Fault roots, shear zones, and lithospheric deformation from receiver functions and rock sample anisotropy

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funding: NSF - EarthScope, Geophysics, Tectonics

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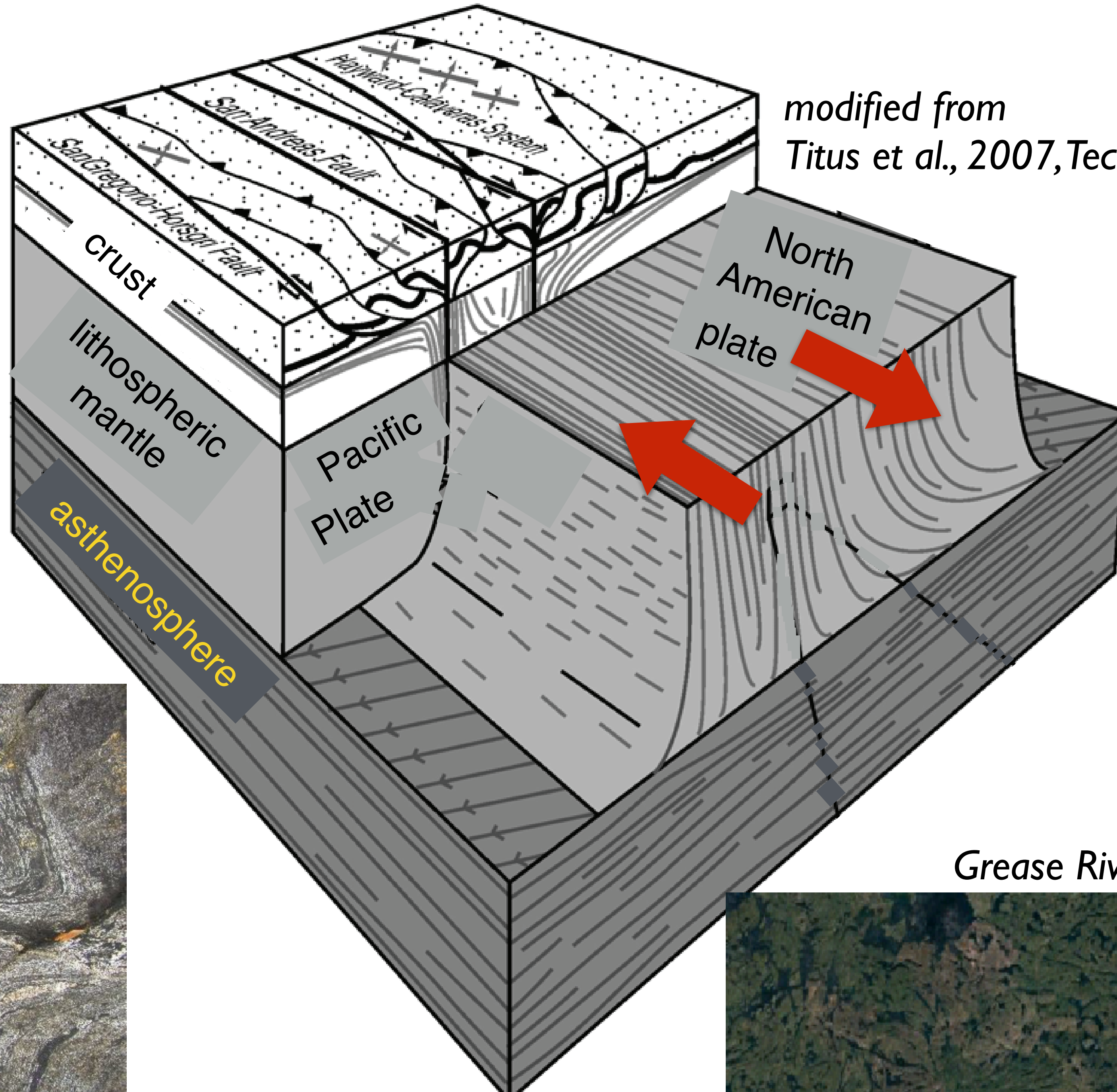
Outline

Faults and shear zones	Crustal anisotropy	RF imaging	Interpretation
Roots of faults?	crustal rock tensor collection	Method Results: Denali Fault zone Rocky Mountains/ Wasatch Southern California, Basin & Range	listric fault fabric through lithosphere role of inheritance?

Motivation

Roots of faults?

Strain localization in deep crust, lithospheric mantle?



modified from Titus et al., 2007, Tectonophys.

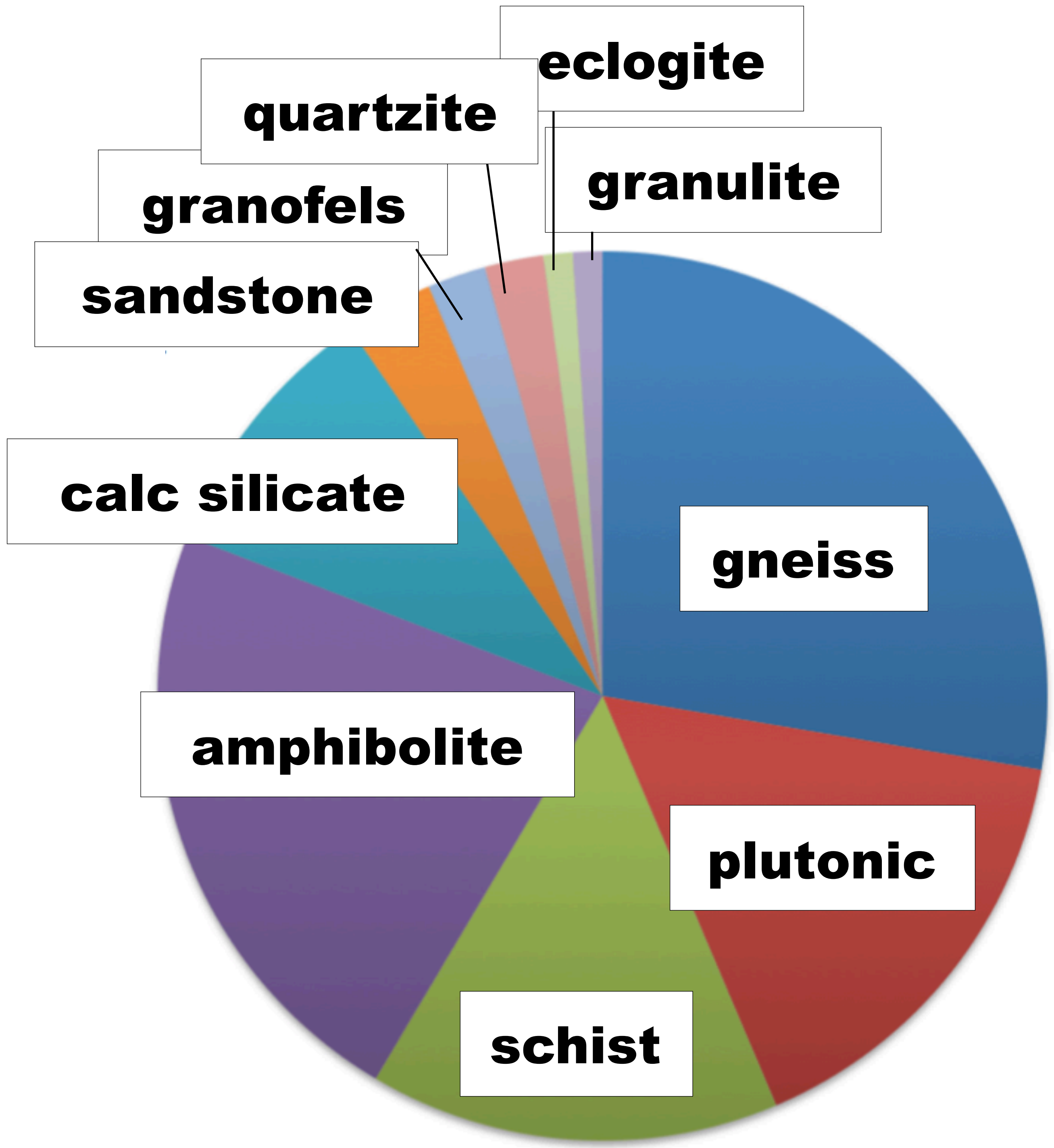
www.uvm.edu/~kklepeis/fieldforum/

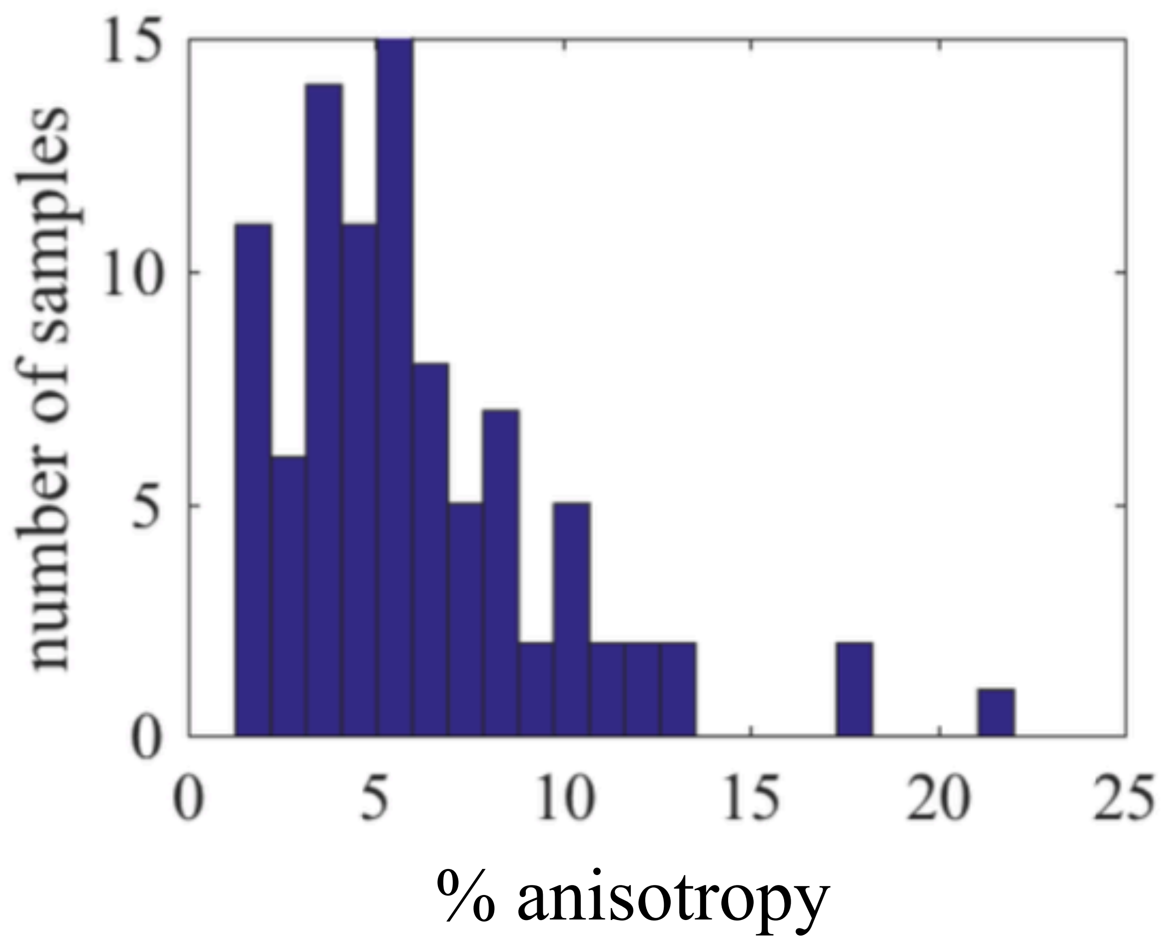
Grease River shear zone/Google Earth

deformation ➞ rock fabric ➞ seismic anisotropy

What does crustal anisotropy look like?

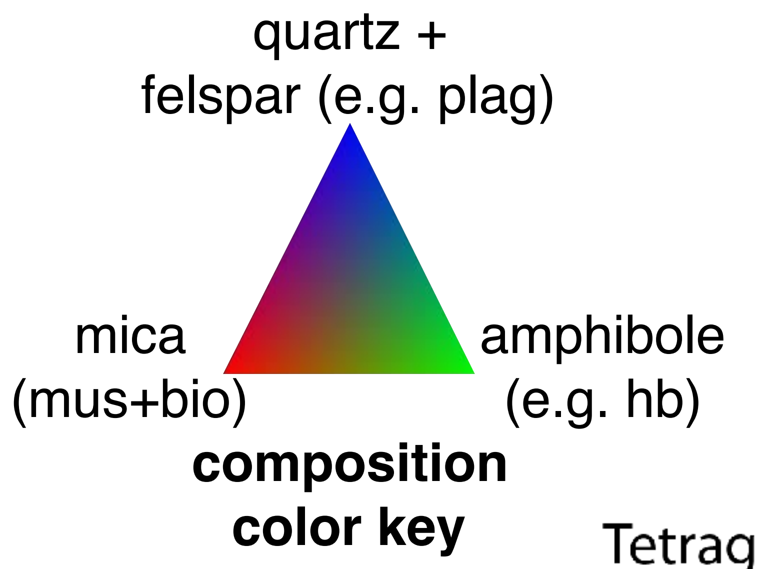
"Ground truth" from ~100 crustal rock full elasticity tensors

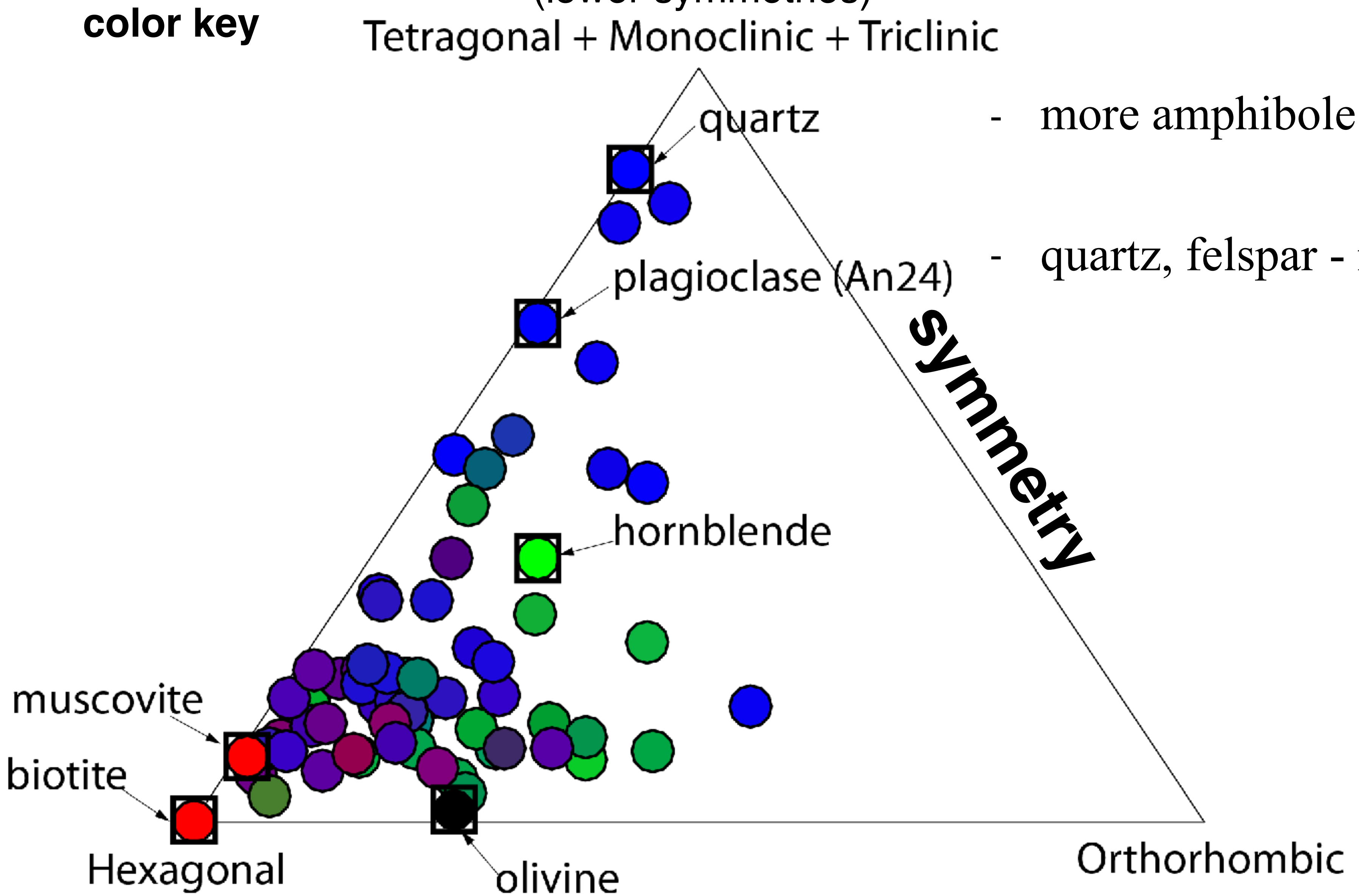




Brownlee, Schulte-Pelkum, Raju, Mahan, Condit, Orlandini 2017, submitted (Tectonics)

Anisotropy symmetry type by composition





- most samples closer to hexagonal symmetry
- more mica - more hexagonal
- more amphibole - towards orthorhombic
- quartz, felspar - more lower symmetry

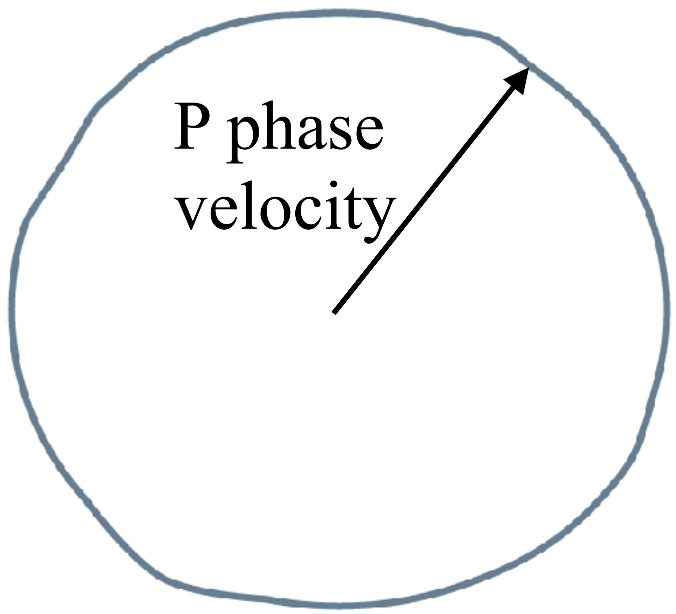
symmetry decomposition:
Browaeys & Chevrot, 2004, GJI

Brownlee et al., 2017, submitted

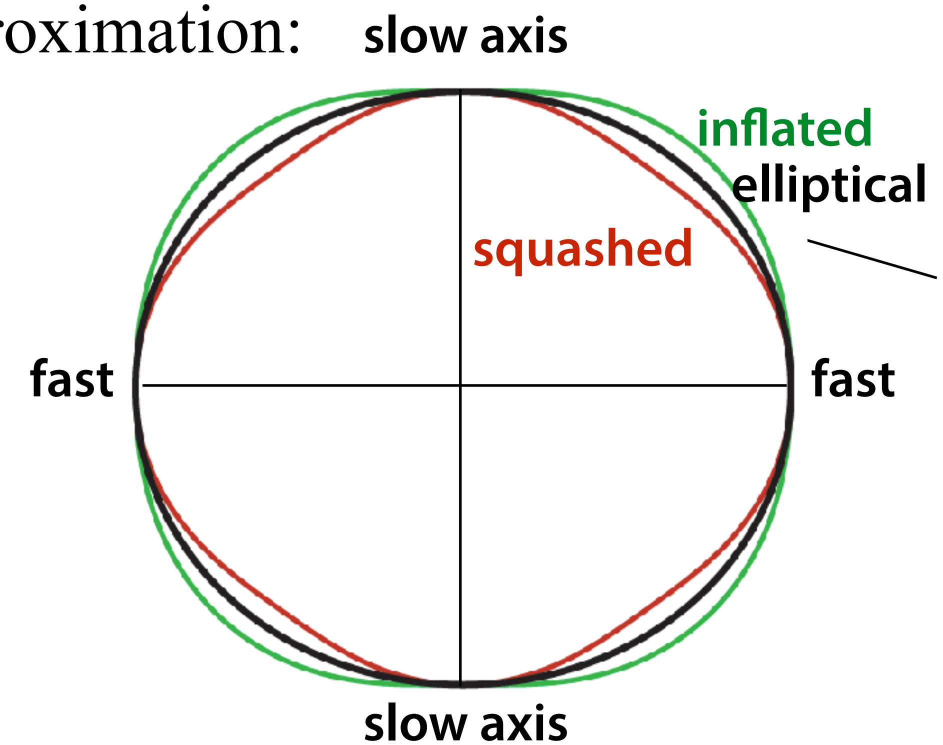
Is hexagonal anisotropy elliptical?

