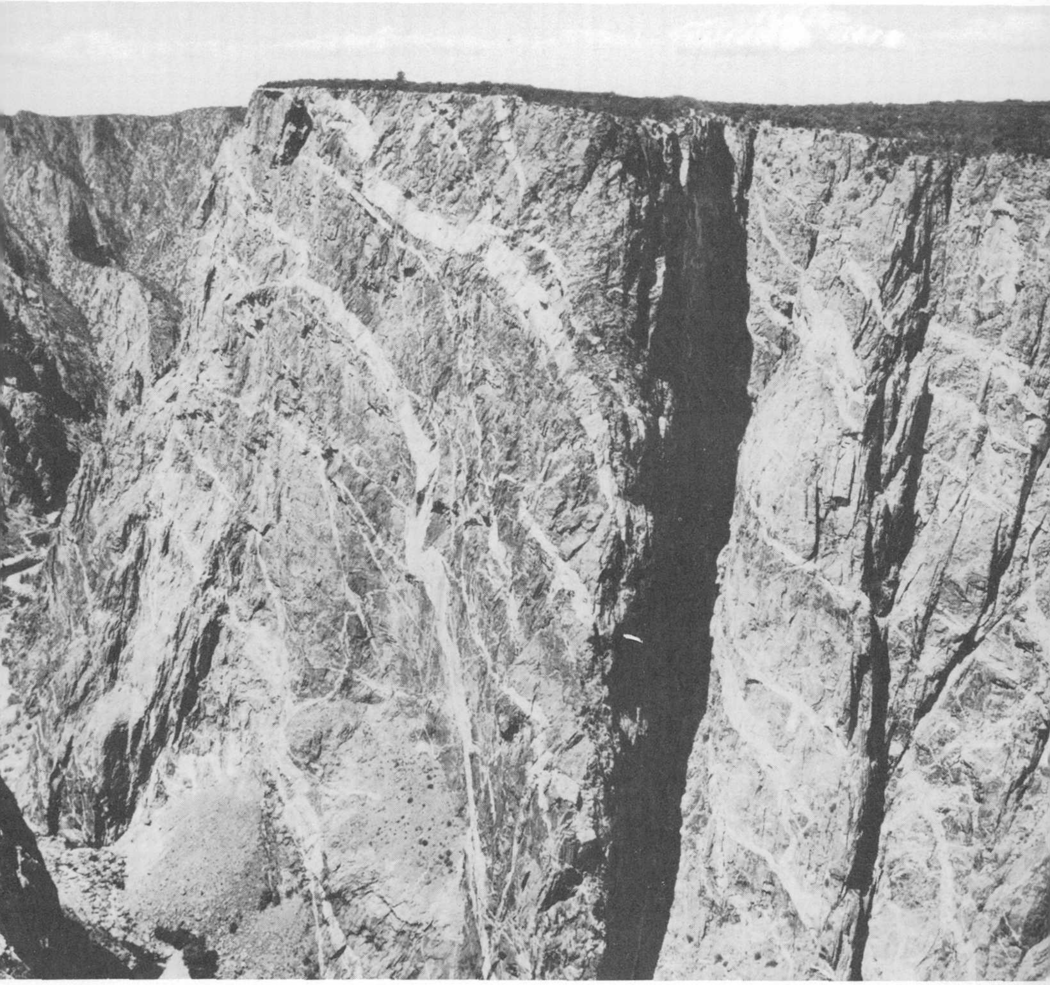
THE BLACK CANYON
OF THE GUNNISON

A close look at a great American canyon—
its rocks, its age, and how it formed



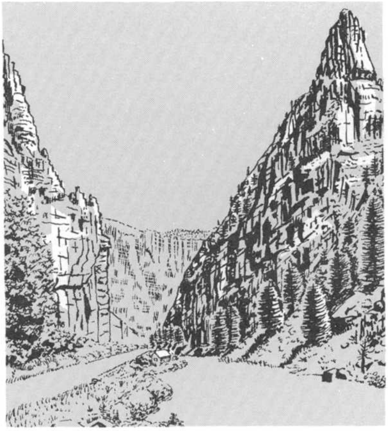
Painted Wall, Black Canyon of the Gunnison National Monument.

Greatest cliff in Colorado, Painted Wall averages about 2,250 feet from rim to river. Cliff is carved from gneiss interlaced with pegmatite dikes. Deep fissures to right of center are controlled by weathering along joints.

THE BLACK CANYON OF THE GUNNISON

TODAY AND YESTERDAY

By WALLACE R. HANSEN



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THE BLACK CANYON OF THE GUNNISON
Today and Yesterday

By Wallace R. Hansen

INTRODUCTION

Since the early visit of Captain John William Gunnison in the middle of the last century, the Black Canyon of the Gunnison has stirred mixed apprehension and wonder in the hearts of its viewers. It ranks high among the more awesome gorges of North America.

Many great western canyons are as well remembered for their brightly colored walls as for their airy depths. Not so the Black Canyon. Though it is assuredly not black, the dark-gray tones of its walls and the hazy shadows of its gloomy depths join together to make its name well deserved. Its name conveys an impression, not a picture.

After the first emotional impact of the canyon, the same questions come to the minds of most reflective viewers, and in about the following order: How deep is the Black Canyon, how wide, how does it compare with other canyons, what are the rocks, how did it form, and how long did it take? Several western canyons exceed the Black Canyon in overall size. Some are longer; some are deeper; some are narrower; and a few have walls as steep. But no other canyon in North American combines the depth, narrowness, sheerness, and somber countenance of the Black Canyon.

In many places the Black Canyon is as deep as it is wide. Between The Narrows and Chasm View in the Black Canyon of the Gunnison National Monument (fig. 15) it is much deeper than wide. Average depth in the monument is about 2,000 feet, ranging from a maximum of about 2,700 feet, north of Warner Point (which also is the greatest depth anywhere in the canyon), to a minimum of about 1,750 feet at The Narrows. The stretch of canyon between Pulpit Rock and Chasm View, including The Narrows, though the shallowest in the monument, is also the narrowest, has some of the steepest walls, and is, therefore, among the most impressive segments of the canyon (fig. 3).

Profiles of several well-known western canyons are shown in figure 1. Deepest of these by far is Hells Canyon of the Snake, on the Idaho-Oregon border. Clearly, it dwarfs the Black Canyon in the immensity of its void, though its flaring walls lack the alarming verticality of the Black Canyon. Arizona's Grand Canyon of the Colorado is acknowledged as the greatest of them all; it is not as deep as Hells Canyon, but it is wider, longer, more rugged, and far more colorful. Its depth is two to three times that of the Black Canyon. Zion Canyon, Utah, combines depth, sheerness, serenity, and color in a chasm that ranges from capacious to extremely narrow. Its Narrows have a depth-to-width ratio unmatched by any other major American canyon.

California's Yosemite Valley, in a setting of sylvan verdure, is unique among the gorges shown in profile in figure 1 in being the only glacial trough; its monolithic walls bear witness to the abrasive power of moving ice. Few cliffs in the world match the splendor of its El Capitan. Lodore Canyon, on the Green River in Dinosaur National Monument, Colorado, is best known, perhaps, for its noisy splashy rapids, first made famous by John Wesley Powell. Lodore Canyon also features towering cliffs of deep-red quartzite. Grand Canyon of the Yellowstone River, Wyoming, is noted for its great waterfalls, dashing river, and bright coloration. The Royal Gorge of the Arkansas River, Colorado, features the "world's highest suspension bridge."

The profiles shown in figure 1 afford some basis for comparing one canyon with another. They cannot abstract in

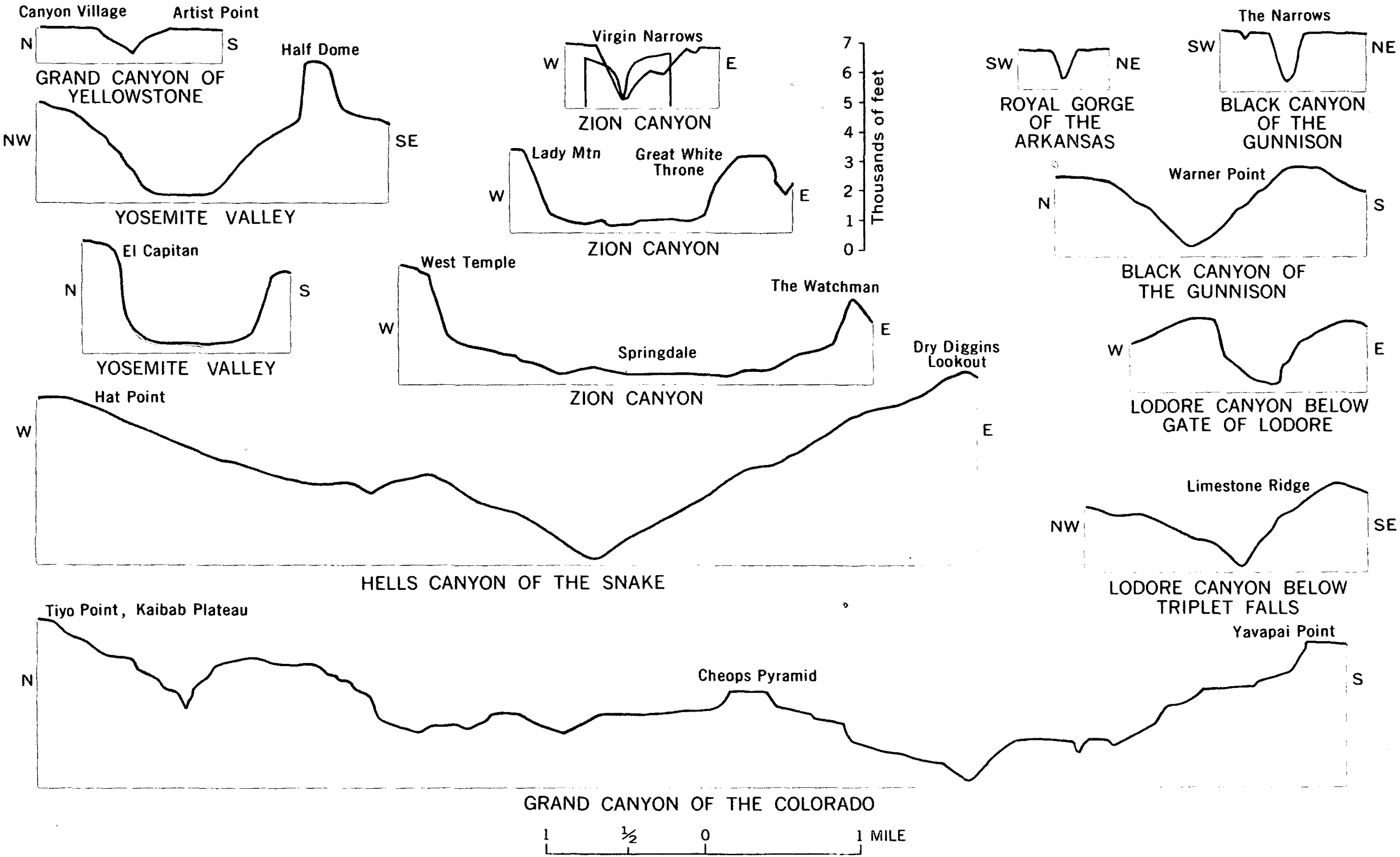

FIGURE 1.—Comparative profiles of several well-known American canyons.

two dimensions the overall impression that each canyon makes. Color, vegetation, outcrop habit, vantage point, season of year, length of visit—even the roar of the river or lack thereof—all contribute to this highly personal effect.

For a river of its size, the Gunnison has an unusually steep gradient through the Black Canyon. The river falls about 2,150 feet from the head of the canyon at Sapinero to the mouth at its junction with North Fork—a distance of about 50 miles and an average rate of fall of about 43 feet per mile. By comparison, the Green River flowing through Dinosaur National Monument—a comparable-sized stream in a comparable-sized canyon—has an average fall over a distance of 50 miles of about 12 feet per mile, and its maximum drop is near to the average drop of the Gunnison. The Colorado in Grand Canyon—a much larger stream—averages 7½ feet per mile. To be sure, the Gunnison drops considerably less than 43 feet per mile through some stretches, but in the monument section it drops much more. The overall fall through the monument is about 95 feet per mile, the greatest drop being in the 2-mile stretch from Pulpit Rock to Chasm View. In that stretch the Gunnison falls nearly 480 feet and locally drops as much as 180 feet in half a mile.

So steep a gradient on a large stream is rare indeed, although notably steeper descents characterize a few rivers. The Yellowstone River in its Grand Canyon descends 1,600 feet in 20 miles at an average rate of 80 feet per mile, this rate including sheer drops of 140 feet and 330 feet at Upper and Lower Falls, respectively. And aside from these famous waterfalls, the Yellowstone still descends more than 56 feet per mile through its Grand Canyon.

Several geologic factors in combination helped create the Black Canyon. Appearances to the contrary, the canyon did not result from some great cataclysmic upheaval in the remote geologic past. It is a result, rather, of the slow tedious process of erosion, and though the day-to-day changes are all but imperceptible, the process is still very much at work. The more obvious manifestations include the turbidity of the river—swollen by floods—in early summer, a mud-laden wash after a heavy rain, an occasional rockfall from a high cliff, and the relentless creep of a landslide. The actual excavation of the canyon was done by the Gunnison River and its tributaries with a strong assist by various other agents of erosion. But the coincidental interplay of several other factors was necessary before the job of removing 25 cubic miles of rock was possible. These factors are discussed at length on the pages that follow.

PHYSIOGRAPHIC SETTING

The Black Canyon of the Gunnison lies in a transition zone between two physiographic[1] provinces—the Southern Rocky Mountains on the east and the Colorado Plateaus on the west. In this area the boundary between the two is ill defined. The entire Black Canyon area has attributes of both provinces and could be assigned to either.

For a better understanding of the physical and spatial relations of the Black Canyon, topographic maps are an invaluable aid. Fortunately, excellent coverage is available. Regional topographic relations are well portrayed on the 1: 250,000-scale (4 miles per inch) Montrose topographic sheet prepared by the Army Map Service and published in civil edition by the U.S. Geological Survey. This map covers the area between Montrose on the west, Salida on the east, Grand Mesa on the north, and Ouray on the south. It shows unusually well the relation of the Gunnison River system to the West Elk, Sawatch, and San Juan Mountains and the extraordinary setting of the Black Canyon across the Gunnison uplift.

At a larger scale and in greater detail, the Black Canyon is covered by seven topographic quadrangle maps recently published by the Geological Survey at a scale of 1 : 24,000 (2,000 feet per inch). These maps shows roads, trails, other cultural features, streams, lakes, and woodland areas, besides showing in detail the contour of the canyon walls and adjacent areas. They also identify most of the important named landmarks referred to in this report. Most of the national monument—all the more accessible part—lies within the Grizzly Ridge quadrangle. The remainder is in the Red Rock Canyon quadrangle. The index map (fig. 2) shows the topographic map coverage of the Black Canyon area.

High Point, at the end of the South Rim Drive in the Black Canyon of the Gunnison National Monument, pro-

[1] See glossary, p. 70, for a description of semitechnical terms.

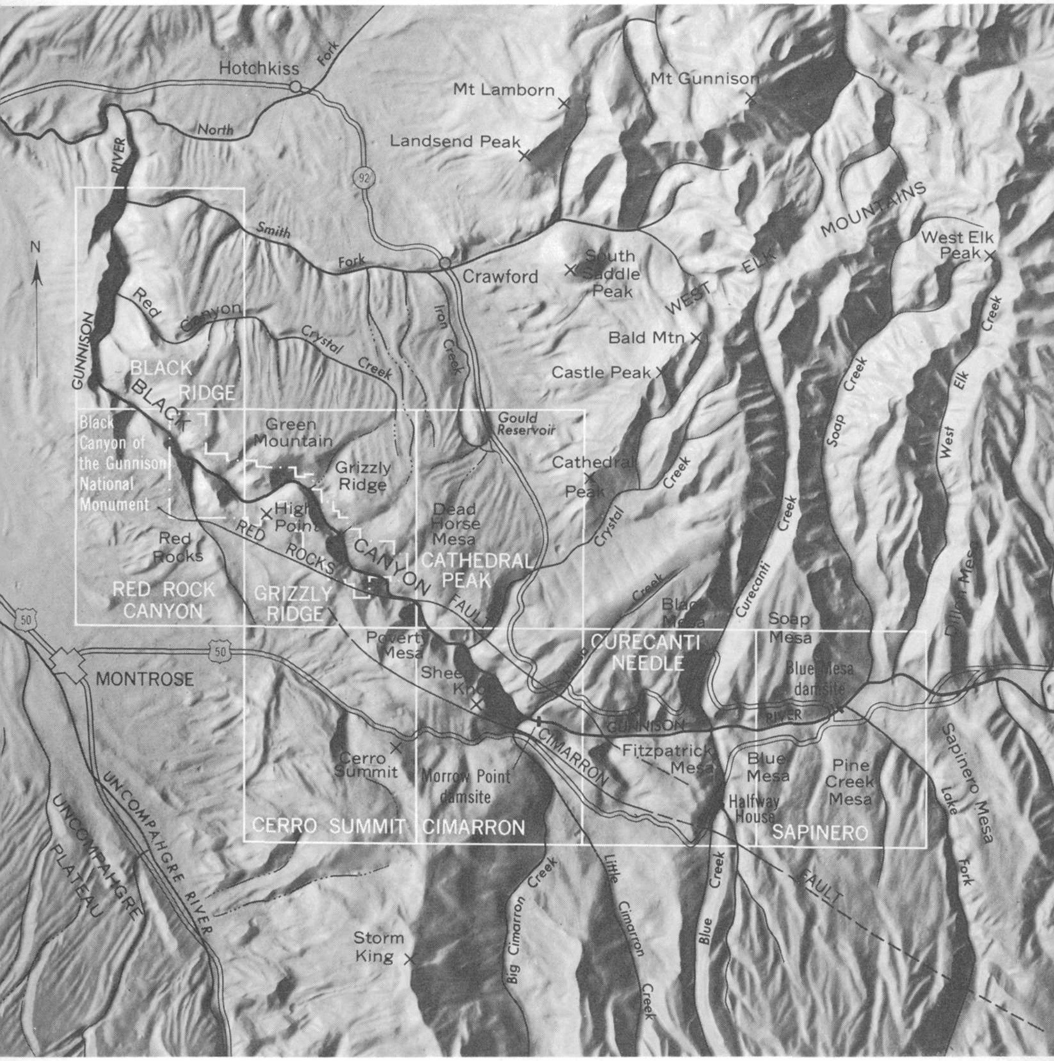

FIGURE 2.—The Black Canyon area.

vides a good bird's-eye view of regional physiographic relations. High Point is near the topographic and structural crest of the Gunnison uplift, an elevated part of the earth's crust through which the Gunnison has cut its canyon. From High Point the view is unobstructed in all directions. Looking northeast across the canyon, one sees the isolated laccolithic peaks and volcanic mesas of the West Elk Mountains. These mountains much resemble other laccolithic groups on the Colorado Plateaus, but they are closely tied to the Rocky Mountains topographically, and they are included in the Southern Rocky Mountains by most physiographers. Their western front is taken as the boundary of the Southern Rocky Mountain province.

