Section F

Selected Theories and Speculation

Lake Overflow: An Alternative Hypothesis for Grand Canyon Incision and Development of the Colorado River

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Abstract: Based on observations from a much younger Mojave River analogue, and a careful examination of previous research, the Colorado River could have developed by the episodic downstream extension of its trunk channel from multiple lake-overflow events between ~10 and 4 Ma. The lake-overflow hypothesis might help to explain rapid incision of Grand Canyon. It also fits with the downstream sedimentary record, and it could explain the lack of evidence for a major lake upstream of Grand Canyon in latest Miocene and Pliocene time. Finally, the overflow hypothesis does not require any late Cenozoic uplift of the Colorado Plateau to explain incision within and upstream of Grand Canyon because rapid dissection is a consequence of an overflowing drainage reaching a much lower base level.

The development of the Colorado River through Grand Canyon has long defied explanation based solely on existing field data, largely because the Colorado Plateau is an erosional landscape, preserving little in the way of Miocene or Pliocene surfaces. Previous well-cited researchers focused on antecedence (Powell, 1875), superposition (Dutton, 1882), stream piracy (McKee and others, 1967), and a variety of composite theories (Hunt, 1969; Lucchitta, 1990a) to explain how the Colorado River crossed the Kaibab Plateau. In this paper we revisit a hypothesis that was originally suggested for the entire Colorado River drainage system by Eliot Blackwelder in 1934: lake overflow. Blackwelder outlined a trunk-stream prolongation model whereby the Colorado River began overflowing basins in the Colorado Rockies. It eventually reached the ocean after ponding behind, and then overflowing and breaching, topographic barriers. However, working in an era predating isotopic dating, Blackwelder (1934) hypothesized that the drainage became integrated in early Pleistocene time, when the onset of the ice ages would have supplied abundant runoff. Moreover, he did not provide any details about where the lakes were probably located, their extent, or details about how the process works. Unfortunately, his insights appear to have been downplayed in the last half century.

In this paper we describe the lake-overflow process in more detail and in light of new work conducted in the Colorado Plateau region since Blackwelder's early research. Our understanding of lake overflow was formulated after the study of a late Pleistocene Mojave River, a potential analogue where most of the field evidence still remains and where Blackwelder also worked (Blackwelder and Ellsworth, 1936). Lessons learned from the Mojave River explain how some drainage networks extend downstream via lake overflow, and why so much of the evidence for the overflowing lake disappears rapidly following the breach.

The use of a Mojave River analogue to explain the Colorado River's development can be easily criticized for several reasons: (1) The Colorado Plateau is a much larger region, and is structurally different from the Basin and Range where the Mojave River evolved. (2) The climates of the two regions differ. (3) The Colorado Plateau has not witnessed the growth and demise of large pluvial lakes during Pleistocene time that characterize the Basin and Range Province. (4) The sizes of the lakes being compared, their duration, and the outlet canyons that formed when they overflowed differ by several orders of magnitude. Nevertheless, geomorphologists have a long tradition of drawing conclusions from evidence viewed at different scales, and the Mojave River system reveals important clues about lake-overflow processes and the preservation of the sedimentary record—insights that justifiably warrant a reexamination of the lake-overflow model at this time.

The lake-overflow model is consistent with much field evidence in the Colorado River drainage network (Spencer and Pearthree, this volume). In addition, the deductive approach has the advantage of predicting what should be found through additional field studies both upstream and downstream of Grand Canyon, and suggests new avenues for future research where scientists can test predictions.

The Mojave River Analogue

The Mojave River drainage network provides a recent example of how a trunk stream lengthens over time through lake-overflow processes (Figure 1). The Mojave River originated with the rapid uplift of the San Bernardino and San Gabriel mountain ranges during Pliocene time (Meisling and Weldon, 1989; Nagy and Murray, 1996), and then grew downstream by ponding in, and then breaching, a series of internally drained basins in the Mojave Desert (Cox and Tinsley, 1999; Meek, 1999). When the Mojave River appeared in the Manix Basin ~500 ka (Jefferson, 1985), a large deltaic complex slowly filled the basin with sediment and reduced the basin's capacity to hold water. During a massive influx of water during the Late Wisconsinan glacial period, overflow across the lowest rim of the Afton subbasin of Lake Manix caused rapid incision (Meek, 1989). This incision formed Afton Canyon and extended the Mojave River into the Cronese and Silver-Soda basins where it terminates sedimentologically (but not hydrologically) today. Radiocarbon dates on fossil shells from the highest shoreline in the Afton subbasin indicate that the basin was intact at 18.1 ka.

