High-Resolution Holocene Alluvial Chronostratigraphy at Archaeological Sites in Eastern Grand Canyon, Arizona

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HIGH-RESOLUTION HOLOCENE ALLUVIAL CHRONOSTRATIGRAPHY AT
ARCHAEOLOGICAL SITES IN EASTERN GRAND CANYON, ARIZONA

by

Erin Margaret Tainer

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

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ABSTRACT

High-resolution Holocene Alluvial Chronostratigraphy at Archaeological Sites in Eastern Grand Canyon, Arizona

by

Erin M. Tainer, Master of Science
Utah State University, 2009

Major Professor: Dr. Joel L. Pederson
Department: Geology

Understanding the nature of Colorado River deposits in Grand Canyon helps reveal how the river responds to changes in its Colorado Plateau tributaries and Rocky Mountain headwaters. This study focused on Holocene alluvial deposits associated with archaeological sites excavated near Ninemile Draw in Glen Canyon and at Tanner Bar in eastern Grand Canyon. Two previously-developed conceptual models of deposition were tested based on previous work. Previous researchers have suggested that Holocene alluvial deposits in Grand Canyon are a series of inset aggradational packages that correlate to valley fills and arroyo-cutting cycles in Colorado Plateau tributaries and are laterally consistent throughout the river corridor. An alternate hypothesis is that alluvial packages record paleoflood sequences along the Colorado River with no Holocene change in river grade. In this model, deposits are preserved more variably as a function of local hydrologic geometry, and they should be less correlatable.
Detailed stratigraphic columns of terrace deposits and several stratigraphic panels of archaeological trenches, combined with facies interpretations, were used to reconstruct a high-resolution alluvial history at two locations. Optically stimulated luminescence (OSL) and radiocarbon dating methods were used at both locations with consistent results. At both sites, the sediment includes multiple depositional facies of mainstem and local-source material, and it consists of stratal packages bound by unconformities.

These stratigraphic relations, combined with geochronology, lead to the interpretation that the alluvium is composed of six correlatable alluvial packages at overlapping heights above river level throughout the canyon. The four older packages include facies that imply aggradation throughout the river corridor, suggesting oscillations in river grade. The youngest two packages consist only of mainstem flood deposits. These packages suggest that preservation of deposits over the past ~1 ky has not been driven by aggradation, although incision since ~1 ky is possible. Comparison of the interpreted chronostratigraphy to climate records suggests that this large river’s grade has not responded visibly to smaller century to millennial-scale climate oscillations. This work is the first to document that the alluvial record in Grand Canyon spans the entire Holocene, and conclusions support to both previous conceptual models of deposition.
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INTRODUCTION

The Colorado River is well-known for the spectacular erosion it has driven along its length, especially in Grand Canyon. The river receives most of its water from the Rocky Mountains but most of its sediment from the Colorado Plateau (Andrews, 1991), and it has integrated conditions in both regions into a complex alluvial history. This history has undoubtedly been influenced by changes in runoff and sediment yield, some of which have been recorded in alluvium along the Colorado River corridor in Grand Canyon. Human habitation of the area was also influenced by changes in river behavior (Fairley, 2003), and the alluvial record preserves important information about archaeology along the river corridor.

The overall objective of this research was to gain a better understanding of the Holocene alluvial history of Grand Canyon by combining detailed stratigraphic data and interpretations with geochronology. The study areas include Ninemile Draw, in Glen Canyon, and Tanner Bar, in eastern Grand Canyon. These two locations host some of the best preserved and exposed Holocene deposits in the eastern Grand Canyon region. Excellent stratigraphic exposure was available because this research was done in conjunction with archaeological excavations in 2008.

A better understanding of Holocene stratigraphy in Grand Canyon has both practical and theoretical applications. First, results have importance for the ongoing archaeology studies of the river corridor in Grand Canyon. The stratigraphy at archaeological sites provides the record of paleoenvironment during early human occupation and abandonment of these locations. By determining the river’s behavior
throughout the late Holocene in the context of archaeological sites, a clearer picture of how humans were living along the river corridor can be revealed.

Second, a refined record of Holocene stratigraphy in Grand Canyon can help us understand the fluvial geomorphic processes that created the preserved stratigraphy. Two end-member models of Holocene deposition in Grand Canyon have been proposed by previous workers. One model is that these Holocene alluvial deposits are a series of inset aggradational packages that correlate to the valley-fill and arroyo cycles identified in Colorado Plateau tributaries (Hereford et al., 1996). This hypothesis implies that deposits should correlate throughout the canyon, and that river grade has changed over the Holocene with a link to changing climate and sediment supply.

An alternate model, following work on the same deposits by O’Connor et al. (1994) and Ely (1992), is that the Holocene alluvium primarily represents a record of flood frequency and magnitude along the mainstem of the Colorado River. In contrast to Hereford’s model, this conceptual model implies that river grade has not changed over the Holocene and that deposition responds only to hydrology and not tributary sediment supply. The nature of these models and differences between them is further explored in the Background section. With optically stimulated luminescence (OSL) dating to supplement radiocarbon ages, much more detailed age control is available in this study and these models of deposition are tested.
BACKGROUND

Holocene Alluvium in the Colorado Plateau

Past research on Holocene alluvium in the Colorado Plateau has revealed alluvial packages related to cycles of erosion and deposition. Hack (1942) distinguished three units of alluvial fill in northern Arizona valleys. He termed the depositional packages the Jeddito, Tsegi, and Naha, and he provided age control based on artifacts found within each unit. Abundant subsequent research on these deposits and other Holocene alluvium in the Southwest has varied in terms of approach and interpretation.

Historically, there has been no clear consensus on the degree to which cut-and-fill cycles in the Southwest are synchronous across the region or whether climate is the main driver of these cycles. Hack (1942) noted a correlation between his depositional units and periods of wet climate, and this general link between climate and deposition has been supported by subsequent research (e.g. Cooke and Reeves, 1976; Hereford et al., 1996; Hereford, 2002). Likewise, several studies have supported the idea that aggradation and incision in the Southwest correlate regionally (e.g. Waters and Haynes, 2001; Hereford, 2002; Mann and Meltzer, 2007). In contrast, multiple studies support the idea that alluvial packages do not correlate between locations and are not driven by climate (e.g. Boison and Patton, 1985; Waters, 1985; Patton and Boison, 1986). Some studies also suggest that correlating depositional packages across a region may be difficult because of internal geomorphic variables that can cause cycles independent of external forcing mechanisms (e.g. Schumm and Hadley, 1957; Graf, 1987). Graf suggested that there may be lag time in a large river’s response to climate change as compared to the response
time of smaller streams. Specifically, drainages with areas greater than 10,000 km² have discontinuous sediment transport and storage because of their integrated response to both mountain-headwater hydrology and lower-plateau sediment supply (Graf, 1987).

**Holocene Paleoclimate in the Colorado Plateau**

To evaluate linkages between paleoclimate and the Grand Canyon alluvial record, it is necessary to compare the results of this study with records of Holocene climate in the Colorado Plateau and surrounding areas. Most paleoclimate studies of this region do not span the entire Holocene, but in combination they provide a broad understanding of Holocene climate in the Grand Canyon region.

Anderson et al. (2000) synthesized paleoclimate data in the southern Colorado Plateau, including pollen, packrat middens, and stratigraphic deposits such as lake sediments. The synthesis focuses on the middle to late-Wisconsin or Marine Oxygen Isotope Stages (MIS) 2 and 3, but includes some information from MIS 1, the Holocene. The data suggest that the mean annual temperature during the last glacial maximum (MIS 2) was ~5°C cooler than today. In eastern Grand Canyon, paleobotanic records suggest that vegetation shifted in elevation and from glacial to modern assemblages with an overall warming of temperature between ~13 and ~9.5 ka, which spans the Younger Dryas oscillation (Anderson at al., 2000). Also, based on the expanse of ponderosa pine across the southern Colorado Plateau during the beginning of the Holocene, a maximum in summer precipitation is inferred at ~9 ka (Anderson et al., 2000).

Early Holocene climate of the region is also revealed through studies of packrat middens and bat guano in Grand Canyon. Data of δ¹³C values from packrat middens
reveal that temperatures cooled ~4° C during the Younger Dryas, between 11.8 and 11.5 ka (Cole and Arundel, 2005). Additional studies using paleobotanic data from packrat middens indicate that immediately after the Younger Dryas, conditions were ~1° C warmer and there was more effective moisture than today (Cole, 1990). Wurster et al. (2008) used δ13C and hydrogen isotopes from bat guano in the Grand Canyon as a climate proxy and showed that early Holocene climate gradually became warmer with increased summer precipitation until ~9 ka, which coincides with a summer solar insolation maximum. Results confirm cooler and drier conditions during the Younger Dryas than present and an abrupt temporary decrease in δ13C values at ~8.2 ka, suggesting cooler conditions with less summer precipitation at that time (Wurster et al., 2008). Overall, paleoclimate studies of the early Holocene reveal a cold Younger Dryas followed by warming and an episode of increased monsoonal precipitation at ~9 ka.

Climate proxies bridging records between the early and mid-Holocene include lake sediment cores and speleothems. These studies indicate a period of warmer, drier climate in the mid-Holocene, known as the Altithermal. Weng and Jackson (1999) used data from pollen on the Kaibab Plateau to show that from ~11 to 8 ka climate was cooler and wetter than today with a stronger summer monsoon. Their data indicate that the middle Holocene Altithermal was dry and warm, and that the late Holocene was wetter and cooler with increasing effective moisture due to changes in summer insolation (Weng and Jackson, 1999). Asmerom et al. (2007) present a high-resolution Holocene climate record from speleothems in southeastern New Mexico. Using δ18O values, variations in annual band thickness, growth-no growth records, mineralogy changes, and uranium-series dating for age control, their study shows millennial and centennial-scale climate
variation. They similarly conclude that after the Younger Dryas, the early Holocene was characterized by warming with a wet period lasting until 10 ka, followed by a dry period until 7 ka, and then a return to a wetter climate (Asmerom et al., 2007).

In terms of late Holocene climate, Polyak and Asmerom (2001) present an additional mid and late Holocene paleoclimate record from speleothems from the same cave as the 2007 study. These results show that climate was similar to today from 4 ka to 3 ka, immediately following the Altithermal (Polyak and Asmerom, 2001). From 3 to 0.8 ka, wetter and cooler conditions were present, followed by conditions similar to today except for a wetter interval from 0.44 to 0.29 ka, which corresponds to the Little Ice Age (Polyak and Asmerom, 2001).

Late-Holocene paleoclimate records for the Colorado Plateau also include paleoflood studies and tree ring records. Ely (1992) established a composite chronology of flood deposits on rivers in Arizona and southern Utah. This was created by correlating flood deposits between sites dating deposits using radiocarbon and cesium-137 dating (Ely, 1992). In the paleoflood studies, flood events were compared to an El Niño-Southern Oscillation (ENSO) index, concluding that there is a correlation between large floods and episodes of more frequent El Niño conditions over the past millennium (Ely, 1992). Overall, the paleoflood results imply that large floods over the last 5 ka occurred specifically from 3.8 to 2.2 ka, 1.1 to 0.9 ka, and after 0.5 ka until present (Ely, 1997).

Also relating to flood hydrology, Cook et al. (2004), Woodhouse et al. (2006), and Meko et al. (2007) used tree ring data for drought analyses and to extend the record of annual Colorado River stream flows at Lees Ferry as far back as 1.2 ka. These records
provide evidence for a dry period, corresponding to the Medieval Climate Anomaly from 1 to 0.7 ka (Cook et al., 2004).

A theme in the extensive climate research from this region is that the Holocene epoch in the Colorado Plateau contained three broad climate episodes. The early Holocene is generally characterized as a period of warming that was more monsoon-dominated than today, the middle Holocene was warmer and drier than today, and the past 4 ka have been similar to today with century-scale climate shifts associated with the Medieval Warm Period and the Little Ice Age.

**Holocene Paleoclimate in the Rocky Mountains**

Because the Colorado River integrates sediment signals from the Colorado Plateau with a hydrology dictated by Rocky Mountain headwaters, the geomorphic response to climate is likely driven by changes in both regions. A synthesis of studies using these proxies in portions of the Rocky Mountains in Colorado, Utah, and New Mexico is presented by Refsnider and Brugger (2007). These researchers used lichen diameters on rock glaciers in central Colorado to determine that there were periods of glacial activity, indicating cooler conditions, at ~1.15 ka, ~2.07 ka, and ~3.08 ka. These periods correlate to other proxies of Rocky Mountain climate including glacial records, pollen assemblages, packrat middens, lake sediment cores, beetle assemblages, and tree ring data (Refsnider and Brugger, 2007).

A study of sediment in the Henry’s Fork, ID drainage shows a similar pattern of climate change in the Rocky Mountains (Munroe, 2003). Using a study of vegetation changes coupled with changes in mode of deposition (fluvial, lacustrine, or wetland), the
study concludes that the mean annual temperature of this region at ~9.5 ka was ~1°C greater than today. They also conclude that the area’s maximum temperature was between 6.5 and 5.4 cal yr BP, with near-modern climate present from 5.4 to 3.8 ka.

An additional study of Rocky Mountain Holocene climate is a synthesis by Fall (1997). Her study used timberlines as a paleoclimate proxy in eight sedimentary basins in southern Colorado. Pollen and plant macrofossil data show that before 11 ka, the climate in the southern Rocky Mountains was 2-5 °C cooler than today with 7-16 cm greater precipitation. From 9 to 4 ka, the temperature was 1-2°C warmer than today with an intensification of the monsoon and increased solar insolation between 9-6 ka that raised the mean annual precipitation (Fall, 1997). Conditions from 6-4 ka were drier than present, followed by a cooling to 1° C warmer than today and finally modern climate at 2 ka (Fall, 1997).

Proxies for Rocky Mountain paleoclimate indicate the same broad climatic episodes that have been found in proxies of Colorado Plateau Holocene climate. First, they indicate that conditions changed at ~11 ka. They reveal warmer, wetter conditions between 9 and 6 ka, which corresponds to the warming and increase in monsoonal precipitation identified in Colorado Plateau climate proxies. In addition, Rocky Mountain climate proxies reveal a dry period in the mid-Holocene, which corresponds to the Altithermal. For the past 4 ka, the climate has been at near-modern conditions with episodes of slight cooling as indicated by proxies for glacial extent.

Previous Geomorphic Research in Grand Canyon
Previous Grand Canyon researchers have produced a wealth of literature on geomorphic topics such as debris fans, sediment supply and limitation related to human management of the river, fill terraces and their relations to climate, and the Holocene alluvial stratigraphy. Leopold (1969) first identified that the channel geometry and longitudinal profile of the Colorado River is controlled by the rapid-and-pool sequences found in the canyon. An early study on the geomorphology of the Colorado River by Howard and Dolan (1981) described the geomorphic settings and features along the river and analyzed its sediment supply. These researchers state that both rock type and tributary debris fan control local channel geometry. Subsequent geomorphic research in Grand Canyon has focused on these debris fans and debris flow frequency, including their control on the longitudinal profile of the Colorado River (i.e. Webb et al., 1989; Melis, 1997; Griffiths et al., 2004; Hanks and Webb, 2006). The effect of debris fans on the local geomorphology of these study locations is discussed below.

Draut and Rubin (2007, 2008) also studied Holocene sedimentation in Grand Canyon, with a focus on eolian transport along the river corridor. A detailed grain size analysis showed that grain size differences can be used, along with sedimentary structures, to distinguish deposits from fluvial deposits in Grand Canyon (Draut and Rubin, 2007). These techniques were applied to three archaeological areas in the canyon, with the general conclusion that most of the archaeological sites in Grand Canyon are set in fluvial deposits (Draut and Rubin, 2008). Nevertheless, eolian processes are important for preservation of archaeological sites along the canyon corridor (Draut and Rubin 2007, 2008).
Fluvial systems respond to changes in hydrology and sediment supply in complicated ways. For example, drastic fluvial response to changes in hydrology and sediment supply at short time scales in Grand Canyon can be observed through studies of the effects of the closure Glen Canyon Dam in 1963. Grams et al. (2007) detail the transformation of the Colorado River corridor in Glen Canyon due to reduction in magnitude and duration of floods and sediment delivery. Changes at Ninemile Draw include river bed lowering of $< 2.5$ m, an increase in bed grain size from 0.25 mm to 25 mm, and erosion of a large portion of the pre-dam alluvium (Grams et al., 2007). Their study is useful in revealing how decreased sediment supply and stream power affect channel morphology and erosion, although whether changes due to the dam are on the same scale as Holocene climate change is unknown.

Large fluvial systems like the Colorado River may take time to adjust completely to changes in climate because they are incorporating signals from multiple tributaries and a large and varied drainage area (Blum, 2008). Research on fill terraces in the eastern Grand Canyon region generally supports this idea, finding that the Colorado River responds strongly to orbital-scale climate changes and is less sensitive to Holocene-scale fluctuations (Anders et al., 2005). In these studies, optically stimulated luminescence, uranium series, and $^{10}$Be cosmogenic nuclide dating were used to provide age control for middle to late Quaternary fill terraces, and results show a temporal link between Colorado River fill terraces and glaciations in Rocky Mountain headwaters (Anders et al., 2005; Pederson et al., 2006; Cragun, 2007). Holocene alluvium was generalized as a single unit (“M1”) that was interpreted to overlie an older gravel fill mostly below modern river grade (Anders et al., 2005; Pederson et al., 2006). Thus, it was interpreted
that all smaller-scale Holocene changes are superimposed on a trend of post-glacial aggradation (Pederson et al., 2006). Nevertheless, the possibility remains that small, temporary, subtle changes in river grade have occurred over the Holocene.

**Previous Work on Holocene Alluvial Terraces in Grand Canyon**

Hereford and others (1996) define three prehistoric late Holocene fill terraces of the Colorado River in Grand Canyon, with constraints from 27 radiocarbon ages (Figure 1). The oldest of these units is the striped alluvium, or sa, deposited from before 770 B.C. to A.D. 300 (Hereford et al., 1996). The sa is named for the interbeds of reddish tributary-derived material and mainstem sand common in this unit (Hereford et al., 1996). The alluvium of Pueblo II age, ap, is inset into the sa and dates from A.D. 700 to 1200 (Hereford et al., 1996). This package is generally characterized by mainstem flood sands and little local-slope material. The third prehistoric fill terrace defined by Hereford is the upper mesquite terrace, umt, which was deposited from A.D. 1400 to 1880 (Hereford et al., 1996). The umt is also a distinct package of mainstem flood deposits and is inset into the sa and ap. Hereford et al. (1996) state that early and middle Holocene deposits had not yet been recognized because they were evidently not preserved adjacent to the river or were buried by younger deposits.

Hereford’s conceptual model of alluviation was developed based on these three prehistoric Holocene terraces and additional historic deposits (Figure 2). By using the same unit names along the entire Colorado River, Hereford’s model clearly implies that the same depositional packages are found throughout the canyon, and he uses the same unit names along the entire Colorado River corridor. Hereford relates the inset terraces
Figure 1. Previous chronology of Holocene terraces in Grand Canyon. Temporal relations to cultural history are also noted. From Hereford et al., 1996 and Fairley, 2003.
Figure 2. Conceptual model of inset packages of Holocene alluvium. sa= striped alluvium, ap= alluvium of Pueblo II age, umt= upper mesquite terrace, lmt= lower mesquite terrace pda= pre-dam alluvium, ‘83= 1983 flood deposits, e= eolian sand deposits. Arrows indicate erosion or deposition associated with changing river grade. Modified from Hereford et al., 1996 and Fairley, 2003.
to cycles of aggradation and incision of the river, as well as to alluvial chronology of
tributaries on the Colorado Plateau (Hereford et al., 1996; Hereford, 2002). Specifically,
the sa, ap, and umt terraces result from systematic river aggradation, while the younger
packages are paleoflood deposits with no associated downcutting (Hereford et al., 1996).

Hereford suggests that the sa and ap terraces correlate to Hack’s Tsegi, while the
umt corresponds to the Naha. Within the Paria River watershed, Hereford (2002)
documented the drainage-wide Naha alluviation, and he linked it to deposition of the umt
in Grand Canyon, suggesting that the entire Colorado River basin was responding to the
same forcing mechanisms. Also, he has made links between climate and the pattern of
alluvial deposition in Grand Canyon. For example, Hereford’s ap appears to correspond
to the Medieval Warm Period revealed by tree ring paleohydrology records (Hereford et
al., 1996; Cook et al., 2004). Also, Hereford linked stream entrenchment on the Colorado
Plateau to a period of erosion in Grand Canyon around A.D. 1200-1400, the time period
between the deposition of the ap and umt terraces (Hereford, 2002).

Holocene terrace formation in Grand Canyon was also studied by Lucchitta and
others (1995). Through observations of stratigraphy within 10 meters in elevation from
the modern river, Lucchitta identified an aggradational depositional package that he
termed the “archaeological unit”, which corresponds to Hereford’s sa and ap. Lucchitta
also states that there has been ~10 m of downcutting since the end of deposition of the
archaeological unit at ~800 years ago (Lucchitta and Leopold, 1999). The
archaeological unit is formed through aggradation based on three pieces of evidence.
First, the package was interpreted to be correlative throughout the canyon. Also, deposits
of tributaries are graded to the top of this terrace. A third observation is that the unit is
present in reaches of different morphology and not just in back-water eddy areas, implying system-wide aggradation. In addition to identifying the archaeological unit, Lucchitta observed two younger, non-aggradational deposits, the Green Arrowweed and Silver Arrowweed terraces (Lucchitta et al., 1995). These terraces are both within historic flood stages, similarly to Hereford’s lmt, pda, and younger deposits.

O’Connor et al. (1994) and Ely (1992) interpreted some of these same Holocene deposits to be paleoflood packages preserved at discrete locations in the canyon (Figure 3). In a conceptual model of deposition that we base on this work, alluvial terrace are underlain by a series of stacked and inset slackwater deposits representing progressively larger floods preserved towards the top, with smaller floods inset. This conceptual model was not explicitly stated in their work, but is clearly implied through their analysis. For example, they calculate the magnitude of paleofloods based on present stage-discharge relations, with the largest flood having a discharge of 14,000 m$^3$/s (O’Connor et al., 1994). At Axehandle Alcove, two river miles downstream from Lees Ferry, a sequence of 15 flood units over the last 4500 years was used to calculate this discharge (O’Connor et al., 1994). Paleoflood deposits were also studied at -3 Mile, three river miles upstream from Lees Ferry. No correlations could be drawn between different stratigraphic columns in the field, so they were matched using radiocarbon dating.

We suggest that, if this approach is correct and paleofloods are driving deposition without changes in river grade, then a single consistent stratigraphic ordering of inset relations and ages should not be found throughout the length of the canyon. This is because the relative stages of individual flood deposits should vary, as dependent upon local hydraulic channel geometry.
Figure 3. Conceptual model of stacked and inset flood deposits, based on the approach of O’Connor et al., 1994 and Ely, 1992.
STUDY LOCATIONS

Two locations along the Colorado River are part of this research, and they were both subject to archaeological excavations in 2008 (Figure 4). The first study location is upstream from the mouth of Ninemile Draw in Glen Canyon, ~10 river miles upstream of Lees Ferry, AZ, on river left (Figure 5). Its archaeological site designation is C:02:032, and excavations took place there in February 2008. The second location is at Tanner Bar, ~68 river miles downstream from Lees Ferry on river left, and it is directly downstream of the mouth of Tanner Wash (Figure 6). Two archaeological sites at Tanner Bar, C:13:323 and C:13:327, were excavated in September 2008.

The study locations lie in two different geomorphic reaches, each with a distinct river and canyon geometry. The average channel gradient in the Glen Canyon reach is 0.0003 (Grams et al., 2007), and the average channel width is 149 m (Mackley, 2005). Here, the river flows through the Jurassic Navajo sandstone in a tight entrenched meander known as Horseshoe Bend. The bedrock-to-bedrock width at the Ninemile Draw site is ~400 m, with the channel width in the Glen Canyon reach being ~300 m wide. This is approximately twice as wide as the overall Glen Canyon reach average because of the presence of a mid-channel gravel bar (Figure 5).

The Furnace Flats reach, which includes the Tanner Bar Study site, is narrower and steeper than the Ninemile Draw reach. Furnace Flats, from Lava Chuar to Unkar
Figure 4. Location map of eastern Grand Canyon sites. Modified from Pederson et al., 2003.
Figure 5. Detailed location map of Ninemile Draw study site.
Figure 6. Detailed location map of Tanner Bar study site.
(river mile 61.6 to 77.4), has a channel gradient of 0.0021, seven times steeper than at Ninemile Draw (Schmidt and Graf, 1990). Also, the average channel width in the Furnace Flats reach is 98 m, ~50 m less than the width in the Ninemile Draw reach (Mackley, 2005). At Tanner Bar, the Colorado River is in a reach underlain by Precambrian Dox sandstone, which accommodates a relatively broad canyon floor. The average width to depth ratio in this reach is 26.6 and the average channel width is 390 ft (Schmidt and Graf, 1990).

Along with differences in canyon geometry and bedrock type, the sites also differ in terms of smaller-scale geomorphic features along the channel. Pleistocene gravelly alluvial terraces are absent at Ninemile Draw, whereas large Pleistocene gravel deposits are prominent in the Furnace Flats reach. Also, there is no debris fan at Ninemile Draw, whereas Tanner Bar has a prominent debris fan that has led to the formation of Tanner Rapids. In addition, sediment supply is different at both sites. The Paria and Little Colorado rivers are major tributaries to the Colorado River downstream of Ninemile Draw and upstream of Tanner Bar, and they supply fine-grained sediment to the Colorado River. The average pre-dam suspended sediment concentration at Lees Ferry was $6.0 \times 10^{10}$ kg/yr (Andrews, 1991). Because of the closing of Glen Canyon Dam, the Ninemile Draw study area currently receives no fine-grained sediment. In contrast, the Tanner Bar study area receives an average of $1.8 \times 10^{10}$ kg/yr of suspended sediment entering downstream of Lees Ferry, and ~70% of that sediment comes from the Paria and Little Colorado rivers (Andrews, 1991).
Ninemile Draw Geomorphic Setting

Ninemile Draw is a tributary to the Colorado River and is located near the downstream end of a long cutbank at this location (Figure 5). The cutbank extends for ~900 m along the inside of the meander bend. Although there is coarse tributary material at the mouth of Ninemile Draw, there is no discernible debris fan landform. Multiple gullies have cut through the terrace tread and exposed stratigraphy, but the best exposure is along the cutbank face parallel to the river. The sediment in the cutbank includes mainstem sand, local tributary and slopewash material, and eolian sand. The archaeological and geomorphic research at site C:02:032 took place in the upstream portion of the cutbank (Figure 5).

