A unified model of crustal stress heterogeneity from borehole breakouts and earthquake focal mechanisms

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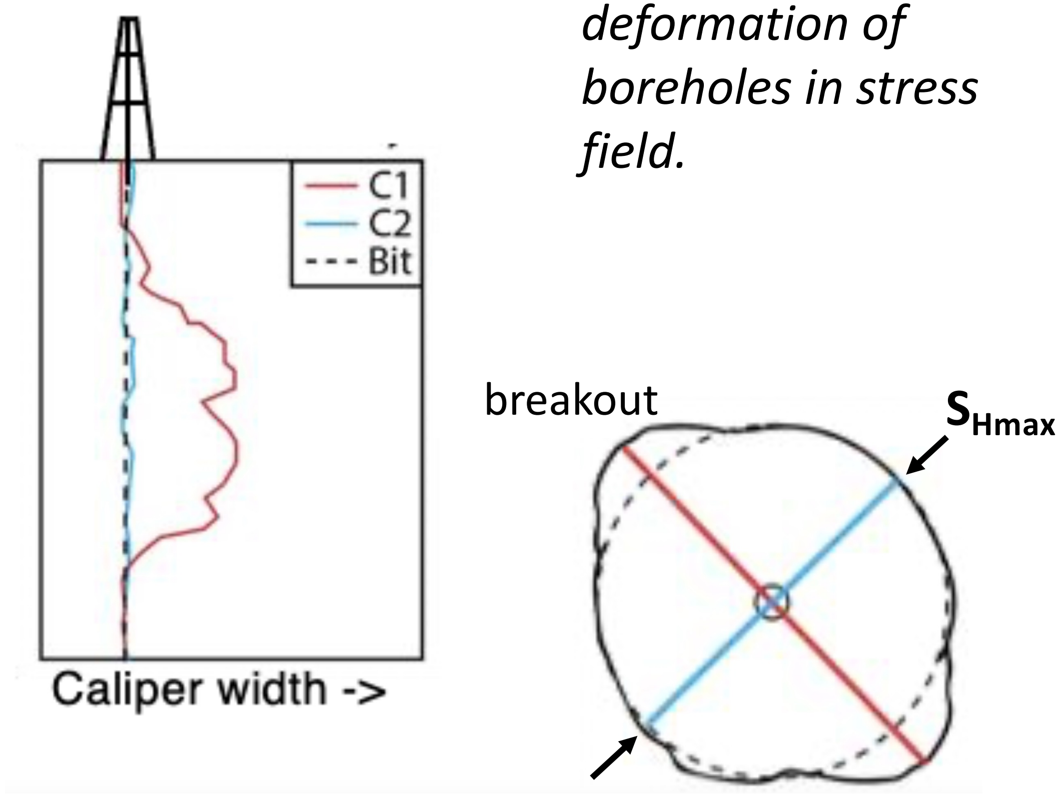
stress from borehole breakouts

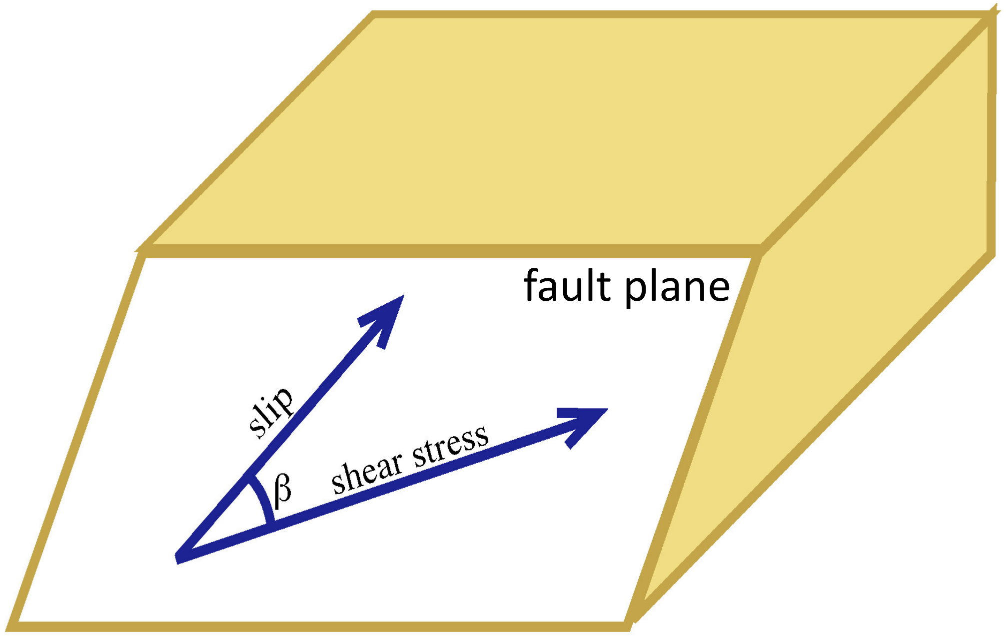
Stress orientations inferred from deformation of boreholes in stress field.



(e.g. *Stock & Healy,* JGR 1988; *Mount & Suppe,* JGR 1992)

stress from focal mechanism inversion

Earthquakes as stress probes: minimize misfit between shear stress and slip directions.



(e.g. *Angelier,* JGR 1984; *Michael,* JGR 1984)

Problem: reconcile stress orientations from borehole breakouts and focal mechanism inversions.

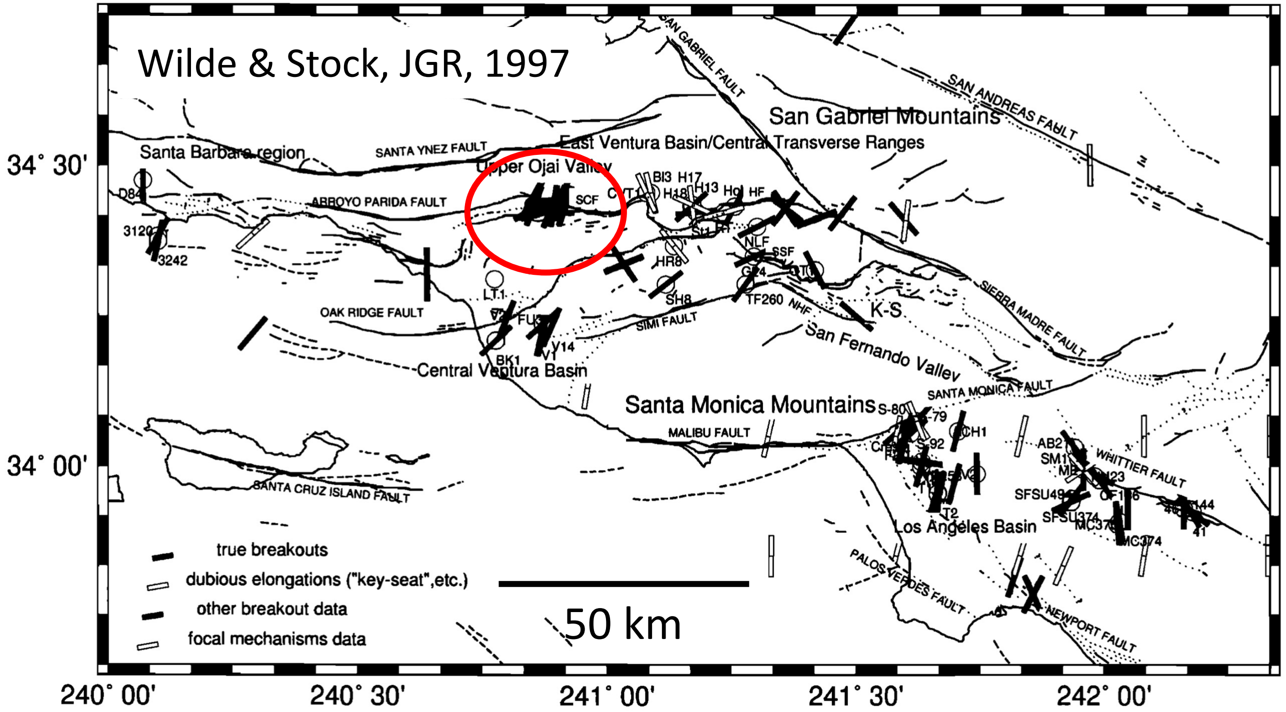
Maximum compressive horizontal stress (S_{Hmax}) directions often appear to disagree.

