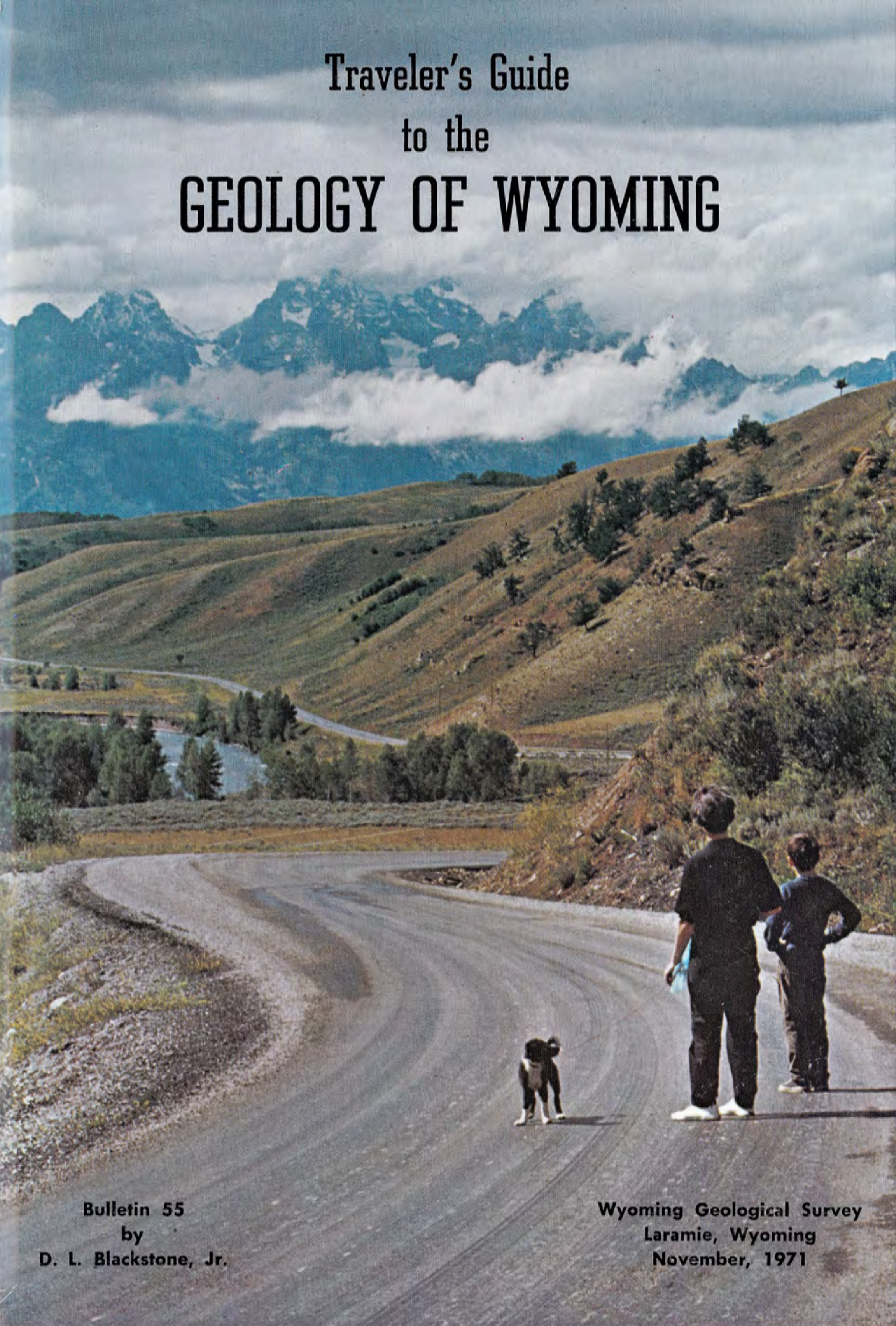
Traveler's Guide to the GEOLOGY OF WYOMING



Bulletin 55

by
D. L. Blackstone, Jr.

Wyoming Geological Survey
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THE GEOLOGICAL SURVEY OF WYOMING

DAN MILLER, State Geologist

BULLETIN 55

TRAVELER'S GUIDE TO THE GEOLOGY OF WYOMING

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Second Edition

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FOREWORD

Traveling in Wyoming becomes a pleasant and meaningful experience if one knows something about the geologic history and development of the landscape. It becomes even more meaningful when these factors can be related to our much traveled highways and to community and industrial development.

Here, for the first time, is an illustrated, non-technical description of the more significant geological and historical relationships that exemplify Wyoming, compiled by Dr. D. L. Blackstone, Jr., Professor of Geology, University of Wyoming, who for 25 years has lived and worked amidst the mountain ranges and basins of the State. As a practicing geologist, western history buff, and naturalist, he has a broad understanding and a deep appreciation for both Wyoming's past and present character. In this booklet he has placed Wyoming in a different kind of perspective in order that others may more fully enjoy the panoramic views that pass before the traveler's eyes along the highways of the State.

The Geological Survey of Wyoming is pleased to present this information in order that you, as a traveler, may become better acquainted with our Rocky Mountain heritage.

Dan Miller
State Geologist

TRAVELER'S GUIDE TO THE GEOLOGY OF WYOMING

INTRODUCTION

During the writer's tenure at the University of Wyoming, he has been questioned on numerous occasions by visitors who wanted some information on the general geology of the State. Many times the questioner's lack of background made it necessary to devote a large amount of time to providing an answer that would be helpful. As a result of these experiences, the writer decided to prepare a summary of the physical features of Wyoming, the basic geology, and some information on the origin of the features that make up the landscape.

The physical geography, or physiography, of the State is the result of the continuing action of a wide variety of physical processes, some quite apparent and others more obscure. The movement of the earth's crust has in past geologic time allowed the oceans to transgress across the continental interior, and in those seas were deposited much of the material (sedimentary rocks) from which our hills and valleys have been carved. Once these rocks were elevated above sea level, the physical processes of weathering, erosion, and transport continually acted upon them, finally to create the scenic wonders of the Wyoming landscape.

Presented here is a brief summary of geography, basic geology, mineral resources and scenic highlights in the hope that the traveler's understanding and hence his appreciation and enjoyment of his visit to Wyoming will be enhanced.

WHERE IS WYOMING?

The physical geography of the United States can be best understood by visualizing a number of provinces, each of which has a similarity of land form and underlying geology. Along the continental divide the mountainous terrane has been assigned to a province called the Rocky Mountains, a part of the vast system of ranges that stretch from the plains to the Great Basin, of which Fenneman, a noted physiographer, said:

> 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 as parts of a larger whole.

FIG. 1. Map showing position of Wyoming in the coterminous United States.

East of the Rocky Mountains are the seemingly endless prairies in a province called the Great Plains, of which Mark Twain said in *Roughing It:*

> 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.

Wyoming lies astride the continental divide, or backbone of the continent, and extends eastward into the Great Plains. The Rocky Mountain province as a whole is further subdivided into lesser 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 subprovince.

The boundaries of Wyoming, and its geographic coordinates are shown on Figure 2, as are the boundaries of the geomorphic provinces in which it lies.

The landscape and the underlying geology in each of the provinces is different. Each province is briefly described, and as the discussion proceeds you will see details from each which illustrate its characteristics.

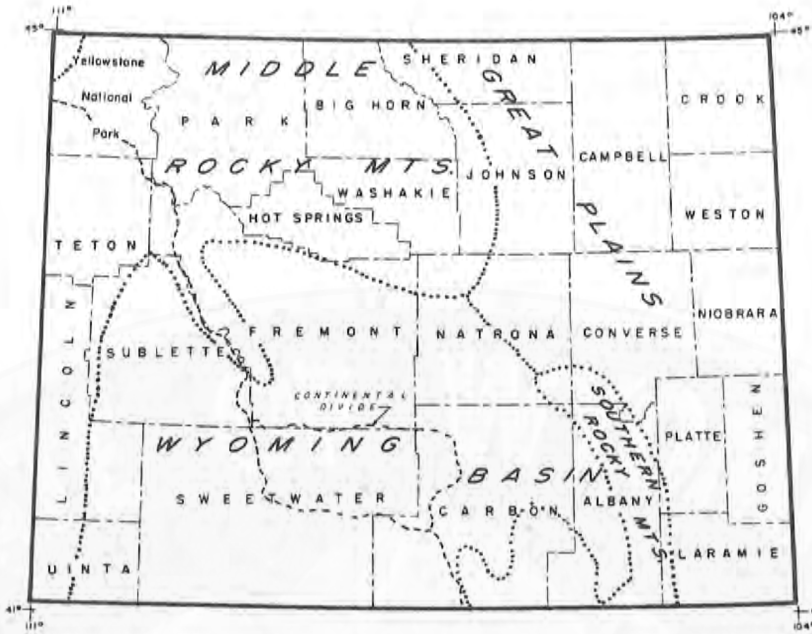

FIG. 2. Map delimiting geomorphic provinces and the Continental Divide.

Great Plains

To quote Fenneman again:

> The name "Great Plains" has long been in use for a broad belt of highlands which 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 term "Great Plains" has commonly been associated in the popular mind with monotony of landscape and also with short grass, which has in a rough way distinguished the Great Plains from the Prairies or "long-grass country" to the east.

Southern Rocky Mountains

The Southern Rocky Mountains lie largely in Colorado and consist of elevated bands of ancient basement rocks, flanked on the margins by tilted successions of sedimentary rocks. This pattern extends northward into Wyoming in a three pronged fashion — the Laramie Mountains, the

Medicine Bow Mountains, and the Sierra Madre. A marked aspect of the Laramie and Medicine Bow Mountains is a rolling upland surface of low relief at an elevation of about 9,000 feet, above which rise local groups of higher peaks such as the Snowy Range.

Wyoming Basin

The Wyoming Basin is really a group of intermontane depressions which lie within the Rocky Mountains and between which both large and small uplifts exist. Because the topography of the basins merges eastward into the high plains without great change in character, the eastern boundary is indistinct. The large uplifts lack the continuity expressed in the surrounding provinces, and in travelling west from Rawlins on Interstate Highway I-80 one may not realize how many mountains Wyoming has.

Middle Rocky Mountains

The province as seen on a map is shaped like the letter C, open to the east and enclosing in its central area the Wyoming Basin. The mountain uplifts that make up the province are mainly linear in form with a single range likely to be a single fault block or fold. A diversity of features exist in the province, ranging from the east-west trending Uinta Mountains, through the Wasatch front facing westward to Great Salt Lake, to the pile of volcanic materials known as the Absaroka Plateau in northwest Wyoming.

Northern Rocky Mountains

Only the extreme southern tip of this province extends into Wyoming and can be visited only in the northwest corner of the state. The mountains are long, linear, and geologically arranged in a belt that continues northward across Montana and on into Canada.

The answer to the question "Where is Wyoming?" cannot be answered simply. It is for the most part a segment of the Rocky Mountain Cordillera, lying astride the Continental Divide, and extending eastward at lower elevation to merge into the plains. The area all lies west of the 100th Meridian which Major John W. Powell designated the beginning of the arid west, and its unique physical character is due in part to the elevation and in part to the aridity.

SOME WYOMING GEOGRAPHY

The State of Wyoming has an area of about 100,000 square miles, all of which lie at an elevation greater than 3,100 feet above sea level. The maximum relief or difference in elevation is 10,605 feet, with Gannet Peak having the greatest elevation (13,785 feet), and a point in the channel of the Belle Fourche River in northeast Wyoming having the least (3,180 feet). In general the elevation is higher in the southeastern part near Laramie and in the northwestern part near Cody, but marked differences in elevation occur locally.

Rivers

Since the backbone of the continent passes through Wyoming, it is to be expected that some major rivers would have their headwaters within its boundaries. The major river draining the east flank of the Rocky Mountains in the United States is the Missouri, made famous by Lewis and Clark. Two of the three tributaries which join at the Three Forks of the Missouri arise in Wyoming — the Madison and the Gallatin. Another major tributary, the Yellowstone, also originates in the State. In turn, the Yellowstone's major tributaries, the Wind River — Bighorn and the Powder River, flow northward out of the state, as do the Belle Fourche and the Cheyenne.

FIG. 3. Map of major drainages in Wyoming.

The Pacific Ocean receives the waters of the Snake River, a major tributary of the Columbia which heads near Yellowstone Park, and indirectly the waters of the Green River via the Colorado River and the Gulf of California.

Another major drainage system in the state, the North Platte River, rises in Colorado, is fed by streams from the mountains nearby and swings in a U-shaped loop through the southeast quarter of Wyoming.

The Sweetwater River, a major tributary of the North Platte, rises in the southern end of the Wind River Mountains and flows eastward across central Wyoming. The valley of this river is famous in history, as it was the main route of emigration to Utah, Oregon and California in the period around 1847-1849. In this valley are such landmarks as Independence Rock, Split Rock, Devil's Gate and the Sweetwater Crossing.

A lesser river—the Bear—flows northward out of Wyoming and its waters finally empty into the Great Salt Lake to end their 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. In fact, at Two Ocean Pass south of Yellowstone Park, water from a single small pond that has two outlets departs for two oceans — the Atlantic and the Pacific.

A more fascinating situation is that in which some precipitation falling along the continental divide never flows out of Wyoming and is removed from the state only by evaporation. Near South Pass the Continental Divide splits, with one part trending south-southeast and the other eastward. The twin divide encloses an area of interior drainage, then becomes a single divide again at historic Bridger Pass approximately 20 miles southwest of Rawlins. The western divide is low and indistinct, but nonetheless a basin some 3,000 square miles in extent on top of the continent contains shallow lakes that have no outlet.

Plains

The term "plains" is usually associated with a landscape of low relief, broad valleys, low rolling hills, a reasonable soil cover, a grassland type vegetative complex, and a monotonous repetition of scene. Such a landscape is perhaps associated with the wheat farms of western Kansas, Nebraska, eastern Colorado, or some of the prairie provinces of Canada. The "prairies" of the states to the east of Wyoming are somewhat different from the high dry plains because of the greater annual rainfall and, therefore, a thicker grass cover.

In Wyoming the high plains are developed for the most part on a series of essentially flat lying rocks of Cenozoic age that had their origin in debris ejected from volcanoes far to the west and carried eastward by a complex of rivers. Later elevation of the crust allowed streams to cut deeply into these rocks, to develop broad floored valleys, and to leave broad interstream divides and occasional scarps with small buttes along the margins.

A typical high plains landscape is seen as one drives westward along Interstate 80 from near Pine Bluffs toward Cheyenne. The surface of the plains rises steadily in elevation until at a point about 20 miles west of

Cheyenne it extends continuously onto the flank of the Laramie Mountains forming the famous "Gang Plank", by means of which the highway and the railroad effect an easy crossing of the first mountain barrier as they enter the Rocky Mountains.

The "Gang Plank" is a narrow strip of Tertiary rocks upon which the plains surface is preserved, so that the traveler crosses directly from the High Plains surface to a surface of low relief cut upon older rocks of the Laramie Mountains. So smooth is this transition that the traveler arrives at the summit of the Laramie Range — elevation 8,816 feet — without any sense of crossing a mountain range.

The High Plains surface is also well developed in the vicinity of Lusk, Wyoming, and merges eastward into the Nebraska sand hills country. The High Plains surface once extended much farther to the north but the headward erosion of the Cheyenne River tributaries has caused a scarp to develop. The scarp known as the Pine Ridge Escarpment is a receding one, and extends eastward for over a hundred miles into Nebraska. Erosion is slowly removing the Tertiary rocks and in the process creating a strip of badlands topography along the Pine Ridge Escarpment.

Mountains

If we accept the definition that mountains are areas of rocks which stand at a considerably higher elevation than the surrounding lands, we allow room to include mountains of various kinds and sizes and of varying origins. The answer to how large and high the rock mass must be to qualify as a mountain varies from place to place. That which is called a mountain in North Dakota probably would qualify only as a hill or butte in Wyoming.

Since the definition includes the concept of elevation greater than the surrounding landscape, we must consider how this difference in elevation has developed. In many places the difference of elevation is in part due to uplift of large segments of the earth's crust in the form of folds or wrinkles, or blocks bounded by fractures, or a combination of both. High piles of volcanic flows and ash, such as Mt. Rainier, are certainly mountains. Other more or less mountainous features exist in the Colorado Plateau where the area has been uplifted *en masse* and then deeply eroded.

All the landscape is continually being modified by the action of the atmosphere — wind, running water, moving ice, freezing and thawing, gravity, and chemical reactions. The action of these processes may be said to be actively sculpturing mountains out of major blocks of rocks. In this work the elements are carving a material already there — the product is analogous to the work of a sculptor and the product is younger than the material from which it is carved.

The frequently asked question — "How old are the mountains?" — may be answered in two ways. We might consider that the age of the oldest rocks exposed to the elements and in the process of being eroded is the age of the mountains. In another sense we might consider the time elapsed since the rocks were elevated so that they began to be carved by erosion.

Most mountains in Wyoming were elevated about 60 million years ago and are quite *young* by geologic standards, since the *oldest* rocks in the core of the Wyoming mountains are about 2.5 billion years old.

In the clear air of Wyoming it is possible to see great distances, and in that distance there is almost always a mountain. The clean 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.

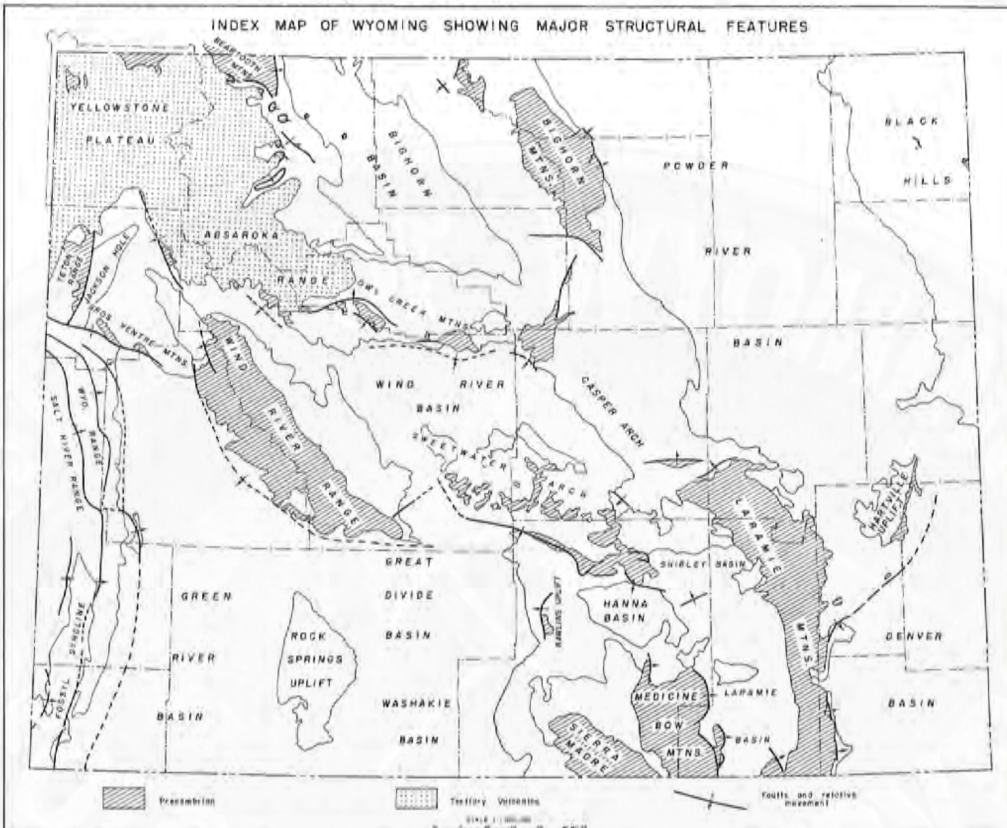

FIG. 4. Map of major structural elements in Wyoming.

The major mountain areas, as well as the intermontane basins between them, are shown on Figure 4, so that their mutual relationships can be better understood. The characteristics of the more prominent mountain masses are sketched out in the sections to follow.

Black Hills

The highest parts of the Black Hills are in the adjacent state of South Dakota, and only the northwestern segment locally known as the Bear Lodge Mountains continues northwestward into Wyoming in the vicinity of Sundance. The mountains are of low relief and for the most part are due to the intrusion of igneous rocks into the sedimentary rocks along the crest of a major structural arch or uplift. The Devil's Tower within this area is a spectacular, isolated remnant of igneous activity.

Laramie Mountains

Some confusion in nomenclature exists in the early accounts of the exploration of the state. The mountains now known as the Laramie Mountains were referred to by many trappers and military men as the "black hills" because of their dark profile when viewed from the east near old Fort Laramie.

One of the famous landmarks on the Oregon Trail was Laramie Peak (elevation 10,274 feet), the highest point in the range, and situated near the northeast corner of the mountains. The mountains are rugged in the northern part of the range, and more subdued in the southern part near the Colorado border. Actually, the Laramie Mountains are a direct continuation of the Colorado Front Range and have been reduced by erosion to low relief in the vicinity of Interstate 80. The basic geologic structure is that of a large asymmetric arch in the crust of the earth with a steep flank on the eastern side and gentle slope of the rocks to the west.

Medicine Bow Mountains

Near the Wyoming-Colorado border south of Laramie the mountain masses of Colorado divide into two prongs. One of these is called the Medicine Bow Mountains and is separated from the Laramie Range by a basin known as the Laramie Basin or Laramie Plains. The mountains are characterized by a rather broad flat summit at an elevation of about 9,000 feet above sea level, above which rise two erosional remnants of rugged peaks with much higher elevation. One cluster of peaks near the southern end of the range is called the Rawah Peaks, and the other in the northern part is called the Snowy Range.

The uplift is another example of a broad upfold in the earth's crust in which are exposed the basement rocks of great antiquity. The oldest gneisses and schists of this range are about 2.5+ billion years old and have had a very complex history. Also among the basement rocks are found *Stromatolites*, which are some of the oldest known forms of life found as fossils in sedimentary rocks. These fossils are the remains of a type of marine algae which lived approximately 1.7 billion years ago.

Sierra Madre

Often a topographic feature has two or more names dependent upon who saw it first and from what view. This is particularly true of mountains which often have two names because people living in valleys on opposite sides of the mountain gave it different names. Sierra Madre is the name applied in Wyoming to a section of mountainous terrain which is continuous with a mountain mass in Colorado forming the western margin of North Park and known there as the Park Range.

The Sierra Madre is quite similar to the Medicine Bow Mountains in geological aspect, 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-Haggerty copper mine — in the Grand Encampment district, which led to the establishment of the town of Encampment.

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.

Bighorn Mountains

Sweeping in a great arc concave to the west from southern Montana around the Bighorn Basin and then westward toward Yellowstone Park, is a more or less continuous chain of mountains. The highest and most rugged part of this arc lies west of the town of Buffalo, Wyoming, where the 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 uplift is asymmetric with the steep side facing the deep structural depression on the east flank. The southern part of the range is lower and less rugged, in fact characterized by a rolling upland which drops off in elevation into the area around Badwater Creek at the southern end of the mountains.

Owl Creek and Bridger Mountains

A low range of mountains extends from the southern Bighorn Mountains westward to the area near Dubois. The Wind River flows north across these mountains in a magnificent canyon also followed by U.S. Highway No. 20. The walls of this canyon tower over 3,000 feet above the river bed and in them can be seen a spectacular cross section of the geology of a mountain range.

That part of the mountain range lying east of the Wind River Canyon has been termed the Bridger Mountains. The western extent of the mountain mass is named the Owl Creek Mountains after the stream of the same name that drains the northern slopes.

The Wind River Canyon which separates these two geographic entities is so deep and so 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 laid out by freighters crossed the Bridger range over Bridger Pass, at the head of Bridger Creek, and 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.

