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GEOLOGIC AND PHYSIOGRAPHIC HIGHLIGHTS OF THE BLACK CANYON OF THE GUNNISON RIVER AND VICINITY, COLORADO

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GEOGRAPHIC SETTING

The Black Canyon of the Gunnison straddles the boundary between two physiographic provinces, the Southern Rocky Mountains to the east and the Colorado Plateau to the west. Inasmuch as the boundary there is ill defined, the area shares characteristics of both provinces—sharp ridges, broad mesas, precipitous canyons, complex geology, and vegetation communities that range from desert shrub to boreal forest. The ultimate cause of this dramatic setting is the Gunnison River which, down through time, has carved the Black Canyon out of the heights of the Gunnison uplift. The river and its reservoirs separate the West Elk Mountains on the north from the San Juan Mountains on the south (fig. 1).

Physiographically and geologically, the Black Canyon is divisible into three sections—lower, middle, and upper—which merge gradually with one another but have marked differences. Common to all three, and imparting a certain unity, is an inner gorge of

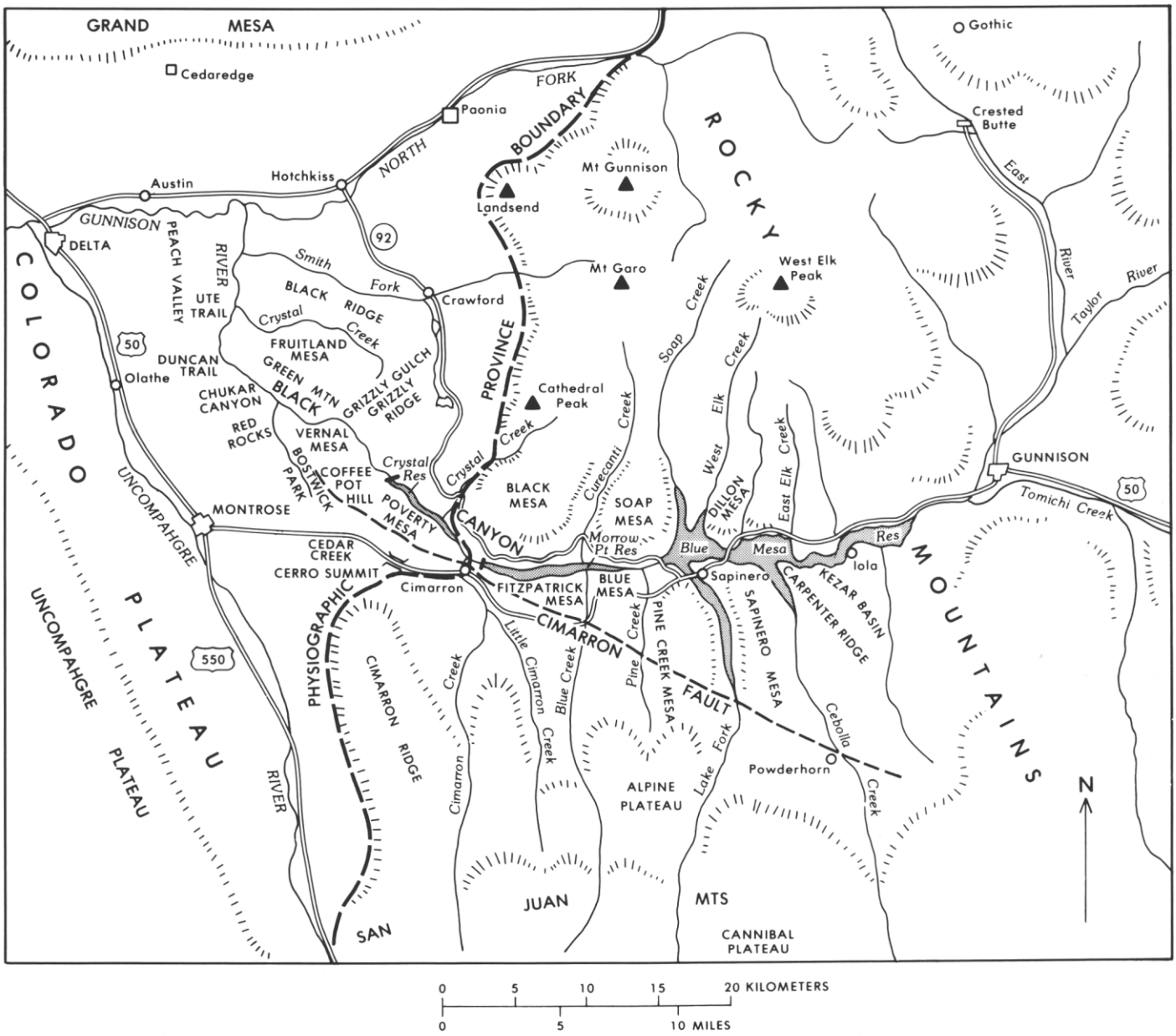


Figure 1. Location map of the Black Canyon area, western Colorado.

crystalline rock renowned for its sheer walls, startling depths, and awesome countenance. At one time the entire canyon area was covered by a capping of middle Tertiary volcanic rocks. This capping, which provided the means for subsequent superposition of the river, has been differentially eroded, so that none remains in the lower section of the canyon and most is gone from the middle, but in the upper it is well preserved on the high mesas above Morrow Point and Blue Mesa reservoirs.

In the lower section, flaring walls of bright-colored Mesozoic sedimentary rocks, 300 m thick and nearly free of soil, surmount a narrow inner gorge of dark Pitts Meadow Granodiorite (fig. 2). The lower section is eroded into the plunging crest of the Gunnison uplift, and resistant Dakota Sandstone forms the outer canyon rim, sloping away in long, barren dip slopes. Successively older strata—the Burro Canyon, Morrison, Wanakah, and Entrada Formations—underlie the Dakota above the inner gorge. At the top of the Precambrian, the well-exposed Uncompahgran unconformity truncates the roots of the old Uncompahgre highland, formed in Pennsylvanian time with the rise of the Ancestral Rocky Mountains. In the middle section, which contains Black Canyon of the Gunnison National Monument and Crystal Reservoir, the rim view is dominated by a rather flat skyline formed of hard Precambrian rocks on the south rim and poorly exposed sedimentary rocks on the north. Most of the sedimentary capping has been stripped from the south rim, exhuming the Uncompahgran surface. The sedimentary section, though preserved on the north rim, is largely concealed by soil and shrubbery. Here the inner gorge attains its greatest depth and grandest development, particularly between Pulpit Rock and Painted Wall (fig. 3), where it is 11/2 times deeper than wide (fig. 4), rimmed by the highest cliffs in Colorado.

