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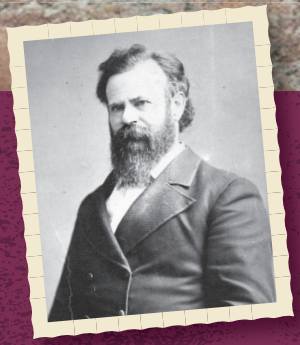
...we sweep around another great bend to the left, making a circuit of nine miles, and come back to a point within 600 yards of the beginning of the bend...we name it Bowknot Bend.

Major John Wesley Powell, July 15, 1869



Celebrating the 150th Anniversary of Major John Wesley Powell's Historic 1869 Expedition Down the Green and Colorado Rivers in Utah

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Design | Jenny Erickson

Cover | View to the west of Bowknot Bend along the Green River in Labyrinth Canyon north of Canyonlands National Park. The entrenched meanders of the river cut through cliff-forming sandstones of the Triassic-Jurassic Glen Canyon Group and into slope-forming shales of the Triassic Chinle and Moenkopi Formations (Google Earth image, © 2018 Google). Inset: Major John Wesley Powell, circa 1874—Union Civil War soldier, explorer, and geologist (National Park Service).

UGS STAFF

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DIRECTOR'S PERSPECTIVE

by Bill Keach

The UGS is celebrating two anniversaries this year. First is the 150th anniversary of John Wesley Powell's historic three-month expedition down the Green and Colorado Rivers (see the main article in this issue for highlights of that trip). The University of Wyoming along with the United States Geological Survey (USGS) are recreating the trip with a 70-day excursion, which can be followed online at https://share.garmin.com/SCREE-Powell150.

Second is the 70th anniversary of the Utah Geological Survey. The Utah State Legislature founded the Utah Geological and Mineralogical Survey in 1931 but without funding or personnel. In 1949 the Legislature transferred the Survey to the University of Utah, appropriated funding for the first time, and appointed Arthur L. Crawford as the first director. Today we honor him by giving a prestigious annual award in his name to a current UGS scientist(s) to recognize outstanding achievement, accomplishment, or contribution to the understanding of some aspect of Utah geology or Earth science. This year's winner is Tom Chidsey and nine co-authors for their work on UGS Bulletin 138 (see "Survey News" in this issue).

A common thread to these anniversaries is the talented and dedicated folks who give their all in the pursuit of geological knowledge. Powell left with a crew of ten. Six endured until the end when they took out at St. Thomas (now a ghost town buried by Lake Mead), about 60 miles north of Las Vegas. Their work produced the first detailed descriptions of the Green River, the Colorado River, and the Colorado Plateau. Powell went on to become the second director of the USGS.

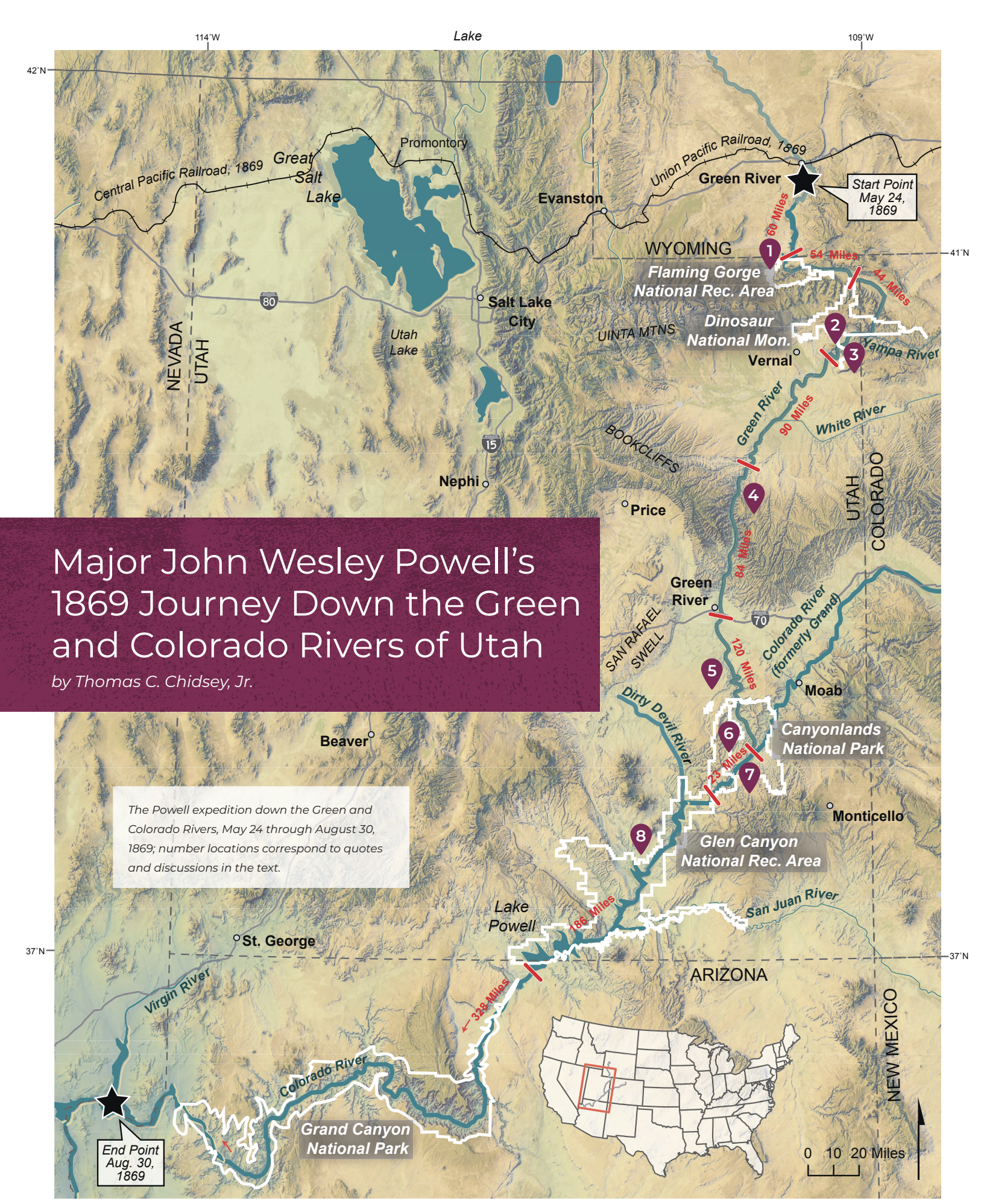
Now in the job barely six months, I am often asked "How's the new job?" and "Are you liking it?" My answer is always "The people I work with are amazing." They make the Survey a wonderful place to work. They do science that is both interesting and critical to the well-being of Utah and the people who live here. In any given week you will find UGS folks monitoring landslides, mapping faults and wetlands, evaluating the groundwater system for a watershed, and assessing the energy and mineral resources of the state.

One of my responsibilities is to approve all publications and reports involving UGS staff. What a pleasure it is to read firsthand the good work being done, communicated, and delivered to those who need it. In the past few weeks I have reviewed a report on the groundwater resources in Ogden Valley (to assist local leaders on best use for future development), the *2018 Utah Mining* report (an in-depth assessment of where and how much for use by economic development groups), and a paper on the Redmond Hills geosite (where "Real Salt" is mined in central Utah). A recent UGS map of earthquake epicenters and recently active faults in Utah was honored by being featured on the cover of ESRI's 2019 *Map Book*, a publication by the developer of visualization/mapping software, that exhibits the best GIS maps created by professionals around the world.

Each publication is more than that of the author or authors whose names are under the title. Behind each of these publications is a great group of dedicated professionals. There are those who gather data, hike the hills, make the maps, research the background, and proofread the copy. All with the goal to deliver "timely, scientific information about Utah's geologic environment, resources, and hazards."

Major John Wesley Powell's 1869 Journey Down the Green and Colorado Rivers of Utah

by Thomas C. Chidsey, Jr.



The Powell expedition down the Green and Colorado Rivers, May 24 through August 30, 1869; number locations correspond to quotes and discussions in the text.

Past these towering monuments, past these mounded billows of orange sandstone, past these oak-set glens, past these fern-decked alcoves, past these mural curves, we glide hour after hour, stopping now and then, as our attention is arrested by some new wonder...