Geologically the mountains consist of a series of tilted blocks with a gentle slope to the north and escarpments and a major fracture bounding the south side.

Wind River Range

The Wind River Range is the largest discrete mountain mass in the state and also has the highest summit peaks, such as Gannett Peak, Fremont Peak, Mt. Bonneville and Wind River Peak. Trending N. 40 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. In a broad way, the mountain mass has an east sloping flank in which the sedimentary rocks are exposed in a series of hogbacks. Glaciated peaks mark the central region, and permanent ice fields lie in the higher valley heads. 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 lakes of glacial origin. Finally, at the western base are the long deep lakes, such as Fremont and New Fork, occupying valleys in which glacial ice once flowed down from the higher regions onto the basin floor.

The great elevation of the mountain block was achieved by movement on a fracture plane that is inclined about 45 degrees under the elevated block, but this fracture cannot be directly observed because of the overlap of younger rocks.

Gros Ventre Mountains

Offset a little to the northwest and across the Green River drainage from the Wind River Mountains 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. Major crustal fractures which incline northward pass under the mountain mass.

Teton Mountains

Rising with spectacular grandeur from the floor of Jackson Hole is a medium sized but unique mountain range. The bold east front standing above the glacial lakes at the base is a result of intermittent but major movement of more than 20,000 feet on a steeply inclined fracture plane that slopes to the east. The rugged mountain peaks have been carved from the elevated segment of the crust. Matterhorns and U-shaped valleys are the characteristic land forms.

The Tetons are extremely young in geologic sense, having attained their height less than 10 million years ago. This fact 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 enough to be still growing.

Beartooth Mountains

Just north and northeast of Yellowstone Park is the highest mountain range in Montana culminating in Granite Peak. The backside of the uplift slopes gently down into Wyoming, and at the base is the Clark's Fork River, a tributary of the Yellowstone. The mountains may best be seen by traversing from the Park northwestward over the Cooke City-Red Lodge highway.

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 state boundary into Idaho. The structural style of these mountains is quite different from that of the uplifts in central Wyoming in that the mountains are remnants of large folds which have been forcibly pushed eastward upon fault planes that pass westward under the mountains at low angles. Such planes on which the lateral movement, measurable in miles, has taken place are called thrust faults, and this belt of mountains is known among geologists as the "Overthrust Belt".

South of Jackson, Wyoming, 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 separated by the valley of Greys River. These ranges continue southward to about LaBarge Creek, beyond which the mountain ranges have new names. The Wyoming Range continues southward as Commissary Ridge, and the Salt River Range has its general continuation as the Tunp Range, separated by the Hams Fork valley. The most westerly range at this latitude is the Sublette Range, lying between the Bear River and the Smiths Fork of the same drainage.

In the vicinity of Kemmerer a low ridge faces the Green River basin and is known as Oyster Ridge because of the abundance of fossil oyster shells in some of the sandstone ledges. Between Oyster Ridge and the Tunp range lies the Fossil Syncline, containing the fish bearing beds of the Green River formation.

Granite Mountains on the Sweetwater River

In 1847, the "Year of Decision" according to the historian DeVoto, some 50,000 emigrants toiled westward up the valley of the Sweetwater River after fording the North Platte near Casper, passing through Emigrant Gap, and achieving the heights beyond. Along the Sweetwater are the famous landmarks on the Oregon Trail — Independence Rock, Devil's Gate, Split Rock, Sweetwater Crossing and many more. A number of these landmarks are cut in the massive pink granites that crop out in bald stark knobs standing above the light colored, flat-lying sediments at their feet. The landscape is reminiscent of central Africa or parts of Australia.

The Granite Mountains are not particularly high by Wyoming standards, since they are the erosional remnants of the core of the Sweetwater Arch or Uplift. In the later history of the region this area also subsided somewhat to its present elevation, and the bare topography called the Granite Mountains actually occupies an area that is depressed, and bounded by east-west trending marginal 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. A broad rolling upland above timberline at about 11,000 to 12,000 feet elevation reminds one of the moors of Scotland. One looks across a landscape of bogs, small lakes and numerous small streams, but 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.

The summit of the Absaroka Range is essentially a plateau coinciding with the top of a vast pile of nearly horizontal sheets of rock materials 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 mountains are those of erosion — the deep dissection of relatively flat-lying rock layers — and are a classic example of this type of development.

Washakie Range

One mountain range in Wyoming is only partially visible. West of the Owl Creek Mountains are a series of topographic eminences including Black Mountain and Crow Mountain that are separated from the western part of the main range by a broad syncline. These isolated mountains are the exposed southern representation of a feature that has been named the Washakie Range. The major part of the mountains are buried beneath the great pile of flat lying rocks of volcanic derivation that underlie the Absaroka Plateau. The extent of the Washakie Range is not known but probably extends as far north as the south fork of the Shoshone River.

Basins

Scenically the basins of Wyoming are less satisfying 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 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 very different appearances as it is accentuated by low level lighting and can be very beautiful.

Viewed from a geological perspective, these same basins are much more stimulating than some of the uplifts, and are just as profound in terms of the movements of the earth's crust. In fact, the amount of downfolding of the crust 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 are compound downfolds in which the layered sedimentary rocks dip toward the lowest point or trough. Many of the exciting aspects of these downwarps are hidden from the eye because they lie at great depths.

In terms of economics and natural resources, Wyoming would be unable to prosper without the raw materials that exist 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 stones. Farther out in the basin at the surface one finds some of the great coal fields of Wyoming and its uranium deposits. The rock units that extend under the basin at depth act as the reservoirs for oil and gas accumulations. Special products such as trona and oil shale are found in the central part of one of the basins, and 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 pasturage for sheep, cattle and wild life that is utilized particularly in the winter months, when snow melt provides water for animals.

Powder River Basin

Between the Black Hills and the Bighorn Basin is a very wide, moderately deep basin which takes its name from Powder River — "a mile wide and an inch deep". The surface rocks over broad areas are of Tertiary age and contain very extensive coal beds. Red "clinker" capped buttes and ridges are a common part of the landscape and have been formed by the natural burning of coal beds, which baked the overlying shales in a manner similar to the action of a brick kiln. The Powder River Basin has on its margins a number of oil fields of the anticlinal trap type. Among these are Salt Creek, Teapot Dome, and Lance Creek, all of which were discovered over forty years ago. More recent exploration activity has been concentrated in the deeper parts of the basin where oil and gas production has been established at depths in excess of 12,000 feet.

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 volcanic field. Almost perfectly elliptical in shape, the basin is rimmed on all but the north end by high mountains. Major deformation of the rocks has 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 section of the basin has widespread rugged badlands carved in the red and purplish claystones of the Eocene Willwood Formation, from which famous collections of vertebrate fossils have been taken.

The basin is drained by the Bighorn River, named by Lewis and Clark in 1804 when they passed the mouth of the river on their way to the Pacific. The river leaves the basin through a great canyon across the Bighorn Mountains now partially filled by water impounded behind the Yellowtail Dam. Early trappers visiting the headwaters of the river applied to it a different name, so the canyon and the river south of Thermopolis bear the name Wind River.

At one time the Shoshone River also exited from the basin through a deep gorge now left as a broad dry valley called Pryor Gap. Stream piracy and later drainage changes diverted the river to its present course. The old floor of the ancient Shoshone is preserved as Polecat Bench north of Powell.

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, since 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 at the north side, immediately adjacent to the Owl Creek Mountains.

The western boundary of the basin is the east-dipping flank of the Wind River Mountains, characterized by northwest trending hogbacks of sedimentary rocks. The southern boundary is for the most part a north-facing escarpment — the Beaver Rim — a feature analogous to the Pine Ridge Escarpment in eastern Wyoming and Nebraska.

The eastern margin of the Wind River basin is a low, broad arch or upfold in the sedimentary rocks — the Casper Arch — which is crossed between Natrona and Powder River by U.S. Highway 20-26 west of Casper. The topographic relief along this stretch of highway is low, but the strata have been greatly elevated relative to the basins on either side.

The north rim of the basin is the geologically complex, discontinuous upland known as the Bridger and Owl Creek Mountains, characterized by a series of large faults and dip northward away from the basin.

Within the Wind River basin is the oldest producing oil field in Wyoming, Dallas Dome field, located about six miles southeast of Lander. Also within this basin are located the first major uranium deposits found in the State.

Cheyenne-Denver Basin

The surface rocks in the southeastern corner of Wyoming east of the Laramie Range are nearly horizontal strata of Late Tertiary age, which lie unconformably on rocks of Paleozoic and Mesozoic age that are down-folded 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-Carbon-Hanna Basins

The Front Range of Colorado extends into Wyoming in a three pronged fashion (See Fig. 2). Between the Laramie Range prong and the Medicine Bow Mountains prong 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 basin is shallowest in the southern part but reaches an extreme depth in the area north of the coal mining community of Hanna. The deep 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 beneath the sedimentary rocks lies about 30,000 feet below sea level.

The coal reserves of the Hanna and Carbon basins are extensive and also reflect the great change in climate since the days of subtropical coal swamps 60 million years ago.

Basins of Southwestern Wyoming

In a large triangular area in southwestern Wyoming, with its apex near Bondurant and the base along the Colorado-Wyoming boundary, there is a broad uniformity in the geology. The area is bounded on the west by the linear ranges that make up the "Overthrust Belt"; the northeastern margin is flanked by the Gross Ventre and Wind River Mountains 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 centering near Rock Springs and named after that town. East of the Rock Springs fold is a compound depression, the northern part of which is called the Red Desert or Great Divide Basin, and the southern part the Washakie Basin. The structural separation of the two basins is accomplished by an arch that parallels U.S. Interstate Highway 80 and passes through Wamsutter.

West of the Rock Springs Uplift is a very large structural depression as well as drainage basin named for the Green River, which drains the entire area.

Early in the exploration of the region, it was recognized that there were both fluvial and lacustrine deposits cropping out over large areas in southwestern Wyoming. These sedimentary rocks were designated the Green River Formation, because exposures of the rocks are excellent near that town. During the Eocene geologic period (50 m.y. ago), 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 salt by evaporation. In and adjacent to these lakes, a remarkable sequence of intertonguing fluvial and lacustrine sediments were deposited, including conglomerates, limestones, siltstones, oil shales, marlstones bearing fossil fish, and trona. All these rock types are now well displayed in the badlands topography characteristic of the basin.

Jackson Hole Basin

A favorite tourist spot is the small basin in northwest Wyoming known as Jackson Hole. The basin is very young and reflects active crustal movement from mid-Pliocene (8 m.y. ago) to Recent. The flanking Teton Range is the youngest major mountain range in the state, and the basin floor is still sinking today, as evidenced by occasional minor earthquakes.

LANDSCAPE STYLES IN WYOMING

The landscape is the ultimate product of a long series of events extending back in geologic time almost to the inception of the earth as a planet. Each major event in the earth's history is recorded in the rocks, and hence in some fashion influences the land forms of the present.

The underlying principles governing the development of the landscape as seen today were set forth in 1909 by William Morris Davis, dean of American geomorphologists. Among his concepts, the following are perhaps the most important for the layman seeking an understanding of how land forms develop. If we accept the assumption that physical processes have been operative in about the same fashion in the geologic past as they are operating today, then the concepts seem quite reasonable.

Davis pointed out that geologic structure or spatial arrangement of the rock units is the dominant control in the evolution of land forms. He also set forth the concept that each geomorphic agent (i.e. running water, glaciation, wind, wave action) developed a characteristic set of land forms that can be readily recognized. Further, each process is somewhat cyclic, and, therefore, there are recognizable stages in the development of land forms caused by a specific agent.

To understand the origin of the land forms in Wyoming, one must accept the fact that the crust of the earth, some 35 km. thick and composed of dense, crystalline, igneous and metamorphic rocks, was subsiding relative to sea level for a long period of time, and that in the oceanic waters or along the shore line areas, there accumulated several thousand feet of sedimentary rock. In a period of strong crustal movement termed the Laramide period of mountain building (60 m.y. ago), the essentially flat-lying sedimentary rocks were uplifted, strongly folded, and fractured, creating 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 stream gradients whereby the streams of the region could proceed to dissect the rocks into the existing land forms.

Erosion is the term applied to the process whereby the geologic agents such as running water, wind, waves, and ice obtain and remove rock debris. Running water is the most common agent of erosion in Wyoming, though on some days wind seems to run a close second. The result of erosion by running water is the formation of an intricate network of drainage channels, each of which is extending itself headward and is also being deepened.

The components of the channel system have a wide variety of names, depending upon the place and historical background. Some names describing a channel down which water may move are — creek, gully, gulch, arroyo, canyon, coulee, draw, sag, ditch, and wash. All are products of downcutting by streams and demonstrate the continual erosion of the land surface.

There are a few standard landforms that are repeated in endless variation and at many scales, and most of them depend upon the variation in resistance to erosion of the rock units. The basic land forms will be illustrated and briefly discussed in the section following.

Land Forms Due to Erosion

Simple Dendritic Drainage Pattern

The bedrock is massive and relatively homogeneous in character and is being modified by stream action. The result is a system of more or less evenly-spaced streams forming a dendritic pattern. Continued erosion eventually results in a maximum of slopes. The central Laramie Range provides a good example.

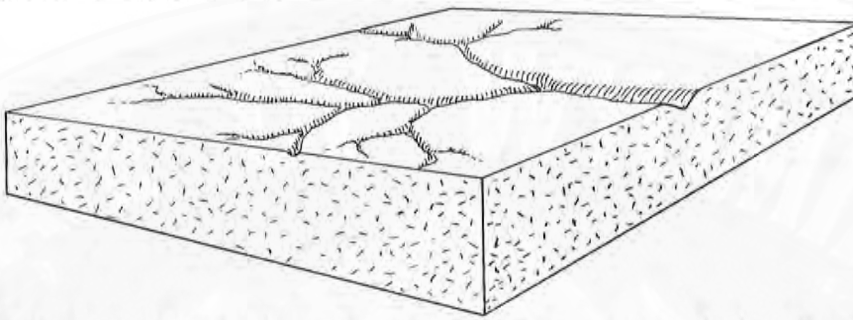

FIG. 5. Drainage pattern developed on homogeneous rock, in this case granite.

Erosion of Flat-lying Sedimentary Rocks

The bedrock, consisting of essentially flat-lying sedimentary rock layers of varying resistance to erosion, is being removed by the active headward erosion of the tributary streams. The resulting land forms are retreating escarpments or rims, with isolated outliers remaining as buttes and mesas. Such land forms are characteristic of the Tertiary rocks in eastern Wyoming as well as in the Green River basin.

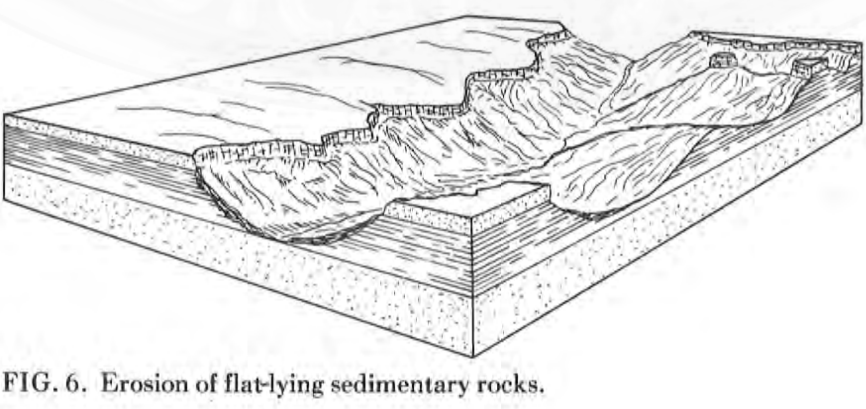

FIG. 6. Erosion of flat-lying sedimentary rocks.

Erosion of Uniformly Tilted Sedimentary Rock

The bedrock is layered and of sedimentary origin and has been tilted in one direction, as on the east flank of the Wind River Range. The resistant rocks appear as ridges, and the soft rocks have been etched out to form the valleys, resulting in long parallel ridges and valleys. If the ridges are nearly symmetrical in slope, they are called hogbacks; but, when asymmetrical, they are called homoclinal ridges. The streams flow down the open valleys, then abruptly turn and cross the ridges through watergaps.

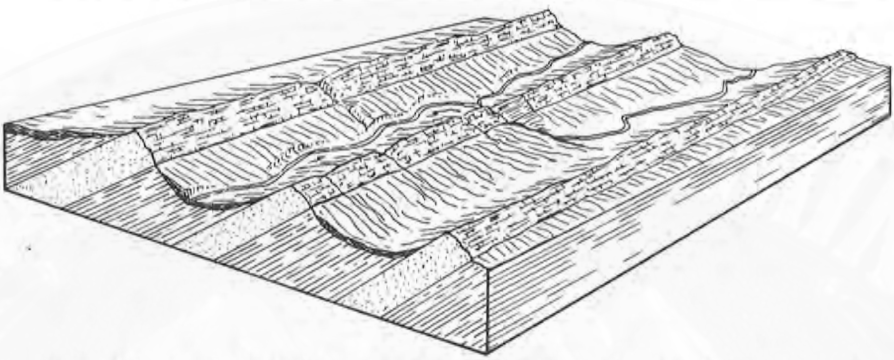

FIG. 7. Ridges and valleys developed by erosion of tilted sedimentary rocks.

Erosion of Folded and Faulted Sedimentary Rocks

The sedimentary rocks may be complexly folded and fractured, giving rise to ridges and valleys that have sinuous or zig-zag patterns. "Race track" valleys may develop, or small closed topographic basins, or there may be offset ridges. Striking examples are seen in the eastern Freezeout Mountains on Wyoming Highway 487 between Medicine Bow and Alcova Junction.

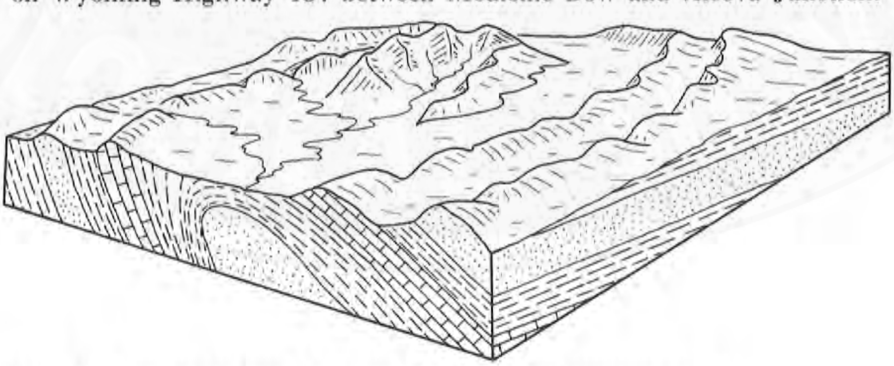

FIG. 8. Erosional forms developed in folded sedimentary rocks.

Land Forms Resulting From Action of Glaciers

The combined actions of frost, permanent snow fields and glaciers create conditions of mountain glaciation. Such conditions prevail now at high elevations in Wyoming in the region of the Dinwoody and Gannet glaciers, but were much more widespread during the Pleistocene period, commonly called the last Ice Age, which began about two million years ago. The rocks exposed in the cores of the mountain ranges are usually crystalline igneous and metamorphic rocks that are quite homogeneous in their physical characteristics and in their response to erosion.

Glacial ice and permanent snow fields occupied stream cut valleys already in existence. The action of a glacier modifies, smooths and widens the older valleys and develops a U-shaped cross-sectional profile in the valley. Sharp peaks 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 these in waterfalls.

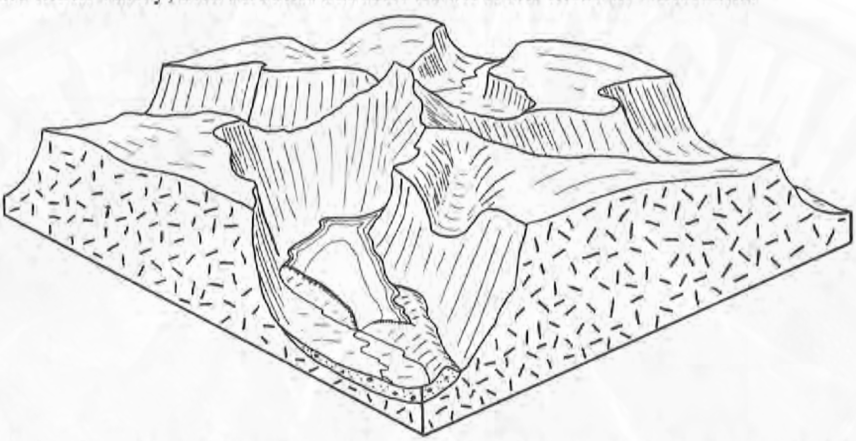

FIG. 9. Horns, cirques, and U-shaped valleys created by the action of glaciers that previously occupied the valleys.

On Figure 10 are shown the areas in Wyoming that were occupied by glaciers during the Ice Age, and which now have a landscape reflecting the action of glacial ice. Fine views of such a landscape can be seen on U.S. Highway 130 across the Snowy Range, east of Pinedale in the Wind River Range, and on the east face of the Tetons.

Land Forms Developed Primarily by Solution of Limestone

Natural rock caves have provided shelter for man over long periods of human history. In fact, much of the knowledge we possess concerning the living habits of ancient peoples has been obtained from rock shelters and caverns.

Underground caverns of any appreciable extent occur only in regions where the underlying bed rock is limestone or dolomite. Classic examples of such regions are the Karst of Yugoslavia, the Mammoth Cave region of Kentucky and the Carlsbad region of New Mexico.

Caves are found in all parts of the state where the thick limestones of Paleozoic age crop out at the surface. The locations of some districts containing caves are shown in Figure 10.

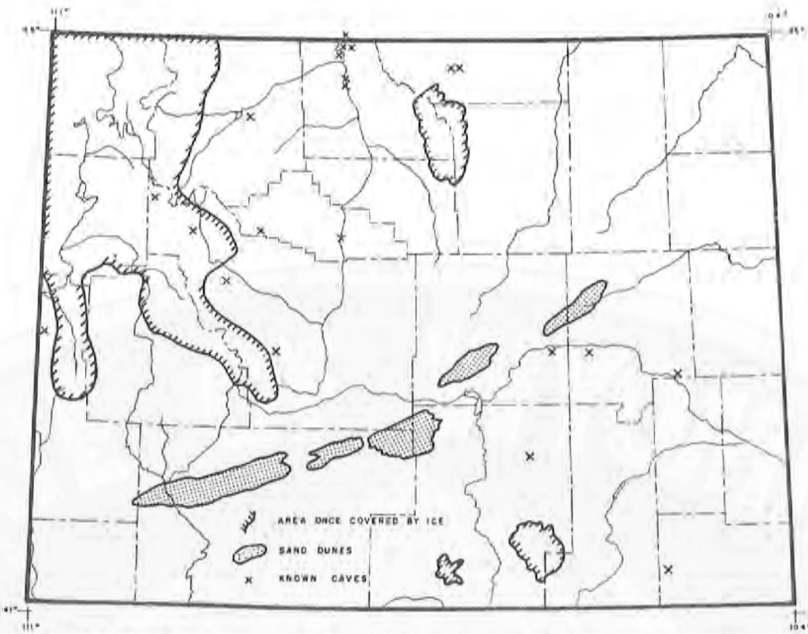

FIG. 10. Map of Wyoming showing areas occupied by glaciers during the Pleistocene Ice Age, and the location of dune sands and caverns probably developed during the same period.