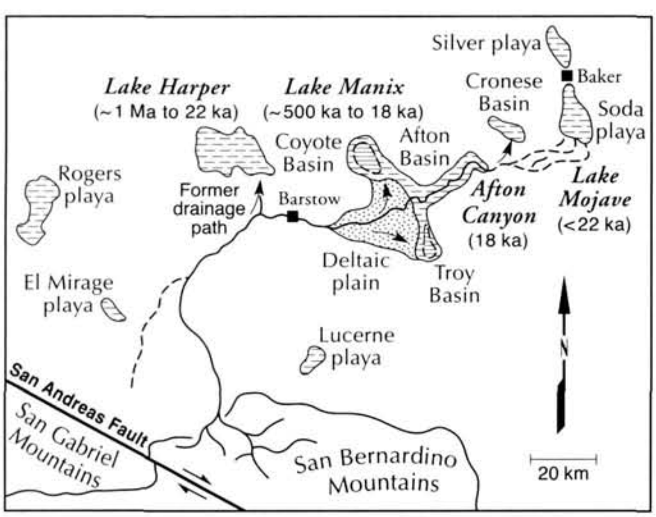

Figure 1. Trunk prolongation model of the Mojave River. Dates refer to times of sediment influxes from the Mojave River.

After the Afton subbasin breached about 18 ka, a 120 m base-level drop generated a deeply dissected landscape (hereafter termed "canyonland topography") over the 100 km^2 Afton subbasin (Blackwelder and Ellsworth, 1936; Meek, 1989), leading to a correspondingly massive sedimentary influx in downstream basins (Wells and others, 1989). A critical observation relating the Mojave River story to the Colorado River story is that >99 percent of the lake clays from the Late Wisconsinan lake have eroded in the past 18 ka from the 100 km^2 Afton subbasin. In contrast to the Afton subbasin, these clays still remain in the adjacent Coyote and Troy subbasins. The only remaining sedimentary evidence of the Late Wisconsinan lake stand that breached the Afton subbasin are some porous beach-ridge gravels, some oncolites on the former lake-floor surfaces, and the uppermost deltaic sediments 20 km upstream of Afton Canyon. The absence of lacustrine sediments can be explained because they rested atop the older, more resistant sedimentary layers, and they were vulnerable to rapid erosion following the large base-level drop. Evidence of Illinoian and earlier lake stands remain in the Afton subbasin, but only where lacustrine sediments are armored by coarse alluvial-fan gravels built into the basin during the Sangamon interglacial. Moreover, given the rapid rate that the lacustrine evidence has eroded from the Afton subbasin in the past 18 ka, we can reasonably speculate that *no* evidence of lacustrine conditions will remain in this eroding subbasin 1 Ma from now.

When applying this model to Grand Canyon, researchers should be careful not to discount lake overflow as a possible mechanism for canyon incision based solely on the fact that little or no lacustrine evidence exists upstream of the outlet canyon. No sedimentary evidence of a major late Miocene or Pliocene freshwater lake has been discovered immediately upstream of eastern Grand Canyon, and probably for this reason lake overflow has not been considered likely, although Spencer and Patchett (1997, Figure 2) suggested the hypothesis.

Early History of the Colorado River

In previous studies, researchers presumed that part or all of the Colorado River has flowed to an ocean at some locality throughout its existence (Powell, 1875; Dutton, 1882; Hunt, 1956, 1969; McKee and others, 1967; Lucchitta, 1990a; Lucchitta and others, this volume). This assumption generated complex explanations of Colorado River development (e.g., McKee and others, 1967; Hunt, 1974; Lucchitta, 1990a). In contrast, the lake-overflow hypothesis does not require that any part of the Colorado River flowed to the ocean before it arrived there as "a haphazard and accidental development of its course" (Blackwelder, 1934, p. 564).

