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Alluvial fan surfaces and an age-related stability for cultural resource preservation: Nevada Test and Training Range, Nellis Air Force Base, Nevada, USA

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ABSTRACT

Surface geomorphology studies, measurements of cosmogenic ^{10}Be concentrations, and satellite imagery analysis are employed to construct a surface stability model for the preservation of archeological features in Stonewall Flat, Nevada, USA. Primary fan processes of incised channel floods and sheet floods construct alluvial fans and secondary processes of sheetwash, eolian erosion and deposition, bioturbation, and soil development subsequently modify fan surfaces. Each process leaves distinctive surface features, but collectively darkens and smooth's the surface with age. Concentrations of cosmogenic ^{10}Be in surface and subsurface samples for fans with recently active surfaces have effectively zero ages, whereas concentrations for fans with mature pavements have ages of 35 to 40 thousand years (ka). Surface age data from other Stonewall Flat studies indicate that fans in transition from primary process to secondary process domination are younger than 13 ka, and that older fan surfaces are dominated by secondary processes. Image analysis demonstrates a correlation between fan surface darkening and age, and permits age estimations for undated surfaces. Results indicate that surfaces dominated by primary processes are younger than 3 ka and unstable for the preservation of older sites; surfaces dominated by secondary processes are older than 10 ka and stable for site preservation.

1. Introduction

Early inhabitants of the Great Basin manifested a mobile subsistence culture that inhabited sites for varying amounts of time, but did not establish permanent occupations. During the late Pleistocene and early Holocene time period these inhabitants exploited pluvial lake and wetland margins as resource-rich environments (Willig, 1989; Grayson, 1993; Madsen, 2007). As such, archeologists identified ancient shoreline deposits surrounding modern dry lake playas as important locations for some of the earliest habitation sites in the southern Great Basin (Campbell and Campbell, 1937; 1940; Tuohy, 1968). Lithic studies suggest that these late Pleistocene/early Holocene habitation patterns were characterized by short occupational episodes that shifted to longer occupational episodes later in the Holocene (Beck and Jones, 1997; Duke and Young, 2007). This usage pattern is confirmed by comparing ^{14}C-dated cultural sites with the post-Younger Dryas shoreline of ancient Lake Lahontan (Adams et al., 2008). The early-to-mid Holocene climate shift to more arid conditions affected the composition and geographic distribution of floral and faunal assemblages in the valleys of the southern Great Basin (Spaulding, 1985; 1991; Thompson et al, 1999). This change in the distribution of resources resulted in more broadly distributed site occupation and an increase in sites located at higher elevations within these valleys (Kelly and Todd, 1988; Kolvet et al, 2000).

As the late Pleistocene and early Holocene lakes disappeared with the onset of more arid climatic conditions, many abandoned shoreline deposits became incorporated into the alluvial fans surrounding the modern playas (Mifflin and Wheat, 1979; Grayson, 1993). Since surface stability is an important factor in the preservation of contextual integrity of older cultural sites, research on the U.S. Air Force's Nevada Test and Training Range (NTTR; Fig. 1) has strived to identify those portions of the surrounding alluvial fans that are sufficiently stable to preserve older sites (Dickerson, 2006; 2009; 2014). These surface stability studies have assisted archeologists on the NTTR (Cook et al., 2009; Lindemuth and Somers, 2011).

Alluvial fan formation is dominated by hydraulic and gravity-driven processes. The primary sedimentary processes that contribute to alluvial fan sedimentation include rockfall, rock slides, rock avalanches, debris flows, incised channel floods, and sheet floods. These processes are triggered primarily by intense precipitation events, although rockfalls, rock slides, and rock avalanches also are triggered by earthquakes.

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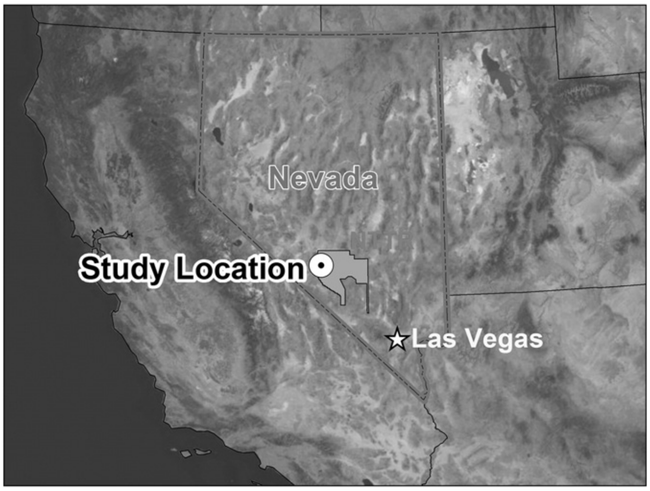

Fig. 1. Stonewall Flat is located in the northwestern part of the Nevada Test and Training Range (NTTR) in southwestern Nevada. The NTTR is under the administrative control of Nellis Air Force Base located in Las Vegas, Nevada.

Each process represents an infrequent, high energy, short duration event that transports and deposits poorly sorted sediment potentially ranging from blocks to sand (Blair and McPherson, 1994). The rare catastrophic flood event dominates sediment transport with high velocity/high volume flow regimes that result in exceptionally high suspended load (Baker, 1977; Powell, 2009). Individual fans often are dominated by a particular primary process that is uniquely suited to the geology of that particular fan (Blair and McPherson, 2009; Blair, 1999a; 1999b; 1999c; 1999d). Secondary processes modify the fan deposits formed by the primary processes, and include overland sheet flow, eolian erosion and deposition, bioturbation, soil development, and weathering. Secondary processes typically consist of more frequent, lower energy events that dominate fan surfaces everywhere that primary processes are not focused, such as in active channels (Blair, 1987).

