

Prologue from *Grand Canyon: Solving Geology's Grandest Puzzle*

In the year 1540, a squadron of men from Coronado's expedition, seeking the fabled Seven Cities of Gold, came instead upon the rim of a great canyon. Though their Indian guides said the stream at the bottom was half a league (about a mile) across, the Conquistadors estimated it at six feet. Three of the lightest and most agile attempted to descend to the river, but after clambering down for most of a day, got only about one-third of the way and gave up. Rock spires that from the rim had appeared no taller than a man turned out to be higher than the Great Tower of Seville. In 1604, the next expedition to arrive, led by Juan de Oñate, Governor of New Mexico, found a muddy, silt-laden river and named it, el Rîo Colorado, "the Red River." The stream would turn out to be the Little Colorado, not the mainstem, the first of many confusions and disagreements over the name of the river. Most of two centuries would elapse before another Spanish explorer, the intrepid Father Garcés, passed by on his way to the Hopi villages to the northeast. The country of the Big Cañon offered neither gold nor souls and was too vast and barren for the Spaniards to comprehend. They saw no reason to remain or to return.

The first American to see the Cañon, Army Lieutenant Joseph Christmas Ives, agreed. He declared it "altogether valueless," adding "Ours has been the first and will undoubtedly be the last, party of whites to visit the locality. It seems intended by nature that the Colorado River along the greater portion of its lonely and majestic way, shall be forever unvisited and undisturbed." [i] Not until the first geologist arrived did anyone begin to appreciate the Big Cañon. He wrote, "The Colorado plateau is to the geologist a paradise. Nowhere on the earth's surface, so far as we know, are the secrets of its structure so fully revealed as here." [ii] The next geologist on the scene concurred, saying, "The grand cañon of the Colorado will give the best geological section of the continent." [iii] The third, a dry, Euclidian sort, said that "the Plateau province offers valuable matter in an advantageous manner"—for him, praise indeed. [iv] The scenery and geology inspired the fourth, the one Grand Canyon geologist who qualified as a poet, to write "It would be difficult to find anywhere else in the world a spot yielding so much subject matter for the contemplation of the geologist; certainly there is none situated in the midst of such dramatic and inspiring surroundings." [v]

The four geologists: John Strong Newberry, John Wesley Powell, Grove Karl Gilbert, and Clarence Edward Dutton, were among the greatest of the nineteenth century, or for that matter, any century. Collectively they redefined the science of geology and gave it a distinctly American cast. The Colorado Plateau provided all they could ask: raw, variegated rock unobscured by vegetation or glacial drift; layer cake bedding nearly uncomplicated by faults and folds; incised canyons to provide the essential but usually scarce third dimension. The pioneer geologists had good reason to believe that, in short order, they would decipher the geological history of the Plateau and its rivers and by doing so would learn lessons that would apply everywhere. How astounded they would have been to find that more than a century-and-a-half after Newberry's arrival, scientists still debated the history of the Colorado River and the origin of the Grand Canyon. Indeed, a few months into the twenty-first century, seventy-seven geologists spent a week on the rim of the Grand Canyon arguing their favorite subject all day and into the night. By the time the symposium ended, not only had they failed to reach consensus, more theories than ever were on the table. Surprisingly, what appeared to the pioneer geologists to be an easy geological puzzle to solve proved just the opposite.

Though the rock exposures of the Colorado Plateau are nakedly displayed and appear simple to understand, in fact the geologic history of the Colorado River and its canyons turns out to be deceptively complicated, vastly more so than the history of that ideal American river: the Mississippi. So fond are we of our longest and widest river that we have given it a variety of respectful nicknames: Father of Waters, Old Man River, Big River. In commerce, the Mississippi is our most important; in music, history, and literature, our most celebrated. The Mississippi is the epitome of a river; the end to which we imagine all rivers must aspire.