P velocity surface

general anisotropy:



best-fit hexagonal approximation:



off-axis velocity

described by shape factor η

geometric definition: ellipticity parameter η_κ

def. Kawakatsu 2016, GJI

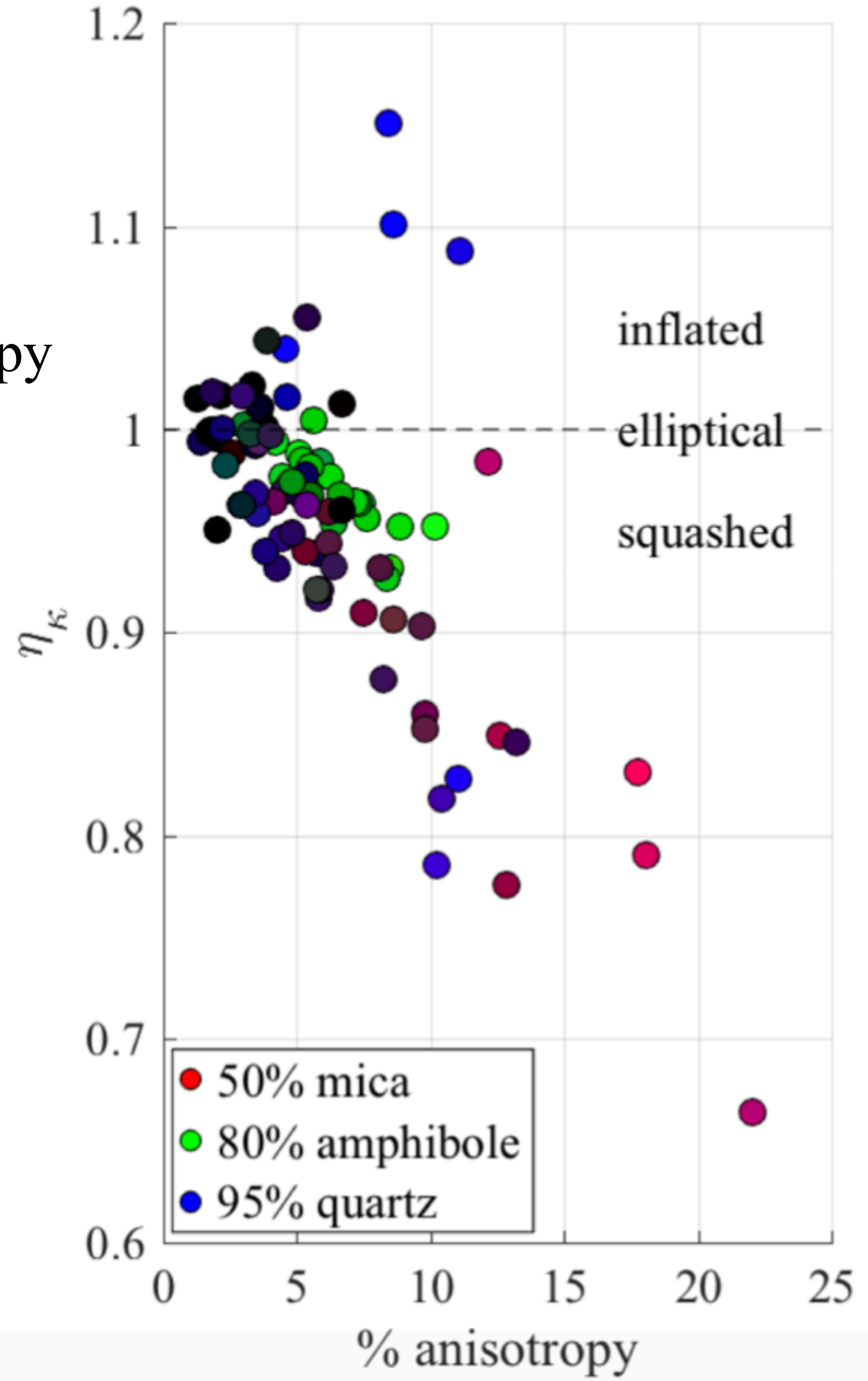
Simplest anisotropy case: hexagonal (5 independent parameters)

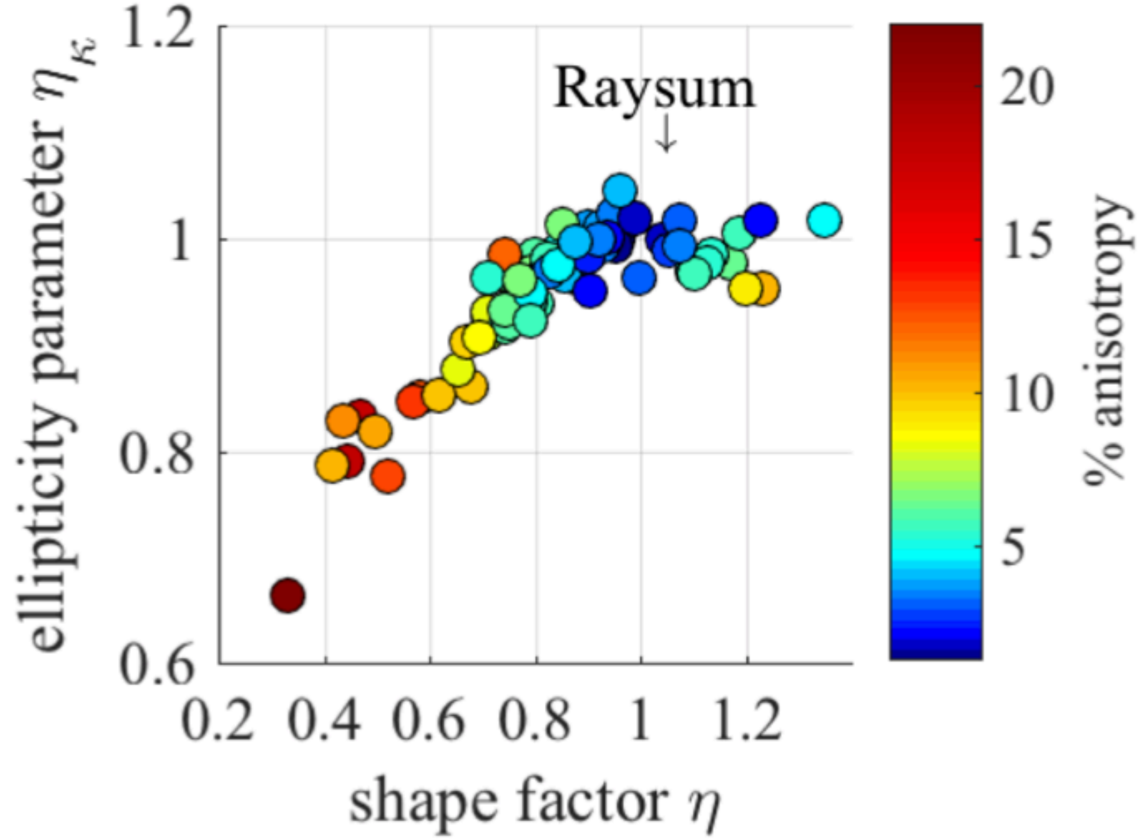
e.g. 1. Vp (avg), 2. Vs (avg), 3. %Vp, 4. %Vs, 5. off-axis velocity

Typical assumption: elliptical anisotropy

Ellipticity in rock tensor compilation

higher anisotropy
= less elliptical



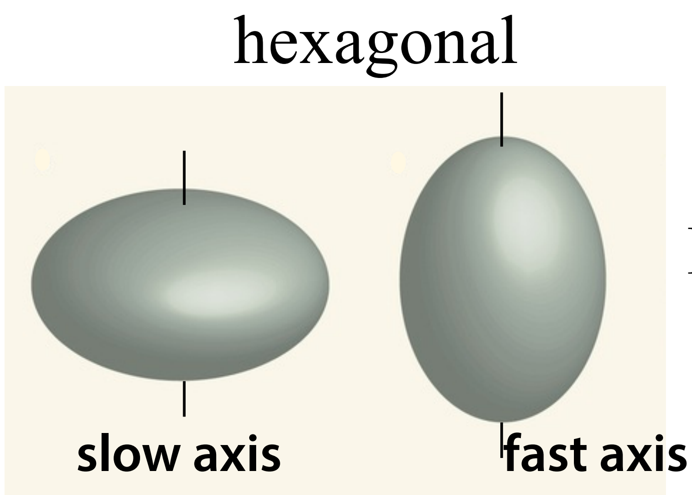


Brownlee et al., 2017, submitted

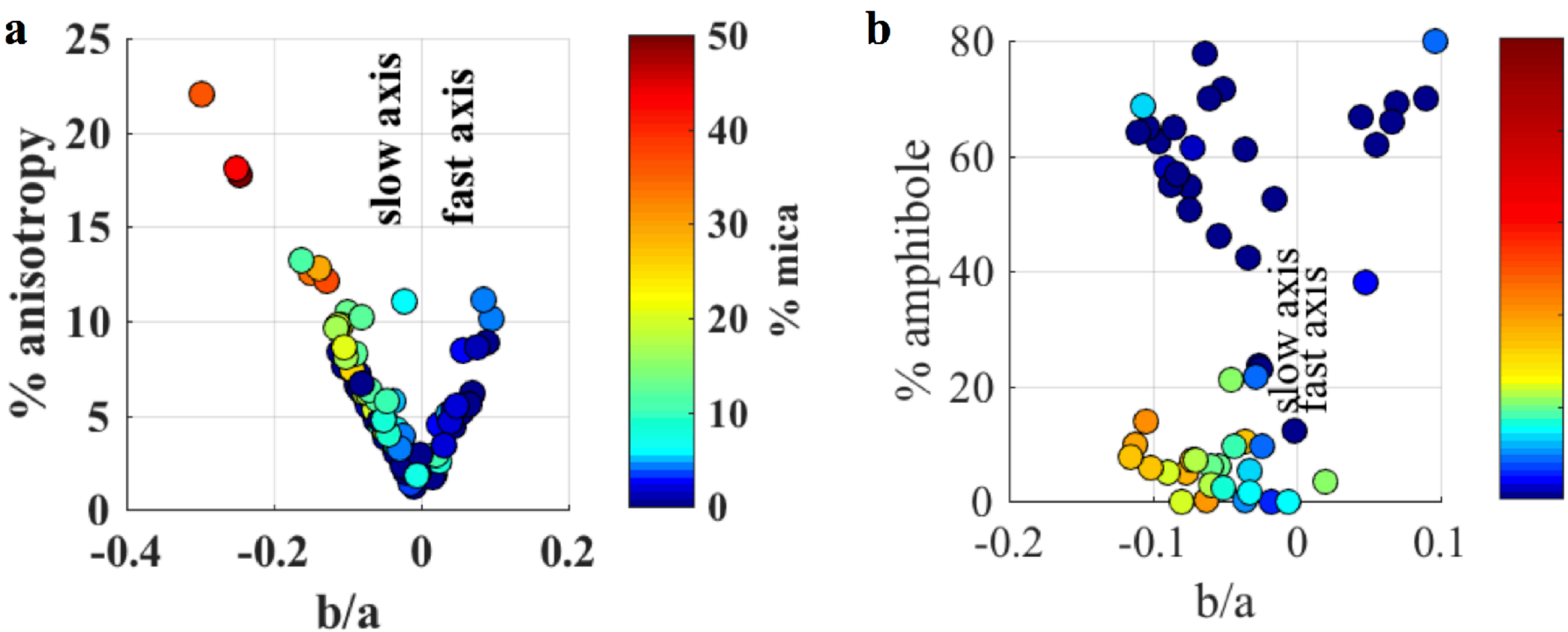
also resolves 90° ambiguity in surface wave anisotropy
(Xie, Ritzwoller, Brownlee, Hacker, 2014 GJI)

Hexagonal component:

slow vs. fast axis symmetry?



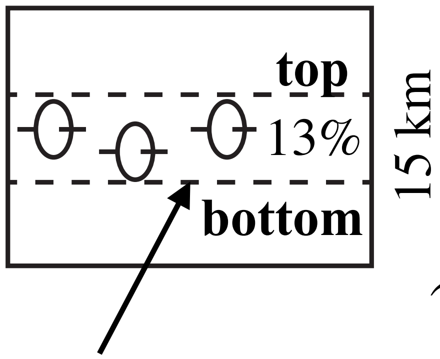
P velocity surfaces



Crustal tensor compilation: **77 % slow** axis symmetry, **23 % fast** axis

Brownlee et al., 2017, submitted

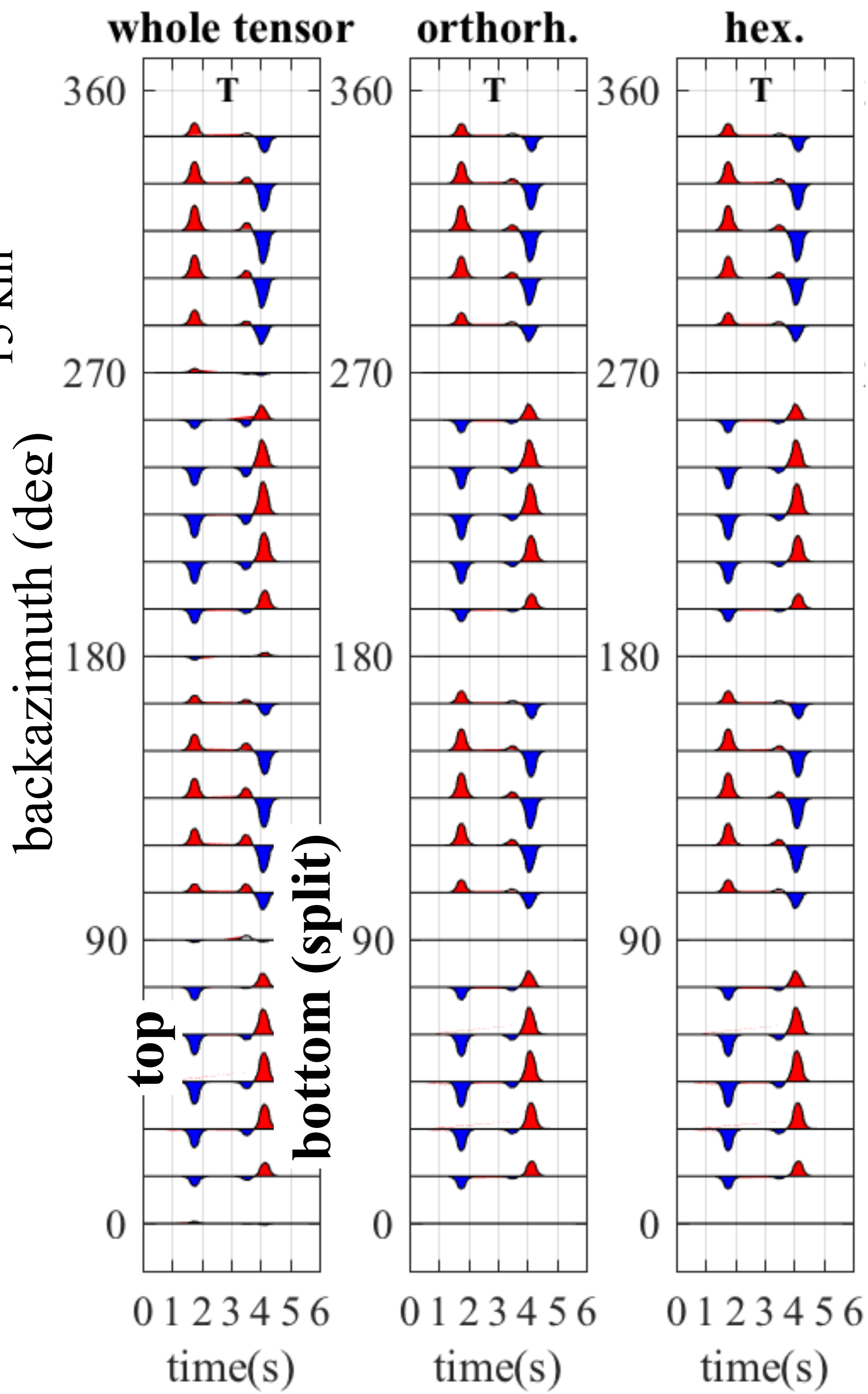
How do receiver functions see anisotropy?

