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# Application of sedimentary-structure interpretation to geoarchaeological investigations in the Colorado River Corridor, Grand Canyon, Arizona, USA

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ABSTRACT

We present a detailed geoarchaeological study of landscape processes that affected prehistoric formation and modern preservation of archaeological sites in three areas of the Colorado River corridor in Grand Canyon, Arizona, USA. The methods used in this case study can be applied to any locality containing unaltered, non-pedogenic sediments and, thus, are particularly relevant to geoarchaeology in arid regions. Resolving the interaction of fluvial, aeolian, and local runoff processes in an arid-land river corridor is important because the archaeological record in arid lands tends to be concentrated along river corridors. This study uses sedimentary structures and particle-size distributions to interpret landscape processes; these methods are commonplace in sedimentology but prove also to be valuable, though less utilized, in geoarchaeology and geomorphology. In this bedrock canyon, the proportion of fluvial sediment generally decreases with distance away from the river as aeolian, slope-wash, colluvial, and debris-flow sediments become more dominant. We describe a new facies consisting of 'flood couplets' that include a lower, fine-grained fluvial component and an upper, coarser, unit that reflects subaerial reworking at the land surface between flood events. Grain-size distributions of strata that lack original sedimentary structures are useful within this river corridor to distinguish aeolian deposits from finer-grained fluvial deposits that pre-date the influence of the upstream Glen Canyon Dam on the Colorado River. Identification of past geomorphic settings is critical for understanding the history and preservation of archaeologically significant areas, and for determining the sensitivity of archaeological sites to dam operations. Most archaeological sites in the areas studied were formed on fluvial deposits, with aeolian deposition acting as an important preservation agent during the past millennium. Therefore, the absence of sediment-rich floods in this regulated river, which formerly deposited large fluvial sandbars from which aeolian sediment was derived, has substantially altered processes by which the prehistoric, inhabited landscape formed, and has also reduced the preservation potential of many significant cultural sites.

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## 1. Introduction

### *1.1. Effects of Glen Canyon Dam on the Colorado River Corridor, Grand Canyon*

The Colorado River corridor through Grand Canyon, Arizona, contains nearly 500 archaeological sites that collectively record several thousand years of prehistoric human occupation. Archaeological research and monitoring in Grand Canyon National Park focus increasingly on the potential effects of Glen Canyon Dam operations on the landscape in which these cultural sites are preserved (e.g., Hereford et al., 1993; Yeatts, 1996; Thompson and Potochnik, 2000). To assess the degree to which selected archaeological sites and the geomorphic surroundings are sensitive to dam operations, we combined techniques of sedimentology, geomorphology, and archaeology to investigate erosional, transport, and depositional processes that have influenced the landscape from prehistoric times through today. Particularly valuable in this work is the use of sedimentary structures, sometimes combined with grain-size analyses, to identify depositional facies. Such methods, commonly used by sedimentologists to infer depositional setting and to characterize flow strength, direction, and depth, are also valuable in

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geoarchaeological studies as a means of identifying processes that formed prehistoric, inhabited landscapes and that affect modern preservation of cultural sites.

Since the closure of Glen Canyon Dam in 1963, the natural hydrologic and sedimentary regimes along the Colorado River in the reach through Grand Canyon have changed significantly (e.g., Andrews, 1986; Webb et al., 1999; Topping et al., 2003; Hazel et al., 2006a). The dam has reduced the fluvial sediment supply at the upstream boundary of Grand Canyon National Park by ~95%. Regulation of river discharge by dam operations has important implications for storage and redistribution of sediment in the river corridor. In the absence of floods, sediment cannot be deposited at the higher elevations that received sediment regularly before dam closure. Riparian vegetation has colonized areas at lower elevation than in pre-dam time when annual floods removed young vegetation (Turner and Karpiscak, 1980). These factors have caused a system-wide decrease in the size and number of subaerial sand deposits over the past four decades, punctuated by episodic aggradation during exceptional high-flow intervals in 1983–1984, 1996, and 2004, and by sediment input from occasional tributary floods (Beus et al., 1985; Schmidt and Graf, 1987; Kearsley et al., 1994; Hazel et al., 1999; Schmidt et al., 2004).

Post-dam alterations in the flow and sediment load of the Colorado River may affect the preservation potential of archaeological sites within the river corridor, even above the annual flood zone (Hereford et al., 1993; Yeatts, 1996; Thompson and Potochnik, 2000). The annual flood zone is defined here by the mean annual pre-dam flood, 2410 $m^3/s$ (85,000 $ft^3/s$); the 'pre-dam flood limit', the highest elevation at which fluvial deposits are locally present, was roughly equivalent to a rare, major event of 8500 $m^3/s$ (300,000 $ft^3/s$; Topping et al., 2003). Many cultural sites located in or on sediment deposits are actively eroding because of aeolian deflation and incision by gullies (Leap et al., 2000; Neal et al., 2000; Fairley, 2003). Hereford et al. (1993) suggested that gully incision of sediment deposits, and the base level to which small drainage systems respond, were linked to dam operations; they hypothesized that pronounced arroyo incision was caused by lowering of the effective base level at the mouths of ephemeral drainages to meet the new, post-dam elevation of high-flow sediment deposition, ~3–4 m below the lowest pre-dam alluvial terraces. Thompson and Potochnik (2000) modified this hypothesis to include restorative effects of fluvial deposition in the mouths of gullies and arroyos, which raises effective base level, and new aeolian deposition on pre-dam alluvial deposits as wind reworks flood-deposited sand. Thompson and Potochnik (2000) concluded that sediment deprivation and lack of floods, caused by dam operations, reduce the potential for new deposition that could heal gullies formed by precipitation runoff.