Turning clockwise and looking south beyond the ridges and mesas that rim the Black Canyon, one sees on the horizon the lofty snow-flecked summits of the San Juan Mountains, an impressive westward-trending bulwark of the Southern Rocky Mountains, dominated by Uncompahgre Peak at the far left, Mount Sneffels near the center, and Lone Cone at the far right. These mountains contain rocks of many types and of nearly all ages.

To the southwest and 2,500 feet below High Point in the bottom of the Uncompahgre Valley is Montrose, a marketing center for the livestock and lumbering industries and for the extensive agricultural enterprises of the valley. The Uncompahgre Valley and forest-topped Uncompahgre Plateau on the skyline beyond are units of the Colorado Plateaus province.

Northwest of High Point, and almost directly below, are the lower reaches of the Black Canyon. Near the canyon mouth the North Fork joins the main stem of the Gunnison River; a few miles farther downstream, the Uncompahgre River joins also. Though not visible from High Point, the main stem continues northwestward in the broad valley between the Uncompahgre Plateau to the left and the Grand Mesa on the skyline to the right. Topographically and structurally, this valley is a northward-trending continuation of the Uncompahgre Valley. Lava-capped Grand Mesa, standing nearly a mile above the Gunnison River valley, is also a unit of the Colorado Plateaus.

For a synoptic view of the canyon itself, the south rim of Fruitland Mesa is an unsurpassed vantage point. Unfortunately, this rim is accessible only by way of trails and a primitive road. Looking south from the rim of the mesa, one gains an otherwise unobtainable appreciation of the setting of the canyon in its immediate surroundings and a positive impression of the relation of the canyon to late Tertiary and Quaternary physiographic events.

SEEING THE CANYON

Most visitors to the Black Canyon, either from choice or necessity, confine their observations to the maintained trails and overlooks of the national monument. These facilities afford safe and convenient access to the more outstanding and informative segments of canyon scenery. Not surprisingly, they also afford outstanding glimpses of canyon geology, for the scenery of the canyon is a direct consequence of the interplay of geologic processes. Each canyon overlook and its approaches differ both in general and in detail from every other one, and the viewer with the time and inclination would enjoy a visit to all, for only in this manner can he fully appreciate the grandeur of the canyon. Viewers obliged to move on a little more rapidly can obtain a representative sampling of canyon geology and scenery by visiting Gunnison Point, Chasm View, and Sunset View, while also driving out to High Point on South Rim Drive. These overlooks provide outstanding views of geologically and topographically unlike segments of the canyon, each within a minimum of trail distance from the rim highway.

Individuals of unusual fortitude may occasionally want to hike to the canyon floor. Though arduous, such a trip is highly rewarding if properly planned and executed, and it provides an insight into canyon geology unobtainable from the rims. Below the rims, the canyon is very scenic, wild, and primitive, but to the uninitiated it is potentially dangerous.

Trips to the canyon bottom should be attempted only by those in excellent physical condition. There are no established trails, but safe descents are possible from several points on both rims. Expensive mountaineering equipment is unnecessary, but suitable foot gear is imperative. Most descents are planned for at least a one-night stay at the bottom.

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Descents can be made at any time from early spring to late autumn. Trips along the canyon bottom, however, are best planned for late summer after the river level has fallen, for passage is impossible without great risk during high water. Even during low water, river crossings are necessary where passage along either bank is blocked by cliffs at the water's edge (fig. 3). Depending on the level of the river, crossings may be made by wading the riffles or by floating a rubber raft.

Float trips, as such, are feasible for experienced runners during low water between the mouth of Cimarron Creek and East Portal, between East Portal and The Narrows, and below Chasm View, but not between The Narrows and Chasm View. The stretch between The Narrows (fig. 3) and Chasm View is the wildest and most scenic in the entire canyon, but it is also the most arduous and potentially the most hazardous; it is too treacherous for good floating. Cimarron Creek to River Portal offers 8 miles of exciting adventure—scores of white-water rapids in a setting of primitive splendor; outstanding geologic features exposed in this segment of canyon include large overturned folds, thick masses of black amphibolite, myriads of pegmatite dikes, and broad fault zones.

For about 15 miles below Red Rock Canyon the river flows past many impressive geologic features which are dramatically exposed. But floating in this stretch is impeded by dangerous rapids—particularly between Crystal Creek and Smith Fork—and should be attempted only after all due precautions have been taken.

◀FIGURE 3.—The Narrows of the Black Canyon. About 40 feet wide at this point, the river impinges on nearly vertical walls of resistant gneiss. Canyon here is about 1,750 feet deep and is about 1,100 feet wide from rim to rim.

HOW THE CANYON WAS CARVED

More specifically, this heading should read "How the canyon is being carved," for the process of cutting is still going on at the present time. And to say blandly that the river is doing the job will satisfy few inquirers, although the river is certainly the driving force. Anyone who has seen the canyon during the high-water stage of early summer can attest to the unleashed fury of the river at that time. Impressive from the rim, the river is almost frightening close at hand. The river is the prime mover of material and the chief agent of erosion, but it is supported in its work by several subsidiary agents. Gullying, rill wash, frost action, atmospheric weathering, and mass wastage of debris under the influence of gravity all tend to widen the canyon walls and transport rock material to the canyon bottom. Material delivered to the canyon bottom is then worn away and carried off by the river, which at the same time erodes its bed with the material in transit.

The work of the river is mainly seasonal—during high water, when it is swollen by the snowmelt of its 4,000-square-mile drainage basin and when its ability to move a suspended load is high—whereas most of the other processes are nonseasonal, frost action excepted. Frost action of course is primarily a wintertime process. It takes advantage of such natural weaknesses in the rocks as fractures and foliation planes. Water seeps into these places, freezes, and slowly forces an opening. Then in a ratchetlike action, repeated freezes and thaws force it wider.

Water is essential also in the slow chemical breakdown of rocks by atmospheric weathering. This process, too, is most effective along lines of natural weakness where moisture can gain access.

Gullying and rill wash take advantage of natural zones of weakness in the rocks, and most of the tributary ravines in the national monument section of the canyon utilize such zones. Joints, faults, foliation planes, and even diabase dikes become loci for natural drainage—diabase dikes, not because of structural weakness but because of rapid chemical breakdown under the influence of weathering.

Through the widening of joints and fractures, the physical stability of large rock masses on the steep canyon walls is reduced ultimately to the point of failure. Blocks then plummet, bounce, or creep to the canyon floor where they are attacked and worn away by the river. The great size of many of these blocks bespeaks the effectiveness of the process. Helter-skelter blocks the size of houses, looking like stepping stones from the canyon rims, pose a challenge to venturesome hikers along the canyon floor.

Blocks in excess of what the river can handle in a given time form aprons of talus against the canyon walls (fig. 4).

FIGURE 4.—Talus blocks in canyon bottom at foot of Painted Wall, August 29, 1962. Foot passage through such areas is precarious. River is flowing at a rate of about 250 cubic feet per second. Falls at left are about 10 feet high. During high water, all the large blocks in the foreground are engulfed in a white-water rapid.

The abundance of talus on the lower slopes, as shown by figure 4, suggests a short-term imbalance between the effectiveness of subsidiary agents of erosion and the capacity of the river, an imbalance destined to increase as water is impounded behind dams upstream. But the great depth of the canyon relative to the width leaves little doubt of the long-term competence of the river—in the long run the river is lowering its bed faster than the rims are receding.

WHY THE BLACK CANYON CROSSES THE GUNNISON UPLIFT

Widespread evidence in the canyon country of the Western United States indicates that rivers once firmly entrenched are little able to alter their courses, despite seemingly anomalous relations to rock hardness and structure. The Black Canyon is an outstanding example of this very principle, as the early geologists who visited the area quickly recognized. Flowing quite normally between highlands north and south in its upper reaches, the Gunnison River strikes through the very heart and heights of the Gunnison uplift in the depths of the Black Canyon. Here it cuts deeply into the hardest of rocks, seemingly aloof to easier possible courses through softer rocks north and south.

But the present course of the river is controlled by its initial course at the time downcutting began—not by the rocks through which it now flows. (See fig. 7.) Downcutting began when the river flowed across a terrane of newly erupted volcanic rocks in late Tertiary time. These rocks were deposited sheetlike without regard to underlying structure. Partly eroded remnants still cap the mesas near the head of the canyon. Once entrenched into these rocks, the river had not alternative but to pursue its established course. Its chance superposition across the hard Precambrian rocks of the then-buried Gunnison uplift was a lucky event that made the Black Canyon possible.

THE ENERGY OF THE RIVER

Another critical factor joined the interplay of coincidences that made the Black Canyon possible. In its passage through the canyon, the Gunnison River drops more than 2,100 feet. This exceptionally steep gradient affords the river the energy needed to incise its bed downward at a rate higher than subsidiary agents of erosion can flare out the rims. The result is a very narrow canyon, deeper in many places than wide.

During high water, the Gunnison River usually has a peak discharge of about 12,000 cubic feet per second through the Black Canyon. At this discharge the river expends energy at a rate of more than 1½ billion foot pounds per second, or about 2¾ million horsepower, through the 50-mile-long stretch of the canyon. Converted to electricity this energy would exceed 2 million kilowatts.

Most of this energy is dissipated by turbulent flow—the frictional churning of the water dashing over rapids and against rocks in its wild descent through the canyon. Part of the energy is expended in scouring the bed of the river, and the remainder is consumed in transporting debris. After construction of the new hydroelectric facilities at Blue Mesa and Morrow Point, a fraction of this energy will be harnessed and converted to electricity.

The steep gradient of the river is dependent on physiographic controls downstream from the canyon in the lower Gunnison valley and even along the main stem of the Colorado River. These controls are partly structural, partly lithologic, and partly purely hydrologic. Entrenchment began as soon as they became effective.

Much impetus was added to the cutting of the Black Canyon by a spectacular physiographic event far downstream in the Grand Junction area, recently described in a paper by Lohman (1961, p. B144). In brief, the combined flow of the Gunnison and Colorado Rivers once crossed the Uncompahgre Plateau in what is now Unaweep Canyon. Unaweep Canyon was abandoned, and flow was diverted around the north end of the plateau in a remarkable sequence of drainage adjustments. As a direct consequence, the energy and competence of the entire upper Colorado River system were vastly increased.

Just below the mouth of the Black Canyon, the upper Gunnison (main stem), the North Fork, and the Uncompahgre merge into a single large river. While the upper Gunnison was cutting the Black Canyon in hard Precambrian rock, the lower Gunnison—rejuvenated by the abandonment of Unaweep Canyon—was excavating a capacious valley in soft Mancos Shale. The lower Gunnison, the North Fork, and the Uncompahgre, moreover, were all lowering their beds more rapidly through soft Mancos Shale than the upper Gunnison was lowering its bed through hard crystalline rock; the net result was steepening of the gradient of the upper Gunnison. If rock conditions were alike both upstream and downstream, therefore, there would be no Black Canyon.

WHY THE WALLS ARE SO STEEP

Basically, two interacting factors are responsible for the steepness of the canyon walls—first, the extreme resistance of the rocks to erosion, especially the granitic rocks (fig. 5), and second, the high efficiency of the river in eroding its bed as opposed to the low efficiency of subsidiary agents of erosion in widening the walls. But why haven't comparable rivers cut comparable canyons through similar rocks in other parts of Colorado? Nearly identical rocks are widespread in Colorado, and many rivers have cut deep canyons through them. Just 50 miles to the east, for example, the Taylor River has cut a great slash through similar if not identical rocks in its descent from the Sawatch Range. The Colorado cuts similar rocks in Glenwood Canyon, and so does the South Platte in the Front Range. Many other examples could be cited. But none of these valleys has both the depth and verticality of the Black Canyon. The Royal Gorge of the Arkansas is perhaps most comparable, but it is far overshadowed by the Black Canyon.

Why then is the Black Canyon unique? Rapid downcutting alone is not the answer. Downcutting must be combined with resistance on the part of the valley walls to forces tending to flare them out. While the Gunnison has cut its Black Canyon the adjacent Uncompahgre has eroded a valley equally deep but 20 to 40 times as wide. The nonresistant sides of the Uncompahgre Valley have enlarged 20 times as fast laterally as vertically.

In most valleys, gullying and rill erosion by tributary streams keep pace with downcutting by the master stream.

FIGURE 5.—Chasm Wall, at north end of Vernal Mesa, has a nearly vertical drop of 1,800 feet. Only the upper half of the cliff is shown in this view. Rock is Vernal Mesa Quartz Monzonite. Exfoliation along vertical joints contributes to sheerness.

Such tributaries respond effectively to changes in regimen of the master stream. If the master stream lowers its bed, so do the tributaries because their gradients are steepened and their energy is increased. Conversely, if the master stream aggrades, the tributaries do the same as their gradients are flattened and their energy is reduced. Major tributaries of the Gunnison such as Lake Fork, Curecanti Creek, Blue Creek, Smith Fork, and Cimarron Creek are fairly well in accord with this rule. All of them are sizable perennial streams having large catchment basins and reliable discharges.

But minor tributaries such as Grizzly Gulch flow intermittently from woefully small catchment basins. They terminate precariously, therefore, at the canyon rims, or they find their way to the river down precipitous ravines along lines of weakness in the rocks. In either event, their erosive power is negligible compared to that of the Gunnison.

The small size of their catchment basins is due chiefly to the form of the Gunnison uplift. Standing as it does above the surrounding country, the uplift sheds most of its precipitation away from the canyon to such streams as Smith Fork, Crystal Creek, and the Uncompahgre River. Many small streams that formerly flowed to the canyon, moreover, have been diverted by natural drainage adjustments into streams that flow away from the canyon. As a result, only the shortest, least competent tributaries flow directly to the river in the depths of the canyon. These tributaries simply cannot keep pace with the Gunnison.

HOW LONG DID IT TAKE

In attempting to evaluate the age of the Black Canyon, the geologist must be mindful of many variables and many uncertainties. First of all, he is not dealing with precise figures but with relative ages covering an incomprehensible immensity of time (fig. 6). In terms of relative geologic age, viewed in the vastness of geologic time, the canyon is very youthful indeed—it formed only yesterday. But in terms of man's experience, his short recorded history, and his even shorter life span, the antiquity of the canyon is staggering.

The long chain of events that led up to the actual cutting of the Black Canyon began to take form in the dimmest recesses of the past, well over a billion years ago during the Precambrian Era. Much of geologic time elapsed while the stage was being set. The really critical interplay of circumstances began about 60 million years ago, at the time of the Laramide orogeny, when the Gunnison uplift first took form. These events are further described on the pages that follow. (See also fig. 7.) But the actual cutting of the canyon started perhaps a scant 2 million years ago.

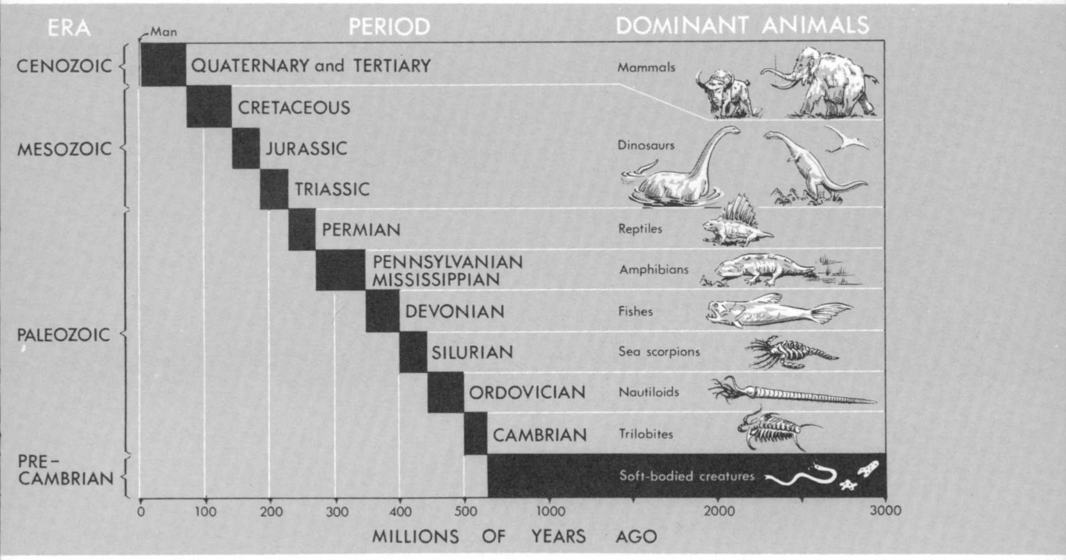
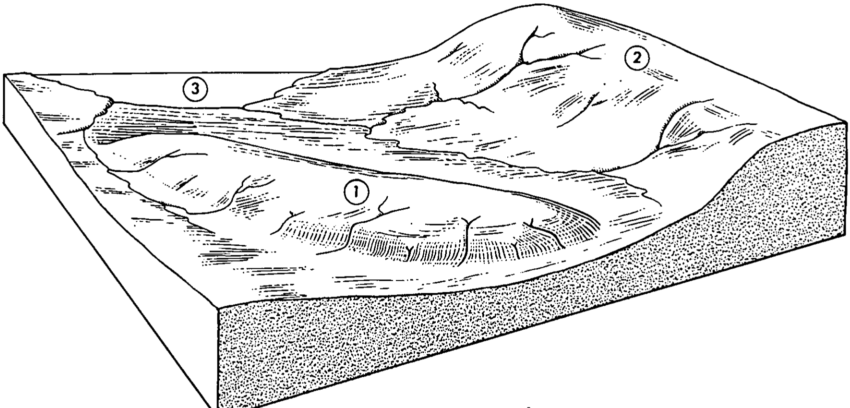


FIGURE 6.—Major divisions of geologic time.

