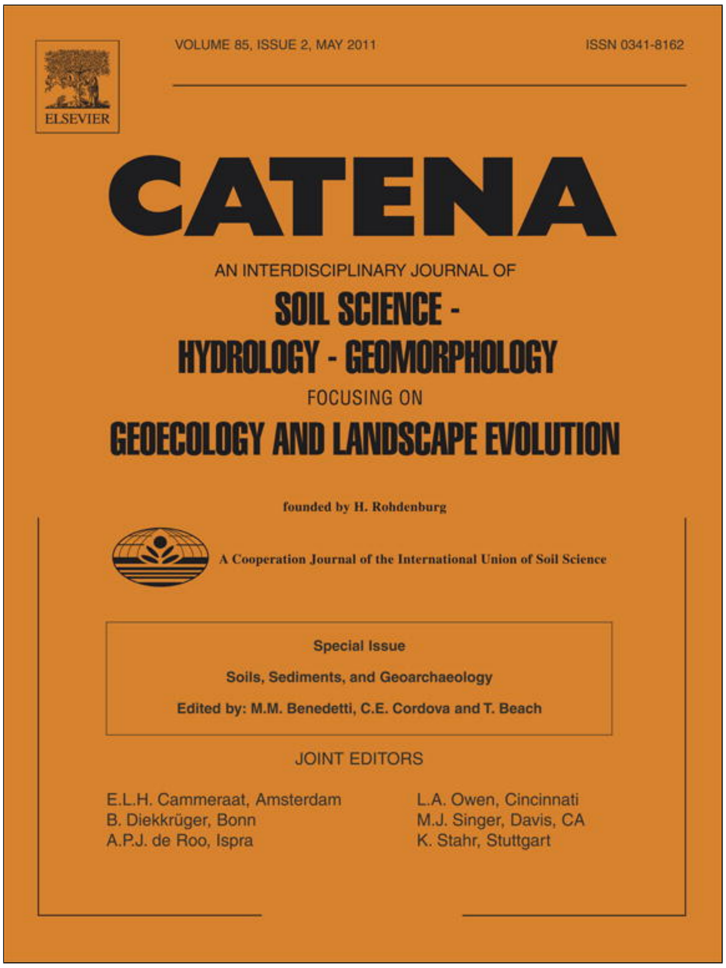
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# The influence of paleofloods on archaeological settlement patterns during A.D. 1050–1170 along the Colorado River in the Grand Canyon, Arizona, USA

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ABSTRACT

Excavations at four archaeological sites consisting of the material remains of A.D. 1050–1170 era farmers along the Colorado River in Grand Canyon National Park, yield geomorphic information used to address questions related to settlement patterns. Archaeological excavation units, test pits, feature fill, and natural exposures contain sediments used to interpret geomorphic history that can, in turn, shed light on archaeological site selection in a challenging environment. The Grand Canyon experiences dramatic geomorphic events such as catastrophic floods and destructive debris flows that are preserved in the stratigraphic record, and can be used to understand cultural/landscape interactions. By combining new geomorphic, stratigraphic, and archaeological data collected during recent excavations with results from previous geomorphic and sediment transport studies, observed trends can be interpreted regarding the possible influence of paleofloods on past settlement patterns. For example, at each of the four sites, reconstructed paleoflood elevations (from existing HEC-RAS virtual shorelines), flood recurrence intervals, site layout, and site stratigraphy/geomorphic setting suggests a temporal trend in site location. The two early sites (Early Pueblo II period: A.D. 1050–1080) contain habitation features located above the approximately 6–8 year high flood (3500 cubic meters per second [cms]) recurrence interval; larger floods (4800 to 5900 cms) of a longer recurrence interval between 40 and 80 years inundate these features. The two later sites in the sample (Late Pueblo II; A.D. 1080–1170) contain habitation features located well above the 40–80 year recurrence high flows. We suggest that early farmers (Early Pueblo II period: A.D. 1050–1080) may not have had adequate experience with flood magnitudes and frequencies and therefore their habitation structures were located in risk-prone areas relatively close to the river. Later habitations (Late Pueblo II; A.D. 1080–1170) were positioned in more protected areas further from the river, perhaps reflecting an acquired knowledge of river dynamics. These trends, although currently based on a limited data set, provide insights into site selection decisions and settlement patterns of early farmers along the Colorado River through Grand Canyon.



## 1. Introduction

The Colorado River through the Grand Canyon is perhaps one of the most intensively studied river systems in the world, partly because of the influence of Glen Canyon Dam on the delicate ecosystem of Grand Canyon National Park (Fig. 1; Webb, 1996; Gloss et al., 2005). Interest in the downstream ecosystem intensified when the dam became operational in 1964, with much of the focus on stream dynamics and sediment transport because the now sediment-starved system negatively influences the biological and cultural resources along the river corridor (Beus et al., 1985; Carothers and Brown, 1991; Webb et al., 1999; Fairley, 2003). Specifically, geomorphic studies strongly suggest that the erosion of archaeological sites is related to the lack of sediment. The dam also prevents the large seasonal floods, as well as the extreme events, from depositing huge volumes of sediment along the river corridor, in contrast to pre-dam times when each spring runoff produced enormous amounts of sediment. The paucity of sediment coming into the system prevents replenishment of sand bars, and this has been linked to erosion of pre-dam fluvial terraces containing archaeology sites (Schmidt and Graf, 1987; Schmidt, 1990; Rubin et al., 1998; Hazel et al., 1999; Topping et al., 2003). Eolian re-working of flood sediments is also sediment-starved, thereby limiting the potential for site burial by eolian processes. Recent stratigraphic studies document the importance of eolian sediment transport on the burial and preservation of cultural resources (Draut et al., 2008). Therefore, the documented erosion of archaeological sites in Grand Canyon and the accompanying loss of valuable data are the motivations for the excavation and data recovery results presented here.

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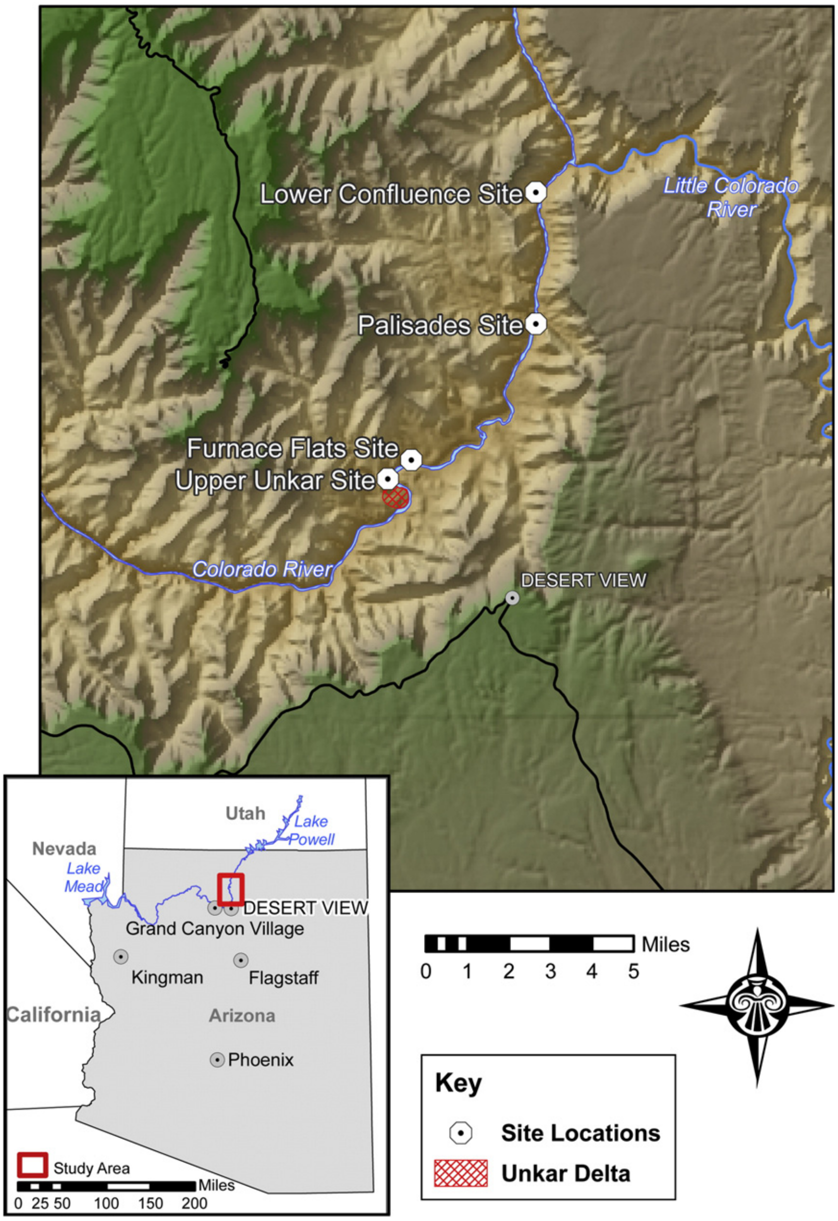


**Fig. 1.** Image showing location of the four archaeological sites and landmarks discussed in the Eastern Grand Canyon. Base map is the USGS National Elevation Data Set. The Colorado River flows to the south and west.

The majority of the more than 475 archaeological sites along the river corridor (Fairley et al., 1994) are associated with pre-dam river terraces, eolian dunes, and debris fans (Fig. 2a and b). Although numerous geomorphic studies have investigated the processes related to site erosion and preservation (Hereford et al., 1993; Hazel et al., 2000; Fairley, 2003; Leap et al., 2003; Balsom et al., 2005; Draut et al., 2005), few have specifically applied the results of the geomorphic investigations to questions related to past human behavior, such as choosing suitable site locations. Our investigations used concepts and data from archaeology, anthropology, geoarchaeology, and geomorphology to address questions related to human ecology (Butzer, 1982) in the Grand Canyon. This project is part of a research program in the Grand Canyon set forth by Fairley (2003) that uses landscape anthropology as the framework and site formation processes (surficial geomorphic processes) were an integral part of a (cultural) landscape history. This paper presents the results from the excavation of four archaeological sites along the Colorado River corridor in the Grand Canyon to interpret past settlement patterns within this dynamic landscape. Specifically, we investigate the potential influence of floods on shifting Pueblo Period settlement patterns. This is a joint endeavor between the Museum of Northern Arizona and Grand Canyon National Park.

The four sites investigated have multi-components with broad age ranges dating between about A.D. 800 and A.D. 1776. However, the focus of this study is the permanent habitation components of these sites that date from A.D. 1050 to A.D.1170. Prior to about A.D. 1050, site components consist of hearths and artifact scatters, not permanent habitations. The two earlier (A.D. 1050–1080) permanent habitation sites consist of masonry dwellings with associated trash middens and activity areas. The portion of the midden area closest to habitation structures contains activity area features such as fire hearths, cists, and postholes. These early sites are extended-family farmsteads, perhaps the first attempts by Kayenta farmers to establish permanent agricultural habitations along the Colorado River corridor. The two later site components (A.D. 1080–1170) consist of several large masonry dwellings with shared walls and associated midden/activity areas. These later sites are aggregated farming hamlets containing more than one extended family that are part and parcel

