A pre–21st century history of ideas on the origin of the Grand Canyon

Wayne Ranney*
255 E. Hutcheson Drive, Flagstaff, Arizona 86001, USA

ABSTRACT

From the mid-nineteenth through twentieth centuries, geologists attained a good, if imperfect, view of the development of the Colorado River and the Grand Canyon. Beginning in the late 1850s and continuing through the 1880s, fundamental concepts such as fluvialism, antecedence, and superposition were invoked to explain the development of the Colorado River. Early proposals envisioned the Colorado River as “old” relative to the surrounding landscape. Challenges to antecedence were slow to emerge, and it remained the most viable theory into the early twentieth century. At that time two distinct periods (and styles) of erosion were proposed: a plateau cycle with lateral stripping of strata and a canyon cycle of deep, vertical dissection. Beginning in the 1930s, newer ideas proposed that the Colorado River was “young,” having been integrated by sequential basin spillover, the timing of which was constrained by interior basin deposits lying across the mouth of the Grand Canyon at the Grand Wash Cliffs (the Muddy Creek constraint). The field entered a period of uncertainty related to the conflicting evidence for an old (Paleogene) river upstream from the Grand Canyon versus a young (Neogene) river at Grand Wash Cliffs. Results from a symposium convened in 1964 offered a solution with a poly-phase history for the Colorado River. The poly-phase theory suggested that the river formed in a complex manner by the integration of two separate drainages, although some aspects became untenable. Efforts to resolve outstanding dilemmas from 1964, such as the ages of the Colorado River and the Grand Canyon, have ultimately led to a modern resurgence in research.

INTRODUCTION

The Grand Canyon is a world-renowned landform that is visited each year by over 4.5 million people, almost half of whom arrive from another country. Geologists continue to debate the specific process or combination of processes that have acted to form it and precisely when excavation commenced. The canyon’s tremendous size along with its striking color and texture are unequalled on Earth. Results from a combination of five independent factors have worked together to create this unique landscape: (1) a thick stack of sedimentary rock; (2) variably and vividly colored strata; (3) epeirogenic uplift that raised the rocks without significant deformation; (4) deep dissection by a continental-scale river system; and (5) location within a modern arid belt where rocks are not encumbered by vegetation or extreme chemical weathering. Remove any one of these five factors, and the Grand Canyon, as we know it, would not exist (Ranney, 2012).

In spite of the intrigue, mystery, and enigmas that remain, much is known about the canyon’s development and formation, resulting from more than 150 years of scientific research (Karlstrom et al., 2012). Numerous workers have sought to understand the origin of the Grand Canyon, and one of the basic underpinnings of this understanding is that the canyon owes its existence wholly to the history and evolution of the Colorado River (Newberry, 1861) or its ancestors. When geologists first gazed into the Grand Canyon, they saw evidence for the intimate relationship between the canyon landscape and the Colorado River. From this initial observation, a good, if incomplete, view of the evolution of both the river and the canyon had been achieved. By the end of the twentieth century, geologists were poised to move beyond the technical and theoretical limitations inherited from the previous one and a half centuries of study (Young and Spamer, 2001; Beard et al., 2010; Karlstrom et al., 2012).

However, modern attempts to unravel the origin of Earth’s largest erosional feature, or the complex history of one of our continents most important rivers, are necessarily framed by the findings obtained from much earlier research efforts. Many seminal conclusions from the nineteenth and twentieth centuries serve to constrain modern studies about how the Colorado River or its ancestors helped to carve the Grand Canyon. For example, the Muddy Creek constraint at the foot of the Grand Wash Cliffs showed that the modern Colorado River could not have existed before ca. 6 Ma (Longwell, 1946; Lucchitta, 1966), while other studies farther upstream in the state of Colorado suggested that the river there might be as old as ca. 20 Ma (Hunt, 1956). Modern workers use these baseline findings to help focus their research efforts to resolve this still intractable problem. This paper presents a summary of the evolution of geologic thinking on the origin of Grand Canyon, based on work before 2000. It is hoped that the perspectives from the nineteenth and twentieth centuries can be a valuable reference point for future workers who will attempt to unravel the mysteries that remain.

PRE-SCIENTIFIC BACKGROUND

Native peoples of the American Southwest likely discovered the Grand Canyon shortly after the continent was colonized some 13,000 years ago. These natives left no written record of their impressions but did impart oral legends that were the first attempts by humans to comprehend the vast scale and origin of the canyon. Passed down through the millennia to today’s modern tribes, these legends are non-scientific but demonstrate nevertheless how humans in

*Email: wayneranney@earthlink.net

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pre-scientific North America sought to explain such an immense landform. The legends only coincidentally mirror later scientific theories, but in some instances they invoke a close genetic association between the Colorado River and the canyon. People of European descent first saw the Grand Canyon in 1541 when members of the Coronado Expedition sought a way to resupply their expedition by river from the Gulf of California. Sparse but illuminating written accounts show that the Spaniards were ill-prepared to comprehend the vast excavated space or significance of the landscape laid out before them. Descriptive passages assert that the canyon was larger than first conceived and that some boulders within it were “bigger than the great tower of Seville” (Winship, 1922, p. 36). In the year 1541, this tower was 282 feet high, less than the thickness of the Kaibab Limestone stratum that caps the rim of the canyon. Disinterested and perhaps dispirited, no Spaniard would revisit Grand Canyon for 235 years.

