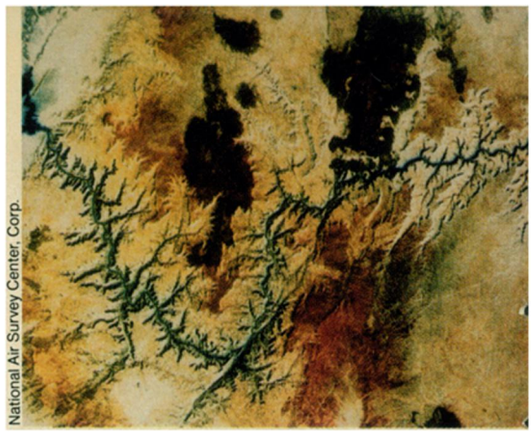
What's New in the Ol' Grand?

Geology's great monument continues to baffle and amaze

By RICHARD MONASTERSKY



National Air Survey Center, Corp.

Only from a distance of 570 miles does the Grand Canyon seem small. This false-color mosiac of Landsat satellite images shows the canyon's full 277 miles, stretching from Lees Ferry in the upper right to Lake Mead at the left. Brown shades represent vegetation.

According to an old Indian legend, it's really a testament to love. Long ago, the great chief of all the Utes lived with his beloved wife. When she died, he mourned day and night, and his sorrow was spread throughout all his people. Seeing such grief, Ta-vwoats, a god, appeared before the chief, and tried to comfort him. But the chief's sorrow did not diminish.

Finally Ta-vwoats offered to take the chief to the blessed world of the dead. The chief could visit his wife and see that she was truly happy if he promised to return to earth and end his mourning. Then Ta-vwoats rolled an immense ball of fire across the plain, creating a chasm that led to the home of the dead, and the two descended in search of the chief's wife. Upon their return, Ta-vwoats placed a raging river into the bottom of the canyon so that no one else could attempt to visit the afterworld.

The first white man to see the Grand Canyon didn't worry about the origin of the huge abyss and the tiny river at the bottom; he was more preoccupied with how to get around it. In 1540, Garcia Lopez de Cárdenas, a Spanish conquistador in search of mythical golden cities, came unexpectedly upon the canyon. After spending several days trying to descend, he decided that the golden cities, if they did exist, were probably not worth the effort.

Three centuries later, Major John Wesley Powell, a one-armed adventurer and geologist, led the first recorded boat expedition down the Colorado River in 1869. When Powell embarked on his monumental journey with nine other men packed into four small boats, the Grand Canyon was a vast uncharted stretch that Powell called "the great unknown." On the best maps of northern Arizona, a conspicuous 200-mile-long blank spot was the only indication that the canyon existed.

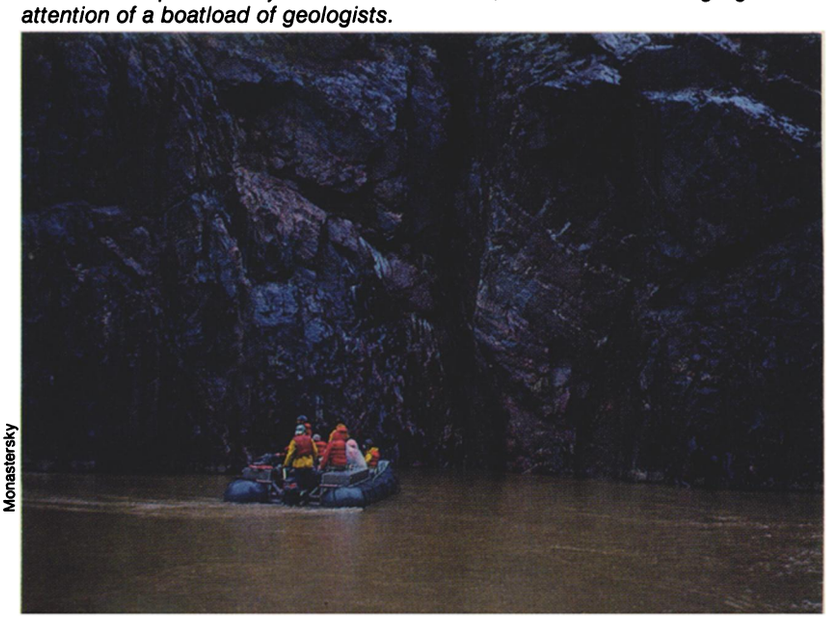
The publicity that surrounded the expedition and false rumors of Powell's demise helped ingrain an awesome image of the canyon into the minds of the American public. But Powell was also one of first to recognize the scientific treasures that lay in the canyon. Here, the Colorado River has provided researchers an unparalleled opportunity to study more than 2 billion years of geology, spanning half the planet's history.