These words by Major John Wesley Powell, August 3, 1869, describe the scene as he and his comrades floated along the Colorado River in what is now southern Utah. Anyone who now travels his same route or visits the various national parks and surrounding regions likewise has their "attention arrested by some new wonder!" Powell is best known for his historic journey down the Colorado River through the depths of the Grand Canyon 150 years ago. However, of that 1,000-mile journey, about 570 miles (roughly 58 percent) were down the Green and Colorado Rivers through Utah. Most of the spectacular areas and landmarks along the way that are so familiar to generations of Utah citizens and visitors were named by Powell and his party.

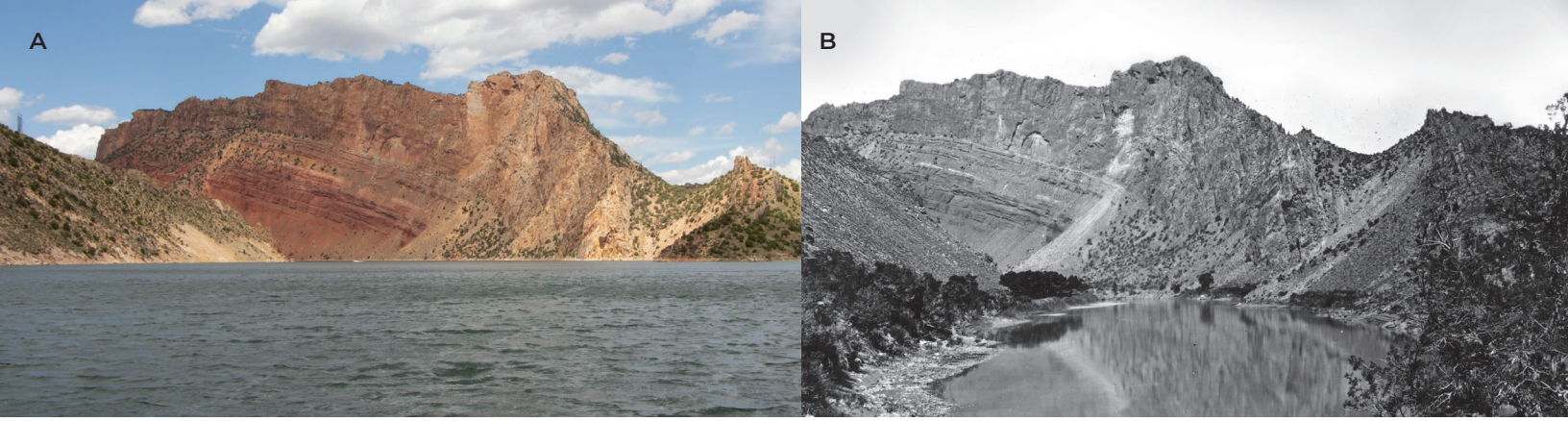
The purpose of Powell's 1869 expedition was to survey the geology, geography, and water resource potential for settling the region, and document ethnography and natural history of the canyons of the Green and Colorado Rivers. Though his expedition was "scientific," Powell was well aware that he was competing with other government surveys for funds, and that adventures such as his river journey drew much public interest and support. The expedition was made possible, in part, by the construction of the Transcontinental Railroad (Union Pacific) through Wyoming, which delivered four modified, round-bottomed Whitehall rowboats that were built in Chicago: *Maid of the Cañon*, *Kitty Clyde's Sister*, *No Name*, and the *Emma Dean* named after Powell's wife and specially rigged for him to command during the trip to accommodate him having one arm.

Powell and his party of nine others departed Green River Station (now the town of Green River, Wyoming) on May 24, 1869, two weeks after the Golden Spike had been laid at Promontory, Utah, completing the Transcontinental Railroad. The boats were laden with supplies to last 10 months and they took several scientific instruments including sextants, chronometers, thermometers, compasses, and barometers (to measure the altitude of the river and surrounding terrain). They would endure numerous hardships along the way including negotiating hundreds of rapids, the loss of two boats with much of their supplies and scientific instruments, surviving near drownings, food spoilage and near starvation, and even outrunning a flash flood. One member of the crew would depart the expedition near Vernal, Utah, having had enough adventure, and three others left near the journey's end thinking an impending rapid too dangerous—they were never seen again.

1 Traveling uneventfully down 60 miles on the Green River, most of which is now Flaming Gorge Reservoir, Powell and his party reached the Utah Territory on May 26.

The river is running to the south; the mountains have an easterly and westerly trend directly athwart its course, yet it glides on in a quiet way as if it thought a mountain range no formidable obstruction. It enters the range by a flaring, brilliant red gorge, that may be seen from the north a score of miles away. The great mass of the mountain ridge through which the gorge is cut is composed of bright vermilion rocks; but they are surmounted by broad bands of mottled buff and gray, and these bands come down with a gentle curve to the water's edge on the nearer slope of the mountain. This is the head of the first of the canyons we are about to explore—an introductory one to a series made by the river through this range. We name it Flaming Gorge [1 on map].

Major John Wesley Powell,
May 26, 1869



A – *Flaming Gorge (view to the southwest) showing folded "bright vermilion" Triassic Moenkopi and Chinle Formations through the Jurassic section. Photo by Michael Chidsey, Sqwak Productions Inc.* ***B –*** *Same view of Flaming Gorge taken by E.O. Beaman during Powell's 1871 expedition, U.S. Geological Survey.*

The mountain range Powell describes is the east-west-trending Uinta Mountains. The rocks at the entrance to Flaming Gorge that so much impressed Powell are the north-dipping, slope-forming, vermilion-colored Triassic (251 to 200 million years ago [Ma]) Moenkopi and Chinle Formations overlain by the buff-gray Triassic-Jurassic (200 to 183 Ma) Nugget Sandstone and the Jurassic (169 to 155 Ma) Carmel, Entrada, and Stump Formations.

2 After crossing the Uinta fault, the Green River follows a generally easterly course through Precambrian (800 to 770 Ma) rocks exposed spectacularly in Red Canyon (now popular for river rafting below the Flaming Gorge Dam) and then Browns Park. Eventually (after about 54 miles), the river enters Colorado through the Gates of the Lodore and turns south into a region that is now part of Dinosaur National Monument where Powell lost the *No Name*, much of their supplies, and scientific instruments in a rapid they appropriately named Disaster Falls. After the river course changes to the west, it reenters Utah.

The Green is greatly increased by the Yampa [River], and we now have a much larger river. All this volume of water, confined, as it is, in a narrow channel and rushing with great velocity, is set eddying and spinning in whirlpools by projecting rocks and short curves, and the waters waltz their way through the canyon, making their own rippling, rushing, roaring music…One, two, three, four miles we go, rearing and plunging with the waves, until we wheel to the right into a beautiful park and land on an island, where we go into camp…The broad, deep river meanders through the park, interrupted by many wooded islands; so I name it Island Park, and decide to call the canyon above, Whirlpool Canyon [2 on map].

Major John Wesley Powell,
June 21 and 22, 1869

The oldest formation exposed in Whirlpool Canyon is the Precambrian (900 Ma) Uinta Mountain Group which is overlain by Cambrian (540 Ma) Lodore Sandstone and Mississippian and Permian (340 to 275 Ma) strata, all relatively resistant to erosion and deeply incised by the river. When Powell exited the canyon and entered the open area he named Island Park, the expedition had crossed the northeast-southwest-trending Island Park fault. This major fault displaces softer, less-resistant Triassic and Jurassic formations on the west side, including the Moenkopi and Chinle Formations exposed in Flaming Gorge, against the Pennsylvanian-Permian (280 to 275 Ma) Weber Sandstone on the east side.

Whirlpool Canyon from Harpers Corner, Colorado (view west into Utah), showing Precambrian through Permian strata cut by the Green River. Photo by Doug Sprinkel.

