ASU School of Earth & Space Exploration
ARIZONA STATE UNIVERSITY

UTAH VALLEY UVU UNIVERSITY
Department of EARTH SCIENCE

The Dry Lake Valley site

Observations of structures formed by modern and prehistoric creep on the central San Andreas fault

Collaborators and Acknowledgements:

UVU - Michael Bunds, Danny Horns, Nicole Abueg, James Anderson (Oklahoma State), J. Kade Carlson (University of Kentucky), Lawrence Kellum (University of Utah), Ephram Matheson, Andrew Lawrence, and Jeff Selck.

ASU - Barrett Salisbury, J Ramón Arrowsmith, and Tsurue Sato.

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Dr. Nathan A. Toké, Assistant Professor of Earth Science, Utah Valley University

SoSAFE Workshop: Palm Springs, CA 9:15-9:30am, 2016

Motivation

- Does the central creeping section of the San Andreas fault participate in great earthquakes on the southern and/or northern SAF?
- Does it rupture in large earthquakes?
    - i.e., does geologic evidence validate model results (e.g., UCERF 3)

Outline

1. Location and overview
2. Paleoseismic excavations and observations
3. Ground rupture patterns from surface creep (measured by SfM)
4. Findings
    - Evidence of large earthquakes is not preserved
    - We know more about confounding issues from creep.
    - SfM is useful for measuring geomorphic change due to creep…

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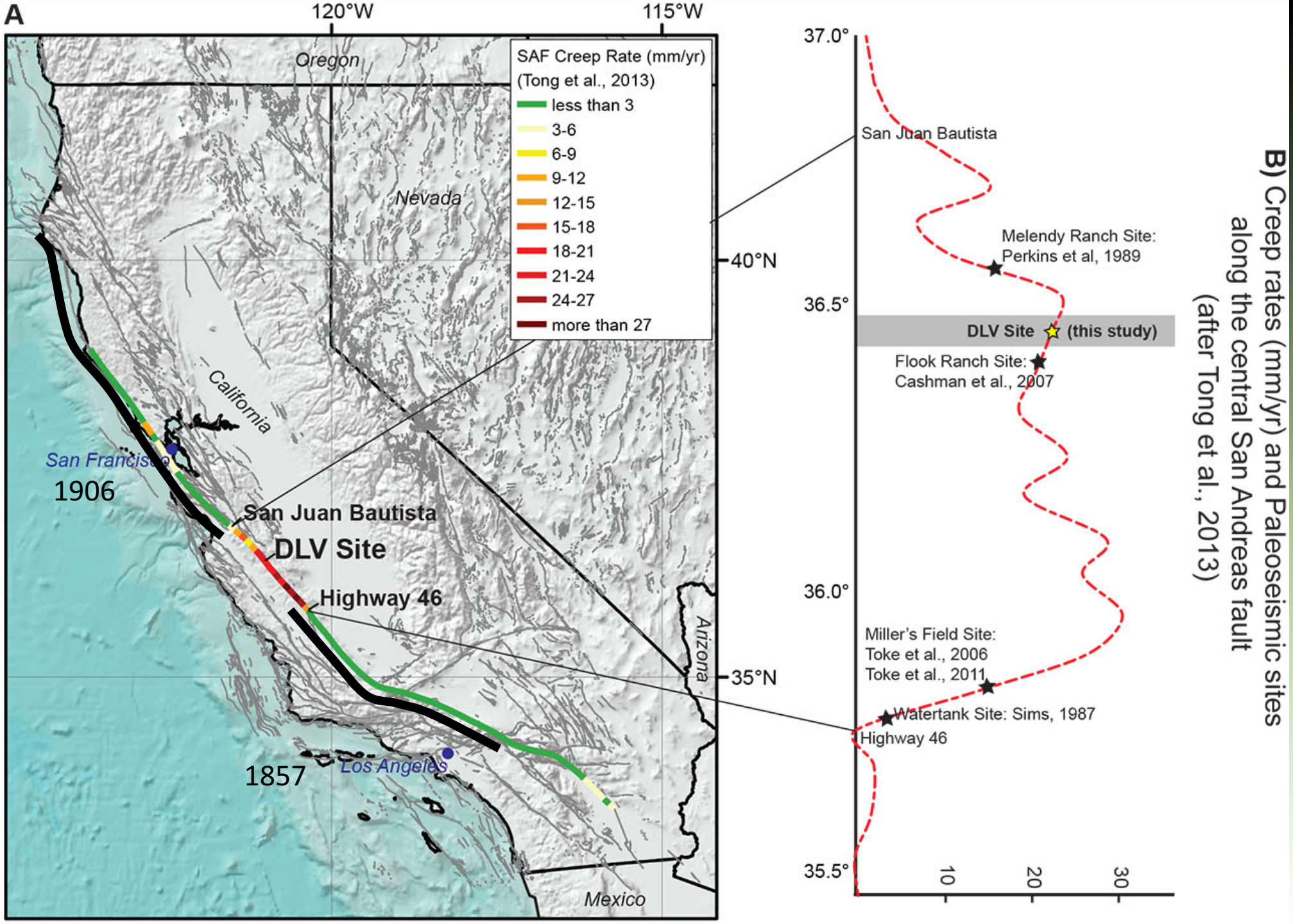
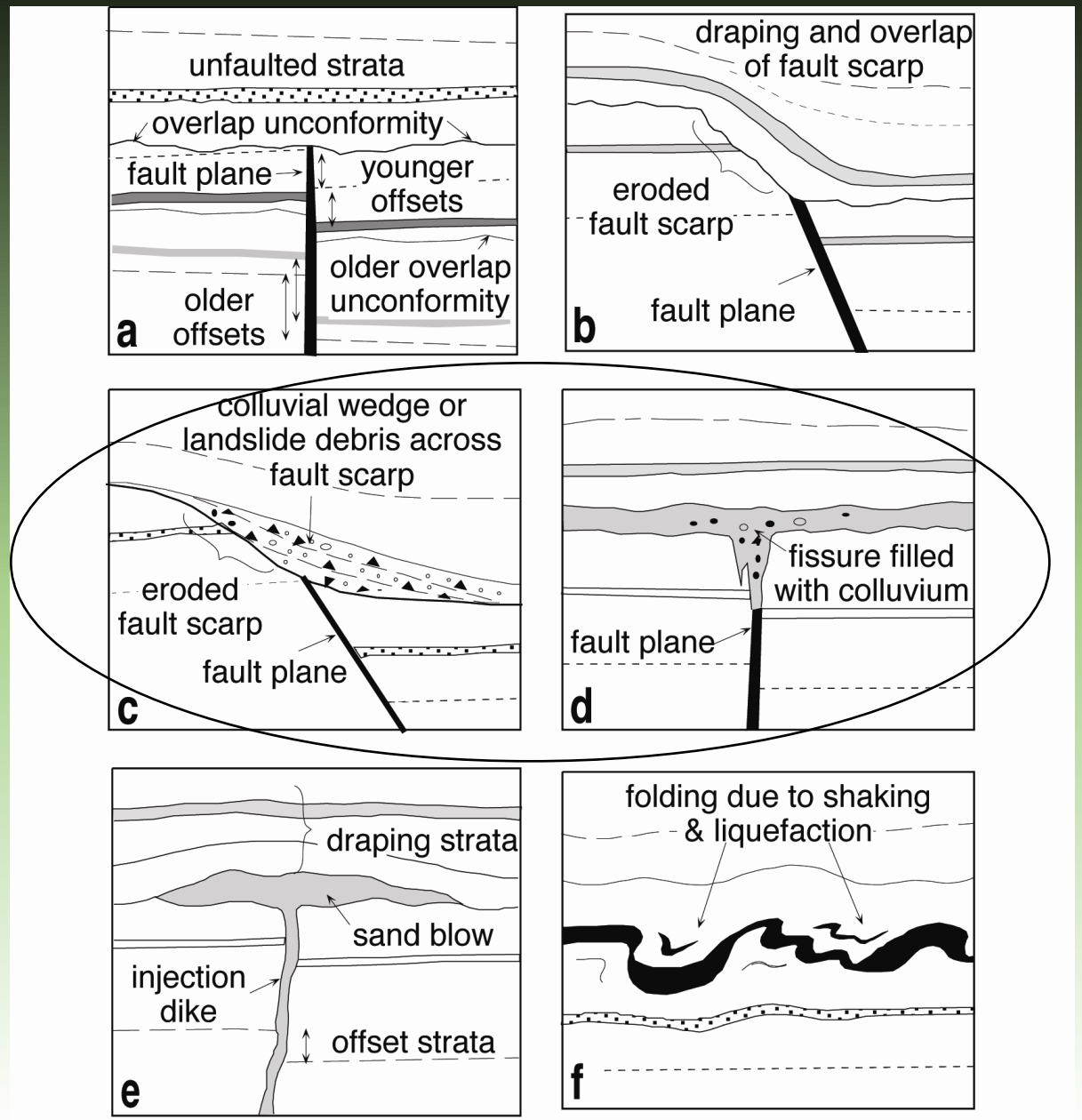
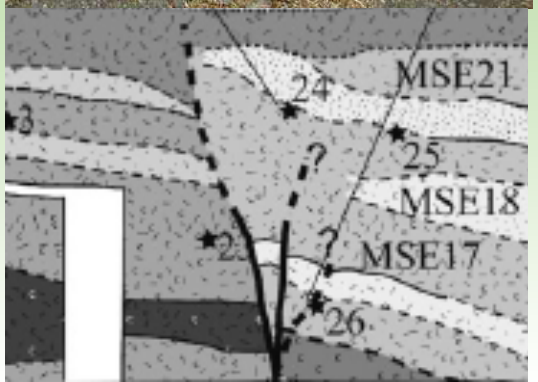
Site locations Creep rates And Earthquakes



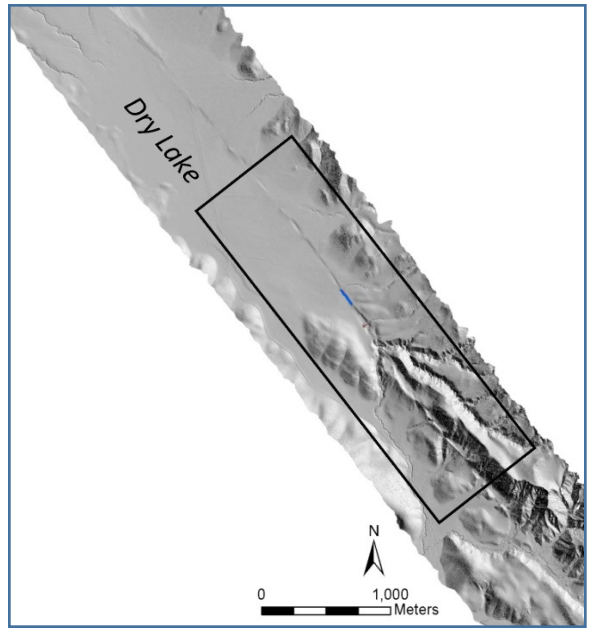
B) Creep rates (mm/yr) and Paleoseismic sites along the central San Andreas fault (after Tong et al., 2013)