On its long journey, the Mississippi travels more or less directly south from the Twin Cities to salt water, there to deposit its sediment load and construct its elaborate birds-foot delta. The Mississippi not only is navigable its entire length, it is comprehensible. Already a sizable stream when it leaves the Minnesota lake country, the Mississippi grows steadily larger as other streams, some great in their own right, pay tribute. But the river never changes in any fundamental way. Why should it? It has no mountain ranges to avoid, no canyons into which to plunge, no quirks of geology to accommodate. The Mississippi can just keep rollin' along, leaving those seeking white water adventure, or a river that can tell them more about how a continent and its rivers evolve, to look elsewhere. The Mississippi impresses us, but it does not awe. Only in degree does the Father of Waters differ from the streams we already know.

Visitors to the Grand Canyon and the Colorado River recognize at once that they have come upon a river that is fundamentally different from the Mississippi and the other familiar streams of the eastern United States. The first glimpse of the giant chasm is such a shock that, years later, most of us can recapture the emotion it inspired. For some, our feelings rival those we have felt at momentous times in our lives: at the birth of a child, the death of a parent, the assassination of a president, or the end of a war. Ever after, we remember the instant when, traveling north through a beautiful pine forest, we arrived at Grand Canyon National Park and approached the rim. We could not yet see the Grand Canyon, for unlike a mountain range, or even the Mississippi River valley, the canyon remains almost entirely hidden until one is right on top of it. Then suddenly, without warning, the land falls away and there, where it has been all along, spreads before us an unimaginably wide and deep chasm, one for which nothing we have ever seen--no photograph or film--truly prepared us. Years and decades later, we can bring back the sense of disbelief that we felt and remember how quickly it passed into awe. Those of us who are not expert photographers soon understood that our puny efforts and modest equipment would not do the scene justice. After a few perfunctory shots, we put away our cameras and simply gazed. Anyone can see that two dimensions cannot capture what is truly important about the Grand Canyon; it takes three.

A few hardy visitors always decide to hike down the Bright Angel or Kaibab trails to get a closer look. Like Coronado's men, most are in for a rude surprise. Just as the apparent simplicity of Grand Canyon geology tempted the pioneer geologists, so the easy downhill trip tempts a hiker to go farther and farther—why not all the way to the river's edge? It is on beginning the return hike that the immensity of the Grand Canyon comes home. Still, by resting at strategic stops, determined not to require rescue by mule or helicopter, the hiker eventually regains the plateau, exhausted, proud, and with a new appreciation of the magnitude of the Grand Canyon.

After recovering from the shock of seeing the Grand Canyon for the first time, questions are bound to occur. Why is the Grand Canyon so different from other river

valleys, even other western canyons? What caused it? Why is it located here and nowhere else? In a flash of inspiration, untold numbers of visitors have realized that the answer is obvious! Some rare, terrible force ripped the earth's surface apart and provided a channel for that tiny stream a mile below. First came the chasm, then the river. But those who espouse this theory ought not forget the saying, "For every difficult question, there is an answer that is clear and simple and wrong." [vi]

The geologists of two hundred years ago, decades before any had seen the Grand Canyon, endorsed the simple answer. They believed that all valleys had been pre-created for the rivers that flow in them. These devout men accepted the Biblical account of earth history and thought that the turbulent waters of Noah's flood had excavated valleys, into which the water then naturally flowed. Even as late as the 1890s, Clarence King, who had served as the first Director of the U. S. Geological Survey, believed that valleys came before the rivers that lie in them. Today some claim that not only did the canyon come before the river, the entire history of the Grand Canyon—indeed, the entire history of the earth—compresses into only the last 10,000 years. But two centuries of progress in geology have taught that because rivers have the deep time of geology at their disposal, they carve their own valleys.

The history of any valley or any canyon, no matter how grand, is inseparable from the history of the river that occupies it. The uppermost headwaters of the Colorado River lie in the Wind River Mountains of Wyoming, where its longest tributary, the Green River, rises. From there to the delta in the Gulf of California, the Green and Colorado together measure 1,750 miles. The Grand Canyon, impressive as are its depth and width, measures only about one-sixth of that total. The Canyon is but one part of the Colorado River, albeit the most important part. We cannot understand the canyon without understanding the entirety of the river. The river is the parent, the canyon is the child.

