Mojave River history from an upstream perspective

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Abstract

Several interpretations of Mojave River history by Enzel et al. (2003) in GSA Special Paper 368 appear to lack solid evidence or realistic conceptualization. Before their geomorphic and stratigraphic interpretations are accepted, researchers working on the history of the Mojave River should consider some serious problems regarding Enzel et al.'s (2003) latest revision of Mojave River geomorphic history.

Introduction

Issues will inevitably arise when scientists attempt to reinterpret the work of their peers, and this is especially true when little or no communication exists between the scientists. Because I was not provided a chance to conduct a peer review of the Enzel et al. (2003) article prior to publication, and no opportunity exists for a "comment and reply" in the Special Paper series of the Geological Society of America, this article is meant to review some mistakes and misinterpretations of Enzel et al. (2003) and to challenge evidence in the Silver/Soda basin for the first time.

How quickly do recessional shorelines vanish?

Fifteen years ago I published a paper suggesting that the final lake in the Afton sub-basin of Lake Manix drained quickly, forming upper Afton Canyon in the process (Meek, 1989a). Since then, researchers under the guidance of Stephen Wells who have worked downstream in the Silver/Soda basin have maintained that Lake Manix drained slowly and therefore that all of Afton Canyon formed in a time-transgressive manner over thousands of years (e.g., Wells and Enzel, 1994; Enzel et al. 2003).

Recently, Enzel et al. (2003, p. 68) have made a claim that is critical to understanding the Afton Canyon controversy: "In addition, we observe recessional shorelines in the Afton basin at elevations below the highest level of Lake Manix, suggesting a longer period of downcutting." Future researchers of the Mojave River and any reviewer knowledgeable about Afton Canyon should realize that this is THE most important issue in the whole debate. All other conflicts are side bars. It is the absence of recessional shorelines that has been the primary basis for my claim of a rapid upper canyon incision (e.g., Meek, 1989a). No evidence of recessional shorelines was presented by Enzel et al. (2003). None has ever been noted by any prior researcher in Afton basin (e.g., Buwalda, 1914; Ellsworth, 1932; Blackwelder and Ellsworth, 1936; Keaton and Keaton, 1977; Jefferson, 1985, 2003). It is difficult to understand why none of the reviewers of Enzel et al. (2003) demanded that the location and evidence for the recessional shorelines be provided. If Enzel et al. (2003) cannot produce unequivocal evidence of recessional shorelines, their claim about the time-transgressive formation of upper Afton Canyon is untenable and their latest stratigraphic interpretations of the Silver basin cores are suspect. Alternatively, if Enzel et al. (2003) truly have unequivocal evidence of recessional shorelines, I will have to reevaluate my interpretations of the history of the Mojave River, Afton Canyon, and the Manix basin.

Consequently, in November 2003 I sent E-mail requests to each of the authors (Enzel, Wells and Lancaster) to provide the location(s) of the recessional shorelines in Afton basin. As of March 2004, no responses have been received. Replication is a foundation of science, and if readers are not permitted to view and evaluate vital evidence for themselves, there can be no trust between author and reader.

No one other than Enzel et al. (2003) has recognized or reported significant depositional features in Afton basin that formed as the final stand of Lake Manix receded. The basin floor of the last stand of Lake Manix is preserved for long distances below each of the large beach ridges in eastern Afton basin. This floor can be recognized by remnants of "tufa" coatings (i.e., some of the oncoids described by Awramik et al., 2000), but this surface was undoubtedly buried in green lake clays when the lake drained. Surprisingly, the wave energy that was sufficient to construct the beach ridges composed of large cobbles did not leave any strandlines of even gravel-sized sediments downslope from the beach ridges in the basin. My belief in a rapid cutting of upper Afton Canyon rests on my assumption that some evidence of strandlines would be visible if the lake drained over a period of years. Thus, the absence of strandlines is the best (albeit negative) evidence that the lake drained rapidly.

I searched the literature and the field widely for evidence of recessional shorelines in Afton basin with the following results: a) there is a tufa-coated bench north of South Afton beach ridge, but U/Th dating indicates that this bench is an exhumed shoreline of an Oxygen Isotope Stage 4 lake stand (Meek, 2000, p. 33); b) west of the Afton Exit beach ridge there are features I once described as "cobble lineations," but these are mining scars from when the interstate was built (Meek, 1990, p. 71-73); and c) there is potential evidence of a recessional shoreline in the form of a subtle shoreline platform on the western slope of Buwalda Ridge beneath the high shoreline platform (Meek, 1990, p. 70), however, shoreline platforms are long-lived erosional features in bedrock that could have been created by numerous earlier stands of Lake Manix. In this case, the subtle wave-cut platforms likely formed at or near the most common lake level in the basin over its long history. Nothing requires that the subtle shoreline platform was formed by the final lake stand, and there are no depositional strandlines that correspond to its elevation in other parts of Afton basin. Until Enzel, Wells and Lancaster publish specific evidence of recessional shorelines and disprove other explanations, one must suspend judgment on the alternative history they propose.

