Continental Shelf Research 128 (2016) 1–9

Contents lists available at ScienceDirect

Continental Shelf Research

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

Fuerte River floods, an overlooked source of terrigenous sediment to the Gulf of California

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ARTICLE INFO

Key words:
Gulf of California
Fuerte River
Flood events
Flood deposit
Laminated sediment

ABSTRACT

Sediments deposited on the southeastern continental shelf of the Gulf of California, near the Fuerte River mouth, have been investigated using sediment XRF elemental composition, magnetic parameter and radiogenic element activities, and imply lithogenic elements as a promising proxy for terrigenous input and river discharge. Clastic mud beds are observed in the sediment core DIPALV-C33. These layers are massively bedded and characterized by coarser terrigenous sediment than typically observed in the Gulf of California. Based on this distinct lithology observed recurrently in the Fuerte River mouth region, we suggest these beds form during flooding events of the river. Comparing our results with instrumental data, we associate these unusual beds with Hurricane Lidia in October 1981 and a strong winter storm in January 1944. Elemental ratios Zr/Rb and K/Ti in the sediment core are strongly correlated with the lithologic changes, supporting their use as flood event proxies. Finally, we show that the three events observed account for 15% of the cumulative sediment deposited in DIPALV-C33 locations during the last two centuries, suggesting that in addition of seasonal eolian supply, floods events may contribute significantly to terrigenous delivery to the Gulf of California.

1. Introduction

Fluvial load, generated by weathering and erosion of bedrock and soils, and controlled by precipitation, temperature and wind intensity, contributes to ~95% of sediment delivery to the world's oceans (Milliman and Meade, 1983; Milliman and Syvitski, 1992; Syvitski, 2003). During the last several decades, climate change and human activity have altered this fluvial sediment flux from land toward ocean basin (e.g. Dearing and Jones, 2003; Bobrovitskaya et al., 2003; Thodsen et al., 2008). In particular, the damming of the world's largest rivers is thought to be responsible for the decrease of sediment load delivery (Walling and Fang, 2003; Walling, 2005). This is the case for the Colorado River, with sediment load rarely reaching the Gulf of California.

Like the Colorado River, the semiarid Sonora, Matape, Yaqui, Mayo, and Fuerte Rivers enter the Gulf of California after originating in the mountains of the Sierra Madre Occidental and flowing through the Sonora Desert (Van Andel, 1964; Baumgartner et al., 1991; Hudson et al., 2005). The contribution of these rivers to the sediment flux load to the Gulf is poorly known. However based on no change observed in sedimentation rate in the central Gulf before and after the damming of the rivers, it has been assumed that these rivers contribute very little to sediment delivery to the Gulf, with eolian transport the main sources of terrigenous sediment supply to the Gulf (Baba et al., 1991b; Baumgartner et al., 1991; Thunell, 1998; Dean, 2004).

The model of sediment flux from land toward the Gulf of California presented by these studies does not take into account effects of discrete climatic events such as winter storms and hurricanes, widely common in this region. In response to high precipitation events of short duration (a few hours to a few days), these mountain rivers can be dominated by exceptional flood events surpassing their seasonal high discharge, thus dominating their annual erosion and sediment supply to the shelf (Milliman and Syvitski, 1992; Mulder and Syvitski, 1995). Known as "arroyos" floods (Nava-Sanchez et al., 1999; Warrick and Milliman, 2003; Warrick et al., 2008), these events could strongly affect sediment delivery to the Gulf. Warrick and Milliman (2003) illustrated their potential effects in a study on a southern California semiarid river where flood events account for up to 75% of the cumulative sediment load discharged over the past several decades. Despite the importance of the flood events in contributing to the overall sediment load in this region, no study has yet identified flood-related deposits on marine sediment from the Gulf of California, and thus these flood events have

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http://dx.doi.org/10.1016/j.csr.2016.09.006
Received 7 December 2015; Received in revised form 14 September 2016; Accepted 16 September 2016
Available online 20 September 2016
0278-4343/

