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Earthquake Recurrence, Northern Hayward fault: Paleoseismic investigation of San Pablo Creek flood deposits

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Abstract

We carried out excavations of the Northern Hayward fault (NHF) at San Pablo Creek (SPC) in San Pablo, California. At this location the prominent southern terrace of SPC is blanketed with placed fill over a layered sequence of overbank flood deposits. The creek is a large drainage of the East Bay Hills (catchment area $\simeq$ 110 km^2). Despite upstream control, the creek experienced over-bank flow in 1940, 1958, and 1998 (Anderson and Balazs, 2004) thus is prone to regular flooding and accompanying overbank deposition associated with potential to produce a complete paleoseismic record. The excavation site is within the corporation yard of Saint Joseph's Cemetery. We are extremely grateful to the managing staff of St Joseph's for permitting access for these studies. The project is designed to provide data for sufficient formal fault hazard modeling, specifically for the evaluation of the northern portion of the Hayward fault in the eastern San Francisco Bay Area.

We note that a prior investigation obtained substantial NHF paleoseismic evidence at a site on the Mira Vista Golf Course, ~four kilometers south of SPC. However, because the paleoseismic record described at Mira Vista is believed to be incomplete, additional studies are needed to seek to obtain a more complete history to advance empirical rupture-probability models of the NHF and to clarify its role in the Hayward - Rogers Creek Fault system (HRCF).

The NHF is the central ~30-km-long segment of the 140-km-long Hayward-Rodgers Creek fault system (HRCF). The absence of rupture of the northern segment of the Hayward fault, and the adjacent Rogers Creek fault since before the time of continuous Spanish habitation in the San Francisco Bay Region (beginning in 1776) suggests that this segment, and perhaps the entirety of the HRCF, is due or overdue for a large earthquake. It is clearly important for regional and local seismic hazard evaluations to obtain substantial evidence of the recurrence history of ruptures of the northern Hayward fault (NHF), and to improve and extend those for the entire HRCF system. The Working Group on California Earthquake Probability (WGCEP, 2007) assigned a 39% 30-year rupture probability to the NHF. The evaluation was based on slip rate data and generic fault parameters, and equivocal paleoseismic data from the Mira Vista Golf Course site (Figure 1). Findings of the Mira Vista study indicate that at least four, and possibly seven or more, surface-faulting earthquakes occurred during a 1,630-2,130 yr interval (1880±250 b.p.), with the most recent event (MRE) dated after AD 1640 and prior to AD 1776 (Figure 2). These timing data yield an average recurrence of about 270 to 710 yr for large earthquakes. Because the trenches

intersect only secondary fault traces, and depositional hiatuses are present that probably prevent recording of a complete event chronology, the Mira Vista record was considered likely to be incomplete by the Hayward fault Paleoearthquake Group (HPEG, 1999) and WGCEP (2003, 2007).

Findings

The highlight of the reported work is discovery of a substantial multi-event prehistoric earthquake record for the northern Hayward fault at the San Pablo Creek site (Figure 1). A general chronological context has been developed for the site (Table 1), and complex faulting, extensional fissures and tilted fluvial beds have been described in a stratigraphic context (Table 1, Figure 3). Preliminary evidence from our 2010 excavations indicate that at least four, and possibly five surface rupturing events occurred during the past ~1000 year period. The primary trench exposure (Figure 3) disclosed well-bedded fluvial stratigraphy, and detrital and in-situe charcoal were collected from several stratigraphic intervals. Complex faulting, extensional fissures and tilted fluvial beds were described (Figure 3) and indicate that continued paleoseismic exploration will clarify and amplify evidence of individual events and improve the possibility of developing a sufficient dataset to compare with the Mira Vista site on the NHF as well as the adjoining southern Hayward fault and Rogers Creek fault segments.

