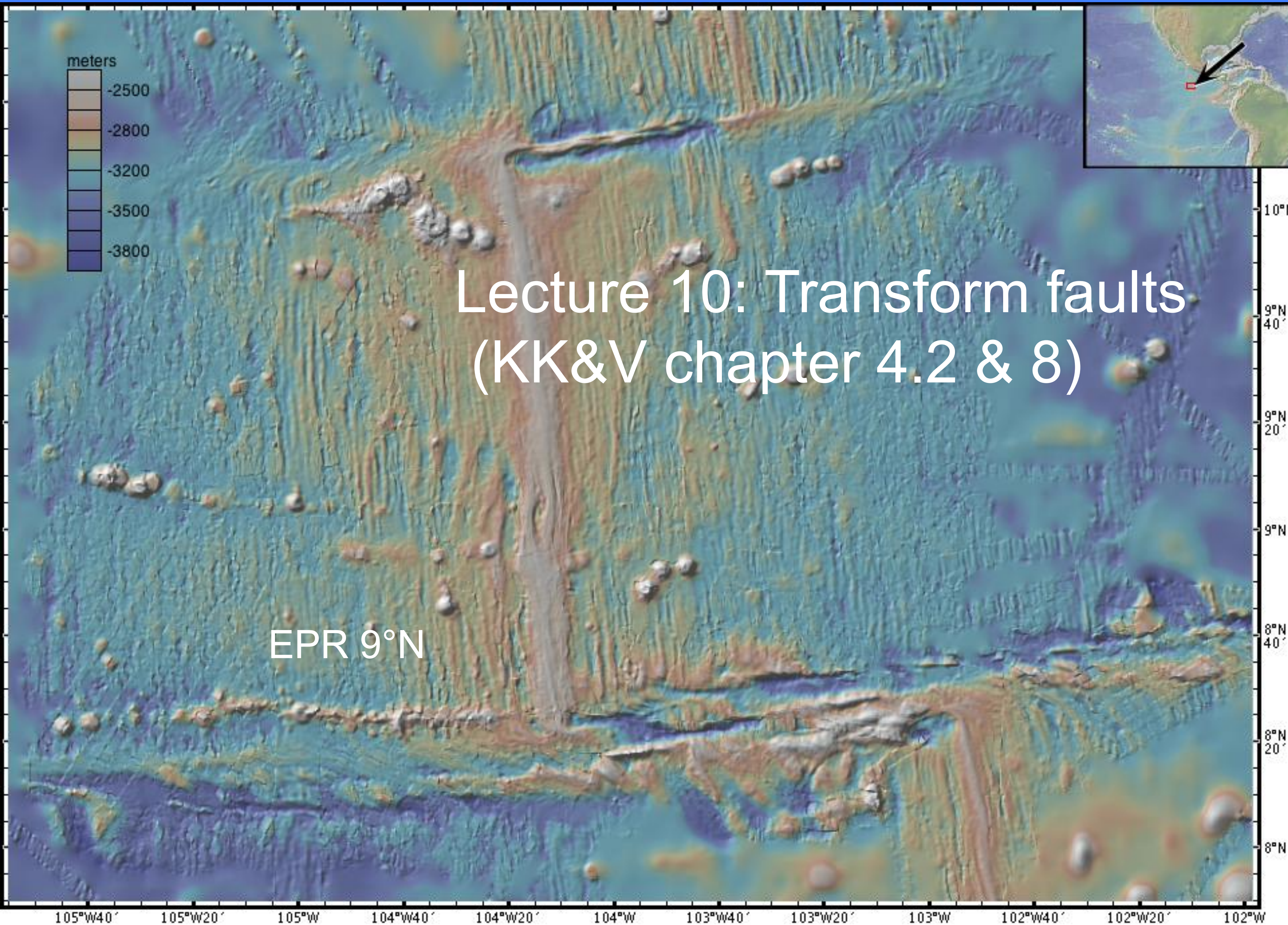
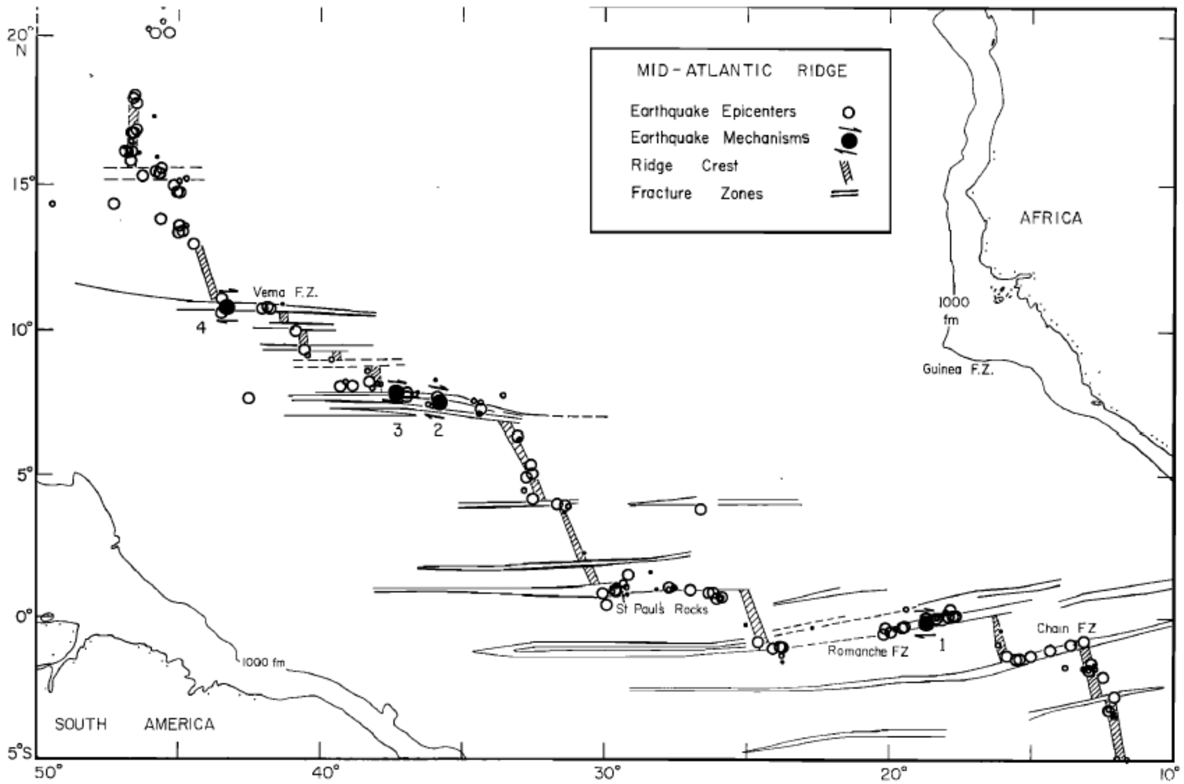
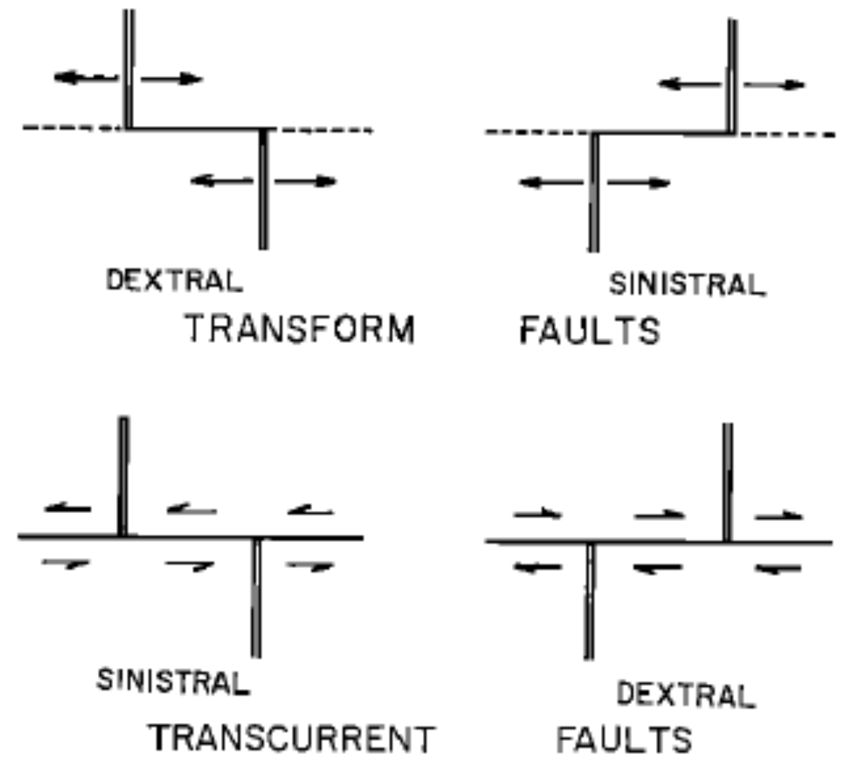
Lecture 10: Transform faults (KK&V chapter 4.2 & 8)

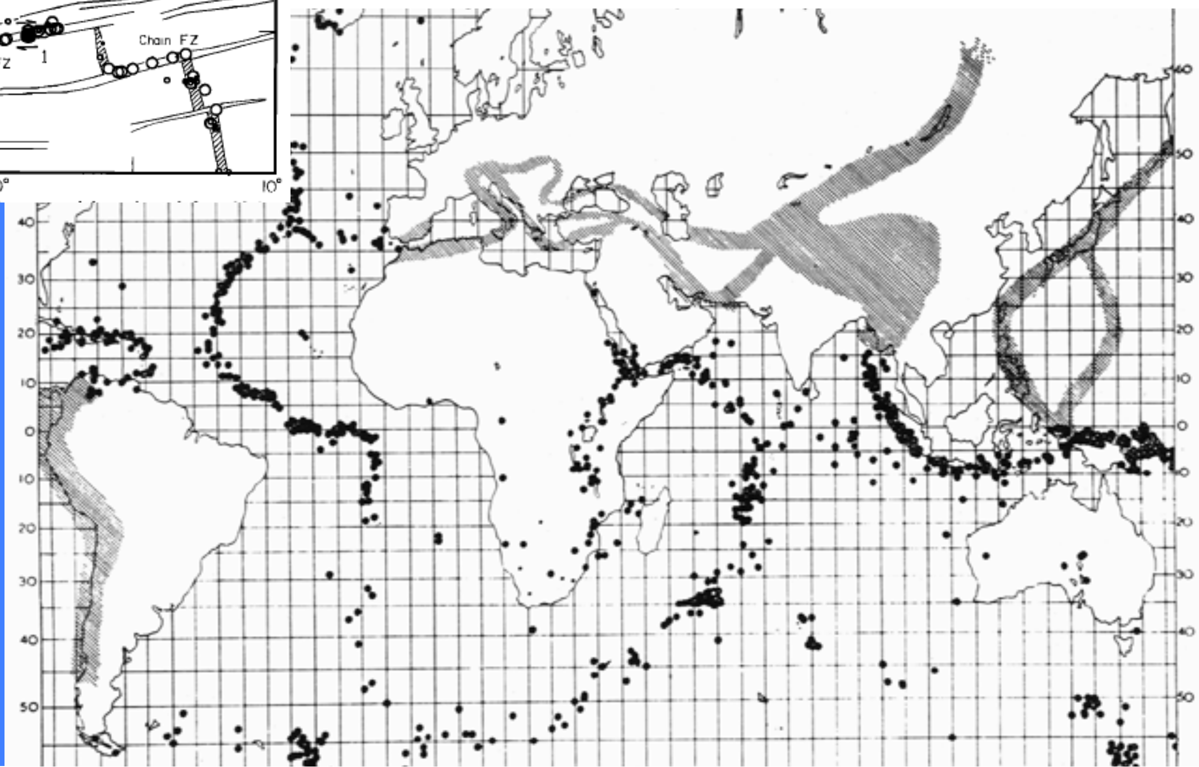


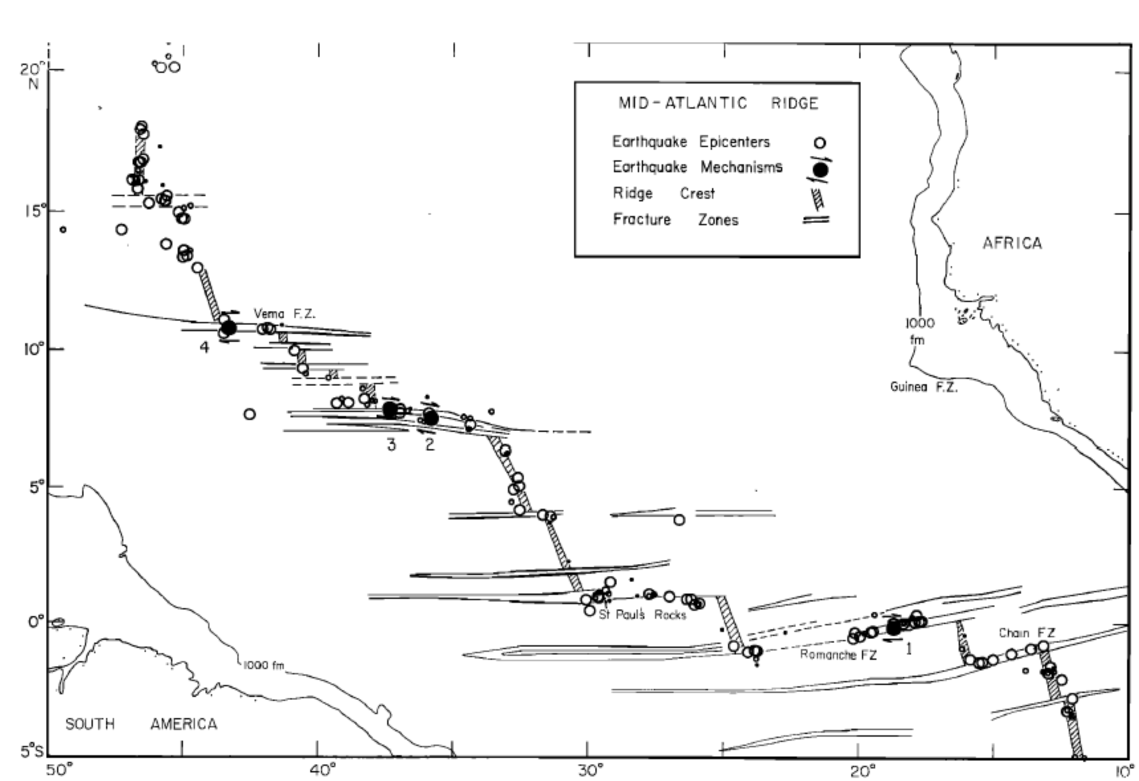
What happens at the ends of spreading ridge segments?

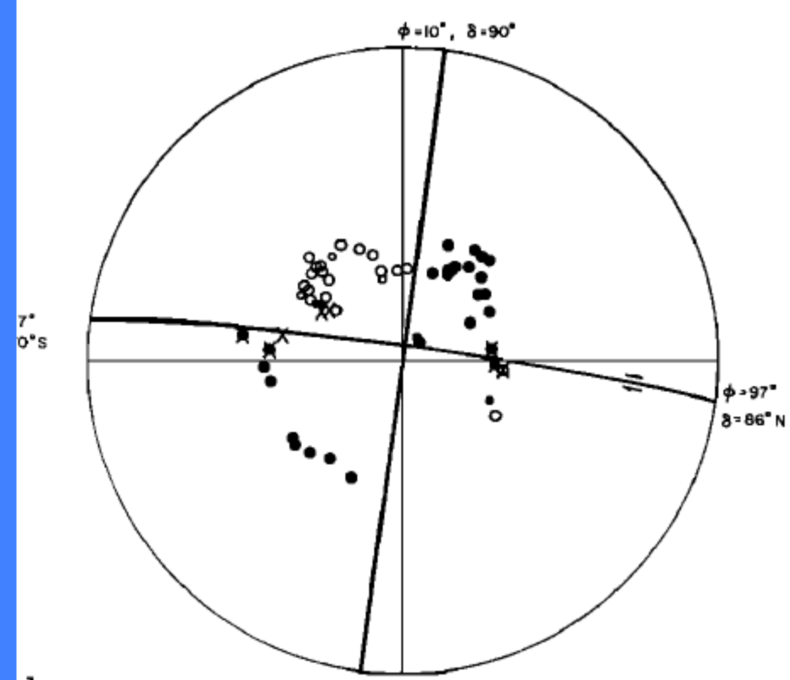




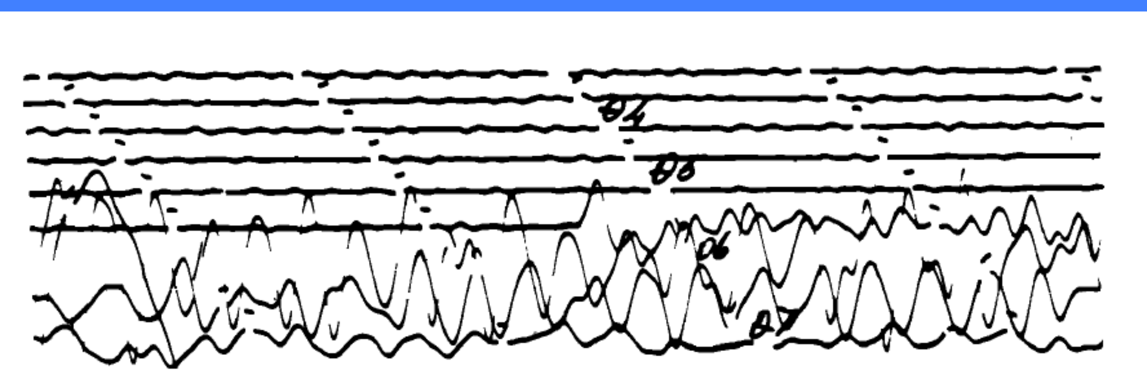
J. Tuzo Wilson (1965)



