2006 SCEC Proposal

Tectonic geomorphology and earthquake geology of the 1857 reach of the San Andreas Fault: a new look from Airborne Laser Swath Mapping

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Institution: Arizona State University
Proposal Categories: 1) Data Gathering and Products and 2) SCEC Intern Project
Disciplinary Committee: Geology
Focus Groups:

1. Earthquake Geology
2. Fault Systems – fault-system behavior

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* note that Arrowsmith did not submit a SCEC proposal for 2005; therefore no progress report will be submitted.

Technical Description:

Introduction

Important information about paleoearthquakes is recorded in the meter-scale tectonic geomorphology of the fault zones. Such information is available from both the longer term (100s of meters) and shorter term (10s of meters) records of offset. In addition, detailed understanding of the geomorphology is essential for any paleoseismic siting effort. Typically, the tectonic geomorphology is assessed with aerial photography, 10-30 meter resolution Digital Elevation Models (DEMs) from the USGS, and manual field survey. However, until now, only field survey really provided topographic information at an appropriate scale for characterization of the tectonic geomorphology of the San Andreas Fault zone over distances relevant for complete characterization of paleoearthquakes.

The 1857 reach of the SAF stretches from Parkfield in the NW to near Cajon Creek in the southwest (Figure 1; Sieh, 1978). While much effort is currently focused on understanding the paleoearthquake history of these segments of the fault using paleoseismology, the geomorphic record of the last few earthquakes has not been carefully characterized in its entirety since Sieh's groundbreaking 1978 study. That effort was notable for its thorough field-based characterization of the rupture, and the resulting offset distribution is still widely accepted as a good measure of the 1857 slip. Sieh's work included field observations of offset landforms for at least 15 minutes at each site and in a number of cases careful topographic and geomorphic maps documented the offset features. The study included more than 180 offset determinations (mostly for the 1857 event, but prior offsets were inferred and measured as well, Figure 1). A notable re-assessment of the observations along the northern portion of the rupture along the Cholame segment by Lienkaemper (2001) discovered a number of new features and reinterpreted some offsets to infer a somewhat higher slip than Sieh for that fault reach (~3 vs. ~5 m). Such a difference has large implications for interpretation of the 1857 event magnitude and for the potential of an M7 earthquake along the Parkfield and Cholame segments where slip since 1857 has accumulated to almost 5 m (e.g., Arrowsmith et al., 1997; Harris and Archuleta, 1988; and Toke and Arrowsmith, in review). Detailed stratigraphic study such as that by Liu, et al., 2004 provide high quality measurements of offsets along a ~100 m reach of the SAF in the Carrizo Plain. While the field-based efforts provide the best opportunity for understanding the geomorphic and tectonic history of a site, they require the classic tradeoff between coverage and detail.

The emergence of Airborne Laser Swath Mapping (ALSM; also known as LiDAR "Light, Distance, And Ranging") has stimulated new research in the fields of tectonic geomorphology and paleoseismology. The technology uses ~10 μs laser pulses fired at 10s of khz from a plane to scan the ground surface. Reflections from surfaces separated by >0.5 m are recorded. Returns include vegetation (e.g., forest canopy), other objects, and the ground. Given a typical aircraft position of 600 m above ground surface and 100 mph speed, a swath width of about 350 m with decimeter spacing between shots on the surface is achieved. Wider coverage comes from multiple passes with 50% overlap. Global Positioning System (GPS) position control and Inertial Navigation Unit (IMU) data are combined with the time of flight for the laser data to produce a point cloud of absolutely located 3D laser returns. Filtering the data for the ground returns produces a bare earth model showing detailed topographic features that may have never been previously imaged (Harding, 2001). High-resolution topographic images have been especially usefully in mapping new faults in areas of dense forestation and canopy cover such as in the Puget Sound (*e.g.* Harding and Berghoff, 2000). The first post-seismic ALSM survey was conducted after the Mw 7.1 1999 Hector Mine earthquake in the Mojave Desert of California (Hudnut *et al.,* 2002).

A major effort by Mike Bevis (Ohio State University), Ken Hudnut (USGS) and many others to "laser scan" the southern SAF (Parkfield to southernmost SAF and San Jacinto fault) has recently been completed (Bevis, et al., 2005) with the B4 segment (Cajon Creek to Mission Creek) data released. The rest of the survey data will be released in the coming months. This effort used ALSM technology with enhanced GPS and IMU to deliver a high precision dataset that is about 1-2 km wide with more than 4 ground returns per square meter. Their plan is to not only gather the topographic data for its geomorphic characterization, but also use it as the "before surface" which will be compared to deformed topography following a major rupture along the SAF in the future.

