Using Active Source Seismology to Image a Strike-Slip Fault Damage Zone as a Function of Depth, Distance and Geology

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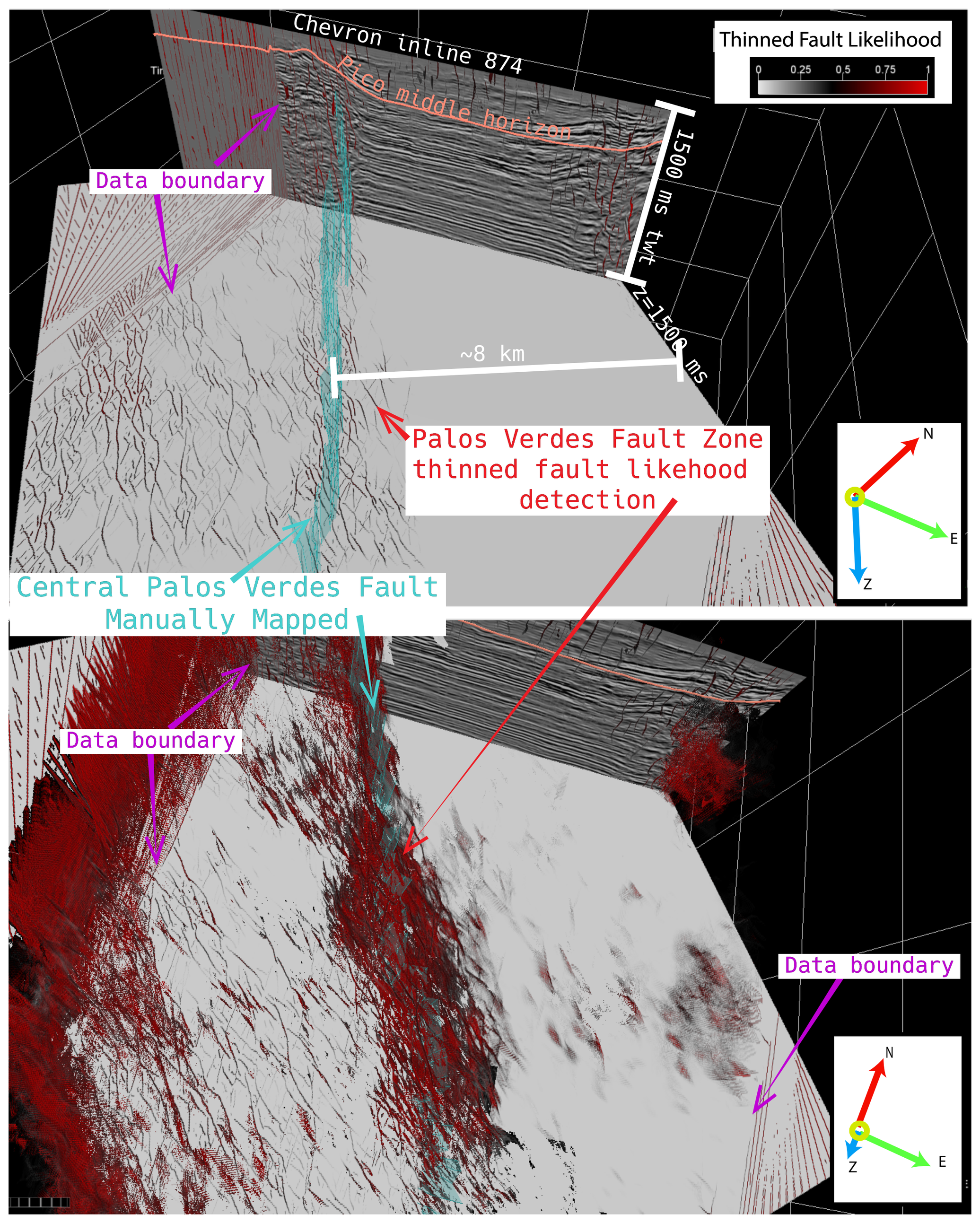
Questions

- Can we image a fault damage zone is 3D seismic data?
- Are there damage zone scaling systematics?
- Does depth, distance or geology matter?