The Afton Canyon straw man

Enzel et al. (2003, p. 68) claim three types of evidence prove that Afton Canyon incised slowly: 1) the slow upstream migration of the nickpoint formed by the incision; 2) the existence of marsh and lacustrine conditions in the Mojave River delta in western Lake Manix as late as 12–9 ka; and 3) the existence of pronounced Holocene terraces within the canyon. They follow the last point with this statement: "...indicating that the incision of Afton Canyon to its present form was not a continuous, but episodic and a relatively long process." On page 67, Enzel et al. (2003) make the following claim: "The rapid-incision idea was based mainly on the lack of recessional shorelines in the Afton basin, the lack of terraces within the canyon, and the presence of deeply incised tributary channels into the canyon (Meek, 1989a). Wells and Enzel (1994) analyzed the geomorphology of Afton Canyon, including these specific observations, and concluded that an alternative hypothesis such as time-transgressive incision during at least a few thousands of years is a more realistic explanation." Since this section of their paper is meant to challenge my interpretation of a rapid canyon incision, one might reasonably assume that I have claimed that all, or nearly all, of Afton Canyon formed in a single flood event.

Such is not the case. Careful reading of the Meek (1989a) article includes the following statements: "*At elevations above the lake floor*, no resistant rock units that may have once extended across the canyon, forming long-lived spillways, are evident in either wall of Afton Canyon," and "No river terraces (strath or fill) are present in the canyon *at elevations above the lake floor*. Had canyon cutting been episodic, some evidence of terraces might remain, given the late Wisconsin age of the canyon cut" (Meek, 1989a, p. 10). Note that both statements include the phrase "above the lake floor" and it is clear that I was making the case that the portion of Afton Canyon above the floor of Lake Manix, not the whole canyon, was eroded in the draining event. Subsequently, I explicitly stated that "the upper half of the canyon could have eroded rapidly as Lake Manix drained" (Meek, 1990, p. 95).

To clarify the issue again after Wells and Enzel (1994) made the claim that the whole canyon formed in a time-transgressive manner, I wrote (Meek, 2000, p. 33): "Sometime about 18 ka, water overtopped the lowest rim of the Manix basin immediately above Afton Canyon, and the water spilled out, removing that part of the canyon above the lake floor in as little as 10 hours. Some people who have read my 1989 paper and accompanied me to the area have told me that they thought I suggested in the paper that the entire canyon was eroded in this event. There is no evidence that this happened. Rather, a series of strath terraces on the meander bend and upstream of the canyon indicate that the *lower half* [italics in original] of the canyon was incised over much longer periods."

Large late Wisconsinan and Holocene terraces do exist in the Afton Canyon vicinity, but they all lie far below the reconstructed floor of Lake Manix, and thus have no bearing on the speed at which the lake drained. Further proof that my interpretation has been misstated is found in my written response to Wells' peer-review of the manuscript where I proposed the rapid incision of upper Afton Canyon. In my direct response (written communication to Wells, 2 June 1988), I wrote: "Comment 20, p. 7: Statement: 'I have observed fluvial terraces and fan surfaces 35 m above the canyon floor; are these insignificant?'" To which I responded: "At 35 m above the canyon floor at ANY location in Afton Canyon you are significantly below the bottom of the Lake Manix basin floor. Therefore, I would conclude that these features, if they are indeed terraces, probably have little relevance to the draining of the lake."

In a related matter, Wells and Enzel (1994, p. 178-179) have claimed that: "a topographically high fluvial terrace (> 45 m above the canyon floor) has been observed at the mouth of Afton Canyon.... This terrace occurs as isolated remnants on bedrock ridges along the north wall of the canyon, sloping downstream and away from the canyon. These terrace remnants are topographically much higher than early Holocene alluvial fans near Basin railroad siding at the mouth of Afton Canyon.... These field observations imply that an ancestral Mojave River was debauching from Afton Canyon prior to the deposition of early Holocene alluvial fans." An important observation here is that they did not present any evidence that the terrace is older than the breaching of Lake Manix, and they also failed to provide sedimentary evidence that the terrace was formed by overflows from Lake Manix or an ancestral Mojave River.

Wells and Enzel (1994) and Wells et al. (2003, p. 111) have also argued that the Mojave River once flowed down Baxter Wash and "offer the hypothesis (Wells and Enzel, 1994, p. 181) that the lower part of Afton Canyon formed by progressive headcutting as Baxter Wash valley served as the outlet for Lake Manix. Eventually stream piracy along the headward migrating Afton Canyon diverted flow from Baxter Wash." First, no evidence yet presented indicates that overflows from Lake Manix have flowed down Baxter Wash. However, if Baxter Wash hosted such flows, its gradient is very steep, especially when one realizes that the lower reaches have been deeply buried. The steep gradient would have been sufficient to allow the flows to rapidly erode the weak Miocene deposits that can be found near the rim of Afton Canyon throughout the area (Meek, 1990, p. 101-107). Unequivocal evidence is needed to assert the bizarre geomorphic alternative that a hypothetical stream without substantial flows in the Afton Canyon vicinity could have eroded headward to pirate a stream in Baxter Wash that would have had a very steep gradient and substantial flows.

In summary, future researchers should not confuse the straw-man argument that most or all of Afton Canyon was carved by the draining of Lake Manix with the need of Enzel and Wells to provide valid evidence that: 1) the terraces in lower Afton Canyon pre-date the rapid incision of Afton basin, 2) Baxter Wash once carried Mojave River water, and 3) stream piracy by headward incision has indeed occurred here.