A significant conclusion from the research by Larsen and others (1975, p. 170) is that an integrated ancestral Colorado River probably did not exist before 10 Ma in the Middle Park area of central Colorado. Sometime after about 10 Ma, the ancestral river began to extend downstream from its headwaters region, perhaps by basin overflow. Recent evidence suggests

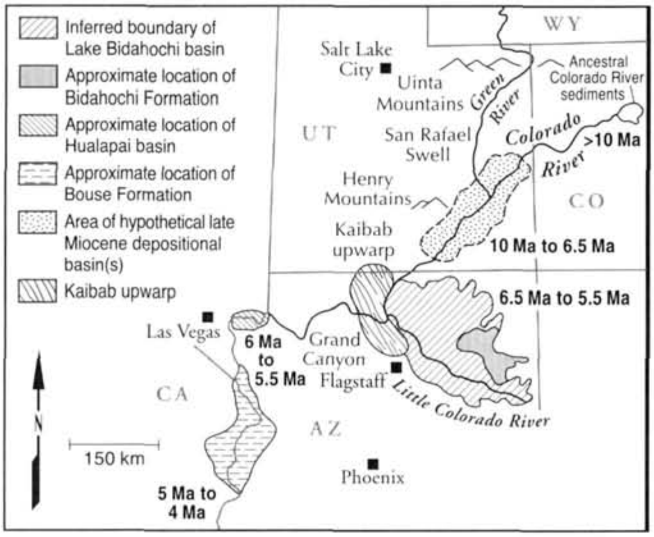

Figure 2. The Colorado River drainage network showing important deposits and approximate age of the first appearance of the Colorado River in each region. In the case of the hypothetical late Miocene depositional basin(s), the 10 to 6.5 Ma age estimate is inferred.

that this extension might have occurred earlier, perhaps between 10 and ~20 Ma (Kirkham and others, this volume). In any case, central Colorado has the oldest remaining sedimentary evidence of an ancestral Colorado River system (Figure 2). The limited evidence suggests that an early stage of drainage integration of the Colorado River headwaters was beginning during late Miocene time, perhaps associated with renewed tectonism in the central Rockies (Larsen and others, 1975).

The early history of drainage on the southern Colorado Plateau can be summarized as follows. Prior to early Miocene time, a sluggish northeastward-flowing regional drainage network flowed onto the Colorado Plateau from a highland in central Arizona (Elston and Young, 1989; Potochnick and Faulds, 1998, p. 155). With the development of Basin and Range faulting, the central Arizona highlands broke up and subsided relative to the Colorado Plateau at ~18 Ma (Potochnick and Faulds, 1998). Collapse of the central Arizona highlands removed the primary water source for the Colorado Plateau's northeastward-flowing Laramide-age drainage networks, and this coincided with the development of the Bidahochi basin at ~16 Ma in northeastern Arizona (Ort and others, 1998; Dallegge and Ort, this volume). When the ancestral Colorado River headwaters may have begun to breach closed basins at ~10 Ma in central Colorado, the river would have begun to flow westward onto a Colorado Plateau that had previously drained northeastward.

Because the Tertiary rocks have been completely stripped from this vast region, very little is known about the Oligocene and Miocene history or topography of the large region in southeastern Utah where an emerging river may have terminated in a closed basin. In adjacent regions where the early and middle Tertiary record has been preserved by resistant volcanic cap rocks, the Colorado Plateau is characterized by internal drainage and slow rates of sedimentation (Hunt, 1956, p. 76–77; Goldstrand and Eaton, this volume). Some 50 years of consensus holds that broad sedimentary basins existed in this region, and that only the plateau margin and the broad Laramide plateau uplifts may have projected through the Tertiary sedimentary cover as low uplands (Hunt, 1956, p. 80–81; Young, 1987, p. 275).

If the Miocene topography in southeastern Utah was controlled by Laramide structures, one or more broad basins probably existed east of the San Rafael Swell and Henry Mountains, and north of the Monument upwarp, near the present confluence of the Green and Colorado Rivers (Hunt, 1969, p. 100). Referring to Hunt's (1956, p. 52) structure map of the Colorado Plateau based upon the Kaibab Formation, it appears that the Colorado River took the lowest structural (and perhaps topographic) path southwestward toward the Kaibab upwarp after exiting western Colorado, terminating in one of these broad basins as a large, perhaps ephemeral, lake. This time of relative base-level stability and wide valleys corresponds with a long-held belief that Colorado Plateau topography is the product of two major periods of erosion, one of which preceded the cutting of the canyons (Thornbury, 1965, p. 437).

