

GEOLOGIC GUIDE ALONG FLAMING GORGE RESERVOIR, FLAMING GORGE NATIONAL RECREATION AREA, UTAH-WYOMING

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INTRODUCTION

Flaming Gorge Reservoir, formed by the impoundment of the Green River behind Flaming Gorge Dam, is well known by fisherman as a world-class sport fishery. Other visitors simply enjoy boating on its waters, camping along its shores, or marveling at its surrounding scenery offered by the Uinta Mountains in Utah and the “badlands” country of Wyoming. However, Flaming Gorge Reservoir also offers a glimpse into the region’s long geologic history recorded in the rocks exposed along its shores. This geologic guide provides a brief description of the geology along the reservoir from near the north end of Flaming Gorge National Recreation Area at Firehole Canyon, Wyoming, to Flaming Gorge Dam, a distance of about 80 miles (figure 1). More complete descriptions of the geology of Flaming Gorge and the Uinta Mountains are available in Hansen (1965, 1975) and Sprinkel (2000).

THE ROCKS

Flaming Gorge National Recreation Area contains 33 exposed formations that regionally add up to nearly 72,000 vertical feet—almost 14 miles—of rock, spanning as much as 3 billion years of geologic history (figure 2). Within that 3-billion-year span, 14 known unconformities represent about 2 billion years of missing rocks. Most of the formations within the recreation area crop out along the course of the reservoir. The exceptions include the oldest rocks in the recreation area—the Owiyukuts Complex and the Red Creek Quartzite, which crop out only north of the reservoir in the Uinta Mountains (figure 3). The oldest rocks exposed along Flaming Gorge Reservoir are part of the Middle to Upper Proterozoic Uinta Mountain Group. They are well exposed in deeply incised Red Canyon in the southern part of the recreation area. The youngest rocks along Flaming Gorge Reservoir, members of the Eocene Green River Formation, are exposed in the Wyoming sector of the recreation area.

The rocks in Flaming Gorge National Recreation Area have been bent, broken, and tilted during periods of mountain building and basin formation for nearly 3 billion years. Some rocks have been deformed many times since their deposition. The oldest structural features are in the Precambrian section and formed more than a billion years ago, and the youngest structural features formed within the Browns Park Formation in the past 2 million years. However, the dominant structural feature exposed along Flaming Gorge Reservoir is the Uinta fault zone, which accommodated uplift of the Uinta Mountains during the Laramide orogeny about 70 to 40 million years ago (latest Cretaceous to latest Eocene time) (figures 3 and 4).

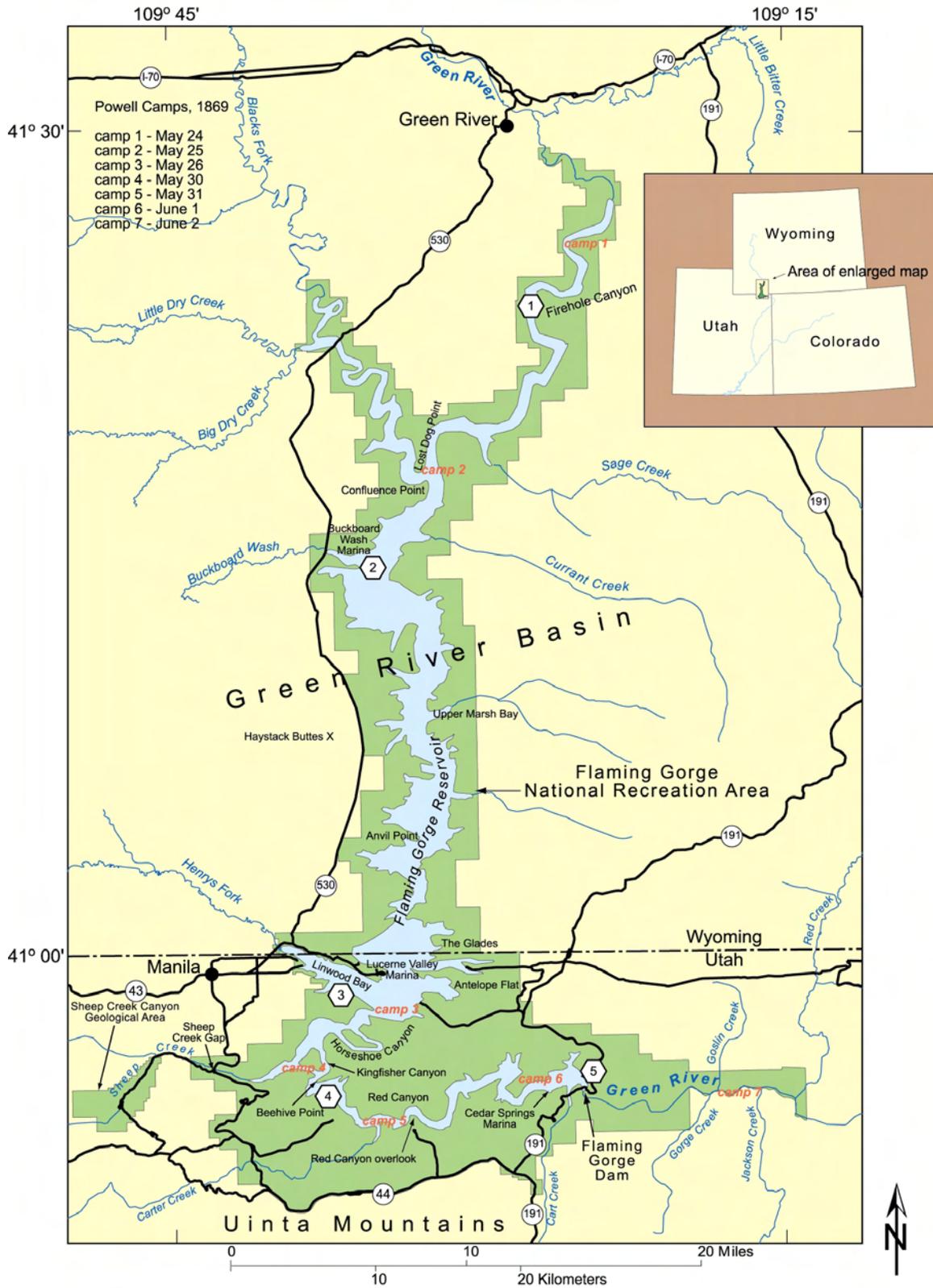


Figure 1. Index map of Flaming Gorge National Recreation Area, northeastern Utah and southwestern Wyoming showing key geographic features and STOPS that are discussed in the guide. The approximate locations of the camps used by Major John Wesley Powell during his first expedition in 1869 down the Green and Colorado Rivers are also shown.