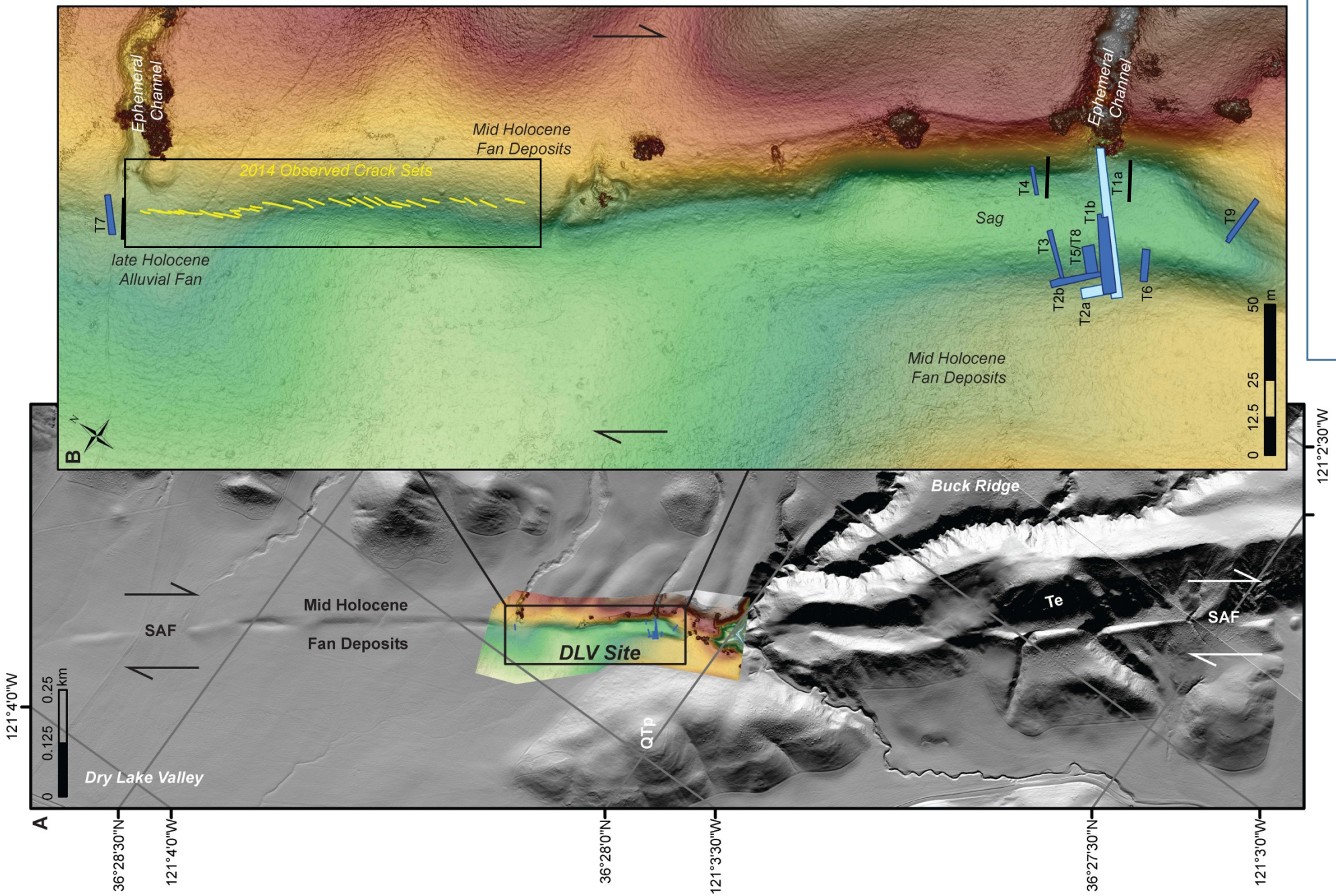
Paleoseismic Evidence





DLV Site





Nine Trenches

Stratigraphy

Sag Fill

Colluvium

Alluvial Fan

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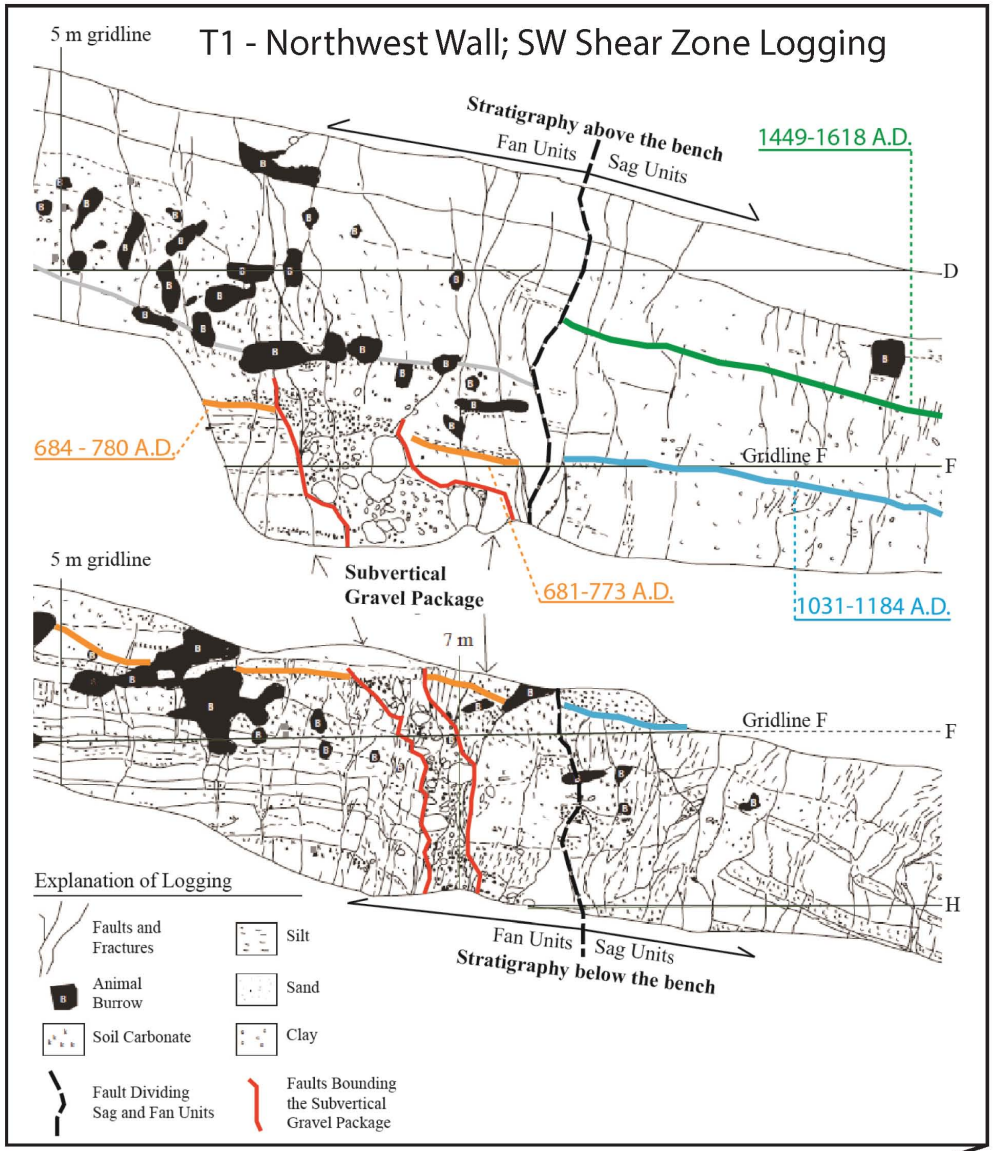
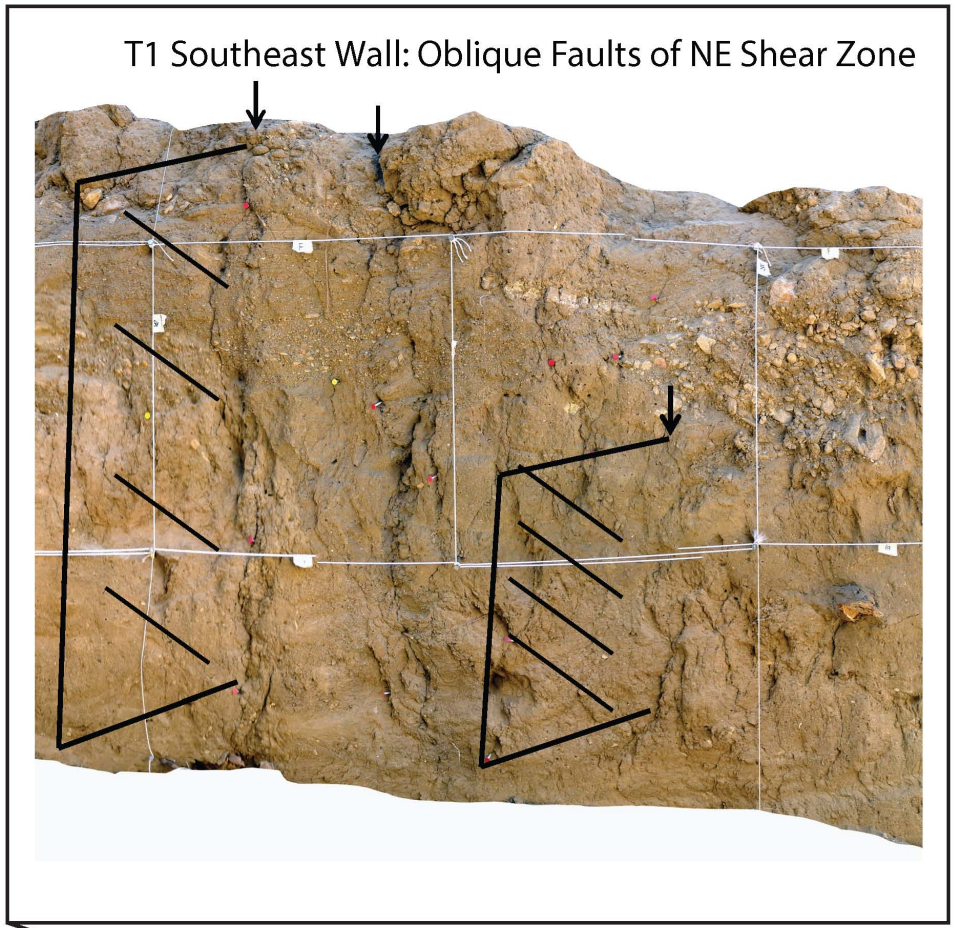
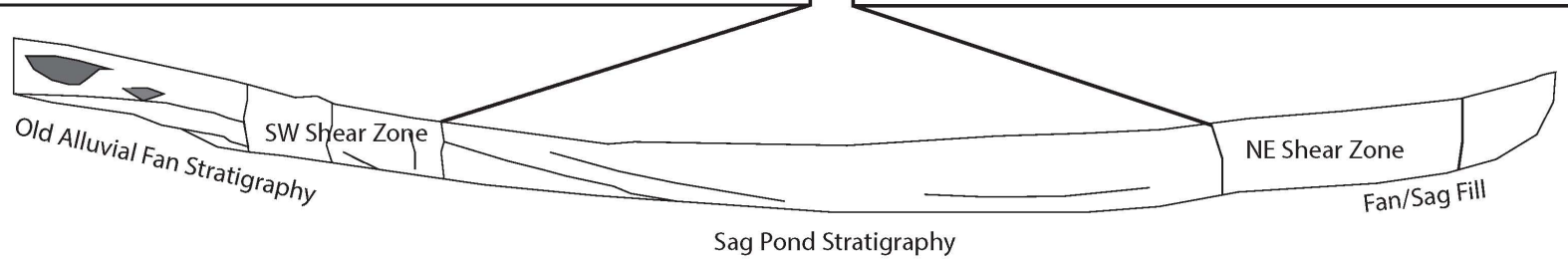




- **Pervasive Cracking**
- **Wide Zones of Shear (>7 m)**
- **Significant deformation**
- **45 degrees CW Oblique to Overall Fault Trend**



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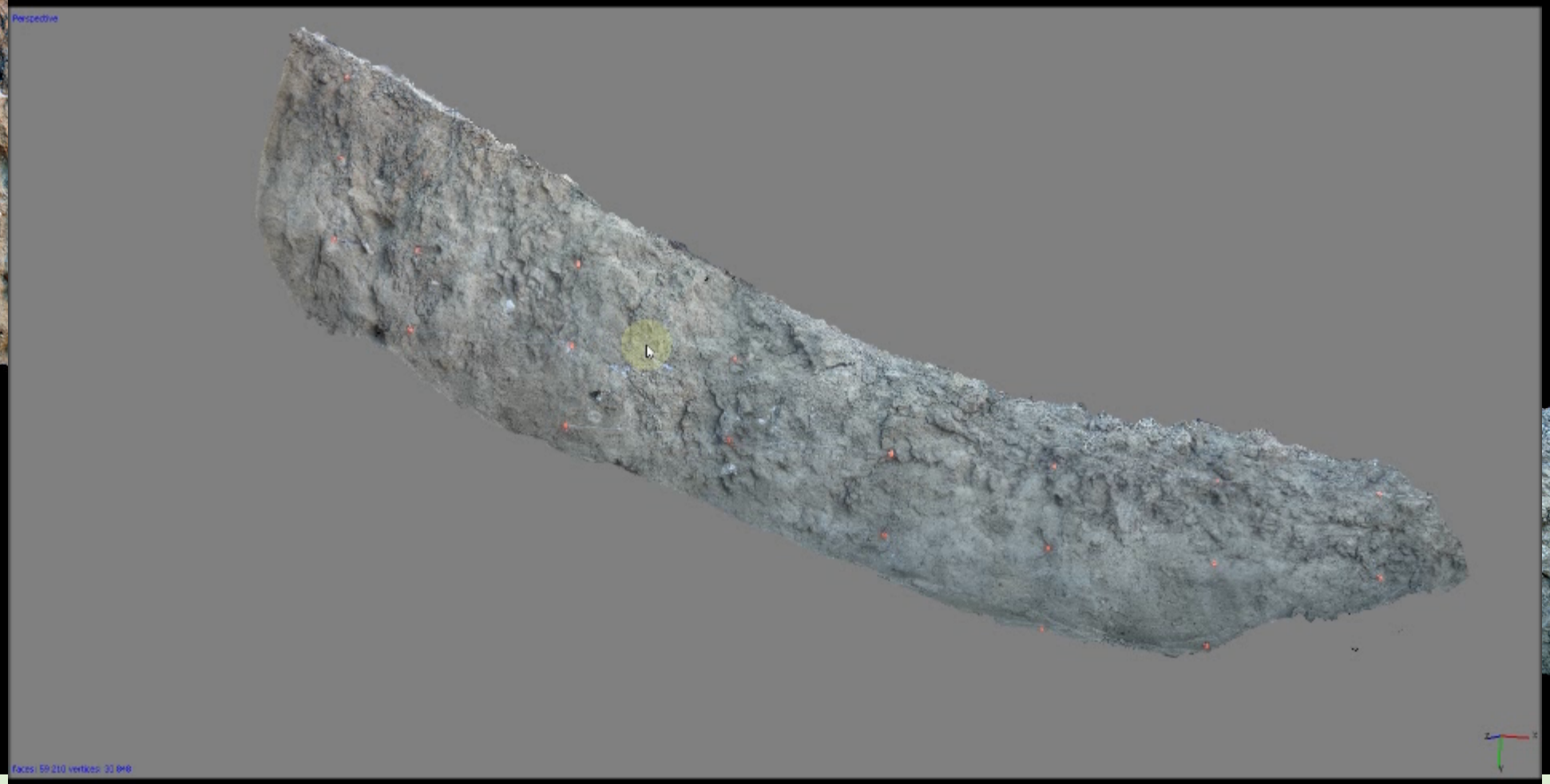
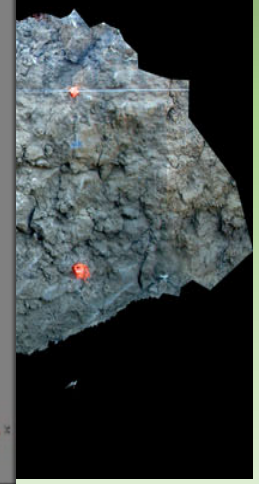
Southeast Wall of T4

