SUPPLEMENTAL MATERIALS

S1 Additional Information on Methods

S1.1 Geologic Mapping

We conducted geologic mapping at Badger Canyon (Fig. 3) at scales ranging from 1:1500–1:6000, using as a base digital, georeferenced, 1-foot-resolution, color aerial photography flown on 1 April 2007 and available from the U.S. Geological Survey (USGS) at http://earthexplorer.usgs.gov/. We overlaid these digital aerial photographs onto a hill shade digital elevation model constructed from 0.5-m-resolution light detection and ranging (LiDAR) imagery from the B4 project (Bevis et al., 2005). Other base-map resources included stereo aerial photography (1983, USDA, 1:14,000 scale; 1971, I.K. Curtis, 1:6300 scale; and 1938, unknown source, 1:20,000 scale). We mapped the Pitman Canyon landslide at a scale of 1:24,000 onto the USGS topographic quadrangle for Devore, using the 1938 and 1971 aerial photographs as a reference (Weldon, 1986) (Fig. 14).

S1.2: Geochronology

We collected samples for luminescence dating by hammering opaque plastic or steel tubes (~20 cm long) into freshly cleaned natural exposures. The tubes were sealed and placed in light-proof photographic bags pending the initial processing at the University of Cincinnati. Laboratory preparation follows methods described in Seong et al. (2007). Luminescence signals were measured using a Risø TL/OSL reader (model DA-20). Luminescence from quartz grains was stimulated using an array of blue light-emitting diodes (470 nm, 50mW/cm2) filtered using a green long-pass GG-420 filter. Detection was through a Hoya U-340 filter. All quartz aliquots were screened for feldspar contamination using infrared stimulation with infrared light-emitting diodes (870 nm, 150 mW/cm2). All optically stimulated luminescence (OSL) signals were detected using a 52-mm-diameter photomultiplier tube (9235B). The equivalent dose (DE) measurements were determined on multiple aliquots using the single aliquot regenerative (SAR) method protocol developed by Murray and Wintle (2000). Growth-curve data were fitted using linear and exponential trend curves. The DE value for every aliquot was examined using Risø Analysis 3.22b software. Aliquots with poor recuperation (>10%) were not used in the age calculations. For each sample, equivalent doses of all aliquots were averaged and then divided by the dose rate to give a mean age (Table 2).

For each soil profile, we used standard measures of field properties, including color, texture, structure, dry and wet consistence, and clay films (Soil Survey Staff, 2010; Birkeland, 1999). After determining a profile development index using rubification, texture, clay films, and dry consistence (Harden, 1982; Harden and Taylor, 1983), we used these indices to assist with correlation of units and with assessing the reliability of radiocarbon and luminescence ages.

For 10Be dating, we selected boulders based on height above ground surface to minimize chances of recent exhumation, stability of surrounding fan surface (e.g., away from slopes at the edges of the alluvial fan surface), and lack of evidence for spallation and other forms of surface weathering. The samples were processed at the Geochronology Laboratories at the University of Cincinnati. Each sample was crushed and sieved to obtain the 250–500 µm grain size fraction. Quartz isolation, dissolution, chromatography, isolation of Be, and preparation of BeO followed the methods of Kohl and Nishiizumi (1992) for all samples. These methods are described in detail in Dortch et al. (2009). Ratios of 10Be/9Be were measured using accelerator mass spectrometry at the Purdue Rare Isotope Measurement Laboratory at Purdue University (for samples from Pitman Canyon) and at the Center for Accelerator Mass Spectrometry at the Lawrence Livermore National Laboratory (for samples from Badger Canyon).

S2. Additional Descriptions and Age Constraints for Geologic Units at Badger Canyon

This section of the appendix provides more detailed descriptions of many of the geologic units described briefly in the text of the paper, as well as more thorough discussion of the age constraints on these units and exploration of alternative interpretations. Material from the text of the paper is generally not repeated here.

Geologic mapping by the USGS in the San Bernardino Valley region has led to a regional classification of surficial units (e.g., Miller et al., 2001; Morton and Matti, 2001). Although for simplicity we developed our own labels for many of the surficial units, here we also provide the equivalent unit labels in the USGS scheme so as to place our mapping into a regional context. We consider our Late Pleistocene units (Qf1, Qf2, Qf2a, Qt2-w, Qf2b, Qc2, and Qls2) to be equivalent to the USGS Qo3-designations, our latest Pleistocene to early Holocene unit (Qf3) to be equivalent to the USGS Qy1-designation, and our Holocene units (Qf4, Qa4, and Qa5) to be equivalent to the USGS Qy5-designation. In the Pitman Canyon study area, map unit designations are consistent with Weldon (1986).

