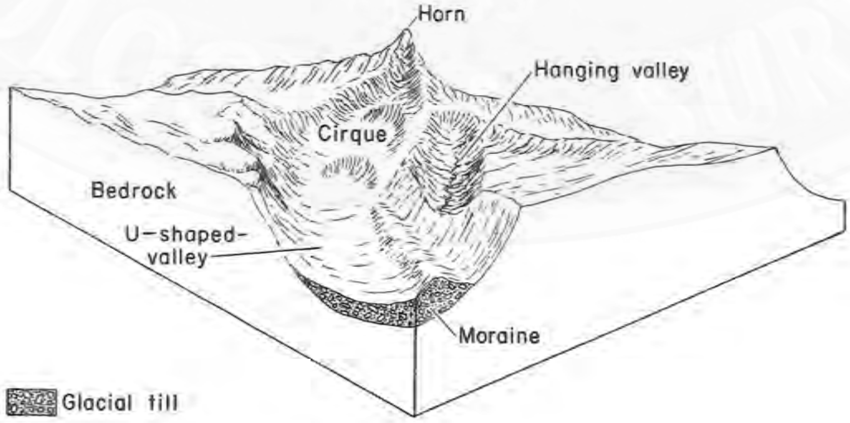


Figure 16. Landforms created by the action of glaciers.

The Pleistocene climate was very severe and at times extremely arid. In Wyoming, glaciers occupied high mountainous areas and some of the lower elevations were underlain by permafrost, as evidenced by fossil ice wedges and polygons (Mears, 1987). Glaciers moved down the mountain valleys and advanced out onto the plains where their maximum advance is marked by moraines, piles of debris carried by the glacial ice and left behind when the ice melted (Figure 17). During dry interglacial intervals, extensive sand dunes formed and were spread northeastward across the State by prevailing winds (Figure 17). Caves formed during the wetter intervals in many areas (Figure 17).

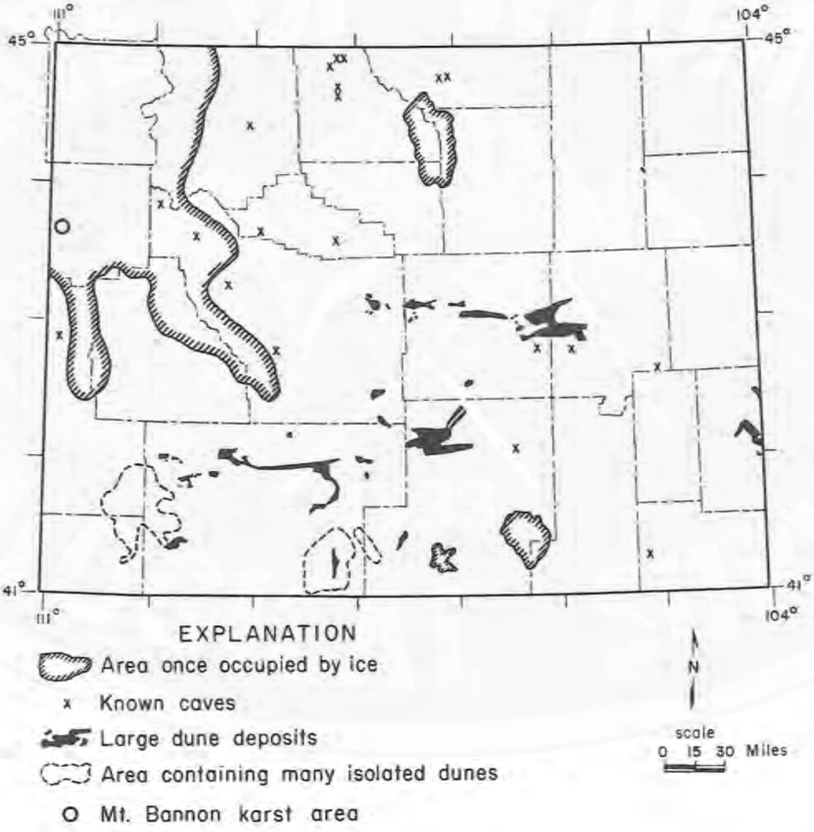


Figure 17. Map of Wyoming showing areas occupied by glaciers during the Pleistocene ice age and the location of sand dunes and caverns probably developed during the same period. (Sand dune distribution modified from Case and Boyd, 1987; cave localities from Hill and others, 1976.)

Landforms developed primarily by solution of limestone

The requisite conditions for the formation of limestone caves are quite simple. The underlying rock must be limestone or dolomitic limestone that is reasonably thick and extensive. The region should be humid, with 40 or more inches of precipitation per year. The cavern system is likely to be more extensive if the rocks are not strongly tilted or folded.

Water from rainfall, snow melt, and stream flow percolates downward from the ground surface through factures and along bedding planes and moves laterally toward lower elevations. Such surface water takes carbon dioxide into solution, which combines with the water to form carbonic acid. Natural organic acids derived from decaying plants may also be added to the water. The natural acid dissolves the limestone and removes it as a soluble bicarbonate. Continued underground movement of the acidic water will dissolve large amounts of limestone and create underground openings, channels, and caverns.

The first stage of cave development is the creation of an underground opening during a period of abundant water supply, such as the Pleistocene ice age. The second stage occurs under a diminished water supply and may result in deposition of calcium carbonate in the form of stalagmites and stalactites, which give some caves their spectacular linings.

Classic examples of landforms developed by solution of limestone are found in the Karst of Yugoslavia, the Mammoth Cave region of Kentucky, and Carlsbad Cavern region of New Mexico. Caves are found in all parts of Wyoming where thick Paleozoic limestones crop out at the surface. The locations of some districts containing caves are shown in **Figure 17**. One of the most spectacular karst surfaces in Wyoming is located on the west flank of the Teton Range (see **Figure 17**).

Special situations result in sinks, such as those in Dinwoody Canyon and in Sinks Canyon near Lander. In these places, the limestone dips away from the core of the Wind River Range. Surface water enters porous zones along the bedding planes of the rock and moves downward below stream level. Fractures in the rock farther downstream provide a route for the water to move upward to the surface (**Figure 18**). The channel through which the water moves is enlarged by solution to accommodate all the stream flow except spring floods, when overflow goes down the regular channel.

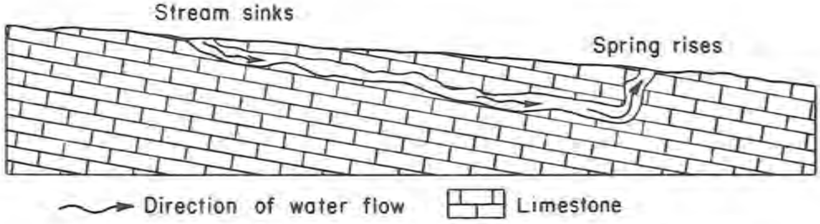


Figure 18. Simplified diagram of the flow of water at a sink.

The term ice cave is applied to any natural cavern in which ice is preserved during the summer months. In the winter, air temperature frequently falls below freezing, the colder and heavier air flows down into the cavern, and any water seeping into the cave from the walls is frozen, building an ice pan up from the bottom (**Figure 19**). During summer months, the air above the cavern mouth is warm and rises upward, allowing the colder air adjacent to the ice to remain in the cave. Melting under such circumstances is very slow; therefore, some ice may remain in the cave from season to season.

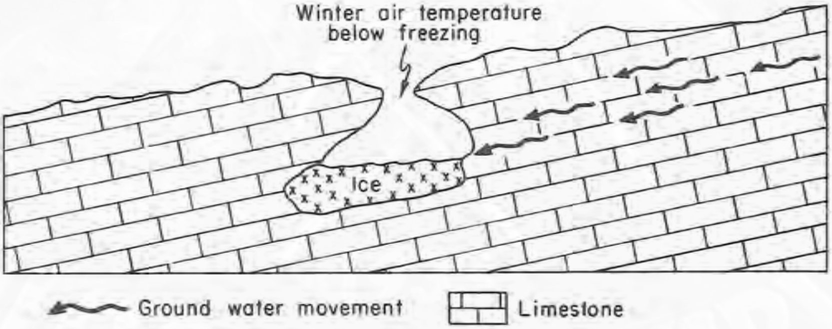


Figure 19. Cross section showing formation of an ice cave.

Landforms developed along mountain flanks

The flanks of many mountain ranges in the arid west are characterized by long sweeping slopes of low relief, which extend out into the basins away from the higher regions. These surfaces, or benches, have slopes of only a few feet per mile and are quite smooth. The surfaces are preserved on the divides between present stream courses and present a very uniform profile in cross section. Another characteristic of such erosion surfaces is that they bevel or truncate underlying rocks having varying degrees of dip and varying resistance to erosion. A thin veneer of cobble-sized gravel usually caps the surfaces (**Figure 20**).

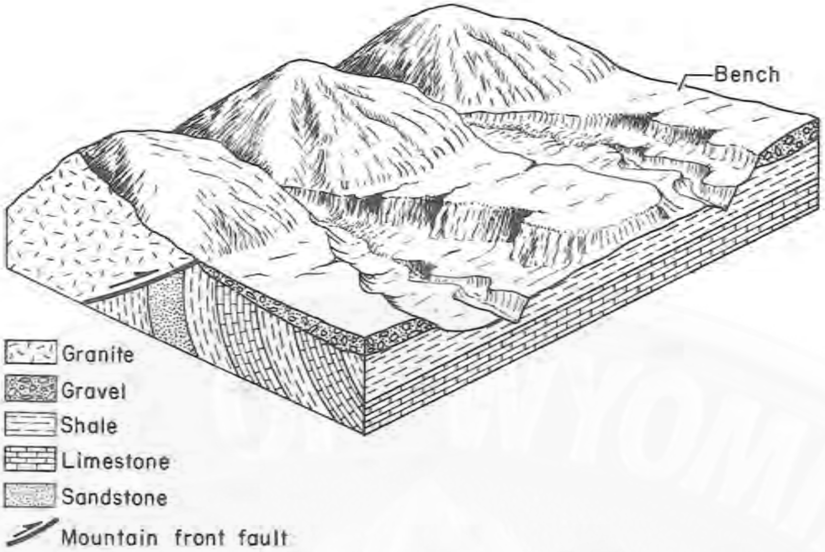


Figure 20. Gravel benches along a mountain front. Upturned strata are beveled to a sloping surface and veneered by gravel.

The described landform has in the past been called a pediment, reflecting its position at the foot of a mountain. Today geomorphologists prefer the term bench to describe these forms. The presence of gravels is evidence that the area was once the floor of a stream valley, and that beveling of underlying rocks has taken place. The present position of the gravels on interstream divides indicates that erosion has lowered the intervening areas causing an inversion of relief as gravels protected the bench from erosion (**Figure 21**).

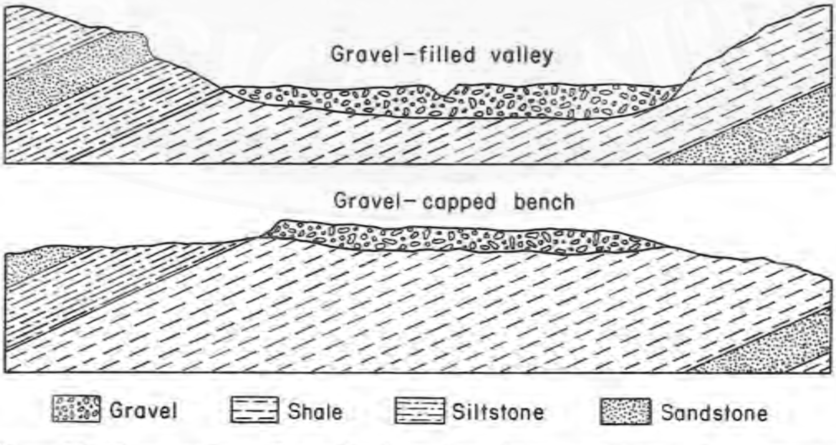


Figure 21. Cross sections illustrating inversion of topographic relief in formation of some gravel-capped benches.

Landforms developed by wind

In arid and semiarid regions the wind is a powerful erosive agent. Throughout southeastern Wyoming and northeastern Colorado there are many large undrained depressions, or blowouts, that were excavated by wind action during a particularly dry interglacial epoch. Some blowouts now receive runoff from irrigation and contain lakes. There is a very large, nine-mile-long, wind-eroded depression, known as Big Hollow, west of the Laramie Municipal Airport and south of Wyoming Highway 130 en route to Centennial.

Depositional landforms

Stream deposits

In the process of moving its load of sediment, a stream works intermittently. During periods of flood, a great deal of material is moved along the bed of the stream and in suspension in the water. During normal flow, streams move much less sediment.

The gradient of streams flowing out of areas of high elevation often changes drastically at the canyon mouth. When the velocity of the flowing stream decreases it loses some of its transport power and therefore drops some of the sediment load. Coarse materials (boulders, cobbles, gravel) are deposited near the gradient break and finer materials (sand, silt, clay) are deposited farther away. This sediment builds up an alluvial fan spreading away from the canyon mouth.

During high water, rivers and streams overflow their banks. As the water levels fall, deposition occurs and the available sediment load is spread out on the floodplain (**Figure 22**). The wide flat floors of major rivers are the result of such deposition. Most streams have floodplains. Such valley bottoms are often the sites of farms and ranches in the west.

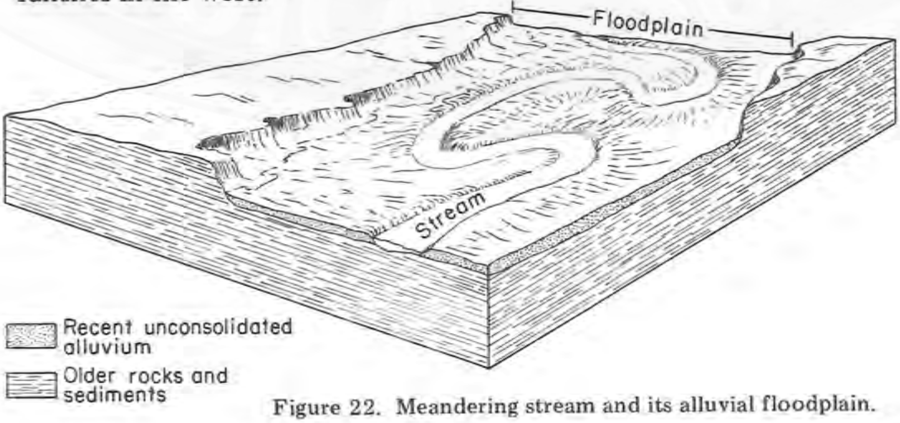


Figure 22. Meandering stream and its alluvial floodplain.

Eolian deposits

Material that is picked up by the wind when blowouts are eroded is moved across the country and may be deposited locally to form dunes (**Figure 23**). Sand dunes are common in a rather wide belt across central Wyoming, from a point near Farson to a point northeast of Casper (**Figure 17**). Some of these dunes are actively moving, but others have been stabilized by vegetative cover. The dunes are as much as 200 feet high, and the landscape includes low rolling hills and small undrained depressions.

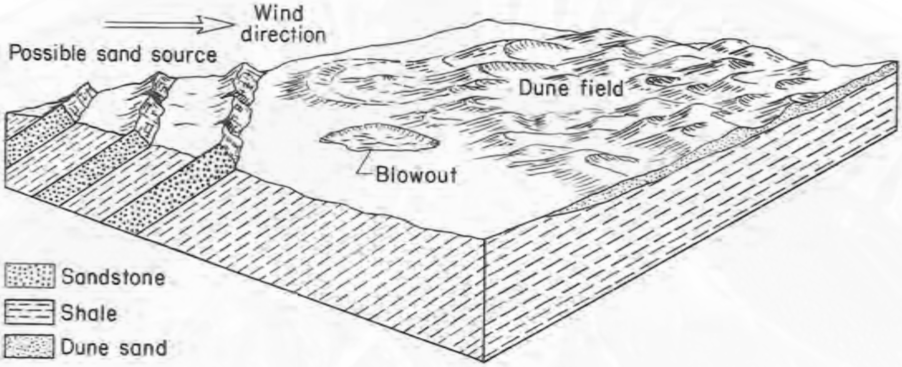


Figure 23. Sand dune field and a blowout.

Deposits related to slope movements

The force of gravity is continually acting upon all rock masses, moving them to lower elevations. Commonly, this force results in rock slides, rock falls, creep, mudflows, debris flows, and landslides. The general term, mass wasting, is applied to such types of gravitational transfer of material. Sometimes the transfer is slow and scarcely perceptible, but sudden, violent and catastrophic mass movements do occur. Classification of mass-wasting phenomena is based on the type of movement as well as the rate of movement, which are often related to the type of material involved and the degree of water saturation.

Many hillsides in Wyoming show scars where landslides have detached, and irregular piles of debris that have moved downslope under the action of gravity occur at the base of the slopes (**Figure 24**). In a few unfortunate situations, highways have been located across ground that is unstable due to mass-wasting phenomena, or highway excavations have created unstable slopes, thus starting mass gravity movements.

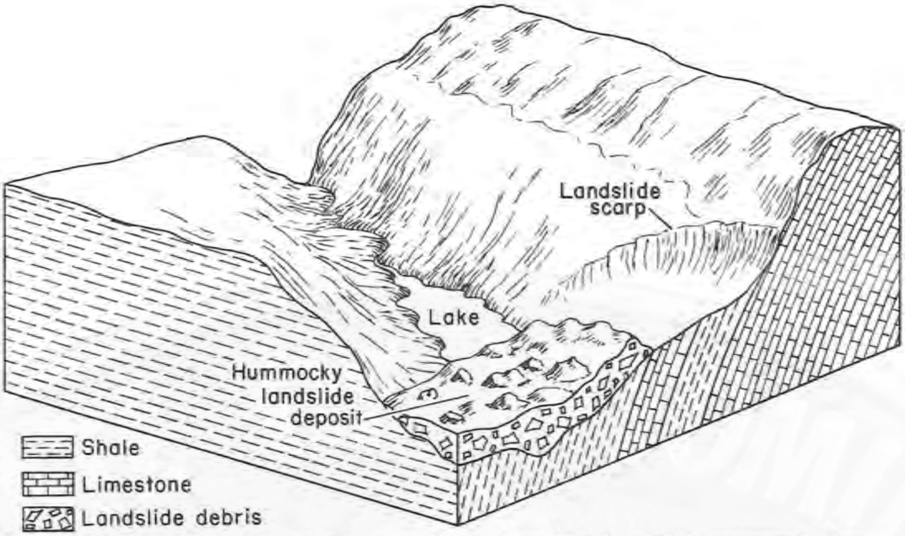


Figure 24. Landslide along a steep-walled valley. The landslide occurred when material broke off the hillside along the scarp and slid onto the valley floor, damming a river and creating a lake. The Gros Ventre slide in northwestern Wyoming is an especially good example of this type of mass movement.

Playa lake deposits

In regions of low rainfall, surface waters derived from sporadic rain storms and limited snow melt may accumulate in depressions previously eroded by wind or other action. These intermittently flooded depressions are called playa lakes. The water may not be over a foot or two deep and usually evaporates completely in the early summer. The floors of playa lakes are very flat and are covered by fine clay, silt, and saline minerals carried in by surface water.

Over the years, the saline content of playa water becomes very high. Dissolved mineral matter is precipitated as salts when the water is removed by evaporation, and some playa lakes actually have salt layers interbedded with clays. These lakes are commonly termed alkali because of the white crusts of bitter, astringent salts that line their shores and beds. Some good examples of playa lakes are found near the Sweetwater River. Deposits of the evaporite mineral natron are the source of the name Natrona County. Playa lakes are found in all the non-mountainous areas of the State.

Common minerals occurring in these lakes, all of which may form white crusts are:

Glauber salt — mirabilite	$Na_2SO_4 \cdot 10\,H_2O$
Epsom salts — epsomite	$MgSO_4 \cdot 7\,H_2O$
Natron or sal soda	$Na_2CO_3 \cdot 10\,H_2O$
Trona	$Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$

Glacial deposits

By definition, a glacier must be a moving body of ice. In this sense, a glacier is a type of conveyor belt that carries rock debris from the cirque at the head of the glacier and from the walls of its glacial valley down onto the plains. At the lower elevation of the plains, the air is warmer and the ice melts as rapidly as it advances down the valley. Here the glacier (conveyor belt) is unloaded, and an irregular pile of rock debris is deposited.

The topographic features formed by this debris are called moraines. The unsorted material of which they are composed is called till. Moraines characteristically have hummocky surfaces with small irregular undrained depressions and are strewn with both large and small boulders called glacial erratics (**Figure 25**).

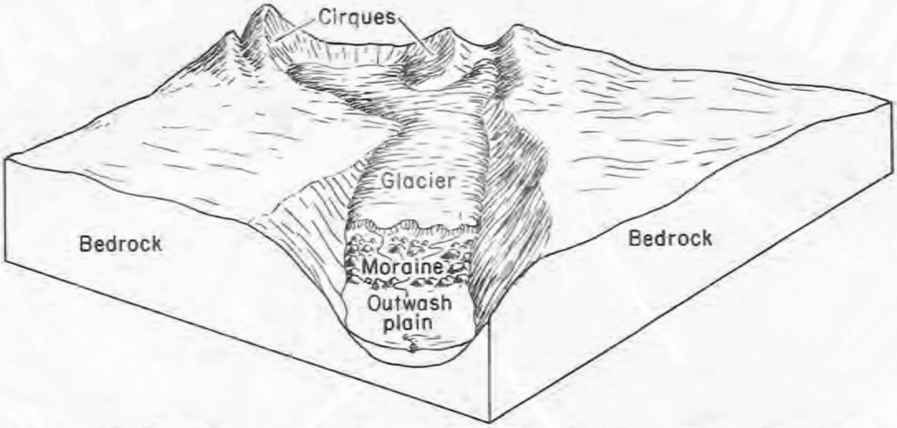


Figure 25. Glacial moraine and outwash associated with an active valley glacier.

The maximum advance of the ice in valley glaciers is marked by a terminal moraine and later stages in the recession of the ice are marked by end moraines. Fine examples of terminal moraines are crossed by U.S. Highway 26/287 between Fort Washakie and Dubois. Lateral moraines, long ridges much like railroad embankments, are deposited in some cases along the valley walls and reflect the level to which the ice filled the valley.

Along the west flank of the Wind River Range, a series of large lakes including New Fork, Willow, Fremont, Half Moon, and Boulder Lakes are the result of the impoundment of water behind moraines, which act as natural dams.

The melting of glaciers provides a great flood of water that is capable of moving large volumes of rock debris, which is often spread out in a sheet beyond the terminal moraine as an outwash plain.

Deposits related to thermal springs and geysers

The temperature of the earth increases with depth at a rate of approximately 18°F/1,000 feet, so ground water circulating at depth will be heated before discharging at the surface. Thermal springs are natural discharges of ground water at temperatures appreciably above the local annual mean air temperature. Some waters may be near boiling, others merely warm.

Surface discharge of heated waters may result in deposits of calcium carbonate or silica, which build up in terraces or mounds around the discharge points. The calcium carbonate deposits, called travertine, are usually porous and spongy, though they may also form a massive deposit. The siliceous deposits are denser and thinly laminated and are called siliceous sinter.

Sizable thermal springs occur in Wyoming at Saratoga, Thermopolis, Granite Creek, Kendall, Cody, and Auburn. Thermopolis Hot Springs is an excellent example of how a hot spring may form (Figure 26). Thermal springs are common in areas of recent volcanic activity such as Yellowstone National Park, where we see fumaroles, mud pots, steam vents, hot springs, and geysers. Yellowstone National Park is described by some geologists as a mantle "hot spot", over which the Earth's crust is slowly moving southwestward. Associated with the more or less permanent rising plume of heated material from the earth's mantle is a subsided area containing Yellowstone Lake and associated lava flows. This is a huge caldera similar to Crater Lake in Oregon.

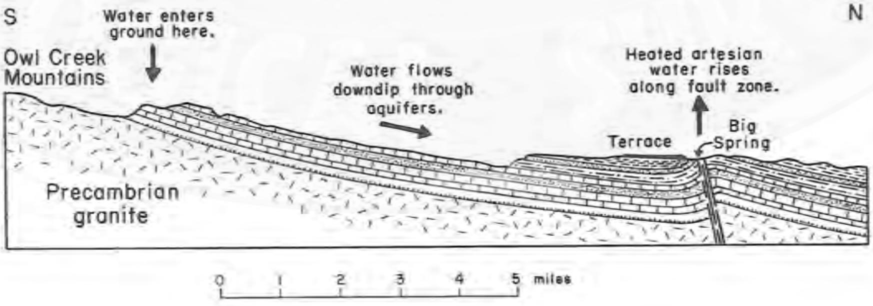


Figure 26. Cross section showing circulation of water that created Thermopolis Hot Springs. The water circulates through Paleozoic rocks northward from the flank of the Owl Creek Mountains to a depth sufficient to heat it to a temperature of 135°F, then rises along a fault and discharges at Big Spring.

The most spectacular thermal phenomena are the geysers, named after the first described example in Iceland — the Geysir. A geyser requires a heat source, a complex network of cavities to contain the water, and a renewable supply of ground water. The underground water fills the cavities and is heated by the surrounding hot rocks to the boiling point, which varies at different pressure levels in the system. A release of pressure due to any agitation, such as the escape of dissolved gas, causes the heated water to convert to steam and erupt to the surface. The regularity of many geyser eruptions is amazing.