Vedges
l mass)

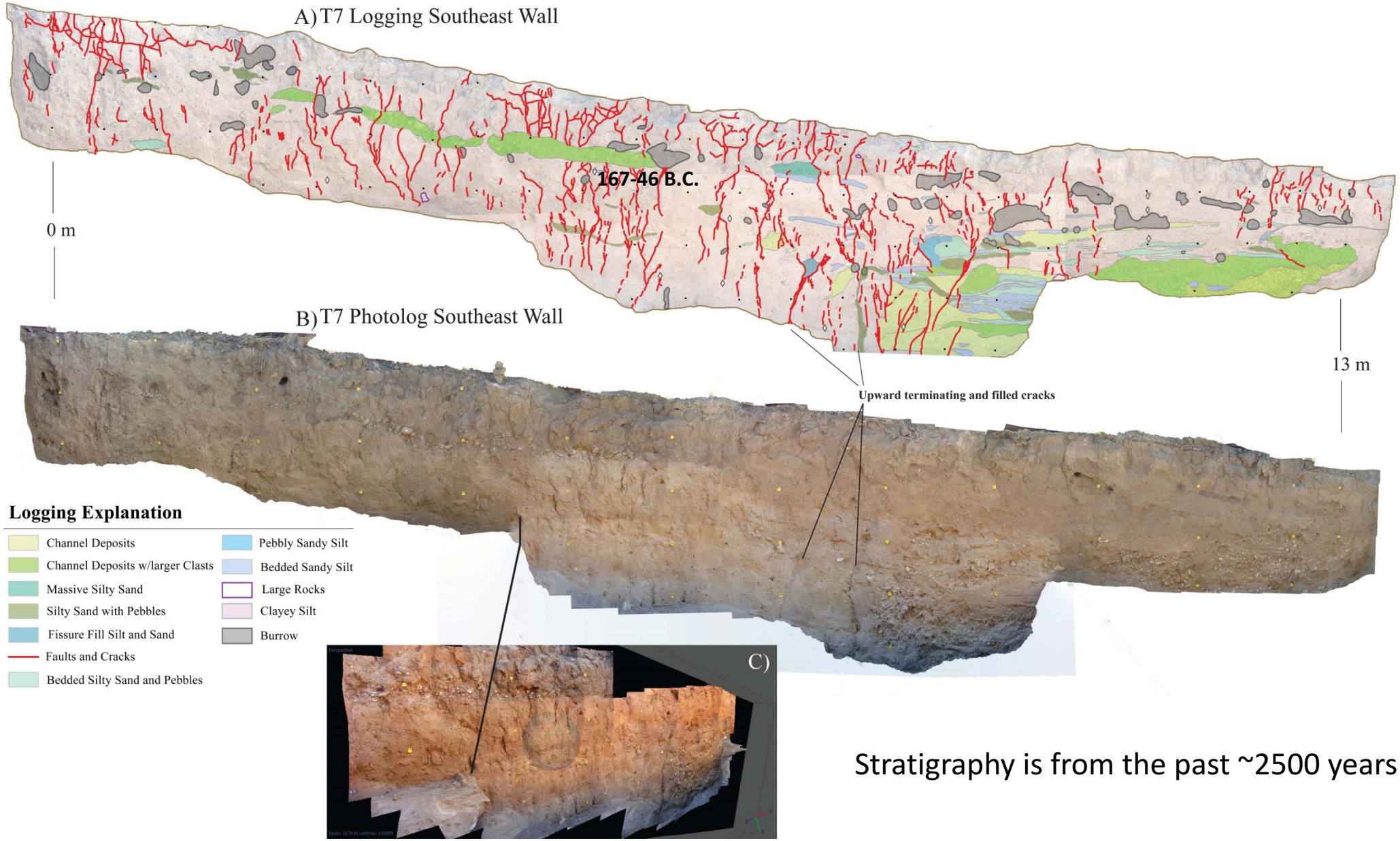




NE

SW

T7: Evidence of open paleo-ground-cracks



Stratigraphy is from the past ~2500 years

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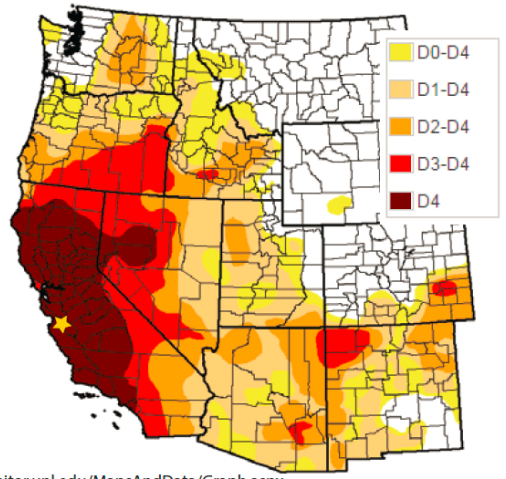
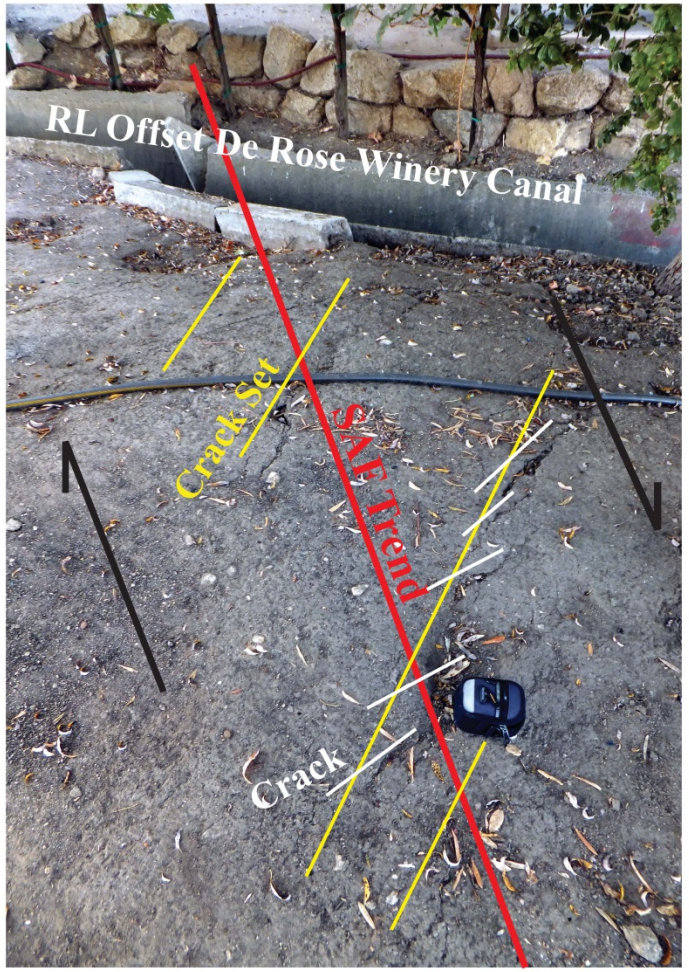
2013-2014 drought/creeping rupture

San Benito County has been in a record drought since December 2012. We observed the creep-induced rupture at the DLV site on 9/20/2014, this is a drought map from 9/30/2014



