# Shear development and overprinting in a back-arc basin, Klamath Falls, Oregon


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## Tectonic Setting

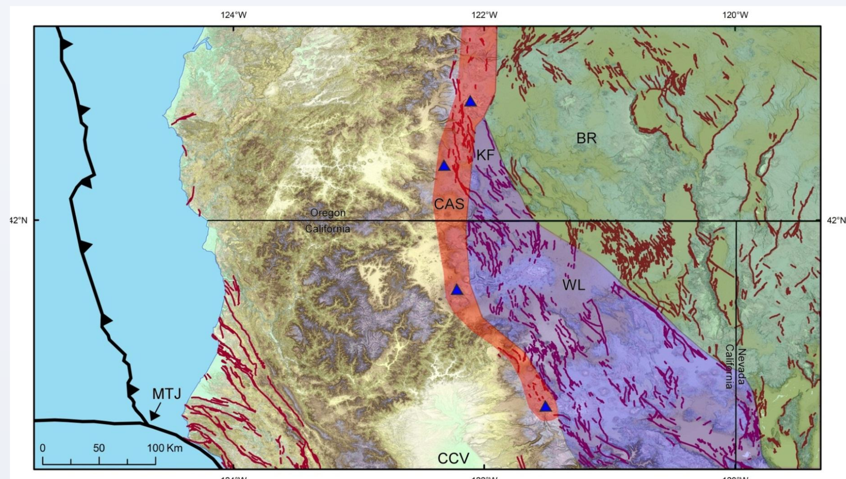



**Figure 1**: Shaded Relief map showing major tectonic provinces of western North America. WL-Walker Lane Fault Zone, CAS-Cascade Volcanic Arc, BR-Basin and Range extensional province, CCV-California Central Valley, KF-Klamath Falls, MTJ-Mendocino Triple Junction.

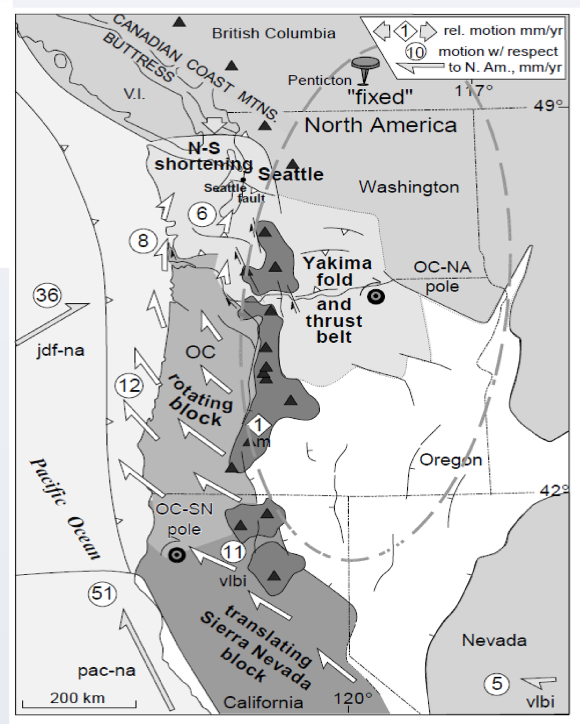



**Figure 2:** Geodetically determined plate motions of the Pacific Northwest from Wells, 2001. OC-Oregon Coast block, NA-North American plate, JDF-Juan de Fuca plate, PAC-Pacific plate, SN-Sierra Nevada block, vlbi-Very Long Baseline Interferometry.

- North America-Pacific plate boundary is wide and evolving.
- San Andreas Fault (SAF) steps eastward with time and was set in present location by ~13 Ma.
  - The Walker Lane Fault Zone (WL) is an incipient fault zone east of the San Andreas and presently accommodates ~30% of NA-Pacific relative plate motion (Faulds and Henry, 2008)
- WL grows northward and accommodates more of NA-Pacific plate motion with time.
- Northern WL shows north and northwest trending faults in a stair-stepping pattern.
  - N-striking faults are extensional.
  - NW-striking faults are translational.