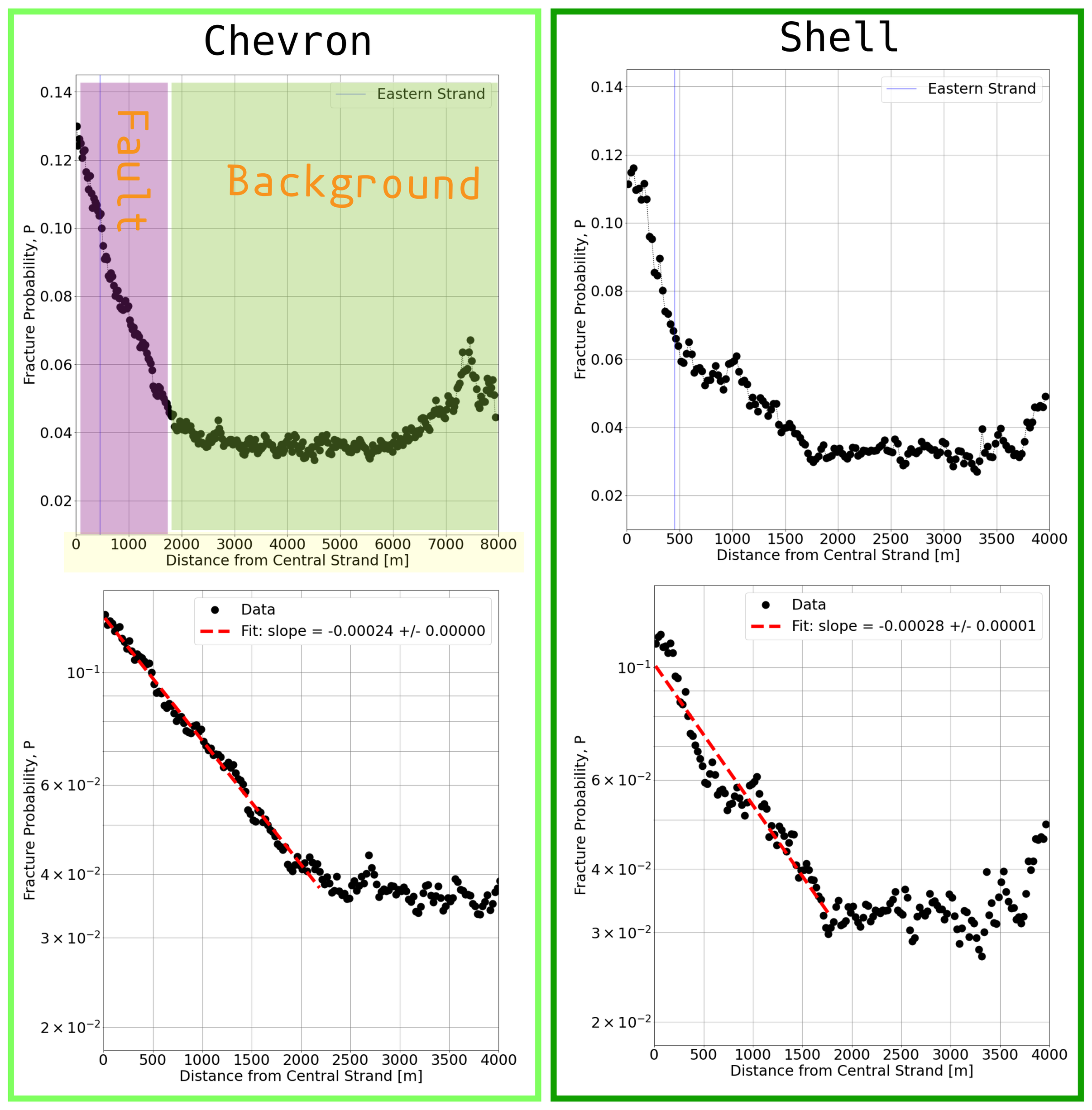
Results

Fault Detections Near Mapped Fault



Perspective views of Thinned Fault Likelihood attribute results for the Chevron volume along the Palos Verdes Fault. The transparent to red colormap indicates the fault probability. (top) The attribute is projected onto Chevron inline number 874, and a z-slices at 1500 ms twt. Note the variable width of the damage zone along strike, and how the results for thinned fault likelihood are concentrated around the fault. (bottom) A top down perspective view of the Thinned Faulk Likelihood attribute rendered as a 3D volume, showing concentration of fault detections around the mapped fault trace.