3 ***At the lower end of the park, the river turns again to the southeast and cuts into the mountain to its center and then makes a detour to the southwest, splitting the mountain ridge for a distance of six miles nearly to its foot, and then turns out of it to the left. All this we can see where we stand on the summit of Mount Hawkins, and so we name the gorge below, Split Mountain Canyon [3 on map].***

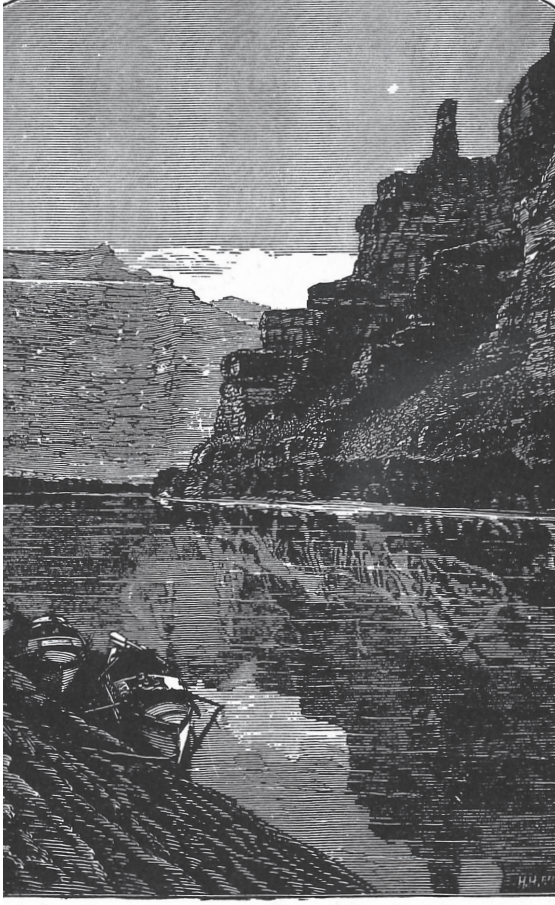
Major John Wesley Powell,
June 24, 1869

For the description of Split Mountain Canyon, see the "Glad You Asked" article in this issue.

4 After passing through Split Mountain, the Green River follows a gentle, south-southwesterly meandering course through the Eocene (55 to 43 Ma) Uinta and Green River Formations in the Uinta Basin. Powell passed many major oil and gas fields that would not be drilled for many years. After about 90 miles the river again downcuts into older rocks which created another major and perilous canyon for the Powell expedition.

After dinner we pass through a region of the wildest desolation. The canyon is very tortuous, the river very rapid, and many lateral canyons enter on either side. These usually have their branches, so that the region is cut into a wilderness of gray and brown cliffs. In several places these lateral canyons are separated from one another only by narrow walls, often hundreds of feet high—so narrow in places that where softer rocks are found below they have crumbled away ... Piles of broken rock lie against these walls; crags and tower-shaped peaks are seen everywhere, and away above them, long lines of broken cliffs; and above and beyond the cliffs are pine forests, of which we obtain occasional glimpses as we look up through a vista of rocks. The walls are almost without vegetation; a few dwarf bushes are seen here and there clinging to the rocks, and cedars grow from the crevices—not like the cedars of a land refreshed with rains, great cones bedecked with spray, but ugly clumps, like war clubs beset with spines. We are minded to call this the Canyon of Desolation [4 on map].

Major John Wesley Powell,
July 8, 1869



Sketch of Lighthouse Rock in Desolation Canyon from Canyons of the Colorado, *by J.W. Powell, 1895.*

Desolation Canyon exposes rocks of the Eocene (55 to 45 Ma) Green River and Paleocene-Eocene (about 60 to 55 Ma) Wasatch Formations which, in this area, were deposited as shallow-water muds, shoreline river deltas, and alluvial plains along or near the southern parts of an ancient lake called Lake Uinta. The Green River and Wasatch Formations are major producers of oil and gas in the Uinta Basin.

Again, the large rapids in Desolation Canyon posed major difficulties for Powell and his party. Most of the rapids that they encountered here and along the entire journey formed adjacent to major side canyons when large flash floods deposited boulders in the rivers. These boulders dammed up the rivers (a calm before the storm!) with the rapid created where the water flows over the "dam."

5 The Green River continues to follow a southerly course into Gray Canyon, cutting down through the coal-bearing formations of the Cretaceous (84 to 67 Ma) Mesaverde Group until it exits the canyon at the Book Cliffs near the town of Green River, Utah. From there the river continues south, eroding deeper into older strata that create the classic Colorado Plateau canyon country of southern Utah.

...with quiet water, still compelled to row in order to make fair progress. The canyon is yet very tortuous. About six miles below noon camp we go around a great bend to the right, five miles in length, and come back to a point within a quarter of a mile of where we started...There is an exquisite charm in our ride to-day down this beautiful canyon. It gradually grows deeper with every mile of travel; the walls are symmetrically curved and grandly arched, of a beautiful color, and reflected in the quiet waters in many places so as almost to deceive the eye and suggest to the beholder the thought that he is looking into profound depths. We are all in fine spirits and feel very gay, and the badinage of the men is echoed from wall to wall. Now and then we whistle or shout or discharge a pistol, to listen to the reverberations among the cliffs... we name this Labyrinth Canyon [5 on map].

Major John Wesley Powell,
July 15, 1869

View of Desolation Canyon showing typical outcrops of the Green River Formation. Photo by Zach Anderson.

The Green River meanders through Labyrinth Canyon exposing spectacular sandstone cliffs of the Triassic-Jurassic Glen Canyon Group (see cover image). These strata were deposited in great "seas" of wind-blown sand like those of the modern Sahara, separated by a period when the climate changed and westerly flowing, sand-laden braided streams dominated the region.

The Colorado Plateau began rising during the Miocene Epoch (23 Ma). At that time the ancestral Green River and its tributaries flowed through meandering channels in wide valleys on easily eroded rocks such as the now-removed Cretaceous Mancos Shale, still exposed just south of the Book Cliffs. Once these river channels were established, they later became superimposed and entrenched into resistant rocks, such as the sandstones of the Glen Canyon Group, as the landscape changed from one of deposition to one of massive erosion where thousands of feet of sedimentary rocks have been removed.

6 From Labyrinth Canyon the river continues a similar meandering course, cutting into even older rocks, and enters what is now Canyonlands National Park.

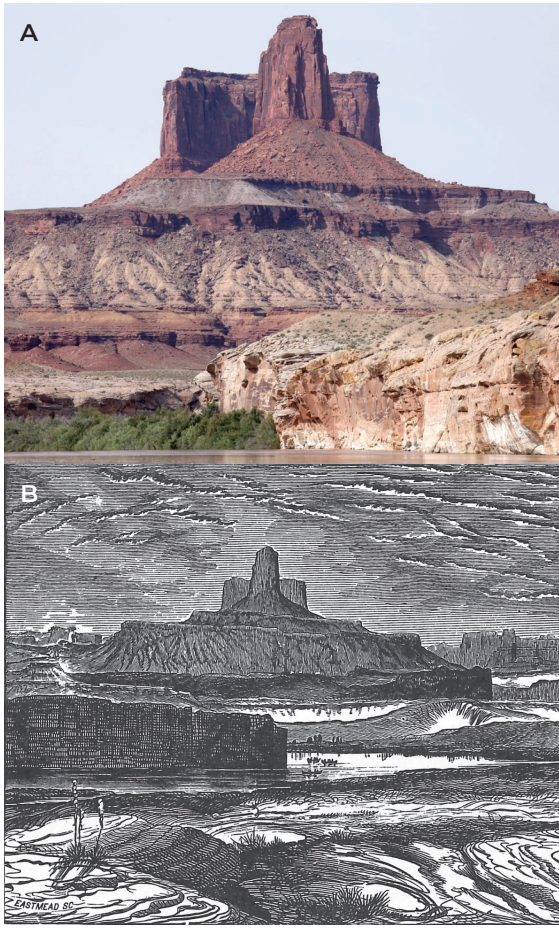
The stream is still quiet, and we glide along through a strange, weird, grand region. The landscape everywhere, away from the river, is of rock—cliffs of rock, tables of rock, plateaus of rock, terraces of rock, crags of rock—ten thousand strangely carved forms; rocks everywhere, and no vegetation, no soil, no sand. In long, gentle curves the river winds about these rocks... rapid running brings us to the junction of the Grand [now the Colorado River] and Green, the foot of Stillwater Canyon, as we have named it [6 on map]. These streams unite in solemn depths, more than 1,200 feet below the general surface of the country.