A striking feature of many terraces and pools associated with thermal springs is the brilliant color. The colors are due to algae that live in hot or boiling water, and, as a result of their life processes, deposit calcium carbonate. The different colors are produced by different algae that live in areas of different water temperature. If water is diverted from the terraces for any reason, the travertine immediately becomes dull and dead looking because of the absence of colorful algae.

Landforms due to igneous activity

Dikes, lava flows, volcanoes, and volcaniclastic debris

Volcanic activity takes many forms. Molten lava may rise to the surface through fissures and move laterally as lava flows of wide extent or it may rise through a cylindrical central vent and flow away in all directions to form a low cone similar to Mauna Loa in Hawaii. Some central vents are characterized by violent explosive activity, spewing forth broken rock, fine-grained debris (ash and blobs of molten lava bombs), and large volumes of gas, eventually building a steep-sided composite volcanic cone (Figure 27). The eruption of Mount St. Helens in 1980 is a classic example of an explosive-type volcano.

The slopes of large volcanic cones are unstable and volcaniclastic debris moves down the slope periodically as debris flows comprised of water, rock fragments, and the finer grained ash.

The Absaroka volcanic field in northwestern Wyoming developed in Eocene time and contains examples of a wide variety of volcanic activity. It is composed of a thick, widespread, relatively undisturbed sequence including lava flows and volcanic debris, as well as some intrusive rocks, from which the present mountainous topography was carved. Lava that cooled and crystallized in fissures remains as dikes (commonly thin, near-vertical, tabular bodies of rock). Volcanic ejecta makes up much of the rock along U.S. Highway 14/20 between Cody and Yellowstone National Park, and excellent exposures are also seen in the cliffs north of Togwotee Pass on U.S. Highway 26/287. The Absaroka Range occupies an area of approximately 3,000 square miles.

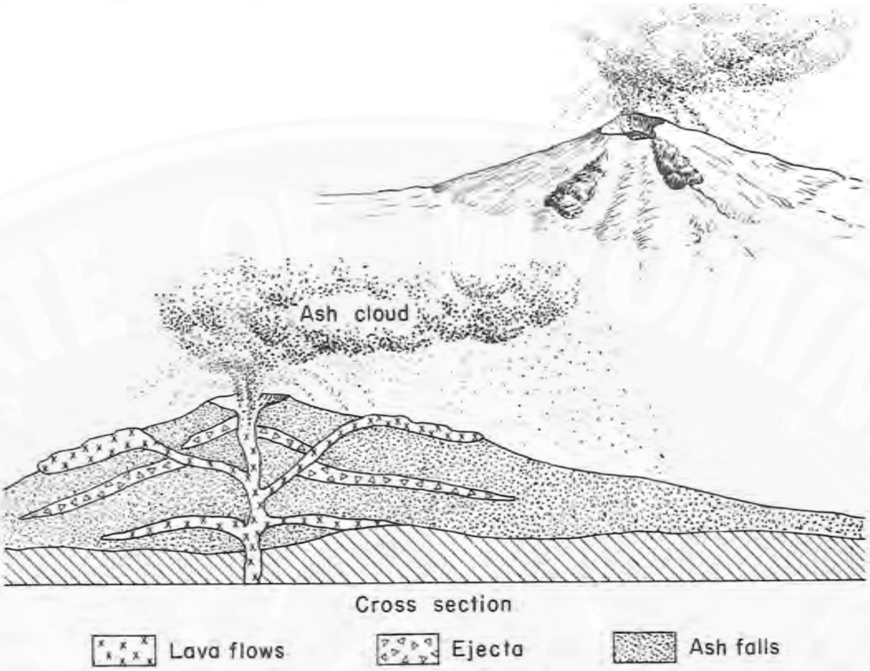


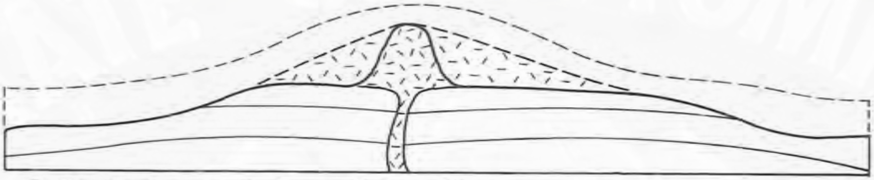
Figure 27. Cross section of typical composite volcano composed of lava flows, ash falls, and other ejected material.

Cores of igneous intrusions

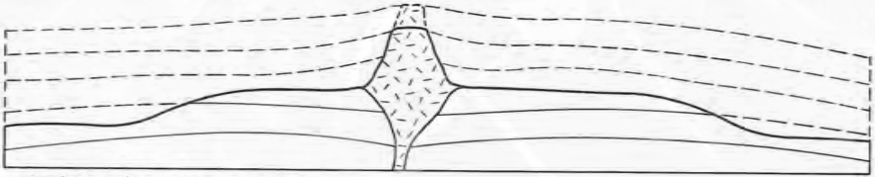
Small igneous intrusions can be seen in a few areas where the surrounding rock cover has been stripped away. Examples of such intrusive bodies are Devils Tower, Sundance Mountain, Washakie Needles, Boars Tusk, and several bodies in the Rattlesnake Hills, which stand up as isolated hills or peaks. Devils Tower (Figure 28) is a good example of this type of feature; it may have formed in one of the two scenarios shown.

Igneous bodies of this type are usually ovoid in plan view, and less than a half mile in diameter. The method of emplacement seems to be a type of jetting action, though some may take advantage of previous fracture systems. Southeast of Laramie near the Wyoming border, there are diamond-bearing kimberlite intrusions which do not stand out because they are made of material that is less resistant to weathering than the surrounding rock.

A.



B. Erosional remnant of a small laccolith.



C. Intrusive plug or neck.

Figure 28. (A) Devils Tower as it appears today (photograph by Sheila Roberts); (B) and (C) are two possible scenarios for the development of Devils Tower. Heavy lines represent the present land surface; dashed lines represent previous land surfaces, showing progressive stages of erosion.

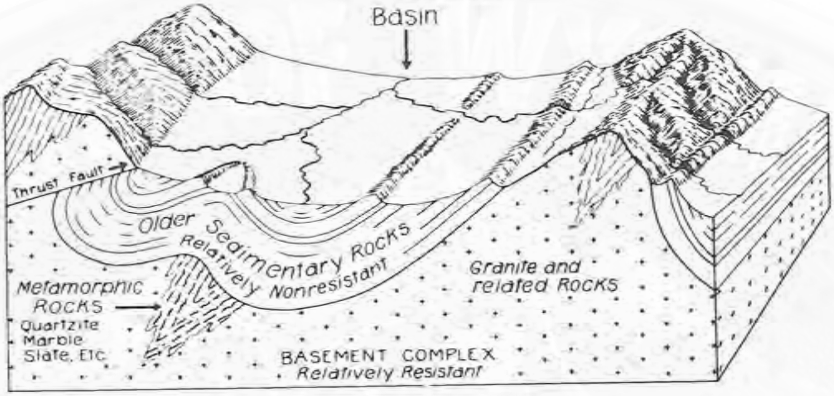
Summary

The types of erosional (destructional) and depositional (constructional) landforms described above may be found either in conjunction or superimposed. Currently, the forces of erosion are dominant in Wyoming, and there is a steady wearing away of rocks and a reduction in elevation of the land surface. The cycle is endless, but through a complex series of interactions, the continents remain high, and the land persists.

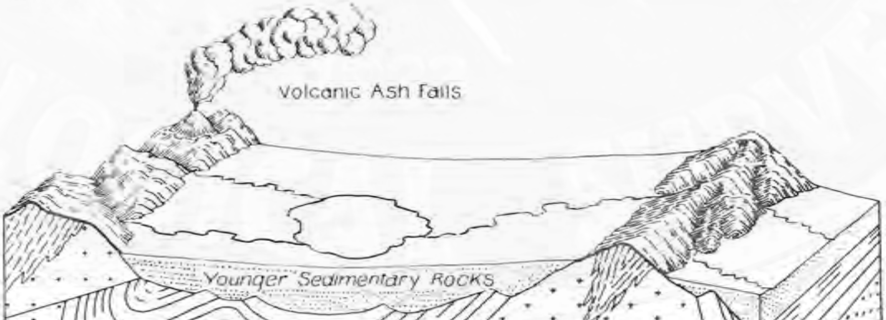
Block diagrams illustrating landscape evolution

In order that the general public might better understand evolution of the landscape of Wyoming from Late Cretaceous through the present, the late Dr. S.H. Knight, former Wyoming State Geologist and Professor of Geology at the University of Wyoming, prepared the block diagrams shown below (Figure 29).

Figure 29.

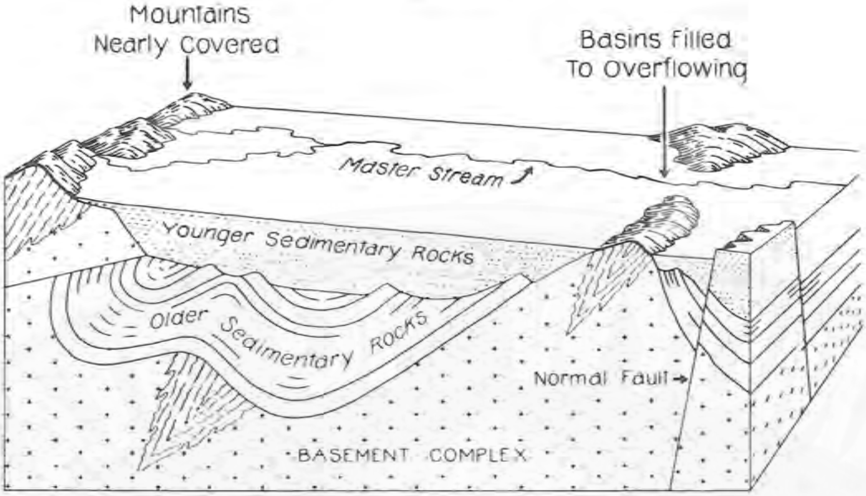


(A) Mountains and basins formed by folding and faulting, extensively modified by erosion.

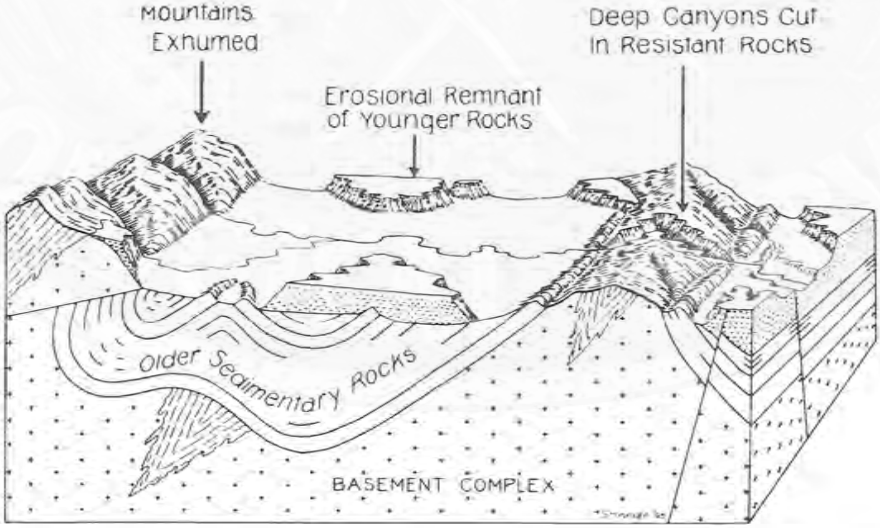


(B). Basins partially filled with younger sediments derived from adjacent mountains and intermittent volcanic ash falls.

Figure 29.



(C). Basins filled to overflowing at low places on divides, followed by regional uplift with tilting and faulting. Present master streams developed on rejuvenated surfaces.



(D). Present cycle of erosion — basins partially excavated. Youthful canyons cut across resistant cores of mountains. Such great canyons as the Wind River and the Bighorn, and several canyons along the North Platte River evolved. Basin floors are lowered as canyons deepen.

Mountain building - how rocks are deformed

Most sedimentary rocks are deposited as nearly horizontal layers, but many have subsequently been tilted and fractured. The change in position and arrangement of rock units is the part of geology referred to as structure. A few terms are necessary to properly describe the position of rock bodies in space.

Some terms used in structural geology

Strike and dip

If the tilted rock body is layered (like a cake), we can describe the tilt in terms of the strike and dip of the rocks (**Figure 30**). Strike is the compass bearing (relative to north) of a line formed by the intersection of a planar rock surface and a projected horizontal plane. Imagine a tilted planar body of rocks sitting in a lake. The water surface is a horizontal plane that intersects the rock surface. The intersection of these two surfaces is a line, which is analogous to a strike line. It might be reported, for example, as N76°W.

Dip is an angle measured downward from the horizontal to the planar rock unit. The value is measured in a vertical plane oriented at right angles to the strike and is reported in degrees.

Faults

Faults are breaks or fractures creating planes of discontinuity in the rock body. Fault planes vary in attitude from flat to vertical but are generally inclined at angles varying from 30° to 60°. A normal fault is one on which the hanging wall appears to have moved downward and the rock body is extended (**Figures 31 and 32**). If the hanging wall appears to have moved upward and the rock mass is compressed, the fault is designated a reverse fault (**Figure 31** and Plate 3B).

The terms hanging wall and footwall are old miners' terms that have been carried over to technical vocabulary. If the miner stands in the fault zone, the section overhead is the hanging wall and that underfoot is the footwall.

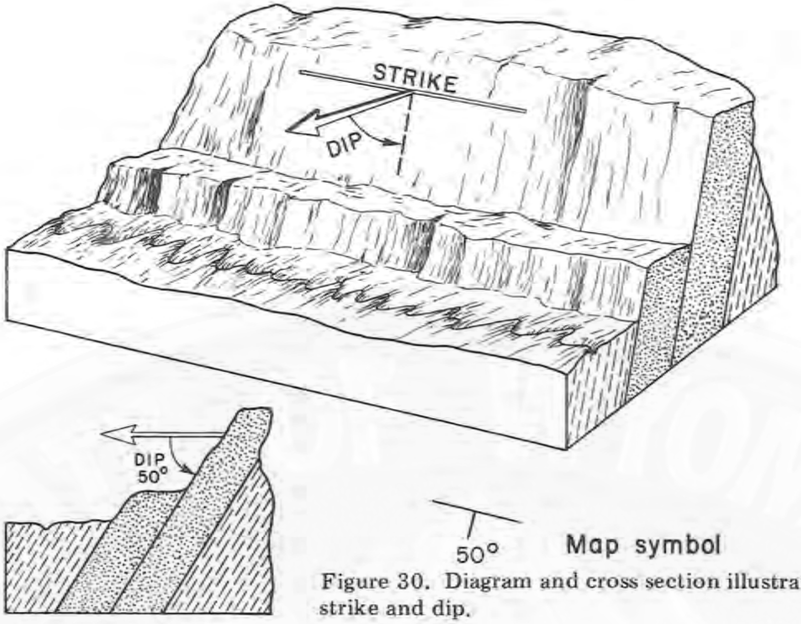


Figure 30. Diagram and cross section illustrating strike and dip.

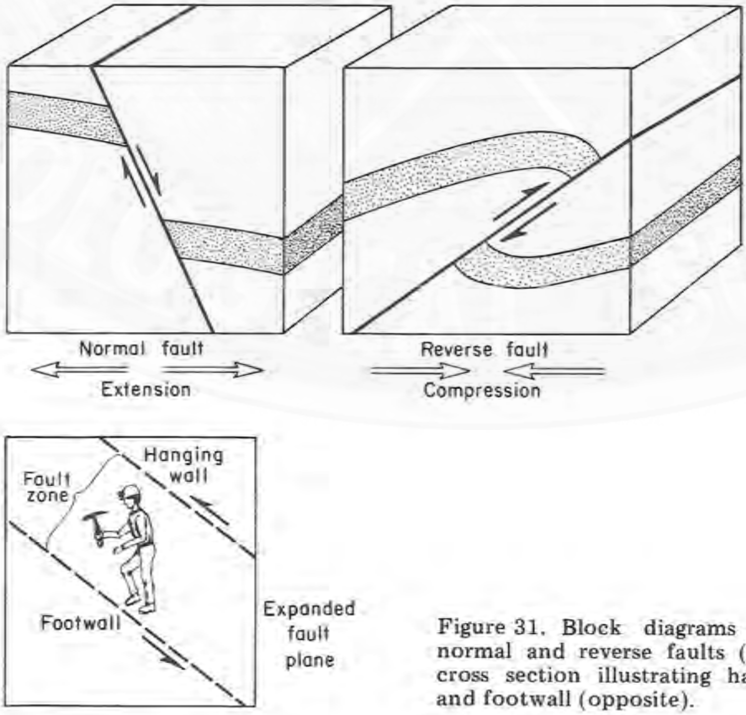


Figure 31. Block diagrams illustrating normal and reverse faults (above) and cross section illustrating hanging wall and footwall (opposite).

Figure 32. Normal fault in the Cretaceous Cloverly Formation on the north flank of the Freezeout Hills. Arrows show direction of relative movement. (Photograph by D.L. Blackstone, Jr.)

Folds

A fold is a geologic structure created when an originally flat, planar surface is bent or curved. An analogy is the wrinkling of a tablecloth or the bending of a magazine. In a geometric sense, folds are evidence that strata have been compressed into a space that is shorter than the original length occupied by the strata at the time of deposition.

Folds are given specific names depending upon their forms (**Figure 33**). The terms include the Greek root *clinos* (an angle), referring to the dip as defined previously. If the rocks incline in opposite directions from a common line and form an arch, the fold is an anticline. If the rocks dip toward a common line and form a trough, the fold is a syncline. If the strata over a large area such as the eastern side of the Powder River Basin dip consistently in one direction, the dip is considered to be regional.

Anticlines and synclines often occur in pairs, so the limb or flank of one is also a limb or flank of the adjacent feature. The structurally highest part of an anticline is the crest, and the lowest part of a syncline is the trough.

If the crest or trough of a fold is inclined, the fold is said to plunge below ground surface. The outcrop pattern of the strata in such folds is zigzag in plan view.

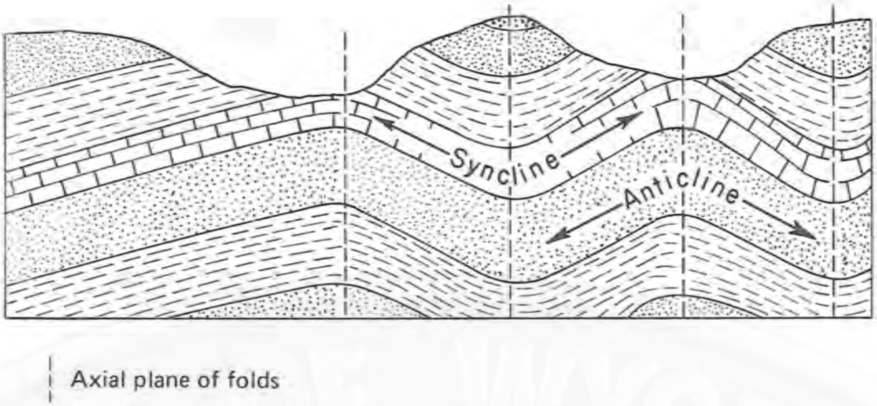


Figure 33. Cross section illustrating simple anticlinal and synclinal folds.

Wyoming structures

Presently, most of the sedimentary rock units in Wyoming have been tilted from their originally horizontal positions by large-scale crustal movements described under the term tectonic activity. The simple cross sections (**Figure 34**) represent vertical cuts taken across Wyoming before and after present-day structures developed.

The greatest subsidence below sea level occurred in western Wyoming, as evidenced by the 30,000 feet of sediment that accumulated in a north-south trending trough since Cambrian time. A broad area east of this trough, on a shelf adjacent to the deeper water areas, received much less sediment, perhaps 10,000 feet, during the same interval. Throughout this long period of time, there were minor upward and downward oscillations of the crust, but the principal activity in Wyoming was subsidence and accumulation of sediments.

Wyoming was last inundated by oceanic waters at the end of Cretaceous time. At that time, a major episode of crustal deformation, the Laramide orogenic event, began and continued into Early Eocene time. A regional compressional stress field crowded the crystalline crustal rocks into a shorter space. The shortening was accomplished by movement on reverse faults, some with displacements on the order of several miles. The sedimentary rocks were deformed and elevated several thousand feet. **Figure 34** illustrates the beginning and the end of this period of deformation.

Geologic processes operate simultaneously, so as crustal movement elevated and depressed segments of the crust, erosion and deposition were also active. The landscape was evolving.

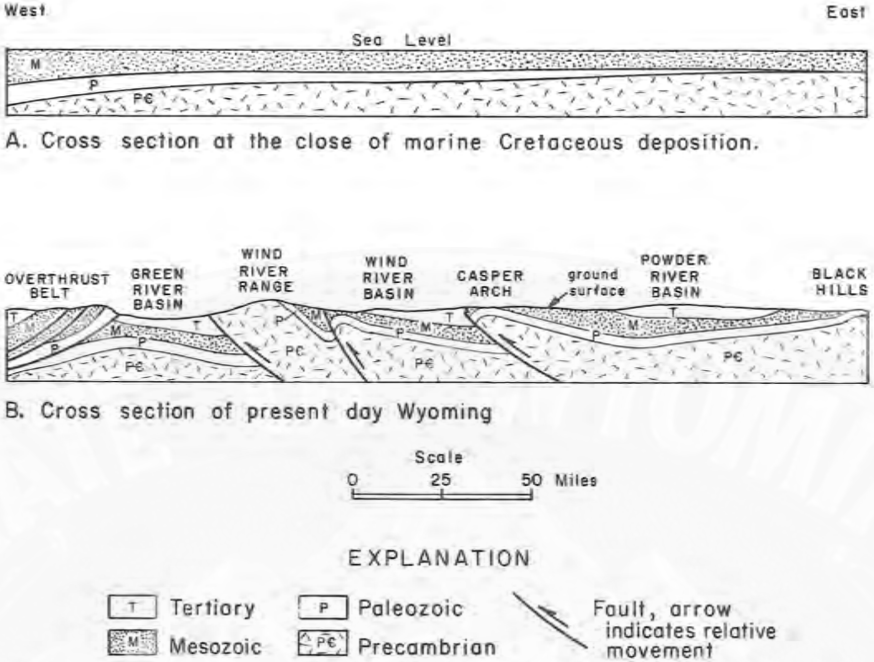


Figure 34. Generalized cross sections showing development of structures across Wyoming. Top diagram illustrates Wyoming in the Cretaceous, before the present structures developed; lower diagram shows Wyoming today.

Minerals and rocks

Common rock-forming minerals

A mineral is a naturally occurring, homogeneous, inorganic compound having definite physical characteristics and a definite chemical composition. A mineral usually has a regular external shape (crystal form) but may occur in fine-grained aggregates in which individual minerals can only be determined by use of a microscope.

Geological Survey of Wyoming Bulletin 66, *Minerals and rocks of Wyoming,* by W. Dan Hausel (1986), provides illustrated descriptions of minerals and their distributions in the State. The descriptions of a few common minerals are given here, but no attempt is made to discuss variations in mineral species and their occurrences.

Quartz (silicon dioxide) — macrocrystalline variety usually clear to smoky but may be pink to purple; glassy to waxy luster; no cleavage; irregular to conchoidal fracture; hardness greater than glass. A common rock-forming mineral; also found as hexagonal crystals in veins in igneous rocks.

The cryptocrystalline variety of quartz is crystalline, but crystals are so small that they can be observed only under high magnification (*cryptos* is Greek for hidden). In hand specimen, these rocks are dense, sometimes translucent, and highly variable in color. Some examples of cryptocrystalline quartz are:

Chalcedony — variable color;
Jasper — red, yellow, brown;
Agate — banded variable color;
Moss agate — gray to white with included moss-like aggregates of manganese oxide;
Chert and flint — dark gray to black;
Silicified wood — variable color with preservation of woody structures.

Feldspar (potassium-, sodium-, or calcium-aluminum silicate) — vitreous to pearly luster; excellent cleavage; hardness greater than glass but less than quartz; cleavage faces may bear minute, parallel striations; short stumpy crystals common. Forms light colored background in some igneous rocks.

Orthoclase (potassium feldspar) — usually white or pink;
Plagioclase (sodium or calcium feldspar) — usually gray or white.

Mica (potassium-iron/magnesium - aluminum silicate) — vitreous to submetallic luster; excellent cleavage; can be scratched with fingernail; weathered, golden appearing flakes of biotite are often mistaken for gold. Occurs as crystals in many igneous and metamorphic rocks and as crystal fragments within sandstone. Biotite and muscovite are very common micas.

Amphibole group (calcium, magnesium, iron-aluminum silicate) — vitreous luster; usually dark green to black; excellent cleavage; hardness equal to that of feldspar. Occurs as crystals in igneous and metamorphic rocks and as fragments in sandstone. Hornblende is a common member.

Pyroxene group (calcium, magnesium, iron-aluminum silicate) — vitreous luster; dark green to almost black; good cleavage; hardness same as hornblende; forms prismatic crystals with square cross sections. Common in dark colored igneous rocks. Augite is a common member.