http://droughtmonitor.unl.edu/MapsAndData/Graph.aspx

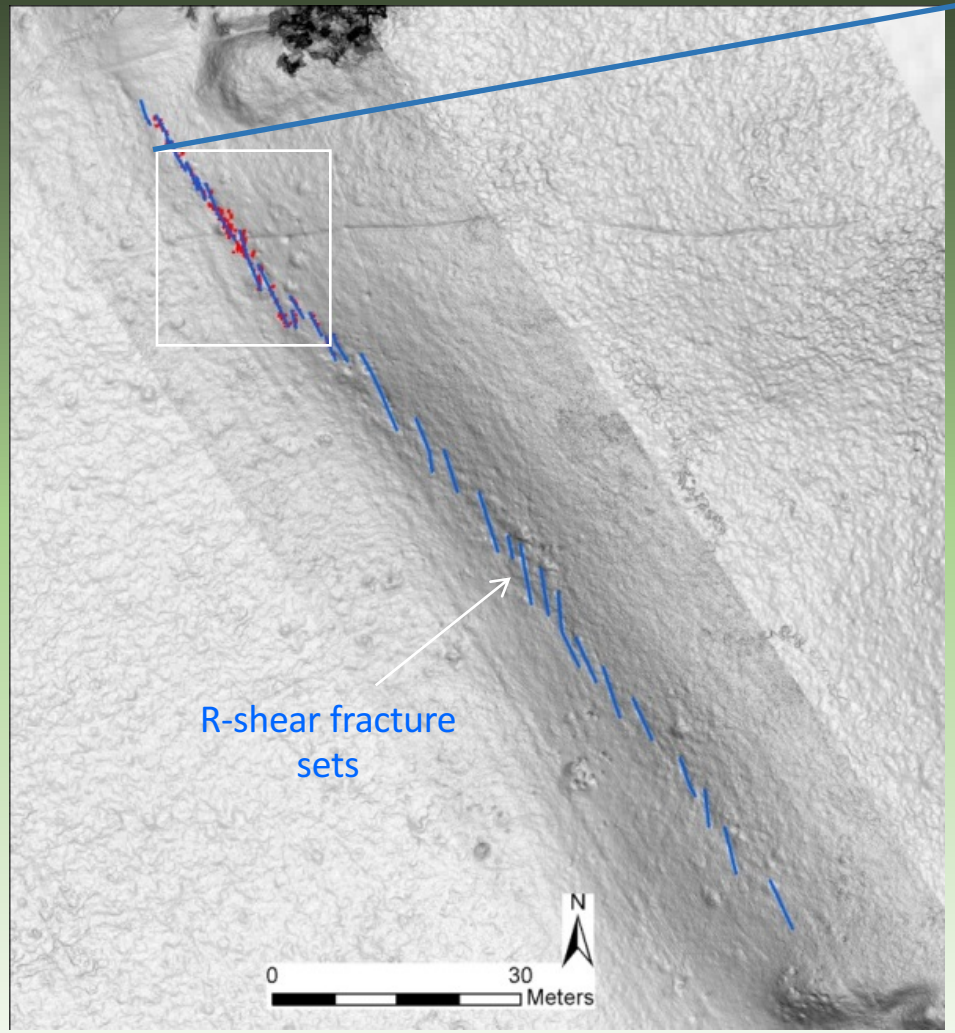
C



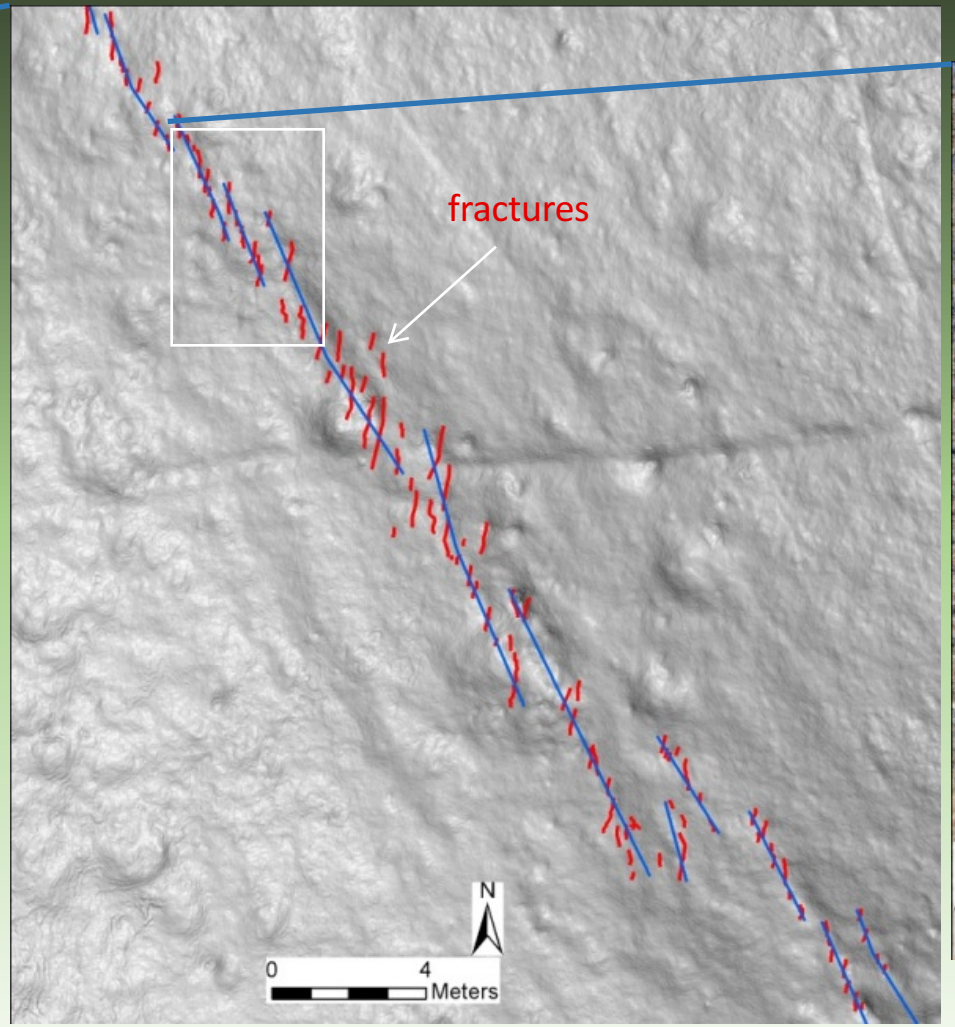
D

DLV Fracturing

- Left-stepping opening-mode fractures (n=119)
- Arrayed in left-stepping sets; incipient R-shears (n=28)
- Near midline of fault scarp
- < 1.8 years of formation time



9cm and 2cm grid DEM slopeshades



2cm grid DEM slopeshade

1mm pixel orthophoto

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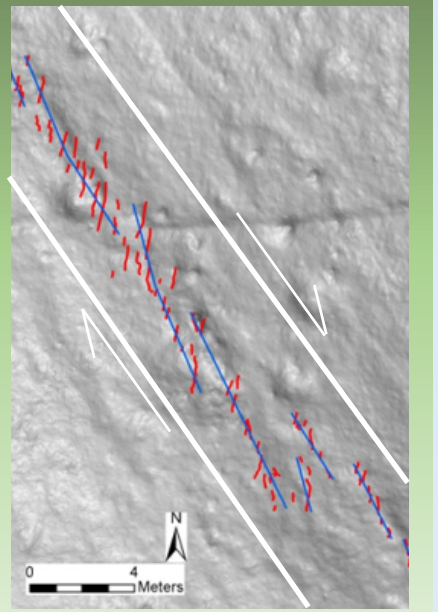
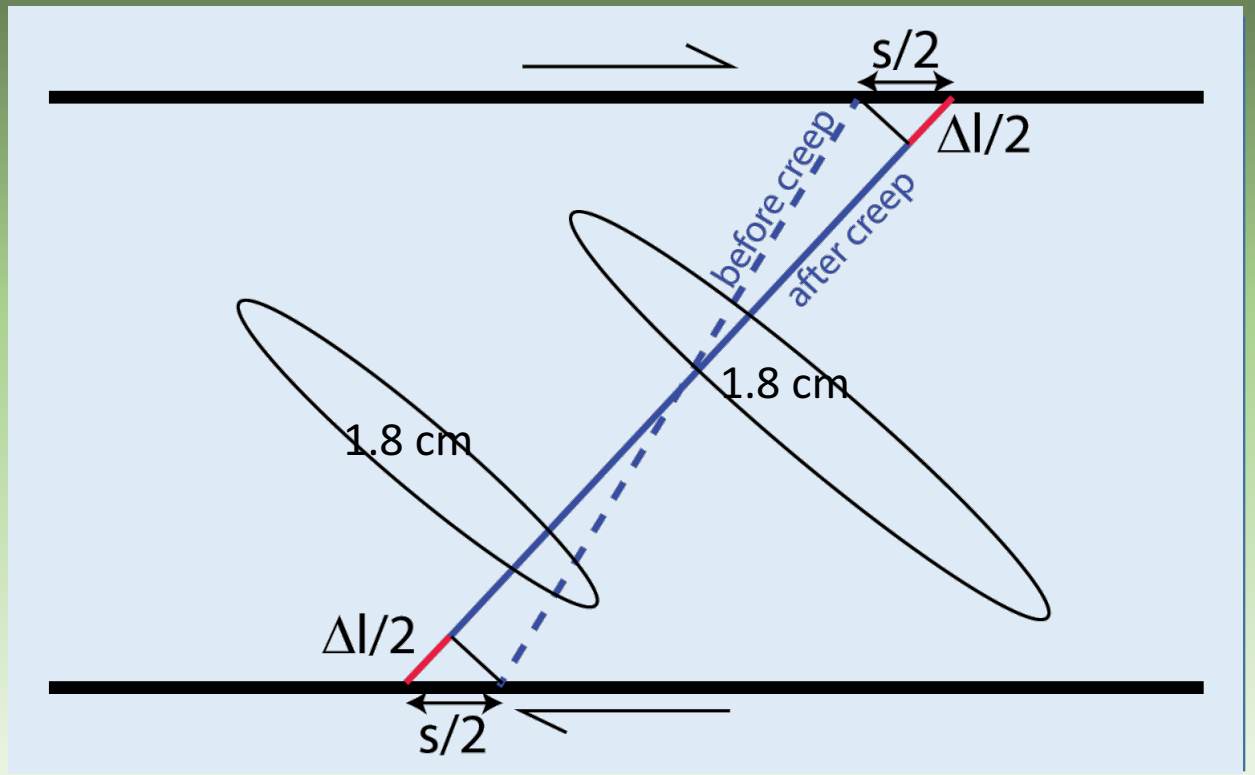
Magnitude of Strike-slip Creep Recorded in DLV Fractures

- Entirely opening-mode fractures, mean opening is 1.8 cm
- Assuming a model of simple shear with < 1° rotation (for 1 m–wide shear zone)
- We infer: 4.8 cm right-slip (between 3.7 & 6.5 cm): ~ 26 mm/yr over a 1m wide zone.
- ~ 3.0 to 5.4 cm creep on SAF during 1.2 - 1.8 years of fracture formation (e.g., Titus et al., 2006 ; Tong et al., 2013)



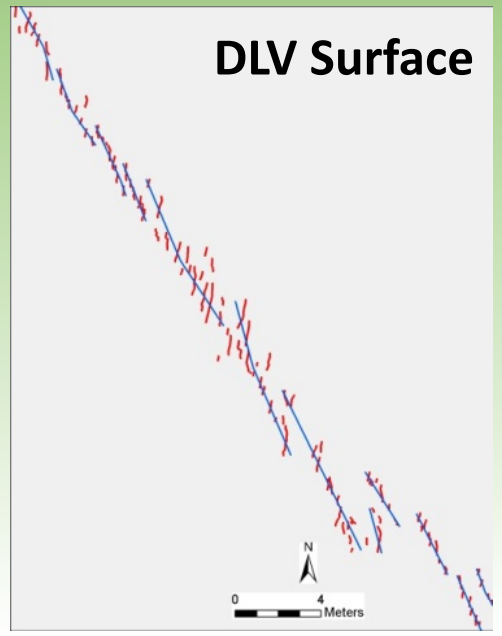


$$\text{slip} = \frac{(\text{lengthening from fracture opening})}{\sin(\text{fracture angle to SAF})}$$

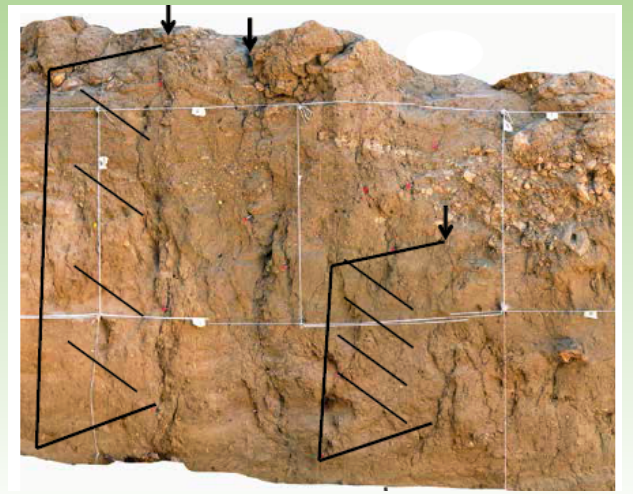
lengthening from fracture opening =
(mean fract max width) x
(fract. overlap) x
(correction for fract. tapering)

DLV Surface Fractures vs DLV Trench Fractures

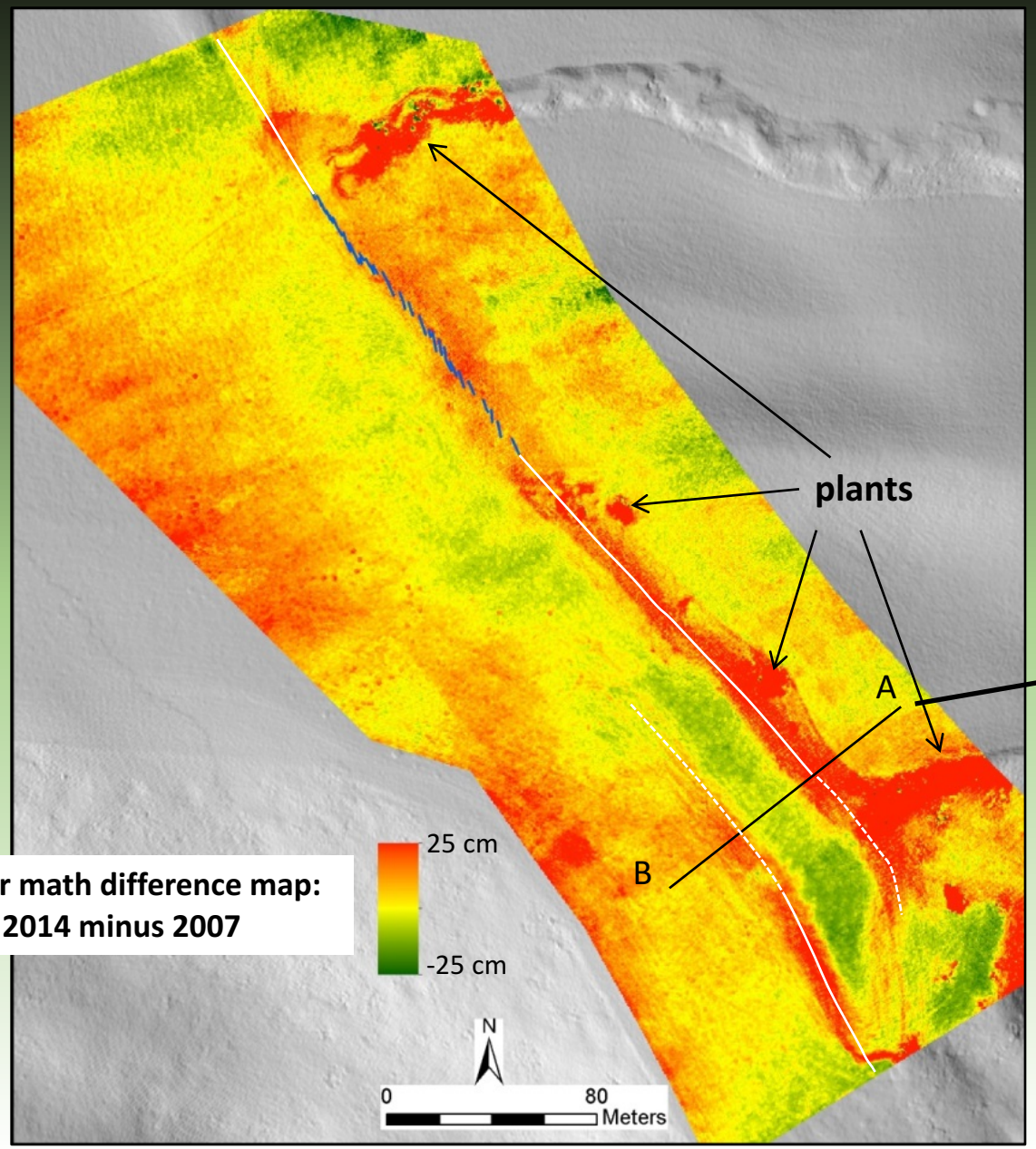
	DLV Surface	DLV Trenches
En echelon	yes	yes
R-shear sets	yes	?
Fracture Length	0-2 m (0.5 m)	Meter scale
Opening Width	1-4 cm (1.8 cm)	1-4 cm
Angle to SAF (clockwise obliquity)	20-60 (~40)	25-68 (~45)
Proportion of slip accommodated by fracture-normal extension	Most or all	Most or all