Age of Afton Canyon

My retraction of the 14,230 radiocarbon date required me to revise the maximum age of Afton Canyon to the next limiting radiocarbon date of 18.1 ± 0.4 ka (Meek 1999, 2000). Enzel et al. (2003, pp. 65, 68, 69) discuss this revision in their article. Yet they go on to write: "We ask again the key question: When did the Afton basin of Lake Manix drain (i.e., the beginning of the lowering of its highest stand from 543 m by spillway incision)? Catastrophically ca. 13 ka (Meek, 1989)? Or after 18 ka (Meek, 1999)? Was it in fact a catastrophic event, or was it a time-transgressive process that continued into the early Holocene (Wells and Enzel, 1994)? Specific answers to these questions will require additional research."

There is no confusion based on reliable limiting radiocarbon dates. Upper Afton Canyon must have formed after about 18.1 ± 0.4 ka because Afton basin was intact and contained a lake near the sub-543 m level until that time. There is no reliable evidence of lakes younger than this in Afton basin, or additional limiting radiocarbon dates younger than 18.1 ka, but since this is an erosional basin, the best evidence has been removed. Because of the absence of recessional shoreline features, I believe the breach was catastrophic. Exactly when it formed after 18.1 ± 0.4 ka is unclear, but the best place to determine the date is not in Afton basin, but downstream from Afton Canyon.

Some difficulties interpreting lake history in eroding basins

The Silver/Soda basin where Wells and Enzel have worked is a closed basin preserving a nearly complete record of upper Quaternary sediments. By drilling cores in such a setting, both shoreline features and basin sediments can be used to construct the lake basin's history.

The Afton basin is much different. When the final lake drained, the lake clays from all of the Wisconsinan stands of Lake Manix were highly vulnerable to erosion because they rested on top of the sedimentary sections. In fact, I have estimated that more than 99% of such clays have been removed from Afton basin (Meek and Douglass, 2001, p. 200), including all(?) of the clays from the eastern three-fourths of the Afton basin. Lake clays from the highest lake stands might remain in the lagoon subsurface at the Afton exit, but to my knowledge that small playa has never been cored. Many casual observers in Afton basin do not realize that all or nearly all of the green clays that they see rest stratigraphically below the Sangamon interpluvial (ca. 125 ka) fanglomerates that have protected them from erosion, and thus have no bearing on the Late Wisconsinan history of lakes that occupied the basin.

Enzel et al. (2003, p. 65) wrote: "Because the sequence of events represented by the various shore features is based on the ages of the shore features and not on stratigraphic relations, this curve [referring to the lake history curve] is subject to modifications with additional ages, different ages, and whether or not the varnish ages are included.... Based on two additional age determinations, the 15-14 ka stand was recently discarded (Meek, 1999) and the same beach ridge from which the earlier age came is now dated at ca. 29 ka (Meek, 1999). This change emphasizes the problem of using ages without a clear stratigraphic context; a beach ridge once considered the youngest in the sequence is now considered older than other late Pleistocene lacustrine features."

Reading this passage, a neutral observer might assume that the present writer does not understand or use basic stratigraphic principles. Yet, in the unique setting of Afton basin, my procedures are fully understandable. Without lake clays from the final lake stand, the only practical way to interpret the Wisconsinan stands of Lake Manix is from the remaining evidence, which in this case means the large porous beach ridges, a few wave-cut platforms and the tufa-coated floor of the lake basin. Nothing else remains from the final lake stands in Afton basin except for the coarse-grained (i.e., gravel, pebbles, granules and sand) braid delta at the western end of the basin. Unlike the small beach complexes in Silver basin, the Lake Manix beach ridges consist mostly of sandy gravel and large cobbles. The beach ridges were built in storms when large waves capable of easily moving cobbles overtopped the ridges. At first glance, one might assume that conventional stratigraphic principles apply—the highest beach ridge deposits are consistently the youngest; but, because multiple stands of Lake Manix reached the same elevation owing to the overflows across an internal spillway into Coyote basin, the beach ridges appear to be composed of a complex assortment of overwash deposits and therefore should produce an assortment of radiocarbon dates from the various lakes. Unlike the much smaller Silver Lake beach deposits, few shell fragments remain in the Lake Manix beach ridges because the wave energy obliterated them. When I was fortunate enough to find a few (extremely rare) fragments of shells in the ridges, I dated them not knowing from which lake stand they came. Interestingly, the beach deposits that contain the most *Anodonta* shells (usually dating to the 21.5 ka to 18.1 ka lake stand) can be found more than 4 m below the beach ridge crests on the foreslopes of the beach ridges, whereas the rare shell fragments within the beach ridges have so far dated to the 31 to 28 ka lake stand.

Someone wishing to decipher the Wisconsinan stands of Lake Manix history further could carefully map the complex mix of beach ridge layers and then radiocarbon date materials from each of the zones if sufficient datable material could be found. But I can make an educated guess as to what they will find: Lake Manix reached the sub-543 m level multiple times, including 21.5 to 18.1 ka, 31 to 28 ka, and probably a few earlier times. I welcome such a detailed site-specific study to test my interpretation.

Harper basin

Enzel et al. (2003, p. 69) also challenge my interpretations by claiming: "This large volume of water and the nonoverlapping ages discussed above led him [Meek] to conclude that Harper Lake was not contemporaneous with late Wisconsinan highstands of Lake Manix. He interpreted that the gaps in the Manix dates could be explained by dates from Lake Harper suggesting to him that Lake Harper was filled when Lake Manix was low." Without providing any new evidence, Enzel et al. (2003, p. 70) then proceed to propose two new interpretations: "...one or more of the following scenarios: (1) shifting of the river between basins on millenial time scales (Meek, 1999), (2) the river feeding both basins all the time, and/or (3) frequent shifting of the river on its delta resulting in a permanent but shallow body of water in each basin." The primary impetus for their claim is that "the Mojave River was able to support Lake Manix and Lake Mojave at the same time" (Enzel et al., 2003, p. 70), and thus it is possible that the river could have once supported both Lake Harper and Lake Manix at the same time.