Calcite (calcium carbonate) — vitreous luster; color variably white, brown, yellow; cleaves in rhombs; easily scratched with knife. Occurs as crystals and as cement in sedimentary rocks; veins of calcite filling fractures are common. Will bubble in dilute hydrochloric acid.

Dolomite (calcium-magnesium carbonate) — very similar to calcite; slightly harder. Will bubble in dilute hydrochloric acid only if it is powdered or acid is heated.

Clay minerals (hydrous aluminum silicates) — the clay minerals comprise a large group including kaolin, a common clay used in ceramics, and montmorillonite, a clay that absorbs water and swells. The clays are soft and plastic when wet, and make up the bulk of the sedimentary rock, shale.

Magnetite (iron oxide) — metallic luster; black; no cleavage; heavy; forms eight-sided crystals; makes a black streak when rubbed on a rough surface; magnetic.

Hematite (iron oxide) — earthy appearance, except in crystals, which are silver metallic; reddish brown. Forms cementing material in red sandstones; often forms irregular or oolitic masses; the most abundant ore of iron. Name is derived from Greek word meaning blood, because of the red color of the powdered mineral.

Limonite (hydrous iron oxide) — dull, earthy appearance; various shades of yellow or brown (common coloring agent in sandstones). Occurs as encrustations, as cement around concretions, and as irregular masses.

Anhydrite and gypsum (calcium sulfate and hydrous calcium sulfate) — vitreous to transparent, usually white; can be scratched with fingernail; occurs in crystals, fibrous veins, and massive layers.

Rock types

Igneous rocks

The term igneous (Latin *ignis*, fire) derives from observing the extrusion of hot, molten silicate melts (magma) from fiery volcanic vents. The igneous rock type that forms upon cooling and solidification of magma depends upon the chemical composition of the magma and whether it solidified at (extrusive) or below (intrusive) the Earth's surface (Table 1). Size of crystals is controlled largely by the rate of cooling and solidification. Much of the igneous material extruded upon the Earth's surface is either andesitic or basaltic in composition. Some magma never reaches the surface but remains embedded in the crust until solidified.

Sedimentary rocks

Sedimentary rocks are derived from preexisting rocks by weathering and erosion. Differences in color, changes in shape of outcrops, and variation in vegetational cover accent the layering characteristic of sedimentary rocks. However, the basic causes of the observed layering are: (1) differences in composition of the layers; (2) differences in size and shape of the component particles; and (3) differences in arrangement of particles (**Figure 35**).

Table 1. Simplified classification of igneous rocks (from Hausel, 1986).

Intrusive	Texture or grain size	Light colored. Principal minerals: orthoclase feldspar, some biotite or amphibole.		Intermediate. Principal minerals: plagioclase and orthoclase feldspar, amphibole, biotite, proxene.		Dark colored. Principal minerals: plagioclase feldspar, pyroxene, amphibole, olivine.
		With quartz	No quartz	With quartz	No quartz	
	Very coarse grained	Pegmatite				
	Coarse to medium grained	Granite	Syenite	Granodiorite Quartz diorite	Diorite	Gabbro Pyroxenite (pyroxene only) Peridotite
Extrusive	Fine grained[1]	Rhyolite	Trachyte	Dacite	Andesite	Basalt
	Porous	Pumice		Pumice		Scoria
	Glassy	Obsidian				
	Fragmental or broken	Fine-grained ash or tuff; Coarse-grained breccia or agglomerate.				

[1] If mixed grain or crystal sizes occur, then the rock is called a porphyry — example, andesite porphyry.

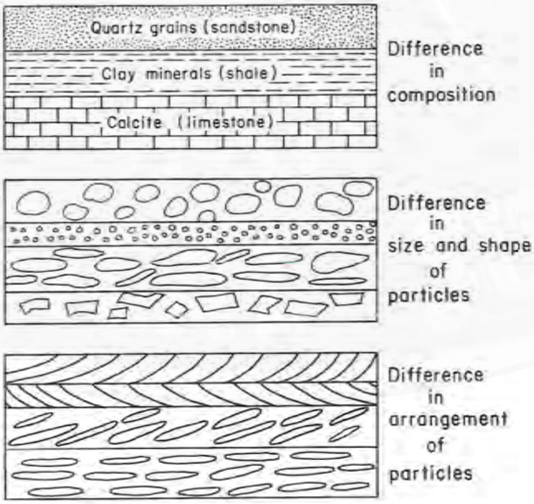


Figure 35. Diagrams illustrating types of layering in sedimentary rocks.

Sedimentary rocks can be classified into two broad groups (Table 2):

(a) Clastic or detrital rocks composed of particles (clasts) derived from preexisting rocks by mechanical breakdown and disintegretion. Examples are conglomerate and sandstone.

(b) Chemical and biological (organic) rocks that are formed of sediments precipitated from solution, extracted from solution by organisms, or extracted from the air by living organisms. Examples are limestone and coal.

One of the distinctive aspects of sedimentary rocks is fossil content. Fossils are the preserved record of former living organisms, either plant or animal. In some fossils, the original skeletal parts of animals, or the particularly resistant fibers in the case of plants, have been replaced by mineral matter introduced by circulating ground water. In other cases, the original material is preserved or only imprints remain. A few fossils have been recovered from frozen ground, in which case the original tissue is sometimes preserved. Evidence of former life also occurs in the form of trace fossils: tracks, trails, burrows, borings, and fecal material.

Table 2. Simplified classification of sedimentary rocks (from Hausel, 1986).

Grain size	Principal mineral(s)	Cement/matrix	Rock name
Clastic rocks			
1/16 inch or greater	Any rock or mineral fragment	Silica, calcite, iron oxide, clay, sand, silt	Breccia (angular) Conglomerate (rounded)
Less than 1/16 inch but still visible	Quartz, feldspar	Silica, calcite, iron oxide, clay, gypsum or anhydrite	Sandstone (coarser) Siltstone (finer)
Too small to see with naked eye	Clay minerals		Shale (bedded, fissile) Claystone (more massive)
Chemical and organic rocks			
Variable	Calcite	Calcite	Limestone
	Dolomite	Dolomite	Dolomite
	Gypsum, anhydrite	Not applicable	Gypsum, anhydrite
	Halite	Not applicable	Rock salt
Too small to see with naked eye	Silica	Not applicable	Chert
Not applicable	Carbon	Not applicable	Coal

Sedimentary rocks contain many internal structures of inorganic origin that are confused with true fossils, and are called false fossils or pseudofossils. The most common structures of this type are concretions. A typical concretion is a rounded to irregular-shaped mass of rock that is more firmly cemented than the surrounding material. The cementing material is commonly calcite or iron oxide. Such concretions are often collected and described as fossil eggs. Chert concretions are common in carbonate rocks, limestone concretions are abundant in shale, and iron-cemented masses are common in some sandstones.

Metamorphic rocks

Metamorphic rocks (Table 3) are the most complex, since they form by the physical and(or) chemical reconstitution of previously existing rocks under conditions of high temperature and(or) high pressure, shear stress, or chemical change. Such conditions may develop at times of mountain building, when segments of the crust are deeply downfolded well below the surface of the Earth into regions of very high temperature and pressure. Metamorphism may also occur in rocks that are heated by igneous intrusions at any depth (contact metamorphism). Some common metamorphic rocks are schist, gneiss, and marble.

Table 3. Simplified classification of metamorphic rocks (from Hausel, 1986).

Texture or grain size	Principal mineral(s)	Rock name	Original rock type
Equigranular (equal grain size)	Quartz	Quartzite	Sandstone
Equigranular to foliated	Calcite and (or) dolomite	Marble	Limestone and/or dolomite
Broadly foliated parallel layers or bands)	Feldspar, mica, amphibole, quartz, garnet	Gneiss	Granite, rhyolite, some sedimentary rocks
Thinly foliated	Feldspar, mica, amphibole, quartz	Schist	Andesite, basalt, rhyolite, some sedimentary rocks
Very thinly foliated	Mica, quartz, clay, (these minerals normally cannot be seen with the naked eye).	Slate	Shale

Geologic history of Wyoming

Introduction

Geology is the science that deals with the history of the planet Earth and the physical processes affecting it. Professional geologists (earth scientists) have synthesized sufficient geologic evidence to establish significant historical relationships. New investigations such as studies of the ocean floor, examination of drill holes, geophysical profiles, paleomagnetism studies, and satellite imagery are continually underway.

Geologists attempting to unravel the early history of the Earth use several methods of determining the age (time) of events:

(1) Radiometric-age determinations based on the rate of decay of radioactive elements (for example, potassium-argon, rubidium-strontium, carbon 14).

(2) Physical relationships of sedimentary rocks, cross-cutting relationships of igneous bodies, and cross cutting by faults.

(3) Fossil content of rocks (based on the evolution of organisms).

(4) Paleomagnetic time scale (based on reversals of the Earth's magnetic polarity).

(5) Chemical constitution of rocks (as an indicator of the time and place of changes in temperature and pressure).

By utilizing all the best evidence, it is possible to establish the order of geologic events and to trace the progress made by living organisms in adapting to changing conditions through time.

In order for investigations in one area (such as Wyoming) to be related to studies in other parts of the world, a formal geologic calendar was adopted by geologists (inside back cover). The divisions on the time scale are not of equal lengths. Major events, particularly those involving periods of major evolutionary change, are the anchor points in the chronology that evolved.

Radiometric ages

Use of the rates of decay of radioactive elements has become a powerful tool in solving geologic problems. The technique allows us to accurately fix the time of an event no matter where it took place and to relate that event to others in any part of the world. Intercontinental correlation of rocks had always been a difficult task, but it is now handled rather readily.

Paleomagnetism

The recognition of reversals in the Earth's magnetic polarity, based on the study of remnant magnetism in rocks, has provided a new type of calendar. The changes from the normal polarity of today to periods of opposite or reversed polarity in the past have been well dated by correlation with radiometric dates and fossils and hence can be used to help date rocks.

Geologic time scale

The **inside back cover** shows a geological calendar, or time scale, complete with names depicting the time intervals and their relative positions to each other. A few ages, in millions of years, are shown to indicate the total time expanse of the calendar as well as that of certain important geological events. Note the scale changes that were necessary to show the whole geologic calendar on one page. Wyoming is very fortunate in having at least some geological evidence of events that happened during each major time division, but it must also be remembered that much is missing. Erosion has stripped away the rock record that once represented these missing intervals.

Precambrian

The term Precambrian applies to all geologic time from the planet's origin (approximately 4.6 billion years ago) to the beginning of the Cambrian (0.57 billion years ago); therefore it represents most of the planet's life. The farther one goes back in geologic history the more fragmentary is the record, and the more difficult it is to decipher. The Precambrian is divided into two parts, the Archean Eon (older than 2.5 billion years) and the Proterozoic Eon (2.5 to 0.57 billion years).

All the Precambrian rocks in Wyoming, except for a small area in the southeast part, are Archean. Radiometric ages range from 3.4 billion years or older (in the Beartooth Mountains and Wind River Range) to 2.5+ billion years for most of the State. These rocks are largely granitic gneiss, granite, and some mafic rocks.

There is little hard evidence of geologic events in late Precambrian time during the interval from 1.4 to 0.57 billion years ago because no rocks of that age are preserved within the State.

Paleozoic Era

In Wyoming, the Cambrian rocks record slow subsidence of the land that allowed the sea to encroach from the west. Gravel, sand,

Color Plates 1 through 7

Plate 1A. View on top of the Bighorn Mountains along U.S. Highway 14A west of Burgess Junction. Cliff on the left exposes Ordovician Bighorn Dolomite. (Photograph by Sheila Roberts.)

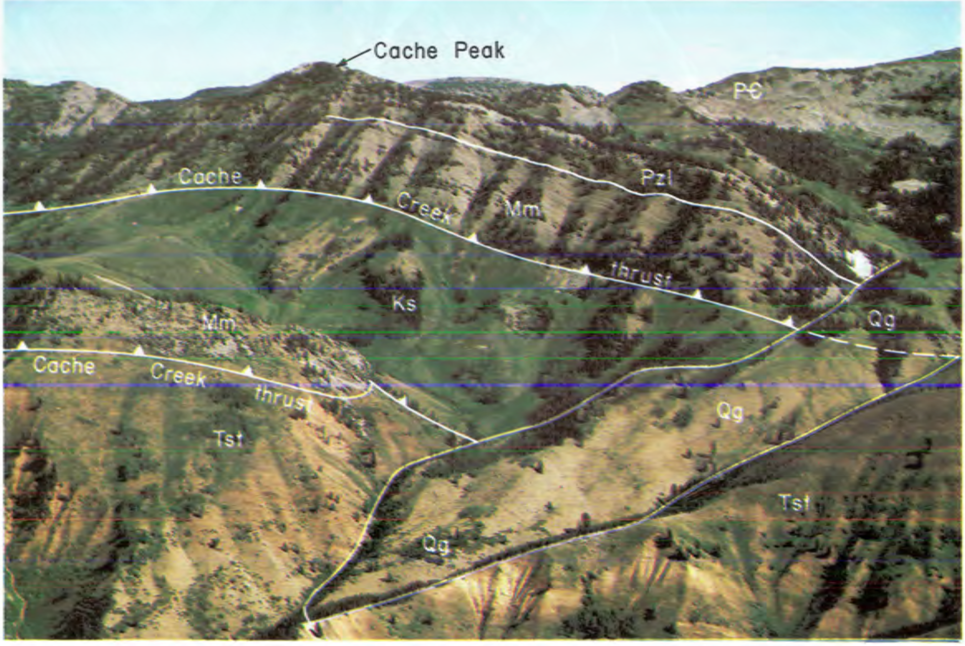


Plate 1B. Gros Ventre Mountains. Cache Creek thrust fault (heavy barbed line) places Mississippian Madison Limestone (Mm) over Cretaceous and Tertiary rocks (Ks, Tst). Cache Peak is on the skyline. Qg = Quaternary sediments; Pzl = Lower Paleozoic rocks; PЄ = Precambrian rocks. (Photography by J. David Love and William B. Hall.)

Plate 2A. View west across the floor of Jackson Hole to the Teton Range. Major normal fault located at break in slope. Precambrian Mount Owen quartz monzonite exposed in high peaks. Historic Pfeiffer homestead (foreground) is located on large Ditch Creek alluvial fan. (Photograph by Rodney H. DeBruin.)

Plate 2B. Beartooth Butte in the Beartooth Mountains, seen from U.S. Highway 212. View is to the northwest across Island Lake. Red lens of Devonian Beartooth Butte Formation in the center. (Photograph by D.L. Blackstone, Jr.)

Plate 3A. The Willwood Formation (Eocene) forms colorful badlands throughout much of the central Bighorn Basin. (Photograph by Gary B. Glass.)

Plate 3B. Exposure of a steeply dipping reverse fault on the south margin of the Seminoe Mountains. View is to northeast. Red Triassic Chugwater Formation is in fault contact with black Cretaceous Frontier Formation shale. (Photograph by D.L. Blackstone, Jr.)

Plate 4. Oil shale in the Green River Formation (dark brown ledge at center). (Photograph by Ray E. Harris.)

Plate 5A. Red clinker (baked and fused rock), caused by natural burning of coal beds below the rock, caps upper part of roadcut at Lake De Smet, north of Buffalo. White and gray rock below clinker is unaltered; black rock layers below clinker in left part of photograph are remnants of coal that did not burn. Exposure is about 50 feet high. (Photograph by Richard W. Jones.)

Plate 5B. Rocks of the Absaroka Volcanic Supergroup exposed in the Rampart, viewed from U.S. Highway 287/26 at Togwotee Pass. (Photograph by Sheila Roberts.)

Plate 6A. The Big Spring at Hot Springs State Park in Thermopolis. (Photograph by Gary B. Glass.)

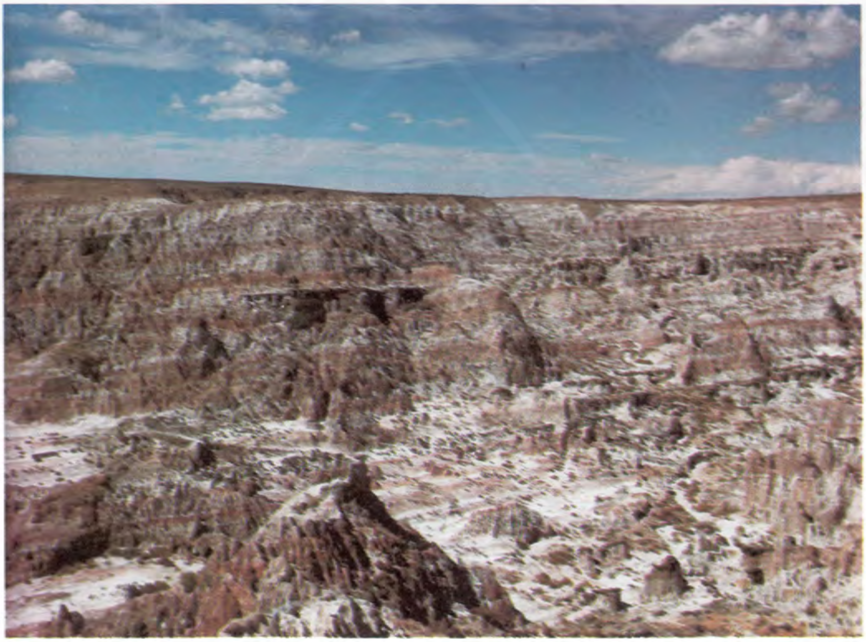


Plate 6B. Hell's Half Acre, viewed to the southwest across typical colorful badland topography developed on Eocene Wasatch Formation (Photograph by D.L. Blackstone, Jr.)

Plate 7A. Flaming Gorge. This view is at Sheep Creek in northern Utah, looking northeast into Wyoming. The colorful rock exposures are Triassic to lower Jurassic: Dinwoody Formation (TR d), Moenkopi Formation (TR m), Chinle Formation (TRc), and Navajo Sandstone (TR Jn). (Photograph by Gary B. Glass.)

Plate 7B. Bessemer Bend region, looking west from Casper Mountain. Speas Dome in the center of the photo exposes Permian-Triassic Goose Egg Formation. Red cliffs just beyond the dome are Triassic Chugwater Formation. The North Platte River is at left center. (Photograph by Dana Van Burgh.)

limy sediments, and mud were deposited as the sea transgressed. Subsidence continued through Ordovician time, when a thick sequence of dolomitic carbonate sediments accumulated over much of the State. What transpired during the Silurian is largely unknown, since only small areas of Silurian rocks have been found in Wyoming. Widespread erosion may have again beveled the land surface and destroyed almost all of the Silurian deposits, or most of Wyoming may have been above sea level receiving no sediments. Marine carbonate deposition was renewed in Devonian seaways over most of the State. The Mississippian is now represented by thick sequences of limestone (somewhat thinner to non-existent in southeastern Wyoming) providing evidence that the area was covered by a warm shallow sea where marine life flourished.

The first marked change in depositional pattern occurred in the Pennsylvanian, when crustal uplift disturbed many parts of North America. At this time, a range of mountains rose in Colorado, part of which was located at about the present site of the Front Range. The range is referred to as the Ancestral Rocky Mountains. The uplifted area increased in gradient, and streams stripped away great thicknesses of sedimentary rocks in southeastern Wyoming. Coarse clastic sediments (gravels and sands) were deposited on the sides of the uplift, where they are found today resting on Precambrian or Mississippian rocks. Throughout the rest of Wyoming, sands, thin dolomitic carbonates, and associated marine sediments accumulated in areas lying below sea level and dune sands were deposited locally on the land.

The Permian sedimentary deposits reflect a new phase of deposition. In Idaho and western Wyoming, a remarkable sequence of locally phosphatic dark clays, carbonates, and siliceous sediments accumulated. Contemporaneously with the deposition of this organically rich marine sediment in the western seaways, nearshore tidal flat sediments accumulated in central and eastern Wyoming and are seen today as a thick sequence of red siltstone, shale, gypsum, and sandstone. Occasionally, the marine waters spread far to the east, depositing thin marine carbonates interbedded with terrestrial red sands, silts, and muds.

Mesozoic Era

The beginning of the Mesozoic is not marked by any significant change in depositional pattern, as red sediments continued to accumulate throughout the Triassic Period. Broad regional uplift occurred in Early Jurassic time, but very little erosion took place. The land surface was apparently low relief and near sea level. By Late Jurassic time, the area was again covered by an advancing sea, which is known as the Sundance sea. The sediments deposited included clay, calcareous mud, and sand, which contain numerous marine fossils. The entire sequence is now called the Sundance Formation, after the town of Sundance, Wyoming, where the rocks were first described.

Near the close of the Jurassic, the seas withdrew and Wyoming was dominated by a continental environment. Fluvial systems spread varicolored clay, silt, and sand over a wide area from central Montana to Mexico. The clays were largely derived from airborne ash from volcanic activity on the western margin of the continent.

The Jurassic Period is known as the Age of Dinosaurs. Numerous fossil dinosaur remains have been recovered from the Late Jurassic Morrison Formation. The classic fossil sites are Como Bluff, Wyoming, and Dinosaur National Monument, Utah. On the west coast, the Sierra Nevada orogeny was occurring at this time, elevating the continent and causing the marine waters to retreat to the major ocean basins.

During Cretaceous time, a wide seaway extended from the Arctic Ocean to the Gulf of Mexico, with the western shoreline somewhere near the boundary of Idaho, Utah, and Wyoming. The western strand line shifted back and forth in response to the rise of highlands to the west. The sediments deposited near the shoreline were coarse grained, including conglomerates and thick bodies of sand that thinned to the east and intertongued with fine-grained marine muds several thousand feet thick. The marine shale contains numerous beds of what were originally volcanic ash falls, now altered by the sea water to clay minerals comprising the rock bentonite. Along the shifting strand line, brackish and fresh-water marshes developed. In these marshes, plant remains accumulated as peat. In the rock record, these peats are now coal beds like the ones mined near Kemmerer and previously mined in nearly all the other basins in the State.

The last time Wyoming was covered by the sea was during the Late Cretaceous, when marine sediments now represented by the Lewis Shale were deposited. A new orogenic episode was in the making, creating tremendous horizontal compressional stresses upon the Earth's crust and overlying sediments. The movements began in Utah and Idaho and migrated eastward. During the long period of deposition, the thickest section of sediments had accumulated in a trough near the western edge of Wyoming. During the orogeny, the rocks that were derived from those sediments were broken by low-angle faults and moved eastward in a series of huge slabs tens of miles long and several miles wide to create the Overthrust Belt of the Rocky Mountains (Figures 4 and 34).

The end of this era also coincides with the disappearance of dinosaurs in the geologic record. The cause of their extinction is a puzzling problem undergoing renewed scrutiny. One current concept suggests that the earth collided with a large extraterrestrial body creating a cloud of debris that cut off radiant energy from the sun and drastically altered the climate, leading to extinction of certain groups of organisms. An important part of the evidence for the extraterrestrial body is the unusually high concentration of the element iridium in certain clay beds at the Cretaceous-Tertiary boundary (Alvarez and others, 1980). The problem of the role of an extraterrestrial body is not solved, but new research efforts are providing new interpretations.

Cenozoic Era

The term orogeny derives from the Greek *oros* (mountain) and *gens* (genesis) and is used by geologists to refer to an episode of mountain building. The term Laramide orogeny derived indirectly from old Fort Laramie, an early day trading and military post near the junction of the Laramie and the North Platte Rivers. The rocks of Late Cretaceous age in the region were once called the Laramie formation and later the term was applied to the orogenic episode. The Laramide orogeny began in Wyoming in the Late Cretaceous, reached its height in the Paleocene, and was complete by mid-Eocene. At the time of greatest uplift, thick sequences of gravel, sand, clay, and thick peat beds were deposited and preserved as rocks in the basins between the rising mountains. During Paleocene time, a large lake formed in the Wind River Basin, and probably extended northward along the axis of the Powder River Basin.

The aftermath of any major mountain-building episode includes an increase in the gradient and erosive power of streams, climatic change, and biological responses to the new environment. The increased elevation and stream gradients allowed removal of material from the highlands, deposition of a large part of the sediment adjacent to the highlands, and filling of the basins that were subsiding as the mountains rose. The Paleocene rocks record these activities.

Deformation slowed somewhat in Eocene time, but major changes in drainages occurred, so that very large lakes formed in western Wyoming, northeastern Utah, and parts of Colorado. The one in Wyoming is referred to as Lake Gosiute. The large lakes fluctuated in size, depth, salinity, and probably temperature. The lacustrine sediments vary from deltaic types of coarse material at the margins to very fine-grained, organically rich clays in the central parts. At times, the lakes shrank in size because of evaporation and climatic change, and at low water level sodium-rich minerals such as trona and halite precipitated from the waters. The sediments in Lake Gosiute contain an amazing record of the geologic history. The fossil fauna and flora indicate that for most of Eocene time the climate was warm, moist, and subtropical, with occasional periods of aridity.

The Absaroka Volcanic Plateau formed during the Eocene. The region around the northwest corner of the State was the site of extensive outpourings of volcanic material from central vents such as Mount Washburne (in Yellowstone National Park) and the Sunlight Basin volcanic center. The bulk of the material was volcaniclastic, but there were also extensive flows, dikes, and intrusive bodies.