This initial encounter between Europeans and the American Southwest initiated a long period in which non-geologists interacted with the landscape in mostly negative ways. For 320 years, numerous conquistadors, fur trappers, miners, and explorers came to the Grand Canyon with the hope of finding precious metals, beaver pelts, lost souls, or to attain fame. They could not imagine or foresee the scientific treasure that lay at their feet, for the science of geology was far off in the future. These explorers viewed the canyon as a barrier to travel at best, and often deemed it worthless and unworthy of a repeat visit. None of the people from this pre-scientific period in American history returned for a second visit. However, subsequent visits from those with geologic training would change forever the way people related and reacted to the canyon.

**FUNDAMENTAL CONCEPTS—MID-NINETEENTH CENTURY**

**Fluvialism—John Strong Newberry**

It was a vanguard of early Grand Canyon geologists who first announced to the world that this stupendous gorge was not simply a barrier to travel but rather a feature of world-class significance (Ranney, 2013). John Strong Newberry is credited as the first geologist to view the Grand Canyon. He was part of the Colorado Exploring Expedition (1857–1858) commonly called the Ives Expedition for commanding officer Lieutenant Joseph Christmas Ives, who headed a small Army contingent up the lower Colorado River to determine its navigability for the resupply of troops engaged in the Mormon campaign. Ives wrote conflicting statements about his reaction to seeing such a deeply dissected and parched landscape, but he can be considered as one of the last persons from the pre-scientific period to view the canyon in a mostly negative way. He referred to the canyon as “valueless” and stated that it would be “forever unvisited and undisturbed” (Ives, 1861, Part 1, p. 110). His response to the landscape reveals how some people, even today, can react to the southwestern landscape when a geologic perspective is lacking. The few positive comments that Ives penned about the Grand Canyon may have originated from the opposing reactions expressed by his saddle-mate and geologist colleague, Newberry, upon viewing the same landscape.

Newberry was trained in medicine but was also schooled in natural sciences, especially geology and botany. As the expedition explored Grand Canyon, Newberry came to recognize a critical relationship between the canyon and the Colorado River: “…examining with all possible care the structure of the great cañons which we entered, I everywhere found evidence of the exclusive action of water in their formation. The central idea that the Colorado River is responsible for carving the Grand Canyon has never seriously been challenged, although some workers have recently invoked significant excavating by ancient predecessors of the modern river (Flowers et al., 2008; Wernicke, 2011).

In 1859, Newberry was employed as geologist on a second exploration journey called the San Juan Exploring Expedition, led by Captain...
John N. Macomb. Serving on this overland expedition to the confluence of the Green and Grand (Colorado) rivers, Newberry commented, “Though valueless to the agriculturist; dreaded and shunned by the emigrant, the miner, and even the adventurous trapper, 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” (Newberry, 1876, p. 54). With this pronouncement, Newberry sounded a siren call that geologists could not ignore.

**Antecedence—John Wesley Powell**

Fluvialism was never challenged in relation to the formation of Grand Canyon, but the manner in which it evolved occupied the mind of John Wesley Powell, the second geologist to view and remark upon the canyon. He embarked on two historic boat trips that began on the Green and Colorado rivers. Even in Powell’s day, modifications to the explanation of facts, but to be entirely inconsistent with them” (Powell, 1875, p. 166).

Thus an antecedent origin for rivers on the Colorado Plateau remained virtually unchallenged throughout much of the nineteenth century. Ultimately, however, antecedence would lose favor with some geologists as the formative process in determining the course of the Green and Colorado rivers. Even in Powell’s day, modifications to it were already beginning.

**Superposition and the Great Denudation—Clarence E. Dutton**

One of the first variations regarding antecedence came from Powell’s protégé, Clarence Dutton, a Yale-educated Army officer whom Powell befriended in Washington and recruited for geologic work in the West. Dutton was an astute observer of the landscape and eventually sought to elaborate on the manner in which Powell’s antecedent river was positioned on the landscape. First, he defended antecedence: “The river is older than the structural features of the country. Since it began to run, mountains and plateaus have risen across its track and those of its tributaries . . . As these irregularities rose up, the streams turned neither to the right nor to the left but cut their way through in the same old places” (Dutton, 1880, p. 16).