Exponential Scaling to 2 km Distance

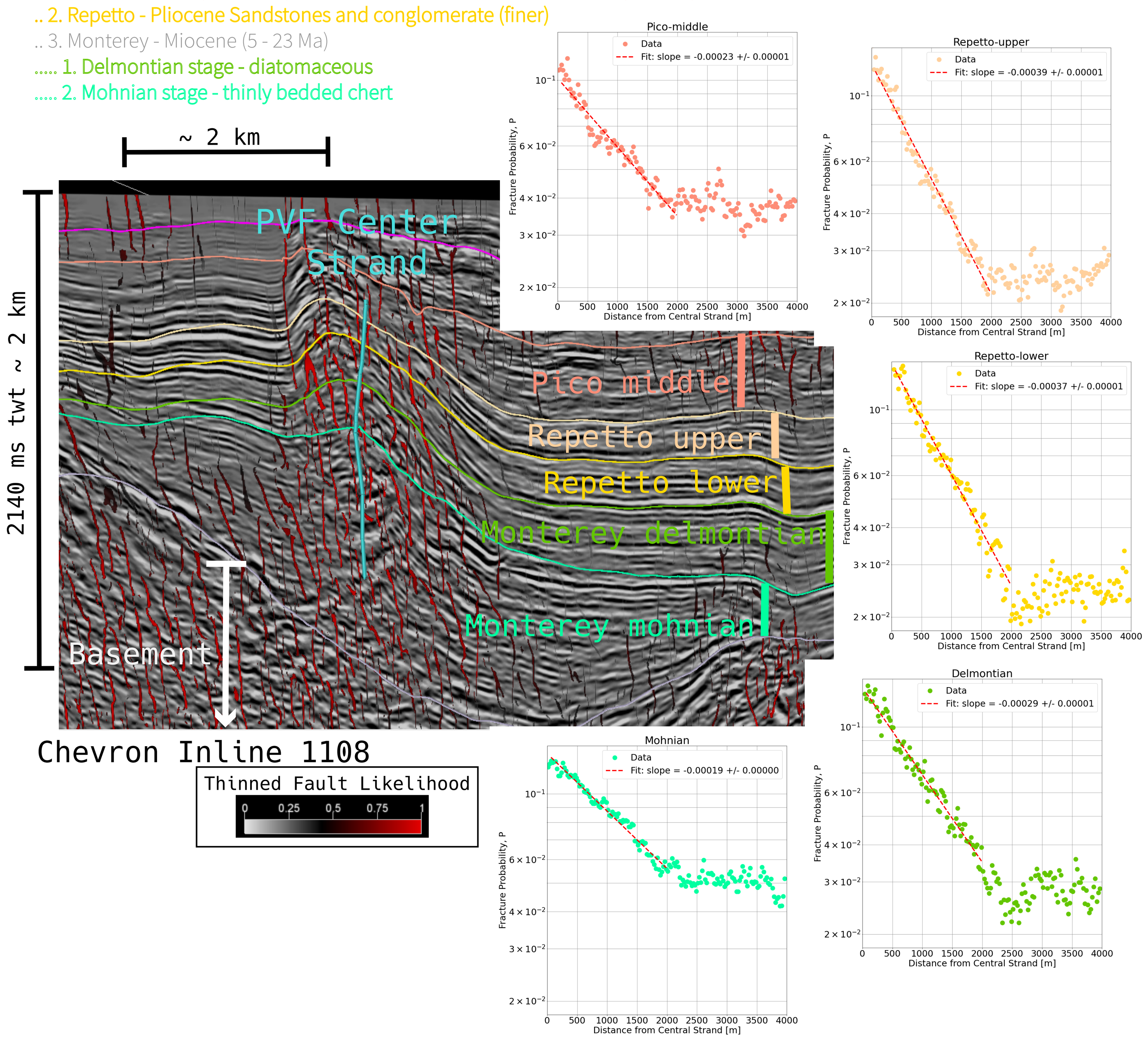


$$P = \sum \frac{<pi>}{N}$$

(top) Fracture probability relationship versus distance from central mapped strand. P is mean probability of the ith voxel being a fault in a spatial bin of N voxels. Fracture probability decays with distance from the central strand to ~ 2.2 km from the fault (note, different x-axis in upper left). The background, low fracture probability, begins at 2.2 km and at greater distances fracturing increases due to the Wilmington fault (and its damage zone) at the eastern edge of the seismic