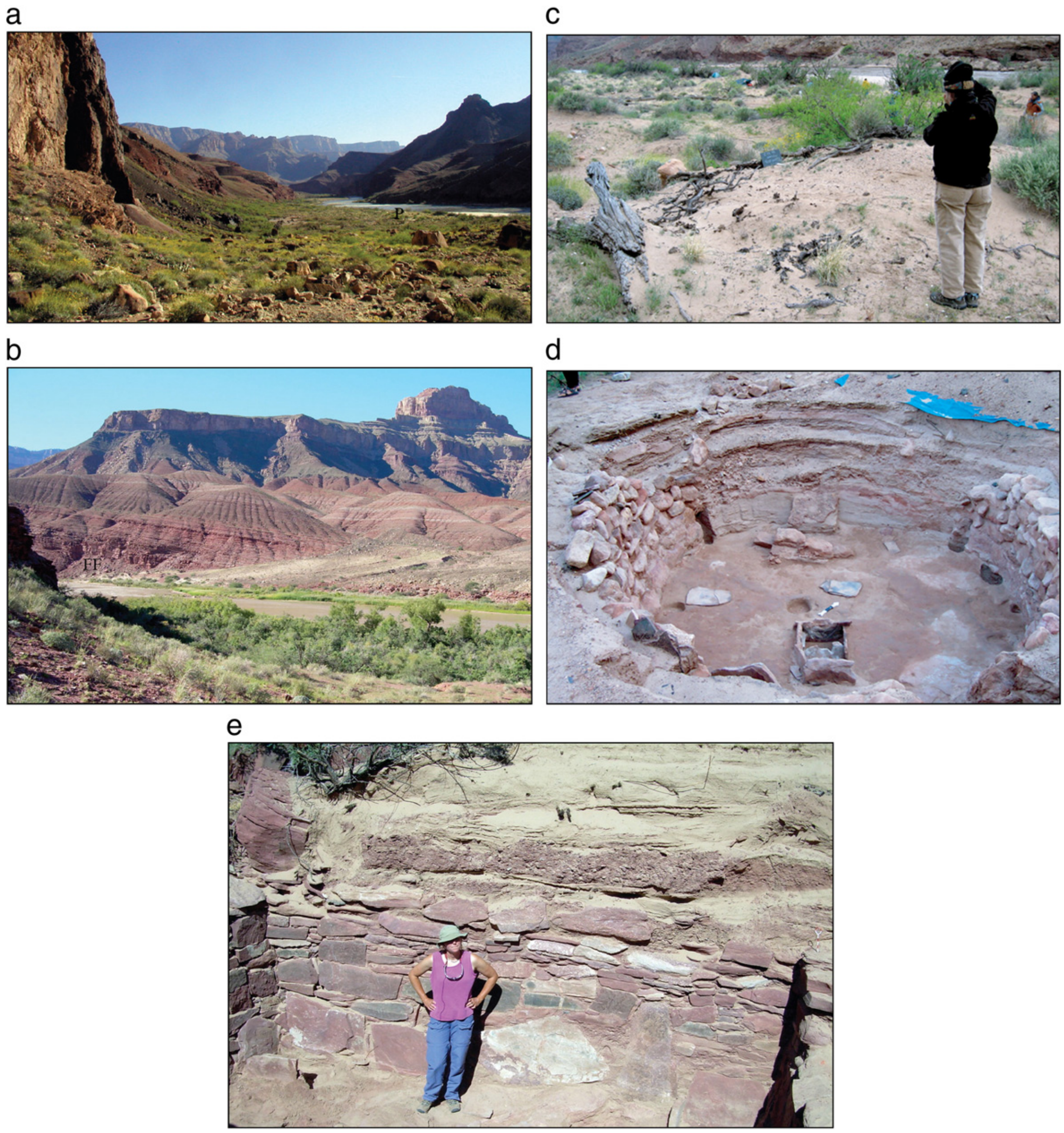

**Fig. 2.** Photographs illustrating the general landscape setting and examples of excavated habitation features. a. Overview of the Palisades debris fan looking downstream. b. Overview of the Furnace Flats reach with Dox Sandstone cliffs. Small patch of white sand in lower left part of photograph is the Furnace Flats site. Colorado River flowing to the left. c. Archaeologist is standing on the unexcavated habitation structure shown in d. where eolian, fluvial, and debris fan materials coalesce. d. Excavated Feature 12 at Palisades. Note river cobble construction materials and central slab hearth. e. Excavated Feature 49 at Furnace Flats. Note large sandstone slabs for wall construction. Feature was buried by approximately 2 m of hillslope and eolian deposits shown above and behind archaeologist.

of the overall river corridor populations. The later aggregated hamlets occur higher on the landscape than earlier farmsteads. Even slightly higher elevations provide a greater margin of safety during flood events.

Our research emphasizes the interconnectedness of archaeological deposits and natural site formation processes, specifically focusing on how large floods may have influenced past site location decision making. This places equal emphasis on the interpretation of the archaeological record, rather than solely on the geomorphic processes. We use the term “site formation processes” to include surficial geomorphic processes that influence an archaeological site from the time prior to occupation of the landform, during occupation of the landform, and post-occupational processes (Schiffer, 1987). Site formation processes at each site include Colorado River fluvial activity, eolian reworking of the fluvial deposits, distal debris fan, and colluvial activity. We present three general lines of investigation related to the cultural use of the area and associated site formation processes. The first line of investigation relates to the analysis of geomorphic setting and site stratigraphy, providing a chronostratigraphic framework for interpreting the history of geomorphic processes related to the period of occupation.

The second line of investigation focuses on the sedimentary deposits recorded during the excavation of large subterranean habitation structures at each of the four sites (Fig. 2c,d,e). The habitation structures are essentially closed basins that preserve a record of surficial processes at each site, thereby representing, for example, a history of floods, debris flows, and eolian activity. This record was then used to infer natural processes that past peoples experienced during their tenure at the site. Specifically, the geomorphic position of habitation structures relative to high flood elevations allowed us to evaluate the inferred risk of flooding to the inhabitants.

The third line of investigation links data from previous studies with our own research, allowing us to synthesize the results. We inferred that the relations between the following four parameters provide insights into temporally significant trends in settlement patterns related to past flooding: (1) Colorado River paleoflood discharge reconstructions and recurrence intervals (Topping et al., 2003); (2) reconstructed "virtual shorelines" from the paleoflood data and the HEC-RAS modeling (Magirl, et al., 2008); (3) site/feature stratigraphy and sedimentology; and (4) site elevation and age. We also suggest that periods of high discharge along the Colorado River during the middle to late Pueblo II period (A.D. 1080–1150) may have been a driver of late Pueblo II (A.D. 1130–1170) movement to higher landscape positions (Meko et al., 2007).

## 2. Background: geomorphic setting and archaeological context

The Colorado River drains approximately 632,000 km$^2$ of the Rocky Mountains, Basin and Range, and Colorado Plateau of the western United States. The river flows 450 km through the Grand Canyon from Glen Canyon Dam to Lake Mead, the reservoir impounded behind Hoover Dam (Fig. 1). The Grand Canyon is an area of extremes with the elevation at the northern rim measuring 2440 m above sea level (masl) while the river elevation is about 800 masl in the project area. This dramatic relief creates a situation whereby intense summer thunderstorms become highly destructive flash flood events. Although rainfall generally does not exceed 25 cm annually, much of that comes during the brief summer rainy season. Two generalized processes control the geomorphology of the river corridor. The first is the annual floods that, during pre-dam time, commonly exceeded 2700 cms. Such large flows have a dramatic influence on sediment distribution, both depositing large amounts of sediment in the creation of paleoflood-constructed terraces, as well as causing extensive erosion. Annual flood processes are countered by the lateral tributary system that contributes enormous amounts of sediment to the main river channel during debris flow events (Melis et al., 1994; Griffiths et al., 2004; Yanites et al., 2006). Even the largest main-stem floods cannot remove portions of debris flow events. Main channel debris remnants change the river's gradient creating the famous cataracts (rapids) that are enjoyed by thousands of river runners each year. These debris fans form a pool-and-riffle sequence (Kieffer, 1987). River eddies formed on the downstream side of the debris fans create a zone of deposition of fine-grained river sediments. Stream terraces, sometimes the only relatively flat locations for archaeology sites, are commonly found downstream from debris fans.

Hereford et al. (1996, 1998) related the ages of debris fans with those of stream terraces and associated archaeological sites. They identified discreet alluvial deposits related to different cultural periods, naming older deposits with Archaic cultural remains as the "stripped alluvium," intermediate age deposits with Puebloan remains as the "alluvium of Pueblo II age," and younger pre-dam deposits as the "mesquite terrace." The majority of deposits investigated here correlate with Hereford's "alluvium of Pueblo II age," though it includes fluvial, eolian, debris fan, and colluvial deposits.

Many of the archaeological sites along the river corridor are located on/in these debris fan/flood sediment/dune complexes. Generally, though, the landscape inhabited by Puebloan-era people along the river corridor consisted of steep cliffs bounding a narrow zone with limited flat areas. Elsewhere in the Grand Canyon area settlements are located up tributaries, on bedrock ridges, or on the rim of the canyon. The sites we investigated are those within the narrow river corridor, below the estimated highest prehistoric flood–8500 cms.

General temporal and socio-economic trends in the archaeological record of the Grand Canyon area are similar to those of the larger North American Southwest (Table 1; see also Fairley, 2003; Huckell, 1996; Jones, 1986). Paleoindian groups used the canyon from about 12,000–8000 B.C. with an adaptation oriented to big game hunting. The longest period of human occupation in the Grand Canyon area was the Archaic Period, running from 8000 B.C. to A.D. 500. During this interval the canyon was inhabited by people who utilized a more broad-spectrum foraging and hunting adaptation. Sometime during the later part of the Archaic Period agriculture spread into the Grand Canyon area. This era of transition to more agriculture-based adaptations is designated as the Late Archaic/Early Agricultural Period from 1000 B.C. to A.D. 500. The Basketmaker III (A.D. 500–800) and Pueblo I periods (A.D. 800–1000) in Grand Canyon are represented by a relatively small number of sites. Along the river corridor in Grand Canyon, Basketmaker III (BM III) and Pueblo I (PI) sites are generally buried by some combination of fluvial, eolian, distal debris fan, and sheetwash sediments, and commonly underlie the later Pueblo II (A.D. 1000–1150) and Pueblo III (A.D. 1150–1250) Period sites. The BMIII and PI sites generally consist of thermal features and artifact concentrations. During the BMIII–PI interval in the North American Southwest generally agriculture-oriented adaptations were the norm. However, BMIII–PI Grand Canyon river corridor sites represent transient resource procurement and processing activities in contrast to more permanent agriculture-oriented loci that were common elsewhere. Because these earlier sites are not permanent or semi-permanent agriculture-oriented habitations and do not represent relatively greater investments of energy focused on a site locus, they are not used in our paleoflood/settlement analysis.

**Table 1**
Cultural chronology in the Grand Canyon.

| Historic period[a] | A.D. 1776–1950 |
|---|---|
| Late Prehistoric/Protohistoric Period[a] | A.D. 1250–1776 |
| Pueblo III Period[b] | A.D. 1150–1250 |
| Pueblo II Period[b] | A.D. 1000–1150 |
| Pueblo I Period[b] | A.D. 800–1000 |
| Basketmaker III Period[b] | A.D. 500–800 |
| Late Archaic/Early Agricultural Period[c] | 1000 B.C.–A.D. 500 |
| Late Archaic Period[a] | 3000–1000 B.C. |
| Middle Archaic Period[a] | 5000–3000 B.C. |
| Early Archaic Period[a] | 8000–5000 B.C. |
| Paleoindian Period[a] | 12,000–8000 B.C. |

[a] Fairley (2003).
[b] Jones (1986).
[c] Huckell (1996).

At the start of the Pueblo II period (ca. A.D. 1000–1075), use of the canyon began to undergo a rather dramatic shift. Just as in other parts of the North American Southwest, people began to inhabit more niches, as populations grew and settlement expanded (Cordell and Gumerman, 1989). In the canyon, we saw the first evidence of permanent habitations in the form of small agriculture-oriented habitations consisting of both above ground and semi-subterranean masonry structures. While the earlier PI groups along the river corridor used ceramics inferred to be affiliated with Cohonina archaeological culture centered immediately south of Grand Canyon (Colton, 1939; McGregor, 1967; Schwartz et al., 1980; Fairley, 2003:93), the Pueblo II and Pueblo III people utilized ceramics inferred to be affiliated with the Kayenta archaeological culture centered to the southeast and east (Colton, 1939; Schwartz et al., 1980; Ambler, 1985; Jones, 1986; Fairley, 2003:93).

The cultural changes initiated at the beginning of the Pueblo II period accelerated and expanded during the latter half of the period (ca. A.D. 1075–1170), both along the Grand Canyon river corridor and elsewhere in the North American Southwest. During this time the North American Southwest witnessed the establishment of large regional systems centered on Chaco Canyon and along the Salt and Gila River valleys (Cordell and Gumerman, 1989). During the ca. A.D. 1075–1170 interval, the most extensive concentration of archaeological sites along the Colorado River in Grand Canyon developed within what is called the Furnace Flats Reach, encompassing 16 miles of river corridor terrain below the Colorado/Little Colorado River confluence (Fairley et al., 1994; Fairley, 2003). The four sites discussed in this paper are located in the Furnace Flats Reach (Fig. 1), as well as the largest concentration of sites along the Grand Canyon river corridor at Unkar Delta (Schwartz et al., 1980; Schmidt and Graf, 1988; Fairley et al., 1994; Fairley, 2003). The majority of the Unkar Delta sites were occupied between A.D. 1130 and 1170 (Schwartz et al., 1980), and attest to a period of increased population similar to the general trend in the North American Southwest.

The final period of relevance for this paper is the Late Prehistoric/Protohistoric Period, approximately A.D. 1250–1776. Buried thermal features from the Late Prehistoric/Protohistoric period aided in defining the more recent extent of our chronostratigraphic record. In 1776 the Spanish explorers Escalante and Dominguez entered the region, thus beginning the historic period.

Four sites were chosen for excavation because they were all undergoing extensive erosion, and because of their high potential for providing useful archaeological and landscape data. Moving downstream, the four sites and their ages are: 1) Lower Confluence (A.D. 1050–1080); 2) Palisades (A.D. 1050–1080); 3) Furnace Flats (A.D. 1070–1130); and 4) Upper Unkar (A.D. 1140–1170). All four sites display semi-formalized Kayenta-style site layouts and orientations consisting of a generalized northwest to southeast organization of features (Cordell, 1997). Towards the northwest are well-constructed permanent habitation features that may consist of one or several surface and/or subsurface dwellings. In the southeast of the site layout is the trash midden area, a zone of charcoal, artifact, bone, and other discarded refuse from daily activities. Between the habitation features and the midden is an activity area that partially co-occurs with the midden and that contains thermal features, storage cists, post holes representing ramadas, and concentrations of ground stone artifacts (Fig. 3).