Major John Wesley Powell,
July 17, 1869

The rocks Powell described from Stillwater Canyon consist of Triassic Moenkopi and Chinle Formations that he first observed in Flaming Gorge, and the Permian (280 to 275 Ma) Cutler Group. The chocolate- to brown-red-colored Moenkopi was deposited in a tidal-flat environment, as attested by its abundance of ripple marks on thin slabs of rocks, and the Chinle, famous for its petrified wood, uranium, and beautiful multicolored mudstone and shale, represents a river floodplain.

The Permian Cutler Group consists of the red-brown floodplain deposits of the Organ Rock Formation at river level capped by prominent cliffs of the White Rim Sandstone which represents ancient coastal dunes.

Large uplifts and basins developed in the Colorado Plateau during the Laramide orogeny (mountain-building event) between the latest Cretaceous (about 70 Ma) and the Eocene (about 34 Ma). Canyonlands National Park and the surrounding region is on the northern end of the broad Laramide-age Monument uplift, which is responsible for exposing the impressive stratigraphic section of older rocks carved into by both the Green and Colorado Rivers in southern Utah.



A – *Buttes of the Cross composed of Wingate Sandstone near the beginning of Stillwater Canyon. Photo by Wayne Ranney.*
B – *Sketch of the Buttes of the Cross from* Canyons of the Colorado, *by J.W. Powell, 1895.*

7 Once past the confluence of the two great rivers, the Colorado River flows in a southwesterly direction descending through one of the wildest series of rapids in Utah until it reaches Lake Powell 23 miles downstream.

We come at once to difficult rapids and falls, that in many places are more abrupt than in any of the canyons through which we have passed, and we decide to name this Cataract Canyon [7 on map].

Major John Wesley Powell, July 23, 1869

A – *Cataract Canyon showing the Honaker Trail Formation and strata dipping away from the Colorado River. Photo by Zach Anderson.*
B – *Sketch of "the heart of Cataract Canyon," from* Canyons of the Colorado, *by J.W. Powell, 1895.*

The geology along Cataract Canyon is unique and the Colorado River likely has been a factor in the canyon's structural development. The river follows a relatively straight course down the axis of a large anticline (upwarp) called the Meander anticline. Open-marine limestone beds of the Pennsylvanian (305 to 300 Ma) Honaker Trail Formation dip to the southeast and northwest, respectively, on each side of the river topped by progressively younger Permian formations. The Honaker Trail is underlain in the subsurface by the older Pennsylvanian Paradox Formation that contains evaporite rocks (gypsum and salt) which were deposited in a restricted marine environment. When under pressure, evaporites can flow like toothpaste being squeezed from a tube and push up the overlying rocks or even reach the surface (Powell recognized one such location and named it Gypsum Canyon, a side canyon to Cataract). The Meander anticline was formed this way and is underlain by a mass of mobilized gypsum and salt. As the Colorado River eroded the overlying section of rocks, the pressure on the evaporites below was reduced allowing them to push up even more. The evaporites withdrew from under the rocks adjacent to the canyon which caused collapse, faulting, and slumping towards the river. This process is still active today and contributes to huge rapids like Satan's Gut and Little Niagara. This area is known as The Grabens in Canyonlands National Park.

8 Upon leaving Cataract Canyon, the Colorado River turns westerly and enters the upper reaches of Lake Powell, named, of course, for the famous explorer. After passing the Dirty Devil River, so-called by one of Powell's men because of its muddy water and foul smell, the rocks become younger in age (Permian, Triassic, and finally Jurassic) to the south.

On the walls, and back many miles into the country, numbers of monument-shaped buttes are observed. So we have a curious ensemble of wonderful features—carved walls, royal arches, glens, alcove gulches, mounds, and monuments. From which of these features shall we select a name? We decide to call it Glen Canyon [8 on map].

Major John Wesley Powell, August 3, 1869

The features Powell used to name Glen Canyon are most prominently displayed in the Jurassic (190 Ma) Navajo Sandstone, famous for its classic cross-bedding and representing ancient dunes of windblown sand.

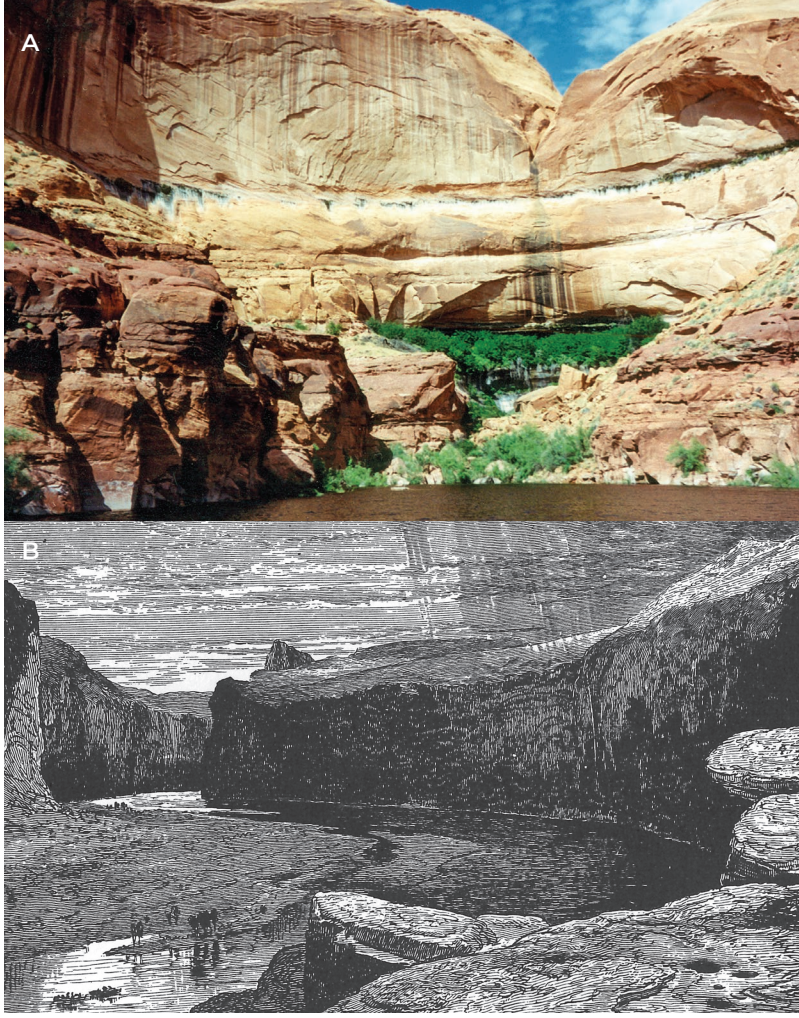
Glen Canyon and the canyons in the surrounding region, including those that Powell explored, formed within the past 5 million years by vigorous downcutting of the Colorado River and its tributaries, exposing more than 8,000

feet of bedrock that spans a period of about 300 million years. Powell no doubt would be shocked and amazed to see the reservoir that bears his name. All outcrops at river level and in many of the side canyons that Powell explored are covered by water, in many places hundreds of feet deep. Fortunately, the lake level creates an ideal horizontal datum along which large folds (anticlines and synclines) bring most of those outcrops, ranging in age from Triassic to Jurassic in the heart of Glen Canyon, to places where they can be observed from the comfort of a boat.

The 710-foot-high Glen Canyon Dam, located just south of the Utah border near Page, Arizona, was authorized by Congress in 1956 to provide water storage in the upper Colorado River basin, and construction began that same year. Lake Powell is the second largest reservoir in the United States (Lake Mead in Nevada and Arizona is the largest). The lake is 186 miles long, and with 96 major side canyons, it has more than 1,960 miles of shoreline—more than twice the length of the California coastline. The surface area of Lake Powell is 266 square miles and it is 560 feet deep at the dam. Lake Powell holds up to 27 million acre-feet of water, enough to cover the state of Ohio with one foot of water! The hot arid climate causes an average annual evaporation of 2.6 percent of the lake's volume. Siltation in the lake averages 37,000 acre-feet per year, brought in principally from the San Juan and Colorado Rivers. That is the equivalent of 6 million dump trucks of silt each year! Even at that rate, it will take 730 years to fill the lake with silt.