## Questions and Motives

- How do the major tectonic provinces (SAF, WL, CAS, BR) of N. America interact?
- What is the northernmost extent of the WL?
- What is the future of the North America-Pacific Margin?
  - Will the WL become the main plate boundary after the San Andreas Fault dies?

## Why study the Klamath Basin?

- Intersection of Cascade Arc, Basin and Range, and Walker Lane fault Zone.
- N-NW stair-stepping faults stop in Klamath Basin.
- 1993 Earthquake sequence.
- New high resolution LiDAR (Light Detection and Ranging) reveals previously unseen details of topography and allows detailed mapping of surface-rupturing faults.

## Hypothesis

- If deformation in the Klamath Basin is being influenced by the Walker Lane, Cascade arc, and Basin and Range, then NW-striking faults will be predominantly strike-slip and N-striking faults will be predominantly dip-slip.

## Methods

- Bare-Earth LiDAR analysis of topography reveals fault scarps and unconformable geomorphic features in previously unseen detail by eliminating vegetation.
- Traditional geologic mapping of lithologic unconformities.
- Determination of slip vectors to characterize sense of slip across faults.
- Slip vector calculation and comparison to geodetic vectors.

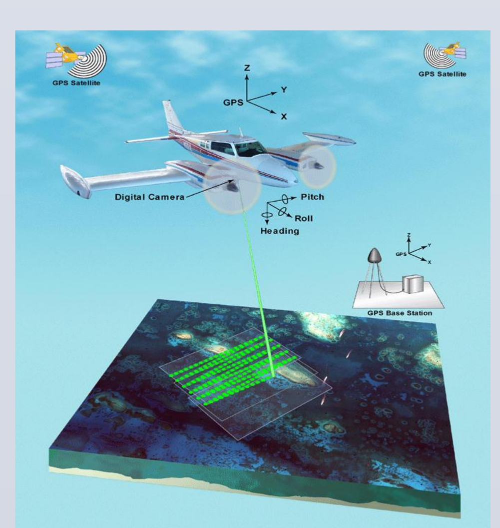



**Figure 3:** Schematic of the collection of LiDAR data (USGS, 2013).

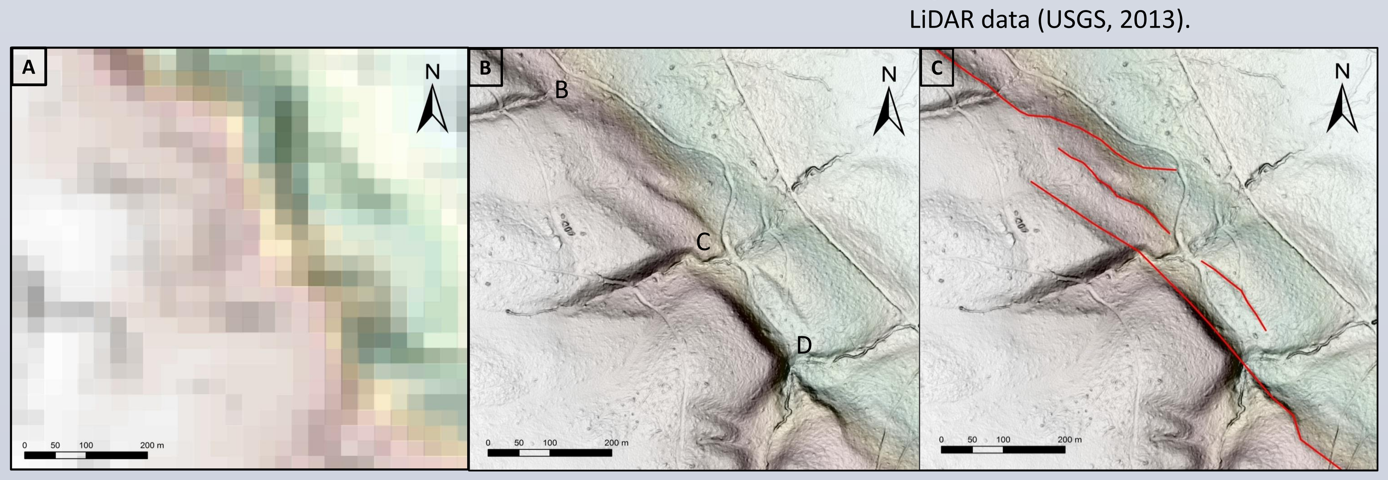



**Figure 4:** (A) 30-meter gridcell resolution Shuttle Radar Topography Mission (SRTM) and (B) 1-meter gridcell resolution Light Detection and Ranging (LiDAR) of an active fault in the Klamath Basin. (C) Note mapping advantages from clarity of vertical separation, lateral movement, and geomorphic features attainable with LiDAR.