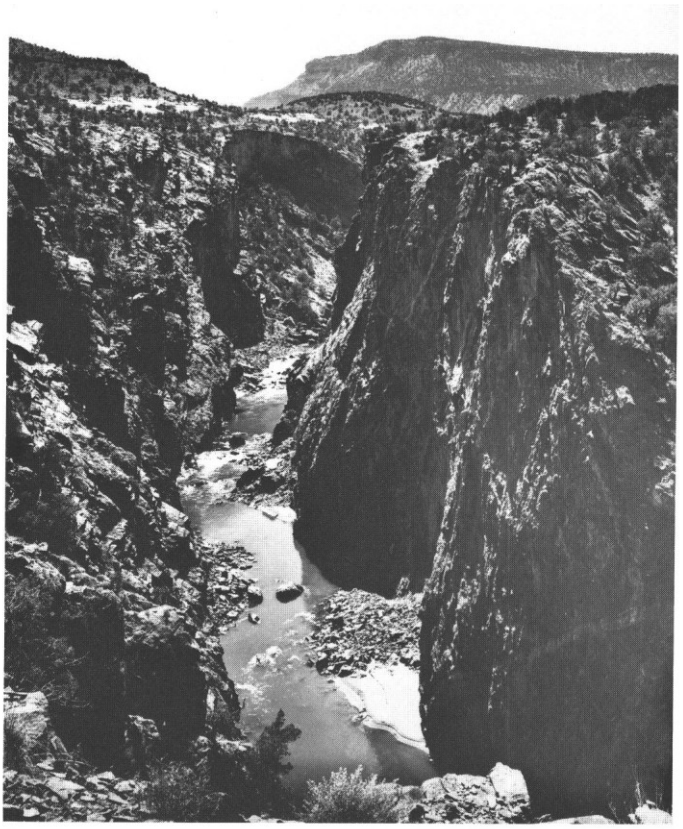


Figure 2. Inner gorge of the lower Black Canyon about 5 km upstream from Smith Fork. Walls of Pitts Meadow Granodiorite are topped with Entrada Sandstone. Dakota Sandstone at the skyline.

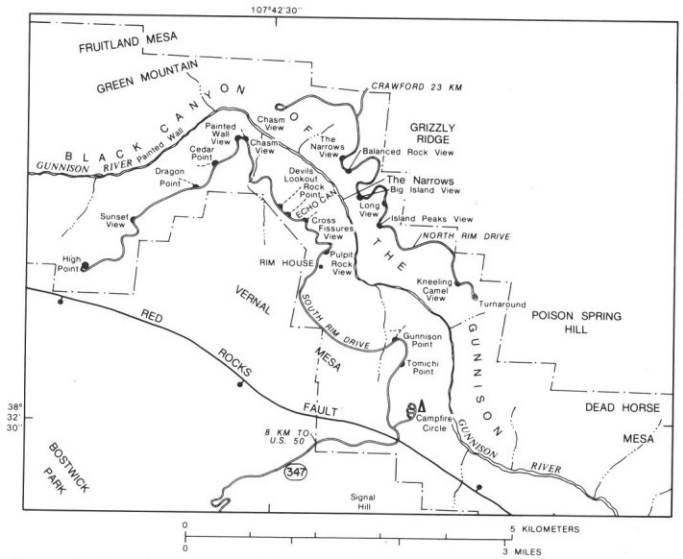


Figure 3. Road access and rim overlooks, Black Canyon of the Gunnison National Monument.

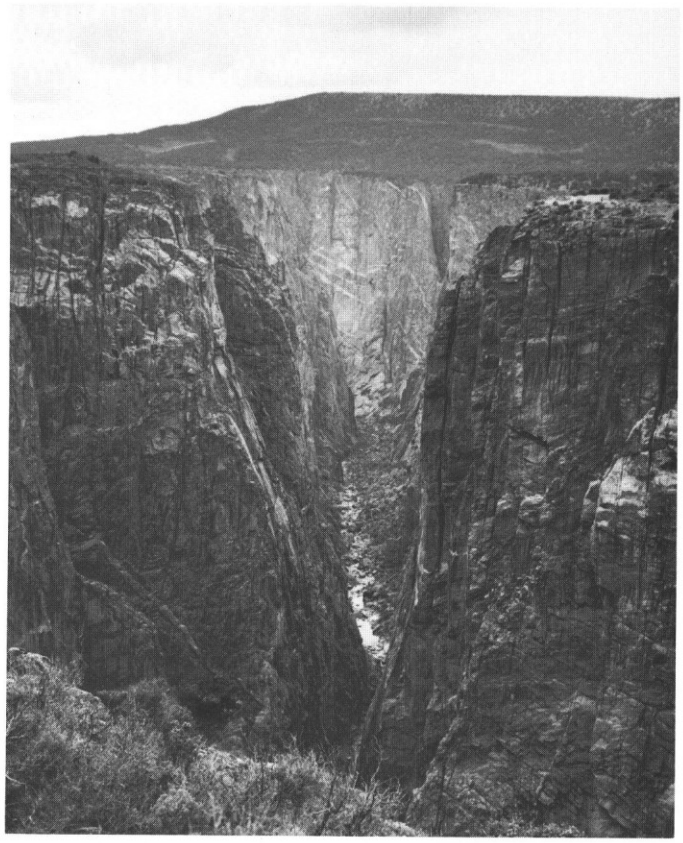


Figure 4. The Narrows of the Black Canyon, looking downstream toward Green Mountain. The canyon here, 12 m wide at river level, is about 520 m deep. Note the well-formed joints parallel to canyon walls, and the lineations plunging gently to the left (west). The abrupt rim at the top of the Precambrian is the old Uncompahgran erosion surface. The outer rim on the skyline is capped by Dakota Sandstone.

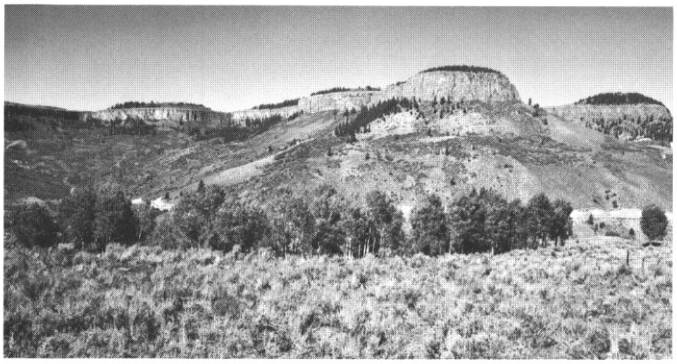


Figure 5. Palisade-like cliff of Blue Mesa Tuff forming outer rim of Upper Black Canyon at Soap Mesa. Inner gorge 300 m deep is out of view just behind the aspen grove in the foreground. Distant slopes are mostly West Elk Breccia.

In the upper section, remnants of the once broader volcanic cover rest directly on the Precambrian basement and form the heights of the canyon walls, although a thin wedge of Mesozoic rocks intervenes toward the head of the canyon. The rim is uneven and indefinite, merging with higher rolling back country or, locally on the south, becoming a serrated ridge. But its chief attribute is a nearly continuous palisade of resistant welded Blue Mesa Tuff 15-100 m thick, forming a line of cliffs 300-600 m above the canyon floor and rising toward the west (fig. 5). The canyon has the V-shaped profile of a typical, though exceptionally rugged, mountain stream valley modified by fjord-like Morrow Point Reservoir. At Morrow Point Dam, the north rim is 1,000 m above the river.

Clearly, the middle section is the most dramatic reach of the Black Canyon, and few gorges in the world are its peer. The more verdant upper section is impressive in its own right, especially in autumn as seen from Colorado Highway 92, when the frosted oaks, choke cherries, and aspens herald the coming of winter. So far as the rocks are concerned, the lower section is the most colorful, and it best displays the sedimentary capping of the Gunnison uplift, the geologic setting of the canyon, and the regional structural framework.