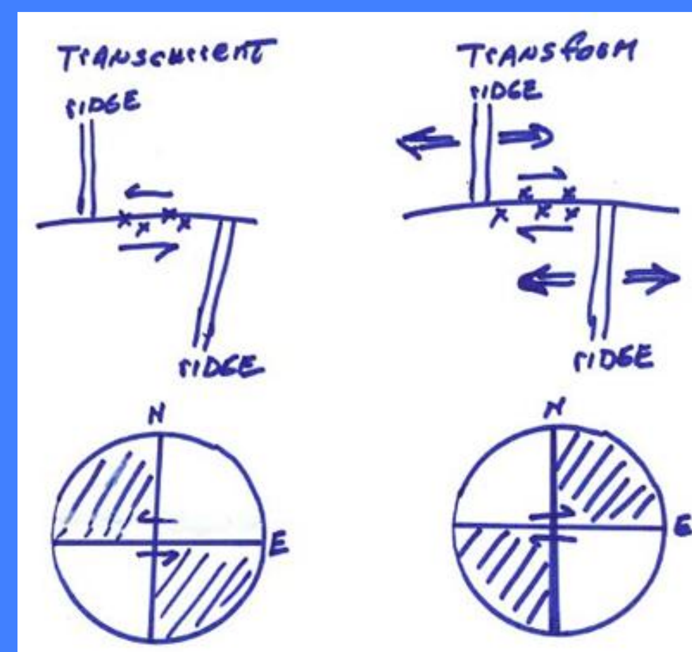




Focal mechanisms; fault plane solutions



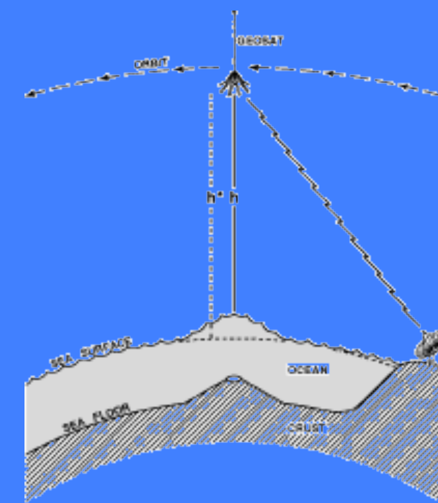
The seismologists verify Wilson's transform fault hypothesis;
World wide seismic network

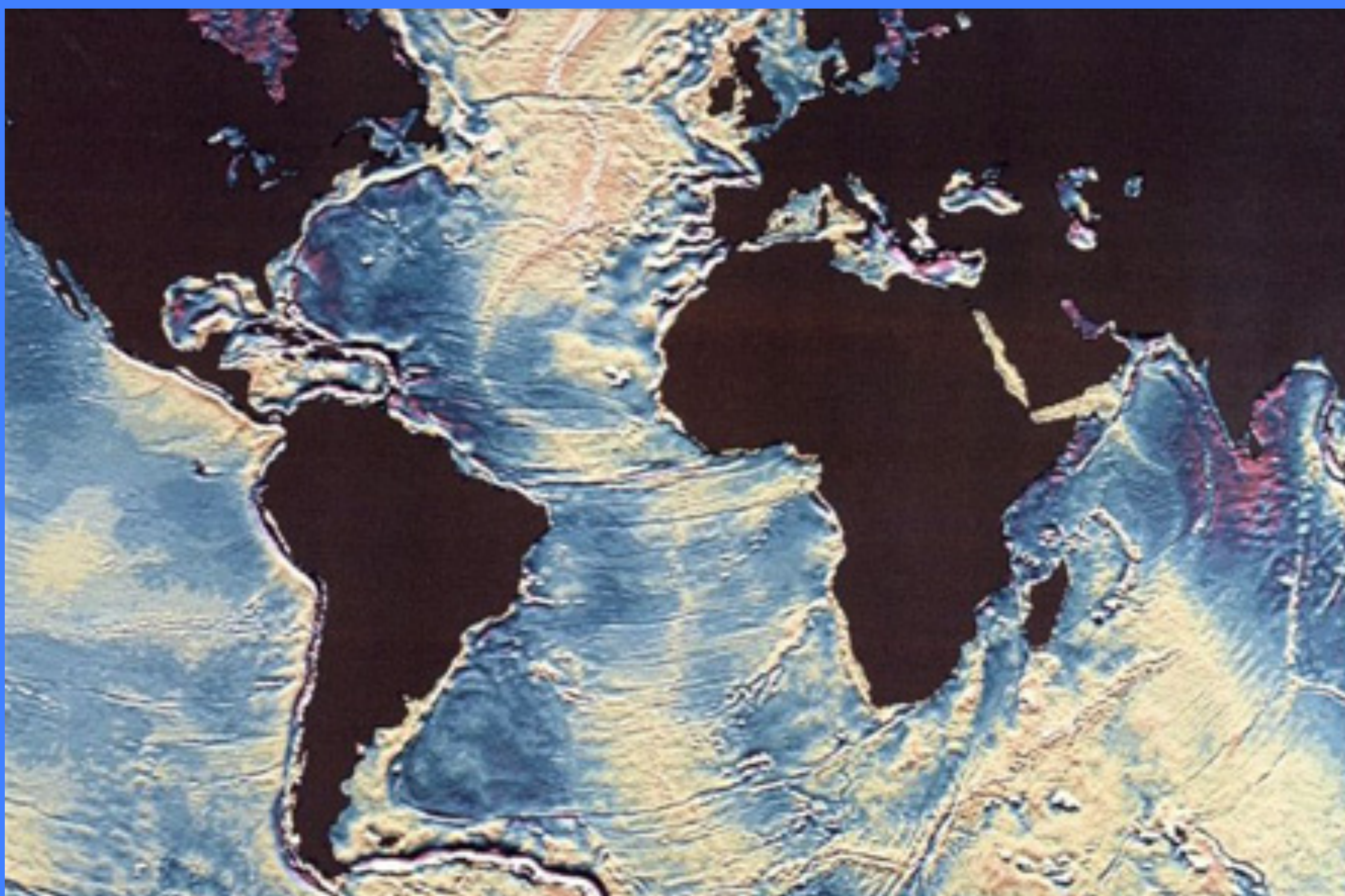


Lynn Sykes (1967)

Satellite radar altimetry observations, starting in the early 1980’s, revolutionized the mapping of features on the ocean floor.

For the first time, fracture zones could be accurately mapped in remote areas of the oceans.

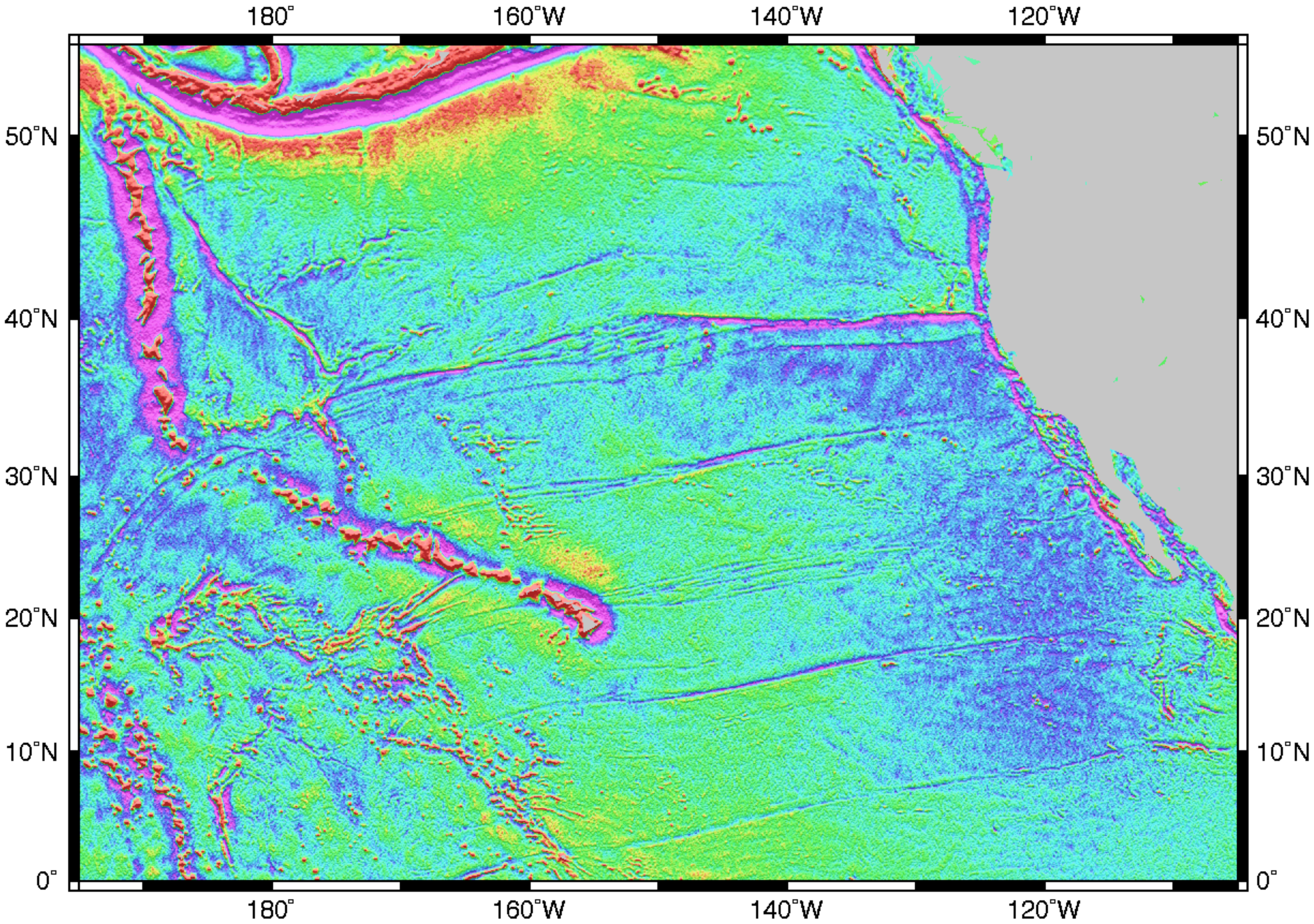




Bill Haxby’s 1985 gravity map based on Seasat

Measure distance from satellite to sea sea surface to a few cm’s.

Water piles up over seamounts and ridges, is lower over trenches

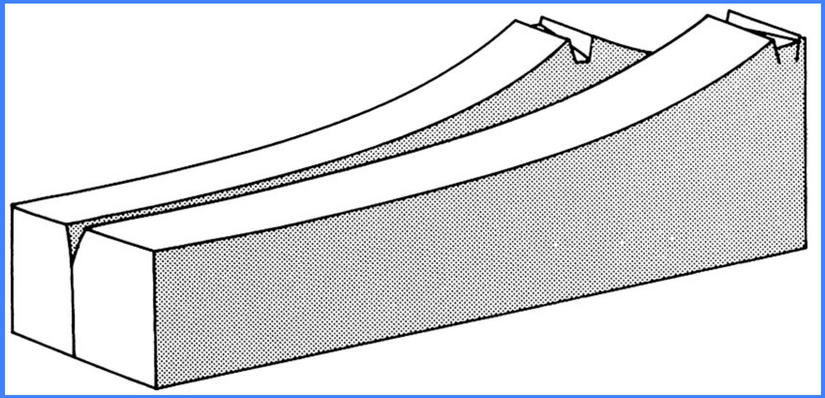

180°
160°W
140°W
120°W
50°N
40°N
30°N
20°N
10°N
0°

Explore our planet with GeoMapApp

GeoMapApp is an earth science exploration and visualization application that is continually being expanded as part of the Marine Geoscience Data System (MGDS) at the Lamont-Doherty Earth Observatory of **Columbia University**. The application provides direct access to the Global Multi-Resolution Topography (GMRT) compilation that hosts high resolution (~100 m node spacing) bathymetry from multibeam data for ocean areas … and NED (National Elevation Dataset) topography datasets for the global land masses.

GeoMapApp.org
(also, try Google Earth)

Transform faults

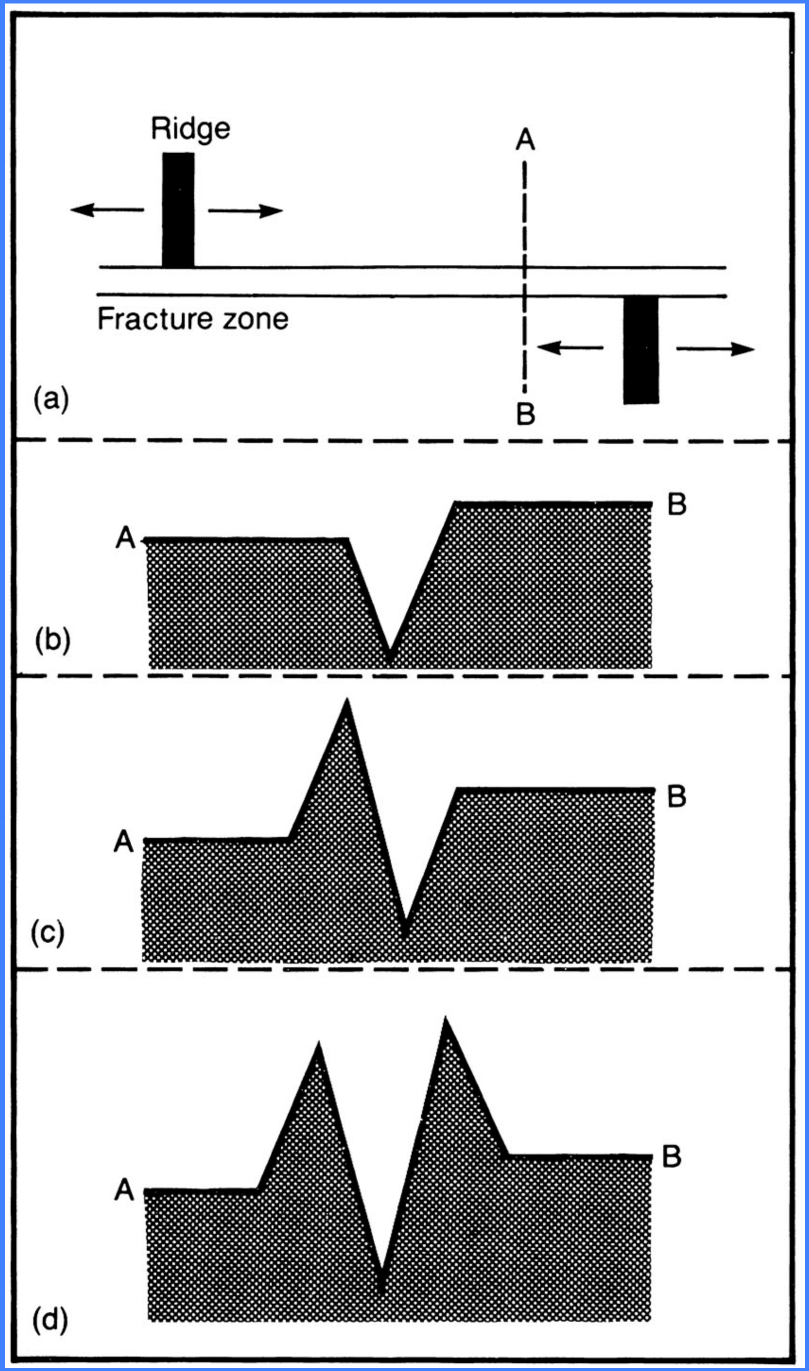


Crust on both sides is subsiding as √ t

Ridge axis is across from cold lithosphere

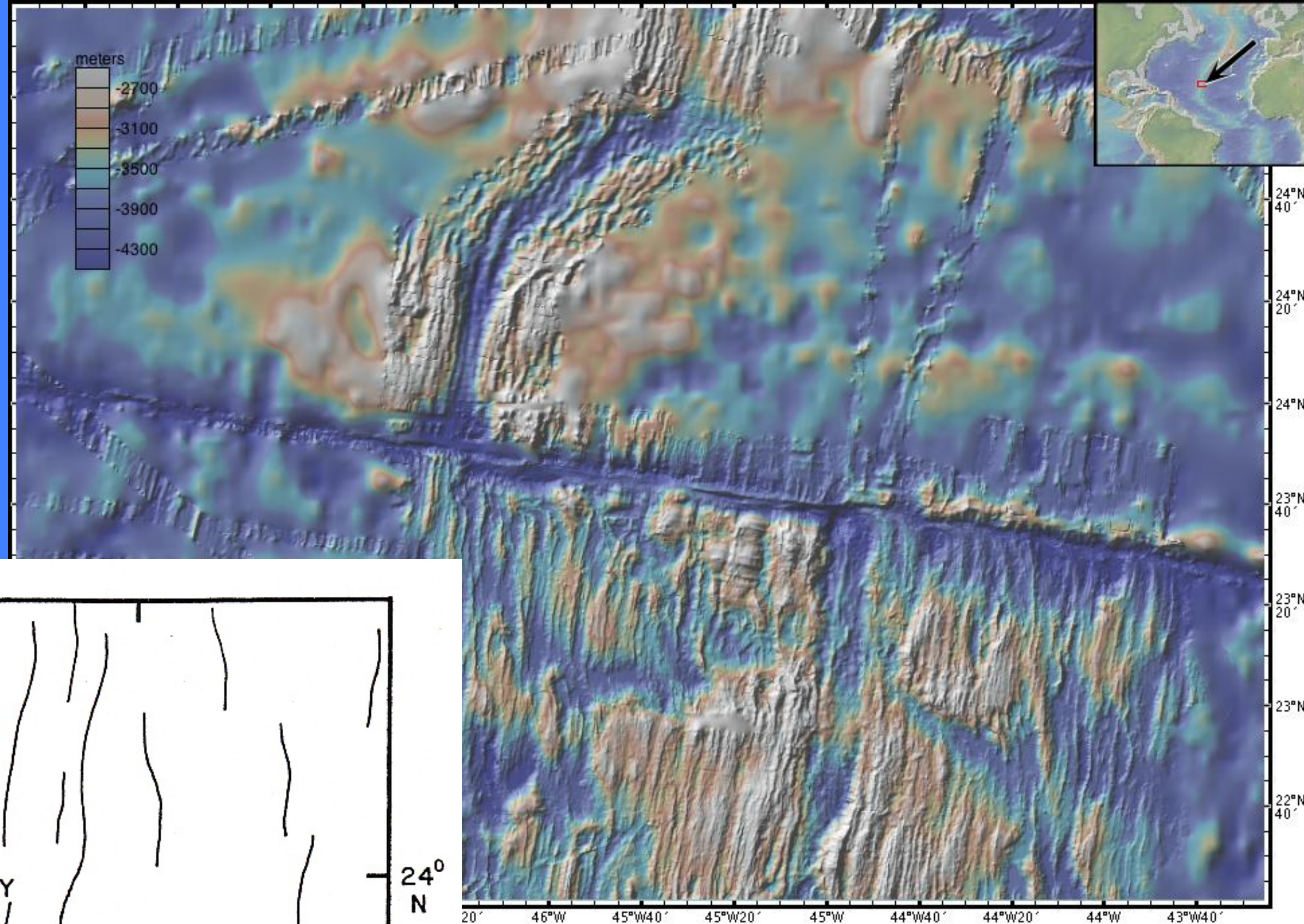
The greater the offset in millions of years, the colder the crust

