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From extreme rainfall to drought: 250 years of annually resolved sediment deposition in Santa Barbara Basin, California

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ABSTRACT

The Mediterranean climate of southern California is marked by droughts and extreme precipitation events. Here we use elemental variations generated by scanning X-ray fluorescence (XRF) to identify droughts and floods in recently deposited (1755–2008) sediments of Santa Barbara Basin (SBB) from box core SPR0901-04BC. The first principal component (PC1) of the scanning XRF elements has high loadings for elements associated with the lithogenic component of SBB laminae couplets, while the second (PC2) is associated with biogenic components. We interpret PC1 as a proxy for river runoff and PC2 as a proxy for marine productivity. High values of PC1 are associated with El Niño events and positive (warm) phases of the Pacific Decadal Oscillation (PDO), while low values of PC2 are associated with El Niño events and negative (cool) phases of the PDO. Droughts such as the 1934–40, 1949–56, and 1989–91 events coincide with low PC1 values. In addition to distinguishing interannual and decadal variability in the elemental composition of SBB sediments, several historic floods can be recognized including a gray flood layer associated with the 1861–62 flood, and a peak in PC1 associated with the flood following the St. Francis Dam disaster in 1928.

1. Introduction

Extreme weather events can have a severe impact on society, such that understanding the frequency of these events is critical to disaster management and mitigation planning. In southern California, historical records of extreme weather events are limited by the short duration of settlement in the region. Crucial insight into infrequent, severe weather events can be obtained from paleoclimate reconstructions if the records contain sufficient resolution to preserve weather events rather than climate change. Most paleoclimate reconstructions are limited by the resolution of the proxy records. The well-studied sediments deposited in Santa Barbara Basin (SBB) in southern California are ideal for paleoclimate research. The seasonal climate, high sedimentation rate, coastal upwelling, basin topography, and suboxic bottom water all combine to produce and preserve laminated sediments with high temporal resolution. These laminated sediments enable the reconstruction of interannual climate variability, including extreme floods, and most importantly can extend that reconstruction beyond the historical record (Fleischer, 1972; Soutar and Crill, 1977; Rack et al., 1995; Schimmelmann and Lange, 1996; Schimmelmann et al., 1998; Robert, 2004).

The varve chronology based on annual laminae couplets of the last ca. 300 years can provide the high resolution dating required for such reconstructions, however the validity of a given varve chronology relies on consistent, cyclic, seasonal deposition of the two components that comprise the laminae couplet (Schimmelmann et al., 2013). To produce and preserve annual couplets, these components must be distinct in character, must be deposited during different seasons within the same year, and cannot be mixed by biologic or physical processes (e.g., bioturbation, gravity currents). In SBB the laminae couplets comprise biogenic and terrigenous detrital sediments that are deposited in spring–summer and winter, respectively. Coastal upwelling brings nutrient-rich water to the surface, leading to enhanced primary production and deposition of the biogenic component. The terrigenous detrital component of SBB sediments is transported to the basin by river runoff following winter precipitation events (Fleischer, 1972; Soutar and Crill, 1977; Thunell et al., 1995; Thunell,

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1998). Suboxic bottom water inhibits bioturbation, preserving the two seasonal components (Grimm et al., 1996).

Extreme weather in southern California consists of heavy rainfall from warm-wet storms associated with atmospheric rivers (ARs) that generate flooding (Dettinger, 2004), and drought conditions when winter rains do not arrive. The varve chronology is dependent on cyclic deposition of both components each year. Hendy et al. (2013) demonstrated the loss of annual cyclicity in SBB laminations in some sediment intervals older than 300 years. They hypothesize this loss of annual laminae couplets may be attributable to sedimentary processes that produce and deposit each couplet component responding to changes in climate forcing – those being changes in the annual upwelling cycle that produce the biogenic sediment component, and in the winter delivery of terrigenous detrital sediment from river runoff.

A number of studies have investigated river suspended loads, sediment deposition, and transport processes occurring nearshore and on the shelf in the Southern California Bight (Kolpack and Drake, 1984; Thornton, 1984; Nezlin and Stein, 2005; Warrick et al., 2007; Nezlin et al., 2008; Warrick and Farnsworth, 2009b). Sediment flux from river runoff is a function of storm intensity and precipitation amount (Warrick and Farnsworth, 2009b), therefore varve thickness in SBB sediment is dependent on the amount of rainfall (Soutar and Crill, 1977). These observations suggest that the detrital fraction in SBB sediments may be used as a proxy for precipitation events in southern California. In this study we investigate the terrigenous detrital and biogenic component of sediment in box core SPR0901-04BC (34° 16.895′ N, 120° 02.489′ W, 588 m water depth) to characterize the elemental composition and variability of recent SBB sediments from ca. 1755 to 2008. The elemental composition generated through high resolution scanning X-ray fluorescence (XRF) analysis can be used to create an annual record of detrital river input and marine productivity. Here we confirm that the first two principal components of the scanning XRF results are related to the two major components of SBB sediments and demonstrate that extreme precipitation and runoff events, droughts, and changes in marine productivity can be identified through the abundance of chemical elements. Using elemental changes in the laminated sediment, we identify interannual and decadal-scale variability such as El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO).