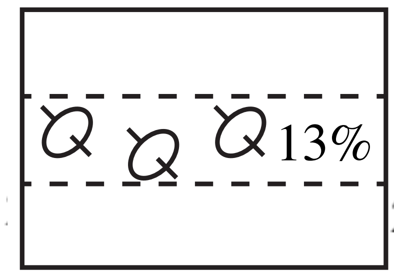


orthorhombic rock tensor

horizontal axis:

4-lobed pattern

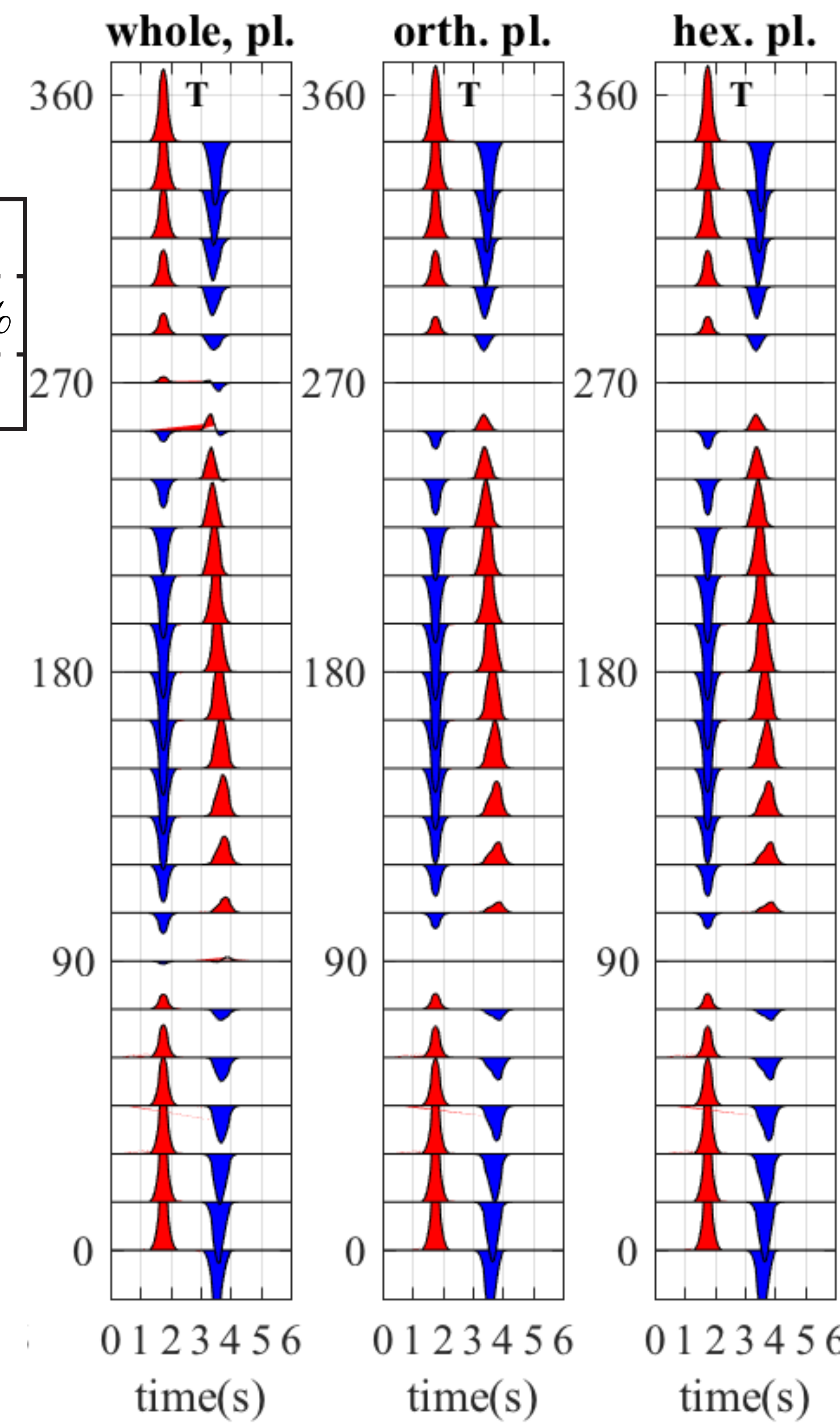




plunging axis:

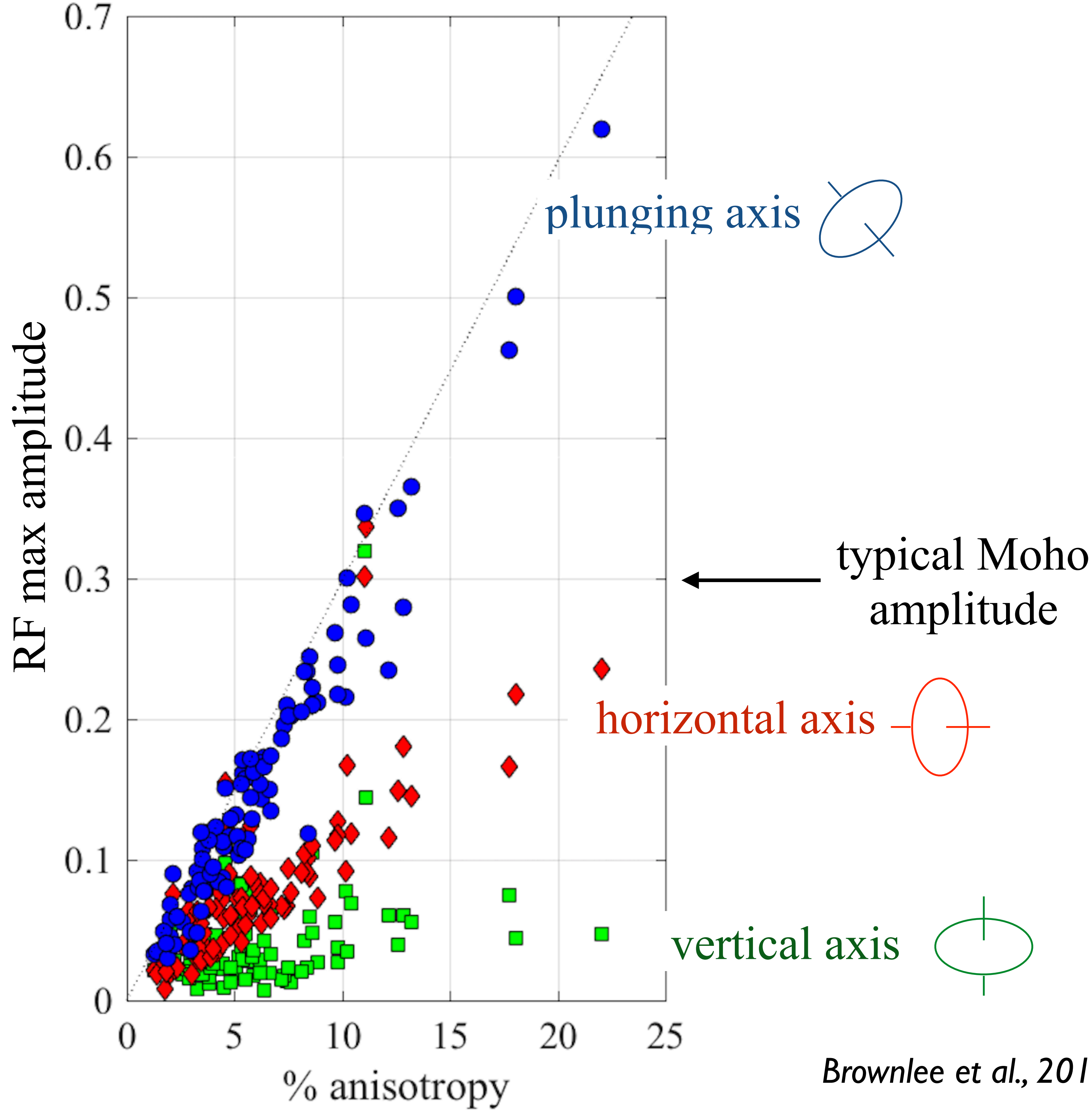
2-lobed

higher amplitude



Brownlee et al., 2017, submitted

Full rock tensors: maximum RF amplitude

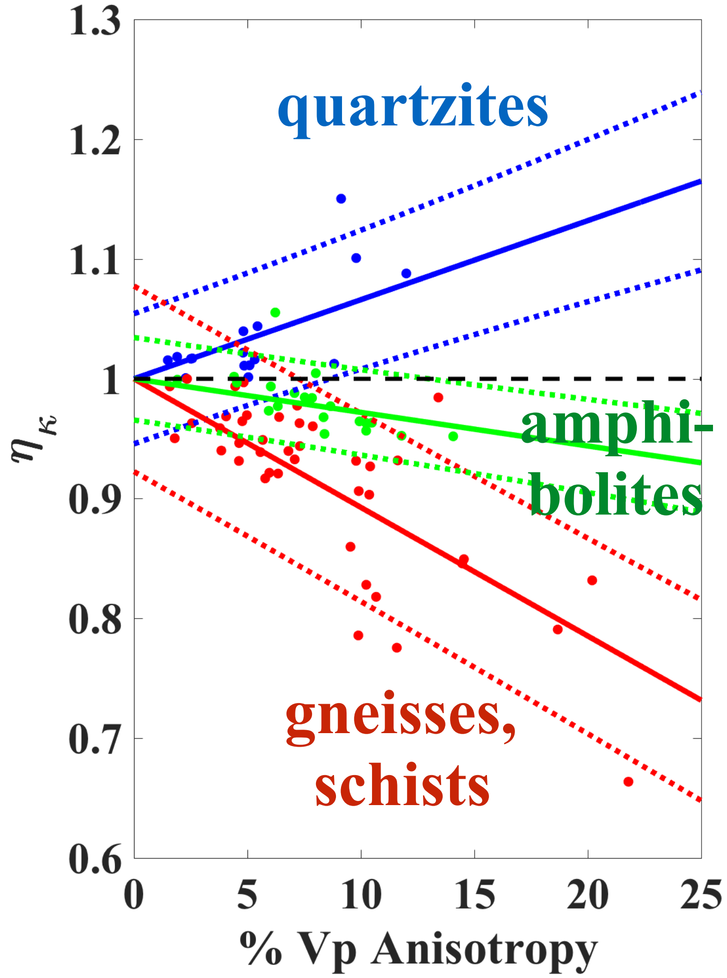


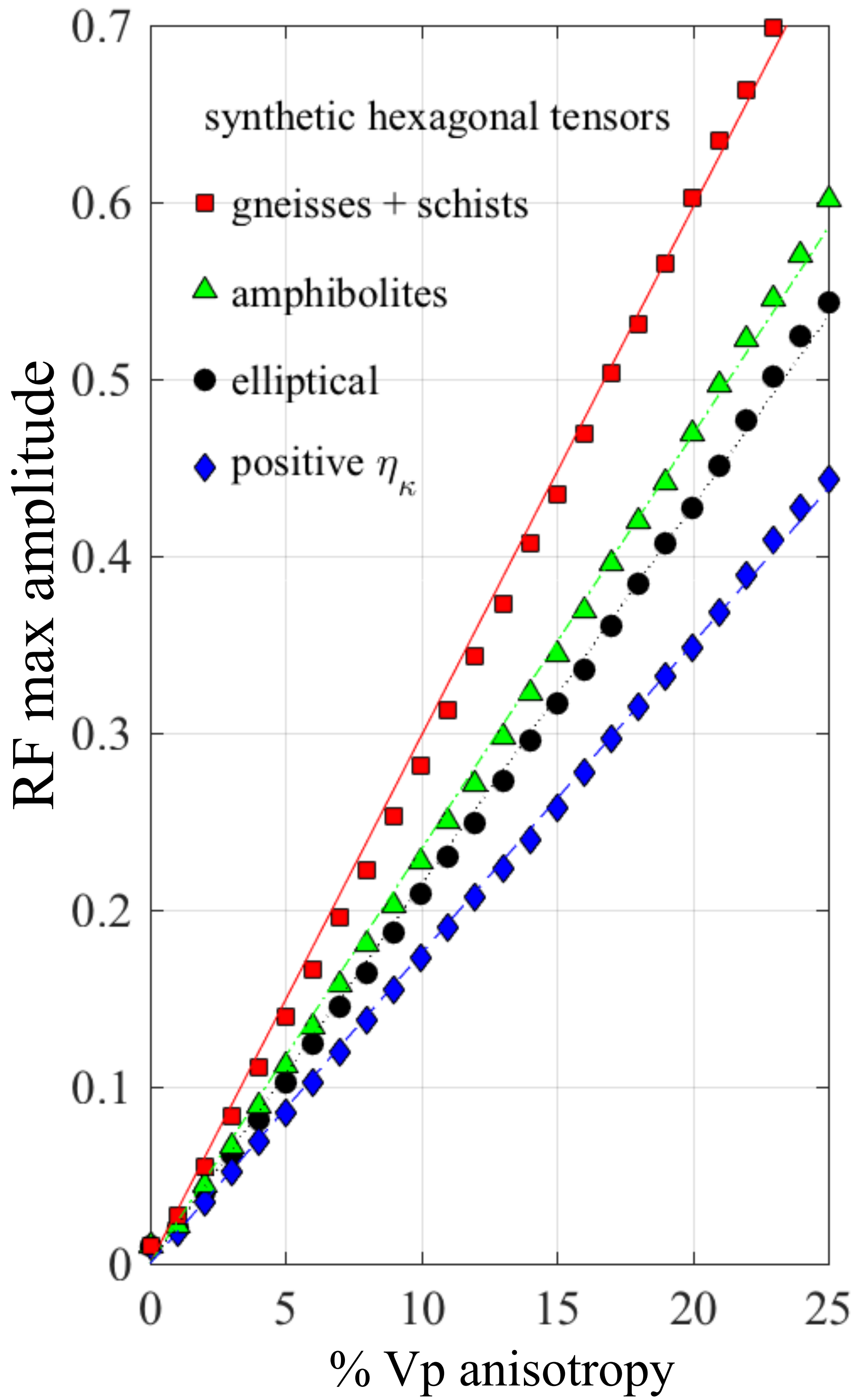
roughly linear scaling

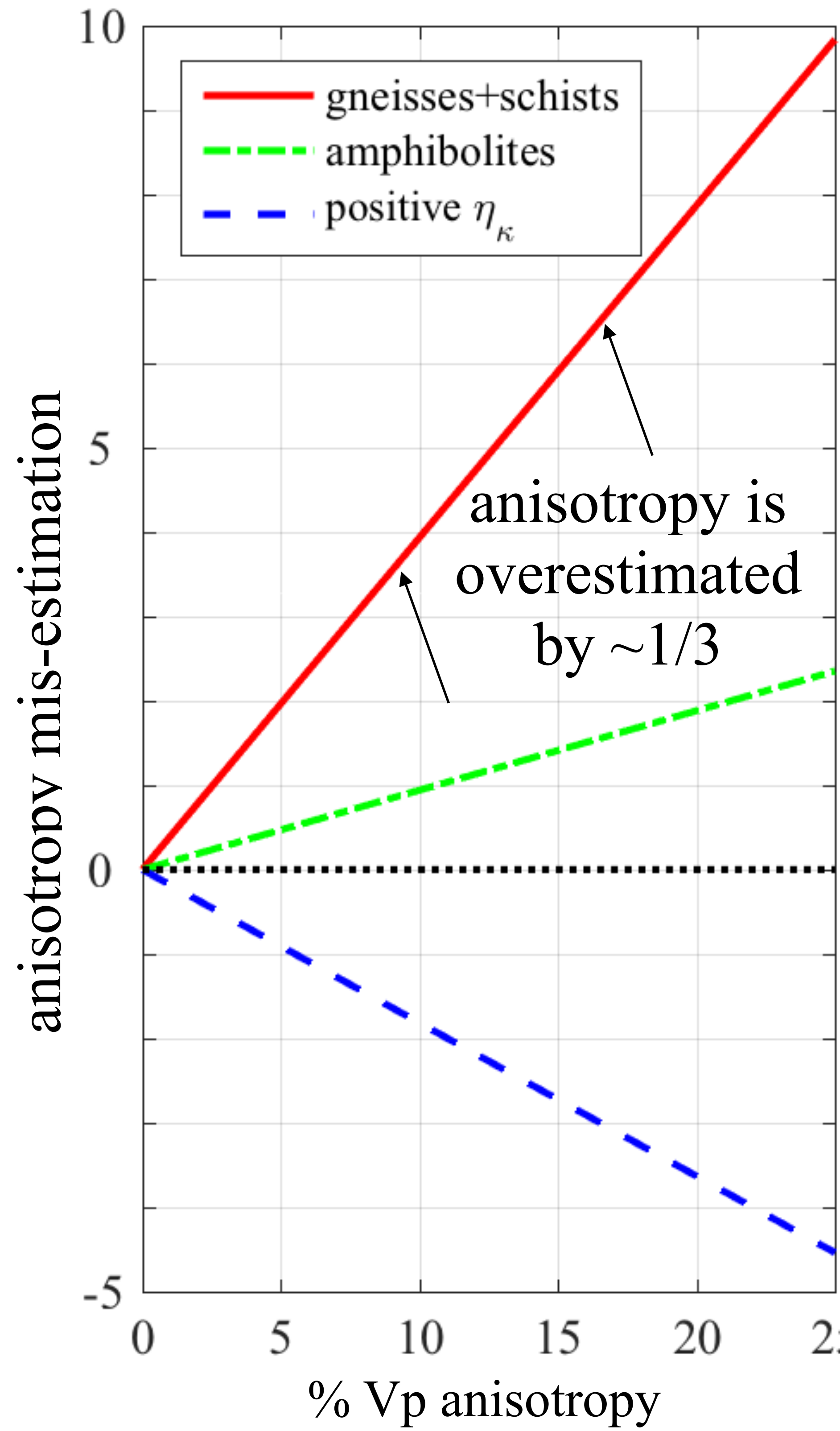
Brownlee et al., 2017, submitted

Hexagonal component:

influence of ellipticity assumption







Brownlee et al., 2017, submitted

Crustal anisotropy cheatsheet:

hexagonal ok to assume

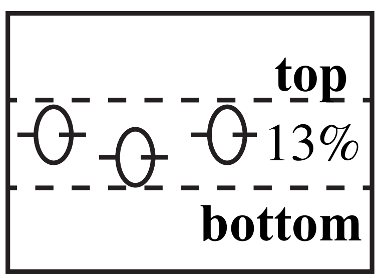
likely slow-axis symmetry

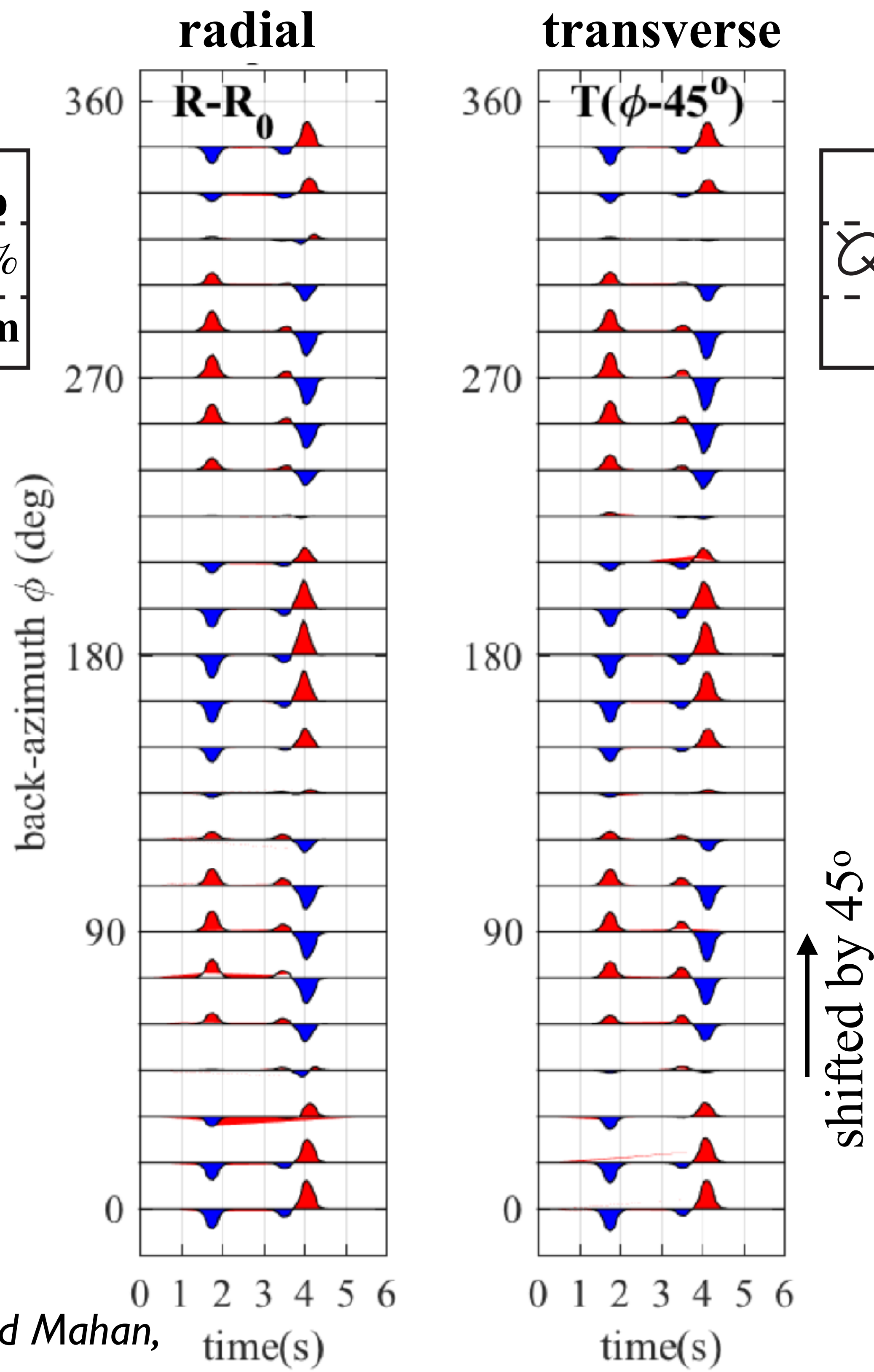
strong: gneiss, schists
(fast orientations: foliation plane)

not elliptical

How to measure foliation strike

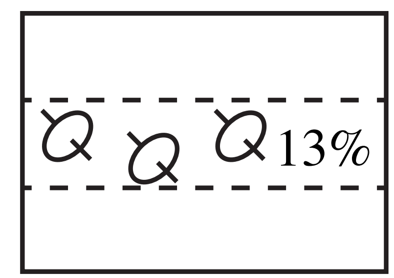
azimuthal (horizontal axis)

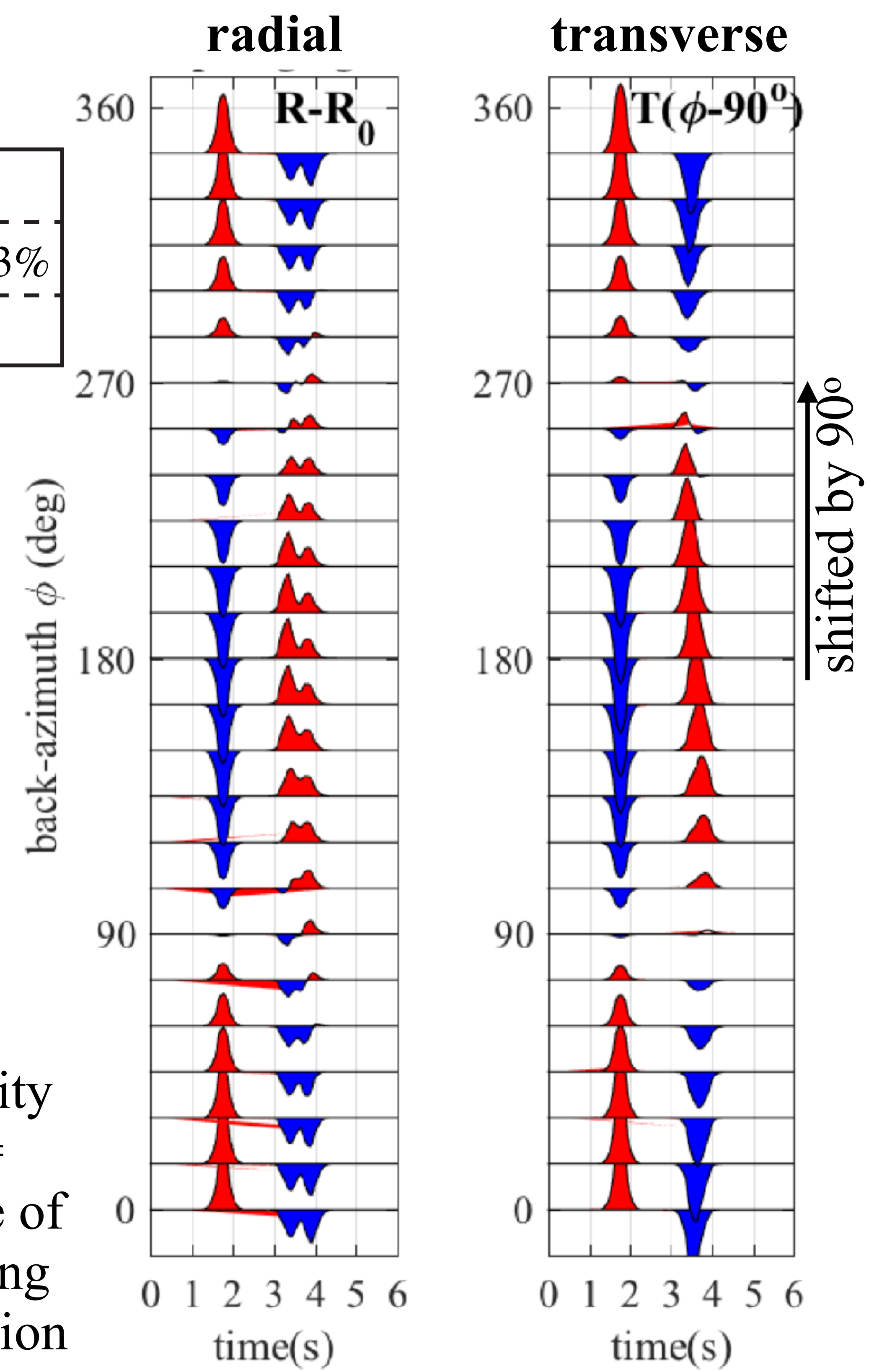




maxima = fast/slow axis

plunging axis anisotropy

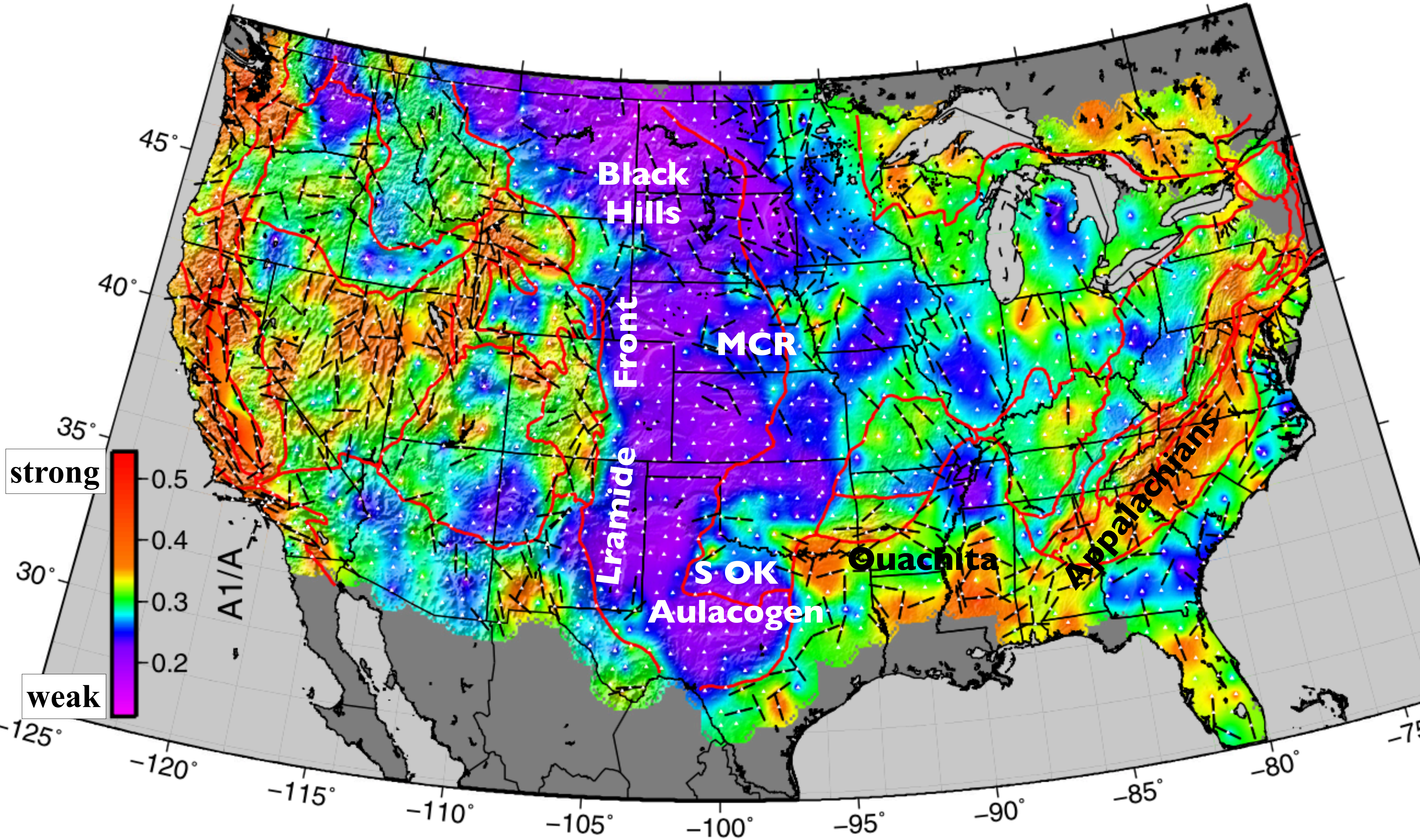




polarity flip = strike of dipping foliation

Schulte-Pelkum and Mahan, 2014, EPSL

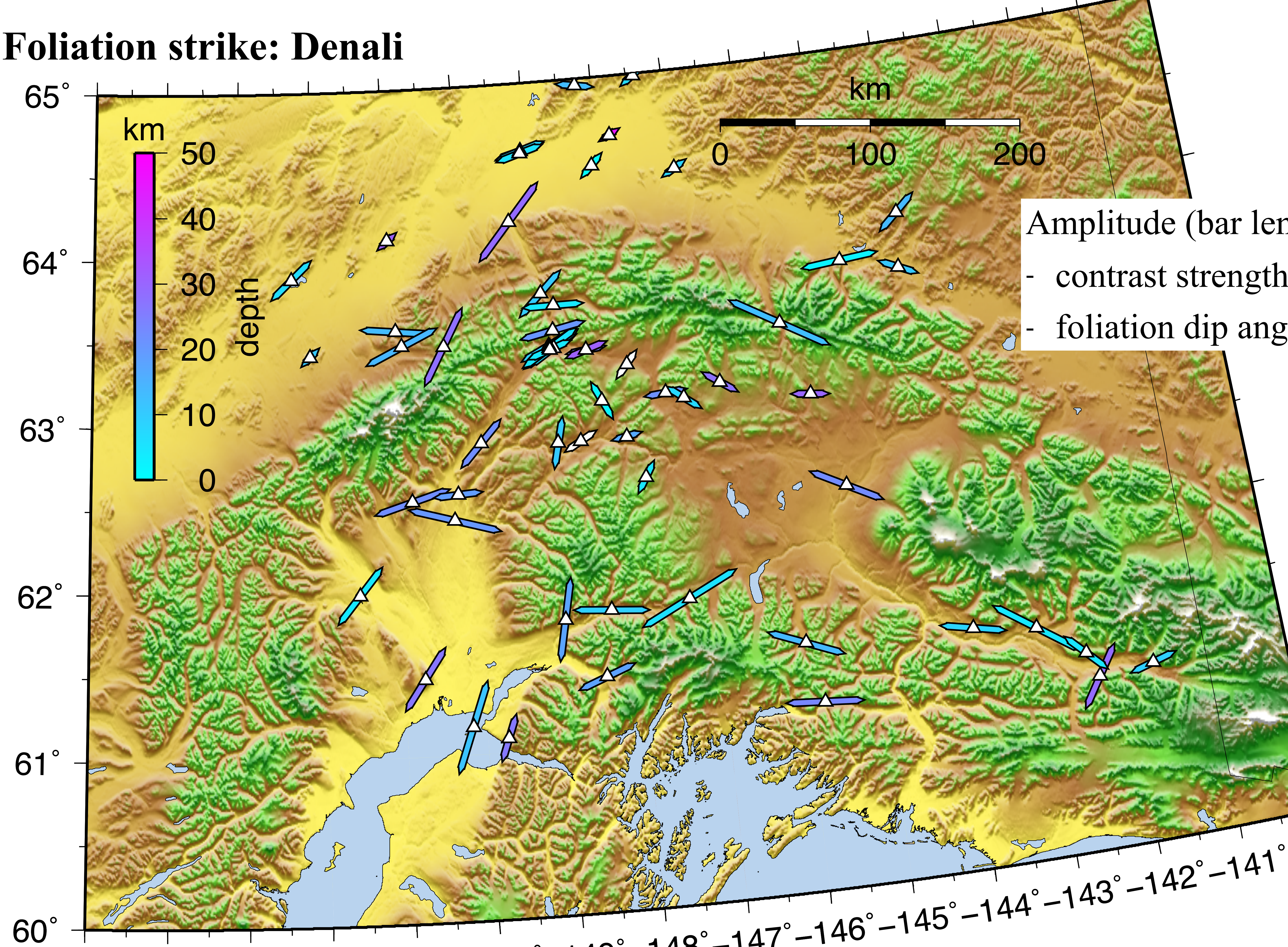
Crustal average of dipping foliation signal strength



