Deep ductile shear localization facilitates near-orthogonal strike-slip faulting in a thin brittle lithosphere

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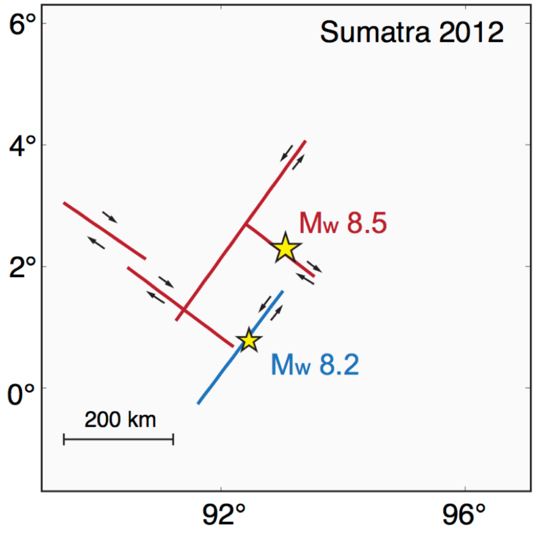
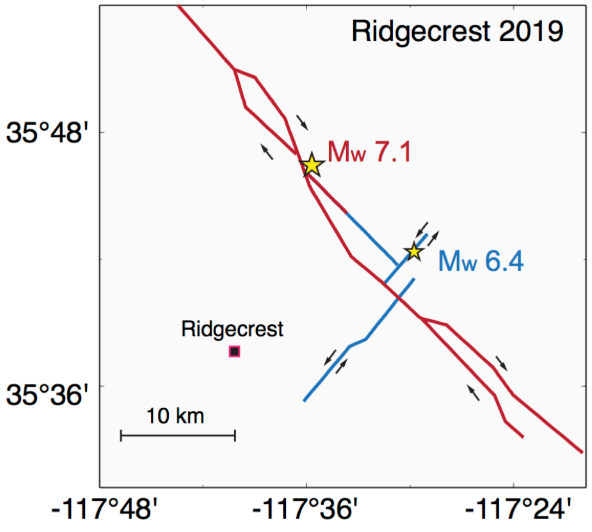
Link to preprint: https://eartharxiv.org/fp8xq/

Puzzling orthogonal strike-slip faults

Example: orthogonal faults revealed by 2012 Sumatra earthquake and 2019 Ridgecrest earthquake sequence.

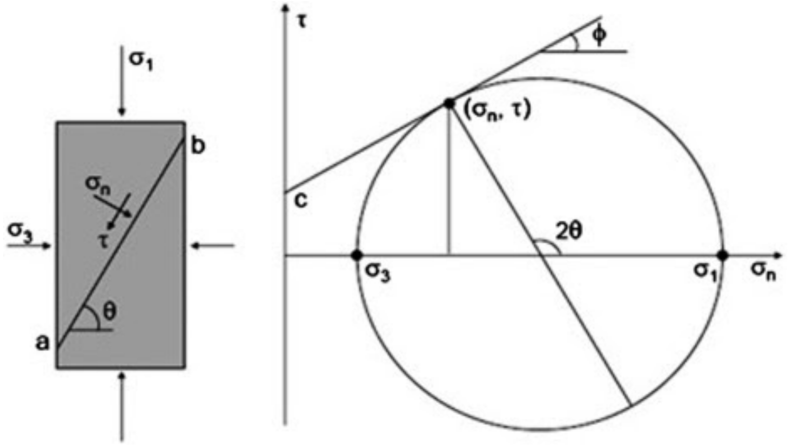




Coulomb friction theory predicts near pressure-insensitive rheology. **Puzzling!**

Existing hypotheses:

- Post-failure rotation (e.g., Freund 1974)
- Poroelastic effect (e.g., Cocco and Rice, 2002)
- **Inherit 90° structure from ductile shear bands (Thatcher and Hill, 1991)**

