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The Geologic Story of Gunnison Gorge National Conservation Area, Colorado

Professional Paper 1699

Prepared in cooperation with the U.S. Bureau of Land Management

U.S. Department of the Interior
U.S. Geological Survey

COVER: Gunnison River canyon looking north toward Grand Mesa in the distance. More information about this image is shown in figure 18.

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Gale A. Norton, Secretary

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Simplified Geologic Map of Gunnison Gorge National Conservation Area, Colorado

LIST OF MAP UNITS

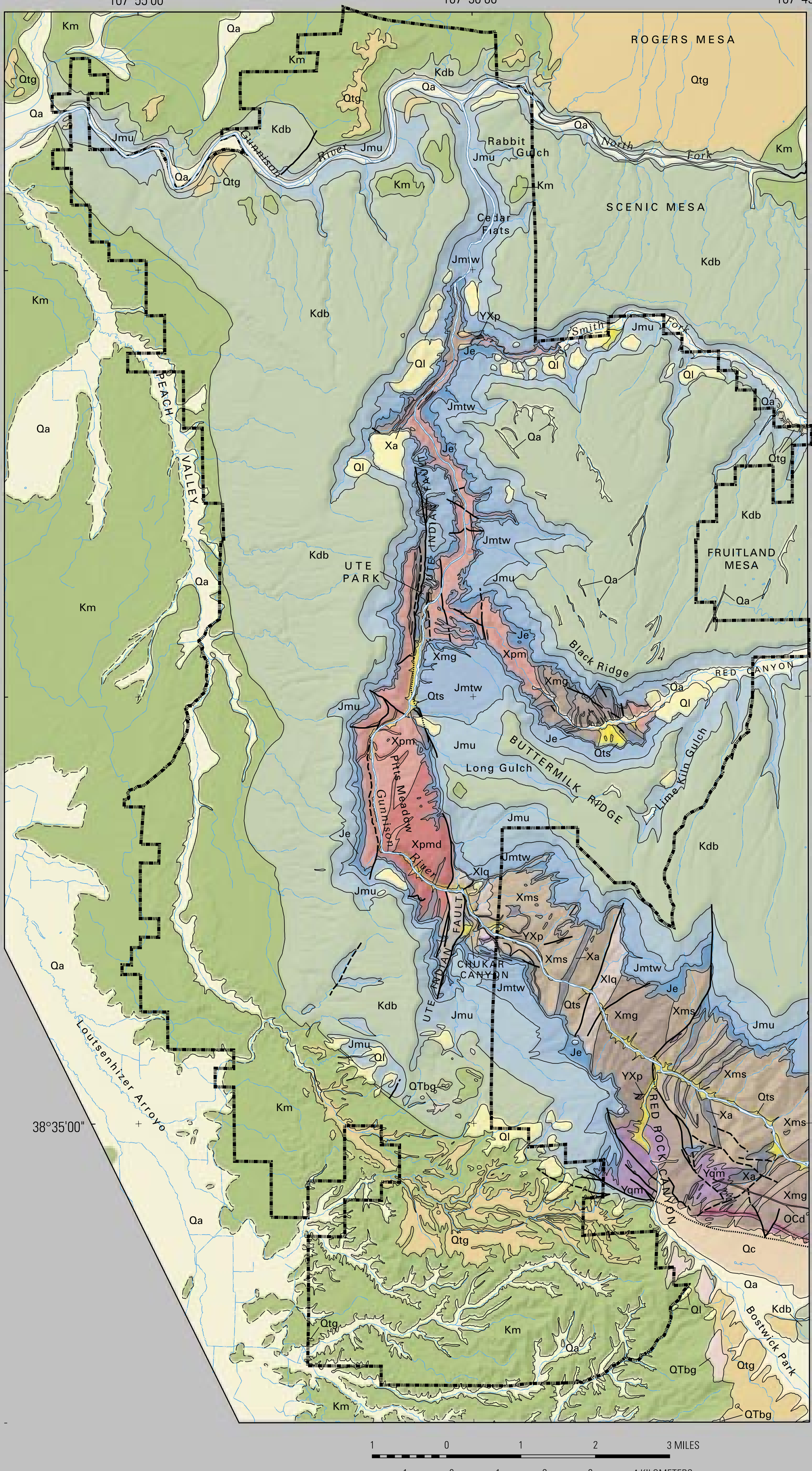
Qa	Valley alluvium (Holocene)
Qts	Talus (Holocene)
Ql	Landslide deposit (Holocene)
Qc	Colluvium (Holocene and Pleistocene)
Qtg	Terrace gravel (Holocene and Pleistocene)
QTbg	Boulder gravel (Pleistocene and (or) Pliocene)
Km	Mancos Shale (Upper Cretaceous)
Kdb	Dakota Formation and Burro Canyon Formation (Upper and Lower Cretaceous)
Jmu	Morrison Formation, upper part (Upper Jurassic)
Jmtw	Tidwell Member of Morrison Formation and Wanakah Formation (Upper and Middle Jurassic)
Je	Entrada Sandstone (Middle Jurassic)
O€d	Diabase dike (Ordovician or Cambrian)
YXp	Pegmatite (Middle or Early Proterozoic)
Yqm	Vernal Mesa Quartz Monzonite (and similar rocks) (Middle Proterozoic)
Xpm	Pitts Meadow Granodiorite (Early Proterozoic)
Xpmd	Pitts Meadow Granodiorite, dark-colored variant
Xa	Amphibolite (Early Proterozoic)
Xlq	Layered quartzitic gneiss (Early Proterozoic)
Xms	Mica schist (Early Proterozoic)
Xmg	Migmatite (Early Proterozoic)

Contact between geologic map units—Dashed where approximately located

Fault—Dashed where approximately located, dotted where concealed by surficial deposits

Approximate boundary of Gunnison Gorge National Conservation Area

(Above and Facing page) Simplified geologic map of Gunnison Gorge National Conservation Area and vicinity. Geology compiled and modified from Hansen (1968, 1971) and Ellis and others (1987). Shaded-relief base created by D. Paco VanSistine. See Kellogg and others (2004) for a large, detailed version of this map.


107°55'00"
107°50'00"
107°45'00"
38°45'00"
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38°35'00"
ROGERS MESA
SCENIC MESA
FRUITLAND MESA
PEACH VALLEY
UTE PARK
Rabbit Gulch
Cedar Flats
Gunnison River
North Fork
Smith Fork
Black Ridge
RED CANYON
BUTTERMILK RIDGE
Long Gulch
Lime Kiln Gulch
Pitts Meadow
UTE INDIAN FAULT
CHUKAR CANYON
RED ROCK CANYON
Loutsenhizer Arroyo
Bostwick Park
Km
Qa
Qtg
Kdb
Jmu
Jmtw
Je
Ql
YXp
Xa
Xpm
Xpmd
Xmg
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QTbg
Yqm
OCd
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The Geologic Story of Gunnison Gorge National Conservation Area, Colorado

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Introduction

Hidden north of an escarpment of barren shale badlands and arid sandstone outcroppings near Montrose, Colorado, is one of the West's most beautiful and unspoiled canyons—the lower reaches of the Black Canyon of the Gunnison. In an effort to preserve this unique yet highly accessible resource for future generations, the 234 km^2 (57,725-acre) Gunnison Gorge National Conservation Area (hereafter referred to as the NCA) was created by Congress in 1999 (figs. 1 and 2). An additional 29.7 km^2 (7,344 acres) were added by Congress in 2003. The outstanding scenery, magnificently exposed geological formations, and recreational opportunities within the NCA attract over 10,000 visitors a year. Kayaking, rafting, fishing, hunting, hiking, mountain biking, horseback riding, and camping are a few of the activities that the NCA has to offer. The spectacular geologic formations within the gorge document a geologic record that encompasses more than a third of the age of the Earth. Unlike the almost inaccessible depths of the Black Canyon of the Gunnison National Park, several good hiking trails descend into the NCA (fig. 2).

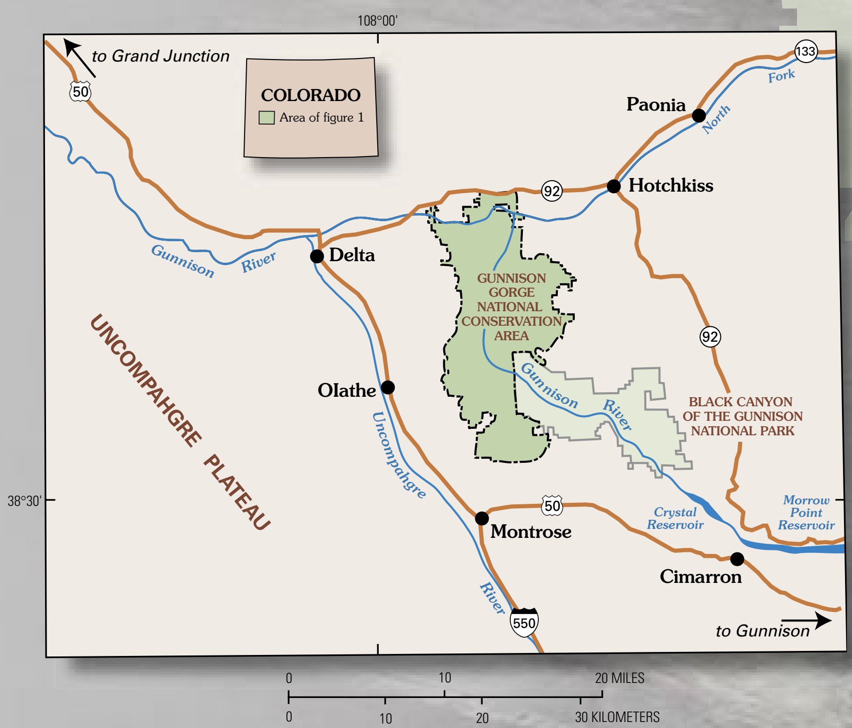


Figure 1. Index map showing the location of Gunnison Gorge National Conservation Area and Black Canyon of the Gunnison National Park.

This guide is intended to introduce the visitor to the remarkable geological features of the NCA and to explain the processes that created them. The geologic story involves ancient seas that covered the land, uplift of mountains, extensive erosion, faulting, volcanism, and a geologically recent history of deep canyon incision. This guide describes these features in non-technical terms; geological concepts and terms used as the story unfolds are defined at the end of the guide.

The NCA shares the same general geologic history as the adjacent Black Canyon of the Gunnison National Park. For the reader who desires an interesting and in depth (but easy to understand by the non-specialist) explanation of the regional geology and geologic history of the Black Canyon of the Gunnison, I refer you to Wallace Hansen's excellent book "Black Canyon of the Gunnison—in depth" (Hansen, 1987). It provides many additional geological details relevant to the NCA. In addition, three geologic maps covering most of the NCA (Hansen, 1968, 1971; Ellis and others, 1987) show in detail the distribution of the various geologic formations and structural features. An excellent waterproof topographic map, published by National Geographic Society and compiled from U.S. Geological Survey 1:24,000-scale quadrangle maps, covers all except the southernmost part of the NCA; the map shows access to all roads and trails in the NCA.

Figure 2. LANDSAT 7 image of the Gunnison Gorge National Conservation Area (yellow dashed line), showing paved roads (solid double lines), dirt roads (dashed double lines) and trails (dashed red lines).

A Brief Sense of Geologic Time

The period of time during which rocks exposed in the Gunnison River canyon were formed is immense: more than one-third of the Earth's 4.5-billion-year history. Yet, the carving of the gorge itself occurred just "yesterday," geologically speaking—only over a couple of million years. A simple analogy is sometimes useful to gain a better grasp of geologic time. If all of geologic time were condensed into one 24-hour day starting at midnight, the hard "basement" rocks exposed in the inner walls of the gorge formed at about 3:30 p.m. during a period of deep burial, recrystallization (metamorphism), and intrusion by granitic magma (molten rock). In real time, this event took place about 1.7 billion years ago in the early Proterozoic era (point A on the geologic time scale shown in fig. 3). The first hard-bodied animals (those that left abundant fossil remains) appeared in the Earth's oceans at 9:05 p.m. (543 million years ago; point B in fig. 3). However, the oldest sedimentary rocks in the canyon, which directly overlie the eroded crystalline basement rocks, were not deposited until 11:09 p.m. (about 160 million years ago; point D in fig. 3); this is long after the first dinosaurs appeared at 10:46 p.m. (about 230 million years ago; point C in fig. 3). The last dinosaur took its final breath at 11:39 p.m. (65 million years ago; point E in fig. 3), and the first true humans walked the Earth at 11:59:22 p.m. (point F in fig. 3), which is also the approximate time (about 2 million years ago) that downcutting of the Gunnison River gorge began.