By the close of the Eocene Epoch, a rather mature landscape had developed. The region was then inundated, in Oligocene time, by the debris of explosive volcanic activity that was taking place in California, Nevada, and Oregon at an unprecedented scale. The prevailing winds were, as now, from the west, so that ash ejected to great heights drifted eastward to settle across the Rocky Mountain region where it was redistributed by rivers. The climate appears to have been moist, and a wide variety of vertebrate animals existed on the floodplains and survived the ash falls. The volcanic activity continued intermittently from Miocene until Pliocene time, and the preexisting landscape was literally covered by the volcanic debris. By mid-Pliocene, probably only the summits of the higher mountains stood above the monotonous plains. The major rivers flowed to the east.

Two events changed the scene. One was the regional uplift of the entire Rocky Mountain region, probably on the order of 3,000 feet. There is still no fully satisfactory explanation of why the uplift occurred. The second was the climatic event of the Pleistocene ice age.

The elevation of the land surface, coupled with increased precipitation during the Pleistocene, inaugurated a new regime of accelerated erosion. In a period of about three million years, most of the late Tertiary volcanically derived cover was stripped away, older topography was exhumed, and the major drainages were superimposed and incised into the older rocks. Today we see only remnants of the once-extensive late Tertiary cover, and we also see the process of removal still in progress. Figure 29 (A through D) presents, diagrammatically, the history of the Late Cretaceous through the Tertiary in Wyoming.

Earth history is a continuum. Today, there are minor earthquakes in the State providing evidence of continued crustal movement. Streams continue to erode and the landscape changes.

Economic geology

Modern society has come to expect a standard of living based on a host of naturally occurring minerals and their derived products. Finding and developing mineral deposits is a very important activity to the economic stability of Wyoming. The State's number one source of income derives from industries dealing with the various aspects of mineral production. The principal raw materials that are found in Wyoming and their geological occurrence are described briefly below. Table 4 shows development of some of the State's major mineral deposits through geologic time.

Special mineral deposits

Gold

Gold is a metal that has a wondrous attraction because it is literally money in hand when found. Almost all the myths and legends of lost mines revolve around gold. Historically, gold was discovered by panning stream gravels for placer deposits and then searching upstream for the source, or mother lode. Gold, derived from veins in metamorphic and igneous rocks, is released by the weathering of the rocks. The heavier particles — free gold and other heavy minerals like magnetite -- are concentrated in favorable places in stream channels. Such deposits are called placers. Placer gold deposits kept the western U.S. prospectors happy for a century. A man with a gold pan or a "rocker box" might recover enough gold from stream gravels to eke out a small living, and always have the expectation of a great strike.

In Wyoming, gold was produced in the past from vein-type deposits in Precambrian rock and associated stream placers at several areas including South Pass, Centennial, Medicine Bow Mountains, and the Sierra Madre. Gold is found in minute amounts in some thick conglomerates of Paleocene age in Jackson Hole and in gravels of the Snake River. Today, small amounts of gold are being recovered from some small placer deposits.

Jade

Wyoming jade has received much publicity. It is a very pleasing semiprecious gem material. Jade occurs in veins and pod-like masses in some metamorphic rocks. It is quite rare. Much of the fine Wyoming jade was found as boulders derived from the mountain cores in central Wyoming. Jade is a very tough material and the boulders can be transported considerable distances from the source areas by streams.

Table 4. Major mineral deposits of Wyoming through geologic time.

TIME[1]	ERA	PERIOD	EPOCH	SOME MINERAL RESOURCES IN WYOMING[2]
0	CENOZOIC	Quaternary	Holocene	Sand and gravel, placer gold, travertine, sulfur, diatomite, clinker, sodium sulfate, epsomite.
			Pleistocene	
1.6		Tertiary	Pliocene	Diatomite, pumicite, agate.
5.3			Miocene	Agate.
23.7			Oligocene	Copper-molybdenum porphyries, paleoplacer gold.
36.6			Eocene	Uranium, coal, trona, oil shale, zeolites, gold paleoplacers, rare earths, fluorite, thorium, copper-molybdenum porphyries.
57.8			Paleocene	Uranium, coal, natural gas.
66.4	MESOZOIC	Cretaceous		Oil and gas, coal, bentonite, silica sand, titaniferous black sandstone paleoplacers, uranium.
144		Jurassic		Gypsum, oil and gas, silica sand, copper-silver-zinc.
208		Triassic		Gypsum, oil and gas.
245	PALEOZOIC	Permian		Phosphate rock and associated vanadium, oil and gas, gypsum.
286		Pennsylvanian		Limestone, oil and gas, silica sand, copper.
320		Mississippian		Limestone, oil and gas, hematitic quartzites ("Rawlins red").
360		Devonian		Limestone, oil and gas, diamond-bearing kimberlites.
408		Silurian		
438		Ordovician		Oil and natural gas (including helium and carbon dioxide), dolomite and limestone.
505		Cambrian		Silica sand; paleoplacer gold, thorium, and rare earths; oil reservoir rocks.
570	Major unconformity			
	PRECAMBRIAN	PROTEROZOIC		Anorthosite. Gold, copper, platinum. Copper and gold. Volcanogenic copper-silver-zinc. Tantulum- and niobium-bearing mafic dikes. Gold-bearing quartz veins. Copper-bearing quartzite. Uranium paleoplacers. Railroad ballast from quartzofeldspathic rocks and metadolomites. Hematite iron ore (probable Proterozoic age).
2,500		ARCHEAN		Pegmatites containing beryl, lepidolite, feldspar, and copper sulfides. Jade, sapphires, rubies. Banded magnetite iron formation. Uranium paleoplacers. Gold-bearing veins and shears. Talc and asbestos.
4,600				

[1] In millions of years before present (from Geological Society of America 1983 Geologic time scale).

[2] In different areas of Wyoming, rocks of nearly all ages act as aquifers for ground water.

Pegmatites

At a late stage in the solidification of a granitic intrusion, the dissolved volatiles escape and move into any available space. The minerals crystallized from the escaping solutions form pod-shaped masses of large-sized well-formed crystals called pegmatites. Common minerals in pegmatites are quartz, feldspar, and mica. Rare and unusual minerals attract amateur mineralogists seeking beryl, spodumene, tourmaline, and minerals containing yttrium, columbium (niobium), tantalum, and the rare earth elements.

Diamonds

Diamond is a mineral of great vlaue as a precious stone and as an industrial material. Diamonds are formed at great depth in the earth and are brought to the surface in conduits similar to the cores of volcanic cones. They are found in a peculiar rock called kimberlite, in pipe-like bodies known as diatremes. Kimberlites are found near the Wyoming-Colorado boundary south of Laramie, where they contain presently noncommercial amounts of both gem and industrial quality diamonds.

Metals

Iron

All major reserves of iron ore in the world are found in rocks of Precambrian age. High-grade ores containing greater than 50 percent Fe_2O_3 consist primarily of hematite. Lower grade ores, containing 30 to 40 percent Fe_2O_3, have a higher silica content and are termed taconite. Taconite ores are beneficiated and pelletized before going to the blast furnace. Iron ore was produced from three mines, the Colorado Fuel and Iron Company Sunrise and Chicago mines near Hartville (hematite), and the U.S. Steel mine at Atlantic City (taconite). The Sunrise mine closed in 1963, the Chicago mine closed in 1975, and the Atlantic City mine closed operations in 1982.

Copper

Common copper ores are copper-iron sulfide minerals such as chalcopyrite, often found in vein-like deposits associated with igneous intrusions. A few copper mines, most notably in the Encampment district of the Sierra Madre (Hausel, 1986), operated in the late 1800s and early 1900s to recover such ores. Recent exploration efforts concentrated on outlining a potential low-grade copper-molybdenum ore body at Kirwin near the head of Wood River. The mineralization there is associated with intrusions into the Absaroka volcanic rocks.

Materials found in sedimentary rocks in basins

Coal

Wyoming basins contain large reserves of low-sulfur coal in rocks of Cretaceous and early Tertiary age. Thick deposits of plant material accumulated as peat beds in times of temperate to subtropical climate in swamps where acid waters inhibited or prevented their complete decay. Coal is formed when the plant material (peat) is chemically and physically altered after burial. Although Wyoming coal ranges from lignite to bituminous in rank, most of the coal mined in Wyoming today is subbituminous with an average heat content of 8,600 British Thermal Units (Btu) per pound and an average sulfur content of less than one percent.

Coal production in Wyoming has expanded greatly since the early 1970s; the State has lead the nation in coal production each year since 1988. Almost 190 million tons of coal were produced from Wyoming mines in 1992. Most of the coal is produced from large surface mines in the Powder River Basin of northeastern Wyoming.

Nearly all the coal produced in Wyoming is used to fuel boilers at coal-fired electric-generating plants. Eighty-five percent of the coal is shipped to out-of-state utility companies in the Midwest and Southcentral United States. Most of the remaining fifteen percent of the produced coal is used to generate electricity at plants located throughout the State. These power plants include the Naughton plant south of Kemmerer, the Jim Bridger plant near Point of Rocks, the Dave Johnston plant near Glenrock, the Wyodak plant east of Gillette, and the Laramie River plant north of Wheatland.

Shale

Shale is a rock composed of clay minerals and silt-size quartz grains, often interlayered with thin limestone, sandstone, and bentonite.

Some shale can be expanded upon heating; this expanded material is used in the construction industry as a light-weight aggregate for concrete floors in buildings.

Shales are the source of most of the hydrocarbons (natural gas and oil) produced in the State. Shales rich in kerogen are a part of the Green River Formation (**Plate 4**) ; they have not been developed as a source of oil, largely because of the problems of handling huge volumes of rock once the oil derived from the kerogen has been removed.

Bentonite

Bentonite is a rock composed primarily of the clay mineral montmorillonite that usually occurs interbedded with dark marine shale. Montmorillonite has the property of absorbing water and expanding the crystal lattice up to fifteen times the original volume. Swelling clays are the principal constituent of drilling muds used in the petroleum industry, and bentonite is also used as binder to pelletize taconite iron ore and as a bond in making molds for castings in foundries. In Wyoming, bentonite is obtained by strip-mining methods from localities in the Black Hills, western Powder River Basin, and the eastern Bighorn Basin. Wyoming is the largest bentonite-producing state in the United States.

Limestone and dolomite

Limestone is a rock composed mostly of the mineral calcite. Magnesium may be substituted for calcium, resulting in dolomitic limestone or dolomite. In the refining of beet sugar, limestone is used as a source of carbon dioxide to control acidity and to aid in filtration. Some limestone is used as the main raw material in the production of cement. The primary use of limestone in Wyoming is for construction aggregate, including road metal and railroad ballast, and as decorative stone. Limestone is also used to control emissions from coal-fired power plants.

Phosphate

In the Western States, the principal source of phosphate for fertilizer is phosphatic shale and limestone from the Permian Phosphoria Formation in Idaho, Montana, Utah, and Wyoming. The Phosphoria Formation crops out over a large area in the Overthrust Belt and consists primarily of dark shales and limestones (which are locally phosphatic), sandstone, and chert. There are no active phosphate mines in Wyoming and primary production is in Idaho, where the raw material is processed by heating in kilns. Phosphate rock is transported by slurry pipeline over the Uinta Mountains from Vernal, Utah, to Rock Springs, Wyoming, where it is treated with sulfuric acid (derived from hydrogen sulfide gas produced in the oil and gas fields in the Evanston area) to produce fertilizer.

Gypsum

Gypsum is a relatively common component in some Permian, Triassic, and Jurassic redbeds in Wyoming. The Permian Goose Egg Formation, the Triassic Chugwater and Spearfish Formations, and the Jurassic Gypsum Spring Formation contain numerous beds of gypsum. Gypsum is an evaporite mineral formed as a precipitate on the floor of shallow sulfate-rich lakes or tidal pools. Most commercial gypsum is a massive, white, finely crystalline rock, but large clear crystals of gypsum (selenite) are often found on the surface where coals or shales rich in pyrite are weathering.

Small quarries and plants, which satisfy local demands for gypsum products, have operated intermittently in Wyoming since 1890. The primary use for gypsum is in the manufacture of sheet rock wallboard.

Trona

Several times, the ancient lake that existed in western Wyoming during Eocene time evaporated to a small area and the water salinity greatly increased. The waters were sodium rich and at a critical point precipitation of trona took place. Trona occurs in beds up to 37 feet thick. Twenty-five beds over three feet thick contain 134.4 billion tons of minable trona (Culbertson, 1986). There is enough trona in Wyoming to meet the world's demand for many hundreds of years. Trona is removed from depths up to approximately 1,200 feet by five mining companies in Wyoming that use room-and-pillar, longwall, and solution extraction methods. The processed product, soda ash, has many uses, including its use as flux in glass manufacturing, and in detergents, baking soda, water purifiers, and sodium chemicals.

Uranium

In Wyoming, radioactive minerals are concentrated principally in Paleocene and Eocene rocks in the Gas Hills district, the Powder River Basin district, the Pumpkin Buttes district, and the Shirley Basin district. Uranium concentrations in these districts may have resulted from the downward leaching of radioactive materials from the late Tertiary rocks comprised largely of airborne ash falls. Ores are concentrated in sandstones and generally contain about 0.5 percent or less of radioactive compounds. In 1979, there were 17 operating uranium mines and about 25 planned for development. Currently (1987) there is one operating surface mine and two new *in situ* solution mines. Wyoming's uranium reserves are the second largest in the continental United States.

Titanium

The minerals ilmenite and titaniferous magnetite contain the element titanium. Because they have relatively high specific gravities, these minerals were concentrated in beach placers of black sand similar to those forming today along the Carolina coast. The fossil placers are preserved in Late Cretaceous rocks in Wyoming. Minor amounts of radioactive materials, particularly zircon, are associated with the fossil placers.

Clinker

The red-capped hills in the northern Powder River Basin and some other parts of Wyoming where coal beds are exposed at the ground surface are covered by clinker. The material is rock that was baked and fused by the natural burning of underlying coal beds (Plate 5A). The process is like the baking of clays to form tile and brick. The red rock has been called scoria, clinker, and porcellanite. The principal use is for surfacing roads.

Fluids occurring in layered rocks in basins

Sedimentary rocks, particularly sandstones, have voids or pore space between the grains that may amount to over 20 percent of the rock by volume. If the voids are interconnected, so that fluids can pass through the rock, the rock has permeability. These porous rocks often contain fluids such as water and oil as well as natural gases (methane, carbon dioxide, and others).

Water

Many of the major sandstones in the Wyoming basins are water saturated. When one of these sandstones is tapped by drilling, water in the pore spaces enters the bore hole and, under optimum conditions, may flow to the surface as an artesian well or it may be pumped to the surface. The requisite conditions for a flowing well are shown in Figure 36.

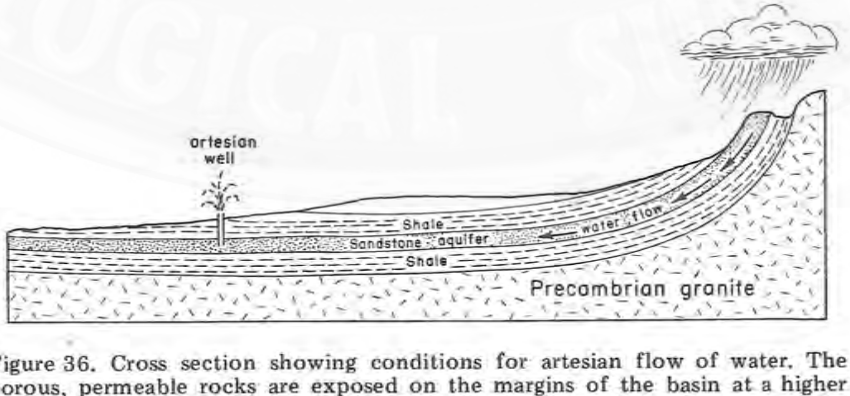


Figure 36. Cross section showing conditions for artesian flow of water. The porous, permeable rocks are exposed on the margins of the basin at a higher elevation than the basin floor, so the fluids within the rocks in the center of the basin have a hydrostatic pressure or head and flow out of the well without pumping.

The chemical quality of the water contained in these rocks varies a great deal. Usually, along the basin margins, the water may be used for drinking (U.S. Public Health Service standards consider 500 parts per million dissolved solids the potable limit for humans). Deep in the basin, the same rock units may contain water that has more than 100,000 parts per million of dissolved solids. Some areas in Wyoming have waters that are warm enough to be useful in geothermal applications.

Petroleum and natural gas

Sedimentary rocks are both the source and the reservoir for petroleum and natural gas. Petroleum is a complex of organic compounds varying in chemical composition, viscosity, density, and energy value. Natural gas may be organic (methane, butane, etc.) or inorganic (carbon dioxide, nitrogen, helium, hydrogen sulfide). Recoverable hydrocarbons such as oil and natural gas are derived from organic material, broadly described as kerogen, incorporated in the sediments at the time of deposition. Subsequent burial and tectonic activity exposed these rocks to increased temperatures and pressures that in turn affected hydrocarbon generation. The kerogen may be converted to oil or gas, or it may be entirely destroyed, depending upon time, temperature, and pressure. Research dealing with the conversion of kerogen to oil and gases is very active.

The pore space in potential oil reservoir rocks is usually water saturated, so new fluids or gases must displace existing fluids. A newly formed globule of oil is less dense than water so it travels up dip through the water-saturated permeable reservoir until it is trapped by a barrier to the upward movement.

The classic trap for hydrocarbons in Wyoming is the crest of a so-called sheepherder's anticline, meaning an anticline that even a sheepherder would have recognized (Figure 37A). Many of the early discoveries of oil in the State such as Lance Creek, Big Muddy, Salt Creek, and Oregon Basin fields were of this type. Stratigraphic traps are dependent on an up-dip decrease in permeability or truncation of the reservoir rock (Figure 37B). Such traps are common in the Cretaceous sand bodies of the Powder River Basin.

Oil seeps were discovered in western Wyoming at the time of the great westward migration in the mid 1800s. Oil fields were developed in all of the major basins of Wyoming beginning in the 1880s and continuing through the present. Improvement in exploration methods, particularly reflection seismic techniques, and improvement in deep drilling technology led to the discovery of major reserves of hydro-

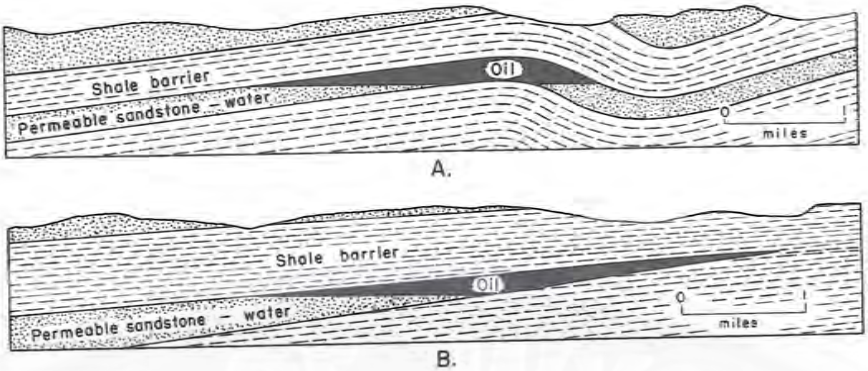


Figure 37. Cross sections showing oil in (A) an anticlinal trap and (B) a stratigraphic trap.

carbons in the Overthrust Belt of Wyoming and Utah in 1975. The geologic structure there is complex and the drilling depths approach 20,000 feet. In this area, much of the gas (methane) is sour, carrying large quantities of the poisonous gas hydrogen sulfide, which must be extracted before the hydrocarbons can be delivered to the pipeline. Elemental sulfur is recovered in this process.

An unusual situation exists in the area west of Big Piney in the Green River Basin where the natural gas contains only 22 percent methane. This gas is 66 percent carbon dioxide, 7.0 percent nitrogen, 0.5 percent helium, and 4.5 percent hydrogen sulfide. Gas treatment facilities extract the hydrogen sulfide to produce sulfur, the helium is sold, and the carbon dioxide is separated and piped to older oil fields to be used in tertiary recovery methods.

Oil production in Wyoming during 1992 was 96,810,000 barrels, but this production is in a slow decline. Natural gas production was 1,012 billion cubic feet and appears to be increasing.

Maps

Any map may be defined as a graphic presentation of data in plan view showing the distribution and space relationships of any group of elements. All objects shown are in a definite proportional relationship to their true sizes and locations.

Cartography, the art of map making, is a very ancient form of communication. A trace drawn in the sand with a stick, pointing the way to a water hole, was a map, perishable though it may have been. The art, as developed by geographers, resulted in the presentation of the spherical globe on a flat piece of paper suitable to use for navigating or for showing national boundaries.

All manner of information has been depicted on maps. Some examples include land and water distribution, climatic zones, population distribution, daily weather, highways, and city streets. The variety of maps is almost infinite, but for geologic purposes the three most important categories of maps are planimetric, topographic, and geologic.

Planimetric maps

A planimetric map is one on which a plan view (depicting relative horizontal position of features) is presented (**Figure 38**). The traveler has a variety of such maps at hand, called road maps or highway maps, upon which are shown road locations, distances between towns, rivers, major points of interest, insets with city street plans, etc. The Wyoming Transportation Commission distributes such a map of Wyoming without charge. The value of their map is enhanced by shading and coloring of the major landforms.

Topographic maps

A topographic map depicts physical landforms by appropriate symbols (**Figure 39**). The word topographic means a graph of a place (topos, place, and graph, to write). The configuration of the land surface is depicted by contour lines that represent points of equal elevation on the ground surface. The interval between contours varies with the scale of the map and the degree of elevational relief, but is usually consistent for a particular map. It may be ten feet, 40 feet, 250 feet, or whatever is needed. Roads, trails, rivers, lakes, cultural features, boundaries of political subdivisions, etc. are located accurately on such maps by appropriate symbols, sometimes in varying colors.

Map scale is the ratio of the size of an object as shown on a map to its actual measured size. A scale of 1:24,000 means that one inch on the map represents 24,000 inches or 2,000 feet on the ground. Presently the Topographic Division of the U.S. Geological Survey prepares maps for most of the country at several scales (1:24,000, 1:100,000, and 1:250,000) in both English and metric measurements. The most widely used topographic map series is that covering 7½ minutes of latitude and longitude at a scale of 1:24,000 (approximately 60 square miles per sheet).

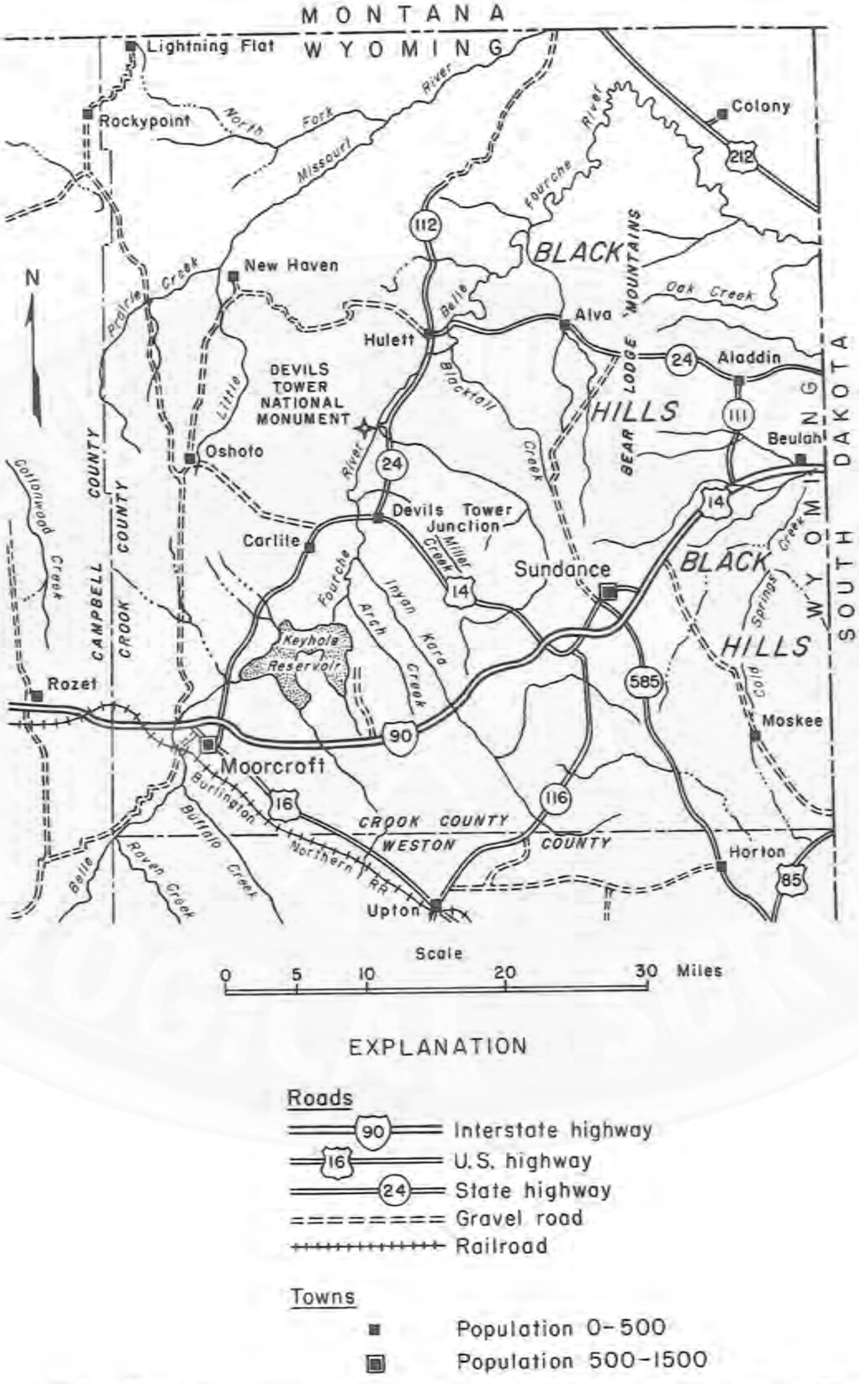


Figure 38. Planimetric map of a portion of northeastern Wyoming (modified from the Wyoming Highway Commission's 1986 highway map).