The primary process of incised channel flooding remains confined to active washes on alluvial fans. During rising flow bed erosion commences, with sediment erosion and transport accompanying peak flow. Falling flow initiates deposition, with increasingly finer sediment deposited with decreasing flow (Blair, 1987; 1999a; 2000). Drapes of finer sediment form overbank deposits when channel floods broach their banks. Lateral repositioning of channels accompanied by channel incision results in new active channels and the formation of abandoned channels and terraces (Blair, 1999b). The second primary process of sheet flooding entails short term, high energy, high flow events where an incised channel flood becomes unconfined when it broaches the banks of the channel without appreciable loss of velocity or volume. Large sheet floods are catastrophic events that deposit tremendous volumes of sediment as distinct horizontally bedded couplets of alternating coarse, imbricated, clast-supported sediment and finer, laminated sediment (Blair, 1987; 2000). The upper surfaces of such deposits typically manifest cobble-rich and gravelly patches surrounded by finer sandy deposits caused by temporary critical flow regimes that form, migrate, and dissipate (Blair and McPherson, 1994; Blair, 1987).

The most common secondary process modifying fan surfaces is sheet flow. Sheet flow occurs far more often than any of the primary constructive processes discussed above, winnowing silt and sand out of surface deposits and leaving a coarser lag of gravel on the surface. Silt and sand is thus transported towards the distal margins of the fan (Blair and McPherson, 2009). Eolian erosion can also winnow out the finest fraction from mixed fine and coarse surface sediment (Al-Farraj and Harvey, 2000), but it can also deposit sheet sands, sand ramps, dunes, and coppice deposits (Blair and McPherson, 1992). Microbiotic soil crusts grow on the sandier portions of a fan surface, trapping moisture and fixing nitrogen to the soil (West, 1990). Bioturbation via plant root growth, burrowing insects, and burrowing animals disrupts primary bedding and homogenize at-surface sediment. Plants also host small coppice deposits and attract small burrowing animals and insects which act to further mix the sediment to a greater extent than the plant roots could have accomplished alone (Blair and McPherson, 2009).

Recent research has shown that many desert pavements and their subjacent Av soil horizons are primarily accretionary features. Sheetwash can be an important process for concentrating gravel clasts into topographically low areas on desert surfaces, and may comprise the first stage in desert pavement and Av horizon development in certain environments (Williams and Zimbelman, 1994). Wind-blown dust composed of clay, carbonate minerals, salts, and silt is deposited on gravel-rich desert soil and becomes concentrated by the vertical movement of infiltrating rain water and snow melt along pores and bedding planes (Anderson, et al., 2002; McFadden, et al, 1987; McFadden et al, 1998; Valentine and Harrington, 2006; Wells et al, 1985). Rock varnish is a slowly accreting Mn- and Fe-rich dark coating on subaerially exposed rock surfaces in arid to semiarid deserts (Dorn and Oberlander, 1982; Liu and Broecker, 2000). As such, rock varnish has a sedimentary origin that exhibits a layered microstratigraphy under microscopic examination (Liu and Dorn, 1996). In the Great Basin, Mn-poor layers in varnish were formed during the dry climatic conditions, and Mn-rich layers formed during wetter climatic conditions (Liu and Dorn, 1996; Liu et al., 2000; Broecker and Liu, 2001).

Earlier work on the NTTR recognized that specific surface deposits and features characterize active channels, abandoned channels, and terraces of various heights and ages above the active channels. The presence of historical sites and artifacts of various ages on some of these terrace surfaces helped establish a qualitative age range since the last major disruption of some of these surface deposits (Cook et al., 2009). Subsequent work on the NTTR strived to expand the age range of surfaces under study, to quantify surfaces ages, and to establish criteria for recognizing the relative age and stability of surfaces where no quantified age data were available (Dickerson et al., 2013; Dickerson, 2014). The current study builds on this earlier body of work by using soil profile data, surface geomorphological data, quantitative age data, and satellite imagery analysis to create a predictive model for assessing the relative surface stability of a broader region for which detailed geomorphic and quantitative age data are sparse to nonexistent.

Our study is predicated on the premise that alluvial fan channels are dominated by higher energy primary processes, that the lower terraces adjacent to active channels are transitional from higher energy primary processes to lower energy secondary processes, and that alluvial fan surfaces higher above and farther away from active channels are dominated by lower energy secondary processes. This progression from active fan surfaces to less active fan surfaces is accompanied by increasing surface age and stability wherein surfaces darken with age as desert pavement and coatings of rock varnish develop. Thus, the categories proposed for fan surface stability are active surfaces, transitional surfaces, and stable surfaces.

The area chosen for this study is Stonewall Flat, located in the northwest part of the NTTR in southern Nevada, USA (Fig. 2). It is bounded by Stonewall Mountain to the south, the Cactus Range to the east, the Goldfield Hills to the north and northwest, and the Cuprite Hills to the west (Fig. 2). Stonewall Flat is located in the Basin and Range province in southwestern Nevada, USA, a region characterized by internally draining basins isolated from one another by mountains. The valleys typically contain a dry-lake playa surrounded by alluvial fans and bajadas composed of sediment originating from the surrounding mountains. All drainages discharging into Stonewall Flat are ephemeral streams that flow only during and after storms with significant precipitation. Stonewall Flat is surrounded by mountains composed primarily of Oligocene and Miocene volcanic rocks with local exposures of Late Proterozoic and Cambrian sedimentary rocks cropping out beneath the volcanic sequence (Ekren et al, 1971).