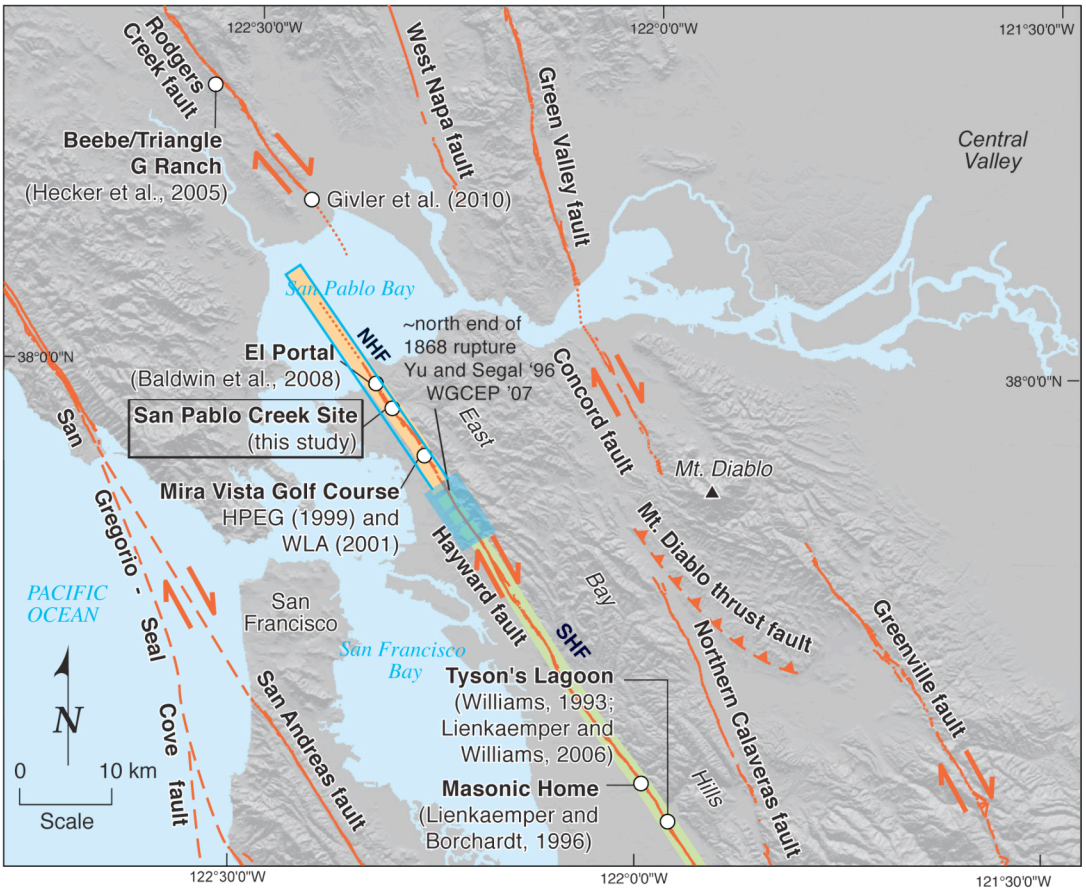

Figure 1. Regional fault map illustrating the location of the Northern and Southern Hayward fault (NHF and SHF, respectively) and locations of the San Pablo Creek site and fother field sites discussed in the text. Segment boundary approximated by area of blue box from WGCEP (2003, 2007) is the northern extent of 1868 rupture as derived from triangulation data (Yu and Segal, 1996), and is associated with evidence of reduced fault coupling (Bürgmann et al., 2000, Simpson et al., 2001; Lienkaemper et al., 2010)

Future work will focus on developing a more substantial chronological framework, and developing clear and robust evidence for all the events inferred or established to date. The location of the primary exposure, at an intermediate position on the terrace (Figure 4), suggests that continued paleoseismic exploration could extend the record to additional events if yet older deposits are demonstrated at the site. Most importantly the current results encourage the possibility that a sufficient dataset can be developed to compare the SPC event ages with those that have been (or will be) developed at sites on the southern Hayward and adjoining Rogers Creek fault. Initial radiocarbon dating indicates good bracketing of the age of the section, and support the likelihood that the most recent event (MRE) has been identified at the site.