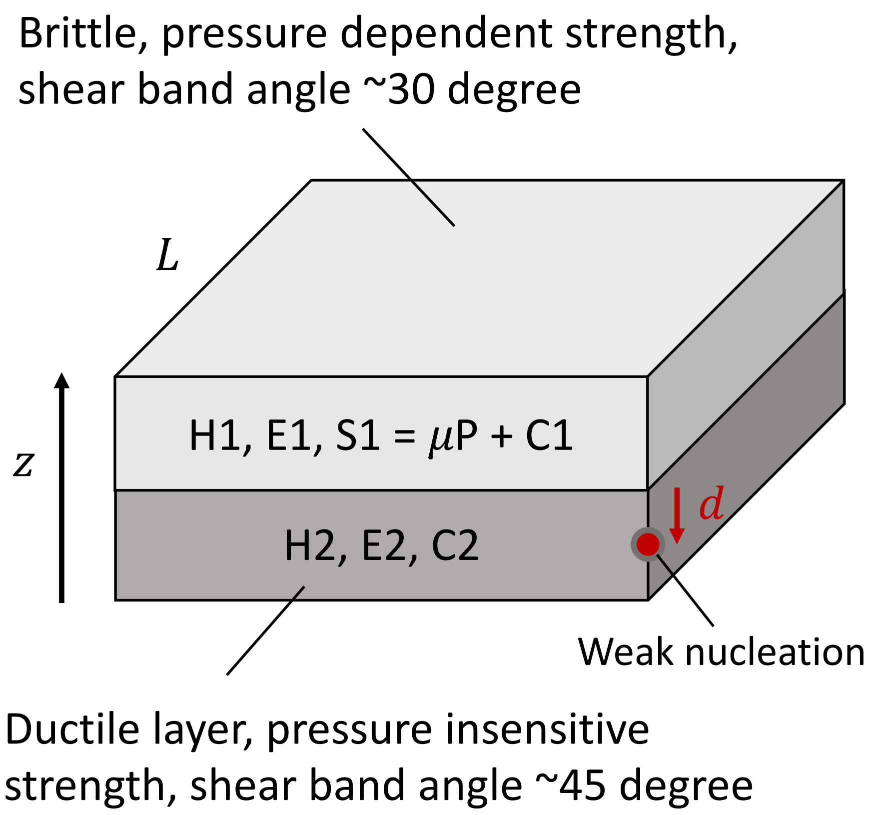


We use 3D numerical simulation to explore the hypothesis by Thatcher and Hill (1991) and further hypothesize that the inheritance is favored by a thin brittle lithosphere.