*S2.1: Bedrock Units*

Bedrock northeast of the San Bernardino strand in the vicinity of Badger Canyon (Fig. 3) includes: (1) Cretaceous biotite monzogranite (Kmg) between the Arrowhead Springs and Mill Creek strands; and (2) Miocene (age uncertain) conglomerate and arkose locally known as Potato Sandstone between the Mill Creek and San Bernardino strands of the San Andreas fault zone (Miller et al., 2001).

In addition to the bedrock units described above, there is a ~15-m-wide strip of granitic bedrock similar to Kmg located immediately northeast of and parallel to the San Bernardino strand. This strip is mappable east of Badger Canyon and is also exposed just north of the San Bernardino strand in WT-1A (beneath Qf2a) and in WT-2 as well as in road-bed outcrops along the dirt road north of the north end of WT-2. We interpret this strip of granitic rock as a fault-bounded sliver between the San Bernardino strand and an older, unexposed, subparallel fault strand located ~15 m farther northeast. The granitic outcrops within this sliver exposed in WT-1A and WT-2 are white, highly weathered, and locally powdery. We initially considered interpreting these as landslide deposits, but if they were landslides, they would also have covered the outcrops of Tc north of these deposits (just west of WT-1A).

*S2.2 Early to Middle Quaternary Stratigraphy*

Early to middle Quaternary deposits include (Fig. 3): (1) a remnant of gravel with granitic and gneissic boulders derived from Badger Canyon (Qvof1), located just southwest of the Arrowhead Springs fault on the west margin of Badger Canyon; (2) an early Quaternary, marble-rich landslide (Qvols-m), which overlies Qvof1; (3) a veneer of alluvium or colluvium (Qvoc2) with strong red soil that overlies Qvols-m. These Qvoc2 deposits are thin but extensive, extending beyond Badger Canyon and covering many of the hillslopes between major canyons in the San Bernardino area.

*S2.3: Latest Quaternary Alluvial and Landslide Stratigraphy*

***S2.3.1: Qf1.*** Deposits of the Qf1 alluvial fan were exposed in trenches WT-9A, WT-10, and WT-11 (Figs. 3 and S1). Qf1 deposits consist of both clast-supported and matrix-supported, cobble- to small boulder-gravel. Clast lithologies include felsic to intermediate plutonic rocks, gneiss, pegmatite, aplite, and rare epidote. Some clasts are weathering in place. The deposits are mostly unstratified, but sand layers are locally present.

Qf1 deposits comprise alluvial fan remnants that have been incised near the fault; the distal portions of this alluvial fan are buried by younger deposits (Fig. 3). This suggests either that these alluvial fan deposits have been tilted down to the southwest or that they were deposited at a steeper gradient than the younger alluvial fans. Limited exposures of alluvium with a strong red soil are present along the western margin of Badger Canyon northeast of the San Bernardino strand (Qa1 in Fig. 3). These deposits were not exposed in any excavations, and their age is unknown but is likely Late Pleistocene. These deposits may be correlative with Qf1 southwest of the San Bernardino strand and are designated as such in Figure 3. They are right-laterally separated from Qf1 by ~700 m across the San Bernardino strand.

We collected two OSL samples from a sand layer ~2.8 m below the surface of Qf1 in WT-9A (Figs. 3 and S1). These samples yielded ages of 18.1 ± 2.8 and 18.4 ± 3.6 ka (BC8 and BC9 in Table 2). These ages cannot be an accurate estimate of the age of Qf1, however, because they are comparable to or slightly younger than the OSL dates from Qf2 (20.6 ± 3.0 and 22.2 ± 3.6; Table 2), yet Qf1 must be older than Qf2 because it is offset a greater distance from the mouth of Badger Canyon and has a better developed soil profile.

Three 10Be exposure ages on boulders from the Qf1 surface have overlapping ages between 26 and 36 ka (samples BC1, BC2, and BC3 in Tables S2 and S3). The 10Be ages from Qf1 could underestimate the age of Qf1 due to the possibility of exhumation and erosion of the boulders, or they could overestimate the age of Qf1 due to the possibility of inherited 10Be from a prior exposure history. The soil developed at the surface of Qf1 (described in trench WT-10) has a 180-cm-thick argillic horizon with few moderately thick and common thin clay films (Table S3), suggesting an age of *circa* 45 ka based on soil correlation techniques. If taken at face value, the 10Be ages and soil age estimate from Qf1 would yield a slip rate ~15–27 mm/yr, but this range does not represent the full uncertainty in the ages nor in the amount of offset. Because of the large uncertainty in the age of Qf1 and the difficulty in quantifying that uncertainty, we do not have confidence that any meaningful slip rate can be reported for Qf1.