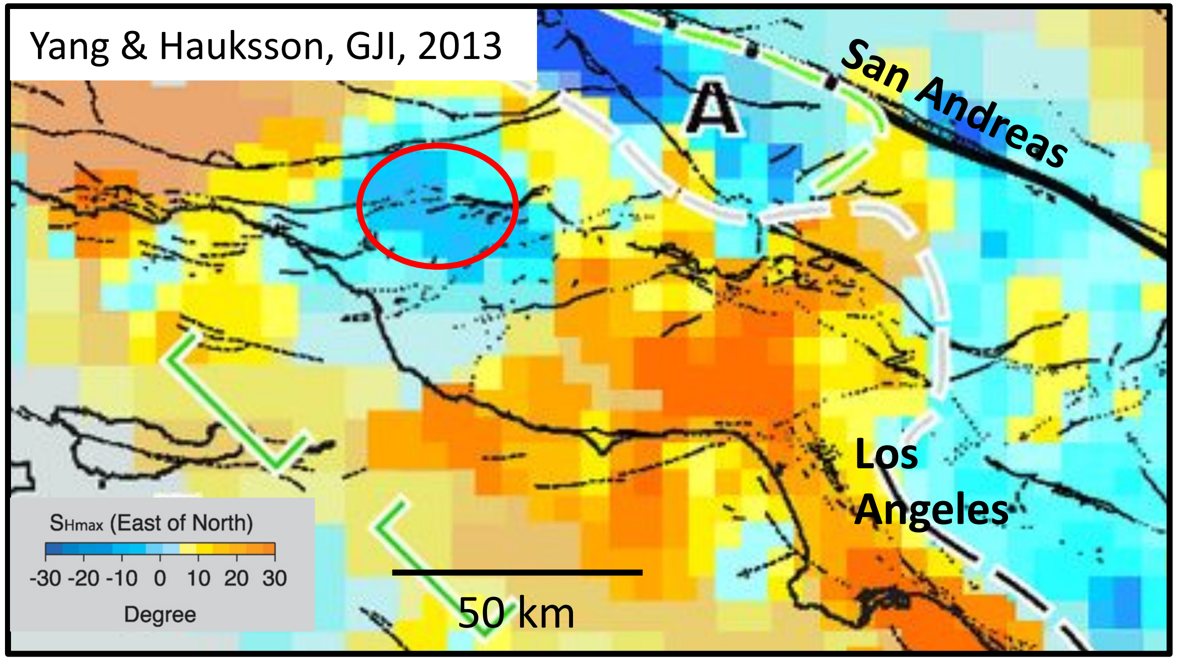
Different length scales of features:

- *Borehole breakouts imply short length-scale (<1 km) heterogeneity.*
- *Focal mechanism inversions imply smoothly-varying stress on longer length-scales (>10 km).*

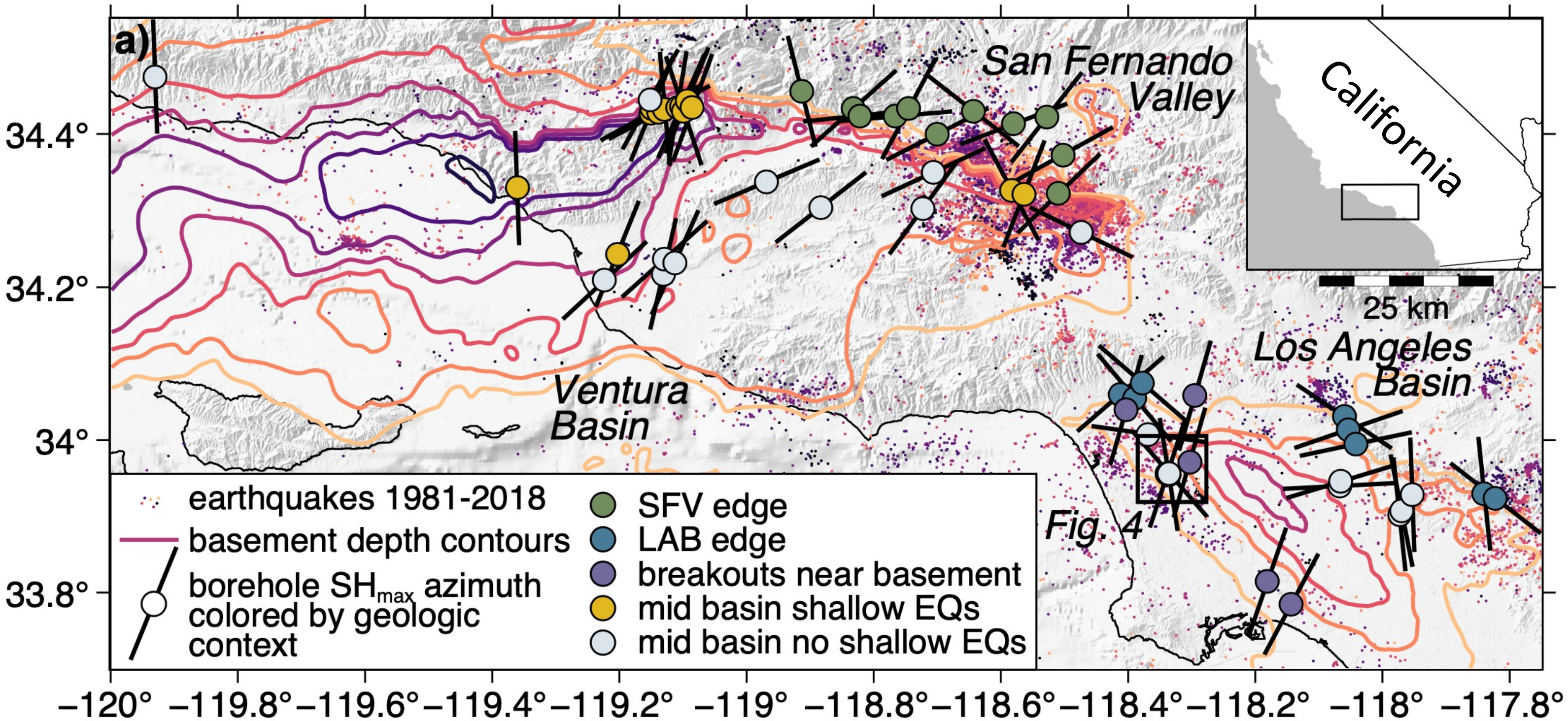
Direct comparison is complicated:

- *Boreholes are approximately point measurements, usually shallow.*
- *Focal mechanism inversion in a volume, usually at seismogenic depths.*





Data:



Borehole data from: *Mount and Suppe (JGR 1992), Kerkela and Stock (GRL 1996), and Wilde and Stock (JGR 1997).*

Borehole breakouts:

- Published S_{Hmax} from boreholes in Los Angeles area.
- Near-vertical boreholes with reliable S_{Hmax} only.

