Marine Geology 397 (2018) 29–42

Contents lists available at ScienceDirect

Marine Geology

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

A 9000-year flood history for Southern California: A revised stratigraphy of varved sediments in Santa Barbara Basin

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ARTICLE INFO

Editor: G.J. de Lange

Keywords:
Radiocarbon chronology
Sedimentation rate
Flood event
Turbidity
Earthquake

ABSTRACT

The center of Santa Barbara Basin (SBB) preserves annual laminations through most of the Holocene providing an important locality for high-resolution late Quaternary paleoclimate and paleoceanography reconstructions. An accurate chronology is necessary for these sediment-based records and enables comparisons with more distal data time-series of similar quality. Here we present an improved high-resolution radiocarbon chronology for the last 9000 yrs. based on 89 accelerator mass spectrometric (AMS) ^{14}C dates of mixed planktonic foraminiferal carbonate from three sediment cores collected in SBB (MV0811-14JC, SPR0901-06KC and ODP Hole 893A). Accurate core-to-core correlation is demonstrated using prominent gray flood and olive turbidite layers identified in SBB and dated in multiple cores. Gray layer deposits were found more frequently in wetter intervals as determined by multi-proxy hydroclimate records in Southern California (e.g., lake deposits and tree rings). Mass accumulation rates (MARs) calculated for the SBB depocenter using the improved radiocarbon age model indicate high MARs are associated with these gray layers that have been associated with floods. Thus sediment accumulation in SBB is largely controlled by sediment delivery via river runoff following precipitation events although MARs may also be influenced by other factors that enhance erosion in river catchments. Folded sediment is observed within the basal core section of MV0811-14JC which stratigraphically correlates with ^{14}C age reversals in ODP Hole 893A. We associate this sediment slump feature with the large Goleta submarine slide complex in Santa Barbara Channel and estimate the submarine slide event occurred at ~ 9000 ± 200 yrs. BP. Furthermore, small olive turbidite layers identified and dated in SBB can be temporally linked with large earthquakes along San Andreas Fault and can therefore potentially reconstruct earthquake history in Southern California.

1. Introduction

The study of Holocene paleoclimate is crucial for understanding climate variability from millennial to interannual time scales (Mayewski et al., 2004; Wanner et al., 2008). The sediment record at the depocenter of Santa Barbara Basin (SBB) offshore of Southern California has been the basis of several paleoclimate and paleoceanography reconstructions (e.g. Lange et al., 1987; Kennett and Venz, 1995; Heusser, 1998; Schimmelmann et al., 2006). The predominantly annually laminated sediment record in SBB during the Holocene has the potential to resolve decadal and even interannual-to-annual paleoenvironmental and paleoceanographic changes (Weinheimer and Cayan, 1997; Hendy et al., 2015). However, an accurate chronology is needed to provide a time scale for SBB sediments and is essential for detailed comparisons with other paleoclimatic and paleoceanographic records.

Numerous investigations of SBB sediments chronology have taken place over the past 40 yrs. Soutar and Crill (1977) developed a chronology for 19th and 20th century SBB sediment based on annual layer/lamination or varve counting and ^{210}Pb dating. The establishment of a precise varve chronology and core-to-core correlation for the 19th century was followed by a detailed description of the ODP Hole 893A (34°17.25′N 120°02.2′W) varve stratigraphy (Lange and Schimmelmann, 1995). Additionally a number of AMS ^{14}C dates have been produced using mixed planktonic foraminiferal carbonate from ODP Hole 893A samples with 31 dates from the Holocene (Ingram and Kennett, 1995; Roark et al., 2003). Schimmelmann et al. (2006) expanded the chronology of partially varved sediment to the past 6700 yrs. using piston core 6P based on varve counting and ^{14}C–AMS dating. However, disagreements were found when comparing the traditional varve-count-based chronology to independent ^{14}C dates of planktonic foraminifera in multiple cores (Schimmelmann et al., 2006;

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https://doi.org/10.1016/j.margeo.2017.11.014
Received 15 May 2017; Received in revised form 8 November 2017; Accepted 23 November 2017
Available online 28 November 2017
0025-3227/

Fisler and Hendy, 2008).