## Mapping

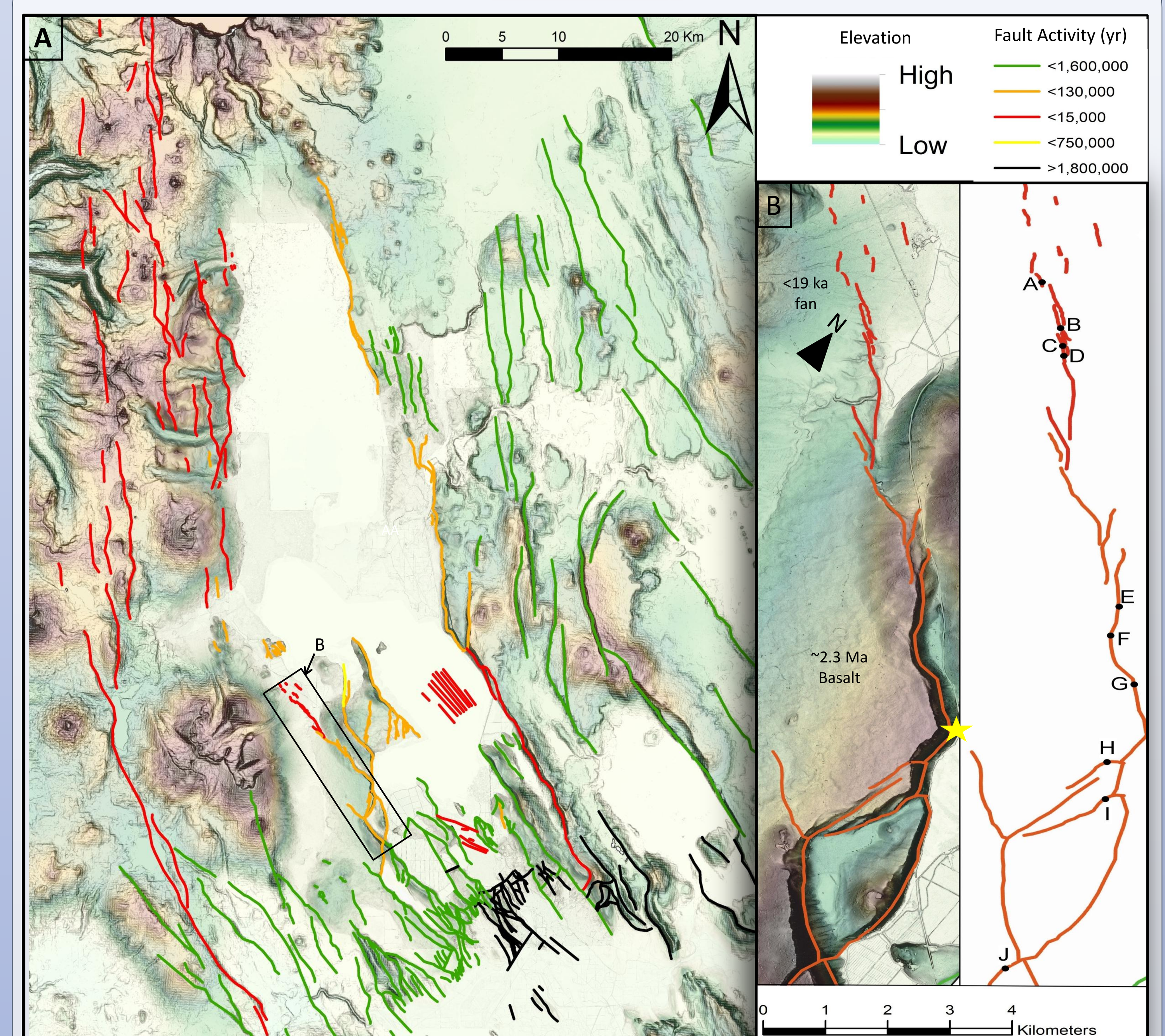



**Figure 5:** (A) Shaded relief map of the Klamath Basin. Lines are fault traces colored to annotate age. (B) Active strand of NW-directed strike-slip faulting in the basin interior. Locations of piercing points are labeled A-J. Star denotes arbitrary location used for figure 7.

- Klamath Basin is defined by north and northwest-trending faults.
- Fault activity is characterized by relative ages of offset features.
- Located 10 piercing points along inner-basin active fault strand.
- NW striking active faults in the basin center cut glacial deposits (<19 ka) (Locations A-D) and show right-lateral separation.