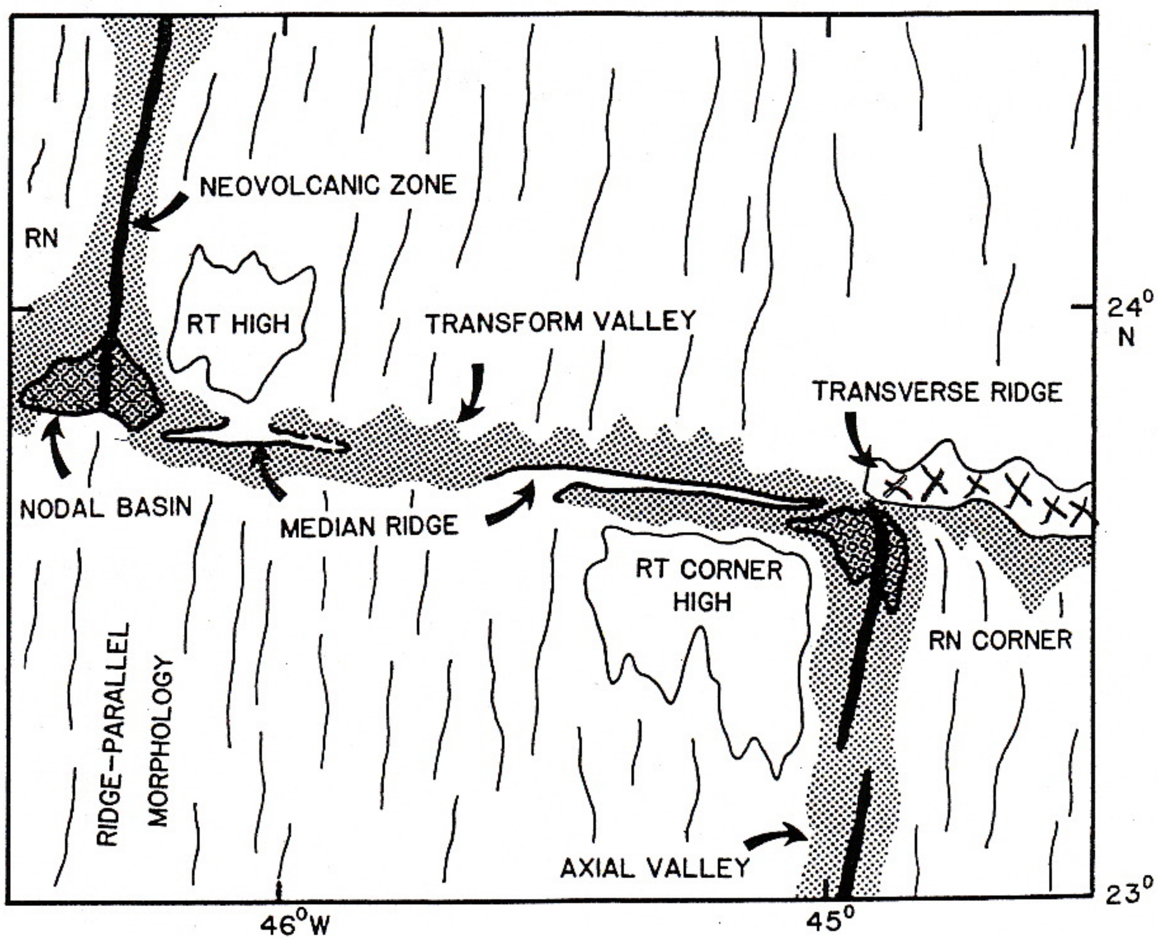
Result: “transform edge effects”



Kane FZ (Central Atlantic)
Slow spreading, large offset = large “transform edge effects”

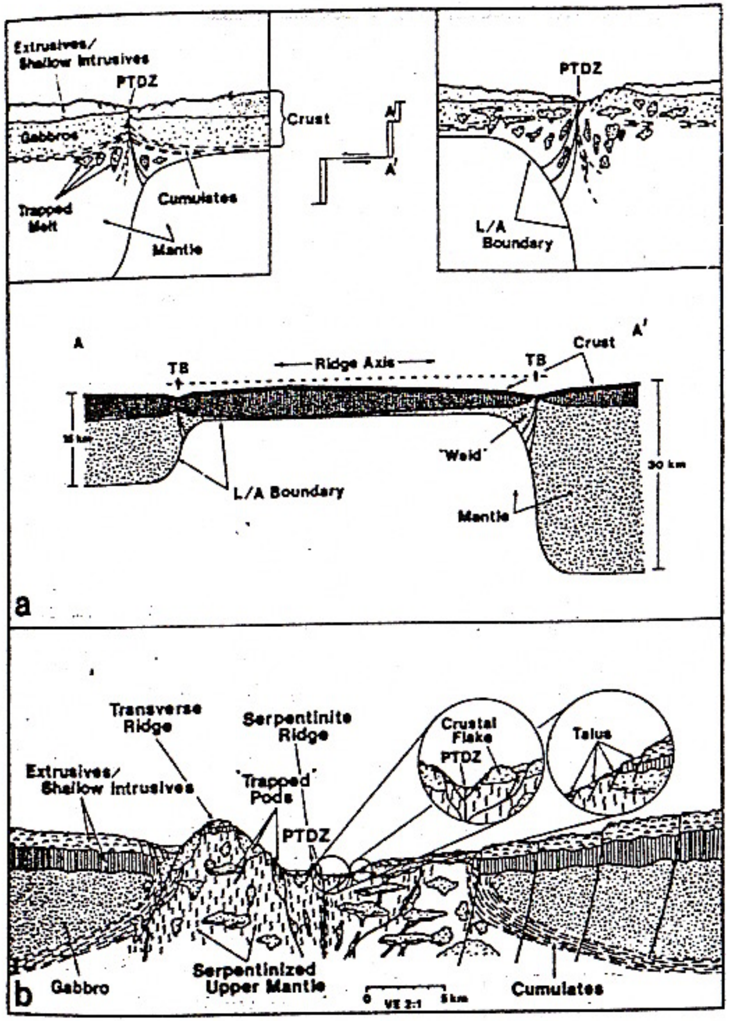
Classic examples of median and transverse ridges and nodal basins





RT = ridge-transform
RN = ridge non-transform
RT Corner High = ICH
RN Corner = OC
RTI = ridge transform intersection

Tucholke and Schouten (1988)

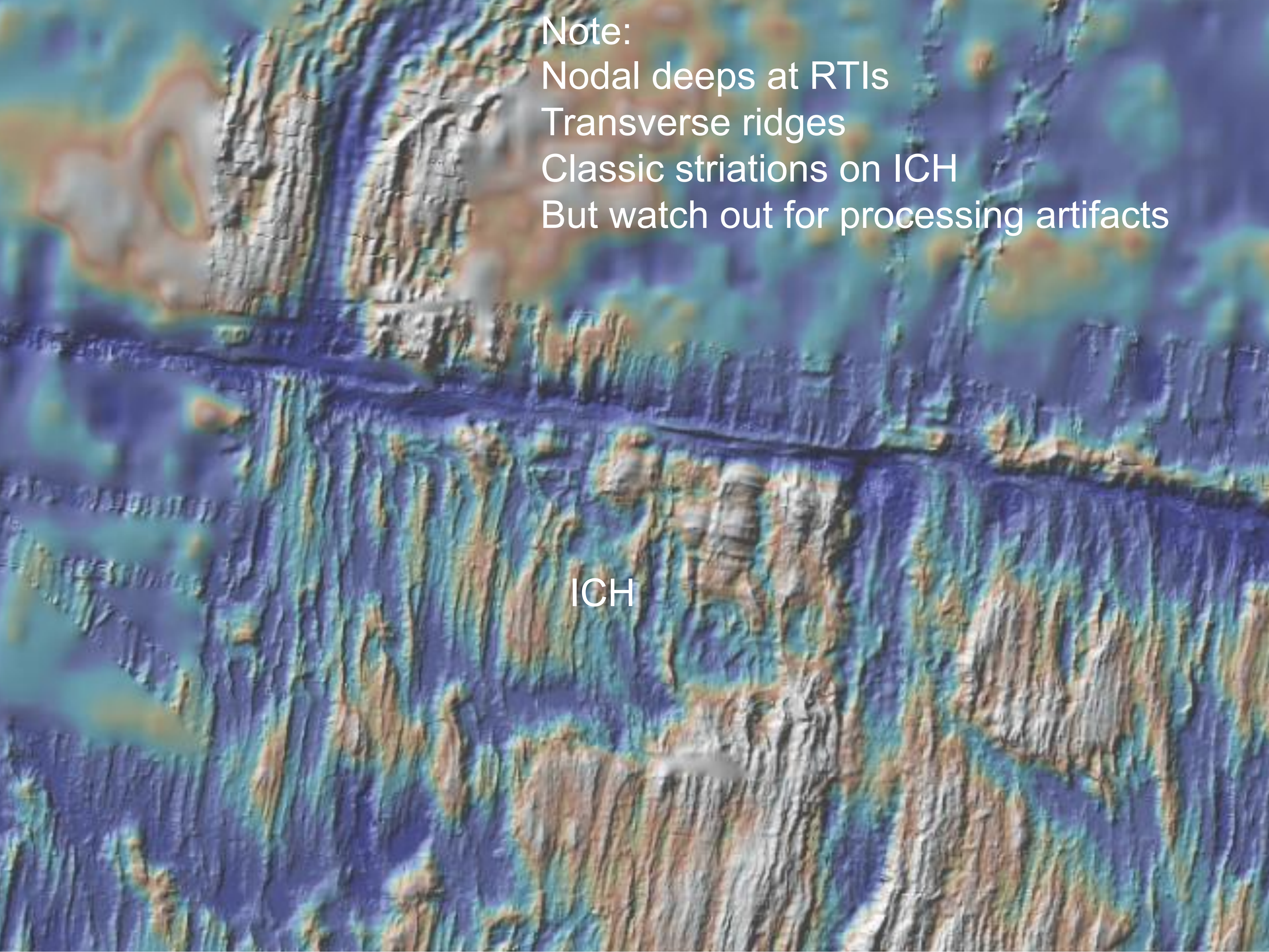


"Transform Edge Effect"

- The transform boundary places cold lithosphere against the spreading axis; the greater the age offset, the colder the lithosphere
- This cold boundary perturbs mantle upwelling – resulting in smaller amounts of melt for distances up to 10 km
- Consequently, there is a dramatic thinning of crust and the upper mantle is more heterogeneous
- Because crust is thinner and more fractured, seawater migrates down and hydrates ultramafics creating serpentinized ridges
- The greater the age offset, the greater the thinning of the crust

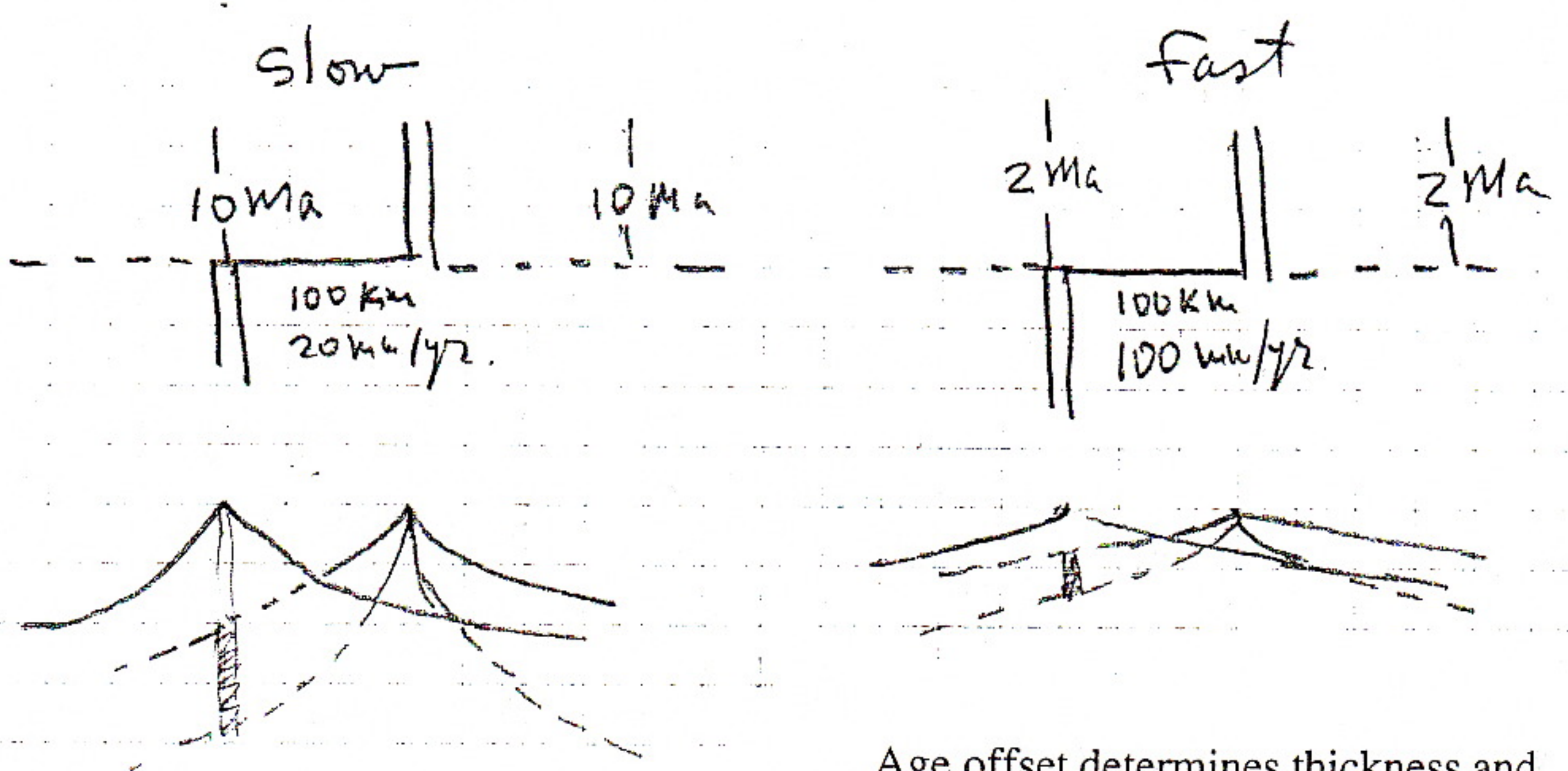
PTDZ = principal transform deformation zone

Fox and Gallo (1984)


Note:
Nodal deeps at RTIs
Transverse ridges
Classic striations on ICH
But watch out for processing artifacts
ICH

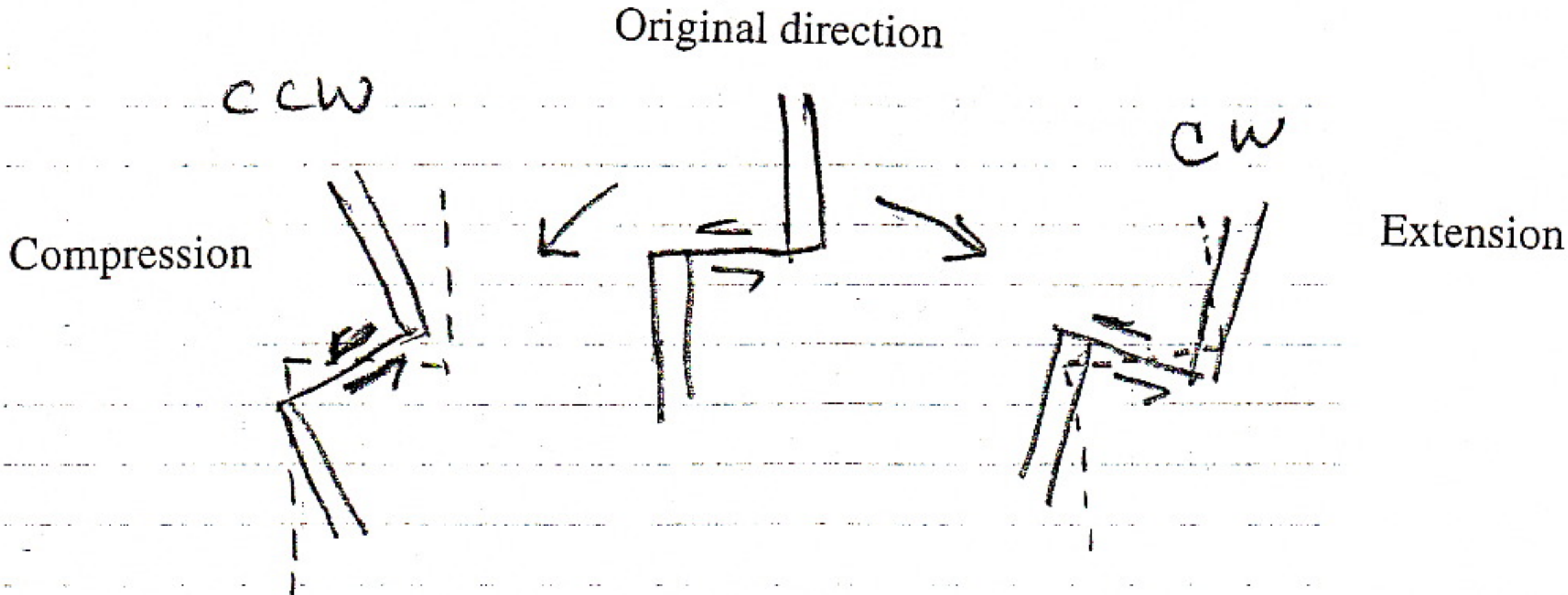
Factors controlling transform fault structures