After stating this support for antecedence, Dutton sought to explain how the specific placement of the river might have been positioned on the landscape. He looked to the Green River Formation, an Eocene-age lake deposit found at the foot of the Uintah Mountains. According to Dutton, when the lake water drained upwarp: “Though the entire region has been folded and faulted on a grand scale, these displacements have never determined the course of the streams . . . All the facts concerning the relation of the water-ways of this region to the mountains, hills, canyons, and cliffs, lead to the inevitable conclusion that the system of drainage was determined antecedent to the faulting, and folding, and erosion, which are observed” (Powell, 1875, p. 198).

Powell’s ideas regarding antecedent theory led to widespread acceptance by his contemporaries. He did, however, remark that he struggled between an antecedent or superposed origin of the Green River. He and a colleague, Archibald Marvine, had together found evidence for superposed valley formation in the Rocky Mountains, and Powell stated that he initially was inclined toward that view for the Green River. However, when Marvine questioned Powell about why he settled on an antecedent origin for the Green River Powell stated that, “the [superposition] hypothesis was found to be not only inadequate to the explanation of facts, but to be entirely inconsistent with them” (Powell, 1875, p. 166).
away, the Green River found a course through the diminutive swales and depressions on top of the lacustrine beds. Subsequent uplift of the Uintah Mountains then caused the river to carve down into the deeply buried quartzite to create the Canyon of Lodore. Powell had previously coined the term superposition to describe such a process (Powell, 1875, p. 166), and Dutton showed a continued respect toward him: “What then determined the present distribution of the drainage? The answer is that they were determined by the configuration of the old Eocene Lake bottom at the time it was drained” (Dutton, 1880, p. 17). Thus we see how Dutton offered both a validation and a refinement to Powell’s antecedent theory (Fig. 3).

Dutton made other contributions closer to Grand Canyon by noting two vastly different styles of erosion that occurred on the landscape there. The first he called “the Great Denudation,” referring to the lateral stripping of post-Paleozoic strata away to the north. The second he called “the Great Erosion,” representing the deep vertical dissection that sliced through Paleozoic strata within the canyon (Dutton, 1882). This distinction, noticed by Powell on his overland expedition in 1871–1872, concerned the way in which a vastly superior amount of rock was removed laterally toward the north during the Great Denudation, relative to the amount removed in the vertical excavation of the deep canyons (Powell, 1875, p. 208). While pondering this observable fact, Dutton noted how erosion had acted to create “a great stairway” of progressively rising strata to the north of Grand Canyon. (The idea ultimately led to the name of the Grand Staircase.) Later enhancements to Dutton’s original ideas would determine that the Great Denudation was initiated during the Sevier and Laramide orogenies, followed by a much later period of Neogene vertical dissection. Dutton added substance to the prior work of his heroic predecessors.

CHALLENGES TO ANTECEDENCE—LATE-NINETEENTH CENTURY

The Butte Fault and the Relative Age of the Kaibab Uplift—Charles D. Walcott

Challenges to antecedence came subtly at first (Walcott, 1890) and forcefully by the close of the century (Emmons, 1897). Alternative explanations began to emerge after Powell identified the eastern section in Grand Canyon as critical to the next line of study. In 1882, he undertook the construction of the Nankoweap Trail leading from the Kaibab Plateau to the Colorado River and placed Charles Walcott in charge of the survey party that spent the next 72 days exploring and mapping geology from Nankoweap Canyon to near present-day Hance Rapid. Structurally and stratigraphically, this is one of the most varied and interesting sections of the canyon. Here Walcott recognized and named the Butte fault (Walcott, 1890, p. 50), which was a more deeply exposed expression of the East Kaibab monocline, named and previously studied by Powell and Dutton. This fault and fold system has experienced a complex history, known to have at least 3200 m of late Proterozoic normal offset, overprinted by 800 m of Laramide reverse movement (Timmons et al., 2003).

What concerned Walcott was the evidence for structural flexing of the strata adjacent to the Butte fault, and he wondered if this would have required fault movement before thick sections of Mesozoic strata were eroded: “It is difficult to understand how the cañon could have existed even to a limited depth, in its present position, at the time of the elevation of the Kaibab Plateau. An explanation more in accord with observations on the Eastern Kaibab displacement is that while the uplifting of the plateau and the East Kaibab displacement were progressing, the Colorado River was cutting its channel through the Mesozoic groups that then rested on the Paleozoic rocks in which the present cañon is eroded, and that, instead of cutting a channel down through the limestones and sandstones of the Paleozoic, as the plateau was elevated, it was cutting through the fold in the superjacent Mesozoic rocks (Walcott, 1890, p. 60). Walcott offered this evidence to show how the present-day canyon could not have been cut before the uplift of the Kaibab Plateau.

This initial view of an older age for plateau uplift would eventually become known as the Laramide orogeny. Walcott, still appearing to defer to the prestige of his mentor, continued to envision the course of the river as essentially changeless through time. But he could not dismiss the evidence from the Butte fault for the timing of the uplift of the Kaibab Plateau, likely occurring before the present-day canyon was cut. Three periods of uplift would eventually be proposed for the region, and it is from the work of Walcott that the debate on the timing of Plateau uplift commenced.