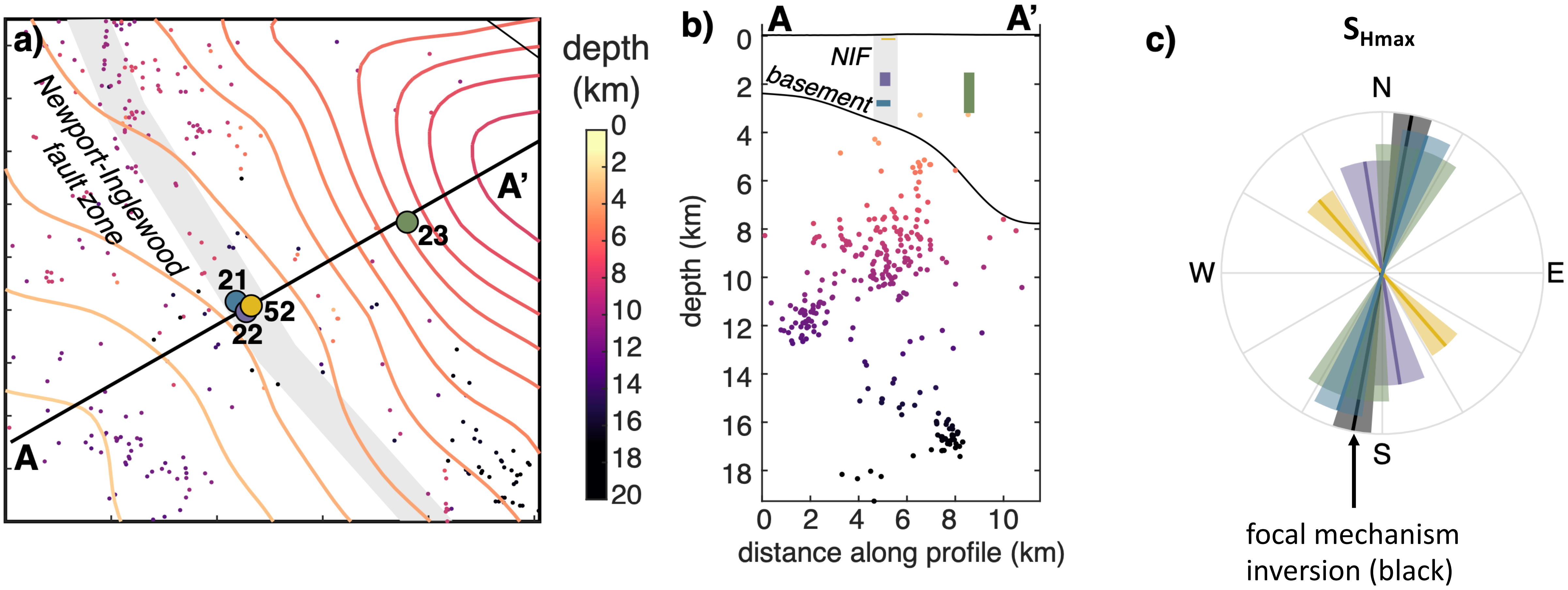
Focal mechanisms:

- Focal mechanisms from *Yang et al. (BSSA 2012)*
- Standard focal mechanism stress inversion methods (*Michael* JGR 1984, 1987; *Vavryčuk GJI* 2014).

For more details see: Luttrell, K., & Hardebeck, J. (2021). A unified model of crustal stress heterogeneity from borehole breakouts and earthquake focal mechanisms. Journal of Geophysical Research: Solid Earth, 126, e2020JB020817.

Example: four nearly-collocated boreholes

- S_{Hmax} rotates ~60° with depth within basin.
- Deeper boreholes agree with focal mechanism S_{Hmax}.
- *The two methods can agree when they sample locations close enough in space.*
- *Stress heterogeneity in basin, homogeneous stress in and near basement.*



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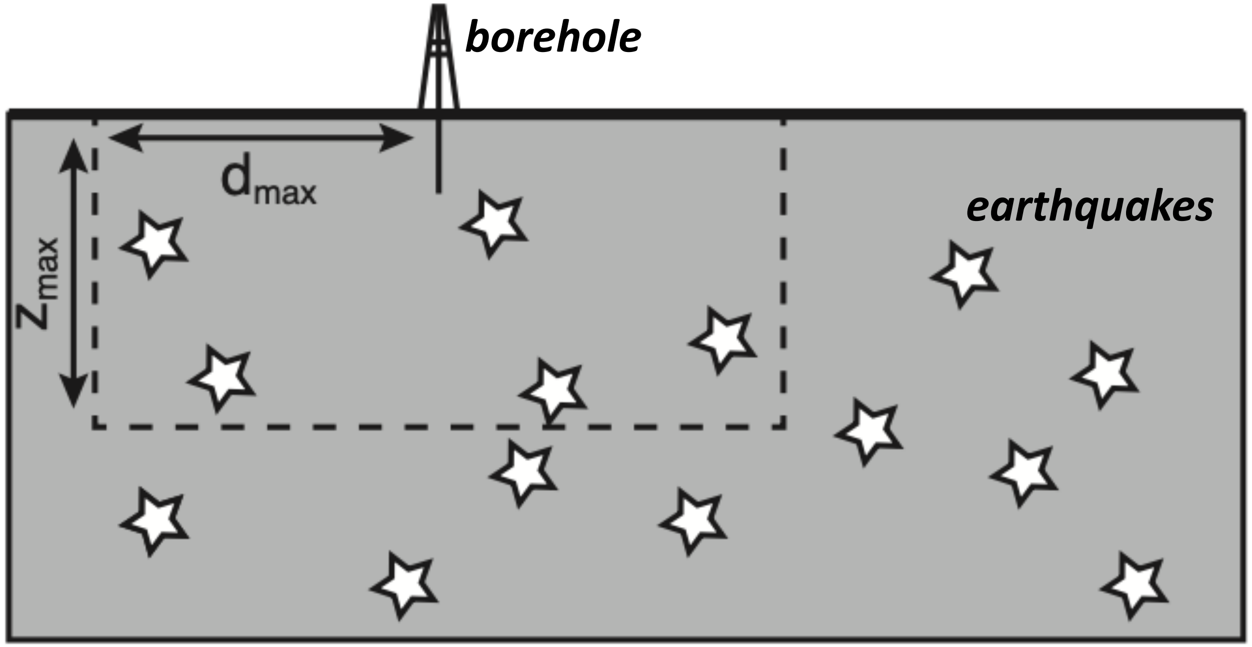
- *Stress heterogeneity in basin, Homogeneous stress in and near basement.*

Quantifying how close is “close enough” for the two methods to agree gives a measure of the length scale of stress heterogeneity.

Method:

- Invert focal mechanisms within some depth (z_{max}) and distance (d_{max}) from a given borehole.
- RMS angular misfit between borehole and focal mechanism S_{Hmax}, stack over multiple boreholes.
- Vary z_{max} and d_{max} to investigate vertical and/or lateral stress heterogeneity.