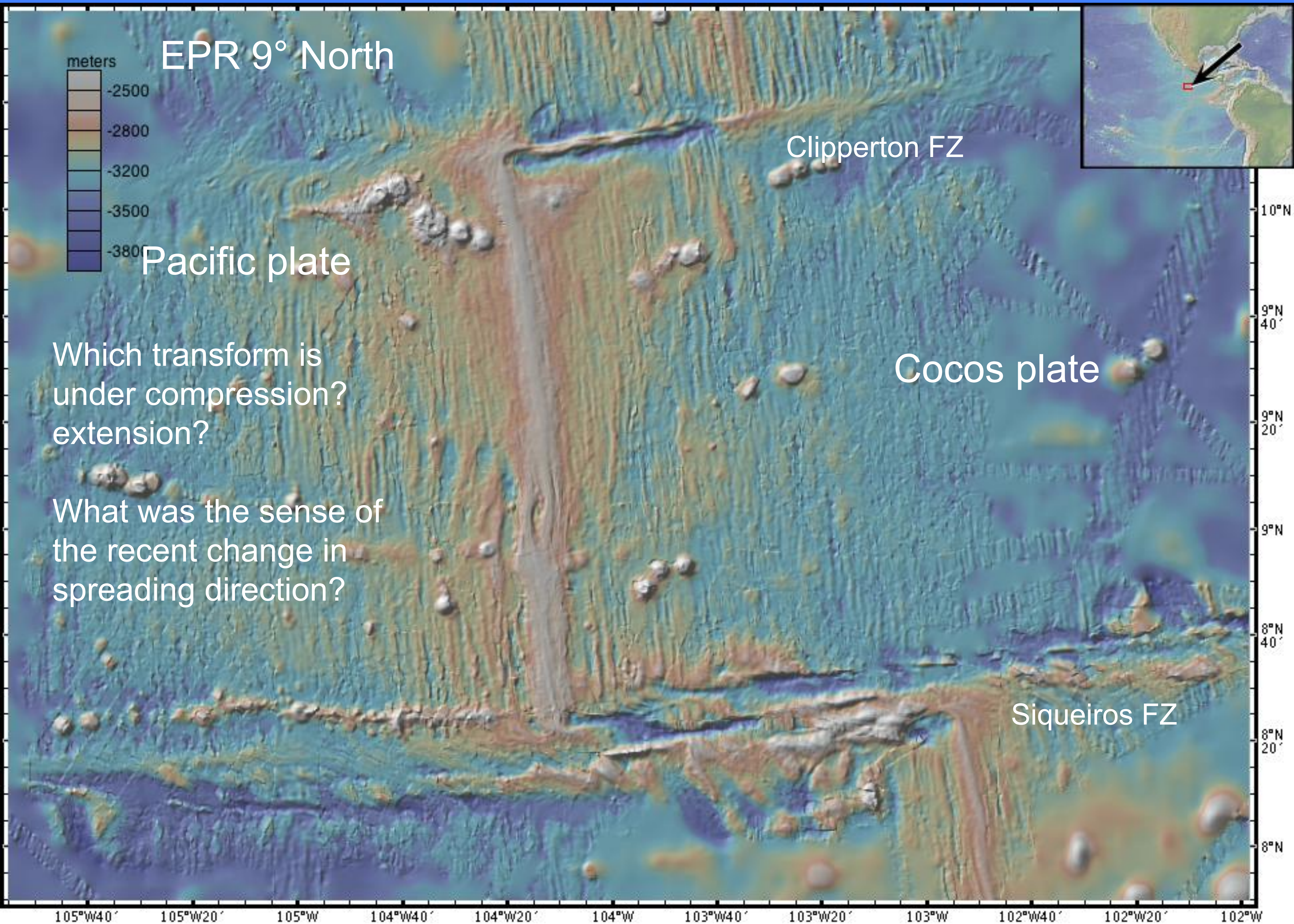
1) Age offset – function of <u>length</u> and <u>spreading rate</u>



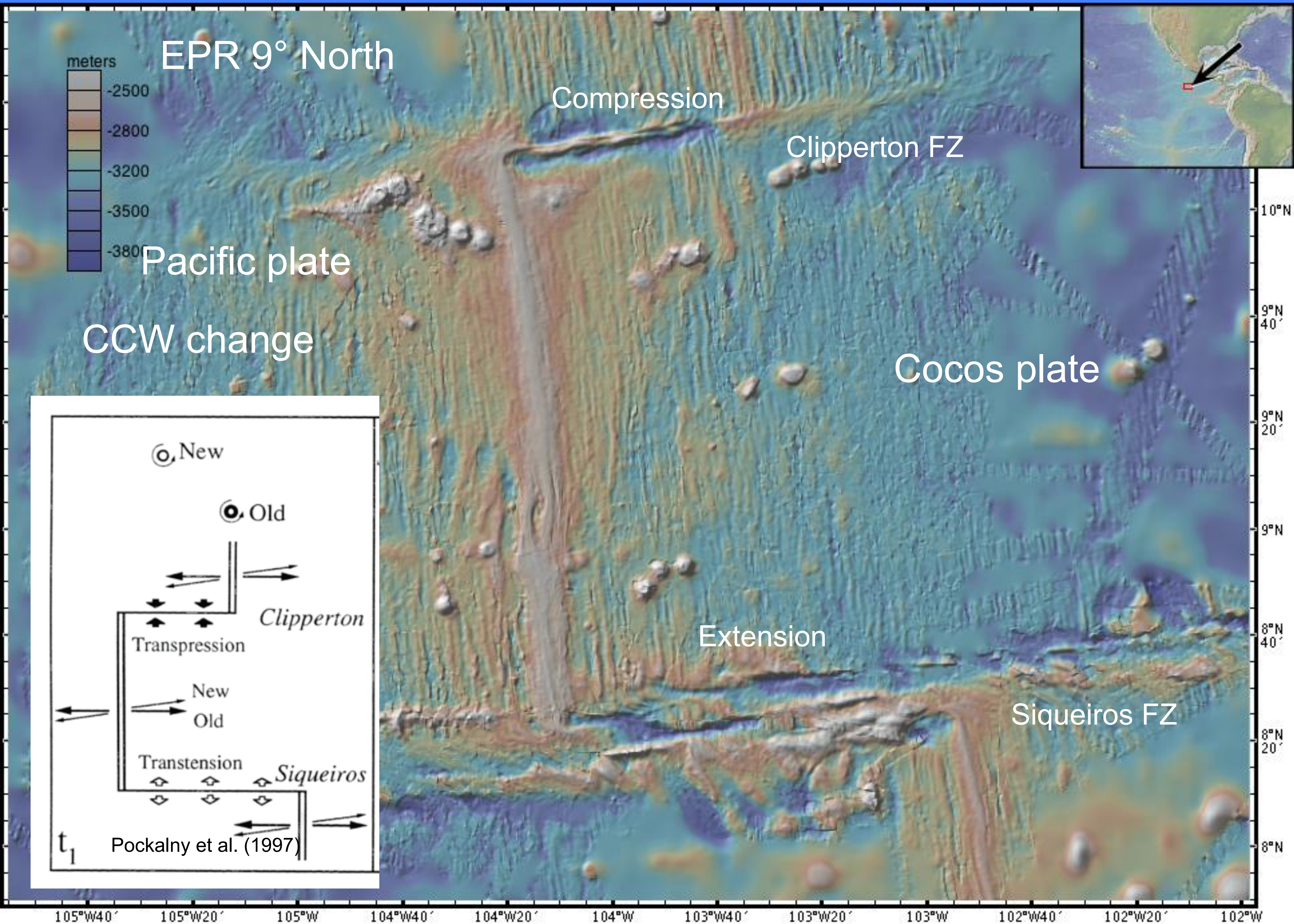
Age offset determines thickness and coldness of lithosphere across from spreading axis

2) History of extensional and compressional changes in spreading direction

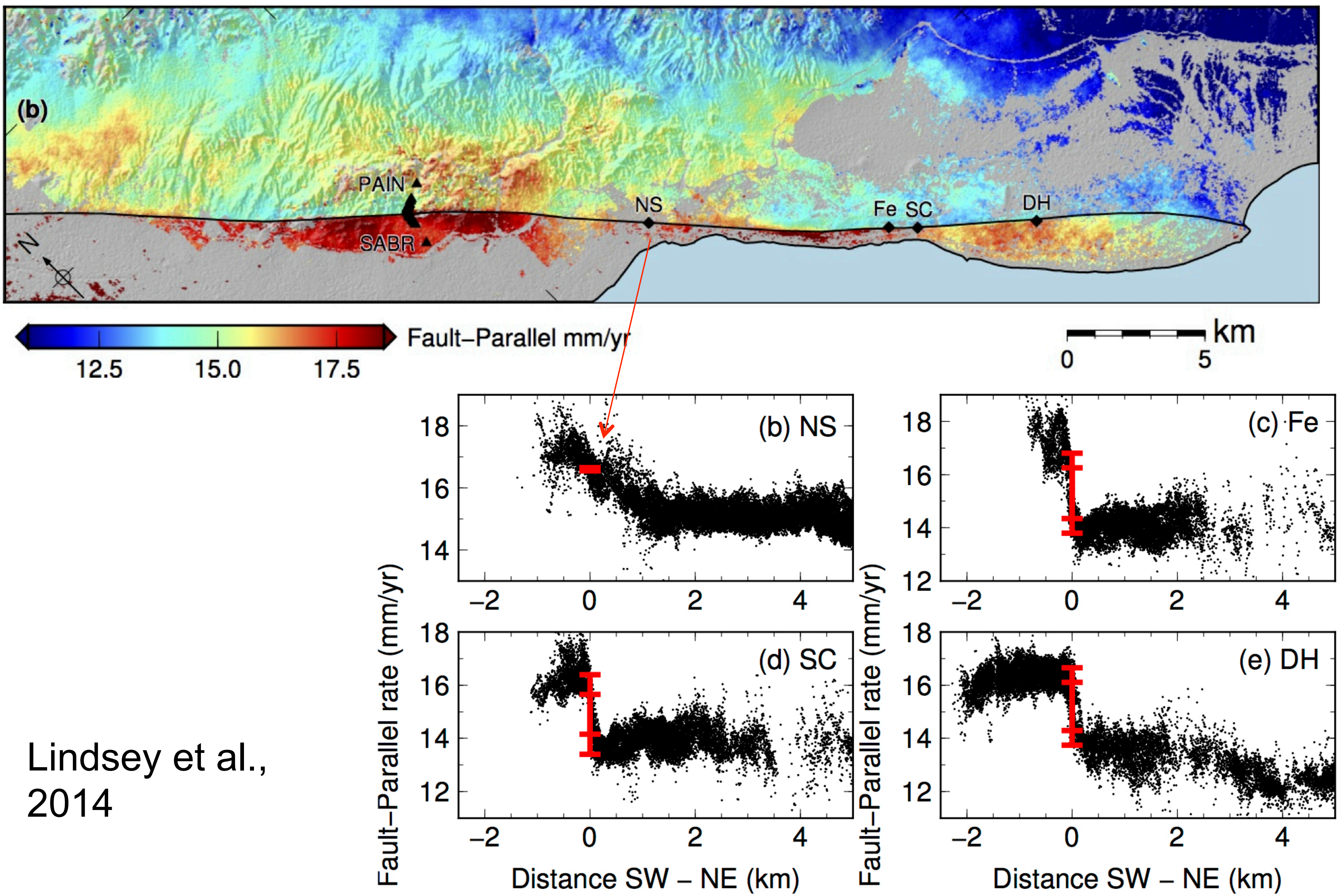




EPR 9° North
meters
-2500
-2800
-3200
-3500
-380
Pacific plate
Which transform is under compression? extension?
What was the sense of the recent change in spreading direction?
Clipperton FZ
Cocos plate
Siqueiros FZ
10°N
9°N 40′
9°N 20′
9°N
8°N 40′
8°N 20′
8°N
105°W40′
105°W20′
105°W
104°W40′
104°W20′
104°W
103°W40′
103°W20′
103°W
102°W40′
102°W20′
102°W

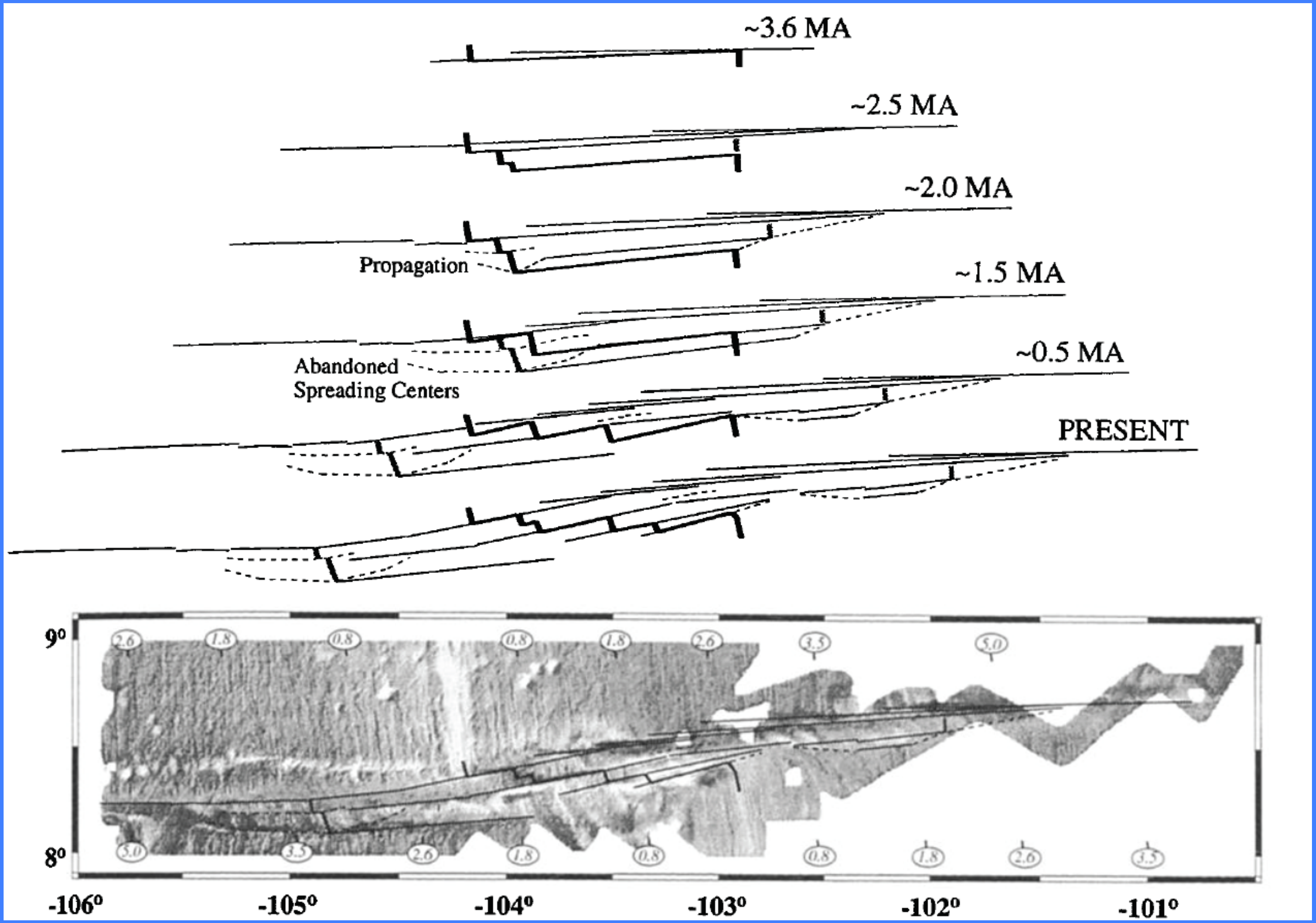

EPR 9° North
meters
-2500
-2800
-3200
-3500
-3800
Compression
Clipperton FZ
Pacific plate
CCW change
Cocos plate
Extension
Siqueiros FZ
New
Old
Clipperton
Transpression
New
Old
Transtension
Siqueiros
t_1
Pockalny et al. (1997)
10°N
9°N 40´
9°N 20´
9°N
8°N 40´
8°N 20´
8°N
105°W40´
105°W20´
105°W
104°W40´
104°W20´
104°W
103°W40´
103°W20´
103°W
102°W40´
102°W20´
102°W

Southern San Andreas: localized surface creep in transpression, and distributed shear in transtension