Previous Work at Ninemile Draw

Archaeological studies began at Ninemile Draw when charcoal and ash stains within the top meter of stratigraphy were tested for cultural content (Leap and Neal, 1992). Radiocarbon age results were 1715 ± 55 years BP and 3150 ± 55 years BP, both uncalibrated (Leap and Neal, 1992). During a 2005 site reassessment by the Navajo Nation Archaeology Department (NNAD), charcoal was obtained from a hearth in the cutbank and dated with a calibrated radiocarbon result of 2780-2400 years BP (Anderson, 2006). This date is significant because it is from the Archaic period and is older than most of the established cultural history of Grand Canyon (Anderson, 2006).

During stratigraphic analysis by Anderson, terraces were named based on their local depositional chronology, with T1 being the youngest and T6 being the oldest (Anderson, 2006). Anderson produced a stratigraphic column of the upper ~3 m of the
oldest depositional sequence, which he called the “T6”. Anderson’s report does not include individual unit descriptions, but his interpretation of this depositional package was that it contains interfingered mainstem fluvial and local alluvial fan deposits, which are characteristic of Hereford’s striped alluvium (Anderson, 2006).

The deposits at Ninemile Draw were studied by Burke and Hereford (1998), who created a map of the surficial geology of the location. Historic units, including the lower mesquite terrace (lmt) and postdam alluvium (pda) were mapped along with the prehistoric striped alluvium (sa), alluvium of Pueblo II age (ap), and upper mesquite terrace (umt) (Burke and Hereford, 1998). Eolian, colluvial, and alluvial-fan deposits were also mapped. The importance of this mapping effort is that Burke and Hereford identified depositional packages based using their framework of terraces elsewhere along the river corridor, suggesting that the terraces are correlatable across the canyon. The map has not yet been published, so it is not included as a figure, but select features of this previous mapping is compared to results of this study below.

**Tanner Bar Geomorphic Setting**

The second study location is Tanner Bar, which encompasses two archaeological sites on river left (Figure 6). The broader geomorphic setting is important when considering this site. As mentioned above, the Furnace Flats reach is distinct because of its broad canyon geometry influenced by Tapeats Sandstone and Unkar Group bedrock (Schmidt and Graf, 1990). Channel-margin deposits are common in this reach (Schmidt and Graf, 1990).
The presence of the debris fan formed at the mouth of Tanner Creek controls the local geomorphology at the Tanner Bar study site. The reach from river mile 38 to 77, has an average of 2.6 debris fans per river mile (Hanks and Webb, 2006). A few of these debris fans, not including the Tanner Creek fan, have been dated using dissolution pitting. Results suggest that they have experienced active deposition multiple times over the past ~4 ka (Hereford et al., 1996). Thus, there may be some degree of local geomorphic control on river grade since ~4 ka. Because Tanner Wash supplies coarse tributary material to the area, a tributary debris fan has developed at the confluence of Tanner Wash and the Colorado River. Downstream of the tributary debris fan at Tanner Wash lies a large gravel bar between the river and the Holocene terrace scarp. The archaeological sites are located at or near the surface of these Holocene deposits. In addition, stratigraphic exposures are observed in several gullies that cut across the terrace tread. One of these gullies, located between the two archaeological sites, was the site of significant work in this study (Figure 6).

**Previous Work at Tanner Bar**

Research specifically at Tanner Bar includes stratigraphic studies of Holocene alluvium, surficial mapping, and soil studies. The Tanner Wash debris fan was studied by Melis et al. (1994). This debris fan has been active as recently as 1993, when a debris flow aggraded the fan and constricted the river by ~30 m (Melis et al., 1994). Repeat photography also suggests that the 1993 debris flow was the first fan activity since at least 1890. Boulders from Tanner Canyon are present on river right, opposite the debris
fan, indicating that the fan was significantly larger in the recent geological past (Melis et al., 1994).

A detailed soil survey from Palisades to Unkar was completed by Davis et al. (1995). Results from this soil survey, including buried surfaces with corn pollen and other vegetation, were interpreted as evidence for aggradation of the “archaeological unit” in their research (Davis et al., 2000).

The Tanner Bar terrace stratigraphy has been studied by Hereford et al. (1996) and USU geomorphologists (Damp et al., 2007). This location is especially important because it is the informal type section for Hereford’s striped alluvium (sa). Hereford’s studies included the production of topographic maps made from ground surveys and low-altitude aerial photography, a map of surficial geology, and descriptions of two stratigraphic sections. The stratigraphic columns and the surficial geology map produced by Hereford have not published (Hereford, 2008).

Hereford’s research at Tanner Bar included radiocarbon ages for the striped alluvium, which range from ~2300-1600 years BP, with sample locations ranging from near-surface to the exposure base (Hereford et al., 1996). Hereford also dated charcoal related to cultural features in the alluvium of Pueblo II age (ap) at this location, with results ranging from ~1200-900 years BP (Hereford et al., 1996). No inset terraces have been documented at this location, with the ap resting on top of the sa at this site.

Previous age control at the C:13:323 site consists of a single radiocarbon age from a hearth, at 2170 ± 70 years BP, consistent stratigraphically and chronologically with the top of Hereford’s sa (Damp et al., 2007). More detailed study of part of the Holocene alluvium at the C:13:327 site was conducted during reconnaissance for the archaeological
excavations (Damp et al., 2007). The stratigraphy in the top 3.5 m of alluvium in the
gully at the mouth of Tanner Canyon was described, and samples were collected for OSL
and radiocarbon dating (Damp et al., 2007).
METHODS

Sedimentology Methods

Sedimentology methods were conducted on both naturally-exposed Holocene stratigraphy and archaeological study trenches. The study units were typically 1 m x 1 m or 1 m x 2 m pits dug to expose cultural material or expose stratigraphy. Four study units were dug to expose stratigraphy along the terrace front at Ninemile Draw (Figure 7), eight study units exposed stratigraphy at Tanner Bar C:13:323 (Figure 8), and eight study units exposed stratigraphy at Tanner Bar C:13:327 (Figure 8). These study units only exposed stratigraphy adjacent to archaeological features.

Before observations were made, the best-exposed stratigraphy at each site was cleared using shovels, trowels, and brushes. At Ninemile Draw, this stratigraphy included a ~20 m long and ~10 m high section of the cutbank underlying the C:02:032 archaeological site (Figures 5 and 7). At Tanner Bar, the stratigraphic procedure was applied at three primary exposures (Figures 6 and 8). The first exposure was on the north-facing wall of a gully adjacent to the downstream Tanner Bar archaeological site, C:13:327. The second was the south-facing stratigraphy in the geomorphic study gully ~300 m north of the downstream site. The third stratigraphic exposure was underneath the upstream Tanner Bar archaeological site, C:13:323.

Data collection at each exposure began with general descriptions that included exposure type, dimensions, location, and general geomorphic setting. Then individual depositional units were discerned based on features such as texture, color, sedimentary
Figure 7. Topographic map of Ninemile Draw study site (C:02:032) with archaeological study units labeled. Location of the detailed stratigraphic panel is indicated in orange. Topographic lines are from Burke and Hereford, 1998. Contour interval is 1 m, with lighter grey lines indicating 0.5 m contour interval. Geomorphic features of Ninemile Draw are shown in Figure 5.
Figure 8. Topographic map of Tanner Bar study locations with archaeological and geomorphic study units labeled. Topographic lines were obtained as shapefiles from the Grand Canyon Monitoring and Research Center (GCMRC). Locations of detailed stratigraphic sections are indicated in orange. Geomorphic features of Tanner Bar are shown in Figure 6.
structures, and bed geometry. Unit descriptions were recorded, and they included the following characteristics: unit thickness, bed geometry, contacts with adjacent units, sedimentary structures and grading, grain size, texture and composition, sorting, bioturbation, effervescence, cultural material if applicable, and color. Depositional hiatuses and possible unconformities were also identified. In addition to detailed descriptions, field interpretations of each unit were recorded.

After the stratigraphy was described, each exposure was photographed and sketched. Also, paleocurrent directions were measured if ripples were present and well-preserved. The last step of the field procedure was to collect samples for AMS radiocarbon and OSL dating, as described in subsequent sections.

In addition to descriptions of naturally-exposed stratigraphy, the stratigraphy of archaeological study units was described using the procedure outlined above. In each study unit, dimensions and locations were recorded along with the aspect of the face with the best-exposed stratigraphy. At Ninemile Draw, C:02:032, four archaeological study units were described. At the upstream Tanner Bar site, C:13:323, the archaeological excavation included five described study units. At the downstream Tanner Bar site, C:13:327, seven study units were described. All of the study units were at the top of the landforms and included only the upper ~1-2 m of Holocene stratigraphy. Some study units were not used to analyze the overall stratigraphy because they were repetitive or did not provide important data. Others provided important information about paleoenvironment during human occupation and helped with overall stratigraphic analysis.
A classification system was developed to categorize depositional facies at both sites and aid in the interpretation of recurring depositional processes and environments. Facies were named based on source, texture, composition, and sedimentary structures. This facies classification system was applied to all of the depositional units described in this study.

Depositional units were first interpreted based on source, with mainstem river, local tributaries or hillslopes, and eolian sources each having a modifier. They were subdivided based on grain size and then sedimentary structures such as ripple cross-stratification or imbrication. The facies names were used to reconstruct a sequence of depositional events and an interpretation of changes in river behavior and depositional environment.

To distinguish local tributary or slopewash deposits from mainstem or eolian, three characteristics were used. First, the texture of the deposit, especially grain size, was an important indicator of source. Locally-sourced material has grain sizes ranging from silt to gravel and is often poorly sorted, whereas mainstem and eolian deposits consist of clay to coarse sand and are better sorted. Secondly, rounding is an indicator of source. Some lithic granules or coarse sand-sized grains may be angular, indicating a local provenance despite grain size similar to mainstem river-sourced material. Alternatively, eolian sediment and mainstem river sediment are well-rounded. The last characteristic used to help determine source was color. Locally-sourced sediment tends to have a redder color value than mainstem sand, generally a Munsell color of 7.5 YR to 2.5 YR instead of 10 YR.
Distinguishing between eolian and mainstem river deposits is more difficult, especially because eolian deposits are often just reworked mainstem river sand. Grain size, grading, and other sedimentary structures are used for this task. Fluvial structures include ripples that are usually asymmetric because most flow is unidirectional. Eolian ripples form at lower climb angles than fluvial ripples and contain very thin strata (Draut and Rubin, 2008). The strata also are inversely-graded due to sorting by wind, resulting in a pinstriped pattern (Hunter, 1977). An additional indicator of eolian processes used is relict rainsplash crust appearing as stacked, thin wavy lamination, indicating continuing deposition during subaerial exposure.

In addition to interpretations based on field descriptions, a more detailed chemical analysis was performed on sediment from Tanner Bar. On the north-facing portion of the gully adjacent to the C:13:327 archaeological site, units were divided into facies based on composition, texture, color, and bed geometry. Approximately 200 g of sediment from the uppermost unit of each facies was collected for detailed chemical and grain size analyses. The representative facies samples were divided and part was sent to Chemtech-Ford Laboratories in Murray, UT, for measurement of the total iron content using an Inductively-Coupled Plasma Spectrophotometer. The remaining portion was sent to Utah State University Analytical Laboratories, where three properties were analyzed. Calcium carbonate content was measured using a pressure transducer, grain size was measured using a hydrometer, and organic matter was measured by the loss-on-ignition method. These properties were analyzed for representative differences between mainstem and local facies.
Surveying

Survey methods were used to determine terrace heights, study unit locations, and geochronology sample locations. Terrace heights and OSL sample locations were documented using measuring tapes along with hand levels and eye heights. Heights above the modern river were measured using these methods at Ninemile Draw because of the deposit’s close proximity to the river. Using ArcMap, stratigraphic heights at Tanner Bar were estimated from a 1-m LIDAR digital elevation model obtained from the Grand Canyon Monitoring and Research Center (GCMRC). Also, placement of study units was precisely surveyed using a Topcon RTK-GPS.

Geochronology

Dating methods include both radiocarbon and OSL dating. Radiocarbon methods were appropriate for units with preserved charcoal from cultural hearths or non-cultural units with preserved charcoal. OSL methods were used for units of mainstem sand with little to no bioturbation.

AMS Radiocarbon

Radiocarbon dating was used to date a basal unit of the gully stratigraphy near the Tanner Bar C:13:327 archaeological site. Detrital charcoal deposited by mainstem fluvial processes, as indicated by low angle cross lamination, was removed from the unit and placed in aluminum foil. It was then transported back to the laboratory, where ~50 mg of the best-preserved charcoal was separated from the rest of the sample. This portion was sent to Beta Analytic, Inc. for Accelerated Mass Spectrometer (AMS) radiocarbon dating. In addition to this radiocarbon result, several radiocarbon ages from near-surface cultural
features at the excavation sites have been obtained by archaeologists. This allows for comparison of radiocarbon and OSL methods and the production of a more complete record chronostratigraphic record.

*Optically Stimulated Luminescence (OSL)*

This dating method provides an estimate of when sediment was last exposed to light, thereby dating sediment deposition or burial. OSL dating can provide good age control for fluvial sediments (Wallinga, 2002), and it has high enough resolution to be applicable to Holocene sedimentation, which are two reasons why it was chosen for this study.

After sediment is buried, its luminescence signal grows as radiation emitted from decay of nearby radioactive isotopes of potassium, thorium, rubidium, and uranium along with incoming cosmic radiation energizes and ejects electrons from their energy bands, and some of these electrons are then trapped in quartz crystal lattice defects. When the quartz receives energy in the form of heat or light, the electrons can gain enough energy to be released from these traps, causing luminescence (Aitken, 1998).

The time since burial can be determined by first measuring the luminescence signal as related to a known amount of radiation, the equivalent dose (De). The equivalent dose is divided by radioactivity of the surrounding sediment and cosmic input, known as the dose rate, to determine the sample age.

\[
Age \ (yr) = \frac{\text{Equivalent Dose} \ (Gy)}{\text{Dose Rate} \ (\frac{Gy}{yr})}
\]
Samples were collected from near the base of each stratigraphic package, from near the top of each deposit, and often from one or more units in the middle of the stratigraphy. A total of fourteen samples were removed from the exposures in opaque metal tubes, following standard procedures of the USU Luminescence Laboratory. Representative sediment was removed from within 30 cm of the OSL sample location for dose rate calculations. The dose rate samples were sent to Chemex Laboratories for analyses of elements including potassium, rubidium, thorium, and uranium in the sediment.

The samples were all processed at the Utah State University Luminescence Laboratory. First, each was wet sieved to remove the appropriate grain size fraction of 63 to 150 µm or 75 to 150 µm. Carbonates and organics were removed with hydrochloric acid and bleach baths, and then heavy minerals were removed through density separation using 2.72 g/cm³ sodium polytungstate. Hydrofluoric acid was used to remove feldspars and etch the quartz. The quartz in each sample was then dry sieved to remove the fraction less than 63 or 75 µm in diameter, depending on the grain size removed by wet sieving.

Aliquots of the remaining quartz were mounted on 2 mm stainless steel disks and placed in a Riso TL/OSL-DA-20 reader with blue-green light stimulation (470 nm). To determine the equivalent dose, the procedure used was the single-aliquot regenerative-dose (SAR) protocol of Murray and Wintle (2000). Regenerative doses of 100, 200, and 300 seconds were used. To find the equivalent dose, the natural luminescence signal was interpolated onto a saturating exponential curve fit to the regenerative doses, and a line of best fit was interpolated from the luminescence signals of all of the regenerative doses.
This partial bleaching process is taken into account by discarding the aliquots with greater than 2σ standard deviation. Aliquots were discarded if they had a greater than 10% recycling ratio, indicating the presence of feldspars. They were also discarded if they had high recuperation values, indicating that some energy was transferred as heat and not light. No natural signal or a poor fit to the regenerative curve were additional reasons some aliquots were discarded.

The luminescence signal measured in the laboratory is a function of burial time and surrounding radiation. It is also affected by water content, and cosmic radiation, which varies by sample depth, elevation, latitude, and longitude (Prescott and Hutton, 1994). Therefore, each environmental dose rate was corrected for these factors in order to increase accuracy. The new OSL ages reported here are preliminary because they have less than 20 aliquots, the number needed for a statistically significant age.
RESULTS AND INTERPRETATIONS

Facies

Eleven distinct depositional facies are present at Ninemile Draw and Tanner Bar (Table 1). Five of these facies are interpreted to be mainstem in origin or depositional process, four are the result of local slope overland flow processes, one is eolian, and the last is anthropogenically deposited or disturbed. The criteria for interpreting depositional system and process were outlined in the Methods section above.

There are five mainstem facies. MSlr and MSSlr include tan sand and/or silt with a variety of sedimentary structures including cross-beds, climbing ripples, and planar laminations (Figure 9). Most units of these facies are tabular and continuous. These facies likely encompass multiple flow regimes during mainstem flooding, from the rising to falling limbs. It could not be determined whether laminations are from upper or lower plane-bed flow. The thicknesses of units of this facies range from a few centimeters to ~1 m.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSlr</td>
<td>Mainstem sand with planar and/or ripple lamination or cross-beds</td>
</tr>
<tr>
<td>MSSlr</td>
<td>Mainstem silty sand or sandy silt with planar and/or ripple lamination or cross-beds</td>
</tr>
<tr>
<td>MSm</td>
<td>Mainstem sand, massive</td>
</tr>
<tr>
<td>MRSlr</td>
<td>Mainstem-reworked local sand with planar and/or ripple lamination or cross-beds</td>
</tr>
<tr>
<td>MCG</td>
<td>Mainstem channel gravel</td>
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<tr>
<td>LM</td>
<td>Local mud</td>
</tr>
<tr>
<td>LGS</td>
<td>Local-slope gravel and sand</td>
</tr>
<tr>
<td>LGSI</td>
<td>Local-slope gravel and sand, imbricated</td>
</tr>
<tr>
<td>LSm</td>
<td>Local-slope massive sand</td>
</tr>
<tr>
<td>Es</td>
<td>Eolian-deposited sand</td>
</tr>
<tr>
<td>A</td>
<td>Anthropogenic influence or disturbance</td>
</tr>
</tbody>
</table>
Massive mainstem sand, MSm (Figure 10), is also characterized by its tan color and good sorting, but it lacks sedimentary structures. This could be the result of either very rapid deposition or bioturbation after deposition. In the field, traces of burrows, roots, or rhizoliths provided indicators of bioturbation. The only mainstem facies coarser than sand is the mainstem channel gravel facies, MCG, which was only found at Tanner Bar (Figure 11). This facies includes well-rounded cobbles and pebbles. The imbrication of these clasts indicates that they were deposited by mainstem river processes.

Mainstem-reworked laminated or rippled sand, MRSlr, has the reddish Munsell hue of 2.5 YR to 7.5 YR of local-slope sediment (Figure 12). Despite this, its depositional environment is interpreted to be mainstem because of its good sorting and fluvial sedimentary structures. The thickness of beds of these facies range from a few to 50 cm, and most of these beds are tabular and continuous.
Figure 10. Massive mainstem sand, facies MSm. Rhizoliths are present, indicating bioturbation.

Local mud (LM) occurs most often in lenses (Figure 13) and was seen primarily in the study trenches at Ninemile Draw, specifically in the upper ~1 m of the stratigraphy. These are interpreted as local depressions on the surface where water collected and evaporated, leaving behind silt and carbonate cement. They are all discontinuous, with lateral extents of less than one meter and a maximum thickness of 0.1 m. This facies was found only in the top 1 m of stratigraphy at Ninemile Draw.

Local massive sand (LSm) ranges in Munsell hue from 2.5 to 7.5 YR and it appears less well-sorted than the MSm facies, indicating that it is the result of local-slope overland flow or wash processes. It is primarily composed of sand but includes angular or subangular coarse sand to granule-sized grains. This facies is massive as a result of
Figure 11. Mainstem channel gravel facies, MCG.
Figure 12. Mainstem-reworked sand with laminations, MRSlr.

Figure 13. Local mud lens facies, LM.
bioturbation or rapid deposition, so no sedimentary structures are preserved. LSm is present at all sites, but it is a distinguishing feature at Ninemile Draw because it exists in discontinuous, broad, lens-shaped units in most of the cutbank.

The LGS facies consists of clasts of locally-sourced gravel and a matrix of red local sand (Figure 14). This is the only gravelly facies present at Ninemile Draw, and is conspicuously absent in the younger, inset depositional packages there. At Tanner Bar, it is present in the geomorphic study gully and at site C:13:327, and it is composed of more angular clasts than at Ninemile Draw. If the gravel has imbrication, it was designated as LGSi. At Ninemile Draw, this facies is present at all stratigraphic levels with a typical thickness of 5 to 20 cm. Along with the LSm facies, this facies is pervasive along the cutbank at Ninemile Draw. At Tanner Bar, this facies is also present at all stratigraphic levels, although the typical thickness there is 50 to 100 cm, significantly greater than the thickness at Ninemile Draw. At both sites, units of this facies are broadly lens-shaped and laterally discontinuous.

Eolian-deposited sand, or ES, is relatively rare, but occurs most often in the upper ~1 m of stratigraphy encompassing archaeological units at Tanner Bar and Ninemile Draw, or the upper ~1 m of stratigraphy (Figure 15). ES can be observed on the present terraces as coppice dunes. Eolian sand units are either massive or contain sedimentary structures including crinkly laminations, as described in the Methods section, or inversely-graded cross-bed sets. Despite the range of sedimentary structures found in eolian sand units, they are grouped into one facies here because the exact mode of eolian deposition is not necessary for this analysis. The lack of this facies in the deeper stratigraphy may be due to poor preservation or changes in the environment through time.
Figure 14. Local-slopewash gravel and sand (LGS). Local-slope gully fills are present at both Ninemile Draw (left) and Tanner Bar (right).
Figure 15. Eolian sand, facies ES. Cross-bed foresets in top portion of the picture are inversely graded. Lower half of unit includes “crinkly” laminations representing rainsplash-crust and eolian sand.
Units containing hearths, artifacts, trampling, or other evidence of cultural activity were given the facies designation A (Figure 16). In this case, cultural processes obscure or alter the original depositional processes.

A detailed texture and compositional analysis of facies was completed on the matrix of deposits from the lower Tanner Bar stratigraphy. Results highlight the distinctions between mainstem and local facies. Ten units from the measured section of the main gully exposure were classified as either mainstem, mixed, or local facies based on field observations. Results of lab analyses indicate the local facies are coarser, with notably more sand and less silt than the mainstem and mixed facies, but about the same amount of clay (Table 2, Appendix A).

Figure 16. Anthropogenic unit, facies A. The reddish lens is within an indurated and mixed horizon, suggesting it is a zone of trampling.
Local facies have less calcium carbonate and somewhat higher iron content than mainstem facies and the mixed facies had slightly more iron than the mainstem facies (Table 2). The local bedrock is composed of sandstone and siltstone with little calcium carbonate, whereas elsewhere on the Colorado Plateau the river flows through limestone. The high iron content in local bedrock is evident in its reddish iron oxide hues.

More precise grain-size and grading measurements would be necessary to determine if the patterns of inverse grading of modern flood deposits in Grand Canyon (Rubin et al., 1998) are present in pre-dam strata. Such results could help better understand pre-dam sediment supply.

Ninemile Draw

Stratigraphy

Stratigraphic results from Ninemile Draw are presented in a primary stratigraphic panel and four archaeological study units. A total of 53 units were described in the stratigraphy of the terrace front at Ninemile Draw, where four main stratigraphic

<table>
<thead>
<tr>
<th>Source</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>CaCO3</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainstem</td>
<td>48.6</td>
<td>40.6</td>
<td>10.3</td>
<td>6.7</td>
<td>7720</td>
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<tr>
<td>Mixed</td>
<td>59.0</td>
<td>31.3</td>
<td>9.5</td>
<td>6.1</td>
<td>9900</td>
</tr>
<tr>
<td>Local</td>
<td>81</td>
<td>9</td>
<td>10</td>
<td>3.1</td>
<td>11600</td>
</tr>
</tbody>
</table>

* See Appendix A for detailed results.
packages were identified, bounded by three unconformities (Figure 17). The majority of the cutbank is composed of continuous mainstem flood deposits alternating with local massive sand and gravelly sand facies (LSm and LGS). Burke and Hereford (1998) mapped most of this cutbank as the sa terrace, with a small package of ap material inset into the sa on the upstream portion of the cutbank. This is the contact between the T5 and T6 recognized by Anderson (2006). The entire 400-m cutbank was not described in detail in this study, but the upstream portion with these contacts was described (Figure 7).

The oldest stratigraphic package, A, was first described in February 2008. During a subsequent visit to the site in October 2008, this package was covered due to erosion and bank collapse after the March 2008 high-flow experiment. Package A is distinct from the stratigraphy above it because it is composed of thickly-bedded, tan mainstem sand (Figure 17, Appendix A). Package A’s uppermost bounding surface is a highly burrow-bioturbated, wavy contact that cuts the underlying beds, indicating an unconformity. The section is ~1.1 m thick and contains six units of mainstem sediment. Units are composed of mainstem facies MSlr, MSSlr, and MSm with no local-slope facies present.

Above the erosional unconformity capping package A lies 5.3 m of package B, which includes 31 units (Figures 17 and 18, Appendix B). This stratigraphic package includes a hearth that was previously dated at 2780-2400 Cal yr BP (Anderson, 2006). Overall, this stratigraphic sequence represents mainstem deposition alternating with local-slope deposits. Discontinuous, meters-wide, lens-shaped units of facies LGS are present at multiple stratigraphic levels. These deposits are interpreted to be gullies or local-slope drainage channels. Mainstem facies include MSlr, MSSlr, MRSlr, and MSm.
Figure 17. Ninemile Draw stratigraphic panel location and enlargement with unconformity-bound stratal packages A-D. Archaeological study units are also indicated. Bottom photo is oblique and not to scale.
Figure 18. Ninemile Draw generalized stratigraphic column with geochronology sample locations. Packages are labeled A-D and relations can be seen in Figure 17. See Appendix B for unit designations and detailed unit descriptions including facies designations. Radiocarbon date in package B is from Anderson, 2006. Preliminary OSL dates can be found in Table 3.
Mainstem deposits in this section are commonly inversely-graded from silt at the bottom to sand at the top, suggesting that the rising limb of paleofloods is preserved. Paleocurrent indications of climbing ripples are bimodal, with approximate directions being south and southeast, or downstream (Appendix D).