THE ROCKS

The rocks of the Black Canyon area are summarized in Table 1. Precambrian rocks of varied types are exceptionally well exposed along the full length of the canyon (Hunter, 1925; Hansen, 1965 and 1971). The name Black Canyon Schist, sometimes applied to these rocks, has little stratigraphic or lithologic significance. Age and general relations are given by Hansen and Peterman (1968). Sedimentary rocks of Jurassic and Cretaceous age (fig. 6) are best exposed along the lower section (Hansen, 1965, 1968, and 1971), accessible, however, only by rough jeep roads and trails. Volcanic rocks of Tertiary age on the high mesas along the upper canyon (Olson and others, 1968; Hansen, 1971) are readily seen at close range along Colorado Highway 92. These rocks were erupted from volcanic centers in the West Elk and San Juan Mountains (Gaskill and others, 1977; Lipman and others, 1978).

Precambrian

*Metamorphic Rocks (>1,700 m.y.)**

Metamorphic rocks of the Black Canyon—largely metasedimentary and metamorphosed to the almandine-amphibolite grade—range widely in composition and texture. Some variations must reflect original differences, but others likely reflect metamorphic changes accompanied by the introduction of feldspar, either by injection or, perhaps more commonly, by metasomatism, including extensive migmatization between Morrow Point and Blue Mesa Dam. Rocks of the staurolite subfacies crop out in the eastern part of the Monument. Sillimanite is prevalent in the migmatites near Morrow Point. The original rocks probably were mostly impure arkosic sandstone, graywacke, and sandy shale, although some may have been volcanic, as Hunter (1925, p. 28) suggested. Bedding is well preserved in a few rocks, particularly the more quartzitic varieties. Primary sedimentary structures other than bedding generally are lacking, although crossbedding is suggested in some places, and metaconglomerate is present locally but is rare. Chemically some rocks approach rhyolite (fig. 7), but primary textures that might indicate a volcanic origin are lacking.

Table 1. Rock formations of the Black Canyon area.

SUBDIVISION	FORMATION	THICKNESS (m)	AGE (m.y.)[1]
Quaternary System	Alluvium, talus, landslides	< >25	< >1
	Hinsdale Formation	<45	18.5
	Carpenter Ridge Tuff	<70	27.5
	Fish Canyon Tuff	<90	27.8
Tertiary System	Sapinero Mesa Tuff	<70	28
	Dillon Mesa Tuff	<25	>28
	Blue Mesa Tuff	<80	>28
	West Elk Breccia	< >300	< >32
	Mancos Shale	< >680	∿ 80
Cretaceous System	Dakota Sandstone	<30	∿105
	Burro Canyon Formation	<35	∿110
	Morrison Formation		∿145
	Brushy Basin Member	<120	
Jurassic System	Salt Wash Member	35-55	
	Wanakah Formation	<80	∿155
	Junction Creek Member	<30	
	Pony Express Member	<2	
	Entrada Sandstone	<30	∿170
Ordovician or Cambrian System	Diabase	<90	510±60
Precambrian (Proterozoic Eon)	Pegmatite	<100's	< >1700
	Curecanti Quartz Monzonite		1420±15
	Vernal Mesa Quartz Monzonite		1480±40
	Pitts Meadow Granodiorite		1730±190
	Metamorphic rocks	>1000's	>1700

[1] Tertiary ages from Lipman and others, 1973
Mesozoic age based on Van Eysinga, 1978

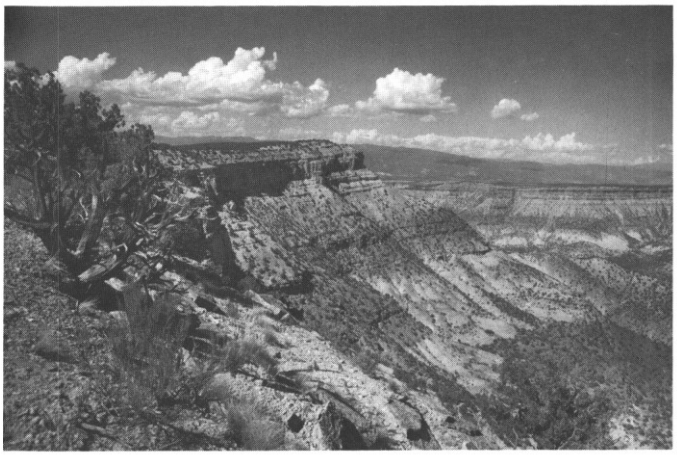


Figure 6. Outer wall of the lower Black Canyon. Dark Precambrian rock, lower right, capped by 300 m of Jurassic and Cretaceous rocks: Entrada, Wanakah, Morrison (Salt Wash and Brushy Basin Members), Burro Canyon (forming cliff), and Dakota at the rim.

**All ages are taken from Hansen and Peterman (1968), based on whole-rock Rb-Sr analyses.*

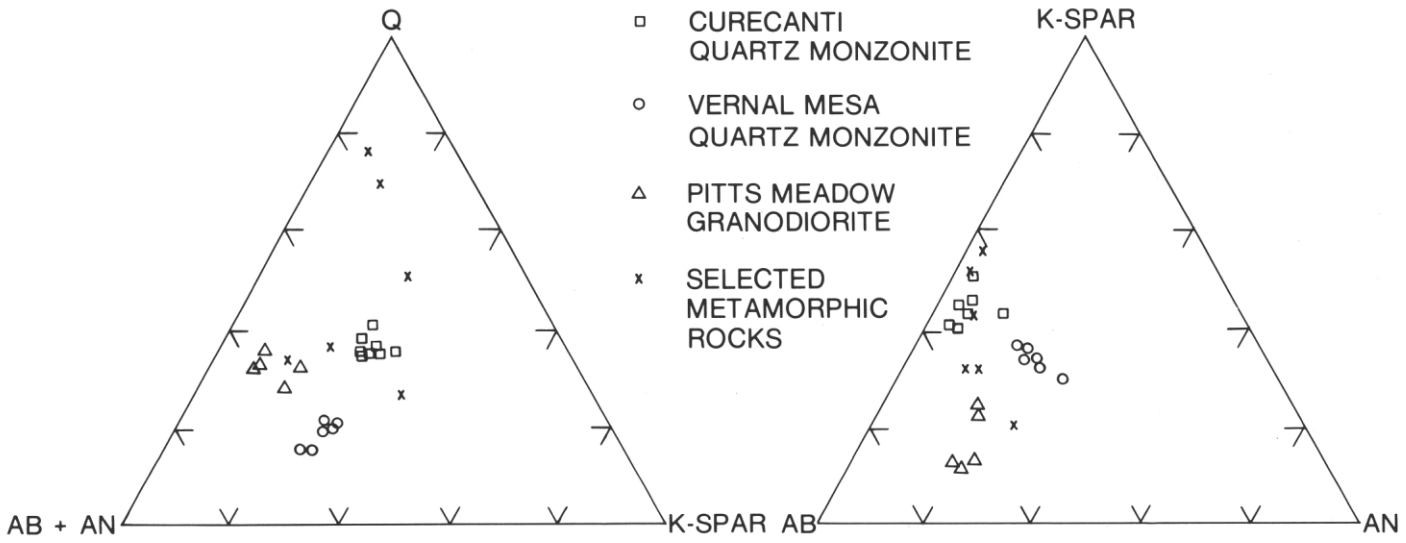


Figure 7. Triangular diagrams of chief plutonic and metamorphic rocks of the Black Canyon area, showing quartz and feldspar ratios.

Rather abundant amphibolites are problematical; zoned plagioclase in some specimens suggests an igneous parentage, possibly basaltic tuff or flows. Some masses seem to have been intruded as podlike or waferlike bodies, and a few are clearly metamorphosed dikes. Some plutonic breccias (pipes?) are amphibolitized. Former pyroxenite (?) pods have been amphibolitized also.