Lindsey et al., 2014

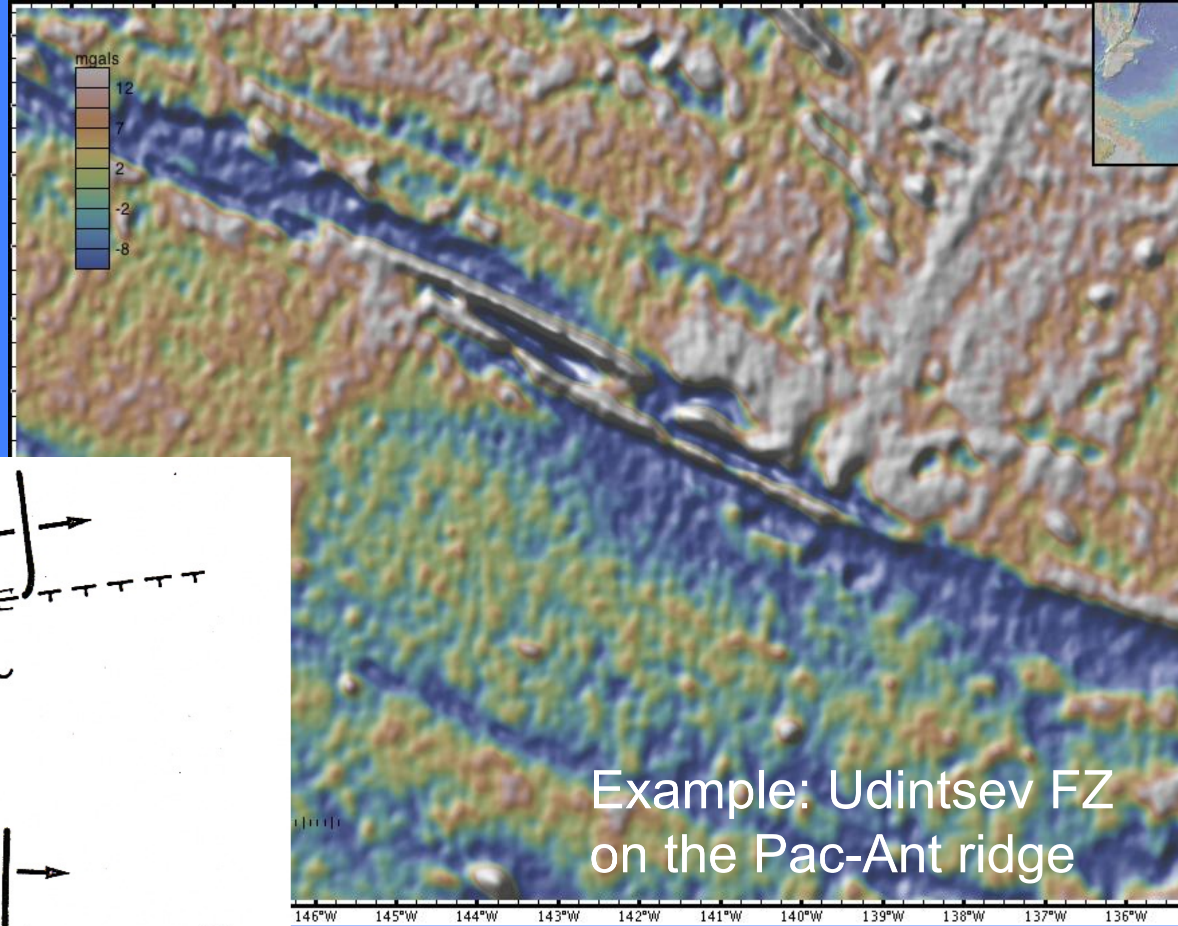
Sequeiros transform fault



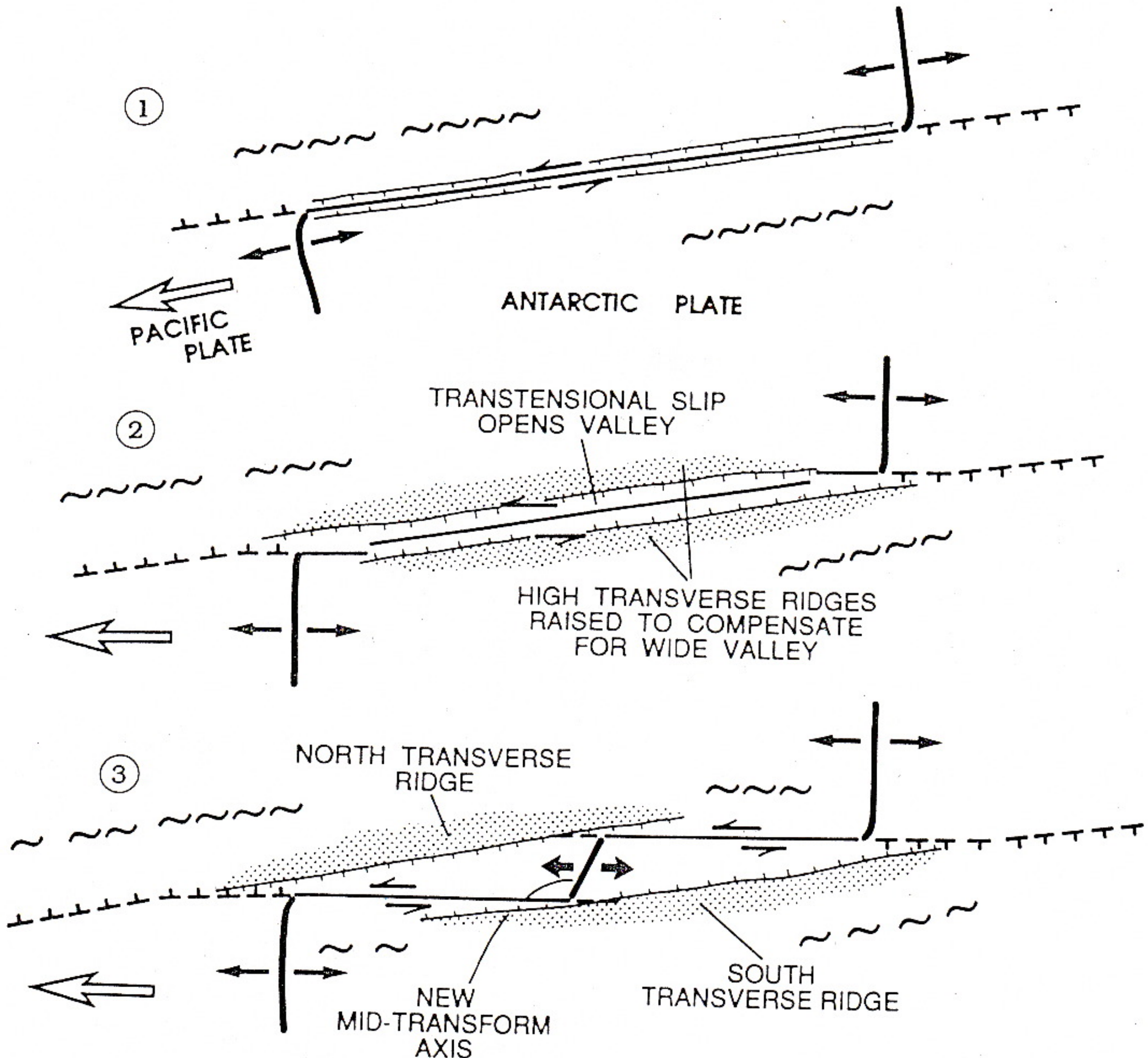
When under extension, a long transform fault develops multiple small offsets with short ridge segments

Pockalny et al. (1997)

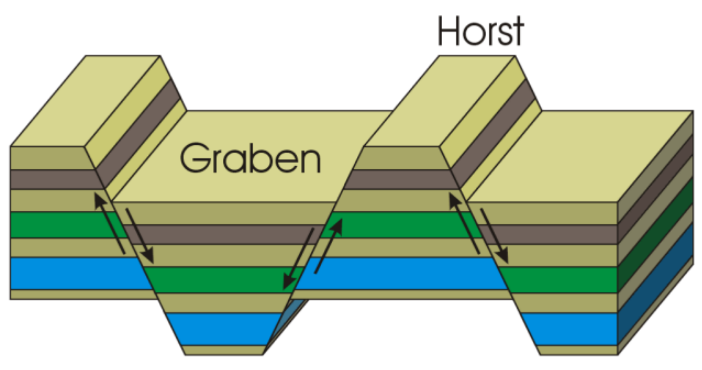
Transverse ridges parallel to the transform fault can also be caused by isostatic uplift in response to extension caused by changes in spreading direction



Example: Udintsev FZ on the Pac-Ant ridge

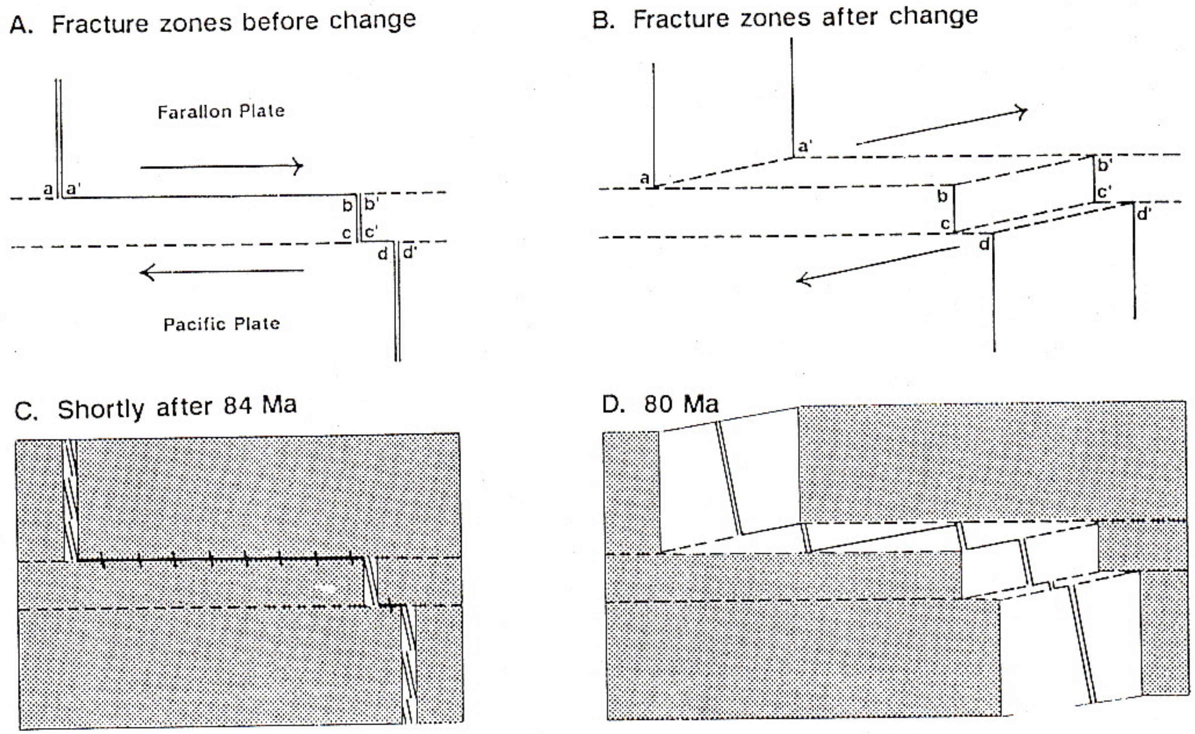


(Lonsdale, 1991)



Requires a moderate dip on the faults (not 90°)

When long offset transform faults undergo major extension they tend to develop multiple splays, often with a staircase of short ridge segments

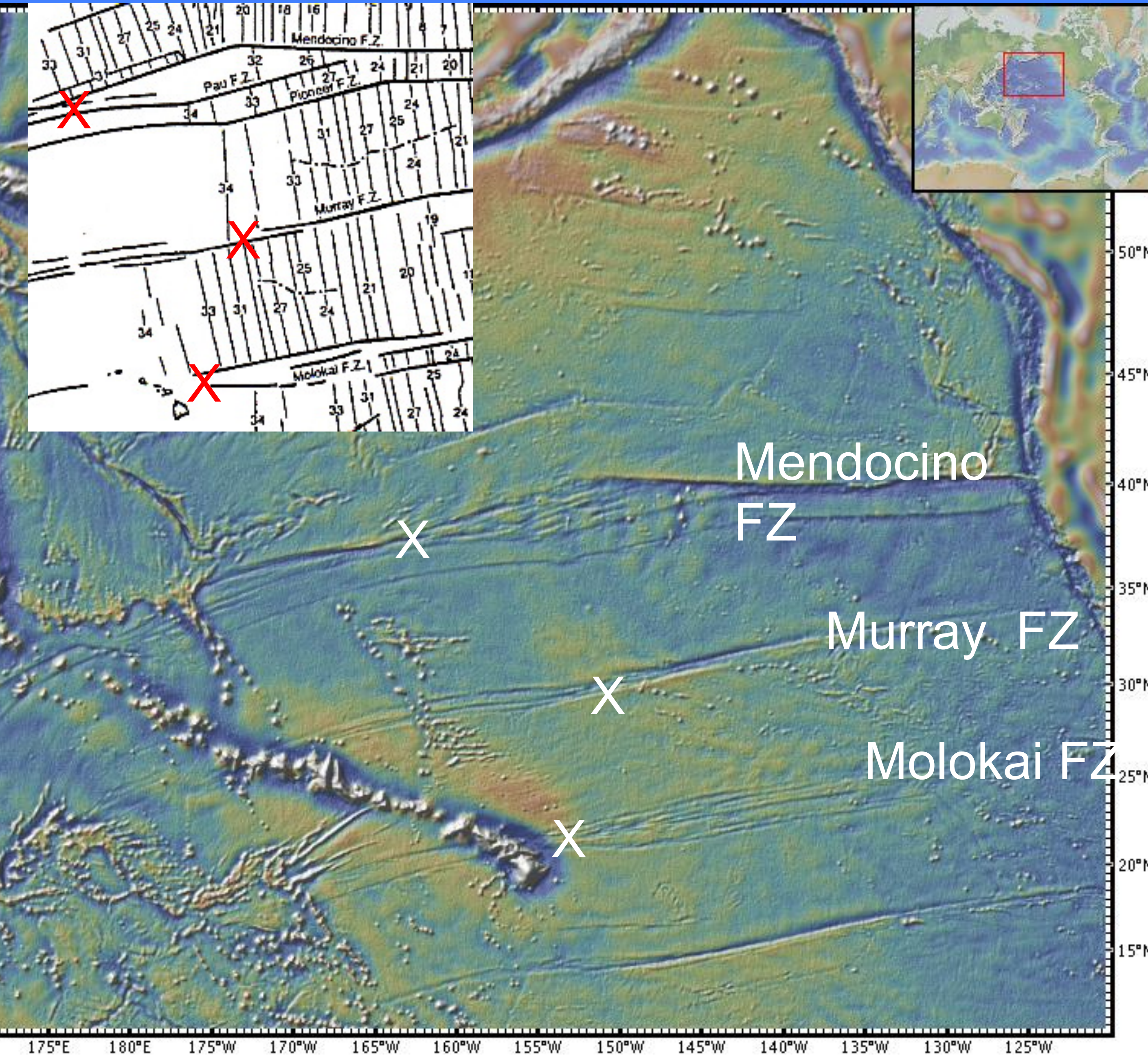


Searle et al. (1993)

Classic examples:

a) Northeast Pacific

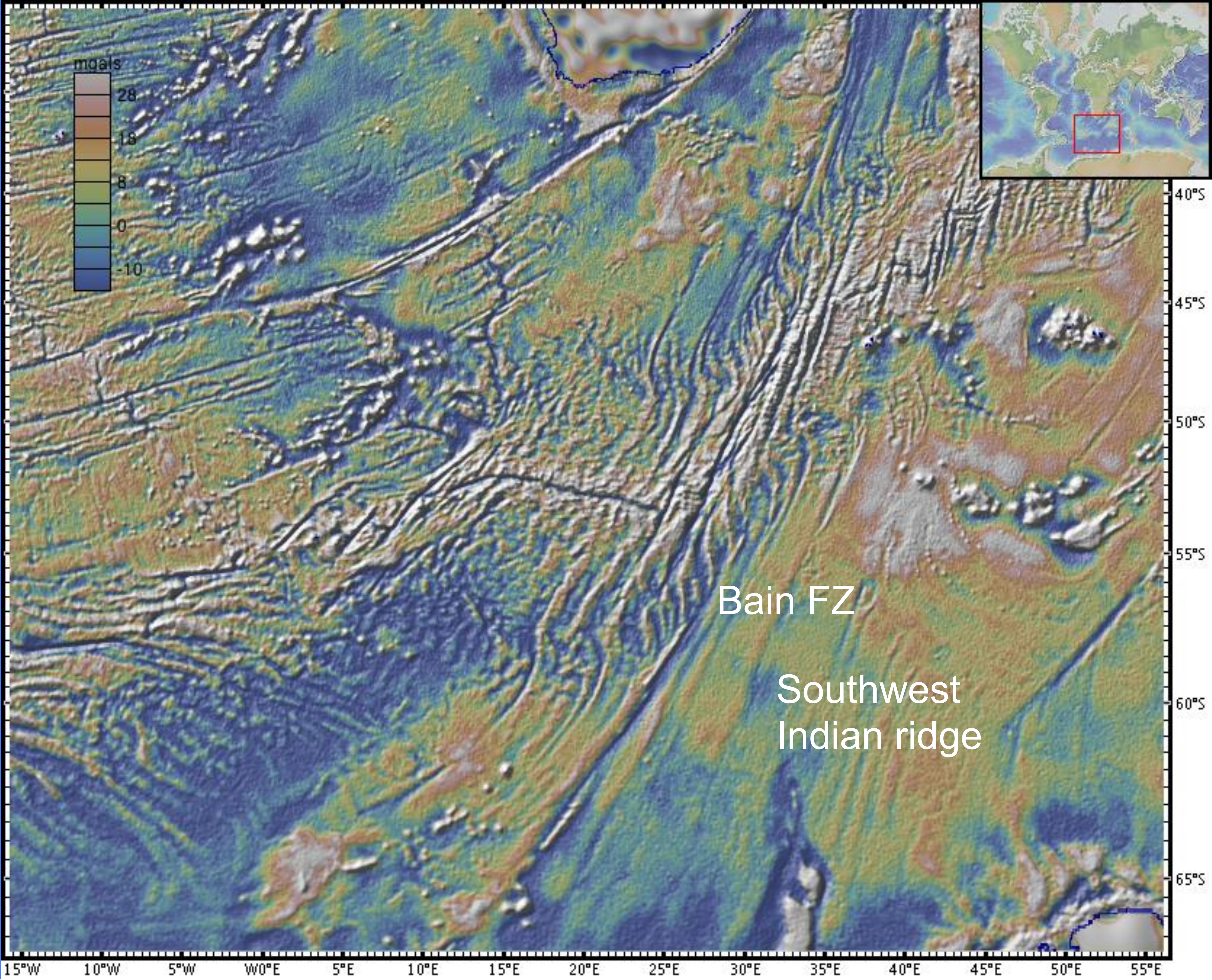
b) Southwest Indian Ridge



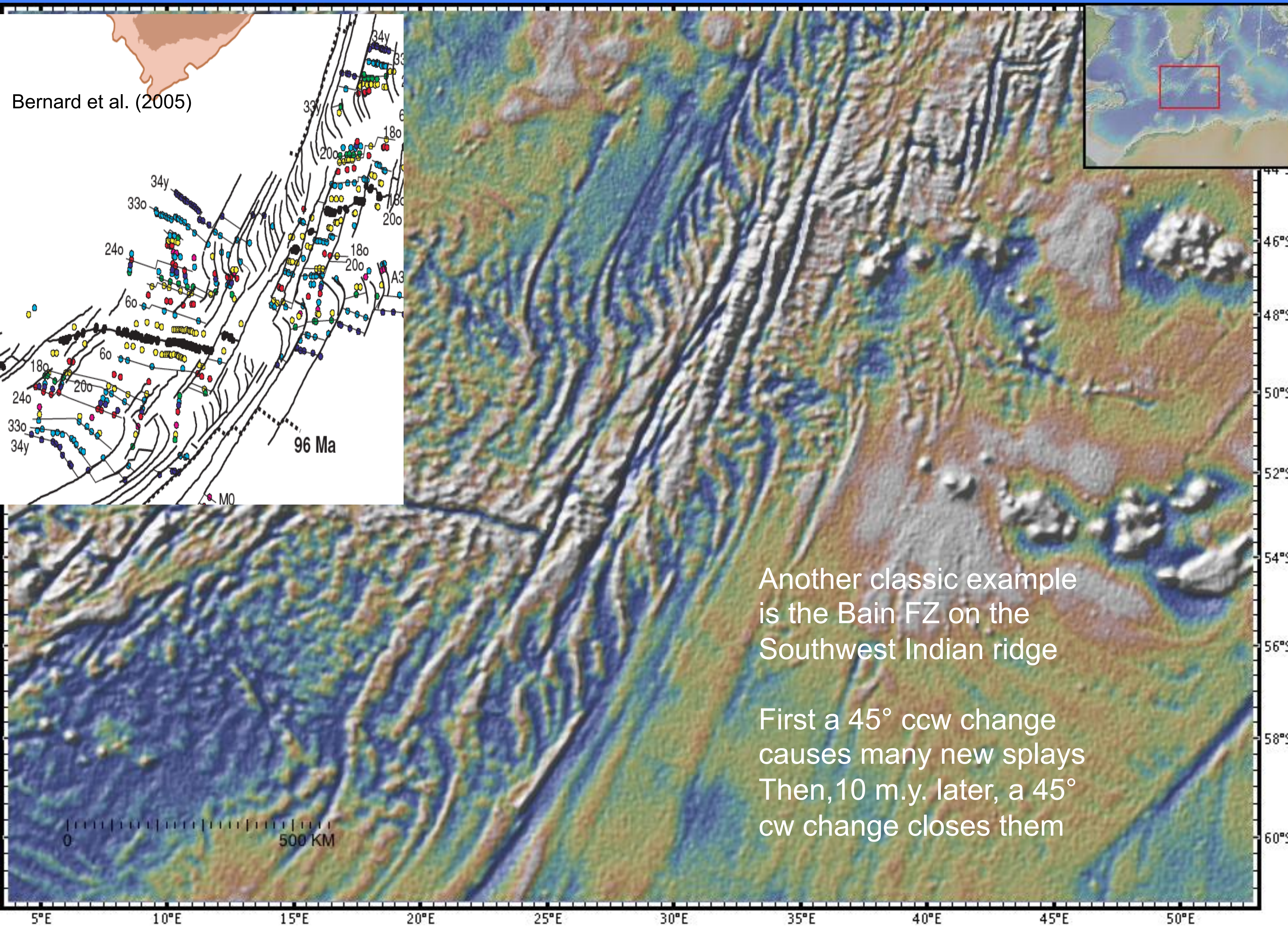
Effect of changes in spreading direction

With a counterclockwise change in spreading direction (X) the left-stepping Mendocino and Molokai FZs go into extension (and develop multiple splays) while the right stepping Murray FZ goes into compression (and loses splays) ..

and vice versa.



mgals
28
18
8
0
-10
40°S
45°S
50°S
55°S
60°S
65°S
15°W
10°W
5°W
W0°E
5°E
10°E
15°E
20°E
25°E
30°E
35°E
40°E
45°E
50°E
55°E
Bain FZ
Southwest
Indian ridge

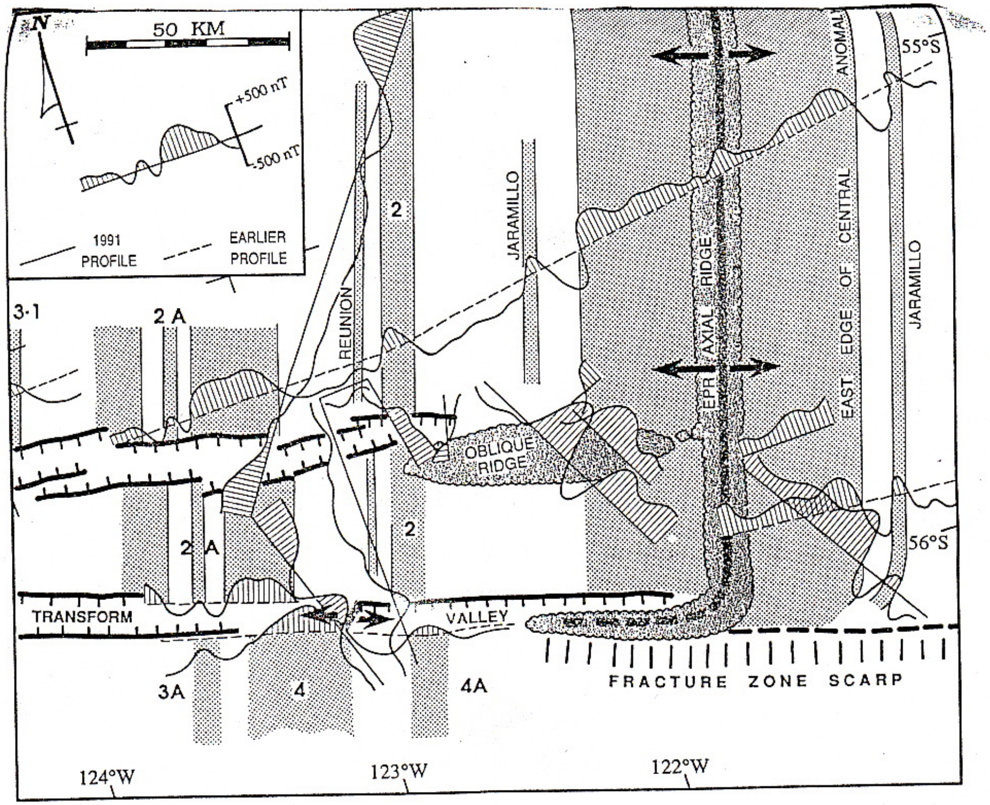


Bernard et al. (2005)

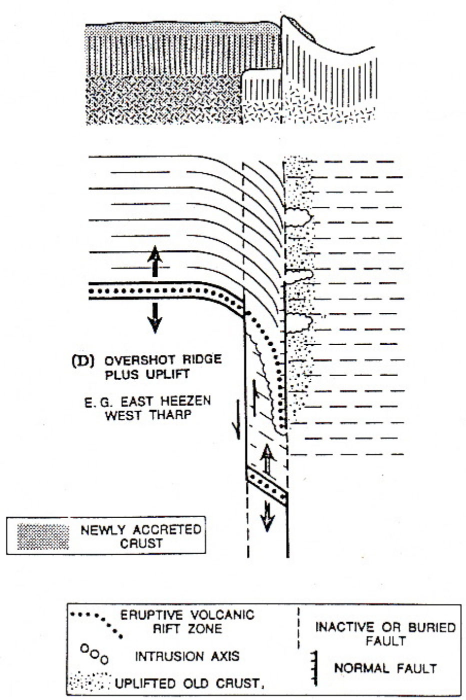
Another classic example is the Bain FZ on the Southwest Indian ridge

First a 45° ccw change causes many new splays Then, 10 m.y. later, a 45° cw change closes them

Features at the ridge-transform intersection (RTI)



Lonsdale (1994)



"Over-shot ridges"

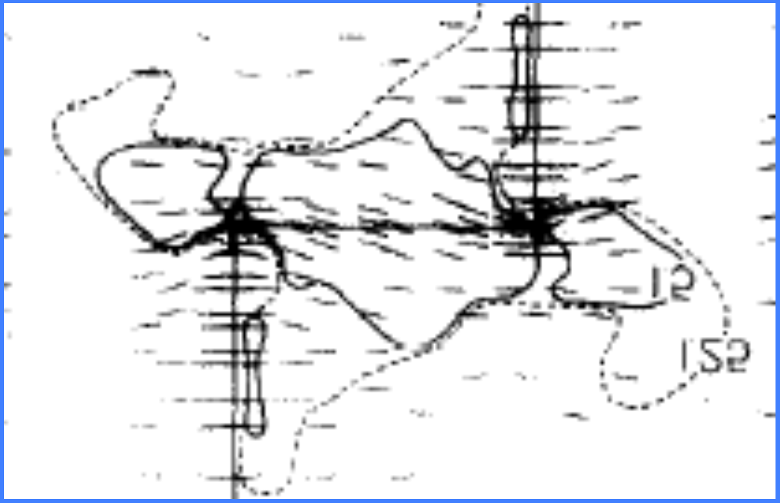
- complex stress field near RTI encourages magma to leak out onto old plate across fracture zone
- medium to fast spreading ridges

Also know as "J structures"

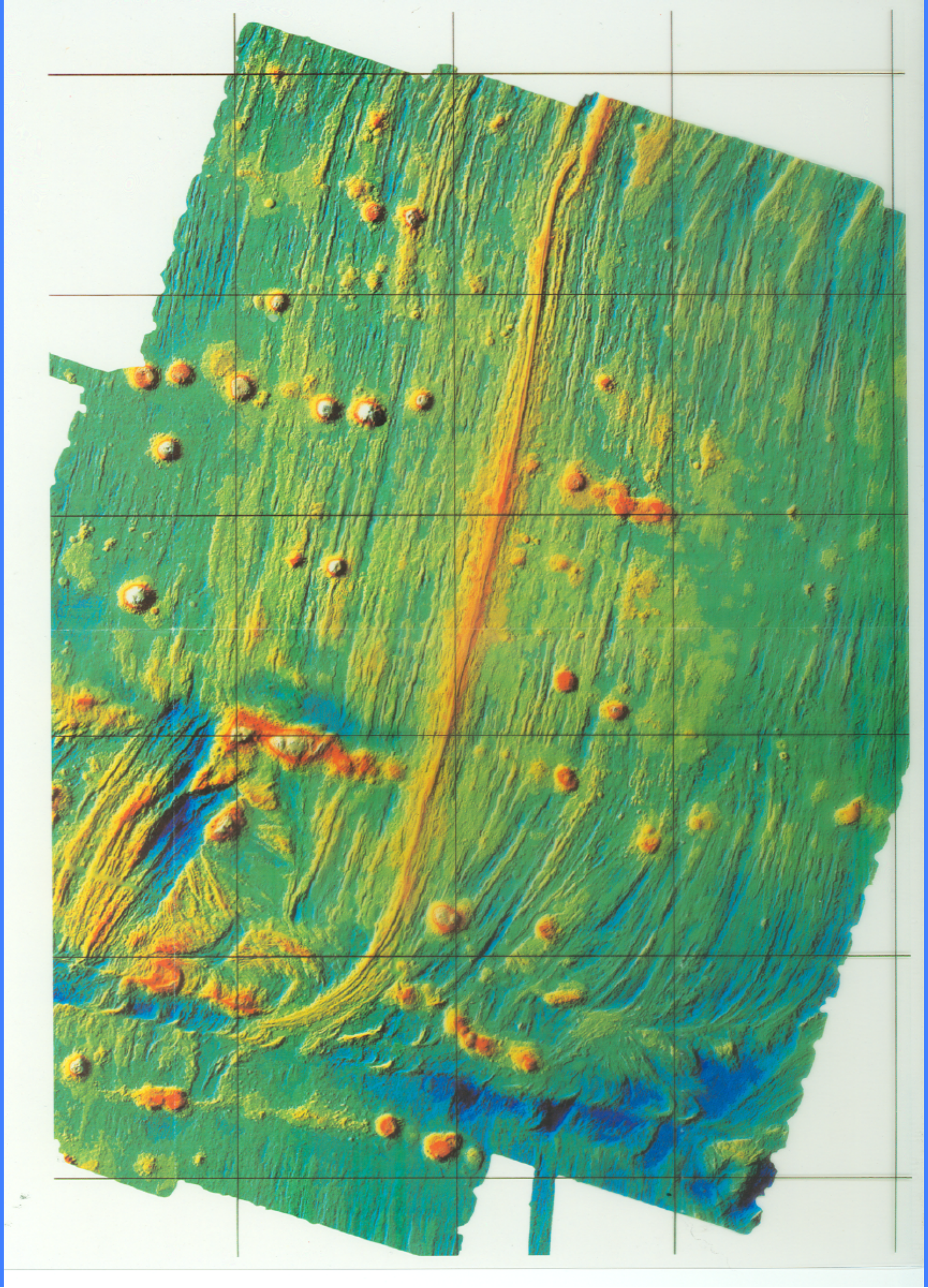
Right: bathymetry data from the EPR

Bottom: Model of the stress field near RTIs

Arrows show direction of maximum tensile stress

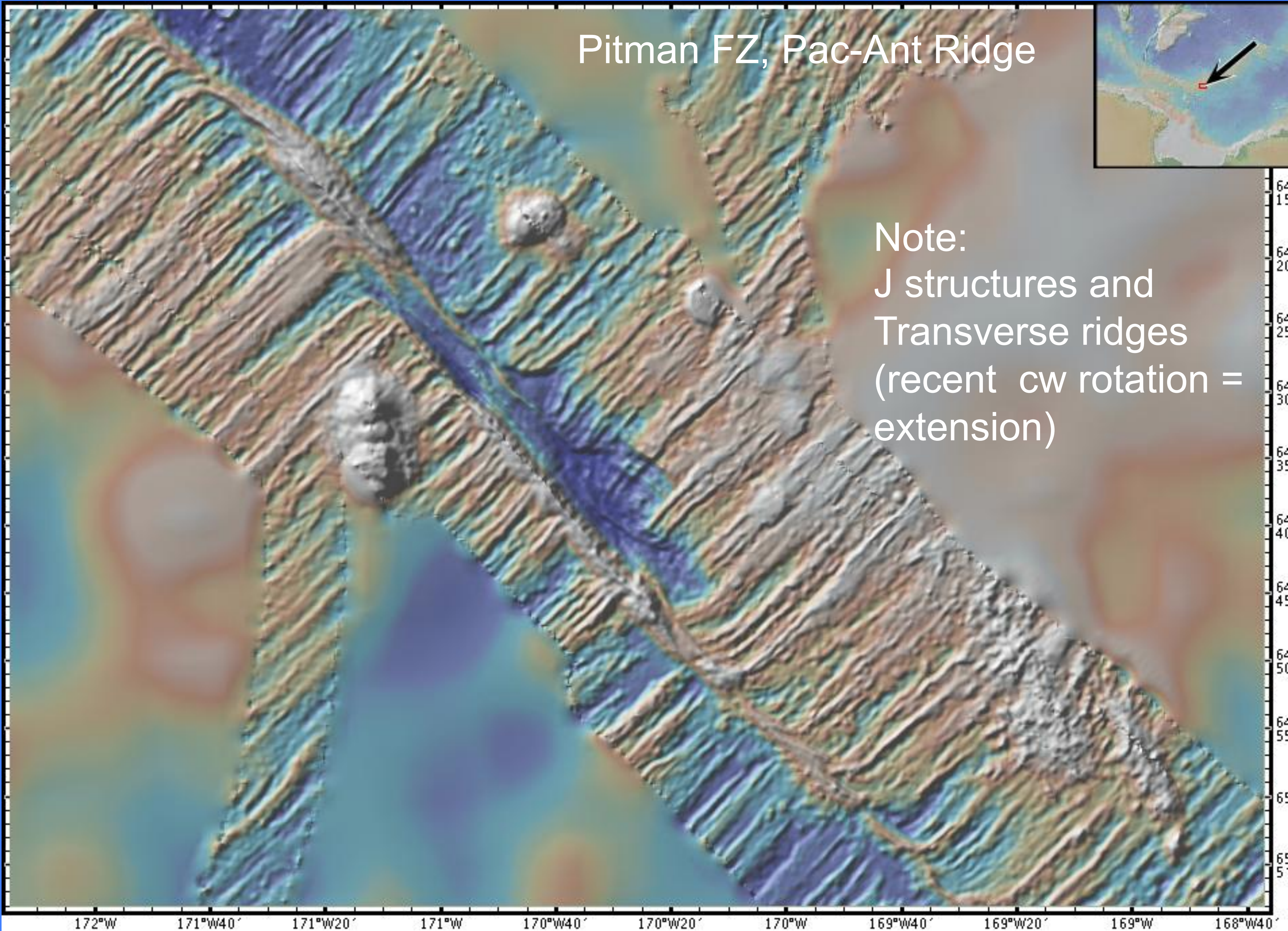


(Fujita and Sleep,1978)