Two inset depositional packages were identified (Figures 17 and 18, and Appendix B). Package C was not discernible during the original archaeological field excursion, but after the March 2008 high-flow experiment, erosion of the cut bank uncovered lateral unit truncations, indicating a distinct package. This 3.0 m thick depositional package contains sedimentary structures including plane-bed laminations, climbing ripples, and massive sand. Five couplets of facies MSSlr and MSm with varying thicknesses were identified, and they all coarsen up. Although there is a slight incorporation of local sediment as indicated by sand with a hue of 7.5 YR, the units are all well-sorted mainstem facies. Paleocurrent indicators in this package are all downstream (Appendix D).

One explanation for the alternating couplets of facies MSSlr and MSm in this package is that they represent fluvial deposition followed by eolian reworking, as identified by Draut and Rubin (2008). The couplets they identified are flood deposits alternating with distinctively eolian or massive units. Alternatively, each couplet could represent one flood with two pulses of sediment, corresponding to limbs of the flood, one silty sand and one primarily sand. The flood deposits in this package alternate with massive, slightly redder units that may be eolian, but the massive structure may be due to bioturbation.
Package D (Figures 17 and 18, Appendix B) is the youngest and is inset into the first three packages. Package D consists of at least six mainstem beds with no local sediment. Units are notably thicker than units in the other packages, up to ~1 m, with six units of MSSlr or MSm, all 10 YR 6/3 in color. Sedimentary structures include cross-beds, ripples, and wavy laminations with no obvious pattern. The ripples are interpreted as fluvial because of their form, thickness, and lack of reverse grading. The bottom two units contain slumped portions of sediment along the buttress contact that are interpreted as toppled portions of the paleocutbank. The other observed paleocurrent indicators were highly variable and suggest that these units were deposited in an eddy.

Archaeological Study Unit Stratigraphy and Interpretations

In addition to the primary stratigraphic section along the cutbank at the Ninemile Draw study site, four smaller archaeological study units were described (Figure 7). Here, I focus on SU 1 (Figure 19) because it ties directly to the top of package B at the primary study outcrop. More detailed stratigraphic panels were produced for each study unit (Appendix C), and radiocarbon ages from potential cultural features were obtained by archaeologists.

Study Unit (SU) 1 was located on the western end of the site, closest to the primary stratigraphic section described above (Figure 7). The depositional units consist of entirely local facies and are interpreted to have been deposited by both local slopewash and eolian processes, including eolian sand (ES), local massive sand (LSm), and local gravelly sand (LGS). Four discontinuous carbonate lenses of mud and silt (facies LM) are also present, indicating at least four depositional hiatuses. No cultural material was
Figure 19. Stratigraphic panel of C:2:032 SU 1. Top photo is oblique view of study trench. Numbers indicate units (see Appendix C). Charcoal lens with 2340-2120 cal yr BP age is from floor of this study unit, directly beneath unit 1.
found in this unit, but a radiocarbon age obtained by archaeologists from a charcoal 

lens \(\sim 2\) m below the top of this study unit is 2340-2120 cal yr BP (Table 3, Appendices 

E and F).

SU 2, east of SU 1 (see Figure 7 for location), has a burn unit at the base that is 
pervasive across the site but may not be cultural (Damp et al., 2009). This corresponds to 
the lens dated in SU 1. The trench exposed units of ES, LSm and lenses of LGS, similar 
to SU 1. The stratigraphy revealed by SU 3, east of SU 1 and SU 2, also consists of 
alternating MSm and LGS. A discontinuous ash stain \(\sim 1\) m deep is present, capped by 
charcoal and ash, and was found to be 3210 to 2940 cal yr BP (Table 3). This ash feature 
is \(\sim 1\) m higher than the feature in SU 1 but \(\sim 900\) cal yr BP older, which is inconsistent 
but may be the result of local cut-and-fill processes on the terrace tread (Damp et al., 
2009).

SU 4, \(~80\) m downstream from SU 3, exposed a hearth feature at the base of SU 
4. This hearth is underlain by an indurated tan sand unit, which is underlain by a 3 cm-
thick ash lens. Artifacts found in or around SU 4 include sherds, groundstone fragments, 
and other lithic scatter, indicating a Pueblo II age, which is younger than the other study 
units (Damp et al., 2009). Sedimentary facies include LSm and ES with numerous 
indurated anthropogenic horizons, suggesting multiple times of use. In summary, these 
archaeological study units reveal exposures of the stratigraphy in the upper \(\sim 1\) to 2 m of 
the alluvium at this location. SU 1 and SU 2 exposed the upper 1-2 m of package B. SU 
3 and SU 4 exposed alluvium that is slightly younger and older than package B, 
suggesting a complicated sequence of erosion of deposition along the terrace tread.
TABLE 3. NINEMILE DRAW LUMINESCENCE PRELIMINARY AGES AND RADIOCARBON RESULTS*

<table>
<thead>
<tr>
<th>Sample name</th>
<th>OSL Sample #</th>
<th>location</th>
<th>depth (m)</th>
<th># aliquots**</th>
<th>dose rate (Gy/ka)</th>
<th>De (Gy)</th>
<th>age (ka)</th>
<th>package</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLCA-10.1L-8</td>
<td>USU-289</td>
<td>Ninemile Draw</td>
<td>0.3</td>
<td>13</td>
<td>2.97 ± 0.13</td>
<td>1.01 ± 0.57</td>
<td>0.34 ± 0.19</td>
<td>VI</td>
</tr>
<tr>
<td>GLCA-10.1L-10</td>
<td>USU-457</td>
<td>Ninemile Draw</td>
<td>4.3</td>
<td>12</td>
<td>2.96 ± 0.13</td>
<td>0.78 ± 0.36</td>
<td>0.26 ± 0.12</td>
<td>-</td>
</tr>
<tr>
<td>GLCA-10.1L-4</td>
<td>USU-283</td>
<td>Ninemile Draw</td>
<td>3.8</td>
<td>10</td>
<td>2.44 ± 0.10</td>
<td>1.95 ± 1.26</td>
<td>0.79 ± 0.52</td>
<td>V</td>
</tr>
<tr>
<td>GLCA-10.1L-12</td>
<td>USU-458</td>
<td>Ninemile Draw</td>
<td>3.1</td>
<td>15</td>
<td>2.91 ± 0.13</td>
<td>4.34 ± 2.39</td>
<td>1.48 ± 0.82</td>
<td>IV</td>
</tr>
<tr>
<td>GLCA-10.1L-7</td>
<td>USU-288</td>
<td>Ninemile Draw</td>
<td>1.2</td>
<td>13</td>
<td>2.45 ± 0.90</td>
<td>6.18 ± 1.56</td>
<td>2.52 ± 0.64</td>
<td>IV</td>
</tr>
<tr>
<td>GLCA-10.1L-9</td>
<td>USU-355</td>
<td>Ninemile Draw</td>
<td>3.9</td>
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<td>2.84 ± 0.11</td>
<td>8.64 ± 1.42</td>
<td>3.04 ± 0.52</td>
<td>IV</td>
</tr>
<tr>
<td>GLCA-10.1L-5</td>
<td>USU-284</td>
<td>Ninemile Draw</td>
<td>6.2</td>
<td>12</td>
<td>1.57 ± 0.06</td>
<td>7.87 ± 3.06</td>
<td>5.01 ± 1.97</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Beta #</th>
<th>location</th>
<th>material</th>
<th>method</th>
<th>△¹³C/¹²C</th>
<th>conventional 14C age</th>
<th>calibrated age (cal yr BP)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2032FS3A</td>
<td>252216</td>
<td>SU 3 Feature 1</td>
<td>charcoal</td>
<td>AMS</td>
<td>-24.5 o/oo</td>
<td>2910 +/- 40 B.P.</td>
<td>3210-2940</td>
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<tr>
<td>C02032FS1A</td>
<td>252215</td>
<td>SU 1 Feature 3</td>
<td>charcoal</td>
<td>AMS</td>
<td>-26.5 o/oo</td>
<td>2210 +/- 40 B.P.</td>
<td>2340-2120</td>
</tr>
</tbody>
</table>

*See Appendices E for detailed results
**All OSL results with <20 aliquots are preliminary.
***2σ calibrated age, calibrated by Beta Analytic
Sedimentary units in all of these study units consist of poorly-sorted local slopewash or gully facies alternating with massive sand. No distinct mainstem flood structures were visible in the study units, suggesting that they are the result of local depositional processes instead of mainstem overbank floods. In addition, eolian reworking may have occurred during hiatuses in deposition, but the sand units are massive, possibly because of bioturbation, so they were indeterminate. Based on the anthropogenic facies observed in the study trenches, occupation occurred at multiple times as the landform was slowly aggrading due to local hillslope and tributary wash processes.

**Geochronology**

Seven OSL samples from Ninemile Draw were processed and initial results are presented in Table 3. These results are preliminary, so that the ages will become refined as analyses are complete. Nevertheless, these results constrain the timing of the stratigraphic packages above and support the observed unconformities (Figures 18 and 20). The base of package A is \(~5.0\) ka. Overlying this package, the base of package B is \(~3.0\) ka, which suggests the presence of an erosional unconformity spanning up to \(~2\) ky. An initial OSL age from 5.0 m above the base of package B is \(~2.5\) ka. Within error, these package B OSL ages are stratigraphically consistent with the radiocarbon age of 2780 to 2400 cal yr BP previously obtained from the hearth between them (Anderson, 2006), as well as the radiocarbon age in the upper package from SU 3 (2340 to 2120 cal yr BP).

Two initial OSL ages from package C confirm that it is younger than A and B, as observed in the field, but the ages are stratigraphically reversed (Figure 18, Table 3).
Figure 20. Initial geochronology results from the Ninemile Draw stratigraphic panel outcrop. Lower radiocarbon age is from Anderson (2006) and upper age is from Damp et al. (2009).
Sample USU-457 was collected from 4.3 m below the present day terrace tread and its preliminary age is ~0.3 ka. Sample USU-458 was collected from 1.2 m above USU-457, but its age is ~1.5 ka. This younger age stratigraphically below an older age may be due to bioturbation of the lower units or because an upper portion of the stratigraphy slumped or slid from its original stratigraphic location. The upper age does fit within the rest of the chronostratigraphy, and so the lower age is assumed to be erroneous.

Preliminary results from the youngest stratigraphic package, D, include a basal OSL age of ~0.8 ka and an upper OSL age of ~0.3 ka (Table 3, Figures 18 and 20). These ages are consistent with this package being stratigraphically higher than the other three packages and inset into them. Deposition within package D spans at least a few hundred years and is composed of only six flood packages, yet no abrupt unconformities are visible.

**Tanner Bar- C:13:323**

*Stratigraphy*

In the ~6.5 m of stratigraphy exposed underlying the upstream archaeological site at Tanner Bar, mainstem channel gravels (facies MCG) are interbedded with mainstem sand (Figure 21). The paleocurrent directions indicated by imbricated gravels and dipping gravel foresets in the lowest strata underneath the archaeological site focus about 180°, or downstream (Appendix C). This sequence is interpreted as a prograding lateral-channel gravel bar because it includes mainstem channel gravels in dipping foresets. The top of this gravelly sequence is ~10 m above the modern river shoreline. The channel
Figure 21. A) Stratigraphy and initial OSL sample results from the Tanner Bar C:13:323 archaeological site, facing north. B) Stratigraphy and initial OSL results from the Tanner Bar geomorphic study gully, facing northwest. Upstream archaeological site is in the background. Inferred zones of unconformities are indicated, although their locations are not known precisely.
Gravels at Tanner Bar are interpreted to be sourced from the mainstem and not local tributaries because they are strongly imbricated downstream in dipping foresets and they are composed of rounded cobbles and gravels of rock types besides what is present in the Tanner Creek tributary.

Above these basal mainstem channel deposits, units of finer-grained mainstem sand are interbedded with eolian sand, which both encompass the archaeological features. These interfingering units have a cumulative thickness of up to 2 m. Eolian-reworked sand currently caps the stratigraphy. No detailed overall stratigraphic panel was measured at this upstream site, but archaeological study units associated with the uppermost stratigraphy were.

Archaeological Study Unit Stratigraphy and Interpretations

Stratigraphy was described and stratigraphic columns were produced at five study units at the archaeological site (see Figure 8 for study unit locations). Here I focus on SU 5 and SU 7 because they were dug in different stratigraphic locations and constrain the stratigraphy around the main archaeological features at this site (see Appendix C for detailed stratigraphic panels of additional study units).

SU 7 is stratigraphically the lowest archaeological study unit. At the base of SU 7 is sandy gravel, facies LGS, that is at the very top of a channel gravel sequence underlying the archaeological site (Figure 22). Facies MS1r, mainstem laminated sand, tops the gravel sequence. Directly above the mainstem sand is a ~0.5 m thick unit of crinkly-laminated sand, which is interpreted to be eolian-reworked fluvial sand (facies
Figure 22. Stratigraphic column of C:13:323 SU 7 with preliminary OSL age of 6.8 ka (Table 4). See Appendix C for detailed facies designations and unit descriptions.
On top of this sand lies massive mainstem sand (facies MSm), which has likely been heavily bioturbated. On the terrace tread above this study unit a zone of scattered lithics was found, although these lithics were creeping down the surface and from stratigraphically above SU 7.

The lithics found above SU 7 correspond to a cultural baked zone and charcoal at the base of SU 5, ~10 m northwest of SU 7 (Figure 23). SU 5 is stratigraphically higher than SU 7 by at least 1 m. Along with anthropogenic horizons, SU 5 exposed units of eolian sand and mainstem flood sand. The sequence is interpreted to be at least three mainstem floods alternating with periods of eolian reworking. The lowest unit is mostly massive but contains a few faint fluvial ripple laminations it has a hearth dug into it. This hearth part of a unit of trampled, ashy sand with reworked charcoal fragments. The charcoal laterally correlates to the main living surface at this site. It is overlain by massive mainstem sand (facies MSm) interbedded with eolian sand. Because the artifacts are Late Archaic based on radiocarbon ages (Damp et al., 2009), at least one significant unconformity must exist between this stratigraphy and that exposed by SU 7.

The general geomorphic interpretation of this archaeological site is that Late Archaic people occupied a sandbar at the margin of the river, and that sandbar was deposited on top of an older, mainstem gravel bar. Mainstem depositional units, indicated by the abundance of facies MSlr at this site, alternates with eolian deposition and reworking.

**Geochronology**

Two samples from the stratigraphy underlying the C:13:323 archaeological site
Figure 23. Stratigraphic column of C:13:323 SU 5 with radiocarbon age of 2310-2040 cal yr BP (Table 4). See Appendix C for detailed facies designations and unit descriptions.
<table>
<thead>
<tr>
<th>OSL Sample #</th>
<th>location</th>
<th>depth (m)</th>
<th># aliquots**</th>
<th>dose rate (Gy/ka)</th>
<th>De (Gy)</th>
<th>age (ka)</th>
<th>package</th>
</tr>
</thead>
<tbody>
<tr>
<td>USU-440</td>
<td>C:13:327 SU 8</td>
<td>0.2</td>
<td>6</td>
<td>1.80 ± 0.08</td>
<td>-</td>
<td>modern ±</td>
<td>-</td>
</tr>
<tr>
<td>USU-439</td>
<td>C:13:327 SU 4</td>
<td>0.6</td>
<td>14</td>
<td>1.82 ± 0.08</td>
<td>1.94 ± 0.62</td>
<td>1.06 ± 0.34</td>
<td>V</td>
</tr>
<tr>
<td>USU-142*</td>
<td>C:13:327 gully</td>
<td>3.6</td>
<td>20</td>
<td>2.65 ± 0.12</td>
<td>3.93 ± 1.21</td>
<td>1.48 ± 0.13</td>
<td>IV</td>
</tr>
<tr>
<td>USU-141*</td>
<td>C:13:327 gully</td>
<td>4.6</td>
<td>20</td>
<td>3.01 ± 0.13</td>
<td>4.63 ± 1.19</td>
<td>1.50 ± 0.11</td>
<td>IV</td>
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<tr>
<td>USU-140*</td>
<td>C:13:327 gully</td>
<td>5.4</td>
<td>20</td>
<td>2.72 ± 0.12</td>
<td>4.64 ± 1.21</td>
<td>1.71 ± 0.13</td>
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<tr>
<td>USU-370</td>
<td>C:13:327 gully</td>
<td>5.3</td>
<td>12</td>
<td>4.5 ± 0.20</td>
<td>7.17 ± 2.63</td>
<td>1.60 ± 0.59</td>
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</tr>
<tr>
<td>USU-436</td>
<td>Geomorphic study gully</td>
<td>0.6</td>
<td>16</td>
<td>3.12 ± 0.14</td>
<td>16.93 ± 2.12</td>
<td>5.42 ± 0.73</td>
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<tr>
<td>USU-437</td>
<td>C13:323 SU 7</td>
<td>0.6</td>
<td>16</td>
<td>2.34 ± 0.10</td>
<td>15.96 ± 2.54</td>
<td>6.82 ± 1.14</td>
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</tr>
<tr>
<td>USU-434</td>
<td>Geomorphic study gully</td>
<td>3.1</td>
<td>13</td>
<td>2.75 ± 0.12</td>
<td>23.13 ± 4.73</td>
<td>8.40 ± 1.7</td>
<td>II</td>
</tr>
<tr>
<td>USU-438</td>
<td>C13:323 basal stratigraphy, top of gravel sequence</td>
<td>1.6</td>
<td>13</td>
<td>2.16 ± 0.09</td>
<td>24.00 ± 4.50</td>
<td>11.10 ± 2.15</td>
<td>I</td>
</tr>
<tr>
<td>USU-512*</td>
<td>Geomorphic study gully</td>
<td>4.5</td>
<td>24</td>
<td>2.83 ± 0.13</td>
<td>33.04 ± 4.38</td>
<td>11.64 ± 0.62</td>
<td>I</td>
</tr>
</tbody>
</table>

**See Appendices E and F for detailed results.**

**All OSL results with <20 aliquots are preliminary.**

***2σ calibrated age, calibrated by Beta Analytic.***

****Previously designated as UNL-1390, processed at the University of Nebraska-Lincoln Luminescence Laboratory.
were dated with OSL (Figure 21). A thin mainstem sand unit within the gravel bar topsets has a preliminary age of ~11.1 ka (Table 4). This unit is ~1.5 m below archaeological Feature 1. A mainstem sand unit overlying these gravels in SU 7 has a preliminary OSL age of ~6.8 ka. This unit is only 10 cm above the gravel sequence, indicating the presence of an unconformity. The 2310-2040 cal yr BP age from SU 5 (Table 4, Appendices E and F), suggests an additional unconformity between SU 5 and SU 7.

Overall, this site includes early Holocene mainstem channel deposits, mid-Holocene mainstem flood sands, and ~ 2 ka Late Archaic archaeological features encompassed by eolian and mainstem fluvial sand deposits. The three depositional packages are separated by erosional unconformities.

**Tanner Bar Geomorphic Study Gully**

**Stratigraphy**

The Tanner Bar geomorphic study gully is located 150 m south of the C:13:323 archaeological site (Figures 6 and 8). The gully crosses the terrace perpendicular to the terrace riser ~30 m long, although only the stratigraphy exposed closest to the terrace riser is well-exposed. The south-facing wall of this gully was originally covered with modern slope detritus, four exposures were hand-dug to better reveal the stratigraphy (Figure 21B). A distinct top edge of the terrace tread at this location is ~11.5 m above the modern river shoreline perpendicular to the channel across the bar, and the measured stratigraphy is ~8.0 meters thick. Five depositional zones were described, although they are strongly lenticular and interfinger, so none were laterally continuous for more than a
few meters. Therefore, the stratigraphic column produced was a generalized representation (Figure 24).

The lowest sedimentary package observed is a ~0.5 m-thick, laterally-discontinuous massive sand unit, (Facies MSm, Figure 24, see Appendix B for detailed unit descriptions). This is overlain by up to 3.5 m of interfingering local gravelly sand (facies LGS) and massive mainstem sand (Facies MSm). The top of this sequence contains abundant root bioturbation, indicating a depositional hiatus. Rhizoliths are also present near the base of the third unit, indicating more than one depositional event. The third unit is mainstem sand with interfingering Dox colluvium that is similar in composition and clast size to the underlying unit, but this unit has a higher percentage of mainstem sand.

The fourth depositional unit also contains interfingering mainstem sand units and local gravelly sand, with more mainstem sand than local material present. This unit is classified as facies MSlr because it contains occasional faint fluvial ripples. This is overlain by two distinct units of alternating massive mainstem sand (facies MSm) and local hillslope material including Dox lithics and reworked Pleistocene gravel (facies LGS). All of the beds in these depositional units are laterally discontinuous, and maximum bed thickness is ~0.5 m. The total thickness of the upper two units is ~2 m.

Portions of the mainstem deposits may have been eroded by gullies that were subsequently filled by local tributary material. Although no unconformities were visible, rhizoliths and root bioturbation throughout this sequence indicate depositional hiatuses and are evidence that it is an aggradational sequence. Three samples were collected for OSL dating. Observations from imbricated gravels at this location reveal two dominant
Figure 24. Generalized stratigraphic column of Tanner Bar geomorphic study gully with OSL sample locations. See Appendix B for detailed unit descriptions and Appendix D for paleocurrent data.
paleocurrent directions (Appendix D). The average paleocurrent measured at the bottom of the gully is west, or towards the river. The paleocurrent direction from seven imbricated gravels sequences in the middle of the exposure is east, away from the river (Figure 24). The top ~2 m of stratigraphy also displays a paleocurrent direction of west, towards the river. Because these directions were measured on units of the local-slope gravelly sand facies, they have preserved the direction of gully material movement and reworking, not mainstem processes.

**Geochronology**

Three initial OSL results from the geomorphic study gully span ~6 ky (Table 4, Figure 24). The sand unit at the base of this measured stratigraphy has an OSL age of 11.64 ± 0.62 ka, a sand unit from the middle of the section is ~8.4 ka, and a sample from unit 5, ~0.6 m below the present terrace tread, is ~5.4 ka. These results indicate that at least two erosional unconformities are present, but field observations failed to find evidence for their precise locations. Alternatively, this sequence could represent incremental deposition of local-slope material interfingering with occasional mainstem overbank floods. No true buried soils were observed, though gully and mainstem erosion at the onset of each depositional event may have removed any such markers.

**Tanner Bar C:13:327**

**Stratigraphy**

The C:13:327 archaeological site lies ~100 m downstream from the geomorphic study gully and is set where a gully cuts through the terrace (Figures 6 and 8). Here, ~8 m of stratigraphy was measured and described as exposed by the main gully. In addition,
the upper stratigraphy was observed in archaeological study unit exposures adjacent to the gully and along the terrace riser south of the gully. The top tread of the terrace is \( \sim11.5 \) m above the modern river shoreline, as measured perpendicular to flow. This is approximately the same height above the river as the terrace tread at the other two Tanner sites. There are at least two meters of additional basal stratigraphy that was not exposed. No cross-cutting unconformities were visible in the main body of stratigraphy during field observations.

The stratigraphy includes alternating mainstem and local deposits (Figure 25). The thickest three units are all facies LGS with angular, imbricated Dox cobbles and pebbles. Other facies include mainstem-deposited MSlr, MSSlr, MSm, and MSlr and local-slope sands of LSm. No eolian units were observed in the stratigraphy exposed along the gully, but they were observed in the archaeological study units of the upper stratigraphy. Over 40 paleocurrent directions were measured in the stratigraphy exposed by the gully from sedimentary structures including climbing ripples, cross-bedding, and imbrication (Figure 25, Appendix D). Mainstem fluvial sand units exposed by the gully in the upper \( \sim3 \) m of stratigraphy have paleocurrent directions that vary from north to west, or approximately upstream to towards the river and gravel bar, suggesting deposition in an eddy. Additional mainstem fluvial sand units in the \( \sim3 \) m below that have paleocurrent directions of west to south, which is additional evidence for variable flow direction and the presence of an eddy. Imbricated gravels are generally oriented west to north, or towards the river and slightly upstream.
Figure 25. Stratigraphic column of sediment exposed by the gully cutting through the C:13:327 archaeological site. OSL and radiocarbon sample locations are indicated. See Appendix B for facies designations and detailed unit descriptions and Appendix D for detailed paleocurrent data.
Figure 26. Stratigraphic panel of C:13:327 SU 6. See Appendix C for detailed unit descriptions. At least one erosional unconformity is present.
In addition to the stratigraphic section along the gully, six archaeological study units and two geomorphic study units were excavated and described in the upper strata at C:13:327 (Appendix C, Figure 26). Here, I focus on SU 6, SU 4, and SU 7 to provide a complete picture of the stratigraphy here. The stratigraphically lowest of these, SU 6, was a ~2 m deep exposure set near the top of the main gully stratigraphy (Figure 25). It exposed a slab-lined hearth that was one of the main features of this site, and a radiocarbon age indicates that it was used 1280-970 cal yr BP (Table 4). This cultural feature was first overtopped by a mainstem flood (unit 1) and charcoal from the slab-lined hearth is reworked into this sand. At least four additional mainstem flood events are interpreted in the overlying strata, depositing units 2 through 5 (Figure 25). These are either ripple-laminated or massive, likely because of human trampling. At least one erosional unconformity exists along the top of unit 3.

Approximately 2 m higher and 20 m northeast of SU 6 (Figure 8; Appendix C, Figure C.14), SU 4 contained only one unit that was not obscured by bioturbation. This unit is ~0.5 m thick and is composed of facies MSlr with large fluvial cross beds. An OSL sample from this fluvial sand has an initial age of ~1.1 ka (Table 4).

Two geomorphic study units were dug into near-surface eolian coppice dunes to expose the highest stratigraphy at this site. One of archaeological study units, SU 8, at the eastern edge of the C:13:327 archaeological site (Figure 8), exposed two distinct units of eolian sand capped by a single mainstem flood unit (Appendix C, Figure C.18). An OSL
sample from 0.2 m below the surface in this study unit has an average of less than zero equivalent dose.

Regarding the archaeological context, the oldest archaeological features were found within the top ~1 m meter of the stratigraphy exposed by the gully at this site, which is in the top ~3 m of overall stratigraphy. Mainstem floods younger than ~1 ka overtopped the terrace here after Puebloan occupation. Eolian facies indicate that wind-driven deposition has alternated with fluvial deposition, and there is no evidence of eolian deposition in strata underneath archaeological features.