Whether the Mojave River could have supported both Lake Manix and Lake Mojave at the same time rests on the assumption that the age control and extrapolated deposition rate in the Silver/Soda basin prior to 18 ka are reliable, and prove conclusively that Lake Manix and Lake Mojave existed at the same time. At best, this assumption is a tenuous one (see below).

I have asked several knowledgeable physical geographers if they can name a location on the Earth where a single river, flowing across a broad sandy plain, splits and *simultaneously* terminates in two different lake basins. No one has yet been able to identify a place where this happens. Except in the most extraordinary of circumstances, the two basins would probably have different base levels and hypsometries, and consequently the hypothetical river would have a difficult time maintaining multiple, continuous flows in different directions at the broad interfluve between the basins. For example, when the Colorado River began to flow directly into the Salton Trough in 1905 to eventually form the Salton Sea, and despite heroic efforts to return the Colorado River to its channel, "the main canal was carrying 87% of the total flow of the river, and the water was deepening and widening the Alamo River, along which the canal extended, to a great gorge. Strong efforts by the Southern Pacific Railway Company resulted in the control of the Colorado in the early fall of 1906, but it broke out again on December 7, and was only closed finally in February, 1907" (Freeman and Bolster, 1910, cited in Bowman, 1911, p. 241; see also de Stanley, 1966, pp. 28-38). Since there seem to be no known examples of rivers *simultaneously* flowing into two different terminal lake basins across a broad, sandy plain, I believe that the second hypothesis of Enzel et al. (2003, p. 70) where they claim it happened for lengthy periods of time is unrealistic.

Finally, the third hypothesis (frequent back-and-forth channel avulsions maintaining two separate shallow lakes) directly conflicts with the likely time and paleodischarges needed to fill the large volumes of Lake Manix at 28 and 21.5 ka, and Harper Lake at 25 ka. Each lake was at its *maximum* stage and surface area at these times, and no evidence yet exists for major lakes simultaneously in both basins. Shallow lakes probably existed in the alternate basin periodically, but the presence of shallow lakes does not warrant the proposition that the Mojave River changed flow directions near Lenwood several more times than the lake evidence currently indicates.

In a related matter, the fact that rivers do not normally split to flow to multiple lake basins simultaneously makes the claim that the Mojave River was "capable of delivering water simultaneously to Coyote Lake and, through an incising Afton Canyon, to Lake Mojave" (Enzel et al., 2003, p. 69) quite unlikely.

Coyote basin

Enzel et al. (2003, p. 69) cite written communication from me in 1990 in order to make it appear that I argued for the following baseless claim "(1) Coyote Lake basin could have received Mojave River water only as an overflow from the Afton and Troy basins after these basins reached a sill elevation of 543 m, and (2) only after Coyote Lake also filled to that elevation could the joint Lake Manix have risen to higher levels. Therefore, Meek (1990, written commun.) suggested that the lakes in the Coyote Lake basin after 13 ka (i.e., after his proposed draining of Afton basin ca. 13.5 ka) are residual water bodies that were trapped as remnants of the larger Lake Manix after the formation of Afton Canyon. However, the retraction of the 14.5 ka age means that all the ages from Coyote Lake are < 18.1 ka, which is the youngest age from Afton basin (Meek, 1999). We postulate that simple calculations will show that even for lowest estimations of latest Pleistocene evaporation rates, Coyote Lake would dry up within a few to tens of years were it not being fed continuously by discharge of the Mojave River." Enzel et al. (2003, p. 69) then go on to propose that the Mojave River flowed directly into Coyote basin multiple times after Lake Manix drained.

Enzel et al. (2003) chose to cite personal communication not intended for publication rather than (1) my dissertation (Meek, 1990, p. 146) where I wrote: "Following the draining of Lake Manix, the Mojave River delta remained active throughout a long mesic interval which continued to about 9 or 8 ka. Until 12.3 ka, and possibly 11.3 ka, the delta shifted into Coyote basin, and was responsible for one or more deep lakes in Coyote basin long after the remainder of the Manix basin had drained and was dry."; or (2) the detailed discussion of the deltas in Coyote basin that accompany the different lake stands in Coyote basin in an article titled: "The geomorphology of Coyote basin" (Meek, 1994, p. 6-7); or (3) the map and statement: "...several radiocarbon dates from the topographically intact subbasins of Lake Manix indicate that lakes continued to exist in the Coyote and Troy subbasins long after Afton Canyon had formed and the Afton subbasin was permanently drained. Major lakestands produced by a shifting Mojave River occurred in Coyote basin about 17,500, 13, 600, 12,900 and 11,800 years B.P" (Meek, 1999, p. 115-116).