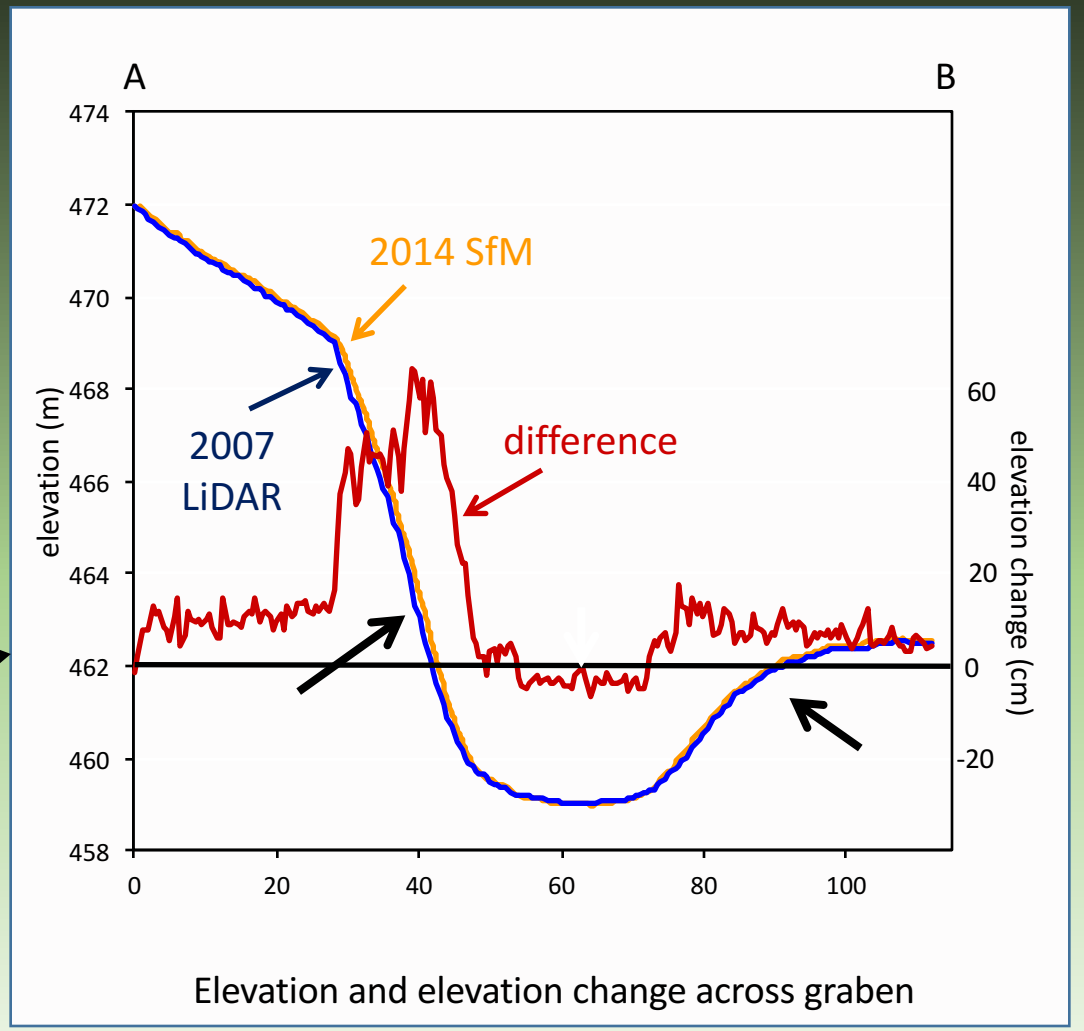
DLV Trenches



Comparison of 2007 LiDAR DTM to 2014 SfM DSM



Raster math difference map: 2014 minus 2007



Elevation and elevation change across graben

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DLV Site Conclusions

- **Evidence for large surface ruptures is not preserved/recognized at the DLV site.**

- **Overprinting earthquake evidence by deformation due to creep presents a problem for these types of investigations… (i.e., preservation time vs recurrence rate is an issue)**

- **Surface creep in the absence of surface processes may confound interpretations in high and dry slip rate environments.**

- **Short-aperture and short-term creep measurements are consistent with wide aperture and geodetic (and geologic) slip rates at this site.**

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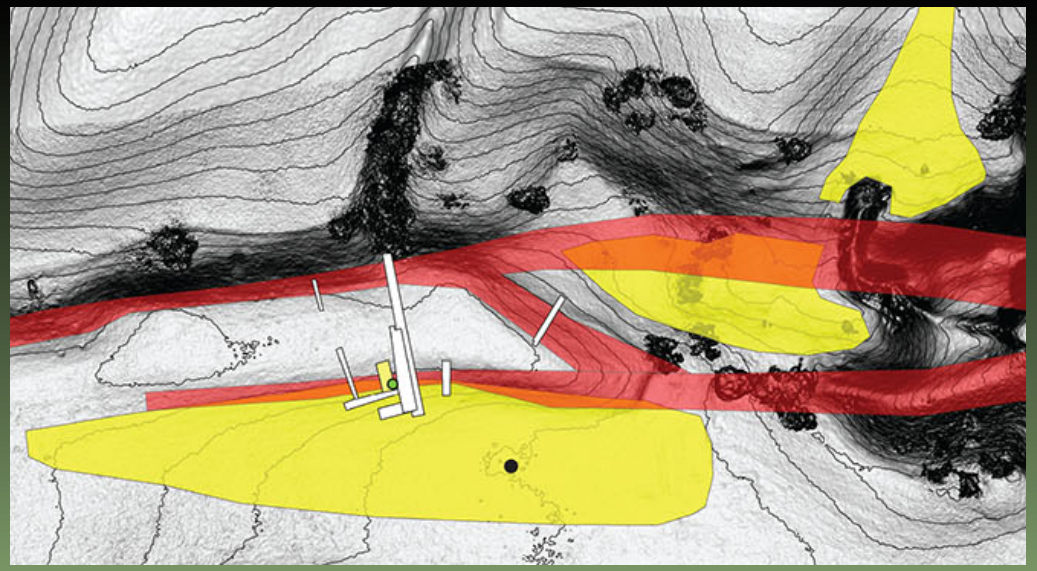
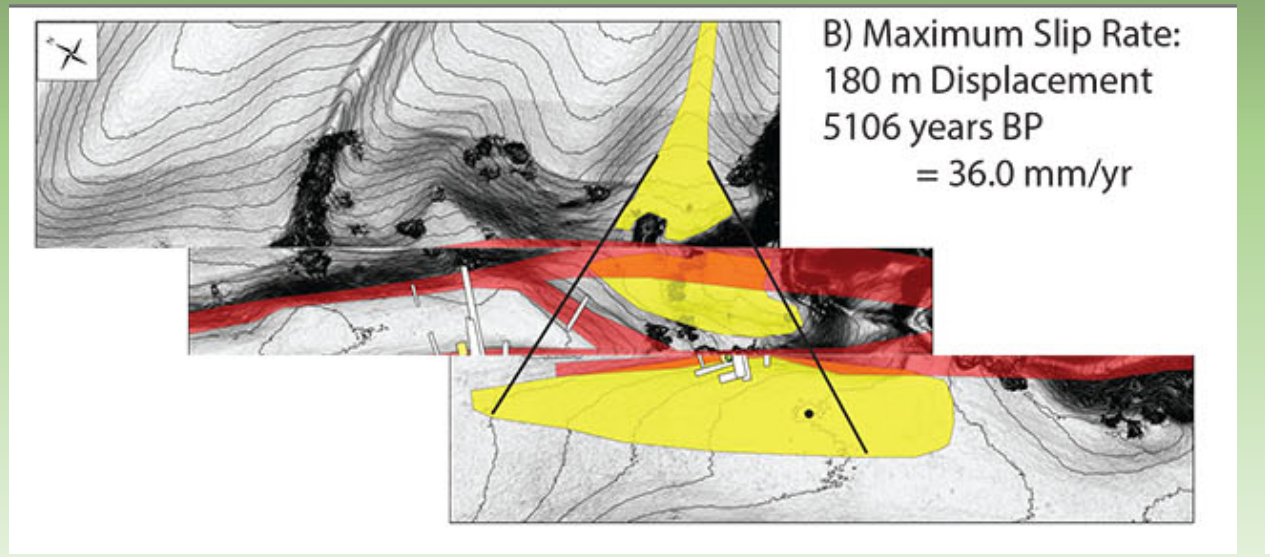
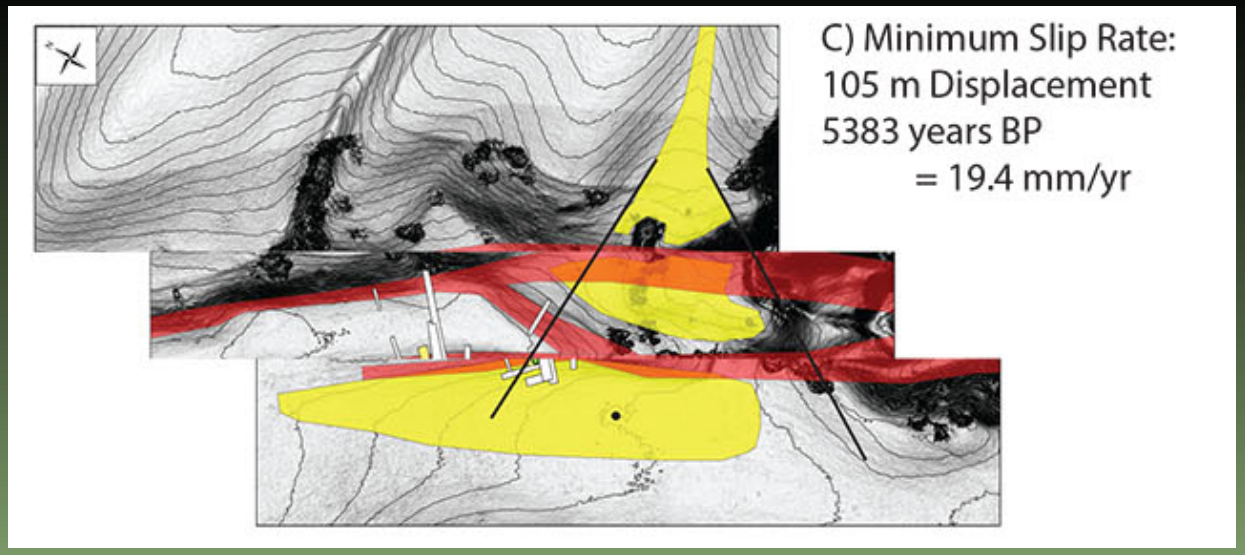
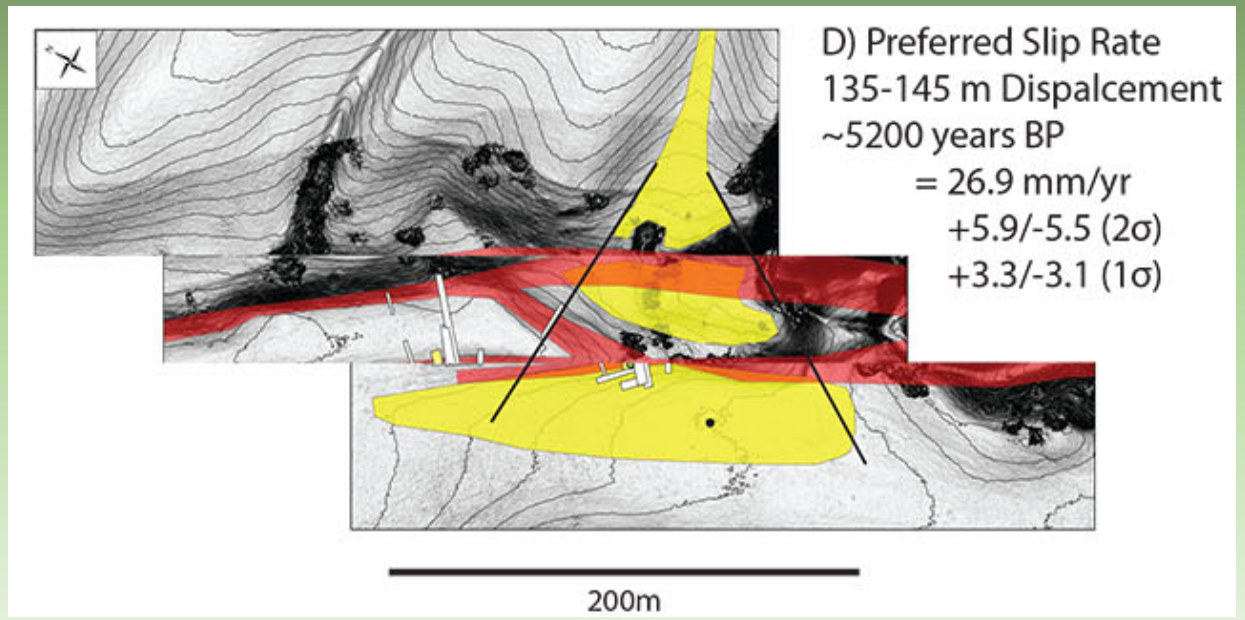
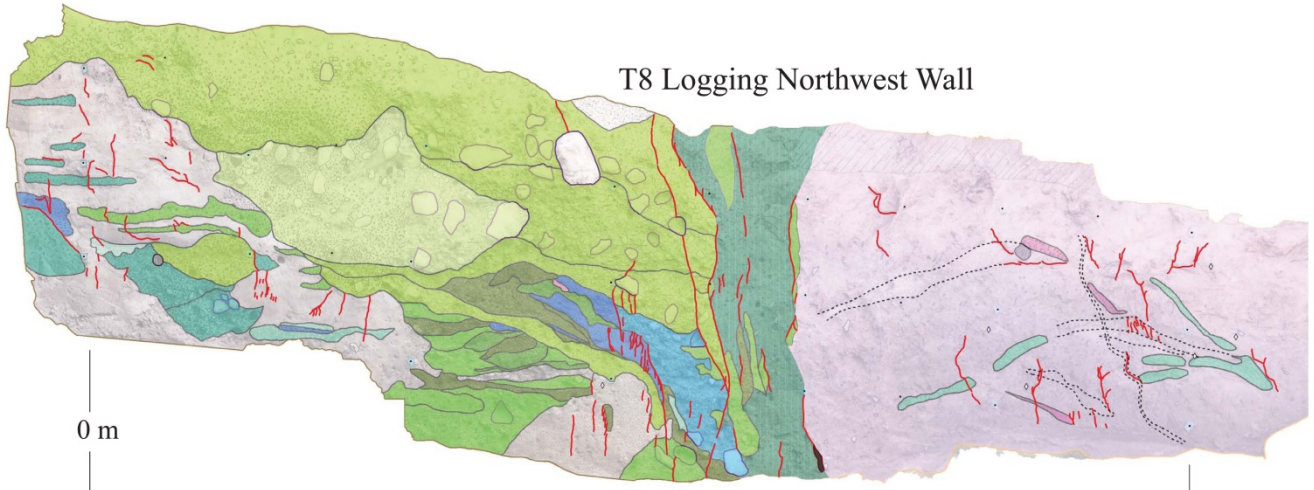
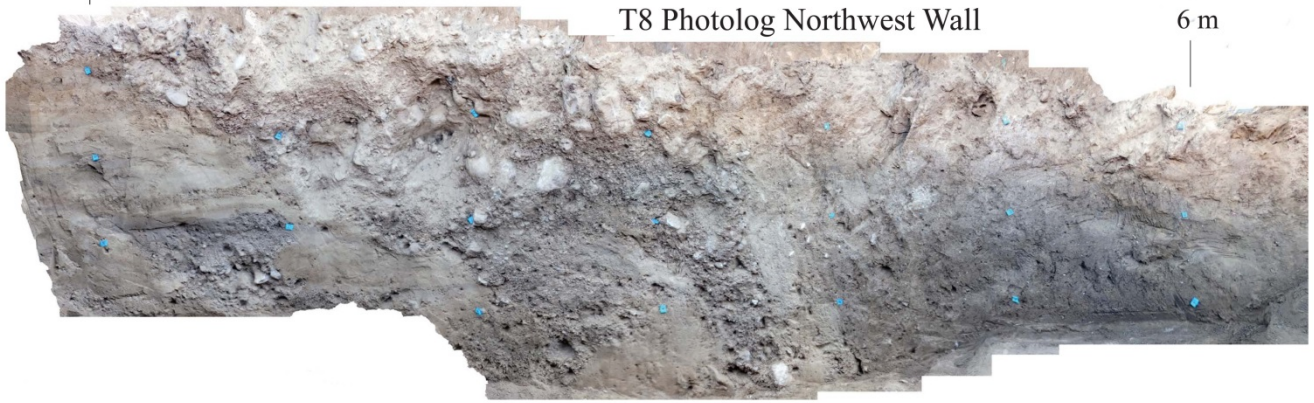