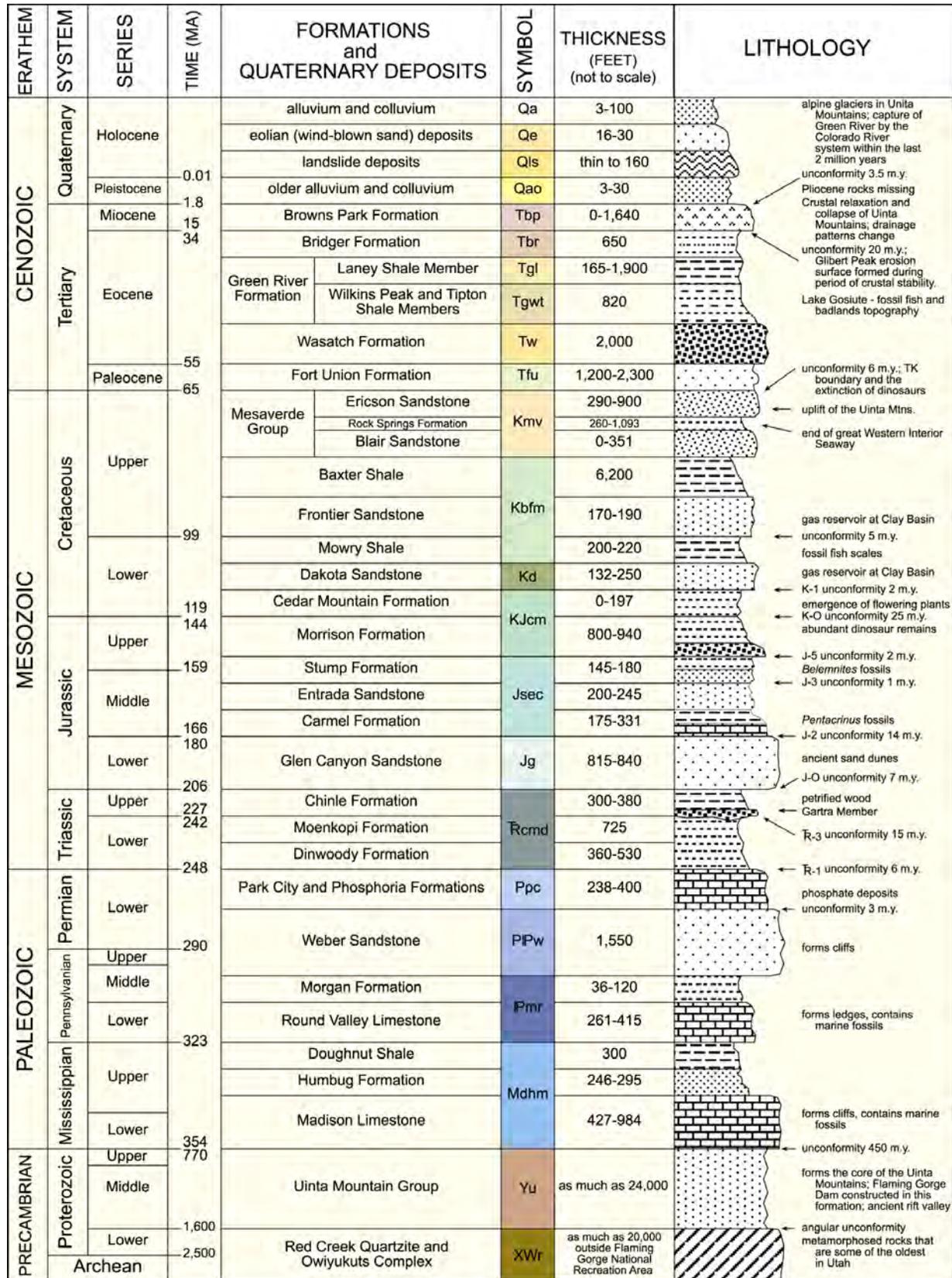


Figure 2. Stratigraphic column of rock formations and Quaternary deposits within Flaming Gorge National Recreation Area.

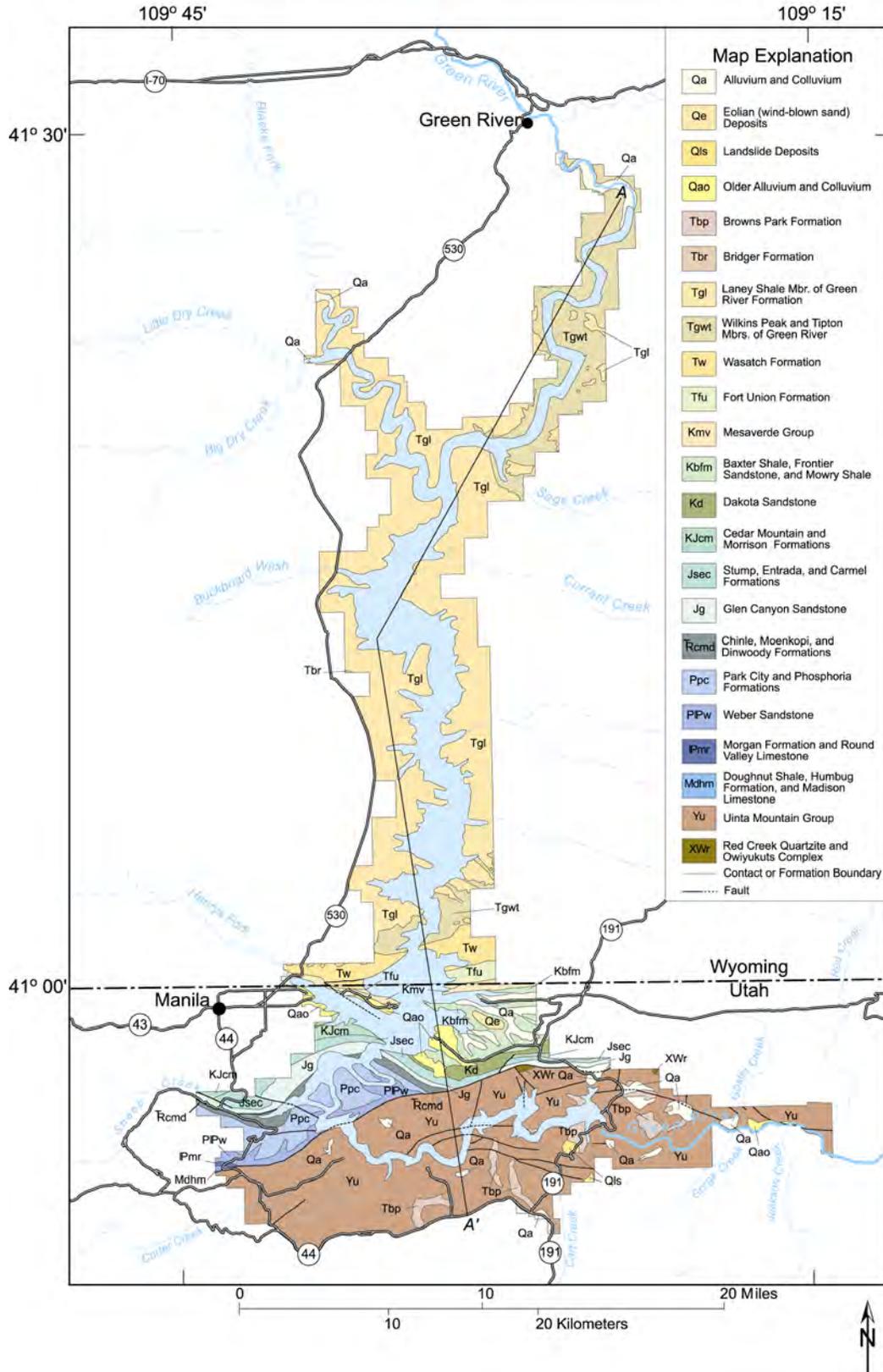
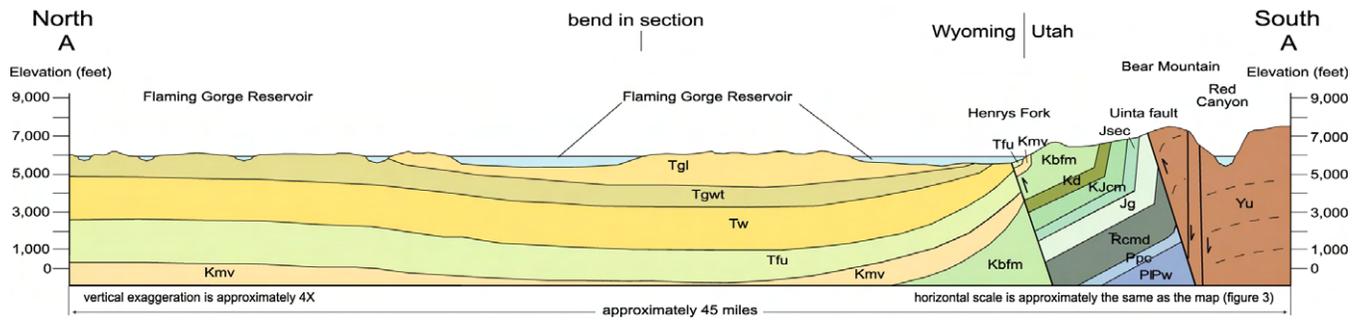