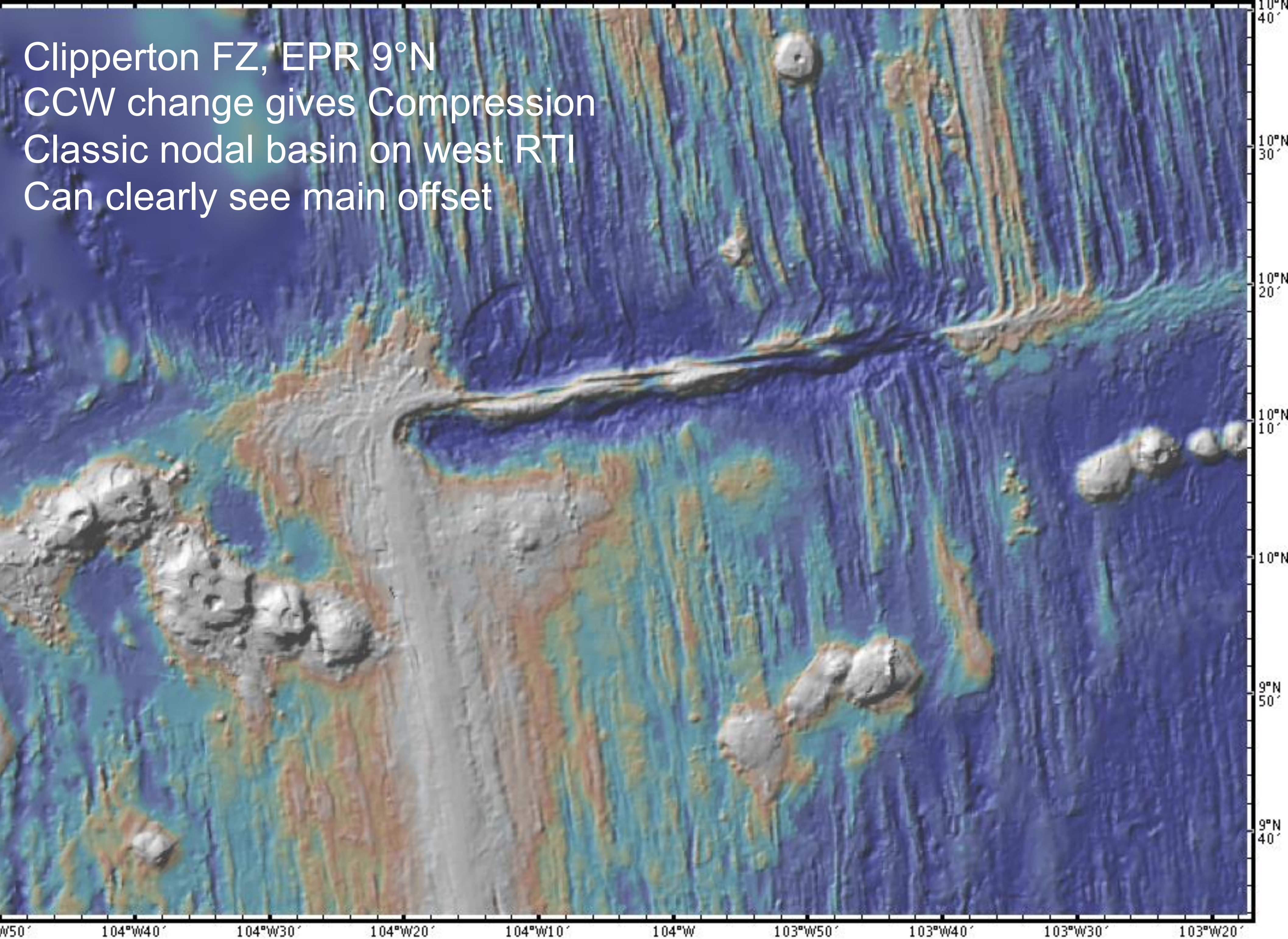


Pitman FZ, Pac-Ant Ridge

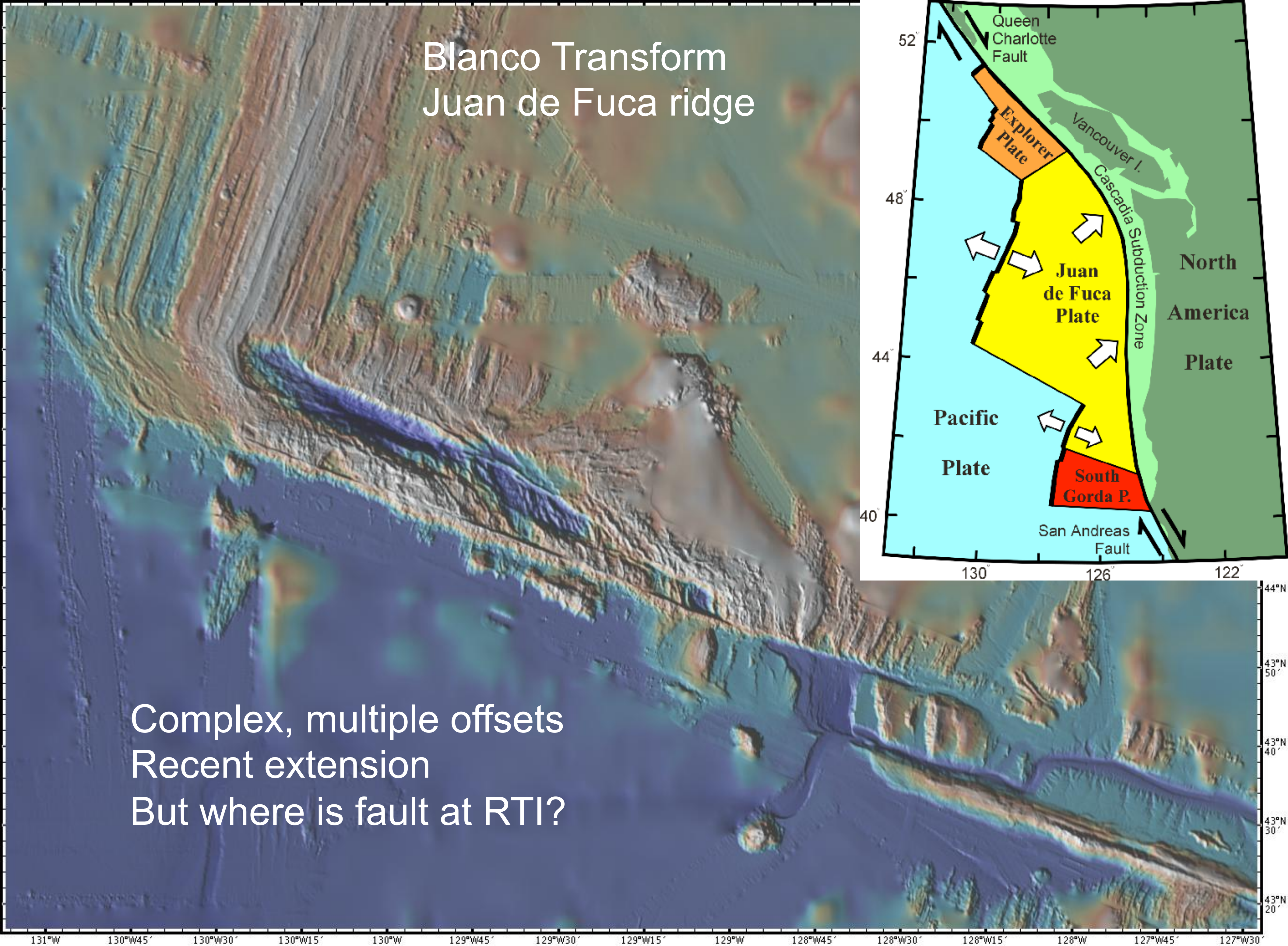
Note:
J structures and Transverse ridges (recent cw rotation = extension)



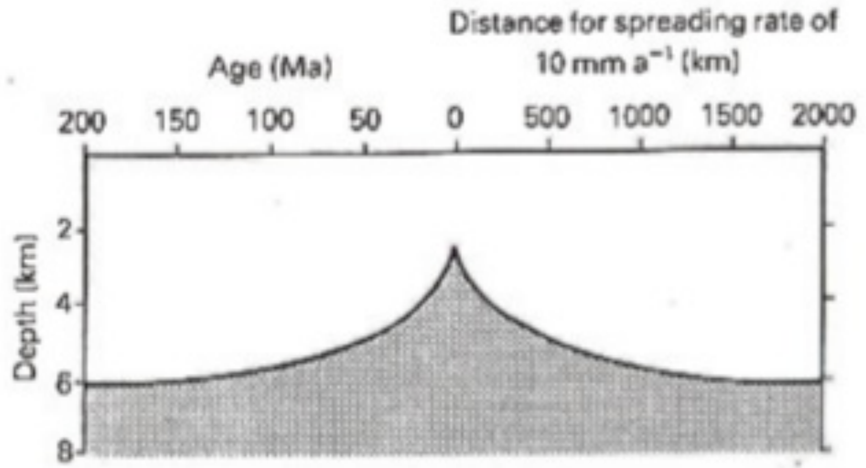
Clipperton FZ, EPR 9°N
CCW change gives Compression
Classic nodal basin on west RTI
Can clearly see main offset



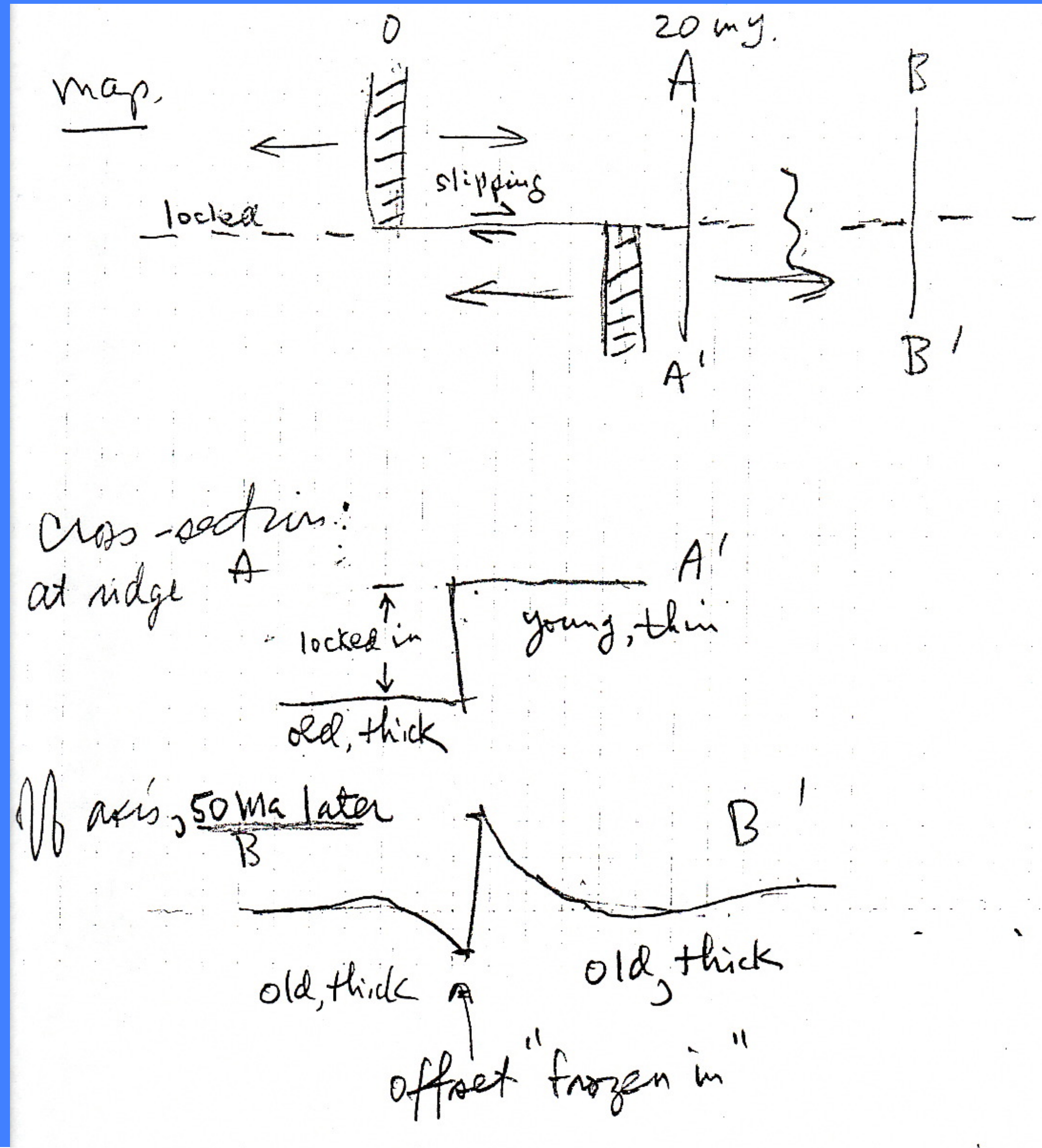
Blanco Transform
Juan de Fuca ridge



Complex, multiple offsets
Recent extension
But where is fault at RTI?



Another location where flexure plays an important role: oceanic fracture zones

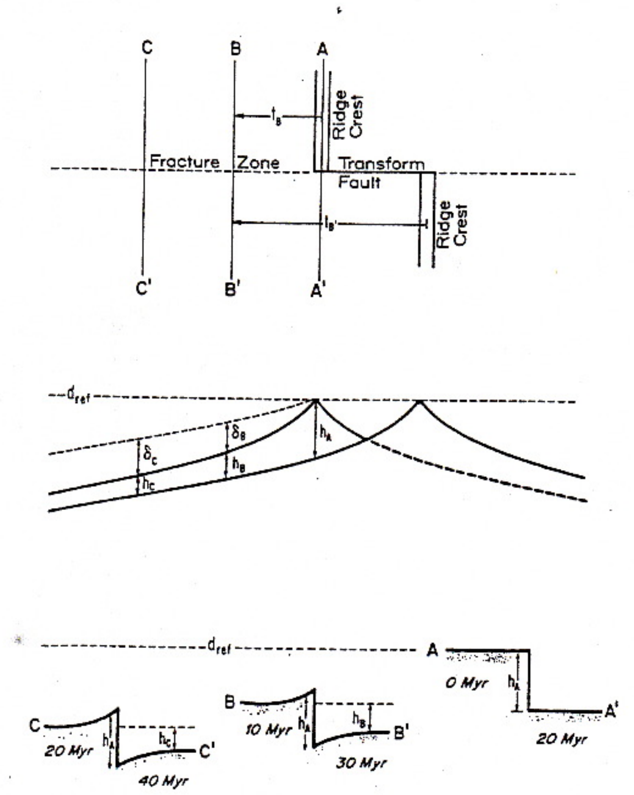


Young oceanic crust is shallower than older oceanic crust; topographic step is frozen in at the ridge axis.