Geologic Time Chart

Eon	Era	Period	Epoch	Event	Estimated age
Phanerozoic	Cenozoic	Quaternary	Holocene		10,000 years
			Pleistocene		1.8 (Million years)
		Tertiary	Pliocene	F	5.3
			Miocene		23.8
			Oligocene		33.7
			Eocene		54.8
			Paleocene		65.0
	Mesozoic	Cretaceous	Late Cretaceous	E	99.0
			Early Cretaceous		144
		Jurassic		D	206
		Triassic		C	248
	Paleozoic	Permian			290
		Pennsylvanian			323
		Mississippian			354
		Devonian			417
		Silurian			443
		Ordovician			490
		Cambrian		B	543
Proterozoic	Late Proterozoic				900 (Million years)
	Middle Proterozoic				1.6 (Billion years)
	Early Proterozoic			A	2.5
Archean	AGE OF THE EARTH				4.5 (Billion years)

Figure 3. Geologic time chart. The letters (A–F) refer to events mentioned in the text.

Geologic Evolution of Gunnison Gorge

The Gunnison River canyon is a fantastic geologic laboratory, in which we can examine close at hand both the rocks and the geologic structures present in the gorge, as well as learn about various processes that shaped the surrounding land. We will begin by looking at the ancient basement rocks of the inner canyon, which formed many kilometers deep within the Earth's crust. These rocks have risen to the Earth's surface during several periods of uplift and mountain building, and they eventually eroded to form a widespread erosional surface. We will then look at the sequence of sedimentary rocks that are on the eroded basement surface and explain the environments in which these rocks were deposited. The next part of the story involves a period of regional mountain building, called the Laramide orogeny, during which many large crustal blocks (including the Gunnison uplift) rose. Uplifts of the crustal blocks marked the initial growth of the present Rocky Mountains, although they were subsequently modified over time by considerable additional uplift, volcanism, and erosion. Finally, we'll look at how the canyon itself was paradoxically carved right through the heart of the Gunnison uplift. Why didn't the river, instead, flow around this uplifted region?

The Gunnison uplift is a broad, topographically high region that extends from just south of the Gunnison River northward to the West Elk Mountains. The uplifted region can be seen when looking north from near Montrose (fig. 4). In the uplift, the bedding south of the Gunnison River is tilted (or dips) generally to the southwest, in some places quite steeply. Farther northeast, the bedding dips gently in the opposite direction (to the northeast), forming a broad arch with the crest or highest point of the arch located just northeast of the Gunnison River where it flows through the canyon.

Hikers sitting on Pitts Meadow Granodiorite high above the Gunnison River. View is to the north (downriver). Photograph by Jeff Karson.

The Basement Rocks of the Gorge

The oldest rocks in the gorge—the mostly steep, dark-colored rock walls—formed during the Proterozoic Eon (fig. 3). These rocks are sometimes referred to as Precambrian rocks, the basement complex, or simply basement rocks. The oldest basement rocks are metamorphic, meaning that the original sedimentary or igneous rocks were recrystallized due to elevated heat and pressure during burial many kilometers deep in the Earth's crust. Heat from a large igneous intrusion (such as a granite) may also recrystallize or metamorphose rocks adjacent to it. The metamorphic event that formed the metamorphic rocks of the canyon took place about 1.74 billion years ago.

Certain sandstones rich in feldspar (the most common rock-forming silicate mineral in the Earth's crust), lava flows, or tuff (rock formed by welding or fusion of volcanic ash) can recrystallize into a foliated metamorphic rock called gneiss; shale can metamorphose into a mica-rich metamorphic rock called schist; and quartz-rich sandstone can recrystallize into the metamorphic rock quartzite or quartzitic gneiss.

Excellent outcrops of layered quartzitic gneiss are exposed along the Chukar trail, which follows Chukar Canyon down to the Gunnison River. The rock is composed of as much as 85 percent quartz, variable amounts of feldspar, and a silvery, transparent mica called muscovite. The original rock was impure quartz sandstone, probably deposited in an ancient riverbed. In places, where the original quartz sandstone graded into more shaly beds, the rock metamorphosed into schist. Commonly, the mica flakes in the schist are aligned parallel to the foliation (the layering in the rock); the foliation is not always parallel to the original bedding.

Mica schist, containing muscovite, is exposed on the canyon walls at several places just downstream from the mouth of Chukar Canyon. The schist also commonly contains small, brown, tabular crystals of staurolite (an iron-bearing aluminous silicate mineral), fine-grained, fibrous, white sillimanite (a pure aluminous silicate mineral), and small, well-formed, equant, red crystals of garnet (an iron-bearing aluminous silicate mineral), all formed at high temperatures and pressures during metamorphism.

At a few places in the canyon, a dark metamorphic rock called amphibolite is interlayered with a lighter colored igneous rock (the Pitts Meadow Granodiorite, described next). The amphibolite is generally black and composed mostly of hornblende (a common, rock-forming, black, tabular, silicate mineral) and variable amounts of biotite (a black mica) and plagioclase feldspar. Amphibolite probably formed from the metamorphism of basalt lava or a sedimentary rock derived from the breakdown of basalt lava. Amphibolite is exposed along the river about a mile upriver from Smith Fork (fig. 5) and can also be seen at several places along the Ute trail. It is also prominently exposed several miles up Red Canyon.

Figure 4. View from 7 km (4.5 mi) north of Montrose looking northeastward at the Gunnison uplift. The Dakota Formation and Burro Canyon Formation cap the highest ridges, and the light-colored badlands below are formed on the Mancos Shale. The hayfield is on an old (Pleistocene) terrace of the Uncompahgre River, which is now about 6 km (4 mi) to the west.

Figure 5. Photograph of amphibolite (Xa) intruded by coarse-grained, speckled, black and white Pitts Meadow Granodiorite (Ypm), which is, in turn, intruded by light-colored, coarse-grained pegmatite and white aplite (YXp), composed almost entirely of quartz and feldspar. Aplite locally grades into coarse-grained pegmatite. Pocket knife is 9 cm (3.5 in.) long.

About 1.0 km (0.6 mi) downriver from Chukar Canyon, the rock type changes dramatically to an igneous rock that formed deep in the Earth's crust as a magma that intruded the older metamorphic rocks. This igneous rock is called the Pitts Meadow Granodiorite. Most of the basement rocks exposed in the canyon in the NCA are composed of the Pitts Meadow Granodiorite. The rock is dark gray and composed of uniform, coarse crystals of quartz and feldspar (the quartz is slightly darker and has a more glassy luster than the opaque, white feldspar, which is mostly plagioclase), black, platy crystals of biotite mica, and black, tabular hornblende. The contrast between the white and black minerals gives the rock a speckled appearance (fig. 6). The composition is quite variable and the rock locally shows flow-induced layering (foliation) caused by the alignment of the mineral grains. A particularly dark variety of the granodiorite is exposed along the canyon walls for the first kilometer (0.6 mi) downriver from where the river first encounters the Pitts Meadow Granodiorite below Chukar Canyon (Hansen, 1968).

Numerous dark inclusions that are finer grained and contain a slightly higher percentage of black minerals than the granodiorite itself are present throughout the Pitts Meadow Granodiorite (fig. 6). These inclusions, generally less than about 10 cm (4 in.) long, but locally much larger, formed by solidification along the margins of the magma chamber as the rock slowly cooled; they were subsequently ripped off the chamber wall by moving, viscous magma and incorporated into the melt. The Pitts Meadow Granodiorite intrudes the metamorphic rocks and has been dated by the radiometric method at 1.71 billion years (Jessup and others, 2002).

At some places in the canyon are exposures of a distinctive layered rock, called migmatite, composed of alternate layers of gray quartz-feldspar-mica gneiss and lighter colored granitic rock that was injected as magma generally parallel to the layering or foliation in the gneiss. The source for the light-colored layers, which are generally less than about 5 cm (2 in.) thick in the canyon, was probably the Pitts Meadow Granodiorite. Migmatite is much more common upriver in the Black Canyon of the Gunnison but is exposed at several localities in the NCA near the mouths of Red Canyon (called Crystal Creek on older maps) and Smith Fork.

Figure 6. Speckled Pitts Meadow Granodiorite enclosing a dark, fine-grained inclusion.

Throughout the canyon are very noticeable, abundant, irregular-shaped or tabular, light-colored rock bodies that cut the canyon walls. The tabular variety is called a dike, and these rock bodies are composed of a rock called pegmatite. Pegmatite is a very coarse grained rock composed mostly of crystals of alkali feldspar, quartz, and mica (mostly the transparent muscovite variety). In places, the individual feldspar crystals are as much as one meter (3 ft) or more in length. An example of pegmatite that is well known to river runners is the "T dyke" (the spelling of "dyke" is the British version), which is about 2 km (1.2 mi) downriver from Red Canyon (fig. 7). The "T-dyke" is actually two prominent pegmatite dikes that intersect to form a "T." Pegmatite bodies and dikes are present almost everywhere basement rock is exposed along the river. Pegmatite forms from hot, water-rich magma commonly left over after a large granitic (including granodiorite) magma cools and partly solidifies. The water dissolved in the magma tends to lower the melting temperature, allowing the melt to stay liquid after the main granitic mass solidifies, contracts, and cracks. Then, the last-remaining melt is injected into the irregularly oriented cracks, in both the cooling granite body and in older, surrounding rocks, to form pegmatite dikes. The water-rich nature of the melt also permits the growth of very large crystals, because water makes the melt less viscous (more "runny"), which allows atoms to move readily and be easily ordered into crystal lattices.

Repeatedly during Middle and Late Proterozoic time, deep-crustal rocks were uplifted many kilometers during complicated and poorly understood periods of mountain building. By the close of the Proterozoic Eon (about 540 million years ago), the mountains were eroded to form a vast erosional surface, or peneplain, which stretched over a large part of what is now North America, including Colorado. This surface is sometimes referred to as the "Great Unconformity" (an unconformity is a gap in the geologic record that generally represents a long period of erosion or non-deposition of sediment).

Beginning late in the Cambrian Period (about 500 million years ago), the land began to slowly sink, and sandstone and limestone were deposited over the peneplain; most of the limestone was deposited in a shallow sea. Cambrian sedimentary rocks are the oldest rocks that contain abundant fossils, because before Cambrian time most organisms did not have hard body parts that could be preserved. Although deposition of sedimentary rocks continued intermittently throughout the Paleozoic Era in Colorado and much of North America, none of these Paleozoic rocks is preserved in the NCA region, as they are elsewhere in most of Colorado. The reason for the removal of the Paleozoic rocks from this region brings us to the next chapter of the geologic story.

Ancestral Uncompahgre Highlands

Beginning during the Pennsylvanian Period and lasting into the Permian Period (refer to fig. 3), various regions of western North America were uplifted to form a chain of mountains generally referred to as the "ancestral Rocky Mountains." One of the uplifted areas was the ancestral Uncompahgre highlands (fig. 8), which extended across southwestern Colorado. Another large uplift, the ancestral Front Range highlands, lay to the east. As both highlands rose, the overlying sedimentary rocks were stripped away, and the underlying crystalline basement rocks were deeply eroded. Tremendous quantities of sediment were shed into basins surrounding these mountain uplifts; some basins, such as the "central Colorado trough" between the ancestral Uncompahgre and Front Range highlands, contained shallow, enclosed seas in which thick deposits of salt and gypsum were deposited due to rapid evaporation of seawater in the hot, arid climate.

In the NCA, it took millions of years, until the middle of the Jurassic Period, for erosion to reduce the crystalline rock core of the ancestral Uncompahgre highlands to a flat peneplain. After the erosion cycle, sedimentation across the area resumed, and a new chapter of the geologic story began.

The Sedimentary Rocks of the Gorge

A sequence of sandstone, shale, limestone, and gypsum that overlies the eroded basement surface of the ancestral Uncompahgre highlands tells a story of ancient rivers, lakes, swamps, and vast oceans. Dinosaurs roamed the earth during the middle Jurassic Period when the oldest sedimentary rocks of the region were deposited, and their bones are locally found in some of these rocks. To the northwest, such as in Colorado National Monument near Grand Junction, a thick sequence of older sedimentary Triassic rocks were deposited on the flanks of the highlands, but no Triassic sediments were deposited in the NCA area.