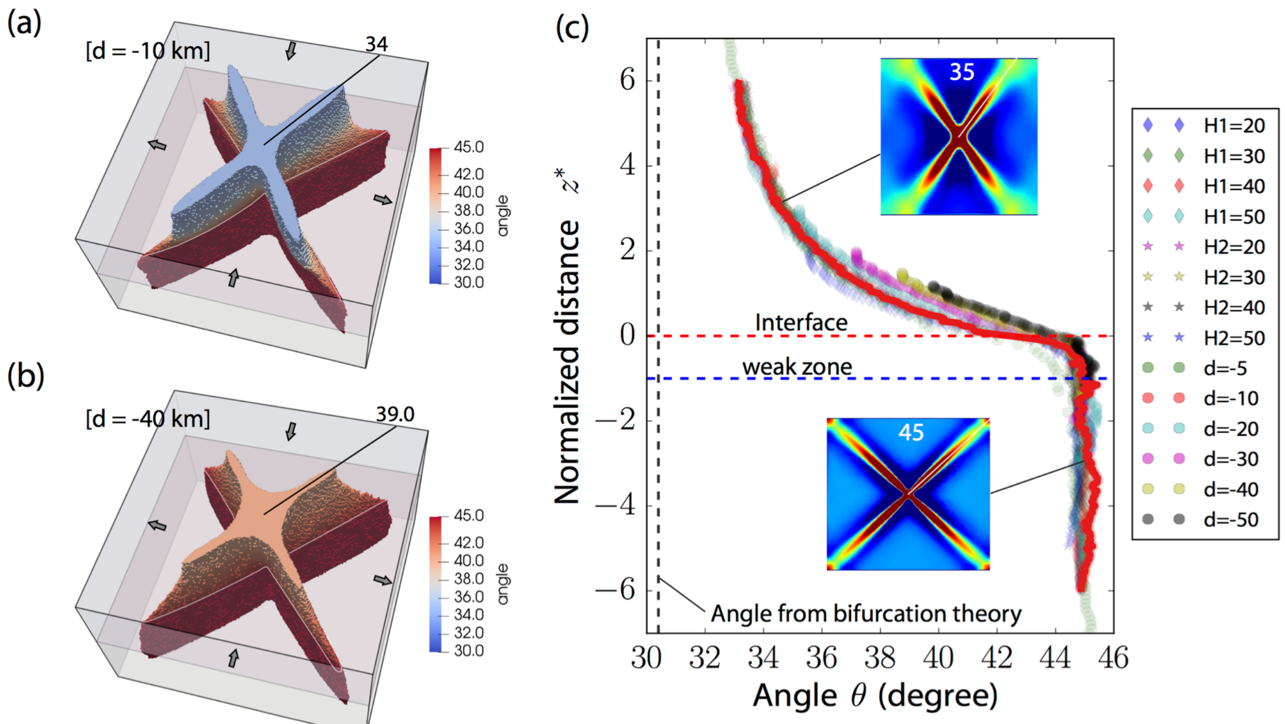
Meng et al., 2012; Ross et al., 2019

Fault angle driven by ductile shear bands

A two-layered elastoplastic model:



Fault angles varying layer thicknesses and nucleation position



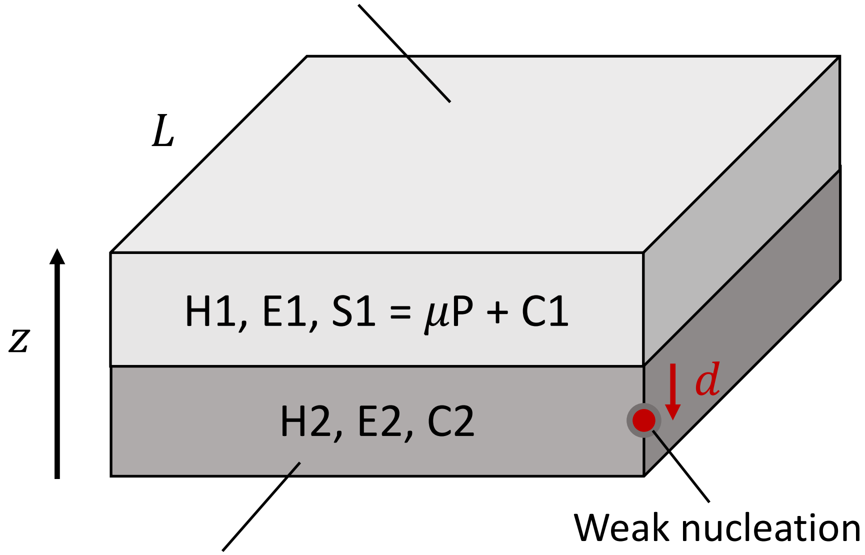
$$z^* = (z + H_1)/|d|$$

Near orthogonal faults can develop in the brittle layer given that the brittle layer is sufficient thin and the nucleation in the ductile layer is deep.