Antecedence Attacked—Samuel F. Emmons

U.S. Geological Survey geologist Samuel F. Emmons had completed mapping in the Green River and Uintah Mountain area as part of the Hayden Survey in 1871. But almost 30
years later, he presented a strident challenge to antecedence in the journal Science (Emmons, 1897). Emmons recalled how the Green River Formation was seen to lap horizontally onto the upturned edge of the Uintah Mountains. This strongly suggested to him that the Uintah uplift was older than the lacustrine sediments: “What, then, became of the river while these 8,000 feet of Tertiary sediments were being deposited? It could hardly have continued its course at the bottom of the Tertiary lake . . . its bed must have been filled with sediments . . . and when the lakes were finally drained, it is hardly conceivable that, in redetermining its course across 150 miles of Tertiary beds . . . it should have attacked the flanks of the Uintah range . . . at the same point it should have entered before” (Emmons, 1897, p. 20).

Emmons’ reasoning was sound and perhaps illustrates how prior fame can oftentimes obscure the more practical findings of those not as well revered. Powell could only respond that his own line of reasoning in accepting antecedence was too far in the past to recall why he settled on it, and apparently the nascent debate ended there. But Emmons had delivered a viable alternative to antecedence, which by the end of the twentieth century was still a favored theory, but one that would later in the century be more roundly challenged.

EVIDENCE FOR A YOUNG GRAND CANYON—EARLY TWENTIETH CENTURY

Geomorphology of the Grand Canyon—William Morris Davis

The twentieth century would begin with geologists taking to the field in horse and buggy wagons, and it would end with astronauts traveling to the Moon and scientists encircling Earth using global positioning system technology. Geologists had studied the canyon for over 40 years and were drawn to it by the enthusiastic and vivid reports generated by their earlier colleagues. At this time, antecedence was a favored theory for the origin of the Colorado River system (and by extension, the Grand Canyon), in spite of certain limitations highlighted by some. William Morris Davis was the first geologist to undertake an examination of the canyon landscape at the dawn of the new century. He made three excursions to the region, arriving first in June 1900, when he completed a 23-day journey by horseback and wagon that took him to both rims as well as the interior of the canyon. During this and later trips, he offered many cogent and innovative remarks about the canyon’s formation and its geomorphology.

Davis reaffirmed the two cycles of erosion proposed by Dutton and added that they were an imperative based on the evidence. He chose alternate names for them, calling the first the plateau cycle for the lateral stripping of strata (Dutton’s Great Demudation) and the latter the canyon cycle of vertical dissection into the strata (Dutton’s Great Erosion). Davis went a step further, however, and argued that two separate periods of uplift facilitated the two erosional cycles, with two different kinds of landforms resulting from each—linear escarpments in the plateau cycle and sheer-walled gorges in the canyon cycle (Davis, 1901, p. 136).

Another finding was the manner in which normally dry and much smaller tributary streams in the Grand Canyon entered the Colorado River at grade. Upon making this observation, Davis surmised that “corrasion [deepening] of the canyon must at present be proceeding at a slower rate than at some earlier time” (Davis, 1901, p. 168). Davis also showed how antecedence could not explain every aspect of the modern drainage configuration: “The facts now on record . . . warrant the consideration of at least one hypothesis alternative to the theory of antecedence, as an explanation for the origin of the drainage lines in the Grand Canyon district. I do not on the one hand consider the antecedent origin of the Colorado disproved, but, on the other hand, such an origin does not seem compulsory. The chief objection to the theory of antecedence is not that rivers cannot saw their way through rising mountains . . . but rather that this theory makes a single stride from the beginning to the end of a long and complicated series of movements and erosions, overlooking all the opportunities for drainage modifications on the way” (Davis, 1901, p. 166). Davis argued that antecedence was too simple an explanation given the many complications he observed here, such as the numerous displacements on faults and folds and the possible reorganization of the drainage system during the plateau cycle of erosion.

In addition, Davis classified the major side streams in Grand Canyon as having formed in a manner inconsistent with antecedence. Cataract (Havasu) Creek was a consequent stream (one that flowed down an existing gradient), but Paria Creek and Kanab Creek were obsequent ones (flowing against stratigraphic dip), while the Little Colorado River was subsequent (parallelizing strike), except in its last 40 miles, where it becomes obsequent; and House Rock Valley also was a subsequent stream. This was an affirmation that the Colorado River was a complex drainage that foretold of a complex evolution. In a later paper, given at the American Geographical Society, Davis summarized his many observations on the evolution of the landscape: “The most emphatic lesson that the canyon teaches, is that it is not a very old feature of the earth’s surface, but a very modern one; that it does not mark the accomplishment of a great task of earth sculpture, but only the beginning of such a task; and that in spite of its great dimension, it is properly described as a young valley” (Davis, 1909, p. 346). Here marks a paradigm shift from earlier ideas, which held that an immense landscape must have necessarily formed through an immense period of time. Davis argued that the Grand Canyon was a geologically young feature.