**Geochronology**

Six depositional units at this site were dated with OSL and one with radiocarbon dating to constrain the stratigraphy, and there are radiocarbon ages from two archaeological features (Table 4). The radiocarbon date from the bottom of the stratigraphy excavated along the terrace front is 3210-2950 cal yr BP, which is stratigraphically consistent with four younger OSL ages of 1.71 ka to ~1.5 ka, all in stratigraphic order within error. These results also agree with the 1520 to 1330 and 1280 to 970 cal yr BP radiocarbon ages from hearths within the stratigraphy (Table 4). The ~1-1.5 ka age difference between the lowest OSL age and the radiocarbon date suggests a depositional hiatus or slight erosional unconformity between ~7 and ~8 m depth (Figure 25). Still, all of the deposits dated at this location are ~3 ka or younger, with at least 8 m of deposition in less than 1.5 ka. This indicates more rapid deposition preserved at this location than in the stratigraphy observed at the geomorphic study gully.
The OSL sample from a fluvial cross-bedded sand unit in SU 4 has a preliminary age of ~1.1 ka, and this unit is ~2 m above the 1520 to 1330 and 1280 to 970 cal yr BP radiocarbon ages from SU 6, based on RTK-GPS survey results. The stratigraphically highest sample from this location, collected from SU 8, has OSL results that indicate the deposit is too young for OSL dating or has been bioturbated and contaminated with modern, bleached sand. Modern roots were seen in the depositional unit that this sample was collected from, and the sample location was only 0.2 m below the modern surface, so both a modern age and bioturbation have likely affected this sample.

Summary of Tanner Bar Stratigraphy

Although the three study sites at Tanner Bar contain distinct stratigraphy and ages, they can be compared to create a better understanding of the overall processes at this location (Figure 27). A few patterns emerge from this schematic. First, every location includes at least two unconformities. Second, the stratigraphy of the geomorphic study gully and the C:13:327 site contain thick Dox colluvial wedges, but these are not present at C:13:323. Third, stratigraphy of different ages is present at the same elevation in this location. The oldest ages are at the C:13:323 archaeological site and the geomorphic study gully, while the lowest sampled stratigraphy at the C:13:327 site is ~8 ka younger than at the other sites. The stratigraphy at this location is progressively younger and inset in the downstream direction.
Figure 27. Upstream-to-downstream transect schematic of Tanner Bar Holocene alluvium along the ~400 m-long along the terrace riser. Site C:13:323 schematic is wider because a greater lateral extent of stratigraphy was exposed there than at the other two sites. Absolute elevations are based on Topcon RTK surveyed elevations and are likely to have an uncertainty of ~0.5 m. Roman numerals indicate interpreted depositional packages addressed in the Discussions section of the text.
DISCUSSION

Revised Eastern Grand Canyon
Holocene Stratigraphy

Ninemile Draw and Tanner Bar terraces have distinct preserved chronostratigraphies, but together they help refine the record of Holocene stratigraphy in Grand Canyon. A plot of geochronology results (Figure 28) helps better analyze trends. The first apparent trend in the geochronology results is that more age control exists from the late Holocene than the middle and early Holocene. This is likely because of the concentration of radiocarbon ages from late Holocene archaeological features and because later Holocene deposits are better-preserved.

The plot of geochronology results also elucidates a pattern of six possible discrete depositional packages separated by erosional episodes ranging from ~1-2 ky-long in the early Holocene to ~0.1-0.2 ky-long in the late Holocene (Figure 28). The breaks in deposition between the youngest four packages are consistent with stratigraphic relations observed in the field. The oldest four packages consist of interbedded local slopewash and gully deposits and mainstem flood deposits. They include tributary material up to 10 m above the modern channel. They also include rhizoliths and root bioturbation throughout, suggesting incremental aggradation (Lucchitta and Leopold, 1999). The youngest two packages consist of solely mainstem sandy and silty flood deposits with no discernible depositional hiatuses.

The early Holocene deposits, designated packages I and II, include both MCG and MSm facies up to 9 m above the present river at Tanner Bar (Figure 29). These packages unconformably underlie younger sediments at the upstream cultural site and the geomorphic study gully between the two Tanner cultural sites. Because of the distinct MCG facies, downstream-oriented gravel foresets, and generally downstream paleocurrent
Figure 28. Graph of preliminary geochronology results from Ninemile Draw (in blue) combined with results from Tanner Bar (in red). Error bars are only shown for radiocarbon samples and OSL samples with >20 aliquots (Tables 3 and 4). Preliminary ages are shown without error bars. Disproportionate representation of younger deposits and ages is due to preservation and sampling bias.
Figure 29. Compiled schematic of Holocene Grand Canyon alluvium at both study locations. Shaded red tone represents local-slope and gully-fill deposits. I: earliest Holocene alluvium (12-11 ka), II: early Holocene alluvium (9-8 ka), III: middle Holocene alluvium (7-4 ka), IV: late Holocene alluvium (3-1.5 ka), V: Puebloan flood deposits (~1.2 ka-0.9 ka), VI: Protohistoric flood deposits, (0.8-0.3 ka), h= historic flood deposits, e= eolian deposits. Blue circle indicate OSL sample locations and grey circles indicate radiocarbon sample locations.
directions, this depositional package is interpreted to represent a higher river grade at ~11 ka than present.

The early Holocene deposits, designated packages I and II, include both MCG and MSm facies up to 9 m above the present river at Tanner Bar. These packages unconformably underlie younger sediments at the upstream cultural site and the geomorphic study gully between the two Tanner cultural sites. Because of the distinct MCG facies, downstream-oriented gravel foresets, and generally downstream paleocurrents directions, this depositional package is interpreted to represent a higher river grade at ~11 ka than present.

The overlying stratigraphy (package II, ~8-9 ka) is present at the Tanner Bar geomorphic study gully, where interfingering mainstem and local slopewash facies sit unconformably on top of package I. The unconformities are inferred here based on the OSL ages, but because there are no buried soils or distinct erosional contacts, the exact locations are not known.

Unconformably overlying package II at the geomorphic study gully exposure is an additional mid-Holocene package of interfingering mainstem and tributary slopewash material (package III, ~5.5-3.5 ka). The morphology of this package is distinct from the underlying units here because the local gravelly slopewash beds are thinner, indicating either more frequent mainstem floods, reduced preservation of local material, or reduced local sediment yield. This inferred package is also present as a <0.5 m thick mainstem flood sequence directly overlying package I at the downstream Tanner Bar site. In addition, the deepest stratigraphic deposits observed at Ninemile Draw represent package III with an initial OSL age of ~5 ka. At Ninemile Draw the deposit does not include
interfingering mainstem and local deposition and is only ~3-4 m above the modern river. Although only 1 m of the package is exposed and an unconformity separates it from above strata, it was most likely thicker before erosion.

Late Holocene package IV (~3.5-1.5 ka) is well-preserved at both Tanner Bar and Ninemile Draw. It is constrained by more age control than previous packages because it hosts Late Archaic cultural features were found. At Ninemile Draw, this package unconformably overlies package III as indicated by both geochronology results and a visible unconformity. In addition, the stratigraphy consists of alternating mainstem flood deposits and coarser, redder tributary and local slopewash deposits in gully-fill sequences, whereas package III is composed solely of mainstem sand, but may be due to lack of preservation of package III. Package IV also displays this characteristic striped morphology at Tanner Bar C:13:327, where it includes units of facies LGS up to 1 m thick. Packages II and III also display a striped morphology, but their local facies (LGS) exist in thicker units and are composed of sandy gravel, instead of the gravelly sand frequent in package IV.

Although the basic interpretation of package IV is that it represents alternating mainstem and local deposition, multiple hypotheses may explain this alternating, incremental sedimentation. First, increased local sediment yield may be caused by increased local runoff, perhaps in the form of strong summer monsoons. Also, lack of vegetation due to drought may have increased local sediment yield from slopes. A third possibility is decreased mainstem flood discharges due to changes in headwater hydrology, leading to more incremental aggradation of thin deposits and lack of removal of local sediment by the mainstem river.
Inset into the late Holocene alluvium at Ninemile Draw is a package of mainstem sand and silt deposited during Puebloan occupation, package V (~1.5-1 ka). The ~1.5 ka age at Ninemile Draw is preliminary, and subsequent age control may reveal that it is either younger or partially bleached. The depositional package at Ninemile Draw consists of couplets of well-sorted tan and redder sand, although both are mainstem-deposited. The slightly redder sand indicates pulses of more locally-sourced sediment and helps distinguish this package from the overlying package. Whereas package V is inset into package IV at Ninemile Draw, at Tanner Bar it sits unconformably atop package IV. There, a mainstem fluvial package overlies package IV and indicates that large floods overtopped the terrace, approximately 13 m above the modern river level. The OSL age may in fact be younger than the initial age of ~1.1 ka from Tanner Bar C:13:327 SU 4 because this package also buries Pueblo II artifacts. The location of this package at greater than 10 m above the modern river level may be significant and is discussed below.

A mainstem flood package at Ninemile Draw represents the youngest deposits (package VI, ~0.8-0.3 ka). Because these deposits are inset into the Puebloan flood deposits, they are interpreted as a distinct depositional episode. No deposits of this age were identified at Tanner Bar, where the youngest-dated and highest flood deposits have a modern OSL age. This package VI, the Protohistoric flood deposits, consists of thick mainstem flood packages ranging from ~0.8 to ~0.3 ka. At both locations sand in this package is purely tan mainstem sand, unlike the couplets of tan and redder sand in package VI.
Based on the observed stratigraphic relations, morphology, and chronology described above, a refined model of the Grand Canyon Holocene alluvial chronology was produced (Figure 29). This conceptual model shows the deposition of four aggradational alluvial packages, I-IV, and oscillating grade. Packages V and VI consist of mainstem flood deposits and are not necessarily associated with changes in river grade, although there may have been downcutting since the deposition of package V. Therefore, using these deposits to reconstruct paleofloods is a valid practice, whereas reconstructing paleoflood discharges from units in the other depositional packages should be approached with caution unless the river channel geometry at the time of deposition is known.

At Tanner Bar, Package V is present near the top of the terrace, as indicated by the preliminary OSL age of ~1.1 ka from C:13:327. This sample, USU-439, was taken from less than 1 m below the terrace top in SU 4, or 12 m above river level at ~700 m$^3$/s. In order to determine a very rough estimate of the flood magnitude, I developed a stage-discharge relation based on the stages of floods of historic discharges using virtual flowlines from 1-dimensional modeling by Magirl et al. (2008). Based on modern hydraulic geometry, the rating curve suggests that a discharge of ~1,800,000 ft$^3$/s, or ~51,000 is necessary to deposit a flood at the elevation of the OSL sample USU-439.

Enzel et al. (1993) evaluated gage records and paleoflood studies from throughout the Colorado River Basin to determine an upper bound of flood magnitude, which is ~480,000 to 501,000 ft$^3$/s, or 13,600 to 14,200 m$^3$/s. They suggest it is unlikely that a flood has occurred in prehistoric time exceeding this upper bound. If their analysis is correct, then my estimate of the hypothetical flood required to deposits the upper sediment at the Tanner Bar C:13:327 site, based on the lower stage calculations of Magirl
et al., is over three times larger than possible in this system. This deviation is evidence for channel incision, at least locally, since Puebloan time.

**Correlations to Previous Work and Paleoclimate**

The preferred but tentative interpretation of these results is of six depositional episodes, alternating with five possible erosional episodes. Broadly, this timing of deposition and incision can be compared to other records from the Colorado River and greater Colorado Plateau. Portions of this record correspond to Hack’s Colorado Plateau alluvial record. The oldest of Hack’s depositions, the Jeddito Formation, is older than 6 ka, and there are deposits of this age in Grand Canyon (Hack, 1942). The Tsegi was deposited between ~5 ka and ~0.8 ka (Hack, 1942), a time span that encompasses both packages III and IV. The period of incision following the Tsegi could be the same as the erosional period between the package IV and package V, although poorly constrained because of limitations in geochronology methods. Hack’s Naha formation, deposited since 0.7 ka, correlates to the Protohistoric flood deposits observed at Ninemile Draw.

The youngest three packages suggested by this study correlate to the depositional packages originally identified by Hereford et al. (1996). The previously identified sa terrace is equivalent to package IV, or late Holocene alluvium (Figure 29). This is the last aggradational package preserved and is present both at Ninemile Draw and Tanner Bar, although the ages differ slightly between locations. The strata preserved at Tanner Bar are ~ 0.5 ka younger than Ninemile Draw, most likely due to preservation. Considering the resolution of OSL geochronology, package V correlates to Hereford’s ap terrace and package VI correlates to the umt terrace. The ages of these packages are
better-constrained with radiocarbon dating from other archaeological sites, but because archaeological features may be placed after sedimentary deposition, they often only provide minimum ages. Both geochronology and stratigraphic relations support this correlation, and this study complements Hereford’s by establishing the beginning of deposition of the sa at ~3 ka, an age that was previously poorly-constrained. Three packages older than Hereford’s terraces are inferred from this study, so these results build on his record by extending it to the early Holocene.

Comparing these results to Ely’s (1997) cumulative paleoflood record of the Southwest, including data from eastern Grand Canyon, shows no correlation in the mid-Holocene and a weak correlation in the late Holocene (Figure 30). Her results show a cluster of floods from 5-3.6 ka (Ely, 1997), a time with little deposition in Grand Canyon, according to this study. Ely’s study also suggests fewer floods from 3.6 to 2.2 ka, which partially overlaps with the deposition of package IV. Reduced paleoflood events from ~1.8 and ~1.6 ka correlate with our results, while numerous floods at ~1 ka coincide with the end of the deposition of package V.

The latest paleoflood pattern was a drop in flood frequency from 0.8 to 0.6 ka followed by an increase in deposition from ~0.6 ka to present (Ely, 1997), which coincide with deposition of package VI and Hereford’s umt. Thus, the age of package IV deposition does not correlate well with frequent paleofloods, whereas the deposition of packages V and VI does. This is significant because these two packages are composed solely of mainstem flood deposits, suggesting that there may be preferential preservation of the largest and most recent floods.
Figure 30. Graph of middle-late Holocene depositional episodes (grey boxes) in Grand Canyon compared with those reported in previous studies from this region. LIA= Little Ice Age, MWP= Medieval Warm Period
These results can also be correlated to the most pertinent local and regional climate proxies (Figure 31). First, results are compared to the Greenland Ice Sheet Project $\delta^{18}$O values, which are a proxy for Northern Hemisphere air temperature (Stuiver et al., 2005). Higher $\delta^{18}$O values indicate warmer temperatures, and this record shows low $\delta^{18}$O values at $\sim$12 ka, which is evidence for a cold Younger Dryas event followed by temperatures increasing to near-modern levels. The early Holocene Grand Canyon depositional package (I) may correlation to changes in climate at the end of the Younger Dryas.

Early Holocene climate proxies within Grand Canyon come from packrat middens and bat guano. A curve of $\delta^{13}$C values was developed based on Grand Canyon packrat midden data (Cole and Arundel, 2005, Figure 31). Deposition of package I coincides with a general increase in $\delta^{13}$C from packrat middens, which indicates higher temperatures and summer-dominated precipitation and corresponds to a change in vegetation (Wurster et al., 2008). The $\delta^{13}$C and $\delta$D values in a bat guano cores also show a correlation to these results. Higher $\delta$D values indicate increased precipitation and temperature. Both proxies indicate a climatic shift around $\sim$11.5 ka at the end of the Younger Dryas and during the deposition of package I. Both bat guano curves indicate an abrupt cooling and decreased precipitation at 8.2 ka, an event that is interpreted to be a change in atmospheric circulation, possibly a period of maximum insolation and strong summer monsoons (Wurster et al., 2008). This event corresponds to the end of deposition of package II, although the exact relation between this event and earlier deposition is unclear.
Figure 31. Graph of early Holocene paleoclimate proxy curves, including global and regional proxies. A: $\delta^{18}O$ values, modified from Stuiver et al., 1995. B: Packrat midden $\delta^{13}C$ values (modified from Cole and Arundel, 2005). C: Bat guano $\delta D$ values (modified from Wurster et al., 2008). D: Bat guano $\delta^{13}C$ values (modified from Wurster et al., 2008). Shaded grey bars correspond to inferred Grand Canyon depositional packages I, II, and III. Vegetation shift and maximum monsoonal precipitation time frames are suggested by Wurster et al., 2008.
In the mid-Holocene, the Alithermal was a climatic episode warmer and drier than present, as observed in data from microfossils from lake sediment cores and $\delta^{18}$O values from stalagmites (Weng and Jackson, 1999; Asmerom et al., 2007). This warm, dry episode seems to correspond to the deposition of package III (~7-4 ka) in the middle Holocene. This package consists of both terrace-top mainstem flood deposition and local slope facies, suggesting incremental aggradation on the Colorado River while drought was occurring elsewhere in the Colorado Plateau. Incremental aggradation may be due to low to moderate flood discharges during drought. After the Alithermal, an additional aggradational episode is preserved as the deposition of package IV, which does not correlate to any large climate anomaly, although Ely (1997) suggests that it is a period of stronger ENSO activity.

These depositional packages can also be compared to late Holocene climate proxies in Grand Canyon. Tree rings records, was used to reconstruct both drought in the Upper Colorado River Basin and flow at Lees Ferry (Cook et al., 2004; Meko et al., 2007; Figure 32). The Medieval Warm Period and the Little Ice Age are both discernible from these curves, and there is no apparent correspondence between depositional packages and either climatic episode. Both overlap episodes of erosion and deposition. If the final results from the preliminary ~0.8 ka age (USU-283, Ninemile Draw) indicate that it is younger, then package VI will correspond better to the Little Ice Age and Hereford’s umt terrace.

In addition, no pattern immediately emerges when comparing these packages to recent paleoflood packages identified in the Southwest (Figure 32). Paleoflood frequency
Figure 32. Graph of Grand Canyon paleoclimate proxies from the Grand Canyon region for the past 1.2 ka. Top curve is modified from tree ring studies (Cook et al. 2007), and is a plot of % drought area over time. Middle curve is a 25-yr running average % of 1906-2000 mean flow (Meko et al., 2007). Bottom curve is total paleoflood counts modified from Ely et al., 1993, with floods grouped into 0.2 ka intervals. Medieval Warm Period and Little Ice Age time constraints are local values from Cook et al. (2007).
increased towards the later part of the past 1.2 ka (Ely, 1997), but there was no fluvial depositional package younger than ~0.3 ka identified in this study. These results are weighted towards the present because of increased preservation, but the paleoflood study indicates a period of increased deposition between the age constraints on packages V and VI and after package VI. If the final OSL age on the oldest portion of package VI is younger than the initial age of ~0.8 ka, it will correspond to increased paleoflood deposition.

Overall, Holocene paleoclimate records do not necessarily correspond to the Holocene alluvial record in Grand Canyon. Such correlations will likely become clearer with more continued work. One possible explanation for the lack of correlation is that the resolution of these geochronology results is too poor to properly constrain to flood packages on timescales as short as climate variability. An alternative explanation is that the Colorado River has such a large drainage area and integrates climate signals from numerous locations throughout the Colorado Plateau, it is likely that it does not respond to small oscillations in climate like the Little Ice Age and the Medieval Warm Period as a smaller tributary drainage would, as documented on the Colorado Plateau.
CONCLUSIONS

1) Eleven distinct sedimentary facies at Ninemile Draw and Tanner Bar can be used to help determine the depositional environment of preserved terrace sediment, including those surrounding archaeological sites. Most facies are preserved at both study sites. Five facies are interpreted as mainstem river deposits and are evidence for Colorado River flood events. Four facies are interpreted as local-slope deposits along the channel margin. One facies is interpreted to be influenced by anthropogenic activity. Where mainstem or local deposits dominate, it may indicate relatively active sedimentation or preferred preservation of that system. One facies is interpreted as eolian deposit and is only common in late Holocene strata.

2) This study has produced a refined understanding of the Holocene chronostratigraphy in Grand Canyon. Stratigraphic observations at Ninemile Draw and Tanner Bar indicate Holocene alluvium includes sediment older than previously known, as old as 12 ka. Observed and implied unconformities in the stratigraphy suggest these may encompass six distinct packages, all at overlapping elevations or stages. These packages are potentially correlatable between reaches along the corridor, but neither of the two study sites includes all six.

3) Sedimentary patterns and trends within the stratigraphic packages provide circumstantial evidence for changing river grade over the Holocene. For example, facies reflecting local-slope depositional systems at both low and high landscape positions suggest episodic floodplain accretion and true aggradation, not just paleoflooding. Also, ~11 ka mainstem channel gravels at 8 m above the present-day shoreline indicate higher
local grade in the early Holocene at Tanner Bar. The suggestions of changing grade are limited to the first four inferred depositional packages. The younger two flood packages, V and VI, have solely mainstem sandy and silty facies of flood deposits, and they may reflect a static river grade over the past ~1 ky.

4) In terms of correlations to previous work, the younger mainstem flood packages do not correlate well with the overall Colorado Plateau late Holocene paleoflood record of Ely (1992; Ely et al., 1993). Nevertheless, packages V and VI correspond to paleoflood episodes identified specifically in Grand Canyon (Ely, 1992; O’Connor et al., 1994), as well as to Hereford’s previously identified ap and umt terraces.

5) There is a loose correlation between the inferred older depositional packages, I and III and early to mid-Holocene climate. It appears that deposition may coincide with drier episodes, including the post-Younger Dryas and the Altithermal. The younger inferred alluvial packages do not correlate well with late Holocene climate. For example, deposition occurred during both the Medieval Warm Period and the Little Ice Age.

6) These initial results from two sites lend some support to both models of deposition and terrace formation and disprove neither. Inset deposits dominate much of the Holocene record, with evidence for an aggrading river on millennial timescales at least twice. This supports Hereford’s model of inset terrace deposits and changing river grade. On the other hand, purely mainstem paleoflood deposits dominate the past ~1 ky of the record. This suggests that caution should be taken before using present-day stage-discharge relations to determine paleoflood magnitude before ~1 ky, because channel geometry and grade have likely varied over Holocene timescales.
REFERENCES


Anderson, K.C., 2006, Geoarchaeological investigations of 53 sites between Glen Canyon Dam and Paria Riffle: Navajo Nation Archaeology Department Report No. 05-229. Ms. on file, United States Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.


Mackley, R.D., 2005, Relating the bedrock strength to hydraulic driving forces along the large-scale profile of the Colorado River in Glen and Grand Canyons [MS thesis]: Logan, Utah State University, 173 p.


Mann, D.H., and Metzler, D.J., 2007, Millennial-scale dynamics of valley fills over the past 12,000 14C yr in northeastern New Mexico, USA: GSA Bulletin v. 119, nos. 11-12, 1433-1448.


APPENDICES
Appendix A: TANNER BAR TEXTURE AND COMPOSITION RESULTS
<table>
<thead>
<tr>
<th>USU ID**</th>
<th>CaCO3</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Texture</th>
<th>Organic Matter***</th>
<th>Iron****</th>
<th>Interpreted Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>4384</td>
<td>6.8</td>
<td>66</td>
<td>23</td>
<td>11</td>
<td>sandy loam</td>
<td>NA</td>
<td>5150</td>
<td>mainstem</td>
</tr>
<tr>
<td>4385</td>
<td>6.2</td>
<td>75</td>
<td>14</td>
<td>11</td>
<td>sandy loam</td>
<td>NA</td>
<td>11300</td>
<td>mixed</td>
</tr>
<tr>
<td>4386</td>
<td>6.8</td>
<td>41</td>
<td>48</td>
<td>11</td>
<td>loam</td>
<td>0.8</td>
<td>8240</td>
<td>organic/mainstem</td>
</tr>
<tr>
<td>4387</td>
<td>6.5</td>
<td>41</td>
<td>49</td>
<td>10</td>
<td>loam</td>
<td>NA</td>
<td>7980</td>
<td>mixed</td>
</tr>
<tr>
<td>4388</td>
<td>6.8</td>
<td>33</td>
<td>52</td>
<td>15</td>
<td>silty loam</td>
<td>NA</td>
<td>10300</td>
<td>mainstem</td>
</tr>
<tr>
<td>4389</td>
<td>6.8</td>
<td>34</td>
<td>55</td>
<td>11</td>
<td>silty loam</td>
<td>NA</td>
<td>8110</td>
<td>mainstem</td>
</tr>
<tr>
<td>4390</td>
<td>6.2</td>
<td>69</td>
<td>25</td>
<td>5</td>
<td>sandy loam</td>
<td>NA</td>
<td>6800</td>
<td>mainstem</td>
</tr>
<tr>
<td>4391</td>
<td>6.2</td>
<td>58</td>
<td>32</td>
<td>9</td>
<td>sandy loam</td>
<td>NA</td>
<td>9220</td>
<td>mixed</td>
</tr>
<tr>
<td>4392</td>
<td>3.1</td>
<td>81</td>
<td>9</td>
<td>10</td>
<td>loamy sand</td>
<td>NA</td>
<td>11600</td>
<td>local</td>
</tr>
<tr>
<td>4393</td>
<td>5.6</td>
<td>62</td>
<td>30</td>
<td>8</td>
<td>sandy loam</td>
<td>NA</td>
<td>9399</td>
<td>mixed</td>
</tr>
</tbody>
</table>

**average** 6.1 56 33.7 10 8810

| standard deviation | 1.13 | 17.51 | 16.44 | 2.56 | 1991 |

*All samples from Tanner Bar C:13:327 stratigraphy. Location is UTM 12 N, 220594 E 565500 N.
**Processed by the Utah State University Analytical Laboratory.
***Only measured in sample containing visible organic content.
**** Processed by Chemtech-Ford Laboratories, Murray, UT.
Appendix B: STRATIGRAPHIC COLUMNS AND DESCRIPTIONS
Figure B.1. Stratigraphic column of Ninemile Draw Packages A and B with units and geochronology sample locations labeled. See Tables B1 and B2 for detailed unit descriptions.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology sample</th>
<th>Preliminary age (ka)</th>
<th>Paleocurrent (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.06</td>
<td>Carbonate silt, 6-10 cm, planar unit with horizontal basal contact, bed thins slightly downriver, massive, no grading, mottled appearance, minor root bioturbation, 10 YR 6/6</td>
<td>MSm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>Silty sand, 60 cm, basal contact rises downriver, climbing ripples throughout, rare carbonate laminae near bottom, grain size is vfl, minor root and burrow bioturbation, effervescence at bottom, 7.5 YR 6/4</td>
<td>MSSlr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>0.05</td>
<td>Sand, 2-10 cm, basal contact is irregular, no grading, grain size is vfl-fi, subrounded, burrow bioturbation, effervescence, 7.5 YR 6/4</td>
<td>MSSlr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.15</td>
<td>Sand, 15 cm, thickens downstream, upper contact gets higher away from river, a few thin laminae, no grading, grain size is fl-fu sand, rounded, no visible bioturbation, 7.5 YR 6/4</td>
<td>MSSlr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.03</td>
<td>Sandy silt, 3 cm, massive, no grading, grain size is silt to vfl sand, matrix is carbonate, root bioturbation, effervescence, 10 YR 6/6</td>
<td>MSm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Sand, 17-20 cm, bottom contact was not visible, 1-4 mm thick laminations, normally graded, rounded, grain size is fu-fl at bottom, vfl-fl at top, no visible bioturbation, no effervescence, sand completely unconsolidated,