Site stratigraphy consists of older channel deposits, Tertiary bedrock, and moderately to well-bedded, generally fining-up overbank deposits containing fine sands, abundant silt and traces of clay. The overbank stratigraphy contains common detrital and apparent in-situe carbon residues in several of the mapped intervals. Preliminary interpretation of stratigraphic and structural relations, coupled with limited radiocarbon results, indicates that the most recent surface rupture (MRE) occurred just prior to the late 18th or mid 17th century. While several sites have been explored previously along the entirety of the Hayward fault, the San Pablo Creek site is just the third showing clear promise to disclose a substantial earthquake record.

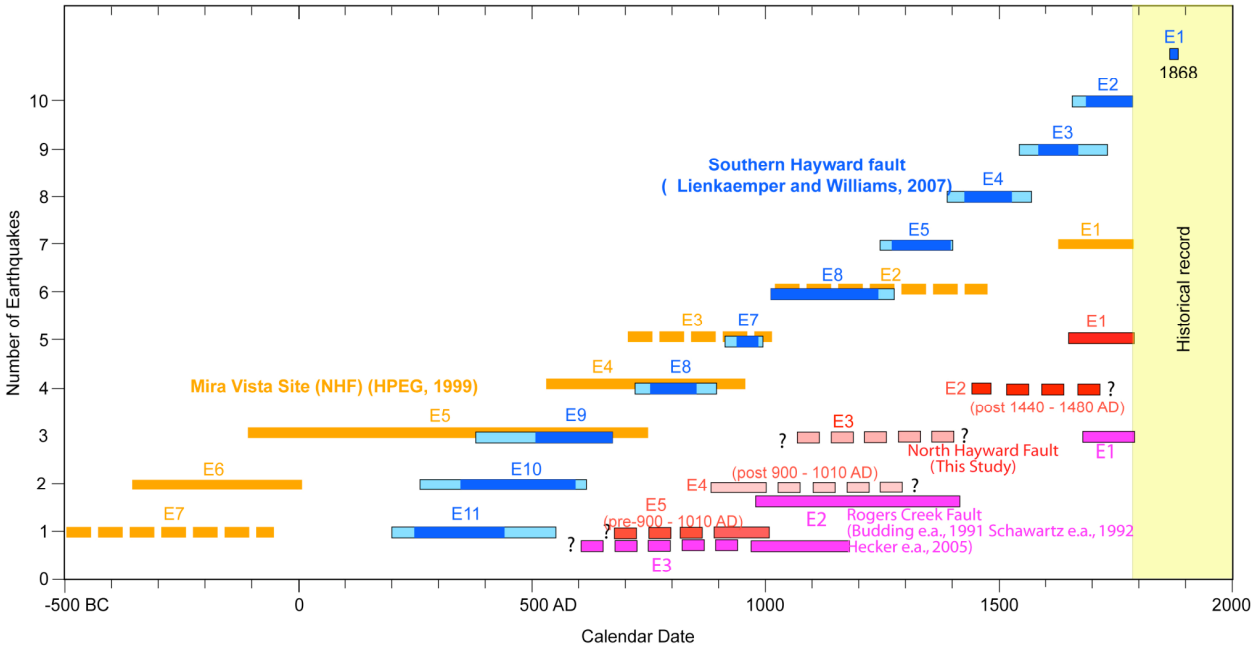

Figure 2. Event chronology data for the northern Hayward fault (orange- HPEG, 1999; red- this study); southern Hayward fault (blue- Lienkaemper and Williams, 2007); and Rogers Creek fault (magenta- Budding et al., 1991; Schwartz et al., 1992; Hecker et al., 2005). Event numbers are shown above each event bar symbol. Note that the orange-colored events shown as dashed were reported with less certainty than those that are solid (HPEG 1999). Red colored NHF events E3 and E4 have weaker physical evidence so are shown in lighter shading, Queries represent lack of constraining age data.