We speculate that when the Green River drainage overflowed from the Browns Park basin across the Uinta Mountains (Hansen, 1986, p. 63) and joined the ancestral Colorado River, the increased discharge of the combined rivers caused the ancestral Colorado River system to progress toward the ocean using the lowest set of topographic spillways then available. Based on fish distributions, Hansen (1986, p. 69) speculated that this integration happened during middle Pleistocene time, but sedimentary evidence in Browns Park basin requires only that it happened after ~8 Ma. The progress toward the ocean of the combined Green–Colorado River system was probably also aided by the southwestward tilting of the Colorado Plateau surface that probably occurred in late Oligocene and early Miocene time (Huntoon, 1990, p. 307; Young, 2001).

Because no sedimentary evidence of an ancestral Colorado River system has been located yet in this vast region, determining what happened with anything approximating confidence is an improbable task. This model is therefore highly speculative, but also consistent with the analogous Mojave River system where that river terminated in the Victorville area (Cox and Tinsley, 1999) and Harper Basin (Meek, 1999) for more than 500 ka before making its way into the Manix Basin. Given that an arid to semiarid climate probably dominated the Colorado Plateau (Elston and Young, 1989; Schmidt, 1991; Young, this volume) and Colorado Rockies (Blackwelder, 1934; Larsen and others, 1975) in middle Tertiary time, we concur with Young's (1987, p. 275) conclusion that "all facts are consistent with a lack of regional drainage integration or incision until middle Miocene time or later".

Skeptics of the overflow hypothesis may point to the lack of evidence for Oligocene or early Miocene sediments in southeastern Utah as being "convenient" for the model. Although it seems improbable that such a record could be completely eroded, there are at least three arguments for why such a sequence could have existed and has been lost: (1) Unlike central Utah, central Arizona, and southwestern Colorado, there were no Tertiary lavas in southeastern Utah that might have protected the Oligocene–early Miocene section from erosion. (2) After the subsidence of the central Arizona highlands in early Miocene time, there were no major sources of alluvial gravels for the northeast flowing drainages that might have formed a thick, resistant cap rock layer on an elevated Miocene surface in this region. (3) Dumitru and others (1994, p. 502) report apatite fission-track data that show between 2 and 3 km of Tertiary burial in the adjacent Waterpocket Fold region of south-central Utah, which corresponds with Hunt's (1956) belief that the Henry Mountains may have been almost buried by Tertiary sediments before the region was exhumed.

The Lake-overflow Hypothesis and Grand Canyon Incision

Just as a large lake overspilled the Manix Basin and initiated the incision of Afton Canyon, we propose that a large lake spilled westward across the Kaibab Plateau, initiating Grand Canyon incision. The deep-water lake that would have spilled over the Kaibab Plateau could be called Lake Bidahochi after the Bidahochi Formation of northeastern Arizona. However, this hypothetical lake probably existed after most of the remaining deposits of the Bidahochi Formation were laid down, just as the Late Wisconsinan Lake Manix postdates the older Pleistocene strata that still remain in the Afton subbasin.

