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Wayne Ranney

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A SHORT HISTORY OF IDEAS ON THE ORIGIN OF THE GRAND CANYON

WAYNE RANNEY
255 E. Hutcheson Dr. Flagstaff, AZ 86001, wayneranney@earthlink.net

ABSTRACT—For as well known and highly regarded as the Grand Canyon is, its precise age and the specific processes involved in its formation remain somewhat elusive to the geologist. This is not due to a lack of trying, for the great gorge has been the subject of passionate inquiry since John Strong Newberry first laid eyes on it over 155 years ago. Research into the canyon's origin has accelerated greatly since the turn of the millennium and a survey of the ever evolving ideas related to its development can serve to frame the foundations of many modern proposals. Historic ideas on the canyon's origin generally sought to relate the deeply dissected modern landscape (that continues to captivate practically anyone who encounters it), with the possible evolution of the Colorado River. The earliest geologists however, could not perceive of the dynamism that can be involved in a rivers' history, nor could they benefit from a larger understanding of the tectonic evolution of the American Cordillera. It took nearly seventy years of research before definitive evidence was found that showed that the modern Colorado River, one that begins in the Rocky Mountains and drains across the elevated Colorado Plateau to the foundered Basin and Range and the Gulf of California, might actually be one of the younger geologic features found upon the southwestern landscape. Since this relative youthfulness of the river has been detected, myriad searches for prior ancestors, cut-off channels, past configurations, or flow reversals have been postulated, presented, debated upon and accepted or rejected. Ideas that the river and canyon might be as old as the Laramide Orogeny have never gone away but consensus points to younger dates. A familiarity with historic theories for how the Grand Canyon and Colorado River evolved is presented below to help to frame modern debate.

THE 19TH CENTURY

It is interesting to note how important geology has been in the development of a worldwide appreciation of Grand Canyons' significance. People of European descent first saw the canyon in 1541 when members of the Coronado Expedition sought a resupply route from the sea to the interior. With nothing of its kind found on the European landscape, these conquistadors had no reference in which to comprehend the spectacle before them – no Spaniard returned for 235 years. In fact, as far as we know, not one of the numerous explorers, mountain men, or trappers who saw the canyon during the period of exploration (from 1541 to 1858) ever returned for a second time. Yet when the first geologist laid eyes on it in April 1858, he and every geoscientist that followed sounded a siren call for the display of earth history and the extravagant exposure of strata that could be read like a book. From the first geologist to all who followed in the 19th century, each returned for at least a second look, as the profound meaning of the landscape was never lost on scientists trained to see earth history so acutely. In a very real way, geologists told the world how to appreciate Grand Canyon's unique and endearing landscape (Ranney, 2013).

John Strong Newberry

John Strong Newberry is credited as the first geologist to view the Grand Canyon. He was part of the Ives Expedition (1857-58), led by Lt. Joseph Christmas Ives, who made what is considered by many to be the least prophetic statement about the Grand Canyon:

> *The region ... is, of course, altogether valueless. It can be approached only from the south, and after entering it there is nothing to do but leave. Ours has been the first, and will doubtless be the last party of whites to visit this profitless 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.*

Newberry fortunately was not swayed by the views of his commander on the perceived shortcomings of this parched landscape. Rather, he made the first seminal observation about its geologic nature - that it was *"the exclusive action of water"* (Newberry, 1861, p. 46) that led to the formation of the great chasm. The emerging visage of the American West, the Colorado Plateau, and Grand Canyon in particular, led to the important concept that rivers could play a dominant role in the shaping of landscapes. Old World geologists, where the science was born, were hindered perhaps by the reality that much of northern Europe was shaped by recent glacial action and they at first seemed to resist this new American *fluvialism*. At Grand Canyon, an untrained or more casual observer might surmise that it could have formed as the result of a giant rift in Earth's crust that was only later occupied by the Colorado River. With his geologic training Newberry observed that, *"opposite sides of the deepest chasm showed perfect correspondence of stratification,"* (Newberry, 1861, p. 46) meaning that the river was not placed here merely along a pre-existing fault or fissure. How instructive are the