1 | 0.2 | 7.5 YR 6/4 | MSSlr | USU-284; OSL | 5.0 ± 1.97 | - |

| total thickness (m) | 6.34 |

*See Appendix E for OSL results.  
** See Appendix D for paleocurrent data.
### TABLE B.2. NINEMILE DRAW PACKAGE B UNIT DESCRIPTIONS

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology sample*</th>
<th>Preliminary age (ka)</th>
<th>Paleocurrent (°)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.08</td>
<td>Silt, 8 cm, wavy basal contact and irregular upper contact, thickness does not vary, very thin sand bed 2 mm up unit, planar laminations and few faint climbing ripples, no grading, major root bioturbation especially at upper contact, effervesces, 10 YR 6/3</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13/14</td>
<td>0.25</td>
<td>Sand with pebbly sand lenses, 25 cm, wavy basal contact, pebbly sand lenses have red sand and pebbles clasts 1-5 cm in mean diameter, a few faint laminae and thin beds of alternating red and tan sand, normal grading, grain size at bottom is f1 to ml sand, vt to ml at top, 70% red sand at bottom, decreases to 30% towards top of unit, minor root and burrow bioturbation, slight effervescence, 2.5 YR 6/6- 5 YR 6/6</td>
<td>MRSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11/12</td>
<td>0.27</td>
<td>Sand with pebbly sand lenses, 27 cm, red sand with laminae of tan sand, rare floating red sandstone pebbles, plane bed laminations and some gentle ripples, fines upward, grain size is f1 to ml sand at bottom and vt-fl sand at top, minor burrow bioturbation, 5 YR 5/6 at bottom grades to 7.5 YR 6/6 at top</td>
<td>MRSIr</td>
<td>-</td>
<td>120, 260</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>0.1</td>
<td>Sand capped by silt, 10 cm, basal contact is slightly wavy, discontinuous cross bedding, subcritical and critical climbing ripples, normally graded, grain size is vt sand to silt at the base, strong effervescence, burrowing at top and bottom contacts, sand is 10 yr 6/3, silt cap at top is 10 YR 6/2</td>
<td>MRSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9b</td>
<td>0.18</td>
<td>Sand, 18 cm, sharp upper contact, rare local pebbles, 1-2 cm thick very low angle, thin cross beds, normal grading, ms at bottom and fl sand at top, bioturbated by burrows, 5 YR 6/6</td>
<td>MRSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9a</td>
<td>0.23</td>
<td>Sand, 23 cm, erosional scoped basal contact with 20 cm of relief, interbedded silt laminae, capped by 3 m broad evaporative mud pan, local pebbles, planar laminations and low-angle ripples throughout, normally graded, grain size is ml-cl, sand at bottom and fL-ML sand at top, burrows at bottom contact, minor root bioturbation, silt is 5YR 7/2, sand is 5 YR 6/6</td>
<td>MRSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>0.55</td>
<td>Alternating silt and sand, 55 cm, alternating laminae of tan silt and sand, thin beds, basal contact is wavy, sand has climbing ripples and plane bed laminae, isolated lenses of red tributary sand are present, no grading, subrounded, grain size is vsu-vft, grain size in lenses of sand is fu-vft, root and burrow bioturbation throughout, rhizoliths, silt is 7.5 YR 6/2, lenses of sand are 5 YR 6/4</td>
<td>MRSIr</td>
<td>-</td>
<td>110, 230</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>0.15</td>
<td>Sand, 15 cm, basal contact is planar to slightly wavy and very bioturbated, climbing ripples and cross bedding that are less distinct towards top, no grading, grain size is vt-fl, rounded, slight bioturbation, rhizoliths, 7.5 YR 7/2</td>
<td>MRSIr</td>
<td>USU-355; OSL</td>
<td>3.0 ± 0.52</td>
<td>-</td>
</tr>
</tbody>
</table>

*See Appendix E for OSL results.

** See Appendix D for paleocurrent data.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology sample*</th>
<th>Preliminary age (ka)</th>
<th>Paleocurrent (°)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>25c</td>
<td>0.18</td>
<td>Sand, 20 cm, wavy basal contact, some laminations, no grading, grain size is fl to fu sand, small pieces of organic matter throughout, no effervescence, minor burrow bioturbation, 2.5 YR 6/6</td>
<td>MRSir</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>0.44</td>
<td>Sandy silt, 44 cm, massive, no grading, grain size is silt to vfu sand, root and burrow bioturbation, no effervescence, 10 YR 6/3</td>
<td>MSm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23</td>
<td>0.06</td>
<td>Carbonate silt, 6 cm, maximum thickness of 10 cm, wavy and indistinct basal contact, no structures, no grading, major root and burrow bioturbation, rhizoliths effervesces, 10 YR 7/2</td>
<td>LMI</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>22</td>
<td>0.08</td>
<td>Pebble sand, 8 cm, wavy basal contact, sandstone pebbles at throughout unit, no structures, no grading, grain size of sand is fl to mu and pebbles are 1 to 5 cm in mean diameter, lots of root bioturbation on top, rare charcoal fragments, 2.5 YR 6/6</td>
<td>LGS</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>21</td>
<td>0.07</td>
<td>Silt, 1-7 cm, laterally discontinuous, irregular basal contact, no structures, no grading, root bioturbation, effervesces, 10 YR 7/2</td>
<td>LMI</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>0.39</td>
<td>Sand, 38-42 cm, capped by lens of burned organic matter, thin charcoal bed and burn horizon, 70% sand and 30% pebbles, pebbles throughout concentrated between 6 and 12 cm and 5 cm at top, no visible structures, no grading, grain size of sand is fl to mu, sand is 2.5 YR 6/6</td>
<td>LGS</td>
<td>14C*</td>
<td>2700-2300 cal yr BP</td>
<td>-</td>
</tr>
<tr>
<td>19</td>
<td>0.02</td>
<td>Silt, 1-2 cm, irregular and indistinct basal contact, discontinuous, contains some red sand, no structures, no grading, major burrow bioturbation at top, effervesces, 10 YR 6/6</td>
<td>LMI</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>0.05</td>
<td>Silty sand, 14 cm, planar bed but basal contact is slightly wavy, no grading, burrow bioturbation throughout, effervesces, 10 YR 6/6</td>
<td>LGS</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>0.15</td>
<td>Sand, 15-17 cm, irregular basal contact, planar laminations and thin ripple cross-stratification and climbing ripples, inversely graded, grain size is fl to ml sand at bottom, upper 4 cm is pulse of fine to medium sand, insect burrow bioturbation at contacts, rhizoliths</td>
<td>MSSir</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>0.16</td>
<td>Sand, 20 cm, wavy basal contact, some laminations, no grading, minor burrow bioturbation, 2.5 YR 6/6</td>
<td>MRSir</td>
<td>-</td>
<td>-</td>
<td>230</td>
</tr>
</tbody>
</table>

*See Appendix E for OSL results.

** See Appendix D for paleocurrent data.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology sample*</th>
<th>Preliminary age (ka)</th>
<th>Paleo-current (°)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.08</td>
<td>Silt, 8 cm, wavy basal contact and irregular upper contact, thickness does not vary, very thin sand bed 2 mm up unit, planar laminations and few faint climbing ripples, no grading, major root bioturbation especially at upper contact, effervesces, 10 YR 6/3</td>
<td>MSSr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13/14</td>
<td>0.25</td>
<td>Sand with pebbly sand lenses, 25 cm, wavy basal contact, pebbly sand lenses have red sand and pebbles clasts 1-5 cm in mean diameter, a few faint laminae and thin beds of alternating red and tan sand, normal grading, grain size at bottom is ft to ml sand, vfl to ml at top, 70% red sand at bottom, decreases to 30% towards top of unit, minor root and burrow bioturbation, slight effervescence, 2.5 YR 6/6- 5 YR 6/6</td>
<td>MRSlr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11/12</td>
<td>0.27</td>
<td>Sand with pebbly sand lenses, 27 cm, red sand with laminae of tan sand, rare floating red sandstone pebbles, plane bed laminations and some gentle ripples, fines upward, grain size is fl to ml sand at bottom and vfl-ft sand at top, minor burrow bioturbation, 5 YR 5/6 at bottom grades to 7.5 YR 6/8 at top</td>
<td>MRSlr</td>
<td>-</td>
<td>-</td>
<td>120, 260</td>
</tr>
<tr>
<td>10</td>
<td>0.1</td>
<td>Sand capped by silt, 10 cm, basal contact is slightly wavy, discontinuous cross bedding, subcritical and critical climbing ripples, normally graded, grain size is vfl sand to silt at the base, strong effervescence, burrowing at top and bottom contacts, sand is 10 yr 6/3, silt cap at top is 10 YR 8/2</td>
<td>MSSr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9b</td>
<td>0.18</td>
<td>Sand, 18 cm, sharp upper contact, rare local pebbles, 1-2 cm thick very low angle, thin cross beds, normal grading, ms at bottom and ft sand at top, bioturbated by burrows, 5 YR 6/6</td>
<td>MRSlr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9a</td>
<td>0.23</td>
<td>Sand, 23 cm, erosional scoped basal contact with 20 cm of relief, interbedded silt laminae, capped by 3 m broad evaporative mud pan, local pebbles, planar laminations and low-angle ripples throughout, normally graded, grain size is mL-cL sand at bottom and fu-ml sand at top, burrows at bottom contact, minor root bioturbation, silt is 5YR 7/2, sand is 5 YR 6/6</td>
<td>MRSlr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>0.55</td>
<td>Alternating silt and sand, 55 cm, alternating laminae of tan silt and sand, Thin beds, basal contact is wavy, sand has climbing ripples and plane bed laminae, isolated lenses of red tributary sand are present, no grading, subrounded, grain size is vfu-vfl, grain size in lenses of sand is fu-vfl, root and burrow bioturbation throughout, rhizoliths, silt is 7.5 YR 6/2, lenses of sand are 5 YR 6/4</td>
<td>MSSr</td>
<td>-</td>
<td>-</td>
<td>110, 230</td>
</tr>
<tr>
<td>7</td>
<td>0.15</td>
<td>Sand, 15 cm, basal contact is planar to slightly wavy and very bioturbated, climbing ripples and cross bedding that are less distinct towards top, no grading, grain size is vfl-vfu, rounded, slight bioturbation, rhizoliths, 7.5 YR 7/2</td>
<td>MSr</td>
<td>USU-355; OSL</td>
<td>3.0 ± 0.52</td>
<td>-</td>
</tr>
<tr>
<td>thickness (m)</td>
<td>1.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE B.2. NINEMILE DRAW PACKAGE B UNIT DESCRIPTIONS (CONTINUED)**
Figure B.2. Stratigraphic column of Ninemile Draw Package C with units and geochronology sample locations labeled. See Table B.3 for detailed unit descriptions.


TABLE B.3. NINEMILE DRAW PACKAGE C UNIT DESCRIPTIONS

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology sample*</th>
<th>Preliminary age (ka)</th>
<th>Paleocurrent (°)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.8</td>
<td>Sand, up to 80 cm, erosional upper contact and erosional contact with buttress unconformity, thin crossbeds and ripples climbing upstream, lots of rooting bioturbation, 10 YR 6/3</td>
<td>MSSr</td>
<td>USU-458; OSL</td>
<td>1.48 ± 0.82</td>
<td>250</td>
</tr>
<tr>
<td>9</td>
<td>0.9</td>
<td>Silty sand, 90 cm, start of this unit blankets unlevel surface, deposited on slope to bedding is slope-parallel, laminated and thinly interbedded, silt to vfs thinly interbedded with vfs, 10 YR 6/3</td>
<td>MSSr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>0.28</td>
<td>Sand, 28 cm, massive, bioturbated at top, 7.5 YR 5/4</td>
<td>ES</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>0.17</td>
<td>Silty sand, 17 cm, 10 YR 6/3</td>
<td>MSSr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>0.05</td>
<td>Sand, 5 cm, massive, grain size is vfs to fs, burrow and root bioturbation, 7.5 YR 5/4</td>
<td>MSSm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>0.16</td>
<td>Silty sand, 16 cm, 10 YR 6/3</td>
<td>MSSr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>0.06</td>
<td>Sand, 6 cm, grain size is vfs to fs, very bioturbated, 7.5 YR 5/4</td>
<td>MSSr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>Silty sand, 25 cm, wavy but sharp basal contact, planar laminations and ripples, 10 YR 6/3</td>
<td>MSSr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.04</td>
<td>Sand, 4 cm, massive, grain size is vf-f, extremely bioturbated, 7.5 YR 5/4</td>
<td>MSSm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>0.28</td>
<td>Silty sand, 28 cm, ripples up to 7 cm tall oriented upstream, 10 YR 6/3</td>
<td>MSSr</td>
<td>USU-487; OSL</td>
<td>0.26 ± 0.12</td>
<td>-</td>
</tr>
</tbody>
</table>

total thickness 2.99

*See Appendix E for OSL results.
** See Appendix D for paleocurrent data.
Figure B.3. Stratigraphic column of Ninemile Draw Package D with units and geochronology sample locations labeled.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology sample*</th>
<th>Preliminary age (ka)</th>
<th>Paleo-current (°)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.8</td>
<td>Sand, up to 80 cm, erosional upper contact and erosional contact with buttress unconformity, thin crossbeds and ripples climbing upstream, lots of rooting bioturbation, 10 YR 6/3</td>
<td>MSIr</td>
<td>USU-458; OSL</td>
<td>1.48 ± 0.82</td>
<td>250</td>
</tr>
<tr>
<td>9</td>
<td>0.9</td>
<td>Silty sand, 90 cm, start of this unit blankets unlevel surface, deposited on slope to bedding is slope-parallel, laminated and thinly interbedded, silt to vfs thinly interbedded with vfs, 10 YR 6/3</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>0.28</td>
<td>Sand, 28 cm, massive, bioturbated at top, 7.5 YR 5/4</td>
<td>ES</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>0.17</td>
<td>Silty sand, 17 cm, 10 YR 6/3</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>0.05</td>
<td>Sand, 5 cm, massive, grain size is vfs to fs, burrow and root bioturbation, 7.5 YR 5/4</td>
<td>MSm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>0.16</td>
<td>Silty sand, 16 cm, 10 YR 6/3</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>0.06</td>
<td>Sand, 6 cm, grain size is vfs to fs, very bioturbated, 7.5 YR 5/4</td>
<td>MSm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>Silty sand, 25 cm, wavy but sharp basal contact, planar laminations and ripples, 10 YR 6/3</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.04</td>
<td>Sand, 4 cm, massive, grain size is vf-f, extremely bioturbated, 7.5 YR 5/4</td>
<td>MSm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>0.28</td>
<td>Silty sand, 28 cm, ripples up to 7 cm tall oriented upstream, 10 YR 6/3</td>
<td>MSSIr</td>
<td>USU-457; OSL</td>
<td>0.26 ± 0.12</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>total thickness (m)</td>
<td>2.99</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*See Appendix E for OSL results.

** See Appendix D for paleocurrent data.
Figure B.4. Tanner Bar geomorphic study gully stratigraphic column with OSL sample locations labeled. See Table B.5 for detailed unit descriptions and Appendix D for paleocurrent data.
**TABLE B.5. TANNER BAR GEOMORPHIC STUDY GULLY UNIT DESCRIPTIONS**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit description</th>
<th>Facies</th>
<th>Geochronology sample</th>
<th>Preliminary age (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1</td>
<td>Stripes at the top of exposure are approximately 1 meter thick interfingering hillslope and mainstem material, percentage of mainstem increases into the gully, lots of rodent holes in these beds</td>
<td>LGS and MSm</td>
<td>USU-436</td>
<td>5.42 ± 0.73ka</td>
</tr>
<tr>
<td>5</td>
<td>variable</td>
<td>Alternating mainstem and Dox/Pleistocene hillslope material, overlaps in stratigraphic level with Unit 3</td>
<td>LGS and MSm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.45</td>
<td>Sand, differs from unit 2 because it is more red, approximate thickness is 45 cm, a few faint mud drapes and ripples, some strings of Dox granules, composition of sand is fine to medium, some rhizoliths, slightly effervescent, 7.5 YR 6/4</td>
<td>MSIr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>variable</td>
<td>Mainstem sand with interfingering Dox colluvium, unit dips toward gully, some small strings of Dox granules are present, sand is subrounded, fine to medium, some carbonate development, root bioturbation, slight effervescence, 7.5 YR 5/4</td>
<td>LGS and MSm</td>
<td>USU-434</td>
<td>8.40 ± 1.7 ka</td>
</tr>
<tr>
<td>2</td>
<td>1.2 m minimum</td>
<td>Dox lithic unit, 1.2 m minimum thickness, angular to subrounded clasts, clasts range in size from 0.5 cm intermediate diameter to cobble-sized, matrix ranges in size from fine sand to Dox granules, poorly-sorted, clasts-supported, 2-4% of clasts are Pleistocene gravels, root bioturbation, white carbonate development on some clasts</td>
<td>LGS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>?</td>
<td>Massive mainstem sand</td>
<td>MSm</td>
<td>USU-512</td>
<td>11.64 ± 0.62 ka</td>
</tr>
</tbody>
</table>

*See Appendix E for OSL results.*
Figure B.5. Tanner Bar C:13:327 stratigraphic column with OSL sample locations labeled. See Table B.6 for detailed unit thicknesses and descriptions.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology sample*</th>
<th>Preliminary age (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>0.2</td>
<td>Sand, 20 cm, climbing ripple cross-bedding, vf-fl qtz sand</td>
<td>MSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>41</td>
<td>0.08</td>
<td>Sand, 8 cm, reverse graded with inset colluvial rill-fill structures, w/ anthropogenic floating cobbles at top, vf-f qtz sand, cross-stratified coarse sand to granule Dox lithic dominated layers at top</td>
<td>MSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>40</td>
<td>0.13</td>
<td>Sand, 13 cm, normally graded from pebbly sand to sand, coarse Dox lithics entrained at base, vf-fl qtz sand</td>
<td>LGS</td>
<td>USU-142 and radiocarbon</td>
<td>OSL= 1.48 ± 0.13 ka radiocarbon= 1420-1360 BP</td>
</tr>
<tr>
<td>39</td>
<td>0.77</td>
<td>Pebble gravel, 77 cm, clasts entirely angular Dox ss, up to 8 cm diameter, matrix vf sandy silt, clast-supported, strongly imbricated to ENE.</td>
<td>LGS</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>38</td>
<td>0.09</td>
<td>Sand, 9 cm, climbing ripple cross lamination-to-thin bedding, vf-f qtz sand, trace of charcoal bits, m grained lithics.</td>
<td>MSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>37</td>
<td>0.08</td>
<td>Sand capped w/ mud drape, 8 cm, bioturbated at top, vf-f qtz sand, Dox vf sand lithics at base.</td>
<td>MSm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>36</td>
<td>0.08</td>
<td>Sand, 8 cm, normally graded from qtz sand to silty sand at top organic ash stain w/ charcoal fragments at top.</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>35</td>
<td>0.09</td>
<td>Silty sand, 9 cm, normally graded, vf-f qtz sand to vf sandy silt at top, mud drapes within, and lithics at base</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>34</td>
<td>0.06</td>
<td>Silt, 6 cm, fines up to clay drape, sharp bounding contacts</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>33</td>
<td>0.15</td>
<td>Sand, 15 cm, climbing ripples below cross-bedding, vf-f qtz sand, Dox lithics at base, bioturbated</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>32</td>
<td>0.14</td>
<td>Sand, 14 cm thick, normally graded; climbing ripple cross-laminated, vf-m qtz sand, lithics concentrated at base</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>31</td>
<td>0.11</td>
<td>Sand, 11 cm, climbing ripple cross laminated, vf sand at base and top, c-m qtz sand with Dox sss lithics in center of unit</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
<td>0.25</td>
<td>Sand, 25 cm, inversely graded vf sand to vf-cl qtz sand at top, climbing ripples, thin cross bedding</td>
<td>MSSIr</td>
<td>USU-141</td>
<td>1.5 ± 0.11 ka</td>
</tr>
<tr>
<td>29</td>
<td>0.25</td>
<td>Lithic sand, normally-graded c-f sand at base to silty fs at top. Paleocurrent climbing ripples. Mainstem overbank flood reworking</td>
<td>MSSIr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>28</td>
<td>0.24</td>
<td>Pebble-granule sand, 24 cm, Dox ss lithics at base normally graded to massive, well-sorted vf-f sand and mud drape at top</td>
<td>LGS</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*See Appendix E for OSL results and Appendix F for radiocarbon results.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology sample*</th>
<th>Preliminary age (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>0.14</td>
<td>Silty sand, 14 cm, tabular, thins to right, set of 4 normally graded thin beds, mud drapes on massive upper bed and on thin top bed, climbing ripples in basal thin beds, massive upper beds, vfU to CU at base, grades to silty vfu sand, slight effervescence, 7.5 YR 6/4 to 5 YR 4/4</td>
<td>LGS</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>26</td>
<td>0.085</td>
<td>Sandy silt, 8.5 cm, thins to left and thickens to right, capped by 1-2 mm mud drape, plane-bed laminations to thinly bedded interlaminations of fU Dox lithic sand over small pebbles, no grading, vfL sandy silt, moderate effervescence, 5 YR 5/4</td>
<td>MSSir</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25</td>
<td>0.1</td>
<td>Sandy silt, 10 cm, 1 mm capping mud drape, faint climbing ripples at base, reverse grading, fl sandy silt to vcl lithic sand, bioturbated by modern roots, no effervescence, color grades up from 7.5 YR 5/4 to 2.5 YR 5/4</td>
<td>MSSir</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>0.02</td>
<td>Silty sand, 13.5 cm, lenticular, thins to right and pinches out within 40 cm, thin crossbeds, ripples cross laminated with very thin mud drape atop ripples, no grading, silty vfU sand, few coarse sand Dox lithics throughout, few rhizoliths and roots, slight effervescence throughout except mud drapes effervesces moderately, 7.5 YR 5/4</td>
<td>MSSir</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23</td>
<td>0.135</td>
<td>Silty sand, 13.5 cm, lenticular, thins to right and pinches out within 40 cm, thin crossbeds, ripples cross laminated with very thin mud drape atop ripples, no grading, silty vfU sand, few coarse sand Dox lithics throughout, few rhizoliths and roots, slight effervescence throughout except mud drapes effervesces moderately, 7.5 YR 5/4</td>
<td>MSSir</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>22</td>
<td>0.085</td>
<td>Sand, 7-10 cm, capped by 0.5 cm clay, distinct but wavy contacts, planar laminations, normal grading, silt to vfU sand at bottom and silt to fu sand at top, bottom 1 cm is vcl to vfU Dox lithic sand, rhizocretions and root bioturbation, no effervescence, 7.5 YR 5/4</td>
<td>MSlr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>21</td>
<td>0.09</td>
<td>Silty sand, 9 cm, capped by clay, at least 1 internal discontinuous mud drape, lenticular, wavy contacts, wavy laminations, no grading, silt to vfU sand, rhizocretions throughout, slight effervescence, 5 YR 5/4</td>
<td>MSlr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>0.05</td>
<td>Sand, 0-10 cm, discontinuous very thin clay bed throughout, contacts are wavy, unit pinches out downstream, crossbeds, no grading, vf to ml sand, rhizoliths and flecks of organic matter present, sand does not effervesce but clay does, sand is 7.5yr 5/4, clay is 5 YR 5/4</td>
<td>MSlr</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**TABLE B.6. TANNER BAR C:13:327 UNIT DESCRIPTIONS (CONTINUED)**

**thickness (m): 0.655**
<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology Sample*</th>
<th>Preliminary age (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>0.13</td>
<td>Sand, 13 cm, tabular bed, capped by clay, Dox lithics present in lenses, bottom contact is distinct but top is diffuse, planar laminations at top, normally graded, lithics are concentrated in bottom 7-9 cm, lithic lens at bottom has matrix of vcu angular dox to vfU Dox and clasts of Dox gravel with 1.5 cm mean diameter, sand at top is vfU to vfL, occasional features that look like reworked unit 7, present, root bioturbation and rhizoliths, no effervescence.</td>
<td>Preliminary age (ka)</td>
<td>MSir</td>
<td>19 0.13</td>
</tr>
<tr>
<td>18</td>
<td>0.11</td>
<td>Sand, 11 cm, capped by 1 cm of coarse Dox sand, wavy laminations and climbing ripples at the bottom, normally graded, grain size at bottom is fl to cu sand, grain size at top is vfL to cu sand, root bioturbation, bottom effervesces slightly, top does not effervesce.</td>
<td>Preliminary age (ka)</td>
<td>MSir</td>
<td>18 0.11</td>
</tr>
<tr>
<td>17</td>
<td>0.06</td>
<td>Sand, 6 cm, lenticular, sharp upper contact, massive, inversely graded, bottom is fl to cu angular sand, top is fl to granule-sized angular and subangular sand, rare gravels 6 cm mean diameter, proportion of mainstem sand increases going up unit, bottom does not effervesce but top does.</td>
<td>Preliminary age (ka)</td>
<td>MSm</td>
<td>17 0.06</td>
</tr>
<tr>
<td>16</td>
<td>0.065</td>
<td>Sand, 6.5 cm, wavy contacts, very thin clay drape on top, discontinuous string of vcl Dox lithic sand 2 cm up unit, planar laminations, normally graded, bottom is angular fu to mu sand, top is vfL to fu, rhizocretions, effervesces.</td>
<td>Preliminary age (ka)</td>
<td>MSir</td>
<td>16 0.065</td>
</tr>
<tr>
<td>15</td>
<td>0.09</td>
<td>Gravelly sand, 9 cm, no structures, seems tabular but is probably lenticular, wavy basal contact, coarse Dox lithics with gravels up to 6 cm mean diameter, matrix is vcu sand, 5 YR 5/4</td>
<td>Preliminary age (ka)</td>
<td>LGSi</td>
<td>15 0.09</td>
</tr>
<tr>
<td>14</td>
<td>0.18</td>
<td>Sand, 15 cm, wavy basal contact, massive, 6 cm thick red sand lens with red clay cap pinches out away from river, no grading, 5% lithic fragments, grain size is vfL to cl sand, some charcoal present, rhizocretions, slight effervescence, 7.5 YR 5/4</td>
<td>Preliminary age (ka)</td>
<td>MSm</td>
<td>14 0.18</td>
</tr>
<tr>
<td>13</td>
<td>0.065</td>
<td>Silty sand, 6.5 cm thick, thickness varies by about 4 cm, climbing ripples, normal grading, grain size is silt to vfL sand, rhizocretions, some charcoal present, effervesces.</td>
<td>Preliminary age (ka)</td>
<td>MSStr</td>
<td>13 0.065</td>
</tr>
<tr>
<td>12</td>
<td>0.32</td>
<td>Sand, 32 cm, 7/5 YR 5/4, 1 cm diffuse clay layer is present 4 cm from the bottom, thin mud drape over top, wavy laminations, a few cross beds visible, inversely graded, bottom is silt to fl sand, top is silt to mu sand, root bioturbation, rhizoliths, effervesces.</td>
<td>Preliminary age (ka)</td>
<td>MSir</td>
<td>12 0.32</td>
</tr>
<tr>
<td>11</td>
<td>0.98</td>
<td>Dox lithic unit, 98 cm, sandstone clasts supported by pebbly colluvial gravel, amount of matrix decreases up the unit, matrix imbricated, clasts are Dox sandstone up to 6 cm mean diameter, grains are fu to mu sand in matrix, matrix is 10 yr 5/4</td>
<td>Preliminary age (ka)</td>
<td>LGSi</td>
<td>11 0.98</td>
</tr>
<tr>
<td>10</td>
<td>0.09</td>
<td>Sand, 9 cm, two distinct colors of sand are present but there is no distinct contact between the two, visible cross beds, normally graded, grain size at the top is vfL to cu sand, bottom is vfL to cu sand, effervesces.</td>
<td>Preliminary age (ka)</td>
<td>MSir</td>
<td>10 0.09</td>
</tr>
</tbody>
</table>