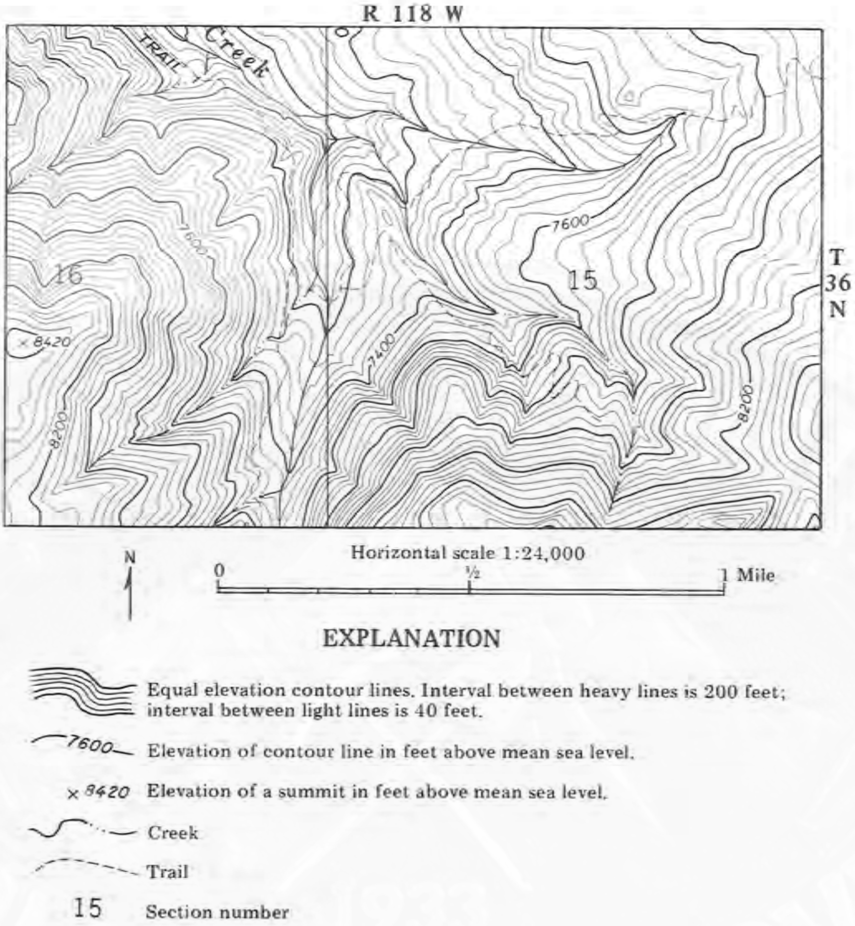
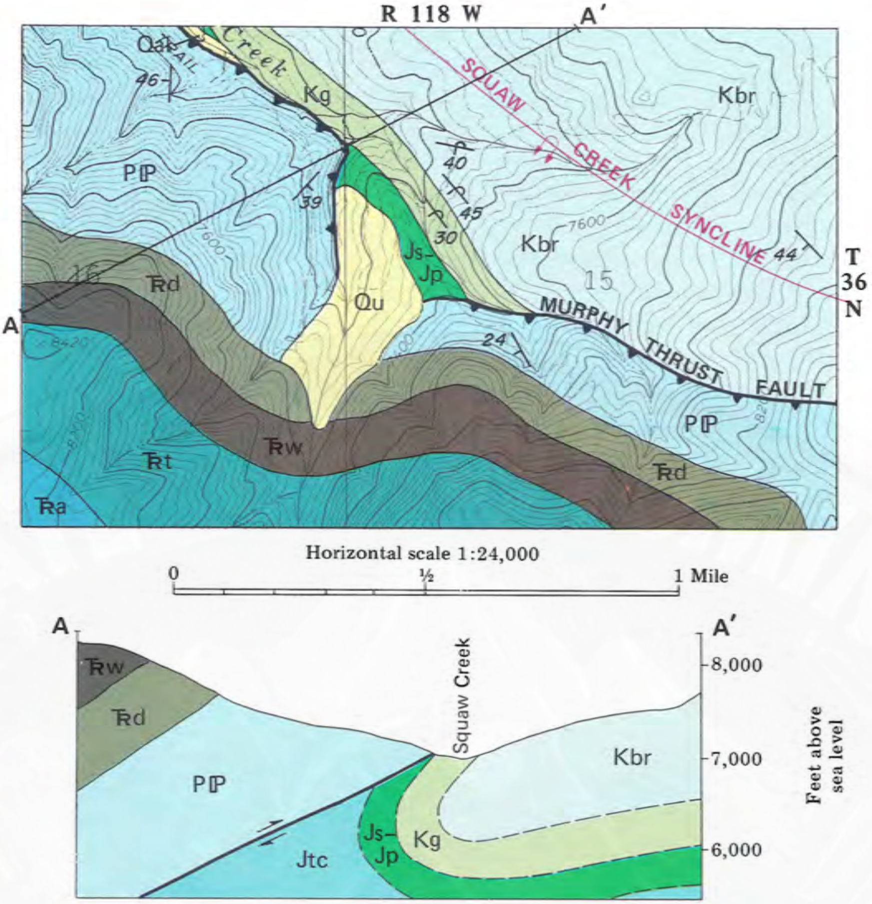


Figure 39. Topographic map of a part of the Stewart Peak Quadrangle in western Wyoming (U.S. Geological Survey). T.36N. and R.118W. refer to Township 36 North and Range 118 West, coordinates of the U.S. Public Land Survey System.

Geologic maps

Geologic maps show the areal distribution of different kinds and ages of rocks by means of colors and symbols (**Figure 40**). They may also depict many other types of information of geologic interest. The best geologic maps use a topographic map for a base so that the relative elevation of the rock units can be determined.

Geologists prepare maps to convey information concerning a wide variety of geologic subjects. The usual geologic map depicts the areal distribution of rock bodies. Rocks of comparable character and



EXPLANATION

ROCK UNITS

Quaternary

Qal/Qu Qal = alluvium
Qu = undifferentiated

Cretaceous

Kbr	Bear River Formation
Kg	Gannett Group

Jurassic

Js – Jp	Stump-Preuss Sandstone
Jtc	Twin Creek Limestone

Triassic

TRa	Ankareh Formation
TRt	Thaynes Formation
TRw	Woodside Formation
TRd	Dinwoody Formation

Permian/Pennsylvanian

PIP	Phosphoria and Wells Formations, undivided

LINE SYMBOLS

Contact

Thrust fault (on map)–sawteeth on hanging wall

Trace of syncline axis (overturned)

A. 44 B. 44
Strike and dip of beds (A. normal, B. overturned)

Fault (on cross section)–arrows show relative movement

Figure 40. Geologic map of the same area shown in Figure 39; using the topographic base (modified from Lageson, 1986). Cross section A-A′ (location on map above) illustrates the arrangement of rock formations at depth.

equivalent geologic age are mapped as a unit called a formation, the fundamental unit in the local classification of the rocks; it is the ordinary unit of geologic mapping consisting of a large and persistent stratum of some kind of rock or a distinct package of rock types. Laymen commonly speak of rock formations when they mean any unusual exposure of rock, or some naturally occurring feature such as a concretion or stalagmite, or just an unusual mass of rock with some peculiar marking or shape. Obviously, this is not the same meaning of "formation" as used by the geologist.

It is customary to give formations formal names, which are derived from a geographic feature in the area (for example streams or mountains) where the rock unit is first described; such a locality is referred to as the type locality. Some Wyoming examples are the Green River Formation, the Mowry Shale, the Frontier Sandstone, and the Sherman Granite.

In preparing a geologic map, the geologist selects the boundaries between formations on the basis of the original definition. Such boundaries are recognizable differences in the rock types that can be seen in the exposed rocks in the field (**Figure 41**).

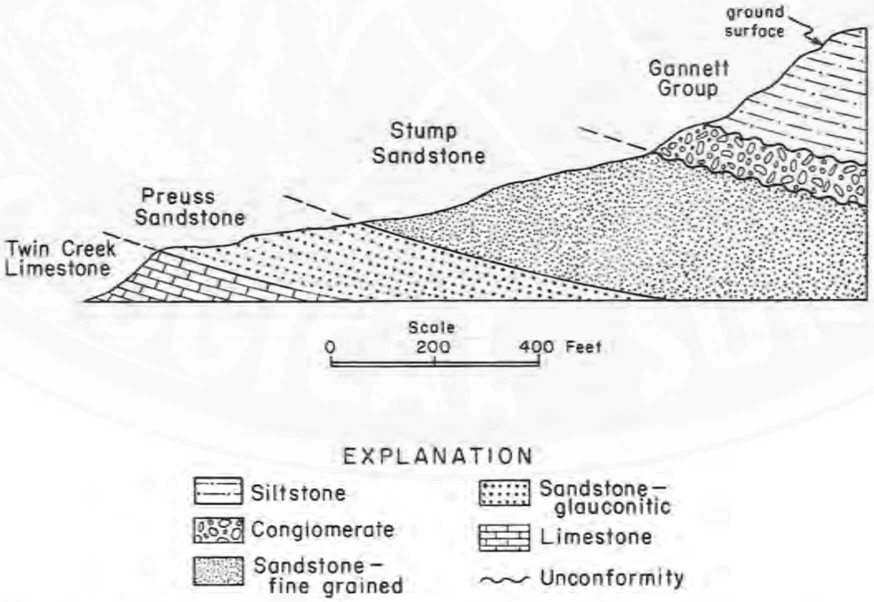


Figure 41. Cross section illustrating boundaries between mappable sedimentary formations. The boundaries established between the units are traced on the ground, and the positions mapped on an appropriate base map (see **Figure 40**). Such lines are referred to as the contacts between formations, or between different rock types in the case of igneous or metamorphic rocks.

The area on the ground occupied by each map unit is shown on the map, and the attitude of the layered rocks is shown by strike and dip symbols. Any developments involving mineral deposits, such as prospect pits, mines, quarries, and tests drilled for hydrocarbons should be accurately located.

A properly prepared geologic map includes an explanation, which shows the types of rocks present and the geologic age of the map units. Often, the average thickness of each formation and a brief lithologic description of the rocks comprising that formation are included. Many geologic maps include a cross section that provides an interpretation of the distribution and extent of the rock units in the subsurface (**Figure 40**).

It is thus possible to determine from a geologic map the kinds of rocks present, the geologic age of the rocks, the areal extent of the units, and the structure of the rocks below the ground surface.

Geologic maps are published in a variety of scales to show different degrees of detail. The *Geologic map of Wyoming* (Love and Christiansen, 1985) is the best map showing the entire State (scale 1:500,000). A convenient 1:1,000,000-scale *Wyoming geologic highway map* (Christiansen, 1986) is also available.

Selected sites

The geology of Wyoming is complex and always interesting. A full description of even the most conspicuous features would require several volumes. We have chosen a few sites in Wyoming that the traveler is likely to see. The highlights of these sites are presented so that you might better understand the geology underlying the landscape. (See "References cited" and "Additional reading" for sources of more information.)

Northwest Wyoming

Togwotee Pass

The Continental Divide is crossed on U.S. Highway 27/287 at Togwotee Pass, at the head of Wind River and Blackrock Creek. The pass lies in an area of open meadows and pine forest, but a short distance north of the road, and in full view of the highway, is an impressive wall of volcanic rocks, called The Rampart.

The Rampart rises to an elevation of 10,908 feet, which is 1,364 feet above the elevation of the pass. In the bare rock walls, roughly stratified volcanic conglomerates striped with white bands of volcanic ash can be seen (**Plate 5B**). The escarpment marks the southernmost extent of the Absaroka Range, but the scarp is being eroded and is slowly migrating northward.

North Fork of the Shoshone River

Many travelers will enter Yellowstone National Park from the east, by way of U.S. Highway 14/14A and 20 across the Bighorn Basin, through Cody and up the valley of the North Fork of the Shoshone River. The river originates along the crest of the Absaroka Range east of Yellowstone Lake and has cut a canyon into the volcanic rocks (**Figure 42**). The rocks of the range are composed of alternating lava flows, ash falls, and volcaniclastic debris. The lava flows reached the surface through fissures that are now filled with andesite and appear as high-angle dikes cutting across other rocks. Ash falls appear as light colored bands of fine-grained material. The bulk of the material in the Absaroka Range is volcaniclastic in origin, ejected from central vents and reworked by streams flowing down the slopes of the volcanic piles. The rock often has a *puddingstone* texture, that is large fragments in a finer grained matrix.

Figure 42. Absaroka Volcanic Supergroup in the Wapiti area between Cody and Yellowstone National Park. View is looking north from U.S. Highway 14/16/20. (Photograph by Gary B. Glass.)

Buffalo Bill Dam (**Figure 43**), the first such structure built by the Bureau of Reclamation (1910), is sited on Precambrian basement in the core of the Rattlesnake Mountain uplift. From the observation point at the dam, one sees nearly vertical strata on the west flank of the uplift. Water from the dam is used to irrigate crops east of Cody; the reclamation project was one of the first such projects in the arid west. A construction project to raise the height of the dam and increase the storage capacity of Buffalo Bill Reservoir was begun in 1986.

Figure 43. Buffalo Bill (Shoshone) Dam shortly after it was built. The dam is sited on Precambrian granite exposed on both sides of the dam. Steeply dipping Paleozoic rocks (Madison Limestone, Amsden Formation, and Tensleep Sandstone) are exposed on the cliffs across the reservoir. Madison Limestone can also be seen on top of Sheep Mountain on the skyline. (Courtesy of the American Heritage Center, University of Wyoming, Laramie.)

Five miles west of the dam is Wapiti Ranger Station (the oldest in the United States) and near there the volcanic rocks can be seen at road level. Farther up the valley are columnar-jointed lava flows, dikes, breccia cliffs, and hoodoos. Near the head of the valley is Pahaska Tepee, originally the hunting camp of "Buffalo Bill" Cody, for whom the town of Cody is named.

Cody area

The geology near Cody is diverse and spectacular. Hot springs along the east foot of Rattlesnake Mountain in the valley of the river emit sulfurous fumes that gave the river its original name — Stinking Water. This was later changed for aesthetic reasons to Shoshone River.

Along the river are excellent examples of both travertine and gravel-capped terraces.

South of Cody a few miles, along Wyoming Highway 120, is a large anticline with a topographic basin. The anticline, known as Oregon Basin, is one of the largest oil fields in the State. The topographic basin is outlined by prominent hogbacks developed upon sandstones of the Mesaverde Formation. The anticline actually lies in the hanging wall of a major thrust fault, the Oregon Basin fault, on which there has been over three miles of movement.

Northeast of Cody and east of Wyoming Highway 120, is Heart Mountain, a prominent, isolated, pyrmidal shaped mountain (**Figure 44**). This isolated body of Paleozoic limestones rests upon the Eocene Willwood Formation, a complete reversal of the normal stratigraphic order. The Paleozoic limestones have moved downslope over 25 miles from their original location, all under the influence of gravity, on a surface of very low eastward gradient. Other similar masses of Paleozoic limestone can be seen from Wyoming Highway 296 over Dead Indian Hill and into the Sunlight Basin country along the upper reaches of the Clarks Fork River. The mechanics of emplacement of these large detached masses of Paleozoic limestone poses one of the most enigmatic problems in Wyoming geology.

A short drive up the South Fork of the Shoshone River on Wyoming Highway 291 gives the traveler an excellent view of Carter Mountain, the prominent peak on the eastern edge of the Absaroka Plateau. Extensive landslides mask the bedrock on the flank of the mountain.

Bighorn Canyon National Recreation Area

The Bighorn River leaves the Bighorn Basin through a deep canyon trending northeast across the northern end of the Bighorn Mountains (Figure 45). Yellowtail Dam (named for a prominent chief of the Crow Indian tribe) was constructed on the east flank of the mountains near Old Fort C.F. Smith, Montana. The lake occupies the canyon and extends south to U.S. Highway 14A east of Lovell.

At Horseshoe Bend Ranger Station, located about 10 miles north of the highway, one looks north toward the southern end of Big Pryor Mountain. The south end of the mountain is a sharp anticline, well exposed at Sykes Spring, where the Wyoming Game and Fish Department operates a fish hatchery. Water is derived from the large spring that discharges through a fault system along the limb of the anticline. The deep narrow canyon begins north of the headquarters site, and can be reached by boat. A half-day boat trip down the lake into the canyon provides an excellent opportunity to see the geology. A paved road

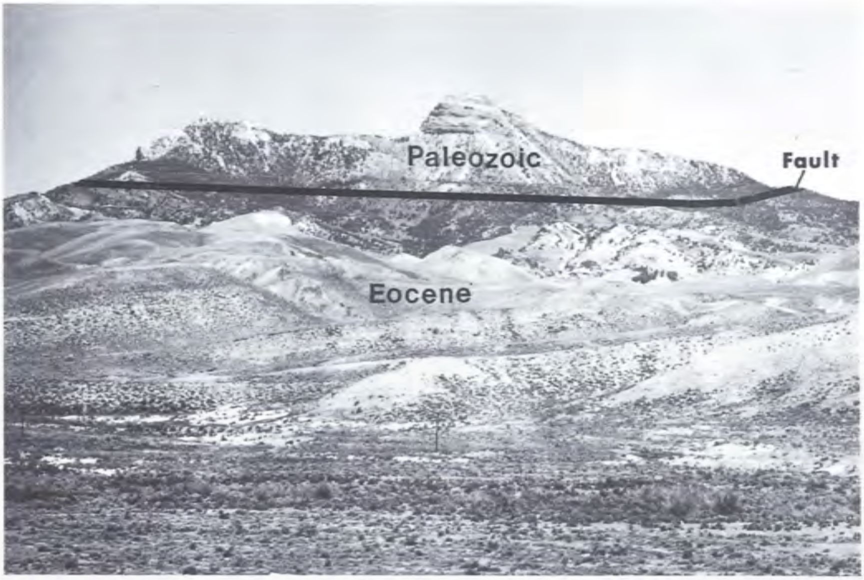


Figure 44. View northeast to Heart Mountain from Wyoming Highway 120 north of Cody. Paleozoic strata are in fault contact with light colored Eocene Willwood Formation. Source of Paleozoic rocks is 25 miles to the northwest. (Photograph by Sheila Roberts.)

Figure 45. View of Bighorn Canyon looking north from Devils Canyon Overlook. The canyon is from 700 to 1,000 feet deep. Canyon walls in this photograph are composed of the Madison Limestone (Mississippian). Note boat wake in the lower part of photograph for scale (Photograph by Richard W. Jones.)

parallels part of the canyon on the west side, and there are overviews to see the geology. There are extensive caves in the limestone east of the river on Little Mountain.

South of the headquarters on the east flank of Sykes Mountain, there is a well-exposed section of Permian, Triassic, and Jurassic rocks. The marine Jurassic Sundance Formation contains abundant invertebrate fossils, but the underlying Triassic Chugwater Formation (redbeds) is barren of fossils. Fossil collecting is prohibited within the Recreation Area, however.

Wind River Canyon

Wind River Canyon is traversed by U.S. Highway 20 between Shoshoni and Thermopolis (Figure 46). The deep canyon is an excellent example of the superimposition of a major drainage across a mountain uplift. It is also an excellent place for travelers to observe some Wyoming geology because roadside signs designate the formations that are exposed en route.

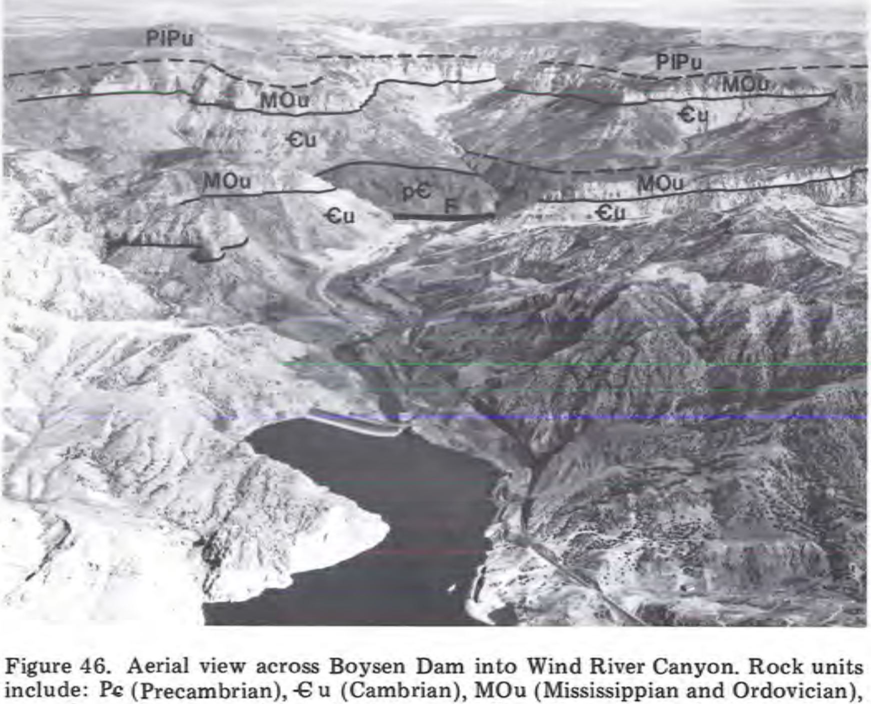


Figure 46. Aerial view across Boysen Dam into Wind River Canyon. Rock units include: Pє (Precambrian), Є u (Cambrian), MOu (Mississippian and Ordovician), PIPu (Pennsylvanian and Permian). Lower half of photo is a faulted complex of Paleozoic and Mesozoic rocks. F = Boysen normal fault. (Photograph by P.T. Jenkins, J. David Love collection.)

Near Boysen, the Wind River is impounded by an earthfill structure to create a reservoir to store water for irrigation. The canyon downstream from the dam is about 10 miles long; it extends to a spot called The Wedding of the Waters, where the name changes to Bighorn River.

Relatively flat-lying multicolored sediments of the Eocene Wind River Formation are traversed between Shoshoni and the mountain front. About a mile south of Boysen, older Paleozoic rocks are exposed in a complex faulted arch (Figure 47). Small faults can be observed in the west wall of the valley near the State Park, and the arch is terminated on the north by the Boysen fault, a normal fault downthrown 1,500 feet to the south. Driving north, the narrow canyon begins in Precambrian crystalline basement in the footwall of the Boysen fault near the first tunnel on the highway. Intrusion of light colored Precambrian granitic rocks into the dark schists is well exposed in highway and railroad cuts.

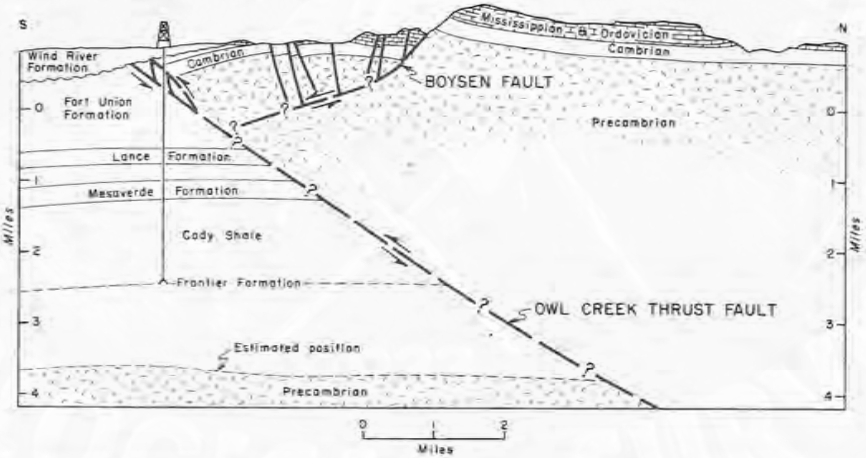


Figure 47. North-south cross section through the Owl Creek Mountains near Wind River Canyon. Exploratory well at toe of fault is included to show geologic control on subsurface interpretation.

The unconformable contact of the basal Cambrian sandstone with the crystalline basement is seen about 1.6 miles north of the Boysen fault. The unconformity represents a time interval of approximately 1.8 billion years. From this point northward, the sedimentary rocks dip about 10° to the north (downstream) so that a complete section of the Paleozoic rocks can be seen along the road. Individual formations are indicated by roadside signs. On emerging from the canyon, one sees extensive outcrops of Triassic redbeds in a broad valley on the north flank of the Owl Creek Mountains. The canyon exposes a cross section of a large, faulted, asymmetric anticline.

Thermopolis Hot Springs

Thermal springs have attracted attention for centuries because of their reputed therapeutic value, which is primarily in the heat that relieves many muscular pains. "Taking the waters" has been popular, and many spas have arisen around thermal springs. Chief Washakie of the Shoshone tribe visited the Thermopolis area and used the waters.