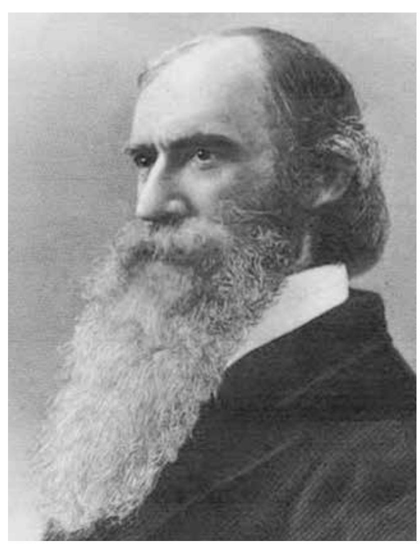

Photo courtesy of Wikimedia

opposed reactions to the landscape by Newberry and Ives. Ives saw it as a profitless locality, while Newberry later penned on a subsequent expedition that *"to the geologist the Colorado Plateau is a paradise"* (Macomb, 1876, Part III, p. 56). The first theory about the canyon's origin had been proposed and showed a vital relationship between the Colorado River and the Grand Canyon. Newberry's initial idea that the Colorado River carved Grand Canyon has never seriously been challenged, although some workers have recently invoked significant excavating by ancient predecessors of the Colorado River (Flowers et. al., 2008; Wernicke, 2011).

John Wesley Powell

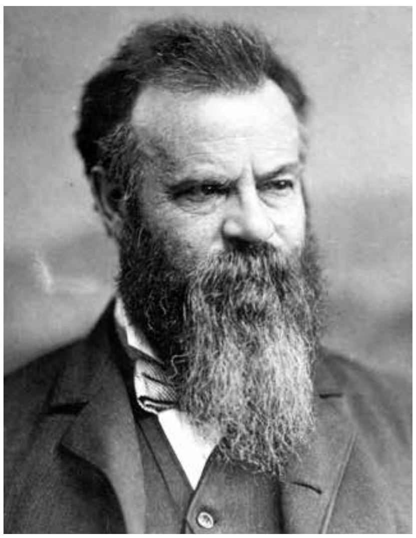

Photo courtesy of USGS Archives

Powell needs little introduction since his two river trips down the Colorado River became widely publicized, and his status as explorer *"par excellence"* was assured. But first and foremost, Powell was trained in geology and always concerned himself with the origin of the landscape he traveled through. By the time he and his men reached Grand Canyon in late August 1869 (on the first of two river voyages by Powell), they were in a race for survival nearing the end of a harrowing 101-day expedition. He therefore made no direct suggestion on the origin of the Grand Canyon or the Colorado River, but by inference did so from earlier observations for how the Green River plunged headlong into the northern flank of the Uintah Mountains, in modern-day Dinosaur National Monument. Rather than take the seemingly easier course to the east through lower country, the river there turned abruptly ninety degrees to the south and sliced headlong into resistant Proterozoic quartzite, becoming entrenched 1,500 feet in less than a mile at the entrance to the Canyon of Lodore. Powell sought to explain this odd arrangement and invented a process that could explain it, calling it *antecedence:*

> *To a person studying the physical geography of this country, without a knowledge of its geology, it would seem very strange that the river should cut through the mountains, when, apparently, it might have passed around them to the east…why did the river run through the mountains?*

Powell then explained his reasoning for antecedence:

> *…the river did not cut its way down through the mountains, from a height many thousands of feet above its present site, but . . . cleared away the obstruction by cutting a cañon,* [as] *the walls were thus elevated on either side. The river preserved its level* [as] *the mountains were lifted up.*

At this early stage in American geology the relative age of the Laramide uplifts were not known and based on the field relationships he saw, Powell invoked river antecedence as the major landscape forming process (Powell, 1875). His ideas would later prove untenable but Powell's growing reputation and his later directorship of the U.S. Geological Survey meant that most criticism of his idea would be muted at most. As an exception, S.F. Emmons (1897) strongly sought to challenge antecedence when he published a paper in the journal *Science*. But Powell could only respond that his own line of reasoning for antecedence was too far in the past to recall precisely why he settled on that idea. And although antecedence is rarely, if ever, associated with modern ideas on Grand Canyon's formation, Powell nevertheless inspired many generations of future geologists. Powell set the stage for future work and recruited and introduced the next two geologists to the wonders of the Grand Canyon.