Pitts Meadow *Granodiorite* (1,700 ± *190 my.)*

The Pitts Meadow Granodiorite (Hansen, 1968; Hansen and Peterman, 1968) crops out along the lower Black Canyon and its tributaries in a pluton that probably is batholithic in size. Exposed 13 km north to south and 61/2 km west to east in the narrow canyon walls, its outcrop is limited to the few square kilometers of the lower canyon, but there is no reason to believe that it does not extend much farther under cover of overlapping sedimentary rocks. In fact, similar rocks crop out near the north end of the Uncompahgre Plateau (Hedge and others, 1968).

Though locally massive, the Pitts Meadow generally is gneissic—being well foliated and lineated and, in places, having two sets of lineations concordant with those in the adjacent wallrocks. It contains abundant oriented inclusions, some of which contain sil limanite. Streaky schlieren look like disintegrated xenoliths smeared out by flowage.

Complex wallrock relations suggest both metasomatism and magmatic intrusion: where the wallrock is paragneiss or metaquartzite, the boundary commonly is gradational over many meters; where the wallrock is amphibolite, the contact may be sharp but nearly concordant; vaguely bounded "skialiths" deep within the pluton include ghostlike masses several meters long. Such field relations suggest parautochthonous emplacement at katazonal depth (Buddington, 1959), contemporaneous with the deformation and high-grade regional metamorphism of the enclosing rocks.

The composition of the Pitts Meadow ranges from predominant granodiorite or sodic quartz diorite (trondhjemite) to diorite and highly mafic border phases that are mostly hornblendite. Most of the rock is about 45-55 percent plagioclase ($An_{„}$), 25-35 percent quartz, 2-18 percent microcline, 5-15 percent biotite, and from less than 1 to about 5 percent hornblende. Quartz and feldspar ratios are given in Figure 7.

Vernal Mesa Quartz Monzonite (1,480 ± 40 my.)

The Vernal Mesa Quartz Monzonite crops out in and near the Black Canyon of the Gunnison National Monument, where it forms a moderately large semiconcordant pluton, probably phacolithic in shape but modified by faulting and partly hidden by overlapping sedimentary rocks. Locally it is sharply discordant. In most places, the rock is moderately well foliated parallel to its near-vertical walls but locally lacks obvious foliation. Abundant inclusions of country rock are oriented parallel to the foliation. Foliation, in fact, is due chiefly to a preferred orientation of the wallrock inclusions and of large microcline phenocrysts. This relation suggests magmatic flowage late in the cooling history of the rock. Some phenocrysts have granulated margins, seemingly caused by protoclasis. Wallrock relations, form, and fabric together suggest emplacement in a late-syntectonic mesokatazonal environment, shallower than the inferred emplacement of the Pitts Meadow. Analyzed specimens of Vernal Mesa are mostly very coarse grained porphyritic biotite-quartz monzonite, but they range from quartz monzonite to granodiorite to subordinate nonporphyritic biotite-hornblende diorite. Owing to the coarseness of the rock, an accurate modal composition is difficult to obtain. Point counts in the field and in the laboratory indicate 20-30 percent (volume) microcline phenocrysts 15-40 mm long. The normative composition of four typical samples averages about 15 percent quartz, 22 percent orthoclase (microcline), 43 percent plagioclase ($An_{„}$), and 17 percent femic minerals (mostly biotite).

Curecanti Quartz Monzonite (1,420 ± 15 m. y.)

The Curecanti Quartz Monzonite forms one major pluton in the Black Canyon and many minor ones. Named and first described by Hunter (1925, p. 49), it has more recently been discussed by Hansen (1964,1965, and 1971) and by Hansen and Peterman (1968). Curecanti plutons are sharply discordant. The major body, which has the shape of a thick subhorizontal sheet or wedge rooted on the west, cuts across steeply dipping gneiss. Both its roof and its floor are exposed in the canyon walls. Minor bodies are mostly lenticular or irregular, short thickened dikes or pipes. Most of them are slightly foliated, and they appear to be late syntectonic. The major pluton lacks foliation and appears to be nontectonic, even though its emplacement was forcible.

An epimesozonal environment of emplacement is suggested by the uniform granularity of the rock, isotropic fabric, and discordant wallrock relations. The plutons lack chilled borders, but they rose to shallow enough depths for the major body to lift its roof in a somewhat laccolithic fashion.

Fresh rock is light-gray to light-orange-pink, medium-grained sodic-potassic quartz monzonite or albite-microcine granite. Its modal composition is about 34 percent quartz, 33 percent plagioclase (An,„ commonly An„), 26 percent microcline, 4 percent biotite, and 3 percent muscovite. A trace of garnet is ubiquitous in the major pluton but is lacking from most of the minor ones. Analyzed samples from the minor plutons are appreciably more calcic than samples from the major one.

Pegmatite (ranges widely in age)

Pegmatite is exceedingly abundant in the Black Canyon, and the countless dikes, sills, and irregular bodies of all sizes aggregate a very large total volume (fig. 8). Nearly all the pegmatite is mineralogically simple, consisting of microcline (much of it perthitic), quartz (much of it graphic), muscovite, and local albite. Biotite, hematite after magnetite, tourmaline, garnet, hornblende and rarely, beryl are local accessories.

The largest single mass of pegmatite is a stocklike body nearly 21A km long and nearly a kilometer across, just southeast of the national monument at Coffee Pot Hill. Bodies almost as large crop out on Poverty Mesa north of U.S. Highway 50 near Cerro Summit. Black Canyon pegmatite obviously ranges widely in age. Most of it, however, seems to be related in time and origin to the Curecanti Quartz Monzonite. A quarried sample near the Curecanti pluton was dated at 1,360 ± 40 m.y. by Rb-Sr (feldspar) analysis; a biotite sample from another dike had a K-Ar age of 1,290 ± 40 my.; both these ages probably are minimums (Hansen and Peterman, 1968). Few pegmatites actually cut the Curecanti, although some vaguely bounded masses grade transitionally into it. Many pegmatites, on the other hand, intrude the Vernal Mesa Quartz Monzonite. Thus, an important period of pegmatite injection followed emplacement of the Vernal Mesa and accompanied or preceded emplacement of the Curecanti.

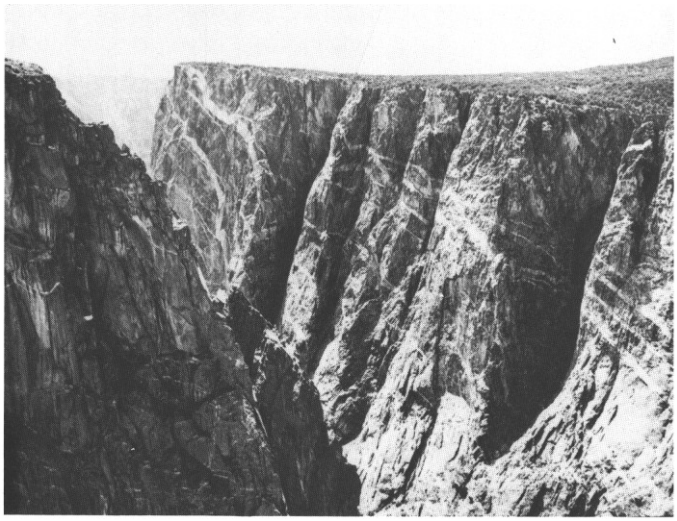


Figure 8. Painted Wall in Black Canyon of the Gunnison National Monument, Colorado's highest cliff (700 m). Metasedimentary gneiss interlaced with pegmatite. The sloping rim is an exhumed part of the old Uncompahgran erosion surface. The deep cleft to the right is a widened joint.