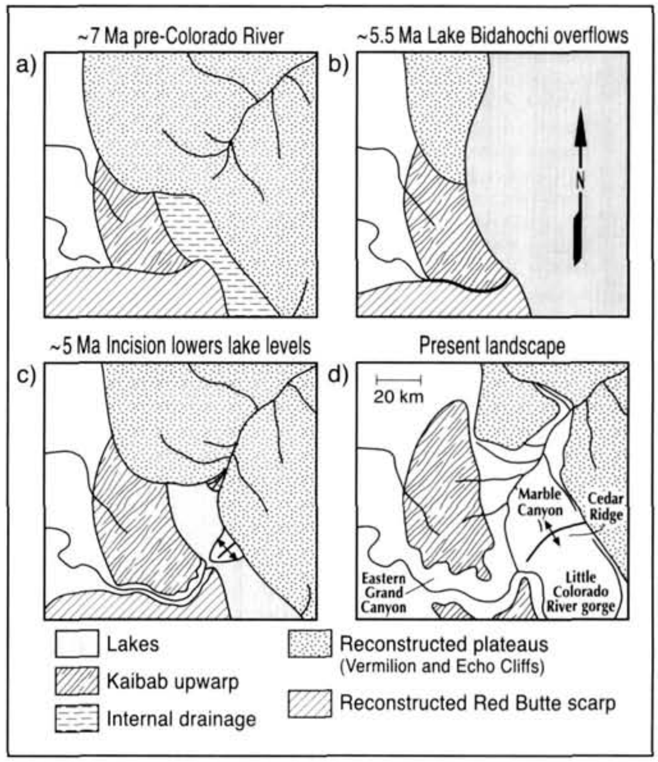

Figure 3. Landscape evolution time series of the eastern Grand Canyon region (after Douglass, 1999). The reconstructed plateaus are based on average scarp retreat rates of the Vermilion Cliffs, Echo Cliffs and Red Butte scarp. The surface elevation and extent of the hypothetical 5.5 Ma Lake Bidahochi is unknown, and some cliffs may have projected through the lake to form linear islands within the area shown. The estimated timeline is only approximate.

The Bidahochi Formation consists of volcanic (Hopi Buttes), lacustrine, eolian, and fluvial facies (Scarborough, 1989; Ort and others 1998). During the depositional time frame of the formation (~16 Ma to ~6.5 Ma), the sedimentology supports the existence of a large closed basin (White, 1980) with some lacustrine horizons. The Bidahochi basin was integrated with the Colorado River sometime after 6.5 Ma (Ort and others, 1998), and western Grand Canyon probably began to incise sometime after 6 Ma (Lucchitta, 1990a). Thus, there is an apparent temporal sequence of the apparent demise of a basin that persisted for 10 Ma (Ort and others, 1998; Dallegge and Ort, this volume), followed by incision of a large canyon along the basin's western boundary. A key issue is whether this evidence can be explained easily in terms of lake-overflow creating canyon incision.

A hypothetical paleogeographic time series (Figure 3) was constructed using scarp-retreat rates for the Vermilion and Echo Cliffs, estimated from Schmidt (1988). Scarp-retreat rates vary depending on numerous factors (Young, 1985), including cliff height and whether the scarp is retreating up or down a structural slope. These and other factors were taken into account when trying to reconstruct the paleogeography of the eastern Grand Canyon region (Douglass, 1999). Also, the existence of a hypothetical Red Butte scarp (Lucchitta, 1990a) explains the curved course of the Colorado River across the Kaibab Plateau.

The reconstructed scarp model is critical because it illustrates that the Kaibab upwarp would have been the lowest spillway in late Miocene time (Lucchitta, 1990a), rather than a more northerly route through the Virgin River drainage basin. Secondly, if the reconstructed scarp positions are continued further back in time than the latest Miocene, much of the Kaibab Plateau and surrounding landscape might have been covered with a sequence of younger strata. The possible presence of such layers argues against a dual phase Laramide-Pliocene origin of Grand Canyon (Scarborough, this volume) with a hypothetical Laramide valley within the modern canyon. Either scarps such as Red Butte did not begin to retreat from the hypothetical Laramide-age river valley until the late Miocene, or their rates of retreat have been overestimated by Lucchitta (1990a) by at least an order of magnitude.

The paleogeographic time series begins ~7 Ma (see Figure 3a) and estimates positions of the Vermilion Cliffs, Echo Cliffs, Red Butte scarp, and an undissected Bidahochi basin in relation to the Kaibab upwarp. Based on the Bidahochi Formation's stratigraphy, the Colorado River probably did not flow into the region at this time (Scarborough, 1989; Ort and others 1998), but instead ponded somewhere in eastern Utah.

Our hypothesis is that the Colorado River arrived and ponded in the Bidahochi basin sometime after 6.5 Ma. The deep-water Lake Bidahochi that eventually overtopped the Kaibab Plateau (Figure 3b) probably discharged water through, and then downstream of, the Grand Canyon region using an assortment of lowest spillovers and preexisting topographic pathways that probably already existed in the western Grand Canyon region (Spencer and Pearthree, this volume). Evidence for this spillover event includes Spencer and Patchett's (1997) and Patchett and Spencer's (this volume) analysis of strontium concentrations in the Bouse Formation along the lower Colorado River corridor. The strontium concentrations are consistent with inflow of Colorado River water, and the event occurred after 6 Ma (Spencer and Pearthree, this volume).