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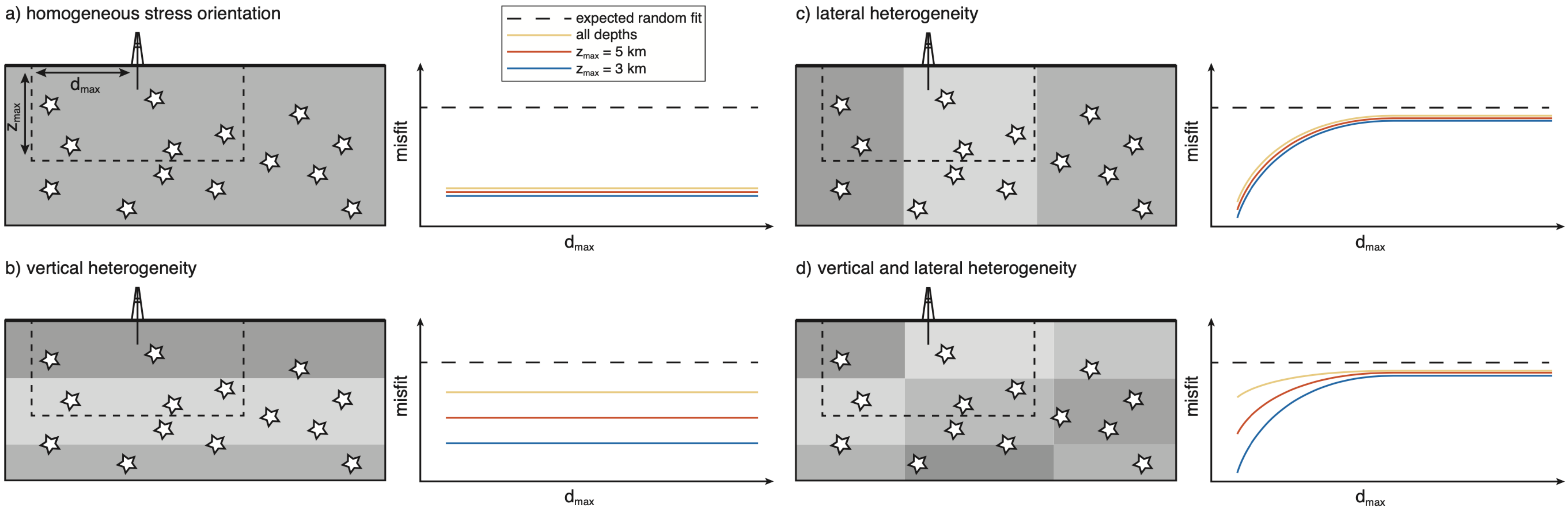

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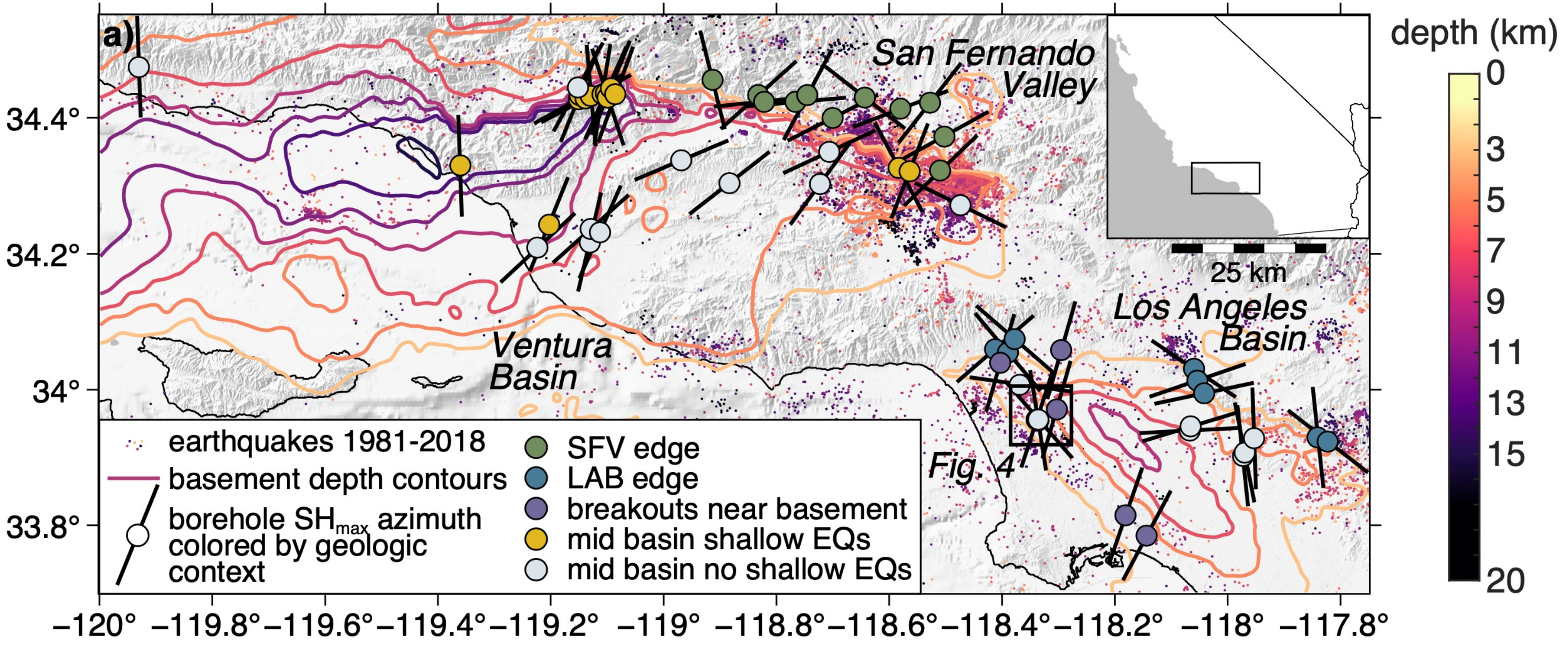
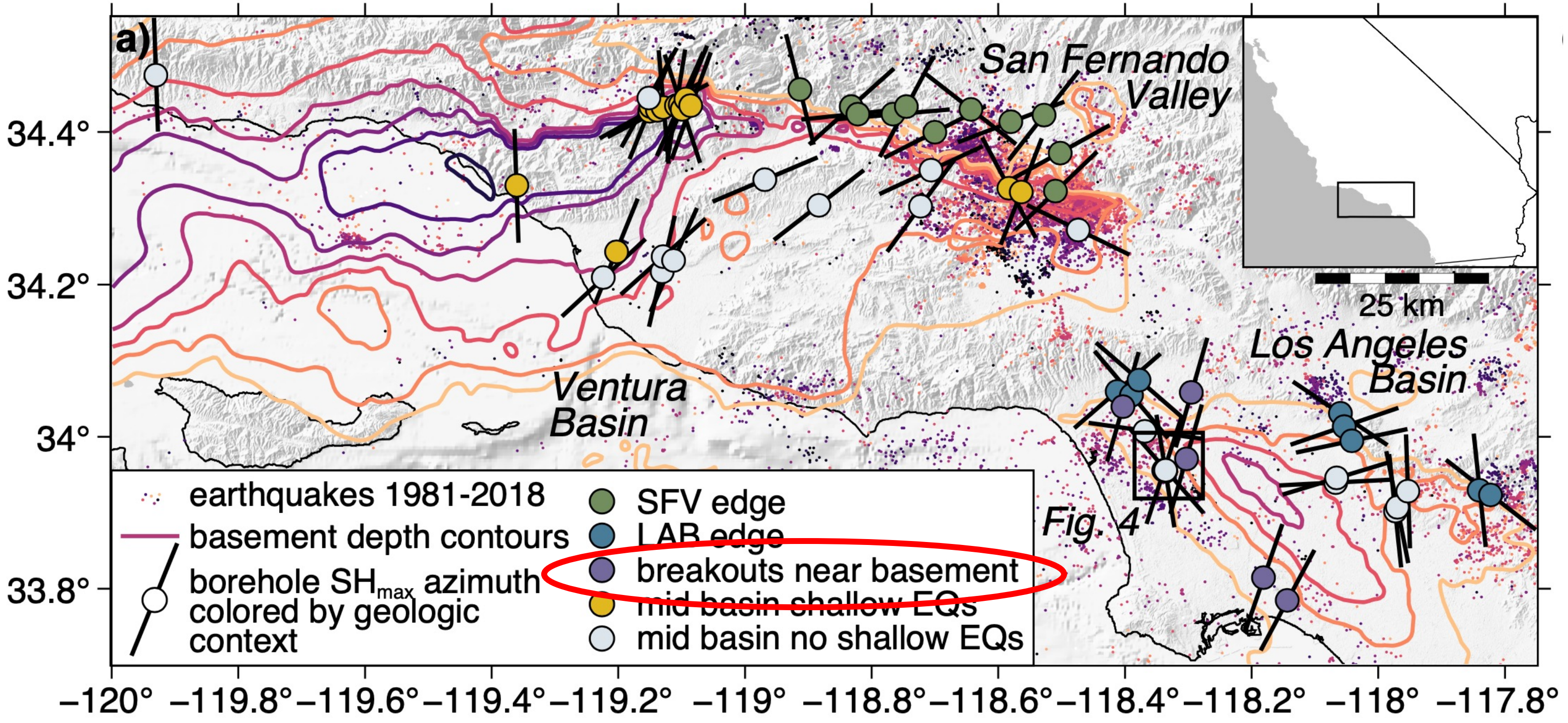