Many small pegmatite dikes are associated with the Pitts Meadow Granodiorite. Two or three separate injections cut across earlier-formed aplite, as well as across the granodiorite itself.

The oldest pegmatite forms small irregular pods emplaced along the foliation of the country rock, deformed along with it, and truncated by younger rocks.

Lamprophyre (>1,430 my. but <1,700 m. y.)

Two types of lamprophyre, reminiscent of those in the Sawatch Range and described by Pearson and others (1966, p. 1113), have been noted in the Black Canyon. One type, a plastically deformed, weakly to strongly foliated hornblende-biotite-microcline metavogesite, crops out sparsely in widely scattered localities and forms small northwest-trending dikes that, in the upper canyon, are cut by the Curecanti pluton. Despite metamorphism, these dikes retain porphyritic textures and chilled borders that together suggest hypabyssal emplacement. Similar dikes cut the Pitts Meadow Granodiorite, thereby bracketing their time of injection.

The other type of lamprophyre, also a vogesite, is not obviously deformed or metamorphosed but forms straight-walled dikes and pipes in the headward part of the canyon and adjacent Lake Fork. It has not been observed in contact with any other igneous rock.

Cambrian or Ordovician

Diabase (510 ± 60 *my.)*

Diabase is the youngest known intrusive rock in the Black Canyon, cutting all adjacent crystalline rocks, although a pre-Laramide camptonite sill (Larsen and Cross, 1956, p. 234; Hansen, 1971) intrudes Mancos Shale just south of the Black Canyon at U.S. Highway 50 near Little Cimarron Creek. Diabase dikes of this age in the Black Canyon are of special interest, inasmuch as they are among the few igneous rocks as yet so dated in Colorado and are the only diabases. Alkalic plutons of Early Cambrian or late Proterozoic age have been dated from the Wet Mountains and from Iron Hill in the Powderhorn District (Z. E. Peterman, oral communication, 1968). A recently discovered tephritic leucitite dike in Lodore Canyon in the Uinta Mountains (Hansen, 1977) has been dated at 483 ± 29 m.y. by Sambhudas Chandhuri of Kansas State University.

Most diabase dikes in the canyon area trend N. 60°-70° W., and dip steeply south. They form a zone or set as much as 3 km across that extends an exposed distance of about 26 km from the mouth of Red Rock Canyon southeastward to and beyond Powderhorn, where they cut the alkalic complex. Some of the larger dikes reach 60 m across, have gabbroic cores, and can be traced for several kilometers. All have chilled borders. The smaller ones—down to a centimeter or so across—are dense and aphanitic.

Radiometric dating of the diabase by the Rb-Sr method has been possible because the rock contains appreciable K-feldspar in interstitial micropegmatite. The diabase in turn is helpful in placing a minimum time on the first movement of a system of conjugate fractures that moved before and after the diabase was emplaced, including such major fractures as the Red Rocks fault.

GEOLOGIC STRUCTURE

The dominant structural feature of the region is the Gunnison uplift (fig. 9), the upraised block through which the river has carved the Black Canyon. Though the Gunnison uplift is fundamentally a Laramide structure, its bounding elements began to take form in Precambrian time. It is outlined by old Precambrian faults that readjusted themselves to renewed earth movements during the Uncompahgran and Laramide orogenies. The uplift thus is mainly a composite tilted fault block rather than an updomed fold, but it is

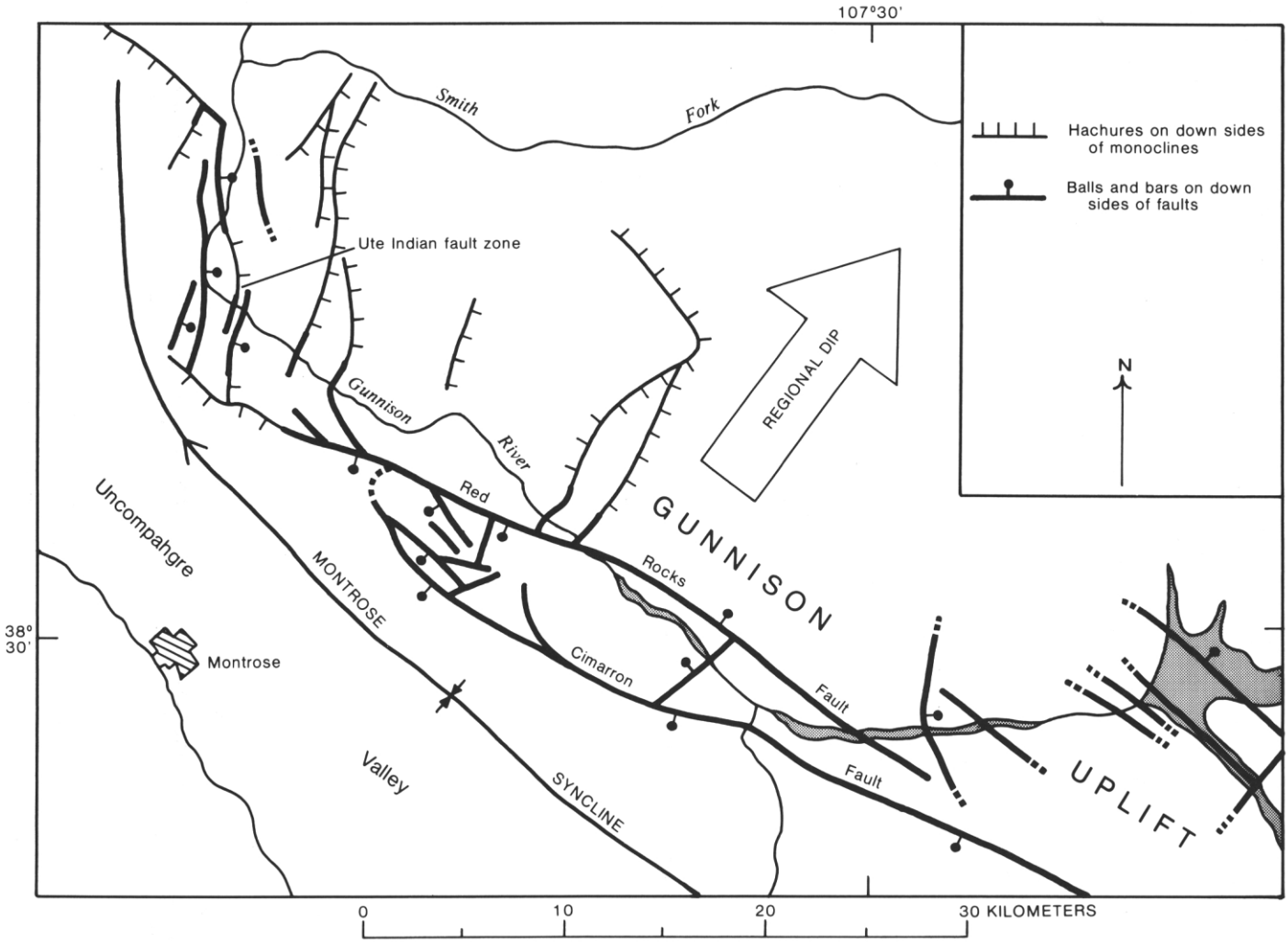


Figure 9. Sketch map showing faults and monoclines of the Black Canyon region.

sharply folded locally along faults and is gently flexed across the crest. To the northwest, the uplift passes into a plunging anticlinal nose, skirted by Colorado Highway 92 east of Austin, almost surely controlled by faulting at depth. Overall, the Gunnison uplift slopes off to the northeast into the Piceance Creek Basin. On the southwest and west it is bounded by faults and (or) monoclines. If minor fractures and displacements are ignored, the Gunnison uplift is thus seen as a broad tilted block, still partly capped by the Dakota Sandstone but stripped down to the Precambrian basement along the canyon rims and overlapped toward the southeast by volcanic rocks. The sloping tops of Fruitland Mesa, Grizzly Ridge, Vernal Mesa, Poison Spring Hill, Dead Horse Mesa, Poverty Mesa, and the several mesas near the head of the canyon are manifestations of this great block. The steep south slopes of Vernal Mesa and Poverty Mesa coincide with lines of faulting.