- Surfaces cut by right-lateral faults are strongly tilted (10°- 40°) suggesting extension prior to translation.

## Measuring Offset

- Displacement across fault can be represented as a vector and is broken into dip-slip (perpendicular to strike) and strike-slip (parallel to strike) components.
- Dip-slip displacement accommodates extension.
- Strike-slip faulting accommodates translation.
- $\frac{Strike-Slip}{Dip-Slip} = \frac{Translation}{Extension}$

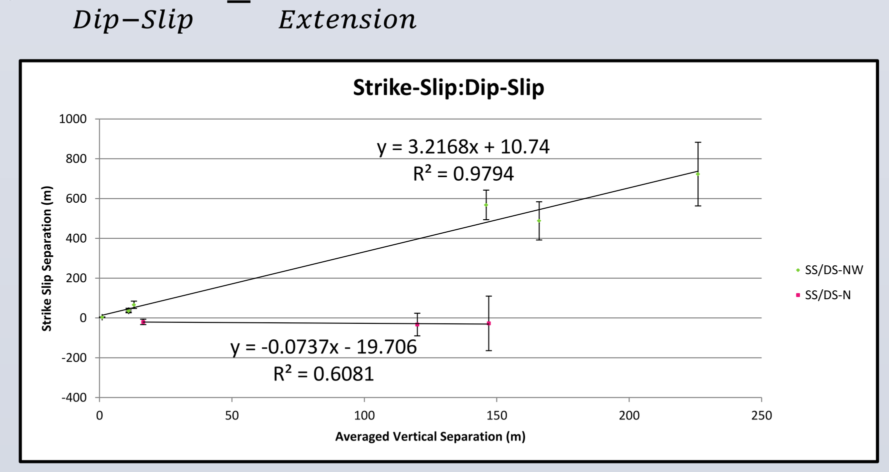



**Figure 6:** Plotted displacements across fault traces. NW-striking faults (locations A-G) are green data points. N-striking (locations H-J) faults are red data points. Note that right-lateral motion is defined to be positive and left-lateral motion is negative.

