Slip Behavior of Faults through Several Earthquake Cycles
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Investigations Undertaken

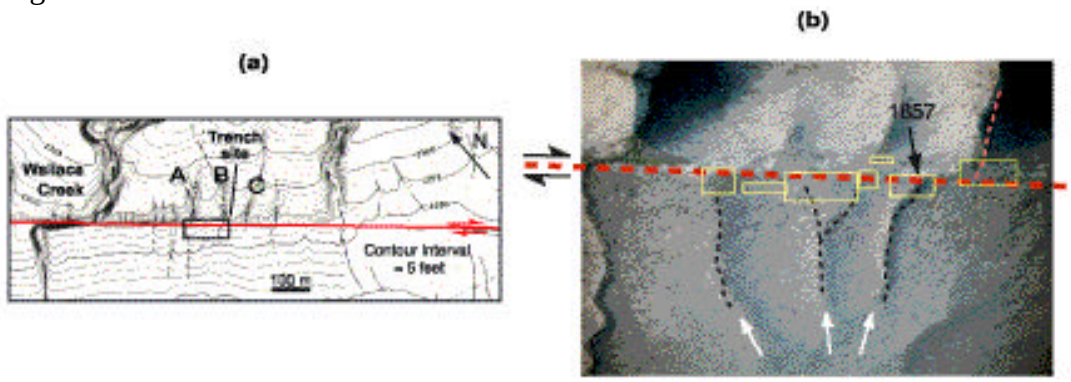

Fig.1 Location of our trench site. Fig.1a shows that our trench site is about 300 meters southeast of Wallace Creek, on the Carrizo section of the San Andreas fault. Fig.1b is the blow-up of the rectange region in fig.1a. Yellow rectangles are areas of our hand excavations, which straddle the channels. Four channels are still visible on surface, shown here as dashed lines and white arrows. 1857 event is indicated by the smallest offset of 8-9 meters.

This study is designed to document the offsets of recurrent earthquakes at a single location to see how slip varies through earthquake cycles. One of the best places to determine if a fault segment experiences similar amount of slip through time is a 100-meter section along the Carrizo segment of the San Andreas fault, just a few hundred meters southeast of Wallace Creek (Figure 1). There, small channels about a half-meter deep are cut by the simple, narrow, rectilinear trace of the San Andreas fault, three such small channels (labeled A, B, and C) have been incised several meters into the Pleistocene alluvial fan on the NE side of the fault. On the SW side of the fault, several small gullies are dextrally offset from these upstream channels. We proposed to excavate across the gullies shown as boxes in Fig.1b. Last year, we started excavating the

upstream trench and the youngest offset channel on the downstream side, both shown as yellow rectangles in Fig.1b.

During the past year, we continued the 3D excavation at this site, logging about 80 trench walls. Fig.2 shows the traces of the principal excavation walls in map view. In each trench cluster, the initial trench was parallel to and several meters from the fault. Subsequent faces were cut progressively closer to the fault, at increments of 50-60 cm, or 10-25cm if needed (for example, in the vicinity of the fault).

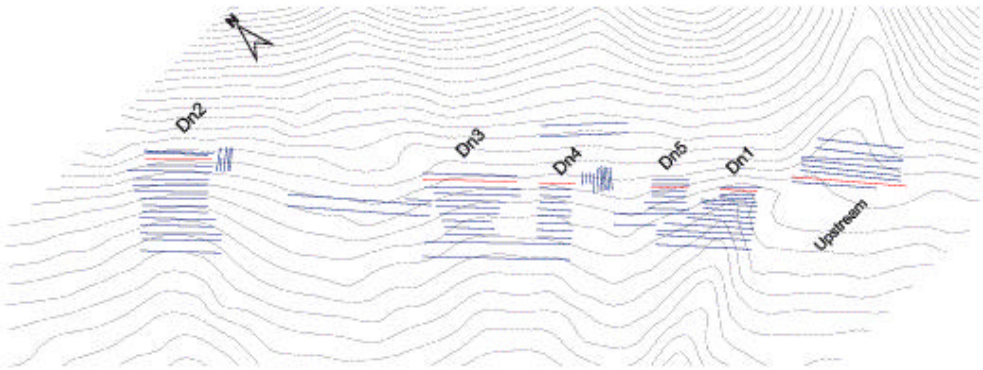

Fig.2 Traces of the principal excavation walls. The red lines indicate the locaion of the exposures shown in Fig.3a-f

Results:

Trench exposures

Fig. 3 shows the logs of representative cuts in each trench cluster, looking upstream, whose locations are shown as the red labeled lines on a map view in Fig.2. Fig.3a through e are those of the downstream channels. They are arranged from NW to SE, and by their geomorphic distance from the upstream channel. The distance indicates the relative ages of the channels, with the farther one being older. Fig.3f is the log on the upstream side.