Precambrian Folds

Precambrian rocks of the Black Canyon have been intricately and repeatedly folded and faulted, both at large scales and small. As one wag aptly put it:

> The greater folds have lesser folds
> upon their flanks to right 'em
> And these, in turn, still smaller folds
> and so ad infinitum
> (With apologies to Robert Burns)

Large-scale Precambrian folds range from a few to several kilometers across the limbs (fig. 10). Anticlines tend to be broad and flat topped, the limbs steep or overturned. Many minor folds are isoclinal. Major axes trend and plunge within a few degrees of north except in the middle section of the canyon, where they trend generally southwestward. Plutonic activity accompanied and followed deformation.

Large-scale folding is discernible directly on the ground in only a few places where it is not masked by details. One such place is Morrow Point, where a north-trending anticlinal axis crosses the Black Canyon about a kilometer below the mouth of Cimarron Creek. This fold is visible from Cimarron; from Poverty Mesa or Crystal Reservoir one can see the west limb gradually steepen and

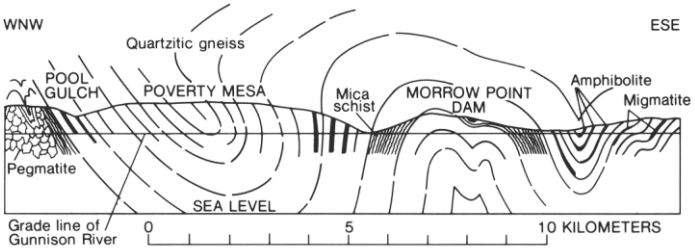


Figure 10. Sketch section along the Black Canyon near Cimarron, showing style and scale of folding.

overturn. Morrow Point Dam is built on the east limb, about at the axis of a subordinate syncline a few score meters across.

Joints

Joints vary greatly in age, size, attitude, and origin, and a detailed description of their many variations is beyond the scope of this paper. They are, however, among the more spectacular manifestations of past earth stresses in the Black Canyon, and large well-formed sets contribute greatly to the character of the canyon scenery, particularly in the steep-walled sections of the national monument (see figs. 4, 8).

Two main high-angle joint sets extend throughout the canyon area, one trending northwestward, the other northeastward. The northwesterly set is the more prominent in the national monument where some individual fractures extend more than 2 km. These fractures are regarded as shear joints. A few large low-angle joints are also visible from the canyon rims. In the upper canyon, well-formed exfoliation joints, best seen by boat, add distinction to the Curecanti pluton.

Faults

Most faults of the area are ancient fractures that have had several periods of displacement. The largest displacements, which produced mylonite, were pre-Laramide, either Precambrian or Uncompahgran. Some have had no Laramide displacement, and no fault in the area offsets the Tertiary volcanics. The large Red Rocks fault, which bounds Vernal Mesa on the southwest, arises near the head of Red Rock Canyon and trends east-southeast 30 km or so toward Blue Creek (see figs. 3, 9). This fault has a pre-Laramide strike-slip displacement of about 51/2 km, offsetting the Vernal Mesa pluton and several large diabase dikes. Its Laramide habit was scissors-like—up about 1,200 m on the south, toward the west, and down about 120 m on the south, toward the east. Its hinge or node is just south of the south-rim campground in the Monument. As the Red Rocks fault dies out toward the southeast, its displacement is taken up by the Cimarron fault, which extends about 64 km from Bostwick Park to Powderhorn. These faults together form the southwest boundary of the Gunnison uplift. The Cimarron fault has a high-angle reverse habit, clearly shown by wall relations at Cimarron, where its dip is about 60 degrees and its throw is about 1,200 m.

The best-exposed faults in the area are in the lower reach of the canyon, and their large escarpments dominate the local scenery. Access, unfortunately, is poor. The Ute Indian fault zone is a north-trending line of fractures along which Pitts Meadow Granodiorite has been thrust at least a hundred meters up and over the Entrada Sandstone. Field evidence indicates repeated offset. Pre-Jurassic movements caused local mylonitization. Laramide movements produced no mylonite, but caused considerable shattering and brecciation, especially in the hanging wall. Like most other faults in the Black Canyon, the faults of the Ute Indian zone are reverse faults; measured dips on well exposed fault planes are as low as 32 degrees.

Monoclines

The remarkable monoclines of the Black Canyon area are Laramide features caused by the draping of sedimentary rocks across the previously faulted crystalline basement, owing in large part to plastic flowage of the gypsiferous Wanakah Formation and warping in the overlying strata. Monoclinal folding is best exemplified in the lower section of the Black Canyon (fig. 11), particularly along the well-exposed vertical and lateral extensions of the Ute Indian fault zone. Elsewhere, monoclines expressed as warps or bends in the Dakota Sandstone on top of Green Mountain and Grizzly Ridge can be seen passing downward into faults in the wall of the Black Canyon. The large Red Rocks fault passes laterally into a monocline west of Bostwick Park, where it becomes the steep northeast limb of the Montrose syncline.



Figure 11. View west from Green Mountain across the lower Black Canyon toward the Uncompahgre Valley and Plateau, showing monoclinal draping over the Ute Indian fault zone. Fault here, increasing rapidly in throw toward the right (north), dips west about 26–30°. Note inner gorge in middle distance at left and far right.

GEOLOGIC HISTORY

Precambrian Events

Prior to about 1,700 million years ago, a thick sequence of arkosic sandstones, graywackes, sandy shales, and perhaps rhyolitic to basaltic volcanic rocks was deposited across the area on an unexposed basement. Subjected to intense folding and amphibolite-grade metamorphism, this sequence was then transformed essentially to its present metamorphic character. At about the same time, the Pitts Meadow batholith (cf., Boulder Creek intrusions of the Front Range) and its associated pegmatite and aplite dikes were intruded into the lower Black Canyon area.

Renewed crustal movements 1,500-1,400 m.y. ago accompanied the intrusion of the Vernal Mesa and Curecanti plutons (cf., Silver Plume of the Front Range). The Vernal Mesa pluton, which has no exact Front Range counterpart, was strongly foliated by protoclastic flowage, but deformation had died out by the time the main body of the Curecanti was emplaced. A few small lamprophyric dikes (metavogesite) were intruded after the Pitts Meadow but before the Curecanti and probably before the Vernal Mesa. Countless pegmatite dikes were injected during or soon after emplacement of the Curecanti pluton. Another metamorphic event in the range of 1,300-1,200 m.y. ago is suggested by altered mica ages (Giffin and Kulp, 1960). Possibly this event accompanied early fault movements.