For more than a century, geologists have flocked to the canyon, using it as a textbook and deriving fundamental concepts within its sheer walls. But the textbook is by no means closed; scientists are still studying its lessons, and many pages lie yet unturned.

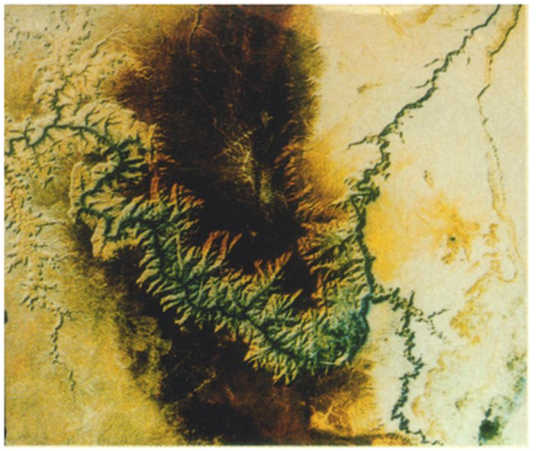
While floating down the Colorado on a recent field trip into the Grand Canyon, researchers from the U.S. Geological Survey (USGS) discussed some of the new work being done in that old canyon.

The Indian tribes of the Southwest have several legends for the origin of the canyon and Colorado River, and since Powell's time, scientists have woven their own tales about nature's greatest chasm. While it's clear that a river has cut the canyon and deserves one of the starring roles in any origin tale, other aspects are less clear and have provided a source of continuing debate.

Scoured and polished by the sand in the river, a wall of the inner gorge attracts the attention of a boatload of geologists.



Monastersky



Still outstanding are questions concerning the origin of the Colorado River. Specifically, how old is the river that flows through the canyon and how did it develop? As they seek to answer these questions, geologists are refining their ideas about the development of rivers. Abandoning simpler concepts, they are beginning to see rivers as evolving entities that adapt to environmental pressures much as biological systems develop.

It is in the snow-mantled mountains of Colorado that the modern form of this river is born. It starts as mere rills of icy water, trickling out from beneath scree slopes and granite boulders. Flowing southwest, the Colorado converges with the larger Green River, which originates in the Wind River Mountains of Wyoming. Together these two rivers and a multitude of smaller tributaries drain the western side of a 500-mile-long section of the Rocky Mountains.

The canyon itself lies at the southwest end of the Colorado plateau, a relatively mountain-free expanse that stretches from Arizona north into Utah, and west into Colorado and New Mexico. The plateau is actually a series of huge, gently dipping platforms that start at an elevation of 5,000 feet in Arizona and rise at places to 10,000-foot-high sections, which abut the base of the Rocky Mountains to the northeast.

Flowing out of the Rocky Mountains, the Colorado River runs southwest and then west across the Colorado plateau, drops into the desert country along the western border of Arizona and flows south until it finally reaches the Gulf of California. From the plateau to the desert, the river has to drop some 6,000 feet, and for this purpose it has cut its own 277-mile-long sluice into the plateau. Over a mile deep in certain sections, the canyon spans 12 to 20 miles.

As facts on the page, these numbers, though impressive, cannot inspire the awe that each visitor feels standing at the edge of the abyss. For some perspective, Powell wrote: "If a hundred mountains, each as large as Mount Washington, were tumbled into this cañon, they would scarcely fill it." He called it "the most sublime spectacle on earth."

Moved by such an immense monument to erosion, the early geologists felt that the canyon must be an old structure, representing 50 million years or more of cutting. An ancient Colorado river, flowing in the same course as today's river, would have carved the canyon over this time period as the surrounding plateau rose up from sea level to its present height.