volumes. (bottom) Shows spatial relationship between fracture density and distance from the central strand, and the red line indicates the least squares exponential fit through the data extending from the central fault strand to the background (2.2 km).

Similar yet Unique Trends in Different Geologic Units

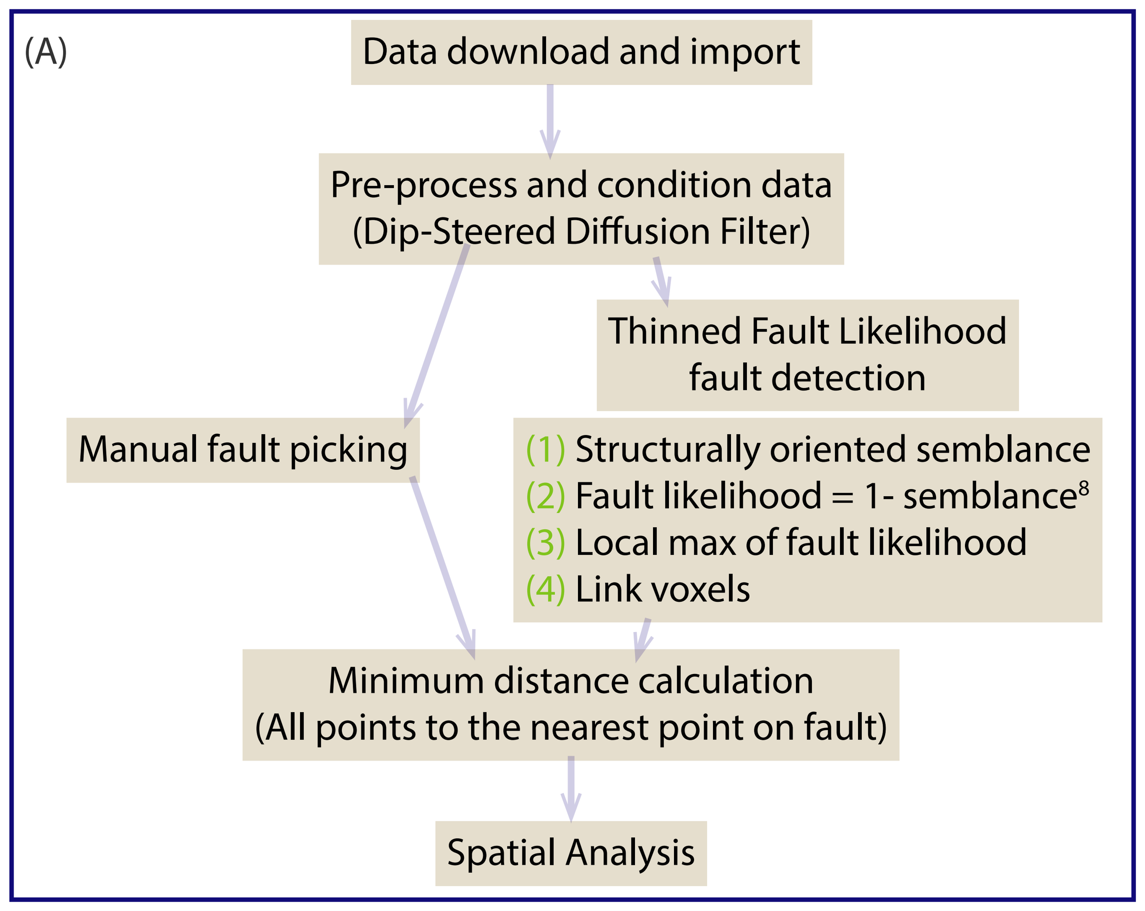
Lithologies
1. Pico - Pliocene (2.5 - 5 Ma) Interbedded siltones and sandstones (coarser)
2. Repetto - Pliocene Sandstones and conglomerate (finer)
3. Monterey - Miocene (5 - 23 Ma)
1. Delmontian stage - diatomaceous
2. Mohnian stage - thinly bedded chert