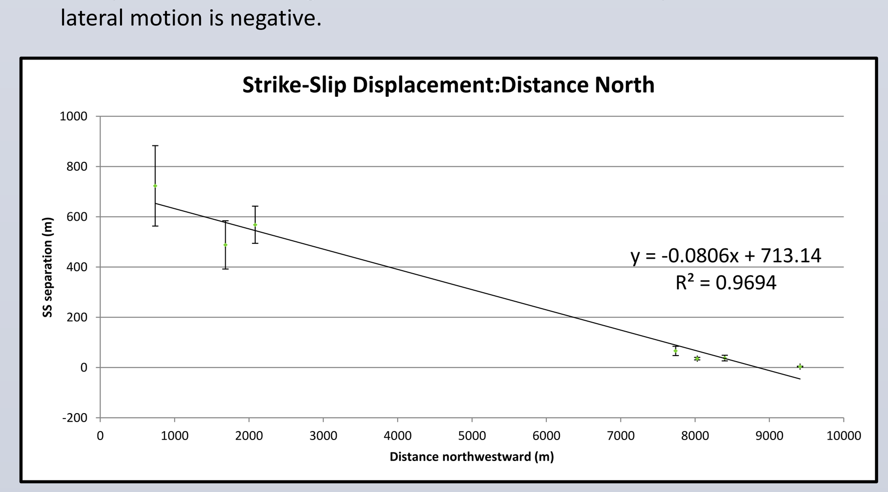
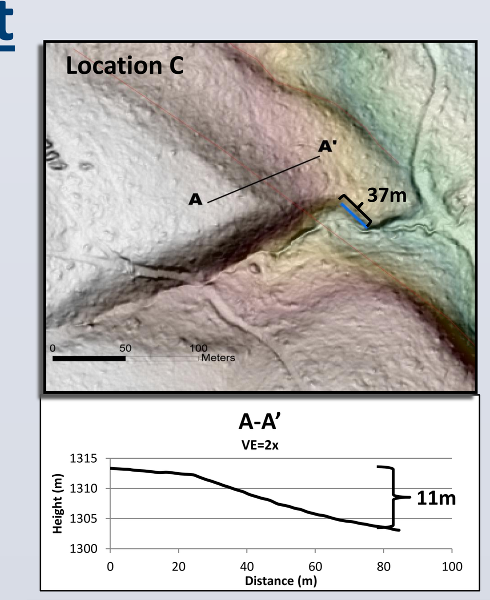
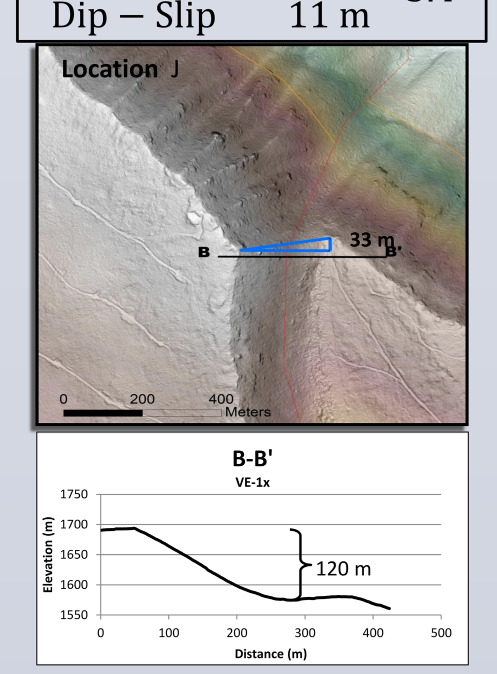