The requisite conditions for the formation of caves are quite simple. The underlying rock must be limestone or dolomitic limestone and must be reasonably thick and extensive. Perhaps a thickness of over a hundred feet would be a good minimum value. The region should have rather abundant precipitation — enough to class the region as climatically humid (40 inches 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 fractures and along bedding planes, and moves laterally toward lower elevations. Such surface water takes into solution carbon dioxide, 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, as shown by the chemical reactions below:

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Carbonic Acid}}{H^{+} + (HCO_3)^{-}}$$

$$\underset{\text{Limestone}}{CaCO_3} + \underset{\text{Carbonic acid}}{H_2CO_3} \rightarrow \underset{\text{Calcium bicarbonate (in solution)}}{Ca(HCO_3)_2}$$

The surface water has now become underground water and may travel long distances before again joining the surface streams. Continued movement of the acid water will dissolve large amounts of limestone and create underground openings, channels, and caverns.

The formation of caves is a cyclic process. The first stage is the creation of the underground openings during a period of abundant water supply, such as prevailed during the Pleistocene Ice Age. The second stage in cave development 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 crystal linings.

Special situations result in "sinks," such as those in Sinks Canyon near Lander and in Dinwoody Canyon. In these examples, the limestone has an eastward dip away from the core of the Wind River Mountains, so surface water may enter the bedding planes and move downward below stream level. Fractures in the rock further downstream provide a route for the water to again move upward to the surface. Nature has provided a U-shaped tube with one limb a little shorter than the other, thus allowing water to spill out at the lower end. The channel through which the water moves has been enlarged by the process of solution, so that it now accommodates all the stream flow except during spring floods when overflow goes down the regular channel. The diagram below illustrates how the "sinks" operate.

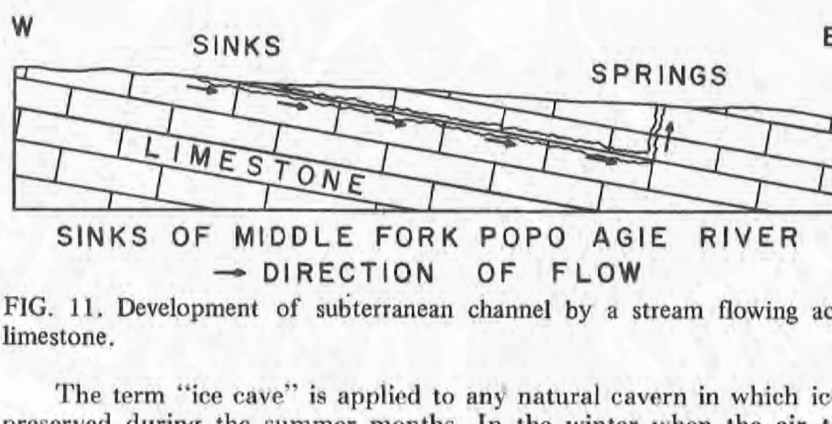

FIG. 11. Development of subterranean channel by a stream flowing across limestone.

The term "ice cave" is applied to any natural cavern in which ice is preserved during the summer months. In the winter when the 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. 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. The situation is shown in Figure 12.

Land Forms 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

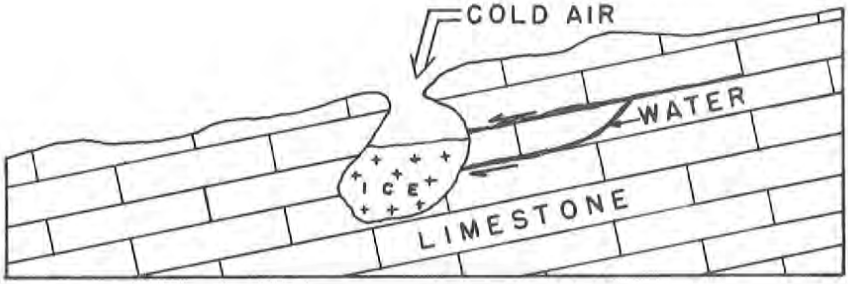

FIG. 12. Cross section showing formation of ice in caves.

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 longitudinal section. Another characteristic of such erosion surfaces is that they bevel or truncate underlying rocks which have varying degrees of dip and varying resistance to erosion. A thin veneer of cobble size gravel usually caps the surface.

The land form having the above described characteristics is known as a pediment, reflecting its position at the foot of the mountain. The presence of gravels indicates that, at the time of formation, the pediment was the floor of some type of stream course where erosion and bevelling of underlying rocks was taking place. The present position on the interstream divides indicates that subsequent erosion has lowered the intervening areas, causing an *inversion of relief.* The gravels have protected the underlying rocks from erosion.

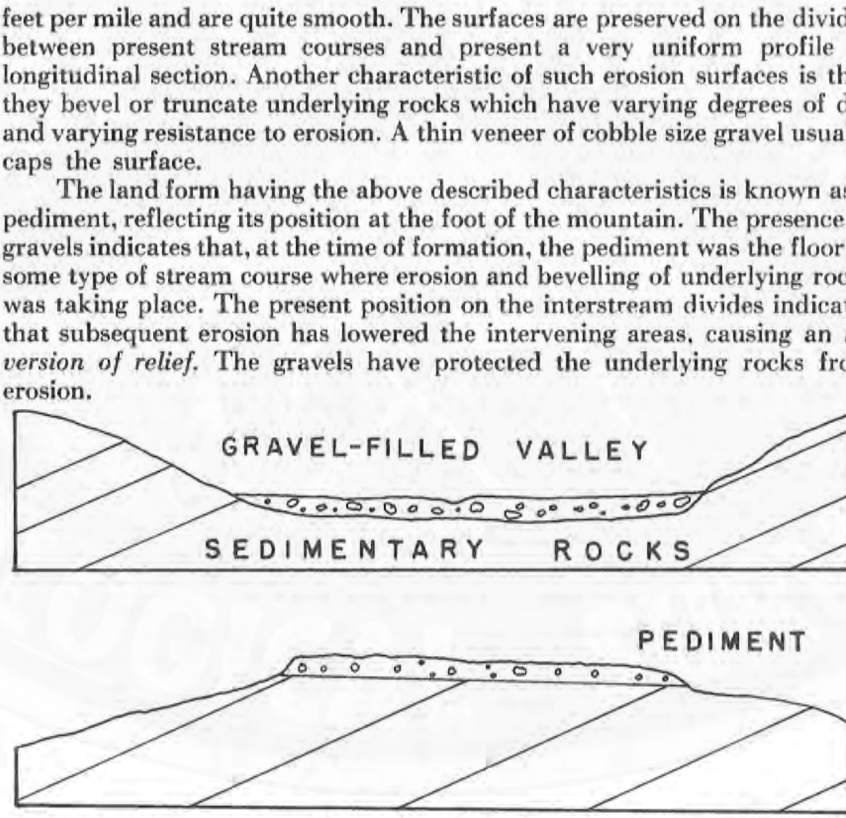

FIG. 13. Cross sections illustrating inversion of relief in pediment formation.

Land Forms Due to Deposition

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. The stream overflows the banks, and then, as the water level falls, deposition occurs, and available

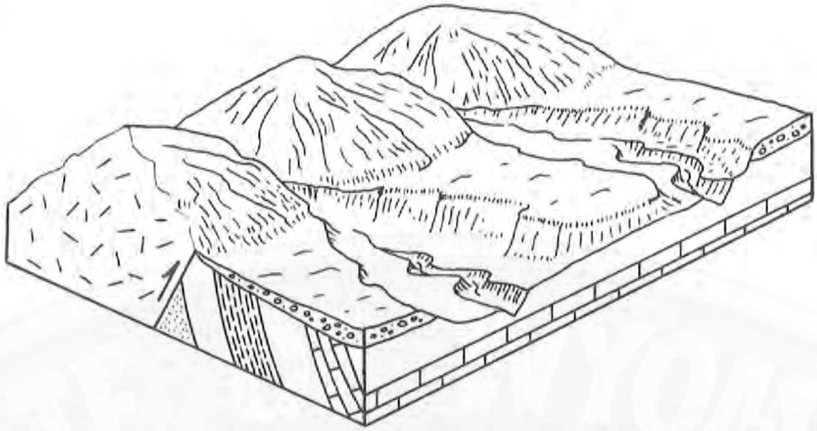

FIG. 14. Block diagram showing pediment surfaces along a mountain front.

load is spread out to form the flood plain of the stream. The wide flat floors of major rivers are the result of such deposition. Most streams have some flood plain, though it may be narrow. Such valley bottoms are the sites of farms and ranches in the west.

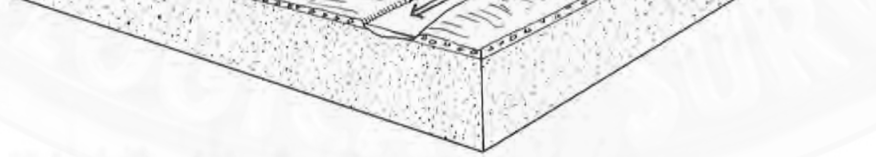

FIG. 15. Meandering river and its alluvial flood plain.

Aeolian Deposits

In arid and semi-arid regions the wind is a powerful erosive agent. Throughout southeastern Wyoming and northeastern Colorado there are many large, undrained depressions or "blow outs" that were excavated by wind action during a particularly dry inter-glacial epoch. Some blowouts now receive reject irrigation water and contain lakes. A very large, nine mile long wind eroded depression known as Big Hollow occurs west of the Laramie Municipal Airport and south of U.S. Highway 130 en route to Centennial.

The material that is picked up by the wind as "blow outs" are eroded is moved across the country and may be deposited locally to form dunes. Sand dunes are common in a rather wide belt across central Wyoming, from a point near Farson to a point northeast of Casper. 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 is one of low rolling hills and small undrained depressions.

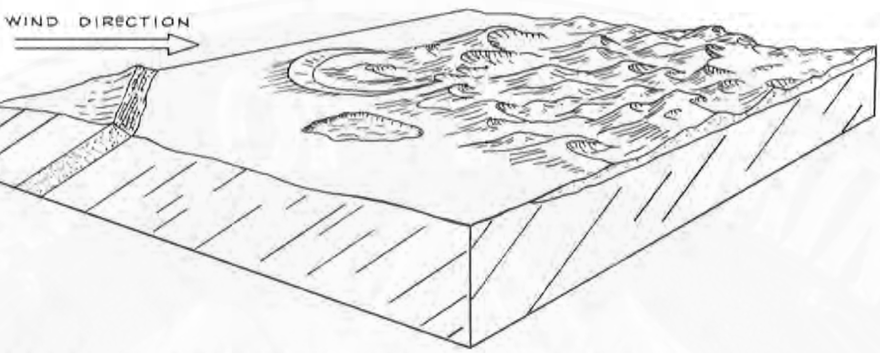

FIG. 16. Block diagram showing sand dunes and a blowout.

Mass-wasting Deposits

The force of gravity is ever-present and continually acting upon all rock masses in an attempt to move them to a lower elevation. The common results of this inexorable action are rock avalanches, mud flows, rock falls, landslides and ground subsidence.

The term "mass-wasting" is applied to such types of gravitational transfer of material. Usually, the transfer is slow and scarcely perceptible, but sudden, violent, and catastrophic mass movements do occur. The classification of mass-wasting phenomena is based on the rate of movement, which is in turn controlled by the type of material involved and the degree of water saturation. Most such movements can be compared to the slow flow of a highly viscous fluid.

Slow flowage types of displacement are called creep, and observation must be made over a period of years to fully establish the effects. Rapid flowage types of movement are described as earthflow, mudflow, and rock avalanches. Landslides are a third type, with the material usually dry and the motion rapid enough to be easily observed. Subsidence occurs over old mine workings or in areas where large volumes of fluids have been withdrawn from the subsurface by wells producing either water, or oil and natural gas.

The valley of the Gros Ventre River east of Jackson contains many examples of mass gravity movement. The largest and most striking example is the Lower Gros Ventre slide, which occurred in a period of a few minutes on June 23, 1925. The season was one of heavy rainfall, and the high degree of water saturation may have triggered the slide. About 50 million cubic yards of material moved down and across the Gros Ventre valley and created the natural dam behind which Lower Slide Lake is impounded. Subsequently, on May 18, 1927, flood water over-topped the dam, creating a sudden and disastrous flood.

Many hillsides in Wyoming show scars where slides have detached, and at the base of the slope will be observed the irregular pile of debris that has moved down slope under the action of gravity. In a few unfortunate situations, highways have been located across ground that is creeping, or highway excavations have created unstable slopes, thus starting mass gravity movements.

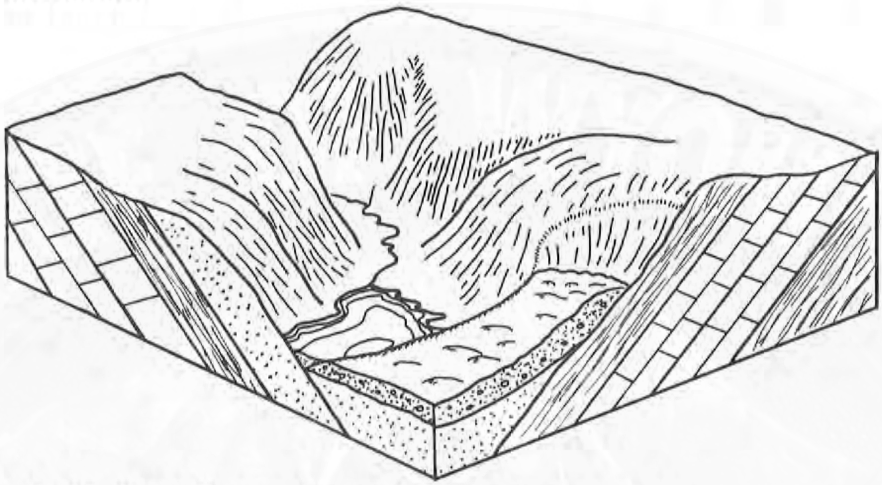

FIG. 17. Block diagram showing development of a landslide.

Playa Lake Deposits

In regions of low rainfall, surface waters derived from sporadic rain storms and limited snow melt accumulate in depressions eroded by wind action. The shallow, ephemeral bodies of water that accumulate in such 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 such depressions are very flat as the result of deposition of fine clays, silts, and saline material carried in by surface water.

All the mineral matter that was in solution in the water is precipitated as salts when the water is removed by evaporation. Over the years, the saline content becomes very high, and some lakes actually have salt pans interbedded with clays. The common term to describe these lakes is "alkali" because of the white crusts of bitter, astringent salts that line the shores and beds of these lakes. Lakes of this type are found near the Sweetwater River and are the source of the name of Natrona County.

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	$Mg\,SO_4 \cdot 7\,H_2O$
Natron or sal soda	$Na_2CO_3 \cdot 10\,H_2O$
Trona	$Na_2CO_3 \cdot NaH\,CO_3 \,.\, 2\,H_2O$

Glacial Deposits

A glacier by definition must be a moving body of ice. In this sense, a glacier is a type of conveyor belt carrying rock debris from the cirque at the head of the glacier and from the walls of the valley down the canyon to the plains. At the lower elevation, the air is warmer and the ice melts as rapidly as it advances down the valley. The glacier (conveyor belt) is unloaded, and an irregular pile of rock debris is deposited.

The topographic features so formed are moraines, and the unsorted material of which they are composed is till. A moraine has a hummocky, irregular surface with small irregular undrained depressions, and usually is strewn with both large and small boulders called erratics. The moraine at the lower end of a valley, marking the point of maximum ice advance, is called the terminal moraine. Farther up the valley, there may be other moraines called end moraines, marking points of still-stand of the ice front as the ice melted back at the close of the Ice Age. Some valleys contain long ridges like railroad embankments along the sides of the valley. These are lateral moraines and mark the margins of the ice along the valley side.

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

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

Fine terminal moraines are crossed in U.S. Highway 26-287 between Fort Washakie and Dubois.

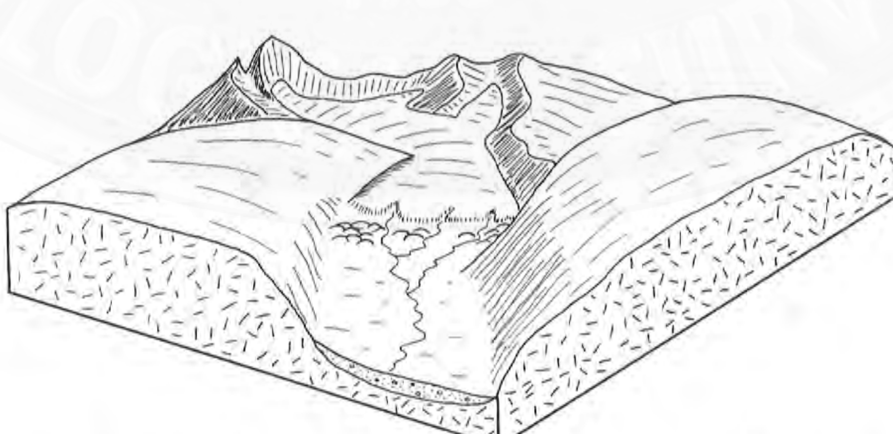

FIG. 18. Glacial moraine and outwash associated with active valley glacier.

Thermal Springs and Geysers

The earth as a planet has a higher temperature in the interior than at the surface, and the increasing temperature with depth can be observed in deep mines and in deep bore holes. Another manifestation of the higher temperature in the interior of the earth is the molten material discharged to the surface during volcanic eruptions. A less spectacular evidence for increasing temperature with depth is a thermal spring.

Thermal springs are defined as natural discharges of water, the temperature of which is appreciably above the mean annual temperature of the atmosphere in the vicinity of the spring. Some waters may be very hot and near boiling, while others are merely warm.

Thermal springs are common in, but not restricted to, areas of recent volcanic activity. The large numbers of fumaroles, mud pots, steam vents, hot springs and geysers in Yellowstone National Park are related to the ancient volcanic field in which they occur. Some volcanic activity took place as recently as the Ice Age, and the thermal spring phenomena are the final vestiges of that volcanism.

The most spectacular of the hot springs are geysers. The first such feature known to man is located in Iceland and called the Great Geyser. The unique aspect of the geyser is the regular period of its eruptions, during which it discharges hot water and steam. The plumbing system beneath a geyser consists of a complex network of openings comparable to the root system of a tree. Underground water percolates into and fills the underground openings. The rocks in the walls of the conduit are hot so that as the openings are being filled, the water is also being heated. The water will finally be heated to its boiling point for the pressure existing at the various levels in the tube. Once the water is at the boiling temperature throughout the tube (bottom to top), any agitation, such as the escape of gases or dissolved air (similar to the bubbling in a pan of boiling water), will change the pressure system and allow the entire column of water to rapidly convert to steam and erupt to the surface. The interval between eruptions depends on the rate of filling of the conduit and the amount of heat available to again raise the temperature of the water to the boiling point.

Ordinary non-erupting hot springs are common, but equally as interesting. Ground water from whatever sources has either passed to great enough depth to be warmed because of the increase of temperature with depth, or has been near some buried intrusive rock mass that is cooling and losing heat. During the passage of the water from the surface to depths and back, it will take into solution any soluble material from the rocks through which it passes. Hot or warm waters can hold more material in solution than cold water, and, therefore, when thermal waters reach the surface and begin to cool, the capacity to hold material in solution is decreased.

The dissolved materials, therefore, are deposited at the surface to form mounds, cones and terraces over which the water cascades and is further cooled. The material deposited is usually calcium carbonate ($CaCO_3$) in a spongy, porous form known as travertine. In a few areas silica (SiO_2) is deposited and is known as siliceous sinter.

A striking aspect of many terraces and pools associated with hot springs is the brilliant color related to the presence of algae that live in the heated waters. If water is diverted from a terrace for any reason, the travertine immediately becomes dull and dead looking because of the absence of the algae.

Sizeable thermal springs occur in Wyoming at Saratoga, Thermopolis, Granite Creek, Kendall, Douglas, and Cody, in addition to the wide variety of such phenomena in Yellowstone National Park.

The Thermopolis Hot Springs are located within Hot Springs State Park with a wide variety of recreational opportunities. The diagram below depicts the geology at the site of the springs. The source of the heat which raises the water temperature to 135 degrees Fahrenheit is deep seated, and not fully understood.

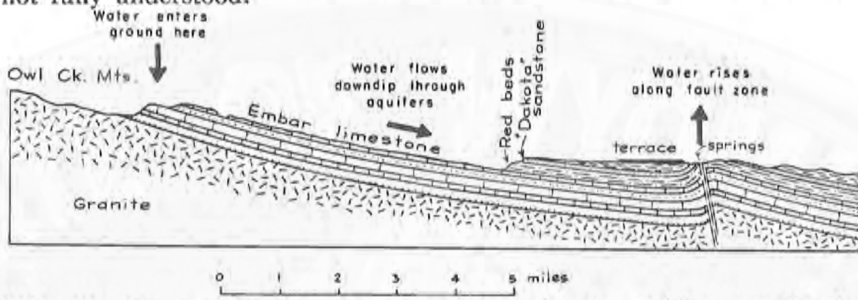

FIG. 19. Cross section showing circulation of water at Thermopolis Hot Springs.

Landforms Due to Igneous Activity

Volcanoes and Piles of Volcanic Ejecta

The Absaroka Range of northwestern Wyoming occupies an area of approximately 3,000 square miles, and is underlain by a relatively undisturbed sequence of rocks including lava flows and volcanic debris, as well as some intrusions.

Volcanic activity may be of two types. Molten lava may rise to the surface through central vents and flow away from the vents in all directions to form volcanic cones, or it may flow out from long linear fissures and form sheets of lava rather than cones. A second type of volcanic activity is violent and explosive from a central vent, resulting in clouds of fragments of broken rock, ash, and some blobs of molten lava called bombs. The fragments ejected vary in size from huge blocks to a very fine dust. The large fragments fall near the vents, and the fine dust may be carried tens of miles away to be further dispersed by streams draining away from the area of the eruption.

The effect of the two types of volcanic activity described above, if continued over any appreciable period of time, is to build up great piles or layers of volcanic debris. Such activity took place in Wyoming during Oligocene, Miocene and Pliocene time beginning about 35 million years ago, and spread volcanic debris, particularly the fine grained material, over most of the state.

Volcanic ejecta makes up much of the rock along U.S. Highways 14 and 20 between Cody and Yellowstone National Park, and excellent exposures are also seen in the cliffs north of Togwotee Pass on U.S. Highways 26 and 287.

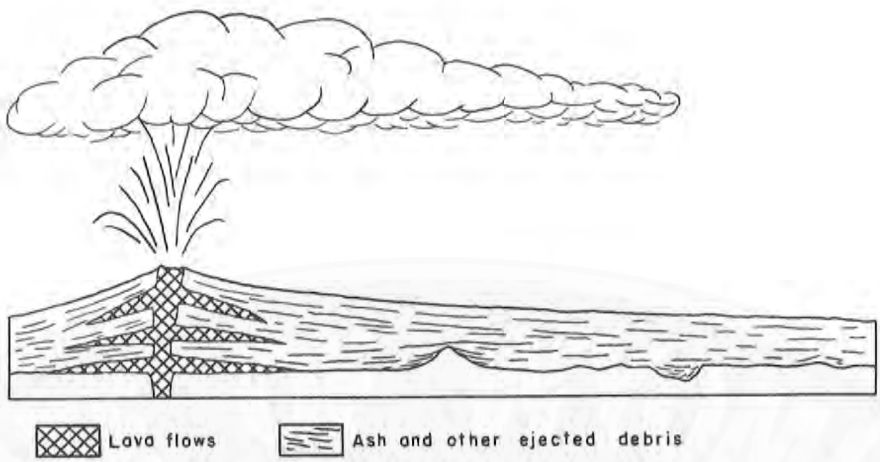

FIG. 20. Cross section of typical volcano composed of lava flows and ash fall.

