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Cosmogenic ^{3}He age estimates of Plio-Pleistocene alluvial-fan surfaces in the Lower Colorado River Corridor, Arizona, USA

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ABSTRACT

Plio-Pleistocene deposits of the Lower Colorado River (LCR) and tributary alluvial fans emanating from the Black Mountains near Golden Shores, Arizona record six cycles of Late Cenozoic aggradation and incision of the LCR and its adjacent alluvial fans. Cosmogenic ^{3}He (^3He_c) ages of basalt boulders on fan terraces yield age ranges of: 3.3–2.2 Ma, 2.2–1.1 Ma, 1.1 Ma to 110 ka, <350 ka, <150 ka, and <63 ka. T1 and Q1 fans are especially significant, because they overlie Bullhead Alluvium, i.e. the first alluvial deposit of the LCR since its inception ca. 4.2 Ma. ^3He_c data suggest that the LCR began downcutting into the Bullhead Alluvium as early as 3.3 Ma and as late as 2.2 Ma. Younger Q2a to Q4 fans very broadly correlate in number and age with alluvial terraces elsewhere in the southwestern USA. Large uncertainties in ^3He_c ages preclude a temporal link between the genesis of the Black Mountain fans and specific climate transitions. Fan-terrace morphology and the absence of significant Plio-Quaternary faulting in the area, however, indicate regional, episodic increases in sediment supply, and that climate change has possibly played a role in Late Cenozoic piedmont and valley-floor aggradation in the LCR valley.

Introduction

Fluvial systems in the southwestern USA often record multiple episodes of Plio-Quaternary aggradation and incision (Haynes, 1968; Bull, 1991). These events are recorded as fluvial deposits (emplaced during aggradation) and their bounding geomorphic surfaces (abandoned during incision) preserved along valley floors and on piedmonts. Studies of cycles of alluvial aggradation and incision in the southwestern USA go back to the earliest days of geomorphology (e.g. Bryan, 1922), but Haynes (1968) was the first to suggest that cycles of aggradation and incision are regionally correlative and provide geochronologic evidence for such a correlation in the Late Quaternary portion of the record. On piedmonts, cycles of alluvial aggradation and incision have been linked to climatic changes (Melton, 1965; Royse and Barsch, 1971; Christensen and Purcell, 1985; Bull, 1996; Reheis et al., 1996), tectonic uplift of the adjacent mountain range (Hooke, 1972; Rockwell et al., 1985), and/or the internal dynamics of the fluvial system, including upstream drainage reorganization (Ritter, 1972) and coupled oscillations of the channel's bed and banks (Schumm and Parker, 1973). Knox (1983), working in Holocene alluvial valleys in Wisconsin, developed the biogeomorphic response model that became the basis for Bull's (1991) suggestion that Plio-Quaternary terraces in the southwestern USA are climatically generated. In Knox's model, changes in hillslope vegetation cover during humid-to-arid transitions increase the sediment supply to piedmonts and valley-floor channels adjusted to a lower sediment supply, thereby triggering aggradation. After the transition, i.e. when the climate has stabilized in a drier state, sediment supply declines from its peak, causing valley incision and abandonment of a fill terrace along piedmonts and valley floors. Adequate age control exists for only a few locales in the southwestern USA, but in places where strong age constraints do exist, Late Quaternary alluvial terraces have ages of ca. 320 ka, 120 ka, 70–40 ka, and the Pleistocene–Holocene transition (e.g. see Anders et al., 2005, for a full suite of ages from eastern Grand Canyon). These ages correlate with glacial-to-interglacial (i.e. humid-to-arid) transitions recognized in regional climate-change proxies (e.g. Anders et al., 2005). In the Lower Colorado River (LCR), additional mechanisms could potentially trigger cycles of alluvial aggradation and incision, including eustatic sea-level changes (Merritts et al., 1994) and catastrophic floods originating in western Grand Canyon (Fenton et al., 2004, 2006).

Several methods may be used for distinguishing among these potential triggering mechanisms. First, absolute stratigraphic and deposit ages are critically important for establishing correlations between chronologies of aggradation–incision cycles and of potential forcing factors, such as time-series data for paleoclimatic proxies. Second, stratigraphic and geomorphic mapping can be used to establish a regional correlation of deposits. Third, the analysis of terrace geometries, including their dips and cross-cutting relationships with other units, enable a sequence of events to be reconstructed and may provide evidence that one mechanism may be favored over another. For example, parallel fan terraces

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that grade to distinct terraces of the valley-floor channel suggest a significant base-level control by the valley-floor channel on piedmont aggradation and incision (Fig. 1; e.g. DeLong et al., 2008). Figure 1A, for example, contrasts the fan terrace geometries within a coupled valley-floor-alluvial-fan system that could be expected from: (1) episodic increases in sediment supply from local drainage basins only, triggering steepening and aggradation of the fan without significant changes to the valley-floor channel that controls the base level of the fan (shown in left diagram); (2) episodic increases in sediment supply from the Upper Colorado River and Grand Canyon only, triggering increases in the bed elevation of the valley floor channel, causing the fan to aggrade in concert with the valley floor but without steepening of the fan terraces (middle diagram); and (3) episodic increases in sediment throughout the region, triggering a combination of the responses in the previous two scenarios LCR (right diagram). Tectonic uplift of the Black Mountains is not considered in Figure 1A because geologic mapping reveals only very minor (i.e. <10 m offset) active folding/faulting in the area during Plio-Quaternary time (Howard et al., 2000).