**Figure 7**: Strike-slip displacement as a function of distance northward from an arbitrary point to the south.



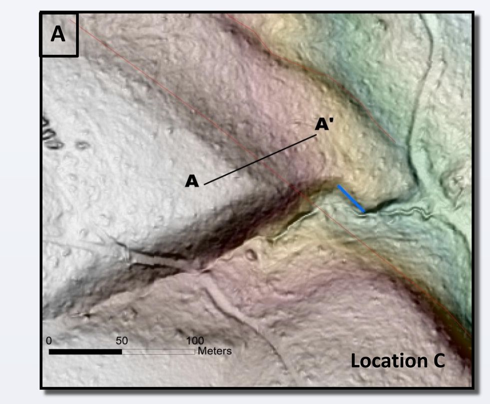

$$\frac{Strike-Slip}{Dip-Slip} = \frac{37\ m}{11\ m} \sim 3.4$$




$$\frac{Strike-Slip}{Dip-Slip} = \frac{33\ m}{120m} \sim 0.28$$

**Figure 8:** Example measurements of lateral and vertical displacement at locations C and J.

## Net slip and comparison to geodesy



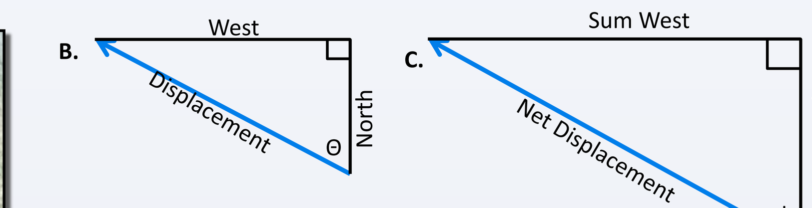




**Figure 9:** Component vector calculations for strike-slip faults. (A) displacement vector (blue) at Location C. (B) Displacement at single locations can be broken into north and northwest component vectors. (C) Component vectors for all locations can be summed to yield a larger net slip vector for the entire fault strand.

- Strike-slip displacement vectors can be broken into azimuthal components (North and West).
- Component vectors at each location can then be summed and combined to yield a net slip vector that represents motion along the entire fault strand.

$$\sum_{A}^{J} North\ Components = 1461\ m \qquad \sum_{A}^{J} West\ Components = 1490\ m$$

$$\tan^{-1}\frac{1490m}{1461m} \sim 46° = N46°W \qquad \sqrt{1461^2 + 1490^2} = 2087\ m$$

- Geodetic vector is oriented at ~N40W and has a rate magnitude of ~5mm/yr (McCaffrey et al., 2013).
- Geological net slip vector is oriented ~N46W and rate magnitudes range from ~0.9 mm/yr to ~4.8 mm/yr.
- Range is probably due to poor age constraints on offset surfaces.

## Summary

- North and northwest trending faults define the Klamath Basin in southern Oregon (Figure 5).
- Deformation in the Klamath Basin is attributed to both the northwest Basin and Range and Walker Lane Fault Zone intersecting the Cascade volcanic arc.
- Right-lateral strike-slip displacement is localized to the basin interior, occurs on northwest-striking faults, and decreases displacement northward (Figures 6-8).
- Strike-slip faults cut tilted strata suggesting that basin extension is being overprinted by NW-directed lateral shear.
- Direction of net displacement along the basin-interior strike-slip faults is supported with geodetic data. However, rates remain uncertain due to poor age constraints of offset surfaces.

## What does this mean for North America?

- As the WL matures and propagates northward, it will accommodate more plate motion with time.
- The Oregon Coast Range will continue to rotate and back-arc extension will also propagate northwestward.
- The WL will likely become the main Pacific-N. America plate boundary.

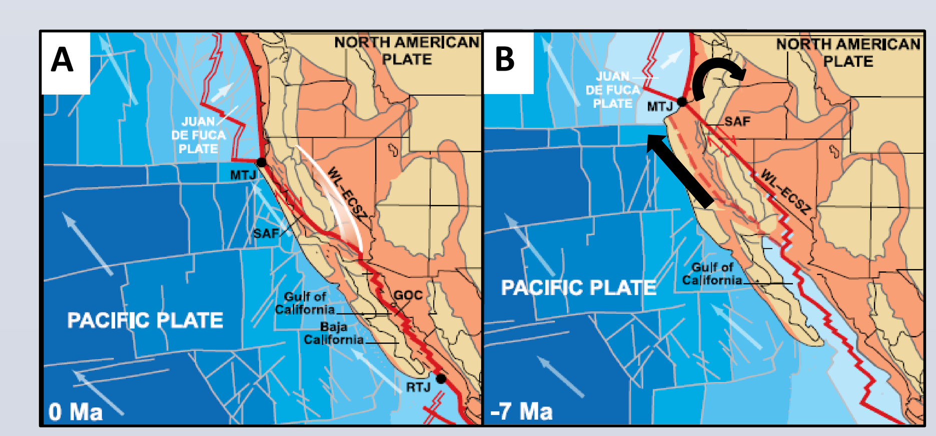



**Figure 10:** North America-Pacific plate margin evolution as interpreted by Faulds and Henry (2008). (A) Modern plate margin geometry. SAF-San Andreas Fault, MTJ-Mendocino Triple Junction, GOC-Gulf of California, RTJ-Rivera Triple Junction. (B) 7 Myr projection that WL becomes main transform boundary. Orange shading denotes extension.

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