Cores of Igneous Intrusions

A few examples of deep seated igneous activity have been made visible to us as the surrounding rock cover has been stripped away. In such cases, magma that had been forced into the sedimentary cover was cooled slowly and crystalline rock resulted.

An example of such activity is seen at Devil's Tower National Monument in Crook County. A possible origin of the present landmark is demonstrated in the sections below.

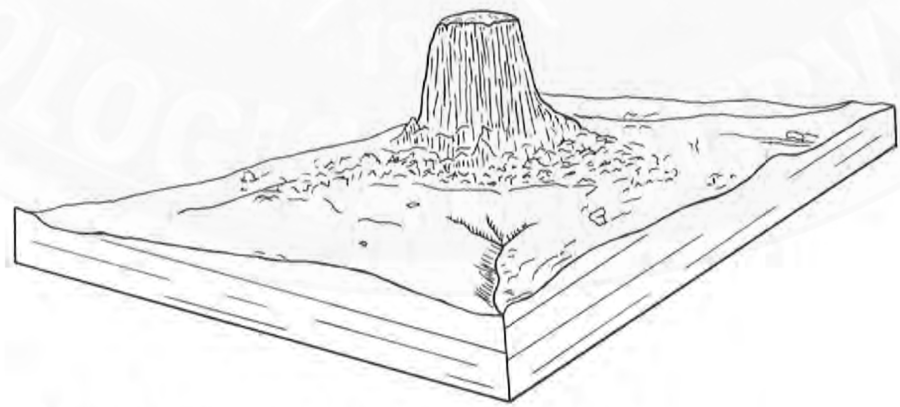

FIG. 21. Diagram of Devil's Tower as it appears today.

The magma was originally intruded or injected under pressure along a bedding plane in the Jurassic Sundance Formation, which is very nearly flat or has a slight dip toward the Tower. If the intrusion was flat floored, then

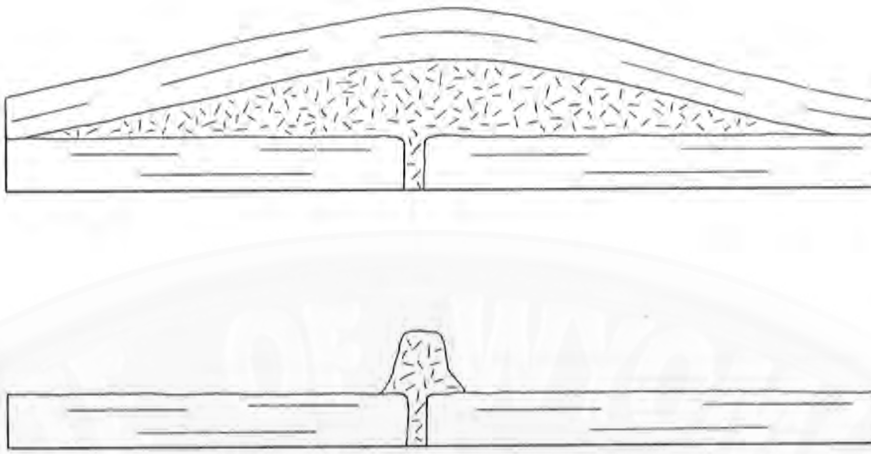

FIG. 22. Development of Devil's Tower.

the sedimentary layers originally present were bowed up and arched by the wedge of igneous material that was injected from below. At a later date, the cover was stripped from the intrusion and partly removed, leaving only a residual core.

Around the western margin of the Black Hills are several examples of intrusive masses from which the sedimentary cover has been stripped. Two examples are Inyan Kara Mountain and the Missouri Buttes.

Summary

The types of destructional and constructional land forms described above are repeated many times over, and may be found either in conjunction or superposed. Currently, the forces of erosion (destructional) are dominant, and there is a steady wearing away of rocks and a reduction in elevation of the land surface. The struggle is endless, but through a complex series of interactions the continents remain high, and the land persists.

BLOCK DIAGRAM ILLUSTRATING LANDSCAPE EVOLUTION

In order that the general public might better understand the landscape of the Rocky Mountains, Dr. S. H. Knight, former Wyoming State Geologist and Professor of Geology, Emeritus, of the University of Wyoming, prepared the block diagrams shown as Figures 23-26 inclusive. Beginning at a time when the mountains and basins were well defined and erosion was active, he portrays the evolution of a typical Wyoming landscape. The major event which governed the position of the major streams in Wyoming was the accumulation of a vast sheet of younger sedimentary rocks in the basin areas, climaxed by a widespread sheet of volcanically derived fine grained sediments. The major streams developed on this aggraded surface. Later, as they cut downward and removed the cover, their courses were locked into the harder underlying rocks and, as a result, such great canyons as the Wind River, the Bighorn and the Platte evolved.

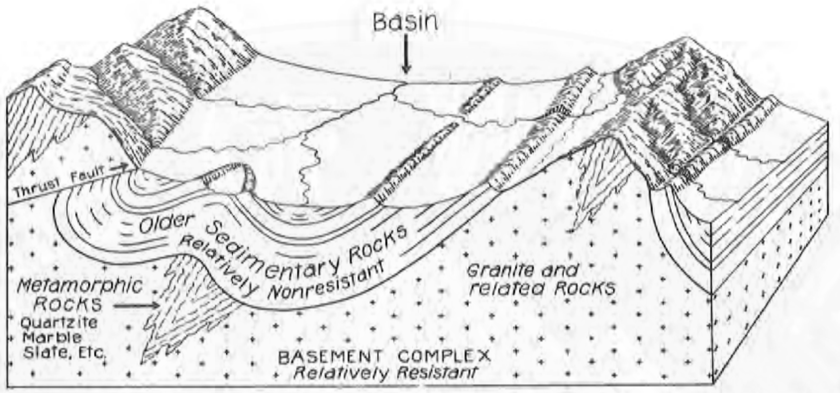

FIG. 23. Mountains and basins formed by folding and faulting. Extensively modified by erosion.

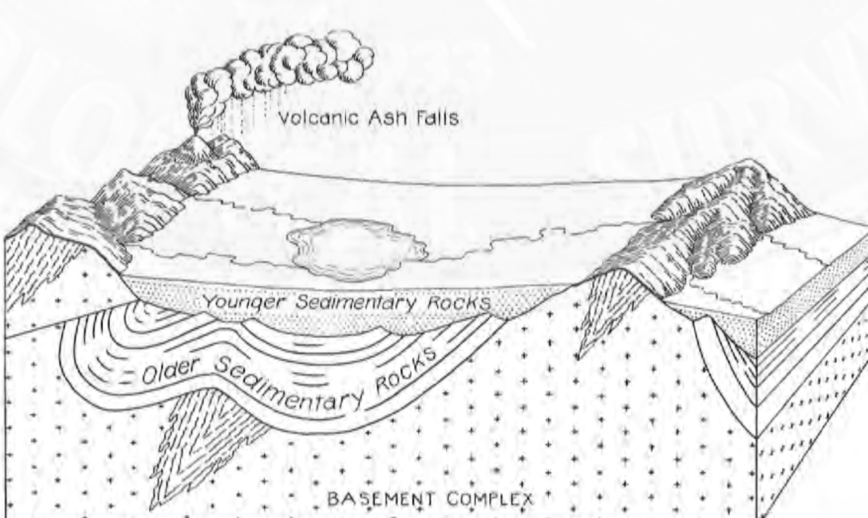

FIG. 24. Basins partially filled with younger sediments derived from adjacent mountains and intermittent volcanic ash falls.

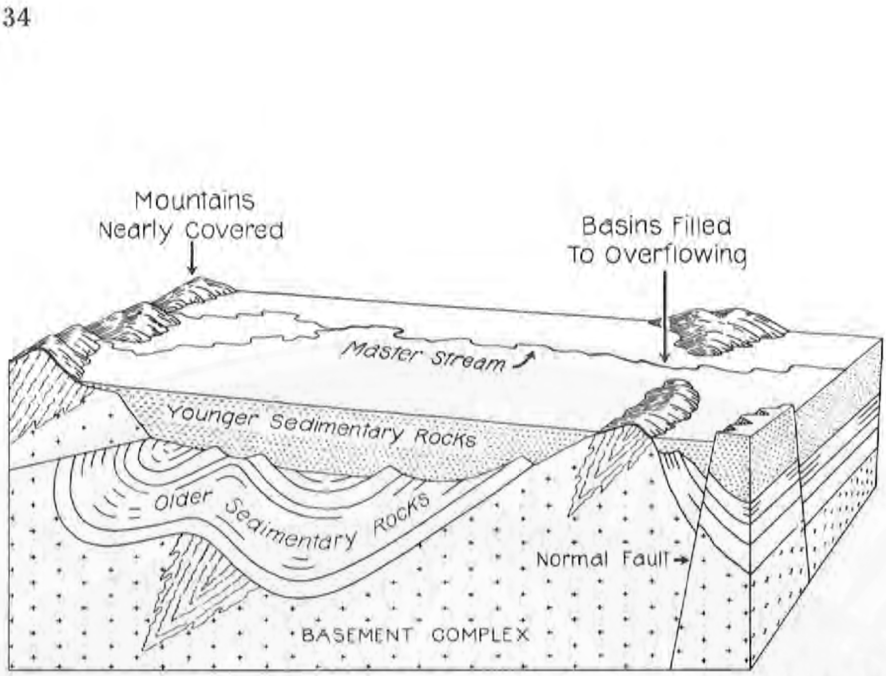

FIG. 25. Basins filled to overflowing at low places on divides followed by regional uplift with tilting and faulting. Present master streams developed on rejuvenated surfaces.

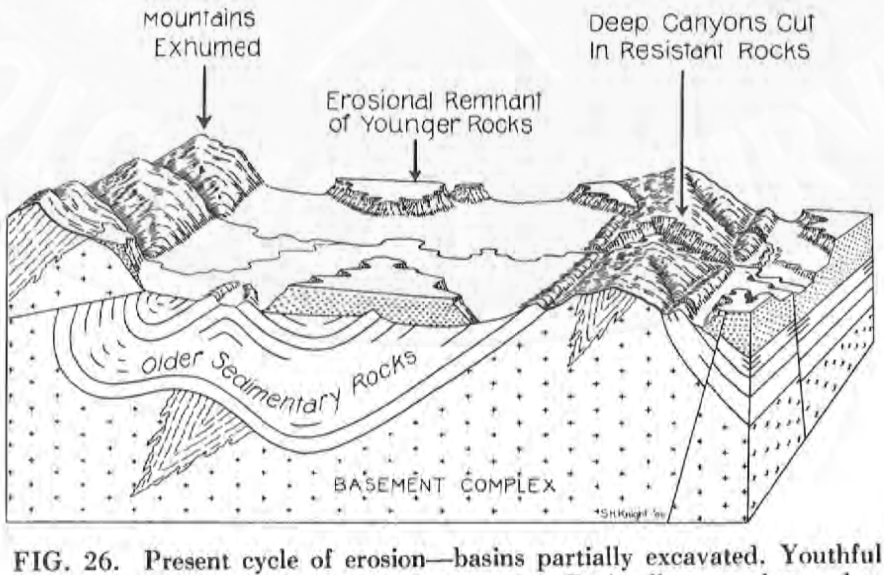

FIG. 26. Present cycle of erosion—basins partially excavated. Youthful canyons cut across resistant cores of mountains. Basins floors are lowered as canyons are deepened.

MOUNTAIN BUILDING—HOW ROCKS ARE DEFORMED

Most sedimentary rocks are deposited in a nearly horizontal position, 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 *geologic structure.* A few terms are necessary to properly describe the position of rock bodies in space. If the rock body is layered (like a plane), we can describe its position in terms of the strike and dip of the rocks. The terms are illustrated and defined below.

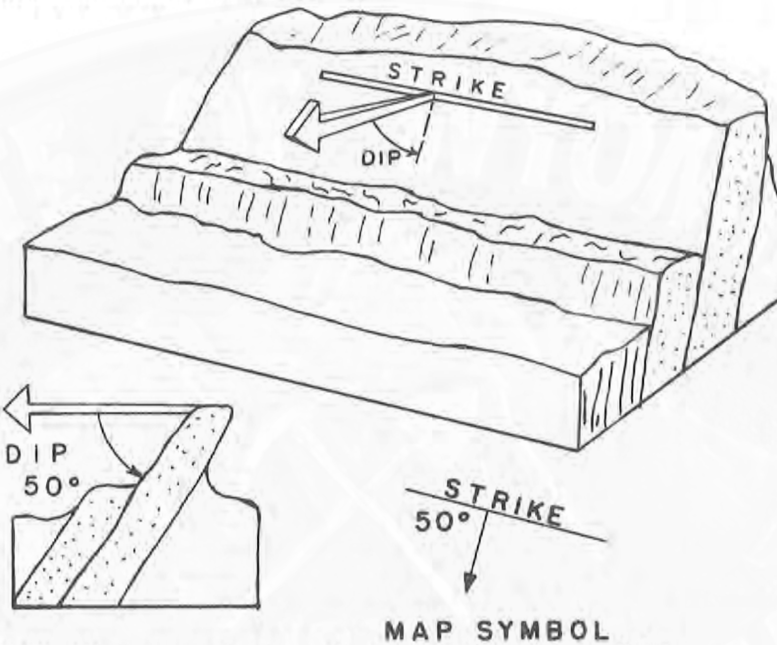

FIG. 27. Diagrams and cross section illustrating strike and dip.

At present time, most of the sedimentary rocks units have been tilted from their originally horizontal positions by large scale crustal movements described under the term *diastrophism* or *tectonic activity.* The simple cross section (See Fig. 28) represents a vertical cut taken across Wyoming at the last time the entire area was at or near sea level, about the close of the Cretaceous period (See Table 4). Using the erosional surface that bevels across the Precambrian rocks as a datum plane, the following events can be deduced.

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 the beginning of 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 time 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.

A major period of crustal activity began about 70 million years ago and has continued intermittently until the present. The effect of this crustal unrest has been to warp and fracture the crust and the overlying sediments, so as to outline the mountain ranges and the basins, and to establish the geologic framework that we see today. The second cross section reflects in a broad way the present position of the crust.

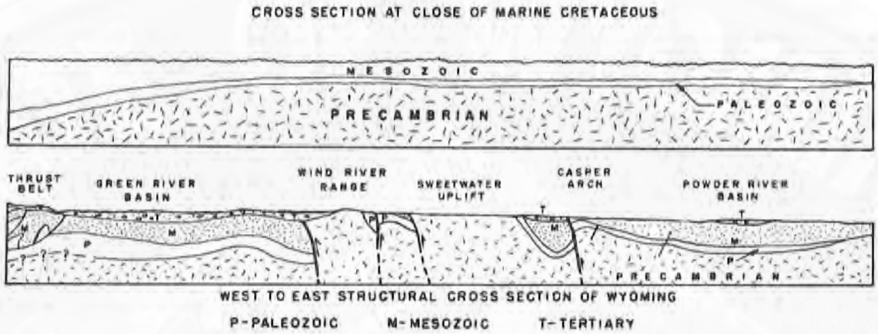

FIG. 28. Cross sections showing development of structure across Wyoming.

STRUCTURAL FORMS

The deformation of the crust and overlying sedimentary cover results in several geometric forms or structures which will be illustrated. During the time that the crustal movements were taking place, the erosional processes were also active, transferring material from the mountains to the deepening basins. The landscape was *evolving* during all this time, and did not spring into full bloom over night.

Folds

The rock layers may be bent, bowed, or wrinkled into folds much as one might wrinkle a tablecloth, or bend a magazine. The folds which result are given specific names dependent upon their form. The words used include the Greek root — *clinos*, an angle — which refers to the dip of the strata as defined earlier in this section. The upfolds in which the rock layers dip away from a line are called anticlines, since the dips are opposed. If the strata dip toward a line, the form is called a syncline, since the dips are toward each other. If, over a large area, the strata all dip rather uniformly in one direction, the form is called a homocline, or the situation may be described as regional dip.

Anticlines and synclines occur together in pairs, and the flank of one feature is also part of the adjacent fold. The cross section and diagram below shows the forms described.

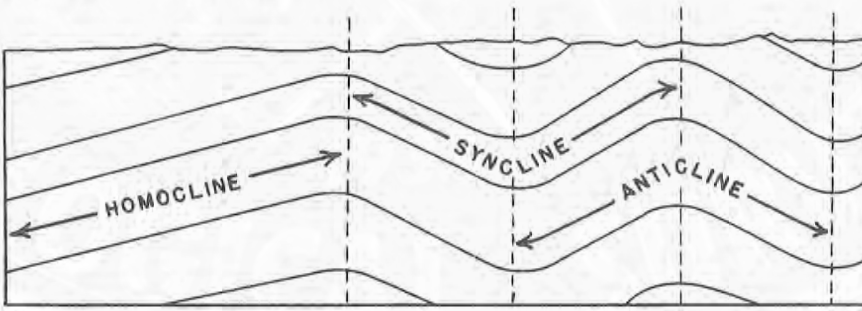

FIG. 29. Cross section illustrating nomenclature of folds.

If the crest of an anticline or the trough of a syncline is inclined, the fold is said to plunge below the ground surface. In groups of plunging folds, the patterns are zig-zag in plan view. In a general way, folds are evidence that the rock layers have been crowded into a space that is shorter than the original space in which they were deposited.

Faults

The second major type of response of rocks to crustal disturbance is by fracturing. Once formed, a fracture may provide a plane of movement for adjustment to earth stresses. When movement occurs on such planes, they are called faults. The movement on the fracture plane must be parallel to that surface. The planes of fracture may be vertical, inclined or on some occasions almost horizontal. The movement may be up, down or sidewise.

Two common fault situations are shown below.

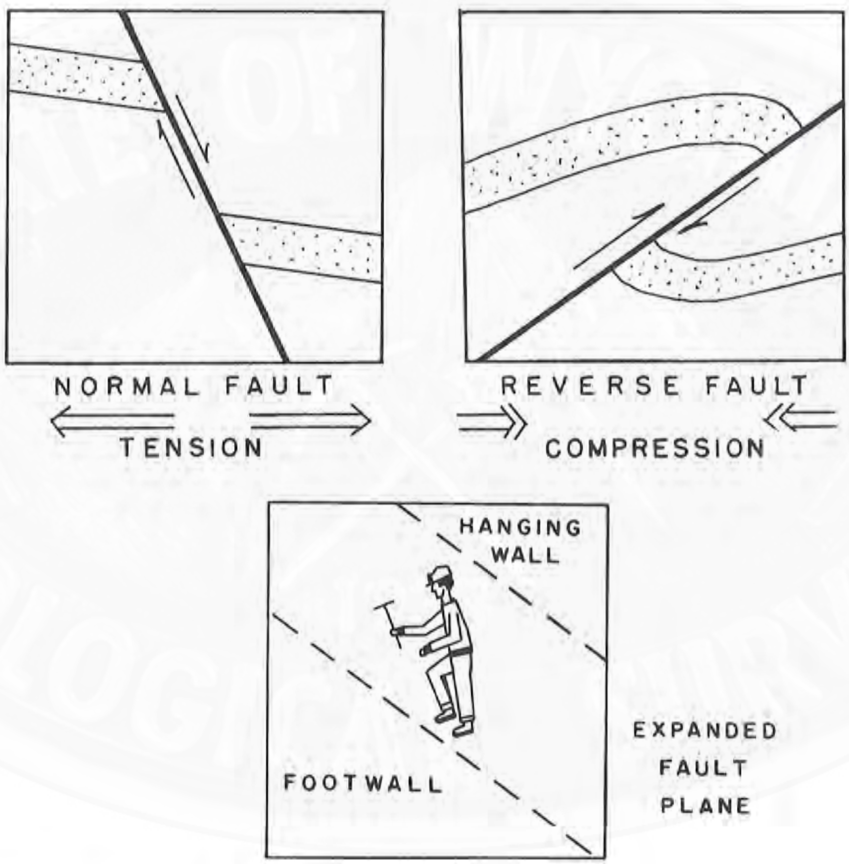

FIG. 30. Cross sections illustrating nomenclature of faults.

The part of the rock mass above the fault plane is called the hanging wall and the part below the footwall. These are old miner's terms that have been incorporated into the technical vocabulary. In the case of a normal fault, the hanging wall is said to have moved downward; but in a reverse fault, the hanging wall can be described as moving upward relative to the footwall.

MINERALS AND ROCKS

Minerals

Common Rock Forming Minerals

A mineral is defined as a naturally occurring, homogeneous, inorganic compound having definite physical characteristics, and a definite chemical composition. A mineral usually possesses a regular external shape, but may occur in fine grained aggregates in which it is impossible to pick out the crystal form of individual minerals.

The Geological Survey of Wyoming has available a publication-Bulletin No. 51, "A Field Guide to the Rocks and Minerals of Wyoming" by William H. Wilson — which includes excellent information concerning a large number of common minerals.

The descriptions that follow are brief, and make no attempt to discuss all the variations in mineral species and their occurrence.

Quartz (SiO_2).—Macrocrystalline variety usually clear to smoky but may be pink to purple in color; glassy to waxy in luster; no cleavage; irregular to conchoidal fracture; hardness greater than that of glass. Commonly found as hexagonal crystals in veins in igneous rocks.

Cryptocrystalline variety (*cryptos* — Greek — hidden) of quartz is crystalline, but crystals can be observed only under high magnification of a microscope. In hand specimen one sees a dense, perhaps translucent material of highly variable color. Some examples 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 (K, Na, or Ca aluminum silicate).—Vitreous to pearly luster; excellent cleavage; hardness greater than that of glass but less than that of quartz; short stumpy crystals common; forms light colored background in some igneous rocks; cleavage faces may bear minute, parallel striations.

Orthoclase—$K\ Al\ Si_3O_8$—pink
Plagioclase—$Na\ Al\ Si_3O_8$ or $Ca\ Al_2Si_2O_8$—gray or white

Mica (K, Fe aluminum silicate).—Vitreous to submetallic luster; excellent cleavage; can be scratched with fingernail; occurs as crystals in many igneous and metamorphic rocks; fragments within sandstone.

Weathered, golden appearing flakes of biotite are often mistaken for gold, hence "fool's gold".

Biotite—$H_4K_2Fe_6Al_2Si_6O_{24}$
Muscovite—$H_4K_2Al_6Si_6O_{24}$

Amphibole group (Ca, Mg, Fe, Al silicate).—Hornblende is a common member. 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 sandstones.

Pyroxene group (Ca, Mg, Fe, Al silicate).—Augite is a common member. Vitreous luster; dark green to almost black; good cleavage; hardness same as hornblende; occur as prismatic crystals with square cross section; common in dark colored igneous rocks.

Magnetite (Fe_3O_4).—Metallic luster; black in color; no cleavage; heavy; occurs as eight sided crystals; makes a black streak when rubbed on a rough surface; magnetic.

Hematite (Fe_2O_3).—Earthy appearance, except in crystals, which are metallic; reddish brown color; cementing material in red sandstones; the most abundant ore of iron; often forms irregular or oolitic masses. Name is derived from Greek word meaning blood, because of the red color of the powdered mineral.

Limonite ($Fe_2O_3 \cdot nH_2O$, *hydrous iron oxide*). —Dull, earthy appearance; various shades yellow or brown (common coloring agent in sandstones); occurs as encrustations, cement around concretions, and as irregular masses of "iron stone".

Calcite ($CaCO_3$). —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 ($CaMg(CO_3)_2$).—Very similar to calcite; slightly harder; will effervesce only in warm, dilute hydrochloric acid.

