Technical Report

Project Goals

In northern Baja California, roughly 14% of total Pacific-North American plate boundary slip is accommodated across the Peninsular Ranges by two active faults capable of producing damaging earthquakes near US and Mexican population centers (Bennett et al., 1996; Dixon et al., 2002; Grant and Rockwell, 2002) (Figure 1). The Agua Blanca Fault extends offshore ~15 km south of Ensenada where it connects with the Palos Verdes-Coronado Bank Fault zone, which parallels the Pacific coast west of San Diego and Los Angeles. The San Miguel-Vallecitos Fault (SMVF) appears to be the southern continuation of the Rose Canyon Fault Zone, which underlies Tijuana and San Diego. The Late Quaternary slip histories for these faults have until recently been poorly constrained, even though the ABF accommodates more slip than the Elsinore Fault (Rockwell et al., 2018) and both faults together accommodate over half as much slip as the San Jacinto Fault (Blisniuk et al., 2013). The remote south end of the SMVF ruptured historically (Doser, 1992; Shor and Roberts, 1958), and paleoseismic evidence based on a single radiocarbon date from the west end of the ABF may record an earthquake early in, or perhaps just preceding, the historic record for this region (Schug, 1987), but the timing and frequency of earlier events is unknown. Earthquake recurrence near San Diego and Tijuana has been estimated from paleoseismology along the Rose Canyon system (Lindvall and Rockwell, 1995). However, early trenching studies along the ABF found surface rupture but little recoverable material for dating the events, and were able to conclude only that there has been rupture in the Holocene and in the past ~2 kyr, in addition to the potential historic event. Holocene rupture along the western ABF is obvious from the unambiguous record of dextral slip preserved by displaced Late Quaternary geomorphology, and slip in the past 2 kyr is required by the new time-invariant post-65 ka ~3 mm/a rate measured by P.I. Behr and former UT Ph.D. student Gold at three locations along the western ABF.

The goal of this project was to collect measurements of earthquake timing from a new paleoseismic trenching site located along the central section of the Agua Blanca Fault and to consider these measurements in the context of evidence of lateral slip-per-event for the past 2 earthquakes and the Holocene-Late Pleistocene slip rate measurements collected by Behr and Gold in complimentary investigations. We discuss these new measurements in the context of complimentary evidence of the Late Quaternary slip history for the ABF and speculate on the near-term potential for damaging earthquakes at the southern boundary of the San Andreas plate boundary system.

The Valle Agua Blanca Paleoseismic Site

We used airborne lidar to identify a new paleoseismic trenching site along the central Valle Agua Blanca section of the ABF. This location (31.476904, -116. 181411) is the same as the Valle Agua Blanca slip rate site described in Section 3.6.3. Roughly 6 km from the eastern end of Valle Agua Blanca the ABF steps ~350 m to the north (a right, or releasing structural step) from its position bounding the south side of the valley.

On the north side of the valley the ABF truncates the toe of an extensive, dissected alluvial fan deposit mapped as Q8 by Hatch (1987), who estimated its age to be >255 ka based on soil development. Across the fault to the south of Q8, lateral slip on the order of 10^0-10^2 meters is recorded by deflected channels and offset alluvial deposits. Across the fault from the apex of Qaf, a ~25 m wide and ~75 m long tectonic depression or sag pond has formed in the wake of a second smaller (~40 m wide) releasing step in the ABF (Figure 2. A sub-meter step down from Qaf into the sag pond suggests a sustained vertical component of fault slip, consistent with a releasing geometry. The north side of the sag pond is bounded by a ~10 m high scarp formed by a strand of the fault that based on gouge exposed in one trench appears to have accommodated the majority of Late Quaternary slip at this position along strike. An active channel incising Q8 that drains the source catchment for Qaf bounds the western end of the sag pond, but flows away to the southeast. The sag pond is currently internally drained and is not directly downstream from any notable sediment source other than the fault scarp and a portion of the Q8 surface to the north. The absence of an entrenched outlet from, or significant sediment source into, this restricted drainage area suggests slow deposition, and the orientation of the active channel should direct sediment-laden debris flows away from the sag pond. Slow sedimentation within a depocenter tectonically renewed by a normal component of fault slip combine at this site to create an environment well-suited to preserve evidence of past surface ruptures.