Fault angle driven by nucleation in brittle layer

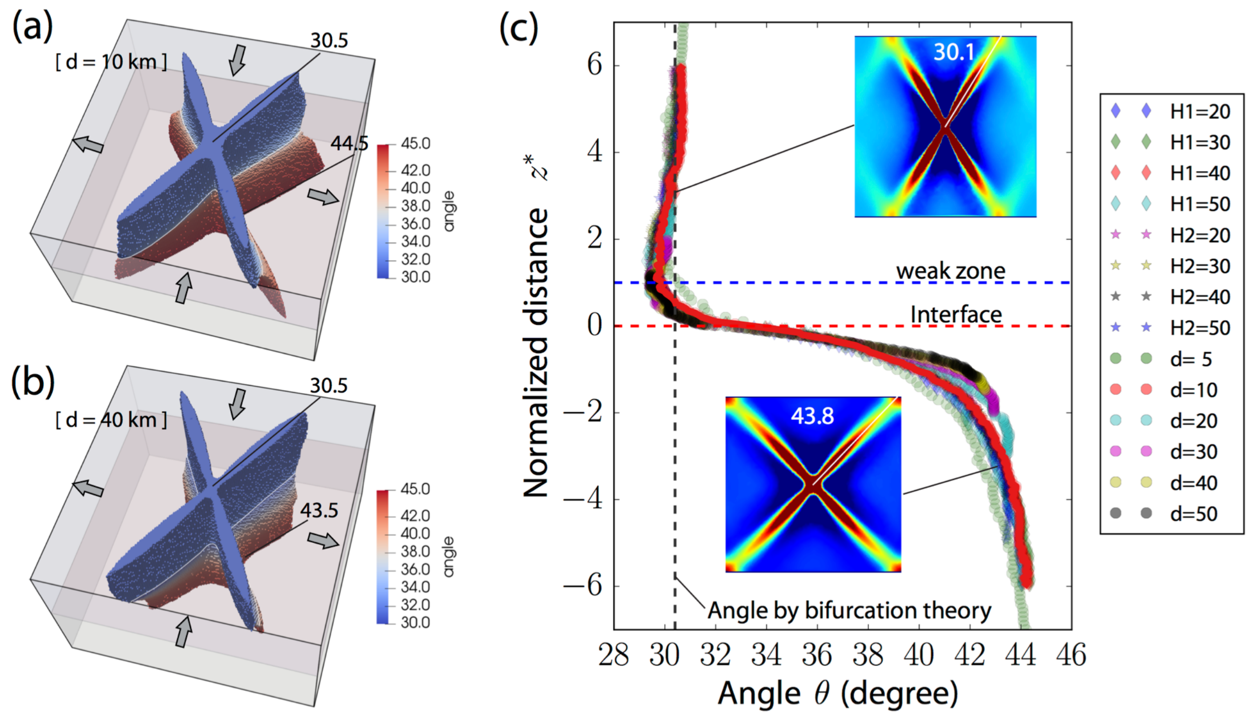
A two-layered elastoplastic model:

Brittle, pressure dependent strength, shear band angle ~30 degree



Ductile layer, pressure insensitive strength, shear band angle ~45 degree

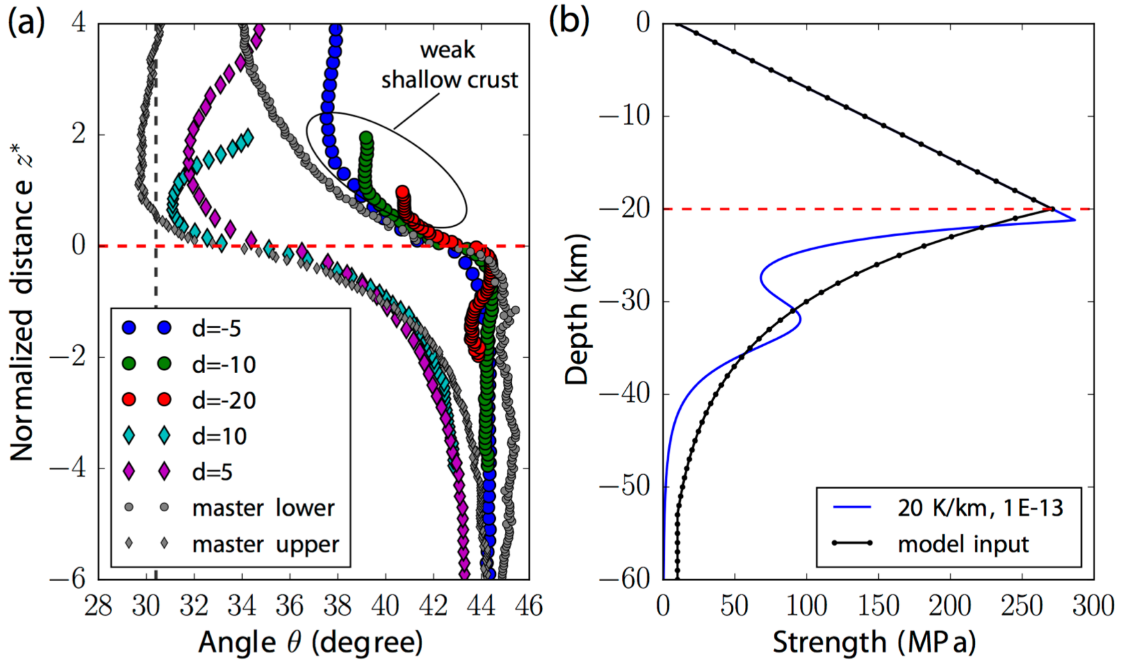
Fault angles varying layer thicknesses and nucleation position