### 2.1. Lower Confluence site

The Lower Confluence site is located at an elevation of 810 masl, between two small debris fans in a box canyon on the outside bend of the river (Fig. 3a). Here the landforms are poorly preserved and indistinct (Fig. 4a). A gully running through the middle of the site has removed much of the fine sediments, and erosional scarps at the base of loose sand deposits attest to the scouring affects of fluvial processes. Talus boulders scattered across the surface and exposed at the base of excavation units underlie the site. Overlying the boulders are a complex association of fluvial, eolian, and colluvial sediments containing cultural material. The oldest cultural materials at the site are PI Period ceramics, lithics, and thermal features buried beneath 4 m of interbedded fluvial and hillslope sediments. The youngest cultural materials are two well-preserved Protohistoric thermal features dated to A.D. 1445–1655 and A.D. 1665–1960 (Leap and Coder, 1995). A historic flood deposit, perhaps from the 1884 flood, buries these features. Bracketed between the underlying PI materials and the overlying Protohistoric features, is a partially exhumed early Pueblo II farmstead consisting of two-coursed-masonry habitation structures and associated trash midden. Early Pueblo II Period flood sediments partially fill the habitation features, and historic flood sediments overlie much of the site. Detailed chronostratigraphy, sedimentology, and archaeological characteristics are presented for this site, as well as the following three sites, in the next section.

### 2.2. Palisades site

The Palisades site is one of several sites located on the broad, gently sloping Palisades Creek debris fan (Fig. 3b; Dierker and Downum, 2004). The site is located at an elevation of 800 masl, at the interface between distal debris fan, eolian dunes, river deposits, and a small formerly internally drained feature commonly referred to as "the playa" (Hereford et al., 1996). Stratigraphic relationships also illustrate the dynamic geomorphic position of the site with complexly interbedded fluvial, distal debris fan, eolian, and cultural deposits (Fig. 4b). The oldest cultural evidence at this site found during excavation is a BM III thermal feature buried by interbedded fluvial and distal debris fan deposits. Hereford et al. (1996) constrained the ages of cultural features and deposits with three radiocarbon ages: A.D. 390–890 and 390–960 on the early end, and A.D. 1030–1250 for more recent deposits and features. The youngest cultural features are early Pueblo II artifacts and structures. As in the previous site, a partially exhumed early Pueblo II farmstead, including a large habitation structure, activity area, and midden is exposed in the eroded walls of several gullies. Much of the site is then buried by historic flood deposits (Topping, et al., 2003). Detailed sedimentary and stratigraphic studies investigated the role of eolian deposition on site preservation (Draut et al., 2008).

### 2.3. Furnace Flats

The Furnace Flats site is located at an elevation of 790 masl along the toeslope of a steep cliff comprised of Dox Sandstone (Fig. 3c). A series of steep and deeply eroded gullies reveal the presence of an extensive settlement buried by colluvial and eolian deposits (Fig. 4c). Large masonry structures, storage cists, thermal features, and midden deposits are all being exhumed. This site is one of the largest along this reach of the river and has multi-components. A dramatic change in the architectural elements and site layout is seen in this site verses the earlier sites. One of the main differences is a use of huge, nearly megalithic-scale, slabs to construct the features. The oldest cultural periods are again represented by deeply buried PI artifact scatters and features indicative of the Cohonina cultural tradition rather than the Pueblo II period Kayenta. Prior to our excavations, park archaeologists conducted archaeological mapping and testing at the site in 1984 and 1997 (Jones, 1986; Miller, 2005; see also Fairley, 2003:50–51). Excavations yielded late Pueblo II period ceramics (Jones, 1986; Miller, 2005). Sherds diagnostic of the Pueblo I period were also found at the site below the Pueblo II architecture (Hereford et al., 1991; see also Fairley, 2003:50, 91). The focus of our excavations at Furnace Flats, reported below, were on the primary occupation at the site that dates from A.D. 1070 to 1130 and includes large semi-subterranean houses with multiple remodeling events.

### 2.4. Upper Unkar

The Upper Unkar site is very similar in age and geomorphic position to the Furnace Flats site (Fig. 3d). The site is located along the toeslope of a steep cliff in the Dox Sandstone at an elevation of 792 masl. Several gullies cut through the site revealing a buried settlement consisting of semi-subterranean masonry structures, storage cists, and midden deposits. The site is buried by colluvial and eolian deposits (Fig. 4d). Initial documentation indicated that the site consisted of masonry structures (F 10) and slab-lined features (F1) eroding out of a steep embankment adjacent to the river. Archaeologists documented an additional feature (F7) eroding out of an arroyo cut in the eastern part of the site. Temporal affiliations based on ceramic analysis indicated a late Pueblo II period of use.

## 3. Methods and materials

Exposed in the eroded walls of gullies are various cultural features, the remains of once thriving farmsteads and hamlets, now in various stages of exhumation. At each of the four sites, investigations included landscape-scale analysis of the exhumed features including geomorphic position, site layout and orientation, associated stratigraphic profile descriptions, and the particle-size distribution and micromorphologic analysis of sediments. Total station mapping incorporated topography, elevation, contacts of surficial deposits, and

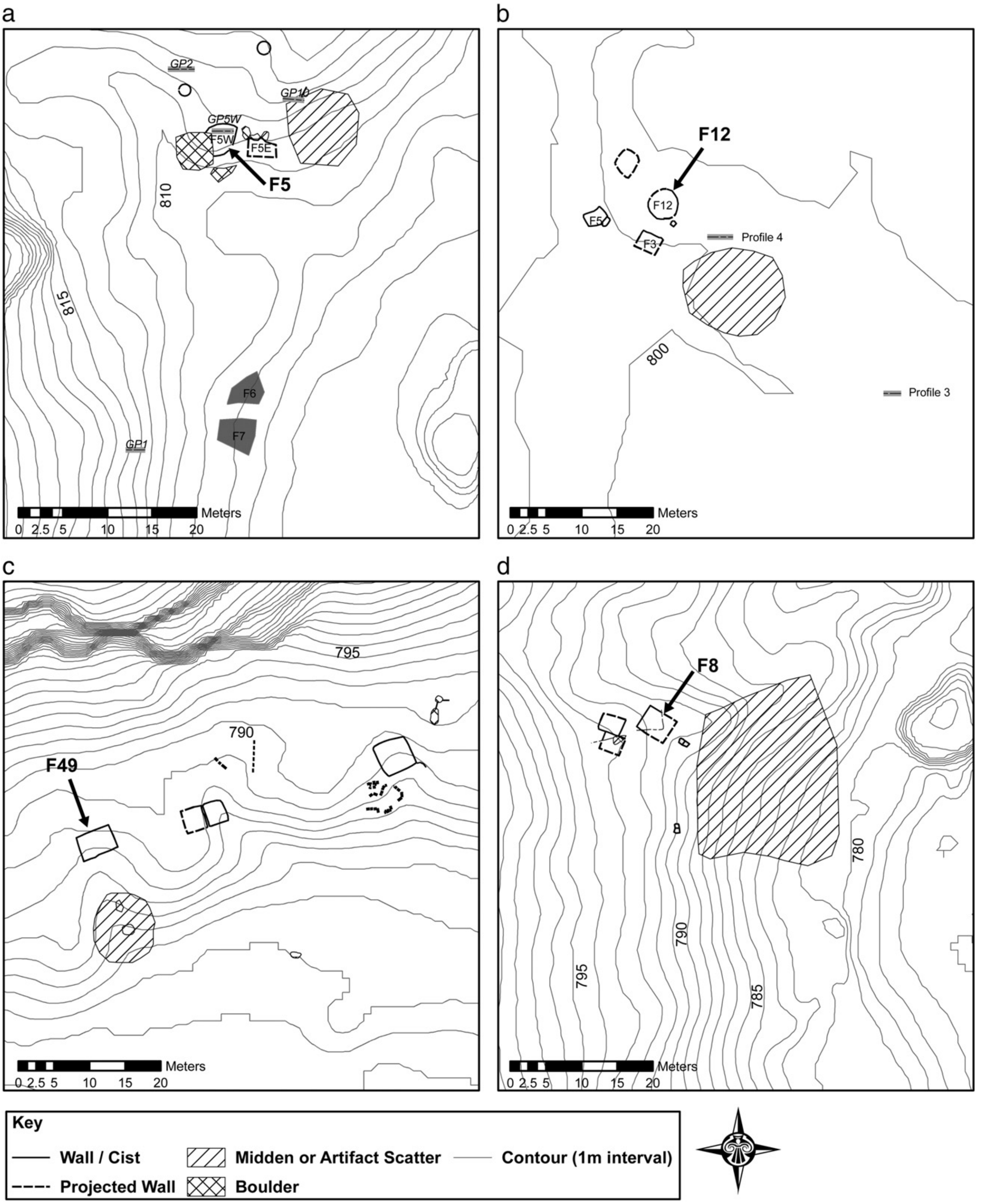


**Fig. 3.** Topographic maps of the four sites showing site layout of habitation features and midden/activity areas. a. Lower Confluence Site. b. Palisades Site. c. Furnace Flats Site. Basemap is amended from Figs. 4.22–4.24 (Jones, 1986:74–76). d. Upper Unkar Site.

dimensions of cultural features. Elevation was recorded in meters above sea level using NAD 83 vertical datum. An evaluation of natural, cultural, and feature fill contexts was undertaken at each site to determine the history of surficial processes, with a primary focus on the identification of Colorado River flood deposits. Results from 12 stratigraphic sections are presented including the stratigraphy from four natural exposures, four midden areas, and four relatively large habitation features. Stratigraphic profile descriptions include sections chosen to represent relations between natural and cultural deposits. Sections were drawn in detail, down to millimeter scale lenses, using line levels, measuring tapes, and total station mapping of profile datums. Beds and lenses were sampled for particle-size analysis. A few locations were chosen for investigating the microfabric characteristics of fluvial, ponded, and cultural layers.

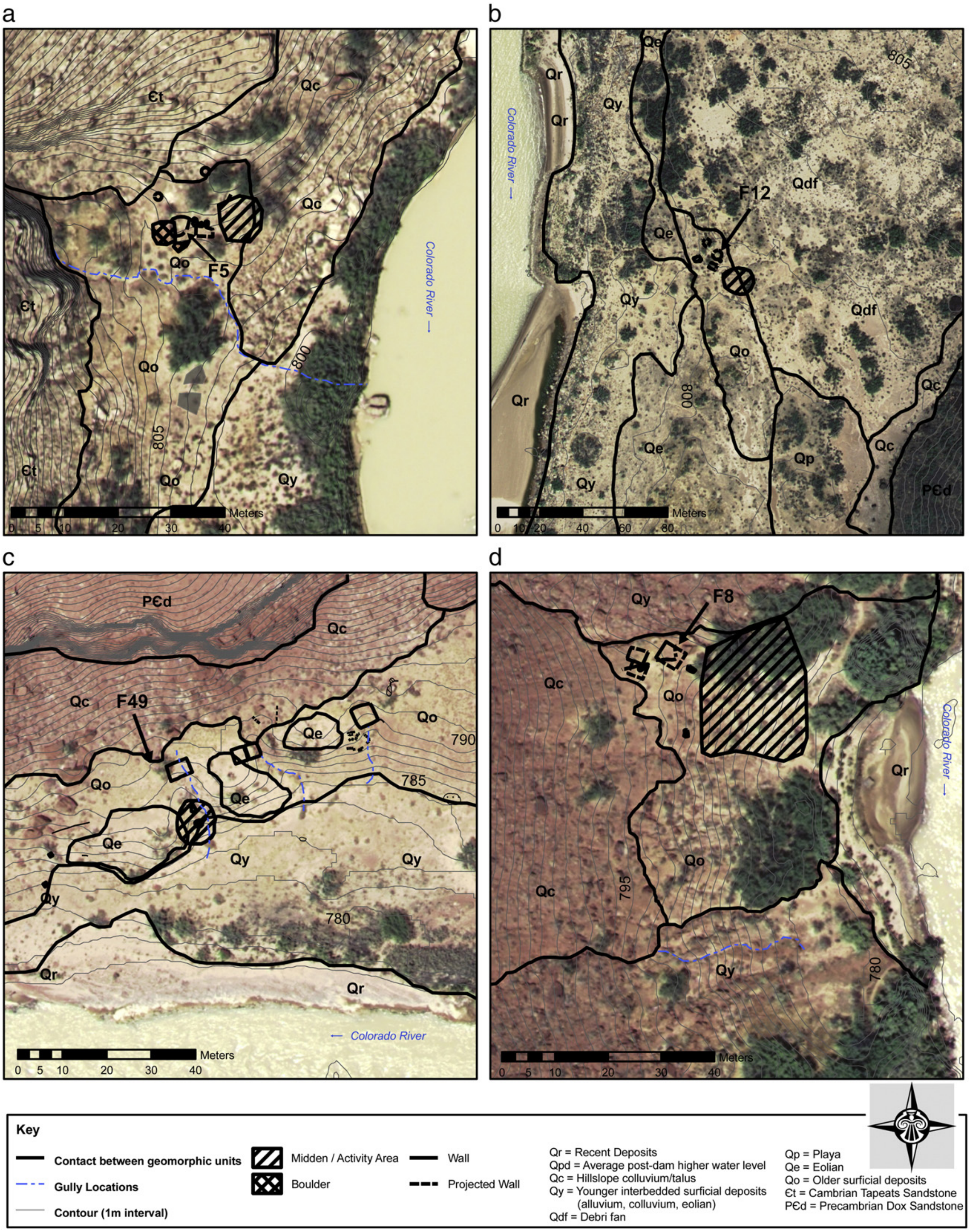


**Fig. 4.** Aerial photographs illustrating geomorphic relations of various bedrock and surficial deposits of the four sites. a. Lower Confluence Site. b. Palisades Site. c. Furnace Flats Site. d. Upper Unkar Site.