The San Pablo Creek site.

The focus of this proposal, the San Pablo Creek site (Figure 1), has yielded evidence of at least four ground rupturing events, possibly five, during a period of ~1000 years, and three of these are deemed to be substantial events. A log of the area containing the majority of the physical earthquake evidence is presented in Figure 3. Event age control is discussed in detail in the following discussion.

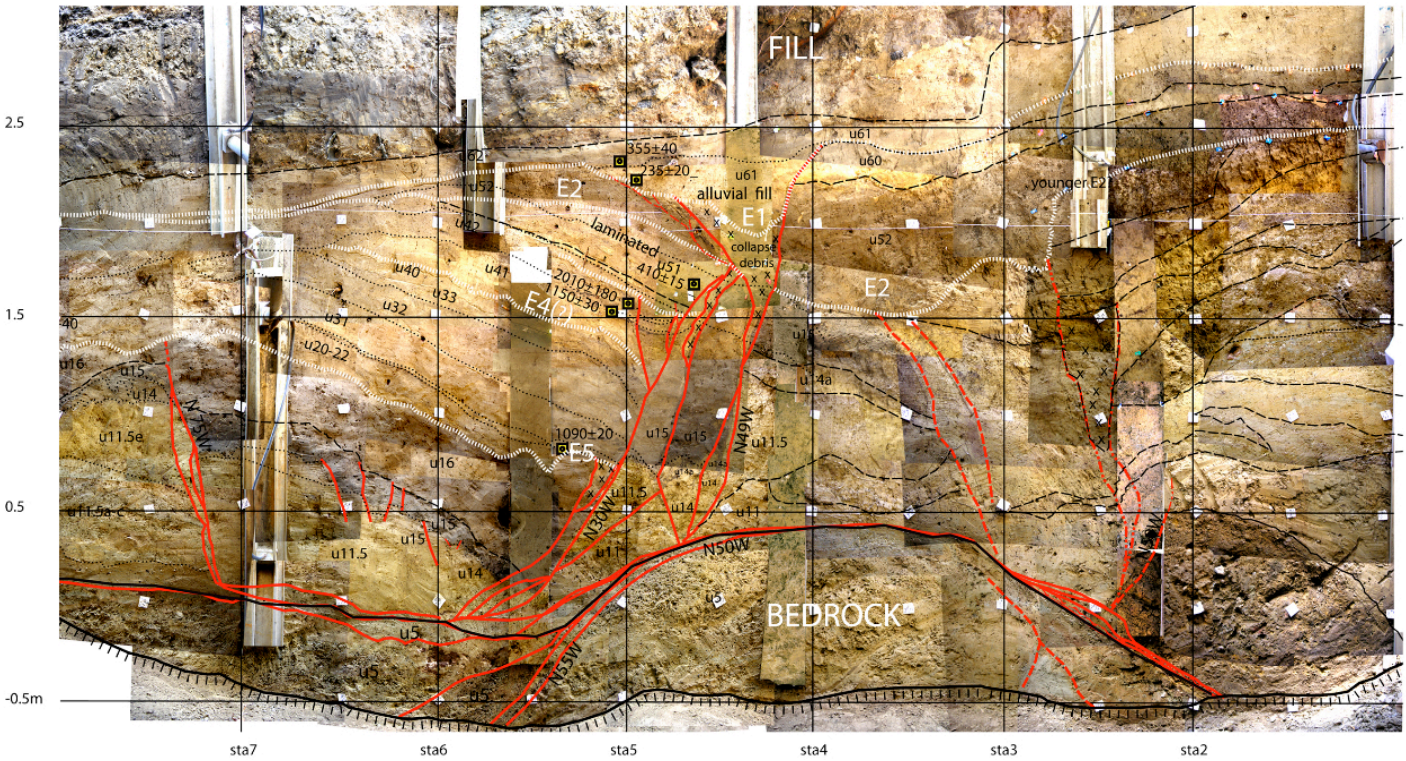

Figure 3. A portion of the south wall T2 trench log from an area of concentrated primary event evidence. Faults are located in red, dashed where unclear or inferred. Event horizons are illustrated by prominent dashed white lines. Event evidence consists of in-filled fissures (E1, E2, E5), upward terminations (E1, 3, E5), tilt and infill (E2), distributed un-rooted fractures (E5), and folding and infill (E3, E4). Event stratigraphy is presented in tabular form in Table 1.

Events

MRE (E1). The MRE is recorded by a large filled-fissure associated with a primary fault branch. Timing of this event is consistent with that at Mira Vista in that it is clearly older than the historical 1868 SHF rupture (Figure 2), but its age falls with a period that is difficult for radiocarbon calibration. A sample recovered immediately above the stratigraphic event horizon is dated 235±20 radiocarbon years. With remarkably small uncertainties (±10-15 years) the calibrated age of the sample is circa either AD~1655 or AD~1780. This result closely approximates the bracketed MRE results at Mira Vista. In the AD 1780 case, the event occurred within the same decade as arrival of the permanent Spanish Mission at San Francisco. Evidence for the MRE is considered substantial; Dating of the MRE remains preliminary.

Table 1.

Unit	Age	Event	Bulk[1]	Carbon[2]	
u63					
u62	355±40		b18	4	
u61	235±20		b17	4	dated sample is at u61/u52 contact
		E1			
u60			b16	6	
u52			b15	2	
		E2			
u51	410±15		b14	2	v. poor sample count in this interval
u50			0	0	
		E3			