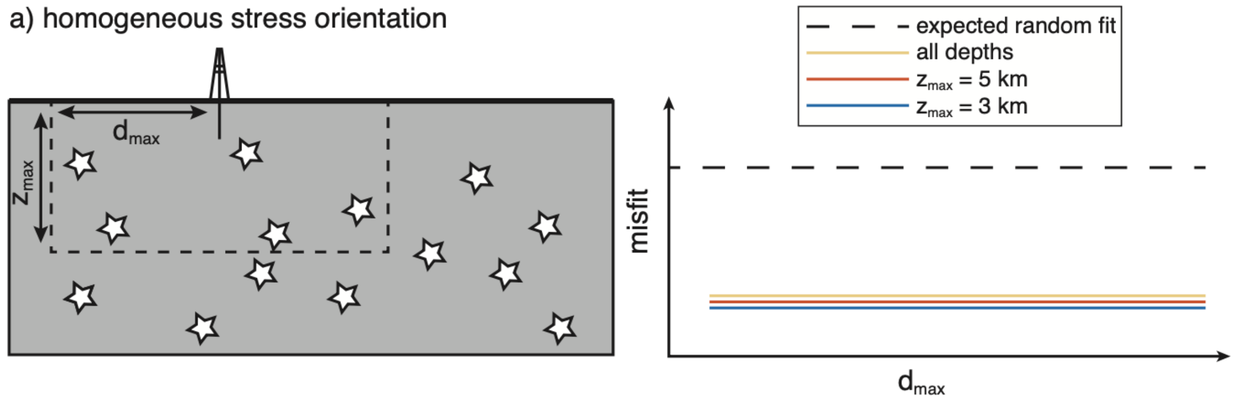
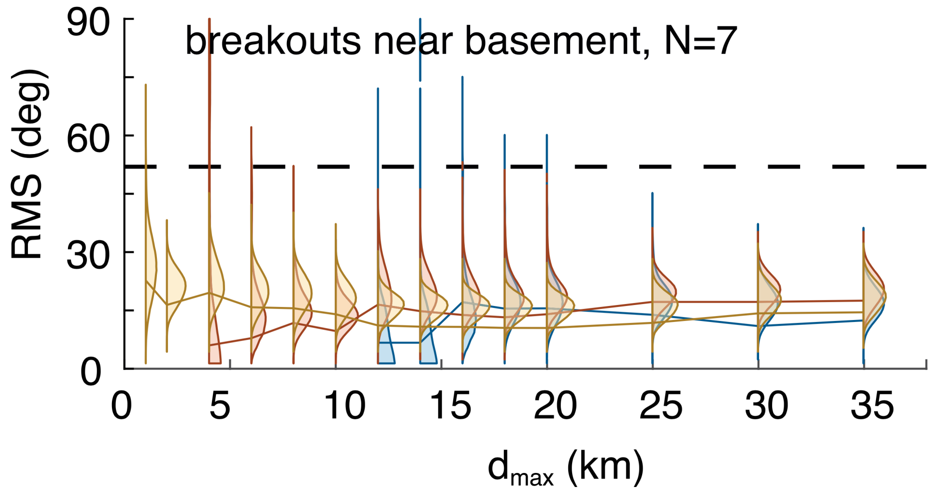
- Investigate different geologic contexts: near basement, within sedimentary basin (with or without shallow earthquakes), basin edges.