At each of the four sites we encountered habitation features about 4 m in diameter and 2 m deep, filled by 2 m of post-occupational deposition, and buried underneath 1 to 2 m of additional sediments.

The habitation structures are closed basins that preserve sediments representative of post-occupational surficial processes. Although the sediments in the fill sequence only represent post-occupation activity, comparison of other natural and cultural deposits at each site indicates that feature fill material accurately represents depositional processes at each site during occupation, such as sheetwash, distal debris fan, colluvial, eolian, and fluvial.

Hundreds of sites comprise the Grand Canyon river corridor archaeology site database. Of these, the vast majority are known from only surface data (Fairley et al., 1994; Fairley, 2003; Grand Canyon National Park site files). For certain research questions, surface data are sufficient, whereas other research questions require excavation data. However, very few river corridor sites have been subject to archaeological or geoarchaeological excavations to date (Damp et al., 2009; Jones, 1986; Miller, 2005; Schwartz et al., 1979, 1980). Due to the types of sites previously excavated, the varying research interests and differing archaeological/geoarchaeological methodologies, we limited our analysis to include only the data derived from sites excavated during the present NPS-MNA collaborative project. The research questions determined our data collection strategies and focus, specifically, addressing the following: (1) excavation at Puebloan-era sites with permanent masonry habitation structures; (2) attention to complete site layout, orientation, and landform position, importantly including features and deposits extramural to masonry habitation features; (3) detailed spatially representative excavations to obtain well-contextualized, from the geomorphic and chronostratigraphic perspectives, ceramic assemblages necessary for precise ceramic and radiocarbon dating. For example, among the kinds of information that our model requires are the discernment of early Pueblo II (ca. A.D. 1050–1080) from Late Pueblo II (ca. A.D. 1080–1170) site components, landform-scale geomorphic description, and excavations with sufficient extent to provide numerous cleaned stratigraphic profiles that clearly illustrate the depositional environments of sediments that underlie, overlie, and are contained within cultural features. Admittedly our data set of four excavated sites is limited and thus we present our model as a testable framework to compare to future excavated sites along the river corridor.

Particle-size analysis on 100 samples at the Northern Arizona University Soil and Sediment Laboratory used a Coulter LS230 laser particle-size analyzer that determines particle-size distribution between 0.002 mm and 2 mm clay to very coarse sand. In our analysis, we used the <0.1 mm (very fine sand, silt, and clay) to characterize and differentiate the fluvial, eolian, ponded, colluvial, and debris fan sediments (see Rubin, 1987; Rubin and Hunter, 1987; Rubin et al., 1990; Draut et al., 2005, 2008).

Six oriented, intact, sediment samples were taken for analysis of the microscopic fabric of depositional units, three from feature fill and floor contexts, and three from playa (ponded) and fluvial context. Samples were collected using plastic rain gutters cut into 7.5 cm by 5.0 cm by 5.0 cm sections. The samples were carefully packed with paper to cushion the collected matrix and they were impregnated and made into thin sections at Quality Thin Sections, in Tucson, Arizona. Both oversized and regular slides were made. Slides were viewed using a Leica petrographic microscope and images were captured with a Canon digital camera. Ceramics found in the natural and cultural deposits are used to determine ages and cultural affiliations.

Dating of features and stratigraphy is integral to developing a chronostratigraphic reconstruction. In the North American Southwest, the ceramic chronology has a resolution of about 25 years, based on systematic variations in temper, paste, and decoration style. The ceramic chronology is pegged to dendrochronology through cross-dating of trees in structures with associated ceramics. Ceramic types include Black Mesa Black-on-white indicating that the primary occupation at Lower Confluence and Palisades dates to the A.D. 1050–1080 period, Sosi Black-on-white indicating the primary occupation at Furnace dates to the A.D. 1070–1130, and Sosi Black-on-white and Flagstaff Black-on-white indicating that the primary occupation at Upper Unkar dates to A.D. 1140–1170. Additional dating includes radiocarbon on charcoal samples collected from archaeological features. Samples were sent to Beta Analytic, Inc. (Miami, FL; http://www.radiocarbon.com/).

Total station maps were incorporated into a GIS database that contained elevational data of known historic floods at each of the four sites along the river corridor. Topping et al. (2003) calculated historic discharges with the largest flood being 5900 cubic meters per second (cms), the next largest 4800 cms, and the next at 3500 cms, occurring in 1884, 1921, and 1957, respectively. The 5900 cms has a recurrence interval (RI) of 80 years, the 4800 cms an RI of 40 years, and the 3500 cms an RI of 6–8 years. For comparison, we include elevations of the highest post-dam flood of 2750 cms that occurred in 1983, the highest controlled post-dam discharge of 1270 cms, and the highest sustained post-dam releases averaging about 708 cms. The elevations of these floods were modeled for the entire river corridor by Magirl et al. (2008), providing a valuable database for visualizing flood elevations on the landscape at each site. The flood elevations were superimposed on site maps and aerial photos to create "virtual shorelines" of known high magnitude floods. Our analysis compares the "virtual shoreline" elevations to the geomorphic positions of various cultural features, including habitation structures, activity areas, and middens. Flood elevations, magnitudes, and recurrence intervals are used to compare the elevations of the cultural features with the elevations of the highest floods to evaluate susceptibility of each site to potential flood risks. The virtual shoreline maps were produced using the HEC-RAS model, which is a one-dimensional, steady state model that uses channel cross section, flow velocity, water viscosity, and Manning's roughness value, to estimate water surface elevations at various discharges (Magirl et al., 2008). Discharges used in the model, and flood recurrence intervals used for cultural interpretations, were determined from historic hydrograph data and modeling using a step-back analysis (Table 2) (Topping et al., 2003). At the four sites, four habitation features and associated activity area/middens were used in the comparison of archaeological feature elevations to flood elevations.

The final part of the landscape analysis uses the long-term temporal trend in prehistoric streamflow for the Colorado River at Lees Ferry for the A.D. 1000–1200 period. We use these data to evaluate the potential impact of retrodicted discharges of the Colorado River to past site location decision making (Meko et al., 2007).

## 4. Results and analyses

Below we present the results of our field investigations and laboratory analysis, including landscape studies, stratigraphic profiles, particle-size distribution, micromorphology, and virtual shoreline/paleodischarge data for each site. The results and analysis are organized according to site. The subsequent section, "Discussion and Conclusions," presents a synthesized evaluation of the site formation processes and culture history of the Canyon to arrive at a new understanding of temporal trends in settlement patterns along the river corridor.

### 4.1. Lower Confluence

Results of the archaeological excavations and geomorphic profile descriptions at the Lower Confluence exhumed farmstead provide

**Table 2**
Discharge, recurrence interval, and deposition for various historic and modern floods.

| Year (A.D.) | Discharge (cms) | Discharge (cfs) | Recurrence interval | Flood deposits |
|---|---|---|---|---|
| Seasonal | 708 | 25,000 | Seasonal | Along edge of river |
| 1996 | 1270 | 45,000 | Only two years (1996, 2004) | Sand bars, lowermost portion of gully mouth |
| 1983 | 2700 | 97,000 | Largest post-dam discharge | Sand bars, fill gully mouths |
| 1957 | 3500 | 125,000 | 6–8 yrs. | 4–5 m in lower parts of gullies |
| 1921 | 4800 | 170,000 | 40 yrs. | >5 m in parts of gullies |
| 1884 | 5900 | 210,000 | 80 yrs. | Completely fill many gullies |

Data source: Topping et al. (2003).

**Table 3**
Radiocarbon ages used in this study.

| Lab number | Site/feature number | Conventional radiocarbon (BP) | Calibrated (2 sigma) (A.D.) | Calibrated (1 sigma) (A.D.) | Reference |
|---|---|---|---|---|---|
| Beta-94284 | Lower Confluence/F2 | 120 ± 50 | 1665–1950 | 1680–1755 | Leap and Coder, 1995 |
| Beta-94283 | Lower Confluence/F4 | 350 ± 50 | 1445–1655 | 1470–1640 | Leap and Coder, 1995 |
| PRI-09-01-271 (AMS) | Palisades/F13 | 1315 ± 15 | 660–690<br>750–760 | 650–710<br>740–770 | This study |
| Beta-51470 | Palisades | 1410 ± 120 | 390–890 | na | Hereford (1996) |
| Beta-51471 | Palisades | 1380 ± 140 | 390–960 | na | Hereford (1996) |
| W-6373 | Palisades | 885 ± 60 | 1030–1250 | na | Hereford (1996) |

1000 years of cultural and natural site formation processes. The ephemeral PI features buried by 4 m of sediment provide a maximum age of A.D. 800–1000 for cultural activity at the site, while two Protohistoric features provide the most recent use of the site at A.D. 1445–1655 and A.D. 1665–1950 (Table 3). Archaeologists excavating the early Pueblo II habitation feature (Feature 5) uncovered a sequence of well-preserved flood deposits overlying the floor (Fig. 5a and b). Indeed, climbing ripples representing fluvial deposits directly overlie the hearth on the center of the floor, indicating that the flood occurred either during occupation, or very shortly after people left the site. Much of the activity area and midden associated with occupation of the farmstead were removed by erosion. Nonetheless, archaeological excavations and geomorphic profile descriptions reveal a sequence of sediments and cultural features including the talus boulders underlying the midden, the early Pueblo II midden deposits, and a Protohistoric thermal feature (Fig. 5b; GP10). The flood on the floor of the habitation structure also directly overlies the associated early Pueblo II midden containing ceramic and groundstone artifacts. Overtopping much of the site are flood deposits, presumably from the A.D. 1884 flood.

The geomorphic profile GP1 records 4 m of interbedded fluvial and colluvial deposits overlying the A.D. 800–1000 features and artifacts. Five fluvial lenses were recorded in GP1. The two uppermost fluvial lenses, Stratum D and F (Fig. 5b), are tentatively correlated with the flood deposits that overtop the midden in GP10, and on the floor of the house in GP5W. Therefore during the A.D. 1050–1080 time frame, or shortly thereafter, a large flood impacted this farmstead, burying and preserving the early Pueblo II features. The two dated Protohistoric features are underlain by colluvial sediments. The historic floods directly overly Feature 2, and cap the sediment sequence of the Feature 5 fill. Feature 3 is located slightly higher on the landscape and was just above the highest flood level of the A.D. 1884 flood.

The particle-size distribution (PSD) for the sampled profiles illustrates that fluvial lenses are, on average, finer-grained than the colluvial and eolian deposits at this site. Two samples from the presumed A.D. 1884 flood have 74.4 and 91% of the <0.1 mm fraction. Fluvial lenses that are tentatively correlated across the site from the GP1, GP5W, and GP10 profiles have similar PSD. For the <0.1 mm fraction, the GP1 profile has, from oldest to youngest, 61.9%, 87.3%, and 64.4%; GP5W has 81%, 92.4%, and 89.9%; and GP10 has 78.1% and 71.9%. The range of particle-size distribution for the colluvial deposits reflects a complex geomorphic history for those sediments. They comprise a mixture of hillslope-derived sand and sheetwash and eolian re-worked flood sediments. The weathered Tapeats Formation sandstone is mixed with quartz sand initially delivered to the site by floods, then reworked by eolian and hillslope processes. Therefore the PSD of the colluvial layers are poorly sorted, with a range of 39.7% to 70.2% for the <0.1 mm fraction (Fig. 5b).

The micromorphology sample F5E1 was taken from the floor of Feature 5 in order to analyze the sedimentary fabric of the floor (cultural) and flood contact (Fig. 6a). In the lower part of the sample, identified as the floor of Feature 5, a weak layering with dominantly fine-grained deposits of silt and very fine sand is seen. The laminae are discontinuous laterally, and show a weak fining upwards trend. These are the upper layers of the floor that experienced reworking of floor sediments, perhaps due in part to settling of water (from rain?) on the floor, and trampling underfoot. Above these weakly laminated sediments is an abrupt change to flood sediments that begins with a 1 mm thick lens of quartz sand, also ending in a fining upward sorting with silt and clay at the top. This is followed in this slide by another three fining upwards lenses of sand, each culminating in a lamina of silt and clay. These upper four lenses are flood sediments that post-date the period of occupation. In macroscopic view, these are the lowermost lenses of the fluvial climbing ripples that overlie the floor of Feature 5.