Figure 3. Generalized geologic map of Flaming Gorge National Recreation Area; created and modified from digital Geographic Information System (GIS) files of the U.S. Geological Survey (1994) and Hintze and others (2000). Cross section A-A' shown on figure 4.



Explanation

Tbp Browns Park Formation	Jsec Stump, Entrada, and Carmel Formations
Tgl Laney Shale Mbr. of Green River Formation	Jg Glen Canyon Sandstone
Tgwt Wilkins Peak and Tipton Mbrs. of Green River Formation	Rcmd Chinle, Moenkopi, and Dinwoody Formations
Tw Wasatch Formation	Ppc Park City and Phosphoria Formations
Tfu Fort Union Formation	PIPw Weber Sandstone
Kmv Mesaverde Group	Pmr Morgan Formation and Round Valley Limestone
Kbfm Baxter Shale, Frontier Sandstone, and Mowry Shale	Mdm Doughnut Shale, Humberg Formation, and Madison Limestone
Kd Dakota Sandstone	Yu Uinta Mountain Group
KJcm Cedar Mountain and Morrison Formations	— Contact or Formation Boundary
	- - - Bedding
	⇒ Fault; arrow shows offset

cross section is modified from Hansen (1965)

Figure 4. Simplified geologic cross section showing the major structural features of Flaming Gorge National Recreation Area. Cross section line A-A' is shown on figure 3 and traverses the length of the recreation area. Cross section was modified from Hansen (1965). Note that vertical exaggeration makes the faults and bedding dips appear steeper than they actually are.

Crustal stability replaced subsidence and uplift of the Laramide orogeny about 30 million years ago, during which time the Gilbert Peak erosion surface developed across the flanks of the Uinta Mountains (Hansen, 1965, 1986). Crustal deformation resumed in early Miocene time (about 25 to 20 million years ago), but this time the region was subjected to extension and the Uinta Mountains were likely down dropped along the Uinta fault zone (Hansen, 1986).

One of the most interesting geologic stories about the Flaming Gorge area is the history of the Green River. Some of the fundamental ideas of where the Green River flowed are still debated; however, it is interesting to contemplate why the Green flows south toward a large mountain range instead of away from it. It seems reasonable—based on the tectonic history of the area—to think that this great western river did not always flow southward to the Colorado River. The discussion below of the Green River is largely summarized from the concepts presented by Hansen (1965, 1986).

About 30 million years ago, a radial drainage system that crossed the Gilbert Peak surface likely developed on the newly uplifted Uinta Mountains. In the Flaming Gorge region, the streams likely flowed north into the Green River Basin and to the ancestral upper Green River, which likely flowed eastward to the North Platte River (Hansen, 1986; Stokes, 1986). Regional extensional deformation resumed in early Miocene time (about 25 to 20 million years ago), which lowered the eastern Uinta Mountains along the Uinta fault zone and warped and faulted the Gilbert Peak erosion surface (Hansen, 1986). In addition, the radial drainage system was also altered. A new east-trending drainage developed along the former crest of the Uinta Mountains and bifurcated the north-flowing streams, causing a reversal of flow (to the south) of the streams that were north of the newly formed river

(Hansen, 1986). As Basin and Range extension developed in the middle Miocene (about 15 to 10 million years ago), relative regional uplift of the Colorado Plateau rejuvenated rivers and streams to the south of the Uintas, and caused vigorous northward headward erosion (Stokes, 1986). Persistent headward erosion from the south by a tributary (the future Green River) of the Colorado River captured parts of the eastern Uinta drainage system (Hansen, 1986). Capture by the Colorado River system of the east-trending drainage that flowed through Flaming Gorge and Red Canyon to Browns Park took place at Lodore Canyon in western Colorado about 35 miles southeast of Flaming Gorge Dam. The cause and timing of capture at Lodore Canyon is speculative. Expanding on the work by Sears (1924), Bradley (1936) suggested that headward erosion by a small vigorous stream captured the stream that flowed eastward through Browns Park at Lodore Canyon and diverted it southward. Hansen (1986), on the other hand, believed that the stream in Browns Park ponded and filled the valley with sediments. Ultimately, this caused water to overtop the valley rim at Lodore Canyon and spill its contents southward, possibly taking advantage of a small preexisting drainage. Whatever the cause for capture, this drainage was now part of the Colorado River system with a lower base level. Downcutting of Lodore Canyon in Pliocene time—perhaps less than 5 million years ago—rejuvenated the drainage upstream, which incised the meander loops that form Flaming Gorge, Horseshoe Canyon, and Red Canyon (Hansen, 1986). Continued entrenchment and headward erosion of this invigorated drainage across the Green River Basin captured streams that had flowed north to the ancestral Green River. Finally, the east-flowing ancestral Green River itself was captured by middle Pleistocene time, perhaps about 1 million years ago, turning its waters southward and completing the link to the Colorado River (Hansen, 1986).