Acknowledging the many gaps in the local geologic record, we can, nevertheless, place fairly close limits on the time when cutting could have started. First of all, the Gunnison River did not incise its canyon until volcanism had died out in the nearby West Elk and San Juan Mountains (fig. 7). Therein is one of the real clues to the mystery. The youngest volcanic rocks that clearly antedate the canyon belong to a sequence of dark basaltic lava flows called the Hinsdale Formation. Scattered remnants are all that remain of this formation near the Black Canyon, although large masses are preserved in the San Juan



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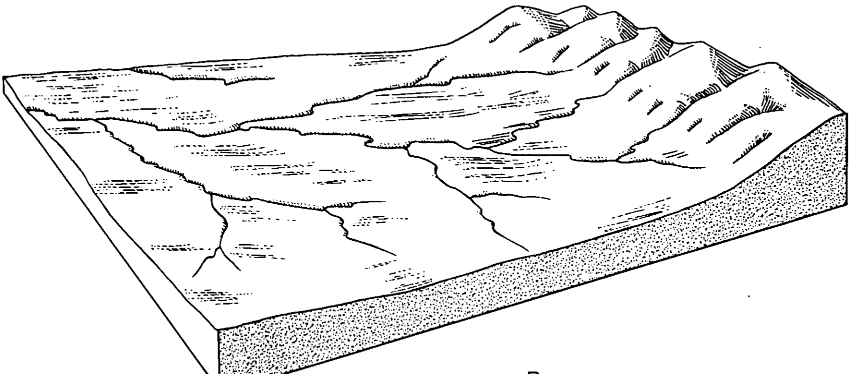

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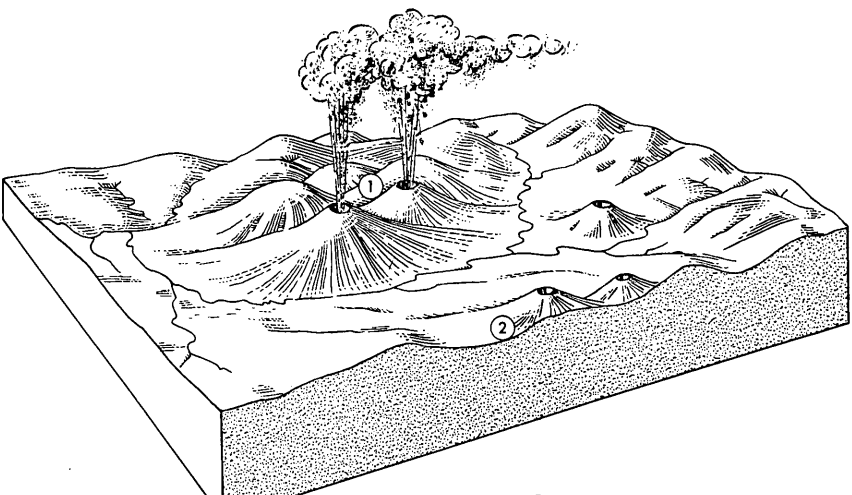

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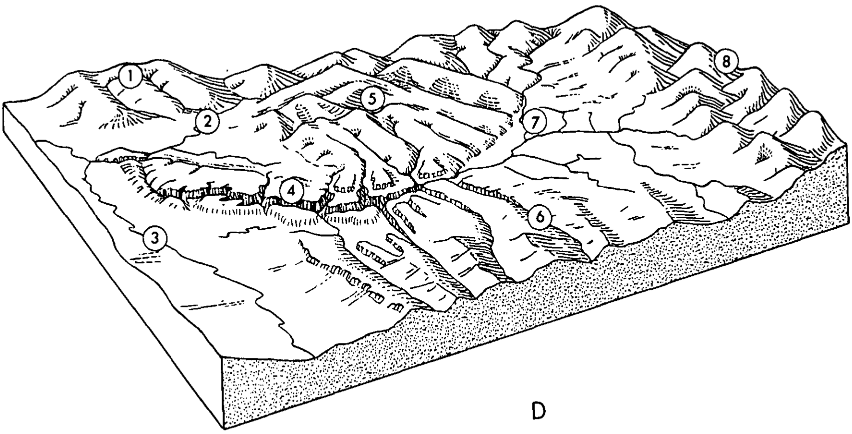


FIGURE 7.—Critical stages in the formation of the Black Canyon landscape.

A. Late Laramide stage (early Tertiary).—The newly formed Gunnison uplift (1) and the Sawatch Range (2) are being attacked by erosion. Initial drainage is north to a large lake (3) centered in central western Colorado and eastern Utah.

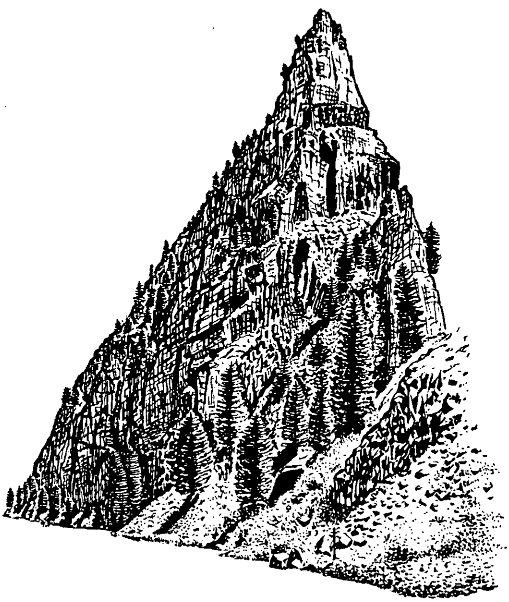
B. Planation stage (middle Tertiary).—Erosion has planed off the Gunnison uplift and has greatly reduced the Sawatch Range. Streams course freely across a broad flat plain, independent of underlying rock structure.

C. Volcanic stage (middle to late Tertiary).—Repeated volcanic eruptions have built up mountainous piles of debris in the newly formed West Elk Mountains (1) and in the San Juan Mountains to the south (2). Drainage has been diverted south around the periphery of the West Elk Mountains across the buried Gunnison uplift.

D. Present stage.—Gunnison River has entrenched itself into Precambrian core of exhumed Gunnison uplift, and in so doing has carved Black Canyon. (1) Shoulder of Grand Mesa, (2) North Fork, (3) Uncompahgre River at Montrose, (4) Black Canyon, (5) West Elk Mountains, (6) Lake Fork, (7) Gunnison River at Gunnison, (8) Monarch Pass.

Mountains. The age of the Hinsdale is generally, but doubtfully, regarded as Pliocene, an epoch that began about 11 million years ago and ended about 1 million years ago.

After the Hinsdale was erupted, it was attacked by erosion, and its debris was redeposited as bouldery gravel. This also was a Pliocene event that preceded canyon cutting. Remnants of the gravel still cap some of the mesas near the head of the canyon. After Pliocene time, during the Ice Age or Pleistocene Epoch, glaciers repeatedly occupied the high valleys of the nearby mountains. Melt waters from the glaciers deposited terrace gravels along the Gunnison and its tributaries at altitudes well below the rims of the Black Canyon. Evidently then, canyon cutting began well before the start of glaciation in Pleistocene time; it must have begun late in the Pliocene. The best guess based on present knowledge places the event about 2 million years ago. Therefore, in a canyon that averages about 2,000 feet in depth, the rate of downcutting has been about 1 foot per 1,000 years.



ROCK FORMATIONS—
Their Attributes and Geologic Settings

People young and old seem to have an innate curiosity about rocks. Possibly, this is a heritage of man's late emergence from the Stone Age, when his very existence depended on their judicious use! Yet, all too few people know what rocks really are, how they form, how they change, and how they differ among themselves; or more significantly, how they affect the course of history and the fortunes of mankind. Whatever the real reason for man's natural interest in rocks, his wonderment grows into a sense of deep enjoyment if he has a basic understanding of rock formations and their attributes.

Visitors to the impressive vantage points along the Black Canyon will gain a fuller appreciation of the canyon if they can relate what they see to the rocks underfoot and relate the rocks in turn to the inexorable forces of nature which through eons of time have shaped and reshaped the face of the earth. Viewed in this light, the canyon acquires new meaning, takes on a unity of design, and becomes an integrated whole.

Many rock formations of the Black Canyon area crop out widely in other parts of the western interior of the United States, particularly in the Rocky Mountains and the Colorado Plateaus. Once recognized, they become old "friends" who greet the traveler again and again as he journeys from place to place.

As shown in figure 8, rock formations in the Black Canyon area vary widely in age and kind. Long spans of geologic time are unrepresented because the area was being eroded or at least nothing was being deposited during much of the time. Rocks that had formed during one geologic period were attacked and removed by erosion during a later period,

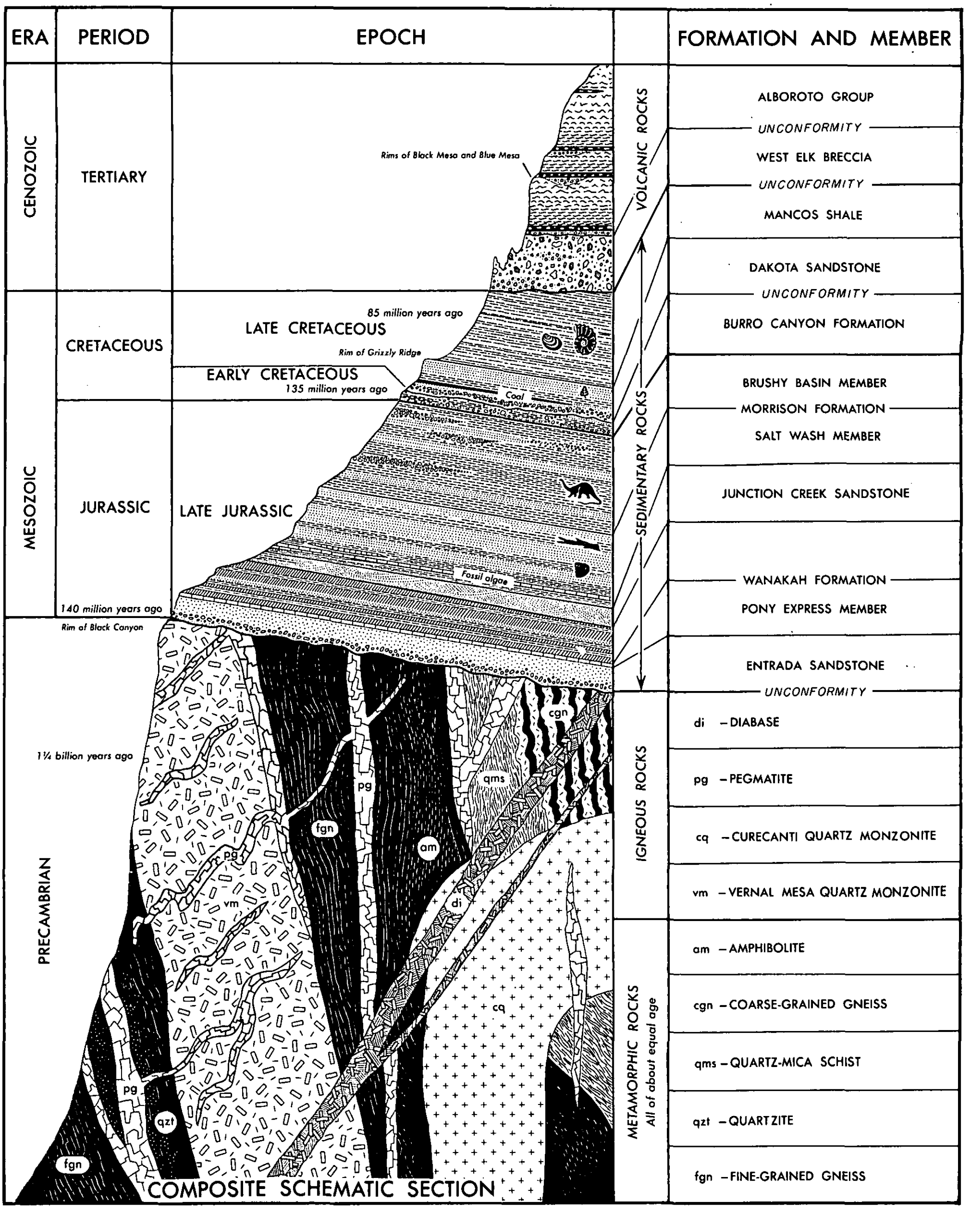


FIGURE 8.—Rock formations of the Black Canyon area.

and parts of the geologic record were destroyed or uninscribed. Much of the geologic history, therefore, is unrecorded or at best is inferred from fragmentary evidence borrowed and pieced together from adjacent areas. Even so, an impressive story can be read from the rocks that remain.

The oldest rocks of the Black Canyon belong to the Precambrian System. These rocks are sometimes called the "basement complex," or more simply, the "basement rocks." Radiometric analyses indicate that their age exceeds 1¼ billion years. Several types of Precambrian rock are well represented in the canyon walls. All can be assigned, however, to two main classes: metamorphic rocks transformed by heat and pressure from preexisting rocks and igneous rocks intruded into the metamorphic rocks as hot molten masses. Precambrian rocks form virtually all the walls and the floor of the Black Canyon, and they are nowhere in the world better exposed. Locally they form broad upland tracts back from the rims of the canyon, especially on Vernal Mesa, Poverty Mesa, and Coffee Pot Hill, and toward the upper end of the canyon at Fitzpatrick Mesa and the canyon of Blue Creek. In some places younger sedimentary or volcanic rocks cap the rims of the canyon or extend down into the canyon along faults.

METAMORPHIC ROCKS—PRECAMBRIAN

Gneiss

Many kinds of metamorphic rocks crop out in the Black Canyon. Gneiss, schist, and quartzite predominate and have a profusion of textural variations. Gneiss is the most common rock in the canyon, and fine-grained varieties of gneiss predominate in areas reached by trail or overlook in the national monument. Petrographers would call some of these rocks "quartz phyllonite." Good examples are seen at Tomichi Point, Pulpit Rock, Island Peaks, The Narrows, and Kneeling Camel, to mention but a few. Coarse-grained varieties predominate downstream below Warner Point, in the vicinity of Red Rock Canyon, and upstream from the monument near Blue Mesa Dam.

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Most of the fine-grained gneisses are conspicuously layered. This layering is chiefly a relict feature preserved from ancient times before the rock was metamorphosed. The rock, in other words, accumulated layer by layer as sands and muds on the floor of a primordial sea. Compaction and crystallization, aided by burial, converted the sediment to rock. Shearing, granulation, recrystallization, and contortion deep within the earth imposed further changes. Strong uplift and deep erosion finally brought the rock to its present position at the surface of the earth.

Close examination of the fine-grained gneisses shows that they consist of mixtures of several different minerals. Though not at all obvious to the naked eye, these minerals are predominantly quartz and mica—chiefly clear mica or muscovite and subordinately black mica or biotite. In

FIGURE 9.—Contorted gneiss, north rim of Black Canyon near Colorado State Highway 92. Contortions caused by flowage under great heat and pressure in the depths of earth's crust. Complicated structures such as these are confined to the Precambrian rocks. Light-colored bands are mostly feldspar and quartz, dark bands mostly quartz and biotite. Note fountain pen for scale.

various proportions are feldspar and traces of other minerals. Feldspar predominates in many of the coarse-grained gneisses, but quartz and mica are invariably present in appreciable quantity. Garnet, sillimanite, and, more rarely, staurolite and tourmaline are accessory minerals found in some gneisses of the Black Canyon. Magnetite, apatite, and zircon in trace amounts are present in most of them.

Many gneisses in the Black Canyon, especially in the upper part of the canyon near such places as Blue Mesa Dam and Pioneer Lookout Point, are "hybrid" rocks that contain about equal parts of igneous and metamorphic material. The igneous material was introduced at great depth into the preexisting rock as a hot fluid which permeated all available cracks, fractures, and other planes of weakness such as bedding or foliation planes. The resultant rock is variously called ribbon gneiss, injection gneiss, or migmatite. It consists generally of light-colored layers of quartz- and feldspar-rich material intermixed with darker colored layers of quartz- and mica-rich material. Gneiss of this sort (fig. 9) commonly shows evidence of severe deformation under high pressure, such as tight wrinkling of bedding planes or intricate folding and faulting on both a small and a large scale.

Quartz-Mica Schist

Schist is much subordinate to gneiss in the Black Canyon, but it is plentiful in some places including parts of the national monument. Despite infinite variations in texture, grain, and mineralogy, only two basic types have wide extent—quartz-mica schist and hornblende schist or amphibolite.

Quartz-mica schist is found in the monument chiefly in the area between Warner Point and the mouth of Red Rock Canyon where it forms the core of a large anticline in the floor and walls of the Black Canyon. Farther north, it is found in Red Canyon of Crystal Creek and to the southeast at Sheep Knob, Morrow Point, Mesa Creek, and adjacent parts of the Black Canyon near Morrow Point damsite. In all these areas it is thought to be the same thick body of schist, repeated from place to place by folding and faulting.

The coarser grained schists are quick to catch the eye of most viewers. They have a glittery spangly appearance caused by countless flakes of muscovite and biotite in a matrix of quartz. Feldspar is present in most specimens, also, and with its volumetric increase the rock grades into gneiss. The finer grained schists are less arresting, having a silky or satiny look on fresh exposures. They gain character, however, from scattered small but well-formed bright-red crystals of garnet a millimeter or two across. Other minerals likely to be present in quartz-mica schist, but mostly in microscopic grains, are sillimanite, hematite, apatite, and tourmaline.

Amphibolite

Amphibolite is a term applied to foliated metamorphic rock composed chiefly of a mineral of the amphibole group (mainly hornblende) and a feldspar of the plagioclase group. Besides these constituents, the amphibolites of the Black Canyon commonly contain subordinate apatite, biotite, diopside, epidote, magnetite, quartz, sphene, and zircon—mostly in microscopic grains. The more strongly foliated amphibolites are sometimes called hornblende schist.

Dark-gray to nearly black masses of amphibolite are abundant in many parts of the Black Canyon, including the national monument where, however, they occur mostly outside the areas served by trails and overlooks. Thin amphibolite bodies crop out sparsely on the rim between Pulpit Rock and Gunnison Point in a zone that reaches across the canyon toward Kneeling Camel. Most of the larger bodies are associated stratigraphically with quartz-mica schist. Thick ones that crop out in the canyon walls between Warner Point and the mouth of Red Rock Canyon are visible at a distance from High Point and Sunset View; northwest from High Point some very dark colored ones can be seen 2 to 3 miles distant on the canyon wall below Green Mountain.