The elevation of the uppermost identifiable walls of the Feature 5 habitation structure is 812.34 masl, and the floor is 810.64 masl (Table 4). The elevation of the uppermost portion of the midden area is 811.57 masl. Reconstructed elevations of the three largest historical floods are 813.15 masl for the 5900 cms flood, 811.80 masl for the 4800 cms flood, and 810.01 masl for the 3500 cms flood.

### 4.2. Palisades

The geomorphic setting of the Palisades site is characterized by its location at the distal edges of the Palisades debris fan, slightly higher than the surrounding landscape (Hereford, 1996; Draut et al., 2008). Here, the site is located where the debris fan is partially buried by an eolian coppice dune field, and where the edges of the fan have been scoured by flood activity (Fig. 7a and b). The interactions of surficial processes related to these landforms produces a complex series of interbedded fluvial, eolian, debris fan, ponded, and cultural features and deposits. The ponded sediments occur in an area that at several times in the past was internally drained, but presently drains via a gully to the Colorado River. A series of gullies cut through the site, exposing cultural and natural stratigraphy. Profiles 3 and 4 are located at the gully walls. Two test pits (PP1 and PP2) located in the playa area correlate well stratigraphically with early Pueblo II midden deposits exposed in Profiles 3 and 4, at the center of the site. Feature 12 is a large habitation structure (see Fig. 2c and d).

Deposits that fill Feature 12 record surficial process active at the site, including eolian, fluvial, sheetwash and alluvial fan deposits (Fig. 7a). Chronostratigraphic relationships indicate that deposits at this site span the period from A.D. 660–770 (Table 3), though the primary occupation at the site dates to the early Pueblo II period (A.D. 1050–1080).

The dominant mechanism for the filling of the large habitation structure (Feature 12) is distal debris fan surface flow that deposited very coarse sand, pebbles, and cobbles. Nonetheless, flood sediments are present about two-thirds of the way to the top. The structure filled relatively rapidly with coarse-grained overland flow, which caused two sides of the structure to collapse. Therefore, although the flood deposit is closer to the top, it most likely closely post-dates the period of occupation.

The two test pits (PP1 and PP2) in the ponded sediment area contained well-stratified eolian, fluvial, and ponded sediments

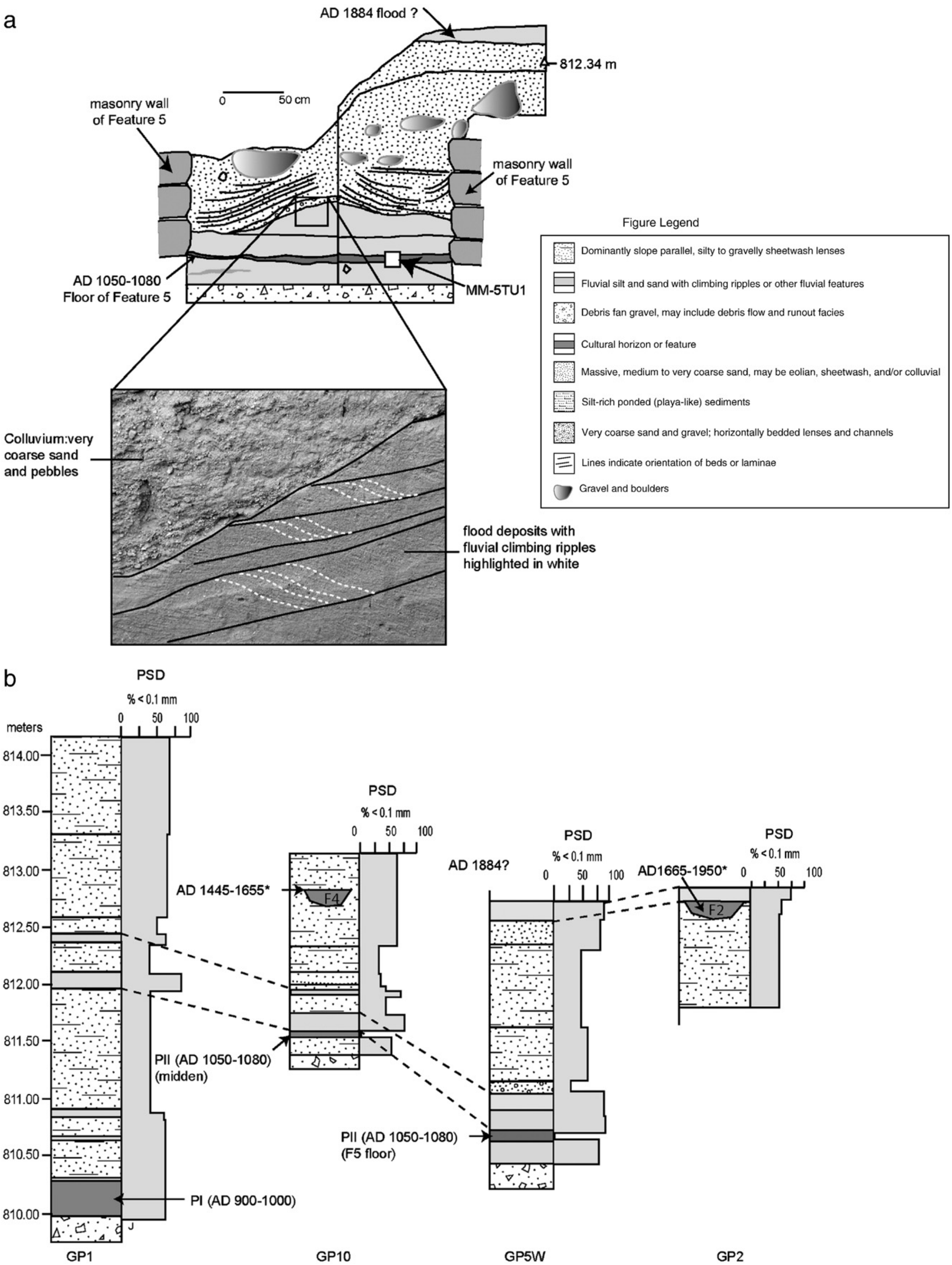


**Fig. 5.** Feature fill and stratigraphic relations at Lower Confluence Site. a. Feature fill stratigraphy for Feature 5. Note climbing ripples (white dashed) and bedding plan (solid lines) indicative of fluvial deposition. b. Stratigraphic correlations for described and sampled profiles discussed in text. Note blue fill indicating fluvial deposits. Shaded area illustrates the particle-size distribution (PSD) for the <0.1 mm particle-size distribution.

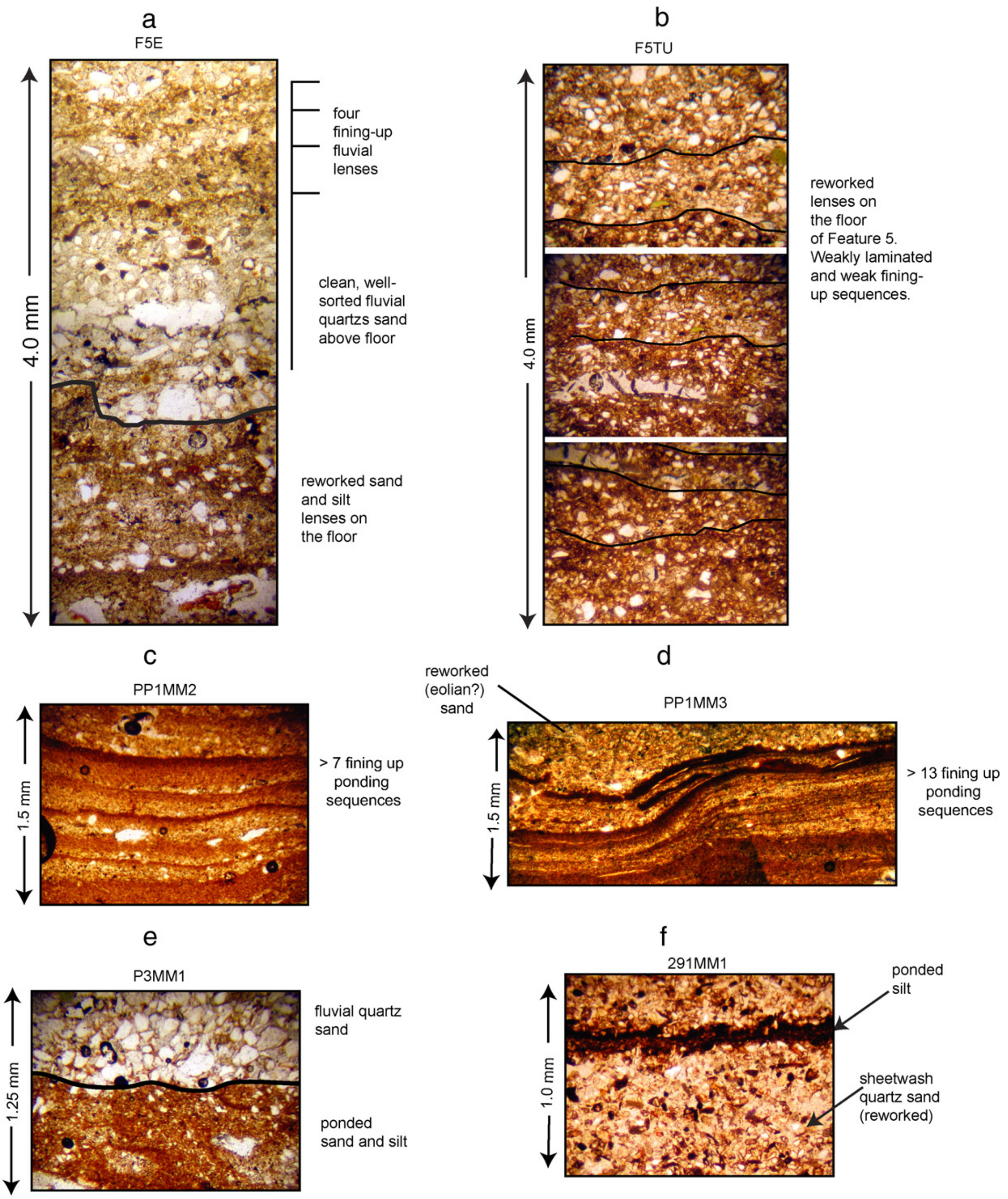


**Fig. 6.** a–f. Photomicrographs in plane polarized light illustrating the microscopic fabric of cultural and natural deposits. See text for discussion.

(Fig. 7b). Based on elevation and stratigraphic correlations, deposits related to the cultural period are also present. These pits reveal that the modern surface, which dominates drainage patterns, is a relatively recent layer that, in places, underlies eolian and fluvial deposits.

As revealed in Profile 3, the lowest stratum at the site significantly predates the primary A.D. 1050–1080 occupation of the early Pueblo II inhabitants. Fluvial sands occur at the base of all of the units investigated, and they are overlain by the "early playa" that predates the site occupation. Profile 3 reveals significant periods of alluvial fan activity at the distal edges of the Palisades debris fan, represented by relatively thick sequences of loose, channel-fill alluvial sands and gravels, as well as matrix-supported debris flows. A thermal feature overlying a matrix-supported debris flow returned a radiocarbon age indicative of A.D. 660–770–late Basketmaker III period. Midden deposits revealed in Profile 3 are directly overlain by fluvial sands, which are in turn overlain by ponded playa-like deposits. Overlying these are other fluvial deposits correlated with the uppermost fluvial deposits in the PP2 playa profile. As at the Lower Confluence site, flood deposits directly overlie a midden stratum.

Particle-size analysis aids in characterizing and differentiating the various deposits at Palisades (Fig. 7b). Particle-size data also illustrate the relatively complex lateral changes in depositional processes that reflect the position of the site on a landscape where playa, fluvial, eolian, and debris fan deposition interact. Even though the two pits,

**Table 4**
Cultural feature type, age, and elevation differences between different flood elevations.

| Site name (river mile[1]) | Feature no. (type) | Feature age (A.D.) | Feature elevation (meters) | Elevation of 4,800 cms flood at each site | Meters above (+) or below (–) 4,800 cms | Elevation of 5,900 cms flood at each site | Meters above (+) or below (–) 5,900 cms |
|---|---|---|---|---|---|---|---|
| Lower Confluence (62.78) | F5 (habitation)[f] | 1050–1080 | 812.34 | 811.80 | 0.54 | 813.15 | –0.81 |
| | F10 (midden)[f] | 1050–1080 | 811.57 | | –0.23 | | –1.58 |
| | hearth[f] | 800–1000 | 810.00 | | –1.8 | | –3.15 |
| Palisades (66.08) | F1 (midden)[f] | 1050–1080 | 800.39 | 801.47 | –1.08 | 802.70 | –2.31 |
| | F12 (habitation)[f] | 1050–1080 | 800.18 | | –1.29 | | –2.52 |
| Furnace (71.97) | F49 (habitation) | 1070–1130 | 786.28 | 784.13 | 2.15 | 785.02 | 1.26 |
| | midden | 1070–1130 | 783.50 | | –0.63 | | –1.52 |
| | storage cist[f] | 800–1000 | 784.82 | | 0.69 | | –0.20 |
| Upper Unkar (72.54) | F8 (habitation) | 1140–1170 | 790.82 | 783.42 | 7.4 | 784.27 | 6.55 |
| | midden[f] | 1140–1170 | 788.96 | | 5.54 | | 4.69 |

Notes:
1. River miles downstream from Lees Ferry.
f - Features contain or are buried by Colorado River fluvial deposits.
Shaded cells indicate features that are under water at given flood elevation.