There is no evidence requiring that the maximum stand of Lake Manix (cresting on the beach ridges at 543 m but normally remaining more than 3 m lower) was maintained by an overflow sill in the Afton Canyon region that carried water towards Lake Mojave (e.g., Weldon, 1982; Enzel et al., 2003, p. 65). The salient point of my 1990 written communication was to notify Wells of the huge increase in surface area and volume of Lake Manix at elevations just below 543 m, and to point out that the Coyote and Afton (and probably Troy) subbasins could each have independent lake histories that reached the same maximum elevation depending on the flow direction of the Mojave River. Only after all three subbasins were filled to the internal overflow sill elevation between Coyote and Afton basin would the level of Lake Manix rise above the sub-543 m stage. Clearly, when the rim of Afton basin failed and Afton basin drained, any water in Coyote basin would be residual until the Mojave River shifted course to flow into the basin—something it appears to have done more than once.

Is the Mojave River deltaic plain a braid delta or a fan delta?

Since I labeled the Mojave River deltaic plain between Yermo and Camp Cady a braid delta (Meek, 1989a, p. 7), Wells and his students have found it necessary to attempt to correct me by incorrectly terming it a fan delta. For example, Enzel et al., (2003, p. 66) title a section of their paper "The Mojave River fan delta" and then, to emphasize their point, write: "The large delta that is observed at the surface and termed 'Mojave River braid delta' (e.g. Meek, 1990) is of late Quaternary age." They also label the landform a fan delta on two figures in their article.

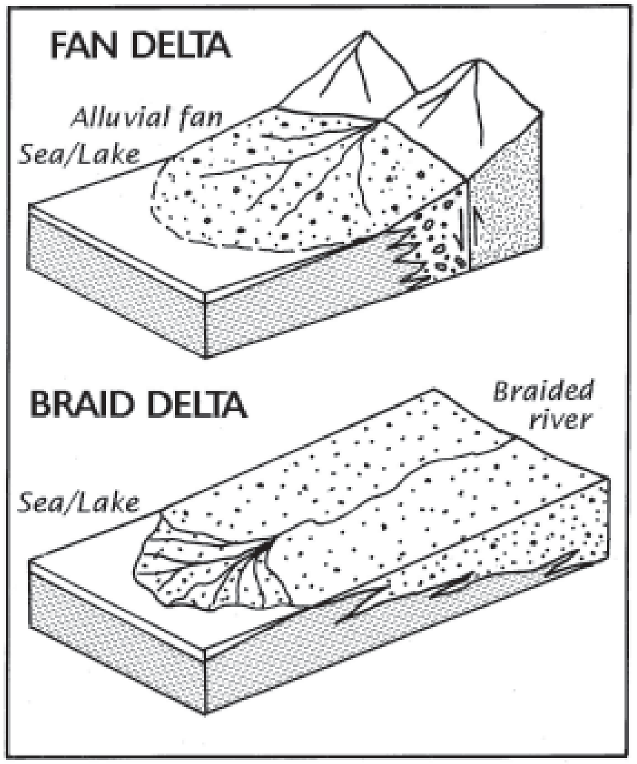


Figure 1 Caption: Fan delta vs. Braid delta (after McPherson et al., 1987, p. 332)

I based my terminology on a paper published in the *Geological Society of America Bulletin* titled "Fan-deltas and braid deltas: varieties of coarse-grained deltas" (McPherson et al., 1987). The purpose of the article is to differentiate between the two types of coarse-grained deltas (see Figure 1), and the article provides 16 criteria to differentiate the two. The Mojave River deltaic plain meets all relevant criteria for a braid delta, but few of the requirements for a fan delta. The first five sentences of the McPherson et al. (1987) article explain the differences: "Two types of coarse-grained deltas are recognized: fan-deltas and braid deltas. Fan deltas are gravel-rich deltas formed where an alluvial fan is deposited directly into a standing body of water from an adjacent highland. They occupy a space between the highland (usually a fault-bounded margin) and the standing body of water. In contrast *braid deltas* (here introduced) are gravel-rich deltas that form where a braided fluvial system progrades into a standing body of water. Braid deltas have no necessary relationship with alluvial fans, as exemplified by fluvioglacial braid deltas." After reviewing McPherson et al. (1987), I have no doubt that the reader will consider the Mojave River deltaic plain in Troy, Afton and Coyote basins to be a braid delta.

Challenging the Silver Lake work

It should be appreciated that a strong bias exists in the Silver Lake research of Wells and his students, because extrapolated deposition rates and other key assumptions of their research program would be overturned by the rapid draining of Lake Manix. In spite of multiple written invitations, no member of their active research group has ever been on one of the many field trips I have led to the Manix basin, including the multiple advertised trips for organizations such as the Association of American Geographers (Meek and Dorn, 1992), the International Association of Geomorphologists (Dorn and Meek, 1993) the Mojave Desert Quaternary Research Symposia (e.g., Reynolds et al., 2000) or the recent National Association of Geology Teachers meeting in 2003. Thus, I have not had the opportunity to show them the field evidence supporting my interpretations in the Manix basin or Harper basin.

On the other hand, I attended the Friends of the Pleistocene trip that visited the Silver basin in 1985 that was partially led by Wells, and also Wells' field trip in the Manix, Troy and Silver basins associated with the 1994 Cordilleran GSA meeting. In October 1985 I witnessed their interpretation of soil pits and shoreline evidence in the Silver basin after having worked in the Manix basin since January 1985. In was obvious that Wells et al. (1985) were attempting to interpret the Silver Lake stratigraphy without detailed knowledge of Late Wisconsinan hydrologic events upstream from Afton Canyon (nothing concerning Afton Canyon or Lake Manix appears in the Wells et al. 1985 or 1987 articles), and since they were suggesting that "an increase in effective moisture between 15,500 and 10,500 yr B.P. was probably necessary to maintain this lake [meaning

Lake Mojave]" (Wells et al., 1987, p. 140), this led directly to my efforts to point out the significance of Lake Manix to their studies (Meek, 1989a).