The sedimentary rocks are grouped into sequences called formations that are generally of distinct age and rock type; subdivisions of formations are called members. The complete sequence of formations (and their various members) in the NCA is shown in figure 9. The following descriptions start with the oldest and stratigraphically lowest rocks.

Figure 7. Light-colored pegmatite dikes cutting the Pitts Meadow Granodiorite, 2 km (1.2 miles) downstream from Red Canyon. River runners call the intersecting pattern the "T dyke," although it is actually two intersecting dikes.

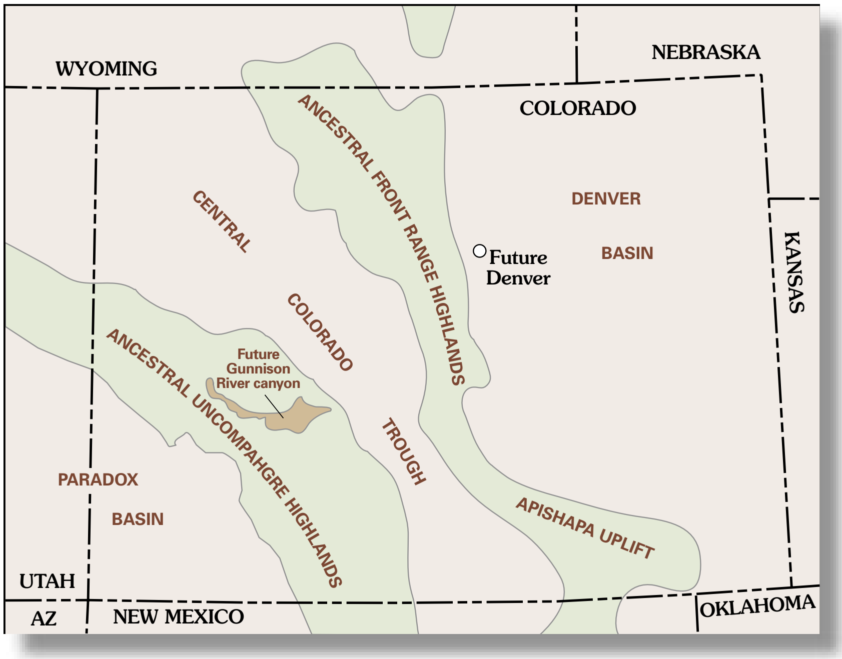


Figure 8. Diagram showing the ancestral (late Paleozoic) Rocky Mountain uplifts and adjacent basins in Colorado. Note the location of the Proterozoic rocks, now exposed in the NCA and Black Canyon of the Gunnison National Park, within the ancestral Uncompahgre highlands.

Jurassic rocks

Entrada Sandstone (Middle Jurassic)

This conspicuous, brightly colored formation, deposited directly on basement rocks, is exposed extensively in the canyon. For example, the trail down Chukar Canyon to the river (Chukar trail) crosses the yellow and pink Entrada Sandstone (fig. 10), and the lower part of the Ute trail follows the Entrada along much of its way. The formation consists of fine-grained, thick-bedded, eolian (deposited by wind) sandstone containing mostly indistinct cross-beds that represent the frontal faces of ancient sand dunes. In most places, the sandstone is quite soft, although it commonly forms cliffs and weathers into large, rounded forms. Near the mouth of Smith Fork, a pale gray-green, chromium-bearing layer at the top of the formation is about a meter (several feet) thick and has been traced over a large region of southwestern Colorado. Elsewhere, this layer is locally associated with vanadium deposits. The Entrada Sandstone ranges in thickness from 15 to 30 m (50 to100 ft), generally thins eastward, and pinches out against low, eroded Proterozoic remnants of the ancestral Uncompahgre highlands.

The basal few feet of the Entrada Sandstone consist of conglomerate containing pebbles of granite, gneiss, pegmatite, and quartz that are derived from the underlying Proterozoic basement. A good place to see the basal conglomerate and a well-developed, lithified (turned to rock) paleosol (ancient soil) that formed on the basement just before the Entrada was deposited is along the Ute trail, about 2.3 km (1.4 mi) north of its junction with the river.

The Entrada Sandstone was deposited as sand dunes in an ancient lowland desert that probably was near a seaway, because to the west, in Utah, the Entrada contains marine mudstone. At the close of deposition of the formation, the sea began to encroach on the area, and the upper few feet of sandstone contain water ripple marks, which signify a change to the shallow-marine deposits of the Wanakah Formation.

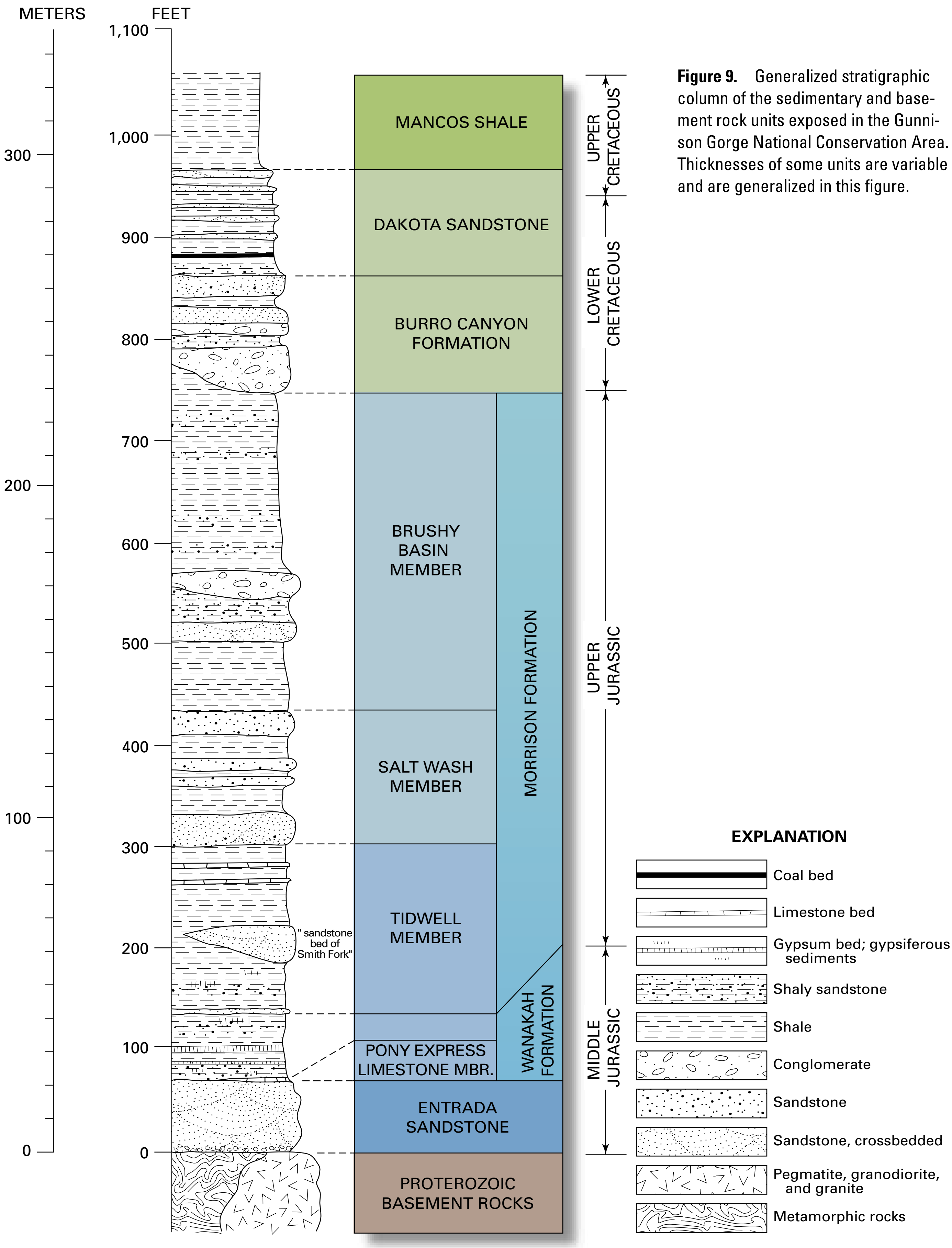


Figure 9. Generalized stratigraphic column of the sedimentary and basement rock units exposed in the Gunnison Gorge National Conservation Area. Thicknesses of some units are variable and are generalized in this figure.

Figure 10. Entrada Sandstone (Je) along the Chukar trail. Some people have remarked on the resemblance of the outcrop to the Starship Enterprise. Dark outcrops of Proterozoic basement rocks (Ꞓb) are below the Entrada, and the light-colored slopes above are underlain by the Wanakah Formation (Jw) and the Tidwell Member of the Morrison (Jmt). Contact line is dashed where approximately located.

Wanakah Formation (Middle Jurassic)

This relatively thin formation consists of white, gray, and tan shale, mudstone, gypsum, and friable (crumbly) sandstone. It is well exposed in Chukar Canyon and in the lower slopes of Smith Fork canyon. From a distance, the formation appears as drab, gray, almost featureless slopes (figs. 11 and 12), but on closer inspection individual layers and rock types become evident. The base of the Wanakah Formation is marked at most localities by a 0.3–1.2-m- (1–4-ft-) thick, locally brecciated (composed of broken, angular pieces), fetid (oily smell on freshly broken surfaces), gray limestone, called the Pony Express Limestone Member; it is particularly well exposed in Chukar Canyon, just above the Entrada Sandstone. The limestone locally contains small (less than 2 mm [0.1 in.] in diameter) spherical bodies, which resemble fish roe and are called ooliths (pronounced oo-oo-liths). Ooliths are thought to form by growth around a nucleus, such as a sand grain, as they roll back and forth on the sea floor.

Gypsum (hydrated calcium sulfate) crops out prominently in the Wanakah Formation as beds as thick as one meter (several feet) that are interlayered with soft, pale-pink, gypsiferous mudstone and calcareous (has calcium carbonate cement) sandstone. The gypsum is a snow-white, sugary-textured variety called alabaster, which is mined in other areas for the manufacture of sheetrock. The gypsum is evidence that the shallow Wanakah seaway was closed to circulation and that the climate was hot, so that evaporation was high. These conditions caused the dissolved minerals in the sea water to concentrate and precipitate on the sea floor. The total thickness of the Wanakah Formation is only about 15 m (50 ft).

The similarity of the Wanakah to the overlying Tidwell Member of the Morrison Formation caused previous geologists (for example, Hansen, 1987) to include the beds of the Tidwell with the Wanakah Formation. However, detailed studies, particularly those of Robert O'Sullivan (1992), have shown that there is a considerable gap (unconformity) in the geologic record between the top of the Wanakah Formation and the base of the Morrison Formation.

Morrison Formation (Upper Jurassic)

The Wanakah seaway gradually dried up and was mostly replaced by broad, meandering rivers and shallow lakes in which the Morrison Formation was deposited. However, the shallow sea was still present during much of early Morrison deposition. Although dinosaurs roamed the land when the Entrada and Wanakah Formations were being deposited, the Morrison Formation is particularly famous for the spectacular and diverse dinosaur bones that have been recovered at such places as Morrison, Colorado (the locality for which the formation is named), Canon City, and Dinosaur National Monument in northwestern Colorado. An excellent and easily accessible exposure of the Morrison Formation is on the north side of Smith Fork, although much of the formation can also be observed along the upper part of the Ute trail. The upper Morrison is easily observed along the Eagle Valley trail in the southwest part of the NCA (fig. 2). The formation is divided into three members: the lower Tidwell Member, the middle Salt Wash Member, and the upper Brushy Basin Member.

Figure 11. View of the north slope of Smith Fork canyon, about 1 km (0.6 mile) upstream from the Gunnison River. (Je, Entrada Sandstone; Jw, Wanakah Formation; Jmt, Tidwell Member of the Morrison Formation; Jms, Salt Wash Member of the Morrison Formation; Jmb, Brushy Basin Member of the Morrison Formation; Kb, Burro Canyon Formation). Contact line is dashed where approximately located.