Clarence Dutton

Photo courtesy of USGS Archives

The first of Powell's protégés in the Southwest was Army officer and Yale educated Clarence Dutton, who sought to further explain the specific placement of the Green River on Powell's antecedent landscape. He postulated that the precise course of the river was accomplished upon exposure of Eocene-age lake sediments (the modern-day Green River Formation). According to Dutton when the lake drained away, the river found a course through the diminutive swales and depressions on top of the lake sediments. Subsequent uplift of the Uintah Mountains then caused the river to carve the Canyon of Lodore, dissection keeping pace with the slowly uplifting terrain. This process is known as *superposition* but Dutton's observations show a continued respect toward antecedent thought:

> *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.*

He added something to it by proposing how the rivers course became fixed:

> *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.*

In his highly regarded monographs, *"Report on the Geology of the High Plateaus of Utah"* and *"Tertiary History of the Grand Cañon District"* (Dutton, 1880 and 1882), Dutton made other key contributions, noting two vastly different styles of erosion in the Grand Canyon region. The first he called "the Great Denudation," referring to the lateral stripping of post-Paleozoic strata away to the north of the canyon. The second he called "the Great Erosion" referring to the deep dissection that sliced through the Paleozoic strata within the canyon. This perceptive and important observation reveals a keen mind able to discern subtle clues about the variable processes that acted through a long span of time. More modern refinements to his original idea, with the widespread lateral stripping of strata during the Sevier and Laramide orogenies followed by a later period of vertical dissection, was accomplished only through the combined work of hundreds of future geologists. Yet Dutton perceived the contrast in the latter part of the 19th century, setting a strong foundation for future work.

Charles D. Walcott

Photo courtesy of USGS Archives

In 1882 Powell became interested in the geology of the canyon's eastern section and ordered the construction of the Nankoweap Trail to the Colorado River. When he returned to Kanab for other work, he placed Charles Walcott in charge of a small survey party that spent the next 72 days exploring and mapping the geology from Nankoweap to present-day Hance Rapid. This is one of the most varied and interesting sections of the canyon and Walcott identified and named the Butte fault (Walcott, 1890), a more deeply seated expression of the East Kaibab monocline (named and studied previously by Powell and Dutton). This fault and fold system experienced a complex history, now known to have at least 3200 m of late Proterozoic normal offset, overprinted by 800 m of Laramide reverse movement. What concerned Walcott was the evidence he found for the structural flexing of strata adjacent to the fault and he reasoned that this must have occurred when considerable thicknesses of strata still covered the area:

> *... 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 down 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.*

The evidence obtained by Walcott along the Butte fault for the relative age of folding and consequent uplift of the Kaibab Plateau did not quite fit with what Powell and Dutton had observed. More importantly, it determined a greater age for the episode of uplift (what we now call the Laramide Orogeny) relative to the Colorado River. Walcott still envisioned the river as essentially changeless through time, but showed that uplift of the surrounding terrain was older than previously envisioned. Details were beginning to emerge as more geologists took to the field. The 20th century would begin with geologists taking to the field in horse and buggy wagons; it would end with astronauts and scientists going to the moon and encircling Earth using GPS technology, and a host of sophisticated instruments and techniques to tease details out of the seemingly stubborn rocks.