I propose to take a new look at the 1857 reach of the SAF using these data. The research questions are both scientific and technical:

1) What was the offset distribution in the 1857 earthquake? Can the Sieh, 1978 (& Lienkaemper, Liu, and other site specific studies) dataset be refined using the ALSM?
2) What were the likely offsets at sites along the same reach in the prior earthquakes?
3) How efficient is the ALSM for quantitative assessment of the tectonic landforms (in particular determination of offset)? How well does the idea of differencing the repeat ALSM after the next earthquake work?
4) Where are new potential paleoseismic sites along the reach and what is the local geomorphic control on the stratigraphic record?
5) Where are the high quality tectonic landforms that record the slip history of the last several earthquakes?

Proposed Plan and Methods

Figure 2 shows a piece of ALSM data collected in summer 2005 along the SAF in the southern Carrizo Plain (see Figure 1 for location; data courtesy of George Hilley). It shows the spectacular rendering of the topography of the SAF in the 1 m DEM. The offset channels along the fault are clear. A major difference from high resolution aerial photography is that with this topography, one can quantitatively compare the offset topography to make high quality offset measurements such as the example shown. In that case, two profiles parallel to the SAF were offset 20.9 m in the last 3-5 earthquakes.

Figure 2 shows the basic work plan:

1) Establish GIS with background USGS aerial photography (and if available, high resolution imagery gathered during the Bevis, et al. flights), other digital data, existing fault zone strip mapping (e.g., Vedder and Wallace, 1970; Alquist Priolo data), and ALSM DEMs.
2) Working with Sieh, 1978 data, locate, reassess, and archive information on offset landforms at all sites. We have already started to build the database illustrated in Figure 1. But some of his locations are uncertain to within a hundred meters. With the ALSM data we can positively associate his measurements with a landform in the imagery; locate it absolutely, and characterize it. This will also be done for all other site specific offset studies (e.g., Lienkaemper, 2001; Liu, et al., 2004; and others to the southeast). We will develop Matlab or ArcGIS-based tools for offset determination and test ways of estimating both the quality of the measurement and its uncertainty.
3) Identify and characterize new offset features.
4) For all offset measurements, determine vertical component of motion if possible and seek to relate that to reach scale fault zone geometry or other controls.
5) In order to do the offset determinations, using all of the geospatial data, but emphasizing ALSM, map the principal active fault traces.

6) Field check (including photography) as many of the sites as possible to assess the ALSM-based characterizations.

The data we gather will be presented as GIS shape files or geodatabases and will include the locations, photography, quality, uncertainty, magnitude, and geomorphic description of all offsets. In addition, we will deliver the fault trace mapping as GIS shape files or geodatabases (this would also include high quality paleoseismic sites useful for either detailed slip per event study or earthquake timing). All of the data will be presented to the SCEC community using an ARCIMS site for interaction with the map data and download. Our research group has built several sites of this type (e.g., http://aspen.asu.edu/website/Geoinformatics/viewer.htm). We will follow the approach developed by Prentice, et al. for presentation of these data in a coherent manner (they used this GIS-based approach for the SF Peninsula segment of the SAF).

I expect that the results of this project will not only be delivered as described in the previous paragraph, but also will form the basis of a journal article (for Bulletin of Seismological Society of America) on the tectonic geomorphology of the 1857 reach of the SAF and its record of the 1857 event. It would include a refinement of the moment estimate for the 1857 event, possible prior event slip distributions, description of the rupture pattern from recent events, and technical commentary about the usefulness ALSM dataset and lessons learned from its application.

This project leverages two other ongoing relevant efforts in my research group. Lisa Grant, Sinan Akciz and I have an NSF-funded project ongoing in the Carrizo Plain to build a long (>10 event) earthquake recurrence record at the Bidart site (Grant and Sieh, 1994; Grant, et al., 2005). The 1857 and earlier events are of great interest to us. Better knowledge of the slip distribution is essential for their proper analysis. Secondly, through our efforts on the GEON project (http://www.geongrid.org), Chris Crosby and I have spent a lot of time thinking about and developing tools for improved ALSM data handling and quantitative analysis (e.g., Crosby, et al., 2005). This proposed effort will take advantage of that Information Technology effort, but also contribute discipline-based data integration and analysis scenarios.

Project Management

This work will be done by me and a graduate student under my supervision. I request consideration for an intern from the SCEC intern program. The graduate student and I will act as mentors for this intern as the intern will learn to characterize tectonic geomorphology, work at a high level with digital elevation models in a GIS environment, and gain a general understanding of active tectonics. Numerous small research projects could be extracted from this research for the intern to take the lead on and present at the annual SCEC meeting. Note that Arrowsmith and Lisa Grant had an excellent experience with SCEC intern Emily Starke in our Bidart paleoseismic investigation in 2005. We anticipate field assistance from other members of Arrowsmith's Active Tectonics research group at Arizona State University. This research will probably be included as a chapter in the graduate student's dissertation.