B) Maximum Slip Rate:
180 m Displacement
5106 years BP
= 36.0 mm/yr

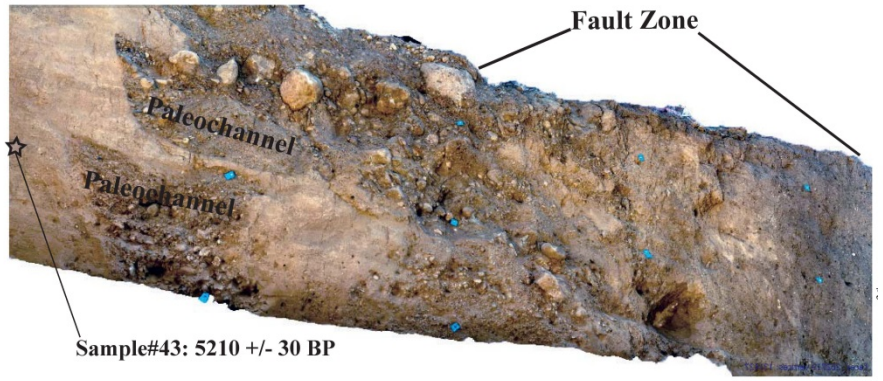

C) Minimum Slip Rate:
105 m Displacement
5383 years BP
= 19.4 mm/yr


D) Preferred Slip Rate
135-145 m Dispalcement
~5200 years BP
= 26.9 mm/yr
+5.9/-5.5 (2σ)
+3.3/-3.1 (1σ)
200m



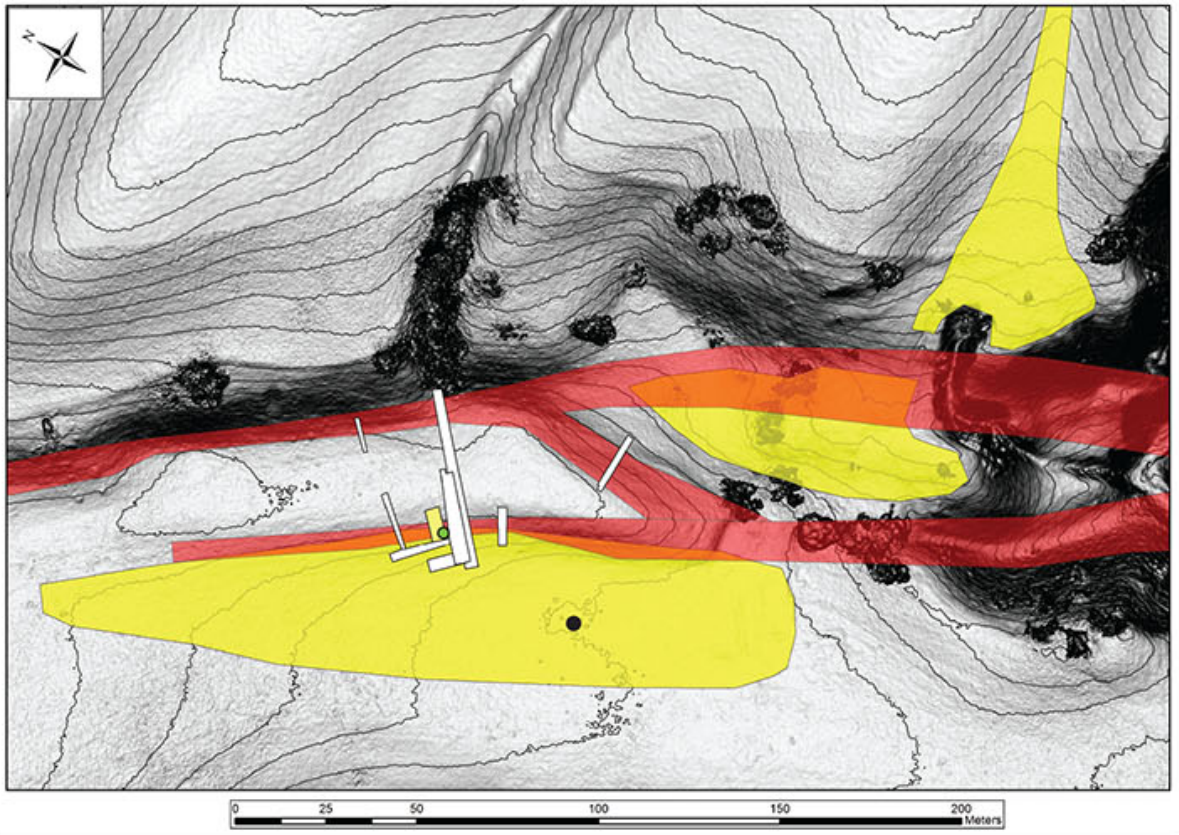


Perspective View of T8 Photolog Southeast Wall (Mirrored View)

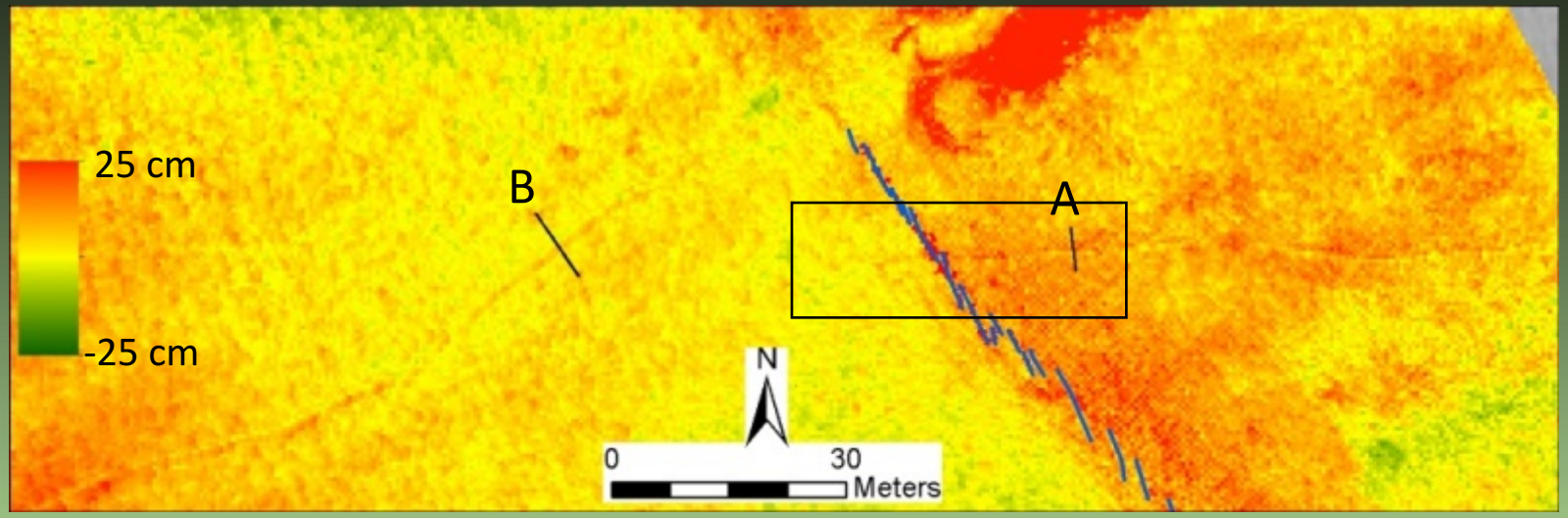


Logging Explanation

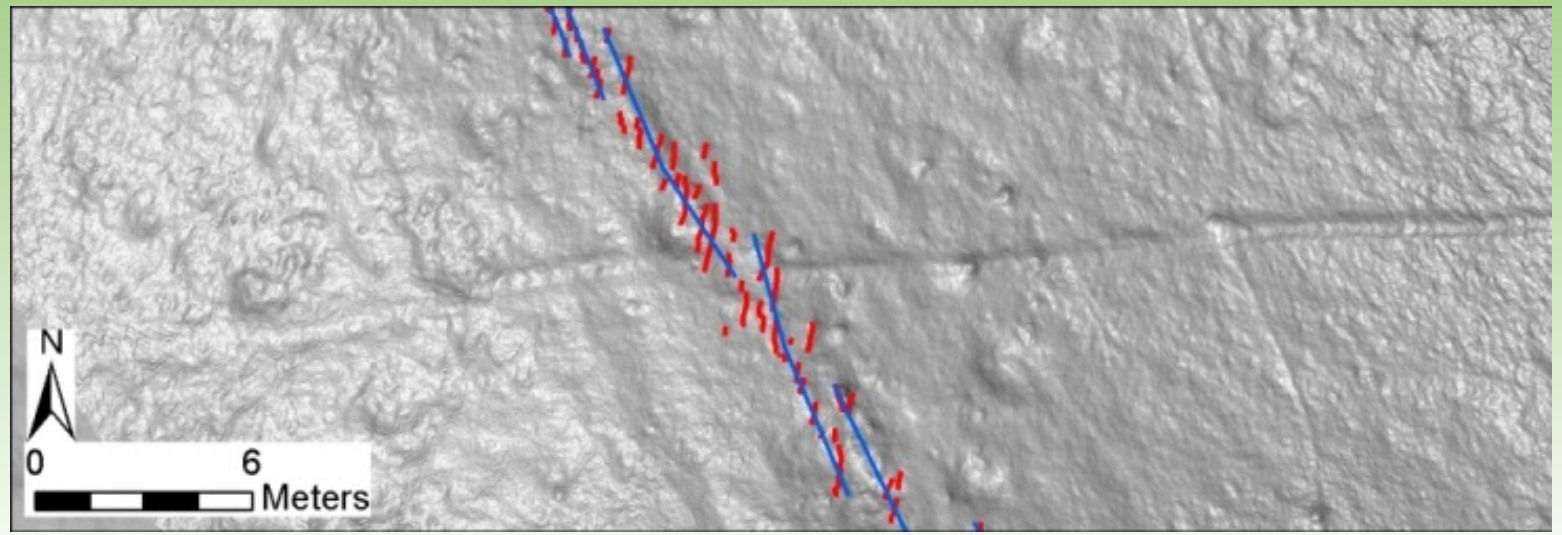
- Channel Deposits
- Channel Deposits w/larger Clasts
- Massive Silty Sand
- Silty Sand with Pebbles
- Fissure Fill Silt and Sand
- Faults and Cracks
- Bedded Silty Sand and Pebbles
- Pebbly Sandy Silt
- Bedded Sandy Silt
- Large Rocks
- Clayey Silt
- Burrow