Downstream

The downstream channels are 1-2m deep, mostly narrow, and covered with homogenous colluvium. Their thalwegs are generally well defined. The channels cut into massive bioturbated matrix-supported gravely sand and silt, with horizontal sandy and gravely lenses. A pedogenic carbonate horizon in this old deposits suggests that these deposits are several thousand years old, since in this region such concentrations of soil carbonate are only found in early Holocene or older deposits (Sieh and Jahns, 1984). The deposits within the channels are generally grayish, in sharp contrast with the surrounding whitish carbonate-coated Holocene alluvial fan deposits they cut into. The in-channel deposits consist of both poorly sorted gravely sand and silt, and well-sorted clast-supported channel sand and gravel beds.

Trench cluster dn2 lies about 55m NW of the upstream trench. Three channels were

exposed in this trench cluster (Fig.3a). The middle channel, “Buwalda” is made up of

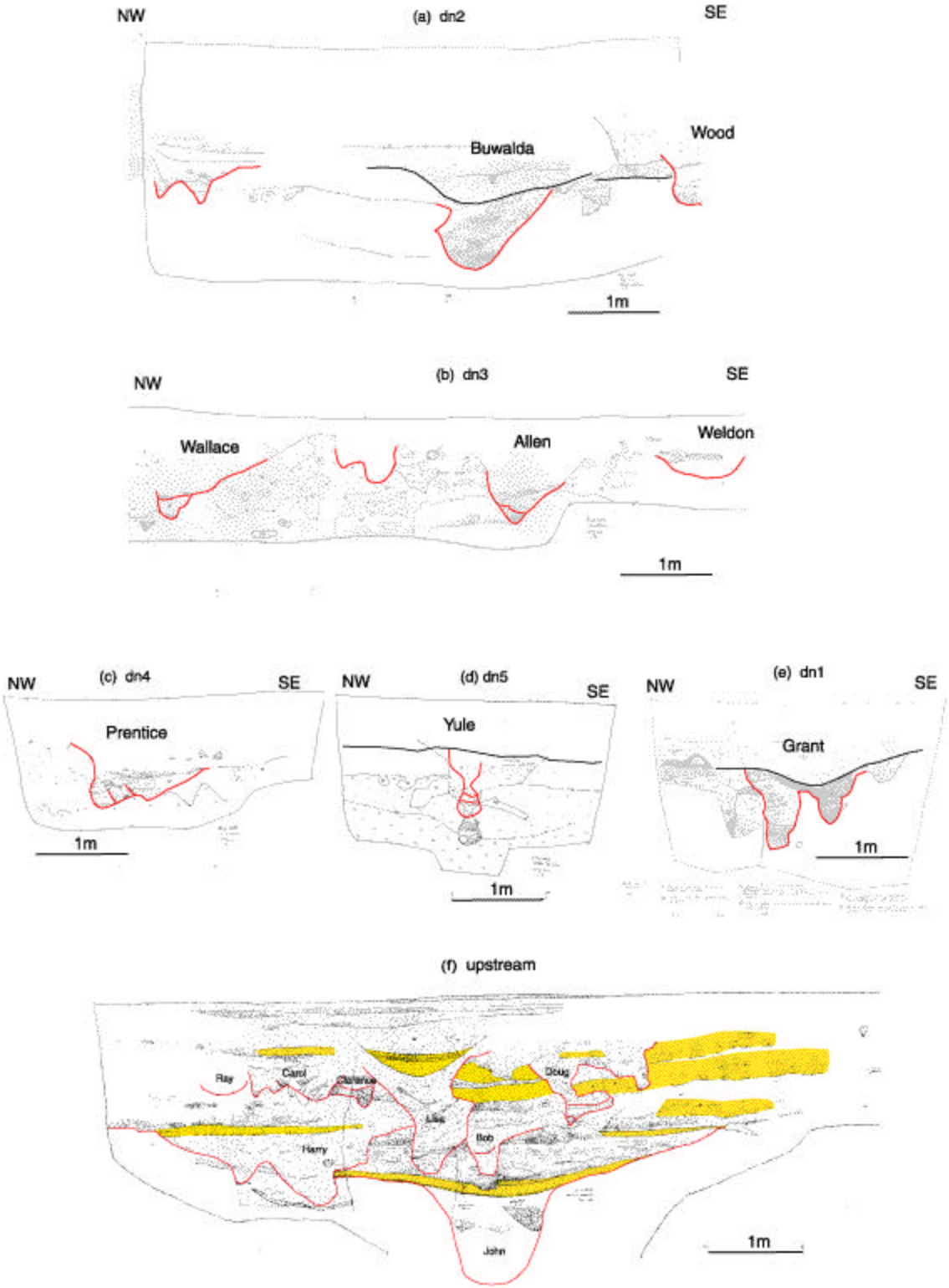

Fig. 3 Logs of the representative trench cuts, looking upstream. a through e are the downstream cuts, and arranged from NW to SE, and by the distance from the upstream trench, f is the upstream log. The channels are traced in red, and named after last names for the downstream one and first names for the upstream of people. Fault traces are shown by dark lines. The highlighted units in f are suspended load layers.

mostly massive loose clast-supported sand and gravels to pebbles. This channel contains the largest clasts among all the downstream channels. On the trench cut shown here, the channel is broad and deep, bounded by a fault on top. The channel deposit is 0.7 m thick on this cut. Yet, on other downstream cuts, the bedload is less than half the thickness. It is possible that the double thickness is due to faulting. There is a channel 3m NW of "Buwalda". A sample from a burn mark in the top part of this channel has 14C age of 2980+/-50 yrs. Given the slip rate of 35 mm/yr, this channel came from about 100 meters to the SE. The most probable candidate of its upstream half is the big channel "C" in Fig.1a. Channel "Wood" sits 2.5m to the SE of "Buwalda". It merges with "Buwalda" 2.5m downstream. The basal layer of bedload sand and gravels in "Wood" is continuous, and traceable.

Four channels were exposed in trench cluster dn3 (Fig.3b). "Wallace" is the leftmost channel. Most of its stratigraphy is destroyed by bioturbation. The remaining strata are two layers of sandy bedloads. One is at the base of the channel, the other one ~25cm above. The shallow channel 2m to the SE of "Wallace" is barely visible due to severe bioturbation. This channel merges with "Wallace" 5m downstream. Channel "Allen" is 1.5m further to the SE. It is deep and narrow, a series of bedloads are still visible near the bottom of the channel. "Weldon" lies SE of "Allen". The precise location of this channel is unclear on this wall due to severe bioturbation. On other downstream cuts, this channel is made up of the bedload of a cluster of 3-4 small channels, which merge with "Allen" 5m downstream from the fault.