u42	2010±180		b13	3	bulk (b13) from “upper c lamination”
			b12		bulk (b12) from “lower c lamination”
	1150±30			2	samples at u42/41 contact
u41U			b10		
u41L			b11	3	
		E4		1	
u40			b09	3	
u33			b08	0	carbon lamination described in bulk (b08)
u32			b07	0	
u31			b06	1	
u30			b05	5	
u22	1090±20			3	
u21			b04	2	
u20			b03	0	
		E5			
u16			b02	7	
u15			b01	0	
u14				0	

Table 1. Summary of sampling and the stratigraphic context, and initial chronological work for the San Pablo Creek site. This summary provides a preliminary age context of the most recent earthquake and for 3 prior earthquakes. E5 is older than the dated portion of the section. These data indicate that a reasonably complete and youthful record is preserved at the site. Six carbon samples processed by the National Ocean Science AMS lab (WHOI - Woods Hole) indicate that strata containing a 2- to 4-event paleoseismic record span ca. 235 to 1090 radiocarbon years in age.

E2. The penultimate event is expressed by multiple evidence of tilt and infill, upward terminations and fissure fill. The age of the event currently is poorly bracketed (Figure 2). One date has been obtained below the E2 event horizon and gives a calibrated maximum age for E2 as 550 calibrated years before present (CYBP), the minimum age so-far determined is pre E1 (AD 1640-1776). Current information for the ultimate and penultimate events show that E1 happened no more than ~360 CYBP, and E2 occurred no more than ~550 CYBP, thus E2 is bracketed between 360 and 550 years CYBP. While evidence for this event is considered substantial, age information is limited.

E3. The pre-penultimate event is recorded by a small area of upward terminations and extensional sag bounded by faulting. Evidence for E3 is credible, but is much less substantial

[1] Identification number of bulk samples;
[2] Number of carbon samples collected in the field;

than that for E1, E2 and E5. Age constraint for E3 is "more than ~550 CYBP. E3 does not have a useful pre-event age constraint.