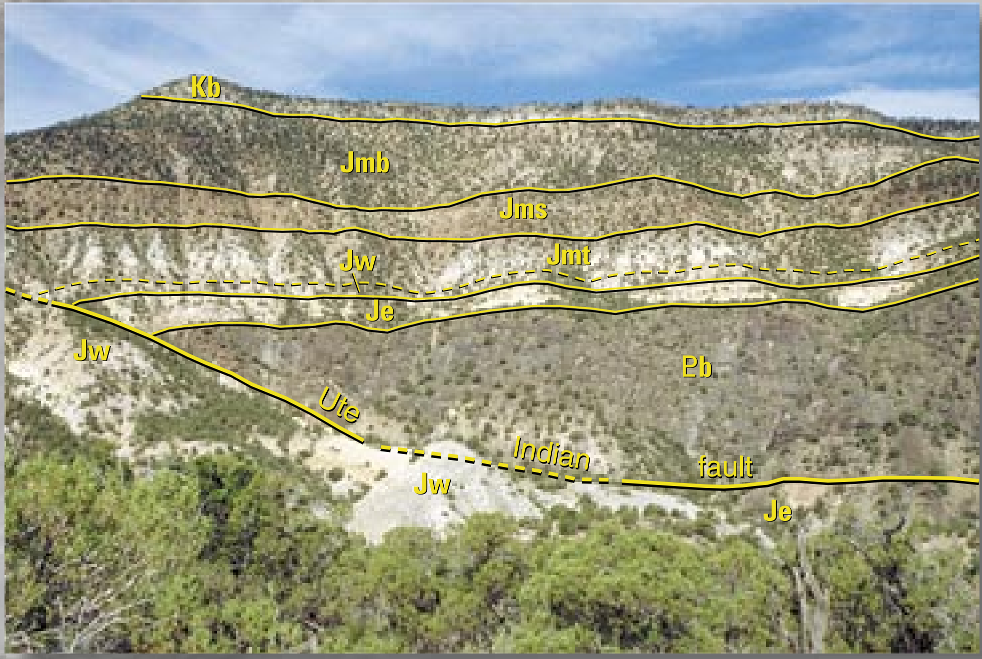


Figure 12. View looking west from the top of Chukar trail of the south end of the Ute Indian fault in upper Chukar Canyon. The fault (at the left margin of the image) passes into a monocline in the Wanakah Formation (Jw). Other units are: Proterozoic basement rocks (Ꮲb); Entrada Sandstone (Je); Tidwell (Jmt), Salt Wash (Jms), and Brushy Basin (Jmb) Members of the Morrison Formation; and Burro Canyon Formation (Kb). Contact line is dashed where approximately located; fault is dotted where concealed.

Figure 13. Iron-oxide-stained ooliths stand out in weathered relief in sandy limestone in upper part of the Wanakah Formation.

The Tidwell Member, which resembles the Wanakah Formation in the NCA region and is easily misidentified with it, is about 60 m (200 ft) thick. It consists of gray and yellow gypsum-bearing shale and sandy shale that form a continuous slope, which extends down to a similar slope on the Wanakah. A 3-m- (10-ft-) thick, yellow, coarse-grained sandstone marks the base of the member. The upper part of the Tidwell Member contains gray, cherty, algal limestone. Native Americans commonly used chert in the manufacture of arrow and spear points. The limestone formed from calcareous algae, as shown by the preserved, wavy algal structures in the rock.

Some sandy limestone beds near the top of the formation also contain small, iron-stained ("rusty"), limy, spherical ooliths (fig. 13). In the Smith Fork area, but not in areas to the south, is a fine-grained, friable, crossbedded, light-yellowish-gray, eolian sandstone, as much as about 25 m (80 ft) thick. Hansen (1968) named this unit the "Junction Creek Sandstone Member of the Wanakah Formation;" now it is simply called the "sandstone bed of Smith Fork" and is included in the Tidwell Member of the Morrison Formation (O'Sullivan, 1992). This sandstone was deposited as dune sand on the temporarily dried-up floor of the ancient seaway that existed during early deposition of the Morrison Formation.

The Salt Wash Member is composed chiefly of light-gray, massive to crossbedded, fine-grained, cliff-forming sandstone and interbedded red, gray, and green shale. The sandstone is stained red from the overlying red shale. Uranium deposits elsewhere in Colorado and Utah are commonly hosted by the Salt Wash Member. This member is about 35–52 m (120–170 ft) thick in the NCA.

The Brushy Basin Member consists of thin-bedded, red, yellow, gray, and green shale and light-yellow sandstone. In places, a distinctive pebble conglomerate bed, containing red and green pebbles (Hansen, 1968, calls it the "Christmas tree conglomerate"), crops out near the middle of the member. Dinosaur bones, such as the famous bone beds of Dinosaur National Monument, are locally abundant in the Brushy Basin Member. In the NCA, the member is 96–99 m (315–325 ft) thick.

Prominent cliff of light-tan, locally cross-bedded, quartz sandstone in the Salt Wash Member of the Morrison Formation in the Smith Fork canyon. Black staining is desert varnish, an iron-manganese oxide common in arid climates, although some of the reddish staining is probably from overlying red sediments of the Brushy Basin Member of the Morrison.

Figure 14. Chert-pebble conglomerate, typical of the Burro Canyon Formation. Pocket knife is 9 cm (3.5 in.) long.

Cretaceous rocks

Burro Canyon Formation (Lower Cretaceous)

Sandstone and conglomerate that characterize the Burro Canyon Formation are prominently displayed in cliffs along much of the canyon rim. The formation consists of light-yellow, gray, and tan, thick-bedded, quartz-rich sandstone that commonly contains well-rounded, white, gray, and black chert pebbles, especially near the top of the formation (fig. 14). Cross-beds are conspicuous in most of the sandstone and conglomerate beds. In most places, the lower part of the formation is interbedded shale and crossbedded, coarse-grained sandstone. The pebbles within the Burro Canyon Formation formed in streams that had enough power to transport the pebbles from as far away as Utah or Nevada (Hansen, 1987). The base of the formation marks an unconformity above the Morrison Formation. A good place to examine the Burro Canyon Formation is along the Eagle Valley trail in the southwest part of the NCA (fig. 2). The thickness of the Burro Canyon Formation is variable, from about 8 to 35 m (25 to 115 ft).

Dakota Formation (Upper Cretaceous)

Figure 15. A 45-cm- (18-in.-) thick coal bed, partly mud coated, in lower part of the Dakota Formation. The coal bed contains a thin sandstone bed in the upper part. This outcrop is exposed along the Eagle Valley trail several hundred meters (about 1,000 ft) northeast of the Chukar Road. Pen is 13 cm (5 in.) long.

The Dakota Formation is widespread throughout the Rocky Mountain region. Tilted, resistant sandstone of the formation commonly forms linear ridges called hogbacks. In the NCA, the Dakota consists mostly of fine-grained, thin, platy, quartz-rich sandstone and dark-gray to black, carbonaceous (containing black, organic material) shale. Chert pebbles are present in some of the sandstone. Coal beds less than 2 ft thick are locally present near the base. Ripple marks, worm tracks, and leaf and twig impressions are common. An excellent, easily accessible exposure of the entire Dakota Formation, including a 0.5-m-thick (1.5-ft-thick) coal bed, can be seen along the Eagle Valley trail (fig. 15).

Most of the Dakota was deposited by slow-moving streams and in swamps; however, the upper part was deposited on coastal tidal flats adjacent to an encroaching seaway and interfingers with the overlying marine Mancos Shale. The thickness of the Dakota Formation ranges from about 20 to 34 m (65 to 110 ft).

Mancos Shale (Upper Cretaceous)

This widespread formation forms drab, gray badlands over much of the Uncompahgre River valley, which forms the west side of the NCA. The rocks of the Mancos consist mostly of dark-gray, silty, clay shale or mudstone. The shale is fissile (contains platy layers); in contrast, the mudstone is more massive and blocky. A few thin, fine-grained, silty sandstone layers are near the base. The Mancos Shale is very soft, easily eroded, and underlies mostly broad valleys in the region. This poorly drained formation forms a barren, "lunar" landscape of light-gray rounded hills and gullies (figs. 4 and 16), and it becomes a sticky gumbo in wet weather. This Mancos landscape is referred to as "adobe lands," a very suitable name. The Mancos Shale was deposited in a shallow inland sea, and careful searching reveals fossils of clams, ammonites (extinct cephalopods related to the modern chambered nautilus), and shark teeth. The Mancos basin slowly sank as clay from rivers feeding the inland sea was deposited. Deposition probably kept up with sinking, so that the water depth remained nearly constant. The Mancos Shale is very thick, more than 1,500 m (5,000 ft), although the upper part has been eroded away in the NCA.

View to the southwest at Pleasure Park, at the confluence of North Fork (left) and the Gunnison River (behind trees at right). The layered rocks at the top of the ridge are Dakota Formation. The prominent light-tan cliff is the Burro Canyon Formation, and the reddish slopes below the Burro Canyon are underlain by the Morrison Formation. Old (middle? Pleistocene) terrace gravel forms the flat lower surfaces on both sides of the Gunnison River.

Figure 16. Typical exposure of Mancos Shale near the Eagle Valley trail and Chukar Road. Scarring is caused by indiscriminant off-road vehicle use.

Surficial Deposits: A Record of Late Tertiary and Quaternary Erosion, Deposition, and Climate Change

Surficial deposits are relatively thin deposits of erosional materials that locally cover the land surfaces, particularly in stream valleys. They reveal important information about the more recent (last couple of million years or so) geologic history of the region.

At a few places in the NCA (such as near the highest point of Chukar Road; fig. 2), deposits of boulder gravel contain large, rounded, black boulders composed of volcanic rock. This boulder gravel is alluvium deposited by the ancestral Gunnison River, probably before or during the early stages of major canyon downcutting about 2 million years ago. The boulders were eroded from extensive beds of Oligocene and Miocene volcanic breccia (rock composed of angular igneous rock fragments) and ash-flow tuff (consolidated or fused ash from a volcanic eruption). Such beds are now exposed to the east of the NCA, but they probably covered parts of the NCA at one time. (See “The Gunnison River Paradox” section for discussion of these volcanic rocks.) The boulder gravel deposits are so old and eroded that no terrace surfaces are preserved.

Terrace gravel represents older alluvium in river- or stream-deposited beds that are now above present stream channels due to the downward erosion of the streams. The deposits underlie flat, terrace-like surfaces; generally, the higher a terrace surface is above a stream channel, the older is its underlying terrace-gravel deposit. Terrace gravel accumulated during periods when deposition in stream channels predominated over channel cutting. In this region, terraces formed when glaciers were actively eroding the high mountain valleys at the headwaters of the Gunnison River and were dumping vast quantities of sediment into the river system. The last major period of glaciation (called the Pinedale glaciation in the Rocky Mountains) is dated at about 25 to 14 thousand years ago, and in many places (mostly outside the NCA, such as along the Uncompahgre River and lower Gunnison River) a prominent terrace was produced at that time. Higher terraces locally record several older glacial periods. If the ages of terrace deposits at different heights above a stream can be determined, the rates of downcutting can be calculated. So, terraces are important recorders of the erosional history of the Gunnison River and its tributaries.

Landslides are common in the canyon, especially on steep slopes underlain by relatively weak rocks of the Wanakah and Morrison Formations. Recent landslides have a hummocky surface and a steep breakaway zone at the upper margin, but most landslides in the NCA have been inactive for a long time, so they are deeply eroded. These old landslides formed during periods of higher precipitation than currently exists, such as during the last (Pinedale) glacial interval.

Talus deposits are sloping aprons of angular rock fragments as much as 3 meters (10 ft) long, generally beneath cliffs where rock fragments accumulate due to rockfall. Talus accumulates more rapidly during episodes of heavy precipitation such as in glacial periods. In the more arid times we live in, very recent rockfall composed of freshly broken rocks without lichens is found at several places in the canyon.

The youngest and most widespread surficial deposit in the NCA is valley alluvium, which is composed of stratified sand, gravel, and boulders in river and stream channels. Valley alluvium is actively transported and deposited by flowing water, especially during periods of flooding. Sand, gravel, and boulders in the alluvium are generally rounded by stream action; some boulders are as large as cars.

What appears to be a fault relationship in this north-facing view is instead a large, almost unbroken landslide block of Brushy Basin Member of the Morrison Formation (reddish, layered rock) that has slid toward the viewer and is now overlying gray Mancos Shale. This outcrop is about 1 km (0.6 mi) north of Chukar Road and about 2 km (1.2 mi) from Peach Valley Road.