In the three trench clusters that are closest to the upstream trench, we found three lone channels about 8 meters apart. Channel "Prentice" is the lone channel in trench cluster dn4 (Fig.3c). It is shallow and broad. Most of the in-channel strata are still well preserved. It has the distinctive domino-style stacking of three channels of sand and gravels. Fig. 3d shows the channel "Yule", a deep and narrow lone channel. It has a characteristic layer of upwardly fining sequence of horizontally bedded well-sorted sand and small gravels. Channel "Grant" is the youngest channel on the downstream side. It was offset 8-9 meters in 1857 earthquake. It is a double channel in this cut (Fig.3e). The main channel is the deep and narrow one on the left. The right one was previously inside the deep channel on downstream cuts. Channel "Grant" was bounded by fault on top.

Upstream

Upstream trench logs document a series of nested channels. There are 8 generations of channels that can be correlated with the downstream ones. The correlation is based on the relative ages, as well as the similarity in the shapes of channels and the initial filling of alluvium and colluvium in the channel. The relative ages of the channels is indicated by the cross-cutting relationships among the channels on the upstream side and on the downstream side by the amount of offset. The larger the offset the older the channel. We assigned names to all of the offset channels: each upstream channel bears the given name of a Caltech geologist who has studied the San Andreas fault; each downstream channel bears the surname.

Here is the brief description of the upstream channels from old to young. The oldest channel "John" is located near the base of our trench exposure. It is made up of a series of channel sand and gravels separated by homogeneous matrix-supported colluvium. Unlike its downstream counterpart, this channel has a broad lens of silty fine sand,

overlain by coarser sandy and gravely alluvium (colored in yellow in Fig.3f). The fines are suspended loads that settled from muddy water ponded upstream from the fault, after the earthquake brought a shutter ridge in front of the channel. The upstream channel was later buried further by coarser sandy gravel. Channel “Harry” was cut after “John” was filled up to the top of the shutter ridge. The earthquake that occurred after creation of Harry also brought a shutter ridge in front of the channel, which led to deposition of another lens of suspended load, on top of “Harry”.

The next channel in this sequence is “Bob”. Like the downstream channel “Wallace”, it has two layers of bed-load sand and gravel near the bottom of the channel. Two suspended-load layers are associated with this channel. They are wide, and extend well outside the channel. These suggest that the event that occurred immediately after the cutting of channel “Bob Wallace” had a large vertical motion, with the downstream side moving up.