***S2.3.2: Qf2 and Qf2a.*** Deposits of the Qf2 alluvial fan were exposed in trenches WT-3B, WT-3C, and WT-7B (Figs. 3, S2, and S3). The Qf2 deposits consist of mostly clast-supported cobbles to small boulders with a matrix of coarse sand, granules and pebbles. Dominant clast lithologies are felsic to intermediate plutonic rocks, gneiss, and pegmatite. The deposits are mostly unstratified, but sand layers are locally present.

Deposits attributed to Qf2a are exposed in trench WT-1A, for the first 100 m northeast of the San Bernardino strand (Fig. 5). They overlie highly weathered granitic rock within the first 15 m north of the fault, and their base is unexposed farther northeast. Qf2a deposits include clast-supported gravel with subangular cobbles of gneiss, diorite, granite, bedded tan sandstone, white to pinkish-white sandstone, and white sandstone or limestone with angular grains.

***S2.3.3: Qt2-w.*** Surface exposure ages were estimated from 10Be concentrations in four boulders on Qt2-w (Fig. 3 and Tables S2 and S3). The oldest 10Be age (BC8 at 41.7 ± 1.74 ka) is most likely not an accurate estimate of the age of Qt2-w because it is older than both the 14C and OSL ages from Qf2, which must be older than Qt2-w. Given the factors that can make surface TCN exposure ages on boulders either too young or too old, we favor the 14C and OSL ages when there is disagreement between the ages. The old apparent age of this boulder could be a result of inherited 10Be from a prior exposure. The two youngest 10Be ages (BC7 at 11.38 ± 0.67 ka and BC5 at 16.07 ± 0.88 ka) cannot provide an accurate estimate of the age of Qt2-w because they are comparable to or younger than the 14C and OSL ages from Qf3 (Tables 1 and 2), which must be younger because it is offset a lesser distance and has a less developed soil profile than Qt2-w. The young apparent ages of these boulders may be a result of erosion or exhumation of the boulders (e.g., Hallet and Putkonen, 1994; Kendrick et al., 2016). The remaining 10Be age from Qt2-w (BC-6 at 21.74 ± 1.0 ka) is roughly comparable to our estimate of the radiocarbon age of Qls2 (23.1 ± 0.35 ka), which is a landslide deposit northeast of the fault that brought deposition on Qt2-w to an end (see below). The location of soil profile BC02 on Qt2-w is shown in Figure S2.

***S2.3.4: Qls2.*** The south-facing slope that we interpret as the toe of the Qls2 landslide was intersected by trench WT-4, and two shallowly north-dipping shear zones were exposed, one at the base of the slope and another ~4 m higher on the slope (Fig. 3) (for a trench log, see J. McKeown, unpublished report titled, “Subsurface investigation of faulting, Paradise Hills project, Badger Canyon area, City of San Bernardino, California, Prepared for Inland Communities Corporation, Job No. 05894-8,” 2006).

We considered and ruled out an alternate interpretation that the shallowly north-dipping shear planes exposed in WT-1A and WT-4 and the south-facing scarp that aligns with them were produced by reverse slip on the Mill Creek strand of the San Andreas fault. In this interpretation, the north-dipping shear plane in WT-1A, along which fractured granitic rock has been thrust over Qc2, would be interpreted as the Mill Creek strand of the San Andreas fault. However, this would imply that the Mill Creek stand has accumulated many meters of reverse slip since the time that Qc2 was deposited, and this is inconsistent with the lack of any scarp in Qf2b to the east, and with the presence of only very subtle scarps along the Mill Creek strand within the, much older, Qvoc east of Badger Canyon.

To further evaluate the plausibility of our landslide interpretation, we compared the lithologies within the proposed landslide deposits (Qls2) with the lithologies in the proposed head scarp region. Pink, potassium feldspar is abundant and easily visible within the granitic rocks (Kmg) of the source region. Within the granitoid rocks of the landslide deposit, pink feldspar is not common and, where present, is paler, perhaps as a result of more intense weathering of the fractured rocks in the slide deposit. The most commonly exposed lithologies found in the landslide deposits are: (1) fine-grained granitoid rock composed of white feldspar and quartz with a few percent biotite; (2) fine-grained plutonic rock (or Potato sandstone?) pervasively fractured into pebble-sized angular blocks (with no matrix between blocks) and with most fracture surfaces stained dark brown); (3) coarse-grained plutonic rock composed of quartz, white feldspar and 10%–20% weathered biotite, locally foliated. The first and third of these lithologies are present locally (probably as inclusions) within the dominant pink-feldspar-rich lithology of Kmg within the proposed source region, and all three lithologies are present elsewhere within Kmg. These three lithologies may be more common in the portion of the head scarp that is now buried beneath the upslope portion of the landslide deposits.