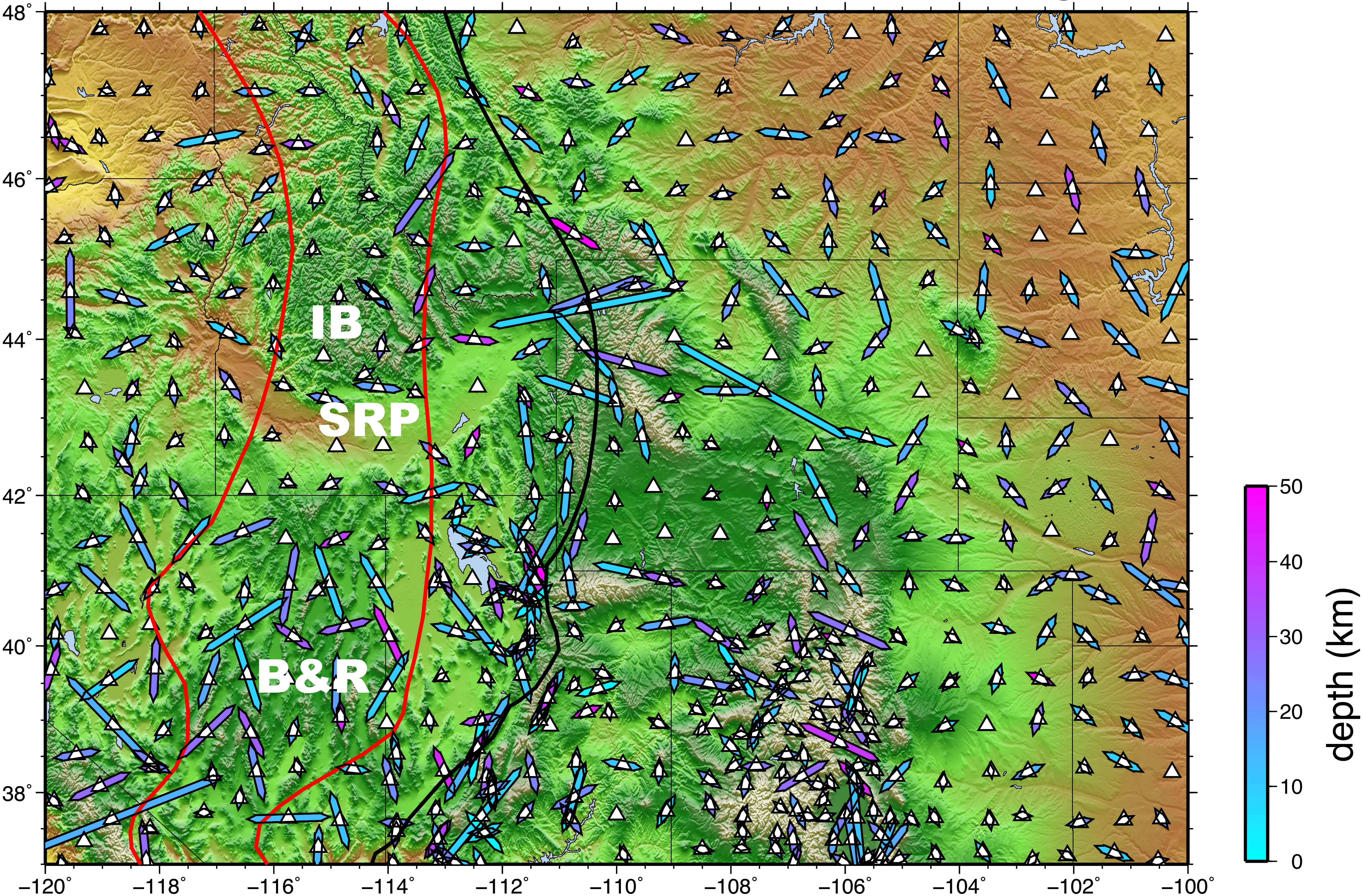
Schulte-Pelkum and Mahan, 2014, EPSL

Faults/shear zones	Crustal anisotropy	RF imaging	Interpretation

Foliation strike: Denali



Foliation strike: Rockies, intermountain West, Basin & Range

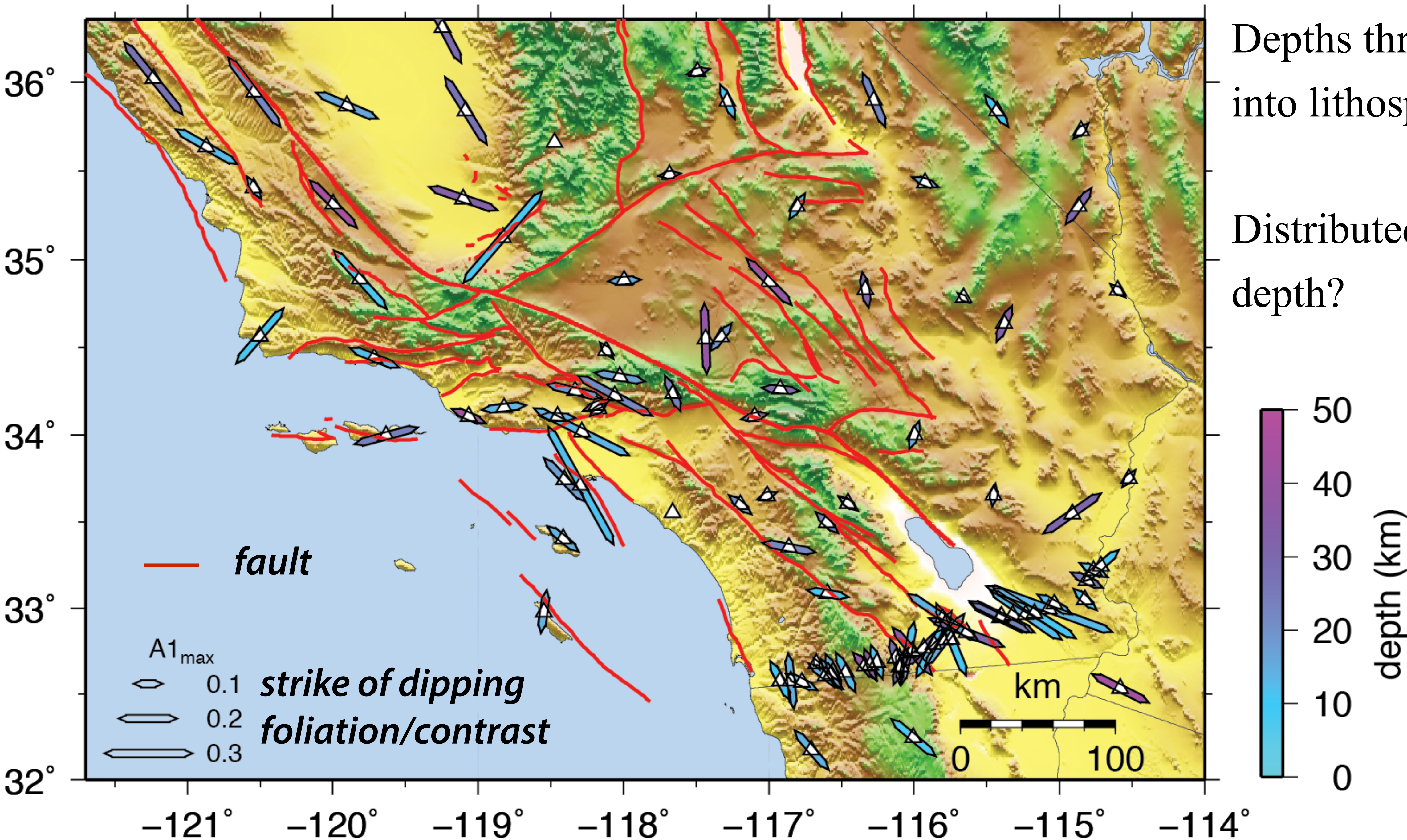


Foliation strike: California plate boundary

foliation strike
~parallel faults

Depths through crust into lithospheric mantle

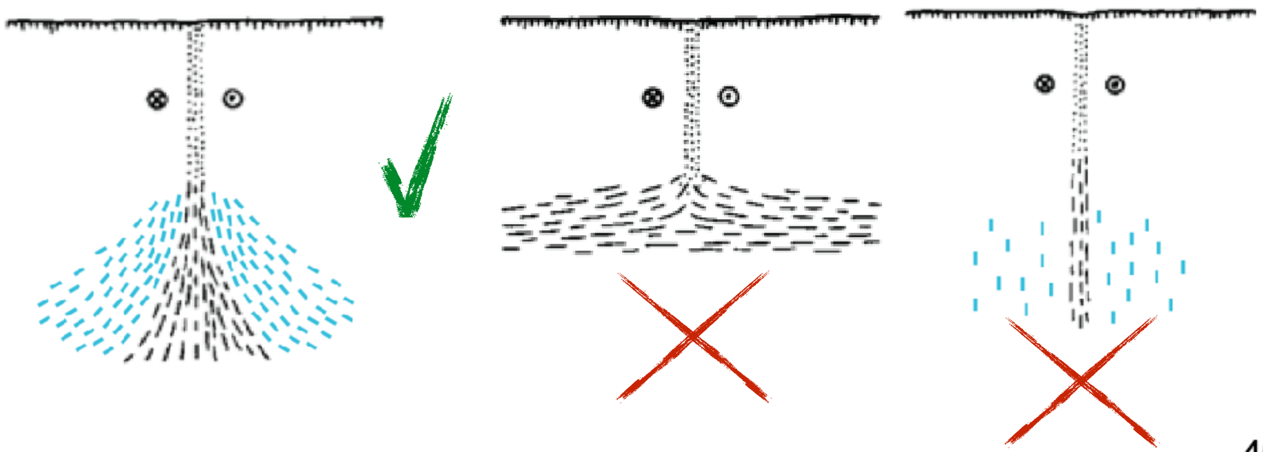
Distributed fabric at depth?



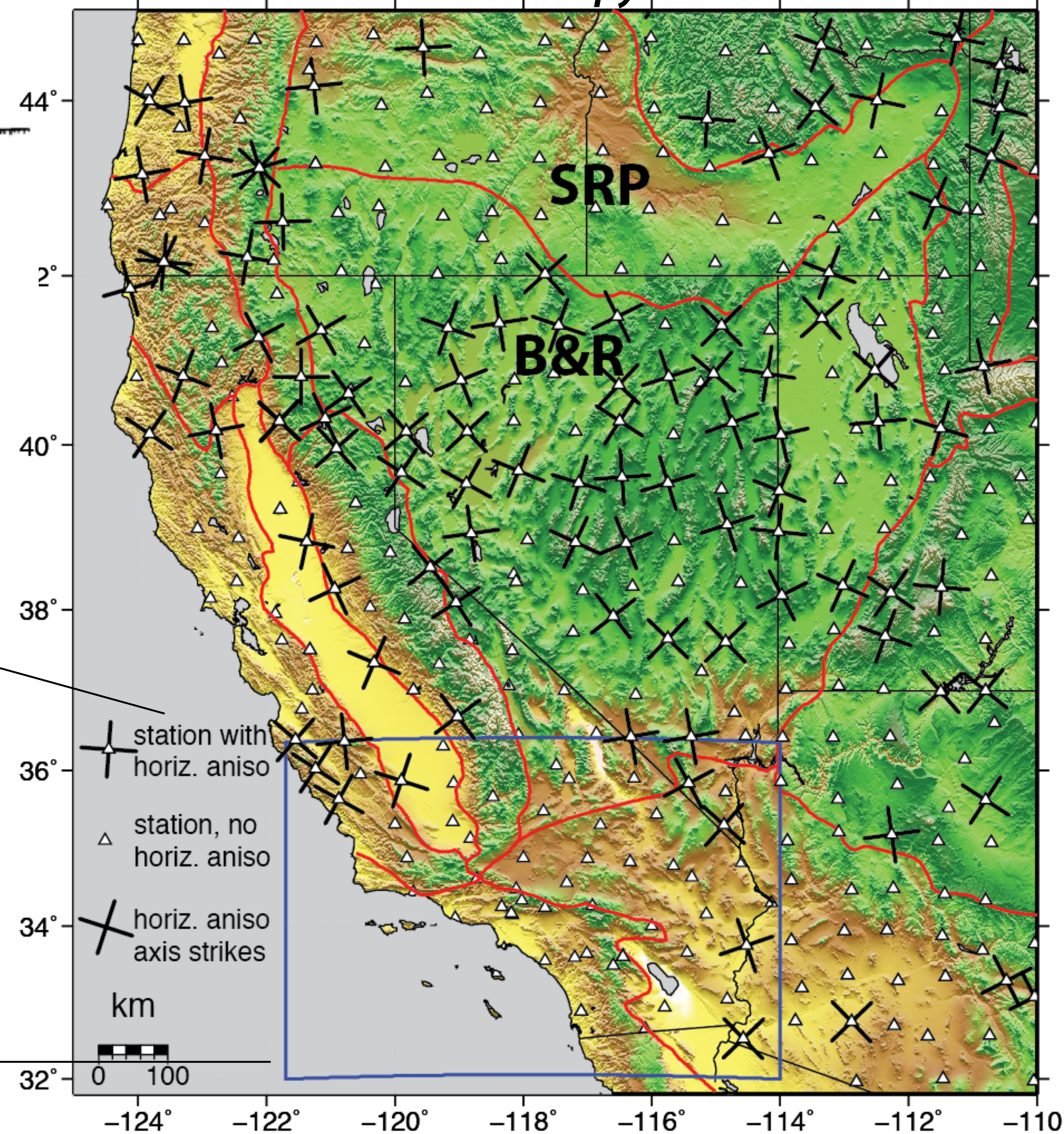
Schulte-Pelkum and Mahan, 2014, EPSL

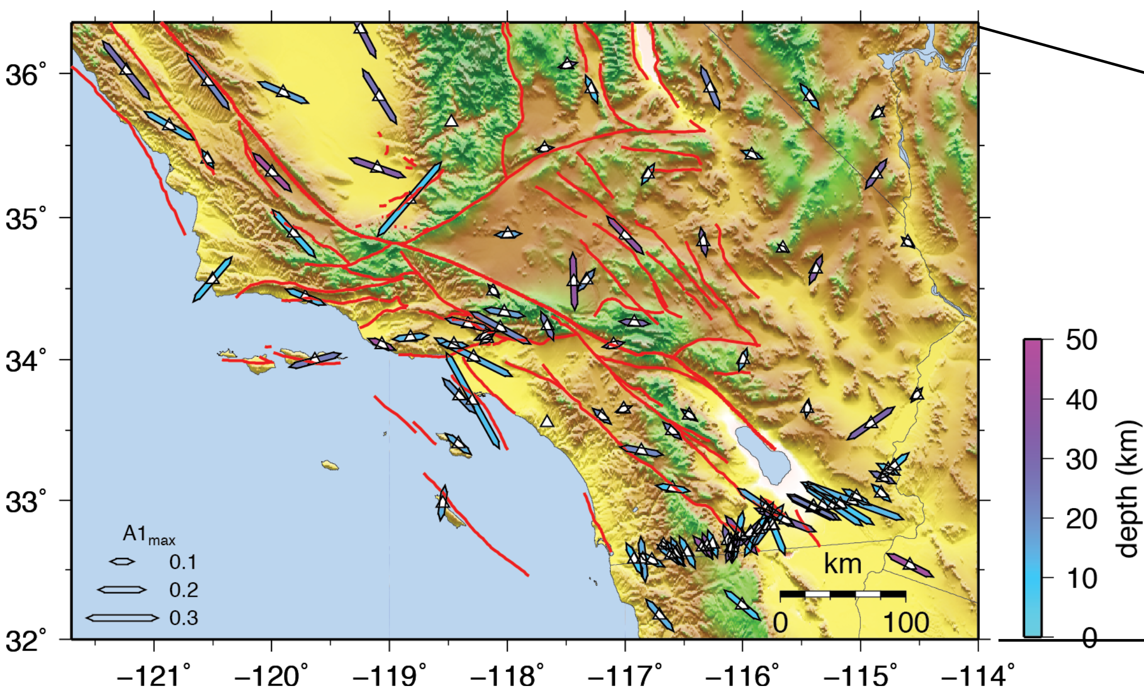
Shear fabric orientation at depth?