What probably is part of the same group of amphibolite bodies just described crops out north of Green Mountain in

Red Canyon of Crystal Creek. Upstream from the monument, amphibolite is abundant in both walls of the Black Canyon a mile east of Morrow Point damsite and 2 miles west, farther east near the mouth of Round Corral Creek (Curecanti Needle quadrangle), and still farther east in the Sapinero area. Possibly the most accessible outcrops are near the south abutment of the U.S. Highway 50 bridge across Blue Mesa Reservoir 4 miles east of the dam. The best and most complete exposures, however, are those in Red Canyon of Crystal Creek.

Quartzite

Quartzite is subordinate volumetrically to gneiss and schist in the Black Canyon, but it has wide distribution and is an important member of the metamorphic sequence. Interbedded with either gneiss or schist, it grades into gneiss by an increase in feldspar content and into schist by an increase in mica. Even the purest quartzite in the Black Canyon contains some feldspar and mica.

Well-exposed quartzite crops out in the monument on the north rim along a primitive road half a mile east of the North Rim Ranger Station. Though thoroughly recrystallized, it shows well-preserved details of original bedding. These outcrops are the most easily reached good exposures of quartzite in the Black Canyon. The same beds trend southwestward to the steep brushy slopes across the canyon north of Gunnison Point. Thick sequences of similar quartzite, possibly the same strata, crop out near the southeast boundary of the monument on the north rim 1 to 2 miles or so east of East Portal. Similar quartzite is exposed 20 miles farther east at Lake Fork. Quartzite, grading into gneiss and interbedded with mica schist, crops out in the cliffs near the mouth of Cimarron Creek.

IGNEOUS ROCKS—PRECAMBRIAN

Igneous rocks are volumetrically less plentiful in the Black Canyon than metamorphic rocks, but they are very abundant nevertheless. They are evident everywhere even to the casual observer, for they are almost singularly responsible for the impressive "architecture" of the canyon walls. Most of the more precipitous parts of the canyon are due to the erosive resistance of igneous rock. In the form of dikes, intrusive sheets, or irregular masses, moreover, they have a buttressing effect on adjacent metamorphic rock, so that the steepness and grandeur of the canyon walls at any given place depend largely on the relative quantity of injected igneous rock. The Narrows, for example, consists of gneiss thoroughly buttressed by dikes of pegmatite. The great cliffs at Chasm View and far upstream at Curecanti Needle are carved wholly from igneous rock. Painted Wall, the highest cliff in Colorado and one of the finest cliffs in the canyon, consists chiefly of gneiss, but it is laced with dikes of pegmatite, and the gneiss is so thoroughly enriched with feldspar that it approaches granite in composition, appearance, and physical behavior. (See frontispiece.)

Several kinds of igneous rock of Precambrian age crop out in the Black Canyon. By far the greater volume consists of only two rock types—quartz monzonite (several varieties) and pegmatite. Subordinate types more rarely observed include diabase, aplite, and certain dark-colored rocks called lamprophyres.

Vernal Mesa Quartz Monzonite

Quartz monzonite is a rock similar to granite in general character and appearance but different in mineralogical and chemical composition. The chief basis for distinction, in brief, is the type of feldspar. Granite contains predominantly an alkalic feldspar (generally microcline or orthoclase), whereas quartz monzonite contains roughly equal parts of alkalic feldspar and plagioclase. Chemically, therefore, granite contains more of the alkali metals sodium and potassium and less calcium than quartz monzonite does. Granite also generally contains more silica. In the terminology of the stone industry, all such rocks and many others as well are referred to collectively as granite, but to the petrographer they are distinctly different rocks.

Two chief varieties of quartz monzonite crop out in the Black Canyon. One called Vernal Mesa Quartz Monzonite (fig. 10) is a dark-gray coarse-grained variety. The other called Curecanti Quartz Monzonite is light colored and finer grained. Both varieties were named many years ago by Hunter (1925). Both form large homogeneous rock masses which lend distinction and character to the canyon walls.

Vernal Mesa Quartz Monzonite forms several separate intrusive bodies in the national monument area. The largest body has an outcrop of about 3 square miles. It forms the sheer walls of the canyon from Rock Point downstream past Chasm View (fig. 5) to Cedar Point, Dragon Point, Sunset View, and High Point. Clearly, this reach of canyon is the most rugged in the entire area. The same body of rock underlies most of the rolling upland between Big Draw and High Point. Undoubtedly its extent is much greater under cover of overlapping sedimentary rocks. Smaller masses of Vernal Mesa Quartz Monzonite crop out at the head of Red Rock Canyon, southeast of

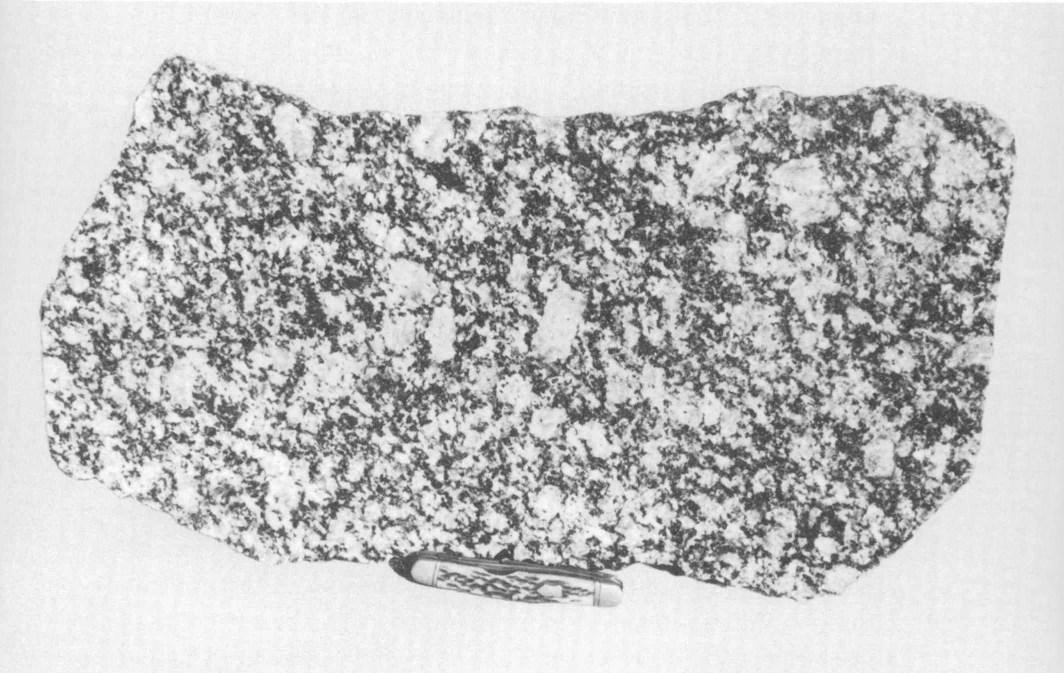

FIGURE 10.—Hand specimen of Vernal Mesa Quartz Monzonite, showing porphyritic texture with large phenocrysts of microcline. Groundmass feldspar is plagioclase. Dark splotchy material is mostly biotite. One-third natural size.

the main body near Big Draw, on the east side of Signal Hill near the River Portal Road, and along the River Portal Road about 4½ miles above its junction with U.S. Highway 50.

Rocks similar to the Vernal Mesa Quartz Monzonite—different in detail, but possibly related in origin—underlie most of the Black Canyon in the Black Ridge quadrangle.

Possibly the best place to view and examine the Vernal Mesa Quartz Monzonite at both close and long range is Chasm View overlook. Inasmuch as the rock differs little from place to place, one good exposure illustrates most of the general features. The most striking petrologic feature of the rock is its very coarse porphyritic texture. This term applies to igneous rocks in which certain mineral grains called phenocrysts greatly exceed the average grain size of the rock (fig. 10). In the Vernal Mesa Quartz Monzonite abundant phenocrysts of microcline feldspar 1 to 2 inches long form about 20 to 30 percent of the rock. Oligoclase, the groundmass feldspar, is less conspicuous than microcline, but it equals or exceeds microcline in total volume. Other mineral constituents in order of decreasing abundance are quartz, biotite, opaque iron minerals, epidote, sphene, hornblende, apatite, and calcite. Percentages are about as follows:

Feldspar:	
Oligoclase	37
Microcline	29
Quartz	24
Dark minerals (mainly biotite)	9
Sphene	<1
	100

Because of its coarse texture, the Vernal Mesa Quartz Monzonite has a mottled appearance—pink caused by microcline and gray caused by disseminated biotite in the groundmass. Viewed from a short distance, the overall color of fresh rock is light brownish gray. On some outcrops a deeper brown cast is caused by oxidation and weathering, and in many places the true color is masked by dark-brown to black encrustations of desert varnish.

Discerning viewers will notice that the rock has a fairly marked "grain" caused by a subparallel orientation of the microcline phenocrysts. Petrographic studies suggest that the rock was strained by slight viscous flowage after most of the mineral constituents had crystallized, but before complete solidification. During such flowage, phenocrysts tend to rotate mechanically into alinement with the direction of flowage. At the same time they may be damaged somewhat by rubbing one against another. Thus, most of the phenocrysts are fractured or abraded, and many of them have granulated rinds or borders. Further manifestations of viscous flowage are oriented inclusions of schist and gneiss torn from the walls of the quartz monzonite body during emplacement and frozen in place as the magma cooled. Though not abundant, such inclusions can be seen in nearly all good exposures of the rock.

Curecanti Quartz Monzonite

Curecanti Quartz Monzonite is widely exposed in the upper part of the Black Canyon where it forms one large central pluton and many smaller ones. It takes its name from Curecanti Needle, a spirelike monolith opposite the mouth of Curecanti Creek in a wildly picturesque section of canyon (fig. 11). Nearly-vertical walls of flesh-colored quartz monzonite exceed a thousand feet in height. The needle itself is nearly 800 feet high. Good views of the area are had from Pioneer Lookout Point on the Black Mesa Road and from the north rim of Fitzpatrick Mesa.

The main Curecanti pluton is a thick lens-shaped body 3½ miles across, west to east, and 2 miles across, north to south. It has a roof and a floor, both exposed in the canyon walls. In general shape it is similar to a flattish laccolith (fig. 12), but it differs fundamentally from a laccolith by being wholly discordant in relation to the intruded rock, which is contorted biotite gneiss. The western part of the pluton extends below drainage and appears to be deeply rooted. Physical conformation suggests that the quartz monzonite arose from depth beneath the western part of the pluton, gained access to a set of low-angle fractures in the country rock, then spread laterally by forcibly lifting its roof.

The quartz monzonite is a relatively uniform rock, light gray to orange pink and medium grained. Hand specimens from the main pluton are virtually indistinguishable from specimens from the minor plutons. A distinguishing mineralogic feature of the main pluton, however, is a scattering of clear pink garnets a tenth of an inch or so across. These garnets are seen in nearly every outcrop of the main pluton, but they are lacking from nearly all of the minor ones.

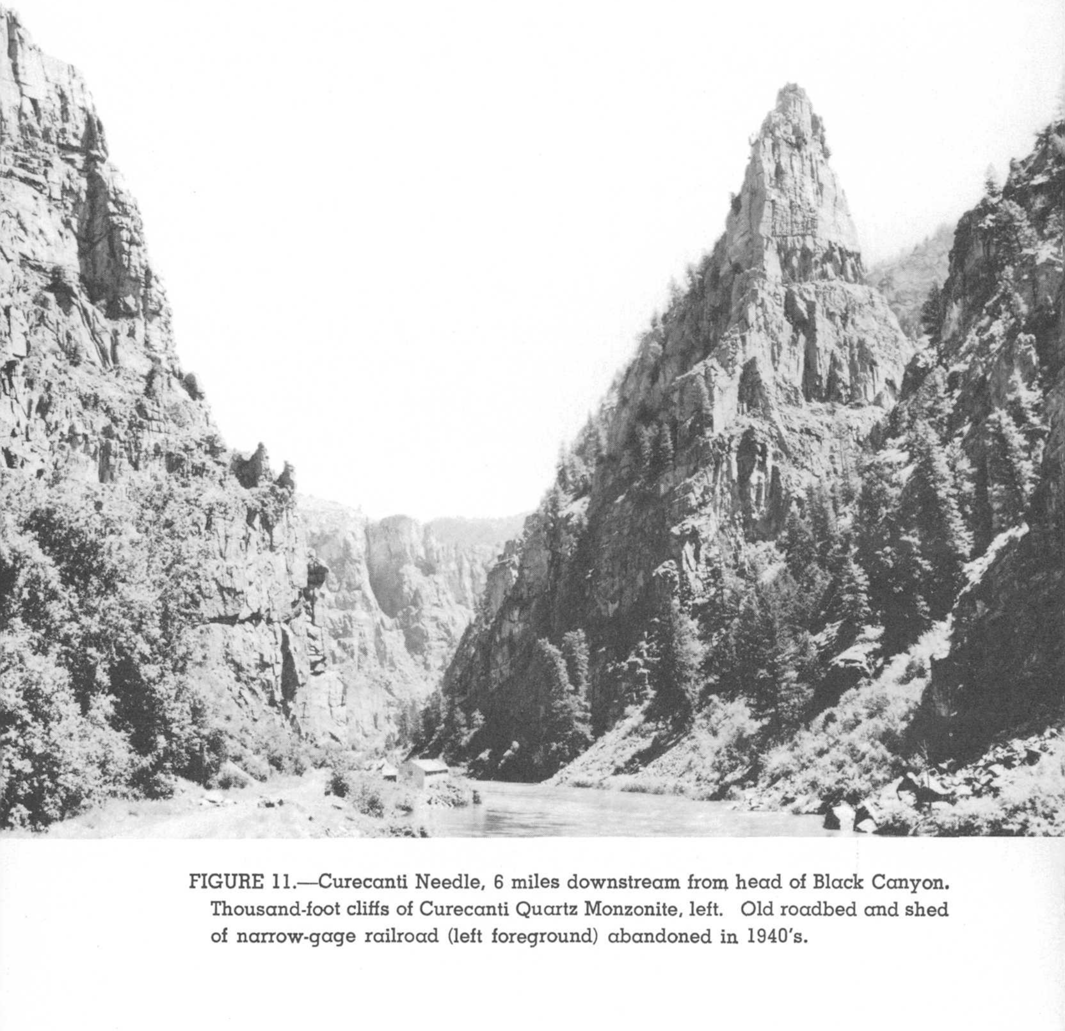

FIGURE 11.—Curecanti Needle, 6 miles downstream from head of Black Canyon. Thousand-foot cliffs of Curecanti Quartz Monzonite, left. Old roadbed and shed of narrow-gage railroad (left foreground) abandoned in 1940's.

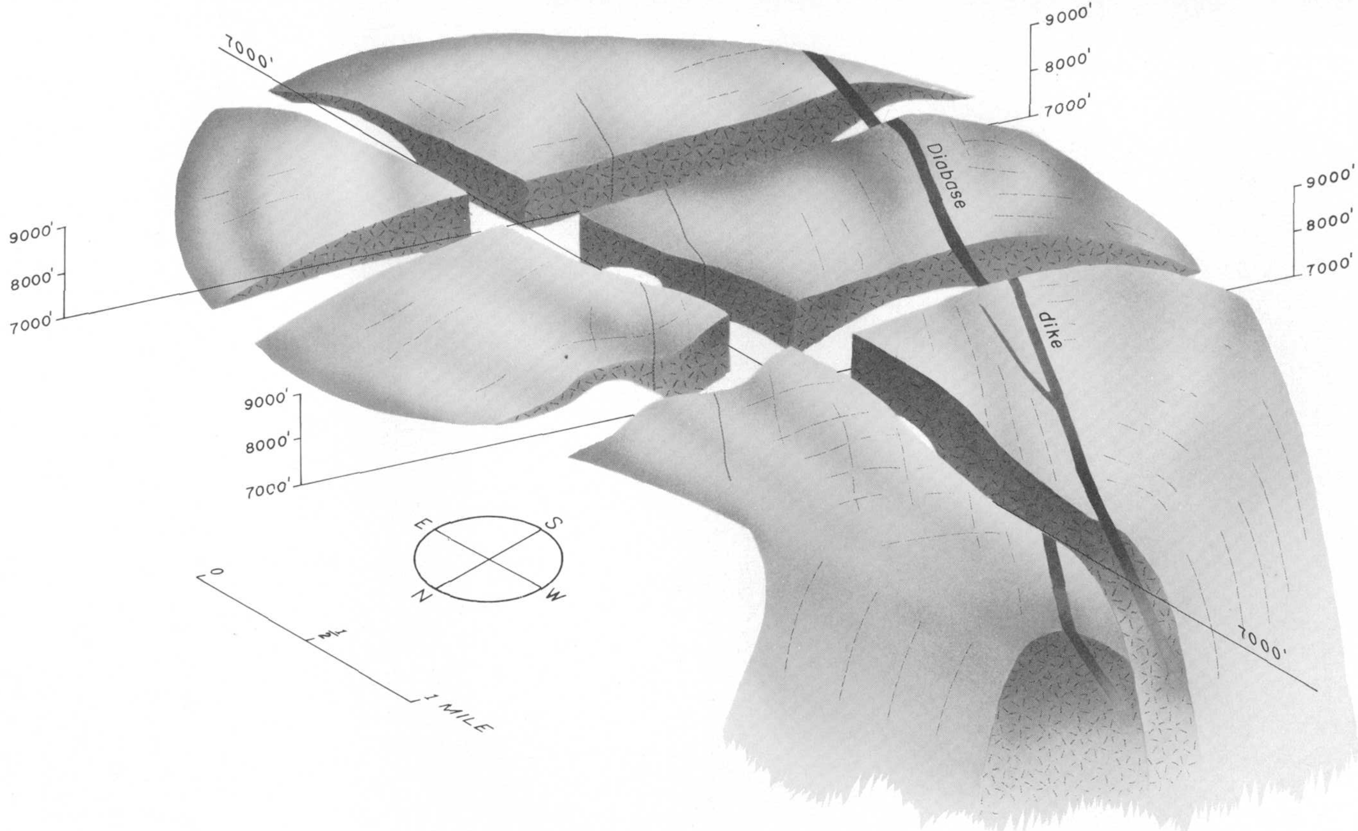

FIGURE 12.—Stereogram of the Curecanti pluton showing generalized restored form of the uneroded body.