Intrusion of Diabase

Diabase dikes were injected into the east-southeast-trending fracture zone in Cambrian or Ordovician time—probably Late Cambrian. Subsequent movements along the fracture zone deformed and displaced some of them. In the Powderhorn District the same dike swarm cuts the alkalic complex there, according to D. C. Hedlund and J. C. Olson (oral communication, 1967).

Late Paleozoic Events

The balance of Paleozoic history prior to Pennsylvanian time has been obscured by the Uncompahgran orogeny and the erosion that followed. Judging from what happened in adjacent areas, we can assume that shallow Paleozoic seas covered the Black Canyon area in much of pre-Pennsylvanian time. In Pennsylvanian and later time, thick wedges of clastic sediment, stripped from the old Uncompahgre highland, were deposited in the adjacent Paradox and Eagle River basins. Ultimately the ancestral Uncompahgre highland was reduced to a low featureless plain, broadly archlike in cross section, with an apex near the town of Gunnison. The Black Canyon area was just west of the crest. Segments of the old plain are well preserved in cross section along rims of the Black Canyon in the conspicuous unconformity between the Precambrian and the overlying rocks.

Mesozoic Time

The roots of the old Uncompahgre highland persisted as a subaerial plain over the Black Canyon until Middle Jurassic time, when sedimentation resumed. The eastward overlap of Jurassic rocks onto the unconformity indicates that the surface sloped westward in the Black Canyon area in Jurassic time, at a gradient of about 0.75 m/km. Mostly nonmarine sediments, deposited by the wind, in brackish lakes, and on river flood plains, accumulated during the Jurassic Period. These are the Entrada, Wanakah, and Morrison Formations. Lapping against the old highland, the Entrada is well represented in the lower Black Canyon, but it thins eastward and wedges out completely in the national monument. The Wanakah Formation persists throughout the canyon but thins markedly toward the east; only its Junction Creek Member extends into the Blue Mesa Reservoir area, where it rests directly on the Precambrian. First fluvial, then littoral, and finally true marine conditions evolved in Cretaceous time—represented by the Burro Canyon Formation, the Dakota Sandstone, and the Mancos Shale. Younger formations, if deposited, were stripped away in the mountain building that followed.

Laramide 0 rogeny

Near the close of Cretaceous time the Gunnison uplift took form as renewed movements along the old faults raised the uplif t above its surroundings. Erosion attacked the heights, slowly reducing them to a common level, so that streams flowing west from the newly risen Sawatch Range were finally able to flow almost unhindered across the beveled crest of the uplift, by then eroded to its Precambrian core. Projecting above the widening plains were scattered hills a few score meters high, now fossil monadnocks buried by Tertiary volcanic eruptions.

Tertiary Volcanism

Volcanic eruptions began in the nearby West Elk and San Juan mountains in middle Tertiary (Oligocene) time, covering the beveled core of the Gunnison uplift with successive blankets Of volcanic debris. Eruptions of intermediate lavas and volcanic breccias (West Elk Breccia and San Juan Formation) from both volcanic centers were succeeded in late Oligocene time by more-silicic pyroclastic eruptions of welded tuff out of the San Juan Mountains and, finally, by localized Miocene outpourings of mafic alkalic lava—the Hinsdale Formation (Olson and others, 1968; Lipman and others, 1978). If earlier Cretaceous or Tertiary volcanism in the San Juan Mountains affected the Gunnison uplift, it left no recognized evidence. As the volcanic piles grew, the west-flowing drainage through the area became channeled between the two volcanic centers. Drainage was curtailed from time to time by volcanic outbursts, but between eruptions it left sheets of gravel of Sawatch provenance. Some of these are well exposed along Highway 92. Volcanism persisted in the San Juan Mountains long after it had ended in the West Elks. Great sheets of pyroclastic tuff poured north from the San Juans across the Gunnison uplift and onto the flanks of the West Elks (Table 2). Concomitantly, synclinal warping began along the axis of the present Black Canyon, probably caused by unloading and doming of the West Elk Mountains (fig. 12). Consequently, each ash flow acquired a synclinal structure and, because of ponding, was thickened over the Black Canyon (fig. 13). Warping continued until after the eruption of the Hinsdale Formation.

Erosion of the Black Canyon

The stage was now set for the cutting of the Black Canyon. Volcanic activity affecting the area ended with the eruption of the Hinsdale Formation, and the Gunnison River began to cut its canyon. When its course became fixed, the river was thus flowing on a thick fill of volcanic rock and gravel and was positioned along the axis of the late Tertiary syncline. Fortuitously, its course also crossed the buried Gunnison uplift, so that when the uplift was finally again breached by erosion, the river—held in by its own steep banks—had no alternative but to erode downward into the Precambrian core. Had its course been only a few kilometers to the south, beyond the bordering faults of the Gunnison uplift, the river would have met only soft sedimentary rocks and today, instead of the Black Canyon, there would be just another broad valley, like the Uncompahgre or perhaps the North Fork.

Formation of the syncline was absolutely critical to the ultimate cutting of the Black Canyon. Because volcanic activity in the West Elk Mountains had largely ceased by the onset of ash-flow eruptions in the San Juan Mountains, erosion was unloading the West Elks all the while that the ash flows were spreading north across the Black Canyon area. Updoming of the West Elks, probably caused by unloading, reversed the dips in the distal parts of the ash flows, one after another, producing the growing syncline along the Black Canyon axis. Without the syncline, drainage would have migrated down dip, locating the Gunnison River far to the north, off the Gunnison uplift, and we would have no Black Canyon.

Late Quaternary Deformation

Although there is no known Quaternary movement on any fault in the Black Canyon area, some regional late Quaternary deformation is probable. The best evidence is in the well-formed terracing along the North Fork and the Uncompahgre River downstream from the Gunnison uplift, contrasted with the near lack of terrac.

Table 2. Ash-flow tuffs of the Black Canyon–Blue Mesa Reservoir area (from Lipman and others, 1973).

Formation	Age (m.y.)	Original Volume (km^3)	Caldera Source
Carpenter Ridge	27.5	1,200–1,500	Creede-La Garita
Fish Canyon	27.8	3,000+	Creede-La Garita
Sapinero Mesa	28	1,000+	Uncompahgre-San Juan-Silverton
Dillon Mesa	>28	50–100	Uncompahgre (?)
Blue Mesa	>28	400+	Lost Lake (?)