Although the most famous part of Major John Wesley Powell's 1869 expedition was the journey of what Powell called "the Great Unknown" of the Grand Canyon, he first spent most of his time exploring the canyons of the Green and Colorado Rivers in Utah. This expedition represents an amazing feat by Powell and his team at that time. Before Powell left the Utah Territory and entered what is now Arizona, he wrote "...we reach[ed] a point which is historic." Powell was referring to a point along the Colorado River known as El Vado de los Padres or Crossing of the Fathers, a ford (now under 400 feet of water in Padre Bay in Lake Powell) named for Fathers Dominguez and Escalante who discovered it during their 1776 expedition through the region. For those of us who boat around Lake Powell or Flaming Gorge Reservoir, or raft the Colorado or Green Rivers, we too reach points that are truly historic—first named and described by Powell and his colleagues 150 years ago. Major John Wesley Powell's expedition was truly a major contribution to science and an incredible adventure that still inspires a spirit of curiosity and sense of wonderment today.

Powell quotes from *Canyons of the Colorado*, by J.W. Powell, 1895.



A – *Classic example of an alcove in the Navajo Sandstone with a hanging garden of vegetation along Lake Powell near Knowles Canyon.*
B – *Sketch of Glen Canyon, from* Canyons of the Colorado*, by J.W. Powell, 1895.*

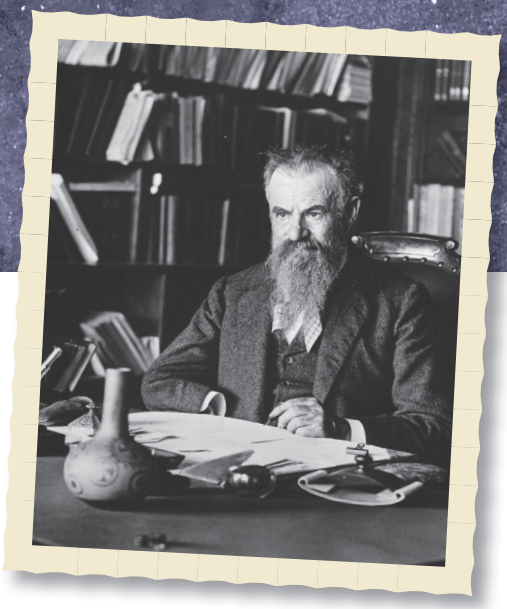
ABOUT THE AUTHOR

TOM CHIDSEY is a senior scientist in the Energy & Minerals Program. He has worked for the Utah Geological Survey for 30 years primarily conducting petroleum geologic studies. Tom is not only passionate about the geology of Utah, but history as well—especially the Civil War, World War I, and Major John Wesley Powell's 1869 journey down the Green and Colorado Rivers. He has retraced more than 800 miles of Powell's route by raft and boat. In addition, Tom was the senior author of the Utah Geological Association's 2012 guide to the geology of Lake Powell.

Son Michael joined "river rat" Tom on his third raft trip through the Grand Canyon.

Major John Wesley Powell: 1834–1902

by Mackenzie Cope



Major John Wesley Powell at his desk in Washington, D.C. circa 1890s (Smithsonian Institution Archives, Record Unit 7005, Box 187, Folder: 1; Record Unit 95, Box 18, Folder: 57)

John Wesley Powell was born on March 24, 1834, in Mount Morris, New York, to Joseph Powell and Mary Dean. He grew up interested in history, literature, botany, zoology, and nature. Powell's family moved to Ohio in 1838, Wisconsin in 1846, and settled in Illinois in 1851. In 1852, he became a teacher and attended college intermittently at the Illinois Institute, Illinois College, and Oberlin College, but never received a degree.

When the American Civil War started in 1861, Powell enlisted in the Union Army at age 27 as a topographer, cartographer, and military engineer and quickly advanced to a second lieutenant. He took leave on November 28, 1861, and married Emma Dean, the daughter of his mother's half-brother, but returned to service soon after. On April 6, 1862, at the Battle of Shiloh in Tennessee, Powell was hit with a bullet in his right arm and field surgeons had to amputate it at the elbow. He became a recruiting officer back home in Illinois while recuperating from his injuries, but returned to active duty in 1863 and was promoted to the rank of major.

After the war, Powell taught natural sciences at Illinois Wesleyan University and later at Illinois State Normal University. In 1867, he became the curator of the Illinois Natural History Society Museum and organized a specimen-collecting expedition to Colorado where he climbed Pikes Peak and explored part of the Rocky Mountains.

In 1868 Powell organized the first of his great expeditions in the West to explore the Colorado River and its tributaries, which included his historic passage through the Grand Canyon. Funding for the trip, which started May 24 and ended August 30, 1869, came from the Illinois Natural History Society and Illinois Industrial University, with Powell's promise of sharing data and specimens for study. Scientific instruments came from the Smithsonian Institution and the Chicago Academy of Science. Rations were provided by the U.S. Army with Congress's authorization and transportation of the boats was courtesy of the Union Pacific railroad. The purpose of this expedition was to explore previously unmapped areas as well as study the geology and native flora and fauna.

Powell conducted a second expedition on the Colorado River from May 22, 1871, to September 7, 1872. This extended trip focused on collecting evidence and scientific data in the form of photographs, detailed maps, and observations for scientific publications. This expedition was funded by the U.S. Congress to obtain an accurate map of the Colorado River and surrounding areas. Powell wrote about his observations and data in his book, known today as *Exploration of the Colorado River and Its Canyons*, which is still printed and sold.

During his second Colorado River expedition, Powell employed Jacob Hamblin, a Mormon missionary from southern Utah, to help negotiate the safety of the trip. Hamblin had an excellent relationship with the Native Americans and Powell was able to study the Native American cultures of the West. From his ethnological work on his expeditions, he published *Introduction to the Study of Indian Languages, with Words, Phrases, and Sentences to Be Collected* in 1877 and *Indian Linguistic Families of America, North of Mexico* in 1891.

In 1879, Powell became the first director of the U.S. Bureau of Ethnology of the Smithsonian Institution and held the position until his death. Among the many organizations he worked for, one of Powell's most respected achievements was serving as the second director of the U.S. Geological Survey (USGS) from 1881 to 1894, which he served concurrently with his other positions. He advocated strict water resource conservation based on his exploration of the American

West's river systems and geology. He published Report on the Lands of the Arid Regions of the United States in 1878 where one of his ideas was to draw state boundaries according to watershed areas. While he was the director of the USGS, Powell emphasized mapping and helped influence the call for nationwide 1:24,000-scale topographic maps. He resigned from the USGS in 1894 due to opposition to his water resource conservation efforts from western politicians.

Throughout his time as a geographer, geologist, and ethnologist, Powell helped organize and take part in many organizations other than the USGS. Some notable organizations include the Cosmos Club in Washington, the Anthropological Society of Washington, the Biological Society of Washington, the Geologic Society of Washington, the National Geographic Society, the Geological Society of America, and the American Association for the Advancement of Science.

Major John Wesley Powell died on September 23, 1902, at the age of 68, in his family's vacation home in Maine and was buried in Arlington National Cemetery with full military honors. Today, Powell is remembered through landforms and natural features named after him (e.g., Mount Powell in the Uinta Mountains and Lake Powell in southern Utah) or by him (e.g., Glen Canyon in southern Utah) across the American West. He is honored for his contributions to geology, geography, ethnology, and the natural sciences as a whole.

Sketch by William Henry Holmes (1882), The Tertiary History of the Grand Cañon District, *(United States Geological Survey), Library of Congress-Maps of Grand Canyon National Park.*

Glad You Asked!