A WORD ABOUT JOHN WESLEY POWELL

One of the great adventures in the annals of the American West was the first-ever exploration of the Green and Colorado Rivers by Major John Wesley Powell in 1869. Powell and his companions began their historic exploration of these two rivers on May 24th near Green River, Wyoming, which is near the north end of present-day Flaming Gorge National Recreation Area.

The good people of Green River City turned out to see us start. We raise our little flag, push the boats from shore, and the swift current carries us down.

—Major John Wesley Powell, May 24, 1869

They spent nearly 10 days in what is now Flaming Gorge National Recreation Area exploring the Green River, its side canyons, and surrounding peaks, making scientific measurements and describing the geology. Powell named many of the formations, canyons, and other geographic features during this first trip down the Green River, including Flaming Gorge itself.

Powell had six camps along the shores of the Green River between the departure point at Green River, Wyoming, and the present-day dam site. All of these camps are now submerged by the reservoir; however, figure 1 shows their approximate locations. All quotes of John Wesley Powell are taken from his 1875 report on the exploration of the Colorado River (Powell, 1875).

FLAMING GORGE GUIDE

This guide begins at Firehole Canyon, Wyoming, near the north end of the recreation area and briefly describes the geology that crops out along the shores to Flaming Gorge Dam. The shores of the reservoir are referred to as the “right shore” and the “left shore” as one follows the lake guide south from Firehole Canyon. Since Flaming Gorge Reservoir does not have a systematic buoy array to mark mileage, the geologic descriptions are tied to geographic features such as points, canyons, and bays that are generally named on standard topographic maps or maps that are available in the recreation area.

The full lake guide covers about 80 miles and will generally take two days to complete, depending upon the speed and fuel capacity of your boat, and weather conditions. If camping, fishing, or swimming are part of your plans, this trip can take longer. Gasoline, water, food, and ice are generally available at the marinas located along the lake at Buckboard Crossing, Lucerne Valley, and Cedar Springs. Boat ramps are also accessible at many locations along both shores of Flaming Gorge. **Please check with officials from Ashley National Forest for permit information, restrictions, and rules on the reservoir.**

The sun is yet two hours high, so I climb the cliffs, and walk back among the strangely carved rocks of the Green River bad-lands ... Barren desolation is stretched before me; and yet there is a beauty in the scene.

—Major John Wesley Powell, May 24, 1869

STOP 1 - Firehole Canyon: Rocks that surround the upper two-thirds of Flaming Gorge Reservoir (in the Wyoming sector) are Eocene Green River Formation. The Green River Formation is a soft, muddy unit that in part weathers to badlands topography that is characteristic of southwest Wyoming. The Green River Formation consists of several members, many of which are separated by tongues of the Wasatch Formation (Bradley, 1961, 1964; Surdam and Stanley, 1980). Three members of the Green River Formation crop out in Flaming Gorge National Recreation Area (figure 3). These are (in ascending order) the Tipton Tongue, the Wilkins Peak, and the Laney Shale Members (Bradley, 1961); however, the Tipton and Wilkins Peak Members are shown as one map unit (figure 3). All three members consist of shale, organic mudstone and marlstone, tuffaceous sandstone, limestone, and oil shale (Bradley, 1961, 1964; Hansen, 1965; Surdam and Stanley, 1980). Subtle differences in color and mixture of rock types distinguish one member from another. The Green River Formation was deposited in a large lake called Lake Gosiute (Bradley, 1964; Surdam and Stanley, 1980). Fossils are preserved in numerous zones within the Green River Formation. Petrified wood can also be found within the formation. Most fossils preserved in the Green River Formation are invertebrate fresh-water faunas, but extremely well-preserved fish skeletons are its signature fossil. The age of the Green River Formation is Eocene (Bradley, 1964; Hansen, 1965).

The right shore at Firehole Canyon consists of cliffs of the Wilkins Peak Member of the Green River Formation. It is a light-green-gray mudstone and siltstone with some sandstone. The Wilkins Peak Member also contains oil shale and trona, an important sodium carbonate mineral mined in southwest Wyoming. The left shore consists of Quaternary sand and gravel deposits from Firehole Canyon. The bluff above and surrounding Firehole Canyon also consist of the Wilkins Peak Member of the Green River Formation.

From Firehole Canyon to Sage Creek Bay: The light-colored (green-gray) cliffs are Wilkins Peak Member of the Green River Formation. These beds dip less than 5 degrees west-southwest. The right shore near Sage Creek Bay is brown cliff-forming sandstone of the Laney Shale Member of the Green River.

Confluence of Blacks Fork arm and main channel of Flaming Gorge Reservoir: Before the reservoir existed, this was the confluence of the Blacks Fork and Green Rivers. Now it is the confluence of the Blacks Fork arm and the main channel of Flaming Gorge Reservoir. The Laney Shale Member of the Green River Formation crops out around the confluence of Blacks Fork arm and the main channel. Lost Dog Point on the north side and Confluence Point on the south of Black Fork arm have excellent exposures of Laney Shale. Not far up the Blacks Fork arm along the south wall are good examples of soft-sediment deformation and possible injection features within the Laney Shale Member of the Green River Formation.

On the way, we pass the mouth of Blacks Fork, a dirty little stream that seems somewhat swollen. Just below its mouth we land and camp.

—Major John Wesley Powell, May 25, 1869

Confluence Point to Current Creek Bay: Laney Shale Member of the Green River Formation crops out along the right and left shores.

Current Creek Bay: Laney Shale Member is at lake level along both shores of the main channel of the reservoir and surrounding Current Creek Bay. The water tower at Buckboard Crossing is visible. Southwest of Current Creek Bay, Black Mountain is on the horizon. Black Mountain consists of the Bridger Formation, which overlies the Green River Formation (figure 2).

STOP 2 - Buckboard Crossing Marina: Buckboard Crossing Marina is at the mouth of Buckboard Wash. The Laney Shale Member of the Green River Formation crops out at lake level and in the hills surrounding the marina. A small cove south of Buckboard Wash has excellent exposures of the Laney Shale, which contains mudstone, sandstone, and some limestone. Fossil snails and petrified wood are preserved in an Eocene sandbar exposed in the area (figure 5).