The Laramide Orogeny: Building the Rocky Mountains

The present Gunnison uplift rose during the Late Cretaceous and early Tertiary Periods, concurrent with an episode of great mountain building called the Laramide orogeny. This was a time of crustal shortening driven by continental-scale forces (commonly called plate tectonic forces, generated by movement of various plates of the Earth's outer shell or lithosphere). These huge forces caused large crustal blocks to rise in a somewhat irregular pattern across the western interior of North America to form various ranges of the present Rocky Mountains. However, later crustal extension, erosion, volcanism, and additional late Tertiary uplift significantly modified the original uplifts. The Laramide uplifts are usually bounded on one or more sides by thrust faults, inclined at low angles (less than 45º), that were the breakage planes along which older rocks (commonly including basement rocks) were shoved over younger rocks. The movement of a block up an inclined thrust fault tends to tilt the thrusted block, causing formerly flat-lying sedimentary rocks to become folded and locally broken.

The Gunnison uplift is a relatively small uplift compared with many other uplifts of Laramide age. It is a simple northeast-tilted block of basement rocks that is bounded on the southwest by two major reverse faults, the Red Rocks and Cimarron faults (fig. 17). These reverse faults are similar to thrust faults except that they are steeper than 45º. Only the west end of the exposed Red Rocks fault is exposed in the NCA. However, its buried trace farther to the west within the basement rocks is evident by the draping and folding of the overlying sedimentary rocks over the fault to form a structure called a monocline.

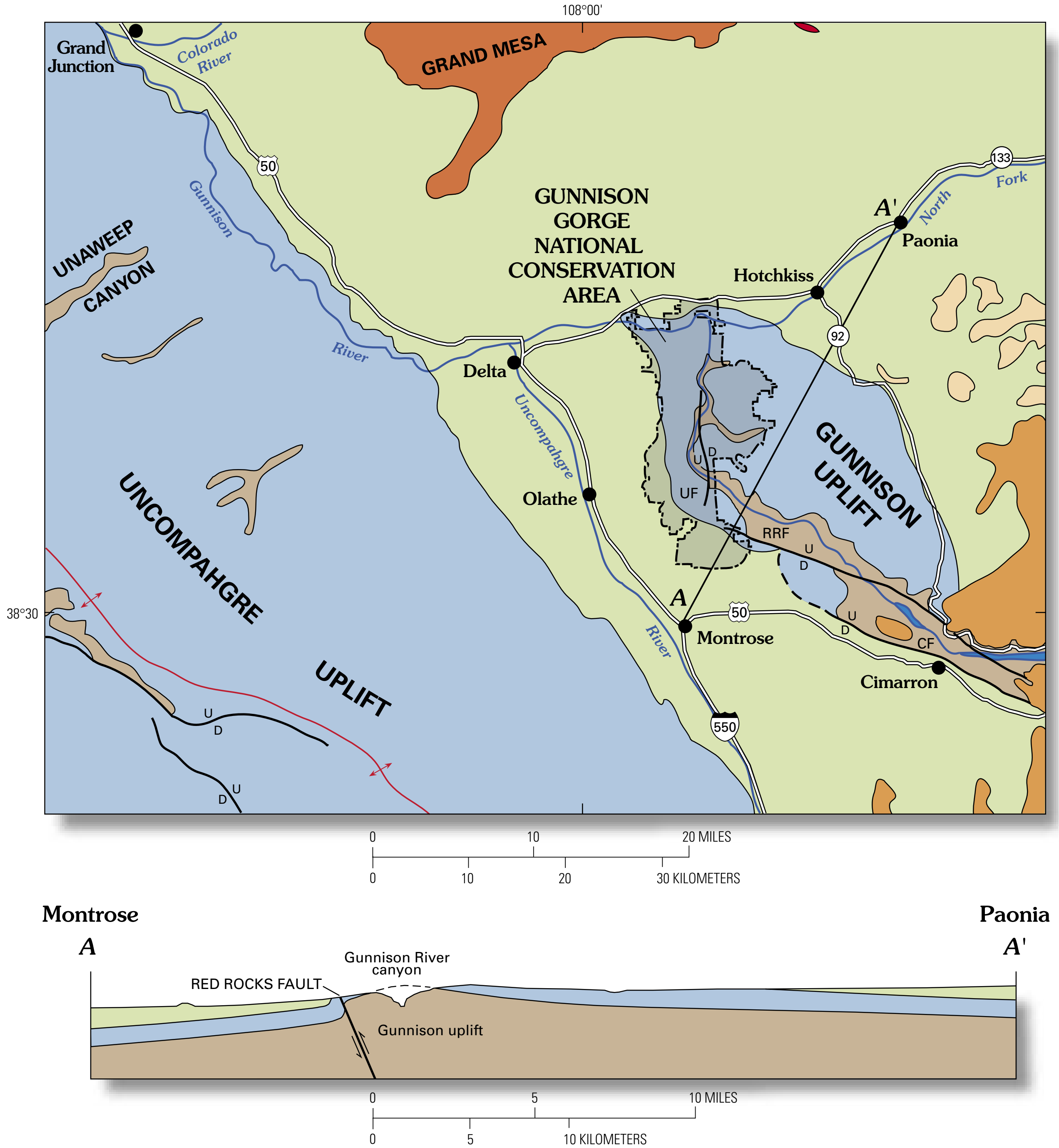
The Ute Indian Fault: A Prominent Laramide Feature

The NCA has one of the most spectacularly exposed Laramide faults in Colorado—the Ute Indian fault—which is clearly visible along much of the gorge (cover photograph and figs. 12, 18, 19, and 20). At most places, the fault dips about 40º to the west and its trace is parallel to the west structural margin of the Gunnison uplift. The Ute Indian fault is a thrust fault along which Proterozoic basement rocks were shoved up and to the east as much as 350 m (1,150 ft) vertically above Jurassic sedimentary rocks. Additional reverse faults in the basement rocks west of the Ute Indian fault are concealed beneath sedimentary rocks, which have been tilted to the west. These hidden faults dip to the east and have movement opposite to that of the Ute Indian fault. Basement rocks were shoved up and to the west on these hidden faults, and the faults mark the west margin of the Gunnison uplift.

The southern end of the Ute Indian fault is prominently exposed in Chukar Canyon (fig. 12) and generally follows the Gunnison River canyon northward, crossing the river at several places. At both its south and north ends, the fault undergoes a remarkable decrease in displacement over a short distance. At both ends, the vertical displacement across the fault decreases to zero, and the fault disappears from view into the basal sedimentary and basement rocks. At both the north and south ends, the overlying beds are not broken by the fault but are folded over it, becoming locally steepened into a monocline (fig. 19). The Ute Indian fault is also well exposed along the Ute trail, about 0.5 km (0.8 mi) from where the trail meets the river. Where the fault is exposed, it is a 1–2-m-wide (3–6-ft-wide) breccia zone that separates the Pitts Meadow Granodiorite on the west from the Entrada Sandstone on the east.

Prominent monocline in the Morrison Formation, just north of Chukar Road. This fold is probably caused by draping of beds over a buried north-trending basement fault. This is a different fold from the larger monocline overlying the buried, northwest-trending Red Rocks fault. The gray mudstone in the foreground is Mancos Shale.

Figure 17 (facing page). Regional map and cross section of the lower Gunnison River area, showing the Laramide uplifts (areas underlain by Lower Cretaceous and older rocks) and major faults. UF, Ute Indian fault; RRF, Red Rocks fault; CF, Cimarron fault. Cross section A–A' is drawn at twice the scale of the map



EXPLANATION

	Basalt of Grand Mesa	Miocene
	Volcanic rocks erupted from West Elk and San Juan Mountains	Oligocene
	Intusive rocks (mostly granite)	Oligocene and Eocene
	Mancos Shale and Mesa Verde Formation	Upper Cretaceous
	Dakota Formation and older sedimentary rocks	Mostly Lower Cretaceous and Jurassic
	Basement rocks	Proterozoic

U/D **Thrust or reverse fault**—U is upthrown side; D is downthrown side; dashed where location is uncertain

Axis of Uncompahgre uplift

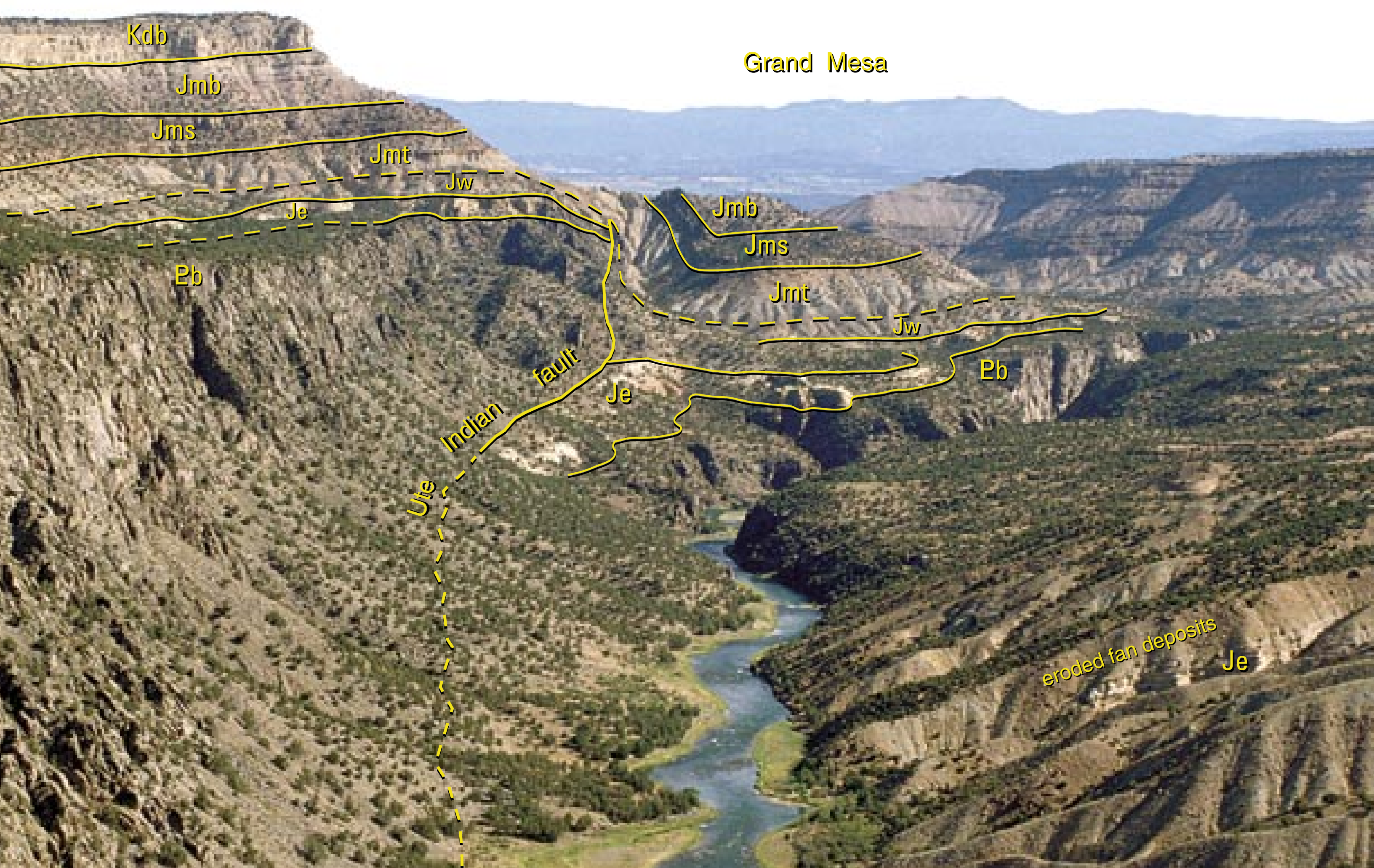
The Gunnison River Paradox

Rivers tend to seek the easiest path for their channels and, therefore, usually follow zones of soft, easily eroded rock. For example, the Uncompahgre River has cut a wide valley mostly in the soft Mancos Shale west of the Gunnison uplift. The Gunnison River, in contrast, has cut its channel through the hard basement rocks of the Gunnison uplift rather than taking an easier path through softer rocks.

A number of factors contributed to this paradox. Following the Laramide orogeny, erosion began to degrade the Gunnison uplift until by late Eocene time a vast erosional surface had formed. This surface consisted of rounded hills and relatively flat areas, and it formed on both the crystalline basement and the overlying sedimentary rocks. Slow-moving, meandering rivers flowed northwestward across the region into a large lake in what is called the Uinta-Piceance Creek basin, northwest of the Gunnison uplift. The thick lake deposits of the basin include the famous oil shale of the Eocene Green River Formation.