Here we provide geomorphic descriptions, surficial geologic maps and topographic analysis of alluvial fans in the Lower Colorado River corridor, adjacent to Black Mountains near the California–Arizona (CA-AZ) border at Golden Shores, Arizona (Fig. 2). To that we add cosmogenic ^{3}He ($^{3}He_{c}$) surface-exposure age estimates for eight separate fan surfaces. The Lower Colorado River and its tributary channels from the Black Mountains experienced at least six synchronous aggradational events in the past 5.3 Ma (House et al., 2008; Lundstrom et al., 2008; Malmon et al., 2011; Matmon et al., 2012). Deposition of the Bullhead Alluvium (House et al., 2005, 2008) is one of the most significant aggradational periods, during which the LCR aggraded at least 200 m above the modern river level. Following each aggradation, the LCR incised to within 40 m of its modern level (Fig. 1B). As such, the Late Cenozoic history of the LCR is characterized by episodic backfilling and entrenchment. Slope gradients of well-preserved terrace treads emanating from the Black Mountains indicate that the alluvial fans of the Black Mountains were steepening at the same time the LCR was aggrading, i.e. slope gradients are significantly steeper on the older deposit (T1, which has a gradient of 0.024) relative to the younger units, which have gradients of 0.021). As such, terrace geometries suggest regional aggradation rather than increases in sediment supply affecting only the Black Mountains or only the LCR.

Geological setting

An alluvial-fan terrace is created when a channel erodes into its deposits, creating an entrenched channel and an abandoned terrace. Successive episodes of aggradation and entrenchment are recorded in many alluvial fans of the Southwest, preserving a series of terraces that rise like a flight of stairs from the modern channel. Our study site is located in Mohave Valley, between the Lower Colorado River on the west and the Black Mountains on the east, near Golden Shores, AZ (Figs. 2 and 3). The Lower Colorado River is defined as the reach of the Colorado River that extends from the western edge of the Colorado Plateau (Grand Canyon) to the Gulf of California. The Black Mountains are a north–south trending mountain range on the CA-AZ border, between the town of Needles and Lake Mead, created during Basin and Range extension between 25 and 10 Ma (Spencer and Reynolds, 1989). The southern end of this metamorphic core complex consists of early to middle Miocene volcanic rocks capped with mesa-forming basalt dated at 15.8 Ma (K–Ar; Gray et al., 1990), though other basalt flows in the Black Mountains have reported K–Ar eruption ages of

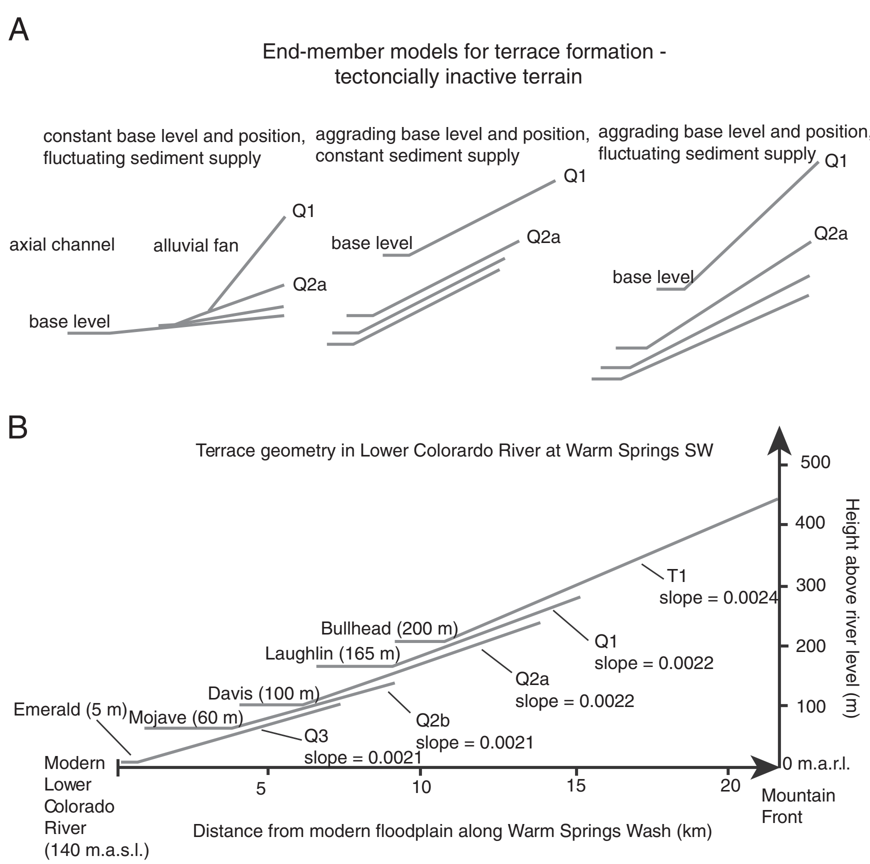

Figure 1. Schematic diagrams illustrating how fan-terrace geometry in a coupled valley-floor/alluvial-fan system can distinguish among regional and local triggering mechanisms. (A) Comparison of terrace geometries resulting from episodic increases in local sediment supply only (left), episodic increases in upstream sediment supply only (middle), and episodic increases in regional sediment supply (right). (B) Terrace geometry of the Black Mountain alluvial fans on the east side of the Lower Colorado River at Warm Springs, AZ. Older fan terraces are steeper and each grades to a specific terrace deposit of the LCR.