Results of previous SCEC funding of investigations along the Agua Blanca Fault

This project is part of a broader effort to constrain the Late Quaternary slip history of the Agua Blanca Fault. Complimentary investigations funded by SCEC, USGS and NSF and led by former UT Ph.D. student Gold as part of his dissertation research have resulted in new slip rate and slip-per-event estimates. Specifically, the results of this project compliment most probable Late Quaternary slip rates for the Agua Blanca Fault of 2.8 +0.8/-0.6 mm/a since ~65.1 ka, 3.0 +1.4/-0.8 mm/a since ~21.8 ka, 3.4 +0.8/-0.6 mm/a since ~11.7 ka, and 3.0 +3.0/-1.5 mm/a since ~1.6 ka. Geologic evidence from another site suggests ~2.5 m of lateral slip in the past two earthquakes.

Late Holocene earthquake history for the Agua Blanca Fault

Two trenches across the ABF reveal evidence for seven earthquakes in ~6500 years, constrained by 74 radiocarbon dates (Figures 2 and 3). This suggests an average recurrence of just under 1000 years, however, earthquake cycle durations suggested by OxCal modeling (Figure 4) range from ~300 to ~1700 years (Bronk Ramsey, 2009; Reimer et al., 2013). This may in part reflect real variability, but it is also likely in part the result of missing events; those that were not preserved in the trench or were overprinted by later ruptures, missed in the trench interpretations or that bypassed this site on the subsidiary fault south of this location. Wide uncertainties in the timing of events 1 and 4 (Figure 4) also contribute to the uncertainty in earthquake timing. The overlap between events 5 and 6 may record the overlapping tails of two approximately coeval ruptures that represent a single strain release event rather than the passage of a full, if relatively short, earthquake cycle. Interpreting event 5 and 6 as a single rupture increases average recurrence to ~1100 years. Compared to faster, structurally simpler faults like the central section of the Alpine Fault in New Zealand or the San Andreas Fault between southern the Mojave and the San Francisco Bay Area, a degree of variability in the timing and magnitude of strain release may not be unexpected (Berryman et al., 2012), and the ~0.55 coefficient of variation suggested by the ABF earthquake record is comparable to those measured from other long-term paleoseismic records on secondary faults within the southern San Andreas system (Rockwell et al., 2014). If the observed variability in earthquake timing along the ABF is real and not the result of an incomplete record, then because the Late Quaternary geologic slip rate appears to remain constant over time (~3 mm/a), the magnitude of strain release must increase or decrease with longer or shorter interseismic periods. Slip-per-event estimates from a nearby site suggest consistent slip of ~2.5 m in the past two events, not a sufficiently long record of earthquake size to really interrogate this issue, but paleoseismic, slip-per-event, and slip rate measurements are consistent over the past 1.6-1.4 ka and suggest that whether or not slip is variable, the ABF is unlikely to produce a large, damaging earthquake in the near future. This research has helped to complete the recent slip history for a previously unconstrained subsidiary fault of the San Andreas system and has provided valuable training for a next generation Quaternary geologist.