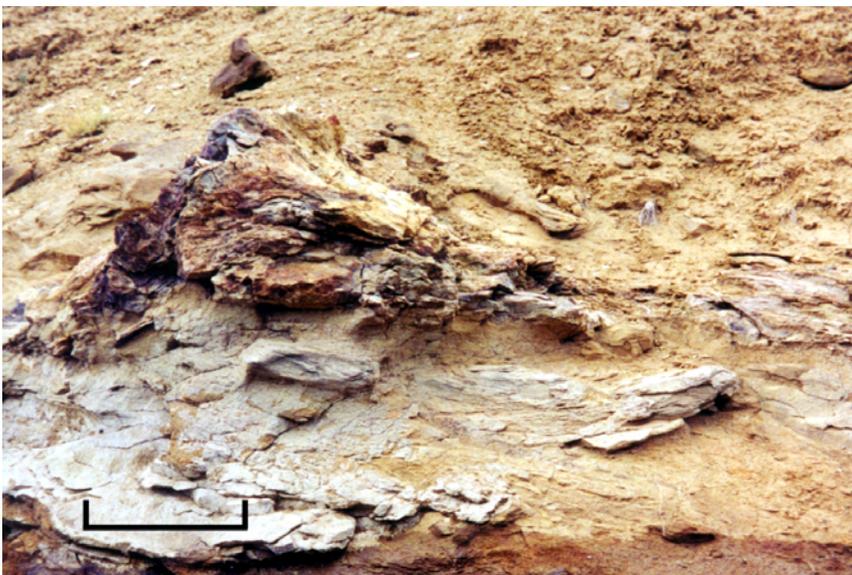


Figure 5. Petrified log in the Laney Shale Member of the Green River Formation near Buckboard Wash. The black line in the lower left corner represents about one foot in length.

Buckboard Crossing Marina to Anvil Point: Laney Shale Member of the Green River Formation crops out along both shores of Flaming Gorge Reservoir between Buckboard Crossing and Anvil Point. There are several bays to stop and examine the Green River Formation along the way. Note that the dip of the Green River Formation is nearly flat. The Green River Formation is folded into a low-amplitude syncline from Firehole Canyon to near Lucerne Valley Marina (figures 3 and 4).

Near Squaw Hollow Bay, the Laney Shale Member of the Green River Formation contains several low-amplitude folds. The fold axes strike northeast.

Haystack Buttes are on the west side of Flaming Gorge Reservoir about opposite Upper Marsh Bay. They consist of the Laney Shale Member of the Green River Formation.

Anvil Point to gas pipeline suspension: From Anvil Point to the pipeline suspended over Flaming Gorge Reservoir, the Green River Formation dips north-northwest less than 5 degrees. We have crossed the axis of the broad syncline and are going into older rocks (figure 4). The lighter colored Wilkins Peak Member of the Green River Formation is now at lake level on both shores with the overlying brown-colored Laney Shale above the reservoir. The gas pipeline suspension is built on Wilkins Peak Member.

Large unnamed bay north of Lucerne Valley Marina: Flaming Gorge Reservoir widens past the pipeline suspension to a large unnamed bay. To the south and on the right shore in the distance is Lucerne Valley Marina (figure 1). Rising from the left shore is The Glades. South of The Glades on the left shore is Antelope Flat. Spring Creek flows into a bay on the left between The Glades and Antelope Flat. As you enter the large unnamed bay, the rocks rapidly get older, beginning with the Wasatch Formation, because they are more steeply tilted northward.

The Wasatch Formation is lithologically varied and complex, and grades vertically and laterally into the fine-grained lacustrine Green River Formation (Bradley, 1961; Hansen, 1965). The Wasatch Formation is varicolored, ranging from shades of red to gray. It consists of conglomerate, sandstone, siltstone, and claystone. The conglomerate beds contain pebble- to boulder-size fragments of Paleozoic to Mesozoic rocks (Hansen, 1965). Mesozoic fragments derived from the Glen Canyon, Entrada, Morrison, Dakota, and Mowry Formations are more common in the lower beds. Paleozoic fragments derived from the Mississippian formations, Weber Sandstone, and Park City Formation are more common in the upper beds. In a few locations, rock fragments derived from the Middle Proterozoic Uinta Mountain Group are preserved in the Wasatch Formation (Hansen, 1965). The inverse stratigraphy reflected by the fragments in the Wasatch Formation records denuding of the Mesozoic and then Paleozoic formations off the rising Uinta Mountains. Furthermore, Uinta Mountain Group fragments indicate that the core of the Uinta Mountains was locally exposed to erosion (Hansen, 1965). The Wasatch Formation is mostly fluvial in origin. Fossils are generally uncommon in the Wasatch Formation within the recreation area; however, they have been collected from lacustrine interbeds that provide an Eocene age (Hansen, 1965; Love and others, 1993).

The oldest Tertiary formation exposed along Flaming Gorge Reservoir is the Fort Union Formation. It crops out in an east-trending belt east of Manila, Utah, and north of The Glades near the Utah-Wyoming state line (figure 3). The Fort Union Formation is light-gray to yellowish-gray sandstone, siltstone, and claystone (Hansen, 1965). The sandstone is lenticular, noncalcareous, and friable. Conglomerate beds are also common. These beds contain pebble fragments derived from Mesozoic

formations that were eroded from the rising Uinta Mountains during the early stage of uplift (Hansen, 1965). The Fort Union rests unconformably on the Mesaverde Group in angular discordance. The Fort Union is nonmarine and was deposited under mostly fluvial conditions; however, some fine-grained beds are lacustrine in origin (Hansen, 1965). Fossils are rare in the Fort Union. However, fossil plant remains collected from beds north of The Glades indicate a Paleocene age (Hansen, 1965).

The Glades, a prominent double hogback north of Antelope Flat and sometimes called the "Devils Racetrack," consists of the Mesaverde Group (Hansen, 1965). The Mesaverde Group is divided into three formations: the lower Blair Formation, the middle Rock Springs Formation, and the upper Ericson Sandstone (figure 2). The southern hogback is the Blair Formation. It consists of fine-grained sandstone with some interbedded marine shale (Hansen, 1965). The northern hogback is the Ericson Sandstone. It consists of coarse-grained sandstone and conglomerate (Hansen, 1965). The intervening strike valley is the less resistant Rock Springs Formation, which consists of fine-grained sandstone with carbonaceous shale and coal (Hansen, 1965). Together, these formations record the last time an ocean occupied the region and the beginning of Laramide-age Uinta Mountain uplift. The age of the Mesaverde Group is latest Cretaceous (Hansen, 1965).

Underlying the Mesa Verde Group is the Baxter Shale. It is a poorly exposed, thick, gray, carbonaceous shale with many fine-grained, rippled-marked sandstone beds. The Baxter was deposited in shallow marine conditions and is Late Cretaceous in age (Hansen, 1965; Love and others, 1993). Antelope Flat is underlain by Baxter Shale covered by alluvium and wind-blown sand (Hansen, 1962, 1965).

STOP 3 - Linwood Bay-Finch Draw Area: Continue south to Linwood Bay (figure 1). Most of Linwood Bay is underlain by the Baxter Shale capped with older river gravels. Along the south shore of Linwood Bay is the Finch Draw area, which consists of steeply dipping beds of the Cretaceous Frontier, Mowry, and Dakota Formations. In general, the resistant beds of the Frontier Sandstone and Dakota Sandstone form ridges and the softer beds of the Mowry Shale form a strike valley.

The Frontier Sandstone is mostly light-brown to light-gray, fine-grained sandstone with minor coal beds. The formation also contains some petrified wood, invertebrate fossils, and was the preferred rock for petroglyphs made by ancient Native Americans (Hansen, 1965). The Frontier is mostly marine, although coastal marsh conditions existed for a period of time to deposit coal beds and preserve the petrified wood. The Frontier is Late Cretaceous in age (Hansen, 1965; Love and others, 1993).