Because lake-outlet water flowed to a base level in the Lake Mead area that was ~1500 m lower than the spillover point (near Grandview Point on the South Rim of Grand Canyon), the channel slope was sufficiently steep to initiate Grand Canyon incision, which probably then created knickpoints that rapidly worked their way upstream. The rate of incision must have been very high, as Hamblin's (1994, p.111) study of lava-dam erosion in the canyon demonstrates.

As portrayed in the next time series map (Figure 3c), the lake elevation may have decreased until it separated into two lakes across Cedar Ridge. Marble Canyon and the Little Colorado River gorge currently dissect the northern portion of the Bidahochi basin adjacent to the Kaibab upwarp. The subtle anticlinal upwarp of Cedar Ridge extends from the confluence of the two canyons northeastward to the base of the Echo Cliffs. Longitudinal profiles comparing the difference in elevation between the Colorado and Little Colorado Rivers and the rims of Marble Canyon and the Little Colorado River gorge illustrate that both rivers now flow against the north and south structural slopes of Cedar Ridge respectively. These relationships cannot be explained easily by a headward-eroding Colorado River system. Rather, current longitudinal profiles make better sense if these rivers were superimposed onto the anticline from uncomformable strata such as the Bidahochi Formation, or if Lake Bidahochi split into two lakes as it drained.

The first appearance of Colorado River gravels downstream of Grand Canyon indicate that through flow definitely occurred by ~4 Ma (Buising, 1990). The last map in the time series (Figure 3d) illustrates the present landscape of the eastern Grand Canyon region.

Field Evidence and the Lake-overflow Hypothesis

Because of the erosional nature of the Colorado Plateau within and upstream of Grand Canyon, no deposits are known to exist in that region that inform on the late Miocene or Pliocene development of the Colorado River. However, new research on several formations and deposits downstream of Grand Canyon shed light on the initial arrival of the Colorado River there (Figure 2).

Prior to the first arrival of Colorado River water in latest Miocene time, interior drainage dominated the region immediately west of Grand Canyon (Blackwelder, 1934; Longwell, 1946). The sedimentary evidence includes fluvial and lacustrine deposits of the Muddy Creek Formation deposited between 10.6 and ~6 Ma (Bohannon, 1984). In several areas the uppermost unit in the Muddy Creek Formation is the Hualapai Limestone (Blair and Armstrong, 1979). Lucchitta (1990a) and Spencer and others (1998) showed that a large river did not empty into the Hualapai basin before 6 Ma, indicating that the Colorado River had not yet arrived west of Grand Canyon during Muddy Creek time.

The presence of the fossils of large freshwater fish in the White Narrows Formation of southern Nevada deposited about 4.7 Ma (Reynolds and Lindsay, 1999) provides evidence for the appearance of the Colorado River downstream of Grand Canyon. The large fish (suckers and perch) indicate a throughflowing drainage system dissecting the Muddy Creek Formation and a connection with a major river system, presumably the Colorado River (Reynolds and Lindsay, 1999).

The Colorado River extended along the lower Colorado River corridor and deposited the Bouse Formation downstream of the Hualapai basin. The mostly lacustrine Bouse Formation (Spencer and Patchett, 1997; Patchett and Spencer, this volume) indicates that at least two, and perhaps four, lake basins were filled and then breached following the arrival of the Colorado River (Spencer and Patchett, 1997). These lakes were contained by the four paleodams (Lakes Mohave, Topock, Havasu, and Chocolate-Trigo) that are depicted by Spencer and Patchett (1977, fig. 3). However, the interpretation of the Bouse Formation as a freshwater deposit remains controversial (see Lucchitta and others, this volume).