Since then, I provided new empirical radiocarbon evidence that dismissed the 14 ka lake stand in the Manix basin (Meek, 1999, p. 115). In 1990 I discussed my suspicions that the 14 ka lake stand might be erroneous because of conflicting varnish dates, the absence of tufa, and the fact that I could not find the inflow delta associated with this lake stand (Meek, 1990, p. 135-137). I was also aware that it did not fit the downstream record that was richly supported with radiocarbon dates on shells after 16.3 ka (Meek, 1990, p. 137; 140). To try and resolve the issue, I collected new shell fragments from the same beach ridge overwash deposit that had been dated at 14.23 ka and submitted them to two different radiocarbon labs (Meek, 1999, p. 115), fully believing that they should produce an older age, either from the 19 or 29 ka lake stands. This is exactly what happened.

Today, I don't believe that the 21.5 to ~18.1 ka stand of Lake Manix will see significant (i.e., more than 1 ka) revisions because there are eight radiocarbon dates from this interval, some of which are from the coarse-grained braid delta associated with this lake stand.

Enzel et al. (2003, p. 67) report that the Silver basin has evidence of a deep lake beginning sometime around 22 ka or earlier, and Wells et al. (2003, p. 111) have now concluded that the waters of a lower Lake Mojave rose to inundate the Silver basin starting at ca. 22.6 ka. Assuming that the radiocarbon chronologies are reliable, an obvious question that arises, then, is how a large quantity of Mojave River water made its way downstream to Lake Mojave several thousand years prior to ~18.1 ka when radiocarbon evidence on *Anodonta* shells suggests that the Lake Manix basin was still intact. Three possibilities exist: 1) there was once an overflow sill at an elevation of about 543 m in the vicinity of Afton Canyon that is close to the height of the present overflow sill between Coyote and Afton basin (Wells and Enzel, 1994; Wells et al., 2003); 2) groundwater leaked from the Manix basin through the Cave Mountain/Afton Canyon/Cady Mountain barrier because of its large hydraulic head and the fracture zones associated with the Manix fault system; or 3) the evidence for major lake stands in the Silver/Soda basin prior to 18.1 ka is problematic. Because of extensive erosion, the first two possibilities are impossible(?) to examine today (unless one believes that Baxter Wash was the overflow channel), but the last option—the Silver/Soda basin chronology—can be investigated.

The Silver/Soda lake chronology prior to 16.3 ka has been based primarily on extrapolated average deposition rates in cores (Enzel et al., 2003, p. 67, Wells et al., 1989, p. 86), but recently Wells et al. (2003, p. 105) added inferred correlations of aeolian deposits to support the age control. *In 1990, I pointed out that the average deposition rate of clays in the downstream Silver/Soda basin should have rapidly changed after Afton Canyon formed* (Meek, 1990 , p. 137), *regardless of when Afton Canyon formed, because erosion of vast quantities of sediments from the Manix basin started then*. Wells et al. (2003, p. 104-105) continue to claim that average deposition rates in the Silver/Soda basin have remained between 1.08 and 1.16 m/1000 yrs from ~22 ka to ~9 ka, and they have developed an elaborate history of lake fluctuations and drying events based partly on those assumptions (e.g., Wells et al, 1989; Enzel et al., 2003; Wells, 2003). A long history of Silver/Soda lake research, then, would have to be substantially reinterpreted if Lake Manix drained rapidly after ~22 ka.