How this Project will help meet SCEC Goals

This project will provide scientific understanding of the slip distribution in recent major SAF earthquakes. By using the valuable Southern San Andreas Fault Laser scan data, we will take advantage of this unprecedented data set and contribute tools for its optimal use and assessment of its utility and limits in the characterization of SAF tectonic geomorphology. This project will also provide mentoring and professional training to graduate and undergraduate students.

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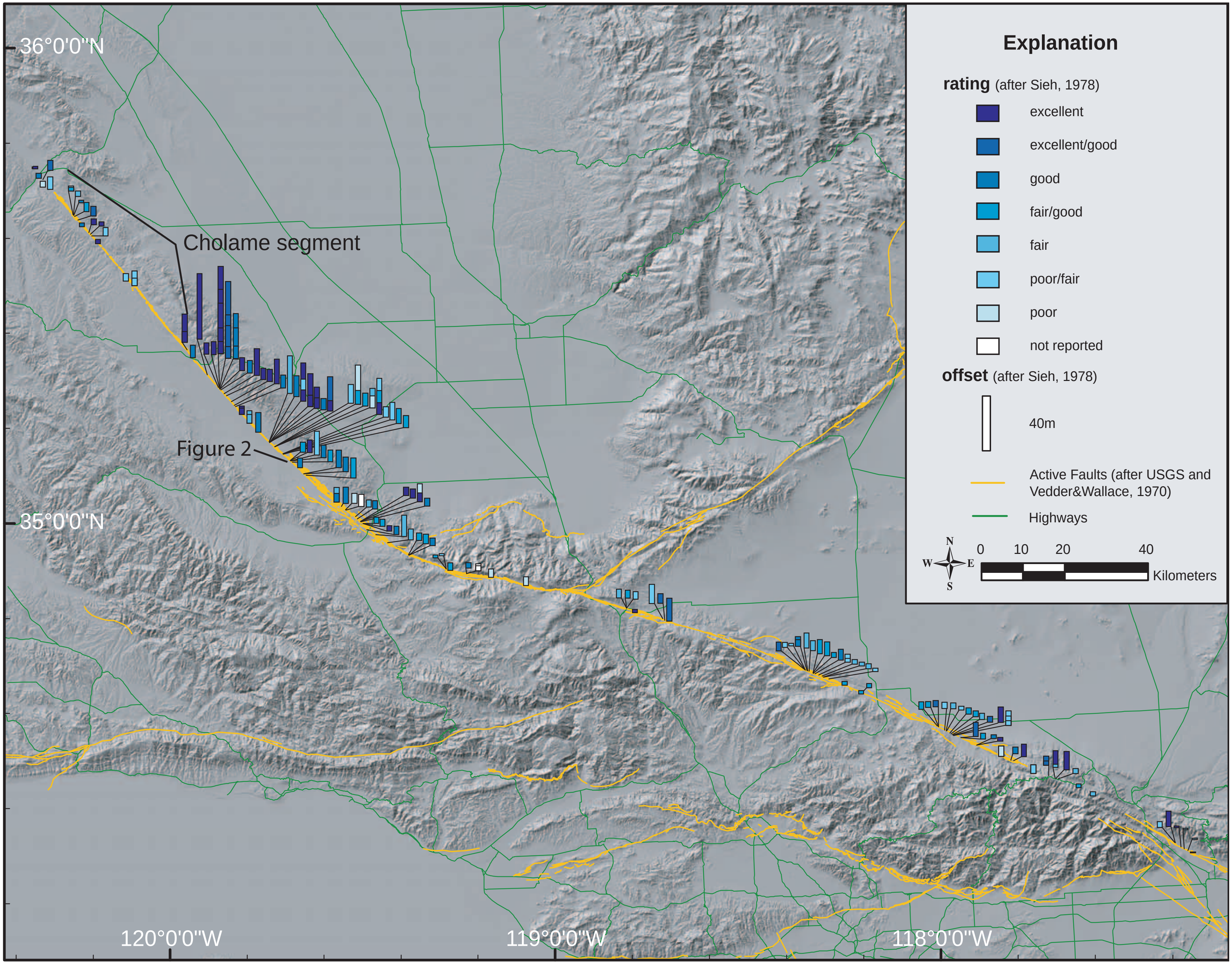

Figure 1. Offsets along the San Andreas Fault in Southern California (Sieh, 1978). The smallest offsets in this group are attributed to the 1857 earthquake. Offsets along the northwestern portion of the Cholame segment were also studied by Lienkaemper. The south central SAF preserves numerous offset landforms that will be uniformly charaterized in detail with high resolution ALSM. The entire SAF shown in this map has been imaged with ALSM. Active faults in yellow from USGS and Vedder and Wallace, 1970.