PP1 and PP2, were excavated in the playa, only 25 m apart, the stratigraphy preserved is quite different. PP1 contains only three fluvial layers and is dominated by finely laminated sequences of ponded sediments. Fluvial layers have between 85% and 92.6% of the <0.1 mm fraction and the ponded layers have between 92% and 98% of the <0.1 mm fraction. In contrast, the PP2 is dominated by fluvial sands, at the same elevation, with only a few ponded lenses. In addition, fluvial sands here are significantly coarser than elsewhere, with the <0.1 mm fraction ranging from 29.9% to 82.5%.

Particle-size distributions for the P3 and P4 sections also help to correlate and differentiate deposits (Fig. 7b). Fluvial deposits in P3 have relatively coarse fraction, ranging from a mere 11.4% of the <0.1 mm fraction at the base, to 91.7% near the top. The uppermost fluvial lens has 12.3% of the <0.1 mm fraction, indicating higher energy deposits. This uppermost deposit might well be the A.D. 1884 flood (see below). In P4, particle-size distributions help to characterize a sequence of fining-upwards fluvial deposits where the flood sands range from 6.8% of the <0.1 mm fraction, to 43.9%. Several of these floods end in silt lenses that have between 88.1 and 91.0% of the <0.1 mm fraction. Fluvial deposits found in the feature fill sequence of Feature 12 contain 94.5% of the <0.1 m fraction.

Micromorphology at the Palisades site reveals characteristics of ponded (playa), fluvial, and floor contexts (Fig. 6b, c, d, e). Sample F5TU1 was analyzed because it was from the floor context. The floor was rather unique, consisting of a natural clay and silt-rich deposit, exhibiting distinct, 5 cm diameter mudcracks across the entire floor. The structure is interpreted as a surface brush-and-mud structure (locally known as jacal). The microscopic fabric of these deposits is characterized by relatively weak horizontal layering with occasionally very weak fining upwards sequences, and poorly sorted grain sizes. Elongated grains are horizontally oriented, indicating settling parallel to the ground surface. The original nature of these deposits is from playa-like deposition, and the elevation and stratigraphic relationships to the "early playa" (Fig. 7b) supports this interpretation. However, the fabrics seen in Fig. 6b indicated reworking of the sediments into the weak laminations representative of sorting by rainfall and small puddling events in an open cultural feature. The nature of these deposits is similar to those from the floor of Feature 5 at Lower Confluence, as previously discussed.

The playa deposits, as seen in samples PP1MM2 and PP1MM3 (Fig. 6c and d) illustrate distinctly laminated, fining upwards sequences representing ponding processes after rainfall events and hillslope runoff fill the playa area. Many of the grains are elongated rock fragments from the Dox Sandstone that are horizontally oriented. Quartz-rich sand underlying the red laminae probably originate from windblown sand across the playa surface prior to reworking and settling in a ponded environment. As can be seen in Fig. 6c, seven ponding events are recorded whereas in Fig. 6d, there are thirteen events recorded, each within a 1.5 mm thick section.

In the P3MM1 photomicrograph, we can see the contact between the underlying ponded playa laminae and the overlying fluvial quartz sands (Fig. 6e). This contact is very abrupt, representing a flooding event from the Colorado River burying the "early playa." This flood represents the culmination of playa-like processes, at this specific location, until after the early Pueblo II occupation.

The elevation of the uppermost identifiable walls of the Feature 12 habitation structure is 800.18 masl, and the floor is 798.75 masl (Table 4). The elevation of the uppermost portion of the midden area is 800.65 masl, whereas the lowest recorded part of the midden is 800.00 masl. Reconstructed elevations of the two largest historical floods are 802.70 masl for the 5900 cms flood, 801.47 masl for the 4800 cms flood, and799.98 masl for the 3500 cms flood.

### 4.3. Furnace Flats

The geomorphic setting of the Furnace Flats site differs from that of the two previous sites in that it is situated along the toeslope of a steep bedrock cliff of Dox Sandstone. The dominant depositional processes at the site are colluvial, with significant eolian reworking of fluvial sands. Detailed investigations were undertaken of the Feature 49 fill sequence which revealed structure filling by dominantly hillslope gravels and sands derived from the Dox Sandstone and from reworked eolian processes (Fig. 8a and b). No fluvial deposits were found in the Feature 49 fill sequence. The A6 profile was a 15-m-long and 4-m-high section that revealed extensive cultural and hillslope deposits (Fig. 8b). Fluvial deposits in this area were limited to the lower parts of the profile and the lower parts of the site.

Particle-size distributions from the feature-fill deposits at the Furnace site are limited because the majority of materials filling features are composed of reddish-brown sand and gravel derived from hillslope processes. Based on the presence of climbing fluvial ripples, the only definitively fluvial deposit here is at the base of the A6 profile, where the <0.1 mm fraction is 37.6%, indicating a coarse-textured fluvial facies for this deposit. Other deposits above this fluvial lens range from 33.9 to 52.4% of the <0.1 mm fraction. Because there were no fluvial deposits in F49, no sediments were analyzed from feature fill contexts.

The elevation of the uppermost identifiable walls of the Feature 49 habitation structure is 786.28 masl, and the floor is 785.25 masl (Table 4). The elevation of the uppermost portion of the midden area is 784.50 masl and the lower portion of the midden is 782.50 masl.

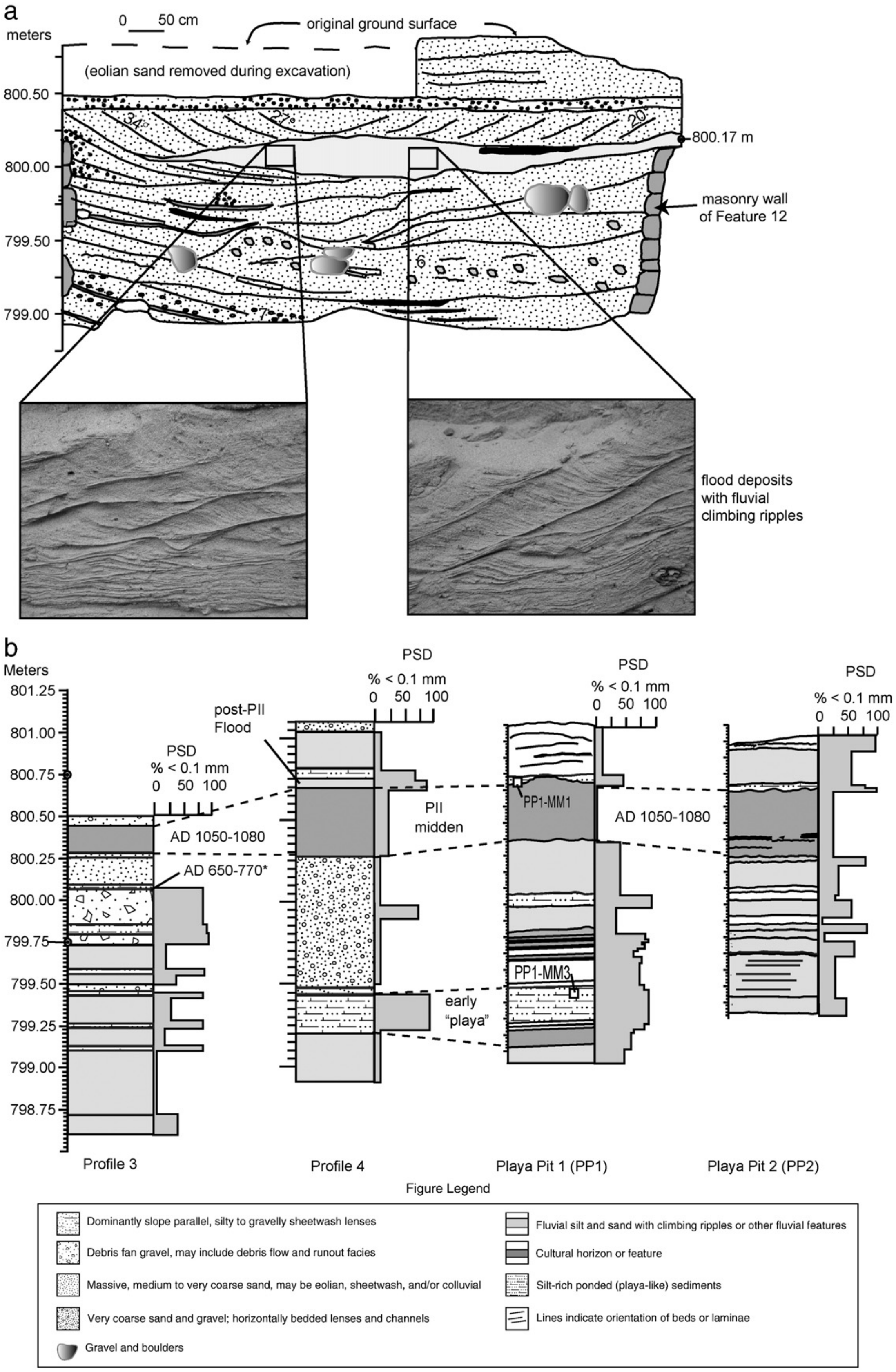


**Fig. 7.** Feature fill and stratigraphic relations at Palisades Site. a. Feature fill stratigraphy for Feature 12. Note blue fill indicating fluvial deposits. Photographs illustrate climbing fluvial ripples. b. Stratigraphic correlations for described and sampled profiles discussed in text. Note blue fill indicating fluvial deposits. Shaded area illustrates the particle-size distribution (PSD) for the <0.1 mm particle-size distribution.

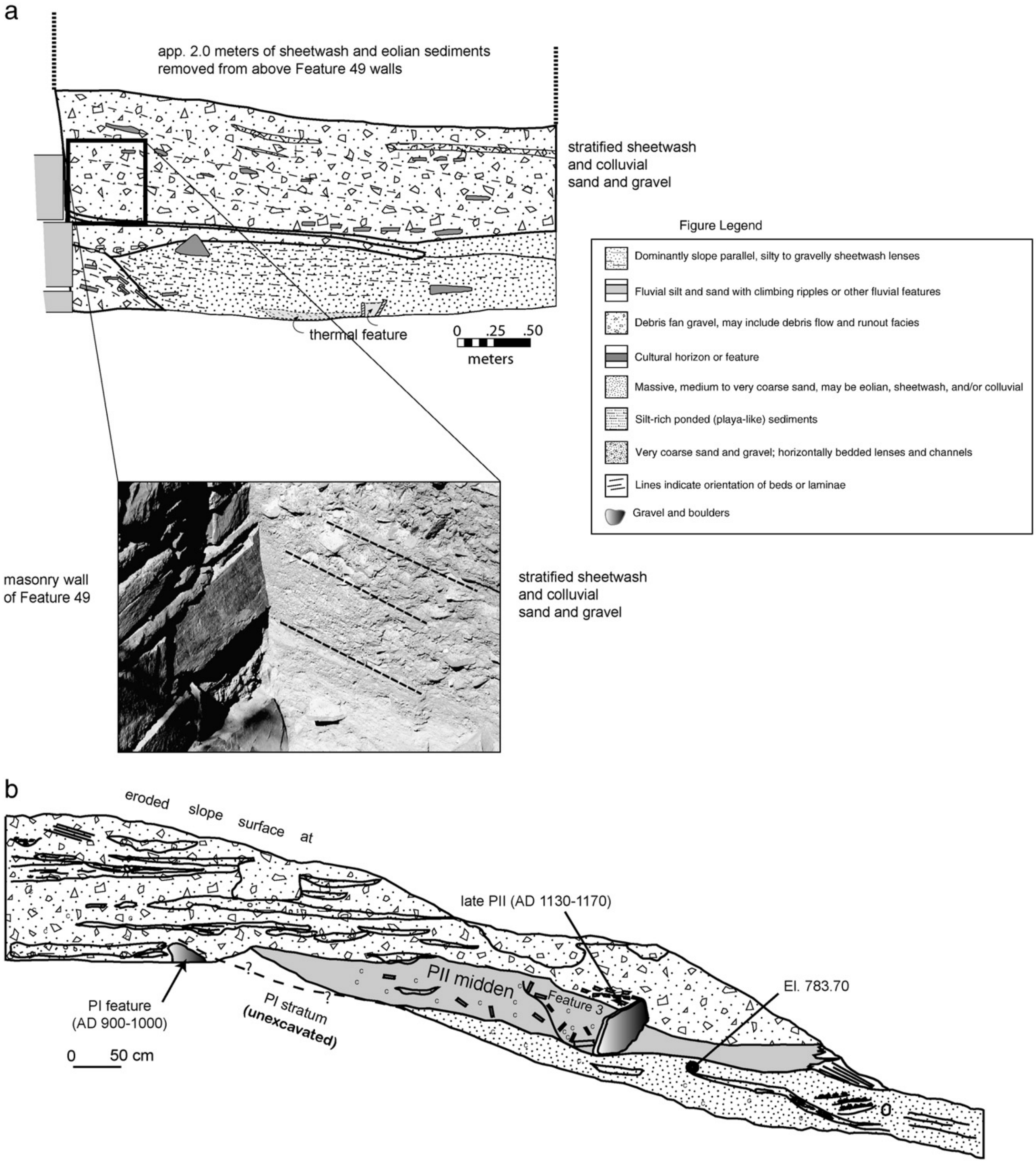


**Fig. 8.** Feature fill stratigraphy for Furnace Flats Feature 12. a. Accompanying photograph illustrates the coarse-grained fill material, dominantly from hillslope processes. b. Stratigraphic profile of the midden deposits for Feature 49 at Furnace. As in the previous figure, note the lack of fluvial deposits in the stratigraphic section. PI feature (A.D. 900–1000) underlies the PII midden.