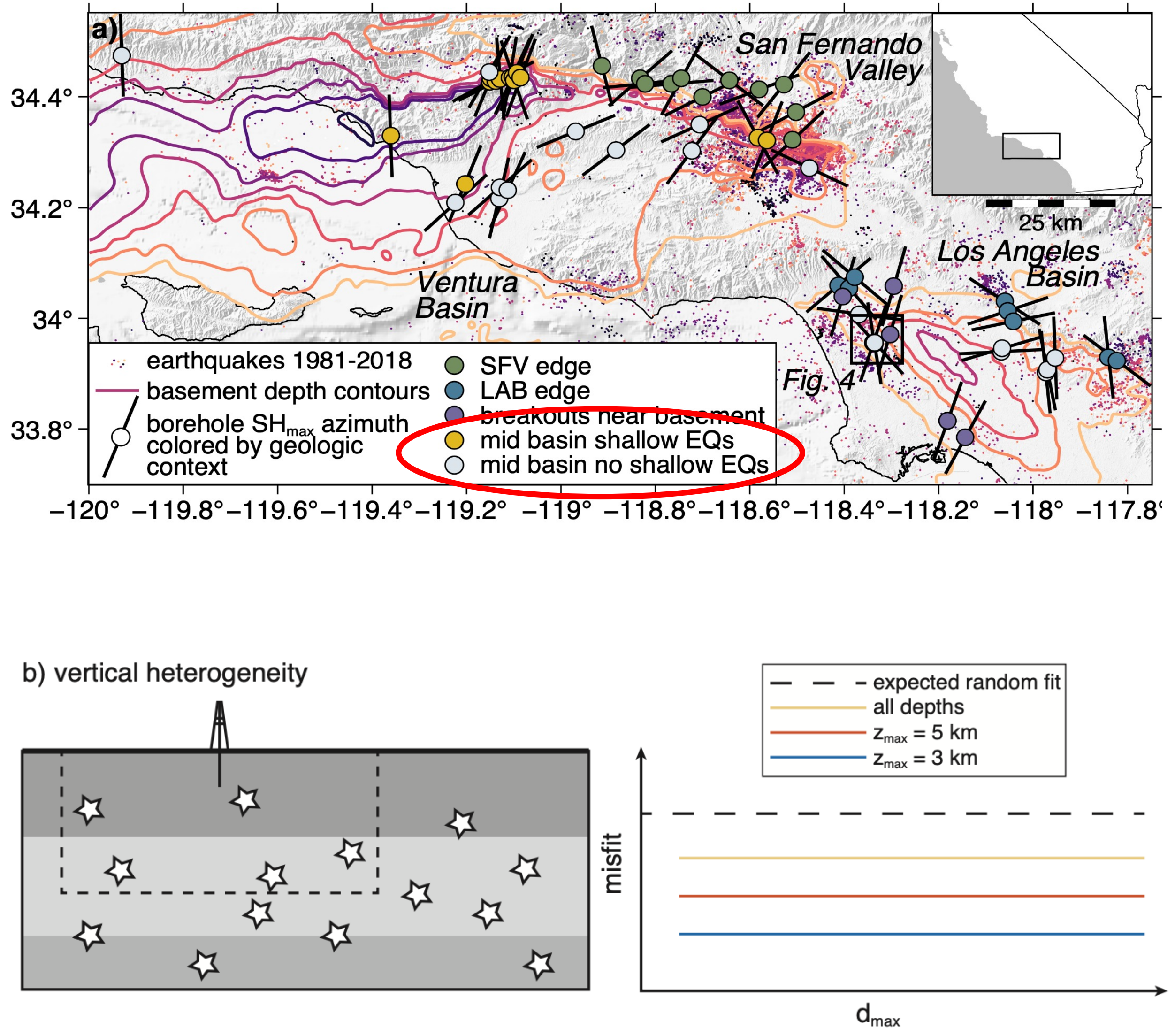
Breakouts near basement: good agreement, stress appears homogeneous on ≥35 km length-scales.