Average mineral composition of 15 samples of Curecanti Quartz Monzonite, each collected from a different locality, is as follows:

Quartz	33.7
Feldspar:	
Oligoclase	33.0
Microcline	25.7
Mica:	
Biotite	4.0
Muscovite	3.0
Other (epidote, garnet, apatite, opaque iron minerals, sphene, zircon)	.6
	100.0

Minor Quartz Monzonite Bodies

Small elongate bodies of light-colored quartz monzonite crop out at a few places in the national monument area, mostly near to masses of Vernal Mesa Quartz Monzonite. They seem, therefore, to be related genetically to the Vernal Mesa Quartz Monzonite, although they differ greatly from it in appearance and composition. They are finer grained and contain far fewer dark-colored minerals. Oligoclase, quartz, microcline, and muscovite, in variable proportions, are the predominant minerals. Biotite, sphene, and thinly scattered garnets are subordinate.

Most of the individual minor quartz monzonite bodies are elongate parallel to the bedding or foliation of the enclosing wallrocks. Most of them are themselves somewhat foliated, and their foliation is parallel to that of the enclosing wallrocks.

Pegmatite

The term "pegmatite" applies to various intrusive igneous rocks of very coarse and variable grain size. Pegmatite is exceedingly abundant in the Black Canyon area, and countless bodies large and small contribute to the unique quality of the canyon scenery (fig. 13). Being highly resistant to erosion, as shown in figure 13, pegmatite crops out boldly where juxtaposed against less resistant rocks, such as schists and most gneisses. Against other igneous rocks, such as the Vernal Mesa Quartz

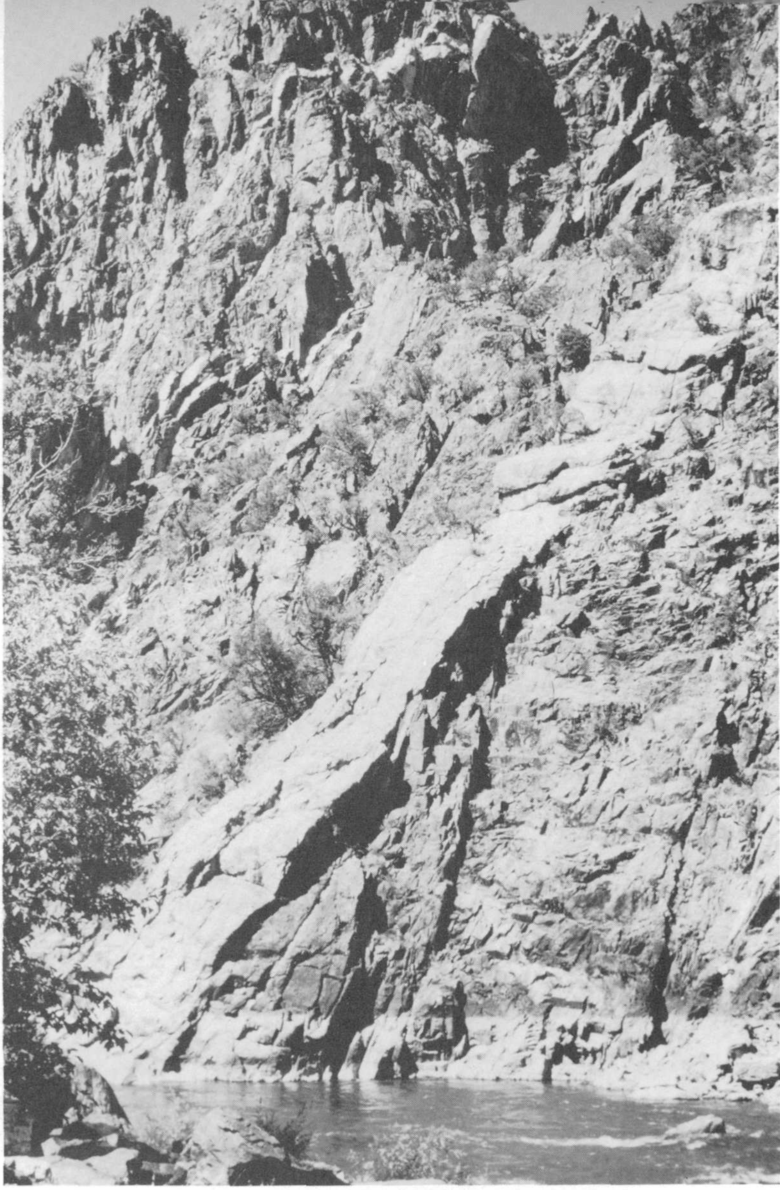

FIGURE 13.—Pegmatite dike intruding biotite gneiss in Black Canyon, about two-fifths mile downstream from mouth of Red Rock Canyon. Dike stands out because of superior erosive resistance. Note similar dikes in cliffs above.

Monzonite, it erodes less differentially, but it forms striking tonal patterns on the canyon walls. Painted Wall (frontispiece) is named for the festoonlike pattern of pegmatite in the sheer cliff below Serpent Point.

Pegmatite—in the form of dikes, sills, and irregular masses—is seen from every rim overlook in the Black Canyon area. Particularly striking outcrops are across the canyon from Pulpit Rock, Chasm View, and Cedar Point. Several overlooks stand on pegmatite outcrops—Gunnison Point is a good example—and afford a close view of the rock.

Upstream from the national monument, many large and excellent examples of pegmatite crop out at Poverty Mesa, Cimarron Creek, Blue Creek (adjacent to U.S. Highway 50), and Pioneer Lookout Point. Countless dikes crop out in the walls of the canyon and along the floor.

The largest pegmatite bodies in the area are between River Portal Road and Big Cimarron Creek; many dikes are hundreds of feet across and thousands of feet long. The largest single mass of pegmatite is a stocklike body that forms the top and rugged east slope of Coffee Pot Hill. This mass is nearly 1½ miles long, is more than half a mile across, and covers an area of more than half a square mile. Only slightly less impressive are the many large dikes on Poverty Mesa and Sheep Knob. Some of these dikes are plainly visible to travelers on U.S. Highway 50 south and west of Cimarron. Even from a distance their light color and rugged aspect set them apart from the country rock.

In close views the pegmatite is seen to consist chiefly of feldspar, quartz, and mica in coarse crystal intergrowths. The feldspar is mostly a pink variety of microcline, less commonly albite. The quartz is massive and milky, although scattered clear specimens have partly formed crystal faces. Feldspar-quartz intergrowths called graphic granite are very abundant. Muscovite is the predominant mica; biotite is subordinate. Some pegmatite dikes contain accessory magnetite or hematite in irregular partly faceted masses an inch or two across. More rarely, they contain well-formed trapezohedral garnets a few tenths of an inch across. A few pegmatite dikes that intrude amphibolite consist mostly of hornblende and plagioclase feldspar.

The coarse texture of the pegmatite is conspicuous to even the most casual viewer. Interlocking feldspar crystals in some places exceed 3 feet across—even 6 feet—and their lustrous cleavage surfaces fairly glitter in the brilliance of the western sun. Great masses of milky quartz are often several feet long. Books of pearly white mica are much smaller but no less arresting. These rarely exceed a few inches across, and most of them are even smaller.

Clear mica in large sheets—rare and valuable—is remembered as the isinglass window of Grandmother's oven door. Today, though no longer so used, clear mica has great industrial value, especially in the electrical industry, and is classed as a strategic mineral. The black variety is attractive but has no commercial value. It is less abundant than clear mica in Black Canyon pegmatites, but it is by no means rare. Bladed crystals as much as 6 feet long occur in some pegmatites.

A striking feature of pegmatite in the national monument area is its markedly different intrusive habit in different rock types. This difference is particularly noticeable between dikes that cut sheared or bedded schist and dikes that cut massive quartz monzonite. East across the canyon from Pulpit Rock, for example, an orderly array of straight-walled nearly vertical dikes "swarms" through the enclosing rock. At Cedar Point and Chasm View, however, low-dipping irregularly bounded dikes trend almost at random through the Vernal Mesa Quartz Monzonite; these dikes trend generally northwestward and dip unevenly to the northeast. Both in horizontal plan and in cross section, therefore, they depart widely from the orientation of dikes to the east. The difference in orientation is attributed to the differing fracture habits of the host rocks.

Aplite

Aplite is relatively scarce in the Black Canyon area and will not be seen by the average visitor. It is closely related to pegmatite in origin and composition but differs markedly in texture and grain size, its fine grain giving it a gray sugary appearance. Black Canyon aplites consist chiefly of quartz and feldspar with subordinate mica. Some contain garnets 1 to 2 mm across. Aplite forms straight-walled dikes, most being only a few tens of feet long in the

Black Canyon area; most of them are only a few inches wide and rarely are more than a few feet wide.

Diabase

Diabase is another dike-forming rock that is uncommon in the Black Canyon area but is of much interest to the geologist for its petrologic and structural significance. Diabase is abundant in some parts of the United States, especially in the North Atlantic States, where it forms great intrusive sheets known commercially as traprock. Physically and petrographically this rock resembles the diabase of the Black Canyon. The Palisades of the Hudson are composed of diabase. The diabase of the Black Canyon area is a dark-colored fine- to medium-grained rock composed chiefly of feldspar and augite. The dominant feldspar is a calcic variety called labradorite. Common subordinate minerals in microscopic grains are quartz, orthoclase, hornblende, biotite, chlorite, iron minerals, and apatite.

Although uncommon in the Black Canyon, diabase forms by far the longest dikes in the area. In a zone only 1 to 3 miles across but more than 26 miles in length, several dikes extend discontinuously from lower Bostwick Park east-southeast beyond Lake Fork. The longest continuous dike crosses the canyon just upstream from Tomichi Point, has an exposed length of nearly 8 miles, and has a maximum width of more than 300 feet. Its full length is unknown, as it is truncated by faults. Other large dikes crop out near the east portal of the Gunnison diversion tunnel. Farther up the canyon a large dike crosses the river near Nelson Gulch (2 miles west of Curecanti Needle) and crosses Blue Creek about a mile above the mouth. This dike is about 200 to 250 feet wide and is exposed for nearly 3 miles. It probably is appreciably longer than 3 miles, as both ends are concealed by overlapping strata, and there is no evident tendency for the dike to taper out in either direction. It might well extend an additional 3 miles beneath cover. Other diabase dikes of the area are mostly a few tens of feet across and mostly less than half a mile in exposed length.

Despite their size, the diabase dikes generally crop out poorly. Where the diabase is fresh, it is hard, tough, and resistant to erosion, but the rock weathers rapidly by chemical

FIGURE 14.—Dikes of lamprophyre cutting across biotite gneiss in Black Canyon about 1,000 feet upstream from Curecanti Needle. Dikes of this type are scarce in the Black Canyon area.

decomposition, and the weathered rock crops out poorly. The best exposures are in craggy areas below the canyon rims. Back from the rims, where the rock is deeply weathered, diabase is poorly exposed or concealed by soil.

Lamprophyre

Rocks called lamprophyre have been observed mostly in the upper part of the Black Canyon, although they are uncommon even there. Their chief interest lies in their unusual composition and geologic occurrence. Several of them crop out at Pioneer Lookout Point. They are dark-colored dike rocks, generally scores or hundreds of feet long but only a few inches to a foot or two wide. (See fig. 14.) They range rather widely in composition and appearance, but the predominant type is a dark greenish-gray fine-grained biotite porphyry. The matrix consists of hornblende, microcline, and oligoclase, with subordinate quartz, biotite, sphene, apatite, and zircon—all in microscopic grains. The lamprophyre dikes at Pioneer Lookout Point are cut by the Curecanti Quartz Monzonite and, hence, are clearly older than the quartz monzonite.

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FIGURE 15.—Black Canyon of the Gunnison National Monument and vicinity, Colorado.

GREAT ANTIQUITY OF THE PRECAMBRIAN ROCKS

Establishing the age of a rock, though likely to be a complex problem, is seldom an end in itself. Such a determination is an essential first step in solving problems in structural geology, which in turn must be resolved before the geologic history of an area can be reconstructed. Much time and energy, therefore, are spent by many highly trained specialists in both private and public research institutions in working out and refining the age relations of key rock formations.

In practice, the "absolute" age of a rock is seldom determined. Relative age is more readily obtained, and for most purposes is generally sufficient. This may be done by carefully noting the field relations that one rock bears to another or by studying the fossils in the rocks. Thus, one rock cutting across another affords clear evidence of relative age—just as a given stratum must be younger than the rock on which it lies, so also a crosscutting dike must be younger than the rock it cuts across. Inclusions of gneiss or schist in a granite must be older than the enclosing granite. Relations such as these help establish relative age.

Paleontology is a major tool in relatively dating fossiliferous rocks. It also has great value in correlating rock formations regionally. But it cannot be applied to the crystalline rocks of the Precambrian System, in which fossils do not exist. Radiometric methods have come to the fore in the past several years as a means of obtaining "absolute" ages for such rocks. These methods utilize known rates of decay of radioactive isotopes in various rock-forming minerals such as mica, certain feldspars, and zircon.

Most, if not all, Precambrian rocks in the Black Canyon are more than a billion years old. The oldest rocks are the metamorphic gneisses, schists, and quartzites which accumulated as sands and muds on an ancient sea floor, were hardened into firm rock, and were metamorphosed to nearly their present form before most of the igneous rocks of the canyon were emplaced. Several episodes of emplacement followed, and field relations indicate the following general succession.

First to be injected were early formed pegmatites, which to some extent shared the severe deformation of the gneisses, schists, and quartzites. Several generations of pegmatite injection may have followed. At any rate, lamprophyre dikes were injected after the early formed pegmatites, and they in turn were followed by renewed but diminished deformation. Quartz monzonite then was intruded, probably over a long span of time.

The minor quartz monzonite bodies of the national monument area seem to be older than the Vernal Mesa Quartz Monzonite, which in turn seems to be older than the Curecanti. The radiometric age of the Vernal Mesa Quartz Monzonite is 1.22 billion years.

At about the same time that the Curecanti Quartz Monzonite was intruded the greater part of the pegmatite in the canyon was intruded. Again, a long span of time probably was involved, totaling perhaps millions of years.

The youngest rock in the Precambrian sequence is diabase. Dikes of this rock cut across all other Precambrian rocks. Its Precambrian age is not firmly established, and conceivably it could be as young as Pennsylvanian—perhaps little more than 200 million years old! All that can be said with assurance is that it definitely is older than the unconformity at the canyon rim and, hence, is plainly pre-Jurassic. But it probably is pre-Pennsylvanian, and most likely is Precambrian.

THE ANCESTRAL UNCOMPAHGRE HIGHLAND— AN ANCIENT LAND SURFACE BURIED AND EXHUMED

During early and middle Paleozoic time—in the Cambrian, Ordovician, Devonian, and Mississippian Periods—a moderately thick blanket of strata accumulated intermittently in the Black Canyon area. These strata were completely removed by erosion in late Paleozoic time, but they still exist in adjacent areas, and their former existence in the Black Canyon area can be inferred from careful restorations of Paleozoic geography.

In Pennsylvanian time sharp uplift ended deposition and started a long period of erosion. During this period the earlier formed strata were removed. Even the Precambrian rocks were deeply scoured. Ultimately, the uplifted mountain mass itself was eroded away, but because its roots are preserved, its former extent can be inferred. Geologists refer to it as the ancestral Uncompahgre highland (fig. 16), not to be confused with the modern, much smaller Uncompahgre Plateau.

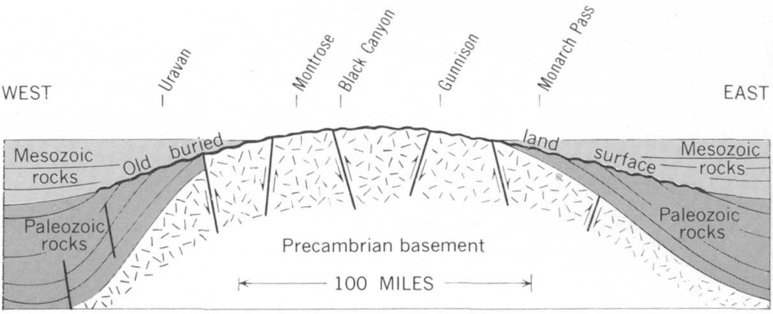


FIGURE 16.—Ancestral Uncompahgre highland just before Entrada Sandstone was deposited. The flanks of the old highland have been buried by earlier Mesozoic strata. Vertical scale is greatly exaggerated.

The ancestral Uncompahgre highland extended across southwestern Colorado from central-eastern Utah into northern New Mexico. Debris swept from its crest formed thick deposits in basins to the northeast and the southwest. These deposits are mostly red beds. They are well preserved near Aspen, Colo., where they form the picturesque Maroon Bells, at Ouray, where they form the colorful canyon walls, and at many other localities.

By Triassic time, the ancestral Uncompahgre highland was reduced to a low featureless plain. As shown in figure 16, it had the form of a broad flat arch or dome that sloped gently eastward and westward from an apex near the town of Gunnison. In the Black Canyon area it sloped westward at a rate of about 4 feet per mile.

In Late Triassic time, the ancestral Uncompahgre highland began to subside, and sediments began to encroach upon its flanks. These deposits, resting on the old Precambrian basement, are well displayed near Grand Junction in Colorado National Monument, where they comprise the Chinle, Wingate, and Kayenta Formations. But in the

Black Canyon area the crest of the old highland remained exposed to erosion until Late Jurassic time.

In the Black Canyon area the first formation to be deposited on the old surface was the Entrada Sandstone.' This formation thins abruptly eastward and wedges out against the slope of the surface near the east boundary of the national monument. The next overlying formation, the Wanakah, also thins abruptly eastward, but it reaches the vicinity of Sapinero before wedging out, about 20 miles beyond the edge of the Entrada. The Junction Creek Sandstone, which overlies the Wanakah, and the succeeding Morrison Formation overtopped the old highland and extended unbroken across its crest.

The planed-off surface of the ancestral Uncompahgre highland is well preserved in the Black Canyon as the conspicuous unconformity at the rim of the canyon. (See frontispiece.) This surface is one of the most striking features of the monument. It has been partly exhumed by erosion, the softer overlying formations having been removed; it forms the summit of Vernal Mesa on the southwest rim and the benchlike top of Mesa Inclinado on the northeast. Thin patches of Entrada Sandstone mantle both mesas.

SEDIMENTARY ROCKS—JURASSIC

Entrada Sandstone

The Entrada Sandstone is thin but well exposed at several places in the national monument along the northeast rim. It is visible from across the canyon as a thin light-colored band at the very rim of the canyon. On the southwest rim its outcrop is spotty because it has been stripped almost entirely away by erosion. The formation thins out completely east of a line joining Poison Spring Hill on the north and Coffee Pot Hill on the south, near the east boundary of the monument. East of this line the formation was never deposited, but it thickens abruptly to the west and on down the canyon to the north. Its most typical and best exposures are just west of the monument in the Red Rock Canyon area and farther north along the Black Canyon and its tributaries as far as Smith Fork (fig. 17).