The Curious Case of the Green River in the Uinta Mountains

by Douglas A. Sprinkel

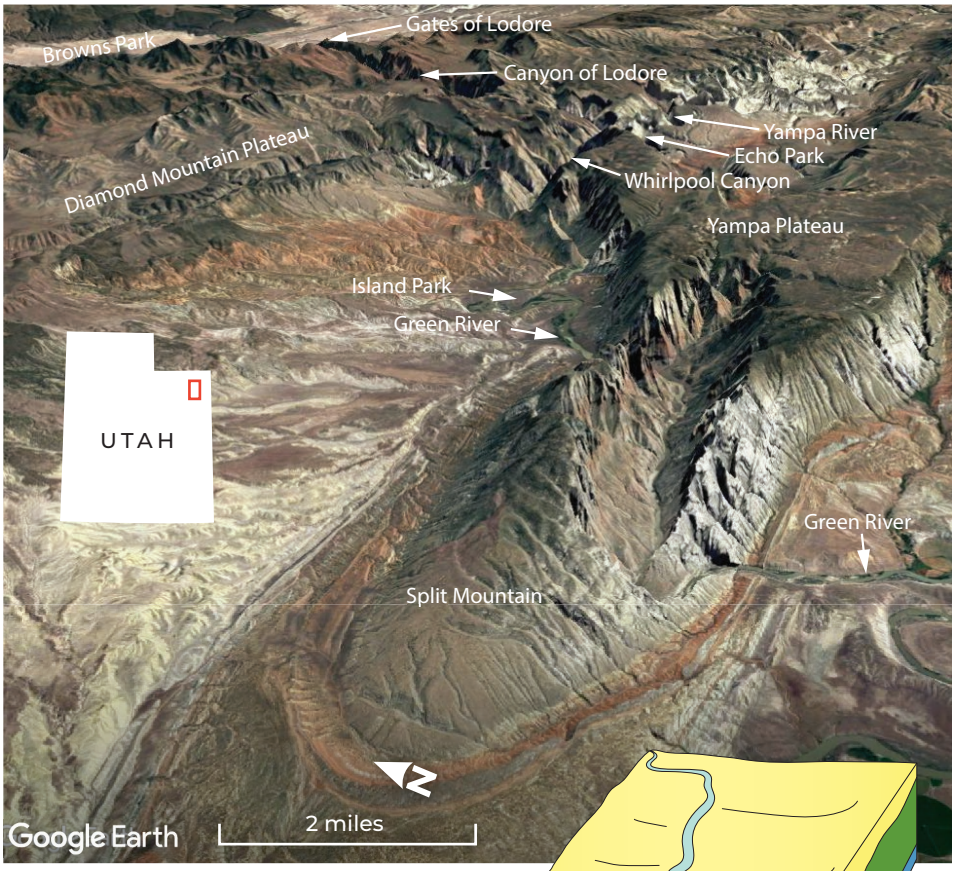
People often ask, *Why does the Green River flow toward and through the Uinta Mountains?* Or, *Why does the Green River cut through the middle of Split Mountain when logically it should have flowed around it?* Those questions also puzzled John Wesley Powell during the first-ever scientific exploration of the Green and Colorado Rivers in 1869 (see main article in this issue of *Survey Notes*).

During their month-long stay in the eastern Uinta Mountains, Powell and his companions explored the Green and Yampa Rivers as well as the side canyons and surrounding peaks. Some of our earliest state-of-the-art scientific measurements and descriptions of the geology were the result of that first expedition. Powell made a second trip down the Green and Colorado Rivers in 1871, as well as several pack trips into the territories of Colorado, Wyoming, and Utah. These overland traverses in 1868, 1869, 1874, and 1875 helped Powell formulate his understanding of the geology of the eastern Uinta Mountains.

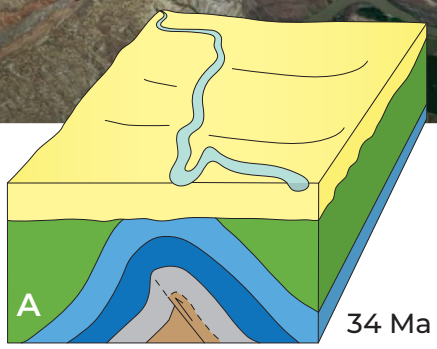
During Powell's first expedition, he noted that the Green River flows from its headwaters in the Wind River Mountains of Wyoming southward across a basin, toward the Uinta Mountains. However, at the foot of this mighty mountain range, instead of being deflected by the obstruction, the river flows directly into the range! This and other examples throughout the Uinta Mountains of where the Green River flows through obvious obstructions instead of around them sparked Powell's imagination to explain such a peculiarity.

So how did the Green River achieve what seems to be an impossible route? At first Powell thought that the river simply followed established fissures within the range. However, Powell rejected that concept because "...very little examinations show that this explanation is unsatisfactory. The proof is abundant that the river cut its own channel; that the cañons are gorges of corrasion." Powell concluded that the Green River had to have been running its course before the mountain range formed. Powell recognized that the Uinta Mountains are a large anticlinal fold that formed by uplift. He hypothesized that the uplift had to be slow enough for the Green River to cut into the rising fold without altering the river course. Thus, he surmised that the Green River cut its canyon as the range rose around it, and tributaries that fed into the Green River were agents of erosion that stripped the rock off the axis of the great arch. Had the uplift been rapid, the river would have been deflected to a new course that would take the Green River around the flanks of the Uinta Mountains. Powell coined the term "antecedent valley" for this hypothesis. He also coined the terms "consequent valley" for channels that form as a result of the existing topography and "superimposed valley" for channels that form on low-gradient surfaces over which the channel maintains its course even as the stream cuts down into pre-existing structures. The term "superimposed" has since been shortened to "superposed." Powell also considered but rejected the notion that the Green River is a superposed stream.

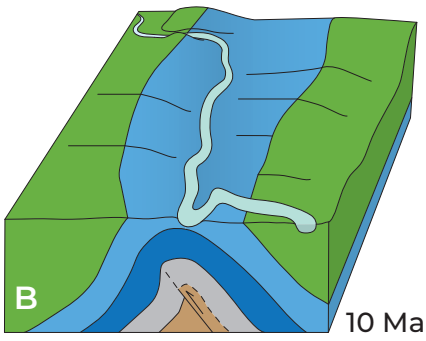
Was Powell right? Work by geologists like Julian Sears in 1924 and Wilmot Bradley in 1936 provided evidence that a network of streams flowed away from the Uinta Mountains into the adjoining basins at the end of Uinta uplift during the Laramide orogeny (mountain-building event) 70 to 34 million years ago including where the Green River now flows toward the range. Sears also provided evidence that later faulting formed Browns Park and argued that the Green River was a superposed stream. However, work by Wallace Hansen from 1965 to 1986 provided the clearest picture of drainage reorganization and capture of the Green River. Stream or river capture (also called stream or river piracy) is the diversion of a stream from its current channel to the channel of the capturing stream, often causing the captured stream to reserve its flow. The lowering of the eastern Uinta Mountains by Neogene (20 million years ago to present) extensional faulting was the agent that caused the change in the eastern Uinta Mountain drainage system and the ultimate capture of the Green River.



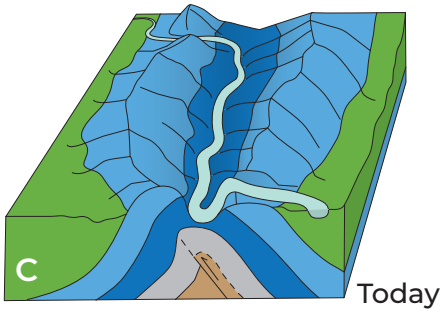
A Google Earth© oblique view of Split Mountain and surrounding regions.



Powell and his companions reached Island Park on June 22, 1869, where they camped on one of the islands on the Green River. While there they explored the area noting topography and geology. They climbed the flank of Split Mountain to view the core of the mountain and the rapids within. Powell noted that the Green River entered the range through its north flank, then turned west down the axis of the fold before it turned south again to exit the mountain through its south flank.