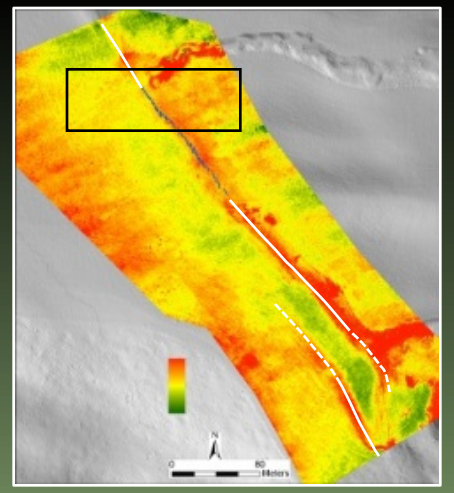
Comparison of 2007 LiDAR DTM to 2014 SfM DSM

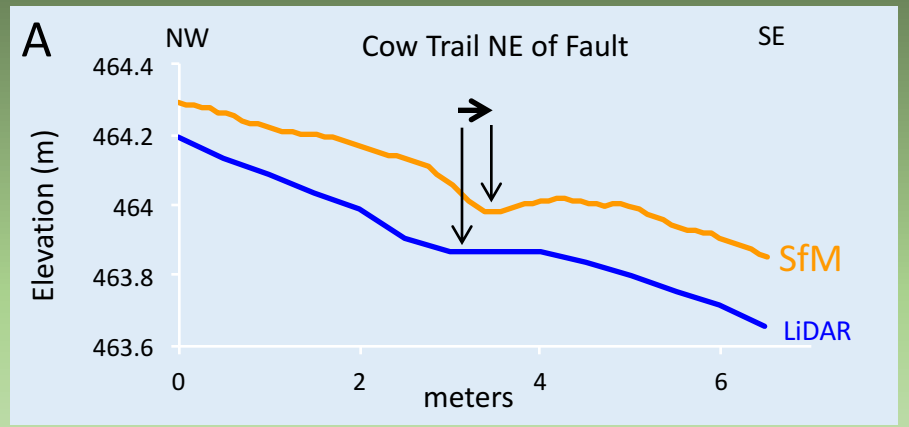


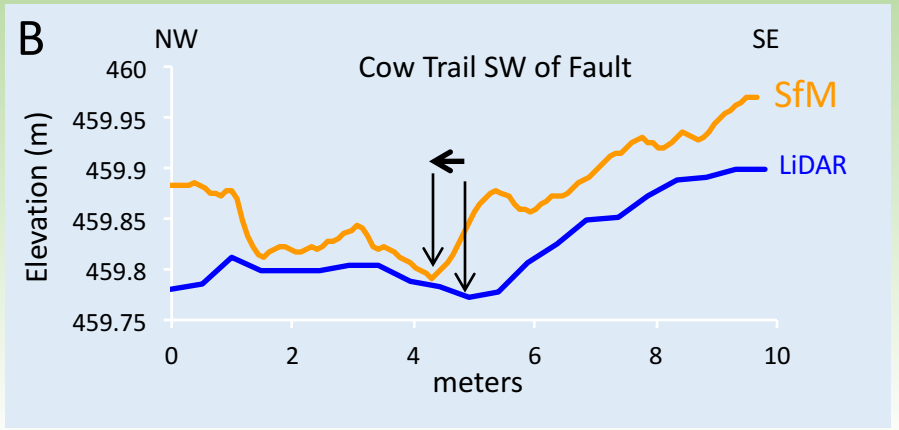
2014 SfM minus 2007 LiDAR



2 cm grid slopeshade





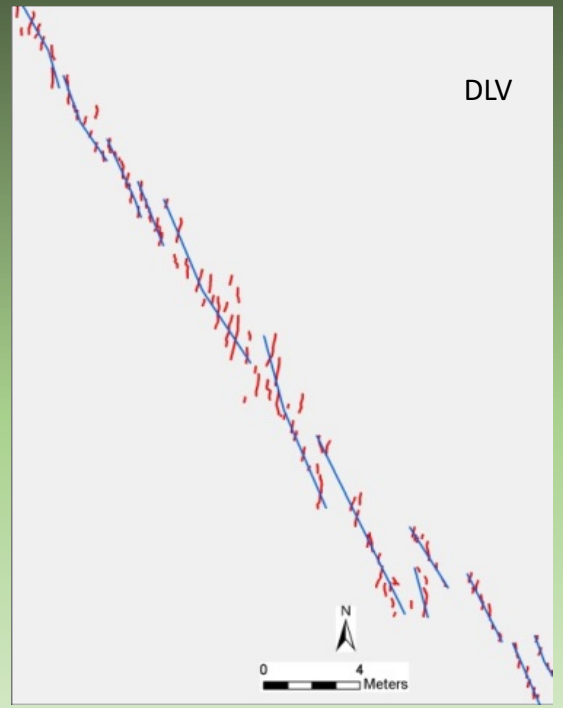


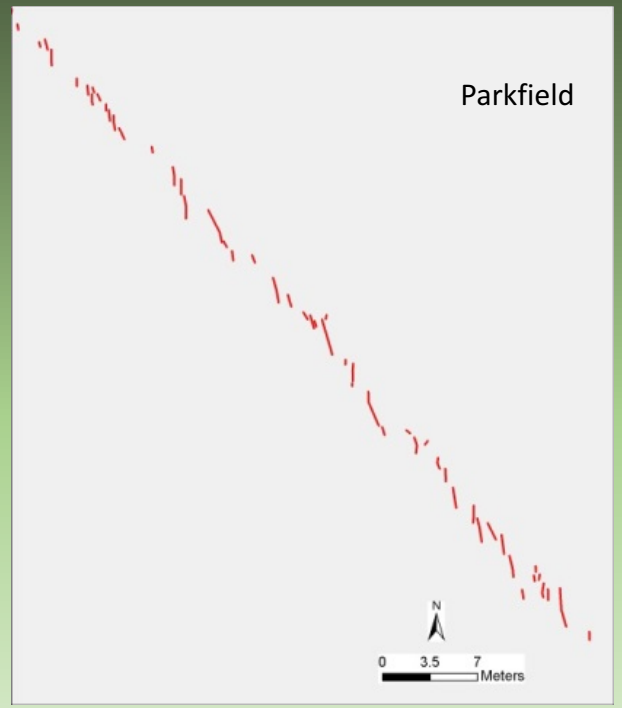
Comparison of Creep Fractures to Seismic Surface Deformation

- Larger displacement ruptures are different

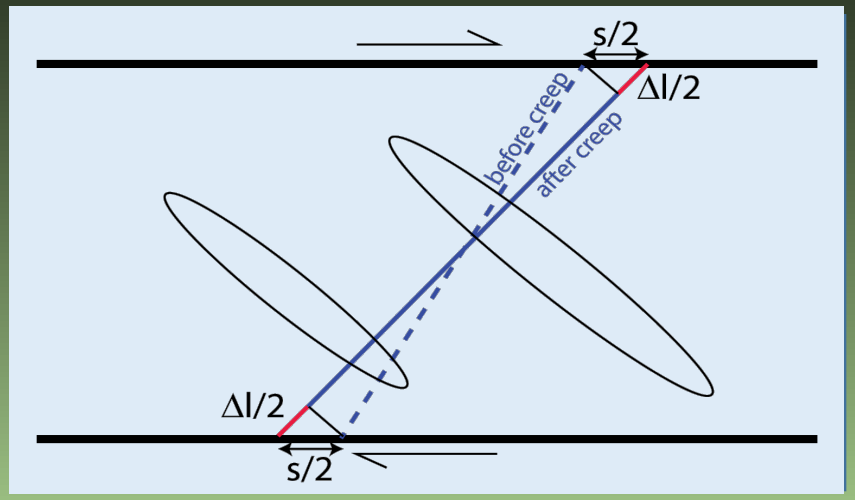
2010 Mw 7.1 Canterbury, New Zealand surface rupture
Photo from GeoNet

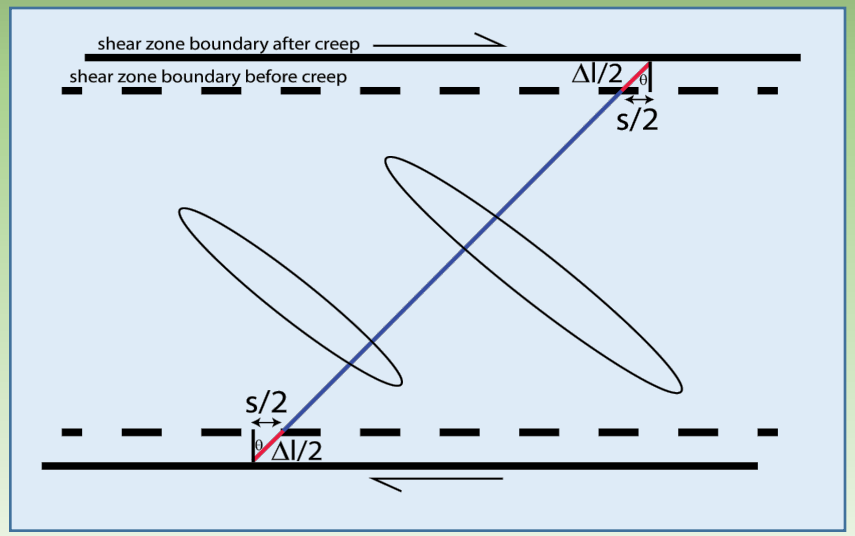
- Events with minor surface rupture may be similar
- E.g., 2004 M 6.0 Parkfield earthquake





Magnitude of Strike-slip Recorded in Fractures from Parkfield 2014 M 6.0





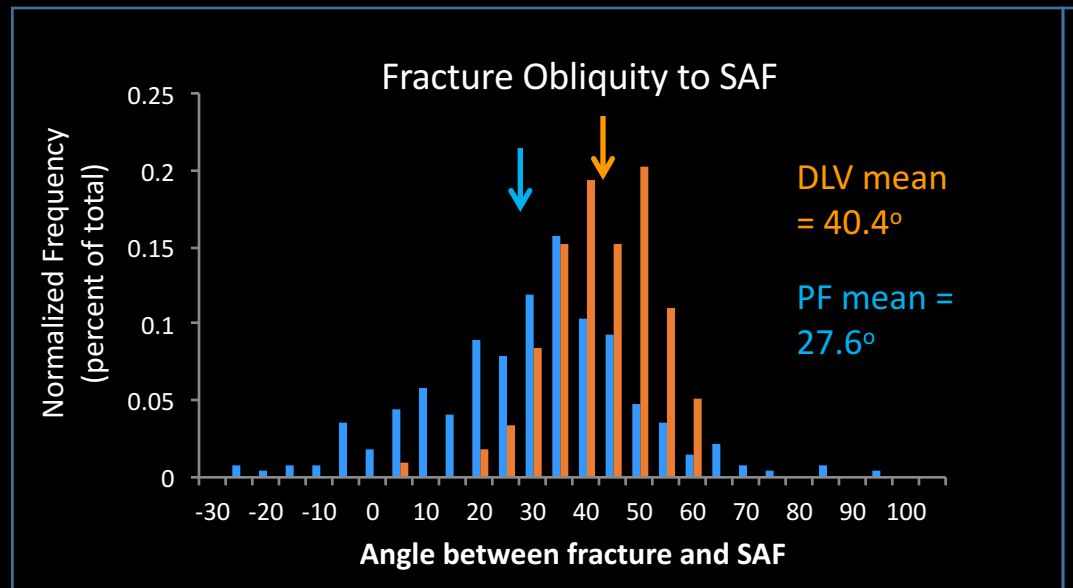
- If extension across cracks entirely due to simple shear along SAF:
- 1.8 cm right-slip
- ~ 1° rotation
- ~ 6 cm of slip at surface at time of fracture measurement