*See Appendix E for OSL results.
TABLE B.6. TANNER BAR C:13:327 UNIT DESCRIPTIONS (CONTINUED)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Unit Description</th>
<th>Facies</th>
<th>Geochronology Sample*</th>
<th>Preliminary age (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0.55</td>
<td>Pebble-gravel, 44 cm, broadly lenticular, wavy contacts, capped by 2 cm silty mud drape, no grading, clast-supported, grain size is fine pebbles and gravels, imbricated Dox clasts &lt;9 cm mean diameter, matrix is vfU to vcu angular lithic sand, rhizoliths only in mud drape, no bioturbation, moderate effervescence, 7.5 YR 6/4</td>
<td>LGSi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.26</td>
<td>Silty sand, 26 cm, tabular bed with wavy contacts, indistinct ripple laminations in sand at base and top, reverse then normal grading with Dox lithic contact in center, base and top have silty vfU sand, center is silty mL lithic sand, moderate sorting, abundant bioturbation with infilled burrows, large and small rhizoliths throughout, moderate effervescence, 7.5 YR 6/4</td>
<td>MSSlr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.25</td>
<td>Sandy silt, 25 cm, tabular bed with wavy top with discontinuous mud drape 1.5 cm thick, two internal discontinuous mud drapes, indistinct wavy lamination, no grading, vfU sandy silt, bioturbated by roots, rhizoliths, root cast, and decayed root within, 7.5 YR 6/4</td>
<td>MSSlr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.015</td>
<td>Silty sand, 29 cm, tabular, top 1-4 cm is lenticular mud drape, indistinct ripple lamination, upper half grades into crinkly laminations and has mud drapes, no grading, silty vfU sand to sandy silt, well-sorted, abundant rhizoliths concentrated at top drape, slight effervescence, 7.5 YR 6/4</td>
<td>MSSlr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.29</td>
<td>Silty sand, 17 cm thick, tabular, top 1 cm is lenticular clayey mud drape, sharp top contact, indistinct low angle ripple lamination at base (~1 cm amplitude), reversely graded, base is silty mL sand, top is fl-cl sand, poorly to moderately sorted, coarse sand is well-rounded, few dispersed rhizoliths and organic flecks, slight effervescence, sand is 7.5 YR 6/4, mud drape is 2.5 YR 5/4</td>
<td>MSSlr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.17</td>
<td>Silty sand, 11 cm thick, tabular, capped by 1 mm mud drape, low angle cross bedding, normal grading, silty mu sand at base to silty fl sand at top, moderately sorted, some small organic charcoal flecks dispersed within, abundant rhizoliths, moderate effervescence, 10 YR 6/4</td>
<td>MSSlr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.11</td>
<td>Silty sand, 18 cm, tabular bed, wavy upper contact, 2 cm bioturbated and discontinuous organic horizon at top, low-amplitude ripple cross lamination, no grading, silty sand, moderately sorted, few rhizoliths below organic layer, moderate effervescence, 10 YR 6/4</td>
<td>MSSlr</td>
<td>radiocarbon- C13327FS1 cal yr BP 3210-2950</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.18</td>
<td>Pebble-gravel, unknown thickness, broadly lenticular, wavy contacts, no grading, clast-supported, grain size is fine pebbles and gravels, imbricated Dox clasts &lt;9 cm mean diameter, matrix is vfU to vcu angular lithic sand, rhizoliths only in mud drape, no bioturbation, moderate effervescence</td>
<td>LGSi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*See Appendix F for radiocarbon results.
Appendix C: ARCHAEOLOGICAL STUDY UNIT STRATIGRAPHIC PANELS AND DESCRIPTIONS

Site C:02:032 (Ninemile) archaeological study units, p. 119-124
Site C:13:323 (Tanner Bar) archaeological study units p. 125-130
Site C:13:327 (Tanner Bar) archaeological study units, p. 131-140
7) Sand, 24 cm, massive, fl to fu sand, 5 YR 5/6, LSm

6) Pebby sand, 9-23 cm, sandstone pebbles in lenses at base, 1-2 cm organic horizon caps unit, fl-fu sand at bottom to vfu-fl sand at top, 5 YR 6/6, LGS

5) Pebby sand, 6-20 cm, inversely graded from vfl to fu sand at bottom and fl to ml sand at top, 5% sandstone pebble clasts, 5 YR 6/6, LGS

4) Pebby sand, 15-40 cm, massive, normally graded with matrix of mu sand at bottom and fl to mu sand at top, 5 YR 6/6, LGS -Capped by unit 4b, discontinuous carbonate silty clay, LMI

3) Pebby sand, 0-16 cm, sandstone pebbles, matrix is silty vf to mu sand, 5 YR 6/6, LGS -Capped by unit 3b, discontinuous carbonate silt, 7.5 YR 7/4, LMI

2) Pebby sand, 10-45 cm, massive, pebbly sandstone gravels less than 2 cm, matrix is silty vf-ml sand, 5 YR 6/6, LGS

Figure C.1. Photo and stratigraphic panel of C:02:032 SU 1. Top photo is oblique view of trench and not to scale. Facies are indicated in bold.
6) Sand with lenses of pebbly sand, 35 cm thick, massive, 3 subunits based on gradational contacts:
   6a: Sand with rare pebbles, 5 cm, vfu-vfl sand inversely graded to fl-ml sand, LGS
   6b: Pebble sand, 10 cm, fl-ml sand, sandstone pebbles up to 5 cm, 5 YR 5/6. LGS
   6c: Sand, 9-20 cm, vfu-ml sand, 7.5 Yr 5/4, LSm

5) Clayey sand, 2-8 cm, silt-fl sand, root and burrow bioturbation, 7.5 YR 6/4, LSm
   -Unit contains centimeter-scale discontinuous clay bodies, 10 YR 6/3, LMI

4) Sand with a lens of pebbly sand, 30-35 cm thick, massive, vfu-ml sand inversely graded to vfu-mu sand at top, rare sandstone pebbles, contains a 5-17 cm lens of 30% sandstone pebbles 0.5-5 cm heavy root and burrow bioturbation, 5 YR 6/6. LGS

3) Silty sand, 5-11 cm, grades up from clay to fl sand, burrows, rizocretions, sand is 5 YR 5/4, clay is 10 YR 7/3, LSm

2) Sand, 15 cm minimum, vfl to fu sand with rare ashy fragments, rare pebbles, burrows and roots truncated against this unit, 5 YR 5/6, LSm

1) Massive ashy sand, 0-7 cm, burn unit pervasive across east end, A

Figure C.2. Photo and stratigraphic panel of C:02:032 SU 2. Photo is oblique view of trench and not to scale. Facies are indicated in bold.
7) Sand, 24 cm, no distinct contact with eolian sand on top, vfl-ml sand, 7.5 yr 5/4, LSm

6) Pebbly sand, approximately 10-30 cm vfu-ml, matrix-supported with subrounded sandstone pebbles, 2.5 YR 5/6, LGs

5) Sand, 10-20 cm with lens of 10 YR 6/3 silty clay laminae with rhizocretions, contains a root cast with dark organic material and ashy sand, bottom of unit contains ashy sand grading up into red sand, 5YR 5/6, LSm

4) Sand, interfingered with clast-supported colluvium of unit 2, vfl-ml, 5 YR 5/6, LGs

3) Clast-supported gravel with sand matrix, interfingers sand of unit 3, sandstone pebbles/cobbles with matrix of red sand, 5 YR 5/6, LGs

2) Ashy sand, discontinuous ash stain that is vfl to ml sand, radiocarbon sample from this unit, 7.5 yr 3/3, capped by lense of charcoal and ash 10-20 cm and 10YR 3/2, A

1) Sand, 37 cm, very slight effervescence, 5 YR 5/6, LSm

Figure C.3. Photo and stratigraphic panel of C:02:032 SU 3. Photo is oblique view of trench and not to scale. Facies are indicated in bold.
7) Sand, 7 cm, tabular bedding, contains organic litter and few very thin clay laminae, vfu-mu sand, rare sandstone pebbles, 2.5YR 5/6, MSSIr

6) Sand, 16 cm, massive, rare pebbles, vfu-ml sand, root bioturbation, 7.5 YR 5/6, MRSm

5) Sand, 10 cm thick, irregular bedding, contains organic litter and very thin clay laminae, vfu-mu sand, rare sandstone pebbles, 2.5 YR 5/6, MSSIr

4) Sand, 5.5 cm, massive, rare pebbles, vfu-ml sand, root bioturbation, 7.5 YR 5/6, MRSm

3) Pebby sand, 13 cm, sandstone pebble clasts up to 3 cm concentrated at base, normally graded, grades laterally to very coarse gravelly lenses, vfl-mu sand, root bioturbation, 5YR 5/6, LGS

2) Sand, 6.5 cm, laterally discontinuous, planar bedding, vfl-fu at bottom coarsens to vfl-mu at top, rootlet bioturbation, 7.5YR 5/4 MSSIr

1) Sand, 32 cm, massive, vfu-ml sand, rare pebbles up to 2 cm, charcoal fragments, rhizocretions and root bioturbation 5YR 5/6, A

Figure C.4. Photo and stratigraphic panel of C:02:032 SU 4 Profile A looking north. Facies are indicated in bold.
Figure C.5. Photo and stratigraphic panel of C:02:032 SU 4, Profile B, facing north. Facies are indicated in bold.
Figure C.6. Photo and stratigraphic panel of C:02:032 SU 4 below the hearth, facing north. Diagram on upper right shows schematic of trench cross section. Facies are indicated in bold.
Figure C.7. Photo and stratigraphic panel of C:13:323 SU 3 1 x 1 meter pit, facing 100°. Facies are indicated in bold.
1) Silty very fine sand, 35-40 cm, crinkly laminations, variable dip but 6° N in places, many rhizoliths grading to many roots at top, 10YR 6/4
-Buried, vegetated dune face with eolian ripples, ES

2) Sand, 15-20 cm, crinkly laminations dipping 15° NW throughout and 22 W in top 2 cm, 10YR 6/4
Interp: Recent eolian-rainsplash slope sediment oriented along modern coppice dune sid, ES

Figure C.8. Photo and stratigraphic panel of C13:323 SU 4 1x1 meter pit, facing 90°. Facies are indicated in bold.
Figure C.9. Photo and stratigraphic panel of C13:323 SU 5 1x1 meter pit, facing 70°. Facies are indicated in bold.
1) Clast-supported gravel, unknown thickness, subangular/subrounded Paleozoic clasts, vf to coarse sand matrix, 7.5YR 5/4
-Top of gravel sequence underlying archaeological site, LGS

2) Sand, 4-10 cm, fluvial ripple laminations up to 3 cm amplitude, some rhizoliths, paleocurrents of 25°, 70°, 140°
Interp: Lower flow regime mainstem flood, MSlr

3) Sand, 33-50 cm, crinkly laminations, very bioturbated, 7.5YR 6/4
Interp: Reworking of fluval sediment by eolian and rainsplash processes, ES
*OSL sample from base of this unit.

4) Sand, 20-37 cm thick, massive and bioturbated, abundant rooting, 10YR 6/4
Interp: Lower flood regime mainstem flood, MSlr

Figure C.10. Photo and stratigraphic panel of C13:323 SU 7 1x1 m pit. Facies are indicated in bold.
5) Sand, 0-20 cm, wavy laminations, inversely graded, 10 YR 6/4
Interp: Possibly eolian, has fluvial cross bedding laterally, MSIR

4) Sand, 13-15 cm, 12° dip, 1 mm mud cap, ripple laminae, 150° paleocurrents, trace of charcoal, 10YR 6/4
Interp: Mainstem flood event with root bioturbation, MSIR

3) Sand, 20-22 cm, 1 mm mud cap, ripple lamina at base, low angle trough cross bedding to left, trace of charcoal, 10 YR 6/4
Interp: Mainstem flood deposit with same 12° dip as unit 2, possible transported clasts downslope from hearth, MSIR

2) Sand, 19-24 cm, massive, charcoal, ash and stone scatter at top, 10 YR 6/4
Interp: Top contact is living surface, potentially trampled. Charcoal is edge of lens of ash pit that coincides with upslope edge of hearth. Living surface is parallel to bedding, strikes 70° and dips 9° S.

1) Sand, 0-15 cm, crinkly laminae, vfl-ml sand, 7.5YR 6/4
Interp: Mainstem overbank flood deposit, MSIR

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**Figure C.11.** Photo and stratigraphic panel of C13:323 SU 16 1x1 m pit, facing 70°. Facies are indicated in bold.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Interpretation</th>
</tr>
</thead>
</table>
| 5    | Sand, 0-20 cm, wavy and tabular bed, bedding parallel lamination, wavy laminations inversely graded in places, same unit down dip is cross-bedded, vfl to ml sand, some rhizoliths, bioturbation increases towards top, moderate effervescence, 10 YR 6/4 | Possibly eolian, but bed shows fluvial cross bedding laterally.  
**MSlr**                                                                                   |
| 4    | Sand, 13-15 cm, wavy bed, 12° dip, 1 mm thick mud drape on top, ripple lamination, with paleocurrents of 150°, no grading, vfl to ml sand, moderate sorting, trace of rooting, few rhizoliths, slight effervescence, trace of charcoal, 10 YR 6/4 | Mainstem flood event with increasing rooting bioturbation at top obscuring things.  
**MSlr**                                                                                   |
| 3    | Sand, 20-22 cm, wavy upper and lower contacts, capped by 1 mm mud drape, wavy lenticular lamination, clear ripple lamination at base identified as low angle trough cross bedding to left, fines upward at base, vfl to ml sand, some rhizoliths, moderate effervescence, trace of charcoal bits, 10 YR 6/4 | Mainstem flood deposit following same 12° dip as unit 2. Possible transported clasts downslope from hearth feature.  
**MSlr**                                                                                   |
| 2    | Sand, 19-24 cm, gradational basal contact and somewhat sharp upper contact, coarsens up slightly, vfl-fu sand at bottom, vfl to mu sand at top, grades up to include charcoal and ash, some rooting and abundant rhizoliths, bioturbation distinguishes this unit, 10 YR 6/4 | Top contact is living surface, potentially trampled. Two stones mark the same horizon as hearth and other surface stone scatter. Charcoal on upper portion of the surface is edge of lens of ash pit. Living surface is parallel to bedding, strikes 70° and dips 9°S., **A** |
| 1    | Sand, 0-15 cm, gradational upper contact, wavy indistinct crinkly laminations, vfl-mu sand, moderate sorting, some rooting, few rhizoliths, slight effervescence, 7.5 YR 6/4 | Bioturbated eolian-reworkd mainstem sand.  
**MSlr**                                                                                   |
2) Silty sand, 17 to 26 cm, faint crossbeds with 80° paleocurrents, silt -fu sand, rooting and trampling, trampled areas are stiffer and 5 YR 6/4, remainder of unit is 7.5 YR 6/4 -Slight anthropogenic trampling of fluvial sand, higher stratigraphically than SU5 trampled surface, may be more modern (archaeologists?)

1) Silty sand, 10 cm, upper contact dips to left where unit becomes 0 cm, faint wavy laminations but no distinct fluvial structures are visible, vfu to fu, sand, root bioturbation, 7.5YR 6/4 -Mainstem fluvial deposit, unit pinches to right because of compaction by trampling in unit 2.

Figure C.12. Photo and stratigraphic panel of C13:327 SU 2 1x1 m pit, facing 45°. Facies are indicated in bold.
6) Silty sand, 5-11 cm, massive, some charcoal and bone, stiff, 7.5 YR 6/4
   Interp: Charcoal and bone reworked from unit 4 hearth. Trampling may be historic.

5) Sand, 0-7 cm, two thin beds of sand with Dox mud at base reversely graded to sand, wavy laminations, faint fluvial ripples, 7.5 YR 6/4
   Interp: Onlapping mainstem flood backwater deposit, MSlr

4) Silty sand, 17-21 cm, firm zone with peds developed, traces of charcoal, 2 cm ash lens overlying unit, 5YR 6/4
   Interp: Base is sloping occupation surface with oxidized zone beneath hearth, compacted by trampling.

3) Sand, 0-9 cm, basal ripple bedding, coarsens up to include Dox lithics, ash stain in lower right 2 cm, 7.5YR 6/4
   Interp: Indeterminant local versus mainstem wash event at base, possible eolian-rainsplash laminations near top, MSlr

2) Sand, 8-11 cm, stiff and massive, faint laminae, few charcoal bits, string of local Dox lithics, 7.5 YR 6/4
   Interp: Indeterminant fluvial versus eolian with local Dox, occupation level same as SU1, LGS or MSm

1) Dox lithic sand, 3-10 cm, massive, 5YR 5/4
   Interp: Dox lithic sand atop Dox gravel marker bed, LGS

Figure C.13. Photo and stratigraphic panel of C13:327 SU 3 1x1 meter pit, facing north. Facies are indicated in bold.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Sand, 5-11 cm, distinct gradual/wavy basal contact, massive/bioturbated to left but on right wall is fluvial/ripple cross-lamination, silty vfu-fl sand, some charcoal detritus and bone entrained within, stiffens to left implying trampling, moderate effervescence, 7.5 YR 6/4</td>
<td>Sand, 5-11 cm, distinct gradual/wavy basal contact, massive/bioturbated to left but on right wall is fluvial/ripple cross-lamination, silty vfu-fl sand, some charcoal detritus and bone entrained within, stiffens to left implying trampling, moderate effervescence, 7.5 YR 6/4</td>
</tr>
<tr>
<td>5</td>
<td>Sand, 0-7 cm, wedge/lenticular, sharp contact, two thin beds of sand each with Dox mud at base slightly reversely graded to sand, wavy/lenticular lamination, faint fluvial ripples, fl-cu sand, moderately to poorly sorted with Dox lithics, no rhizoliths, trace rooting, slight effervescence, 7.5 YR 6/4</td>
<td>Onlapping mainstem flood backwater with maybe changing currents to give basal mud to thin sand beds.</td>
</tr>
<tr>
<td>4</td>
<td>Sand, 17-21 cm, wavy tabular zone striking due N and dipping 15° W, upper parts of units 2 and 3 that have been bioturbated by trampling, faint original sed structures at base, firm/indurated zone with columnar jointing/peds developed, with color zones following ped columns, vf to ft silty sand, traces of charcoal, no rhizoliths, few roots, 5.4 YR 6/4 to 5 YR 6/4</td>
<td>Anthropogenic unit following sloping occupation surface, compacted by trampling to right, oxidized zone within unit is less than 15 cm of baked zone beneath hearth feature. Overlying this and coincident with top is 2 cm ash lens.</td>
</tr>
<tr>
<td>3</td>
<td>Sand, 0-9 cm, wedge-shaped, upper and lower distinct wavy contacts, basal ripple thin bedding, structures in upper portion are indistinct, normal grading, vf-vc sand at base with Dox lithics to vf to coarse at top, ash stain in lower right 2 cm, no rooting or rhizoliths, slight effervescence, 7.5 YR 6/4</td>
<td>Indeterminate local versus mainstem wash event at base, possible eolian-rainsplash laminations near top.</td>
</tr>
<tr>
<td>2</td>
<td>Sand, 8-11 cm, wavy indistinct top contact rises to right, mottled basal contact, stiff and massive, faint lamination, no grading, ft to cl sand, few charcoal bits throughout, no rooting or rhizoliths, likely trampled, moderate effervescence, 7.5 YR 6/4</td>
<td>Indeterminate fluvial versus eolian with local Dox stringer, buried occupation level same as SU1?</td>
</tr>
<tr>
<td>1</td>
<td>Sand, 3-10 cm, wavy and gradational mottled upper contact, lower contact not visible, massive, vf-m sand, ungraded, some rhizoliths, bioturbated, possibly trampled, moderate effervescence, 5 YR 5/4</td>
<td>Dox lithic sand atop thick Dox gravel marker bed.</td>
</tr>
</tbody>
</table>
Figure C.14. Photo and stratigraphic panel of C13:327 SU 4 1x1 meter pit, facing 85°. Facies are indicated in bold.
5) Sand, 20 cm, mottled trampling and slope-parallel material at upper contact, cross beds with paleocurrents of 70° and 140°, vfl-fli silty sand with rare coarse Dox lithics and organics, root ball bioturbation, 7.5 YR 6/4
Interp: Fluvial mainstem deposit with some modern trampling on top

4) Sand, 0 cm-31 cm, massive, silty vfl-cl Dox lithic sand, organic flecks, rooting, bioturbation dominated by root cast, 7.5 YR 5/4
Interp: Zone of massive bioturbation

3) Sand, 20-22 cm, cross beds with paleocurrents of 100°, thin beds of Dox lithics and charcoal, fl-mu sand, frequent rooting and rhizoliths, few charcoal fragments, 7.5 YR 5/4
Interp: Fluvial mainstem deposition and reworking of charcoal/lithics with moderate bioturbation

2) Sand, 27 cm, cross beds with paleocurrents of 280° and crinkly laminations, silty vfu-fu sand coarsening up to silty vfu-mu sand, rhizoliths, rooting and organic flecks, 7.5 YR 5/4
Interp: Fluvial deposit with coarse fragments from bioturbation of unit 3. May be >1 flood event

1) Sand, 9 cm, crinkly and indistinct wavy laminations, vfu-fu silty sand, rooting and rhizoliths, 5 YR 5/4
Interp: Mainstem flood or reworked mainstem sand

Figure C.15. Photo and stratigraphic panel of C13:327 SU 5 1x1 meter pit, facing 10°. Facies are indicated in bold.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Sand, 20 cm, tabular with gradual and slightly wavy upper and lower contact, lower contact is defined by extent of root ball bioturbation and upper contact by mottled trampling and slope-parallel material, cross beds visible with paleocurrents of 70° and 140°, no grading, grain size is vfl to fl silty sand with rare coarse fragments of Dox lithics and organics, slightly effervescent at bottom and not effervescent at top, 7.5 YR 6/4</td>
<td>Fluvial mainstem deposit with some modern trampling on the top. Facies MSlr</td>
</tr>
<tr>
<td>4</td>
<td>Sand, 0 cm on left to 31 cm on right, very wavy and indistinct upper and lower contacts, root ball portion is present on right, massive, no grading, silty vfl to cl sand, coarse sand is Dox lithics, poor sorting, rooting, organic fragments present, bioturbation is dominated by root ball, slight effervescence, 7.5 YR 5/4</td>
<td>Zone of massive bioturbation by plant that formed huge root ball. Facies MSm</td>
</tr>
<tr>
<td>3</td>
<td>Sand, 20-22 cm, wavy and gradational top and bottom contacts, tabular but top contact dips right, cross beds with paleocurrents of 100°, thin beds of Dox lithics and charcoal, no grading, fl to mu sand, lithic strings are fl to cu sand, poor sorting, frequent rooting and rhizoliths, few charcoal fragments, no effervescence, 7.5 YR 5/4</td>
<td>Fluvial mainstem deposition and reworking of charcoal/lithics with moderate bioturbation. Facies MSlr</td>
</tr>
<tr>
<td>2</td>
<td>Sand, 27 cm thick, pinches to right, top contact is wavy and gradational but marked by zone of Dox lithic granules, cross beds and crinkly laminations visible, coarsens up from vfu to fu silty sand at bottom to vfu to mu silty sand at top, frequent rhizoliths, rooting and organic flecks, a few concentrated areas of red sand may be bioturbated mud drapes, slight effervescence, 7.5 YR 5/4</td>
<td>Fluvial deposit with some coarse fragments from bioturbation of unit 3. May represent be more than one flood. Paleocurrents of cross beds are 280°. Facies MSlr</td>
</tr>
<tr>
<td>1</td>
<td>Sand, 9 cm, wavy contact at top and gradual contact, bottom of unit is not visible, tabular, color grades from red at bottom to tan at top, crinkly, indistinct wavy laminations, no grading, vfu to fu silty sand, well-sorted, rooting and rhizoliths abundant, slight effervescence, 5 YR 5/4</td>
<td>Bioturbated red sand does not coincide with top of Dox marker. More mainstem flood or reworked sand. Facies MSlr</td>
</tr>
</tbody>
</table>
6) Sand, 10-30 cm, massive, discontinuous mud drapes, portions of stiff red sand, silty vfugranule sand, root bioturbation, 7.5YR 6/4
Interp: Eolian-reworked surface of mainstem and local material bioturbated by trampling, ESm

5) Sand, 12-18 cm, massive with strings of Dox, slope-parallel contacts, portions of stiff red sand, /vu-cl silty sand coarsens up to /vu-cl silty sand, rooting and trampling, 7.5YR 6/4
Interp: Trampled anthropogenic surface, A

4) Sand, 6-21 cm, thin mud drapes, cross beds and ripples, charcoal flecks and Dox lithics, silty /vu-mu sand, burrows, 10YR 6/4
Interp: Mainstem flood with tributary influence/ redistribution of lithics, MSir