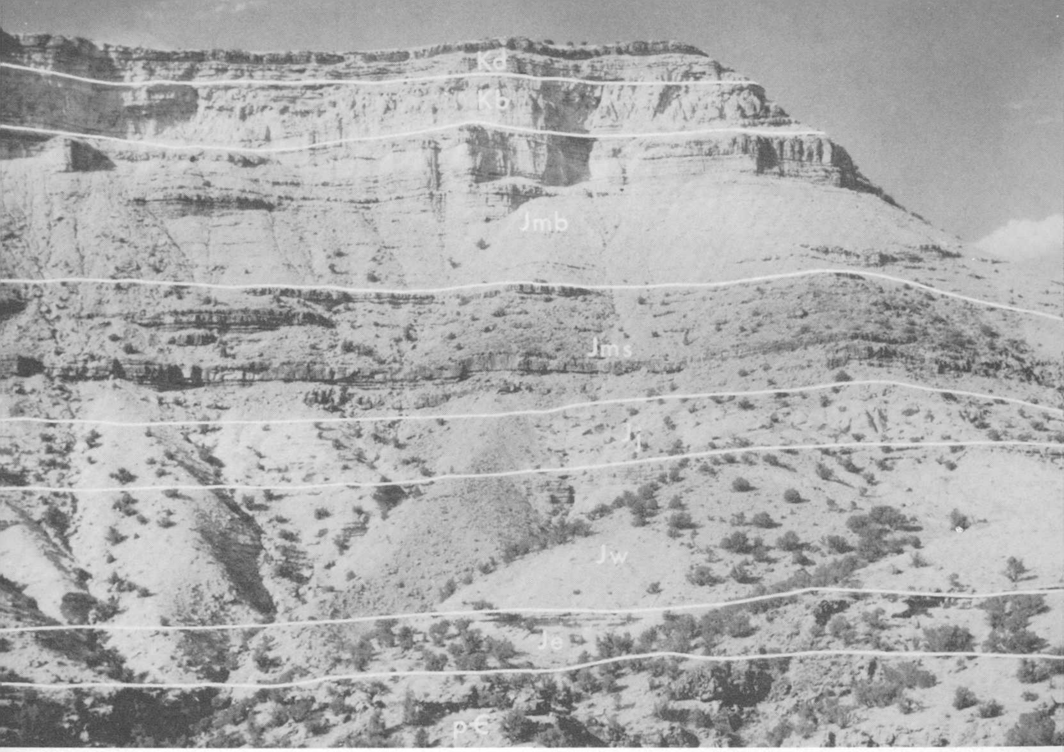


FIGURE 17.—Stratigraphic section about 1,000 feet thick near mouth of Smith Fork. One of the most complete and best exposed Jurassic and Cretaceous sections in the Black Canyon area. Symbols: p€, Precambrian gneiss; Je, Entrada Sandstone; Jw, Wanakah Formation; Jj, Junction Creek Sandstone; Jms, Morrison Formation, Salt Wash Member; Jmb, Morrison Formation, Brushy Basin Member; Kb, Burro Canyon Formation; Kd, Dakota Sandstone.

At Red Rock Canyon the Entrada Sandstone is 85 feet thick and consists of fine-grained massive cliff-forming sandstone. Its colorful outcrop is visible from Montrose, 8 miles distant to the southwest. The greater part of the formation is bright reddish orange, but the upper 17 feet is pale yellowish orange. Farther north, the pale-color phase thickens to about 40 feet at the expense of the underlying darker color phase. In the thin sections in the eastern part of the monument the dark-color phase is completely lacking.

In most places the Entrada has a basal conglomerate about 1 to 4 feet thick. This conglomerate contains angular fragments of the underlying Precambrian rock—gneiss, pegmatite, and vein quartz—in a coarse-grained sandstone matrix. The underlying Precambrian rock was variably weathered to depths of as much as 10 feet during its long pre-Late Jurassic exposure. The old weathered zone is well preserved beneath the Entrada Sandstone. In many places the weathered zone grades indefinitely upward into the basal conglomerate of the Entrada; this relation is well shown in outcrops along the canyon rims.

Most geologists agree that the Entrada Sandstone was deposited on the margin of a shallow seaway, mainly as onshore dunes, but partly in a marine environment and partly, perhaps, under true desert conditions. The uppermost 5 feet at Red Rock Canyon is well bedded and thin bedded and contains oscillation ripple marks. It probably was deposited in shallow water under conditions transitional to the subaqueous environment of the overlying Wanakah Formation.

Wanakah Formation

The Wanakah Formation consists of gypsum, varicolored shale and mudstone, friable sandstone, and gray cherty limestone. It accumulated in an arid landlocked seaway or brackish lake which flooded parts of southwestern Colorado and adjacent New Mexico after the Entrada Sandstone had been deposited. Seen from a distance, the overall aspect of the formation is that of a drab-gray slope separating brighter colored ledges of the Entrada Sandstone below and the Morrison Formation above. Where the Junction Creek Sandstone is present, the Wanakah directly underlies it.

Complete sections of the Wanakah Formation are exposed in the first large ravine west of Red Rock Canyon. Many good but less accessible sections are exposed farther north in the outer walls of the Black Canyon, in Red Canyon of Crystal Creek, and in the lower part of Smith Fork (fig. 17). Partial sections can be seen in the monument on the northeast rim, but completely exposed sections there are lacking.

Like the underlying Entrada Sandstone, the Wanakah Formation thins eastward. It overlaps the Entrada, but it, too, wedges out against the old slope of the planed-off Uncompahgre highland. It is about 150 feet thick at Red Rock Canyon, is about 55 feet thick at Sapinero, and wedges out completely a short distance east of Sapinero.

At the base of the Wanakah Formation in the more westerly parts of the Black Canyon is a distinctive limestone unit called the Pony Express Limestone Member. Outcrops of this unit are abundant along the northeast rim in the monument and can be seen from the north rim road near The Narrows.

The Pony Express was deposited in a brackish lake or an enclosed arm of the sea. Its eastern shoreline passed through the Black Canyon area and trended about south-southeast along a line from Red Canyon of Crystal Creek in Delta County to the south end of Dead Horse Mesa in Montrose County. East of this line the Pony Express Limestone Member never was deposited. Later and broader re-expansions of fresh water, however, are indicated by additional, more extensive limestones higher in the stratigraphic sequence. Some of these limestones contain the fossilized remains of fresh-water clams, snails, and algae.

Junction Creek Sandstone

The Junction Creek Sandstone crops out near the upper end of the Black Canyon at Sapinero and continues eastward toward Gunnison. It forms discontinuous outcrops on the slope of Soap Mesa along Colorado State Highway 92 and is preserved locally on the slope of Black Mesa. It thins generally westward along the Black Canyon and is lacking or doubtfully present in sections near the national monument. Although discontinuous in the lower part of the canyon, it is well represented at the mouth of Smith Fork (fig. 17), where it is 81 feet thick in a section measured by T. E. Mullens of the U.S. Geological Survey. The greatest observed thickness in the area is about 90 feet at Blue Mesa damsite. The Junction Creek Sandstone is only about 25 feet thick at Sapinero but thickens abruptly east of Sapinero. Regionally, it thickens greatly to the south.

The Junction Creek consists of highly crossbedded pale-gray to pink fine-grained sandstone. It somewhat resembles the Entrada Sandstone, but the Entrada in the monument area is much finer grained and less crossbedded. The Junction Creek once was a great tract of dunes on the dried-out floor of the old Wanakah sea.

Morrison Formation

The Morrison Formation, renowned for its dinosaurs, is one of the most widespread rock formations in the Rocky Mountain region. It flanks mountainous uplifts throughout Colorado and in parts of northern New Mexico, northeastern Arizona, eastern Utah, Wyoming, western South Dakota, southern Montana, western Oklahoma, and western Kansas. Its outcrop is extensive in the Black Canyon area, but it is poorly exposed in the national monument. Excellent exposures may be seen at many places downstream from Red Rock Canyon, at Red Canyon of Crystal Creek, and at Smith Fork (fig. 17). A good section is exposed near Sapinero at West Elk Creek. Most of the roadcuts along Colorado State Highway 347 between Bostwick Park and the monument boundary are in the Morrison Formation.

In the Black Canyon area the Morrison Formation has a maximum thickness of about 600 feet. It consists of bright-colored shale and mudstone, light-gray sandstone, and—in the upper part—light-gray mudstone and pebble conglomerate. On most outcrops the sandstone looks red, but this coloration is just a surface stain. Dinosaur remains, which are so characteristic of the Morrison Formation, have never been found in the Black Canyon area, but diligent search probably would discover some.

Two members of the Morrison Formation are recognized in the Black Canyon area—the Salt Wash Member, below, and the Brushy Basin Member, above. These members are widespread in southwestern Colorado and southeastern Utah, and they are readily distinguished from one another throughout the Black Canyon area, except where exposures are poor.

The Salt Wash Member consists of red, gray, and green shale and mudstone interbedded with crossbedded sandstone. Near the base of the member are a few thin fresh-water limestone beds. Total thickness of this member is about 250 feet in the lower part of the canyon and about 180 feet in the upper part. The sandstone beds form conspicuous slope breaks—in most places three successive cliffs or ledges of sandstone are separated by slopes of shale, but the sandstone beds are lenticular and taper out laterally. The top of the uppermost cliff is the arbitrary top of the member, and the overlying beds are included in the Brushy Basin Member. The Salt Wash Member is the host rock for important uranium deposits in many districts of the Colorado Plateau, particularly in western Colorado and eastern Utah; uranium, however, has never been reported in the Black Canyon area.

The Brushy Basin Member, about 350 feet thick, is mostly light-gray shale or mudstone, but it contains considerable red shale, gray sandstone, and discontinuous but very distinctive conglomerate. Much of the shale contains impure bentonite, a clay derived from the alteration of volcanic ash. Conglomerate near the middle of the member or toward the top contains many small pebbles of red and green chert in a matrix of coarse poorly sorted sandstone. This distinctive rock is a reliable guide to the Brushy Basin Member in areas of poor exposure.

Studies by many investigators show that the Morrison Formation accumulated on a broad alluvial plain—the sandstones and conglomerates as fillings in the channels of ancient meandering streams, the mudstones and shales as overflow deposits on a flood plain, and the limestones in ephemeral lakes. Few formations so bestir the imagination: It is easy to visualize a flat dusty plain shimmering under a hot Jurassic sun. Clouds of ash from a distant volcano darken the sky. A sluggish stream meanders across grassy meadows, its backwaters and banks rank with strange vegetation, the scene teeming with reptiles in variety—in the water, on the land, in the air—some small, some large, some agile, some stuporous, all fierce. All the wonderment of little boys is embodied in this formation.

SEDIMENTARY ROCKS—CRETACEOUS

Three formations of Cretaceous age crop out in the Black Canyon area—in ascending order, the Burro Canyon Formation of Early Cretaceous age, the Dakota Sandstone of Late Cretaceous age, and the Mancos Shale of Late Cretaceous age. Cretaceous rocks younger than Mancos, such as the Mesaverde Formation, are present in adjacent areas but have been stripped from the Black Canyon area by erosion during Tertiary time. Lower Tertiary rocks, such as the Wasatch and Green River Formations, if ever deposited, have also been removed. The Mancos Shale is partly overlapped by volcanic rocks erupted in middle and late Tertiary time. A long interval of Late Cretaceous and early Tertiary time, therefore, is unrepresented by any rock formations, and inferences regarding events in this interval must be drawn from adjacent areas.

Burro Canyon Formation

The Burro Canyon Formation overlies the Brushy Basin Member of the Morrison Formation. It is recognized throughout most of the Black Canyon area, although in areas of poor exposure it is distinguished with difficulty from the overlying Dakota, which it resembles. It consists chiefly of crossbedded stream-laid pebble conglomerate and coarse-grained conglomeratic sandstone, but it also contains finer grained sandstone layers and shale. The pebbles in the conglomerate are mostly light- to dark-gray chert and light-gray to cream-colored quartzite, mostly less than half an inch across but rarely several inches. Maximum measured thickness of the formation is about 110 feet. Lithologic character suggests that the Burro Canyon Formation was deposited by meandering streams shifting their channels across a broad alluvial plain.

Casual visitors to the Black Canyon are not likely to see good exposures of the Burro Canyon Formation. In many places the formation crops out poorly and forms brushy rubbly slopes interrupted only locally by ledges. Its line of outcrop is about 100 to 200 feet below the rims of Fruitland Mesa and Grizzly Ridge on the north and east rims of the Black Canyon. Elsewhere, the formation is well exposed in the remote northern part of the area—along the west side of the Black Canyon, in excellent cliff exposures along Smith Fork (fig. 17), and along the north side of Red Canyon of Crystal Creek. Good exposures may also be seen near the head of the Black Canyon near the mouth of West Elk Creek.

Dakota Sandstone

Like the Morrison Formation, the Dakota Sandstone is very widespread in the western interior of the United States. It is well represented in the Black Canyon area, where it forms hogbacks, rimrocks, and dip slopes; it caps mesas to the north and east of the national monument, including Fruitland Mesa, Grizzly Ridge, Poison Spring Hill, Dead Horse Mesa, and Pine Ridge. It also crops out between Bostwick Park and Vernal Mesa.

The Dakota consists mostly of crossbedded sandstone in beds a few inches to several feet thick. Beds are thinner and more uniform than in the underlying Burro Canyon. The Dakota also contains pebbly conglomerate, shale, mudstone, and locally coal.

Fossil ripple marks, worm burrows, petrified wood, impressions of twigs, and carbonized plant matter—all common in the Dakota—indicate deposition in shallow water. The coal accumulated in a swamp. The upper part of the Dakota interfingers with the lower part of the overlying Mancos Shale. Deposition of the Dakota, therefore, presaged the readvance of a seaway across the western interior of the continent.

Mancos Shale

The Mancos Shale also is widespread in the western interior of the United States. It flanks or encircles many mountainous uplifts of the region, including the Gunnison uplift through which the Black Canyon is cut. Being soft and easily eroded, it forms the bottoms of broad valleys and topographic basins. Such valleys are widely utilized for transportation routes, both highways and railroads. U.S. Highway 50, for example, traverses Mancos Shale almost from Cimarron, Colo., to Price, Utah; and the major towns between, including Montrose, Delta, Hotchkiss, Paonia, and Grand Junction, Colo., and Price and Green River, Utah, all stand on Mancos Shale.

Present access routes to the Black Canyon cross Mancos Shale. In ascending the slopes of the Gunnison uplift, one passes across progressively older rocks. Mancos Shale flanks the uplift south of Red Rock Canyon. Nearby, it underlies Bostwick Park and Cerro Summit south of the uplift and the Crawford, Iron Creek, and Crystal Creek areas north of it.

Excellent exposures are at nearly every hand in the Uncompahgre Valley west of the Black Canyon. There the shale presents a wearisome landscape of barren tan-gray slopes. But locally, it forms tracts of unworldly badlands likely to impress travelers looking for an offbeat change of scenery. In late afternoon, heightened by long shadows, the badlands are very photogenic. Extensive tracts just northeast of Montrose are easily reached by passenger car, except in wet weather when travel on the shale is precarious. Commanding views of the entire badlands area, and of the whole Uncompahgre Valley for that matter, are had from the summit of Flat Top Mesa, just 4½ miles northeast of Montrose.

The full thickness of the Mancos Shale is undetermined in the Black Canyon area, as the top is eroded off. Partial sections penetrated by wells exceed 4,000 feet in thickness. As exposed in the Black Canyon area, the unweathered shale is dark gray, very soft, and somewhat fissile; weathered shale is lighter gray to tan. Much of it swells on wetting and contracts on drying; on moist hillsides, therefore, it is very susceptible to landsliding.

The Mancos contains large calcareous concretions, some of which enclose marine mollusks. It contains a few beds of fine-grained calcareous sandstone, also in part fossiliferous. The formation is gypsiferous, and in badland areas many of the slopes are littered with sparkly gypsum crystals.

Deposition of the Mancos Shale coincided with an encroachment of marine waters across the western interior of the United States. At one time an expanse of water reached from Arctic Canada to the Gulf of Mexico. The Mancos was deposited as mud on the shallow bottom of this sea.

As the Mancos accumulated, the sea bottom slowly subsided, so that the water maintained an essentially uniform depth. Finally, however, when the rate of subsidence diminished, deltal and beach deposits crowded the sea from the area. These deposits now comprise the Mesaverde Formation, still preserved at Grand Mesa north of the Black Canyon and at Cimarron Ridge to the south. Rank forests that flourished on the low swampy ground gave rise to extensive coal deposits in the Somerset, Carbondale, and Book Cliffs areas. Repeated expansions and withdrawals of the sea marked Mesaverde time and the remainder of the Cretaceous Period. At about the end of the Cretaceous Period, crustal warping on a very large scale lifted the area above the sea and drained off the marine waters for the last time. This period of uplift is known as the Laramide orogeny.

THE LARAMIDE OROGENY— A TIME OF GREAT MOUNTAIN BUILDING

Near the end of the Cretaceous Period and during the early part of the Tertiary, widespread crustal disturbances in the western part of the United States outlined most of the major mountain uplifts and basins of the Rocky Mountain region. This critical interval in the history of the Rocky Mountain region is called the Laramide orogeny. The Gunnison uplift, into which the Black Canyon is cut, was formed at that time; renewed movements along old faultlines in the Precambrian basement elevated the Black Canyon area relative to what is now the Uncompahgre Valley to the west, the North Fork valley to the northeast, and the Cimarron Creek-Blue Creek drainages to the south. This uplift was caused chiefly by tilting of old fault blocks, but it was accompanied by some flexing of the sedimentary mantle and by considerable warping along the traces of the old faults. Locally, the beds were steeply tilted or even overturned.

Newly formed drainage systems collected runoff from the uplands and carried it to the intervening basins. An enormous lake formed northwest of the Black Canyon in an area called the Uinta-Piceance Basin. This lake probably covered the Black Canyon area also, but if it did, its deposits have since eroded away. Sediments that accumulated on its floor were derived partly from distant volcanic eruptions and partly from debris eroded off the adjacent uplands.

They now compose the Green River Formation, which is the source of the famous oil-shale deposits of western Colorado and eastern Utah.

Significant structural modifications at a later time followed the Laramide orogeny. For one thing, the great volcanic piles of the West Elk and San Juan Mountains were not erupted until considerably later in middle and late Tertiary time. They were preceded by a long period of erosion and were followed by renewed crustal warping.