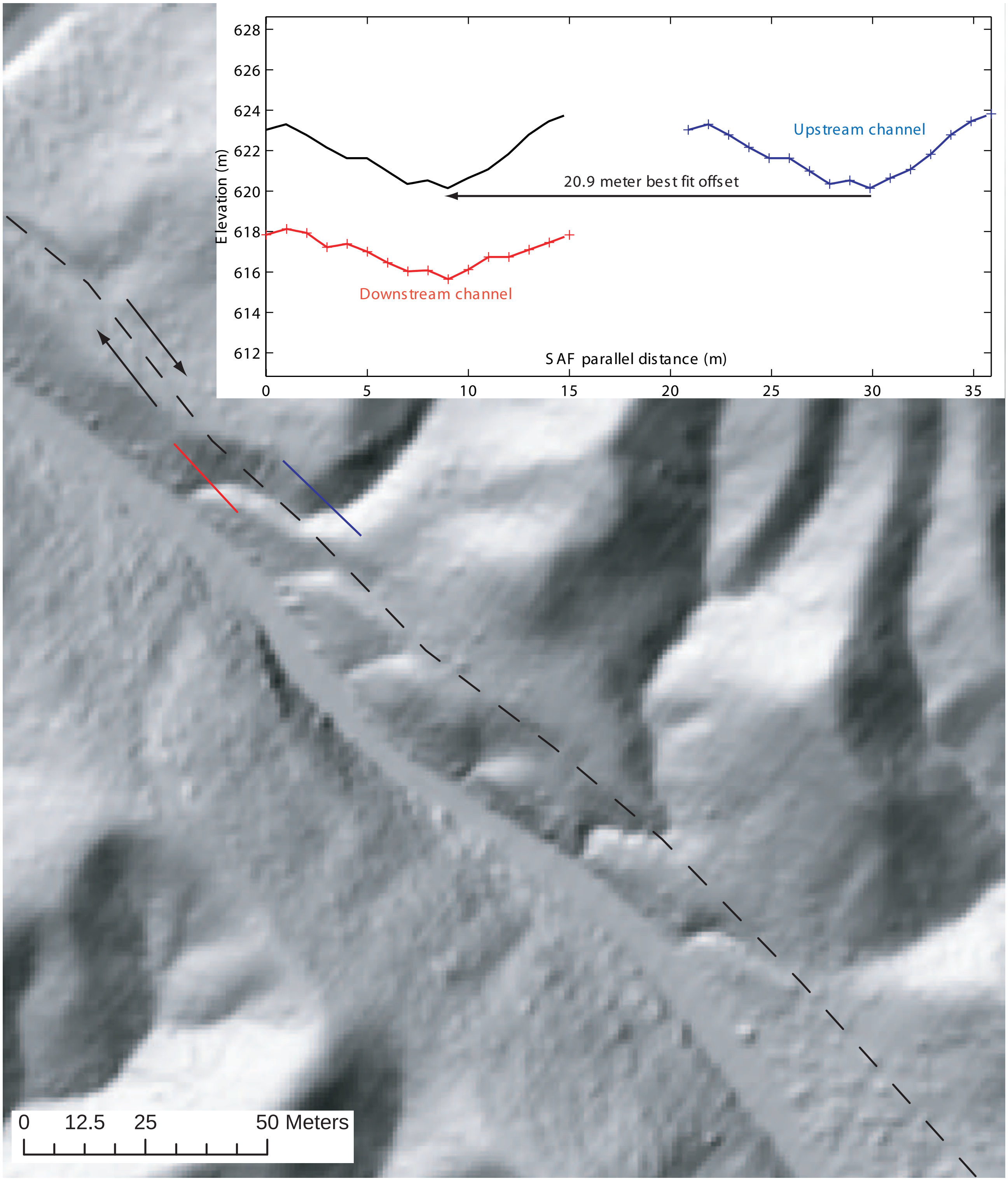

Figure 2. 1 m resolution Digital Elevation Model along the San Andreas Fault in the Southern Carrizo Plain (data courtesty of Geoge Hilley). These data were gridded from ALSM data acquired in summer 2004 as part of a seed project from the National Center for Airborne Laser Mapping. The SSAF data of Bevis, et al., will be of even higher quality. This data set indicates the potential for the project we propose: The tectonic geomorphology of the SAF is shown in unprecedented detail with synoptic coverage. Inset figure shows two topographic profiles across offset down- and upstream channel segments. The best fitting SAF-parallel offset is easily determined with ~1 m uncertainty. The resulting 20.9 m offset probably formed in 3-5 earthquakes (based on results from Liu, et al., 2004 from about 26 km to the northwest). Dashed line is local SAF trace.