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, plastic when wet, and make up the bulk of the sedimentary rock, shale.
Kaolin—$H_4Al_2Si_2O_9$

Anhydrite and Gypsum ($CaSO_4$ *and* $CaSO_4 \cdot 2H_2O$). —Vitreous to transparent; usually white; can be scratched with fingernail; occurs in crystals, as fibrous veins, and as massive layers.

The primary mineral is anhydrite (calcium sulphate without water), which is usually found only at considerable depth below the surface. Near the surface anhydrite takes up water and is hydrated to form gypsum. Gypsum usually occurs as a massive to finely crystalline, earthy, white form. Particularly well consolidated varieties are called alabaster.

Large crystals of gypsum are called selenite and often are found associated with dumps around coal mines,and on the weathered surface of dark marine shale. These crystals are the result of the oxidation of iron sulphide in the zone of weathering.

Rocks

The consolidated materials of which the crust of the earth is composed are called rocks. Rocks may be composed of crystals of minerals, or they may be composed of fragments of other rocks. Unconsolidated materials such as stream gravels, dune sands, and loose volcanic ash are not classified as rocks, but as material which may eventually become rock.

All rocks are classified into three broad categories for purposes of description and study.

(1) Igneous
(2) Sedimentary
(3) Metamorphic

Igneous Rocks

Igneous rocks are fundamental and primary to the whole scheme of rock formation. Such rocks form by the cooling of molten silicate melts which are generated deep within the earth. The molten material is called *magma* and upon solidification becomes igneous rock (*ignis* Gr. — fire), the type depending upon the chemical composition of the magma. The texture of the rock is largely controlled by the rate of cooling. Rapid cooling forms volcanic glass; slow cooling forms granular igneous rocks such as granite.

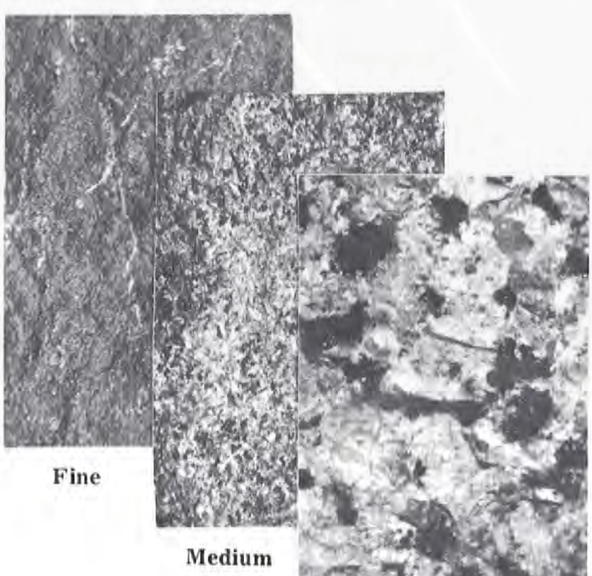

FIG. 31. Photographs illustrating grain size in igneous rocks (true scale).

Sedimentary Rocks

Sedimentary rocks are those that, when seen in nature, exhibit definite layering or bedding. The human eye detects such differences between layers as color, ledges and slopes, and vegetational cover. The basic reasons for the layering, however, are differences in composition (clay vs. sand); differences in sizes of particles (boulders vs. sand grains); or differences in the way the particles making up the rock are arranged. Examples are given below.

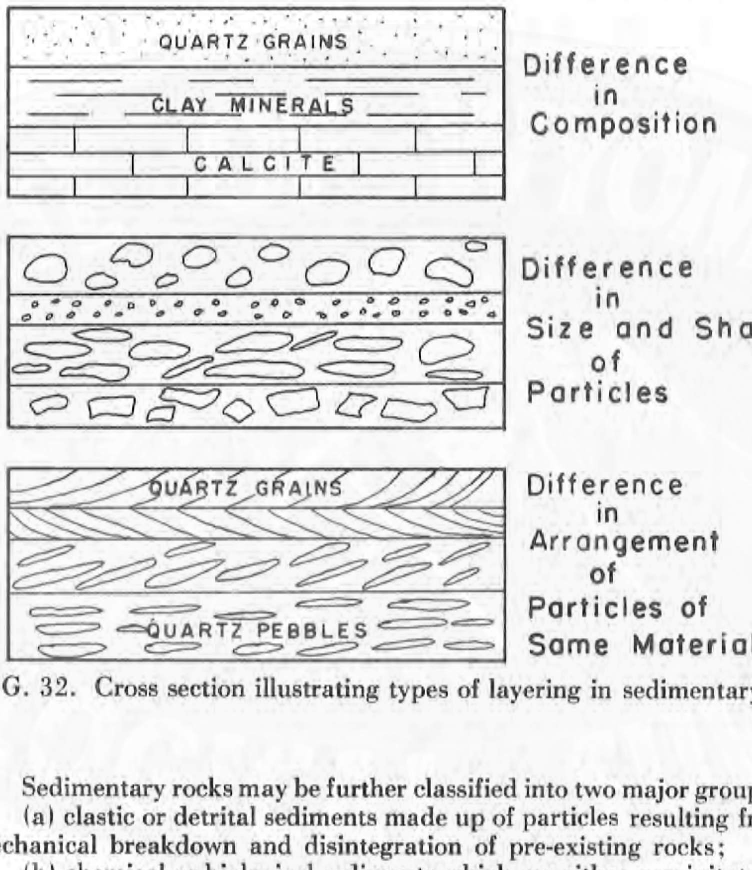

FIG. 32. Cross section illustrating types of layering in sedimentary rocks.

Sedimentary rocks may be further classified into two major groups:

(a) clastic or detrital sediments made up of particles resulting from the mechanical breakdown and disintegration of pre-existing rocks;

(b) chemical or biological sediments which are either precipitated from solution or extracted from aqueous solutions or from the air by living matter. Limestone and coal are examples of such rocks.

One of the distinctive aspects of sedimentary rocks is the fossil content. Fossils are the preserved remains of former living organisms, either plant or animal. The original hard parts or the particularly resistant fibers in the case of plants have been replaced by mineral matter introduced by circulating groundwater. A few fossils have been recovered from frozen ground, in which case the original tissue has been preserved.

Evidence of former life is often in the form of tracks, trails, burrows, fecal pellets, etc. Such evidences of former living organisms are called "trace fossils".

Sedimentary rocks contain many internal structures of inorganic origin that are confused with true fossils, and are called "false fossils" or "pseudo-fossils". The commonest structures of this type are concretions. A typical concretion is a rounded to irregular shaped mass of the rock layer that is more firmly cemented than the surrounding material. The cementing material is commonly calcite or an iron oxide, brown in color. Such concretions are often collected and described as "fossils eggs", but more imaginative individuals see resemblance to many other living things.

Chert concretions are common in carbonate rocks; limestone concretions are abundant in shale; and iron cemented masses are usual in sandstone.

Metamorphic Rocks

Metamorphic rocks are the most complex types, since they may be formed by the chemical reconstitution of any previously existing rocks under conditions of high temperature and pressure. Such conditions develop at times of mountain building in mobile belts, when segments of the crust are deeply downfolded well below the surface of the earth into regions of very high temperature and pressure.

Some common rocks of each class are shown in tabular form below.

Texture or grain size	**Light Colored.** Principal minerals: orthoclase feldspar, some biotite or amphibole.		**Intermediate.** Principal minerals: plagioclase and orthoclase feldspar, amphibole, biotite, pyroxene.		**Dark Colored.** 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 (pryroxene only) Peridotite
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				

Note: (1) If mixed grain or crystal sizes occur, then the rock is called a porphyry—example, andesite porphyry.

Table 1. Simplified Classification of Igneous Rocks.

Grain Size	Chief Mineral	Cement	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)
Dense (not visible)	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
Dense	Silica	Not applicable	Chert
Not applicable	Carbon	Not applicable	Coal

Table 2. Simplified Classification of Sedimentary Rocks.

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, etc.	Gneiss	Granite, rhyolite, shale, etc.
Thinly foliated	Feldspar, mica, amphibole, quartz, etc.	Schist	Andesite, basalt, rhyolite, shale, etc.
Very thinly foliated	Mica, quartz, clay, (these minerals normally can not be seen with the naked eye)	Slate (1)	Shale

(1) Slate is not common as a metamorphic rock in Wyoming; however, some slate crops out in the Medicine Bow Mountains of Albany and Carbon counties.

Table 3. Simplified Classification of Metamorphic Rocks.

The genesis of rocks is a cyclical process which is shown in the diagram below.

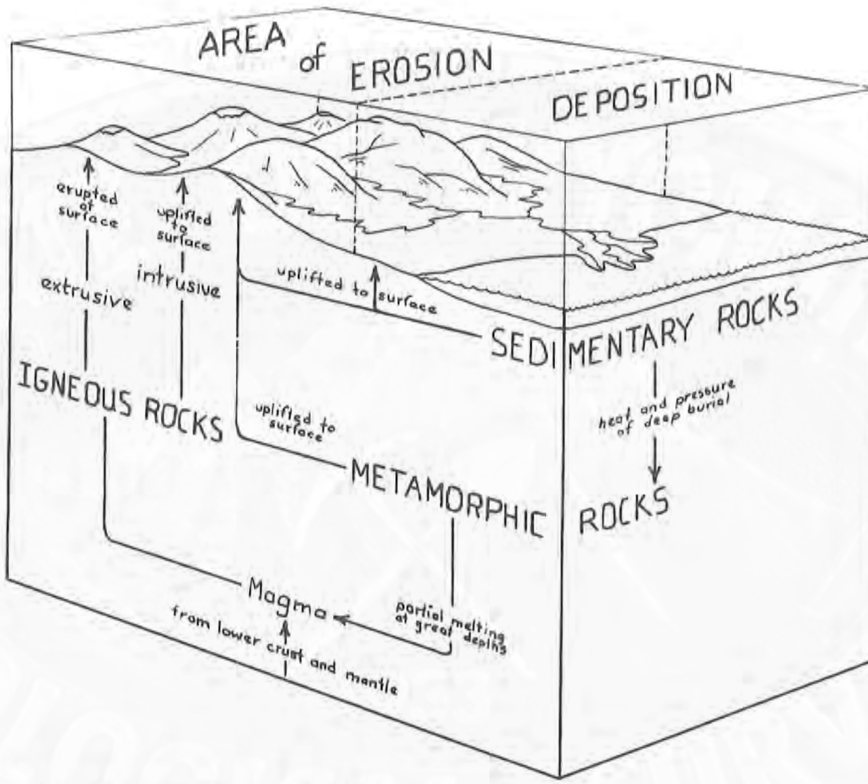

FIG. 33. The cycle of rocks.

The primary material is igneous in origin, and such rocks are most spectacularly shown by volcanic outpourings; less spectacular are the large areas of granite that crop out in the Wyoming mountains as the result of deep erosion of the mountain cores. Any body of igneous rock will be acted upon by all the erosive powers of the atmosphere (oxygen, carbon dioxide, water, ice, temperature change, etc.), and thus are changed both mechanically and chemically. The sum total of such activities is called *weathering* and the result is material that can be transported as stream sediment, and which will in time be deposited and consolidated as sedimentary rock. During times of great crustal mobility, when such mountain ranges as the Appalachians were formed, both igneous and sedimentary rocks were reconstituted into metamorphic rocks. These in turn will be subjected to the weathering process and enter the cycle at a later date.

GEOLOGIC HISTORY

When a visitor first views Wyoming's vast prairies and mountain ranges, his interest normally is attracted to the open space, the sparse vegetation and the accompanying wild life. Little if any thought is given to the geological history or to the vast expanse of geologic time that has passed as this landscape developed into its present form. Though complicated in detail, professional earth scientists have compiled sufficient geological evidence to establish the significant historical relationships. New investigations are continually underway. Besides what one can see on the surface, earth scientists rely on rock samples and records obtained from many thousands of drill holes, some of which are more than 15,000 feet deep. So, like the pieces in a puzzle, the positioning of the geological evidence and the interpretation of the relationships has revealed a substantial basic pattern about Wyoming that is fairly well understood.

Through the radioactive decay rates of certain ancient rocks, it has been established that the planet earth was created more or less in its present form more than 4.5 billion years ago. Here in Wyoming the oldest known rocks are granite and granite gneiss, which occur in the cores of the larger mountain ranges and are at least 2.7 billion years old; but relatively little is known about these most ancient rocks.

The better documented geologic history of Wyoming dates back about 600 million years to a time when sedimentary layers covered the ancient granite. The relationship of sediments overlying crystalline rocks is clearly evident around the margins of the mountains where erosion has exposed the interface between these rock units. The sedimentary layers are distinguishable from each other because they have different color, texture, and mineral composition and because they often contain different assemblages of fossils, or animals that lived during the time of their deposition.

Geologists who attempt to unravel the early history call upon three different but related methods of study: absolute age determinations based on the measurement of the rate of decay of radioactive minerals; physical relationships of layered sedimentary beds and their position relative to each other; and the composition of the rock itself including any fossils that it may contain. By combining the results of all three methods of investigation, it is possible to establish the step by step movement of the earth's crust and understand something of the progress made by living creatures in adapting to the changing conditions on the earth's surface.

Certain well-defined episodes of earth history have been recognized throughout the world. In order that geologists may communicate, they have developed a formal geological calendar with nomenclature that everyone can use. Those who investigate the rocks of Wyoming relate their findings to the standard calendar; thus, they are able to define the major historical episodes and compare them with investigations in adjacent states and elsewhere.

By far the more common practice among all geologists is to relate geological events in terms of their relative occurrence; that is, which event occurred first, second, third, etc. By organizing the sequence of events properly, it is possible to understand which layers were first to form, or the first to be folded or faulted, or the first or last to be eroded.

Major events, particularly those involving periods of strong crustal movement, are the anchor points in the chronology that evolved. An analogy might be made to the informal way that we as individuals regard a year's events and highlights. The average person might say: "It happened right after New Years; we'll leave around Easter; the change will come early in the spring; isn't it nice to see summer begin; the Fourth was a ball; my hayfever is terrible before the first frost; early snow gummed up the football season; and I can hardly wait for Christmas". We all use an informal calendar of major events, but fall back on a rigid absolute calendar to govern interest payments at the bank, or insurance premiums, or pay days.

Absolute age determinations, though desirable from many standpoints, are costly and are only used to establish the precise time at which certain major events started or stopped. It has also become evident that geological events lasted much longer in some places than in others, hence it is impractical with present radiometric techniques to attempt to obtain precise time relationships everywhere. Perhaps some day this can be accomplished.

Table 4 is a geological calendar, or time scale, complete with names depicting the time intervals and their relative position to each other. A few absolute ages, described in millions of years, are shown to indicate the total time expanse of the calendar as well as that of certain important geological events. One should be aware that, while the time scale is complete in terms of the proper time units, there are many episodes in Wyoming history about which nothing is known. Erosion has stripped away the evidence. It has been said that Wyoming is very fortunate in having at least some geological evidence of events that happened during each time period; but it must also be remembered that much is missing. In most instances, geological evidence in adjoining states has helped supply the missing pieces to Wyoming's complex puzzle.

Precambrian Era

The Precambrian history in Wyoming is best known from studies conducted in the Medicine Bow Mountains of southeastern Wyoming. The rocks exposed on the surface there have been carefully mapped and dated by radioactive analytical methods, revealing that two igneous intrusions solidified to rock — the first about 2.7 billion years ago and the second 1.7 billion years ago. In this area, there are also about 25,000 feet of metasedimentary rocks, among which are limestones that contain fossils called *Stromatolites* (a variety of calcareous algae), which are at least 1.7 billion years old, and present some of the oldest known evidence of life on the entire earth. The youngest major event in the Precambrian history of this area was the emplacement of large masses of intruded igneous magma, now solidified as granite. This granite is 1.4 billion years old and is well exposed along the summit of the Laramie Range in the vicinity of Vedauwoo, 12 miles east of Laramie.

Paleozoic Era

The geological record from the end of Precambrian time or the last well dated event of that time, to the beginning of the Cambrian Period, about 510 million years ago, is unknown. No rocks are present in Wyoming which

GEOLOGIC TIME CHART OF WYOMING

MILLIONS OF YEARS BEFORE THE PRESENT

TIME	ERA	PERIOD	EPOCH	EVENTS IN WYOMING
0	CENOZOIC 65 M.Y.	QUATERNARY	HOLOCENE	PRESENT CLIMATE
3			PLEISTOCENE	ICE AGE GLACIERS
12		TERTIARY	PLIOCENE	TETONS FORMED. TERRESTRIAL DEPOSITION.
26			MIOCENE	INTENSE VOLCANIC ACTIVITY IN YELLOWSTONE AREA. TEMPERATE CLIMATE.
38			OLIGOCENE	TERRESTRIAL DEPOSITION OF GREAT AMOUNTS OF VOLCANIC ASH. WARM TEMPERATE CLIMATE.
58			EOCENE	GREEN RIVER LAKE AND TERRESTRIAL DEPOSITION SUBTROPICAL CLIMATE.
			PALEOCENE	TERRESTRIAL DEPOSITS TROPICAL CLIMATE
65	MESOZOIC 160 M.Y.	CRETACEOUS		TRANSGRESSION AND REGRESSION OF SEAS ROCKY MOUNTAINS BEGIN TO RISE. ABUNDANT CEPHALOPODS.
135		JURASSIC		SEAS WITHDREW, BROAD FLOOD PLAINS MANY DINOSAURS
180		TRIASSIC		FLUCTUATION OF SHORE LINE WIDE TIDAL FLATS, MILD CLIMATE
225	PALEOZOIC 375 M.Y.	PERMIAN		SHALLOW SEAS IN WESTERN WYOMING INVERTEBRATES COMMON
270		PENNSYLVANIAN		LOCAL UPLIFT IN SOUTHCENTRAL AND SOUTHERN PART OF STATE
		MISSISSIPPIAN		ENTIRE STATE SUBMERGED IN WARM TROPICAL SEAS
350		DEVONIAN		SEAS IN NORTHWESTERN AND WESTERN WYOMING.
400		SILURIAN		PROBABLY EMERGENT. RECORD INCOMPLETE IN WYOMING.
440		ORDOVICIAN		STATE INUNDATED BY SHALLOW WARM WATERS.
500		CAMBRIAN		SEAS TRANSGRESSED FROM WEST ACROSS ENTIRE STATE.
600	PRECAMBRIAN 4 BILLION YEARS LONG			LONG INTERVAL OF EROSION AT CLOSE OF ERA
				LAND REDUCED TO BROAD PLAINS OF LOW RELIEF.
1000				MOUNTAIN BUILDING.
				ALGAE GROWING IN ANCIENT SEAS.
				WIDESPREAD SEAS.
2000				CONTINENTS IN EXISTENCE
4500	FORMATIVE ERA			FORMATION OF THE EARTH

Table 4. Geologic Time Chart of Wyoming.

record the events for this interval of time, suggesting that a long period of erosion beveled the surface over wide areas and reduced the landscape almost to a plane (peneplane). In other areas such as northern Montana, Idaho and British Columbia, great thicknesses of sediment accumulated during this same time interval.

The widespread erosional surface that bevels the older metamorphic and igneous rocks serves geologists as a reference surface or plane. Because of this, it is possible to study the amount of crustal movement that has gone on since early Cambrian time.

Insofar as Wyoming is concerned, the Cambrian period began with a slow subsidence of the land that allowed the sea to encroach from the west, with sand, gravel, limestone and shale deposited in a transgressive sequence. The subsidence continued on through Ordovician time, and a thick dolomite sequence accumulated over much of the state. What transpired during the Silurian period is doubtful, since only small areas of Silurian rocks are known in the state. Widespread erosion may have again beveled the land surface and destroyed almost all of the Silurian deposits, or Wyoming was above sea level and received no sediments. Limestone deposition was renewed in Devonian seaways over most of the state. The Mississippian is represented by thick sequences of limestone, somewhat thinner in southeastern Wyoming, but providing evidence that the entire area was covered by a warm, shallow sea where marine life flourished.

The first marked change in depositional pattern occurred in the Pennsylvanian period, during which time crustal uplift occurred in many parts of North America. At this time there arose in Colorado a range of mountains, located about on the present site of the Front Range, referred to as the Ancestral Rockies. The axis of this uplift extended into Wyoming and has been designated the Pathfinder Uplift. The uplifted area increased the gradient, and streams stripped away great thicknesses of sedimentary rocks in southeastern Wyoming. Eventually, coarse clastic sediments, gravels and sands, were deposited on the sides of the uplift where they rest today on exposed Precambrian rocks. Throughout the rest of Wyoming, sandstones and thin dolomitic limestones were deposited in areas lying below sea level.

The sedimentary deposits of the Permian period reflect a new regimen of deposition. In Idaho and western Wyoming, there accumulated a remarkable sequence of dark clayey shales and associated phosphatic limestone. Contemporaneously with the deposition of this organically rich marine sediment in the western seaways, near shore, tidal flat type sediments accumulated in central and eastern Wyoming and are seen today as a thick sequence of red siltstones, shales and sandstones. Occasionally, the marine waters spread widely to the east, so that there are now thin marine limestones interbedded with terrestrial "red beds".

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 *lower* Jurassic time, but very little erosion took place. The land surface was apparently low and near sea level. By *upper* Jurassic time, the area was again covered by an advancing sea which is known to geologists as the Sundance sea. The sediments deposited included clay, calcareous mud, and sand, which contain numerous marine fossils that reveal something of the overall environment of deposition. The entire sequence is now called the Sundance Formation, after the town of Sundance, Wyoming, where the rocks were first described.

The sea withdrew near the close of the Jurassic period, and a very widespread series of varicolored clays, sands and silts were deposited upon the land. During this period in Wyoming, reptiles thrived in abundance. The Jurassic has become known as the Age of Dinosaurs, although dinosaurs were only one of the groups of reptiles that flourished during this period of time.

The Cretaceous is represented by a very thick sequence of marine shales and sandstones, interfingered with wedges of coal-bearing rocks deposited either in swamps or in brackish water lagoons near the shore. The ancient shore line of the Cretaceous sea was oriented in a general north-south direction, but it shifted widely east and west, depending on the amount of uplift and deposition. The low relief and the shifting of the strand line allowed swamps to form, only to be flooded and covered by marine sediments, and then later to have the process reversed.

The long history of subsidence and more or less continuous deposition came to a close in Late Cretaceous time.

Near the close of the Mesozoic Era, mountain-making crustal movements began (Late Jurassic) in Utah and Idaho and progressively moved eastward, so that by Late Cretaceous time western Wyoming was elevated above sea level.

Cenozoic Era

During the Paleocene period, the magnitude of the crustal disturbances increased and created widespread uplift and deformation of the entire region. Evidence for this disturbance is reflected in thick sequences of conglomerate, sandstones, shale and coal-bearing rocks that were deposited and preserved in the basins between the rising mountains. In central Wyoming, in the area now known as the Wind River basin, a large lake, probably of brackish water, remained as a last remnant of the formerly widespread seaways.

The Cenozoic period of mountain building is known among geologists as the Laramide orogeny, and was concluded by Late Eocene. Orogeny derives from the Greek *oros*, a mountain, and *gens* referring to genesis. The term Laramide is derived in a rather roundabout way from Old Fort Laramie, an early trading and military post on the North Platte River in southeastern Wyoming. At the culmination of the Laramide orogeny, most of Wyoming's major structural features (mountains and basins) as we see them today had been fully developed.

The aftermath of any major mountain building episode in earth history is an increase in the gradient of all streams; major climatic change; and change in the biological aspect of the area. Certainly such changes occurred here, and the material that was removed from the highlands was in part immediately deposited in the adjacent basins which continued to subside.