During the Oligocene Epoch, tremendous outpourings of volcanic rock from two sources covered large parts of the region, including most, if not all, of the NCA. About 30 million years ago (early Oligocene time), lava flows and voluminous mudflows from a large volcano in the West Elk Mountains, just to the east of the NCA, spread over much of the region and solidified into a formation called the West Elk Breccia. The original volume of the West Elk Breccia is estimated at more than 400 km^3 (90 mi^3) (Hansen, 1987). About 2–3 million years after the West Elk Breccia was deposited, tremendous caldera eruptions, at least 30 km (20 mi) to the southeast in the San Juan Mountains, sent sheets of hot ash across the region; these caldera eruptions lasted less than a million years (about 28–27.5 million years ago). Calderas are enormous volcanoes, with craters commonly wider than 10 km (6 mi), which erupt as much as thousands of cubic kilometers (hundreds of cubic miles) of hot ash that is so hot it welds itself into a rock called ash-flow tuff. Some of the hot ash clouds flowed as far to the north as the south slopes of the West Elk Mountains, covering older volcanic rocks. None of these volcanic rocks is preserved in the NCA because they have been eroded away, although large rounded boulders (composed mostly of black or dark-gray tuff and volcanic breccia) are preserved in boulder gravels deposited about two million years ago by the Gunnison River before it began cutting the canyon. These gravel deposits are now found high on hillsides above the canyon.

Figure 18. View looking north along Gunnison River canyon showing the dramatic offset of Proterozoic and overlying Mesozoic rocks near the north end of the Ute Indian fault. Units are: Proterozoic basement rocks (Ꝑb); Entrada Sandstone (Je); Wanakah Formation (Jw); Tidwell (Jmt), Salt Wash (Jms), and Brushy Basin (Jmb) Members of the Morrison Formation; and Dakota Formation and Burro Canyon Formation (Kdb). Contact lines are dashed where approximately located; fault is dotted where concealed.



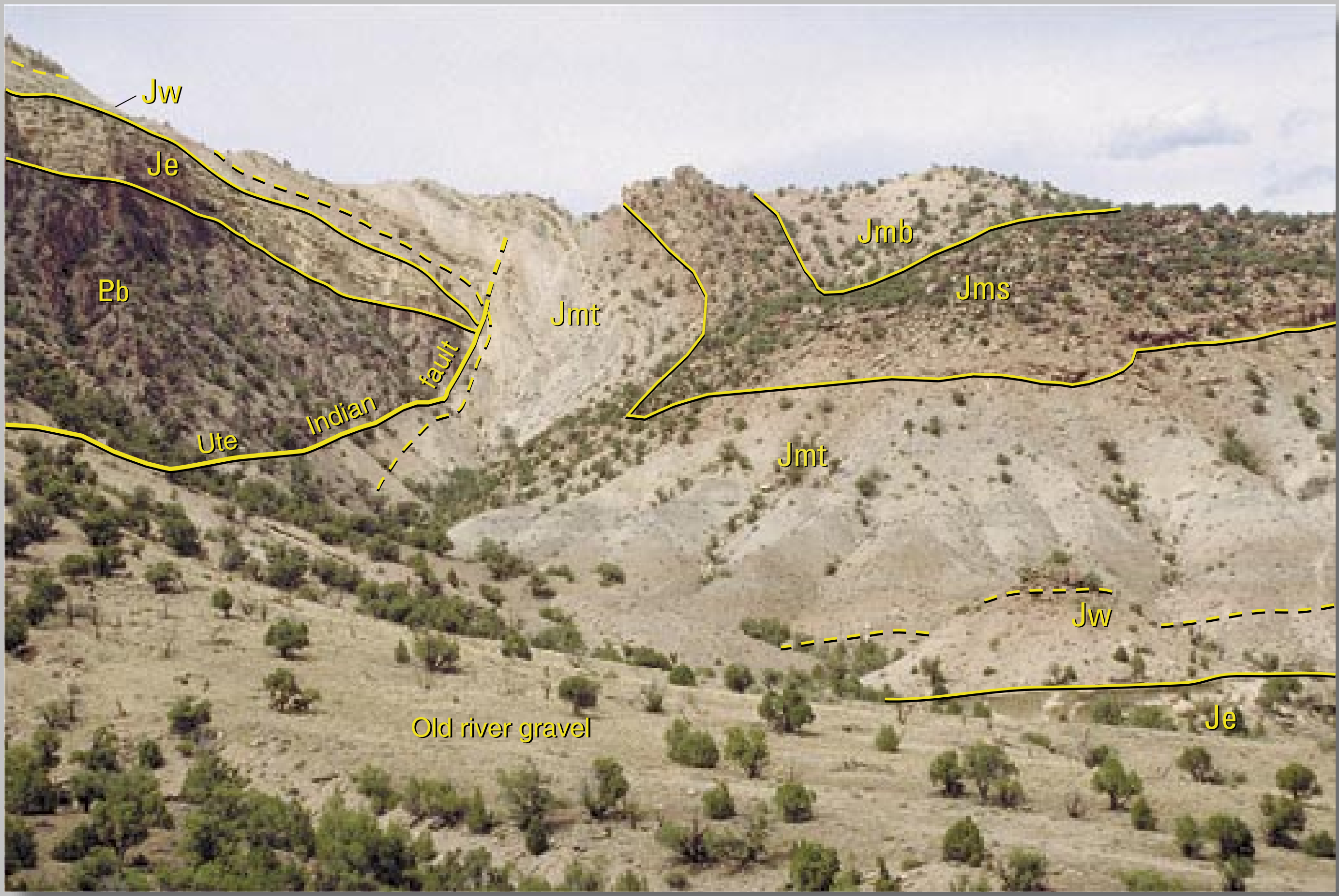


Figure 19. Close-up view of the north terminus of the Ute Indian fault. Note how the ductile sedimentary rocks are more easily folded than the brittle Proterozoic basement rocks (Ꞓb), and therefore "drape" over the fault. Other exposed units are: Entrada Sandstone (Je); Wanakah Formation (Jw); and Tidwell (Jmt), Salt Wash (Jms), and Brushy Basin (Jmb) Members of the Morrison Formation. Contact lines are dashed where approximately located; fault is dotted where concealed.

The ancestral Gunnison River was frequently diverted by outpourings of volcanic rock. It was ultimately confined between piles of volcanic rocks from volcanic centers in the West Elk Mountains and San Juan Mountains. Volcanic rocks upriver from the NCA are unusually thick, an indication that they are preserved in a slight crustal downwarp (a syncline). This structure is along and parallel to the river, so it served to further confine the river's course (Hansen, 1987). Once the Gunnison River was entrenched between two piles of volcanic rocks, it could not seek a new channel, even when it encountered resistant rocks, such as Proterozoic basement rocks.

After the Gunnison River eroded through the relatively soft volcanic and sedimentary rocks overlying the Gunnison uplift, it began to cut its channel into the harder basement rocks in a process called superimposition. This is a process whereby a drainage pattern from a formerly existing geologic terrane is impressed onto a different geologic terrane during erosion and downcutting. If it were not for the confinement of the Gunnison River between thick piles of volcanic rock, the river might have been positioned a few kilometers to the south in an area of easily eroded sedimentary rocks rather than in the hard, crystalline basement rocks of the Gunnison uplift. A broad river valley, similar to the Uncompahgre River valley, would have formed, and the gorge of the NCA and Black Canyon of the Gunnison would not have been carved.

Kayakers exploring upriver from Duncan trail. The Canyon walls here are Pitts Meadow Granodiorite.