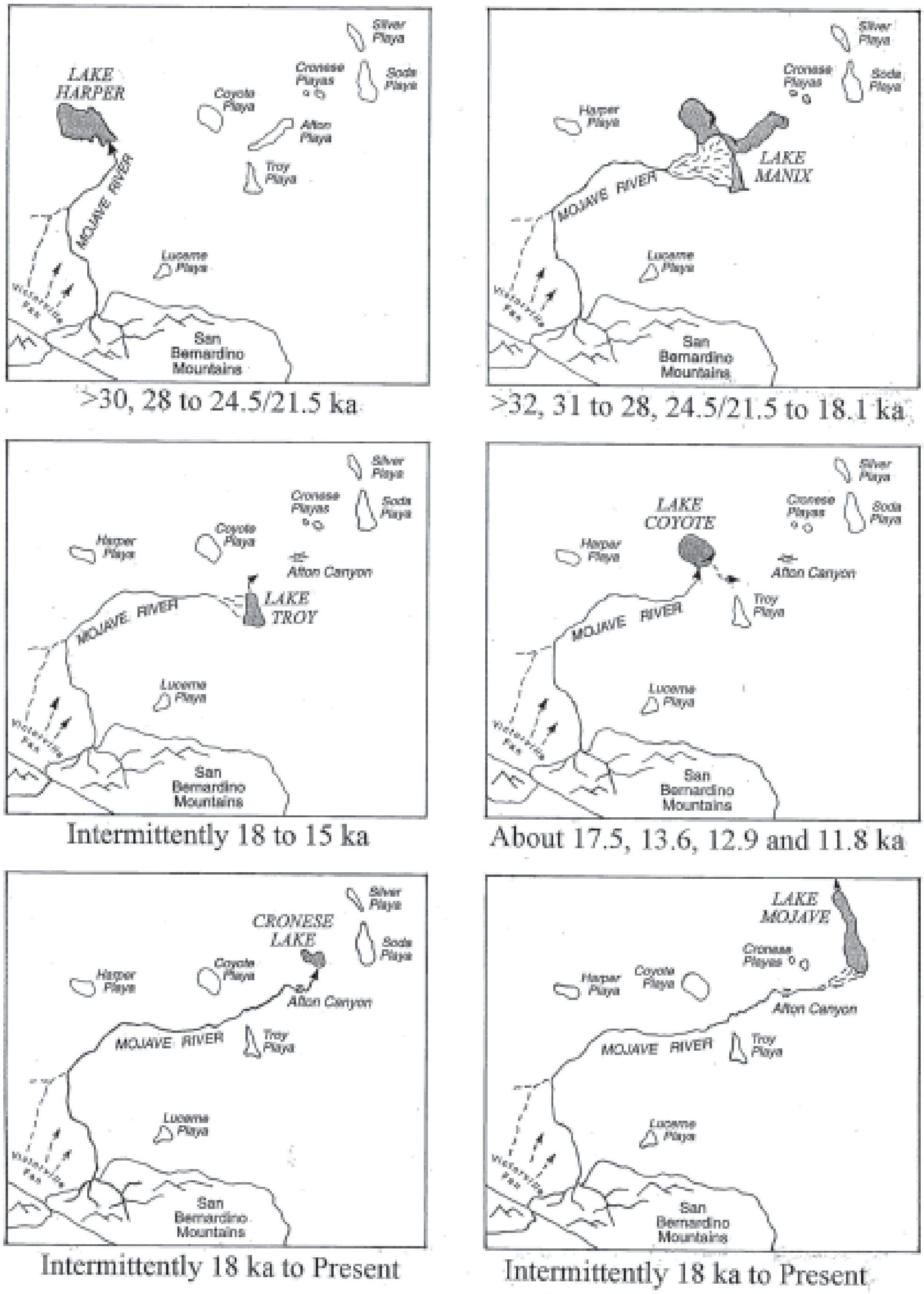
Assuming that there is reliable evidence that Lake Manix drained after ~18.1 ka, the most obvious explanations for the constant clay accumulation rates in the Silver/Soda basin after their inferred inferred 22 ka horizon are: 1) because all of the layers starting with at least the "intermittent lake 1" in SIL-1 of Wells et al. (1989, Fig. 23) accumulated after the rim of Lake Manix failed, and 2) because the age control and extrapolated deposition rates in the Silver/Soda basin prior to at least 16.3 ka are invalid. What is surprising is that Wells et al. (2003, p. 79-80) admit that *"...the beginning of Lake Mojave II appears to have coincided with the incision of Afton Canyon and subsequent draining of Lake Manix, an event which significantly increased sediment loading...*" yet despite this, the graphs of Wells et al. (2003) show no change in the sediment accumulation rates about this time.

It is noteworthy that the sole radiocarbon date that constrains the Enzel et al. (2003) chronology in the Silver/Soda basin prior to 16.3 ka is a single 20.3 ka date on "disseminated organic matter" which they use to infer essentially constant sediment accumulation rates in Silver basin before and after Afton Canyon formed (Enzel et al. 2003, p. 67; Wells et al., 1989, p. 86). Three such radiocarbon dates were produced from their deep core (SIL-I), but one was discarded as "suspect" because it failed to fit their model of sediment accumulation independently developed by study of the nearby beach ridges (Wells et al., 2003, p. 104).

Another of their disseminated organic matter dates is just as "suspect" as the one that they discarded. It is possible that the disseminated organic material dated at 20.3 ka washed into the Silver basin from the Manix basin amid the massive influx of clays and sediments from Lake Manix that began when it drained rapidly, perhaps about 18 ka. There was a substantial lake in the Manix basin from >21.5 to 18.1 ka, and based on similar beds in Coyote basin from this interval, the contemporaneous lake in Afton basin contained abundant clays and organic matter. I would caution researchers to be suspicious of the existing (or any future) "disseminated organic matter" dates on the clayey sediments in the Silver/Soda basin until macrofossils (i.e., shell beds) that could not have washed in from the Manix basin are found in the layers. Researchers should also be aware that without (multiple) reliable disseminated organic matter dates in the cores, much of the detailed climate record in the Silver basin is not constrained temporally, but is based on inferred correlations with the beach ridge strata.

If the assumption of near-constant deposition rate in the Silver Lake cores is erroneous, the timing of events in the Silver basin is subject to change. In spite of my warnings (Meek, 1994, p. 7; Meek, 1999, p. 116) for workers to be wary of interpreting the stratigraphy of any terminal basin

Figure 2: Late Wisconsinan flow directions of the Mojave River. Because of river avulsion across the broad intervening plains, the river has terminated sedimentologically in at least six different terminal basins during the Late Wisconsinan (Modified from Meek, 1999).



>30, 28 to 24.5/21.5 ka

>32, 31 to 28, 24.5/21.5 to 18.1 ka

Intermittently 18 to 15 ka

About 17.5, 13.6, 12.9 and 11.8 ka

Intermittently 18 ka to Present

Intermittently 18 ka to Present

as a record of paleoclimates until proof is provided that the Mojave River was continuously flowing into that basin, Wells et al. (2003, p. 113) have claimed that a major drying event indicates that the Silver Lake region experienced a major drought about 15.5 ka. They made this interpretation even though the Mojave River was migrating laterally across its plain upstream of Camp Cady during this time, periodically terminating in Coyote and Troy basins (Meek, 1999). If one presumes that the timing of their drought is subject to change, then it is possible that the "drought" is simply the result of the Mojave River terminating in another basin such as Coyote or Troy for some unknown interval, perhaps at one of the times already identified (see Fig. 2).