THE 20TH CENTURY

William Morris Davis

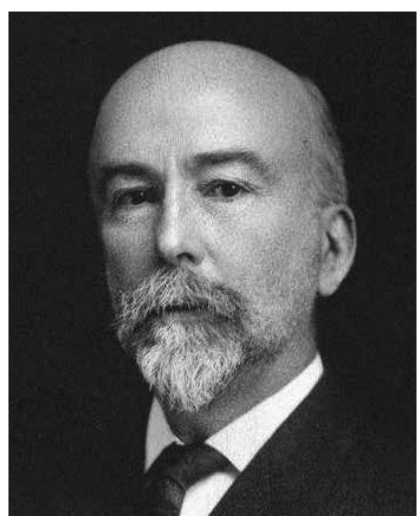

Photo courtesy of National Archives photo no.57-GP-151

At the beginning of the 20th century, geologists had known of the Grand Canyon for 42 years and visitation by them began to increase in response to the enthusiastic reports generated by their earlier colleagues. The first to visit in the new century was William Morris Davis (1901), the father of geomorphology who came in June 1900, completing a twenty-three day excursion by wagon and horseback that took him to both rims as well as the interior of the canyon. During the trip he made a number of original and key observations about the canyon's geomorphology that bear on its origin. He affirmed to himself that Dutton's two cycles of erosion was not only valid but an imperative in contrasting the style of erosion for the two cycles. Although he used different terms than Dutton for these – a *Plateau cycle* of lateral stripping and a *Canyon cycle* of deep vertical dissection, he further invoked two distinct periods of uplift in creating the vastly different landforms associated with each.

Another key observation by Davis was the manner in which normally dry and much smaller side streams entered the Colorado River in Grand Canyon at grade, this in spite of the apparent youthfulness of the canyon. Davis surmised that, *"corrasion* [deepening] *of the canyon must at present be proceeding at a slower rate than at some earlier time"* (Davis, 1903, p. 168). Davis also 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); the Little Colorado River, subsequent (paralleling strike) except in its last forty miles where it becomes obsequent (flowing against stratigraphic dip); Paria Creek, obsequent with additional headward lengthening in its headwater area; House Rock Valley, subsequent; and Kanab Creek, obsequent. Davis wanted to show that antecedence didn't necessarily explain specific aspects of the modern drainage system:

> *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.*

Here was the first affirmation that the Colorado River could be a complex drainage system that foretold of a complex evolution. Other geologists made important observations on expeditions to the river and canyon in the first decade of the 20th century: Willis T. Lee (1906), Douglas W. Johnson (1909), and H. H. Robinson (1910). But work then languished until the 1930's.

Eliot Blackwelder

It was becoming increasing apparent that no one could address the age and formation of the Grand Canyon without also understanding the history of the Colorado River as well. Newberry initially showed the intimate relationship between the two and subsequent workers sought to comprehend the relative age of the various uplifts that led to the period of dissection of the deep canyons. To this point, no geologist had explicitly argued for an exclusively young age for the Colorado River; most ideas were that the river must have had an early Tertiary component to it. Eliot Blackwelder, who completed work from the mouth of the Grand Canyon to the Mexican border, wondered why, if the Colorado River were an old river system, that adjacent interior drained basins had not been captured by it (Blackwelder, 1934). These basins remained closed, yet were merely a few kilometers from the main trunk stream. He also noted how the river flowed through seemingly unrelated basins on its way from 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 was laying the groundwork for his grand assault on the perceived antiquity of the river. He noted that the rivers' course from the Rocky Mountains to the sea flow through a series of open basins, separated by drainage through intervening narrow canyons. He reasoned that *basin spillover* might be a preferred process to integrate the river:

> *It is reasonable to infer that, as the* [Rocky Mountains] *bulged upward, the local streams on the higher and more northerly mountains extended themselves* [southward], *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.*

Photo courtesy of National Archives photo no.57-GP-943

At this time in 1934, the first contrary thought regarding the age of the river and the canyon was presented. Blackwelder dared to challenge the views of his heroic predecessors, not for personal redemption but rather by reporting on what he observed along the course of the lower Colorado River and by inference applying it to the upper river. He was the first to note that the Colorado

River might not have experienced a relatively simple evolution through time:

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.