To understand how the presence and operation of Glen Canyon Dam may influence the stability of archaeological features downstream, site-specific stratigraphic and geomorphic knowledge is essential. Establishing the local importance of fluvial, aeolian, and other processes in pre-dam and post-dam time is an important prerequisite for accurate assessments of dam effects. Detailed investigations of the sedimentary record at three locations along the Colorado River corridor in Grand Canyon were initiated to determine the relative importance of various geomorphic processes in nearby archaeologically significant areas, information that can then be used to evaluate site sensitivity to dam operations. Management applications of this study were addressed in detail by Draut and Rubin (2007); here, we present this work as a case study in geoarchaeology within the river corridor of an arid-land bedrock canyon and discuss the applicability of the sedimentology methods used here to other systems.

### *1.2. Previous work: sedimentary structures and Grand Canyon geoarchaeology*

Fairley et al. (1994) completed the first comprehensive survey of archaeological sites along the Colorado River corridor in Grand Canyon, providing baseline data for defining the depositional context of many archaeological sites. Subsequent monitoring summaries by the National Park Service (NPS) document geomorphic observations related to archaeological-site location, condition, and preservation (e.g., Leap et al., 2003). Geomorphic mapping by Hereford (1993) and by Hereford et al. (1993, 1996) in an area known as the Palisades generated detailed interpretations of the surficial geology and radiocarbon dates that complement this study; the Palisades was one location used by Hereford et al. (1993) and Thompson and Potochnik (2000) to formulate the base-level hypotheses discussed above. Grams and Schmidt (1999) used historical photographs of the Palisades area to document reduction in the extent of surficial sand deposits since 1890. High-resolution mapping by Yeatts (1996) and Hazel et al. (2000) demonstrated net aggradation of sand deposits at Palisades as a result of a 1996 experimental flood released from Glen Canyon Dam, inferred aeolian migration of sediment to higher elevation over the following year, and identified those consequences of the 1996 flood as potentially beneficial for archaeological-site preservation.

Many studies have demonstrated the utility of sedimentary structures for characterizing depositional environments and paleo-flow conditions, notably Walker (1963), Stokes (1968), Harms et al. (1975), Hunter (1977a,b), McKee (1979), Rubin and Hunter (1982, 1987), Rubin (1987), and Southard and Boguchwal (1990). Various sedimentary environments associated with archaeological sites have been discussed in an overview by Stein and Farrand (1985), within which Gladfelter (1985) addressed sediment storage and chronostratigraphy of cultural sites in alluvial settings and Hassan (1985) reviewed arid-land fluvial geomorphology in a geoarchaeological context. Within Grand Canyon, McKee (1938) first presented facies descriptions of Colorado River flood strata. Rubin et al. (1990) and Schmidt (1990) used stratigraphic exposures in river-level sand bars to describe the evolution of separation and reattachment bars in zones of flow recirculation in eddies. Rubin et al. (1994) used sedimentary structures in flood deposits from the early 1980s to estimate rates of deposition and to evaluate the potential effect of various dam-controlled flow regimes on erosion and accumulation of sediment on sandbars, concepts later modeled by Wiele and Franseen (2001). Grain-size trends, in particular upward coarsening, within Grand Canyon flood deposits were shown to indicate a limitation of sediment supply in pre-dam and post-dam floods by Rubin et al. (1998), Topping et al. (2000a,b), and Rubin and Topping (2001). To complement the present study, Draut and Rubin (2005, 2006) measured wind, aeolian sediment-transport, and precipitation patterns in the river corridor over more than two years.

### *1.3. Study sites*

This study focuses on the Palisades, Lower Comanche, and Arroyo Grande areas of Grand Canyon (Fig. 1); by law, specific details of archaeological-site locations cannot be disclosed. These reaches of the river corridor are characterized by alluvial terraces that represent multiple episodes of floodplain aggradation within the pool-and-drop bedrock canyon of the Colorado River. The 'pools' are reaches of the channel up to several km long, bounded at each end by constrictions formed by rockfalls and debris fans at the mouths of side canyons. This environment is broadly similar to the Class A1 (high-energy stream, non-cohesive sediment) floodplain classification described by Nanson and Croke (1992), in which isolated deposits of alluvial sand, silt, and clay overlie poorly sorted gravel and boulders derived from local bedrock. The cross-channel distance between exposed bedrock walls at each study location is on the order of hundreds of meters. The highest alluvial terraces at each site contain deposits left by pre-dam flood events of over 5660 $m^3/s$ (200,000 $ft^3/s$; Topping et al., 2003), much higher than any post-dam floods have been. The terraces at all three sites contain arroyo networks (*sensu* Patton and Schumm, 1981) up to several meters deep and wide resulting from incision by local