But evidence gathered in the last century has forced geologists to reconsider the early theory for the origin of the Colorado. In the 1930s and 1940s, scientists who studied the western part of the canyon and the lower Colorado River became convinced that the river was relatively young, dating back no farther than 6 million years. On the other hand, scientists who studied the river's upper section in the 1960s found evidence that it was at least 20 million to 30 million years old. Researchers puzzled over this river that seemed to be both old and young.

Powell and the geologists who followed him had believed that all parts of the river were of the same age. "They felt that the river had an integral history. What was true of one part was true of the whole thing," says Ivo Lucchitta of the USGS in Flagstaff, Ariz., who has studied the canyon for the last quarter-century.

But the recent findings compelled scientists to reject the idea of an integral history and to adopt, instead, the theory that the river is an evolving system. They proposed that an ancient Upper Colorado River did indeed flow southwest out of Utah and Colorado, but when it reached into Arizona, it would have veered to the southeast, traveling out along the Little Colorado (a current tributary to the Colorado) and then possibly to the Rio Grande and the Gulf of Mexico.

According to the theory, the Colorado as we know it formed nearly 5½ million years ago when plate tectonics created a huge rift in the earth near the west coast of Mexico, separating Baja California from the rest of the continent. As this rift grew, the Pacific Ocean flowed into the opening basin, creating the Gulf of California. This tectonic rearrangement would have shifted drainage patterns in northern Arizona, causing the ancestral river to assume a southwestward course in the direction of the new gulf.

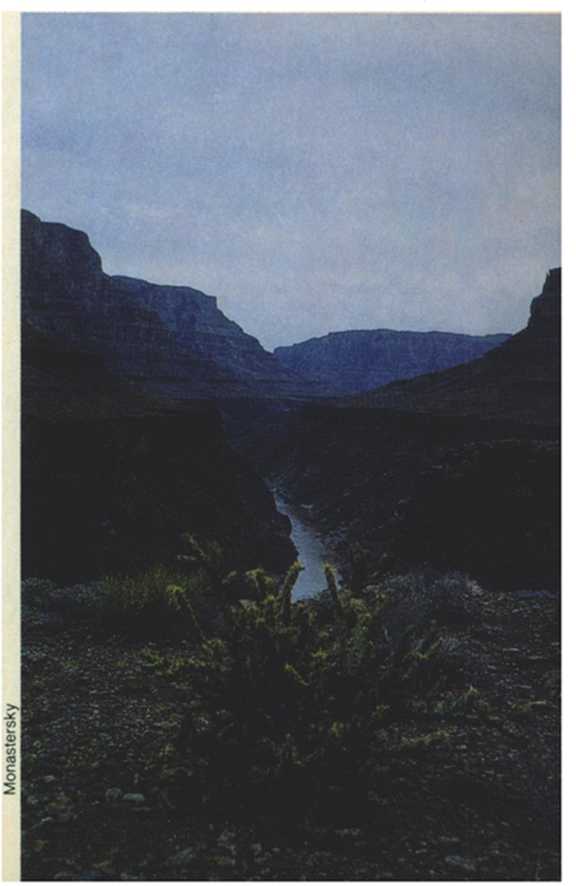
For 20 years, this explanation has appeared in books and popular articles about the origin of the Colorado River. But new evidence is again triggering a revision in thinking, says Lucchitta. He and others are now suggesting that until the Gulf of California opened, the ancestral river flowed to the *northwest* instead of southeast along the course of the Little Colorado.

Searching in the country north of the present canyon, Lucchitta has found ancient gravels that seem out of place; they couldn't have come from nearby rocks. Using the minerals in these gravels as fingerprints, researchers have traced the rocks back to deposits that lie to the south of the canyon.

At first, these gravels seem to present a problem. Specifically, how could they have jumped from one side of the canyon to the other?

But according to Lucchitta, they didn't cross the great chasm. Rather, the streams that deposited the gravels existed long before the time of the canyon. Flowing to the northwest, these streams would have fed into the ancestral Colorado River, which would also have run northwest.