Other notable geologists offered conjectures while participating on expeditions to the region, notably Willis T. Lee (1906), Douglas W. Johnson (1909), and H.H. Robinson (1910). But fresh ideas languished until the 1930s.

Basin Spillover—Eliot Blackwelder

By the 1930s, it became apparent that the age and formation of the Grand Canyon could be better understood without a knowledge of the history of the Colorado River. Newberry had initially shown the close relationship between the two features, with subsequent workers seeking to know more about the age of the uplifts relative to the dissection of the canyons. No geologist, with perhaps the exception of Davis, had expressed the possibility that the Colorado River was young, and most workers inferred a Paleogene age for it. Eliot Blackwelder, professor of geology at Stanford, would change this. He completed work along the river from the Mexican border to the mouth of the Grand Canyon and wondered why, if the Colorado was an old river system, had it not captured the interior basins that adjoined it near Las Vegas (Blackwelder, 1934). These basins were only a few kilometers from the main trunk stream yet remained closed to the sea. He also noted how the river flowed through seemingly unrelated basins on its way to the Rockies to the sea: “The Colorado River is in many ways an anomalous stream, but perhaps in no respect more so than in the course which it pursues. Rising in the high mountains of Wyoming and Colorado, it traverses a series of wide basins, each of which seems to be an entity almost unrelated to the others . . . It runs south for hundreds of miles, then for no obvious reason turns abruptly west, crosses northern Arizona, and again turns due southward in an erratic course” (Blackwelder, 1934, p. 554).

Blackwelder was laying the groundwork for his grand assault on the perceived antiquity of the river. He noted that the river’s course from the Rocky Mountains to the sea went through
a series of open basins, separated by bedrock ridges where the drainage flowed through narrow canyons. He reasoned that basin spillover (Fig. 4) might be a preferred process to create the river’s course: “It is reasonable to infer that, as the region bulged upward, the local streams on the higher and more northerly mountains extended themselves, forming lakes in the nearest desert basins. As this influx exceeded evaporation . . . the lakes rose until they overflowed the lowest points of their rims and spilled into adjacent basins. In time, enough excess outflow may have developed to fill a series of basins all the way to the Gulf of California, thus forming a chain of lakes strung upon a river” (Blackwelder, 1934, p. 562).

This was one of the first contrary thoughts presented regarding the age of the river. Blackwelder dared to challenge the views of his heroic predecessors by highlighting what he had observed along the course of the lower Colorado River. He agreed with Davis that the Colorado River might have experienced a complex evolution, but by inference may have taken too great a step in applying the same thoughts for the upper river: “The foregoing sketch of the origin and history of the Colorado River is frankly theoretical. Science advances not only by the discovery of facts but also by the proposal and consideration of hypotheses, provided always that they are not disguised as facts. This view will not meet with general acceptance. There are doubtless many facts unknown to me that will be brought forward in opposition. Perhaps their impact will prove fatal to the hypothesis. In any event, the situation will be more wholesome, now that we have two notably different explanations, than it was when it was assumed by all that the river had existed continuously since middle or early Tertiary time. It seems to me that the new hypothesis is harmonious with most of the important facts now known about the geology and history not only of the Colorado River but of the Western States in general” (Blackwelder, 1934, p. 564).

Eliot Blackwelder was among the first to open the door to a new way of thinking about the age and history of the Colorado River, which ultimately led to further study of and support for a young Colorado River.

The Muddy Creek Constraint—Chester Longwell

When Boulder (now Hoover) Dam was under construction, geologists were eager to study the soon-to-be-inundated floor of the reservoir, knowing that rocks related to the evolution of the Colorado River and Grand Canyon would not be available for future study. Chester Longwell of Yale (later Stanford) University had worked in the nearby Muddy Mountains and became interested in the geology of the Boulder reservoir area. He was struck by a fact that was becoming more and more obvious to those involved with studies of the river—that a date no more precise than Paleogene to late Neogene could be ascribed to it and highlighted this dilemma in his 1946 paper: “One of the major unsolved problems of the region is the date of origin of the river itself. . . Geologists who have no direct acquaintance with the region will be at a loss to understand so wide a divergence in interpretation” (Longwell, 1946, p. 817).