EARLY TERTIARY DEPOSITION AND EROSION

Early Tertiary formations such as the Wasatch and Green River are preserved a few miles to the north of the Black Canyon at Grand Mesa. After the Green River lake disappeared—partly because of structural deformation and partly because of sedimentation—erosion attacked and destroyed the heights of the Gunnison uplift. Once again, the country was reduced to a flat plain, this time beveling the edges of the tilted Mesozoic formations and the reexposed Precambrian basement. Drainage that previously had flowed off the Gunnison uplift into adjacent basins now flowed at random across it, without regard to rock type or structure.

AN OUTBREAK OF VOLCANISM

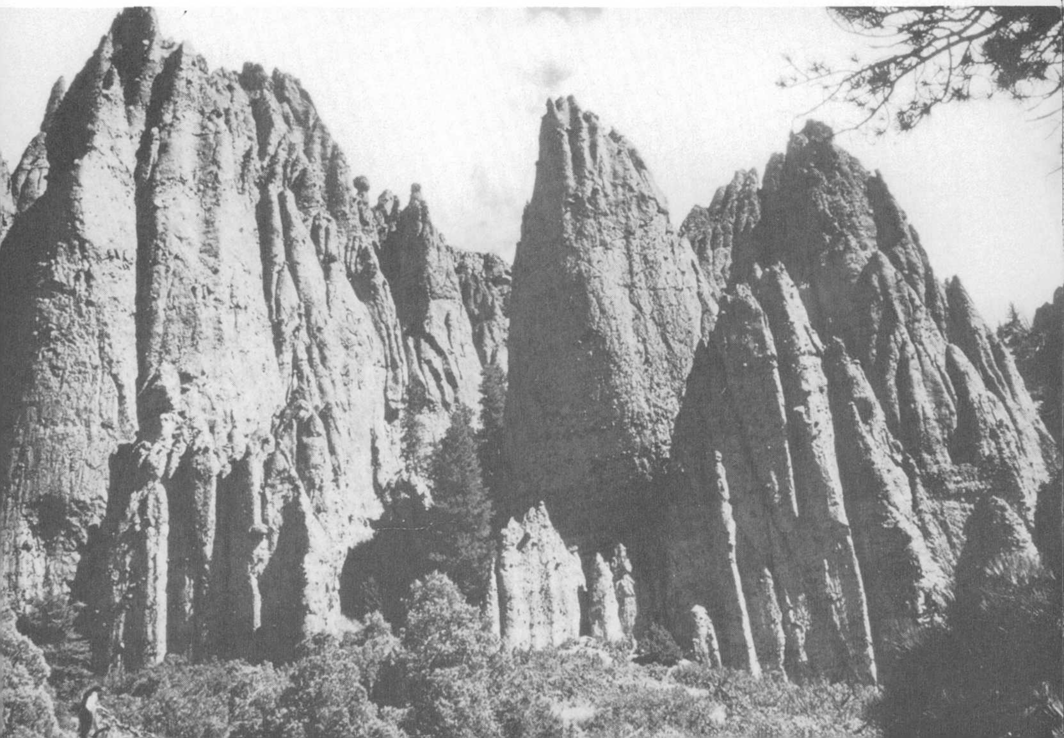
After this long period of erosion, volcanic activity broke out in the West Elk Mountains to the northeast and in the San Juan Mountains to the south, drastically altering the appearance of the Tertiary landscape. One far-reaching consequence was a complete overhaul of the drainage pattern—a step essential, as we shall see, to the ultimate carving of the present Black Canyon. Before volcanism began, streams meandered freely across a broad flat plain. Flowing westward from the newly risen Sawatch Range, they left a train of gravels in their wake. The mounting piles of volcanic rock, however, encroached laterally on the drainage from both sides, forced the drainage first through the narrowing breach between the eruptive centers, and finally perhaps disrupted the drainage completely after burying the accumulated gravels. Between outbursts, drainage was intermittently restored as surges of water made their way across the thickening volcanic cover. Thus arose the ancestral Gunnison River.

Geologists recognize many types of volcanic deposits. Most familiar are the lava flows solidified from streams of molten rock. Flows of this type, however, are very subordinate in the Black Canyon area. Two distinct sequences of dissimilar volcanic material were erupted: an earlier sequence called the West Elk Breccia and a later sequence called the Alboroto Group.

West Elk Breccia

The West Elk Breccia contains flows of solidified lava, but by far the greater part of it consists of coarse fragmental material formed otherwise. No single mode of eruption can explain its diverse character. A large part seems to have resulted from the explosive destruction of previously formed volcanic cones. Some part probably formed from a slurry of mud and blocks. In any event, the volume of material produced was enormous. Remnants in the south half of the West Elk Mountains much exceed a thousand feet in average

FIGURE 18.—Craggy outcrops of West Elk Breccia near head of Black Canyon at mouth of West Elk Creek. Note embedded fragments and crude bedding. Crags are about 600 feet high.



thickness. By conservative estimate, their original volume exceeded 150 cubic miles.

Good exposures of West Elk Breccia are abundant in the headward part of the Black Canyon, particularly in the Black Mesa-Soap Mesa area at such places as Curecanti Creek, Soap Creek, and West Elk Creek (fig. 18). Good exposures abound along Colorado State Highway 92, and fairly good ones are seen along U.S. Highway 50 on the northwest slope of Blue Mesa. Castle Peak and Cathedral Peak southeast of Crawford also consist of West Elk Breccia. The names of these peaks suggest the picturesque erosive habit of the formation. Cliffs, crags, pillars, windows, and boulder-capped hoodoos are characteristic.

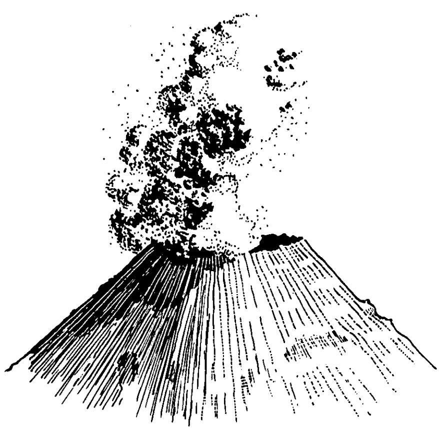
As the West Elk eruptive cycle finally drew to a close, erosion began to attack the irregularities of the volcanic surface by planing off bedrock protuberances. Precisely when the trunk drainage of the area became organized into the Gunninson River as such is uncertain. Perhaps this did not happen until after volcanism had ceased, although drainage probably was channeled into an ancestral Gunnison soon after volcanism started. At any rate, drainage was never curtailed for any great length of time. It quickly reestablished itself after each eruption, as indicated by the interbedded gravels it left behind.

Renewed Volcanism—
Ash-Flow Tuffs of the Alboroto Group

Some time after the West Elk eruptive cycle had ended and after erosion had planed off the irregularities of the West Elk surface, volcanism resumed in the area with the eruption of a drastically different type of material. In several distinct surges, tremendous volumes of hot incandescent ash were erupted from sources as yet unknown—sources presumed to be in the West Elk Mountains nearby, but possibly as far distant as the Silverton, Lake City, or Creede areas of the San Juan Mountains. Eruptions of this type are known variously as ash flows, glowing avalanches, or nuées ardentes. Their origins, geologic relations, and identification have recently been summarized in a definitive paper by C. S. Ross and R. L. Smith (1961).

In the Black Canyon area most ash flows were hot enough to firmly weld the individual ash particles together into a hard coherent rock called welded tuff. This rock is highly resistant to erosion. It forms the line of vertical cliffs above U.S. Highway 50 on Fitzpatrick, Blue, and Pine Creek Mesas and across the canyon on Soap and Black Mesas. Dillon and Sapinero Mesas further upstream are capped by the same formation. Though now much dissected by erosion, the several ash flows which compose the formation once covered at least 400 square miles, had a maximum thickness of more than 600 feet, and had a volume of perhaps 50 cubic miles. Similar possibly related deposits, thicker and even more widespread, cover adjacent areas to the south in the San Juan Mountains.

All available evidence indicates that drainage across the area resumed between ash-flow eruptions. Broadly speaking, the protracted volcanic activity athwart the course of the Gunnison River was but one episode in the still longer life history of the river. After each eruption, the river and its tributaries attacked the newly deposited volcanic rocks, only to be overwhelmed again by each new outpouring. When volcanism ended finally and irrevocably late in the Tertiary Period, the river at last began to cut the wonderful gorges of the present Black Canyon.



GEOLOGIC STRUCTURE

THE GUNNISON UPLIFT

The dominant structural feature of the Blank Canyon area is the Gunnison uplift. Though it is fundamentally a Laramide structure and hence is relatively young in a geologic sense, its outlining structural elements began to take form eons before in Precambrian time. In the main, it is outlined by old Precambrian fault blocks which readjusted themselves to renewed stresses during the Laramide orogeny. The uplift, therefore, as shown by figure 19, is mainly a tilted upfaulted block rather than an updomed fold. It is gently flexed across the crest, however, and is sharply folded locally along faults.

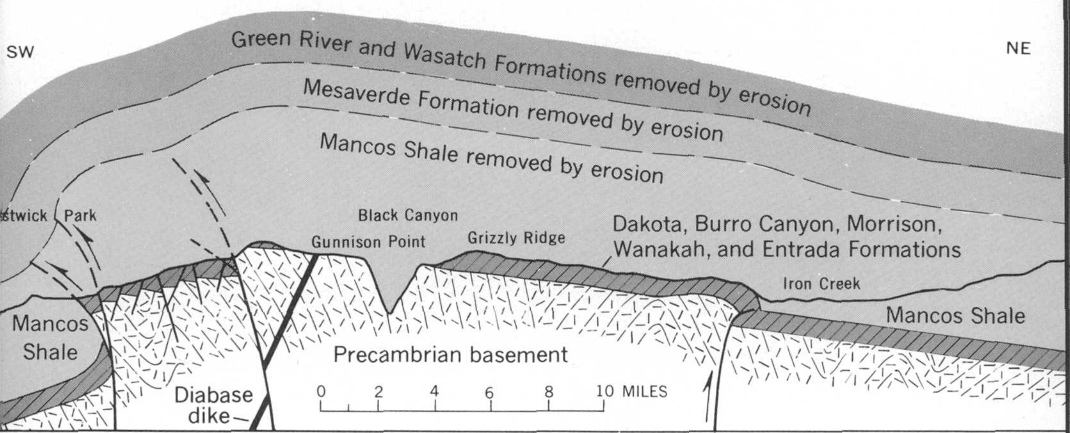


FIGURE 19.—Generalized section across Gunnison uplift showing restored form. Vertical scale is exaggerated about 2½ times.

If minor fractures and displacements are ignored, the Gunnison uplift is thus seen as a broad tilted block, now capped in most places by Dakota Sandstone but stripped down in some places to the Precambrian basement and overlapped in others by younger volcanic rocks. The sloping tops of Fruitland Mesa, Grizzly Ridge, Pine Ridge, and Vernal Mesa are manifestations of this great block. The steep south slopes of Vernal Mesa and Poverty Mesa coincide with lines of faulting. Far to the east, the southward rise of the old Uncompahgre peneplain in the Lake Fork area is a further manifestation of the Gunnison uplift. This rise brings Precambrian rocks from river level at Sapinero to mesa-top level on Willow Creek Mesa, an average rise of about 240 feet per mile.

FRACTURES IN ROCKS

Joints

Joints are fractures in rocks, along which there has been little or no displacement of one side of the fracture past the other. They contrast with faults, along which there has been appreciable or even great displacement. Probably the most prevalent causes of jointing are tensional or shearing forces set up by crustal movements within the earth. Fractures form when the imposed stress exceeds the strength of the rock. Under certain conditions, the rock may fail by bending or even by solid flowage rather than by fracturing. Failure sometimes takes all three forms. In the Black Canyon, joints are among the more spectacular manifestations of past earth stresses. Large well-formed joints contribute greatly to the character of the canyon scenery, particularly in the steep-walled sections of the national monument. (See figs. 5, 20, and frontispiece.)

Two main sets or families of steeply dipping joints extend throughout the area. One set trends northwestward, the other northeastward. Each set contains innumerable individual fractures, all about parallel, some large, and some small. The northwesterly set is the more prominent in the monument, and excellent examples are at every hand. Cross Fissures View in particular, as the name suggests, looks out along a zone of very large joints. Widened by weathering, these joints form great open fissures hundreds of feet deep and thousands of feet long. The same zone passes below Spruce Tree Point where it is visible to the north toward Big Island and to the east across the canyon. Deep fissures controlled by the northwesterly joint set also indent the face of Painted Wall (frontispiece) and the cliffs at Cedar Point and Dragon Point.

Being natural planes of weakness, joints materially aid weathering and erosion by providing access for moisture or frost. By the gradual enlargement of such openings, masses of rock become separated from the main canyon wall, eventually toppling to the floor below. Large isolated monoliths such as Big Island are products of weathering and erosion along master joints. Island Peaks on the opposite rim have formed in about the same manner, although they are partly bounded by dikes and foliation planes, as well as by joints. Countless smaller pinnacles and spires along the canyon walls are partly bounded by joints (fig. 20).

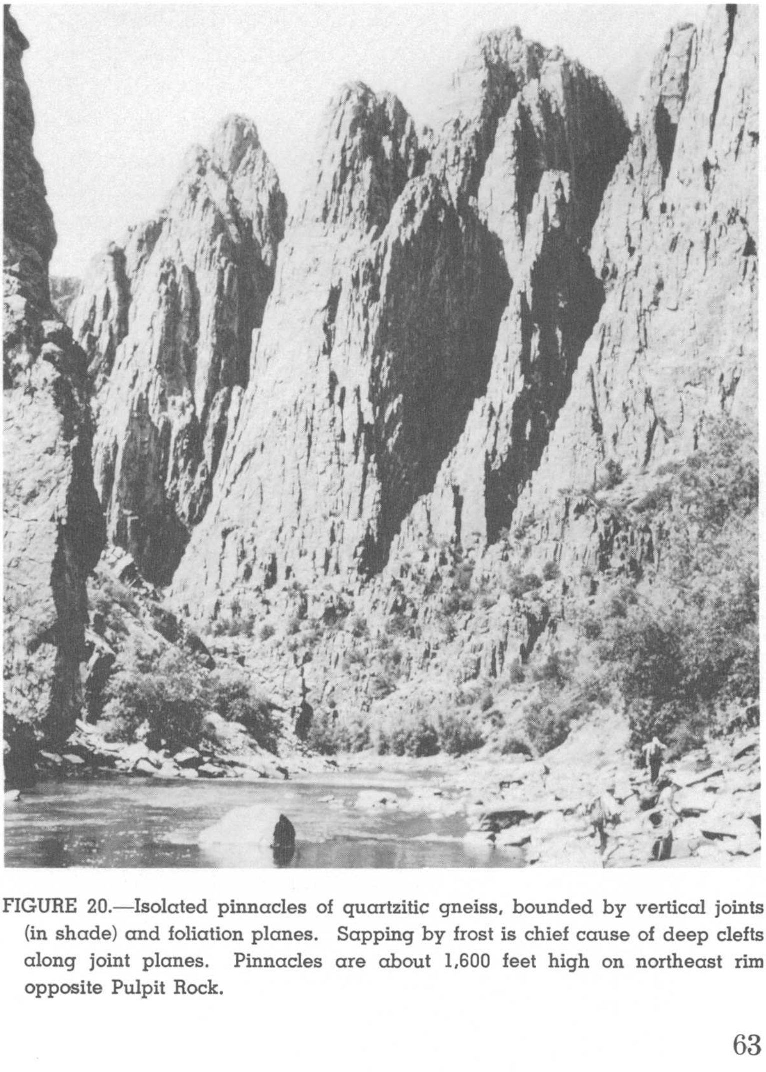


FIGURE 20.—Isolated pinnacles of quartzitic gneiss, bounded by vertical joints (in shade) and foliation planes. Sapping by frost is chief cause of deep clefts along joint planes. Pinnacles are about 1,600 feet high on northeast rim opposite Pulpit Rock.

Low-dipping joints also cut the canyon walls, but they are far less abundant in most places, and certainly less spectacular, than steeply dipping ones. They are most evident, and perhaps most abundant, in the Curecanti Quartz Monzonite pluton in the upper part of the canyon as shown in figure 11, but they are conspicuous also in such places as the north wall of Poverty Mesa. In the national monument a few large ones can be seen from the rim overlooks.

Faults

Two major faultlines and many subordinate ones pass through the Black Canyon area. The major ones and several subordinates trend east-southeastward in a subparallel manner. Other faults trend northward to northeastward. One of the major faults is called the Red Rocks fault. It trends 20 miles or more from the head of Red Rock Canyon to Fitzpatrick Mesa west of Blue Creek. It forms the escarpment south of High Point, trends up Jones Draw toward the South Rim Campground, and continues southeastward beyond East Portal. This fault is marked by a wide zone of intensely shattered rock; hence, in many places it forms the bottom of ravines. Its displacement is visible from Tomichi Point, looking southeast up the river.

The other major fault is called the Cimarron fault for its exposure near Cimarron, Colo. Named by J. Fred Hunter in 1925, it has been known to geologists since the 19th century. It arises near Bostwick Park and trends at least 40 miles east-southeastward to Powderhorn, perhaps farther. Key places where the fault is well shown are the imposing escarpment west of Cimarron (fig. 21) and the narrow gap of Blue Creek south of Half Way House.

Both the Red Rocks and the Cimarron faults are very ancient structural features, reactivated in Laramide time. Their earliest movements probably were Precambrian, and they haven't moved since Tertiary time. The high escarpments along both these faults are due to differential erosion of hard and soft rocks rather than to recent topographic displacements.

FIGURE 21.—Cimarron fault, looking north across valley of Squaw Creek, just east of Cerro Summit. Precambrian rocks in upthrown block above fault trace and Mancos Shale in downthrown block below. Fault here has a vertical displacement of perhaps 5,000 feet. Poverty Mesa forms skyline.

Subordinate faults are plainly visible at several points along the Black Canyon, where they displace the old Uncompahgre peneplain. Most of them die out upward or laterally into Jurassic and Cretaceous strata, their displacements passing into folds (fig. 22).

One of the best exposed fault zones in the entire Black Canyon area trends almost due northward along the lower part of the canyon, mostly in the west wall of the canyon. This zone is very conspicuous from many vantage points because dark Precambrian basement rocks are faulted against bright-colored younger sedimentary rocks. The zone contains several subparallel faults, most of which are upthrown on the west and pass laterally or vertically into monoclines (fig. 22). The longest individual fault of this zone has a surface trace of more than 6 miles, and it displaces the old Uncompahgre unconformity more than 800 feet. It arises from a monoclinal fold—visible from Montrose—at the first large ravine 3 miles downstream from Red Rock Canyon on the southwest side of the Black Canyon.