The Mowry Shale is easy to identify. It is dark-gray siliceous shale that typically weathers silver gray and contains abundant fossil fish scales. The Mowry in Finch Draw contains well-preserved fish scales. The Mowry is a marine deposit and is Early Cretaceous in age (Hansen, 1965).

The Dakota Sandstone consists of medium- to coarse-grained sandstone separated by carbonaceous shale and coal (Hansen, 1965). The base of the Dakota is conglomeratic and is unconformable with the underlying Cedar Mountain Formation. The Dakota grades from fluvial to coastal marsh deposits and is Early Cretaceous in age (Hansen, 1965).

The Cretaceous Cedar Mountain Formation and Jurassic Morrison Formation underlie these units. Though separated by a major unconformity, the Cedar Mountain and Morrison are often lumped into one unit in this area for mapping purposes because the Cedar Mountain is thin and its rocks are similar

in color to the underlying Morrison Formation (figures 2 and 3). The Morrison is a soft varicolored unit that contains shades of green, gray, and purple rocks of diverse lithologies. It consists mainly of bentonitic shale, claystone, and siltstone (Hansen, 1965). It is also locally interbedded with lenticular sandstone, grit, and limestone (Hansen, 1965). Most of the Morrison is poorly exposed within the recreation area because of its soft, non-resistant habit. An unusually good exposure of the Morrison is in Finch Draw.

The steep ramparts south of Finch Draw comprise the dip slope of the Jurassic Stump Formation, which underlies the Morrison Formation. The Stump Formation records the last Jurassic sea that invaded Utah. Regionally, it is divided into two members; the lower Curtis Member and the upper Redwater Member (Pipiringos and Imlay, 1979). Near Manila, Utah, the Stump contains a lower gray shale and interbedded thin limestone and an upper gray limestone (Thomas and Krueger, 1946), which is unlike typical descriptions (Pipiringos and Imlay, 1979) of the members. Belemnites are commonly preserved in the sandstone beds of the Stump Formation. The Stump Formation is bounded by the J-3 unconformity at the bottom and the J-5 unconformity at the top (figure 2). Internally, the J-4 unconformity separates the Middle Jurassic Curtis from the Upper Jurassic Redwater. Locally, at the J-4 unconformity, much of the Curtis Member has been removed by erosion (Pipiringos and O'Sullivan, 1978; Pipiringos and Imlay, 1979).

Entrance to Flaming Gorge: Leave Linwood Bay and proceed south to the entrance to Flaming Gorge (figure 1). Rocky parapets guard the entrance to the gorge. On the left shore is Boars Tusk, which consists of steeply dipping Jurassic Glen Canyon Sandstone. On the right shore are Triassic to Jurassic rocks that were steeply tilted during the Laramide orogeny 70 to 40 million years ago. The outer part of the gorge consists of the Jurassic Stump Formation down through the Entrada, Carmel, and Glen Canyon Formations (figure 6). The inner part of the gorge is striking because of the bright red-colored rocks, giving it a flaming red appearance. On May 26, 1869—two days after leaving Green River City—Powell arrived at the entrance to Flaming Gorge.

It enters the range by a flaring, brilliant, red gorge that may be seen from the north more than a score of miles away... We name it Flaming Gorge.

—Major John Wesley Powell, May 26, 1869



Figure 6. The rocks at the entrance to Flaming Gorge near Linwood Bay. Major John Wesley Powell named the gorge for the brilliant red rocks that rise above the reservoir (the Green River in Powell's days). The red rocks are the Triassic Moenkopi and Chinle Formations. The cliff that caps the ridge is the Jurassic Glen Canyon Sandstone. Stratigraphically above the Glen Canyon Sandstone are the Carmel, Entrada, and Stump Formations (to the right). The rocks are steeply tilted northward, presumably by a thrust fault in the subsurface that moved during the Laramide orogeny. View is southwest.

The “flaming colors” that so impressed Powell belong to the Triassic Moenkopi and Chinle Formations and not to the red quartzite of the Middle Proterozoic Uinta Mountain Group (figure 6). The Entrada down through the Moenkopi Formations are described below.

The Entrada Sandstone consists of lower massive-weathering, light-gray to light-brown and yellow sandstone and an upper reddish-brown siltstone and fine-grained sandstone (Hansen, 1965). Large-scale cross-beds are common within the lower Entrada, owing to its eolian deposition. The upper Entrada is likely marine in origin because of grain size, planar bedding, and oscillation ripple marks (Hansen, 1965; Imlay, 1980). The lower Entrada Sandstone is resistant to erosion, forming massive cliffs typical of exposures along Utah Highway 44 north of Sheep Creek Gap (Hansen, 1965). Some of the Quaternary eolian deposits may be derived from the upper part of the Entrada Sandstone. The Entrada Sandstone lacks fossils; however, the Middle Jurassic age is assigned based on the bracketing age of the underlying Carmel Formation and overlying Stump Formation (Hansen, 1965; Imlay, 1980).

The Carmel Formation is a colorful unit sandwiched between the light-colored beds of the underlying Glen Canyon and overlying Entrada Sandstones (figures 2, 3, and 6). It includes a mixture of red, green, and gray siltstone, fine-grained sandstone, limestone, and calcareous mudstone (Hansen, 1965; Imlay, 1967). Significant amounts of bedded gypsum may also be present. Gray oolitic limestone and sandy shale are common rock types of the lower Carmel, which grades upward to mostly red and green mudstone, siltstone, and interbedded gypsum. The lower limestone beds were deposited in an open, shallow marine environment that eventually gave way to more restricted marine conditions (tidal flat) indicated by the deposition of gypsum (Hansen, 1965; Imlay, 1980). The Carmel Formation is mostly a slope-forming unit; however, the limestone beds are resistant to erosion and form ledges. The well-dated age of the Carmel Formation is Middle Jurassic (Imlay, 1980).

The Glen Canyon Sandstone is the base of the Jurassic section in the Flaming Gorge area (figure 2). It is a pink to light-brown, massive, quartzitic sandstone (Hansen, 1965). Like its counterpart to the south—the Navajo Sandstone—large-scale cross-bedding is its signature characteristic. The Glen Canyon Sandstone rests unconformably on the Triassic Chinle Formation. This surface is the J-0 unconformity, which Pipiringos and O'Sullivan (1978) believe represents at least 7 million years. The top of the Glen Canyon Sandstone probably includes beds correlative to the Page Sandstone. Typically, the Page Sandstone is nearly identical to the underlying Glen Canyon Sandstone, but it can be separated from the Glen Canyon by a lag deposit of chert pebbles. The chert pebbles mark the base of the Page and identify the J-2 unconformity, which separates Lower Jurassic and Middle Jurassic rocks (Pipiringos and O'Sullivan, 1978). For mapping purposes in the Flaming Gorge area, the Page Sandstone was included in the Glen Canyon Sandstone (Hansen, 1965). The Glen Canyon Sandstone is a thick (as much as 840 feet) eolian sandstone deposited in a large dune field that covered parts of six states and was likely similar to the modern Sahara Desert. Ford and Gillman (2000) discussed the details of this extensive dune deposit. Fossils are rarely preserved in the Glen Canyon Sandstone; however, dinosaur tracks have been discovered near the top of the formation around Red Fleet Reservoir to the south (Hamblin and others, 2000), and Stokes (1991) described petrified wood in the correlative Navajo Sandstone. The age of the Glen Canyon Sandstone is Early Jurassic (Imlay, 1980).