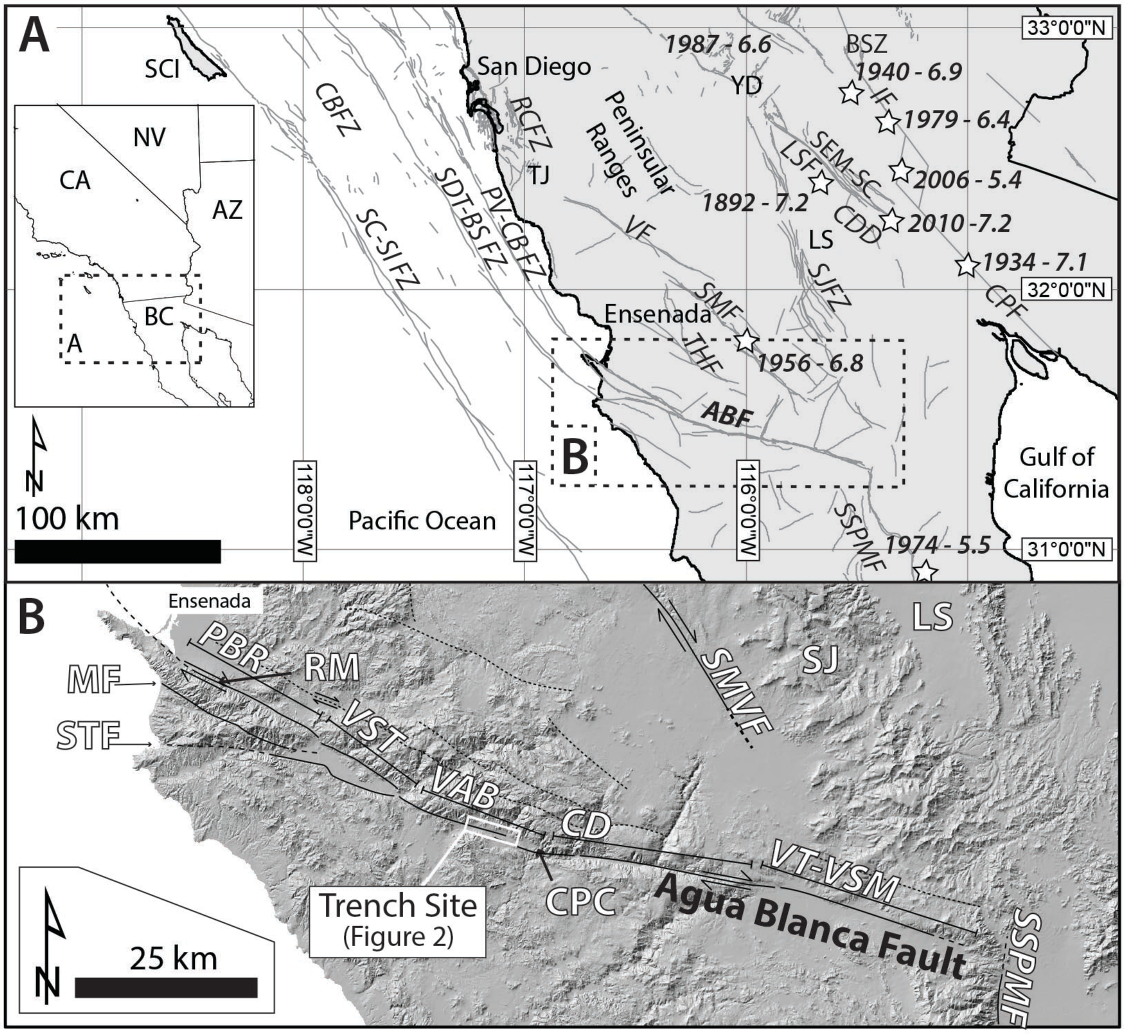

Figure 1

Fault maps of the Big Bend domain of the Southern San Andreas Fault system (a) and the Agua Blanca Fault (b) showing major regional earthquakes in southern California and northern Baja California. Plate boundary slip is accommodated primary along the Cerro Prieto Fault and the Laguna Salada-Sierra Cucapa-Sierra El Mayor systems, but ~14% of plate motion is transferred across northern Baja California by the San Miguel-Vallecitos Fault zone and the Agua Blanca Fault. A) Fault abbreviations: ABF: Agua Blanca Fault; BSZ: Brawley Seismic Zone; CDD: Canada David Detachment; CBFZ: Continental Borderland Fault Zone; CPF: Cerro Prieto Fault; LSF: Laguna Salada Fault; IF: Imperial Fault; PV-CB FZ: Palos Verdes-Coronado Bank Fault Zone; RCFZ: Rose Canyon Fault Zone; SAF: San Andreas Fault; SC-SI FZ: San Clemente-San Isidro Fault Zone; SDT-BS FZ: San Diego Trough-Bahia Soledad Fault Zone; SH: Superstition Hills; SJFZ: Sierra Juarez Fault Zone; SSPMF: Sierra San Pedro Martir Fault; SMF: San Miguel Fault; VF: Vallecitos Fault. Location abbreviations: SCI: San Clemente Island; LS: Laguna Salada; SD: San Diego; TJ: Tijuana; YD: Yuha Desert. B) Abbreviations: CD: Canon Dolores section; CPC: Cañada Paredes Coloradas; MF: Maximinos Fault; PBR: Punta Banda Ridge section; RM: Rancho Mirador; SJ: Sierra Juarez; SMVF: San Miguel-Vallecitos Fault; SSPMF: Sierra San Pedro Martir Fault; VAB: Valle Agua Blanca section; VSF: Valle San Felipe; VST: Valle Santo Tomas section; VT-VSM: Valle de la Trinidad-Valle San Matias section.