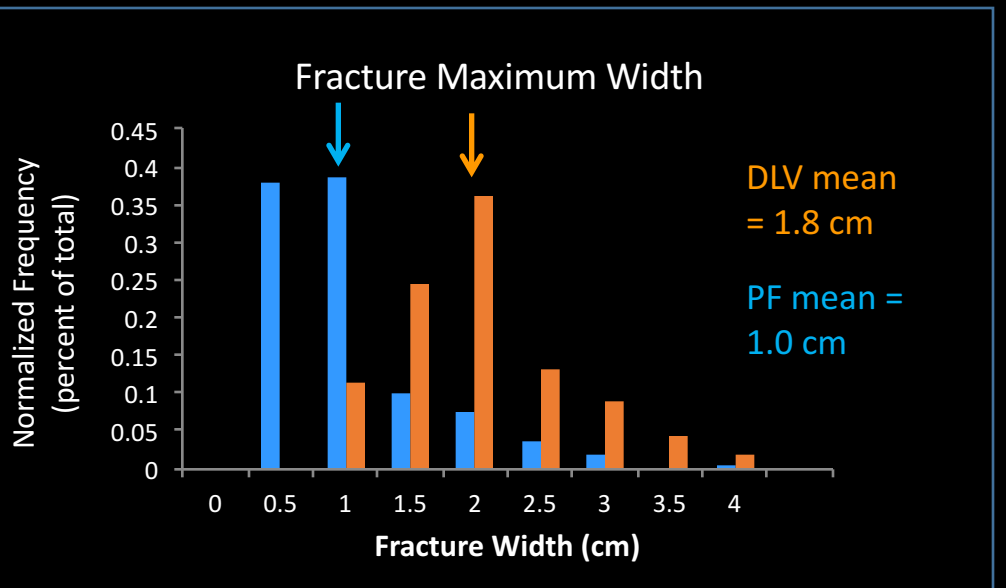
- If extension across cracks due to 'transtension' across SAF:
- 0.4 cm right-slip
- 0.7 cm fault-normal lengthening

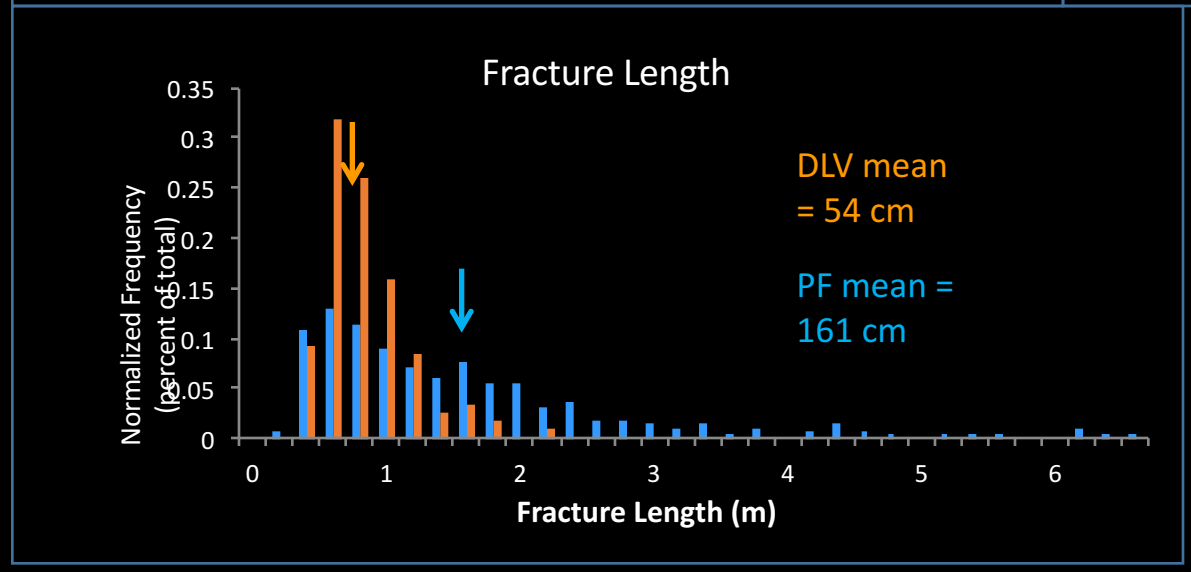
At time of fracture measurement ~ 6 cm of slip had occurred across fault zone

Fault slip accommodated by distributed shearing and/or shear on fractures

Parkfield 2004 M 6.0 Fracture Geometry Compared to DLV







orange = DLV, n = 119
blue = Parkfield, n = 279

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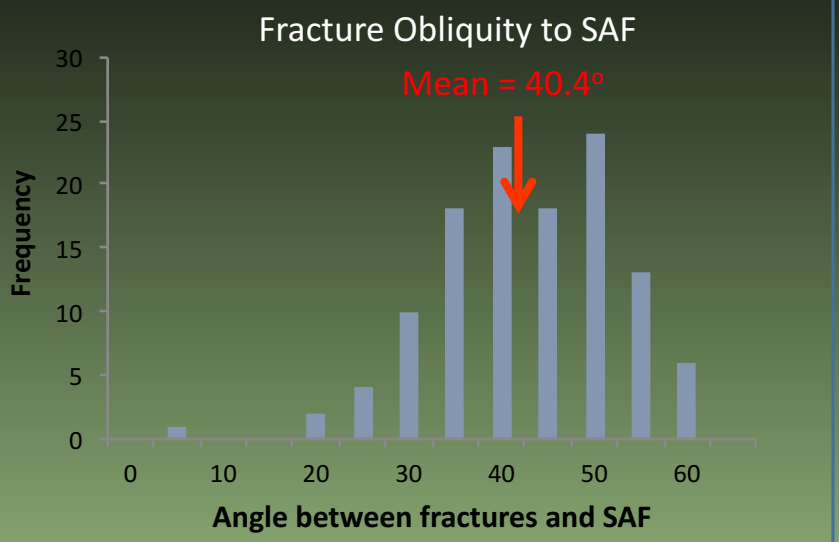
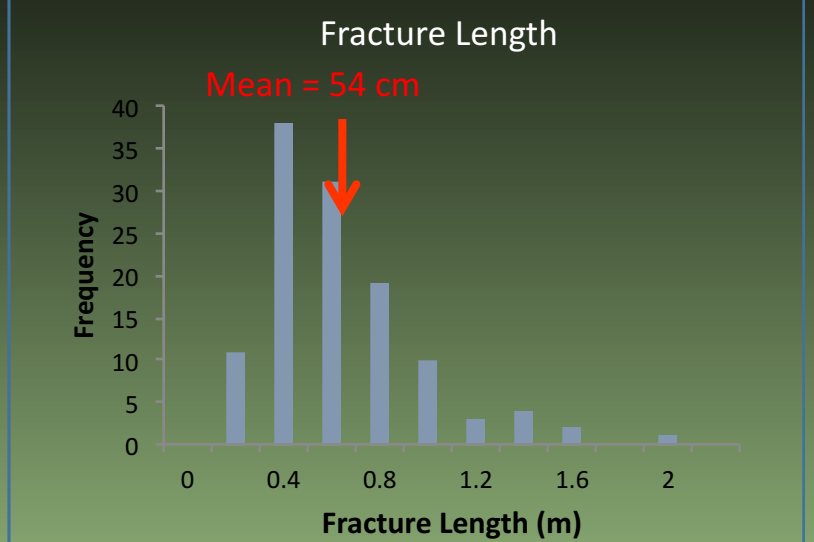
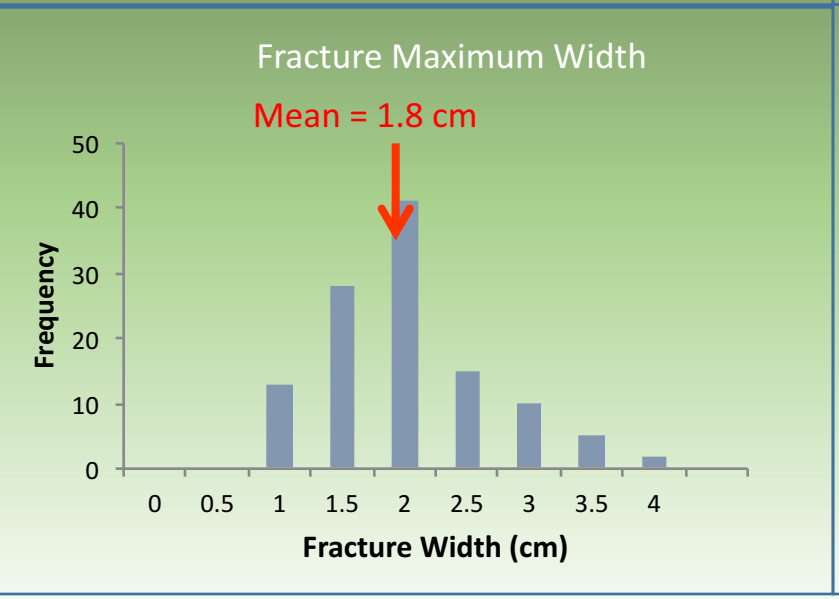
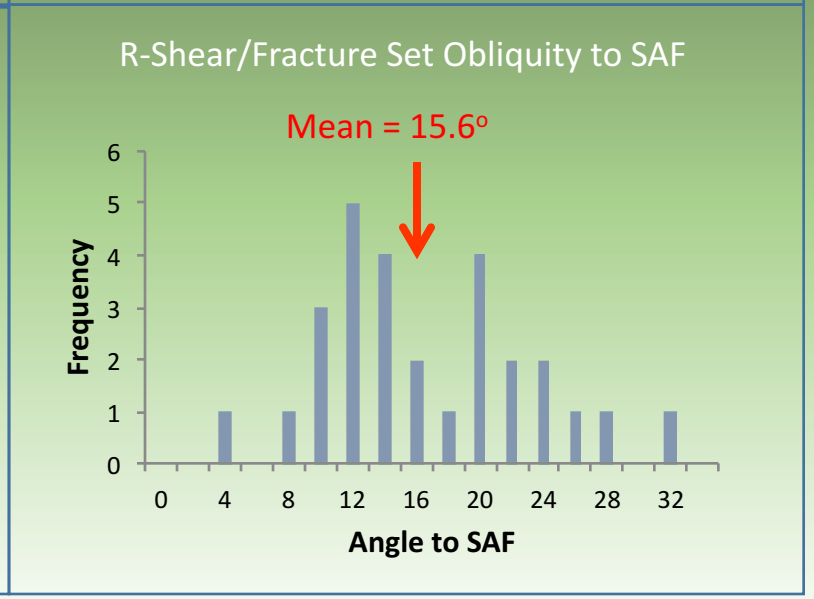
DLV Fracture Geometry

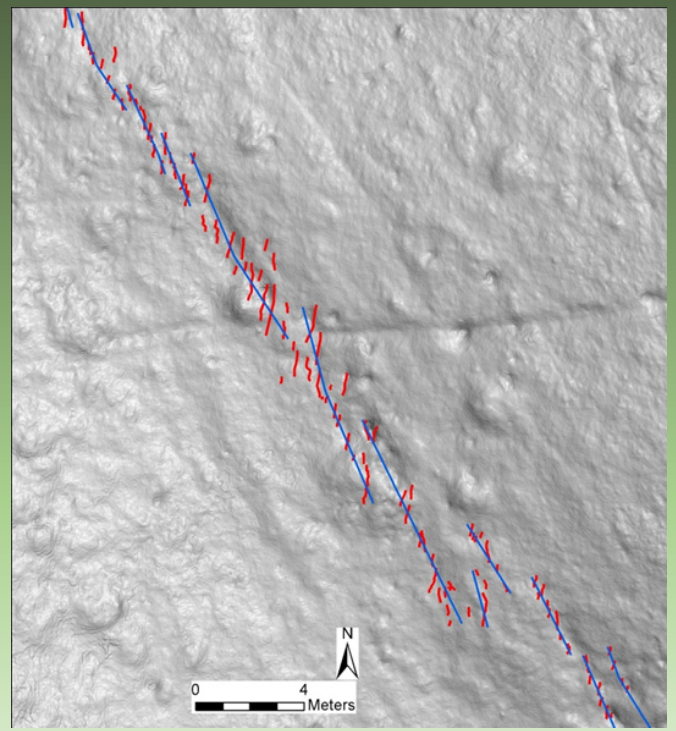








- Fractures (n = 119)
  - nearly perpendicular to incremental e_1 for SAF right-slip
- Fracture sets (n = 28)
  - Interpreted as R-shears



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