The discrepancy between SBB varve and ^{14}C chronologies may be explained by variations in the radiocarbon reservoir age of the regional surface ocean water and/or undercounting of annual layers in the varve chronology. Loss of varves (under-counting of absolute years) could be caused by erosion of varves and/or laminations being not consistently produced during drought intervals (Schimmelmann et al., 2006; Hendy et al., 2013; Schimmelmann et al., 2013). To resolve these issues a new high-resolution ~2000-yr chronology was developed using a combination of organic carbon ^{14}C dates from terrestrial floral macrofossils such as seeds, leaves, charcoal, and twigs and closely sampled planktonic foraminiferal carbonate ^{14}C dates (Hendy et al., 2013). Age differences between the ^{14}C planktonic foraminiferal carbonate and terrestrial organic carbon chronologies revealed variable reservoir ages (ΔR) while increasing offset between the ^{14}C and varve chronologies indicated a cumulative varve count error through the last 2000 yrs. Hendy et al. (2013) produced an improved chronology for SBB sediments with a variable ΔR applied to 49 mixed planktonic foraminiferal carbonate ^{14}C dates, however the chronology does not extend through the remainder of the Holocene.

Here we extend the high-resolution 2000-yr ^{14}C SBB chronology (Hendy et al., 2013) to 9000 yrs. BP (Before Present or before 1950 CE). Fifty new mixed planktonic foraminiferal carbonate ^{14}C dates were produced from jumbo piston core MV0811-14JC. In addition, we created a stratigraphy of 'instantaneous' gray flood and olive turbidite layers in SBB based on highly resolved imaging of core MV0811-14JC. We then employed this stratigraphy to correlate MV0811-14JC with ODP Site 893 and SPR0901-06KC such that the planktonic foraminiferal carbonate ^{14}C dates from these cores could be incorporated into a new master chronology for SBB sediments. Our new chronology is applied to the dated stratigraphic pattern of gray and olive layers and therefore can be applied to any future newly acquired SBB sediment cores to provide an easily accessible chronology for forthcoming paleoclimate studies. Finally we relate the gray flood and olive turbidite layers to regional paleoclimate reconstructions and tectonic activity.

2. Regional setting of SBB

Located off the southern coast of California, SBB is a tectonic depression representing the submerged southwestern part of the Transverse Ranges Province (Fig. 1). Late Quaternary sediments deposited in SBB are mostly composed of laminae couplets including biogenic (e.g., diatoms, radiolaria, planktonic and benthic foraminifera) and terrigenous sediments (Fleischer, 1972; Kolpack and Drake, 1984; Kennett and Venz, 1995; Rack and Merrill, 1995). Terrigenous sediments are delivered to SBB by rivers and streams (the Santa Clara and Ventura rivers and the Santa Ynez Mountains). The rivers and streams drain the tectonically active Western Transverse Ranges that are uplifting at rate of < 5 mm/yr (Duvall et al., 2004) producing an unusually high sedimentation rate (Thunell, 1998; Romans et al., 2009; Warrick and Mertes, 2009).

Southern California has a semiarid Mediterranean climate with cool winters and hot dry summers. Terrigenous material is delivered to SBB during winter precipitation events resulting in detrital siliciclastic sedimentation (dark laminae in X-radiographs) (Warrick et al., 2007) while biogenic sedimentation (light laminae in X-radiographs) occurs during the highly productive spring and summer seasons (Hülsemann and Emery, 1961). The northward migration of the North Pacific High Pressure System during the spring season positions strong northerly winds over the California coast and causes intense coastal upwelling (Lynn and Simpson, 1987). This imports nutrients into the photic zone and drives high regional biological productivity and the deposition of biogenic laminae. Suboxic bottom water in the deep center of the SBB renders the seafloor inhospitable to benthic macrofauna and prevents bioturbation allowing the seasonal variations in sedimentation to be preserved as annual laminae couplets (Behl, 1995; Schimmelmann et al., 2016). Thus the production and preservation of annual laminations provide the scientific basis for a varve chronology in SBB.