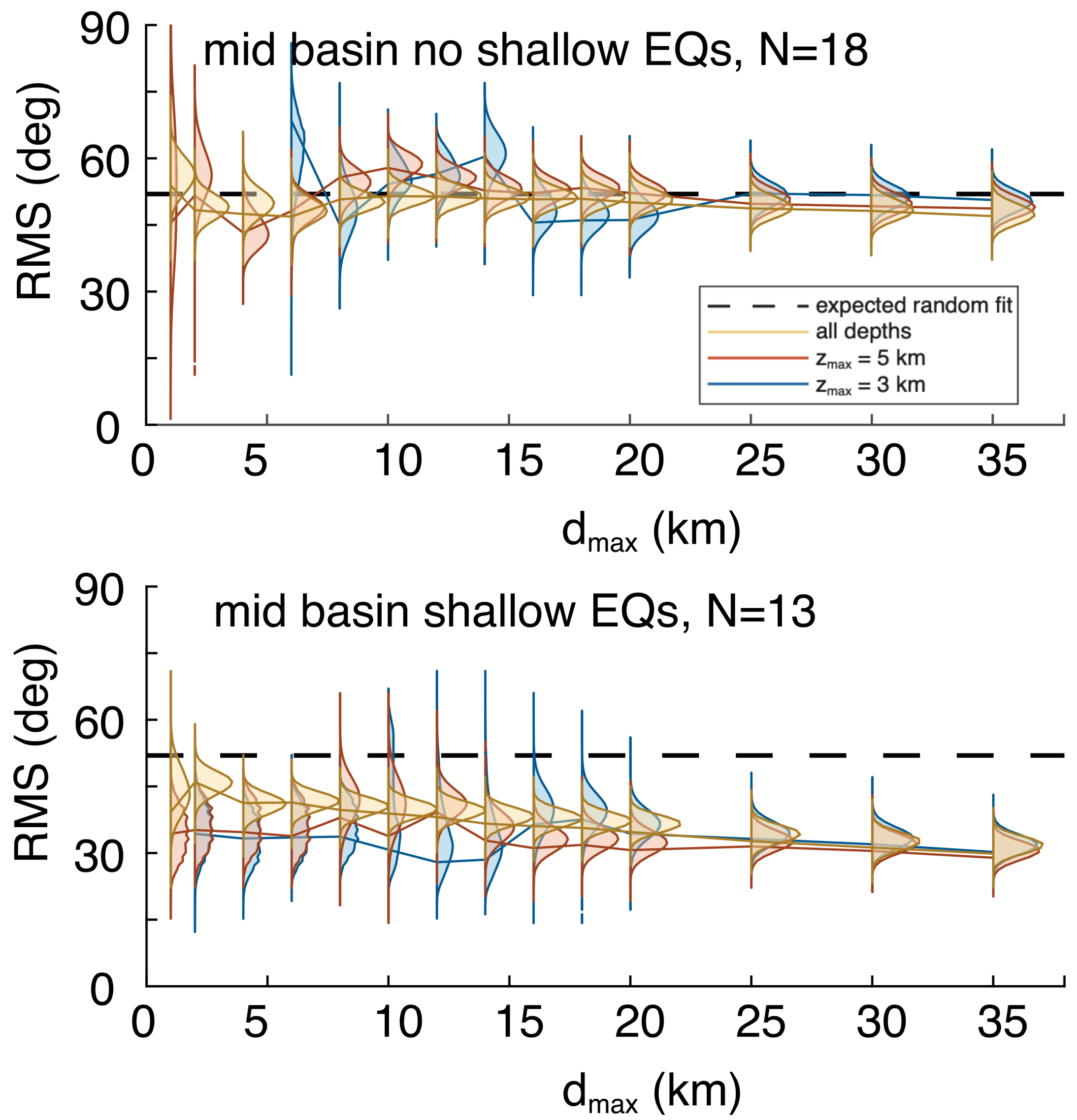




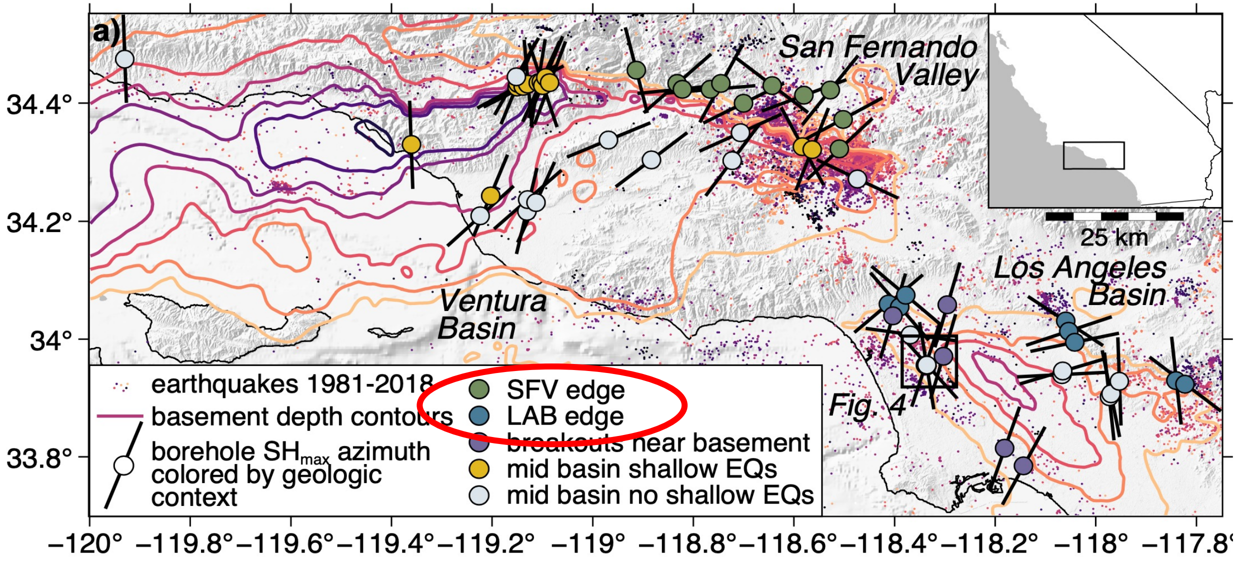


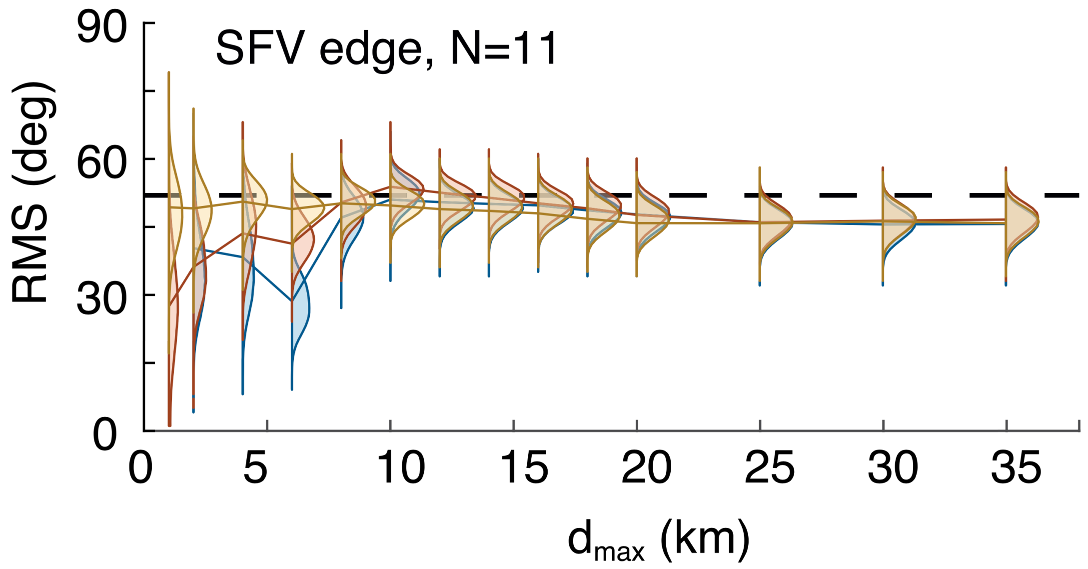
Mid-sedimentary-basin boreholes: (1) poor agreement if no shallow earthquakes sampling basin. (2) when shallow earthquakes are present, suggest vertical stress heterogeneity in basin on length scales ≤ 5 km.

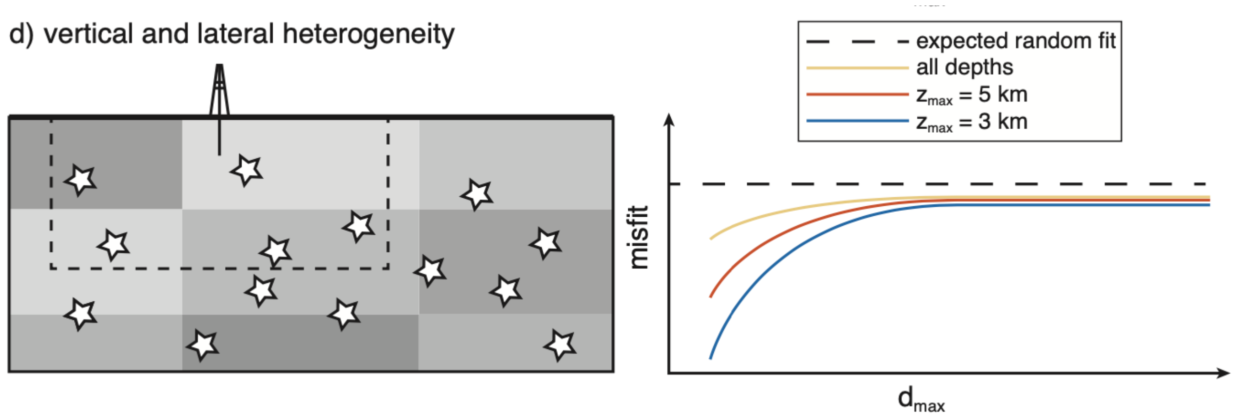


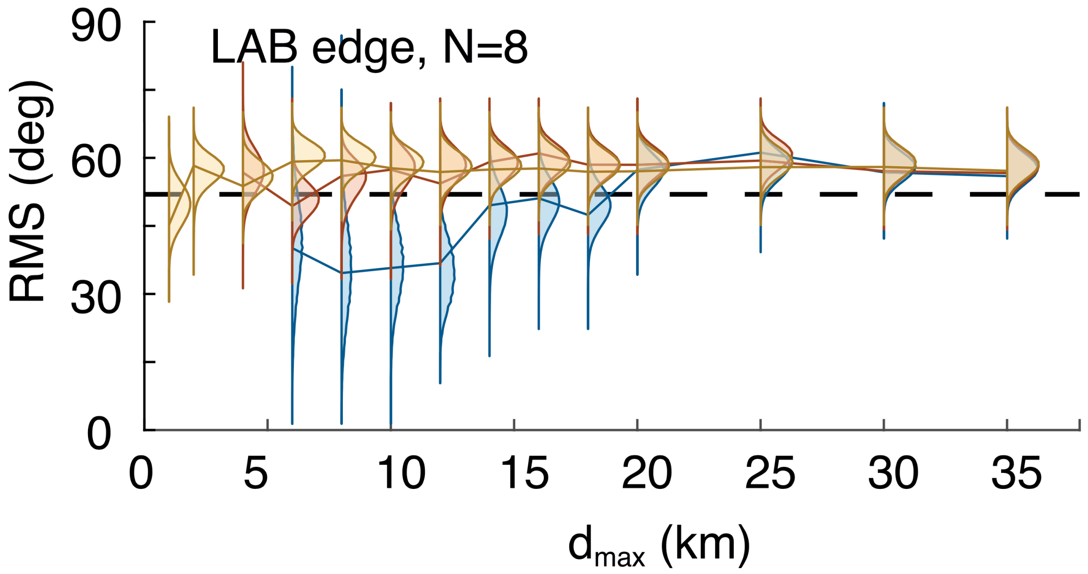


Sedimentary basin edges: Both vertical and lateral stress heterogeneity on length scales ≤ 10-20 km.