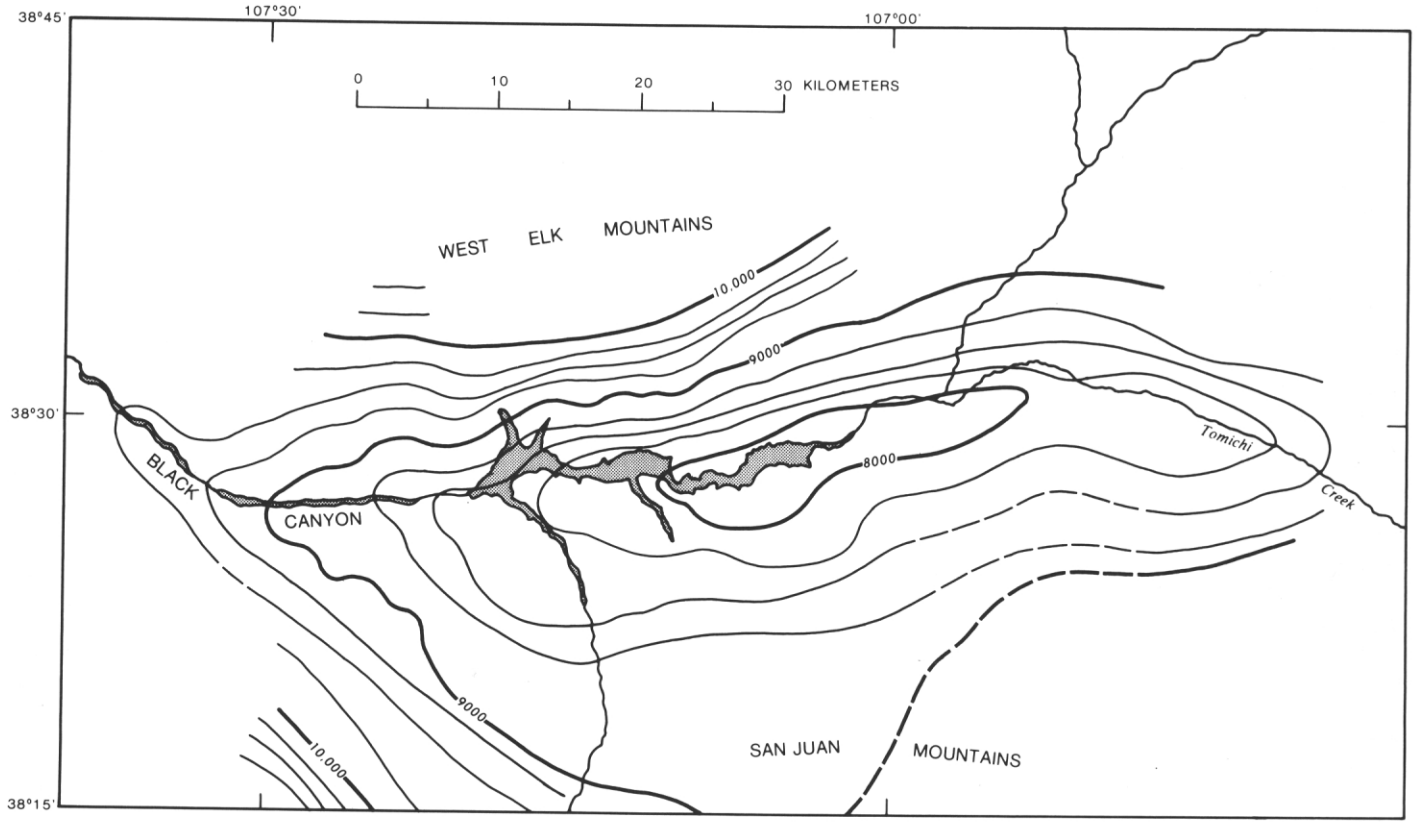


Figure 12. Structure contours drawn at the base of the ash-flow tuff volcanic sequence. Dashed contours indicate area of probable nondeposition. Based on geologic maps by Hansen (1971), Hedlund and Olson (1973), Hedlund (1974), and Tweto and others (1976). Contour interval 250 feet (about 78 m).

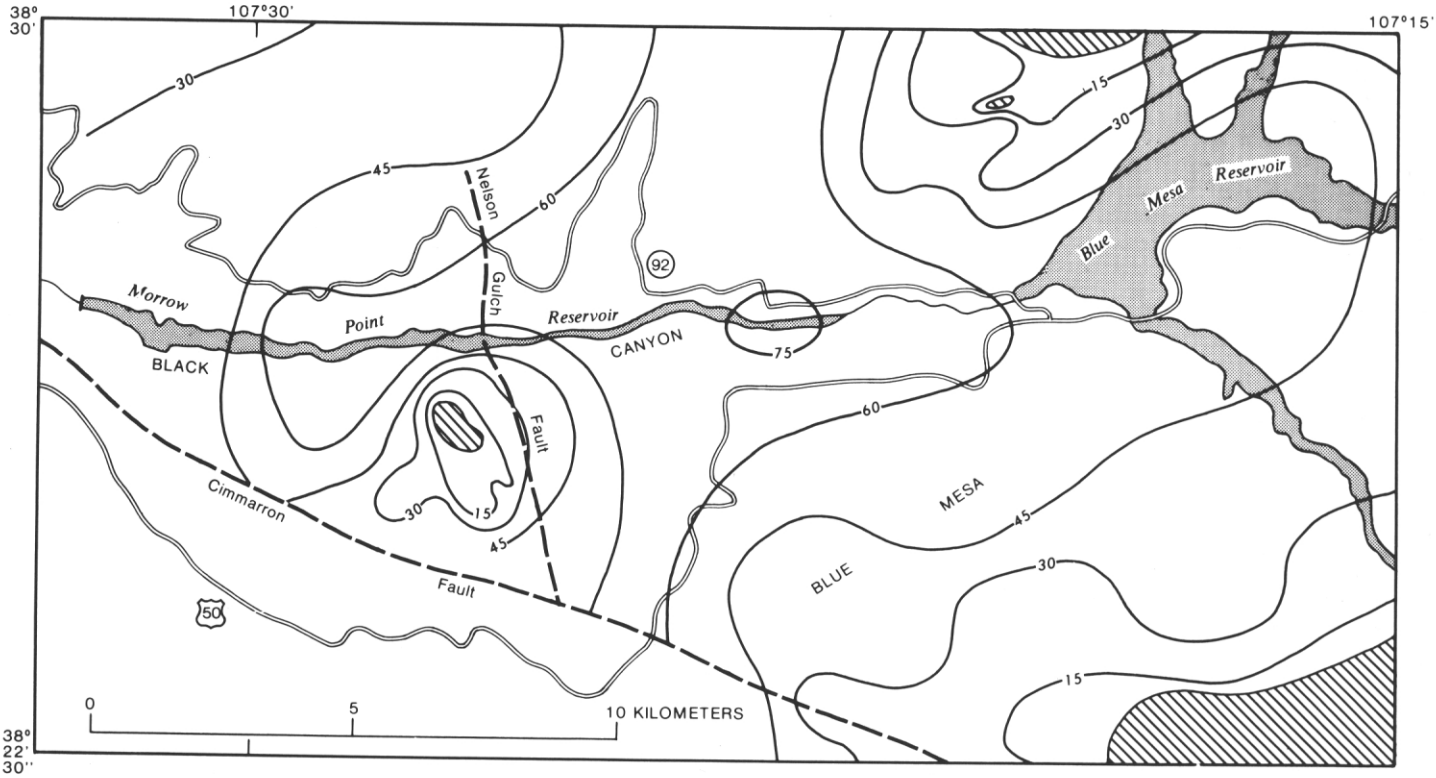


Figure 13. Thickness map of the Blue Mesa tuff. Thickening over the Black Canyon area coincides with the axial region of the syncline shown in Figure 12. Ruled pattern indicates area of nondeposition—either topographic highs ("islands") at the time of eruption or the distal edge of the ash flow. Contour interval 15 m.

ing on the Gunnison River itself immediately upstream of the canyon. The hard-rock core of the uplift has been a local base level to the upstream drainage, and a continued slow rise of the uplift-up toward the southwest, as indicated by the rise of the volcanic rims in that direction-would restrain downcutting and terracing by the river. The lack of terracing is especially pronounced just upstream of the uplift along the river and its tributary Tomichi Creek, at the town of Gunnison and vicinity. Indeed, wintertime lowland flood- ing in the fields below Gunnison, owing to ice blockage of the channel, is aggravated by the absence of confining terraces.

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