after Sibson, 1983



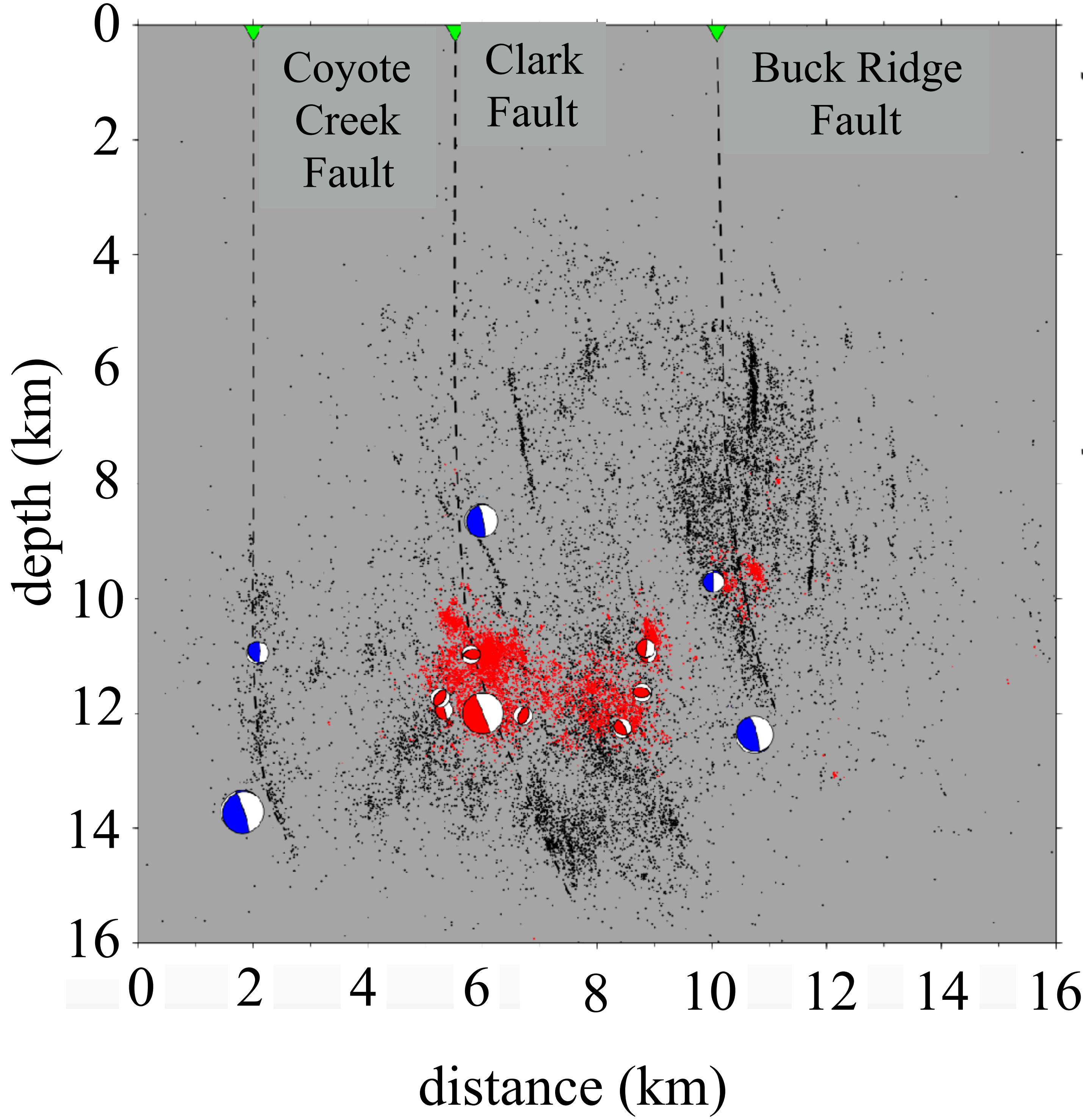
azimuthal anisotropy

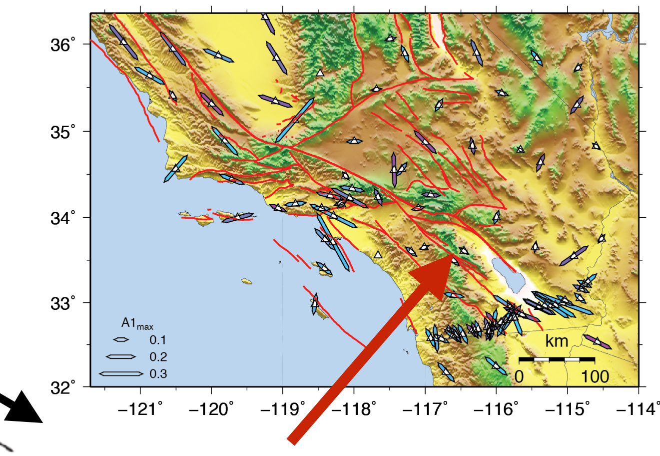


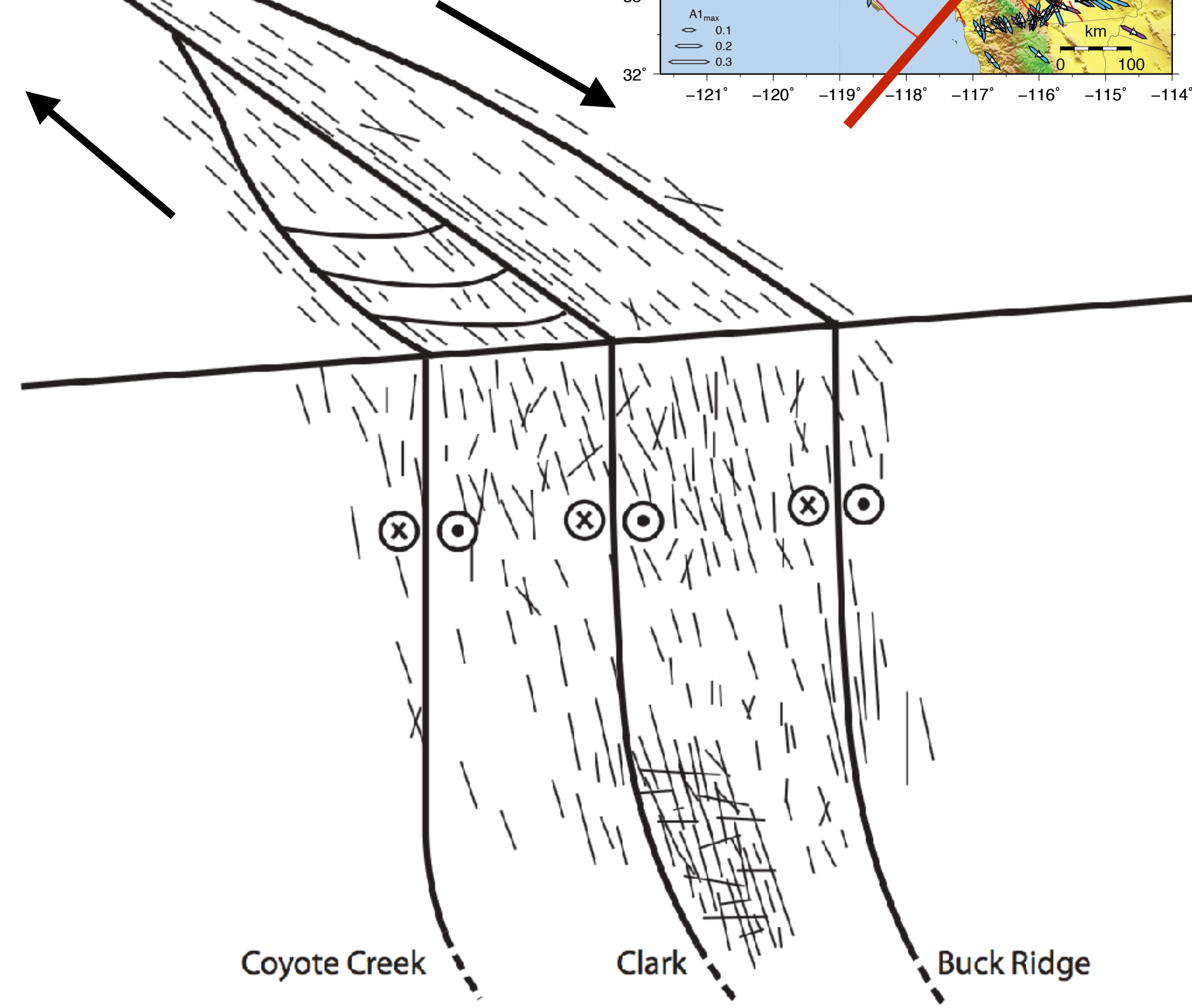


dipping foliation

Listric transform faults below ~ 10 km based on seismicity

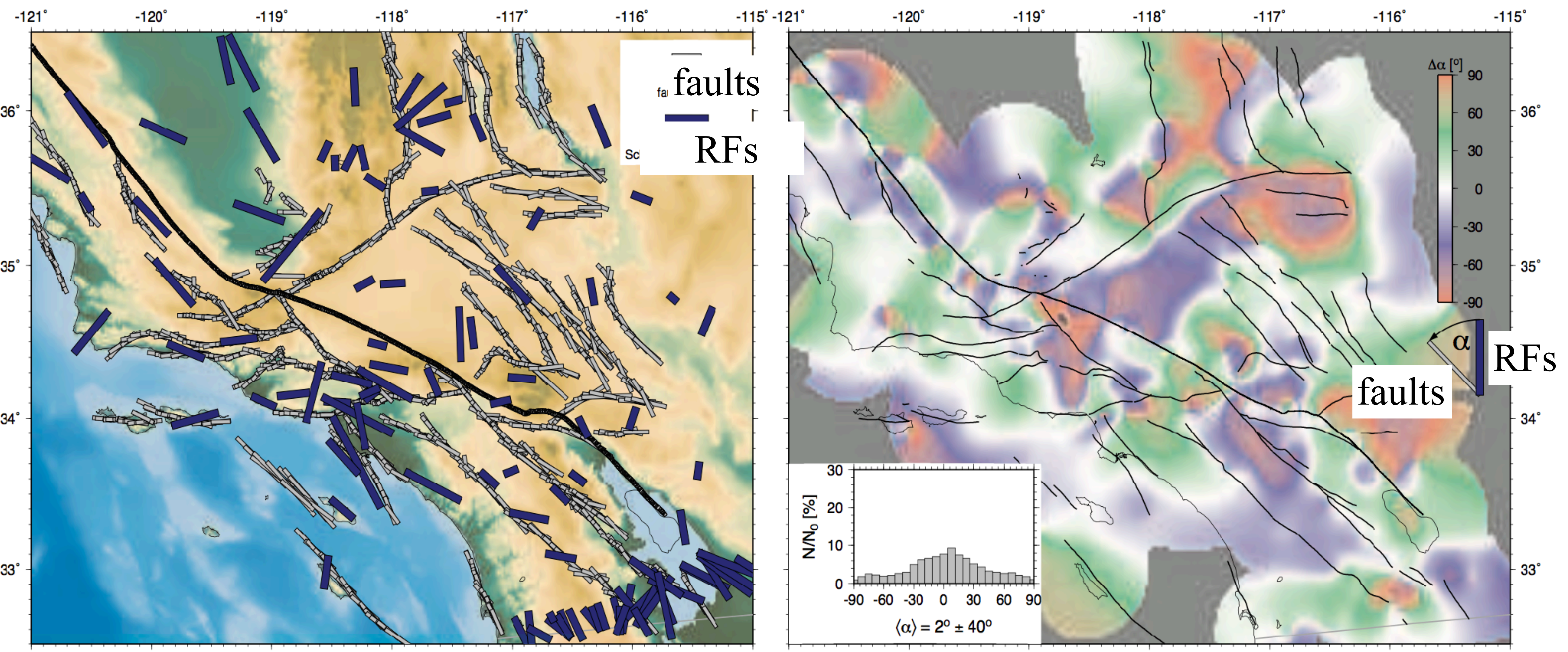






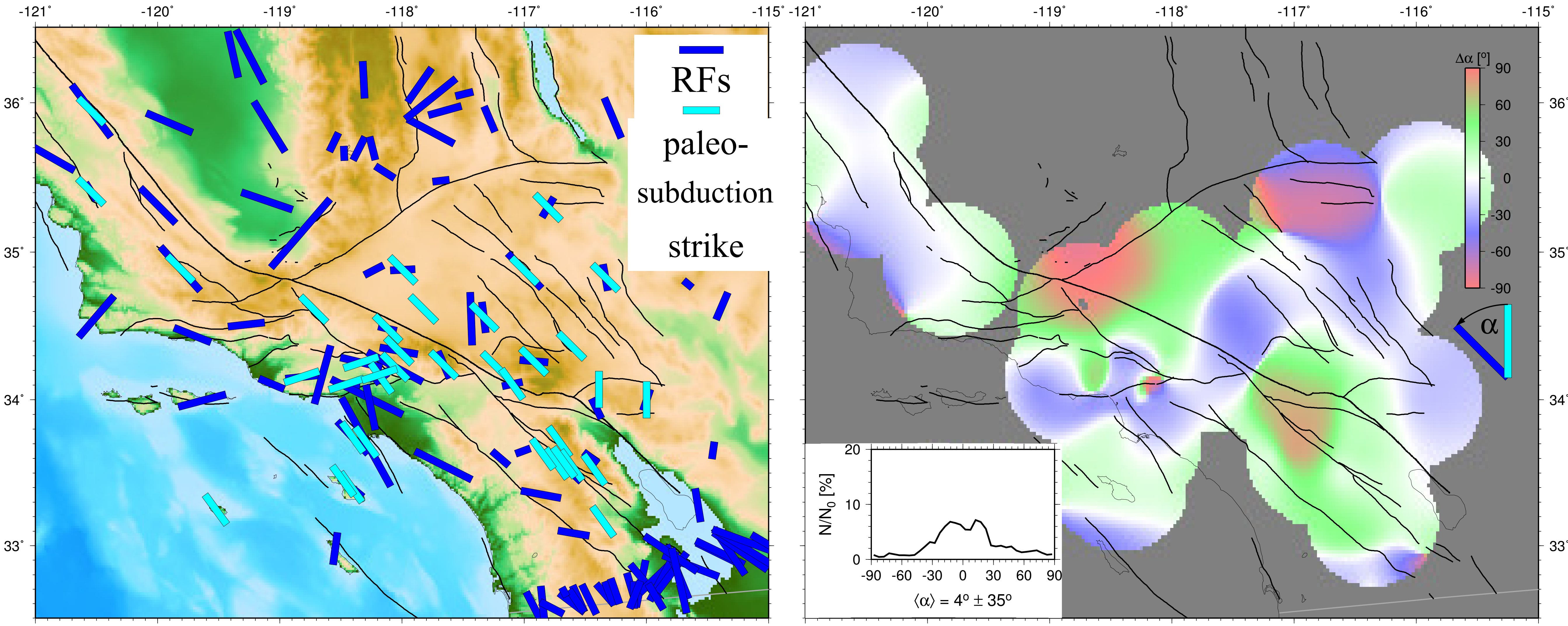
Ross, Hauksson, Ben-Zion, 2017, Science Advances

How fault-parallel are RF strikes?



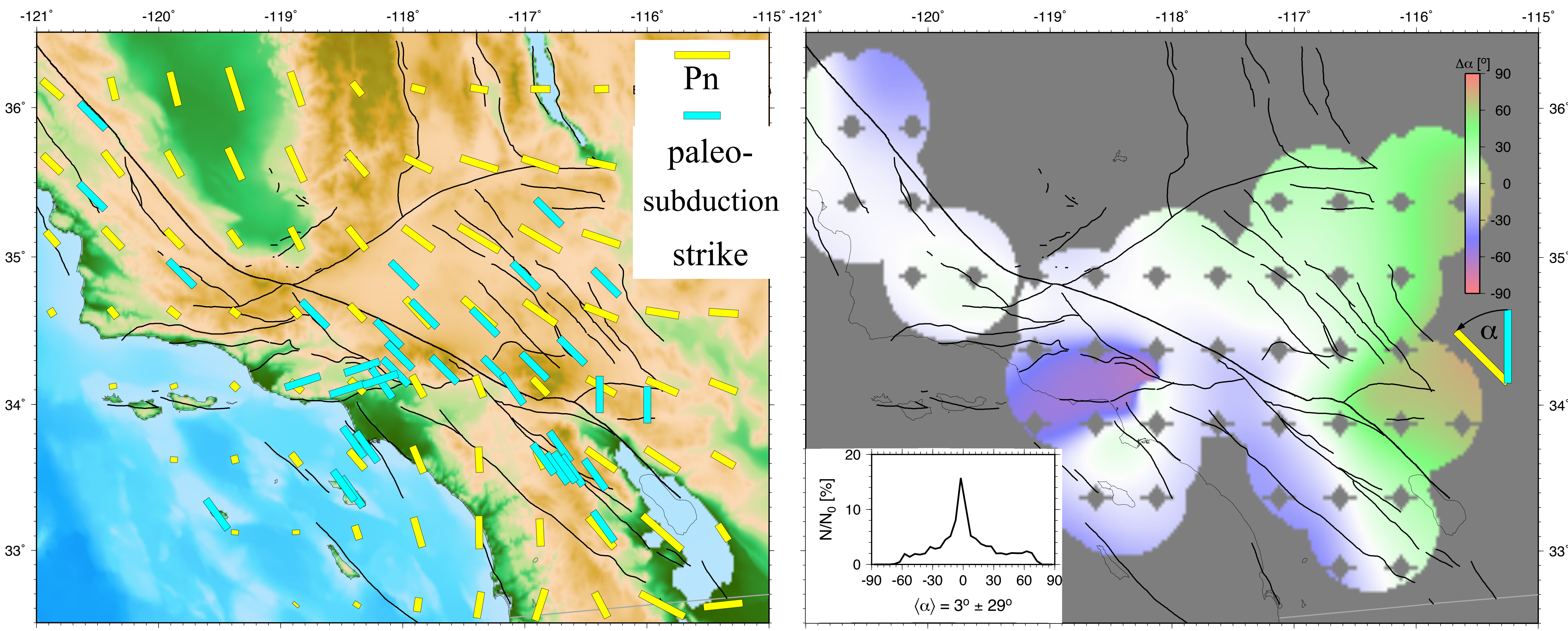
better correlation than RFs to topographic range strikes

Current deformation, or inherited fabric from Farallon subduction?



Farallon average subduction strike, rotated by McQuarrie & Wernicke 2005 reconstruction

Orientation comparison: Pn fast vs. Farallon subduction strike

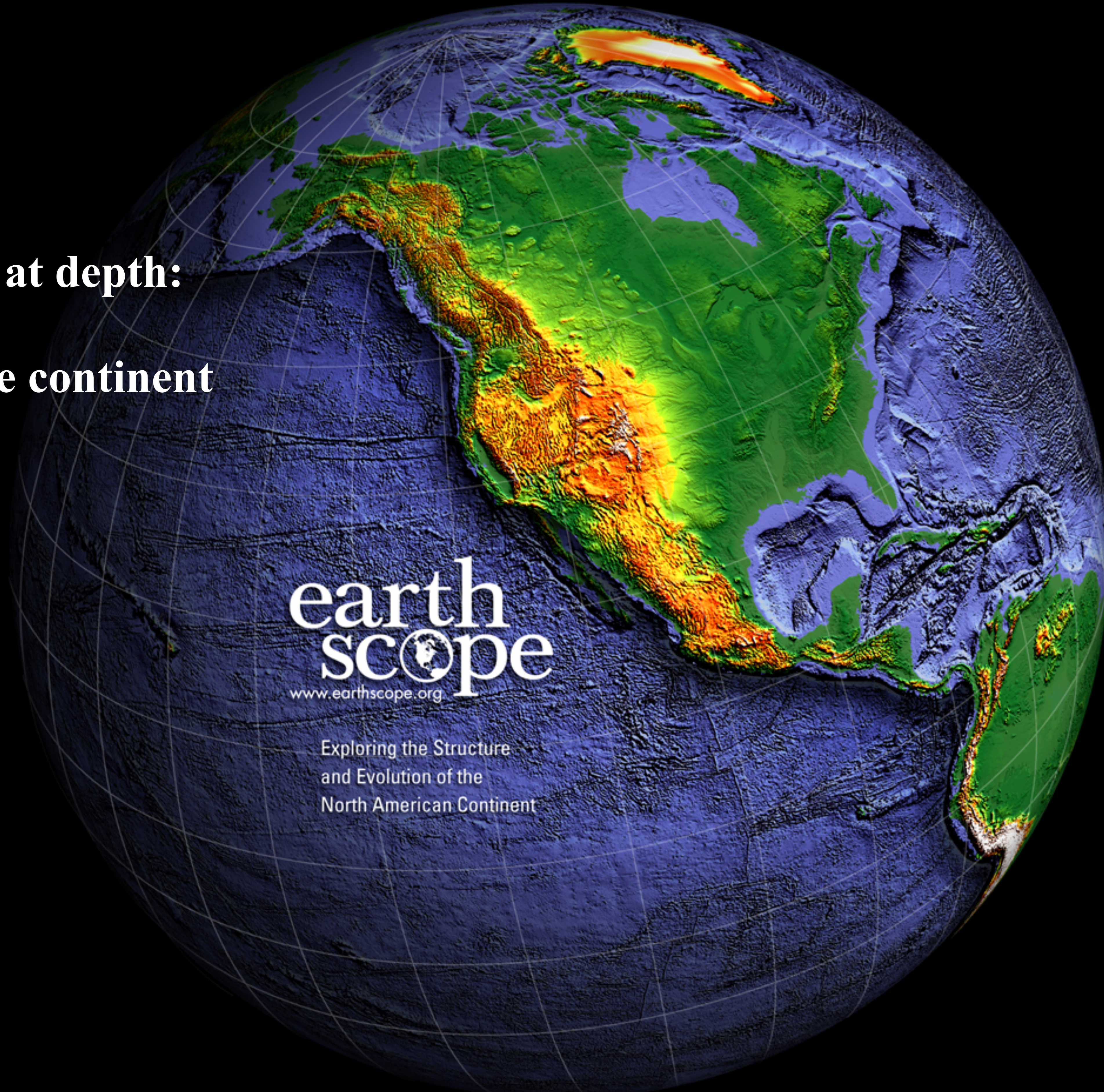


Pn Buehler & Shearer, 2014

Conclusions

Structural geology at depth:

4-D evolution of the continent



Conclusions

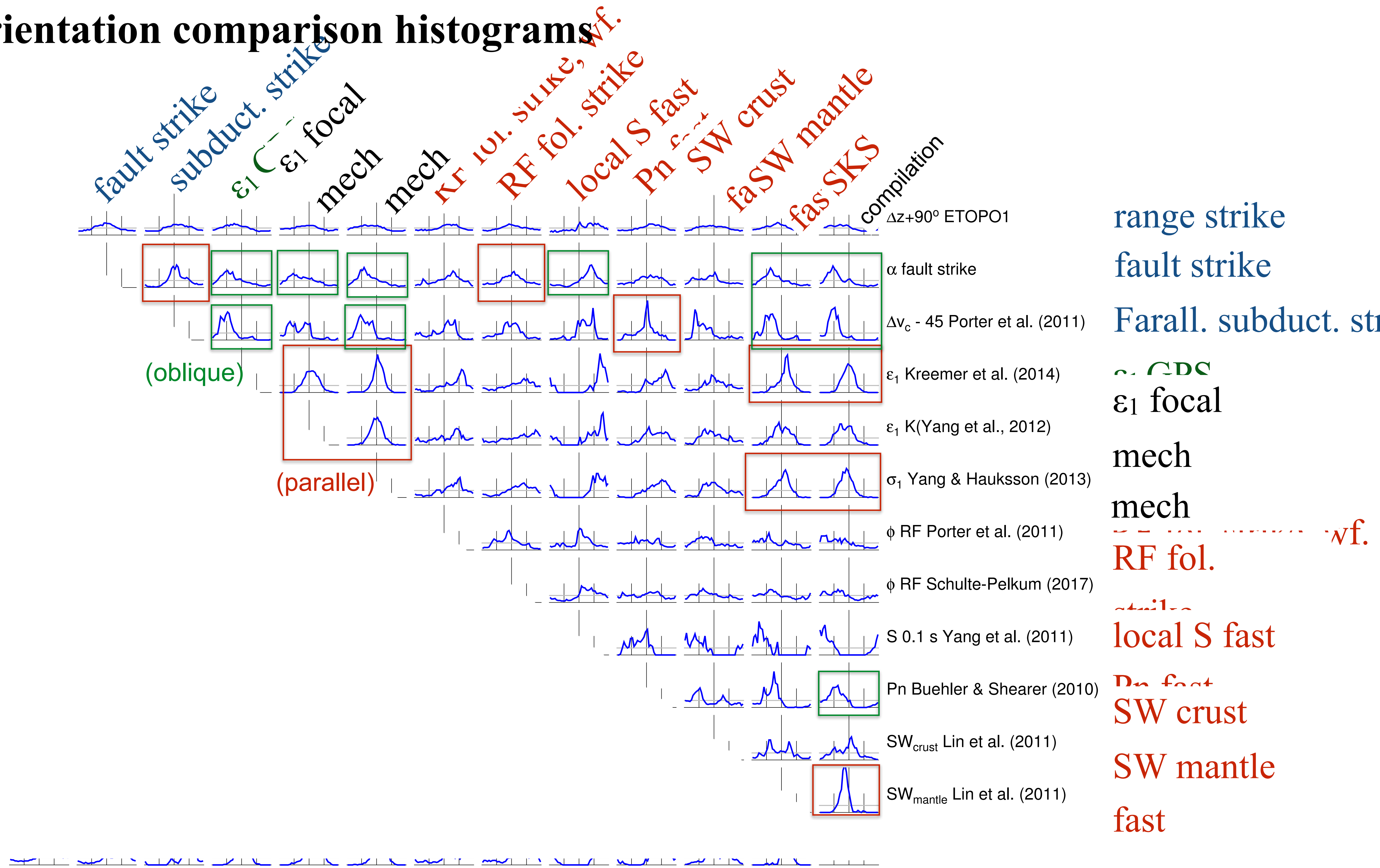
RF azimuthal conversions (not splitting!): image narrow shear zones in crust, depth control

crustal anisotropy:

- hexagonal good assumption
- mostly slow axis anisotropy, even amphibolites
- ellipticity is not a good assumption

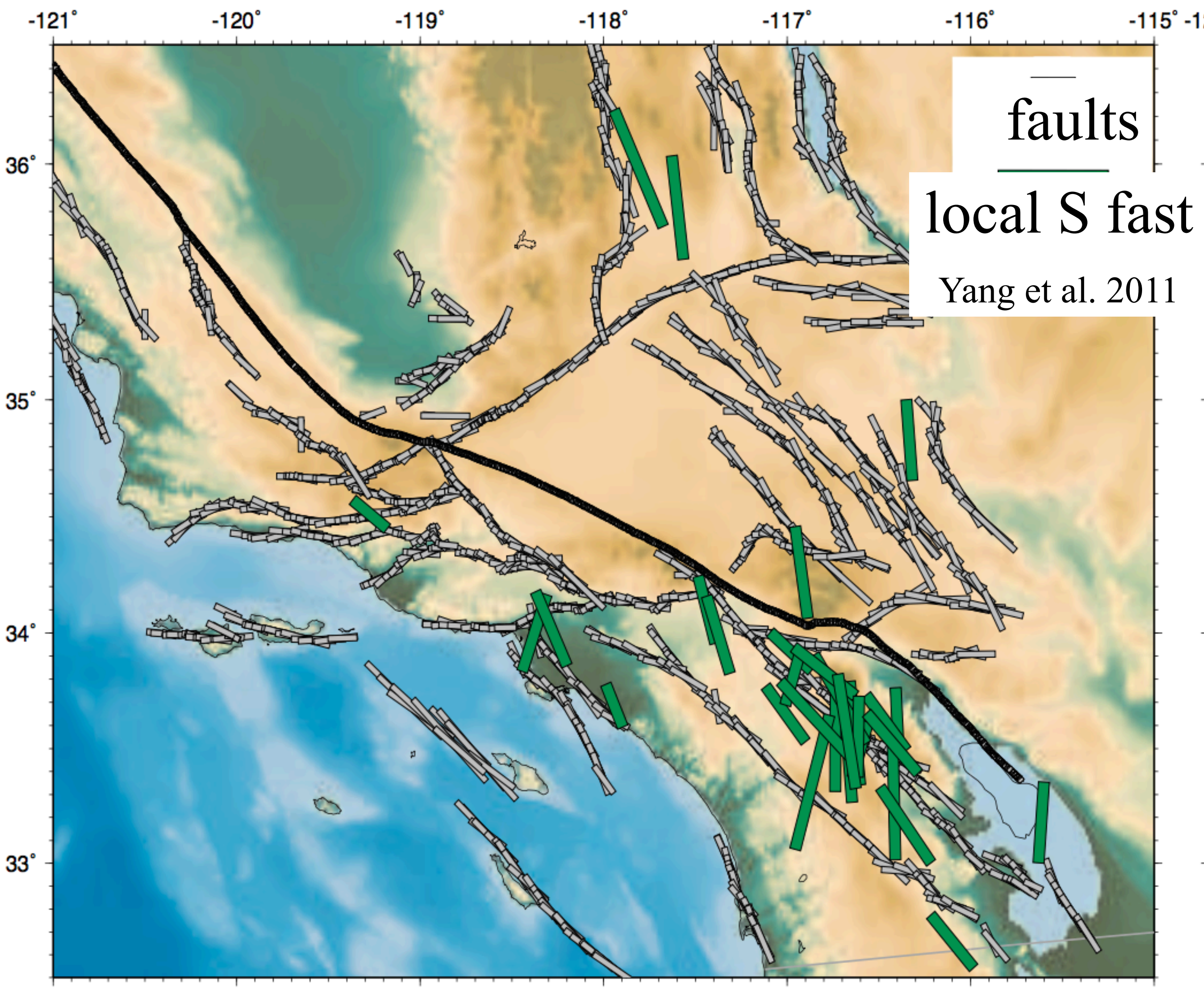
foliation strikes from RF ~parallel faults, often coherent through lower crust

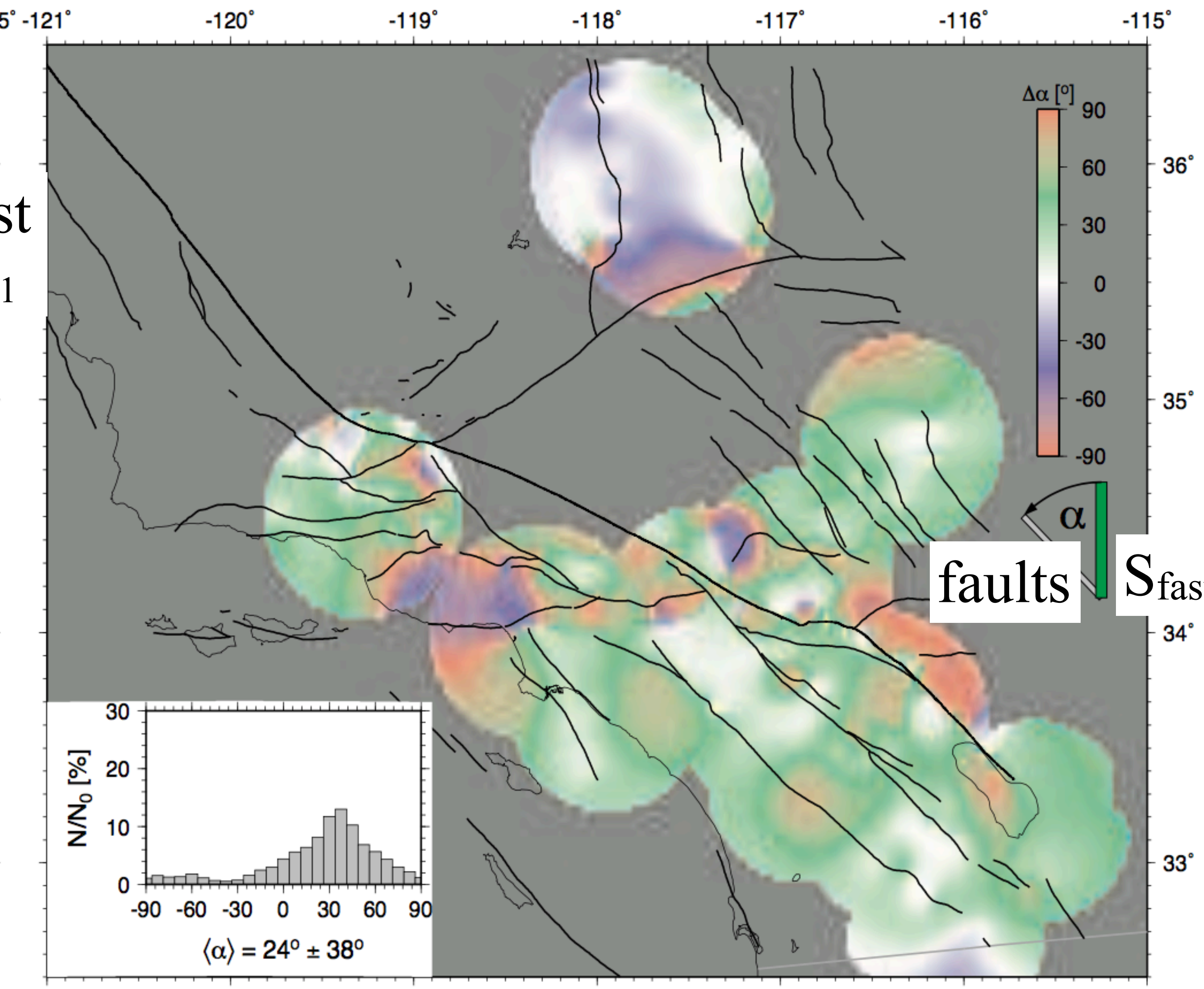
Orientation comparison histograms



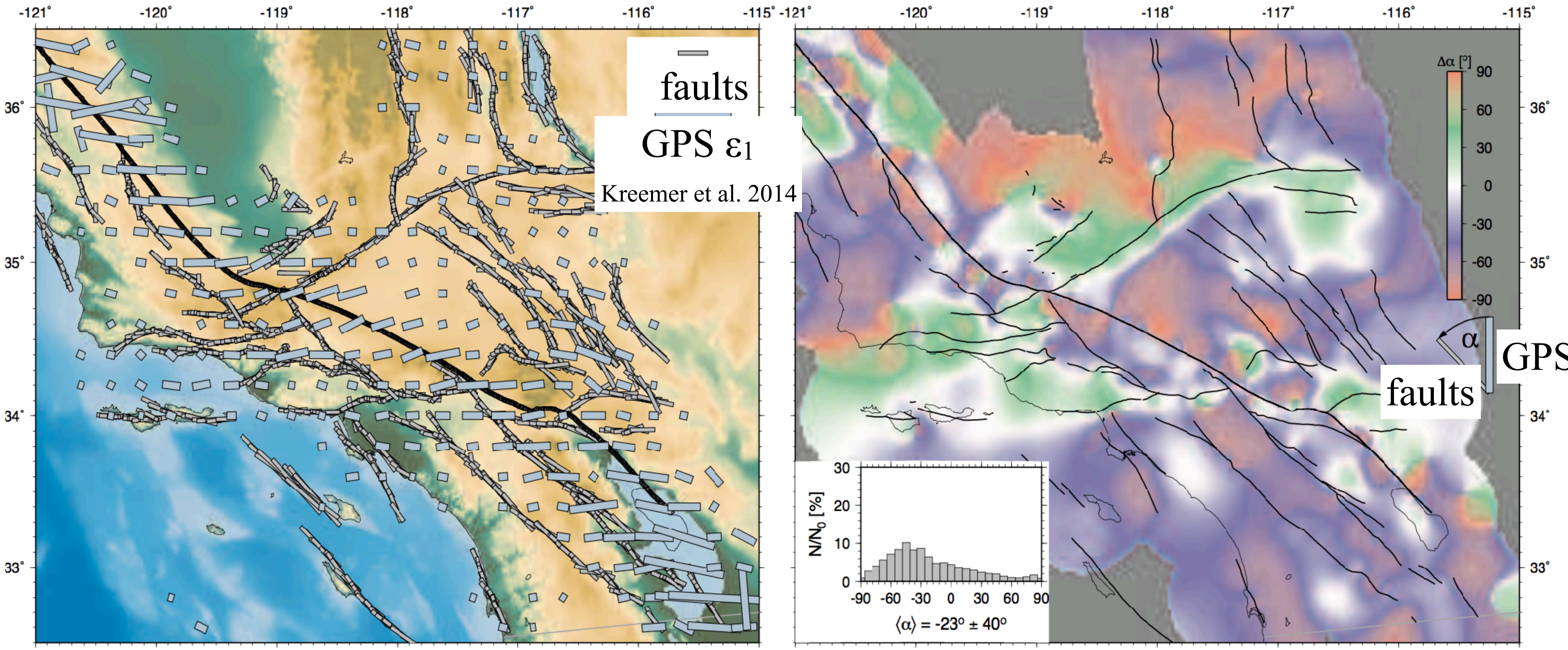
Orientation comparison: local S splitting vs. faults

Local splits: microcracks?





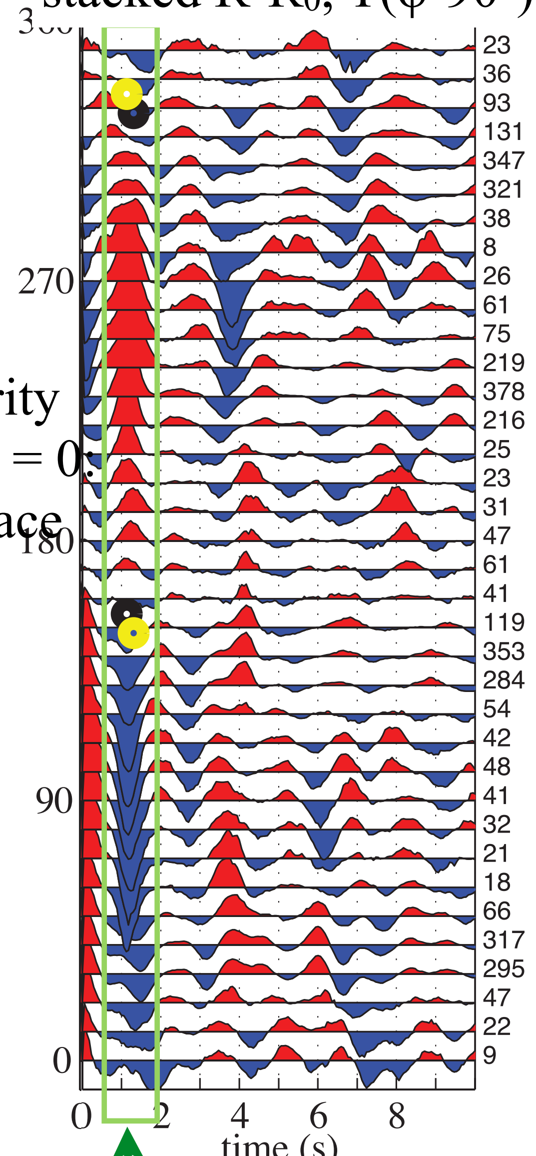
Orientation comparison: GPS stretch vs. faults



1. Motivation | 2. Method | **3. Results** | 4. Conclusions

Robust strike, depth; distinction between dipping interface and plunging axis anisotropy

stacked R-R0, T(φ-90o)