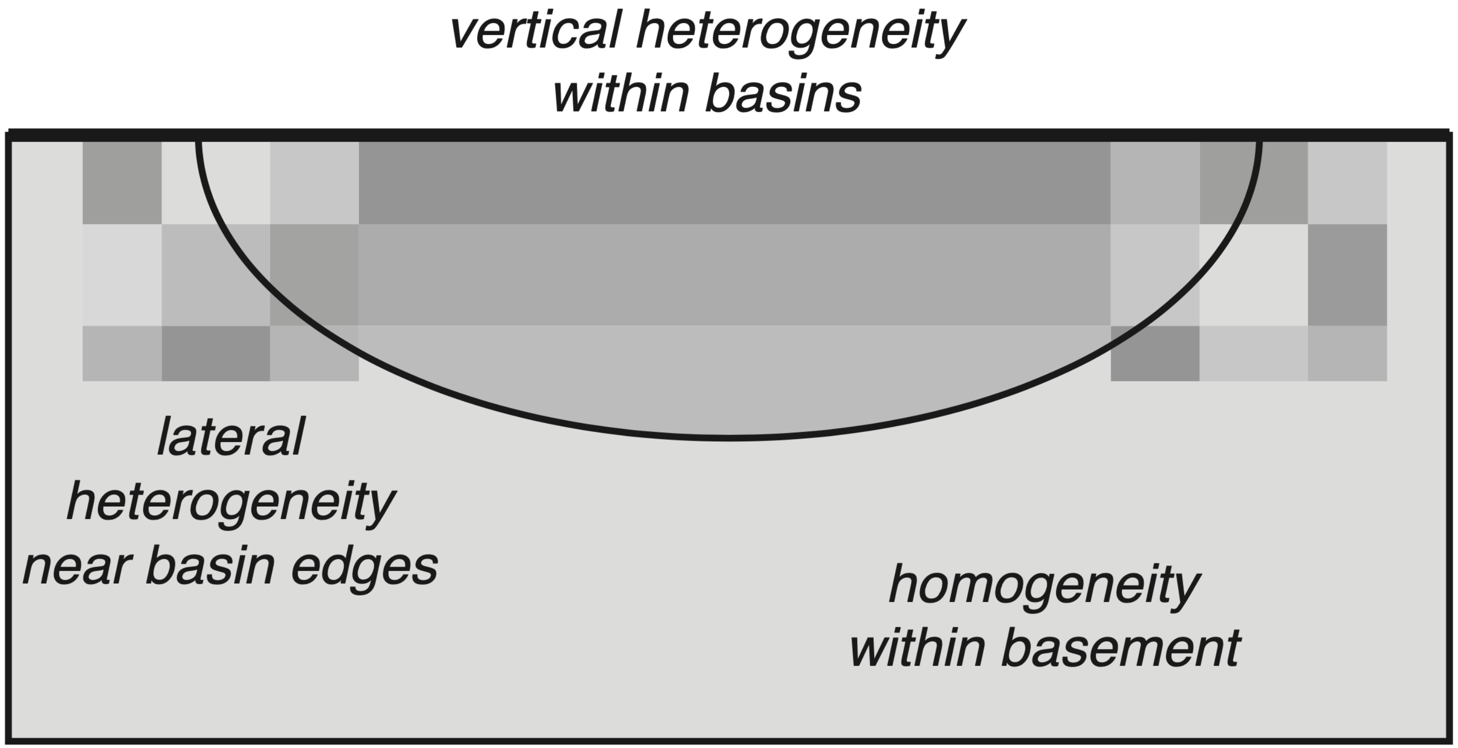








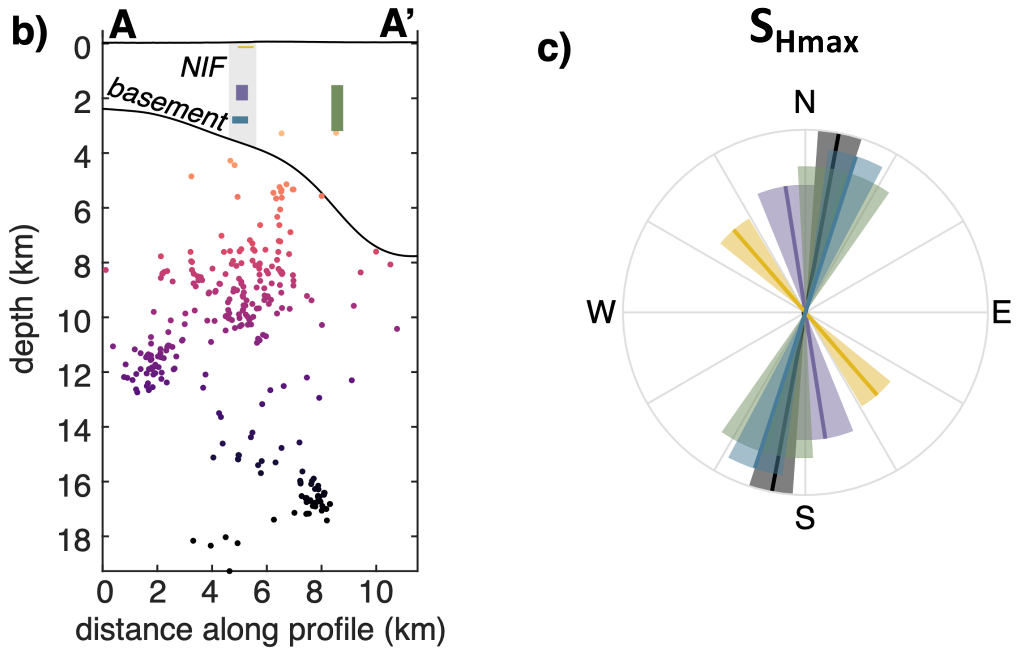
Model for Los Angeles area:

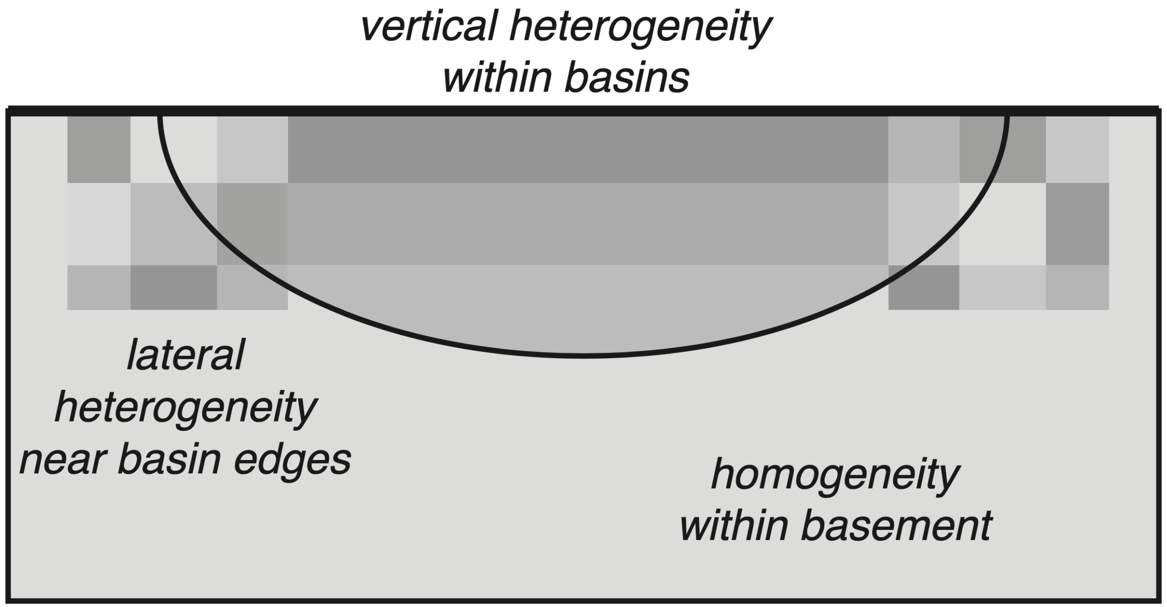


- Homogeneous stress within basement, on ≥ 35 km length-scales.
- Vertical heterogeneity within sedimentary basins, on length scales ≤ 5 km.
- Lateral heterogeneity as well near basin edges, on length scales ≤ 10-20 km.

Conclusions:

- Stress orientations from borehole breakouts and focal mechanism inversions agree when they sample locations close enough in space.
- Misfit between the two, and variation with separation, are indicators of vertical and/or lateral stress heterogeneity.
- For Los Angeles area: homogeneous stress within basement; vertical heterogeneity within sedimentary basins; and lateral and vertical heterogeneity near basin edges.
- Reconciles short-length-scale heterogeneity observed in boreholes (which sample basins) and the relative homogeneity of stress inferred from focal mechanisms (which sample basement).





SKHASH: A Python Package for Computing Earthquake Focal Mechanisms

Robert J. Skoumal, Jeanne L. Hardebeck, Peter M. Shearer

code.usgs.gov/esc/SKHASH

- Modernized version of the HASH focal mechanism software.
- Streamlined environment compatible with traditional or machine-learning workflows.
- Compatible with traditional, machine-learning, and/or cross-correlation P-wave polarity and S/P amplitude ratio measurements.
- Improved misfit reporting to evaluate solution and measurements quality.
- Efficient computation, including use of parallel environment.