Quaternary Research 73 (2010) 425–438

Contents lists available at ScienceDirect

Quaternary Research

journal homepage: www.elsevier.com/locate/yqres

Timing and distribution of alluvial fan sedimentation in response to strengthening of late Holocene ENSO variability in the Sonoran Desert, southwestern Arizona, USA

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ARTICLE INFO

Article history:
Received 5 August 2009
Available online 4 March 2010

Keywords:
Late Holocene
Alluvial fan
Desert soils
Sonoran Desert
Geomorphology
Paleoclimatology
ENSO variability

ABSTRACT

The integration of geomorphic mapping, soil stratigraphy, and radiocarbon dating of alluvial deposits offers insight to the timing, magnitude, and paleoclimatic context of Holocene fan sedimentation near Yuma, Arizona. Mapping of 3400 km^2 indicates about 10% of the area aggraded in the late Holocene and formed regionally extensive alluvial fan and alluvial plain cut-and-fill terraces. Fan deposits have weakly developed gravelly soils and yielded a date of 3200–2950 cal yr BP from carbonized wood. Alluvial plain deposits have weakly developed buried sandy soils and provided a date of 2460–2300 cal yr BP from a terrestrial snail shell. Precipitation records were analyzed to form historical analogues to the late Holocene aggradation and to consider the role of climatic variability and extreme hydrologic events as drivers of the sedimentation. The historical precipitation record indicates numerous above-average events correlated to the Southern Oscillation Index (SOI) in the region, but lacks any significant reactivation of alluvial fan surfaces. The timing of aggradation from 3200 to 2300 cal yr BP correlates well with other paleoclimatic proxy records in the southwestern U.S. and eastern Pacific region, which indicate an intensification of the El Niño-Southern Oscillation (ENSO) climatic pattern and rapid climate change during this period.

Introduction

Quantifying the timing and magnitude of past alluvial sedimentation in the arid southwestern U.S. offers insight to the hydrologic variability of the region and provides data for paleoclimatic models. Most studies with a significant component of surficial geomorphic mapping for paleoclimatic inferences are performed over areas of tens to hundreds of km^2. Many of these studies correlate similar-aged episodes of alluvial aggradation that span several drainage basins to infer the physical linkages between climatic forcing and system response over a much broader region (e.g., McFadden et al., 1989). The majority of these types of studies have focused on dating Pleistocene–Holocene transition alluvial deposits to understand climate change (Wells et al., 1987; Bull, 1991; Waters and Haynes, 2001; McDonald et al., 2003). By comparison, the application of alluvial fans as paleoclimatic proxy evidence to determine the frequency and magnitude of past changes and activity of Holocene global climatic circulation patterns has been underutilized in most studies (Donders et al., 2008). Most geologic-based studies in the western U.S. that aim to understand the connection between geomorphic change and Holocene climate variability and moisture sources have been focused on lake-level and playa lake inundation records (e.g., Enzel et al., 1989; Scuderi et al., 2010). Yet, the timing and response of alluvial fan systems to an increase in frequency and intensity of the El Niño Southern Oscillation (ENSO) climatic pattern at the beginning of the late Holocene (Liu et al., 2000) are not well-documented in the southwestern U.S.

Widespread alluvial fan deposits of late Holocene age have been documented in the Sonoran and Mojave Deserts. In particular, regional alluvial fan deposits mapped as unit Q3c by Bull (1991) were generally estimated to be of late Holocene age based on soil-geomorphic characteristics in the lower Colorado River region of southern Arizona. Most of these fan deposits grade to large stream systems that contain an extensive late Holocene alluvial record (Waters, 2008). Similar geomorphic surfaces and deposits are also present in the Mojave Desert indicating significant periods of Holocene fan aggradation in the form of widespread fill terraces and coalescing distal fan lobes (McDonald et al., 2003; Mahan et al., 2007; Miller et al., 2010). These chronologies also show that alluvial sediments aggraded in the late Holocene at scales not represented in the historical record.

This study uses small- and large-scale geomorphic mapping, field and laboratory characterization of soils, as well as ^{14}C dating of alluvial deposits to show the timing and distribution of sedimentation in southwestern Arizona that coincides with a period of greater precipitation in the region. The goals of this paper are three-fold: (1) to show soil-geomorphic supporting evidence and ^{14}C-based age constraints for the previously undated episode of extensive alluvial fan aggradation in southwestern Arizona; (2) to identify the climatic causes for this aggradation by reviewing historical climatic records to

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doi:10.1016/j.yqres.2010.01.004

develop modern analogues to the late Holocene sedimentation; and (3) to demonstrate how the late Holocene aggradation near Yuma correlates well with other geomorphic and stratigraphic records that are thought to be associated with intensified ENSO cycles.