Large springs of natural water are often advertised as the world's largest hot springs. Big Spring at Thermopolis, temperature 135°F, is a large spring by any standard, discharging 2,900 gallons per minute (**Plate 6A**). By comparison, the average household uses about 250 gallons per day. The discharge at the spring could supply almost 17,000 households.

The water is derived from recharge areas on the north flank of the Owl Creek Mountains, passes underground, is heated, and reaches the surface through fractures along the flank of an anticline (**Figure 26**). Considerable carbon dioxide and hydrogen sulfide gas are also discharged, providing the bubbling action.

A note on Yellowstone National Park and Grand Teton National Park

Yellowstone and Grand Teton National Parks, in Wyoming's northwest corner, are the geologic and scenic extravaganzas of the State. However, they are not described in this bulletin because (1) there is too much to say for the present format and (2) much information is already available and easy to find in bookstores in and near the parks.

Yellowstone National Park lies largely within Wyoming and is the primary objective of many travelers to the State. The National Park Service operates numerous information centers, and provides guided tours and literature about all aspects of the Park. Geologic highlights of the park are described in several books for sale in the park concessions and in bookstores throughout the area (for example *The geological story of Yellowstone National Park,* Keefer, 1971).

The spectacular scenery of the Teton Range (**Plate 2A**) is often depicted on posters, calendars, and publications dealing with the landscape. The scenery and related recreational opportunities attract many visitors. The National Park Service operates an information center at the Park Headquarters at Moose, Wyoming, and conducts guided tours. Two publications are especially recommended: *Creation of the Teton landscape* (Love and Reed, 1971) and *Geologic map of Grand Teton National Park, Teton County, Wyoming* (Love and others, 1992). Both are available from the Geological Survey of Wyoming.

Northeast Wyoming

Buffalo - Sheridan

The Bighorn Mountains (highest elevation Cloud Peak, 13,167 feet above sea level) form the backdrop for the region west of Buffalo and Sheridan. Precambrian metamorphic rocks about 2.4 billion years old are exposed in the core of the range and have been extensively glaciated during the Pleistocene. The sedimentary cover of Paleozoic age has been stripped from the core of the mountains but is preserved along the flanks of the mountains. Lower Paleozoic rocks cover much of the northern parts of the range. The Paleozoic rocks are folded (Figure 48) and faulted and now appear in an intermittent series of hogbacks along the mountain flank.

Figure 48. View northwest along the eastern flank of the Bighorn Mountains. Paleozoic strata from Cambrian Deadwood Formation to Mississippian Madison Limestone are folded into an anticline and syncline. Core of mountains (upper left) is Precambrian igneous and metamorphic rocks. (Photograph by Peter Huntoon.)

The east side of the mountain margin is marked by a series of reverse faults that dip to the west beneath the mountains. One large thrust plate, the Piney thrust near Story, consists of Precambrian and Paleozoic rocks that have been moved at least three miles eastward out over the basin.

The foothills along the mountains consist of two different types of sedimentary rocks. One type formed before the mountains were uplifted and the other formed from material that was shed off the mountains during and after uplift. The Mesozoic and Paleozoic sedimentary rocks were tilted during the mountain-building episode and dip eastward into the Powder River Basin. The dip is steep near the mountains but flattens rapidly toward the basin. As the mountains were rising, streams actively eroded the highlands and debris was spread along the mountain flank as a series of coalescing alluvial fans. The rocks contain large boulders, cobbles, and sand. These deposits form part of the foothills belt, and lie upon the tilted Mesozoic rocks.

Farther out in the basin, fine-grained sediments were deposited during the mountain-building episode, and swamps were common. In some of the swamps, thick deposits of plant material accumulated, from which some of the thickest coal beds in the Nation formed. Thick coal beds occur in the subsurface and crop out around Lake DeSmet and near Sheridan. Also near Lake DeSmet, there are many clinker beds caused by the natural burning of coal. In fact, Lake DeSmet lies in a basin formed by the collapse of rock overlying a thick (280 feet or more) coal that burned thousands of years ago.

Hell's Half Acre

Any forsaken, empty, desolate piece of ground may find this name attached to it, whether it deserves it or not. This locality, on U.S. Highway 20/26, six miles west of Powder River Station, appears to have been so dubbed because of the very rough badland topography and areas of red and brown coloration (**Figure 49 and Plate 6B**). Some popular (but incorrect) versions of the origin include a subterranean eruption, even though the nearest igneous activity is the Rattlesnake Hills 25 miles to the south.

The steeply west-dipping strata seen here are of Cretaceous and Paleocene age. Overlying these rocks with marked angular unconformity are varicolored pink, brown, and yellow strata of the Eocene Wind River Formation. The older units were deposited in a near-horizontal attitude, then elevated and tilted to the west, and finally beveled by erosion. The basin continued to subside and the debris from the rising mountains was deposited across the basin margins (Wind River Formation). The present topography is the result of active erosion, creating badlands within the drainage basin of the South Fork of the Powder River and near its headwaters.

Figure 49. View south illustrating angular unconformity between Paleocene Fort Union Formation (left) and overlying Eocene Wind River Formation in Hell's Half Acre area. (Photograph by W.R. Keefer.)

Salt Creek-Teapot Dome oil fields

Salt Creek oil field (**Figure 50**) was the first giant oil field discovered in Wyoming. The discovery, in 1908, was based on active oil seeps at the north end of the anticlinal structure in the Shannon area north of Midwest (the Shannon area was first tested by drilling in 1889). The first development boom occurred during World War I, when transportation from the field to Casper was changing from horsedrawn vehicles to motor trucks. The producing area is approximately 22,000 acres, located on the crest of a major fold outlined by rims of sandstone. The major production is from the Frontier Formation at depths of 900 to 2,400 feet, and the accumulated production through 1992 was 642,500,000 barrels of light crude oil.

Teapot Dome, a southern and separate extension of the anticline, was the central item in a major political controversy during the presidency of Warren G. Harding in the 1920s. The area was set aside as Naval Petroleum Reserve No.3 in 1915, but problems dealing with the leasing and development of the field led to prosecution of public figures for improper leasing practices. The field still produced over 800,000 barrels of oil in 1992. The field takes its name from a sandstone outcrop shaped like a teapot that can be seen a short distance east of Interstate 25 (although the spout and handle have broken off).

Figure 50. Looking north across a forest of oil well derricks in Salt Creek field, as it appeared in 1922. (Photograph courtesy of American Heritage Center, University of Wyoming, Laramie.)

Pumpkin Buttes

In the vast open prairies of the central Powder River Basin, a series of buttes rise up to break the monotony and to serve as landmarks (**Figure 51A**). The four most prominent buttes (Dome Butte; North, Middle, and South Pumpkin Buttes) are situated along the drainage divide between the headwaters of the east-flowing Belle Fourche River and the north-flowing North Pumpkin Creek and Dry Fork of the Powder River. The buttes rise over 1,000 feet above the countryside, and can be readily seen just north of Wyoming Highway 387 between Edgerton and Savageton.

The buttes are capped by a hard resistant sandstone of Oligocene age. Deposits of Oligocene rocks also appear in the Bighorn Mountains to the west and in the Black Hills to the east. Occurrence of Oligocene rocks on Pumpkin Buttes provides evidence of the former level of basin fill (**Figure 51B**). The underlying Eocene Wasatch Formation is widespread in the basin and is the host rock for several large uranium deposits as well as thick coal beds.

Gillette area coal mines

Gillette is the center of the coal industry in the eastern Powder River Basin. Six large surface coal mines are located north and northeast of town and ten mines are located south of town on the east side of Highway 59 between Gillette and Bill (**Figure 52**). Some of these

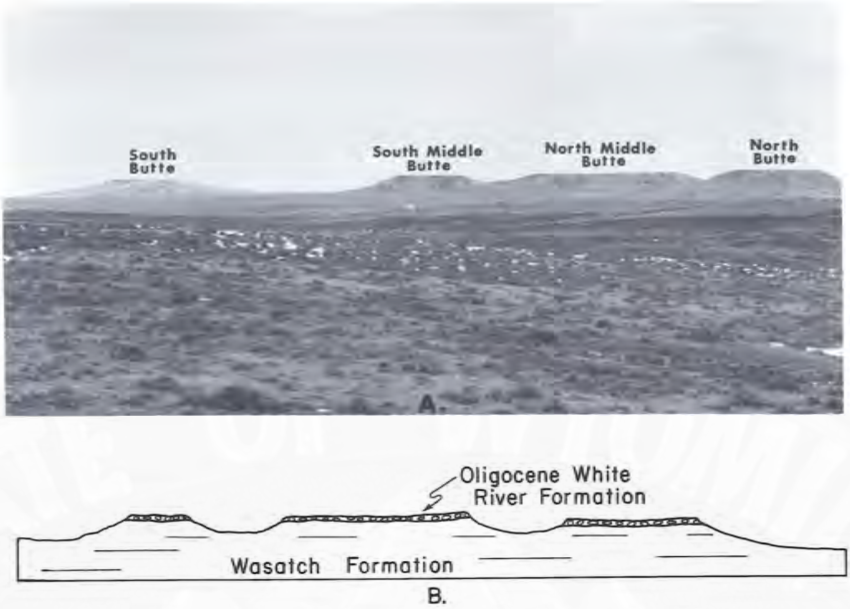


Figure 51. (A) Pumpkin Buttes, in the Powder River Basin, Wyoming (photograph by Gary B. Glass); (B) cross section.

mines are of world-class production size (each mine produces over 10 million tons of coal a year) and rank among the top producing mines in the United States. Many of the coal companies in the area offer guided tours of their operations and can be contacted at the mine sites or at their offices in Gillette.

The Wyodak coal mine is located on Interstate 90, 21 miles west of Moorcroft and seven miles east of Gillette. At Wyodak, subbituminous coal is recovered in an open pit mine from a 90-foot-thick coal bed called the Wyodak. This coal bed can be traced (mapped) on the surface and in the subsurface (through drilling) over wide areas in the Powder River Basin. The Wyodak coal bed and other coal beds equivalent to it form one of the thickest, most extensive coal deposits in the world and provide a tremendous resource of relatively inexpensive, easily accessible energy in the form of fossil fuel. Coal recovered at the Wyodak mine is transported directly to the Wyodak power plant (immediately south of Interstate Highway 90) where it is burned to produce steam to generate electric power.

Figure 52. At this large surface coal mine north of Gillette, miners are stripping the upper half of a coal seam over 110 feet thick. The coal shovel (left) is 50 feet high and has a 40-cubic-yard bucket. The coal haul truck (center) handles about 120 tons (150 cubic yards) of coal. (Photograph by Richard W. Jones.)

Southwest Wyoming

Star Valley

Star Valley, the westernmost large valley in Wyoming, is cut by the Salt River, a northward-flowing tributary of the Snake River. Star Valley roughly parallels the north-trending folds and faults of the Overthrust Belt and is bounded on the east by the Salt River Range and on the west by the Caribou Range.

The beautiful valley was named by early white settlers, who considered it to be a star among valleys. The name Salt River is somewhat of a misnomer, since the water is clear and sweet. However, in the vicinity of Freedom there are salt pans from which the emigrants en route to Oregon were able to evaporate brines and collect salt. The river received its name from these salt-gathering activities.

The valley is bounded by large alluvial fans that act as aquifers, discharging at springs at lower elevations and thus stabilizing the flow of the river. East of Afton, in the valley of Swift Creek, is an unusual spring that has a pulsing periodic discharge.

The east side of the valley is bounded by faults that have been active in fairly recent time, geologically speaking. Near Thayne and Bedford, fault scarps that offset alluvial fans are plainly seen, indicating that there has been fault movement in the not-too-distant past.

Downstream near Swan Valley, the Snake River is impounded to form Palisades Reservoir, which backs water up into the Salt River valley.

Fossil Butte National Monument

At certain stages in Eocene Fossil Lake's history, mass mortality of its fish population occurred for reasons not fully understood. The environment was such that the fish and other animal life were preserved in remarkable detail. The fossils from these lake beds can be seen today in rocks of the Green River Formation (**Figure 53**). One of the thin muddy limestones containing innumerable specimens of fossil fish is exposed west of Kemmerer on both sides of U.S. Highway 30.

Fossil Butte National Monument was set aside to preserve some of the fossil fish beds and to provide an area for research on the occurrence. A public exhibit of material excavated from the fish beds is displayed and an information center is provided. Private collectors have developed quarries outside the monument boundaries where they prepare fossil material for sale. (Read more about the Green River fish in Grande, 1984.)

Evanston to Kemmerer

U.S. Highway 189, from its junction with Interstate 80 north of Kemmerer, parallels the trend of the major thrust faults in the Overthrust Belt and follows a major topographic basin, Mammoth Hollow, which lies in the hanging wall of the most easterly major fault in the Overthrust Belt, the Hogsback (Darby) fault. The eastern rim of Mammoth Hollow is comprised of the coal-bearing Frontier Formation, which is exposed in a well-developed ridge. The strata dip to the west toward the observer.

Bituminous coal was mined underground from the Frontier Formation at Cumberland Gap, Diamondville, and Frontier (the latter just north of Kemmerer). Coal is now mined in a large (400 feet deep) open pit mine west of Kemmerer. This pit is developed on steeply dipping Cretaceous coals of the Adaville Formation. Up to 32 subbituminous coal beds occur in the area currently mined by Pittsburg and Midway Coal Mining Company, and the basal coal bed in this mine is over 80 feet thick in places. This mine can be seen from U.S. Highway 30. Dinosaur tracks found during the mining of these coals are displayed at a privately owned fossil gallery located along the road into Fossil Butte National Monument.

Figure 53. Green River Formation fossils: (A) part of a slab of shale that contains a *Knightia eocaena* (a herring) mass mortality layer (fish are about five inches long); (B) a damselfly about 1½ inches long; (C) a maple leaf; (D) a frog. (Photographs from Grande, 1984.)

Several major oil fields such as Ryckman Creek, Whitney Canyon, Painter Creek, and Anschutz Ranch are located near Evanston (see Blackstone and DeBruin, 1987). Oil is produced from rocks in complexly faulted anticlines at depths ranging from 15,000 to 18,000 feet. All the producing fields are in the hanging wall of the Absaroka thrust fault. Reservoir rocks have moved eastward so that they lie above Cretaceous shale (oil source rocks) in the footwall. Movements on the thrust faults in this area have compressed and shortened a thick panel of sedimentary rocks by about 50 percent.

Lyman-Mountain View-Evanston

This section of Wyoming was traversed by many branches of the Emigrant Trail to the Great Salt Lake Valley and to California. Emigrants often stopped at Fort Bridger, established in 1843 by the mountain man Jim Bridger. For several miles west of Lyman, the rocks are a part of the Bridger and Wasatch Formations, rather poorly exposed along the valley of the Blacks Fork River. Far to the south, in Utah, rise the snow-capped peaks of the east-west trending Uinta Mountains, comprised of a section of Proterozoic metasediments over 25,000 feet thick, bowed up in a large fold.

The Uinta Mountains were severely glaciated during the Pleistocene ice age, and near the mountain flank there are large terminal moraines in the river valleys. Rivers from the north flank of the mountains flow to widely separated areas. Blacks Fork and Cottonwood Creek flow to the north, then make a loop eastward to join the Green River and ultimately the Colorado River. In contrast, the Bear River flows north, then swings westward into Bear Lake and eventually into the Great Salt Lake.

Traveling westward from Lyman roughly halfway to Evanston, the road descends from the high plateau into the valley of Muddy Creek. Variegated claystone and sandstone of the Wasatch Formation are exposed in the road cuts on the long grade into the valley. The Wasatch Formation overlies strongly folded older rocks. Cretaceous shale and sandstone are exposed in the floor of the valley. A very prominent thick white sandstone is seen at road level on the west side of Muddy Creek near some old coal mines. This sandstone, the Lazeart, crops out for many miles to the north in a narrow syncline.

Flaming Gorge

Over 100 years ago, one of the famous exploratory expeditions in the United States began at Green River Station, Wyoming, on the Union Pacific Railroad. John Wesley Powell and his party set out by boat to explore the Green River and eventually the Colorado. During this trip, Powell explored the section of the Green River now known as Flaming Gorge (Plate 7A). The Green River rises in the northern Wind River Range, flows across the rather barren floor of the Green River Basin, and then crosses the Uinta Mountains through a series of spectacular looping canyons, one of which is Flaming Gorge.

The Green River has many meanders (looping curves). Flaming Gorge is part of one series of meanders near the north flank of the Uinta Mountains. The section of metasedimentary and sedimentary rocks, ranging in age from Late Precambrian to Cretaceous, dips steeply to the north along the flank of the Uinta Mountains. The bright colors of the Triassic redbeds and the Jurassic sandstones exposed in the canyon walls led Powell to describe this section of the river course as the Flaming Gorge.

The dam, built in the canyon south of Flaming Gorge in Utah, creates a large lake that extends northward into Wyoming almost to the town of Green River. The lake stores water for downstream users and provides a great recreational area. The spectacular gorge is still present downstream from the dam, and is as colorful as when first viewed by Powell in 1875.

Two ways by which a river might establish a course across a major mountain uplift have been proposed. The first possibility is that the river is older than the uplift and maintained its course as the older rocks were elevated. The second explanation is that the uplift was essentially buried by younger rocks, in this case the Green River Formation, and the river course was established on that fill. Later the river cut its way through the older rocks like a saw. The latter explanation seems most plausible for the Green River.

South of Interstate 80, there are active oil seeps that originally encouraged exploration for oil and gas in the area. Oil was encountered in the Aspen tunnel of the Union Pacific Railroad during excavation. At Piedmont on an unpaved road south of the Interstate, three beehive coke ovens are preserved; they were used to manufacture coke, shipped to smelters in Utah in the late 1800s.

LaBarge area - Green River Basin

The Green River Basin occupies a large area in southwestern Wyoming, which in Eocene time was the site of an extensive inland body of water — Lake Gosiute. The history of this lake is revealed in a remarkable sequence of rocks representing lacustrine (lake), paludal (marsh), and alluvial (river) environments of deposition. The extent of the lake varied from time to time, and the depth of water likewise fluctuated greatly. As a result of the changes of water level and the lateral shift of the shoreline, sediments from the various environments interfinger with each other.

Opposite the town of LaBarge, in the bluffs on the east side of the Green River, a flat-lying series of rocks belonging to the Eocene Wasatch and Green River Formations crop out (Figure 54). Some of the sandstones were deposited near shore, and some of the very thin-layered strata were deposited in the deeper lake waters. In general, the red strata are the continental Wasatch Formation, and the thinly banded white layers are Green River Formation lake beds.

Figure 54. Picture Bluffs opposite LaBarge. (Photograph by S.S. Oriel.)

Pinedale area

The region near Pinedale is a classic one for viewing glacial phenomena (Figures 55 and 56). The area near the higher peaks of the central Wind River Range such as Dinwoody Peak, Gannett Peak, Wind River Peak, and Atlantic Peak was heavily glaciated during the Pleistocene. A few residual glaciers still exist among the numerous horns and steep-walled cirques. During the Pleistocene ice age, the glaciers moved down from the summit area out onto a piedmont at an elevation varying from 9,500 to 8,000 feet. As ice moved down from the piedmont and occupied the existing valleys, it scoured and smoothed the bedrock like a giant file. The valleys now have the characteristic U-shape of valleys once occupied by a glacier. As the ice melted and receded, terminal moraines of these valley glaciers dammed the streams to form a series of lakes. New Fork, Fremont, Half Moon, Boulder, and Willow Lakes are all dammed by moraines.

Figure 55. View northwest across the glaciated core of the southern Wind River Range. Note the upland surface of low relief. Numerous cirques with near-vertical precipitous headwalls with lakes in the cirque basins create a "biscuit board" type of topography. (Photograph by Austin S. Post.)

Rock Springs area

Rock Springs was established in 1869, during the construction of the first transcontinental railroad, the Union Pacific. The railroad was built across southern Wyoming partly because of the availablility of coal. High quality bituminous coal mined at Rock Springs supplied much of the railroad's needs until 1950, when the motive power was converted to diesel fuel. These mines were all underground, but old portals (entrances) and buildings are found throughout the area.

The city is located on the west flank of a large regional uplift, the center of which is a topographic basin, Baxter Basin (**Figure 57**). The east flank of the Rock Springs uplift is seen at Point of Rocks. The Jim Bridger power plant, located several miles north of Point of Rocks, is fueled by subbituminous coal from a strip mine nearby

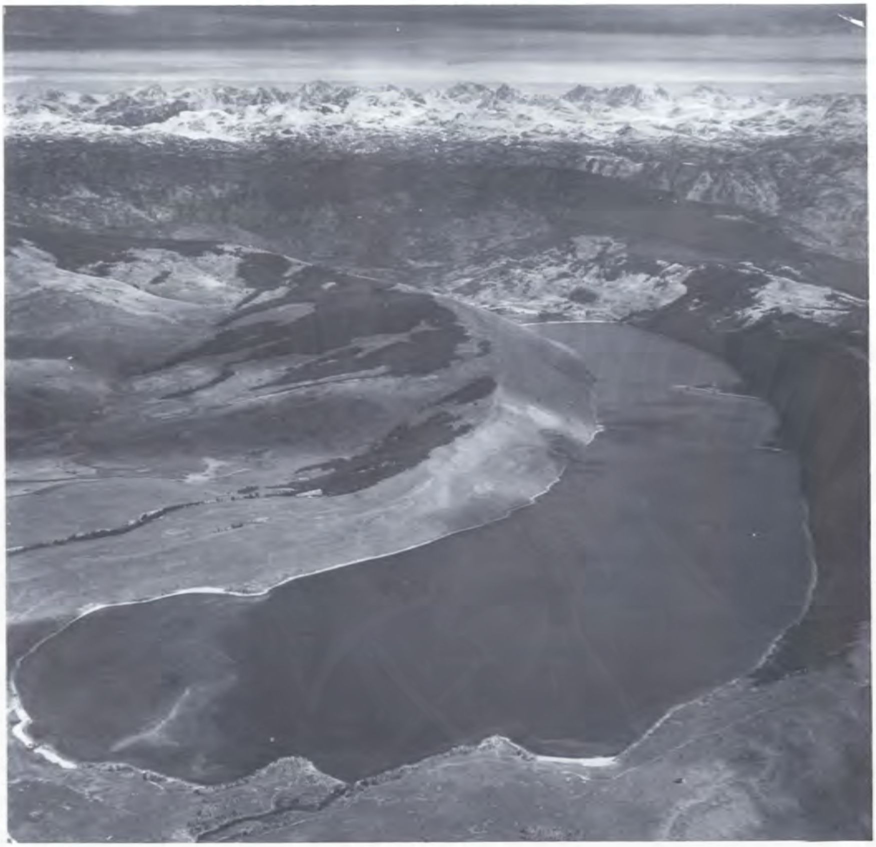


Figure 56. View east toward the crest of the Wind River Range. The peaks in the background rise above the cut surface at an elevation of about 9,000 feet. In the foreground is Willow Lake, dammed by the terminal moraine of a glacier that once occupied the valley. (Photograph by Austin S. Post.)

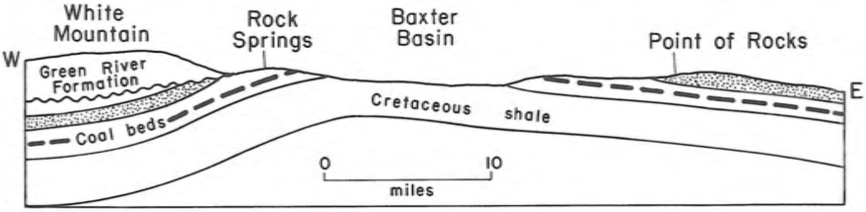


Figure 57. The Rock Springs uplift.

(but not visible from the highway). The only underground coal mining activity in the area at present is a small mine east of Rock Springs that provides coal for domestic heating.

White Mountain, a prominent escarpment exposing the Green River Formation, lies just north and west of the city. North of Rock Springs on U.S. Highway 191 to Farson and Pinedale, one can make a side trip to the Boar's Tusk. This feature is a prominently exposed volcanic neck related to the Leucite Hills volcanic field (about one million years old) a few miles to the east. Farther to the north and east, is the extensive Killpecker dune field, an area of active moving sand dunes trending northwest across the northern plunge of the Rock Springs uplift.

The town of Green River, located about eleven miles west of Rock Springs, is the base of operations for the extensive trona mining industry in the Green River Formation. The famous trip of John Wesley Powell in 1869 through the Grand Canyon of the Colorado began at Expedition Island in the city. Downstream from Green River, water is impounded behind the Flaming Gorge Dam, forming a large lake that is popular with fishermen and boaters. Rugged cliffs surrounding Green River are formed in the Tower Sandstone, a member of the Green River Formation. During excavation for the railroad, a fossil fish-bearing bed was exposed just west of town; this cut was long known as Fish Cut.

Five soda ash (refined trona) processing plants are located west of Green River. Three are easily visible from Interstate 80, FMC and General Chemical to the north and Tenneco to the south. Tg. Inc., and Stauffer Chemical are more distant to the north.