The boundary between the uppermost part of the landslide deposit and the undisturbed rocks of the head scarp region is difficult to delineate precisely because the Kmg source rock for the landslide is also heavily fractured and sheared. Trench WT-6 exposes the upper end of a gently south-dipping basal shear plane (J. McKeown, unpublished report titled, “Subsurface investigation of faulting, Paradise Hills project, Badger Canyon area, City of San Bernardino, California, Prepared for Inland Communities Corporation, Job No. 05894-8”, 2006), which may represent the upper edge (and thin western edge) of the same landslide exposed in WT-4 (Qls2). This interpretation is shown in Figure 7.

Within and near the upslope limit of the Qls2 deposit is a 1–2-m-high, 4–5-m-wide, east-west–trending ridge that is bounded by near-vertical faults. In some locations these faults juxtapose different facies of granitoid rock (Kmg; see the three facies described two paragraphs above) and in other locations the facies are the same on both sides of the faults. Whether these faults formed during the landslide motion itself and are restricted to the landslide deposit or this was a preexisting fault zone within the Kmg bedrock that remained intact as it slid with the Qls2 landslide block is unclear.

We considered and ruled out the possibility that this is a tectonic fault zone on which significant motion has occurred after the time of the landslide. A fault mapped by Miller et al. (2001) east of Badger Canyon, within Kmg, between the Mill Creek and Arrowhead Springs strands of the San Andreas fault zone, does project approximately to the location of this low ridge (Fig. 7). However, if motion on this fault continued after the landslide and was responsible for formation of the low ridge within the landslide deposits, then this fault zone would also have produced a fault scarp within Qf2b (Fig. 3) and would have been (but was not) visible within the Qf2b deposits within WT-1A, as Qf2b overlies granitic rocks of the Qls2 landslide deposit in trenches WT-1A (Fig. 5) and WT-1C.

***S2.3.5: Qf3.*** Deposits of the Qf3 alluvial fan were exposed in trenches WT-1A, WT-1B, and WT-2 (Figs. 3, 8, and S4). The Qf3 deposits consist of unstratified to crudely stratified, tan, poorly sorted gravel, mostly matrix-supported in WT-2 but mostly clast-supported in WT-1A. Clasts include subangular pebbles, cobbles, and small boulders, up to ~60 cm in diameter. Clasts include mostly felsic and intermediate plutonic rocks and gneiss, with minor amounts of pegmatite, biotite schistose rock, white sandstone, and marble. In trench WT-1A, the Qf3 deposits bury a remnant of much older alluvium (Qvof?).

***S2.3.6 Qf4, Qa4.*** The youngest fan, Qf4, is located at the mouth of Badger Canyon. On the northeast side of the fault, a terrace is inset into Qf2a,b and underlain by 2–4 m of sandy and gravelly alluvial fill (Qa4) derived from Badger Canyon. Qa4 deposits are physically continuous with Qf4. A detrital charcoal sample collected from a natural exposure of Qa4 (Fig. S5) has a calibrated radiocarbon age of 1.1–1.3 ka (BC-51, split 1 in Table 1). The Qf4 alluvial fan has likely been offset a small amount during recent earthquakes. The precise amount of offset is indeterminable due to modifications to the alluvial fan for flood-control purposes, but is probably between 0 and 40 m. We do not attempt to estimate a slip rate using this fan.

***S2.3.7: Other deposits southwest of the fault.*** The Qf1 alluvial fan deposits are buried by younger alluvial fans (Qf3-m and Qf4-m) emanating from the next major canyon to the northwest of Badger Canyon, which is locally known as both Ben Canyon (on GoogleEarth) and Sweetwater Canyon (on local street signage). These deposits are easily distinguished from those of Badger Canyon by abundant marble and aplite clasts.

S3. Age Constraint on Alluvial Deposits Offset from Sycamore Canyon

Although the area east of Badger Canyon was beyond the scope of this study, we did view the seven trenches that were excavated by CHJ Consultants east of Badger Canyon (Fig. S6), and we collected and radiocarbon dated one charcoal sample (BC-20) from near the southern end of trench ET-2B (Fig. S6). We report the age of this sample (24.24 ± 0.22 ka) in Table 1 for archival purposes. We also note that this sample is from an alluvial fan whose nearest possible source channel is Sycamore Canyon, which has been offset ~320 m from the fan. This age and estimate of the approximate offset yield a similar slip rate (~13 mm/yr) to the three slip-rate estimates from the Badger Canyon site that are documented in this paper.