2. Regional setting

Santa Barbara Basin is located in the Southern California Bight (Fig. 1). Southern California has a semiarid Mediterranean climate with cool winters and hot, dry summers that is moderated by the North Pacific High (Nezlin and Stein, 2005; Nezlin et al., 2005; Warrick and Mertes, 2009). In summer, the high-pressure system blocks storm fronts and induces coastal upwelling that brings nutrient-rich water to the surface and stimulates productivity, increasing the biogenic flux to the basin sediments (Lynn and Simpson, 1987; Thunell, 1998; Nezlin and Stein, 2005; Nezlin et al., 2005). The North Pacific High atmospheric pressure system moves southwest in winter, diminishing upwelling and allowing storms to enter the region. Mean annual precipitation in the catchments that discharge into SBB ranges between 30 and 70 cm, and varies as a function of elevation and orographic effects (Nezlin and Stein, 2005; Nezlin et al., 2005; Warrick and Mertes, 2009). Precipitation from winter storms increases the detrital flux, although the amount of suspended load in the river runoff is influenced by the intervals between rain events, catchment geology and relief, and human modification of the landscape (Inman and Jenkins, 1999; Nezlin and Stein, 2005; Warrick and Mertes, 2009).

The PDO and ENSO also influence southern California's climate (Schimmelmann and Tegner, 1991; Dettinger et al., 1998; Inman and Jenkins, 1999; Benson et al., 2003; Nezlin and Stein, 2005; Warrick and Mertes, 2009; Warrick and Farnsworth, 2009b). The positive (warm) PDO phase is accompanied by increased sea surface temperature (SST) along the west coast of North America, low sea-level pressure in the North Pacific and high sea-level pressure along the western margin of North America (Miller et al., 1998; Mantua and Hare, 2002). The precipitation pattern is similar for both the positive PDO phase and the El Niño phase, with increased precipitation in the American Southwest, including southern California, and decreased precipitation in the Pacific Northwest (Benson et al., 2003). The PDO, which is determined by the first mode of variation of sea surface temperature within the North Pacific (180–110°W; 25–62°N), has been implicated in major environmental changes that result in physical-biological regime shifts (Mantua et al., 1997; Chavez et al., 2003; Di Lorenzo et al., 2008). The positive (warm) PDO is associated with intensification of the Aleutian Low and a deepening of the coastal thermocline

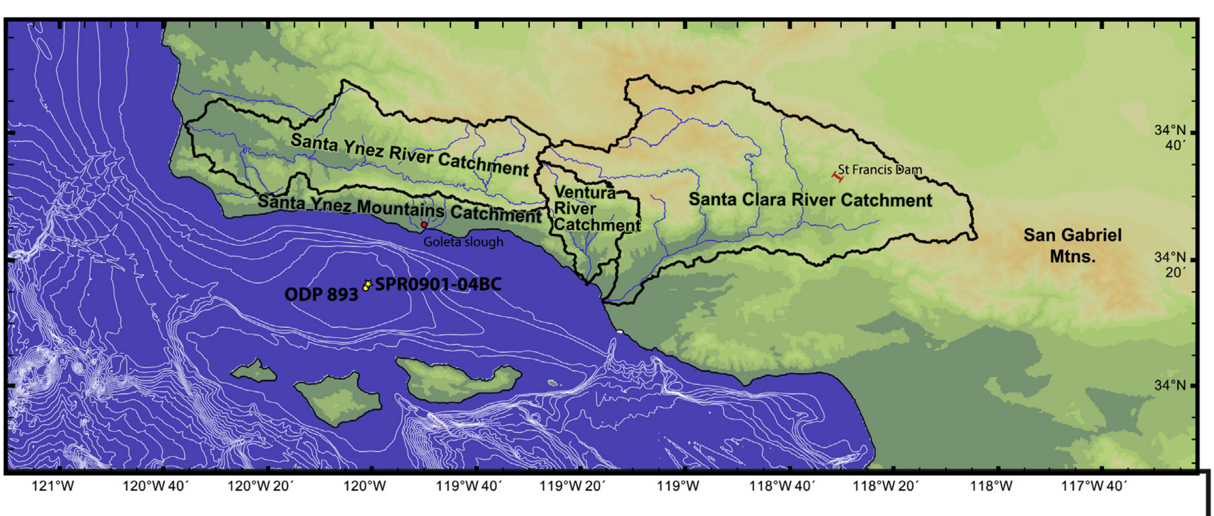

Fig. 1. Map of the Santa Barbara Basin showing the location of box core SPR0901-04BC and Ocean Drilling Program (ODP) Site 893. Topography and bathymetry are in 100 m increments. Thick black lines indicate river catchments and thin blue lines represent rivers draining into Santa Barbara Basin. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)