Eliot Blackwelder had opened the door to a new way of viewing the history of the Grand Canyon and the Colorado River, which would unleash more study and support for the idea of a young river. This might also be the time when the word "controversy" entered the debate.

Chester Longwell


Photo courtesy of National Archives photo no.57-GP-353

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 early Tertiary to Plio-Pleistocene could be ascribed to it:

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 worked in the Grand Wash trough, a mid- to late- Miocene half-graben located where the Grand Canyon exits the Grand Wash Cliffs and the western edge of the Colorado Plateau. Deposits called the Muddy Creek Formation lay strewn across both sides of the Colorado River and Longwell did not find any detritus within it that could be identified as derived from bedrock exposures upstream (Longwell, 1946). His interpretation was that when the Muddy Creek Formation formed, the Colorado River was not in existence beneath 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 was describing what would later be called the "Muddy Creek constraint," the idea that the Colorado River could not have existed in its present location prior to the terminal deposits of the Muddy Creek Formation (now called the Hualapai Limestone Member). Radiometric dating techniques later determined that the Hualapai Limestone is as young as 6 Ma – this is where the widely cited age for the Grand Canyon originates. In just a single decade, Longwell provided critical support for the "young" Colorado River of Blackwelder:

In outlining the foregoing hypothesis, it has been assumed that the Plateau has had exterior drainage continuously though 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.

Charlie Hunt

Charlie Hunt of the U.S. Geological Survey wrote one of the classic papers 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 Uinta Mountains to the Mojave Desert. Hunt may have felt isolated at this time as he was 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. He offered intriguing conjectures on the origin of the river and Grand Canyon.

Hunt wrote that as the plateau became elevated higher with respect to the Basin and Range, drainage had to develop off of the plateau edge but was puzzled because of the evidence from the Muddy Creek Formation. Thus, he proposed that the Colorado might have flowed south out of the Grand Canyon through Peach Springs Wash. (Not long thereafter this became untenable as the deposits found there record northward flow). He was left with two possibilities for the origin of the river in Grand Canyon – superposition or stream capture – and he didn't like either. Superposition demanded that lake sediments be present as high as the top of the Kaibab Plateau and even higher to the north, which 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.*

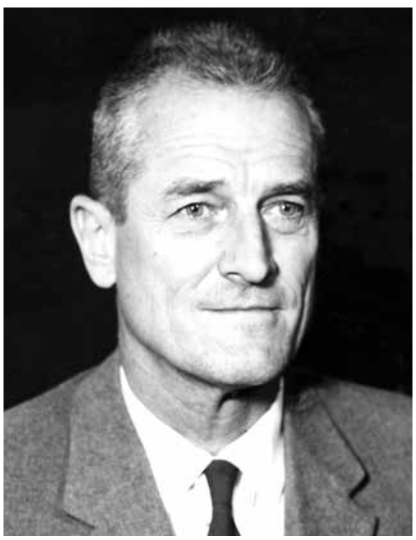

Photo courtesy of USGS archives.

Ultimately, Hunt invented a process to address the dilemma calling it *anteposition,* which incorporates aspects of antecedence and superposition. It 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 to the east, disrupting and halting the flow into the Grand Wash trough, which to him could solve the Muddy Creek problem. He further stated that the river became ponded north and east of Grand Canyon and as the lakes were filled they overflowed to the south and west. The Colorado River then re-established its old course on the lake sediments (superposition) making its way to the Grand Wash Cliffs and initiating the deposition of the Hualapai Limestone.

Later, in a U.S. Geological Survey Professional Paper commemorating the 100th anniversary of the Powell Expedition (Hunt, 1969) he proposed another solution to the Muddy Creek problem, one that had the Colorado River present through most of Grand Canyon but percolating beneath the Hualapai Plateau in western Grand Canyon and emerging as spring flow out of the Grand Wash Cliffs. It too was not widely accepted and although Hunt was a major player in ideas regarding landscape development of the Colorado Plateau, few of his ideas have withstood the test of time.