Reconstructed elevations of the two largest historical floods are 785.20 masl for the 5900 cms flood, 784.13 masl for the 4800 cms flood, and 782.92 masl for the 3500 cms flood.

### 4.4. Upper Unkar

The geomorphic setting of the Upper Unkar site is like that of the Furnace site, at the toeslope of the steep bedrock cliffs comprised of the Dox Sandstone. Here, as at the Furnace site, the stratigraphic setting of the site contains dominantly eolian and hillslope materials, with fewer cultural deposits (Fig. 9). In addition, as at the Furnace site, there are scant few fluvial deposits and those that are present can be found deeper in the profiles, and lower on the site, closer to the river. Exposed in the excavation units were a series of deeply buried cultural features, including Features 7, 8, and 10, all of which contained intact beams, stacked masonry walls, and flagstone floors. Feature 8 fill materials were exclusively hillslope sand and gravel derived from the Dox Sandstone, and reworked eolian deposits that were washed into the structure.

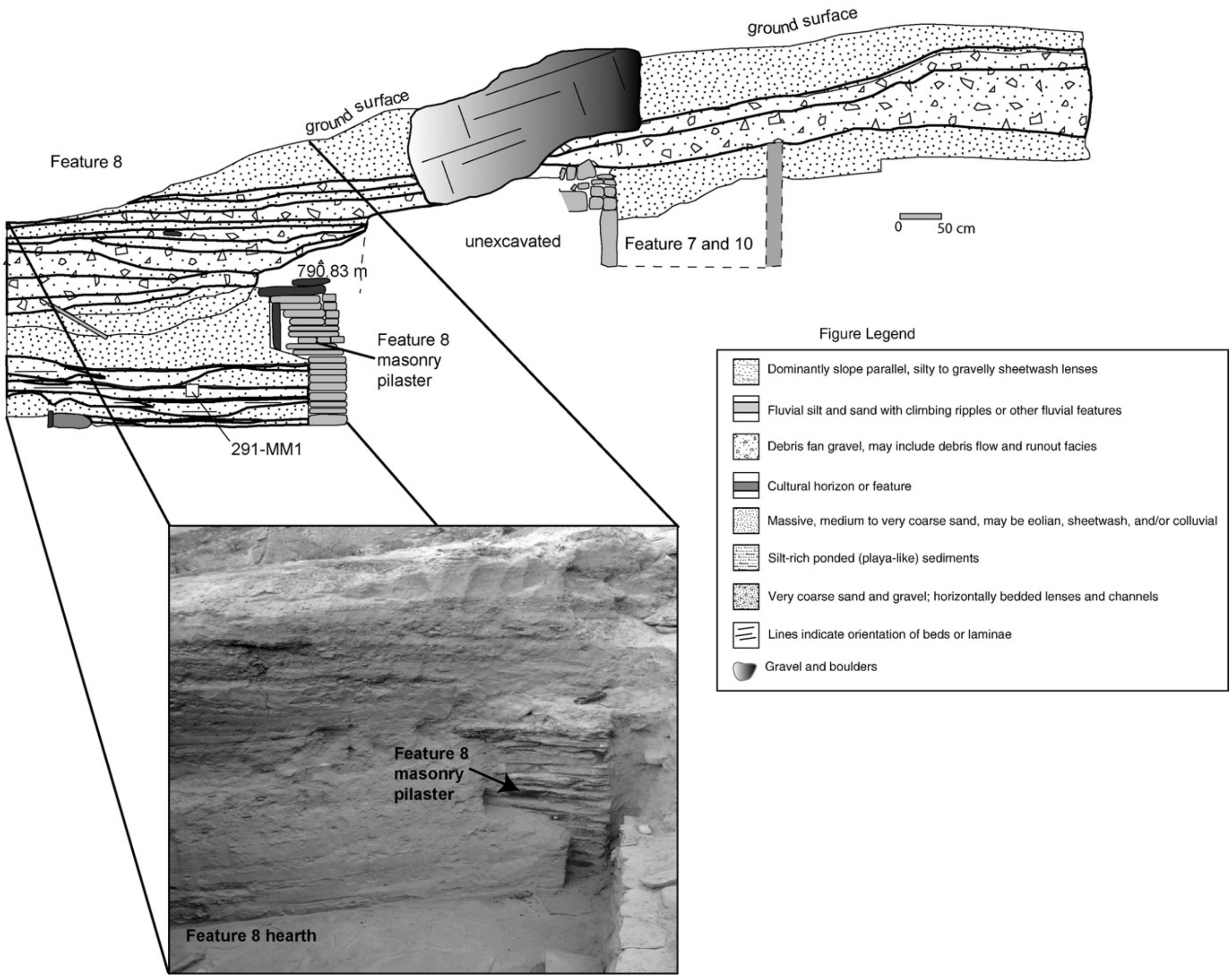


**Fig. 9.** Drawing of feature fill stratigraphy for Upper Unkar Site Feature 8. Photograph illustrates the coarse-grained fill material from hillslope processes. Note the lack of fluvial deposits in the stratigraphic section. Walls, floor, and supporting pilaster visible in the photograph. Feature 7 and 10 (not discussed) did not contain fluvial deposits.

Relatively rare fining upwards sequences with mud cracks were derived from runoff activity above the site (from the bedrock hillslope) flowing into the feature. After flowing into the closed basin of the feature, the ponded sediment deposited very fine sand grading to silt and clay. The mudcracks and fining upward lenses are exclusively derived from runoff from the local Dox Sandstone sediments.

Particle-size distributions for the fill in the Upper Unkar features is coarse-grained gravel derived from hillslope processes. As with Feature 49 at Furnace Flats, Upper Unkar Feature 8 contains stratified materials that are both reddish brown gravel derived from the Dox Sandstone, and brown, quartz-rich eolian reworked sheetwash materials. The lenses exhibit slope parallel stratification with crenulated laminates interbedded with lenses of Dox-derived pebbles.

The photomicrograph from the 291 MM1 sample shows weak laminae representative of the ponded sediments that pooled in the bottom of Feature 8 and formed fining upwards sequences with mudcracks at the surface. The fining upwards sequence is difficult to see at the microscopic scale, and much easier to see at the macroscopic scale. Thin laminae, as seen in Fig. 6f, illustrate brief periods of ponding in this feature-fill sequence.

The elevation of the uppermost identifiable walls of the Feature 8 habitation structure is 790.82 masl, and the floor is 788.92 masl (Table 4). The elevation of the uppermost portion of the midden area is 790.40 masl and the lower part of the midden is 788.96 masl. Reconstructed elevations of the two largest historical floods are 784.27 masl for the 5900 cms flood, 783.42 masl for the 4800 cms flood, and 782.30 masl for the 3500 cms flood.

### *4.5. Retrodicted paleodischarges*

We utilize the retrodicted discharges (from dendroclimate records) of Meko et al. (2007) for Lees Ferry for the A.D. 1000–1200 period to place the four sites within a framework from which to evaluate periods of high or low Colorado River discharge. The original values of total annual flow have been transformed into z-scores, which provide a way of looking at how far a value is from the mean. Z-scores are calculated by determining the difference between the raw values and the mean of the total population, divided by the standard deviation. Significant trends can be seen with lower than average discharges recorded for A.D. 1000 to 1071, and A.D. 1130–1155. This later period was recognized by Meko et al. (2007) as a Medieval hydrologic drought. The intervening period, from about A.D. 1072 to A.D. 1130, is characterized by higher than average discharges, with particular high discharges occurring in A.D. 1080, 1084, and 1087, and again during the years A.D. 1115, 1116, and 1117.

## 5. Discussion and conclusions

As illustrated by particle-size distribution, micromorphic analysis, chronstratigraphic reconstructions, and diagnostic sedimentary

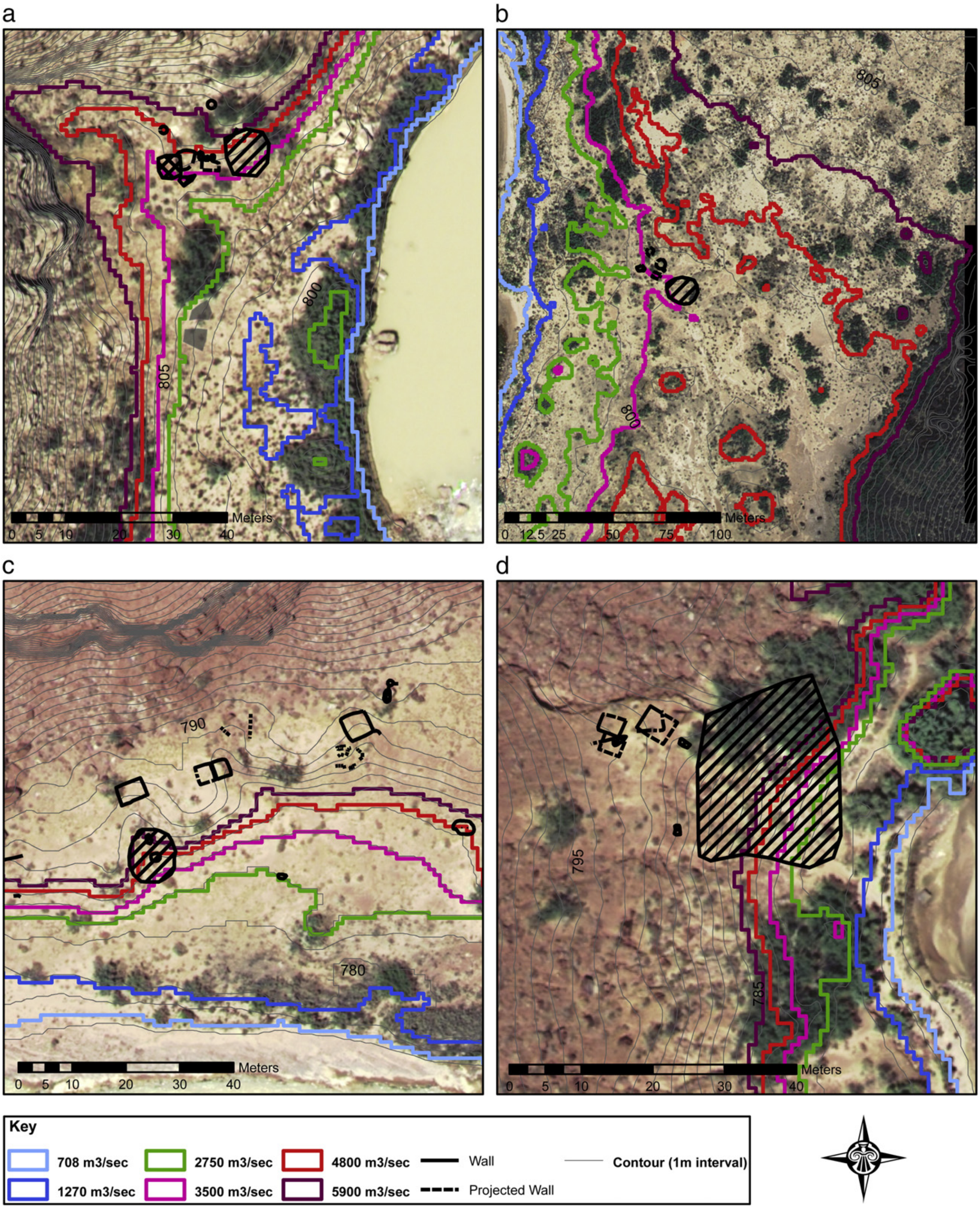


**Fig. 10.** Virtual shoreline reconstructions from GIS displays of Magirl et al. (2008) data. a. Lower Confluence and b. Palisades sites are inundated by the 4800 cms and higher floods. c. Furnace Flats and d. Upper Unkar are not flooded by even the highest, 5900 cms flood. Parts of the midden and activity areas are affected by the 3500 cms flood.

structures, early Pueblo II site components located at lower elevations were flooded by the Colorado River. At the Lower Confluence site flood deposits directly overlie the floor of a habitation feature and the associated trash midden. At Palisades, flood sediments directly overlie the trash midden and partially fill the habitation feature. The two late Pueblo II sites, Furnace Flats and Upper Unkar, had no evidence of flood deposits in the fill of habitation features. However, at both Furnace Flats and Upper Unkar, the activity areas and trash middens were reached by paleofloods (Table 4).