Trending northward, the fault crosses to the east side of the Black Canyon near the mouth of the tributary ravine, recrosses to the west side $2\frac{1}{2}$ miles farther north, then trends almost due northward parallel to the river for an additional $2\frac{1}{2}$ or 3 miles.

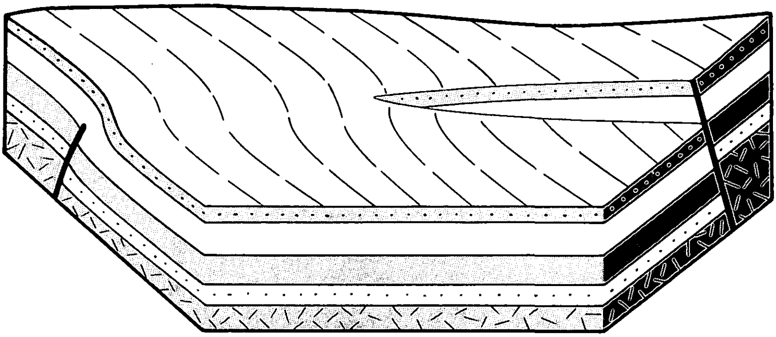


FIGURE 22.—Block diagram showing lateral and vertical passage of a fault into a monocline as exemplified in the Black Canyon area.

STRUCTURAL FEATURES CONFINED TO THE PRECAMBRIAN ROCKS

The Precambrian rocks, in their great antiquity, have been subjected to intensive repeated deformations unshared by the overlying younger rocks. They were intricately folded and fractured on both a small and a large scale before the younger rocks were deposited. Their folds range upward in size from microscopic wrinkles to great bends 5 to 10 miles across; their fractures range from hairline cracks to fault zones hundreds of feet wide and tens of miles long.

Small-scale folds are apparent in nearly every outcrop of metamorphic rock, but most particularly in the migmatitic gneisses (fig. 9). Intricate contortions in these rocks attest to the thoroughness of their deformation. Large-scale folds, though less evident to casual viewing, are demonstrated by detailed geologic studies—a case of the forest being hidden by the trees. The core of one major anticline, however, is well exposed to view from U.S. highway 50 near the mouth of Cimarron Creek. This fold was first described years ago by Hunter (1925), who observed that it is accentuated by large pegmatite dikes intruded along the layering of the folded metamorphic rocks and eroded differentially into sharp relief. Its form and magnitude exemplify other equally large folds less obviously exposed elsewhere in the Black Canyon.

Faults of the area, as noted before, are mostly reactivated Precambrian fractures. Some of them show clear evidence of early movement many times greater than their latest movement. Others have not moved at all since the old Uncompahgre peneplain formed.

Careful scrutiny of nearly any outcrop of metamorphic rock discloses abundant microfaults. These little fractures may have displacements of a few millimeters or several centimeters. Several generations of them may be discerned in a single outcrop. Scarce in the younger rocks, they further confirm the disparate complexity of the older rock structure.

CRUSTAL WARPING OF TERTIARY AGE AND ITS POSSIBLE EFFECT ON DRAINAGE

Warped volcanic ash flows in the mesas along the upper reaches of the Black Canyon indicate late Tertiary crustal adjustments in the area. Ash flows deposited as gently sloping layered sheets—sloping away from their eruptive source—now have the aggregate form of a broad shallow syncline. In section the syncline resembles a great shallow saucer. In plan its contour is more like a celery dish. In other words, it is elongate roughly east-west. It also is somewhat arcuate, concave northward. As shown by figure 23, its axis or keel slopes eastward and has a structural relief of more than 1,400 feet.

Warping is not presently detectable beyond the eroded limits of the ash flows, although its effects may safely be assumed to extend much farther. Warped flows provide an easily recognized datum, but in more complex rock structure, warping is difficult or impossible to detect. And once the flow is eroded away, the evidence of warping is destroyed.

The effect of warping on the drainage history of the Black Canyon may have been considerable. In dipping strata of alternate hardness, drainage lines of downcutting streams tend to shift laterally in the direction of dip as soft layers are

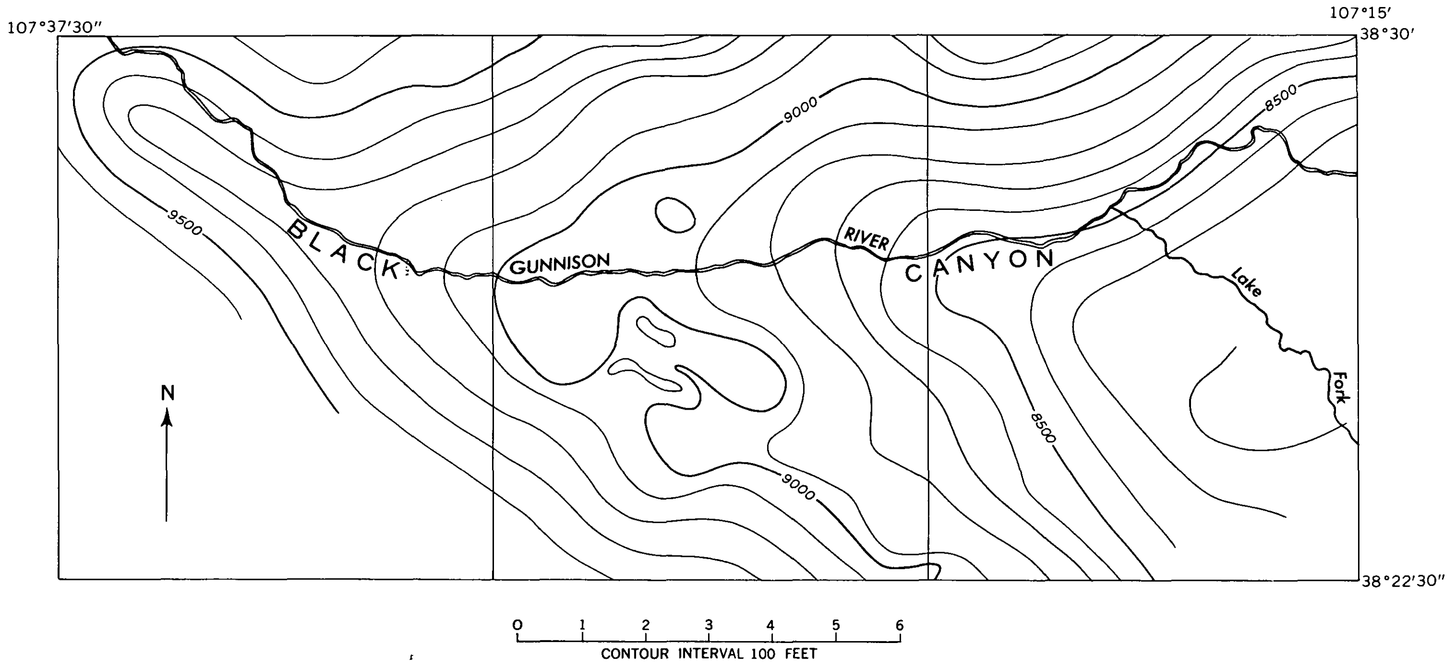


FIGURE 23.—Structure contour map, drawn at the base of the ash-flow tuff volcanic sequence, showing trend of the Gunnison River along syncline axis.

penetrated and hard ones are encountered. As the Gunnison cut downward through the ash flows in the initial stages of entrenchment, its course eventually became fixed along the axis of the syncline. On then encountering the hard crystalline rocks in the core of the buried Gunnison uplift, it continued to cut downward, but it ceased to migrate laterally.

A glance at a regional map shows that the Gunnison River has an arcuate course that is circumferential to the West Elk Mountains almost from its headwaters to its junction with the North Fork. The middle reach of this arcuate course coincides in trend with what remains of the curved axis of the ash-flow syncline. How much of its arcuate course beyond the eroded remnant of the syncline is due to structural controls since erased by erosion can only be guessed. The drainage pattern suggests that the syncline was formerly circumferential to the West Elk Mountains—in other words, a so-called ring syncline. Such a syncline might form by subsidence of the entire West Elk Mountain area, caused by removal of crustal support through eruption of a great volume of molten rock from the roots of the mountains. As previously noted, the volume of rock so erupted from the West Elk Mountains was very large. It may have equaled or exceeded 200 cubic miles.

GLOSSARY

Many terms in day-to-day professional use by geologists are unfamiliar or vaguely familiar to nongeologists. Although the attempt has been made to minimize such usage in this report, some semitechnical jargon is inevitable in any discussion of technical matters. The following short glossary is not intended to be definitive, but it should help clarify most of the terms that are apt to be stumbling blocks. Many of the definitions have been borrowed, with slight modification, from a "Glossary of Selected Geologic Terms" by W. L. Stokes and D. J. Varnes, published in 1955 by the Colorado Scientific Society, Denver, Colo.

Amphibolite, a metamorphic rock of medium to coarse grain composed chiefly of a mineral of the amphibole group (generally hornblende) and plagioclase feldspar.

Anticline, a convex-upward fold; that is, one in which the limbs or sides slope away from the crest, like an inverted trough.

Ash flow, a hot turbulent mixture of gas and volcanic dust erupted down the slope of a volcano; on coming to rest, commonly compacts into a hard coherent rock. See also "Welded tuff."

Badland, an area of intricate erosional dissection, nearly free of vegetation and characterized by steep slopes, sharp ridge lines, and a maze of ravines or gullies. Badlands are abundant in Mancos Shale terranes west of the Black Canyon.

Bedding, the arrangement of rocks, especially sedimentary rocks, in layers or strata.

Breccia, a consolidated rock composed of angular rock fragments. Volcanic breccias are abundant in the West Elk and San Juan Mountains.

Competence, as applied to streams—capacity to transport debris; as applied to rocks—resistance to deformation or capacity to transmit stress.

Conglomerate, a rock, the consolidated equivalent of gravel.

Crossbedding, a diagonal arrangement of layering in sedimentary rock in which layers are inclined at various angles to more general planes of stratification. In the Black Canyon area, common in sandstones of the Junction Creek, Morrison, Burro Canyon, and Dakota Formations.

Desert varnish, a dark-colored surface stain or crust of iron or manganese oxide, coating exposed rock surfaces in desert or semiarid regions.

Diabase, a dense dark-colored igneous rock composed essentially of augite and plagioclase. Forms large dikes in Black Canyon area.

Dike, a sheetlike body of igneous rock intruded while molten into fissures in other rocks. Very abundant in the Black Canyon.

Dip, in structural geology, the angle between a sloping plane, such as a bedding plane or a fault, and an imaginary horizontal plane.

Eolian, pertaining to the wind.

Fault, a fracture in the earth's crust along which there has been movement parallel to the fracture plane.

Fault block, a mass of rock bounded laterally by faults.

Fold, a bend or flexure in layered rock. See also "Anticline," "Monocline," and "Syncline."

Foliation, layering or lamination in metamorphic and igneous rocks.

Gneiss, a layered metamorphic rock having alternate layers of visibly unlike mineral composition, especially, feldspar-rich layers alternating with mica-rich layers.

Gradient, as applied to streams, the inclination of the bed.

Granite, in a strict sense, a visibly granular igneous rock of interlocking texture composed essentially of alkalic feldspar and quartz, commonly with a small percentage of mica or hornblende.

Igneous rock, a rock formed by solidification of hot molten material, either at depth in the earth's crust or erupted at the earth's surface.

Joint, a fracture along which there has been little or no movement parallel with the fracture plane.

Laccolith, a lens- or dome-shaped mass of igneous rock injected between strata so as to distinctly updome its roof.

Laramide orogeny, the mountain-forming episode in which the Rocky Mountains were uplifted.

Limestone, a sedimentary rock composed chiefly of calcium carbonate.

Mass wastage, any process by which large masses of earth material are moved downward by gravity.

Metamorphic rock, rock changed materially in composition or appearance by heat, pressure, or infiltrations at some depth in the earth's crust below the surface zone of weathering.

Mineral, a naturally occurring substance of definite chemical composition and distinctive physical and molecular properties.

Monocline, a steplike bend in otherwise horizontal or gently dipping strata.

Orogeny, the process or the episode in which mountain ranges are formed.

Pegmatite, a name applied to various crystalline igneous rocks characterized by large average grain size and interlocking texture. Very abundant in Black Canyon area.

Peneplain, an extensive land area of very low relief produced by subaerial erosion.

Petrography, a branch of geology that deals with the description and classification of rocks; applied especially to microscopic study of rocks.

Phenocryst, a crystal in an igneous rock, embedded in a finer grained groundmass.

Physiography, as commonly used, the study of the surface features of the land. Also called physical geography.

Pluton, a general term applied to any body of intrusive igneous rock, regardless of shape or size, but commonly applied to bodies of deep-seated origin.

Porphyry, an igneous rock containing abundant phenocrysts set in a finer grained groundmass.

Quartz monzonite, a granitelike igneous rock containing more than 5 percent quartz and nearly equal amounts of alkalic and soda-lime (plagioclase) feldspars. A prevalent rock type in the Black Canyon.

Ripple mark, undulatory washboardlike markings produced on sand by waves, currents, or winds and commonly preserved in consolidated sandstone. Abundant in the Dakota Sandstone of the Black Canyon area.

Rock, any naturally formed aggregate of minerals constituting a sizable part of the earth's crust. Most rocks contain two or more mineral varieties.

Sandstone, a rock composed of cemented sand grains.

Schist, a crystalline metamorphic rock composed chiefly of platy mineral grains such as mica, oriented so that the rock tends to split into layers or slabs. Common in the Black Canyon.

Sedimentary rock, rock formed by consolidation of sediment deposited at the surface of the earth through action of water, wind, glaciers, or organisms.

Shale, a fine-grained sedimentary rock formed from muds or clays and having a fissility that causes it to split along planes parallel to the bedding.

Stock, an irregular conical or cylindrical body of intrusive rock which cuts across the enclosing rock and has a horizontal section of not more than 40 square miles. Larger bodies are called batholiths.

Superposition, as applied to drainage, a drainage pattern impressed on a formerly existing geologic terrane and let down by erosion onto different rocks and geologic structures, often with anomalous-seeming results.

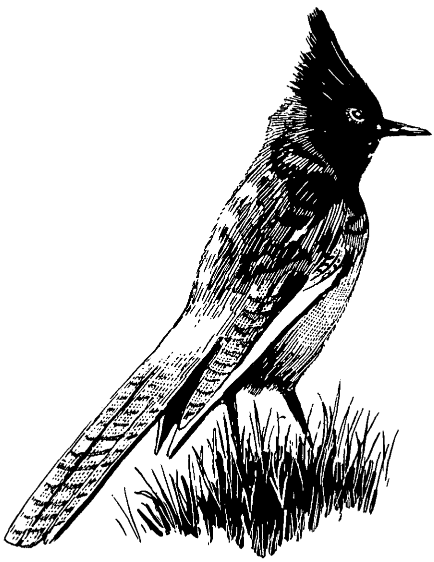
Syncline, in simple form, a concave-upward, or troughlike, fold.

Talus, an accumulation of coarse angular rock fragments derived from and resting at the base of a cliff or very steep slope. Very common in the bottom of the Black Canyon.

Tuff, a volcanic rock formed by induration of volcanic ash or dust. Abundant in the West Elk and San Juan Mountains.

Unconformity, an erosion surface separating an older from a younger sequence of rocks. Formed when strata or volcanic rocks are deposited on an old land surface. An excellent example is preserved at the rims of the Black Canyon.

Welded tuff, a volcanic rock in which the ash fragments have retained sufficient heat following eruption to become partly or completely welded together after emplacement. Excellent examples in the caprocks of the mesas near the head of the Black Canyon.



ADDITIONAL READING

The geologic bibliography on the Black Canyon area is not very extensive. Many concepts, moreover, have changed greatly since the older reports were published. But much descriptive matter is still valid, even in the oldest reports, and some of the old ones have great historic interest. The more important references are listed as follows, together with corollary readings on allied subjects, briefly annotated.

Atwood, W. W. Sr., and Atwood, W. W., Jr., 1938, Working hypothesis for the physiographic history of the Rocky Mountain Region: Geol. Soc. America Bull., v. 49, p. 957–980.

Briefly describes and relates physiographic features of the important canyons and mountain ranges of the region. Photograph and block diagram of the Black Canyon.

Atwood, W. W., and Mather, K. F., 1932, Physiography and Quaternary geology of the San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 166, 176 p.

The first and still most comprehensive discussion of regional physiographic relationships of the San Juan area. Descriptive references to the Black Canyon area are very good, although some of the conclusions have since proved to be in error.

Beidleman, R. G., 1959, The Gunnison River diversion project: The Colorado Mag. of the State Hist. Soc. of Colorado, v. 36, no. 3, 15 p.

Describes early exploratory traverses in the Black Canyon prior to the construction of the Gunnison tunnel.

Cross, Whitman, 1894, The laccolitic mountain groups of Colorado, Utah, and Arizona: U.S. Geol. Survey 14th Ann. Rept., pt. 2, p. 157–241.

Many informative references to the laccoliths of the West Elk Mountains.

Hunter, J. F., 1925, Precambrian rocks of Gunnison River, Colorado: U.S. Geol. Survey Bull. 777, 94 p.

A very good general reference with petrographic descriptions of many rock units. Includes a reconnaissance map.

Larsen, E. S., Jr., and Cross, Whitman, 1956, Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geol. Survey Prof. Paper 258, 303 p.

A storehouse of descriptive and analytical data, particularly on the volcanic rocks of the region.

Lohman, S. W., 1961, Abandonment of Unaweep Canyon, Mesa County, Colorado, by capture of the Colorado and Gunnison Rivers, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–B, p. B144–B146.

Spectacular drainage adjustments in the Grand Junction area had a direct bearing on the cutting of the Black Canyon.

Peale, A. C., 1876, Report on valleys of Eagle, Grand, and Gunnison Rivers, Colo., for the year 1874, *in* Hayden, F. V., 8th Ann. Rept. U.S. Geol. and Geog. Survey Terr.: p. 73–180.

Largely of historic interest, but contains many still-valid observations.

Ross, C. S., and Smith, R. L., 1961, Ash-flow tuffs: Their origin, geologic relations, and identification: U.S. Geol. Survey Prof. Paper 366, 81 p.

Concise and authoritative.

Thornbury, W. D., 1954, Principles of geomorphology: New York, John Wiley and Sons, 618 p.

Very good general reference. Cites Black Canyon in a discussion of superposition.