3. Methods

3.1. Radiocarbon dating

Samples 2 cm in thickness were collected at ~20 cm intervals over a total length of 980 cm from jumbo piston core MV0811-14JC (34° 16.906′N 120° 02.162′W; 580 m water depth; Fig. 1). Sediment samples were oven-dried, washed and wet sieved to retain the > 63 μm size fraction. Mixed planktonic foraminifera primarily consisting of *Globigerina bulloides* and *Neogloboquadrina incompta* were picked from the > 150 μm size fraction in each sediment sample to generate 50 carbonate ^{14}C dates (Table 1). Following standard methods, approximately 11 mg of foraminiferal shells were first leached in dilute HCl, then rinsed using Milli-Q water, dried and hydrolyzed using 85% phosphoric acid to produce CO_2 (Beverly et al., 2010). The resulting CO_2 was extracted, purified and graphitized using vacuum lines with H_2 gas and iron catalyst powder. Both pre-treatment and high-precision accelerator mass spectrometry (AMS) dating were performed at the Keck Carbon Cycle Accelerator Mass Spectrometer at the University of California Irvine.

3.2. Age-depth model

Gray and massive olive layers were logged in cores MV0811-14JC, SPR0901-06KC (34°16.914 N 120°02.419 W; 591 m water depth) and ODP Hole 893A (34°17.25′N 120°02.2′W; 588 m water depth) to create a master stratigraphy. Since flood layers and turbidites represent 'instantaneous' sedimentary events (Hendy et al., 2013; Schimmelmann et al., 2013) the thicknesses of the gray and olive layers were subtracted from the original core to create a corrected depth scale that incorporates only regular background sedimentation (typically laminated) (Table 1). The gray and olive layers were then used as stratigraphic tie points to correlate SPR0901-06KC and ODP Hole 893A depths to the MV0811-14JC depth scale (Table 2). A new composite corrected depth scale was generated so that the 49 ^{14}C dates from SPR0901-06KC (Hendy et al., 2013) and the 10 ^{14}C dates from core ODP Hole 893A (Roark et al., 2003) could be combined with the 50 MV0811-14JC ^{14}C dates.

An age-depth model from 46 to 9066 yrs. BP was generated using the software BACON2.2 (Blaauw and Christen, 2011). BACON uses Bayesian statistics to reconstruct coherent accumulation histories for deposits by combining radiocarbon dates with known sedimentary information (Blaauw and Christen, 2011) (Fig. 2). In this age model ^{14}C dates from cores SPR0901-06KC (Hendy et al., 2013) MV0811-14JC and ODP Hole 893A (Roark et al., 2003) were converted to calendar ages using the Marine13 calibration curves (Reimer et al., 2013). A variable reservoir age was applied to ages younger than 2000 yrs. BP where constraints were available (Hendy et al., 2013). Beyond 2000 yrs. BP a constant ΔR of 147 ± 70 yrs. was applied based on an estimate from the last constrained surface ocean reservoir age (Hendy et al., 2013). Eleven out of 49 ^{14}C ages from SPR0901-06KC, 6 out of 50 MV0811-14JC ^{14}C dates, and 3 out of 10 from core ODP Hole 893A (indicated as open symbols in Fig. 3) fell outside the age-depth line and were not used in this age model.

The ^{14}C plateaus during the last 300 yrs. preclude good calendar year calibration of ^{14}C dates in the youngest sediment sequence. Instead, previously published varve chronology data were employed after correlating stratigraphic marker layers between cores. These marker layers were previously identified in other box and kasten core studies (Schimmelmann et al., 1992; Hendy et al., 2013) and include: the coretop (1905 CE), a gray layer at 1861–62 CE, the *Macoma* layer at 1841 CE, a turbidite at 1811 CE and a gray layer at 1761 CE. Radiocarbon dates were employed downcore of the 1761 CE gray layer