Major changes that occurred in the drainage patterns created numerous lakes, particularly in the Green River Basin. The same situation prevailed in the areas south of the Uinta Mountains in Utah and Colorado. These large lakes fluctuated in depth, in extent, in salinity, and probably in temperature. The sediments deposited in the lakes are preserved as the famous Green River Formation and provide an amazing record of the geologic history of the region. The fossil fauna and flora provide a means of reconstructing the climate in Eocene time, and the conclusion is that it was warm, moist and subtropical. However, prolonged evaporation at times reduced the lakes to very low levels, and the waters became saline, allowing sodium rich carbonate minerals such as trona to be deposited.

A completely different type of earth history began in Oligocene time, namely violent volcanic activity. The principal volcanoes apparently were located in northwest Wyoming in the vicinity of what is now Yellowstone Park and the present Absaroka Plateau. Volcanic ejecta, largely fine grained material, poured forth in tremendous volume, covering many thousands of square miles of the surrounding area. Some was carried in the air as ash and dust for great distances, and all of the streams were choked with the debris which they spread out as extensive flood plains. Near the vents, the material was much coarser and was interbedded with lava flows. Gradually, the volcanic debris spread over not only Wyoming, but in an arc extending into Montana, the Dakotas, Nebraska and Colorado, filling the basins and drowning the earlier topography in the accumulating volcanic debris. The deposition continued in varied form through Miocene time and into at least Middle Pliocene time, at which point only the highest mountain tops are believed to have been standing above the rather featureless alluvial plain.

At this point in time, the region was probably not far above sea level, and a few major, rather sluggish streams drained the area, with a large part of the streams flowing to the Gulf of Mexico. In Late Pliocene time, the entire interior of the continent was elevated to about its present position above sea level. The elevation was not uniform, and, therefore, some faulting and folding took place during the uplift.

This uplift, together with the climatic accident of the Pleistocene Ice Age and the cessation of volcanic activity, completely changed the cycle. From a time of continued aggradation, which created a smooth, near-level landscape, Wyoming passed into a time of extreme erosion. In a period of only about three million years, the Tertiary cover was stripped off and the older topography exhumed, and new land forms were cut in the older rocks. The Late Tertiary rocks that are present today in Wyoming are only remnants of a once almost complete cover. The process of removal is still going on.

Figures 23, 24, 25, and 26 present diagrammatically the history of the Tertiary period 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, the landscape changes, and thus will it ever be.

ECONOMIC GEOLOGY

Modern society has come to expect a standard of living which is based on a host of naturally occurring minerals and their derived products. The finding and developing of mineral deposits is an activity that is very important to the economic stability of Wyoming. The state's major sources of income derive from industries dealing with the varied aspects of mineral production.

The principal raw materials that are found and produced in Wyoming and their geological occurrence will be described briefly.

Materials Found in the Older Rocks in the Cores of Mountain Ranges

Iron Ores

High grade iron ores containing over 50 per cent of iron are usually composed of the mineral hematite. Lower grade iron ores are usually lumped together under the term taconite meaning a rock that is relatively high in silica and containing iron in the range of 30 per cent to 40 per cent. Taconite ores are beneficiated and then pelletized before going to the blast furnace. There are two active iron producing properties in Wyoming — Atlantic City and Sunrise.

Copper

Copper ores in the form of copper-iron sulphides occur as vein type deposits in older rocks and are usually associated with some type of igneous intrusive. A few small copper mines operated in Wyoming early in the century to recover such ores. One of the most publicized was the Ferris-Haggerty mine in the Sierra Madre, which led to the founding of the town of Encampment.

Gold

Gold is a metal which has wondrous attraction because it is literally money in hand when found. Almost all the myths and fables of lost mines revolve around gold. Gold has been produced from vein type deposits in Precambrian rocks at a number of Wyoming localities, including South Pass City, Centennial, the Ferris Mountains, etc., but no mines are active today.

Pegmatites

One phase of igneous activity produces pod like masses called pegmatites, consisting of quartz, feldspar, and books of mica. In addition to the common minerals listed above, many rare or unusual minerals are associated with such bodies, and they are the hunting ground of many amateur mineralogists. The bodies may be a few hundred feet long and tens of feet wide. Among the rare minerals found are beryl, spodumene, tourmaline, and minerals of the rare earths, such as yttrium and columbium.

Marble

Marble is a highly crystalline variety of rock composed of calcite, developed by the recrystallization of limestone in the process of metamorphism. High grade marble is used as an ornamental stone, and in the new, precast, decorative panels.

Materials Found in Basins as Sedimentary Rocks

Coal

The readily recoverable coal reserves of Wyoming are rated at 23 billion tons. All the coals occur in rocks of Cretaceous or Tertiary age, and such rocks are found in all Wyoming basins. Coal represents the remains of plants which grew during times of temperate to subtropical conditions, probably in swamps in which the humic acid content of the waters was high enough to inhibit or prevent bacterial decay of the accumulating organic matter. Burial of the organic material, which initially is high in water, hydrogen and oxygen, reduces the water content and the hydrogen content with increase in fixed carbon, thereby raising the rank of the coal. The majority of Wyoming coals are ranked as sub-bituminous and have an average BTU value of 12,000 per lb. Most coal production in Wyoming is from strip operations and very little from underground mines. Some coal is converted to electrical power on site, but a considerable amount of coal is transported by rail to markets in the Missouri valley.

Bentonite

Bentonite is a rock composed primarily of one clay mineral — montmorillonite. This particular clay mineral has the property of absorbing water in the ratio of two to the original volume, and when wet is very plastic. The original source material of the bentonite was volcanic ash deposited as relatively thin layers in the sea water and subsequently chemically altered by sea water into clay minerals. The bentonite is used in pelletizing taconite ores, in molds in foundries, in drilling muds, and as ditch lining.

Gypsum

The "red beds" of Wyoming contain layers or beds of the mineral gypsum, which is a hydrated calcium sulphate occurring in a massive form. ($CaSO_4 \cdot 2H_2O$). Particularly massive, fine-grained examples are called alabaster. The common form of calcium sulphate encountered in deep bore holes is anhydrite, ($CaSO_4$) calcium sulphate without water. Near the surface, the process of weathering converts the anhydrite to gypsum by the addition of water. Gypsum in pure form is usually white, and rather sugary in appearance, but may occur as single crystals several inches in length in which form it is referred to as selenite. Gypsum is processed by heating in a kiln to drive off the water, and then used for plaster, or in the manufacture of wall board.

Phosphate Rock

The Phosphoria Formation of Permian age, occurring over wide areas in western Wyoming, contains phosphatic limestones associated with dark organic shales. The phosphatic limestone may contain as much as 28 per cent of P_2O_5 (phosphorous pentoxide) and is a potential source of fertilizer. Only one property is producing phosphate rock at the present time in Wyoming, and the material is processed in Idaho. The dark organic shales contain appreciable percentages of vanadium (1 per cent), none of which is being recovered at the present time.

Oil Shale

The term oil shale describes any fine grained shale or marlstone containing significant amounts of hydrocarbons which can be recovered by distillation. In Wyoming such rocks occur in the Green River Formation of southwestern Wyoming. The potential oil reserve within these rocks is large, but as yet technology has not developed satisfactory methods of recovery.

Trona

Trona is a water soluble mineral with the chemical formula $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$. (Sodium sesqui-carbonate). Trona is mined at four sites in the area west of Green River from a depth of about 1,200 feet. The trona now being mined occurs in a bed about 14 feet thick, but numerous other layers are known in the same area. The trona is processed by heating in a kiln to remove the water, and then treated to remove clay and other impurities. The finished product is known as soda ash and is widely used in industry.

Limestone

Limestone is a rock composed in pure form of the mineral calcite ($CaCO_3$). Limestones vary widely in purity as magnesium may be substituted for calcium and form a double carbonate, $Ca \cdot Mg\,(CO_3)_2$. Limestone that is used for the production of lime (CaO) must contain at least 95 per cent of $CaCO_3$. The principal use for limestone quarried in Wyoming is for the production of CaO and CO_2 used in the refining of beet sugar.

Shale

Shale is a rock composed largely of clay minerals but also contains significant amounts of very fine quartz grains. Calcium carbonate and iron sulphides are commonly associated. The principal use of shale is for the manufacture of cement, and only certain shales containing high percentages of calcium carbonate satisfactorily meet the requirements from a chemical standpoint. The basic material in this region is a calcareous shale found in the Cretaceous Niobrara Formation. The shale is sintered in a kiln and then ground to the proper size. Additions of limestone may be necessary to obtain the proper CaO content. Fuel for the kilns may be natural gas or coal, depending upon the local situation.

Uranium Ores

The uranium ores of Wyoming constitute the second largest reserves in the United States. The typical ores occur disseminated (less than .5 per cent U_3O_8) in sandstones and conglomerates. The bulk of the ores are associated with rocks of Lower Eocene age in the Wind River, Shirley and Powder River Basins. The ores are recovered by strip mining from depths of about 200 to 400 feet.

Titaniferous Sands

The element titanium occurs in the minerals ilmenite and titaniferous magnetite, which have relatively high specific gravities. Deposits of "black sands" containing these minerals are found as fossil beach placers in the Cretaceous rocks of Wyoming. Presently, such placer deposits are forming along the beaches of the Carolinas because of wave action and currents moving parallel to the shore. In Cretaceous time, analogous situations and beaches existed along the sea coasts that extended more or less north-south through Wyoming.

Fluids Occurring in Layered Rocks in Basins

Water

Sedimentary rocks, particularly sandstones, have voids or pore space between the grains, and this pore space may amount to over 20 per cent of the rock by volume. If the voids are interconnected so that fluids can pass through the rock, the rock is said to have permeability. In the Wyoming basins, many of the major sandstones are water saturated. When one of these formations is tapped by a bore hole, water enters the bore hole and, under the optimum condition, may flow to the surface as a flowing artesian well. The requisite conditions for a flowing well are shown in Figure 34.

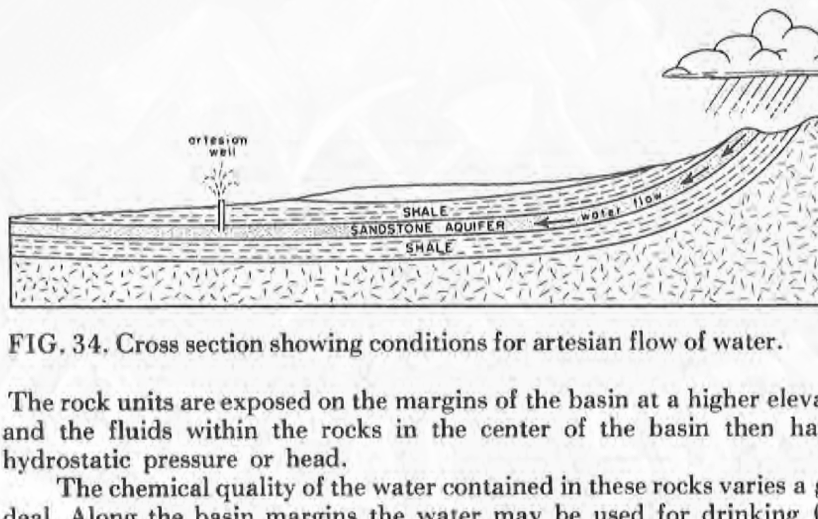

FIG. 34. Cross section showing conditions for artesian flow of water.

The rock units are exposed on the margins of the basin at a higher elevation, and the fluids within the rocks in the center of the basin then have a hydrostatic pressure or head.

The chemical quality of the water contained in these rocks varies a great deal. Along the basin margins the water may be used for drinking (U.S. Public Health Service standards consider 1,000 parts per million dissolved solids the limit). Deep in the basin, the same rock units may contain water that has as much as 60,000 parts per million of dissolved solids.

Petroleum and Natural Gas

Petroleum and natural gas are hydrocarbons occurring as fluids associated with the water contained in the rocks. The hydrocarbons are derived from the organic content of certain fine grained rocks, such as shale, and have migrated into porous reservoir rocks, such as sandstone or porous limestones or dolomites. The reservoir rock contains water, but the primary oil globule is less dense than water and thus rises up dip through the water saturated rock until it is trapped by some barrier to its upward progress.

The classic trap is the top of an anticlinal fold, as figured below, and many Wyoming oil fields are of this type. Others, called stratigraphic traps, are dependent on lateral variation in the permeability of the rocks, as shown.

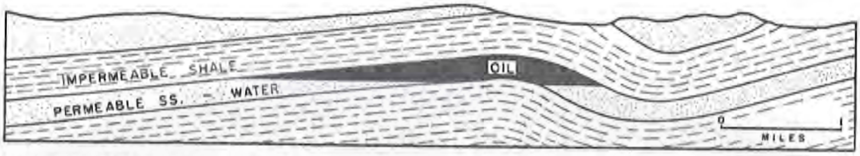

FIG. 35. Cross section of an anticlinal trap for hydrocarbons.

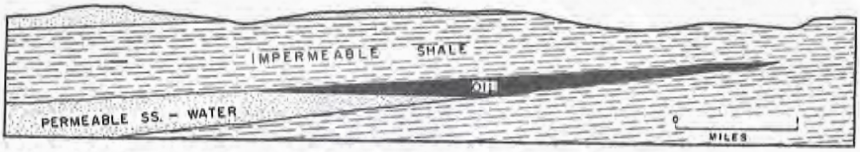

FIG. 36. Cross section of a stratigraphic trap for hydrocarbons.

Special Mineral Deposits

Placer Gold

One type of gold occurrence kept prospectors happy for a century. The single 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. Gold derived from veins in the metamorphic and igneous rocks is released by the weathering of the rocks, and the heavier particles — free gold — are concentrated in favorable places in stream channels. Such deposits are called placers and in times past were worked at many areas in Wyoming. Currently, there are no active placer operations.

Jade

Wyoming jade has received much publicity and is a very pleasing semiprecious gem material. The original occurrences of jade are in vein and pod like masses in the metamorphic rocks and are 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 have been transported considerable distances from the source areas by streams and deposited in conglomerates.

MAPS

Cartography or the art of map making has been practiced since there have been men. 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 expressed by geographers, resulted in the presentation of the spherical globe on a flat piece of paper suitable for use as a navigation chart, or to show national boundaries. The problem of curvature is much less bothersome and can almost be neglected if only a small part of the earth is presented on a map.

All manner of information has been depicted by means of maps. Some examples include the distribution of land and water and hence the coast line; climatic zones; population distribution; daily weather; location of highways; and city streets.

The variety of maps is almost infinite in number, but for geologic purposes perhaps only three categories of maps need be considered.

Planimetric Maps

A planimetric map is one on which a plan view of the objects is presented, such as a map of city streets. The traveler has at hand a variety of such maps called "road maps" or "highway maps", upon which are usually shown road locations, distances between towns, rivers, major points of interest, insets with city street plans, etc. The Wyoming State Highway Commission distributes such a map of Wyoming without charge. The value of the map is enhanced by showing the major land forms by shading.

Topographic Maps

A topographic map depicts the physical features of an area by appropriate symbols. The word topographic means a graph of a place (*topos*-place, plus *graphos*-to write). Presently, the U.S. Geological Survey — Topographic Division — prepares maps for much of the country on a scale of 1:24,000. The individual sheets are known as topographic quadrangle maps and cover 7½ minutes of latitude and longitude (approximately 60 square miles). The configuration of the land surface is depicted by brown lines which represent points of equal elevation on the ground surface. Roads, trails, rivers, lakes, cultural feature, boundaries of political subdivisions, etc., are accurately located on such maps by appropriate colors.

Geologic Maps

Geologic maps show by means of colors and symbols the areal distribution of different kinds and ages of rocks. The best geologic maps use a topographic map for a base so that the relative elevation of the rock units can be seen.

Examples of the three types of maps for the same area, and all at the same scale, are presented below, followed by a discussion of how geologic maps are prepared and how they are used.

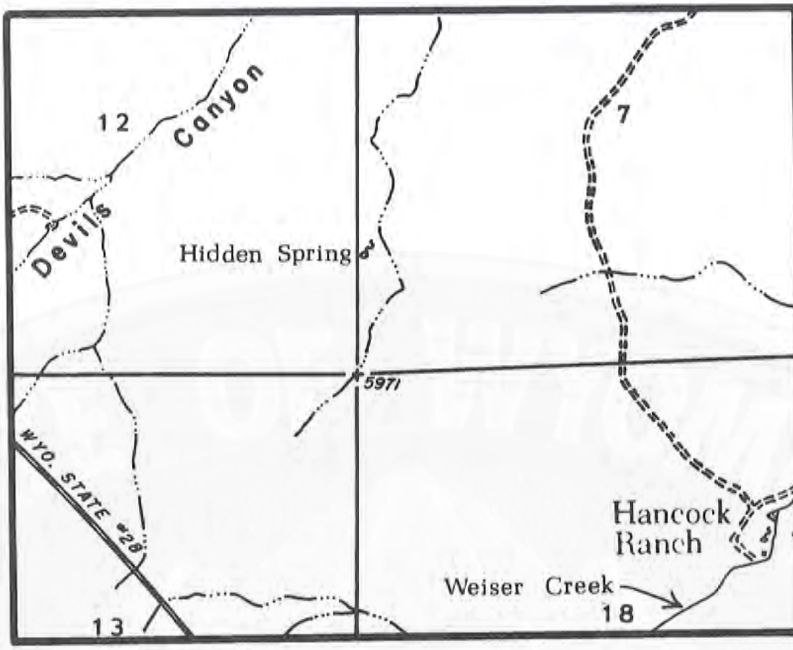

FIG. 37. Planimetric map.

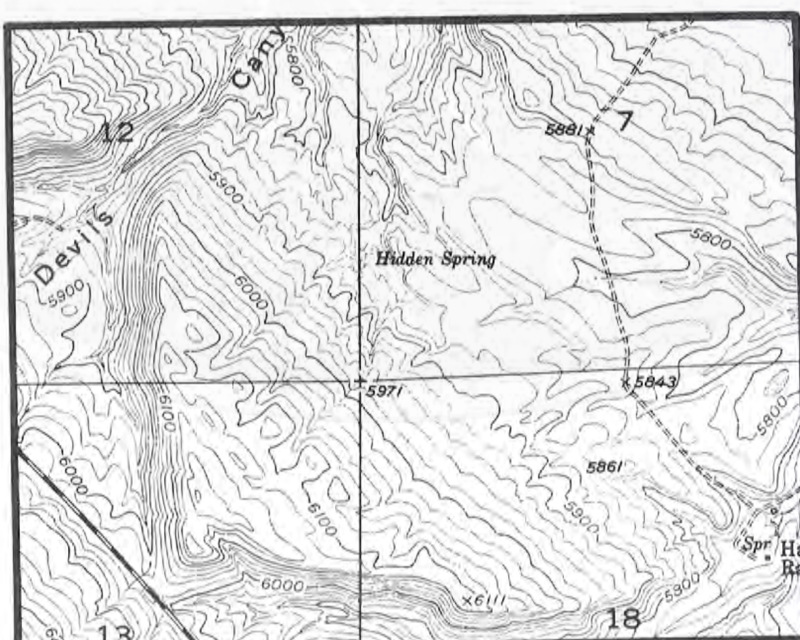

FIG. 38. Topographic map.

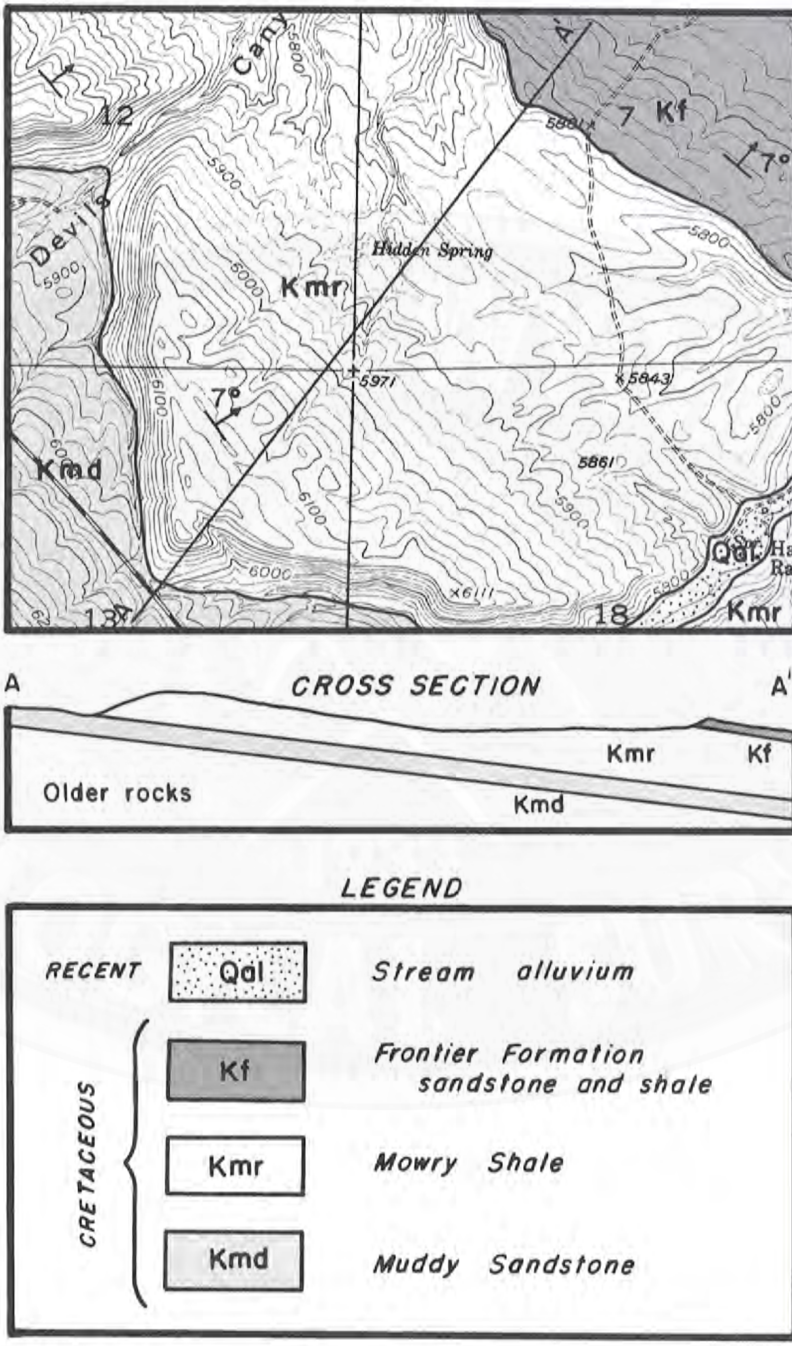

FIG. 39. Geologic map and cross section.

Geologic Maps and How to Use Them

Geologists prepare maps to convey information concerning a wide variety of geologic subjects. To properly appreciate the basic geologic map, it is necessary to understand the process of preparing such a map. Any map may be defined as follows:

> 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 locations.

From this it can be seen that the simplest map would be a picture of the earth's surface taken from an aircraft above the ground, with the camera lens directed vertically downward. On such a base map, the geology could also be shown. A modern topographic map of the U.S. Geological Survey 7½ minute quadrange series at a scale of 1:24,000 and a contour interval of twenty feet also provides an excellent base on which to map the geology.*

The usual geologic map depicts the areal distribution of rock bodies; rocks of comparable character and equivalent geologic age are mapped as a unit called a *formation,*** defined as follows:

> A formation is 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 one kind of rock.

In dealing with formations, it has become customary to give them formal names which are derived from a geographic feature (stream, mountain, etc.) in the area 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 rock type that can be seen in the exposed rocks in the field. An example is given below in cross section.

The boundaries established between the units are then traced or "walked out" on the ground, and the positions "mapped" or located upon an appropriate base map. Such lines are referred to as the *contacts* between formations, or between different rock types in the case of igneous rocks.

A properly prepared geologic map will include a legend upon which are shown the types of rocks present, and the geologic age of the map units. In some cases, the average thickness of sedimentary units and a brief lithologic description are included.