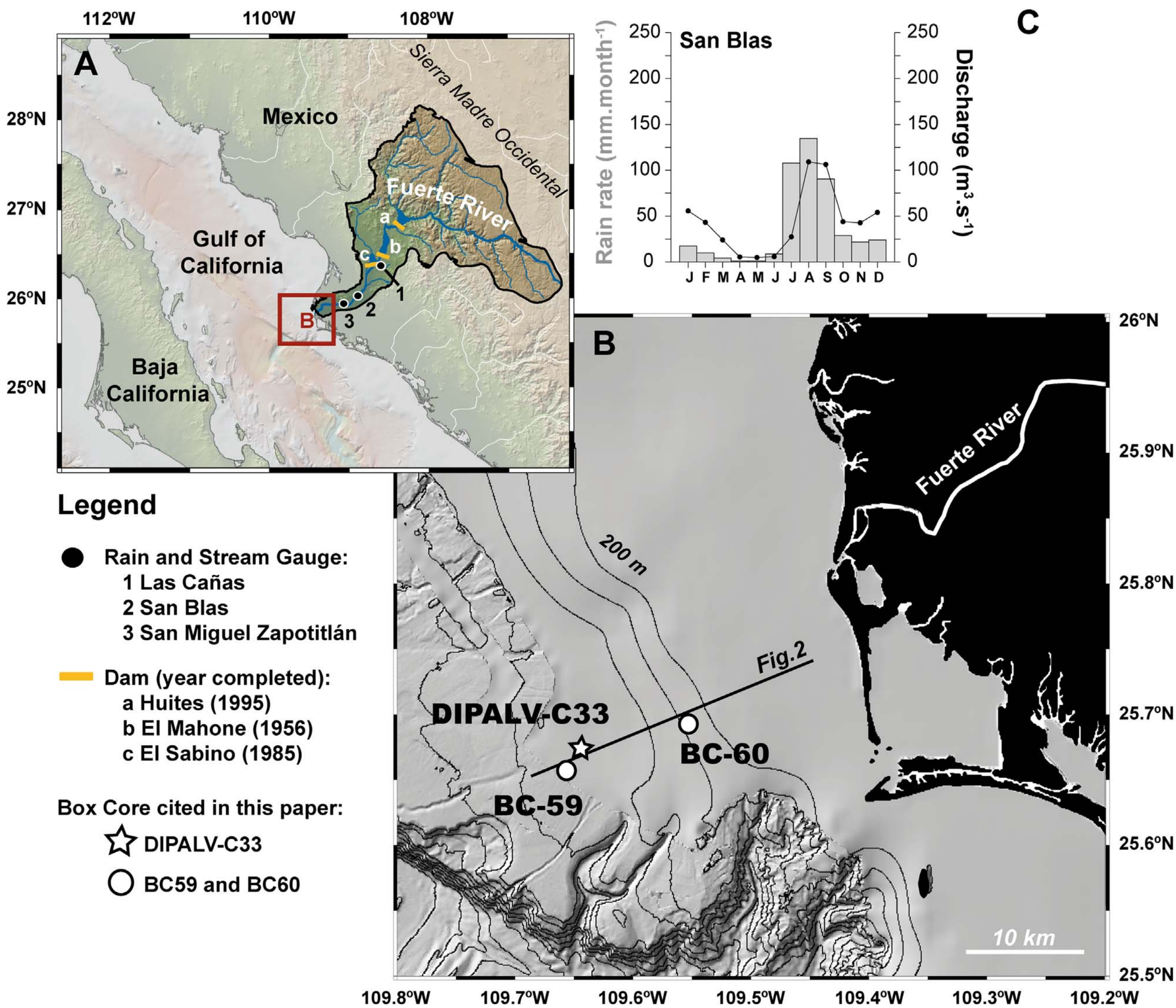

Fig. 1. (A) Map of Western Mexico showing the Fuerte River drainage basin and the study region. (B) Inset map of the Fuerte River mouth region with bathymetry, showing the location of the marine sediment core DIPALV-C33 (this study) and two nearby cores BC59 and BC60 cited in this paper, and the position of the depth profile presented in Fig. 2. (C) Histograms of the mean annual cycle of precipitation and mean annual cycle of the Fuerte River discharge at San Blas gauge. This figure was partly produced with Ocean Data View (Schlitzer, 2015) and GeoMapApp®.

never been considered to contribute significantly to terrigenous material supplied to the Gulf.

This study, using a well-dated, pluri-annual high-resolution demonstrates the presence of sedimentary layers in the Gulf of California, near the mouth of the Fuerte River, which are related to flood events. Specifically, using lithologic observation, XRF elemental composition, magnetic parameter and radiogenic element activities, we identified a distinct sedimentological signature for the flood layers and assigned them ages using the ^{210}Pb method. Correlation with flood events is supported by comparison with the hydrological history of the associated drainage basin. Finally, using the mass accumulation rate, we show flood events could have contributed significantly to terrigenous delivery to the Gulf during the last two centuries.

2. Regional setting

The Fuerte River, with a length of 472 km and located on the western flank of the Sierra Madre Occidental on the Mexican mainland, is one of the largest rivers draining into the Gulf of California (Fig. 1A). Its source is in the Sierra Madre Occidental, in the state of Chihuahua, and it flows across the regions of Durango, Sonora and Sinaloa, where it discharges into the southeastern part of the Gulf of California (Fig. 1A). The Fuerte drainage basin (34,247 km^2) has its maximum headwater elevation at 3000 m and a mean altitude of 1230 m (Hudson et al., 2005). The geology of the drainage basin consists of Oligocene/Miocene silicic ignimbrites and Eocene volcanic rock (predominantly andesitic) in the upper reaches; Upper Cretaceous-Paleocene intrusive rock (granitic) in the middle reaches; and Quaternary alluvial deposits in the lower reaches (Einsele and Niemitz, 1982; Ferrari and Bryan, 2007)..

The mean annual precipitation in the drainage basin is approximately 780 mm y^{-1} (Hudson et al., 2005), and displays strong seasonality driven by the North American Monsoon (NAM) (Fig. 1C; Douglas et al., 1993; Bordoni et al., 2004) with maximum precipitation during summer accounting for 75% of the annual rainfall in the region. The mean Fuerte River discharge is on the order of 31 m^3 s^{-1} (Hudson et al., 2005) with increases in summer reaching 120 m^3 s^{-1} (Fig. 1C). Therefore, summer precipitation is considered to be largely responsible for river discharges and fluvial sediment supply in the Gulf (Thunell et al., 1996; Douglas et al., 2007). Dams were built in 1956, 1985, and 1995 respectively at 110, 90, and 150 km upstream of the river mouth, between the mountains and the alluvial plain of the Fuerte River