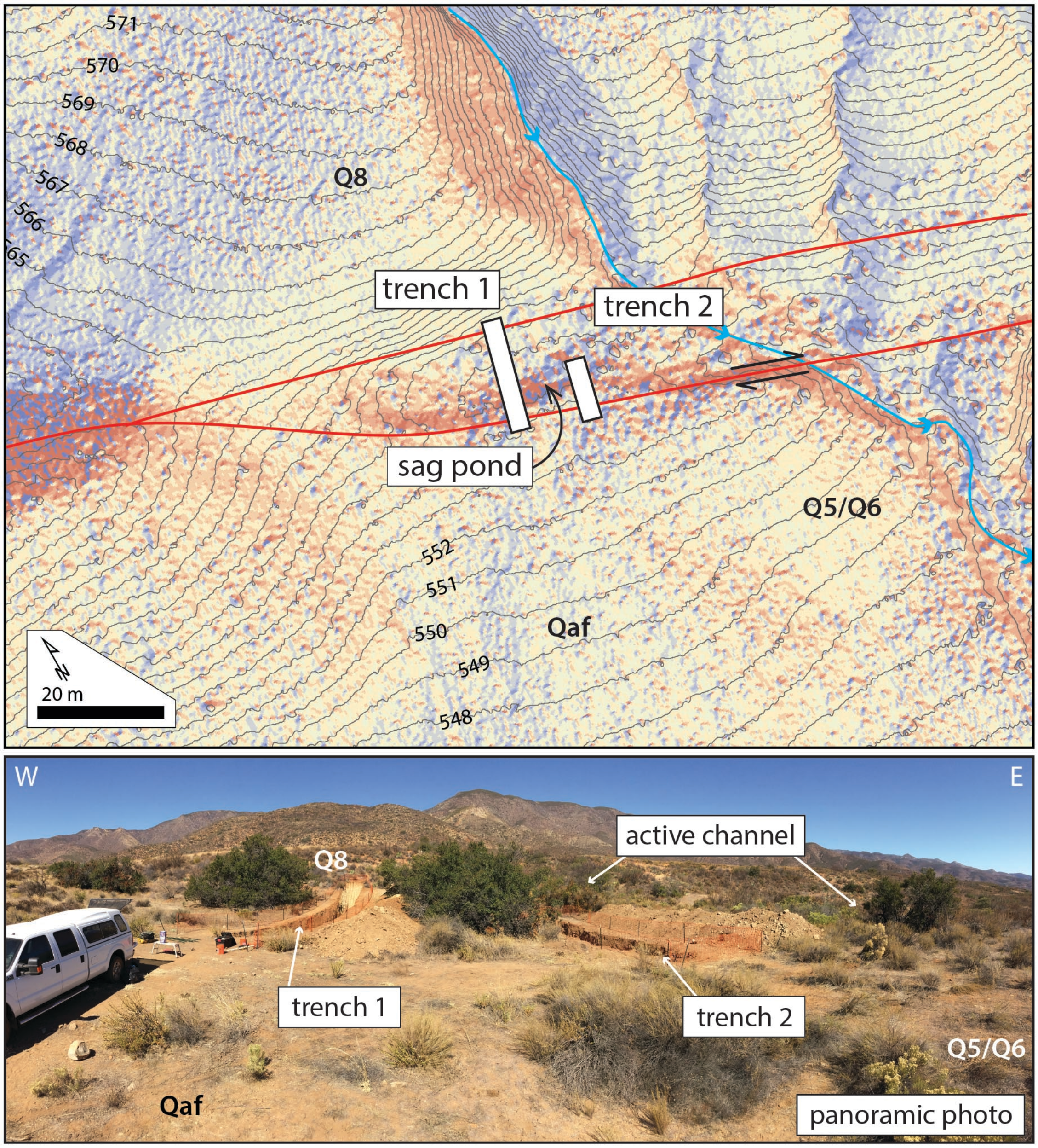

Figure 2 Trench Map and Panoramic Photo

Map (top) and photo of the trench site showing locations of the excavations with respect to the fault, the sag pond