The Chinle Formation can be divided into two members, the basal Gartra Member and an upper unnamed member, which are separated from the underlying Moenkopi Formation by the TR-3 unconformity (Poole and Stewart, 1964; Hansen, 1965; Pipiringos and O'Sullivan, 1978). In Flaming Gorge, the Gartra Member is the first resistant ledge below the red slopes that lie beneath the Glen Canyon Sandstone cliff. The Gartra Member consists of fluvial conglomeratic sandstone in which the bottom of the member is irregular, cuts into the underlying Moenkopi Formation, and commonly contains petrified wood fragments. The upper unnamed member consists of varicolored mudstone and siltstone of fluvial and lacustrine origin (Hansen, 1965). The age of the Chinle is Late Triassic (Hansen, 1965).

The Moenkopi Formation consists of mostly reddish-brown siltstone, shale, and fine-grained sandstone with local gypsum and limestone beds. The Moenkopi Formation signals the end of marine domination in the region, which was so prevalent during the Paleozoic. Although invertebrate fossils are rare in the Moenkopi (Hansen, 1965), phytosaur and amphibian tracks (as well as swim tracks) are preserved in Moenkopi beds south of Flaming Gorge at Red Fleet State Park (Hamblin and others, 2000). The age of the Moenkopi Formation is Early Triassic (Hansen, 1965).

*This morning Bradley and I cross the river, and climb more than a thousand feet
to a point where we can see the stream sweeping in a long, beautiful curve
through the gorge.*

—Major John Wesley Powell, May 29, 1869

Horseshoe Canyon: The entrance to Horseshoe Canyon is on the left. Horseshoe Canyon, so named by Powell because of its large meander, consists of the Permian Park City and Phosphoria Formations (figure 3). They can be divided into three units: the lower Grandeur Member of the Park City Formation, the middle Meade Peak Phosphatic Tongue of the Phosphoria Formation, and the upper Franson Member of the Park City Formation (Hansen, 1965; Schell, 1969). Light-gray sandstone with some limestone and dolomite characterize the Grandeur Member. The Meade Peak is easy to identify because of the dark-gray phosphatic shale beds, and is an important economic unit in the area because it contains rich phosphate deposits (Schell and Dyni, 1973). It is also the source of oil produced from Weber Sandstone reservoirs in fields in the Rocky Mountains region (Maughan, 1984; Sprinkel and others, 1997). The Franson is dominantly cherty limestone and dolomite with interbedded sandstone. The limestone and dolomite beds are hard and protect the underlying softer rocks from erosion (Hansen, 1965).

On the right shore, across from the entrance to Horseshoe Canyon, are light- to greenish-gray siltstone and shale of the Dinwoody Formation. The Dinwoody was deposited in a marine environment and is Early Triassic in age.

In Horseshoe Canyon, the underlying Weber Sandstone crops out at lake level (figure 3). The Weber Sandstone is probably one of the most recognized formations in northeastern Utah. It forms the spectacularly steep sandstone cliffs at Split Mountain in Dinosaur National Monument (about 40 miles southeast of Flaming Gorge National Recreation Area) and the sheer, massive-weathering, highly cross-bedded sandstone cliffs in the adjoining Sheep Creek Canyon Geological Area to the west (figure 1) (Sprinkel and others, 2000).

The Weber Sandstone is divided into a lower light-gray to yellowish-gray, thick-bedded sandstone with limestone interbeds and an upper light-yellowish-gray, massive and highly cross-bedded sandstone (Hansen, 1965). The horizon that separates the lower and upper parts is subtle. It is placed where the rock type becomes exclusively sandstone and the outcrops change from the slightly darker, more angular ledges of the lower part to the lighter, more rounded ledges of the upper part. In addition, the lower part tends to be a little more resistant to erosion than the upper part because of the interbedded limestone. The Weber Sandstone generally forms steep cliffs. It is 1,550 feet thick.

The Weber Sandstone was deposited mostly in an eolian (wind-blown sand) environment, but the thin marine limestone beds in the lower Weber indicate it is transitional between marine and eolian conditions. The Weber Sandstone is Middle Pennsylvanian to Permian based on marine fossils, mainly corals and brachiopods, preserved in the limestone units in the lower part and foraminifera preserved near the top of the formation (Bissell and Childs, 1958; Bissell, 1964; Hansen, 1965).

Half a mile below, the river wheels sharply to the left, and we turned into another cañon cut into the mountain. We enter the narrow passage ... Now the river turns abruptly around a point to the right, and the waters plunge swiftly down among great rocks; and here we have our first experience with cañon rapids ... We name it Horseshoe Cañon.

—Major John Wesley Powell, May 30, 1869

A shortcut that bypasses Horseshoe Canyon is navigable to most boats; however, it is shallow and requires wakeless speeds (figure 1). The left shore through the shortcut is Park City Formation. The right shore is also Park City Formation at lake level with the overlying Triassic Dinwoody Formation forming the gray slope above the shore. The Moenkopi Formation forms the orange-red slope below the ledges about halfway up. The Triassic Chinle is the purple-red ledges and slopes with the Jurassic Glen Canyon Sandstone forming the cliff on the skyline.

Kingfisher Canyon: Flaming Gorge Reservoir surrounds an island of Park City and Phosphoria Formations. To the right is Sheep Creek Bay, which is underlain by Dinwoody Formation. To the left is the entrance to Kingfisher Canyon, which is the original course of the Green River. The Park City and Phosphoria Formations are at lake level; however, the contact with the underlying Weber Sandstone (at lake level) is not far up the canyon. Kingfisher Canyon is spectacular with steep cliffs of Weber Sandstone that display large-scale cross-beds, tafoni (naturally weathered holes), and large-scale soft-sediment deformation. Large-scale cross-beds and soft-sediment deformation are common in eolian deposits.

A connection of water (Kingfisher Creek of Powell) between Kingfisher Canyon and Sheep Creek Bay is on the right near Beehive Point. The rocks exposed along the confluence are Weber Sandstone. There, the Weber Sandstone is folded into a monocline, an indication of what is to come.

The river is broad, deep, and quiet, and its waters mirror towering rocks. Kingfishers are playing about the streams, and so we adopt as names Kingfisher Creek, Kingfisher Park, and Kingfisher Cañon. At night, we camp at the foot of this cañon.