3) Sand, 2-21 cm, thin mud drape cap, Dox lithic strings, crinkly laminations, silty /vu-fl sand, charcoal fragments, some rhizoliths, 10YR 6/4
Interp: Bioturbated and possibly trampled flood packages reworking charcoal, A

2) Sand, 2-4 cm, thin mud drape cap, wavy/crinkly laminations, strings of Dox lithics, silty /vu-cu sand, small pebbles and charcoal, rhizoliths, 7.5YR 5/4
Interp: Charcoal surface on top of prior living surface reworked by flood, A

1) Sand, 2 cm, slab-lined hearth floor, thin mud cap, massive/few wavy laminations, silt-vfu sand coarsens up to silt-fu sand, rhizoliths/burrows, stiff portions with charcoal, 7.5 YR 6/4
Interp: Flood sand overtopping living surface followed by some trampling, A

Figure C.16. Photo and stratigraphic panel of C13:327 SU 6 1x1 meter pit, facing 10°. Facies are indicated in bold. See Table C.3 for detailed unit descriptions.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Sand, 10-30 cm, wavy bed, roughly slope-parallel basal contact is wavy and sharp with a mud drape, top contact is sharp with eolian-reworked surface material, massive, some internal discontinuous mud drapes, poorly sorted, more lithics than unit 5, middle of this unit is stiff with strong structure, no grading, up to 10% coarse sand to granule-sized lithics, grains size is vfu to granule silty sand, root bioturbation, moderately effervescent, no grading, 7.5 YR 6/4</td>
<td>Bioturbated by trampling, mixture of mainstem and local material, anthropogenic surface before eolian reworking, ES</td>
</tr>
<tr>
<td>5</td>
<td>Sand, 12-18 cm, string of Dox, bottom and top contacts are wavy and defined by mud drapes, almost slope-parallel contacts, no visible structures besides concentrations of Dox, portions of stiff red sand, inversely graded from vfu to cl sity sand at bottom to vfu to vcl silty sand at top, higher concentrations of Dox at top than bottom, poorly sorted, root and trampling bioturbation, no visible rhizoliths, all moderately effervescent, 7.5 YR 6/4, Dox lithics are slightly imbricated in places but vary in direction</td>
<td>Interp: Trampling is evident by red, stiff, effervescent areas of sand with strong structure, A</td>
</tr>
<tr>
<td>4</td>
<td>Sand, 6-21 cm, pinches to right, overall slop-parallel, both contacts defined by thin mud drapes, cross beds at base, wavy ripples at top and middle, poor sorting, charcoal flecks and Dox lithic granules are present throughout, grain size is vfu to mu sity sand, no grading, some strings of Dox, few rhizoliths, burrow bioturbation, slightly effervescent, 10 YR 6/4</td>
<td>Mainstem flood with slight tributary influence or redistribution of lithics, slight bioturbation but no anthropogenic influence unless unit 5 is trampled portion of this unit, MSir</td>
</tr>
<tr>
<td>3</td>
<td>Sand, 2-21 cm, top contact is very wavy but sharp and defined by mud drape, bottom contact is wavy and more diffuse but can also be defined by mud drape in placed, unit pinches to right/toward river, strings of Dox are present on right like in unit 2, crinkly laminations are present along with a few discontinuous internal mud drapes, grains size is vfu- fl sity sand with no grading and a few charcoal fragments, some rhizoliths, moderate effervescence, same unit to left has stiff, trampled-looking portions on it, 10 YR 6/4</td>
<td>Bioturbated and possibly trampled flood packages reworking charcoal, MSir/ A</td>
</tr>
<tr>
<td>2</td>
<td>Sand, 2-4 cm, wavy bed with charcoal, top and bottom contacts defined by thin mud drapes and are wavy, crinkly laminations and strings of coarse Dox lithics, are present, poorly sorted, no grading, grain size is vfu to cu sity sand, small pebbles (1 cm intermediate diameter) also present, string of Dox concentrated to right (toward river), some rhizoliths and carbonate development, moderately effervescent, 7.5 YR 5/4</td>
<td>Charcoal surface on top of prior living surface, charcoal was reworked by flood, A</td>
</tr>
<tr>
<td>1</td>
<td>Sand, 2 cm, floor is slab-lined heart, unit’s top contact is very thin mud drape (slope-parallel)- distinct/sharp but wavy contact, structures are crinkly laminations, otherwise massive, inverse grading, possible because of bioturbation, grain size at bottom is silt to vfu sand, top is silt to fu sand with rare coarse sand Dox lithics, rhizolith and burrow bioturbation, slight effervescence, some areas are stiffer with slightly more effervescence and charcoal, 7.5 YR 6/4</td>
<td>Flood sand overtopping living surface followed by trampling, MSir/A</td>
</tr>
</tbody>
</table>
1) Silty sand, up to 65 cm, cross-laminations dipping towards 330°, occasional sub-critical climbing ripples, 3 organic-rich horizons are present near base, normal grading, base is silty vfl-mu sand with some angular Dox clasts, top is fl-ml sand, some zones are very bioturbated by rooting, no effervescence, MSSIr.

Figure C.17. Photo and stratigraphic panel of C13:327 SU 7 1x1 meter pit, facing 20°. Facies are indicated in bold.
Sand, 22 cm, planar laminations at base with ripples migrating to NE above, vfu to ml sand, faint rodent burrows near base, bioturbated near top by roots, no effervescence.
Interp: Mainstem flood deposit, MSlr

2) Silty sand, 50 cm, organic-rich lenses are present in top half of unit, no grading, laminations at bottom dipping to 320°, otherwise massive vfl to ml sand, contains ~3% vcu Dox lithic clasts, very slight effervescence.
Interp: Eolian deposit, MSlr

1) Silty sand, 18 cm, faint cross-bedding, laminations dipping to the NE (~45°), no grading, vfl-mu sand, very bioturbated, some modern roots, no effervescence.
Interp: Eolian deposit, Es

Figure C.18. Photo and stratigraphic panel of C13:327 SU 8 1x1 meter pit, facing 160°. Facies are indicated in bold.
Appendix D: PALEOCURRENT DATA
### TABLE D.1: NINEMILE DRAW SECTION PALEOCURRENT DATA

<table>
<thead>
<tr>
<th>Paleocurrent Direction (°)</th>
<th>Section</th>
<th>Unit</th>
<th>Sedimentary Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>A</td>
<td>10</td>
<td>climbing ripples</td>
</tr>
<tr>
<td>110</td>
<td>B</td>
<td>8</td>
<td>climbing ripples</td>
</tr>
<tr>
<td>230</td>
<td>B</td>
<td>8</td>
<td>climbing ripples</td>
</tr>
<tr>
<td>260</td>
<td>B</td>
<td>11</td>
<td>climbing ripples</td>
</tr>
<tr>
<td>120</td>
<td>B</td>
<td>12</td>
<td>climbing ripples</td>
</tr>
<tr>
<td>230</td>
<td>B</td>
<td>16</td>
<td>ripple cross-stratification</td>
</tr>
<tr>
<td>80</td>
<td>B</td>
<td>32</td>
<td>climbing ripples</td>
</tr>
</tbody>
</table>

**See Tables B.1 and B.2 for detailed unit descriptions.**
### TABLE D.2: TANNER BAR GEOMORPHIC STUDY PALEOCURRENT DATA

<table>
<thead>
<tr>
<th>Paleocurrent Direction (°)</th>
<th>Sedimentary Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>imbricated channel gravels</td>
</tr>
<tr>
<td>185</td>
<td>imbricated channel gravels</td>
</tr>
<tr>
<td>205</td>
<td>imbricated channel gravels</td>
</tr>
<tr>
<td>130</td>
<td>boulders in foresets</td>
</tr>
<tr>
<td>180</td>
<td>imbricated channel gravels</td>
</tr>
<tr>
<td>195</td>
<td>imbricated channel gravels</td>
</tr>
<tr>
<td>160</td>
<td>imbricated channel gravels</td>
</tr>
<tr>
<td>185</td>
<td>imbricated channel gravels</td>
</tr>
</tbody>
</table>

### TABLE D.3: TANNER BAR GEOMORPHIC STUDY PALEOCURRENT DATA

<table>
<thead>
<tr>
<th>Paleocurrent Direction (°)</th>
<th>Unit*</th>
<th>Sedimentary Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>290</td>
<td>1</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>280</td>
<td>2</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>90</td>
<td>2</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>90</td>
<td>2</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>90</td>
<td>2</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>70</td>
<td>3</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>60</td>
<td>5</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>100</td>
<td>5</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>300</td>
<td>6</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>340</td>
<td>6</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>300</td>
<td>6</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>310</td>
<td>6</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>290</td>
<td>6</td>
<td>Imbricated Dox lithics</td>
</tr>
<tr>
<td>260</td>
<td>6</td>
<td>Imbricated Dox lithics</td>
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</tbody>
</table>

*See Table B.5 for detailed unit descriptions.*
<table>
<thead>
<tr>
<th>Paleocurrent Direction</th>
<th>Unit*, **</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>4</td>
<td>climbing ripples, subcritical</td>
</tr>
<tr>
<td>310</td>
<td>3</td>
<td>climbing ripples, subcritical</td>
</tr>
<tr>
<td>300</td>
<td>3</td>
<td>climbing ripples, subcritical</td>
</tr>
<tr>
<td>310</td>
<td>5</td>
<td>climbing ripples, subcritical</td>
</tr>
<tr>
<td>250</td>
<td>5</td>
<td>climbing ripples, subcritical</td>
</tr>
<tr>
<td>260</td>
<td>12</td>
<td>small cross-beds</td>
</tr>
<tr>
<td>240</td>
<td>14</td>
<td>subcritical to supercritical ripples cross bedding</td>
</tr>
<tr>
<td>240</td>
<td>18</td>
<td>subcritical climbing ripples</td>
</tr>
<tr>
<td>270</td>
<td>20</td>
<td>subcritical climbing ripples</td>
</tr>
<tr>
<td>220</td>
<td>20</td>
<td>trough crossbedding</td>
</tr>
<tr>
<td>225</td>
<td>23</td>
<td>subcritical climbing ripples</td>
</tr>
<tr>
<td>260</td>
<td>23</td>
<td>subcritical climbing ripples</td>
</tr>
<tr>
<td>190</td>
<td>24</td>
<td>ripples</td>
</tr>
<tr>
<td>215</td>
<td>24</td>
<td>ripples</td>
</tr>
<tr>
<td>290</td>
<td>25</td>
<td>imbrication of small Dox lithics</td>
</tr>
<tr>
<td>240</td>
<td>25</td>
<td>imbrication of small Dox lithics</td>
</tr>
<tr>
<td>235</td>
<td>27</td>
<td>supercritical ripples</td>
</tr>
<tr>
<td>0</td>
<td>upper 2.5 m</td>
<td>trough crossbedding</td>
</tr>
<tr>
<td>350</td>
<td>upper 2.5 m</td>
<td>trough crossbedding</td>
</tr>
<tr>
<td>280</td>
<td>upper 2.5 m</td>
<td>ripples to low angle cross beds</td>
</tr>
<tr>
<td>230</td>
<td>upper 2.5 m</td>
<td>supercritically climbing ripples</td>
</tr>
<tr>
<td>70</td>
<td>upper 2.5 m</td>
<td>supercritically climbing ripples</td>
</tr>
<tr>
<td>225</td>
<td>upper 2.5 m</td>
<td>ripples</td>
</tr>
<tr>
<td>250</td>
<td>upper 2.5 m</td>
<td>cross beds</td>
</tr>
<tr>
<td>240</td>
<td>upper 2.5 m</td>
<td>trough crossbedding</td>
</tr>
<tr>
<td>95</td>
<td>upper 2.5 m</td>
<td>supercritically climbing ripples</td>
</tr>
<tr>
<td>320</td>
<td>upper 2.5 m</td>
<td>supercritically climbing ripples</td>
</tr>
<tr>
<td>290</td>
<td>upper 2.5 m</td>
<td>supercritically climbing ripples</td>
</tr>
<tr>
<td>350</td>
<td>upper 2.5 m</td>
<td>trough crossbedding</td>
</tr>
<tr>
<td>280</td>
<td>upper 2.5 m</td>
<td>supercritically climbing ripples</td>
</tr>
<tr>
<td>280</td>
<td>9</td>
<td>imbrication</td>
</tr>
<tr>
<td>320</td>
<td>9</td>
<td>imbrication</td>
</tr>
<tr>
<td>250</td>
<td>11</td>
<td>imbrication</td>
</tr>
<tr>
<td>350</td>
<td>11</td>
<td>imbrication</td>
</tr>
<tr>
<td>360</td>
<td>14</td>
<td>Dox lens within unit</td>
</tr>
<tr>
<td>270</td>
<td>15</td>
<td>imbrication</td>
</tr>
<tr>
<td>240</td>
<td>15</td>
<td>imbrication</td>
</tr>
<tr>
<td>290</td>
<td>upper 2.5 m</td>
<td>imbrication</td>
</tr>
<tr>
<td>350</td>
<td>upper 2.5 m</td>
<td>imbrication</td>
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<td>350</td>
<td>upper 2.5 m</td>
<td>imbrication</td>
</tr>
<tr>
<td>300</td>
<td>upper 2.5 m</td>
<td>imbrication</td>
</tr>
</tbody>
</table>

*See Table B.6 for detailed unit descriptions.

**Locations of paleocurrent indicator measurements were accidentally omitted in upper ~2.5 m of stratigraphy.
Appendix E. OPTICALLY STIMULATED LUMINESCENCE RESULTS
<table>
<thead>
<tr>
<th>Sample name</th>
<th>OSL Sample #</th>
<th>location</th>
<th>depth (m)</th>
<th># aliquots*</th>
<th>dose rate (Gy/ka)</th>
<th>De (Gy)</th>
<th>age (ka)</th>
<th>package</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLCA-10.1L-8 USU-289</td>
<td>Ninemile Draw</td>
<td>0.3</td>
<td>13</td>
<td>2.97 ± 0.13</td>
<td>1.01 ± 0.57</td>
<td>0.34 ± 0.19</td>
<td>VI</td>
<td></td>
</tr>
<tr>
<td>GLCA-10.1L-10 USU-457</td>
<td>Ninemile Draw</td>
<td>4.3</td>
<td>12</td>
<td>2.96 ± 0.13</td>
<td>0.78 ± 0.36</td>
<td>0.26 ± 0.12</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>GLCA-10.1L-4 USU-283</td>
<td>Ninemile Draw</td>
<td>3.8</td>
<td>10</td>
<td>2.44 ± 0.10</td>
<td>1.95 ± 1.26</td>
<td>0.79 ± 0.52</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>GLCA-10.1L-12 USU-458</td>
<td>Ninemile Draw</td>
<td>3.1</td>
<td>15</td>
<td>2.91 ± 0.13</td>
<td>4.34 ± 2.39</td>
<td>1.48 ± 0.82</td>
<td>IV</td>
<td></td>
</tr>
<tr>
<td>GLCA-10.1L-7 USU-288</td>
<td>Ninemile Draw</td>
<td>1.2</td>
<td>13</td>
<td>2.45 ± 0.90</td>
<td>6.18 ± 1.56</td>
<td>2.52 ± 0.64</td>
<td>IV</td>
<td></td>
</tr>
<tr>
<td>GLCA-10.1L-9 USU-355</td>
<td>Ninemile Draw</td>
<td>3.9</td>
<td>12</td>
<td>2.84 ± 0.11</td>
<td>8.64 ± 1.42</td>
<td>3.04 ± 0.52</td>
<td>IV</td>
<td></td>
</tr>
<tr>
<td>GLCA-10.1L-5 USU-284</td>
<td>Ninemile Draw</td>
<td>6.2</td>
<td>12</td>
<td>1.57 ± 0.06</td>
<td>7.87 ± 3.06</td>
<td>5.01 ± 1.97</td>
<td>III</td>
<td></td>
</tr>
</tbody>
</table>

* Results from samples with <20 aliquots are preliminary.
# TABLE E.2. OVERVIEW OF PRELIMINARY OSL AGES FROM TANNER BAR

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>OSL Sample #</th>
<th>location</th>
<th>depth (m)</th>
<th># aliquots**</th>
<th>dose rate (Gy/ka)</th>
<th>De (Gy)</th>
<th>age (ka)</th>
<th>package</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCGAP-C13327-4</td>
<td>USU-440</td>
<td>C13:327 SU 8</td>
<td>0.2</td>
<td>6</td>
<td>1.80 ± 0.08</td>
<td>- ± -</td>
<td>modern</td>
<td>- ± -</td>
</tr>
<tr>
<td>GCGAP-C13327-3</td>
<td>USU-439</td>
<td>C13:327 SU 4</td>
<td>0.6</td>
<td>14</td>
<td>1.82 ± 0.08</td>
<td>1.94 ± 0.62</td>
<td>1.06 ± 0.34</td>
<td>V</td>
</tr>
<tr>
<td>GCtreat-67L-11</td>
<td>USU-142*</td>
<td>C13:327 gully</td>
<td>3.6</td>
<td>20</td>
<td>2.65 ± 0.12</td>
<td>3.93 ± 1.21</td>
<td>1.48 ± 0.13</td>
<td>IV</td>
</tr>
<tr>
<td>GCtreat-67L-10</td>
<td>USU-141*</td>
<td>C13:327 gully</td>
<td>4.6</td>
<td>20</td>
<td>3.01 ± 0.13</td>
<td>4.63 ± 1.19</td>
<td>1.50 ± 0.11</td>
<td>IV</td>
</tr>
<tr>
<td>GCtreat-67L-9</td>
<td>USU-140*</td>
<td>C13:327 gully</td>
<td>5.4</td>
<td>20</td>
<td>2.72 ± 0.12</td>
<td>4.64 ± 1.21</td>
<td>1.71 ± 0.13</td>
<td>IV</td>
</tr>
<tr>
<td>GC-TB-1</td>
<td>USU-370</td>
<td>C13:327 gully</td>
<td>5.3</td>
<td>12</td>
<td>4.5 ± 0.20</td>
<td>7.17 ± 2.63</td>
<td>1.60 ± 0.59</td>
<td>IV</td>
</tr>
<tr>
<td>GC-TB-4</td>
<td>USU-436</td>
<td>Geomorphic study gully</td>
<td>0.6</td>
<td>16</td>
<td>3.12 ± 0.14</td>
<td>16.93 ± 2.12</td>
<td>5.42 ± 0.73</td>
<td>III</td>
</tr>
<tr>
<td>GCGAP-C13327-1</td>
<td>USU-437</td>
<td>C13:323 SU 7</td>
<td>0.6</td>
<td>16</td>
<td>2.34 ± 0.10</td>
<td>15.96 ± 2.54</td>
<td>6.82 ± 1.14</td>
<td>III</td>
</tr>
<tr>
<td>GC-TB-2</td>
<td>USU-434</td>
<td>Geomorphic study gully</td>
<td>3.1</td>
<td>13</td>
<td>2.75 ± 0.12</td>
<td>23.13 ± 4.73</td>
<td>8.40 ± 1.7</td>
<td>II</td>
</tr>
<tr>
<td>GCGAP-C13327-2</td>
<td>USU-438</td>
<td>C13:323 basal stratigraphy, top of gravel sequence</td>
<td>1.6</td>
<td>13</td>
<td>2.16 ± 0.09</td>
<td>24.00 ± 4.50</td>
<td>11.10 ± 2.15</td>
<td>I</td>
</tr>
<tr>
<td>Gctreat-2</td>
<td>USU-512*</td>
<td>Geomorphic study gully</td>
<td>4.5</td>
<td>24</td>
<td>2.83 ± 0.13</td>
<td>33.04 ± 4.38</td>
<td>11.64 ± 0.62</td>
<td>I</td>
</tr>
</tbody>
</table>

*From previous work by Pederson and Rittenour, published in Damp et al., 2007. Ages are final but detailed results are not reported here.

** Results from samples with <20 aliquots are preliminary.
GCLA-10.L-4 Ninemile Draw Package D

USU-283

<table>
<thead>
<tr>
<th>De (Gy)</th>
<th>±</th>
<th>Age (ka)</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.95</td>
<td>1.26</td>
<td>0.8</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- wt Mean =
- Median = 1.81 0.7 0.5
- Min = 0.26 0.1 0.1
- Max = 4.31 1.8 1.1
- S.D. = 1.26
- Standard error = 0.40

Random Errors= 64.81 %
Systematic Error= 4.70 %
Total Error= 64.98 %

Bin Width = 0 Gy
n = 10 Disks
+/-
dose rate= 2.45 0.12 Gy/ka
U = 0.80 0.1 ppm
Th = 7.50 0.7 ppm
K2O = 2.04 0.05 wt. %
Rb2O= 43.7 1.7 ppm
H2O= 3.5 3.5 wt. %
Cosmic= 0.14 Gy/ka
depth = 3.7 m
latitude= 36 degrees (north positive)
longitude= -111 degrees (east positive)
elevation= 0.94 km asl

Sample descrit: Unit 1 in Ninemile Draw Package D, laminated silty sand

UTM 12, 248262E, 652870 N
GLCA-10.1L-5  Ninemile Draw Package A

USU-284

<table>
<thead>
<tr>
<th>De (Gy)</th>
<th>Error</th>
<th>Age (ka)</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.81</td>
<td>3.95</td>
<td>2.42</td>
<td>0.95</td>
</tr>
<tr>
<td>4.25</td>
<td>1.04</td>
<td>2.71</td>
<td>1.06</td>
</tr>
<tr>
<td>5.20</td>
<td>0.97</td>
<td>3.31</td>
<td>1.30</td>
</tr>
<tr>
<td>5.83</td>
<td>6.51</td>
<td>3.71</td>
<td>1.46</td>
</tr>
<tr>
<td>6.59</td>
<td>1.98</td>
<td>4.19</td>
<td>1.65</td>
</tr>
<tr>
<td>7.36</td>
<td>1.29</td>
<td>4.69</td>
<td>1.84</td>
</tr>
<tr>
<td>8.19</td>
<td>2.95</td>
<td>5.21</td>
<td>2.05</td>
</tr>
<tr>
<td>8.59</td>
<td>2.30</td>
<td>5.47</td>
<td>2.15</td>
</tr>
<tr>
<td>9.68</td>
<td>2.86</td>
<td>6.16</td>
<td>2.42</td>
</tr>
<tr>
<td>9.93</td>
<td>2.83</td>
<td>6.32</td>
<td>2.48</td>
</tr>
<tr>
<td>10.41</td>
<td>1.47</td>
<td>6.62</td>
<td>2.60</td>
</tr>
<tr>
<td>14.64</td>
<td>3.54</td>
<td>9.32</td>
<td>3.66</td>
</tr>
</tbody>
</table>

Min = 3.81  2.4  1.0
Max = 14.64 9.3  3.7
S.D. = 3.06
Standard error = 0.88

Random Errors= 38.99  %
Systematic Error= 4.52  %
Total Error= 39.25  %

Bin Width = 1  Gy
n = 12  Disks

+/-

dose rate= 1.57  0.07  Gy/ka
U = 0.80  0.1  ppm
Th = 3.20  0.3  ppm
K2O = 1.30  0.03  wt. %
Rb2O= 43.7  1.7  ppm
H2O= 0.9  3.0  wt. %

Cosmic= 0.09  Gy/ka
depth = 6.5  m
latitude= 36  degrees (north positive)
longitude= -111  degrees (east positive)
elevation= 0.94  km asl

Sample descript:  fine mainstem sand with laminations, unit 1 of Ninemile Draw Package A

UTM 12, 248262E, 652870 N
GLCA-10.1L-7 Ninemile Draw Package B

USU-288

<table>
<thead>
<tr>
<th>De (Gy) Error</th>
<th>Age (ka) ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.88 9.22</td>
<td>1.59 0.41</td>
</tr>
<tr>
<td>3.95 7.86</td>
<td>1.61 0.41</td>
</tr>
<tr>
<td>4.85 2.98</td>
<td>1.98 0.51</td>
</tr>
<tr>
<td>5.23 2.73</td>
<td>2.13 0.55</td>
</tr>
<tr>
<td>5.65 2.78</td>
<td>2.31 0.59</td>
</tr>
<tr>
<td>5.66 2.30</td>
<td>2.31 0.59</td>
</tr>
<tr>
<td>6.19 6.42</td>
<td>2.53 0.65</td>
</tr>
<tr>
<td>6.29 5.24</td>
<td>2.57 0.66</td>
</tr>
<tr>
<td>6.52 2.66</td>
<td>2.66 0.68</td>
</tr>
<tr>
<td>7.05 1.35</td>
<td>2.88 0.74</td>
</tr>
<tr>
<td>7.62 3.06</td>
<td>3.11 0.80</td>
</tr>
<tr>
<td>8.61 3.30</td>
<td>3.52 0.90</td>
</tr>
<tr>
<td>8.76 3.27</td>
<td>3.58 0.92</td>
</tr>
</tbody>
</table>

wt Mean = 6.18 1.56 2.5 0.6

Median = 6.19 2.5 0.6

Min = 3.88 1.6 0.4

Max = 8.76 3.6 0.9

S.D. = 1.56 used here

Standard error = 0.43

Random Errors= 25.28 %

Systematic Error= 4.45 %

Total Error= 25.67 %

Bin Width = 1 Gy

n = 13 Disks

+/- dose rate= 2.45 0.11 Gy/ka

U = 1.60 0.1 ppm

Th = 5.30 0.5 ppm

K2O = 1.90 0.05 wt. %

Rb2O= 59.6 2.4 ppm

H2O= 3.0 3.0 wt. %

Cosmic= 0.20 Gy/ka

depth = 1.2 m

latitude= 36 degrees (north positive)

longitude= -111 degrees (east positive)

Sample descript:
silt to very fine sand with planar laminations and root bioturbation, unit 36 of Ninemile Draw Package B