Three channels, “Clarence”, “Ray” and “Carol”, cluster on the upper NW part of the trench wall. “Ray” and “Clarence” are two older channels, cut by “Carol”, and no obvious suspended load deposit was associated with them. Channel “Carol” has the similar domino-style stacking of three inset channels as the downstream channel “Prentice”.

Like “Yule” of the downstream channel, channel “Doug” has the characteristic layer of well-sorted and horizontally bedded sand and gravels. Although “Doug” is a double channel on this cut, subsequent excavation shows that the side channel to the right merges with the deeper left channel 0.5m downstream. The youngest channel “Lisa” sits in the middle of the trench wall. A prominent suspended-load lens of well-sorted fine sand and silt plugs the channel. It is overlain by sand and gravel beds.

Traces of thalwegs of the channels

Our sequential excavation procedure has enabled us to keep track of the locations of channels along their course. It also has allowed us to detect the fault-related shift in channel course.

Our excavation shows that the upstream channels are straight, except channel “Harry” which diverges to the northwest, through the shallow declivity that subparallels the fault. They are offset by a secondary fault 1m upstream from the main fault (Fig.4). Younger channels, “Lisa”, “Yule”, “Prentice” and "Ray" were offset about 45 cm across this secondary fault; older channels were offset double that amount. It suggests that the secondary fault moved at least twice. The main fault zone is only about 0.5 meters wide.

On the downstream side, channels are separated by meters. They are also quite straight. The bases of four channels, “Buwalda”, “Prentice”, “Yule” and “Grant”, runs into the fault at a high angle. Channel “Wood” is 3.5m to the SE of “Buwalda” at the fault and quickly merges with “Buwalda” 5-6 m downstream. It fits with the northwest divergence of the upstream channel “Harry”. Channel “Allen” is straight except a gentle curvature about 1.5 to 4.5 m downstream from the fault. “Wallace” and “Weldon” join “Allen” from left and right respectively. “Wallace” diverges from the fault diagonally, trying to avoid the topographic high to the left. Also note that there is a channel flow almost parallel to fault before it joins “Prentice” 1.5 m downstream.

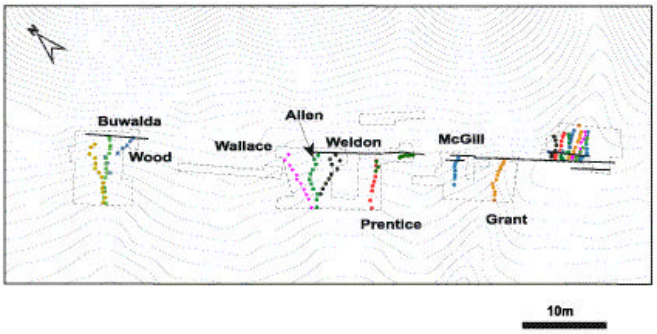

Fig.4 Traces of the thalwegs of the offset channels. The same channel on two sides of the fault is colored the same. For the convenience of references, each channel on the downstream side of the fault is named after a Caltech-graduate scientist who have worked on the San Andreas fault. The dark lines trending NE are fault traces exposed in the trenches. Most channels are straight and intercepted by the fault at a high angle.The main fault zone is narrow, about 1 meter wide, a secondary fault was found on the upstream side of the fault, and there is about 50-80 cm offset occurred on it.

Matching channels on two sides of the fault

The offset of the channels can be best visualized as shown in Fig.5. It is an imaginary view of the fault plane looking downstream. Red dots are the locations where the thalwegs of channels run into the fault. The shapes of the channels are also included for comparison. Upstream channels cluster on the left part of Fig.5, downstream channels spread on the right. Older channels were offset farther from the upstream channels as they experienced more earthquakes. The pairing of the same channel on two sides of the fault gives how much the channel has been offset since formed, both in horizontal and vertical.