Sinks Canyon

Under certain conditions, streams can mysteriously disappear into caverns and reappear at some distance downstream. The local term for such phenomena is sinks. A well-known example occurs six miles south of Lander on the Middle Fork of the Popo Agie (pronounced Pō-pō′-zha) River. The limestone at the sinks dips 15° to the northeast, away from the crest of the Wind River Range. The stream sinks into a cavern in the Mississippian Madison Limestone and reappears several hundred yards downstream (Figure 18). Similar sinks occur in Dinwoody Canyon near Dubois and on the Little Tongue River near Dayton. The origin of such sinks is discussed under "Landforms developed primarily by solution of limestone".

Derby Dome

Derby Dome (Figure 58) is a discrete anticlinal oil trap, one of the long line of folds that extends southeastward from Steamboat Butte on the Wind River (near Crowheart) to Beaver Creek. The line of folds parallels the east flank of the Wind River Range and passes immediately east of Lander.

Derby Dome is crossed by U.S. Highway 287 fourteen miles south of Lander. Approaching from the south, after descending from Beaver Rim, the road parallels hogbacks of the Frontier Formation, then swings to the west across the strike of the rocks and across the crest of the fold. In the core of the fold, Triassic redbeds and Jurassic sandstones are well exposed. A stop near the oil field pump units provides a fine opportunity to see a producing oil field close up. This field has produced oil almost continually from a depth of about 1,000 feet since the discovery of oil here in 1921.

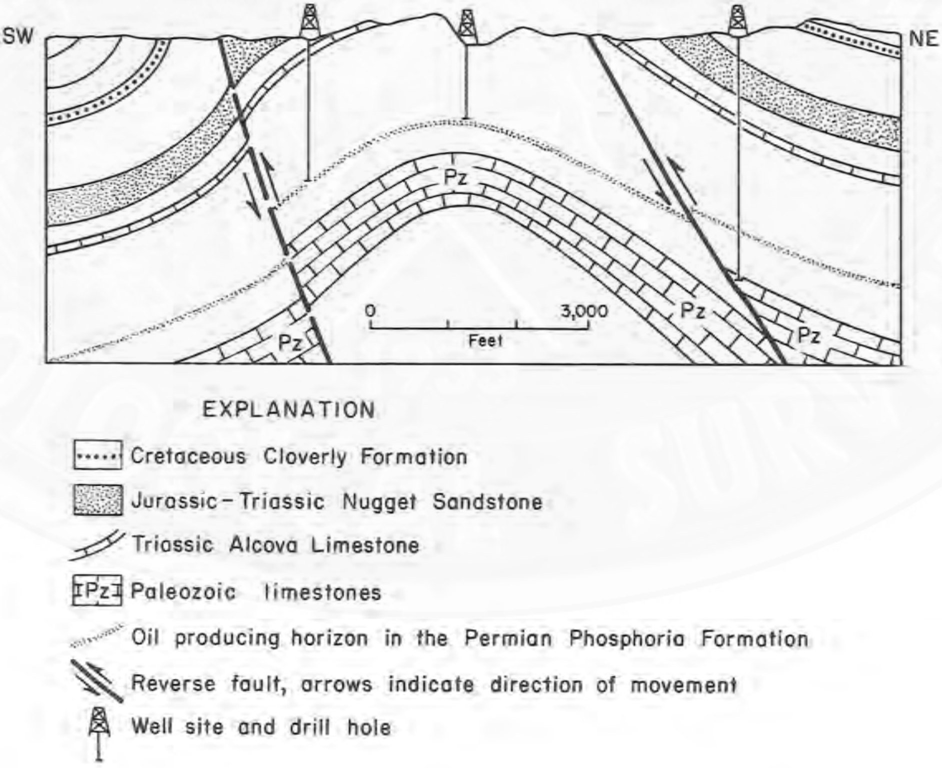


Figure 58. Cross section of Derby Dome, a producing oil field near Lander, Wyoming. Production is from an anticlinal trap in the Permian Phosphoria Formation. Some other important units delineate structure.

Northwestward from Derby Dome, the road crosses the Little Popo Agie River on the west flank of another producing oil field, Dallas Dome. A short trip north of the highway leads to the oil field (turnoff is marked by a sign). Wyoming's first oil field was discovered here in 1884.

Red Grade

The Triassic Chugwater redbeds are widespread throughout Wyoming, with hundreds of square miles of outcrop. Many sections of automobile roads pass over redbeds, and local sections of the road have been dubbed red valley or red hill. One particular section of highway deserves special description.

The original wagon road from Lander to Atlantic City crossed the Little Popo Agie River near Dallas Dome oil field and continued southward up a strike valley occupied by Red Canyon Creek. The long dry haul out of the valley to the uplands beyond was properly known as Red Grade.

This interesting stretch of country can be reached by leaving Wyoming Highway 28 just before crossing the Little Popo Agie River about five miles south of Lander. A well-traveled gravel road follows Red Canyon Creek. From the top of the grade, the view northward includes a sweeping panorama of geology. The valley can also be viewed from an overlook point on Wyoming Highway 28 (**Figure 59**).

Figure 59. Red Grade. View north along strike valley eroded into Triassic Chugwater Formation. Flat surface (left background) is Table Mountain, capped by Eocene boulder beds. Rims on east side of valley are Jurassic Nugget Sandstone and younger rocks.

To the left (west) are long, rather even slopes, developed by stripping all rocks down to a resistant cherty unit in the Permian Phosphoria Formation. In the middle distance, a very sharp anticlinal flexure interrupts the dip slopes. The stream flows down a valley cut in Triassic redbeds, above which (to the east) are scarps of more resistant redbeds, and finally pink and orange crossbedded sandstones of the Jurassic Nugget Formation on the skyline.

Far to the north, near Lander, is the horizontal profile of Table Mountain, capped by giant boulders derived from the Wind River Range to the west. The boulders are the basal unit of the Eocene Wind River Formation. Few valleys provide such a colorful opportunity to see tilted sedimentary rocks and their topographic expression.

South Pass region

Thirty miles south of Lander, on Wyoming Highway 28 in the southern Wind River Mountains, is the South Pass gold and iron mining region. This 200- to 250-square-mile belt includes the historic sites of Atlantic City and South Pass City, which were established in the late 1860s as gold mining centers (**Figure 60**), and also includes the Lewiston and Miners Delight ghost towns.

Figure 60. Remains of the E.T. Fisher washing plant used in the dredging of Rock Creek in the South Pass-Atlantic City district. The dredge operated from 1933 to 1941. (Photograph by W. Dan Hausel.)

There are interesting geological similarities between the South Pass region and many of the gold mining camps in Canada, South Africa, and Western Australia. The South Pass district is considered to lie in a greenstone belt and many rocks in the belt are greenish to black. In this region, igneous rocks and sediments were deposited in an ancient sea more than 2.8 billion years ago. Subsequently, these greenstone belt rocks were metamorphosed and compressed and now stand nearly on end, forming a tightly folded syncline.

Most of the gold deposits occur either in stream gravels (placers) or in the actual hard rock, where the rock has been sheared or faulted (lodes). A great majority of the lodes were formed along the flanks of a belt of metamorphosed mafic igneous rock in the adjacent metasediments.

Iron ore occurs in a narrow belt of banded magnetite-quartz iron formation along the northwestern and eastern margins of the South Pass greenstone belt. The Atlantic City mine, a large open pit, was operated from 1962 to 1983 for taconite, a siliceous banded iron ore. More than 90 million tons of iron ore were produced from the mine before it closed (**Figure 61**). A number of other interesting minerals and metals have been identified in this region including tungsten, aquamarine beryl, copper, and asbestos.

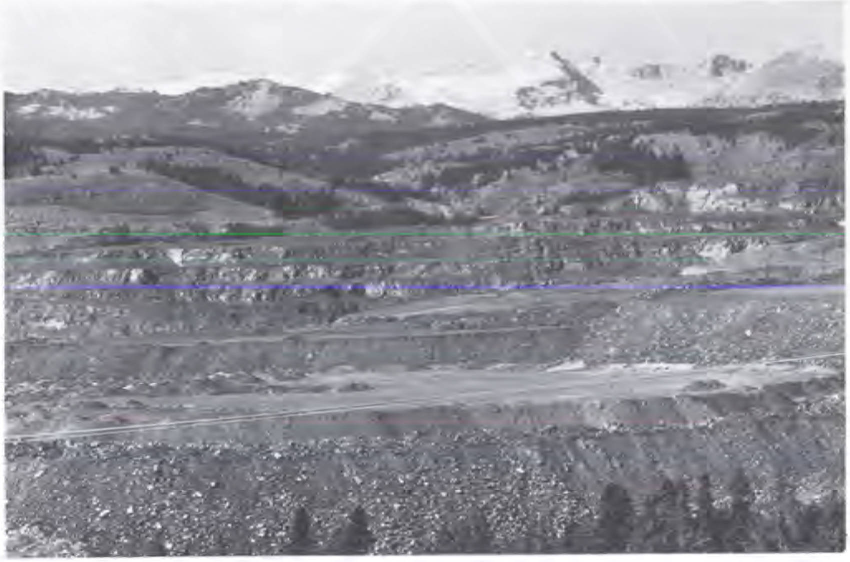


Figure 61. The Atlantic City open-pit mine along Wyoming Highway 28 south of Lander. This mine was operated by U.S. Steel from 1962 to 1983. (Photograph by W. Dan Hausel.)

Split Rock

The great western migration of people to Utah, California, and Oregon, which was at its height from about 1845 to 1852, moved across central Wyoming along the Sweetwater River valley. The landmarks of the Oregon Trail are recorded in dozens of pioneer journals and diaries, though little is said concerning the geology.

Bald, stark knobs of granite dominate the scenery along the Sweetwater River from Independence Rock to the Sweetwater Crossing. Split Rock, a prominent knob with a cleft in the summit, was a landmark for pioneers using the Oregon Trail (**Figure 62**). The cleft summit is the result of weathering away of mafic dike rock intruded along fractures in the granite. The cleft appears like a gunsight on the horizon.

Figure 62. Split Rock, photographed by the famous early western photographer William Henry Jackson during one of the two Hayden Surveys of the area (1870), showing the survey party in the foreground. (Photograph from the U.S. Geological Survey.)

Split Rock Historical Site provides an excellent view of the Sweetwater River valley, site of the Oregon Trail and a Pony Express station, but Split Rock itself cannot be seen there. To observe Split Rock, drive to a granite marker located about three miles west of the Wyoming historical site on Highway 287.

West of Split Rock, dark igneous dikes crosscut the massive, exfoliated granite.

Bessemer Bend

Casper is situated on the north flank of a prominent anticline that trends east-west. The North Platte River makes a sweeping bend to the east and crosses the fold in a narrow canyon. The great bend of the Platte is known as Bessemer Bend.

The traveler passes through the canyon near river level on Wyoming Highway 220 en route from Casper to Rawlins. After leaving Casper, at about 4.5 miles from the Paradise Valley turnoff, the highway crosses the south end of the Emigrant Gap anticline, an Oregon Trail landmark outlined by a series of tan sandstone ridges belonging to the Cretaceous Frontier Formation. The road begins to descend toward the North Platte River and follows a valley between strike ridges in rocks that dip steeply. On the canyon wall above the river to the west, the entire Triassic redbed sequence can be seen arching over the crest of an anticlinal fold (Plate 7B). The thin, dense, Alcova Limestone stands out as a marker bed in the monotonous red sequence. Continuing southward through the canyon, the traveler again reaches the dark sandstones and shales of Cretaceous age dipping southward on the back side of the Casper Mountain fold.

The north face of Casper Mountain is bounded by a south-dipping reverse fault, on which Paleozoic rocks have been transported upward and northward over the gray Cretaceous shale that underlies the city. The North Platte River has been superimposed across the Casper Mountain structure from a preexisting drainage pattern established on a surface of younger Tertiary rocks that once covered the area. The receding scarp in which the Tertiary strata are now exposed can be seen on the skyline to the southwest, and beyond that are the high knobs of the Granite Mountains.

Bates Hole

Driving north from Medicine Bow to Alcova Junction there is a choice of two routes across the Shirley Basin with less than a mile difference in length. Wyoming Highway 77, the western route, descends from Shirley Basin over Shirley rim and down into Bates Hole along the valley of Stinking Water Creek. Before descending into Bates Hole, stop and view the landscape. The high white rim across the basin to the west is capped by the Miocene Arikaree Formation that overlies light colored Oligocene White River Formation. Chalk Mountain stands at the southeast corner of the mesa. At the foot of Shirley rim, varicolored sandstones and claystones of the Eocene Wind River Formation crop out. These sandstones host the uranium deposits mined in the Shirley district. The sagebrush and greasewood covered floor of Bates Hole is underlain by dark marine shales of Cretaceous age.

From the floor of Bates Hole, the view includes the pinnacled buttes along the east rim of the basin, largely developed on the Oligocene White River Formation. At the north end of Bates Hole, older rocks come into view, with one well-exposed anticline at the mouth of Bates Creek.

Como Bluff

Como Bluff is located about six miles east of the town of Medicine Bow and just north of U.S. Highway 30/287. The bluff cannot be seen from the road at the dinosaur cabin exhibit although it lies directly north of that spot. It is best seen from the west, on the highway east of Medicine Bow. The Bluff rises above the valley of Rock Creek and is capped by resistant sandstones of the Cloverly Formation.

Como Bluff is of interest historically and scientifically because a major discovery of dinosaur remains was made here in 1877. A railroad worker, William H. Reed, found sauropod remains and called them to the attention of a famous paleontologist of that time, O.C. Marsh, of Yale University. Fossil material was excavated intermittently until 1902 (**Figure 63**). Many specimens from this site are exhibited in major museums of the world. The intense interest in dinosaurs in recent years has led to renewed fossil quarrying at Como Bluff and in the surrounding area.

The sauropod remains were recovered from pastel colored mudstones of the Jurassic Morrison Formation. The environment during the time the sauropods lived here was probably subtropical, with abundant vegetation such as cycads, and numerous standing bodies of water.

The discovery of dinosaur remains here was made in part because of the original position of the railroad. The old grade of the Union Pacific Railroad can be seen turning east from the highway about four and one half miles north of the present railroad siding of Lookout (seen from U.S. Highway 30). The original roadbed went east down Meiser Creek to Rock Creek and then west along the foot of Como Bluff. The old roadbed returns to the present track near Medicine Bow.

Elk Mountain

Elk Mountain (one of many features bearing the same name) stands out as a large isolated mountain, best seen when traveling west

Figure 63. William Harlow Reed (right) and his assistant, Mr. Kennedy, recovering dinosaur bones from a quarry at Como Bluff. Photograph of a painting by Arthur Lake, dated 1879. (Paul O. McGrew collection, courtesy American Heritage Center.)

from Laramie on Interstate 80. It can be viewed very well from the Wagonhound rest area about seven miles west of Arlington. On the east flank of the mountain, movement on a fault has elevated and tilted the mountain block. The north-sloping profile of the mountain is the surface of the Precambrian basement stripped of overlying sediments.

Beyond the Hanna Exit from the Interstate, prominent sandstone ridges of the coal-bearing Mesaverde Formation outline the northern extension of the uplift.

Glendo-Orin Junction area

A major event in the geologic history of the Rocky Mountains is well displayed along Interstate 25 from Glendo to Orin Junction. The Precambrian basement there is overlain by Paleozoic and Mesozoic sedimentary rocks (**Figure 64**), all of which were deformed about 60 million years ago during the Laramide orogeny. As the mountains grew, erosion immediately began to carve valleys and a mature, well-dissected topography resulted.

Figure 64. View east across North Platte River below Guernsey Dam showing some of the Paleozoic rocks of the Glendo-Orin Junction area. Paleokarst topography developed on top of the Mississippian Guernsey Formation limestone (Mg) before deposition of Permian-Pennsylvanian Hartville Formation (IPPh). (Photograph by L.G. Hembest, J. David Love collection.)

In Early Oligocene time, the scene began to change because of violent and prolonged volcanic eruptions in the Great Basin region of Nevada and eastern California. Tremendous volumes of volcanic ash were spread eastward across the state by both wind and running water, building up a mantle of fine-grained material that covered most of the older topography except the summits of the higher ranges.

Near Glendo Reservoir, the older limestones crop out in bare ridges unconformably overlain or flanked by light colored, fine-grained rocks of the Oligocene White River Formation. The partial removal of the White River Formaton by modern streams has exhumed and exposed an ancient topography buried about 30 million years ago.

Hat Creek Breaks/Pine Ridge

A strip of pine-studded badlands can be followed from near Chadron, Nebraska, across the Wyoming-Nebraska border as far west as Glenrock in Wyoming. The escarpment faces generally northward, with relief of several hundred feet from the rolling uplands at the summit to the shale flats to the north. This escarpment is called Pine Ridge in Nebraska and Hat Creek Breaks in Wyoming. Many springs emerge in the canyons at the foot of the scarp; the waters from the springs drain northward and ultimately join the Cheyenne River.

About five miles north of Lusk on U.S. Highway 85 is the edge of the breaks, which are characteristic of the Pine Ridge country. Scattered strands of Ponderosa pine trees in the valleys appear black and somber among the light, chalky sedimentary rocks (Figure 65).

Figure 65. A portion of Hat Creek Breaks/Pine Ridge north of Manville, Wyoming. Cliffs at the skyline are composed of White River Formation volcanogenic sedimentary rock. (Photograph by Ray E. Harris.)

The escarpment is the result of slow, southward recession of flat-lying Tertiary strata under the continued erosive action of streams. At one time, almost all of eastern Wyoming in the region of the Powder River Basin was covered by several hundred feet of the same type of rock as is now seen in the badlands along the scarp. The source of these sediments was volcanic centers, probably in Nevada and eastern California.

The westward extension of the scarp begins west of Casper and continues on to South Pass on the Sweetwater River. The scarp in this part of Wyoming is known as Beaver Rim.

Sherman Mountains and Vedauwoo Glen

Flat-lying Tertiary strata are seen along Interstate Highway 80 west of Cheyenne to a point near Granite Canyon. From this point westward to the Lincoln Monument, the highway is located upon

Precambrian granite and minor amounts of metamorphic rocks. The topography of low rolling relief is broken by occasional knobby hills standing above the surface. About 23 miles west of Granite Canyon is a rest stop known as Lone Tree, or Tree-in-the-Rock, from which one gets a fine view of the Sherman Mountains to the northwest.

The Sherman Mountains are eroded from massive, homogeneous pink granite over 1.4 billion years old that corresponds very closely in composition and origin to the Pikes Peak Granite in Colorado. The Sherman Granite was intruded into a series of 1.7-billion-year old metamorphic rocks.

A few miles farther west, an exit off U.S. Interstate 80 leads to Vedauwoo Glen and Medicine Bow National Forest picnic areas for a close-up view of the Sherman Granite. Large, subrounded, balanced rocks are seen on the skyline, some of which are as large as a house (Figure 66). Such blocks were originally bounded by fractures that divided the entire rock mass into rough rectangular blocks. Weathering has enlarged the fractures and cracks, removed some of the original granite, and left behind the individual blocks. The more rounded ones have been weathered and eroded more deeply, resulting in subrounded to rounded forms developing in place.

The Gangplank

The geologic phenomenon that provides an easy grade for Interstate 80 from the plains near Cheyenne onto the Laramie Mountains is known as The Gangplank (**Figure 67**). A narrow remnant of flat-lying late Tertiary Arikaree Formation is preserved overlapping the mountain front. An erosional surface of low relief is coincident with the upper surface of the Arikaree Formation and bevels across the crystalline rocks of the mountain core.

The narrow strip of Tertiary rocks provides a bridge between the surface of the high plains to the east and the mountain upland to the west. The surveyors who located the original site for the first transcontinental railroad took advantage of this natural grade to accomplish a crossing of the divide, and named it The Gangplank. Later, the highway took the same route. A turnout from the west-bound traffic lane 1.5 miles east of Granite Canyon provides an excellent opportunity to view the geology.

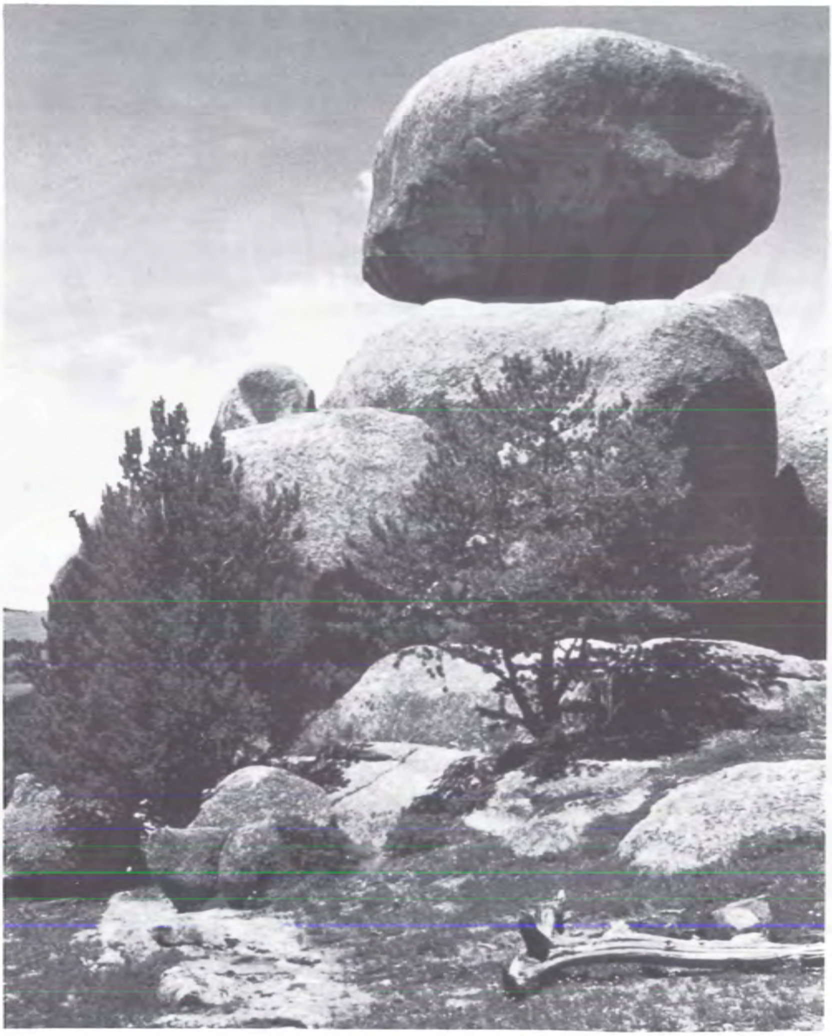


Figure 66. Balanced granite boulder in the Vedauwoo area, Sherman Mountains. (Photograph by Sheila Roberts.)

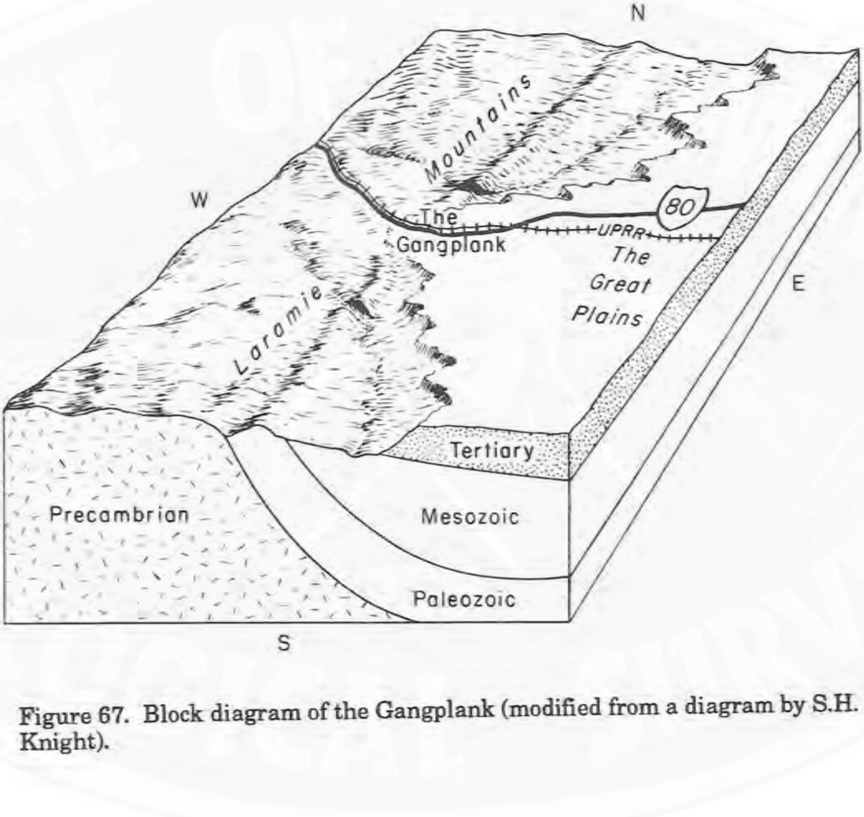


Figure 67. Block diagram of the Gangplank (modified from a diagram by S.H. Knight).

References cited

Aleinikoff, J.N., Williams, I.S., and Compston, William, 1987, Conventional and ion microprobe U-Pb ages of Archean rocks from the Wind River Range, Wyoming: Geological Society of America Abstracts with Programs, 1987 Annual meeting and exposition, Phoenix, Arizona, p. 569.

Alvarez, L.W., Alvarez, Walter, Asaro, F., and Michel, H.V., 1980, Extraterrestrial cause for the Cretaceous-Tertiary extinction: Science, v. 298, p. 1095-1108.