By the 1860s, Indians, explorers, mountain men, and Army surveyors had traveled each of the major rivers in the United States, save one: the Colorado. Trappers knew the upper Green, the site of their annual rendezvous in the 1830s, perhaps better than they remembered their homes back east. Spaniards, Major Ives, and others had explored the Colorado River from its mouth in the Gulf of California past Fort Yuma and on up to the vicinity of present day Las Vegas. But in between the map was blank. At the border between Wyoming and Utah, the river disappeared through an ominous rock portal; a thousand miles downstream, it debouched from a great canyon. What lay in between no one knew, for in that long stretch explorers had reached the Colorado River at only a few places. Even as late as the mid-1860s, not just the river, but the entire Colorado Plateau, as large as several eastern states combined, remained essentially unexplored.

The explorers and geologists of the nineteenth century had no maps, satellite images, and global positioning systems; only word of mouth and Indian trails. Those who set out to explore the Colorado Plateau did not have even those, for if any had gone before, they had not lived to tell the tale, much less bring back a map. Among the many inventions of the late twentieth century, none would have been of more use to pioneer geologists and explorers than the digital relief map shown in this book. Whether the map would have reassured or terrified them, it would certainly have revealed a river completely different from the Mississippi and its eastern kin.

Flowing south from the high lakes of the Wind Rivers, the Green River crosses the high plains of Wyoming, past the town of the same name, and continues southward

on as direct a course as the Mississippi . Soon the river enters the Flaming Gorge reservoir on the Utah-Wyoming border, north of the Uinta Range, with peaks 13,000 feet high. Nearly alone among the mountains of the Western Hemisphere, the Uintas trend east-west, placing the range directly athwart the path of the southwarding river. The Green heads straight for the mountain range; then, as if losing its nerve, swerves ninety degrees to the east and runs for fifty miles parallel to the foot of the mountains through a beautiful natural park. Only a few miles farther east and the Green could have avoided the Uintas altogether, but now it suddenly swings back south and, through the menacing Gate of Lodore, enters a canyon incised into the heart of the mountains.

After twenty miles with enough white water to satisfy any river runner, the Green exits Lodore and comes out into a valley, only to enter another canyon, this one cut right through the center of the aptly named Split Mountain. From there the river passes through Desolation Canyon, then Gray Canyon, cut into the Book and Roan Cliffs, respectively. Downstream the (formerly named) Grand River enters from the east and the direction of the (now) Colorado River swings a bit to the west. Cataract Canyon and Glen Canyon once came next, but now lie under Lake Powell. As the river crosses the Arizona line, below the Glen Canyon dam, it begins to swing back south again, passing on its right the mouth of the Paria River and the plateau of the same name. It flows straight through Marble Canyon, heading for the Kaibab Plateau, the highest obstacle in its path after the Uinta Range.

Although from the map it appears the river could have bent less steeply by following a route south through the valley of the present-day Little Colorado River, that is uphill. Instead, the river cuts across the nose of the Kaibab Plateau and then swings northwest. Thirty miles later, the Colorado makes another sharp bend back to the southwest, placing it on a collision course with the next high plateau, the Shivwits. But the river shifts direction and runs straight beside the Shivwits Plateau for 30 miles, then bends around it and resumes its northwesterly course. At the Grand Wash Cliffs, which we will meet repeatedly, the Colorado leaves the Grand Canyon and flows out into the Basin and Range province and into modern Lake Mead. Here it turns ninety degrees south and now, finally, like the Mississippi proceeds for several hundred miles with little deviation, traveling most of the way in a single large valley, until it reaches the Gulf of California. There it has built a delta and today, if irrigators and thirsty desert cities had not impounded and extracted all its water, would continue to do so.