Farther downstream and upsection from the Bouse Formation, the Palm Springs and Imperial Formations are partially composed of Colorado River fluvial and deltaic deposits (Crowell and Baca, 1979; Fleming 1994). Included in the Imperial and Palm Springs Formations is the sequential deposition of Cretaceous pollen from the Colorado Plateau. The pollen record indicates that massive erosion of Cretaceous rocks of the southern Colorado Plateau began before 4.5 Ma, and that rapid erosion of the Cretaceous rocks of the northern part of the plateau began ~3.9 Ma (Fleming, 1994; Remeika, 1998). Previously, researchers accounted for the upstream proliferation of Pliocene degradation from the Grand Canyon region by demonstrating that the climate was possibly wetter and cooler during this time period (Fleming, 1994). However, climate alone does not explain why the degradation was localized to the Grand Canyon region originally and then proliferated upstream dramatically. Because the degradation radiated from a specific region, a dramatic base-level reduction in the Grand Canyon region initiated by lake overflow and incision plausibly explains this degradation sequence also.

Presently it appears that the Colorado River may have extended its trunk channel via lake overflow in three separate localities: (1) during its inception in the central Rocky Mountains, (2) in the Hualapai basin, (3) and in the Bouse Formation basins. The predominance of the episodic extension of the Colorado River by lake-overflow events coupled with the downstream progression of dates associated with the first arrival of the Colorado River suggests that the lake-overflow hypothesis might apply to the entire Colorado River system, including the Grand Canyon reach—a notion proposed almost seventy years ago (Blackwelder, 1934).

Implications for Timing of Colorado Plateau Uplift

The overflow hypothesis, if valid, may shed light on a controversy regarding the timing of Colorado Plateau uplift. Hunt (1956), McKee and McKee (1972), Lucchitta (1984), Lucchitta and others (this volume), and several others have claimed that the rapid incision of the Colorado Plateau reflects, and is probably a consequence of the late Cenozoic uplift of the Colorado Plateau. Moreover, geomorphologists have long believed that epeirogenic uplift of the Colorado Plateau starting during middle Tertiary time (Thornbury, 1965, p. 436) may be partly responsible for some unusual river features on the Colorado Plateau such as the entrenched meanders of the San Juan River (Moore, 1926, p. 55). The controversy exists because there is no compelling evidence for any significant late Miocene or Pliocene uplift of the southwestern margin of the Colorado Plateau (Lovejoy, 1973; Young, 2001).

However, it is also possible that the large base-level difference between the Basin and Range and Colorado Plateau was caused mostly by the extension and subsidence of the adjacent Basin and Range during Miocene time when much of the Colorado Plateau may have remained comparatively stable at or near its present elevation (Young, 2001; Naeser and others, this volume). If a large ancestral Colorado River system spilled over the Kaibab Plateau in latest Miocene or Pliocene time as we have proposed, the resultant base-level drop of ~1500 m could easily explain the development of canyonland topography in the Colorado Plateau as the trunk stream and its tributaries began to rapidly adjust to the much lower base level in the Basin and Range. Thus, the lake-overflow hypothesis does not *require* any young uplift of the Colorado Plateau, and the principle, "no uplift, no canyons" (Lucchitta and others, this volume), might be edited to read, "no base-level change, no canyons."

Conclusion

Based on a large number of possible parallels between drainage histories and canyonland landscapes of the Mojave and Colorado Rivers, the lake-overflow hypothesis is a simple deductive explanation for the initiation of Grand Canyon incision and Colorado River development. Following their inception, both drainage networks may have encountered successive interior-drained basins downstream from mountainous sources and grew longer through the episodic downstream extension of their trunk channels from lake-overflow processes. Both the Colorado and Mojave River drainage networks incised bedrock canyons at the boundaries of large topographic basins. After incision began, the resultant base-level drop caused the vulnerable lacustrine sediments to be rapidly eroded, thereby removing evidence of the lakes that probably overflowed to start the incision. Finally, the lake-overflow model accounts for the sudden appearance of Colorado River water, seen in its associated sedimentary evidence, downstream from Grand Canyon. Considering the multiple lines of evidence, future research should consider lake overflow as a possible mechanism for the development of the Colorado River across the Kaibab Plateau.

In conclusion, we reiterate Blackwelder's (1934) conclusion, because much of it could also apply today:

"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 basin but of the Western States in general."

Acknowledgments

The lake-overflow hypothesis for Grand Canyon was reinvented in 1992 without knowledge of Blackwelder's paper. Our thanks are extended to Richard Young, Ronald Dorn, Jon Spencer, Michael Ort, and several anonymous reviewers.