Study area

Geomorphic mapping and soil stratigraphic investigations were performed on the U.S. Army Yuma Proving Ground (YPG) north of Yuma in southwestern Arizona (Fig. 1). The study area is within the western Sonoran Desert having an arid climate with a mean annual precipitation measured at YPG headquarters of 93 mm (32°59′N, 114°23′W; elev. 97 m; period of record AD 1958–2007). The region has many physiographic features common to the southern Basin and Range and lower Colorado River regions, which has minimal neotectonic activity. The mountain ranges are of moderate to low relief and composed mostly of Cretaceous- and Tertiary-age granitic and volcanic rocks, and lesser sedimentary rocks (Richard et al., 2000). The mountains ranges separate broad and low-gradient and incised alluvial slopes or piedmonts that have graded to different base levels of the ancestral positions of the Colorado and Gila Rivers (e.g., Wilshire and Reneau, 1992). The piedmont in the study area is dominated by a sequence of middle to late Pleistocene alluvial fans that exhibit well-developed and varnished desert pavement surfaces, with less extensive inset Holocene alluvial fan and alluvial-plain terraces and active washes (Lashlee et al., 2001; Nichols et al., 2006) (Fig. 1).

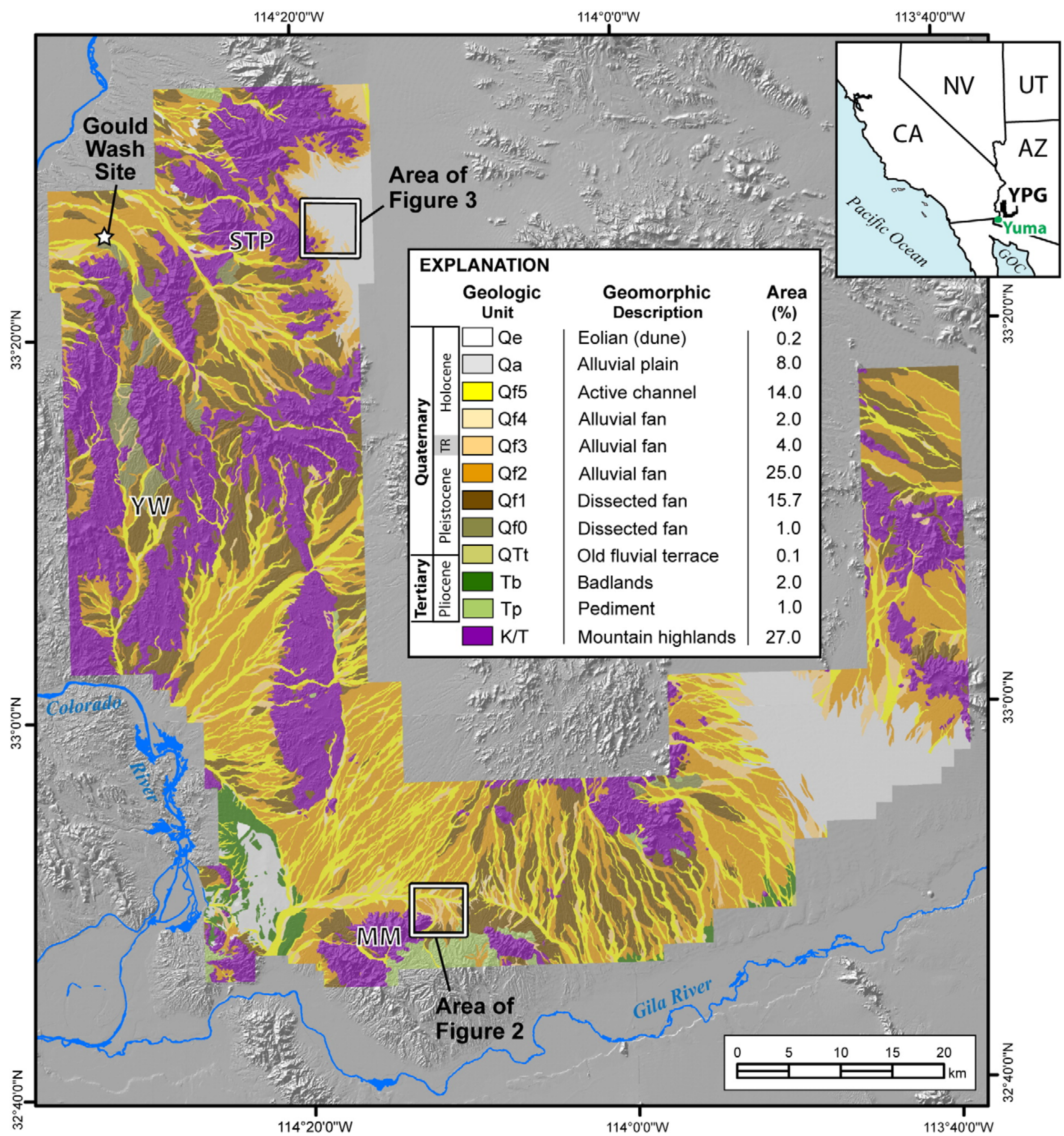

Figure 1. Geomorphic map of landforms mapped at scales between 1:24,000 and 1:50,000 within YPG. Topographic data are based on U.S. Geological Survey 10 m national elevation data. The drainages of the Colorado and Gila Rivers are shown in blue. The white boxes indicate the locations of the Muggins Mountains and South Trigo Peak study sites on Figures 2 and 3, respectively, and the star denotes the location of the Gould Wash study site. STP, South Trigo Peak; MM, Muggins Mountains; YW, Yuma Wash; TR, Pleistocene–Holocene transition; GOC, Gulf of California.