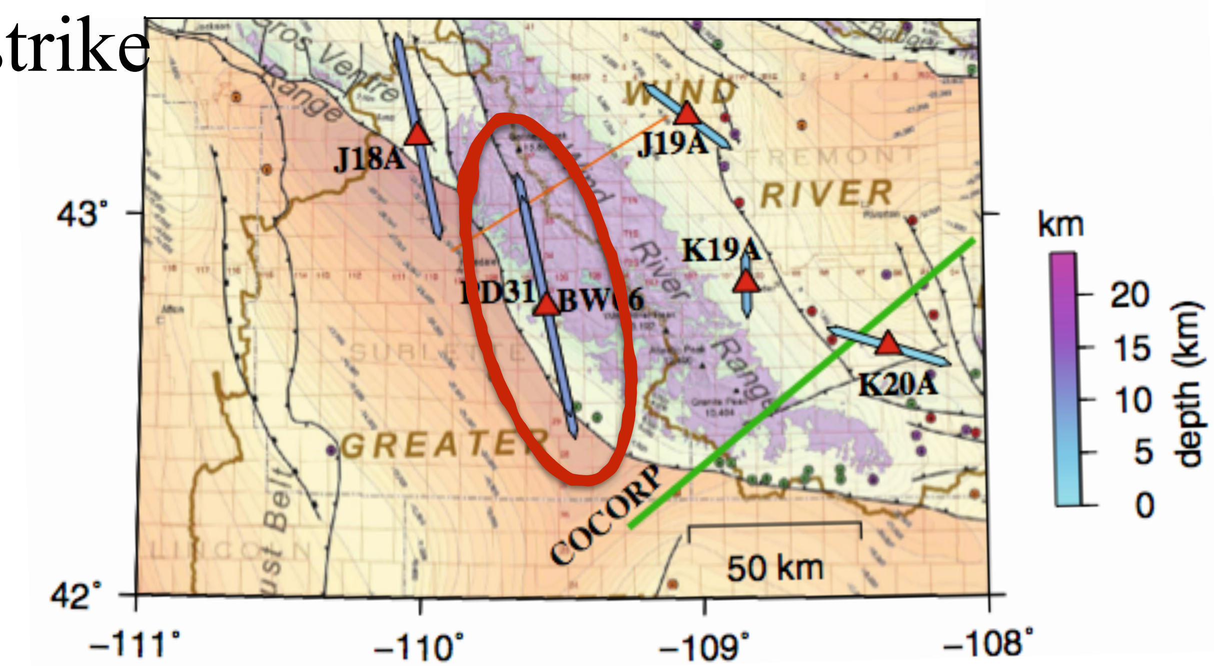


opposite polarity arrival at time = 0: dipping interface

polarity nodes: strike

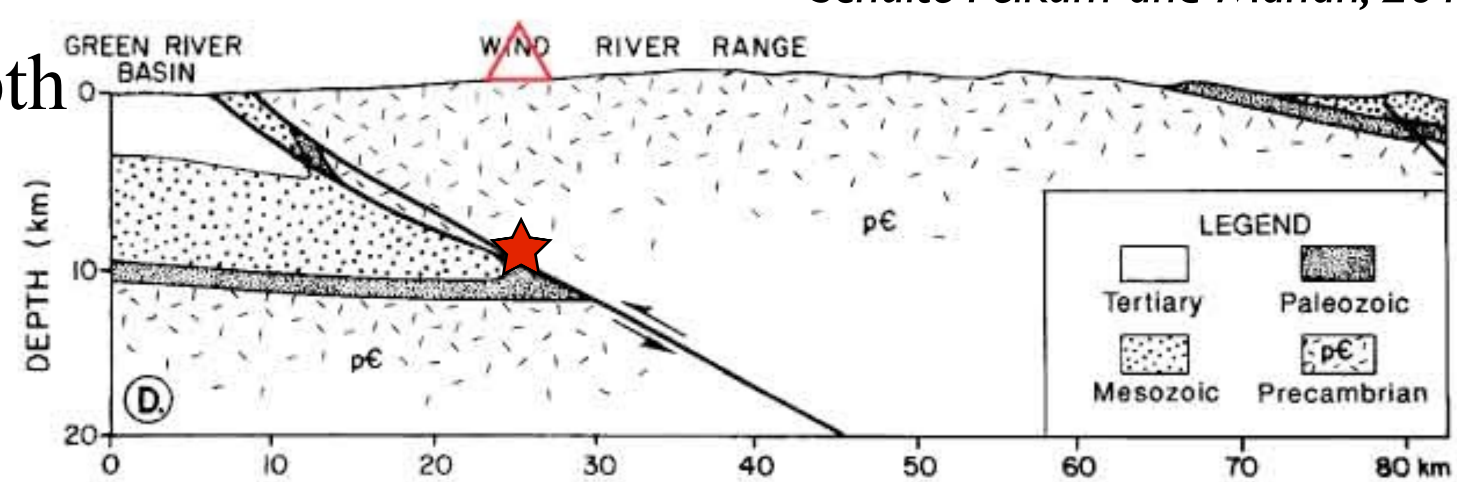
delay time ~ depth

strike



Schulte-Pelkum and Mahan, 2014, PA

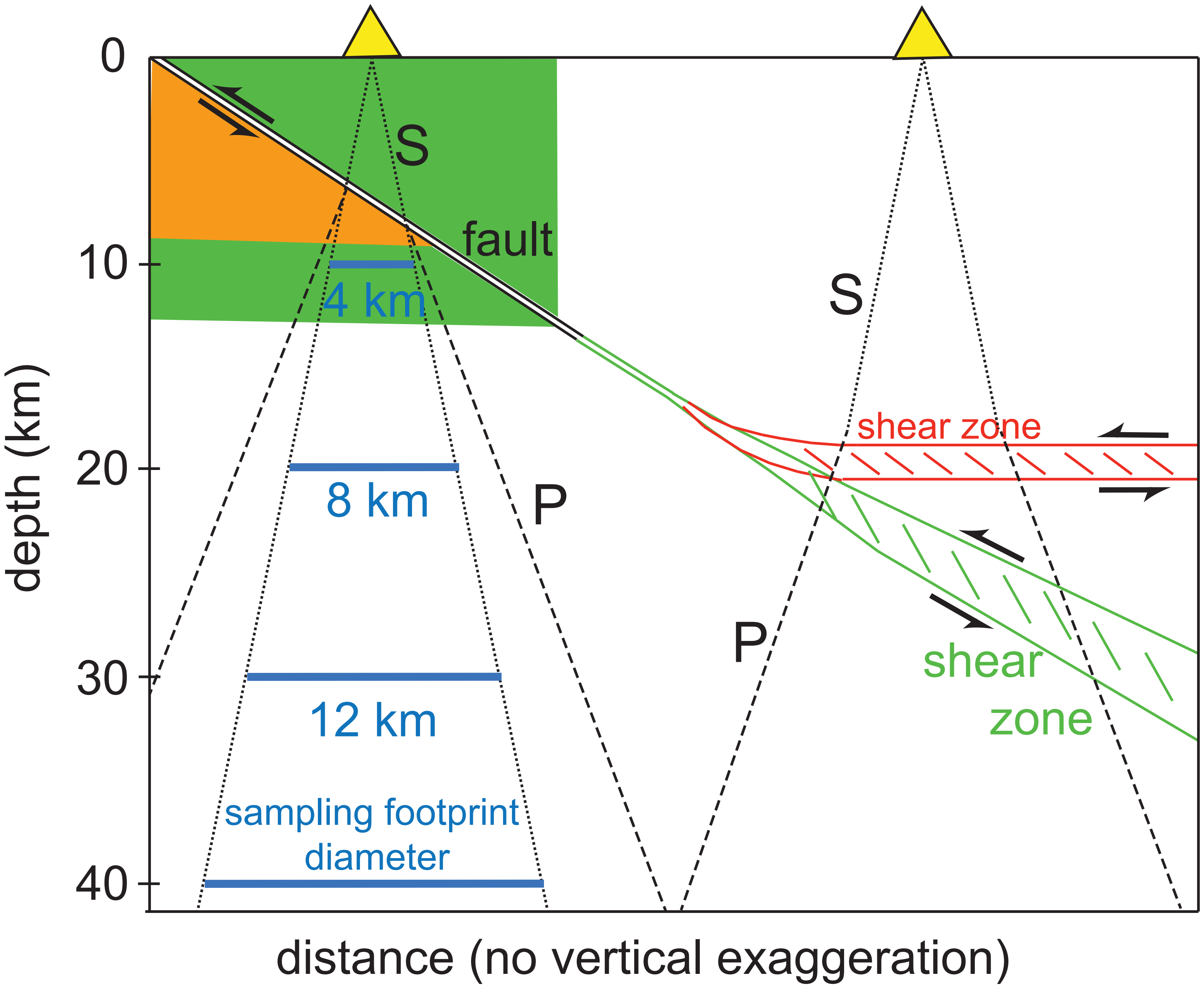
depth



COCORP interpretation from Steidtmann & Middleton, 1991

Summary: image faults and narrow shear zones with receiver functions

- no splitting! P-S conversion amplitud

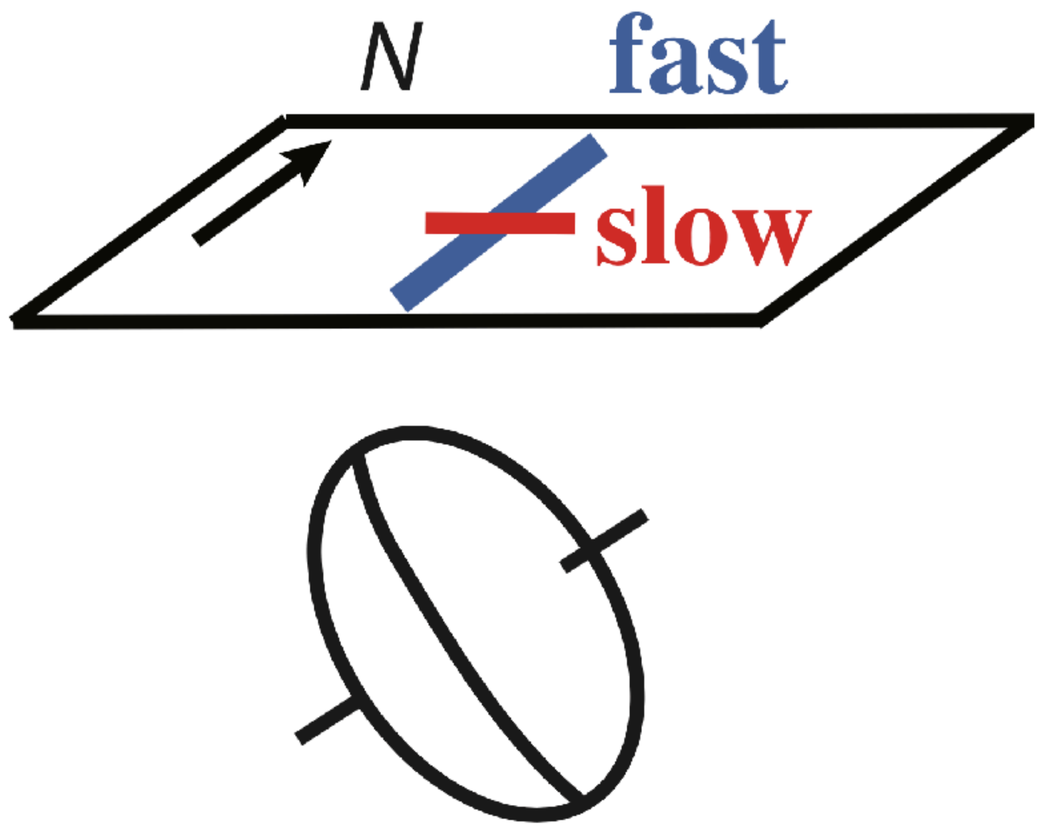


- sees Vp anisotropy contrasts to ~ 3%
- known depth
- required thickness 1-2 km
- required horizontal extent < 5 km (up
  to ~20 km (upper mantle)

Schulte-Pelkum and Mahan, 2014, EPS

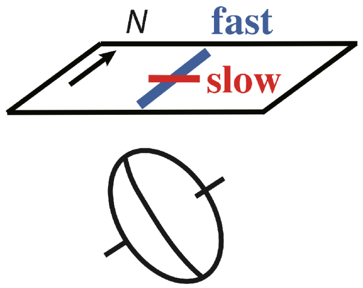
Schulte-Pelkum and Mahan, 2014, PAG

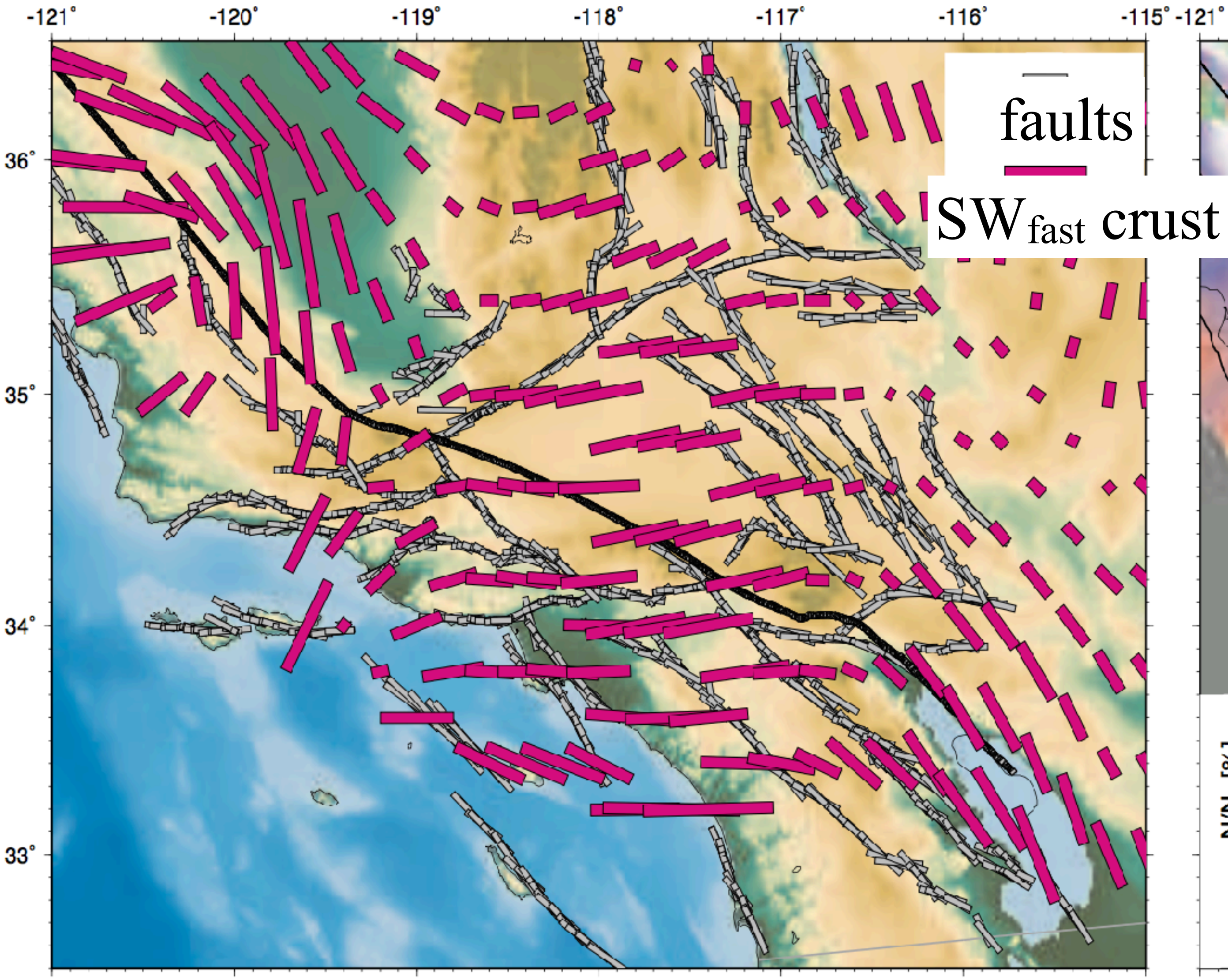
Park and Levin, 2016, GJI

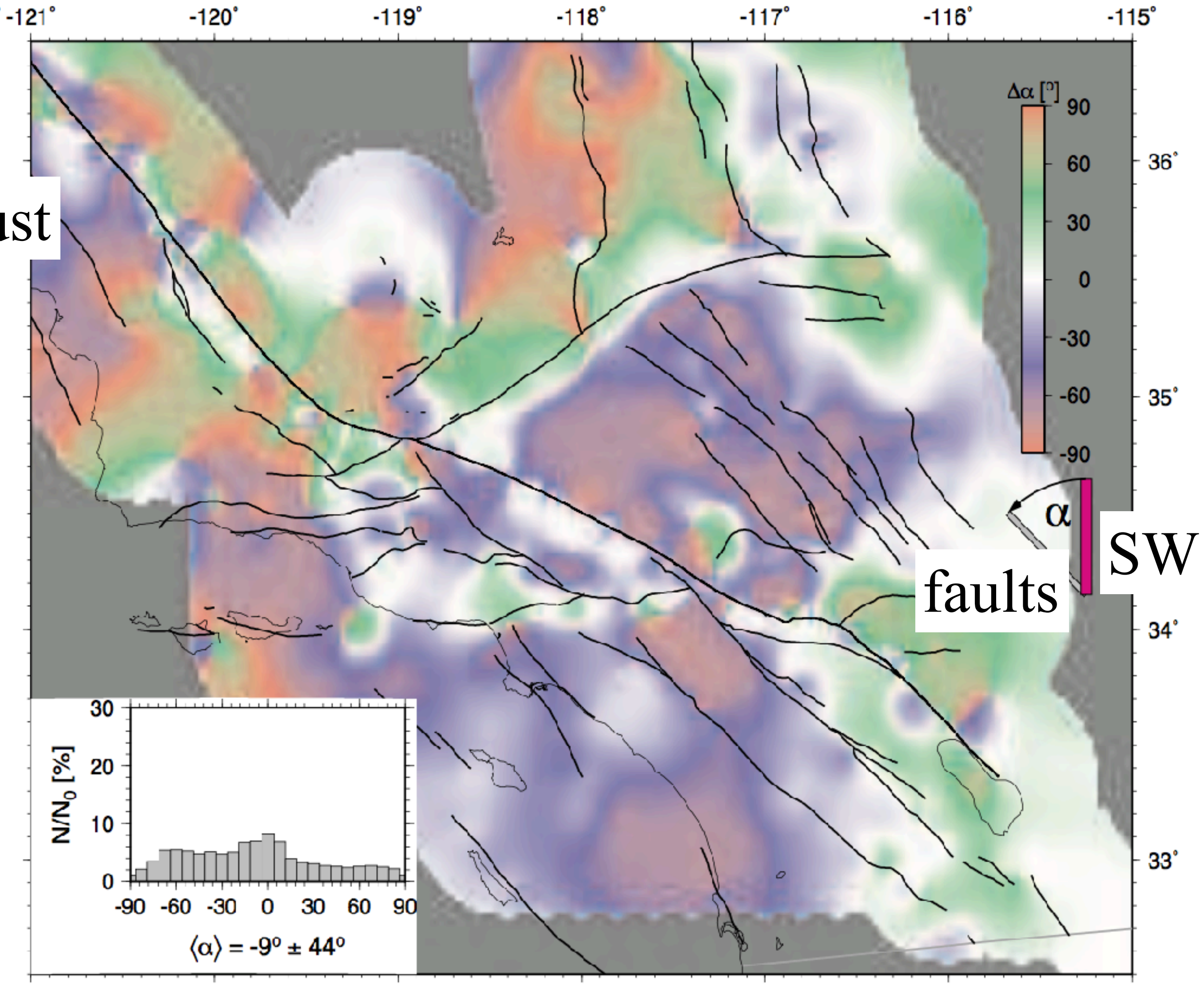


N
fast
slow

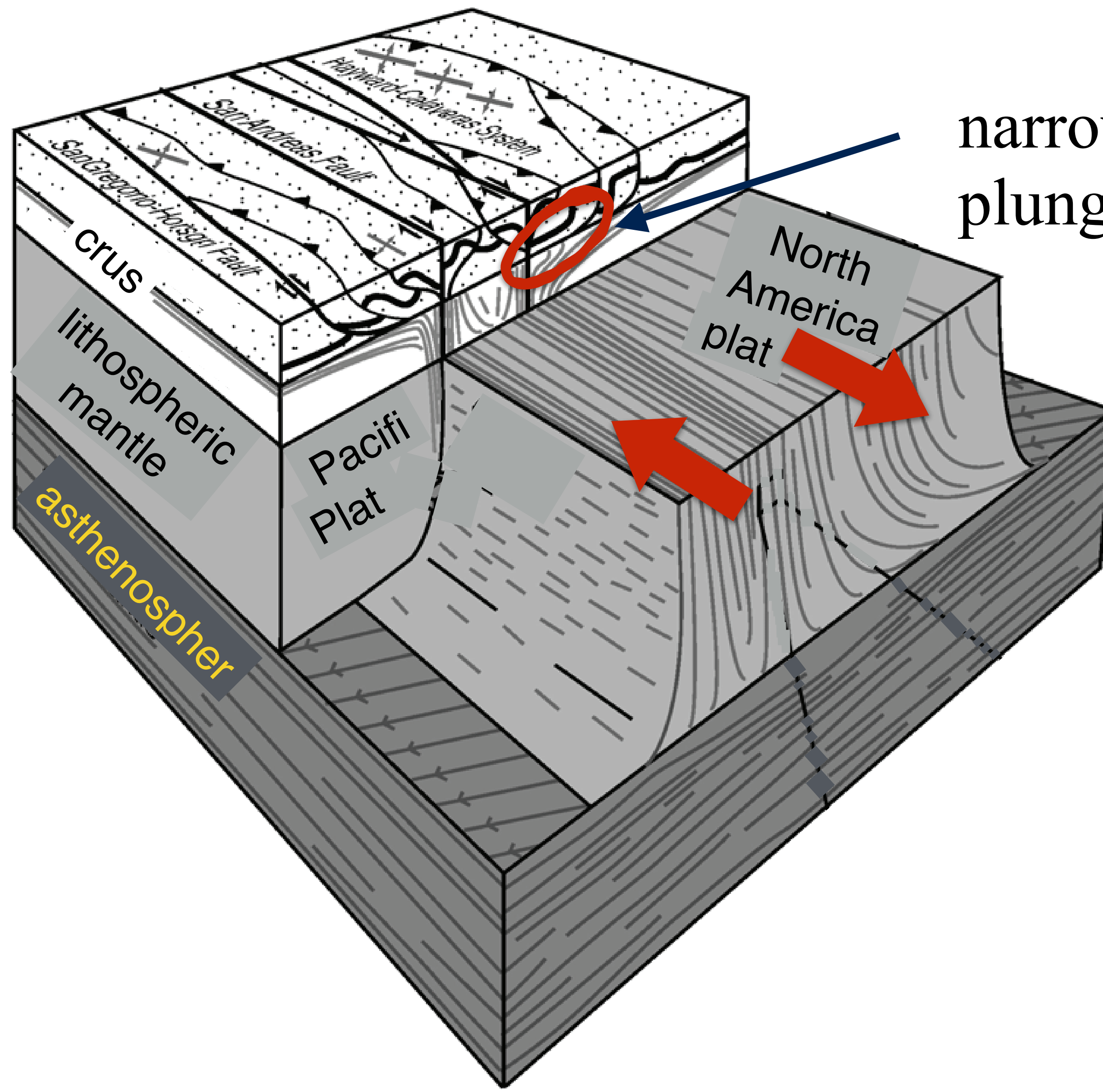
Orientation comparison: surface wave fast axis (crust) vs.







Seismic anisotropy methods



narrow shear zones?
plunging symmetry a

Orientation comparison histograms: oblique