Blackstone, D.L., Jr., and DeBruin, R.H., 1987, Tectonic map of the Overthrust Belt, western Wyoming, northwestern Utah, and southeastern Idaho, showing oil and gas fields and exploratory wells in the Overthrust Belt and adjacent Green River Basin: Geological Survey of Wyoming Map Series 23, scale 1:316,000.

Bown, T.M., 1982, Geology, paleontology, and correlation of Eocene volcaniclastic rocks, southeast Absaroka Range, Hot Springs County, Wyoming: U.S. Geological Survey Professional Paper 1201-A, p. A-1 to A-75.

Case, J.C., and Boyd, Cynthia, 1987, Windblown sand deposits in Wyoming: Geological Survey of Wyoming Open File Report 87-9, scale 1:1,000,000.

Christiansen, R.D., 1986, Wyoming geological highway map: Western Geographics, scale 1:1,000,000.

Clemens, Samuel (Mark Twain), 1871, *Roughing it*: American Publishing Company, Hartford, Connecticut, 591 p.

Culbertson, W.C., 1986, Genesis and distribution of trona deposits in southwest Wyoming, *in* Roberts, S.M., editor, Metallic and nonmetallic deposits of Wyoming and adjacent areas, 1983 conference proceedings: Geological Survey of Wyoming Public Information Circular 25, p. 94.

Davis, W.M., 1909, Geographical Essays, v. 6, 777 p.

DeVoto, Bernard, 1943, The year of decision: 1846: Little Brown and Company, Boston, 524 p.

Fenneman, N.M., 1931, Physiography of the western United States: McGraw-Hill Book Company, Inc., New York, 534 p.

Grande, Lance, 1984, Paleontology of the Green River Formation, with a review of the fish fauna (2nd edition): Geological Survey of Wyoming Bulletin 63, 333 p.

Hausel, W.D., 1986, Minerals and rocks of Wyoming: Geological Survey of Wyoming Bulletin 66, 117 p.

Hill, Chris, Sutherland, Wayne, and Tierney, Lee, 1976, Caves of Wyoming: Geological Survey of Wyoming Bulletin 59, 225 p.

Keefer, W.R., 1971, The geologic story of Yellowstone National Park: U.S. Geological Survey Bulletin 1347, 92 p.

Lageson, D.R., 1986, Geologic map of the Stewart Peak Quadrangle, Lincoln County, Wyoming: Geological Survey of Wyoming Map Series 22 , scale 1 : 24,000 .

Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey, scale 1:500,000.

Love, J.D., and Reed, J.C., 1971, Creation of the Teton landscape (revised edition): U.S. Geological Survey and the National Park Service, 120 p.

Love, J.D., Reed, J.C., Jr., and Christiansen, A.C., 1992, Geologic map of Grand Teton National Park, Teton County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-2031, scale 1:62,500.

Mears, Brainerd, Jr., 1987, Late Pleistocene periglacial wedge sites in Wyoming basins: an illustrated compendium: Geological Survey of Wyoming Memoir 3, 77 p.

Smithson, S.B., Kaufman, J.A., Oliver, J.E., and Hurich, C.A., 1979, Structure of the Laramide Wind River uplift, Wyoming, from COCORP deep reflection data and gravity data: Journal of Geophysical ftesearch, v. 84, p. 5955-5972.

Sundell, K.A., 1982, Geology of the headwater area of the North Fork of Owl Creek, Hot Springs County, Wyoming: Geological Survey of Wyoming Report of Investigations 15, 51 p.

Additional reading

Breckenridge, R.M., and Hinckley, B.S., 1978, Thermal springs of Wyoming: Geological Survey of Wyoming Bulletin 60, 104 p.

Geological Survey of Wyoming, composer, 1982, Landsat image mosaic of Wyoming: Geological Survey of Wyoming Map Series 11, scale 1:500,000.

Glass, G.B., 1983, Description of Wyoming coal fields and seam analyses: Geological Survey of Wyoming Reprint 43, 28 p.

Hager, M.W., 1970, Fossils of Wyoming: Geological Survey of Wyoming Bulletin 54, 51 p.

Harris, R.E., Hausel, W.D., and Meyer, J.E., 1985, Metallic and industrial minerals map of Wyoming: Geological Survey of Wyoming Map Series 14, scale 1:500,000.

Harris, R.E., and Meyer, J.E., 1986, Construction materials map of Wyoming: Geological Survey of Wyoming Map Series 21, scale 1:500,000.

Hausel, W.D., 1980, Gold districts of Wyoming: Geological Survey of Wyoming Report of Investigations 23, 71 p.

Hausel, W.D., 1982, Ore deposits of Wyoming: Geological Survey of Wyoming Preliminary Report 19, p. 39.

Hausel, W.D., 1984, Tour guide to the geology and mining history of the South Pass gold mining district, Fremont County, Wyoming: Geological Survey of Wyoming Public Information Circular 23, 1 sheet.

Hausel, W.D., and Jones, R.W., 1984, Self-guided tour of the geology of a portion of southeastern Wyoming: Geological Survey of Wyoming Public Information Circular 21, 22 p.

Hausel, W.D., McCallum, M.E., and Roberts, J.T., 1985, The geology, diamond testing procedures, and economic potential of the Colorado-Wyoming kimberlite province — a review: Geological Survey of Wyoming Report of Investigations 31, 22 p.

Hinckley, B.S., Heasler, H.P., and King, J.K., 1982, The Thermopolis hydrothermal system, with an analysis of Hot Springs State Park: Geological Survey of Wyoming Preliminary Report 20, 42 p.

Mears, Brainerd, Jr., Eckerle, W.P., Gilmer, D.R., Gubbels, T.L., Huckleberry, G.A., Marriott, H.J., Schmidt, K.J., and Yose, L.A., 1986, A geologic tour of Wyoming from Laramie to Lander, Jackson, and Rock Springs: Geological Survey of Wyoming Public Information Circular 27, 57 p.

Osterwald, F.W., Osterwald, D.B., Long, J.S., Jr., and Wilson, W.H., 1966, Mineral resources of Wyoming: Geological Survey of Wyoming Bulletin 50, 287 p. (revised by W.H. Wilson).

Raisz, Erwin, 1957, Landforms of the United States: Raisz Publishing Company, Cambridge, Massachusetts, scale approximately 1:4,500,000.

Stephenson, T.R, VerPloeg, A.J., and Chamberlain, L.S., 1984, Oil and gas map of Wyoming: Geological Survey of Wyoming Map Series 12, scale 1:500,000.

Surdam, R.C., and Wolfbauer, C.A., 1974, Green River Formation, Wyoming, a playa lake complex: Geological Society of America Bulletin, v. 86, no. 3, p. 335-345.

VerPloeg, A.J., DeBruin, R.H., and Blackstone, D.L., Jr., 1982, The search for oil and gas in the Idaho-Wyoming-Utah salient of the Overthrust Belt: Geological Survey of Wyoming Report of Investigations 21, 108 p.

Glossary

Alluvial — Refers to unconsolidated recent gravels, sands, and clays deposited by a stream or river.

Anhydrite — A mineral consisting of anhydrous calcium sulphate ($CaSO_4$).

Anticline — A structure in which layered rocks dip in opposite directions away from a central crest or axis, similar to opposite sides of a roof.

Arch — A broad regional anticline; regional upbowing of sedimentary strata.

Artesian flow — Ground water that has artesian pressure; water under sufficient head to rise above the containing aquifer.

Ash (volcanic) — A deposit of fine rock fragments resulting from a volcanic eruption.

Basalt — An extrusive igneous rock, dark colored; common rock in lava flows.

Basin — A *topographic* basin is an area of lower elevation surrounded by higher ground; often found in the eroded core of an anticline. A *structural* basin is a synclinal area; all strata dip toward the deeper part; may be regional in extent; may or may not be expressed topographically.

Batholith — Masses of granitic rock having a surface area of 40 square miles (100 square kilometers) or more. Smaller masses are called stocks.

Bedding — Arrangement of rocks in layers that are distinguishable from each other.

Bench (pediment) — A landform characteristic of arid and semi-arid regions. The form is a relatively smooth gravel-capped surface with a very low gradient, sloping away from a mountain front.

Bentonite — A soft, light colored, plastic, porous sedimentary rock composed primarily of the clay mineral montomorillonite (smectite). Known for its capacity to swell when wet.

Blowout — An undrained depression formed by wind erosion.

Butte — Usually isolated, flat-topped hill standing above the general elevation of the countryside. Generally limited in size, may have rounded summit.

Btu (British thermal unit) — The amount of heat required to raise one pound of water one degree Fahrenheit (252 calories).

Calcite — A common rock-forming mineral composed of calcium carbonate ($CaCO_3$).

Chert — Rock composed of microcrystalline silica, variable in color (flint).

Cirque — Bowl-shaped erosional form at the head of a valley that has been or currently is occupied by alpine glaciers. Walls are very steep, and the profile across the valley is U-shaped.

Clinker — Colloquial name applied to rock that has been baked by the burning of coal in place; often red in color and more resistant than the surrounding rock; often contains pipes of natural glass due to fusion of the rocks. Also called scoria or porcellanite.

Coal — A black or brownish black, combustible rock. Original material was vegetable matter that has been altered under increased pressure and temperature due to burial. Coals are classified by rank, ranging from lignitic (lowest class), to subbituminous to bituminous, to anthracitic (highest class).

Concretion — Hard mass of mineral matter, usually roughly spherical, that accumulates around a center after deposition of the sediment.

Conglomerate — A very coarse-grained sedimentary rock composed of rounded to subangular detrital fragments of preexisting rocks surrounded by a matrix of smaller grain size. The larger particles range upward from two millimeters in diameter.

Continental environment — An environment of deposition of sedimentary rocks upon land rather than in the sea; includes stream, lake, and windblown deposits.

Creep — Slow downslope movement of rock debris and soil. Movement discernible only when observed for long periods of time.

Crossbedding — Sedimentary structure in which beds were deposited at an angle to the main stratification of rock layers.

Crystalline — The texture of a rock consisting of interlocking crystals or crystal fragments; usually refers to igneous or metamorphic rocks.

Dike — A tabular body of igneous rock that cuts across (intrudes) the bedding or foliation of adjacent rocks.

Dip (see also strike) — The amount of inclination (slope), measured in degrees, between a rock layer and a horizontal plane.

Dolomite — A common rock-forming mineral composed of calcium-magnesium carbonate [$CaMg(CO_3)_2$].

Dome — A special form of anticline that approximates a circular or elliptical pattern in map view.

Dune — A mound or hill of windblown sand that is capable of moving while retaining its characteristic shape. Many dunes are crescent shaped (barchan) or elongate (seif).

Ejecta — Material erupted from a volcanic vent (pyroclastics). Varies in size from very small fragments (volcanic ash) to very large angular blocks (breccia).

Era — Geologic periods are grouped together into larger time units called eras (for example, the Paleozoic Era).

Erosion — A general term describing all the actions by which agents such as wind, waves, ice, and running water obtain and remove rock debris.

Escarpment — A long, linear, abrupt change in slope which may be due to several causes, for example, headward erosion of streams into flat-lying sedimentary rocks (recessive escarpment). A fault may offset rocks and create an escarpment, called a fault scarp.

Extrusive rock — When a silicate melt called magma reaches the surface and solidifies, the resulting rocks are called extrusive rocks (extruded onto the surface).

Fault — A planar surface of discontinuity in a rocky body. It is the surface on which movement takes place as rock masses are displaced.

Floodplain — The flat floor of a river valley that is covered with water during floods. The relatively smooth surface is the result of material deposited as the high flood stage overflows the banks of the channel.

Formation — The fundamental rock unit used in geologic mapping. Composed of a lithologically distinctive rock package, usually named after a geographic locality (for example Tensleep Sandstone, Thermopolis Shale, Chugwater Formation, etc.).

Fossil — The remains of, or the evidence for the existence of, organisms (either plant or animal) that lived in the geologic past, preserved in the entombing rocks.

Fumarole — A natural discharge of gases and vapors from a localized vent.

Geology — The science that deals with the origin and history of the Earth.

Geomorphology — Part of the science of geology dealing with the origin of landforms.

Geyser — A thermal spring that is characterized by periodic eruptions of hot water and steam.

Granite — A common igneous rock characterized by the presence of free quartz, orthoclase, feldspar, and minor accessory minerals such as biotite, hornblende, and magnetite. Usually light colored with crystals that are big enough to see without magnification.

Ground-water table — A surface or level, below which the rock and subsoil are saturated with water.

Gypsum — A mineral composed of hydrated calcium sulfate ($CaSO_4 \cdot 2H_2O$).

Hogback — A long, sharp-crested ridge. The profile of the ridge is roughly symmetrical, and the dip of the underlying bedrock is usually 45 degrees or more.

Horn — A sharp, three- or more-sided peak, situated at the head of a series of alpine glacial cirques. The name if derived from the shape of the famous Matterhorn in Switzerland.

Hot spring (see thermal spring)

Ice age — A general term applied to the Pleistocene Epoch of geologic time, which covers the period of extensive glaciation in North America and Europe. (See back inside cover.)

Igneous — The word, derived from the Latin word for fire, is used as an adjective. Igneous rocks result from the cooling and solidification of molten silicate melts.

Intrusive rock — Igneous rock that formed by the intrusion and solidification of magma at some depth below the surface of the Earth. The rocks are usually crystalline — that is they have a grained texture.

Iron formation — Chemical sedimentary rock containing at least 15 percent iron of sedimentary origin; typically thin bedded and containing layers of chert.

Kerogen — Fossilized organic material that can yield petroleum products when distilled; found in sedimentary rocks.

Laccolith — A body of intrusive igneous rock that has a flat floor and a curved-upward ceiling.

Lacustrine environment — The depositional environment associated with a lake. This term particularly describes the Green River Formation of western Wyoming.

Landslide — A mass of rock debris and soil that has moved downslope under the influence of gravity.

Limestone — A common sedimentary rock composed primarily of calcite; may contain some impurities such as shale or dolomite.

Lode — A mineral deposit in consolidated rock (as opposed to placer deposit).

Mafic — Dark colored, magnesium- and iron-rich rock.

Magma — A silicate melt from which igneous rocks are formed.

Map scale — The ratio between the linear distance on a map and the actual distance on the ground (for example 1:24,000).

Marine environment — The environment of deposition that exists in the sea or ocean.

Mass wasting — The process of bulk transfer of soil and rock debris down slope under the attraction of gravity. May be in dry state, or in highly water-saturated state. Movement varies from extremely slow to very rapid.

Mesa — A flat-topped land form; a tableland; may be several square miles in extent. Similar to, but larger than a butte.

Mineral — A naturally occurring inorganic element or compound of relatively definite chemical composition and physical character and, usually, a characteristic crystal form. Quartz (silicon dioxide), which crystallizes in the hexagonal system, is a good example.

Moraine — The topographic feature resulting from deposition of unsorted material transported by a glacier. End moraines are often arcuate in pattern and ridge-like in form.

Mudflow, debris flow — Masses of water, saturated soil, and rock debris moving downslope in relatively well-defined channels; the deposit formed in this manner.

Natural gas — The term is applied to a complex of hydrocarbons in gaseous state. Methane is a common constituent. Carbon dioxide, hydrogen sulfide, nitrogen, helium are also natural gases, but noncombustible.

Obsidian — Natural glass, usually black to gray in color, conchoidal fracture, thin pieces are translucent.

Ore — Deposit of mineral matter that is of sufficiently high concentration to extract at a profit.

Orogeny — Profound deformation of rock bodies along restricted zones and within a limited time interval; an episode of mountain building.

Outcrop — An exposure of bare rock without soil cover.

Outwash — The deposit that is washed out in a sheet beyond the end of a glacier by meltwater. Mostly stratified sand and gravel.

Paleogeography — The distribution of land and seas in past geologic time, as reconstructed from the geologic record.

Period — A fundamental unit of the geologic time scale, for example, the Silurian Period.

Petroleum — An inflammable, oily mixture of liquid hydrocarbons.

Placer deposit — A mineral deposit that has been weathered from a vein or other type of deposit and concentrated at the Earth's surface by gravity and water in the gravels and sands of stream and river channels or beaches.

Playa — The flat level floor of a desert depression that has no outlet. May contain a shallow ephemeral lake.

Radiometric age — Age of a geologic event, usually given in years before the present, based on measurement of decay of radioactive elements (also isotopic age, absolute age).

Redbeds — The red sedimentary rocks that are seen throughout the world. In Wyoming, it most often applies to the red sediments of the Permain, Triassic, and Jurassic Periods. Red color is due to hematite (iron oxide).

Rock — (see types: igneous, sedimentary, and metamorphic). A consolidated aggregate of minerals or organic materials that forms a part of the Earth's crust.

Rock slide — A flowing mass of rock debris, essentially dry, moving in a fairly restricted channel down steep slopes.

Sandstone — A sedimentary rock composed of sand-sized grains of rocks or minerals, often mostly quartz. The size of the particles ranges from 1/16 to 2 mm.

Scarp — (see escarpment)

Sedimentary structures — Features that are the result of sedimentary processes at the time of, or shortly after deposition, (for example, crossbedding, mudcracks, ripple marks, channels, etc.).

Shale — A sedimentary rock composed largely of clay minerals, often possessing very thin layering.

Sill — A concordant (parallel to layering) intrusion of igneous rock that has wide extent laterally but limited extent vertically. Thin and tabular in general form, but may cover several square miles.

Siltstone — A sedimentary rock composed largely of particles of silt size — 1/256 to 1/16 mm.

Siliceous sinter — Chemical deposits of silica precipitated from solution, especially around hot springs and geysers.

Strata — Sedimentary beds or layers of sedimentary rock.

Strike (see also dip) — The compass direction, relative to north, of a line formed by the intersection of a rock layer and a horizontal plane.

Superimposed drainage — A system of stream valleys that was established on overlying cover and later incised into the bedrock during erosion.

Syncline — A fold in which the rocks on both limbs dip toward the center line of the fold; opposite of anticline.

Taconite — An iron-bearing siliceous rock (iron formation).

Tectonic — Related to the structure of the Earth's crust, and of the movements and forces which have produced it.

Thermal spring — A natural discharge of water, the temperature of which is higher than the mean annual air temperature at that place.

Travertine — Deposits of calcium carbonate formed around thermal springs and in caves or other environments where rapid precipitation of calcium carbonate occurs.

Trap — A term used to describe any type of natural barrier to the upward movement of hydrocarbons (petroleum and natural gas), which become "entrapped" in rocks to form deposits large enough to exploit. A trap may exist, however, and be barren of hydrocarbons.

Trend — The general compass orientation of a geological feature such as the trend of a mountain range.

Trona — A natural mineral salt of sodium crystallized from saline water by evaporation (sodium sesquicarbonate).

Unconformity — Surface between two rock bodies that represents a substantial gap in the geologic record; overlying rocks are significantly younger than underlying one. Often implies a period of uplift and erosion. The term angular uncomformity describes an unconformity between two groups of rocks whose bedding planes are not parallel.

Uplift — A general term applied to a situation wherein rock masses have been elevated either by folding or by a combination of folding and faulting.

Vein — A fracture (or crack) in the Earth's crust filled with secondary mineral matter.

Volcaniclastic — A clastic rock containing volcanic material.

Volcanic vent — An opening in the Earth's crust, through which volcanic material was erupted at the surface.

Volcano — An accumulation of igneous rock that owes its origin to the eruption of lava and ejecta from a central vent or vents.

Weathering — Physical disintegration and chemical decomposition of rock caused by exposure to atmospheric agents at or near the Earth's surface.

Dr. D.L. Blackstone, Jr. is Professor Emeritus in the Department of Geology and Geophysics, University of Wyoming. He joined the department in 1946 and was Chairman from 1963 to 1968. He was State Geologist from 1967 to 1969, and has been an active member of the Advisory Board of the Geological Survey of Wyoming since 1967.

In over 40 years of study and teaching, Dr. Blackstone has made many outstanding contributions to the understanding of Wyoming's geology, especially in the areas of structural and petroleum geology. He has always been committed to teaching, and with the *Travelers' guide* his range of students is expanded to include any interested residents or travelers in Wyoming.

GEOLOGIC TIME SCALE

AGE [1] (in millions of years)		EON	ERA	PERIOD	GEOLOGIC EVENTS IN WYOMING	MAJOR ANIMAL GROUPS
	66.4	PHANEROZOIC	CENOZOIC	TERTIARY	QUATERNARY Complex history (see enlarged diagrams below)	Mammals
100	144		MESOZOIC	CRETACEOUS	Last marine seaway area; shore line fluctuated W to E; sandstones deposited near shore interfinger into thick, dark marine shales; many beds of volcanic ash (now bentonite) deposited; Laramide orogeny, Rocky Mountains began to form late in period.	Ammonites, swimming reptiles, dinosaurs, pelecypods, foraminifera, fish.
200	208			JURASSIC	Marine seaway in Early Jurassic, limestone common; later in period sea withdrew and deposition was by streams; volcanic ash from remote sources.	Large sauropods common; ammonites, corals, pelecypods.
	245			TRIASSIC	Marine seas in west, with limestone; shallow seas and tidal flats in central and eastern Wyoming with siltstones, anhydrite, and thin limestones.	Ammonites, reptiles, fossils very scarce in redbeds.
	286		PALEOZOIC	PERMIAN	Variable conditions of deposition; mudflats, redbeds, salt-pans, thin limestones; organic phosphatic shales in western Wyoming, source beds for oil	Reptiles, pelecypods.
300	320			PENNSYLVANIAN	Ancestral Rocky Mountains rose in Colorado, some uplift in central Wyoming; sandstones common, some eolian crossbedded sandstone.	Foraminifera, brachiopods, amphibians.
	360			MISSISSIPPIAN	Widespread warm marine seas; thick sequences of fossiliferous limestone.	Corals abundant; brachiopods.
400	408			DEVONIAN	Early in epoch rivers cut channels in older rocks; marine waters advanced again and sandstones, shales, and limestones were deposited; coral reefs locally.	Brachiopods, corals, fish, conodonts.
	438			SILURIAN	Region was emergent, low relief near sea level; one locality associated with diatremes preserved fossiliferous limestone.	Brachiopods, eurypterids.
500	505			ORDOVICIAN	Area covered by shallow, warm marine waters; thick sequence of dolomite deposited, local basal sandstone.	Brachiopods, corals, sponges, nautiloids.
	570			CAMBRIAN	Invasion of marine waters across continent from west: thick sequence of sandstone, shale, and limestone in west, thinning to east.	First shelly fauna: trilobites, brachiopods, sponges, worms.

major unconformity

The Precambrian is not shown to scale. It would be about three feet long at the scale shown above.

Million years				
570 2,500	PRECAMBRIAN	PROTEROZOIC EON	Continued crustal growth and deformation of basement rocks; igneous intrusion; Late Proterozoic erosion.	Soft-bodied single and multi-cellular life with cell nuclei.
2,500 4,600		ARCHEAN EON	The Wyoming Province Archean crust formed.	Single-celled life lacking cell nuclei, bacteria and algae.

Expanded from above

AGE (Million years)		PERIOD	EPOCH	GEOLOGIC EVENTS IN WYOMING	MAJOR ANIMAL GROUPS
0	0.01	QUATERNARY	HOLOCENE	Wyoming today	Modern animals
1	1.6		PLEISTOCENE	Glacial and interglacial episodes; Teton Mountains growth continued; volcanic and hydrothermal activity in Yellowstone National Park.	Large Ice-Age mammals: wooly mammoth, mastodon, sabre-toothed tiger, etc. Dawn of modern man.
Scale Change					
	1.6 5.3	TERTIARY	PLIOCENE	Normal faulting, Teton Mountains, uplift and erosion.	Ancestral Hominids.
	23.7		MIOCENE	Volcanic activity in northwest Wyoming; continued continental deposition; major drainages established.	Mammals common.
	36.6		OLIGOCENE	Airborne ash from Great Basin covered all but high mountains, warm temperate climate.	Large fauna of mammals.
50	57.8		EOCENE	Mountain building uplift completed; deep erosion to mature landscape; lavas in western Wyoming; major volcanic activity in Absaroka Volcanic Plateau region.	Age of mammals begins.
	66.4		PALEOCENE	Tropical climate; strong uplift; basin filling.	Primitive mammals.

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[1] From Geological Society of America 1983 Geologic time scale.

Selected sites described in this bulletin:

Northwest Wyoming
1 Togwotee Pass
2 North Fork of the Shoshone River
3 Cody area
4 Bighorn Canyon National Recreation Area
5 Wind River Canyon
6 Thermopolis Hot Springs

Northeast Wyoming
7 Buffalo-Sheridan
8 Hell's Half Acre
9 Salt Creek-Teapot Dome oil fields
10 Pumpkin Buttes
11 Gillette area coal mines

Southwest Wyoming
12 Star Valley
13 Fossil Butte National Monument
14 Evanston to Kemmerer
15 Lyman-Mountain View-Evanston
16 Flaming Gorge
17 Rock Springs area
18 LaBarge area-Green River Basin
19 Pinedale area
20 Sinks Canyon
21 Derby Dome
22 Red Grade
23 South Pass region
24 Split Rock

Southeast Wyoming
25 Bessemer Bend
26 Bates Hole
27 Como Bluff
28 Elk Mountain
29 Glendo-Orin Junction area
30 Hat Creek Breaks/Pine Ridge escarpment
31 Sherman Mountains and Vedauwoo Glen
32 The Gangplank