Longwell studied rocks near the Grand Wash Cliffs where the Colorado River exits the Grand Canyon at the western edge of the Colorado Plateau. Here, a mid- to late Miocene half-graben had accumulated deposits known as the Muddy Creek Formation, which lay strewn across both sides of the Colorado River. Longwell did not find detritus within the Muddy Creek Formation that could be identified from known bedrock exposures upstream. His interpretation was that when the Muddy Creek Formation was deposited, the Colorado River could not have been

Figure 4. Cartoon depicting the sequential spillover from formerly closed basins. Blackwelder envisioned such a scenario from the Rocky Mountains to the Gulf of California to integrate a young Colorado River (from Ranney, 2012, p. 102).
in its present course at the Grand Wash Cliffs: “There is no possibility that the river was in its present position west of the plateau during Muddy Creek time. The suggestion occurs that a stream, either permanent or intermittent, may have developed on the site of the present Grand Canyon, and debouched into closed basins west of the plateau. However, if such a stream had any considerable length, it should have contributed rounded pebbles representing the varied lithology east of the Grand Wash Cliffs. No such stream-worn pebbles have been found in the basin deposits” (Longwell, 1946, p. 823).

Longwell was describing what would later become known as the “Muddy Creek problem” or the “Muddy Creek constraint.” This idea, as initially presented, stated that the Colorado River could not have existed in its present position or configuration prior to the emplacement of the Fortification Hill basalt near Hoover Dam (which capped Muddy Creek sediments at that location). Sometime later, the evidence was more specifically constrained to the Hualapai Limestone Member of the Muddy Creek Formation near the Grand Wash Cliffs, where an ash bed is radiometrically dated at 5.97 Ma (Spencer et al., 1998). This is the evidence used for the widely cited age of <6 Ma for the Grand Canyon.

In just a little over a single decade, both Blackwelder and Longwell provided critical support for a “young” Colorado River. Longwell summarized these findings at the close of his paper: “In outlining the foregoing hypothesis, it has been assumed that the Plateau has had exterior drainage continuously throughout the Cenozoic era. However, as Blackwelder suggests, the region probably was unable to support a through-flowing stream like the Colorado for a considerable period after the onset of aridity . . . During such an interval the drainage of the Plateau area would have been accomplished by intermittent streams ending in a number of separate closed depressions, as in the Great Basin at present . . . When the Cordilleran region attained such altitude that increased precipitation in the Rocky Mountains supplied a surplus of runoff into the Plateau, the configuration of the surface may have been such as to guide the overflow along a new consequent course to the west” (Longwell, 1946, p. 833).

INTEGRATING THE COLORADO RIVER—MID-TWENTIETH CENTURY

Reviving an Old Colorado River—Charlie Hunt

Charlie Hunt of the U.S. Geological Survey wrote a classic paper in southwestern geology titled, “Cenozoic Geology of the Colorado Plateau” (Hunt, 1956). This was a synthesis of known information about the river and the landscape it traversed, from the Uintah Mountains to the Mojave Desert. Hunt likely was feeling isolated at this time as he found himself being an “old river” advocate in an increasingly “young river” environment. His paper was an attempt to restore luster once again to the earlier ideas of Powell and Dutton, and he offered intriguing and novel ideas on the origin of the river and Grand Canyon.

Hunt agreed that as the plateau became elevated higher with respect to the Basin and Range, drainage had to develop off of the plateau edge, but he was constrained by the Muddy Creek evidence. This led him to propose that the Colorado River might have existed in the western part of Grand Canyon to the south through Peach Springs Wash. A decade later this became untenable as the deposits in Peach Springs Wash showed north-directed flow toward the Hurricane fault zone (Young, 1966). Hunt was then left with two possibilities for the origin of the river in Grand Canyon—superposition or stream capture—and he didn’t like either of them. Superposition demanded that lake sediments be present as high as the top of the Kaibab Plateau at 2750 m and even higher toward the north. This seemed unreasonable to him. Stream capture was also problematic because: “It would indeed have been a unique and precocious gully that cut headward more than 100 miles across the Grand Canyon section to capture streams east of the Kaibab upwarp” (Hunt, 1956, p. 85).

Hunt ultimately invented a process to address the dilemma, calling it anteposition, which incorporates aspects of antecedence and superposition. Anteposition proposed that the current path of the Colorado River through Grand Canyon was established before Muddy Creek time (the antecedent part). Uplift of the plateau edge then tilted the river’s channel toward the east, disrupting and halting the flow of water into the Grand Wash trough, which for him solved the Muddy Creek problem. He further postulated that the river was ponded north and east of Grand Canyon and as this lake became filled at a later time, it overflowed to the south and west. The Colorado River then re-established its old course on the lake sediments and in the previously carved canyon (superposition) making its way to the Grand Wash Cliffs and initiating the deposition of the Hualapai Limestone.

Hunt offered additional ideas in a U.S. Geological Survey Professional Paper commemorating the 100th anniversary of the Powell Expedition (Hunt, 1969). In this paper he proposed a different solution to the Muddy Creek problem, having the Colorado River make its way through most of Grand Canyon but then percolating beneath the Hualapai Plateau in western Grand Canyon with the water emerging in springs from the base of the Grand Wash Cliffs. This view also did not gain wide acceptance within the Grand Canyon community of geologists, and Hunt is often remembered more for his significant contributions regarding the evolution of upper Colorado River basin and the central Colorado Plateau.