Other evidence also points in this direction. Take a look at the major side canyons that run into the Grand, says Lucchitta. "All the better-developed drainages in the Grand Canyon region — the ones that are clearly not short, stubby and immature — have this trend. The Little Colorado is a good example. Cataract Creek is another example. They all trend northwest." According to Lucchitta, this pattern indicates that the oldest, most mature rivers ran toward the north-



Monastersky

While the river cuts in the vertical dimension, landslides and other mass movements of rock carve out the impressive width of the canyon. The layering of different types of sedimentary rock creates the characteristic pattern of alternating cliffs and gravel slopes. Sandstone and limestone, which are relatively resistant to erosion, form the cliffs along the canyon walls. Shales and other weaker rocks crumble to form the slopes of gravel.

west before any uplift and canyon cutting occurred.

For Lucchitta and other geologists, the important lesson drawn from these studies is that rivers are continually evolving systems.

On the geologic timescale, the face of the earth is an animate, expressive entity. Tectonic activity is constantly pushing up mountains in one area, while creating basins and troughs in another.

This rearrangement changes the gradients of rivers, causing drainage patterns to shift. When gradients steepen, a river can expand and capture a larger drainage area. Conversely, if the alterations in landscape tend to flatten the gradient of a river, the river will lose its drainage. In other words, the fittest rivers survive.

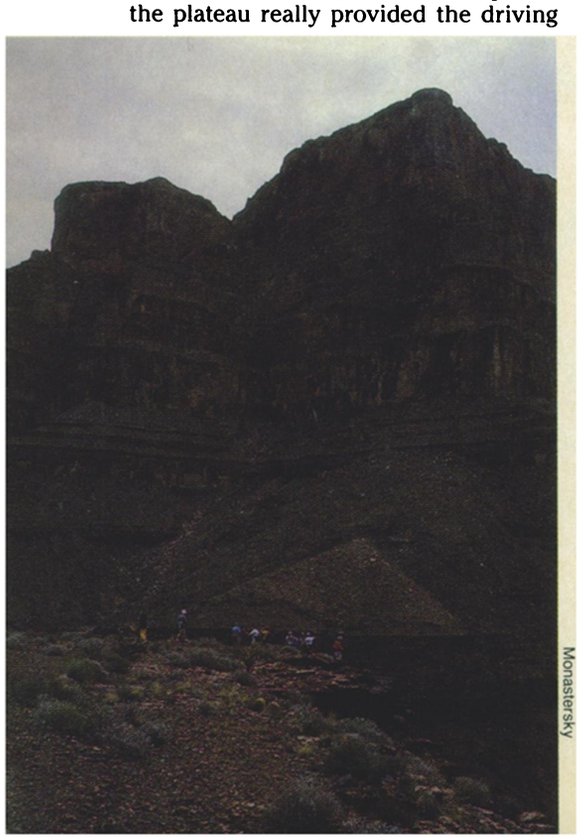
Since the late 1960s, the Colorado River has been teaching geologists that rivers can be a geological analog to biological systems. "I really do think we're seeing a Darwinian competitive situation, survival of the fittest," he says.

When you're floating down the Colorado in the Grand Canyon with geologists, you tend to hear a lot about cakes; it seems to be one of their favorite images for discussions about the canyon. They say the actual canyon was formed as the river cut into the plateau like a knife slicing a cake. But in this case, the knife remained still as the cake rose beneath it, because the uplift of the plateau really provided the driving force for the canyon carving.

Cakes are also useful images because they can be layered, like the strata of sedimentary rocks that make the canyon such a geologic treasure. Before the time of the canyon, even before the time of the ancestral Colorado, this area was at sea level and at times even lower. For billions of years the seas washed over the pre-canyon area, periodically retreating and then reappearing. Ocean floor, estuary, swampland and desert: The layer cake of sedimentary rocks in the canyon records all these environments.

On his trips down the Colorado, Powell studied this sedimentary record of the past. Holding a barometer in his one arm, he would scramble up the walls of the canyon, stopping each half-hour at a boundary between two rock types to take a barometric reading. These he matched against readings taken at similar intervals by a person on the river. Because air pressure changes with elevation, Powell could then measure the thicknesses of the layers.

Helicopters, topographic maps and surveying tools later replaced the barometers, and geologists mapped out a 2-billion-year history of the area. Fossils embedded in the sedimentary layers and lava from ancient eruptions helped them date the many appearances of the sea, called transgressions.



Monastersky

Standing on a plateau along the southern side of the river, a group is dwarfed by a wall of sedimentary rocks across the river. The layered rocks of that wall record more than 200 million years of the earth's history.