The maps of the four sites illustrate the relationship between calculated high discharges and the location of permanent habitation structures at each locus (Fig. 10a, b, c, d). At the Lower Confluence site,

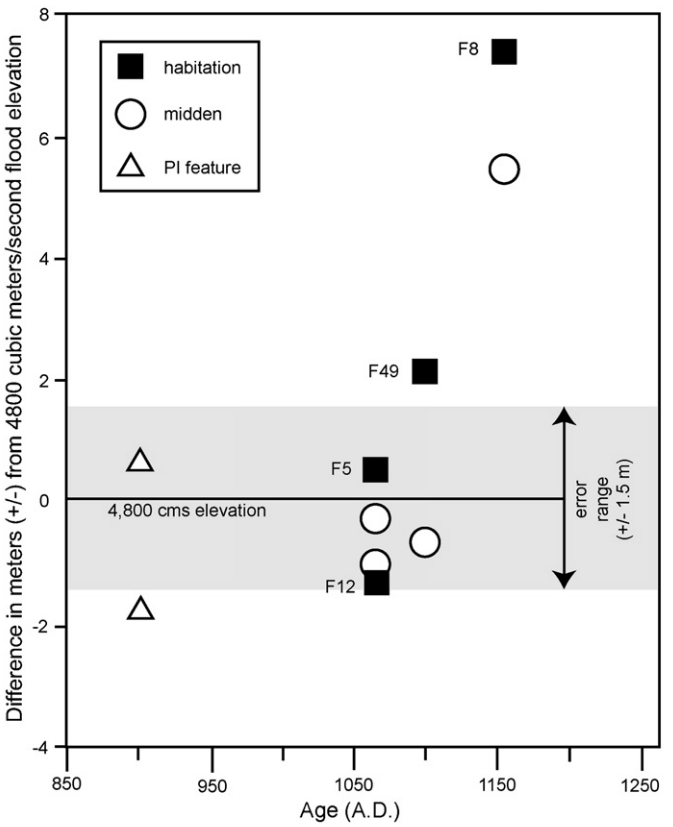


**Fig. 11.** Chart showing the elevation of features relative to the 4800 cms flood elevation. Features above the "0" line are higher than the 4800 cms, whereas those below "0" are flooded by the 4800 cms flood. Shaded area denotes the +/−1.5 m minimum error estimate for the flood elevations. For reference, two PI features, are also shown.

habitation structures are located at an elevation of 812.34 masl, above the 810.01 masl of the 3500 cms flood with a 6–8 year recurrence (Table 2). During flows above 3500 cms, for example the 4800 cms with a 40-year recurrence, the entire site would be under water (Fig. 10a). The trash midden is at 811.57 masl, so it would have been inundated by floods, on average, every 6–8 years. At the Palisades site, the uppermost wall segments of the permanent habitation Feature 12 are at 800.18 masl, above the 799.98 masl of the 3500 cms flood (Fig. 10b). The midden area is between 800.00 and 800.65 masl, indicating that portions of the midden would have been inundated, on average, every 6–8 years. Floods larger than 4800 cms would inundate the entire site.

At the later sites, Furnace and Upper Unkar, the calculated high discharges and location of permanent habitation structures illustrate that they were not affected by the highest flood deposits (Fig. 10c, d). No fluvial materials were identified in Feature 49 at Furnace, or Feature 8 at Upper Unkar. At Furnace Flats, the elevation of the 5900 cms flood is 785.02 masl whereas the elevation of the upper walls of Feature 49 is 786.28 masl. At Upper Unkar, the elevation of the 5900 cms is 784.28 masl whereas the elevation of the upper walls of Feature 8 are 790.82 masl. The trash midden and cists in the activity areas occur lower on the landscape below the 4800 cms level and are therefore in a position to be flooded more frequently (Fig. 10d).

Fig. 11 and Table 4 compare the elevations of the habitation features at the four sites with the elevation of the 4800 cms flow. Clearly, early sites are below this flood elevation, and later sites are above this flood elevation. Also shown are more ephemeral features, such as midden/activity areas, which seem to be located in areas that can easily be affected by the 40-year recurrence of the 4800 cms, as well as affected by the 6–8 years recurrence interval of the 3500 cms flow. This indicates that ephemeral features such as middens and activity area features were located in parts of the site that were more prone to flooding.

An analysis of the retrodicted annual discharges for the Colorado River shows trends in river flow at Lees Ferry (Meko et al., 2007). Meko has identified a mid-1100s' hydrologic drought, but it also seems evident that there are clear patterns in the timing of high flows (Fig. 12). For example, in the early part of the sequence, from about A.D. 1000–1075 or so, the mean flows are below the long-term average, and the running ten-year average illustrates this. This pattern changes at the end of the early Pueblo II sequence, when discharges increased. Indeed, at about A.D. 1080 the highest discharges occurred since A.D. 1065. This was followed by high discharges in A.D. 1084 and 1087. It is possible then, that the flood deposits seen on the floor of Feature 5 and on the midden at Lower Confluence, and possibly helping to fill Feature 12 at Palisades represents one of these high discharge years between A.D. 1080 and 1087. Although there is a drop in the flows between about A.D. 1087 and 1114, the average remains higher than the long-term mean. High discharges return in A.D. 1115, 1116, and 1117. It is, therefore, probable that the high flows in the mid-to-late 1080s, and again between A.D. 1115–1117, left marks on the landscape indicative of high water conditions. Driftwood, sand deposits, and scour lines may have left evidence that people took as clues of high-flow elevations, and relocated to higher ground. It is also possible, too, that the early Pueblo II people passed flood high-flow information along to their descendents, and that this knowledge led to decision-making processes to reduce risk. By the time the high flows returned in A.D. 1180, after the hydrologic drought of the A.D. 1130–1150, people were already relocated to higher and drier locations. Therefore, although large floods along the Colorado River were an unlikely cause of large-scale migrations and reoccupation for the main cultural periods, we find evidence that large floods may have influenced site location choices between the early Pueblo II to Late Pueblo II time period along the Colorado River in Grand Canyon.

The high discharges of the A.D. 1080s and A.D. 1115–1117 may have influenced site location choices. Although the high discharges do not necessarily equate with big floods, years with higher discharge are inferred to produce flooding events (Ely et al., 1993; O'Connor et al., 1994; Ely, 1997). Given this, we can infer that the periods of high flow, for example the A.D. 1080s floods, may be represented in the stratigraphy of flood deposits at both Lower Confluence and Palisades. We suggest that, after the early Pueblo II farmsteads experienced flooding, late Pueblo II farmers were aware of big floods and built on higher ground.

At the scale of the North American Southwest, and within its major subdivisions, researchers have documented broad-scale shifts in Puebloan period settlement patterns through time. Both environmental (for example Cordell and Gumerman, 1989) and social/cultural factors (for example Adams, 1991; Peregrine, 2001) are emphasized in explaining and interpreting these shifts. At more localized scales, like the Grand Canyon area and more specifically the Colorado River corridor, researchers have investigated diachronic settlement patterning and proposed explanations and interpretations. Schwartz et al. (1980) noted a temporal trend at Unkar Delta where younger sites are located higher on the landscape, which they attributed to improved proximity to water and/or arable land. With respect to this interpretation, we note that the entire Unkar Delta landform, with the exception of its riverine margins, is located well above the highest (8500 cms) floods. Schwartz and colleagues' interpretation for the Unkar Delta landform, specifically, is compelling. But are other factors, for example, flooding, important in other parts of the river corridor?

At the sites we investigated, the limited availability of flat ground apparently played a role in the positioning of the site components of early Pueblo II farmsteads posing a greater risk from large floods. Early Pueblo II activity areas and middens are buried by flood, eolian, and

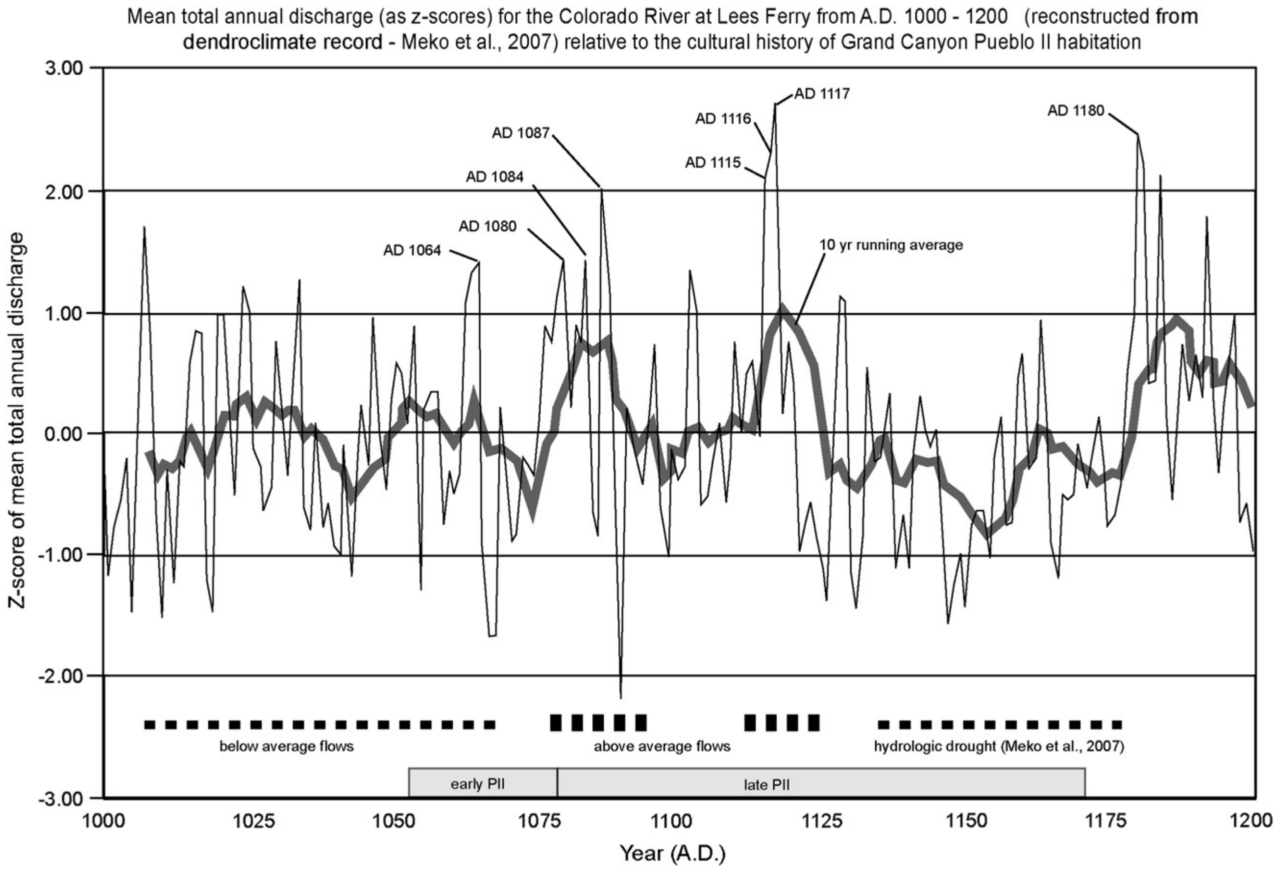


**Fig. 12.** Chart illustrating the z-scores of the total annual discharge at Lees Ferry for the AD 1000 to 1200 period (modified from Meko et al., 2007). Note the particularly high discharges of A.D .1064, 1080, 1084, and 1087 at the end of the early PII, and the high discharges of 1115, 1116, and 1117, during the late PII period. Also, note the late PII to early PIII hydrologic drought. See text for discussion.

colluvial deposits. Importantly, the early Pueblo II habitation features also contain Colorado River flood sediments. In contrast, the habitation features of Late Pueblo II aggregated hamlets are positioned away from the river and were not impacted by flood deposits, whereas the activity areas and trash middens positioned lower on the landscape are buried by flood sediments. Our interpretation is that early Pueblo II farmers settled in high-risk areas with respect to flooding and that through time, farmers along the river avoided flood risks by positioning habitation features on higher ground. We acknowledge that along the river corridor several other factors were likely germane to site location decision making, such as proximity to natural resources, presence of agricultural soils, or simply flat surfaces in the generally steep canyon terrain.

However, along the Colorado River corridor in Grand Canyon during the early Pueblo II period, the first permanent farmsteads were located in areas at higher risk for floods. We suggest that the farmers of this area did not fully appreciate the reoccurrence interval of large-magnitude floods that would impact their habitations. Later during the late Pueblo II period, along with increases in population and the development of aggregated settlements, we propose that perspectives had changed regarding where to locate habitations. Farmers eventually positioned hamlets on higher ground thus reducing impacts to habitation features by large floods.

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