The 1964 Symposium and a Poly-Phase History for the River—Edwin D. McKee et al.

By the 1960s, a solution was needed to address the conflicting evidence for a “young” versus “old” Colorado River. Edwin (Eddie) McKee, a preeminent Grand Canyon geologist, convened a special symposium at the Museum of Northern Arizona (MNA) in August 1964. For the first time in history, scientists gathered in a single location to specifically discuss problems associated with the processes that may have formed the Colorado River and Grand Canyon, and their age. Twenty geologists attended the ten-day symposium to share ideas and proposals to address specific dilemmas. Charlie Hunt was curiously absent from the list of attendees, reflecting a professional rivalry that had likely developed between him and McKee. McKee had already enlisted the help of two doctoral students to look at critical deposits and geologic relationships in the western Grand Canyon. This action may have been done in part to verify or refute some of the claims by Hunt, which ran contrary to those of McKee (see the next two sections regarding the work by Ivo Lucchitta and Richard Young).

Two significant results came out of this pivotal symposium that shaped thinking for the remainder of the century: the development of a timeline outlining a plausible sequence of landscape-forming events; and an original and provocative theory regarding how the Colorado River (and by extension Grand Canyon) formed from the integration of two separate and distinct river systems (Fig. 5). In the final bulletin, the authors outlined a five-stage evolutionary history of the landscape: (1) initial northeast drainage across a subdued, low-lying surface near sea level; (2) Laramide uplift of the plateau surface with continued northeast drainage across monoclinal upwarps and toward freshwater lakes in the northern plateau; (3) the development of two separate and distinct drainage systems, each on either side of the Kaibab upwarp with the younger, steeper, west-directed
Hualapai drainage headed toward the Gulf of California, and the older, more sluggish ancestral upper Colorado River flowing southeast along the present course of the Little Colorado River and possibly into the Rio Grande system; (4) the initiation of interior basins to the west and east of Grand Canyon and the Muddy Creek and Bidahochi basins, respectively; and (5) the integration of the two drainages by renewed uplift, headward erosion, and stream capture (McKee et al., 1967).

McKee et al. (1967) proposed that the steep-gradient Hualapai drainage lengthened its channel in the upstream direction (east) by headward erosion, and intersected and captured the ancestral upper Colorado River. The point of capture was hypothesized to have occurred at the present-day confluence of the Colorado and Little Colorado rivers, but within higher Triassic-age strata now eroded. The ideas generated at this symposium received much exposure, support, and fanfare in the years immediately following the gathering. The symposium introduced new processes to integrate the river—headward erosion and stream piracy—providing an innovative hypothesis for the development of the Colorado River and the Grand Canyon. It also helped solve the dilemma for how the river could be Miocene or older in upstream sections, but no older than Pliocene at the Grand Wash Cliffs.

Headward erosion, stream piracy, and the integration of the Colorado River from separate ancestors would be the lasting legacy of this important meeting and results from it still bear some influence on the thinking on the evolution of the river and the canyon. However, by the mid-1970s, some cracks began to appear in the idea that the upper Colorado River once went to the southeast (Sutton, 1974). He showed that the fluvial member of the Bidahochi Formation was deposited by southwest-flowing streams, precluding that the ancestral upper Colorado River flowed southeast from the area of the Grand Canyon.

**LATE TWENTIETH CENTURY**

**Research at the Grand Wash Cliffs— Ivo Lucchitta**

As a result of the 1964 symposium, new ideas concerning a poly-phase development of the river invigorated the field of Grand Canyon studies. Eddie McKee engaged doctoral students who were conducting research in western Grand Canyon, where critical deposits and field relationships would shed light on the timing and evolution of the river (and perhaps refute the...
proposals of Hunt). Ivo Lucchitta conducted detailed mapping in the Grand Wash trough where the Muddy Creek Formation was deposited near the mouth of Grand Canyon. Lucchitta not only verified the conclusions of Chester Longwell but added finer details to them. He showed, for example, how deposits of non-river alluvium (called the Pearce Canyon fan) emanate from a side canyon on the north side of the river but are found today on both sides of the river. This prohibited the existence of the Colorado River in that location during Muddy Creek time. He also affirmed that the Muddy Creek Formation lacked diagnostic pebbles or cobbles from bedrock exposures upstream of the Grand Wash trough.

Lucchitta continued in the latter decades of the twentieth century to refine his ideas and became a vocal proponent for a Colorado River that was no older than latest Miocene (Lucchitta, 1972, 1987, 1989). He also proposed late Neogene uplift of the Colorado Plateau as the driving force for the deep dissection of the youthful canyon (Lucchitta, 1979), although later workers sought to discount the relative importance of recent uplift by showing that the Bouse Formation was not entirely marine (Spencer and Patchett, 1997). Lucchitta was perhaps the most widely cited researcher concerning Grand Canyon’s evolution in the last quarter of the twentieth century.