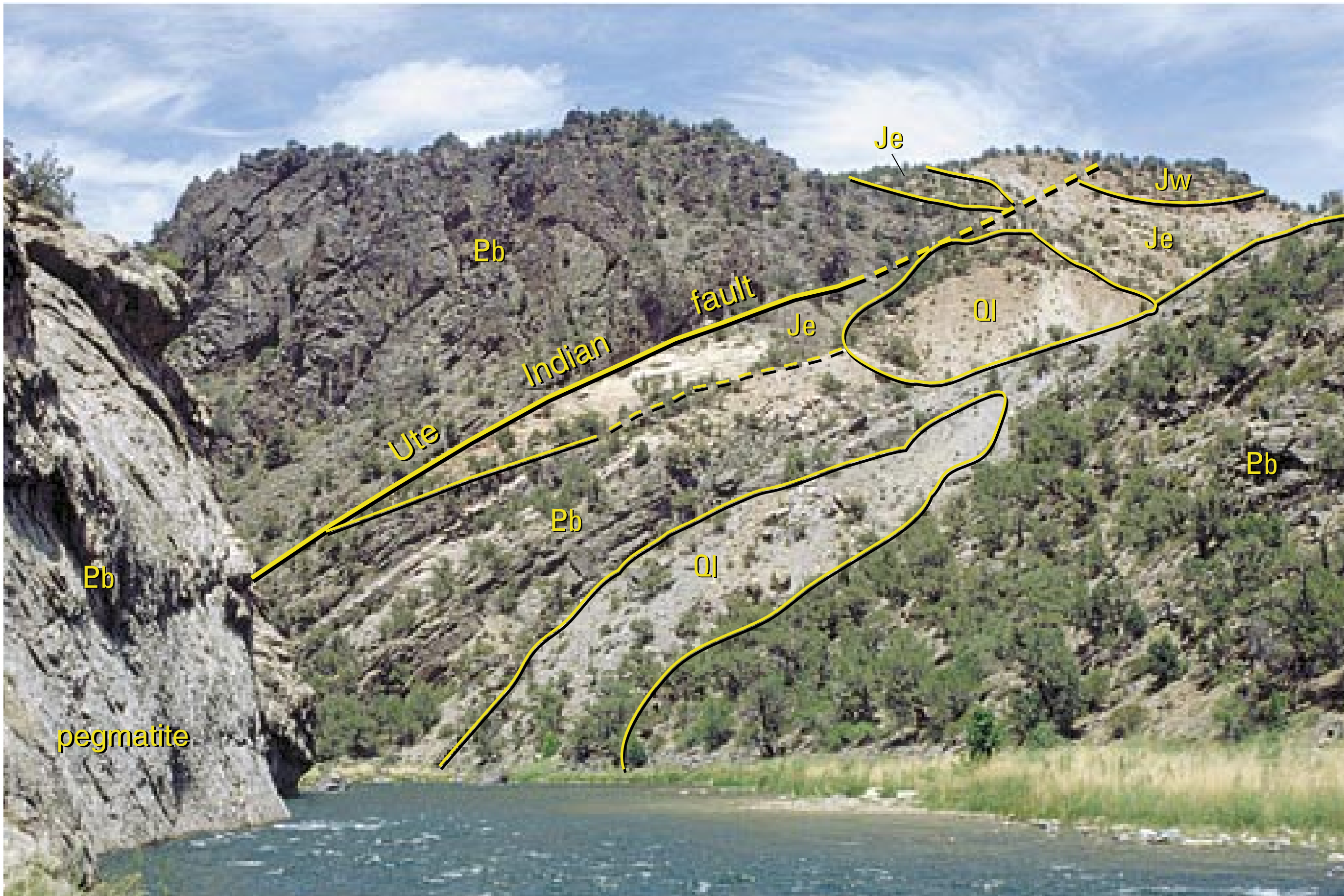


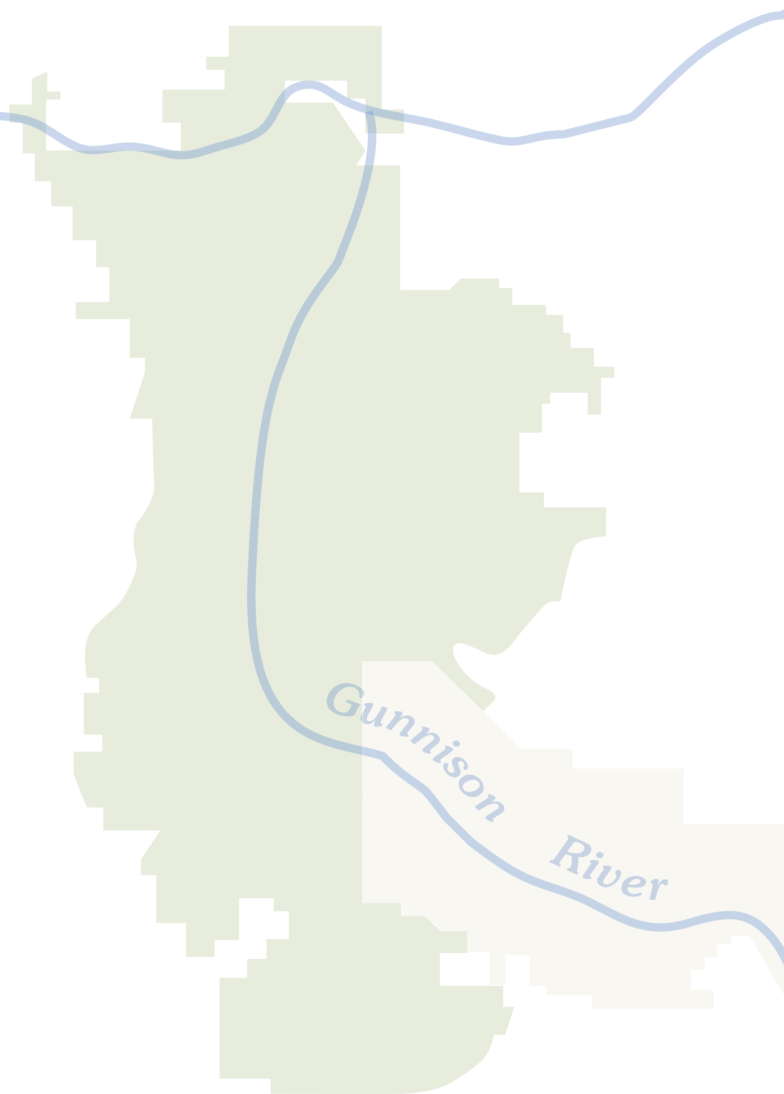
Figure 20. View looking northwest at a north-trending splay (branch) of the Ute Indian fault in the wall of the Gunnison River gorge about 0.8 km (0.5 mi) downriver from Chukar Canyon. Proterozoic rock (Ꝑb) was thrust eastward over Entrada Sandstone (Je). On the west (left) side of the fault, the Proterozoic rock is layered quartzitic gneiss; east of the fault it is mica schist. This splay of the Ute Indian fault dies out in the overlying, easily deformed, gypsum-rich beds of the Wanakah Formation (Jw). Landslide deposits (Ql) cover parts of the rock outcrops. The near outcrop at the left, at river level, is a large Proterozoic pegmatite. Lines are dashed to indicate where they are approximately located.

The Gunnison River began to cut its gorge about 2.5 million years ago, a remarkably short time ago, in terms of geologic time. How do we know this? The evidence, cited by Hansen (1987), is based on the isotopic dating of a volcanic ash bed in Bostwick Park, immediately east of the eastern boundary of the NCA. The ash is 1.2 million years old and is present about 365 m (1,200 ft) below the rim of Black Canyon of the Gunnison and about an equal distance above the bottom of the present canyon. If the ash was deposited at the then bottom of the canyon 1.2 million years ago, the average rate of downcutting at Bostwick Park since that time has been about 0.3 m (1 ft) per 1,000 years. Although the rate of downcutting undoubtedly was not constant, this rate yields an approximate total time for downcutting of the canyon of about 2.5 million years.

Factors that Control the Gunnison River's Ability to Downcut

Downcutting of a river's channel can only occur when a river has a distant outflow region that is significantly lower in altitude than the rocks into which it is eroding. This level, called the stream's base level, is the ultimate level to which a stream or river can erode. The base level concept is extremely important when considering how the Gunnison River canyon formed. Somehow, the base level of the Gunnison River was lowered dramatically about 2.5 million years ago, thus allowing the river to cut deeply into the Gunnison uplift. A large canyon that crosses the Uncompahgre uplift south of Grand Junction, called Unaweep Canyon (fig. 17), presents an intriguing clue as to how this might have occurred. A large river clearly carved Unaweep Canyon, but, curiously, it now contains only small streams that are incapable of carving such a canyon. Stanley Lohman (1961) suggested that the ancestral Colorado River once flowed through Unaweep Canyon (fig. 21*A*). Sometime during the Pliocene Epoch, the flow of the Colorado River, upstream from its ancestral junction with the Gunnison River, was "captured" by headward erosion of a downstream tributary of the Colorado River near present Grand Junction (fig. 21*B*). The Colorado was then diverted into the valley of the tributary stream and flowed around the northwest end of the Uncompahgre Plateau. The erosive power of the Colorado River added to the tributary and caused the river channel to cut down mostly through the soft Mancos Shale, thereby significantly lowering the river's base level. This river capture left only the flow of the Gunnison River through Unaweep Canyon. Evidence recently found by Robert Scott and his coworkers (2002) shows that the Uncompahgre Plateau was being uplifted at this time, so that the flow through Unaweep Canyon, deprived of the flow of the Colorado River, was unable to downcut as rapidly as uplift, causing the Gunnison River to be dammed and creating a lake (fig. 21*B*). Later, a north-flowing tributary of the Colorado River captured the lake's outflow, and the Gunnison River then regained its connection with the Colorado River near present Grand Junction (fig. 21*C*). This reconnection of the Gunnison with the Colorado River greatly increased the river's erosive power because its base level was suddenly lowered to that of the Colorado River, creating a steeper gradient. Initially, the increased gradient was across a region underlain by Mancos Shale, which was easily eroded by the increased cutting power of the river. Concurrently, tributary streams cut into the soft Mancos, and the valley was widened. Gradually, the steepened gradient moved upstream until it encountered the hard, crystalline basement rocks of the Gunnison uplift, causing rapid downcutting into the basement rocks.

A major debate currently among geologists is whether the Gunnison uplift (as well as other uplifts in Colorado) underwent renewed uplift in the late Tertiary while the Gunnison River was cutting its gorge. Some geologists argue that regional erosion of the surrounding soft sedimentary rocks and exhumation of the Gunnison uplift was induced mostly by climatic change to wetter conditions and that renewed uplift either did not occur or was of minor significance. Other geologists point to old (mostly late Eocene), tilted, warped, and possibly faulted erosional surfaces as evidence for significant regional late Tertiary uplift. Both factors, climatic change and renewed uplift, may have played a role, but what is clear is that the river began its journey into the hard, crystalline heart of the uplift only about 2.5 million years ago.



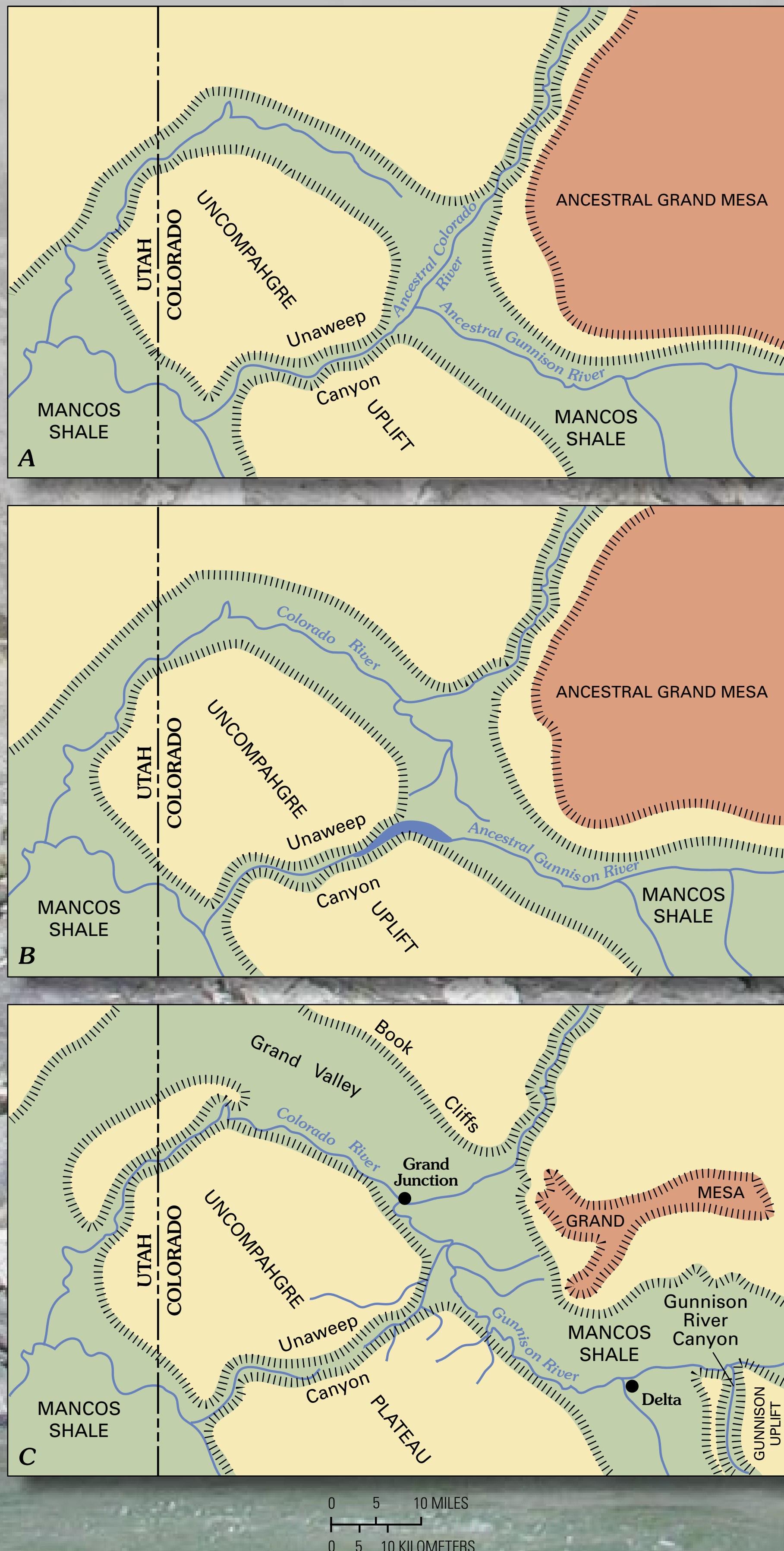


Figure 21. Schematic diagrams showing the relationship of the Colorado and Gunnison Rivers to the Uncompahgre uplift over the past few million years (after Lohman, 1961, as modified by Scott and others, 2002). *A*, Early in the Pliocene Epoch (3–5 million years ago); *B*, Later in the Pliocene; *C*, Late Pliocene to present. In all diagrams, yellow and red areas indicate highlands; red areas indicate a high Miocene basalt plateau, the remnants of which form Grand Mesa. Refer to the text for an explanation of each diagram.

How Steep is the Gradient Through the Gunnison River Gorge?

From Chukar Canyon to North Fork, a distance of 20.4 km (12.7 mi), the average gradient is 3.8 m/km (20 ft/mi), although the gradient over some reaches of the gorge is twice this amount. The average gradient across the Gunnison uplift (from Blue Mesa Reservoir, 50 km [31 mi] upriver from the NCA, to North Fork) is 8.1 m/km (43 ft/mi), although Hansen (1987) points out that there are cataracts within the Black Canyon where the gradient is as high as 68 m/km (360 ft/mi).

Why Are the Canyon Walls so Steep?

Two factors mostly control the steepness of the canyon walls. First, the Proterozoic basement rocks are very resistant to erosion, so where the river gradient is steepest, most of the river's energy is spent in downward cutting instead of lateral cutting. Second, because the Gunnison River flows through the highest part of the exhumed Gunnison uplift, much of the regional drainage is diverted away from the river. Most of the tributaries in the Gunnison River canyon are small, so they do not significantly erode the canyon walls.

The Boulder Garden rapids. Rooster Barnhart (BLM River Ranger) is standing on a boulder of Pitts Meadow Granodiorite.

Environmental Issues in the Gunnison Gorge National Conservation Area

Selenium and Salt Contamination from the Mancos Shale

Selenium and various dissolved salts (mostly sulfates) naturally exist in small concentrations in marine sedimentary rocks. These substances are leached by groundwater and form a small but measurable component in the water from springs and seeps that emanate from the Mancos Shale. Increases in irrigation in the Uncompahgre and Gunnison River valleys (as well as in the Grand Valley near Grand Junction) have dramatically increased the load of selenium and dissolved salts into the surface-water systems. Consequently, there is rising concern that this increase may have significant health effects on humans, fish in the rivers, and livestock. The problem is serious enough that the U.S. Geological Survey is undertaking a study to determine the geologic factors governing the concentration of selenium and other soluble material in the Mancos Shale, the environmental impacts of these substances due to increased irrigation, and the possible health risks involved.