*Map scale is the ratio of the size of an object on the ground and the size as it is shown on the map. A scale of 1:24,000 means that one inch on the map represents 24,000 inches or 2,000 feet on the ground.

**Laymen commonly speak of "rock formation," when they really mean any unusual exposure or rock, or some natural occurring feature such as a concretion, or stalagmite, or just an unusual mass of rock with some peculiar marking, or shape.

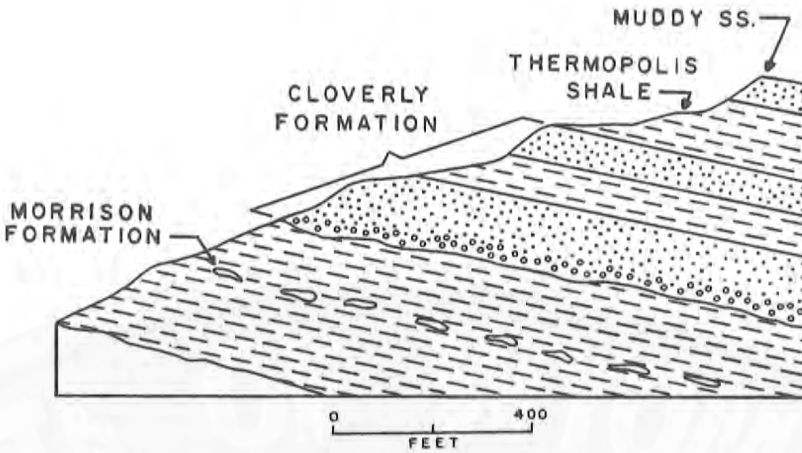

FIG. 40. Cross section illustrating boundaries between mappable sedimentary formations.

On the map will be portrayed the area on the ground occupied by each map unit, and the attitude of the layered rocks will be 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.

Most geologic map sheets will have a cross section that will provide an interpretation of the distribution and extent of the rock units in the subsurface.

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 SKETCHES OF SELECTED AREAS IN WYOMING

Wind River Canyon

The Wind River Canyon is located on U.S. Highway 20 between Shoshoni and Thermopolis. The Wind River flows northward out of the Wind River Basin, and is impounded by an earth fill structure to create Boysen Reservoir immediately south of the canyon. The canyon of the Wind River is about 10 miles long, beginning at the village of Boysen, and extending to a point about four miles south of Thermopolis called the Wedding of the Waters, at which spot the Wind River changes name and becomes the Bighorn River.

As one approaches the canyon from the south, he travels over relatively flat-lying variegated rock units of the Eocene Wind River Formation. About one mile south of Boysen Dam, one enters an area of severely faulted Paleozoic rocks which reflect, in a rough way, a faulted arch; and then, at Boysen, the narrow canyon proper begins, with walls rising 2,500 feet above the river. At the first tunnel, the road crosses the Boysen normal fault, with Precambrian crystalline rocks on the north and upthrown side in fault contact with northward dipping Cambrian shales. Displacement on this fault is about 1,500 feet, and the fault plane inclines to the south at about 65 degrees.

FIG. 41. View north across Boysen dam to mouth of Wind River Canyon. Dark band in center is metamorphic rock of Precambrian age north of Boysen fault. Photograph by P. T. Jenkins.

Approximately 1.6 miles north of the fault, the unconformable contact of the Precambrian crystalline rocks and the overlying sediments of Cambrian age, representing a time interval of 2 billion years, is exposed at road level. From this point northward, the sediments dip about 10 degrees toward the north, and a complete section of Paleozoic formations may be observed. When the road emerges from the canyon at the north end, the observer sees extensive areas of Triassic red beds. The cross section below illustrates the fact that the geologic structure is a faulted, asymmetric anticline.

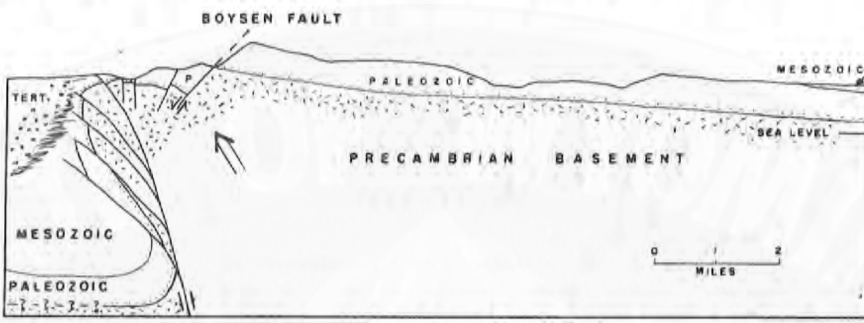

FIG. 42. Cross section through the Owl Creek Mountains. Modified from D. U. Wise, 1963.

The Gangplank

The geologic situation which is colloquially known as "The Gangplank" is located about 16 miles west of Cheyenne on U.S. Interstate Highway 80, in T. 13 N., R. 69 W. The name describes the fortunate circumstance wherein a narrow remnant of the flat-lying sedimentary rocks of Late Tertiary age are preserved along the east front of the Laramie Mountains. The Tertiary rocks are a part of the Arikaree Formation, which extends eastward to the Nebraska border. Coincident with the upper surface of the Arikaree Formation, which unconformably overlaps the steeply dipping rocks flanking the Laramie Mountains, is an erosional surface of low relief bevelled across the older Precambrian crystalline rocks of the core of the mountains. (See Fig. 43)

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 automobile road took the same route. A turnout from the westbound traffic lane one and one-half miles east of Granite Canyon provides an excellent opportunity to view the geology.

Hell's Half Acre

Any forsaken, empty, and desolate piece of ground may find this name attached to it, whether it deserves it or not. The locality of this name on U.S. Highways 20 and 26 six miles west of Powder River Station appears to have

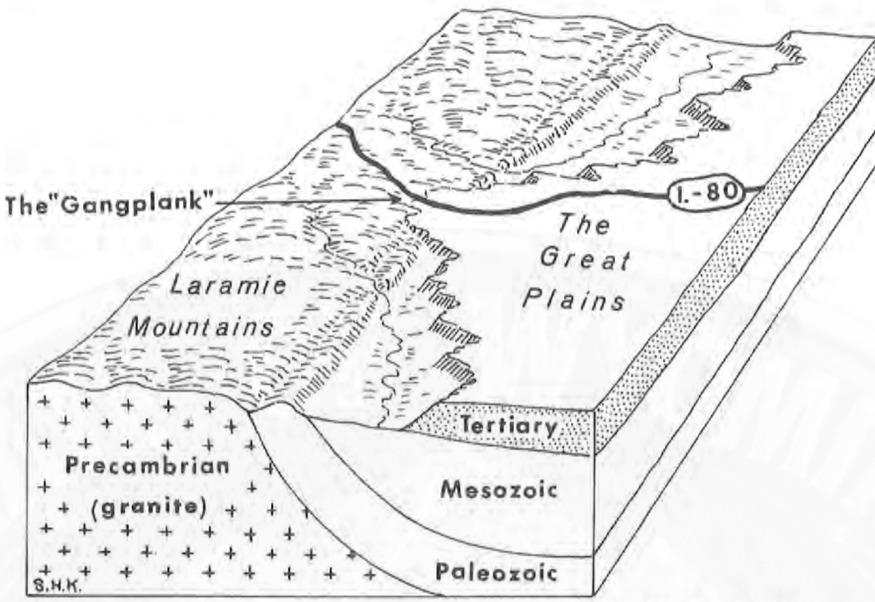

FIG. 43. Block diagram of The Gangplank. Courtesy of S. H. Knight.

been so dubbed because of the very rough badland topography and areas of red and brown coloration. Popular versions of the origin seem foreordained to include some type of subterranean eruption in the explanation, even though the nearest igneous activity is in the Rattlesnake Hills 25 miles to the south.

In actuality, the geology of Hell's Half Acre is very complex and has had a much more involved history than simple subterranean eruption. As one stands at the visitor's vantage point and looks in a southerly direction, the view is along the strike of a series of sedimentary strata of Cretaceous and Tertiary age dipping very steeply to the west, away from the Casper Arch and into the Wind River Basin. The steep dips reflect the fact that the Wind River Basin is over 20,000 feet deep just a short distance to the west of the vantage point.

The strata you are viewing consist of the older Cretaceous Lance Formation to the east overlain by the Paleocene Fort Union Formation. These two units have very steep west dip. Overlying these formations with marked angular unconformity are the light colored pink, red, and yellow vari-colored strata of the Eocene Wind River Formation.

The geologic evidence indicates that the Lance and Fort Union Formations were originally deposited in a near horizontal attitude, were elevated and tilted to the west, and then were beveled by erosion. Upon the beveled edges of these two formations, the Wind River Formation was deposited by streams flowing away from the uplands around the basin. The Wind River Basin continued to subside, tilting the Wind River Formation so that it now dips about twenty degrees to the west. The westward tilting also affected the underlying rocks and increased the dip of those units.

FIG. 44. View south illustrating angular unconformity between Paleocene Ft. Union Formation (left) and overlying Eocene Wind River Formation. Photograph by W. R. Keefer.

The present topography is the result of active erosion, creating the badland type topography within the drainage basin of the South Fork of the Powder River and near its headwaters.

Como Bluff

Como Bluff is located about six miles east of the town of Medicine Bow in T. 22 N., R. 77 W., north of U.S. Highway 30-287 and the Union Pacific Railroad. The original grade of the Union Pacific Railroad crosses U.S. Highway 30-287 at a point about four and one-half miles northwest of the present railroad siding of Lookout. The original road bed followed down the valley of Meisser Creek to the northeast, and then continued down the valley of Rock Creek along the north side of Como Ridge. The small alkali lake now known as Aurora Lake was originally called Como Lake, apparently in a derisive comparison to the lake of that name in Italy. The railroad siding and way station at the west end of the lake received the same name. The original roadbed rejoins the present railroad trackage near Medicine Bow, but the name Como has been transferred to a siding and small pond about eight miles west of that community.

The Como Bluff locality is of great interest historically and scientifically because in the year 1877 a major discovery of fossilized remains of giant sauropods was made there. Fossil material was excavated from a series of quarries intermittently until 1903. At present, no fossil bone can be found on the surface, but many of the fine mounted specimens of dinosaurs in major museums of the world came from Como Bluff.

The original quarries from which the material was recovered were situated along the prominent northwest facing bluff which lies on the north side of Como Ridge. The geologic structure is an asymmetric anticline (See Fig 45 below) which trends N. 70 degrees E. Along U.S. Highway 30-287, one sees the southeast side of the fold expressed in a series of hogbacks and valleys eroded in the Cretaceous Cloverly Formation, Thermopolis Shale, Mowry Shale, and Frontier Formation. At a point about five miles east of Medicine Bow, the highway crosses over the plunging nose of the anticline, and the nearly vertical rocks of the northwest flank of the fold, particularly the Mowry Shale and Frontier Formation, may be seen.

The best view of Como Bluff is obtained when one is east bound from Medicine Bow and looks to the east and northeast. The Bluff stands some 500 feet above the valley of Rock Creek, and the pastel colors of the Morrison Formation are quite obvious. The top of the bluff is upheld by hard, resistant, brown sandstones of the Cloverly Formation.

The sauropod remains were recovered from the Jurassic Morrison Formation, which is composed largely of claystones of red, green, purple, and buff color. These claystones were deposited on a flood plain which was marginal to a withdrawing sea in Late Jurassic time. The environment was probably subtropical, with abundant vegetation and numerous standing bodies of water. Very few localities have yielded the amount and variety of sauropod remains that have been recovered here.

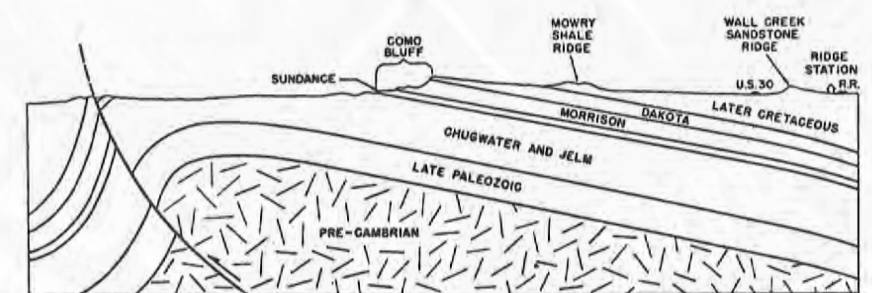

FIG. 45. Cross section at Como Bluff. From R. O. Dunbar, 1944.

Green River Basin—LaBarge Area

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 — Gosiute Lake. The history of this lake is revealed in a remarkable sequence of sediments which represent lacustrine, paludal, and alluvial environments of deposition. The extent of the lake varied from time to time, and the depth of water likewise fluctuated a great deal. As a result of the changes of water level and the lateral shift of the shore line, various types of sediment overlap each other.

Opposite the town of LaBarge in the bluffs on the east side of the Green River can be seen a flat-lying series of rocks belonging to the Eocene Wasatch and Green River Formations. 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 colored strata are the continental Wasatch Formation, and the thinly banded white layers are a part of the Green River lake beds. As one drives north along the Green River, lateral changes will be noted in the coloration and nature of the sediments, and, in general, the farther north one goes the more continental in type are the rocks.

FIG. 46. Picture bluffs opposite LaBarge toursite. Photograph by S. S. Oriel.

Bates Hole

The drive from Medicine Bow northwest to Alcova Junction by way of the Medicine Bow Cutoff on Wyoming State Highway 487 provides excellent exposures of folded sedimentary rocks, etched out in strong relief.

At a point about six miles north of Medicine Bow, the highway crosses a drainage divide located upon the crest of Flattop anticline. At the road pullout, one is standing on cross-bedded, light buff colored sandstone of the Pennsylvanian Tensleep Sandstone, one of the major oil producing reservoir rocks of Wyoming. Looking south and eastward, the south flank of the anticline is well displayed in a series of "red beds".

Proceeding northward, the road crosses an extensive surface of low relief that is in the nature of a pediment. Ahead across the flat, the Freezeout Mountains anticline rises on the skyline. The prominent outer rim or hogback is developed upon the Cretaceous Cloverly Formation, which dips outward in all directions from the central area. The highway follows the strike of the strata and swings to the west along the north flank of the anticline.

The road climbs up from Muddy Creek onto the rolling upland surface, across which one continues for some five miles to the Shirley Rim. Before descending the long grade to the floor of Bates Hole, one should drive off to the west of the highway and enjoy the vista. From any of several vantage points along the Shirley Rim, one may look down to the north to the valley of Stinking Water Creek, a northward flowing tributary of the North Platte River.

The high white rim to the left (west) is capped by strata of the Miocene Arikaree Formation overlying the light colored Oligocene White River Formation. The promontory called Chalk Mountain stands at the southeast corner of the mesa. Below the chalky beds are yellow, red and green claystones and sandstones of the Eocene Wind River Formation, which in turn unconformably overlie the dark gray marine Cretaceous Steele Shale. The sage and greasewood covered floor of Bates Hole is underlain by the gray, somber shales.

Across Bates Hole to the east are pinnacled cliffs, most of which are cut in the White River Formation. Beyond the pinnacled rims in the blue distance are the peaks of the Laramie Mountains.

The observer stands on the Wind River Formation as he looks north into the basin. The basal contact of this unit is well exposed in the road cuts where the highway descends from the rim. The sandstone and conglomeratic sandstones of the Wind River Formation are the host rock for the disseminated ores of uranium which are mined in large scale stripping operations a few miles east of the point where you are standing.

Sherman Mountains

U.S. Interstate Highway 80 west of Cheyenne traverses across flat-lying Tertiary strata to a point near Granite Canyon. From this point westward to the Lincoln Monument, the highway is located upon crystalline metamorphic rocks of Precambrian age. The surface across which the road traverses is one of low rolling relief with 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 in age named the Sherman Granite, which corresponds very closely in composition and origin with the Pikes Peak Granite in Colorado. This granite was intruded into a series of gneisses, schists, and amphibolites that are about 1.7 billion years old.

A few miles farther west, one may leave U.S. Interstate 80 at the Vedauwoo exit and drive into the National Forest picnic areas to see the Sherman Mountains close up. Among the striking aspects of the geology are the large sub-rounded balanced rocks seen on the skyline, some of which are as large as a house. Such blocks were originally bounded by fracture planes 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 sub-rounded to rounded forms developing in place.

The Sherman Mountains are a remnant of the crestal part of the Laramie Mountains that was not eroded to a surface of low relief during the Late Tertiary time.

North Fork of the Shoshone River

The eastgate route into Yellowstone National Park from Cody by way of U.S. Highways 14 and 20 provides an opportunity to see the volcanic rocks of the Absaroka Range at close hand. At the observation point at Buffalo Bill Dam, one sees the steep west face of Rattlesnake Mountain with nearly vertical rocks of Paleozoic age. To the west up the valley lie the Absaroka Mountains. At a point about five miles west of Wapiti P.O., volcanic rocks crop out near the roadside.

The Absaroka Range is made up of layers of a variety of rocks, all having a volcanic derivation. Some are simple lava flows of basaltic composition that exhibit flow structure and occasional columnar jointing. Most

FIG. 47. Chimney Rock on Carter Mountain west of Meeteetse, showing layered volcanic rocks. Photograph by W. H. Wilson.

of the material, however, can be described as volcanic breccias or conglomerates. The old term "puddingstone" comes close to describing the fabric of the rock. In the canyon walls along the highway, one sees rock masses with large to small blocks of dark, dense volcanic rock embedded in a lighter colored, finer grained matrix. The mixing of the materials of various sizes is the result of the breaking up of the flow rocks by volcanic eruption and the subsequent incorporation of the fragments in the stream beds which were choked with fine grained ash from the same eruptions. The streams flowing outward from the volcanic cones were able to spread the mixture over wide areas, resulting in a layered sedimentary deposit composed of volcanically derived materials.

Much of the breccia is weathered and eroded into bizarre forms, some of which are called "hoodoos". The spire shaped forms develop because a large fragment of rock acts as a hat or cap protecting the softer material beneath. The topography in the Absarokas is rugged, with many bare, rubble strewn, rocky slopes and numerous pinnacles. The volcanic debris of ancient eruptions was measurable in terms of hundreds of cubic miles and now covers most of northwest Wyoming.

Split Rock

The great western migration of people to Utah, California and Oregon in 1847-50 moved across central Wyoming along the Sweetwater River valley. The landmarks of that trail are recorded in dozens of pioneer journals and diaries, though little is said concerning the geology.

One of the most prominent of the natural phenomena is the mountainous summit aptly called Split Rock, on the north side of the Sweetwater River near the Natrona-Fremont County line. Along Wyoming State Highway 220 from Devil's Gate westward to Sweetwater Crossing, bald stark knobs of granite dominate the scenery. The granite knobs rise above the light colored sediments of Miocene and Pliocene age and collectively are known as

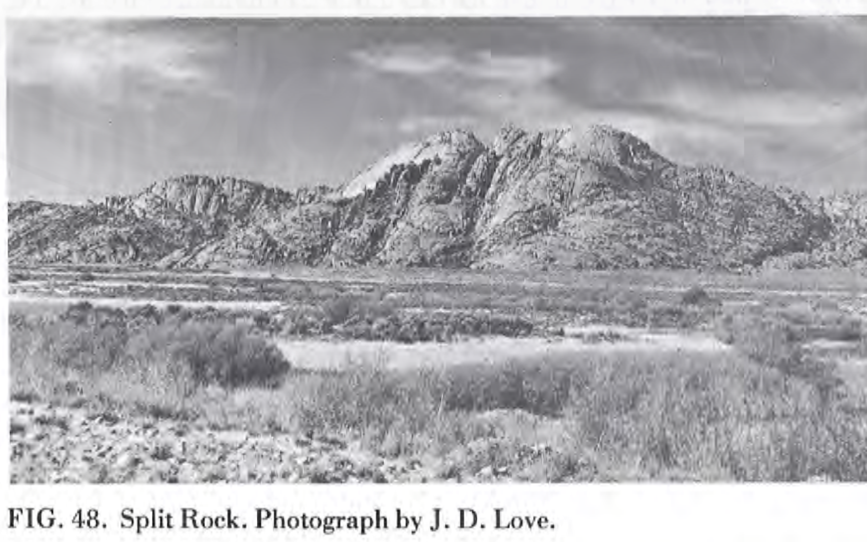

FIG. 48. Split Rock. Photograph by J. D. Love.

the Granite Mountains. Split Rock is one of these knobs, with a summit elevation of 7,305 feet. The summit is cleft by a deep notch that is oriented in an almost east-west direction. As the pinnacle is approached from either up or down the Sweetwater River valley, the cleft summit appears on the skyline like a gunsight, and provides an inspiring landmark.

Geologically, the cleft is the result of differential erosion of the granite bedrock along old fractures and shear zones. The relatively massive granite is broken by two sets of fractures, one of which trends N. 75 degrees W. Erosion along this set of fractures has removed the broken granite and formed the notch.

Westward from Split Rock, one may see dark bands of dike rock cross-cutting the massive granite. The smooth, dome-like mountains are the result of exfoliation or peeling away of slabs of granite.

Pine Ridge Escarpment

A strip of pine-studded badlands can be followed from near Chadron, Nebraska, across the Wyoming-Nebraska boundary as far west as Glenrock in Wyoming. The escarpment faces northward with a relief of several hundred feet from the rolling uplands at the summit down to the shale flats to the north. Many springs emerge in the canyons at the foot of the scarp, the waters from which drain northward to ultimately join the Cheyenne River.

The Pine Ridge Escarpment is the result of the slow, southward recession of the flat-lying Tertiary strata under the continued erosive action of streams. At one time, probably almost all of eastern Wyoming in the region of the Powder River basin was covered by several hundred feet of the same type of sediments as are now seen in the badlands along the scarp. The source of these rocks lay in northwest Wyoming, and the material composing them reflects the volcanic origin.

About five miles north of Lusk on U.S. Highway 85, one reaches the edge of the "breaks" which are characteristic of the Pine Ridge country. In all the valleys are scattered stands of *Pinus ponderosa*, appearing black and somber among the light, chalky sedimentary rocks. The upper part of the rim is underlain by fine grained, gray sandstones with numerous concretionary ledges of the Miocene Arikaree Formation. Below the gray sandstones are the light colored, chalky appearing strata of the Oligocene White River Formation overlying dark shales of the Cretaceous Pierre Shale.

The breaks have a rugged, pinnacled kind of topography, providing rough terrane in which a wide variety of animals find a refuge. From these badlands, paleontologists have recovered a large number of forms of fossilized mammals.

The westward extension of the geology which allows such a scarp to develop is found west of Casper and continues on to South Pass on the Sweetwater River. The scarp in that part of Wyoming is known as the Beaver Rim.

Pumpkin Buttes

In the vast open prairies of the western Powder River basin, a series of buttes rise up to break the monotony and to serve as landmarks. 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 west-flowing 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 State Highway 387 between Edgerton and Savageton.

The Wasatch Formation of Eocene age occupies large areas in the central and deeper sections of the Powder River basin and contains numerous coal seams. At Pumpkin Buttes, the Wasatch is capped by a hard, resistant, conglomeratic sandstone which protects the underlying softer strata from erosion. The resistant sandstone is a part of the Oligocene White River Formation, and is the thin eastward extension of the thick volcanic sequences of the Absaroka Range.

In recent years, uranium has been discovered in the Wasatch Formation in the vicinity of the buttes and has stimulated exploration for further reserves.