Billingsley

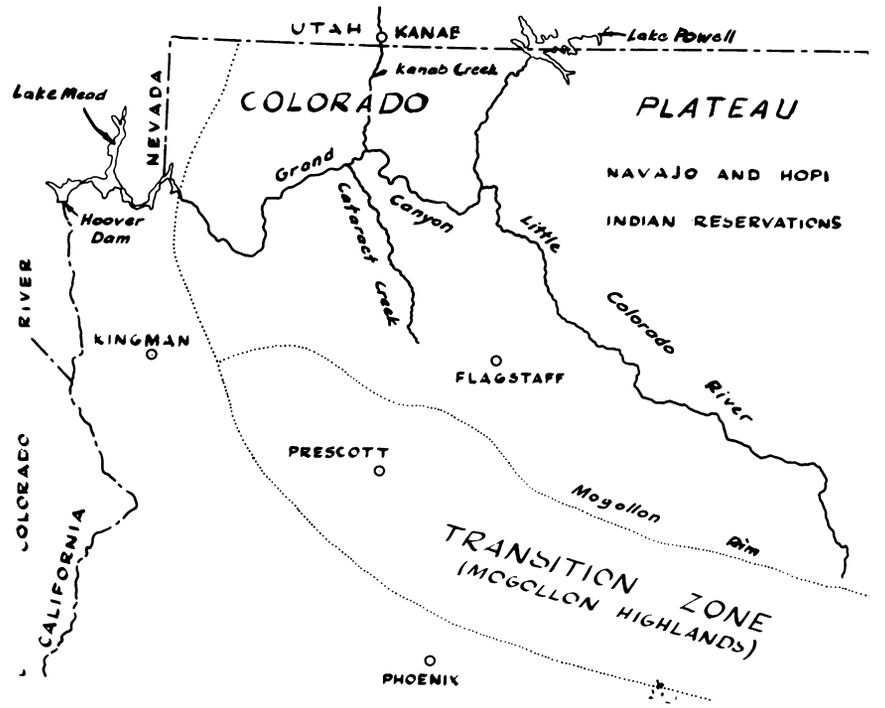
Hundreds of millions of years ago, acidic subsurface water caused the roof of an underground cave to collapse, forming a vertical column, or "pipe," of breccia, broken rock that has been cemented together. In the center, a portion of the breccia-filled cave is visible. While the actual breccia pipe lies hidden behind the wall of the cliff, the top of the pipe forms a pinnacle above the cliff.

But the work is still incomplete. There are always gaps in the sedimentary record that correspond to times when the land was above sea level and subject to erosion. While some sections of time are totally absent, appearing nowhere in the canyon, other gaps in the sedimentary record may appear in selected parts of the canyon. Even now, geologists are finding pieces of the sedimentary puzzle that they never knew existed in the canyon.

During the last decade, George Billingsley of the USGS in Flagstaff has located such a missing piece in a place named Surprise Canyon. Along the walls of Surprise Canyon, he found the cross-sections of ancient river valleys that ran through the area during the Carboniferous period about 340 million years ago, long before the Grand Canyon existed. The rocks that later filled these valleys represent a 20-million-year period missing in most other parts of the canyon.

The Surprise Canyon formation has told geologists that the sea transgressed twice during this 20-million-year span. And it has yielded a greater variety of fossils than any other formation in the Grand Canyon, says Billingsley.

Within the last several years, he has found rocks from the Surprise Canyon formation within other areas of the Grand Canyon and even within ancient caves. Sharks, starfish and a seafull of other creatures swam and crawled over this area during the Surprise Canyon time, their fossilized bones and teeth littering the rocks in that formation.



Lucchitta

Mature tributaries that trend northwest, such as Cataract Creek and the Little Colorado River, are evidence that the ancestral Colorado ran to the northwest before the time of the canyon. The dotted line denotes the edge of the Colorado plateau. On the western side, the Grand Wash Cliffs form a sharp border between the plateau and the lower Basin and Range Province. The transition between these two zones is less distinct in the south, where they are separated by intermediate highlands.