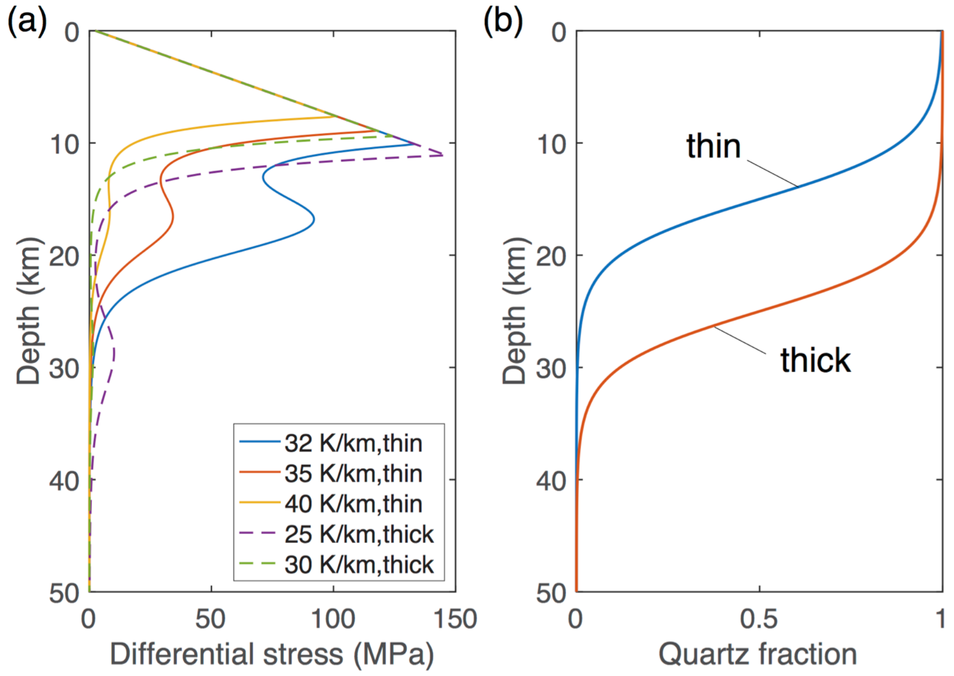
$$z^* = (z + H_1)/|d|$$

Faults remain optimally oriented when nucleation starts in the brittle layer.

A weaker upper portion of the brittle layer (due to lower confining pressure) facilitates preservation of deep orthogonal structure.



A thin crust and upward shift of mafic composition contributes to a thick ductile root and aids the formation of near-orthogonal shear bands in the brittle layer, probably relevant for Ridgecrest and Salton Trough.



Take home messages:

1. **Near-orthogonal strike slip faults can originate from deep ductile shear localization, provided that the brittle layer is thin compared to the depth extent of the ductile roots.**
2. **A lower confining pressure at shallow depth facilitates the preservation of the near-orthogonal structure.**
3. **Faults nucleated in the brittle layer tends to have optimal fault angle predicted by bifurcation theory and are insufficient to generate orthogonal faults.**