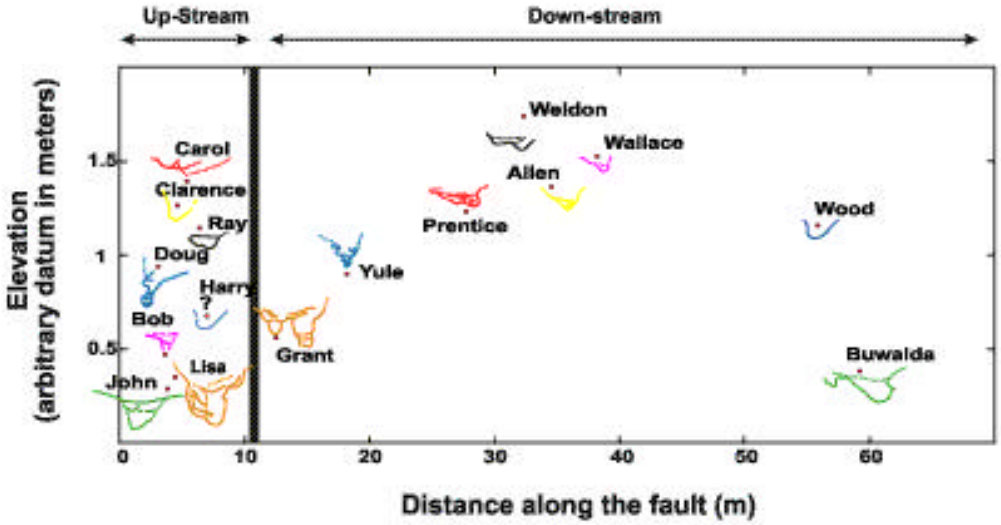

Fig.5 A imaginary view of the shapes and positions of the channels on the fault plane, looking downstream.The red dots are the locations of the thelwags of the channels literally on the fault. Of the same channel, the upstream half is named after the first name and the downstream half the last name of the same person, and in the same color. The pairing of the channels on two sides of the fault, will tell how much the channel has been offset since formed, both in horizontal and vertical.

Slip patterns of earthquakes through time

Fig.6 is the summary of the cumulative offsets of the 8 channels. The slip of individual event is simply the difference in the amount of offset between the two adjacent channels.

Our study shows that slip varies from earthquake to earthquake. But generally there are two types of earthquakes: the three youngest events are similar in slip, with 7-8 meters horizontal component and less than 2% of the horizontal component in vertical. Three earlier events, the fourth to sixth are, in contrast, only half the horizontal amount, but have a large vertical component of 10-20%. The oldest event that was found at this site has slip similar to the three youngest events. There is no systematic variation in the sense of vertical motion. Since "Harry Wood" is offset 14 meters more than "Bob Wallace", it is possible that 14 meters was generated in a single, gigantic event of 14 meters, or accumulated in two 7-8 meter-offset, or three to four 3-5 meters-offset earthquakes. In the latter two cases, there must be a period of depositional hiatus, so that no channels were cut between the earthquakes.

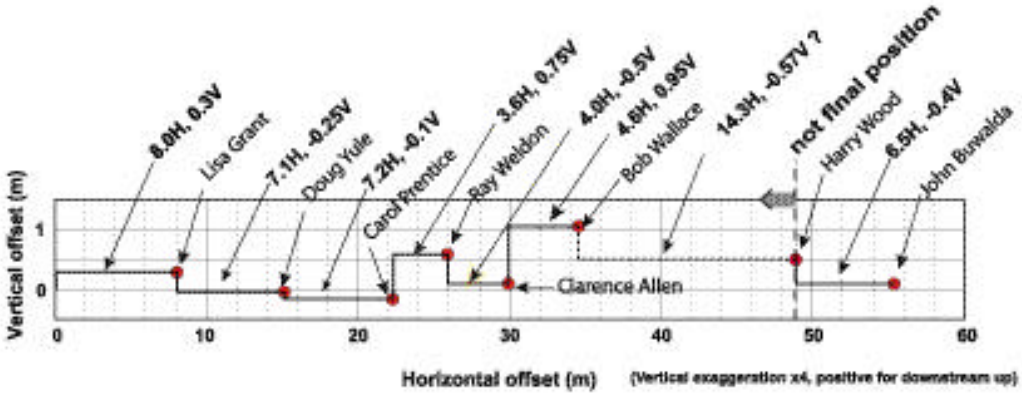

Fig.6 Cumulative offsets of the 8 channels and the slips of individual earthquakes. The red dots show the cumulative offset in both horizontal and vertical, of the channels. The difference between two adjacent channels gives the slip of the earthquake that occurred in between.

Non-technical Summary

This project is designed to understand how fault slip repeats through many earthquake cycles. Are the earthquakes characteristic or do they vary from event to event? The answers to these questions have both theoretical and practical significance. They will help us to better understand how strain is accumulated and released on faults, hence will improve our ability in earthquake hazard evaluation.

Our study shows that there are two types of earthquakes occurred in this section of the San Andreas fault: one with 7-8 m in horizontal, another one of 3-5 m. The events of smaller offsets have larger vertical component.

Reports Published

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Fault through several earthquakes. EUG meeting, April 11-14, France.