—Major John Wesley Powell, May 30, 1869

STOP 4 - Beehive Point: Beehive Point, Hideout Draw, and Hideout Canyon are good places to examine the folding of the Weber Sandstone and to view the trace of the Uinta fault zone (figures 1, 3, 4, and 7). A sliver of red Morgan Formation crops out at the campground in Hideout Draw. The Morgan is a varicolored formation that consists of interbedded fine-grained sandstone, siltstone, fossiliferous and cherty limestone, and minor amounts of red shale. The Morgan was deposited in marine to marginal marine environments and represents the top of a shallowing-up marine sequence during Pennsylvanian time. The contact between the Morgan and overlying Weber is also within Hideout Draw. The formation is generally thin—less than 120 feet thick; however, it may be thinner here because the Uinta fault zone cuts out part of it (as well as the underlying Pennsylvanian Round Valley Limestone and Mississippian formations) (figures 2, 3, and 4).



Figure 7. The Uinta fault zone along Hideout Draw. The Uinta fault placed Middle to Upper Proterozoic Uinta Mountain Group (Yu) next to a sliver of Pennsylvanian Morgan Formation (IPm). Beds of the Pennsylvanian-Permian Weber Sandstone (PIPw) are steeply folded by upward movement of the Uinta fault during the Laramide orogeny. The line represents the approximate trace of the Uinta fault. The “U” is on the upthrown side of the fault and the “D” is on the downthrown side. View is west.

The trace of the Uinta fault zone follows Hideout Draw and the south side of Beehive Point and trends up Hideout Canyon (figure 3). The Uinta fault placed a great thickness of the Middle to Upper Proterozoic Uinta Mountain Group up next to the Pennsylvanian Morgan to Weber Formations (up to the south) (figures 3 and 4). The fault zone dips south. The Uinta fault may have originally formed (down to the south) during the Middle Proterozoic rifting about 1.5 billion years ago, near the northern margin of the rift valley (Hansen, 1965). Rock relations preserved along the reservoir indicate that reverse movement (up to the south) later occurred during the Laramide orogeny between 70 to 40 million years ago. Miocene extension (25 to 10 million years ago) may have lowered the Uinta Mountains along the fault zone (down to the south).

Red Canyon: From Beehive Point to Flaming Gorge Dam, the red rocks of the Uinta Mountain Group, which are the oldest rocks exposed along Flaming Gorge, form the canyon walls. This group forms the backbone of the Uinta Mountains and is the dominant formation in the southern part of Flaming Gorge National Recreation Area (figure 3). It consists mostly of dark-red siliceous sandstone with abundant shale and conglomerate, all of which may have been subjected to low-grade metamorphism. The rocks of the Uinta Mountain Group form the impressive red cliffs of Red Canyon, along Carter Creek, and at Flaming Gorge Dam. The Uinta Mountain Group lies unconformably on the Red Creek Quartzite.

The Uinta Mountain Group was deposited in a rift valley that developed during Middle Proterozoic time (see Willis and Willis, 2000; Willis and others, 2000). Great volumes of clastic sediments (gravel, sand, silt, and mud) were deposited as rifting continued. Eventually more than 24,000 feet of sediment accumulated in the rift valley. In the Flaming Gorge area, the Uinta Mountain Group consists of non-marine rocks that were deposited by alluvial and fluvial processes. To the west, however, the rift was submerged by ancient seas and marine rocks were deposited (Wallace, 1972; Sanderson, 1984, 1986). The Uinta Mountain Group is Middle and Late Proterozoic, ranging in age from 1,100 to 770 million years (Crittenden and Peterman, 1975; Bressler, 1981).

As you travel down the reservoir, Bear Mountain is on the left and the Red Canyon overlook is on the right. The Red Canyon Visitors Center is built on the right canyon rim about 1,350 feet above the reservoir. The overlook and surrounding area above the canyon is constructed on the Gilbert Peak erosion surface, which formed during a period of crustal stability in the late Oligocene, perhaps about 30 million years ago. Subsequently, beginning about 25 million years ago, the Gilbert Peak surface has been warped by the lowering and tilting of the eastern Uintas. Less than 5 million years ago, a pre-Green River drainage incised itself through the Gilbert Peak erosion surface and underlying Middle Proterozoic Uinta Mountain Group. Waters of the Green River probably began to flow down Red Canyon about 1 million years ago (see discussion in the INTRODUCTION of this guide for details).

*The cliffs on either side are red sandstone, and stretch up towards the heavens
2,500 feet ... As twilight deepens, the rocks grow dark and somber; the
threatening roar of the water is loud and constant, and I lie awake of thoughts of
the morrow, and the cañons to come, interrupted now and then by
characteristics of the scenery that attract my attention.*

—Major John Wesley Powell, May 31, 1869

*To-day we have an exciting ride. The river rolls down the cañon at a wonderful
rate, and, with no rocks in the way, we make almost railroad speed.*

—Major John Wesley Powell, June 1, 1869

STOP 5 - Flaming Gorge Dam: Flaming Gorge Dam was constructed between 1958 and 1964 on the Green River. The dam is 43 miles north of Vernal, Utah, and about 6 miles south of the Utah-Wyoming state line (figure 1). It is a medium-thick-arch concrete dam that has a structural height of 502 feet and a crest length of 1,180 feet (U.S. Bureau of Reclamation, 2000). The crest width is 27 feet and the base widens to 131 feet (U.S. Bureau of Reclamation, 2000). About 986,600 cubic yards of concrete was used to construct the dam.

Impoundment of the Green River created Flaming Gorge Reservoir, which stretches 91 miles from the dam to near Green River, Wyoming (Murdock, 1969). The capacity of the reservoir is 3,788,900 acre-feet at a maintained surface elevation of 6,040 feet (U.S. Bureau of Reclamation, 2000). The water is more than 400 feet deep at the dam, about 300 feet deep near the Red Canyon Overlook, and about 180 feet deep in the middle of the reservoir east of Linwood Bay. The primary purpose of the reservoir is to generate electricity, provide irrigation water, and recreation.

Flaming Gorge Dam was founded on the Uinta Mountain Group (Hansen, 1965). The rocks at the dam site dip about 16 degrees north and consist of red quartzite, sandstone, and thin to thick interbedded shale. Because of the interbedded shale in the abutments, special foundation treatment was performed to stabilize the shale zones (Murdock, 1969). Two fault zones are in the dam site area, but neither cuts through the abutments. One of the faults, however, is about 82 feet upstream from the dam (Murdock, 1969). Hansen (1965) considered the faults that cut the Uinta Mountain Group as old and inactive.

ACKNOWLEDGMENTS

I am indebted to Ashley National Forest for all of their logistical support, for without their help, access to the geology along the lake would not have been possible. A special thanks goes to Louis Wasniewski (Flaming Gorge Ranger District) for taking time out of his busy schedule to captain the boat on Flaming Gorge Reservoir for two days. A special thanks also goes to Darlene Koerner (Ashley National Forest) for loaning me aerial photos and providing general support while on the forest. I thank Grant Willis and Mike Hylland (Utah Geological Survey) for reviewing the manuscript.

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