and the flanking alluvial deposits.

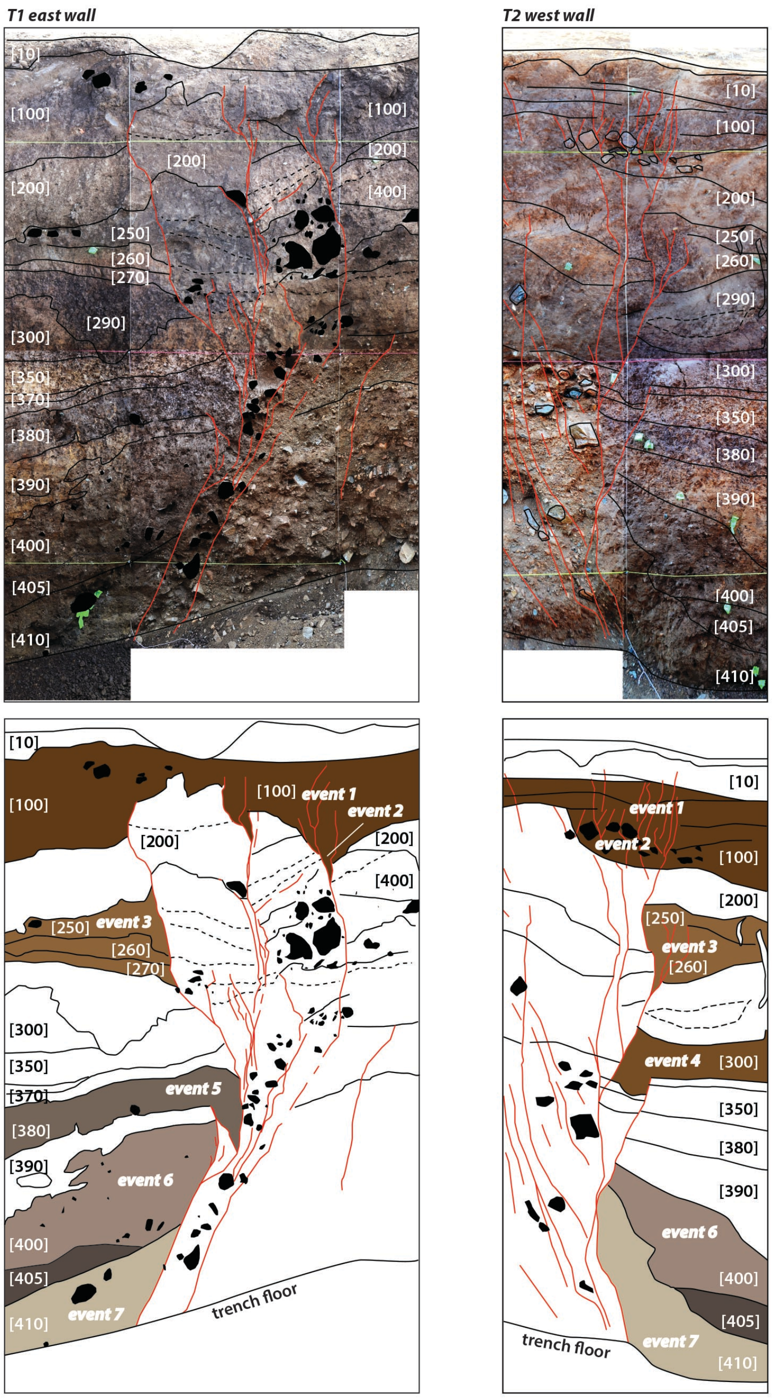

Figure 3 Event Evidence

Stratigraphic deposits correlating with surface ruptures. See text for detailed descriptions.