Until solid evidence is provided that a substantial stand of Lake Mojave coincides with a deep stage of Lake Manix, I believe the conclusion of Enzel et al., (2003, p. 69) that "Lakes Manix and Mojave coexisted during the last glacial maximum, at least for a short period, to form a joint lake area that could have reached up to ~500 km^2 that was supported by the Mojave River" is a speculative proposition, possibly invalidating the paleoclimate analyses that are built on this assumption.

A final point to keep in mind when considering whether evidence of a near catastrophic flooding event should appear in the Silver Lake record is that the Silver Lake basin was not the lowest large basin downstream from Afton Canyon during the Late Wisconsinan (Wells et al., 1994, p. 184), and thus Silver Lake was neither the primary depocenter nor the first place downstream from Lake Manix to record hydrologic changes during the Late Wisconsinan. A massive influx of sediments from Afton basin has infilled the large basin that once existed in the Crucero and southern Soda Lake vicinities. Thus, the elevated paleogeographic position of the Silver Lake record means that similar facies probably record larger hydrologic changes in the region at 18 ka than they did at 13 ka or than they do today, and that much or all of the water from the rapid breach of the Manix basin could have been contained in the larger and deeper basin upstream of the Silver Lake basin that has yet to be studied at the same level of detail.

A different perspective on Mojave River history

From the preceding review, it should be apparent that the Enzel et al. (2003) article is in error in several respects. Having read their critique, a reasonable question is whether and how I would alter my latest graphic presentation of Mojave River history (Meek, 1999, p. 116). The answer is that I would widen the caption listing 21.5 ka as the time of avulsion between Lake Harper and Lake Manix to a broader 24.5 to 21.5 ka interval because I am uncertain when it actually occurred. Nothing else would change based on evidence presented by Enzel et al. (2003). Moreover, given all of the evidence I am aware of from this region, I believe Figure 2 summarizes Late Wisconsinan Mojave River history upstream of Afton Canyon in the most straightforward manner and without the many unsupported assumptions of Enzel et al. (2003).

However, I want to mention two new thoughts about Mojave River history that I have not discussed in previous publications:

1) Enzel et al. (2003, p. 69) claim that “very slow nickpoint propagation” of the Mojave River upstream of Afton Canyon occurred “through unconsolidated sediments.” I once made a similar mistake by analyzing constant nickpoint recession rates and not taking into account the lithologic resistance of the different reaches (Meek, 1990, p. 110-113). For anyone who drives to the Afton Canyon campground it is apparent that the river upstream of the canyon is entrenched in highly cemented fanglomerates. Numerous tributaries in this area have major nickpoints (atop the cemented fanglomerates) that are impassable without ropes, and some large strath terraces are evident along the Mojave River. Thus, it is likely that nickpoint recession of the Mojave River in the two-mile region upstream from Afton Canyon would have proceeded very slowly (i.e., probably taking thousands of years) before reaching the weakly consolidated sediments in the badlands south of Dunn. Moreover, once the nickpoint migrated farther upstream of the Buwalda Ridge area, it would have encountered resistant fanglomerates again, this time associated with Buwalda Ridge and the Mojave River formation (Jefferson, 2003). These fanglomerates might have again slowed nickpoint recession upstream from Buwalda Ridge for thousands of years, allowing the Mojave River to migrate laterally across its braid delta into the Holocene.

2) The resistant fanglomerate barriers in the Buwalda Ridge area might have ponded Mojave River water locally long after Afton Canyon formed. However, because this region has been deeply eroded, the existence of such a subbasin is speculative. However, in several iterative computer analyses recreating the stepwise erosion of Afton basin based on lithologic resistance and local stream gradients, Kempton (2001, Plates 3-5 and 9-11) discovered that one or two small subbasins remained in the Buwalda Ridge vicinity long after Afton Canyon formed.

If these sub-basins existed, they would provide an additional explanation as to why the Mojave River was belatedly transporting unusually large quantities of green clays into the Afton basin after the tributaries in the Afton area had partially incised in resistant fanglomerates. These green clays were interpreted by Blackwelder and Ellsworth (1936) as evidence for a third lake in Afton basin that developed after Afton Canyon formed, but I have interpreted the sediments as possible slackwater or levee-ponded deposits that accumulated in tributary canyons as the Mojave River incised (Meek 1989b, 1992).

Some concluding thoughts for future researchers

This paper outlines a case example of how science should NOT work. Instead, whenever possible:

1) scientists should visit their peer’s field sites in their peer’s company before writing major critical reviews of their work;
2) scientists should conduct thorough literature reviews and/or attempt timely communications rather than use obsolete letters and correspondence that were not intended for publication;
3) scientists should provide the specific locations of field evidence in their publications and if requested by colleagues;
4) scientists should be able to find analogues somewhere on the Earth for processes they invoke;
5) scientists should realize that it is in their best interest to use peer reviewers intimately familiar with the field evidence and differing interpretations in a region;
6) scientists should beware of conflicts of interest and biases, for it is now apparent that a presumed solid research program could be in danger of being washed away by a flood originating upstream.

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