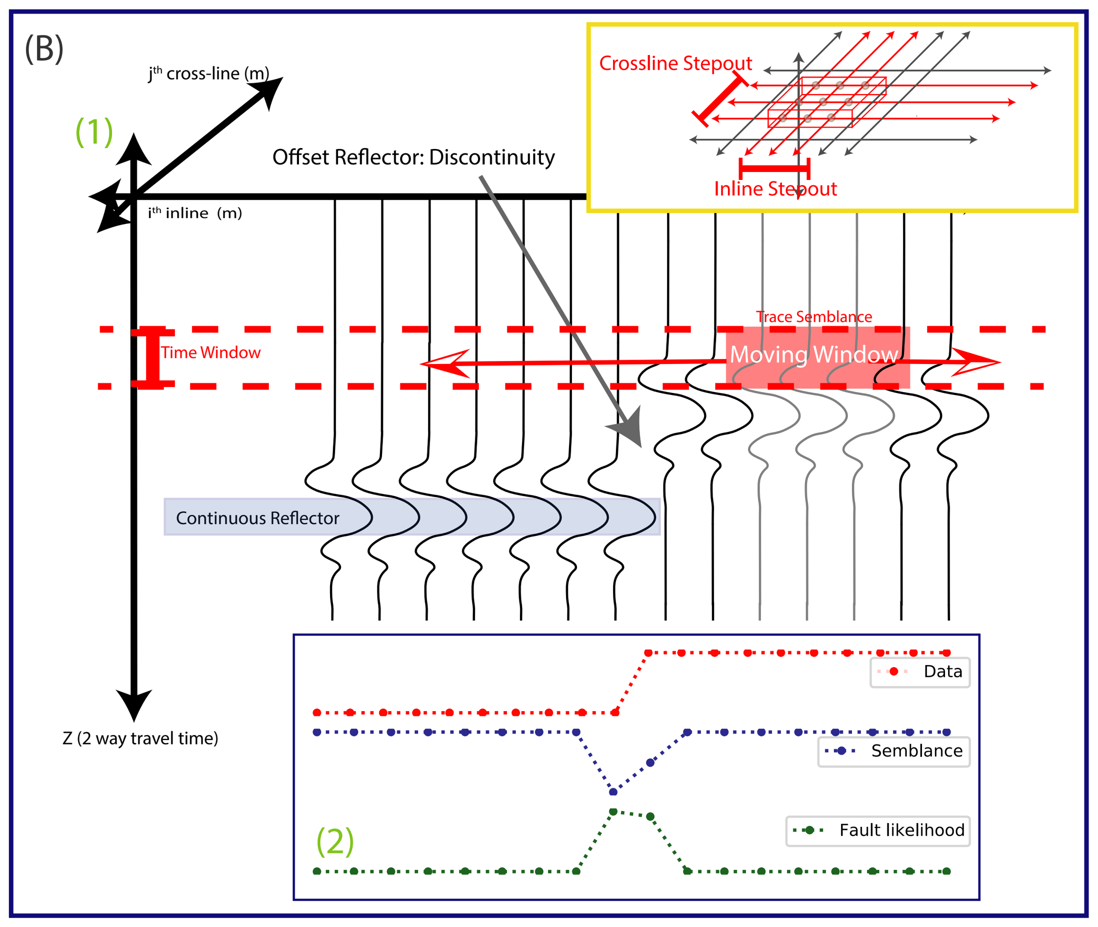


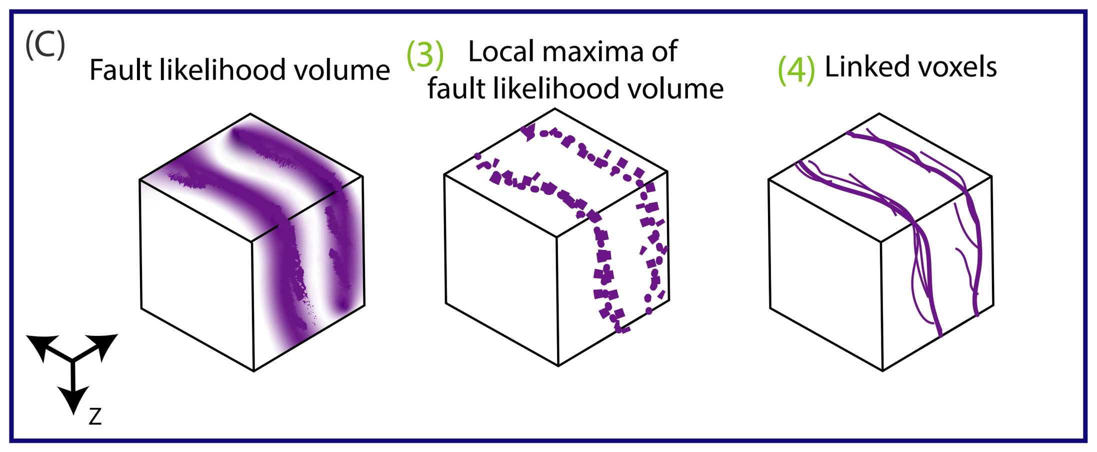
Left figure shows an example of dip-steered diffucion filtered seismics in black and white color scale. Overlain, the vertical teal line is the manually mapped central fault strand. The rainbow colored lines are mapped 3D horizons projected into the inline, that mark lithological differences that have been tied to paleontologic interpretation of formation tops. These formation tops are used as upper and lower bounds to constrain average fracture probability as a function of distance per unit. Note the different exponential fit slopes in different units and variable background (horizontal portion) in the different units.

Methods

Detecting & Mapping Faults







(A) workflow used, green numbers in the thinned fault likelihood calculation shown in cartoon form in panels B & C. (B) Following (Hale, 2013) cartoon showing fault likelihood volume calculated from a semblance volume where semblance is a measure of multi-trace similarity of adjacent traces over a time window that is is structurally orient by dip-steering. (Upper inset) shows a 3D moving window over inline, crossline and two way travel time. (Lower inset) depicts the fault-likelihood of this moving window cartoon. (C) shows the resulting fault likelihood volume, (3) local maxima for fault likelihood preserved, thinning the discontinuity volume. (4) Thinned discontinuities are linked up forming a fault and fracture network identified purely by the data.