To a geologist, nothing surpasses a map. When maps of sea floor topography became available in the late 1940s, for the first time scientists could see the enormous faults, the gargantuan, world-encircling, undersea mountain ranges, and the abyssal trenches that scar the sea floor. To deny that something terrible had happened in the ocean basins, something on the same scale as the continents themselves, was impossible. Geologists could no longer dismiss as absurd the idea that continents had drifted: the seafloor appeared to retain the very scars of their gargantuan passage. In the same way, the modern map reveals that the Colorado River has had anything but the simple history of the Mississippi. The Colorado crosses three distinct geologic terrains: the Colorado Plateau, the Canyon Country, and the Basin and Range Province. It cuts deep canyons in some mountain ranges and goes around, or nearly around, others; changes direction unpredictably; meanders here and runs straight there; and generally behaves without apparent rhyme or reason.

The beauty of the Grand Canyon and the unparalleled exposure of its rocks have drawn generations of geologists. The unexpected complexity of the Canyon's geologic history confounded even the best of them, though gradually and collectively they have been able to put boundaries around the possible explanations. The pioneers had been sure that by studying the Colorado River and the Grand Canyon, they would learn lessons that eastern rivers could never teach them, lessons that would apply everywhere. They were right, but the lessons turned out to be quite different from those they expected and to have even deeper implications for earth history. One hundred and forty years of studying Grand Canyon geology have paid off, but in ways that have surprised even the best geologists.

The myth of the "scientific method" makes it seem that science is so logical, indeed inevitable, that serendipity has no place. But just the opposite is the case. At least in geology, some of the most important discoveries have come about serendipitously. And the most important of all were, strange to say, completely counterintuitive. Take one recent advance: when we observe the quiet night sky, we see the planets move in their predictable orbits and the moon pass through its familiar phases; save for the rare flash of a shooting star, nothing unexpected ever seems to happen. Until the space age, we had no reason to suspect that our solar system was born in colossal, random violence and that the impact of asteroids and comets has since been its most fundamental process. Indeed, only in the last two decades have we discovered that Homo sapiens may only exist because, through a roll of cosmic dice, one errant meteorite out of the thousands that fly through space happened to strike the Yucatan peninsula 65 million years ago and exterminate the dinosaurs and seventy percent of all living species.

In the same way, a rafter floating down the Colorado has no reason to suspect the power which geologic time provides to rivers. Who would guess that they engage in a vicious competition for territory that causes the more energetic streams to capture the waters of the less energetic? That only the fittest survive to carve deep canyons? The pioneer geologists of the Grand Canyon, outstanding as they were for their day, could not have imagined just how far the lessons of the Big Cañon would extend. They had no way to know that, by studying the imprisoned rivers, vast erosion, and dramatic uplift of the Colorado Plateau, they would uncover the underpinnings of a scientific revolution a century ahead. But such is the way of science.

Like a raft trip on the Colorado's white water, following the efforts of five generations of geologists to understand the river and its Grand Canyon stimulates our thinking, but it does require more concentration than a riverboat cruise on the mighty but placid Mississippi. The protagonist of this story had canoed the Father of Waters and other eastern streams for hundreds of miles. Yet they failed to teach him the lessons that the canyons of the Colorado brought home as soon as he set sail upon its waters.

[i] Ives, J. C. (1861). Report upon the Colorado River of the west, explored in 1857 and 1858 by Lieutenant Joseph C. Ives ... under the direction of the Office of Explorations and Surveys. Washington,, Government Printing Office.

[ii] Newberry, J. S., J. N. Macomb, et al. (1876). Report of the exploring expedition from Santa Fé, New Mexico, to the junction of the Grand and Green Rivers of the great Colorado of the West in 1859. Washington, Engineer Dept. U.S. Army: G.P.O.

[iii] Worster, D. (2002). *A River Running West: the Life of John Wesley Powell*. New York, Oxford University Press. 127

[iv] Gilbert, G. K. (1876). "The Colorado Plateau Province as a Field for Geological Study." *American Journal of Science, Third Series XII*: 16-24, 85-103. 18

[v] Dutton, C. E. (1882). *Tertiary history of the Grand Canyon District*. Reston, VA, U. S. Geological Survey. 92