E4. E4 is weakly expressed and is considered to be the least likely of the asserted events to represent substantial NHF fault rupture. The T2 exposure (Figure 3) contains a small area of unrooted (downward terminating) detachment folding with apparent infill beneath that associated with E3. Additional evidence is required to substantiate evidence for this event. The north wall of trench T2 contains apparent sag and infill at the event horizon, providing additional support for the possibility that 4 may indeed be a credible event. On both walls the folding is located beside the most-strongly expressed zone of faulting. Age information is limited to a pre-event age of about 1050 CYBP

E5. E5 is a well-expressed event in the lower part of the section exposed in 2010., with an event horizon located immediately below a carbon sample dated at 1050 CYBP. The event is expressed by localized offset,apparent scarp formation, detached fractures, folding, and minor fissure fill. No lower age constraint has been developed for E5, but upper age-constraint for the event appears to be excellent.

In summary, physical evidence for three well-recorded events has been developed at the SPC site. Physical evidence for two additional events is preliminary and additional work is required to substantiate or remove these events in the record. All the substantiated and conditional event horizons are contained in a stratigraphic section containing 30 major subunits and extending to more than 1100 years in age.

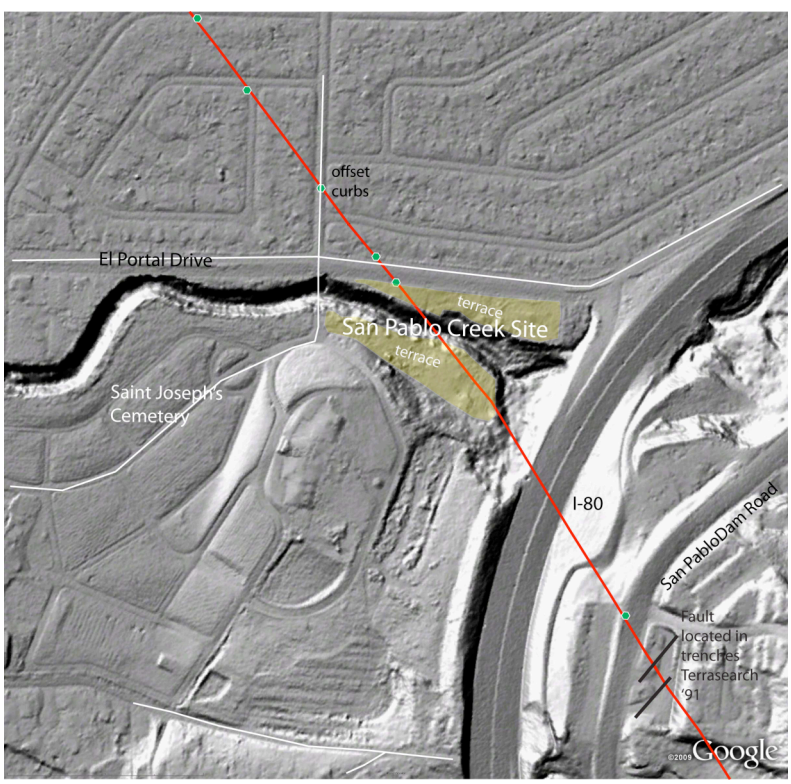

Figure 4. Map of study area derived from Lienkaemper (DS-177, 2008) and Geoearthscope (2007). Green symbols are locations of curb offsets. Green shaded pattern is study site. Trench locations in 3B. Main strand fault location (and several traces to NE) are clear in consulting trenches of Terrasearch (1991). The ridge above the site acts as a large shutter ridge deflecting San Pablo Creek on the order of 250m. Terrace elevation is consistent with the extensive flood plain surface to the north, and the fault passes through undeveloped private property across the stream from the corporation yard, providing a backup site. Stream incision at the site is 7 to 8m. Incision is a common stream response to upland ranching, which was extensive in this watershed. High sediment discharge from this drainage is indicated by the presence of a prominent 1.5 x 3km delta at the Creek's mouth (use this link to access a NOAA kmz file of SF bay bathymetry : http://egisws01.nos.noaa.gov/servlet/BuildPage?template=bathy.txt&B1=Submit&parm1=P090)

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