Data

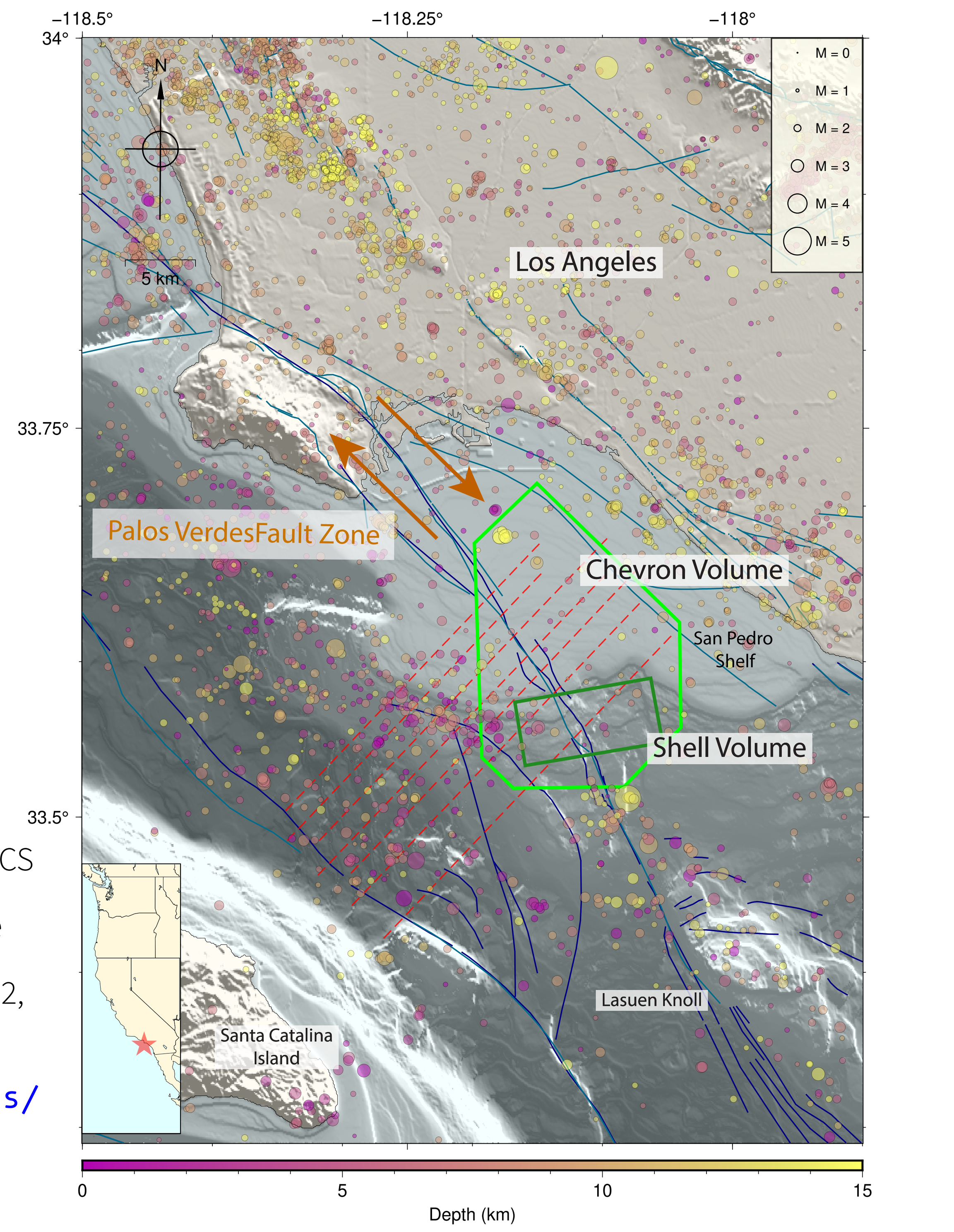
Active Source Seismics

- 3D volumes
  - C-01-76SC-3D -- 1976 Chevron MCS
    - Area ~= 300 km^2
    - Bin spacing = 25 x 50 m
  - B-388-84SC-3D -- 1984 Shell MCS
    - Area ~= 50 km^2
    - Bin spacing = 12.5 x 25 m
- 2D seismic lines
  - W-30-82SC-2D -- 1981 Western Gebco MCS
    - 20 m shotspacing
    - 6 s record length, 4 ms sample rate

Well - Lithology & Geophysical Logs

- P0296-1, P0296-2, P0296-12, P0300-1, P0300-2, P0301-3, P0301-5, P0301-6

https://walrus.wr.usgs.gov/namss/



Map of southern California Inner Borderlands and San Pedro Shelf. Inset map shows western US, the red star indicates the study area. Main map shows location of mapped fault traces from the USGS quaternary faults database, where the navy blue lines are the USGS offshore Quaternary faults dataset and the turquoise lines are the USGS onshore Quaternary faults. Thick green polygon indicates the bounds of the 3D marine active source data sets. Dashed red lines indicate the 2D lines used in the study. Circles indicate earthquakes colored by depth and scaled by magnitude from the Southern California Earthquake Data Center alternate catalog [1981 - 2018] (Hauksson et al., 2012).