Research on the Hualapai Plateau—Richard Young

Another doctoral student who took to the field during the time of the 1964 symposium was Richard Young, who studied gravel deposits on the Hualapai Plateau in western Grand Canyon (Young, 1966). Young’s work provided supporting evidence for an initial north-east drainage across the southern Colorado Plateau after withdrawal of the Western Interior Seaway. In Milkweed and Hindu canyons, Young found clasts that were derived from the south and contained paleocurrent indicators with flow toward the north. This disclosed a source area for the gravel in the Mogollon Highlands, formerly located southwest of Grand Canyon. The deposits were found in paleocanyons 1200 m deep, which inferred significant uplift and dissection at a relatively early age in the area of western Grand Canyon. Although the deposits disappear to the north, Young later postulated that they perhaps were routed along the trace of the Hurricane fault (Young, 2001). Along with Lucchitta, Young was a prolific publisher of data as it concerned the area of western Grand Canyon in the latter parts of the twentieth century.

The Dilemma of an Immovable Object—Earl Lovejoy

Earl Lovejoy, professor at the University of Texas, El Paso, offered an innovative solution to the Muddy Creek constraint (Lovejoy, 1980), derived in part from observations he made along the Rio Grande in Big Bend, Texas, and the Truckee River in Nevada. He postulated that the Colorado River could have been in place within Grand Canyon during deposition of the Muddy Creek Formation, but that it might have been deflected to the south along the base of the Grand Wash Cliffs by the east-directed wedge of sediment in the Muddy Creek deposits. Lovejoy had observed a similar setting where the Rio Grande exited Santa Elena Canyon in the Big Bend area. He also noted how the Truckee River in Nevada had dropped its load of coarse sediment upstream from a narrow canyon and used this as a proxy for why the Muddy Creek Formation held no observable clasts from upstream of the Grand Wash Cliffs. He sought to keep the idea of a Paleogene Colorado River alive and offered these viable solutions. But in the end, virtually no one noticed.

A Cretaceous Laramide Grand Canyon—Don Elston

As the twentieth century drew to a close, another attempt to revive ideas for an old Grand Canyon was made by Don Elston, U.S. Geological Survey geologist. His friend and mentor, Charlie Hunt, had drawn Elston into the Grand Canyon debate. Elston was not deterred by the evidence from the Muddy Creek Formation and introduced distinctive ideas for how the Colorado River could be quite old (Elston and Young, 1991). Claiming that canyon incision began at the beginning of the Late Cretaceous (ca. 100 Ma), Elston argued that the majority of canyon incision occurred no later than the Paleogene, invoking a hyper-arid period during the Miocene in which discharge in the Colorado River became greatly diminished and Grand Canyon became buried in up to 240 m of side canyon sediment. To him this could explain the lack of diagnostic pebble clasts in the Muddy Creek Formation. His ideas were not widely accepted, but he remained a forceful voice in Grand Canyon origin studies, keeping the “old” river concept alive in the latter parts of the twentieth century.

The century came to an end with geologists having resolved some of the earliest issues associated with Grand Canyon’s origin but no consensus on the specific timing, processes, or incision rates that led to the integration of the Colorado River system.

Toward the Twenty-First Century and Beyond

The remaining dilemmas in the aftermath of the 1964 symposium eventually led to a period of renewed interest in the origin of the Colorado River and Grand Canyon. This began with a second symposium at Grand Canyon National Park in June 2000. A volume containing 33 published papers from the 73 geologists in attendance was the result (Young and Spamer, 2001). Heated debates were again evident between old canyon advocates Don Elston and young canyon supporter Ivo Lucchitta. These two essentially filled the roles held by Charlie Hunt and Eddie McKee, respectively, from the previous symposium and showed that after 36 years, the debate over the age of the canyon was not yet resolved.

A third conference was held in May 2010 at the U.S. Geological Survey in Flagstaff, Arizona. With 59 geologists in attendance, there were numerous papers published in two volumes (Beard et al., 2011; Karlstrom et al., 2012). Again there was debate on the specific age of the canyon with numerous workers (foremost among them being Karl Karlstrom) giving evidence for a young canyon, while Brian Wernicke of California Institute of Technology took on the role of old canyon advocate. New analytical techniques such as thermochronology, detrital zircon studies, and high-precision Ar dating were employed and provided a completely new approach to solving intractable problems.

Finally, a two-day Special Session at the 125th Annual Meeting of the Geological Society of America in Denver, Colorado, was held in October 2013, with more innovative ideas presented on the origin of the canyon and the river.

The Grand Canyon continues to attract, educate, and inspire a host of modern geologists, who stand on the shoulders of their heroic predecessors. It was these pioneering geologists who announced to the world that the Grand Canyon was a truly special place and not merely a profitless locality.

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