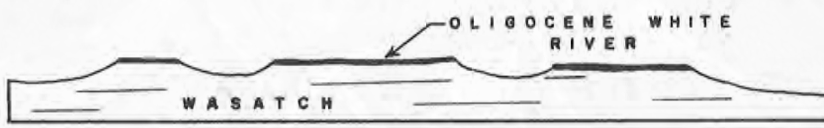

FIG. 49. Cross section to scale of Pumpkin Buttes, an excellent example of a mesa.

Rock Springs Uplift

Rock Springs was established because of the existence of numerous coal seams in the vicinity which could be used to supply fuel for the Union Pacific Railroad at the time of construction in 1869. Coal from these mines furnished the major part of the railroad's need until about 1950, at which date the road converted to diesel power.

Geologically, the coal veins dip to the west, and are contained in sedimentary rocks that are a part of a large regional anticlinal uplift some sixty miles long and thirty miles wide. The central area of the uplift is a

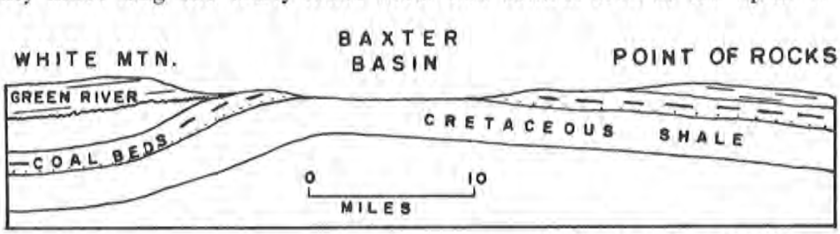

FIG. 50. Cross section from west to east across the Rock Springs Uplift.

topographic basin floored by marine shales of Cretaceous age and surrounded by a rimrock of Upper Cretaceous sandstones. The same sequence of strata that are seen in the vicinity of Green River and Rock Springs can be seen again dipping to the east on the opposite side of the fold near the communities of Point of Rocks and Black Buttes.

The crest of the anticlinal arch is near the airport in the low lying basin area. A simplified cross-section is shown in Figure 50.

Sinks Canyon

Sinks Canyon is located six miles southwest of Lander in the valley of the Middle Fork of the Popo Agie River. In this area, all the sedimentary strata southwest of Lander are dipping about 15 degrees to the northeast and away from the crest of the Wind River Mountains. The mouth of the canyon, at the point where the stream flows out into the flats, is very narrow and is eroded into the cross-bedded white to buff sandstones of the Pennsylvanian Tensleep Sandstone. Some glacial outwash extends eastward from the canyon mouth, and a very faint suggestion of a moraine can be detected.

As one traverses up the canyon toward the Sinks, one goes lower in the stratigraphic section and sees older rocks. At the upper end of the valley near the switchbacks, Precambrian rocks are exposed.

The Sinks are located in the thick limestones of the Mississippian Madison Formation and, in fact, near the top of that unit. The stream disappears into a cavern on the south side of the valley and reappears in a spring on the north side of the road, a few hundred yards downstream.

The origin of such sinks is discussed under Caverns, and a cross-section (Fig. 11) explains the geologic conditions.

Wyodak Coal Strip Pit

The Wyodak coal mine is located on U.S. Interstate 90, 21 miles west of Moorcroft and seven miles east of Gillette.

U.S. Interstate 90 from Sundance to Moorcroft crosses the west flank of the Black Hills and proceeds westward across the Powder River basin to Buffalo. Near Moorcroft, the rocks of Cretaceous age dip about ten degrees to the west, but by the time one reaches Rozet the westward dip is very slight.

At Wyodak, coal is recovered from an open pit in which a seam of coal over 90 feet thick is exposed. The coal seam is known as the Roland coal and marks the boundary between the underlying rocks of the Paleocene Fort Union Formation and the overlying Eocene Wasatch Formation. The coal is the basal unit of the Wasatch and has been traced over wide areas in the Powder River basin. The coal thickness decreases to the south and to the west, and has been determined by drilling. The coal bed at Wyodak is among the thickest coal seams known in the world and will provide a tremendous reserve of energy in the form of fossil fuel.

Coal that is recovered in the pit is transported directly to a steam plant generating electrical power for the area.

FIG. 51. Wyodak coal strip pit. Photograph courtesy Black Hills Power and Light Company.

Derby Dome

The eastern flank of the Wind River Range is paralleled for 60 miles by a series of anticlinal folds, beginning with Steamboat Butte on the Wind River at the north and continuing to Sheep Mountain on Beaver Creek at the south. The original discovery of oil in commercial quantities in Wyoming was made in 1884 at Dallas Dome, one of the separate anticlinal folds along the trend.

Derby Dome is crossed by U.S. Highway 287 about six miles south of Lander, Wyoming. Approaching from the south, the road follows strike valleys in the Frontier Formation for several miles then swings in a more westerly direction to cross the strike of the strata. The dip of the prominent tan and buff sandstones is about 15 degrees east. The drab, tan and gray sandstones and shales are suddenly supplanted by rocks of a bright orange red color, and a few oil field pumping units come into view. At this point, one is crossing the crest of a well-defined and well-exposed anticlinal arch, with the producing area of the field localized near the top of the anticline. Oil is produced from the Embar and Tensleep Formations of Pennsylvanian age, from a depth of approximately 1,000 feet. A stop here will provide a fine opportunity to view an anticlinal fold in some detail.

The road continues in a northwesterly direction toward the Little Popo Agie River, in the process crossing the west dipping limb of the Derby Dome fold, and then follows along the trough of the adjacent syncline on the west.

As one continues to Lander, extensive sequences of "red beds" will be seen to the east down the valley of the Little Popo Agie River in the crestal area of another producing field — Dallas Dome.

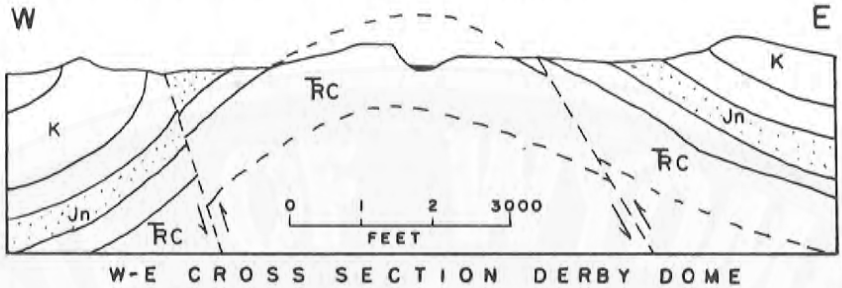

FIG. 52. Cross section of Derby Dome, near Lander, Wyoming.

Togwotee Pass

The continental divide is crossed on U.S. Highways 27 and 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 to the north of the road and in full view of the highway is an impressive rampart of volcanic rocks.

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 can be seen roughly stratified volcanic conglomerates striped with dead white bands of volcanic ash. The escarpment marks the southern-most extent of the Absaroka Range, but the scarp is being eroded and is slowly migrating northward.

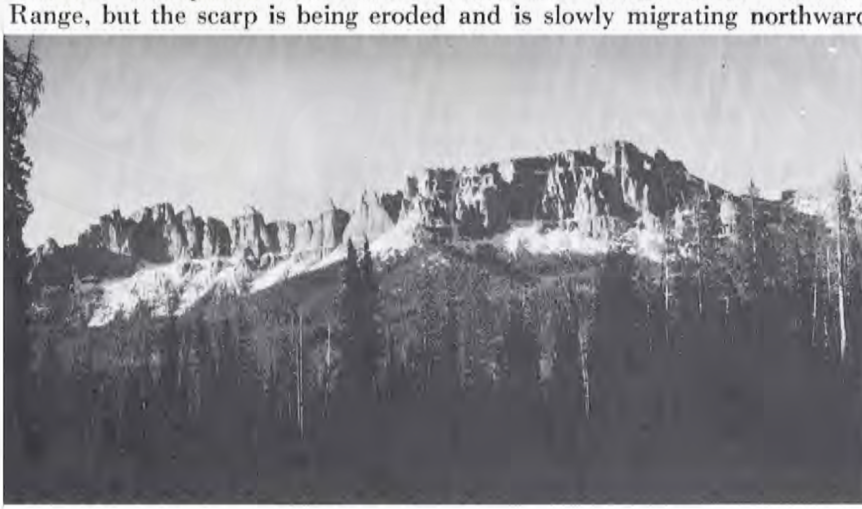

FIG. 53. Rampart near Togwotee Pass.

From Togwotee Pass westward, the road follows the valley of Blackrock Creek through an area of poorly exposed sedimentary rocks.

Star Valley

The westernmost large valley in Wyoming is that of the Salt River, a northward flowing tributary of the Snake River. The 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 Cariboo Range.

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 in 1849 were able to collect salt and to evaporate the brines. From these salt gathering activities, the river received its name.

Salt River is a small stream where it emerges from the mountains south of Smoot, but in a short distance it is a large river because of the discharge from springs in Star Valley. The valley contains large alluvial fans that slope away from the mountains and act as aquifers. The storage of groundwater in the fans is large and provides a stabilizing effect on the river flow through the springs that lie along the lower edges of the fans. The stable flow of cold clear water makes Salt River a fine fishing stream.

Pinedale Area—Fremont Lake

The region near Pinedale is characterized by a number of large lakes at low elevation and a myriad of smaller lakes at a somewhat higher elevation toward the crest of the range. All these lakes are the result of the activity of glacial ice that once occupied the west flank of the Wind River Range, from about two million years ago until about ten thousand years ago.

Ice accumulated first around the summit peaks, then later expanded to form a large piedmont type glacier along the west flank of the mountains. Ice moves down slope under the influence of gravity as a highly viscous material. Rock debris is picked up by the ice and, in turn, acts as a giant file as it grinds and polishes the rock floor beneath the glacier. The past position of the piedmont glacier is marked by a swarm of small lakes lying between about 8,000 feet and 9,500 feet in elevation.

The larger lakes occupying valleys at an elevation of about 7,500 feet above sea level had two stages in their formation. The first stage was the deepening and smoothing of an old stream valley as ice from the higher elevations crowded down through the valley to the basin. The second stage in the lake formation resulted from the melting of the ice.

As ice moved from the mountains to the basin, it carried large amounts of rock debris which was deposited when the ice melted. In certain places in the valleys, the ice advance and the melting were equal — in other words, the position of the glacial snout was stationary. Because the toe of the glacier stayed at one place for some time, all the debris left by the melting ice was piled in an arcuate ridge (moraine) across the valley. If the moraine was high enough, it acted as a dam when the ice eventually did retreat, and water accumulated behind the natural dam to form lakes such as Fremont Lake.

FIG. 54. Glacial landscape near Pinedale.

Glendo-Orin Junction Area

In the vicinity of Glendo along U.S. Interstate Highway 25, one of the major geologic events in the history of the Rocky Mountains is nicely displayed.

The formation of the Rocky Mountains occurred about 60 million years ago. The folded and faulted rocks were then eroded into a topography about as rugged as that which we see today. Near Glendo, the Precambrian basement is overlain by Paleozoic sedimentary strata largely of Mississippian and Pennsylvanian age, all of which were deformed during the mountain building episode.

In Early Oligocene time, the scene changed, and a period of violent volcanic activity began in northwest Wyoming. Tremendous volumes of volcanic ash were spread eastward across the state both by wind and by streams and rivers, building up a mantle that covered most of the older deformed rocks except for the summits of the higher ranges.

In traveling from Glendo to Orin Junction, one sees a sequence of limestones and dolomites of Pennsylvanian age cropping out in bare ridges, particularly near Glendo reservoir. Unconformably overlying the Pennsylvanian age rocks are fine grained, light colored rocks of the Oligocene White River Formation. The removal of the White River Formation by the North Platte River has uncovered the older topography which has been buried since Oligocene time. We are in a sense seeing a fossil landscape being brought to light.

Near Orin Junction, a large area of badlands has developed on the White River Formation. In these badlands, many fossils of vertebrate organisms have been found.

Red Grade

The Triassic Chugwater "red beds" are widespread throughout Wyoming, covering hundreds of square miles of outcrop. Many sections of automobile roads pass over "red beds", 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 pull 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 State 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.

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

FIG. 55. Red Grade.

slopes. The stream flows down a valley cut in Triassic "red beds", above which to the east are scarps of more resistant red beds, and finally on the skyline are pink and orange cross-bedded sandstones of the Jurassic Nugget Formation.

Far to the north near Lander is the horizontal profile of Table Mountain. Table Mountain is 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.

Bessemer Bend

The City of Casper is situated at the foot of Casper Mountain, an asymmetrical, faulted anticlinal fold, steep to the north. In the north face of the mountain are exposed Paleozoic rocks overlying the Precambrian basement, both of which have been moved both upward and northward over Cretaceous shales in the footwall.

At the west end of the anticline, the North Platte River crosses the Casper Mountain fold in a narrow canyon immediately south of the broad sweeping curve known as Bessemer Bend. The traveler passes through the canyon at river level on Wyoming Highway 220 enroute from Casper to Rawlins or Medicine Bow. After leaving Casper at about 4½ miles from the Paradise Valley turnoff, the highway crosses the south end of the Emigrant Gap anticline, outlined by a series of rims eroded from tan sandstones belonging to the Cretaceous Frontier Formation. At about 5½ miles, the road begins to descend toward the North Platte River and follows a valley between strike ridges in rocks that have a steep north dip. On the canyon wall above the river to the west, the entire Triassic "red bed" sequence can be seen arching over the crest of an anticlinal fold. 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 Platte River has been superposed across the Casper Mountain structure from pre-existing cover 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 the high knobs of the Granite Mountains.

Sheridan-Buffalo

The eastern flank of the Bighorn Mountains is clearly visible along U.S. Interstate Highway 25 between Buffalo and Sheridan. U.S. Highway 14 northwest of Sheridan, and 16 west of Buffalo, offer ready access over the summit and across the Precambrian granitic core of the mountains.

More than 60 million years ago, this area which is now the Bighorn Mountains began to bow upward, while the Powder River Basin area to the east began to sag and subside. The uplifting continued for millions of years, and in the process the earth's crust ruptured along the eastern flank, as evidenced today by the regional fault zone that extends along the base of the mountain-front west of Sheridan and Buffalo. Judging from nearby deep boreholes drilled in the course of exploration for oil and gas, in the basin and from surface evidence in the mountains, it appears that the fault has a total vertical displacement of more than 20,000 feet. Faulted shear zones in the rock can be clearly seen in the roadcuts of U.S. Highways 14 and 16.

Most of the sedimentary rocks which once covered the Bighorn Mountains above the Precambrian granite were eroded away by glaciation and stream action. Much of this eroded mud, sand, and rock, can now be found in the Tertiary strata that filled in the sag on the west side of the Powder River Basin.

The view eastward from various vantage points along the high mountain roads shows the relationship between the Bighorn Mountains, the Black Hills uplift 150 miles away, and the intervening Powder River Basin.

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The interested reader is referred to any reasonably large library, where he or she can find under U.S. Documents, in the Bulletin Series of the U.S. Geological Survey Publications, several volumes entitled "Bibliography of North American Geology," which cover essentially all references to the geology of Wyoming.

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GLOSSARY

Absolute age—A finite age of a geologic event based on measurement of decay rates of radioactive materials.

Alluvial—Refers to recent gravels, sands, and clays that have not been cemented to form a coherent rock body.

Anhydrite—Anhydrous calcium sulphate.

Anticline—A rock structure in which layered rocks dip away from a central crest or axis in opposite directions, like the roof of a house.

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

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

Ash fall—A deposit of fine fragments resulting from a volcanic eruption.

Basalt—An extrusive igneous rock, black in color, common rock in lava flows.

Basin—A *topographic* basin is an area of lower elevation surrounded by a rim of higher ground; often found in eroded core of an anticline. A *structural* basin is a synclinal area; all strata dip toward the deeper part; may be regional in extent.

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

Bedding—Sedimentary rocks which occur in layers are said to be bedded; layering.

Bentonite—Name applied to a light gray sedimentary rock that contains at least 75 per cent of the clay minerals beidellite or montmorillonite. Known for its capacity to swell when wet.

Blowout—An undrained depression eroded by wind action.

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

b.y.—abbreviation for billion years.

Calcite—A mineral composed of $CaCO_3$.

Canyon—A major stream valley with steep, precipitous walls.

Cave—A natural underground opening or void found in areas of limestone.

Chert—Microcrystalline form of silica, variable in color.

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

Clinker—Colloquial name applied to shale which has been baked by the burning of coal in place; red in color and more resistant than the underlying rock; often contains pipes of natural glass due to fusion of the shale. Also called "scoria", "porcellainite".

Coal—A black, or brownish black combustible organic material. Original material was vegetable matter which has been partially decomposed under increased pressure and temperature due to burial. Coals are classified by rank ranging from anthracite with the highest carbon content to lignite with the lowest.

Concretion—Segregations of the less common constituents of the rock, such as the cementing materials. Mineral matter accumulates about a center or an axis after deposition of the sediment.

Conglomerate—A sedimentary rock composed of rounded to angular detrital fragments of pre-existing rocks surrounded by a matrix of smaller grain size. The larger particles range upward from 2 mm. diameter.

Continental environment—An environment of deposition of sedimentary rocks upon the continent, including stream, lacustrine, and aeolian deposits.

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

Cross-bedding—A lamination oblique to the main stratification of sedimentary rock layers.

Crystalline—The term refers to the texture of igneous rocks with respect to the mineral crystals and their arrangement therein; however, in this report, it also refers to Precambrian igneous and metamorphic rocks.

Dike—A tabular-shaped body of igneous rock that cuts across (intrudes) the structure of adjacent rocks.

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

Dolomite—A mineral composed of $Ca . Mg (CO_3)_2$.

Dome—A special form of anticline which approximates a circular pattern in map view.

Dune—A mound or hill of sand which rises to a single summit. May be crescentic in shape (barchan) or elongate (seif).

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

Era—Geologic periods are grouped together into larger time units called eras.

Erosion—A general term which describes all the actions by which the typical 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. A common type of escarpment is due to the headward erosion of streams into flat lying sedimentary rocks. Such a landform is called a recessive escarpment. Any fault may offset rocks and create a scarp, called a fault scarp.

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

Fault (normal and reverse)—A displacement of rocks in the earth's crust along a fracture.

Flood plain—The flat floor of a valley which is the result of material deposited after the high flood stage overflows the banks of the channel.

Formation—A group of sedimentary rocks that is used as a geological mapping unit and named after a geographic locality, i.e., Tensleep Sandstone, Thermopolis Shale, 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 sediments.

Fumarole—A natural discharge of superheated steam from a localized vent.

Geology—That science dealing with the origin and physical history of the earth.

Geomorphology—That part of the science of geology dealing with the origin of landforms.

Geyser—A thermal spring that is characterized by periodic eruption 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.

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

Gypsum—A massive, white, earthy form of hydrated calcium sulphate.

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

Horn—A sharp, three or four sided peak, situated on the divide at the head of a series of alpine glaciers. The name is derived from the shape of the famous Matterhorn Peak 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. The beginning of the Pleistocene is placed at about two million years ago.

Igneous—The word derived from the Latin word for fire and is used as an adjective. Igneous rocks are those which result from the consolidation of molten silicate melts.

Intrusive rock—Rocks which have been formed by the consolidation of magma at depth below the surface of the earth. The rocks are usually crystalline — that is they have a grained texture and represent slow cooling.

Laccolith—A body of intrusive igenous rock which has a flat floor, and which has bowed up the overlying sedimentary rocks by the force of intrusion.

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

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

Layering—Sedimentary rocks occur in layers, and therefore, are said to be layered.

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

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

Map Scale—The scale of a map is the ratio between actual distances on the ground and the representation of that distance on the map.

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 directly 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.

Mineral—A naturally occurring inorganic compound of relatively definite chemical composition and physical character. Quartz (silicon dioxide) crystallizing in the hexagonal system is a good example.

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

Mountain—A topographic feature that stands above the surrounding countryside. A relative term, since some features only a few hundred feet high are called mountains.

Mud flow—Masses of water saturated soil and rock debris moving down slope in relatively well defined channels.

m.y.—Abbreviation for million years.

Natural gas—The term is applied to a complex of hydrocarbons in gaseous state. Methane is a common constituent.

Obsidian—Natural glass, black to gray in color, conchoidal fracture.

Ore—Rock containing mineral matter that is of a high enough concentration to make it possible to extract the mineral 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 spread out in a sheet beyond the end moraine of a glacier. Boulders and shallow channels characterize the surface.

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

Pediment—A land form characteristic of arid and semi-arid regions. The form is a relatively smooth surface sloping away from the mountain fronts with a very low gradient, and is capped by gravels.

Peneplane—A regional surface of very low relief, believed to have been eroded very near sea level. The word means "almost a plane".

Period—A fundamental unit of the geologic time scale.

Petroleum—An inflammable, oily mixture of liquid hydrocarbons.

Placer deposit—Refers to a mineral deposit that has been weathered from a vein, or other type of deposit, and concentrated by gravity and water in the gravels and sands of stream and river channels.

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

Red beds—A colloquial geological term which refers to the red sedimentary rocks that are seen throughout the world. In Wyoming, it most often applies to the red sediments of the Permian, Triassic, and Jurassic periods.

Representative fraction—A means of expressing the scale of a map. The fraction expresses a ratio between a distance on the map (i.e. one inch) and the actual number of inches on the ground that is portrayed by the map.

Rocks—(See types: igneous, sedimentary and metamorphic). A rock may be defined as a consolidated aggregate of minerals or organic materials that form a part of the earth's crust.

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

Sandstone—A sedimentary rock composed of grains of minerals, often in large part quartz. The size of the particles ranges from 1/16 to 2 mm.

Scale of map—(See representative fraction)

Scarp—(See escarpment)

Sedimentary structures—Features which are the result of the agent of deposition at the time of rock formation. Included are cross-bedding, mudcracks, ripple marks, etc.

Shale—A sedimentary rock composed largely of clay minerals, and possessing very fine layering.

Sill—A concordant 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 of particles of silt size— 1/256 to 1/16 mm.

Sinter—Deposits of silica associated with hot springs and geysers.

Solution—A homogeneous mixture, the proportion of whose constituents may be varied within certain limits. Solutions may be either liquid, solid, or gaseous.

Strata—Sedimentary beds or layers of sedimentary rock.

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

Superposed drainage—A system of stream valleys that has been incised into the bedrock from some type of overlying cover.

Syncline—A fold in rocks in which the rocks on both limbs dip towards the middle; opposite to anticline.

Taconite—An iron-bearing siliceous rock.

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. Origin may be related to the algae living in such environments.

Trap—A colloquial term used to describe any type of natural situation wherein hydrocarbons (petroleum and natural gas) are "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 salt of sodium formed by the evaporation of saline waters. Sodium sesquicarbonate.

Unconformity—The physical evidence in the rock sequence of a gap in the geologic record.

Uplift—A general term applied to a situation wherein rock masses have been elevated subsequent to formation 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.

Volcano—A mountain or hill which owes its origin to the eruption of lava and ejecta from a central vent or vents.

Volcanic vent—An opening in the earth's crust, out of which volcanic material was erupted at the surface.

INDEX TO GEOLOGIC SKETCHES OF SELECTED AREAS IN WYOMING

Index Map on back cover used with permission of the Wyoming State Highway Commission.

Sheridan
Buffalo
Cody
Powell
Lovell
Worland
Ten Sleep
Thermopolis
Riverton
Lander
Casper
Douglas
Gillette
Newcastle
THUNDER BASIN
NATIONAL
GRASSLAND
Rawlins
Rock Springs
Green River
Evanston
Laramie
Cheyenne
Medicine Bow
Rock River
Chugwater
Fort Laramie
Lusk
Kemmerer
Frontier
Superior
South Superior
Reliance
Mountain Passes shown by this symbol are closed in the winter months. Local inquiry should be made as to opening date.