Eddie McKee and the 1964 Symposium

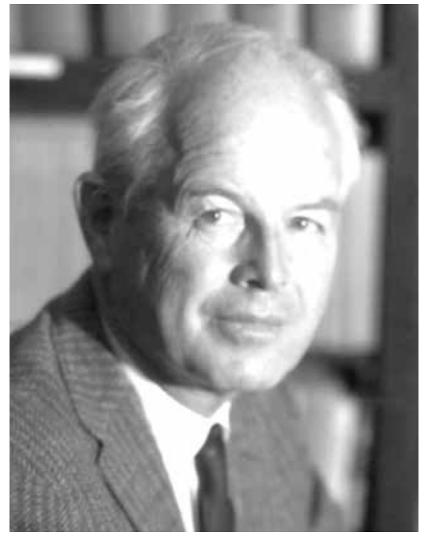

Photo courtesy of USGS archives.

By the 1960's a solution was needed to address the conflicting evidence about the age and evolution of the river. Eddie McKee, the pre-eminent Grand Canyon geologist convened a special symposium at the Museum of Northern Arizona (MNA) in August 1964. For the first time in history, geologists gathered in a single location to specifically discuss problems associated with the Colorado River and Grand Canyon. Twenty geologists attended the ten-day symposium (with one other in absentia) to share their thoughts, ideas, and proposals for further research. Two significant results came out of this pivotal forum: the development of a timeline outlining a plausible sequence of 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.

In the final bulletin, the authors outlined a five-stage evolutionary sequence with: 1) initial northeast drainage across a subdued but uplifted surface; 2) a slight modification of this drainage around monoclinal upwarps, with flow into freshwater lakes in the northern plateau; 3) development of two separate and distinct drainage systems, each on either side of the Kaibab upwarp with the younger, steeper, west-directed Hualapai drainage going to the Gulf of California and the older more sluggish ancestral upper Colorado River going southeast up the present course of the Little Colorado River to the Rio Grande system; 4) the growth of interior basins to the west and east of Grand Canyon, respectively the Muddy Creek basin and the Bidahochi basin; and 5) the integration of the two drainages by renewed uplift, headward erosion, and stream capture (McKee et. al., 1967). McKee led the charge for the importance of headward erosion (the precocious gully of Hunt) and stream capture to create the modern Colorado River and Grand Canyon by proposing that the western Hualapai drainage gradually lengthened its channel in the upstream direction (east) to intersect and capture the more sluggish (and older) ancestral upper Colorado River.

The ideas generated at the MNA symposium received much fanfare, exposure, and support in the years immediately following the gathering. But by the early to mid-1980's it was becoming apparent that the proposed ancestral upper Colorado River could not have gone southeast up the course of the modern Little Colorado River to the Rio Grande as the Continental Divide is located along that route. However, the related concepts of headward erosion and stream piracy would be the lasting legacy of this pivotal meeting and still influence thinking about the evolution of the river. In the later part of the 20th century a few studies sought to solve the Muddy Creek problem through innovative courses for the Colorado River (Lovejoy, 1980) or revived the idea of an old river and canyon (Elston and Young, 1991).

THE 21st CENTURY

In June 2000 a second symposium was held at Grand Canyon National Park with 73 geologists in attendance and a symposium volume with results presented in 33 published papers (Young and Spamer, 2004). Key concepts introduced included attacks and support for headward erosion, the viability of the long-lived Lake Bidahochi, and support for recent deepening of the canyon. A longer lasting result has been the tremendous increase in a broad spectrum of research related to the origin of the Grand Canyon and Colorado River. This surge in interest prompted another professional workshop held in May 2010 at the U.S. Geological Survey in Flagstaff, AZ, with 59 geologists in attendance and numerous papers that were published (Beard et. al., 2011; and Karlstrom et. al., 2012). 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 Grand Canyon was a truly special place, and not a profitless locality.

Workshop held in May 2010 at the U.S. Geological Survey in Flagstaff, AZ, with 59 geologists in attendance. *Photo courtesy of Wayne Ranney.*

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Butte Fault in Grand Canyon. *Photo courtesy of Wayne Ranney.*