Effects of Damming on the River's Profile

Downcutting by the river would normally be greatest during periods of highest runoff, which is usually in the spring during rapid snowmelt in the higher parts of the Gunnison River basin. However, three dams upriver from the NCA that were built in the early 1960s—Blue Mesa, Morrow Point, and Crystal Dams—have drastically changed flow patterns. Peak discharge before the dams were built was commonly more than 15,000 cubic feet per second (cfs); the historic record of 19,000 cfs was in 1921. The controlled release from the dams now rarely exceeds 5,000 cfs, and the scouring power of the river has consequently been severely diminished.

The decrease in discharge will inevitably change the profile of the river over time. As flash floods sweep piles of bouldery debris down steep tributaries, the river will be unable to remove this debris as effectively as it once did. Also, talus below steep cliffs will also build up. These factors will gradually lead to damming of the river at various points, especially at the mouths of side canyons, and will result in steeper rapids at the ensuing boulder fields. Perhaps river runners wishing for enhanced whitewater challenges may not object to these changes!

Effects of the Upriver Dams on River Ecology

The decreased sediment load and the decreased ability of the river to transport sediment due to the upstream dams have had a profound effect on the ecology of the river. Fine-grained sediment, now derived only from tributary streams, is deposited along the riverbanks rather than being scoured by spring floods. The result is a proliferation of riverbank vegetation (Elliott and Parker, 1997). Grasses, scouring rushes, poison ivy, tamarisk, and other water-loving plants now crowd the riverbanks. Cottonwood, box elder, and willow trees are also making inroads along the river corridor. BLM is now attempting to remove all tamarisk, an introduced invasive species, from the NCA.

Before the dams were built, spring floods brought large quantities of sand and gravel down the river, which were deposited in eddies and reaches of slower moving water. The floods also invaded lowlands adjacent to the main channel and deposited sand and gravel bars that were spawning grounds for a variety of fish, such as the razorback sucker, Colorado pikeminnow, humpback chubb, and bonytail. These habitats are now mostly, if not entirely, gone from the Gunnison River. The gravel bars of former floods remain above river level and are mostly overgrown with vegetation. In addition, the reduced flow has resulted in the reduction of fine sand and gravel in the river channel, leaving mostly large cobbles and boulders. These changes in the channel character have severely threatened the ability of native fish to reproduce.

Perhaps even a greater threat to the endangered, warm-water fish species is the drastically lower water temperature caused by the dams. During the spring and summer, the water emerging from the bottoms of the reservoirs is considerably colder than the water in the river before dams were built. In addition, introduced cold-water species, such as northern pike and trout, compete with the diminishing numbers of native fish. This has raised the issue of whether the advantages of having a blue-ribbon trout-fishing stream outweigh the loss of native species.

Erosion Due to Off-Road Vehicle Use

One of the recreational activities enjoyed by visitors to the NCA is traversing the multitude of challenging, scenic trails and roads using mountain bikes, motorcycles, all-terrain vehicles (ATVs), and 4-wheel-drive vehicles. Numerous trails and roads have been established for this purpose, and most visitors are happy to obey the signs imploring people to stay on the established routes. However, an increasing number of people are ignoring these rules, and numerous areas, particularly in the Mancos badlands, are beginning to show the effects of indiscriminant off-road travel (fig. 16). Tracks from both 2- and 4-wheeled vehicles cause gullying, increased wind erosion, and are increasingly visible in many places.

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(Facing page) A Water Ouzel (American Dipper) nest perched on a ledge on a vertical cliff of Pitts Meadow Granodiorite.

(Facing page insert) Water Ouzel (American Dipper). Courtesy of the National Park Service and U.S. Fish and Wildlife Service.

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Except as noted, photographs by ***Karl Kellogg*** (U.S. Geological Survey) and personnel of the U.S. Bureau of Land Management; cactus photograph by ***Craig Brunstein***

Glossary of Selected Terms

A

Alkali feldspar *See* feldspar.

Alluvium Material deposited by a stream or running water. Alluvium is generally stratified and composed of grains ranging in size from clay to boulders.

Amphibolite Black or dark-gray metamorphic rock composed almost entirely of hornblende, lesser amounts of plagioclase, and little or no quartz.

Anticline Generally a convex-upward ("arch-shaped") fold in layered rocks; opposite of a syncline.

Aplite Fine- to medium-grained intrusive igneous rock composed almost entirely of equal-size crystals of feldspar and quartz; commonly forms dikes.

Ash As applied to volcanic rocks, refers to the fine, airborne particles from a volcanic eruption. If hot enough, may weld into a tuff.

B

Base level The level below which a stream cannot erode its bed; for example, the base level of the Mississippi River is mean sea level.

Biotite A black mica; an iron-potassium-aluminum silicate mineral forming bendable flakes.

Breccia Sedimentary or volcanic rock composed of angular fragments. In sedimentary breccia, the angularity of the fragments indicates that they have not traveled far from their source. Also, a rock composed of cemented, angular fragments that originated by movement along a fault.

C

Caldera More or less circular depression, commonly larger than 10 km in diameter, formed by the collapse of an area following an enormous volcanic eruption that evacuates an underlying magma chamber. The caldera is subsequently filled by a great thickness of ash-flow tuff from the eruption.

Chert An extremely hard rock containing microcrystalline, interlocking quartz crystals or amorphous silica (SiO_2). Chert generally has a waxy texture, glass-like fracture, comes in a variety of colors (due to impurities), and often forms nodules in limestone and limy sandstone. Bedded chert may also result from deposition of siliceous skeletons of one-celled organisms called radiolaria.

Cross bed A sandstone bed that formed on the downstream or downwind side of a moving dune-shaped mass of sand; it is inclined to the plane of the overall bedding.

D

Dike A tabular igneous intrusion that cuts across the bedding or foliation of the enclosing rock.

E

Eolian Pertaining to the deposition of material by wind, such as in sand dunes.

F

Feldspar Along with quartz, feldspar minerals are among the most common rock-forming minerals. The two primary types of feldspar are plagioclase, a sodium-calcium aluminum silicate, and alkali feldspar, a potassium aluminum silicate.

Foliation A planar fabric in metamorphic rock formed by the alignment of mineral grains. Causes a banded or "streaky" appearance.

G

Gneiss A foliated metamorphic rock commonly composed mostly of feldspar, quartz, and lesser amounts of mica.

Granite A coarse-grained, intrusive igneous rock containing approximately equal amounts of plagioclase and alkali feldspar and greater than 20 percent quartz. Also contains minor amounts of other minerals such as biotite.

Granodiorite Similar to granite, but the percentage of plagioclase to total feldspar (alkali feldspar plus plagioclase) is greater than 65 and less than 90; also generally contains a higher percentage of black minerals (mostly biotite and amphibole), so is darker than most granites.

H

Hornblende A black, prismatic silicate mineral containing calcium, magnesium, iron, and aluminum; hornblende is the primary mineral in amphibolite and is common in many dark igneous and metamorphic rocks.

I

Igneous rock A rock that solidified from molten or partially molten material. Granite, granodiorite, pegmatite, ash-flow tuff, and lava are examples.

L

Limestone Sedimentary rock composed chiefly of calcium carbonate.

Lithosphere The upper, approximately 100-km-thick, relatively strong shell of the Earth. Includes the crust and upper part of the mantle and forms the various tectonic plates that move relative to each other (the crust, mantle, and core are the three layers that make up the Earth); also see plate tectonics.

M

Magma Hot, molten material generated within the Earth that can intrude other rocks beneath the Earth's surface or erupt at the surface. May contain suspended rock fragments or crystals.

Metamorphic rock Rock derived by mineralogical and (or) chemical changes in pre-existing rock due to heat, pressure, and (or) shearing. These changes generally occur either adjacent to igneous intrusions or at depth (at least 10 km) in the Earth's crust.

Mica Common rock-forming mineral characterized by thin, flexible flakes and glassy (vitreous) surfaces; see biotite and muscovite.

Migmatite Layered crystalline rock composed of well-foliated gneiss containing igneous (or igneous appearing) layers parallel to foliation that were either injected from a nearby magma source or formed by partial melting of adjacent rock. Migmatite layers are commonly very contorted.

Monocline A fold in which otherwise uniformly and gently dipping (tilted) sedimentary beds are locally steepened. Vertical movement on a buried fault in the underlying basement rock commonly causes such steepening.

Muscovite A mica; a potassium-aluminum silicate mineral consisting of clear, bendable flakes.

O

Oolith A small (commonly less than 2 mm), round body, resembling fish roe, in a sedimentary rock, generally composed of calcium carbonate. Formed by back and forth rolling and gradual build-up of concentric layers around a nucleus such as a sand grain. Forms oolitic limestone or sandstone and is found locally in the Wanakah Formation.

Orogeny The process of mountain building, generally associated with folding, faulting, and the intrusion of magma.

P

Pegmatite A very coarse grained igneous rock composed mostly of feldspar, quartz, and subordinate mica; the rock is close to the composition of granite. Typically forms dikes.

Peneplain A low, nearly featureless, flat land surface produced by erosion nearly to base level.

Plagioclase *See* feldspar.

Plate tectonics A theory, generally accepted, whereby the lithosphere of the Earth is divided into a number of plates that move relative to one another and interact at their boundaries in various ways to produce earthquakes, mountains, ocean trenches, ocean ridges, and great faults (such as the famous San Andreas Fault in California).

Q

Quartz Next to feldspar, the most common mineral in the Earth's crust. Generally a clear or white (impurities may create almost any color), very hard mineral composed of silicon dioxide (SiO_2).

Quartzite A metamorphic rock composed chiefly of quartz and formed by recrystallization of quartz sandstone or chert.

R

Radiometric method The measurement of the relative amounts of an unstable "parent" isotope of an element and a "daughter" isotope that forms by the radioactive decay of the parent. Once the rate of decay is determined, the age of the mineral or rock sample in which the measurement was taken can then be calculated. For example, the uranium-lead method generally uses tiny zircon (zirconium silicate) grains extracted from a rock sample. Zircon contains relatively high amounts of uranium ("parent") in its crystal lattice, and the amount of lead ("daughter") derived from the decay of uranium is measured on an instrument called a mass spectrometer.

Reverse fault A high-angle (more than 45°) fault on which the upper block (the body of rock above the fault) has moved upward relative to the lower block.

S

Sandstone A sedimentary rock composed mostly of angular to rounded, cemented grains of quartz, feldspar, other minerals, and rock fragments; may contain a matrix of silt or clay.

Schist A strongly foliated metamorphic rock (can be split into slabs parallel to the aligned minerals in the rock) that generally contains abundant mica. Schist forms from the metamorphism of shaly (mud-rich) sedimentary rocks.

Sedimentary rock A rock formed at the Earth's surface. Sedimentary rocks are formed from consolidation and cementation of loose sediment (examples are shale and sandstone), from chemical precipitation from solution (examples are rock salt and gypsum), and cementation of organic remains or secretions (examples are coal and most limestone).

Shale A finely laminated sedimentary rock formed by the consolidation of mud (clay and (or) silt).

Silicate mineral A mineral whose crystal structure is composed of molecules composed of one silicon atom and four oxygen atoms (SiO_4 tetrahedra) grouped either individually (as in quartz), or in various geometrical arrangements with metallic atoms. Most minerals in the Earth are silicate minerals.

Surficial deposit Generally uncemented sediment or rock fragments overlying bedrock derived by generally recent geological processes; includes alluvium, landslide deposits, talus, and glacial deposits.

Syncline Generally a concave-upward ("trough-shaped") fold in layered rocks; opposite of an anticline.

T

Talus Angular rock fragments that accumulate due to rockfall, commonly beneath a cliff.

Terrace A bench-shaped surface along a valley margin representing a period when the stream was at the level of the bench, before it cut to its present level. Higher terraces are therefore older than lower terraces. Terraces are generally covered with terrace gravel deposited by the earlier stream.

Thrust fault A low-angle (less than 45º) fault on which the upper block (the body of rock above the fault) has moved upward relative to the lower block.

Tuff Welded ash from a volcanic eruption. Ash may settle from a hot, eruptive cloud. If hot enough, the ash may fuse into a hard rock called ash-flow tuff or welded tuff.

U

Unconformity A generally significant break or gap in the geologic record wherein one rock in a stratigraphic sequence is overlain by a significantly younger rock. Implies a period of time during which erosion occurred, with loss of a previously formed geologic record, or a period during which no deposition occurred.

View downstream (north) from near the Ute Trail. The base of the Entrada Sandstone is on basement rocks (mostly amphibolite and migmatite here), and is visible at the upper left and right sides of the photograph.

View downstream (north) from just above the confluence of Smith Fork with the Gunnsion River. Basement rocks here are mostly migmatite.