UTM 12, 248262E, 652870 N
GLCA-10.1L-8 Ninemile Draw Package D

<table>
<thead>
<tr>
<th>De (Gy) Error</th>
<th>Age (ka) ±</th>
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<tbody>
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<td>0.16</td>
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<tr>
<td>0.49</td>
<td>0.17</td>
</tr>
<tr>
<td>0.56</td>
<td>0.19</td>
</tr>
<tr>
<td>0.61</td>
<td>0.20</td>
</tr>
<tr>
<td>0.63</td>
<td>0.21</td>
</tr>
<tr>
<td>0.85</td>
<td>0.29</td>
</tr>
<tr>
<td>0.85</td>
<td>0.29</td>
</tr>
<tr>
<td>0.94</td>
<td>0.31</td>
</tr>
<tr>
<td>0.95</td>
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<tr>
<td>0.98</td>
<td>0.33</td>
</tr>
<tr>
<td>1.59</td>
<td>0.54</td>
</tr>
<tr>
<td>1.99</td>
<td>0.67</td>
</tr>
<tr>
<td>2.24</td>
<td>0.75</td>
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<table>
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<th>±</th>
<th>±</th>
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<td>1.01</td>
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<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>0.85</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>0.46</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>2.24</td>
<td>0.8</td>
<td>0.4</td>
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<tr>
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<tr>
<td>0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>56.81</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>4.41</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>56.99</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bin Width =</th>
<th>0</th>
<th>Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>n =</td>
<td>13</td>
<td>Disks</td>
</tr>
<tr>
<td>dose rate=</td>
<td>2.97</td>
<td>0.13</td>
</tr>
<tr>
<td>U =</td>
<td>2.30</td>
<td>0.2</td>
</tr>
<tr>
<td>Th =</td>
<td>7.60</td>
<td>0.7</td>
</tr>
<tr>
<td>K2O =</td>
<td>2.11</td>
<td>0.05</td>
</tr>
<tr>
<td>Rb2O=</td>
<td>69.9</td>
<td>2.8</td>
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<td>H2O=</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Cosmic=</td>
<td>0.24</td>
<td>Gy/ka</td>
</tr>
<tr>
<td>depth =</td>
<td>0.3</td>
<td>m</td>
</tr>
<tr>
<td>latitude=</td>
<td>36</td>
<td>degrees (north positive)</td>
</tr>
<tr>
<td>longitude=</td>
<td>-111</td>
<td>degrees (east positive)</td>
</tr>
<tr>
<td>elevation=</td>
<td>0.94</td>
<td>km asl</td>
</tr>
</tbody>
</table>

Sample description: silty sand with planar laminations in unit 6 of Ninemile Draw package D

UTM 12, 248262E, 652870 N
GLCA-10.1L-9 Ninemile Draw Package B

De (Gy) Error  Age (ka) ±

USU-355
De (Gy) ± Age (ka) ±

wt Mean = 8.64 1.42 3.0 0.5
Peak fit =
Median = 8.46 3.0 0.5
Min = 6.62 2.3 0.4
Max = 11.21 3.9 0.7
S.D. = 1.42 used here
Standard error = 0.39
Random Errors= 16.66 %
Systematic Error= 4.45 %
Total Error= 17.25 %

Bin Width = 1 Gy
n = 13 Disks

+/-
dose rate= 2.84 0.13 Gy/ka
U = 2.30 0.2 ppm
Th = 7.90 0.7 ppm
K2O = 2.05 0.05 wt. %
Rb2O= 78.6 3.1 ppm
H2O= 3.0 3.0 wt. %

Cosmic= 0.13 Gy/ka
depth = 3.9 m
latitude= 36 degrees (north positive)
longitude= -111 degrees (east positive)
elevation= 0.94 km asl

Sample descript:
Bottom of Ninemile Draw package B, in very fine mainstem sand with climbing ripples and cross-beds

UTM 12, 248262E, 652870 N
<table>
<thead>
<tr>
<th>Sample</th>
<th>De (Gy)</th>
<th>Age (ka)</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCTB-1</td>
<td>3.45</td>
<td>0.77</td>
<td>0.28</td>
</tr>
<tr>
<td>Tanner Bar C:13:327</td>
<td>4.13</td>
<td>0.92</td>
<td>0.34</td>
</tr>
<tr>
<td>USU-370</td>
<td>4.97</td>
<td>1.10</td>
<td>0.41</td>
</tr>
<tr>
<td>De (Gy) Error</td>
<td>5.53</td>
<td>1.23</td>
<td>0.45</td>
</tr>
<tr>
<td>Age (ka) ±</td>
<td>6.52</td>
<td>1.45</td>
<td>0.54</td>
</tr>
<tr>
<td>wt Mean =</td>
<td>7.17</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Median =</td>
<td>7.22</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Min =</td>
<td>3.45</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Max =</td>
<td>13.14</td>
<td>2.9</td>
<td>1.1</td>
</tr>
<tr>
<td>S.D. =</td>
<td>2.63</td>
<td></td>
<td>used here</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Random Errors=</td>
<td>36.72</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Systematic Error=</td>
<td>4.54</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Total Error=</td>
<td>37.00</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Bin Width =</td>
<td>1</td>
<td>Gy</td>
<td></td>
</tr>
<tr>
<td>n =</td>
<td>12</td>
<td>Disks</td>
<td></td>
</tr>
<tr>
<td>+/- dose rate=</td>
<td>4.50</td>
<td>0.20</td>
<td>Gy/ka</td>
</tr>
<tr>
<td>U =</td>
<td>3.30</td>
<td>0.2</td>
<td>ppm</td>
</tr>
<tr>
<td>Th =</td>
<td>10.30</td>
<td>0.9</td>
<td>ppm</td>
</tr>
<tr>
<td>K2O =</td>
<td>3.64</td>
<td>0.09</td>
<td>wt. %</td>
</tr>
<tr>
<td>Rb2O=</td>
<td>152.6</td>
<td>6.1</td>
<td>ppm</td>
</tr>
<tr>
<td>H2O=</td>
<td>3.0</td>
<td>3.0</td>
<td>wt. %</td>
</tr>
<tr>
<td>Cosmic=</td>
<td>0.10</td>
<td>Gy/ka</td>
<td></td>
</tr>
<tr>
<td>depth =</td>
<td>5.3</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>latitude=</td>
<td>36</td>
<td>degrees (north positive)</td>
<td></td>
</tr>
<tr>
<td>longitude=</td>
<td>-111</td>
<td>degrees (east positive)</td>
<td></td>
</tr>
<tr>
<td>elevation=</td>
<td>0.82</td>
<td>km asl</td>
<td></td>
</tr>
</tbody>
</table>

**Sample descript:**

Unit 1 in stratigraphy exposed by gully cutting through C:13:327 arch site, mainstem tan sand with cross-bedding

Zone 12N, 220594 E 565500 N
<table>
<thead>
<tr>
<th>De (Gy)</th>
<th>Error</th>
<th>Age (ka)</th>
<th>Error</th>
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</thead>
<tbody>
<tr>
<td>14.72</td>
<td>2.34</td>
<td>5.35</td>
<td>1.13</td>
</tr>
<tr>
<td>19.46</td>
<td>1.59</td>
<td>7.07</td>
<td>1.49</td>
</tr>
<tr>
<td>19.67</td>
<td>2.43</td>
<td>7.15</td>
<td>1.51</td>
</tr>
<tr>
<td>20.18</td>
<td>3.21</td>
<td>7.33</td>
<td>1.55</td>
</tr>
<tr>
<td>20.42</td>
<td>0.53</td>
<td>7.42</td>
<td>1.56</td>
</tr>
<tr>
<td>20.18</td>
<td>3.21</td>
<td>7.80</td>
<td>1.64</td>
</tr>
<tr>
<td>20.42</td>
<td>0.53</td>
<td>8.14</td>
<td>1.72</td>
</tr>
<tr>
<td>20.42</td>
<td>0.53</td>
<td>8.53</td>
<td>1.80</td>
</tr>
<tr>
<td>20.60</td>
<td>%</td>
<td>9.29</td>
<td>1.96</td>
</tr>
<tr>
<td>28.19</td>
<td>1.84</td>
<td>10.24</td>
<td>2.16</td>
</tr>
<tr>
<td>4.47</td>
<td>%</td>
<td>9.42</td>
<td>1.99</td>
</tr>
<tr>
<td>21.08</td>
<td>%</td>
<td>12.16</td>
<td>2.56</td>
</tr>
</tbody>
</table>

| wt Mean | 23.13 | 4.73 | 8.4  | 1.8  |
| Median  | 21.94 | 8.0  | 1.7  |
| Min     | 14.72 | 5.3  | 1.1  |
| Max     | 33.49 | 12.2 | 2.6  |
| S.D.    | 4.73 | used here |
| Standard error | 1.31 |

Random Errors= 20.60 %
Systematic Error= 4.47 %
Total Error= 21.08 %

Bin Width = 1 Gy
n = 13 Disks

+/-
dose rate= 2.75 0.12 Gy/ka
U = 2.10 0.1 ppm
Th = 7.40 0.7 ppm
K2O = 2.05 0.05 wt. %
Rb2O= 75.3 3.0 ppm
H2O= 3.0 3.0 wt. %

Cosmic= 0.12 Gy/ka
depth = 4.5 m
latitude= 36 degrees (north positive)
longitude= -111 degrees (east positive)
elevation= 0.82 km asl

Sample descript:
unit 2 in Tanner Bar geomorphic study gully, massive mainstem sand with some rhizoliths, interfingers with local slope-wash material

UTM 12, 220699 E, 565662 N
GC-TB-4  Tanner Bar geomorphic study

<table>
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<tr>
<th>De (Gy)</th>
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<th>Age (ka)</th>
<th>±</th>
<th>±</th>
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</thead>
<tbody>
<tr>
<td>USU-436</td>
<td>13.92</td>
<td>0.75</td>
<td>4.45</td>
<td>0.60</td>
</tr>
<tr>
<td>wt Mean =</td>
<td>16.93</td>
<td>2.12</td>
<td>5.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Median =</td>
<td>17.30</td>
<td>5.5</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Min =</td>
<td>13.92</td>
<td>4.5</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Max =</td>
<td>22.08</td>
<td>7.1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>S.D. =</td>
<td>2.12</td>
<td>used here</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard error =</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Random Errors=</td>
<td>12.75 %</td>
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<tr>
<td>Systematic Error=</td>
<td>4.43 %</td>
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</tr>
<tr>
<td>Total Error=</td>
<td>13.49 %</td>
<td></td>
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</tbody>
</table>

| Bin Width = | 1 Gy |
| n = | 16 Disks |
| dose rate= | 3.12 Gy/ka |
| U = | 2.50 ppm |
| Th = | 7.90 ppm |
| K2O = | 2.23 wt. % |
| Rb2O= | 86.6 ppm |
| H2O= | 3.0 wt. % |

Cosmic= 0.22 Gy/ka
depth = 0.6 m
latitude= 36 degrees (north positive)
longitude= -111 degrees (east positive)
elevation= 0.82 km asl

Sample descript: mainstem sand unit with rare rhizoliths
<table>
<thead>
<tr>
<th>De (Gy) Error</th>
<th>Age (ka) ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.91 2.04</td>
<td>5.09 0.85</td>
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<tr>
<td>13.01 2.67</td>
<td>5.56 0.93</td>
</tr>
<tr>
<td>13.05 2.29</td>
<td>5.58 0.93</td>
</tr>
<tr>
<td>13.79 1.09</td>
<td>5.90 0.98</td>
</tr>
<tr>
<td>14.18 1.76</td>
<td>6.06 1.01</td>
</tr>
<tr>
<td>15.01 1.61</td>
<td>6.42 1.07</td>
</tr>
<tr>
<td>15.27 1.23</td>
<td>6.53 1.09</td>
</tr>
<tr>
<td>15.46 2.15</td>
<td>6.61 1.10</td>
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<tr>
<td>15.88 2.98</td>
<td>6.79 1.13</td>
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<tr>
<td>16.53 3.44</td>
<td>7.07 1.18</td>
</tr>
<tr>
<td>16.70 0.60</td>
<td>7.14 1.19</td>
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<tr>
<td>17.27 2.67</td>
<td>7.38 1.23</td>
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<tr>
<td>17.31 3.72</td>
<td>7.40 1.24</td>
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<td>19.41 1.41</td>
<td>8.30 1.39</td>
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<td>19.89 1.94</td>
<td>8.50 1.42</td>
</tr>
<tr>
<td>20.68 2.62</td>
<td>8.84 1.48</td>
</tr>
</tbody>
</table>

| wt Mean = 15.96 2.54 6.8 1.1 |
| Median = 15.67 6.7 1.1 |
| Min = 11.91 5.1 0.9 |
| Max = 20.68 8.8 1.5 |
| S.D. = 2.54 used here |
| Standard error = 0.64 |
| Random Errors= 16.10 % |
| Systematic Error= 4.44 % |
| Total Error= 16.70 % |
| Bin Width = 1 Gy |
| n = 16 Disks |
| dose rate= 2.34 0.10 Gy/ka |
| U = 1.50 0.1 ppm |
| Th = 4.80 0.4 ppm |
| K2O = 1.81 0.05 wt. % |
| Rb2O= 64.2 2.6 ppm |
| H2O= 3.0 3.0 wt. % |
| Cosmic= 0.22 Gy/ka |
| depth = 0.6 m |
| latitude= 36 degrees (north positive) |
| longitude= -111 degrees (east positive) |
| elevation= 0.82 km asl |

Sample descript: unit 2 of C:13:323 SU 7, mainstem sand with crinkly laminations

UTM 12, 220721 E,565809 N
GCGAP-C13323-2 C:13:323 underneath arch site De (Gy) Error Age (ka) ±

USU-438

<table>
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<tr>
<th>De (Gy)</th>
<th>± Age (ka)</th>
<th>±</th>
</tr>
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<tbody>
<tr>
<td>15.41</td>
<td>2.36</td>
<td>7.12 1.38</td>
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<td>20.22</td>
<td>0.51</td>
<td>9.35 1.82</td>
</tr>
<tr>
<td>21.10</td>
<td>1.59</td>
<td>9.76 1.89</td>
</tr>
<tr>
<td>21.26</td>
<td>4.48</td>
<td>9.83 1.91</td>
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<td>21.77</td>
<td>1.27</td>
<td>10.07 1.95</td>
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<tr>
<td>22.44</td>
<td>1.40</td>
<td>10.38 2.01</td>
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<td>23.42</td>
<td>3.01</td>
<td>10.83 2.10</td>
</tr>
<tr>
<td>24.59</td>
<td>0.77</td>
<td>11.37 2.21</td>
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<td>1.74</td>
<td>11.58 2.25</td>
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<tr>
<td>25.75</td>
<td>1.91</td>
<td>11.91 2.31</td>
</tr>
<tr>
<td>28.43</td>
<td>1.38</td>
<td>13.15 2.55</td>
</tr>
<tr>
<td>30.61</td>
<td>0.83</td>
<td>14.16 2.75</td>
</tr>
<tr>
<td>31.97</td>
<td>5.27</td>
<td>14.79 2.87</td>
</tr>
</tbody>
</table>

wt Mean = 24.00 4.50 11.1 2.2

Median = 23.42 10.8 2.1
Min = 15.41 7.1 1.4
Max = 31.97 14.8 2.9

S.D. = 4.50 used here
Standard error = 1.25
Random Errors= 18.89 %
Systematic Error= 4.44 %
Total Error= 19.41 %

Bin Width = 1 Gy
n = 13 Disks
/+-
dose rate= 2.16 0.09 Gy/ka
U = 1.50 0.1 ppm
Th = 4.60 0.4 ppm
K2O = 1.65 0.04 wt. %
Rb2O= 65.1 2.6 ppm
H2O= 3.0 3.0 wt. %

Cosmic= 0.18 Gy/ka
depth = 1.6 m
latitude= 36 degrees (north positive)
longitude= -111 degrees (east positive)
elevation= 0.82 km asl

Sample descript: mainstem sand interbedded with imbricated channel gravels

UTM 12, 220724 E, 565724 N
GCGAP-C13327-3 Tanner Bar C:13:327

De (Gy) Error Age (ka) ±

USU-439

<table>
<thead>
<tr>
<th>De (Gy)</th>
<th>±</th>
<th>Age (ka)</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.44</td>
<td>1.73</td>
<td>0.79</td>
<td>0.26</td>
</tr>
<tr>
<td>1.43</td>
<td>3.81</td>
<td>0.79</td>
<td>0.26</td>
</tr>
<tr>
<td>1.73</td>
<td>2.84</td>
<td>0.95</td>
<td>0.32</td>
</tr>
<tr>
<td>1.83</td>
<td>2.04</td>
<td>1.00</td>
<td>0.33</td>
</tr>
<tr>
<td>3.30</td>
<td>1.33</td>
<td>1.81</td>
<td>0.60</td>
</tr>
<tr>
<td>1.84</td>
<td>0.95</td>
<td>1.01</td>
<td>0.34</td>
</tr>
<tr>
<td>1.26</td>
<td>1.69</td>
<td>0.69</td>
<td>0.23</td>
</tr>
<tr>
<td>2.26</td>
<td>1.02</td>
<td>1.24</td>
<td>0.41</td>
</tr>
<tr>
<td>2.38</td>
<td>1.33</td>
<td>1.31</td>
<td>0.44</td>
</tr>
<tr>
<td>1.32</td>
<td>2.75</td>
<td>0.73</td>
<td>0.24</td>
</tr>
<tr>
<td>2.51</td>
<td>1.38</td>
<td>1.38</td>
<td>0.46</td>
</tr>
<tr>
<td>1.27</td>
<td>1.06</td>
<td>0.70</td>
<td>0.23</td>
</tr>
<tr>
<td>2.69</td>
<td>2.00</td>
<td>1.48</td>
<td>0.49</td>
</tr>
<tr>
<td>3.30</td>
<td>1.33</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Median = 1.82 1.0 0.3 1.84 0.95 1.01 0.34
Min = 1.26 0.7 0.2 1.26 1.69 0.69 0.23
Max = 3.30 1.8 0.6 2.26 1.02 1.24 0.41
S.D. = 0.64 used here
Standard error = 0.18
Random Errors= 33.00 %
Systematic Error= 4.46 %
Total Error= 33.30 %

Bin Width = 0 Gy
n = 13 Disks
Dose rate = 1.82 0.08 Gy/ka
U = 0.90 0.1 ppm
Th = 3.00 0.3 ppm
K2O = 1.51 0.04 wt. %
Rb2O = 51.1 2.0 ppm
H2O = 3.0 3.0 wt. %
Cosmic = 0.21 Gy/ka
depth = 0.8 m
latitude = 36 degrees (north positive)
longitude = -111 degrees (east positive)
elevation = 0.82 km asl

Sample description: tan mainstem sand from C:13:327 SU 4, large fluvial cross-beds

UTM 12N, 220618 E, 565513 N
GCCAP133274  Tanner Bar C:13:327 SU 8

USU-440

<table>
<thead>
<tr>
<th>De (Gy) Error</th>
<th>Age (ka) ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.71</td>
<td>4.88</td>
</tr>
<tr>
<td>-0.03</td>
<td>4.23</td>
</tr>
<tr>
<td>-0.26</td>
<td>3.25</td>
</tr>
<tr>
<td>-0.79</td>
<td>5.09</td>
</tr>
<tr>
<td>-0.47</td>
<td>3.44</td>
</tr>
<tr>
<td>0.01</td>
<td>4.05</td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

wt Mean = -0.38  0.34  -0.2  -0.2

Median = -0.37  -0.2  -0.2

Min = -0.79  -0.4  -0.4

Max = 0.01  0.0  0.0

S.D. = 0.34
Standard error = 0.14

Random Errors= 89.39 %
Systematic Error= 4.41 %
Total Error= 89.50 %

Bin Width = 1 Gy
n = 6 Disks

+/-
dose rate= 1.80  0.08  Gy/ka
U = 0.90  0.1  ppm
Th = 3.30  0.3  ppm
K2O = 1.42  0.04  wt. %
Rb2O= 48.6  1.9  ppm
H2O= 3.0  3.0  wt. %

Cosmic= 0.24  Gy/ka
depth = 0.2  m
latitude= 36 degrees (north positive)
longitude= -111 degrees (east positive)
elevation= 0.82 km asl

Sample descript: mainstem flood sand with planar laminations at base and ripples migrating to NE above, massive root bioturbation at top

UTM 12, 220628 E, 565512 N
GLCA-10.1L-10  Package C, Ninemile Draw

USU-457

<table>
<thead>
<tr>
<th>De (Gy)</th>
<th>± Age (ka) ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.78</td>
<td>0.36 0.3 0.1</td>
</tr>
</tbody>
</table>

wt Mean = 0.78 0.36 0.3 0.1

Median = 0.72 0.2 0.1
Min = 0.12 0.0 0.0
Max = 1.39 0.5 0.2
S.D. = 0.36 used here
Standard error = 0.11

Random Errors= 46.75 %
Systematic Error= 4.46 %
Total Error= 46.96 %

Bin Width = 0 Gy
n = 12 Disks

dose rate= 2.96 0.13 Gy/ka
U = 2.50 0.2 ppm
Th = 8.30 0.7 ppm
K2O = 2.10 0.05 wt. %
Rb2O= 79.7 3.2 ppm
H2O= 3.0 3.0 wt. %

Cosmic= 0.12 Gy/ka
depth = 4.3 m
latitude= 36 degrees (north positive)
longitude= -111 degrees (east positive)
elevation= 0.94 km asl

Sample descript: | unit 1 of package VI, mainstem silty sand with ripples

UTM 12, 248262E, 652870 N
<table>
<thead>
<tr>
<th>Package C, Ninemile Draw</th>
<th>De (Gy) Error</th>
<th>Age (ka)</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLCA-10.1L-12 USU-458</td>
<td>1.63 ± 0.56</td>
<td>0.56 ± 0.31</td>
<td></td>
</tr>
<tr>
<td>wt Mean</td>
<td>4.34 ± 0.77</td>
<td>0.8 ± 0.45</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>3.74 ± 0.45</td>
<td>0.7 ± 0.37</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>1.63 ± 0.33</td>
<td>0.3 ± 0.18</td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>9.67 ± 2.32</td>
<td>1.8 ± 0.90</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>2.39 ± 0.17</td>
<td>0.7 ± 0.40</td>
<td></td>
</tr>
<tr>
<td>Standard error</td>
<td>0.62 ± 0.03</td>
<td>0.3 ± 0.15</td>
<td></td>
</tr>
<tr>
<td>Random Errors=</td>
<td>55.05 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systematic Error=</td>
<td>4.45 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Error=</td>
<td>55.23 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Bin Width =             | 1 Gy          |
| n =                     | 15 Disks      |
| dose rate=              | 2.92 ± 0.13 Gy/ka |
| U =                     | 2.40 ± 0.2 ppm |
| Th =                    | 7.90 ± 0.7 ppm |
| K2O =                   | 2.08 ± 0.05 wt. % |
| Rb2O=                   | 79.2 ± 3.2 ppm |
| H2O=                    | 3.0 ± 3.0 wt. % |

| Cosmic =                | 0.15 ± 0.05 Gy/ka |
| depth =                 | 3.1 ± 0.1 m       |
| latitude=               | 36 degrees (north positive) |
| longitude=              | -111 degrees (east positive) |
| elevation=              | 0.94 ± 0.05 km asl |

Sample descript: unit 10 of package C, mainstem sand with thin cross beds and climbing ripples

UTM 12, 248262E, 652870 N
Appendix F. AMS RADIOCARBON RESULTS
<table>
<thead>
<tr>
<th>Sample #</th>
<th>Beta #</th>
<th>Location</th>
<th>Material</th>
<th>$^{14}$C method</th>
<th>$^{13}$C/$^{12}$C</th>
<th>conventional 14C age</th>
<th>age (cal yr BP)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>C13323FS28A *</td>
<td>252217</td>
<td>C:13:323 SU 5 Feature 2</td>
<td>charcoal</td>
<td>AMS</td>
<td>-25.4 o/oo</td>
<td>2130 +/- 40 B.P.</td>
<td>2310-2040</td>
</tr>
<tr>
<td>Beta-232598</td>
<td>232598</td>
<td>C:13:327 SU 1 Feature 3</td>
<td>charcoal</td>
<td>AMS</td>
<td>-22.9 o/oo</td>
<td>1200 +/- 60 B.P.</td>
<td>1520-1330</td>
</tr>
<tr>
<td>Beta-252219</td>
<td>252219</td>
<td>C:13:327 SU 6 Feature 9</td>
<td>charcoal</td>
<td>AMS</td>
<td>-24.4 o/oo</td>
<td>1520 +/- 40 B.P.</td>
<td>1280-970</td>
</tr>
<tr>
<td>C13327FS1</td>
<td>250688</td>
<td>C13:327 gully</td>
<td>charcoal</td>
<td>AMS</td>
<td>-25.4 o/oo</td>
<td>2920 +/- 40 B.P.</td>
<td>3210-2950</td>
</tr>
</tbody>
</table>

*See Damp et al., 2007 for detailed AMS radiocarbon results. Raw data are not included here.

**Calibrated by Beta Analytic.
### TABLE F.2. DETAILED TANNER BAR RADIOCARBON RESULTS

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Beta #</th>
<th>Location</th>
<th>Material</th>
<th>(^{14})C method</th>
<th>(^{13})C/(^{12})C</th>
<th>conventional 14C age</th>
<th>age (cal yr BP)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>C13323FS28A *</td>
<td>252217</td>
<td>C:13:323 SU 5 Feature 2</td>
<td>charcoal</td>
<td>AMS</td>
<td>-25.4 o/oo</td>
<td>2130 +/- 40 B.P.</td>
<td>2310-2040</td>
</tr>
<tr>
<td>Beta-232598</td>
<td>232598</td>
<td>C:13:327 SU 1 Feature 3</td>
<td>charcoal</td>
<td>AMS</td>
<td>-22.9 o/oo</td>
<td>1200 +/- 60 B.P.</td>
<td>1520-1330</td>
</tr>
<tr>
<td>Beta-252219</td>
<td>252219</td>
<td>C:13:327 SU 6 Feature 9</td>
<td>charcoal</td>
<td>AMS</td>
<td>-24.4 o/oo</td>
<td>1520 +/- 40 B.P.</td>
<td>1280-970</td>
</tr>
<tr>
<td>C13327FS1</td>
<td>250688</td>
<td>C13:327 gully</td>
<td>charcoal</td>
<td>AMS</td>
<td>-25.4 o/oo</td>
<td>2920 +/- 40 B.P.</td>
<td>3210-2950</td>
</tr>
</tbody>
</table>

*See Damp et al., 2007 for detailed AMS radiocarbon results. Raw data are not included here.

**Calibrated by Beta Analytic.
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

Laboratory number: Beta-250688

Conventional radiocarbon age: 2920±40 BP

2 Sigma calibrated result: Cal BC 1260 to 1000 (Cal BP 3210 to 2950) (95% probability)

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 1120 (Cal BP 3070)

1 Sigma calibrated result: Cal BC 1200 to 1040 (Cal BP 3150 to 2990) (68% probability)

References:

Database used
- INTCAL04

Calibration Database
- INTCAL04 Radiocarbon Age Calibration


Mathematically:
- A Simplified Approach to Calibrating C14 Dates