Split Mountain is an anticline formed by uplift along the Island Park reverse fault zone, which is on the north limb of the fold. This faulting and folding are part of the general uplift of the Uinta Mountains. At the time of this deformation, the Mesozoic formations that typically overlie the Paleozoic formations were still present and involved in the folding. During a period of relative tectonic quiescence 34 to 25 million years ago, the flanks of the Uinta Mountains, including Split Mountain and the anticline, were buried by a thick blanket of sediments that became the Oligocene-age Bishop Conglomerate. The Bishop Conglomerate formed a low-gradient slope on which streams meandered. Before the Green River was captured and redirected toward the Uintas, it is thought that the Yampa River meandered across the landscape at nearly the present elevation of the Diamond Mountain and Yampa Plateaus **(A)**. The relatively unobstructed Yampa River incised a canyon into the Bishop Conglomerate generally southwest to the Uinta Basin crossing what would become Echo



Ma = million years ago

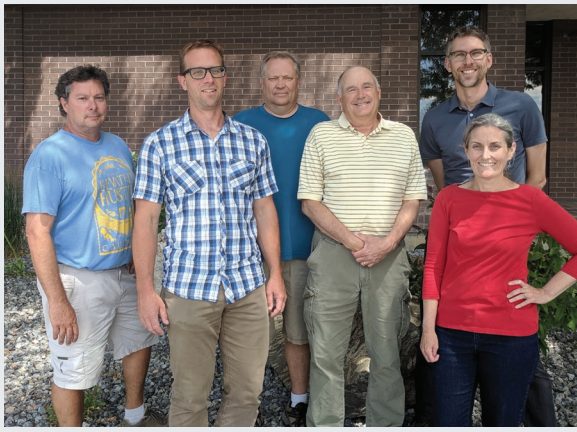
Park, Whirlpool Canyon, Island Park, and Split Mountain. As downcutting continued, the canyon deepened and eventually cut into the emerging Split Mountain **(B)**. The ancestral Yampa River probably took advantage of Laramide fractures on the flanks and crest of the anticline. The Yampa could have been captured by a stream that flowed down the anticlinal crest. Intriguing, beheaded valleys on nearby Blue Mountain, which could be either an ancestral channel of the Yampa, or of a major tributary, support this theory. Regardless, it seems clear to geologists that Split Mountain is a classic example of a superposed stream **(C)**.

The final chapter in this story is the integration of the Green River into the Colorado River basin. Researchers now think that at Echo Park a tributary of the ancestral Yampa River occupied what is now Canyon of Lodore. In 2005, geologists Joel Pederson and Kevin Hadder argued that the tributary formed as Browns Park filled with sediment around the Gates of Lodore. This accumulation of sediment allowed the tributary to spill over and connect the drainage system in Browns Park with the Yampa River drainage and flow into the Uinta Basin, eventually joining the Colorado River below Green River, Utah. The Green River was now captured and redirected to flow toward the Uinta Mountains, through Flaming Gorge and Red Canyon, and down Browns Park to the spill-point near the Gates of Lodore, completing the river system we see today (perhaps the river in the Uinta Basin should have been called the Yampa since the Yampa was there first!). So, Powell's keen observations were amazingly astute, though evidence now shows a much more complicated story than he surmised.

Survey News

Crawford Award

The prestigious 2019 Crawford Award was presented to **Thomas Chidsey** (compiler and editor), **Taylor Boden**, **Stephanie Carney**, **Stefan Kirby**, **Craig Morgan**, **Peter Nielsen**, **Robert Ressetar**, **Rebekah Stimpson, David Tabet**, **Michael Vanden Berg** (contributing authors) in recognition of their work on the outstanding publication *Produced Water in the Uinta Basin, Utah: Evaluation of Reservoirs, Water Storage Aquifers, and Management Options* (UGS Bulletin 138).



From left to right, UGS authors Taylor Boden, Stefan Kirby, Peter Nielsen, Thomas Chidsey, Michael Vanden Berg, and Stephanie Carney.

UGS Bulletin 138 covers the geology, chemistry, and best practices related to saline water production in the Uinta Basin, and provides a framework to address the divergent water uses and disposal interests of various stakeholders. The authors of Bulletin 138 have produced a comprehensive report that can be used by industry and government regulators to help better inform decisions related to produced water management and protection of groundwater resources.

The Crawford Award recognizes outstanding achievement, accomplishments, or contributions by current UGS scientists to the understanding of some aspect of Utah geology or Earth science. The award is named in honor of Arthur L. Crawford, first director of the UGS.

URM Summit

The Utah Division of Emergency Management, the Utah Geological Survey, and the Federal Emergency Management Agency sponsored the Unreinforced Masonry Building (URM) Summit in Salt Lake City on June 25–26, 2019, to address the issue of dealing with dangerous URM buildings during earthquakes. The summit brought together approximately 100 stakeholders from local/state/federal government, emergency management, and municipal building departments, the private sector, elected officials, regional earthquake consortia, and nonprofit/religious groups. The Summit closed with strong commitments by local, state, and federal officials to collaboratively pursue additional mitigation efforts at the state and local level.

Employee News

Congratulations to **Martha Jensen** who accepted a Data Manager position with UGS Web Services. Best wishes to **Chelsea Samuelson** who left the UGS Hazards Program to become an elementary school teacher.

GEOSIGHTS

Park City Sunrise Rotary Regional Geologic Park, Summit County, Utah

by Mark Milligan and Robert F. Biek

After 4.5 billion years of geologic evolution, 35 million years of turning wood into stone, two decades of community vision, and a year of developing informational signage, the Park City Sunrise Rotary Regional Geologic Park was unveiled at a ribbon cutting ceremony on September 21, 2019!

In 1997 a heavy equipment operator uncovered an enormous 5- to 10-ton piece of petrified wood while excavating a water line near Silver Creek Junction, roughly 5 miles north of Park City's historic downtown. This discovery from an area already known for smaller pieces of petrified wood prompted members of the Park City Sunrise Rotary Club to begin searching for a way to create a space devoted to telling the amazing story of the area's unique geology. They approached developer Matt Lowe as he began planning a new subdivision, Silver Creek Village. Mr. Lowe liked their idea and subsequently dedicated the space and constructed the Regional Geologic Park to tell the story of the petrified wood and its interconnections with the Park City mining district, local ski resorts, beautiful mountain scenery, and other aspects of the natural history of the Park City area.

The park includes a welcome panel, nine information panels, and specimens of petrified wood. The signage includes something for everyone, from the casual visitor to geology students on field trips and traveling geologists. Here are some highlights from the panels.

Geologic Foundation: The modern landscape surrounding the Regional Geologic Park is built upon geologically ancient events. Two continental-scale features dominate the geology of the greater Park City area: the north-south-trending Utah hingeline and the east-west-trending Uinta-Cottonwood arch. Both owe their origin to the formation and subsequent break-apart of the supercontinent Rodinia, between 1.7 billion and 780 million years ago.

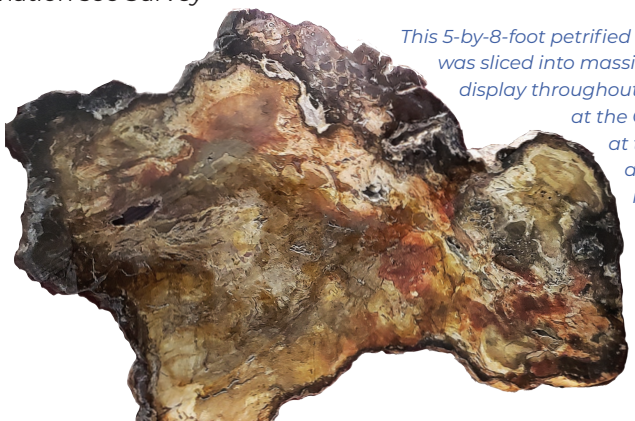
Keetley Volcanics: Roughly 30 to 40 million years ago, active volcanoes towered over the area. The volcanic rocks (known as the Keetley Volcanics) and related igneous intrusions are responsible for the petrified wood and mineralization in the Park City mining district. For more information see *Survey Notes*, v. 50, no. 3, p. 4–5.

Ancient Landscape: What did the region look like 35 million years ago? Volcanoes pocked the landscape and explosive eruptions of rock and ash leveled forests that provided the area's petrified wood.

Petrified Wood: Following burial from eruptions, glass shards in volcanic ash weathered to form mineral-rich groundwater, providing silica that slowly turned wood to stone.

Park City Mining: Park City was born as a mining town. At its peak, the Park City mining district had 300 operating mines and 1,000 miles of tunnels. From 1875 to 1982 the mines produced 1.45 million ounces of gold, 253 million ounces of silver, 2.7 billion pounds of lead, 1.5 billion pounds of zinc, and 129 million pounds of copper! The rich ores owed their existence to mineral-rich hydrothermal (hot) fluids circulating from the magma which fed the Keetley volcanoes.