More recently, Billingsley has also been working on a different project with Karen Wenrich of the USGS in Denver and Peter Huntoon of the University of Wyoming in Laramie. Together they have been crisscrossing thousands of miles in the land surrounding the canyon, searching for breccia pipes, the ancient remains of underground caves whose roofs have collapsed, forming a vertical column of broken rock fragments. They are created by circulating subsurface fluids that dissolve away limestone.

Millions of years after the collapse, briny fluids seep through and cement the broken fragments together, forming what is called breccia. These breccia pipes, which measure less than 300 feet across, can extend vertically for several thousand feet. So far, the researchers have found more than 1,000 collapsed surface features that may be breccia pipes on the Hualapai Indian Reservation, which borders the southwest section of the canyon.

For geologists, the breccia pipes have been stimulating questions that are yet unanswered. Those who have studied these pipes and the relatively few others that appear elsewhere in the world know that the subsurface fluids circulating up and down the pipes leave behind deposits of valuable minerals. But fewer than 8 percent of the breccia pipes are enriched in these minerals, and no one can explain this selectivity.

The early prospectors who visited the canyon in the late 1800s were also interested in the pipes. But rather than ponder geological questions, they were seeking the deposits of copper, silver and zinc. In the 1950s, people recognized that certain pipes contain another substance: uranium ore.

Because of the high-grade uranium deposits, these pipes are now generating considerable interest, says Billingsley. Under a contract with the Hualapai Indian tribe, the researchers have been mapping the pipes so that mining might provide an additional income for the Indians.

While mining is prohibited in the parts of the canyon that belong to the national park, the Hualapai control the use of their own land. Many pipes also lie inside federal lands near the park, and their existence raises some controversy over the possibility of mining in that land. Still, those who have run the Colorado River in the park's western end know that mining is no stranger to the federal lands, including the park itself. Prospectors have mined within the park for gold, mineral deposits and even "bat guano."

The Bat Cave, as it is officially known, is located 800 feet above the river and was discovered in the 1930s to contain tons of bat guano, a valuable fertilizer formed by deposits of bat excrement. Merle Emery and Beal Masterson, two prospectors who first tried to mine the guano, had to abandon the project because their transportation barges sank in the river. In the early 1950s, the King-Finn Fertilizer Co. tried to transport the guano in aircraft that landed on a sandbar below the cave. But their luck ran out when floods washed away the makeshift airstrip, according to Billingsley, who has traced the history of Bat Cave.

In 1958, the U.S. Guano Corp. bought the rights to the cave. A survey estimated that the guano deposit neared 100,000 tons, and the company decided to build a $3.5 million tramway across the canyon to solve the transportation problem. They started to mine, hauling the guano out by tram; but in 1959, they realized that the survey had tragically erred. Only 1,000 tons of guano lay in the cave; the rest of what was left was decomposed limestone. Shortly after miners removed the last guano, a hotdogging jet from a nearby Air Force base hit the tram cable with its wing tip, and hobbled back to base minus 6 to 8 inches of wing. From the river, boaters can see the legacy of that ill-fated mining venture, a tram tower high on the south rim and the severed tram wires, which rest against the walls of the canyon.

Geologists who work in the canyon feel their own sense of awe, a response that differs from that experienced by most visitors who stand at the dizzying precipices along the rim. "You're overwhelmed by things to look at and information you have to take into account," says Lucchitta. "There's still a great deal of work to be done here."

Researchers have yet to study in detail the oldest rocks that lie at the bottom of the canyon in the inner gorge. These rocks, from the Precambrian time, were the roots of 2-billion-year-old mountains that eroded away even long before the time of the Surprise Canyon formation.

At the other end of the scale, geologists need to work out the most recent history of the canyon. Most researchers acknowledge that the present form of the Colorado River is less than 5.5 million years old, but just how long did the river take to cut its mile-deep canyon? Geologists think it took only 3 million to 4 million years, but they may be able to narrow the time span even further.

There are also questions about the processes that widen the canyon. While the river cuts the vertical dimension, avalanches and other landslides eat away at the sides, providing the canyon with its majestic width. However, says Billingsley, "Nobody's studied [the landslides] to find out why they occurred where they did."

"In general," he says, "there are a lot of things that need to be studied in order to complete the geologic history of the Grand Canyon. I'd say it's barely been touched."

There's no doubt. Even for geologists, or perhaps especially for geologists, it's an awfully big place. □