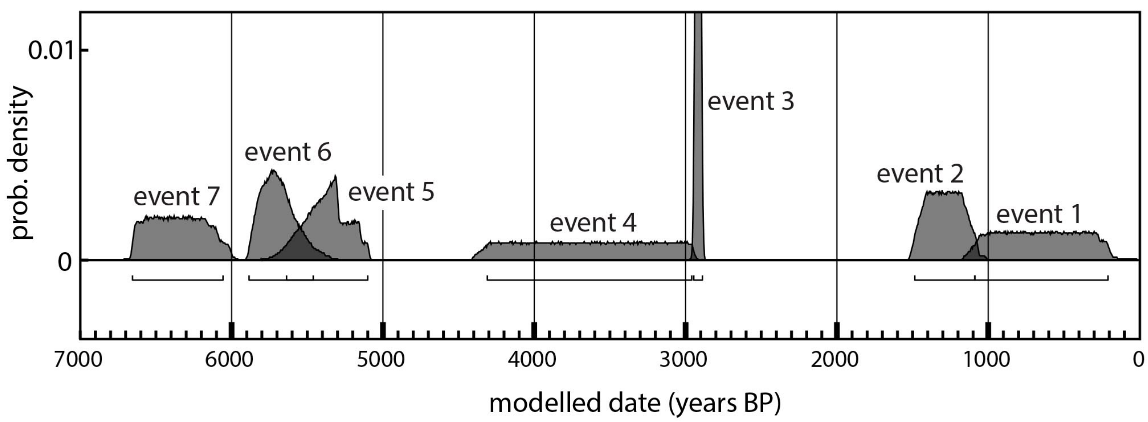

Figure 4 Event Evidence

OxCal PDFs for the timing of 7 events identified in trench 1. Events 5 and 6 may represent a single earthquake cluster rather than signify the passage of a full earthquake cycle.

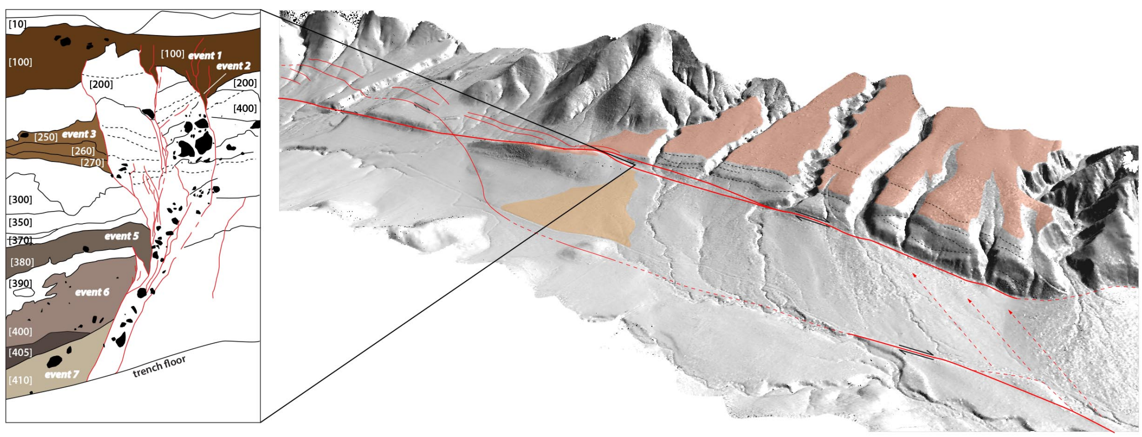

Figure 5 Valle Agua Blanca Lidar Perspective Map (Exemplary Figure)

Oblique view of the central portion of the Valle Agua Blanca section of the ABF showing the along-strike position of the trench site and the trench log from the east wall of Trench 1. The topography is visualized using a hillshade effect over the lidar point cloud. The ABF makes a ~350 m right releasing step from the southern to northern side of the valley.

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