Modern Landscape: Tectonic-scale forces and erosion created Utah's current landscape in the 35 million years since forested volcanoes loomed over the area. Today, Utah contains parts of three physiographic provinces, each with distinctive landforms and geology: the Basin and Range Province, the Colorado Plateau, and the Middle Rocky Mountains, where the Regional Geologic Park is located.

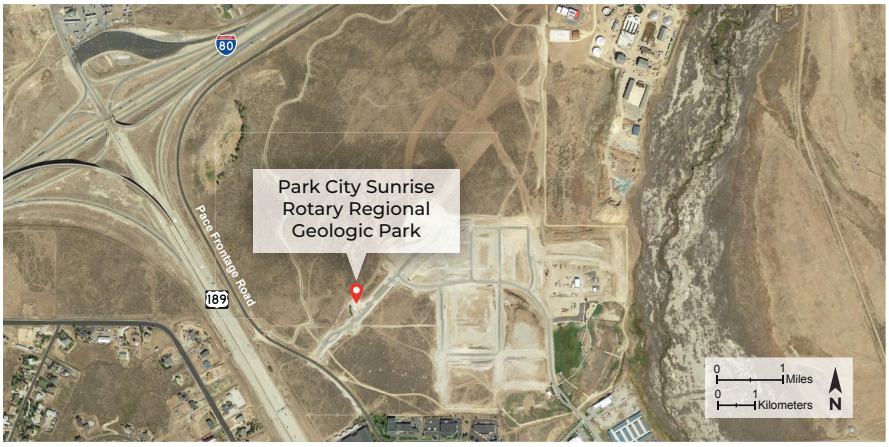


This 5-by-8-foot petrified log collected near the park was sliced into massive slabs, three of which are on display throughout Summit County. This slab is at the Courthouse in Coalville, one is at the Sheldon Richins Building at Kimball Junction, and one is at the Justice Court near the Regional Geologic Park. Photo by Tom Gadek.

Ice Age: During the most recent Ice Age in Utah, glaciers blanketed high mountain valleys and peaks, and Lake Bonneville covered most of Utah's western valleys. The first extensive collection of Ice Age land animals from Utah was discovered in 1963 about a half mile northwest of the Regional Geologic Park.

Water: Park City lies within the Snyderville drainage basin, an area of complex geology that is interesting to geologists but frustrating to water managers, real estate developers, and politicians. To meet growing demands for water in the Park City area, suppliers have utilized creeks, springs, mine drainage tunnels, groundwater, and imported water from outside the basin.

Geologic Maps: Perhaps the best way to communicate the complex geologic story of the Park City area is through geologic maps. A geologic map is a tool that can be used in many ways—from learning about the geologic history of an area, to natural resource and hazard assessment, to providing information for intelligent land-use planning and growth. For more information see Utah Geological Survey Public Information Series 66 (https://geology.utah.gov/map-pub/maps/geologic-maps/geologic-maps-what-are-you-standing-on).



A Google Earth© view of Park City Sunrise Rotary Regional Geologic Park.

HOW TO GET TO THE REGIONAL GEOLOGIC PARK:

From the Wasatch Front, head east on Interstate 80 to exit 146 for U.S. Highway 40/189 toward Heber City/Vernal. After the interchange take the first exit (exit 2) for Silver Summit. At the end of the off-ramp turn left (east) onto Silver Summit Parkway, which becomes Silver Creek Drive after crossing over the highway. In less than a quarter mile from U.S. Highway 40/189, at the traffic circle, take the third exit onto Pace Frontage Road (northbound). After half a mile turn right (east) onto Old Forest Road. The park is located a couple hundred yards past the intersection on the left.

From Park City's historic downtown, head east on Kearns Boulevard (UT 248) to U.S. Highway 40/189 and go north. Take exit 2 for Silver Summit. At the end of the off-ramp turn right (east) onto Silver Creek Drive and follow the directions above.

GPS Coordinates: 40°43'37" N 111°29'23" W

Teacher's Corner

Enhance Your Earth Science Educational Activities with a UGS Teaching Kit

The new Park City Sunrise Rotary Regional Geologic Park provides a wonderful opportunity to learn about the geologic occurrence of petrified wood in northern Utah. To help your students learn more about petrified wood as well as other fossils, rocks, and minerals, consider making use of a Utah Geological Survey teaching kit as part of your classroom Earth Science education activities. In addition to rocks, minerals, and fossils, other teaching kits provide interactive educational opportunities related to plate tectonics, landforms, stream erosion and deposition, and the Ice Age.

For more information on UGS teaching kits and other online teacher resources, including virtual field trip guides and the UGS's annual Earth Science Week activities, please visit our Teacher Resources web page at https://geology.utah.gov/teachers/.

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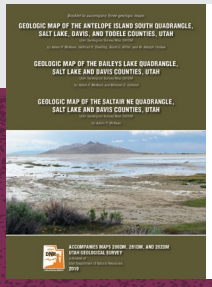
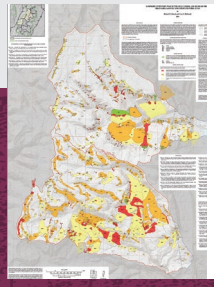


Geologic Maps of the Antelope Island South, Baileys Lake, and Saltair NE Quadrangles, Salt Lake, Davis, and Tooele Counties, Utah, by Adam P. McKean, Hellmut H. Doelling, Michael D. Hylland, Grant C. Willis, and W. Adolph Yonkee, 28 p., 2 pl., scale 1:24,000, **M-280DM**, **M-281DM**, and **M-282DM**.



Landslide Inventory Map of Seely Creek and Big Bear Creek Drainages, Sanpete and Emery Counties, Utah, by Richard E. Giraud and Greg N. McDonald, 1 pl., scale 1:24,000, **SS-164**.

2020

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Learn more about Utah's geologic diversity through scenic photographs taken by UGS employees who are often on assignment in some of the state's most interesting and unique locations.

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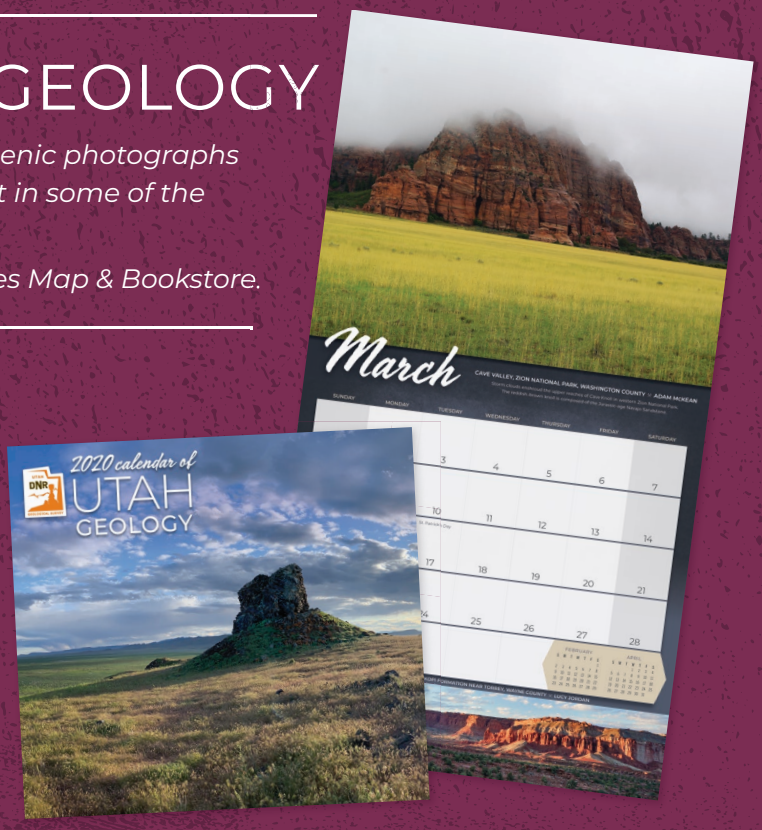

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