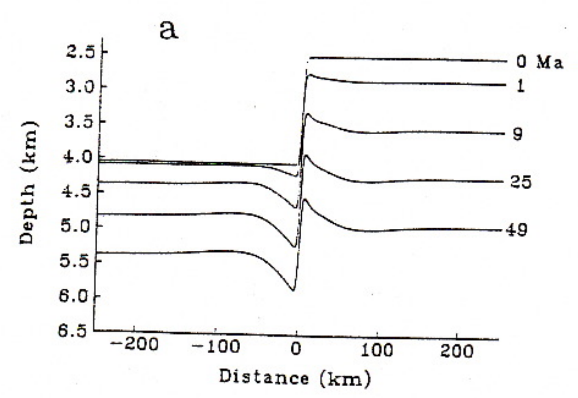
Young oceanic crust subsides faster and difference in depth across fracture zone gradually decreases

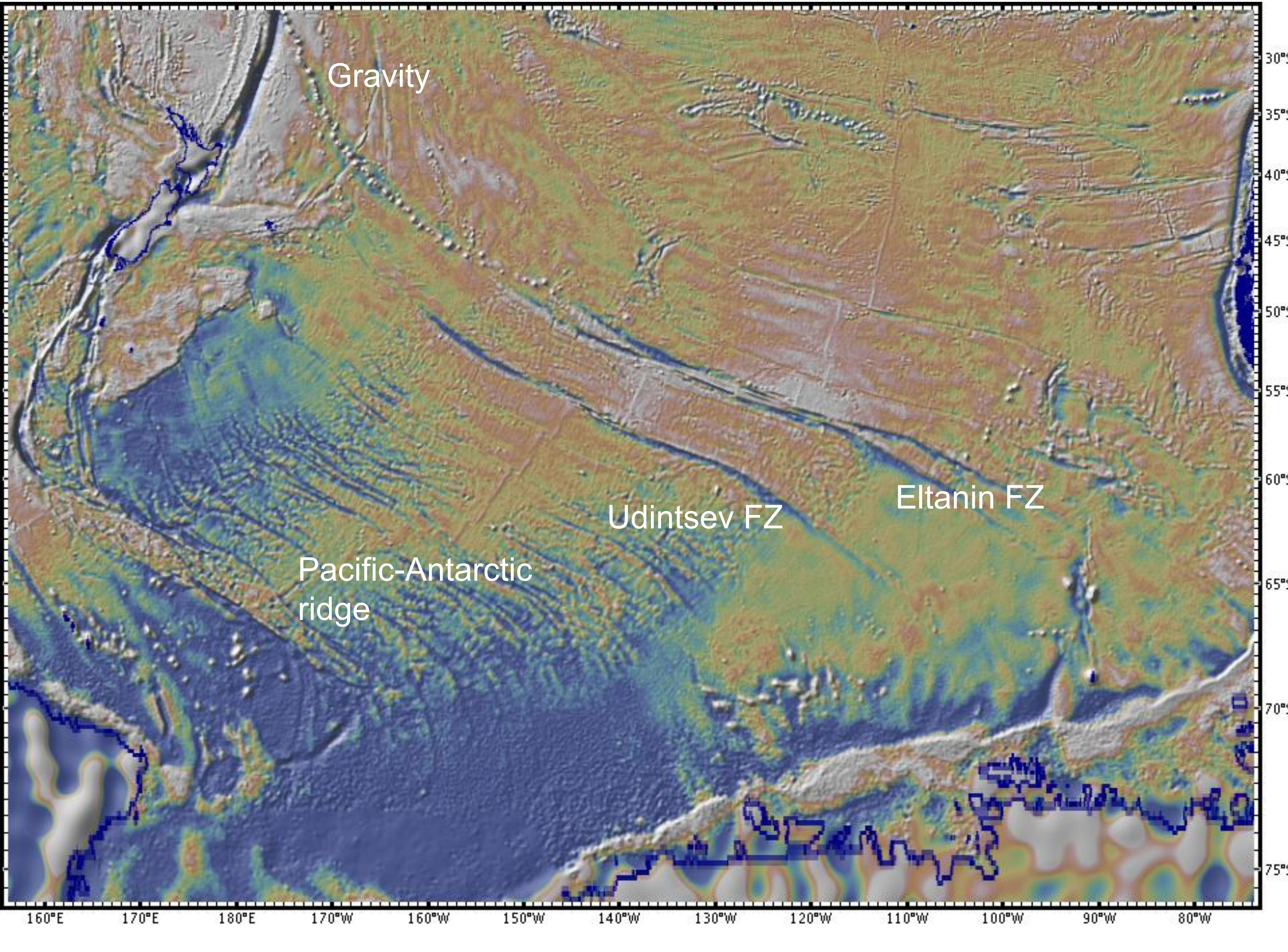
Plate flexes to accommodate decreasing difference in depth

Flexure caused by differential subsidence



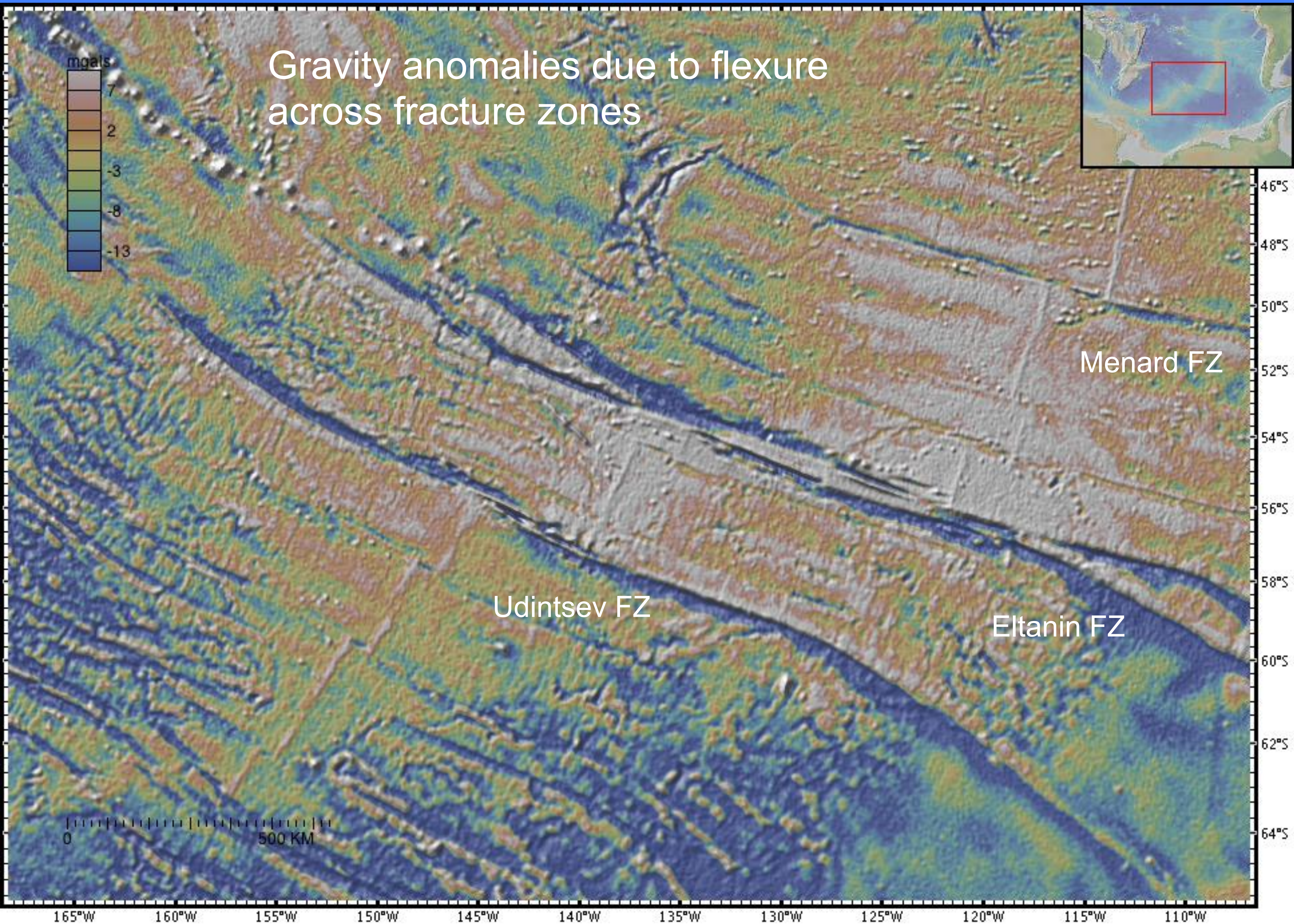
- Depth offset at ridge transform intersection is "frozen in" as lithosphere quickly thickens
- Initial offset, h_a, stays constant as crust on either side of fracture zone cools and subsides at different rates
- Crust near fracture zone has to bend in response, generating large gravity anomalies





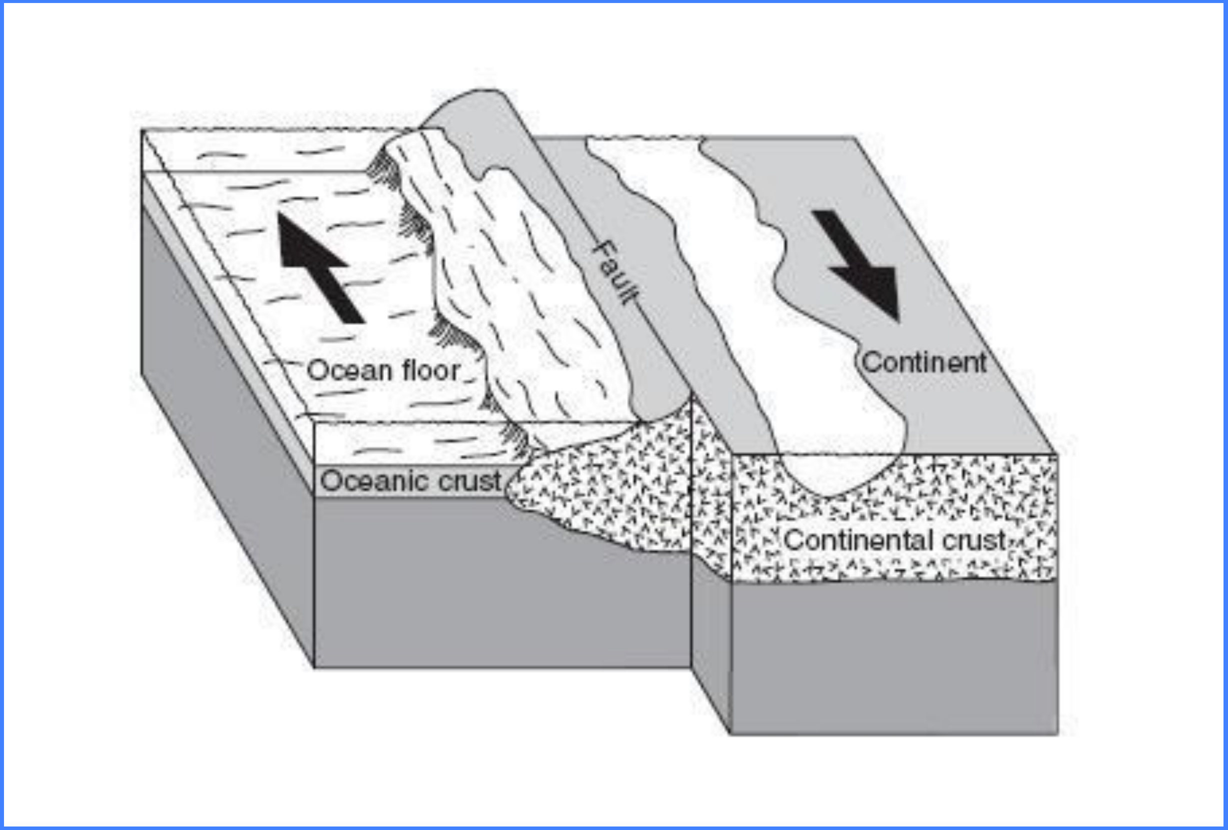
Gravity
Udintsev FZ
Eltanin FZ
Pacific-Antarctic
ridge
30°S
35°S
40°S
45°S
50°S
55°S
60°S
65°S
70°S
75°S
160°E
170°E
180°E
170°W
160°W
150°W
140°W
130°W
120°W
110°W
100°W
90°W
80°W

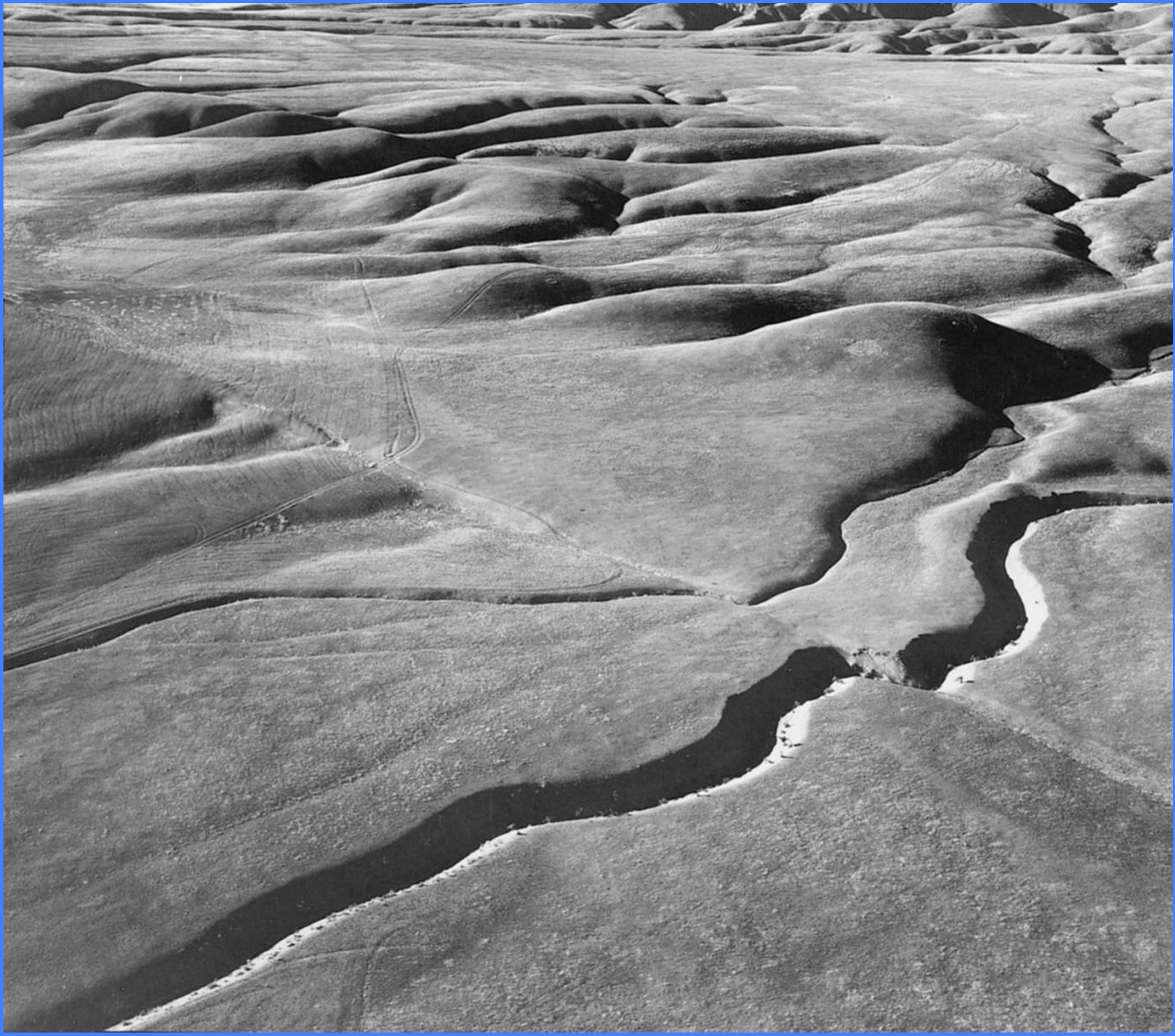
Gravity anomalies due to flexure across fracture zones



Continental transform faults

Continental transform faults





SAF, Carrizo plains

Continental transform faults

Continental transform faults

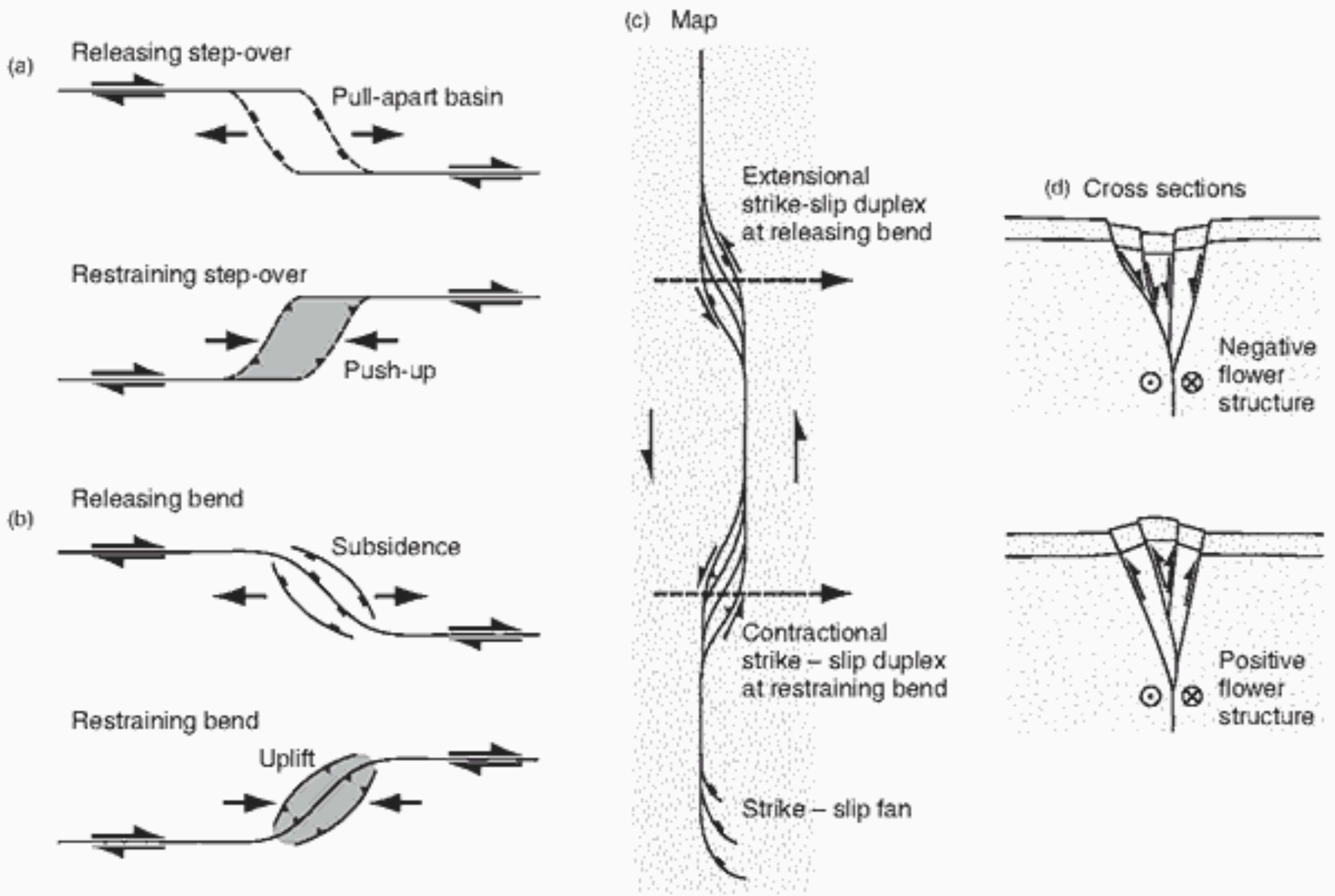


Figure 8.5 *Map views of (a) step-overs and (b) bends and associated structures (after McClay & Bonora, 2001,* Bull. Am. Assoc. Petroleum Geols. *AAPG © 2001, reprinted by permission of the AAPG whose permission is required for further use). (c) Map and (d) cross-sections of strike-slip duplexes, fans and flower structures developed at bends (after Woodcock & Rickards, 2003, with permission from Elsevier).*

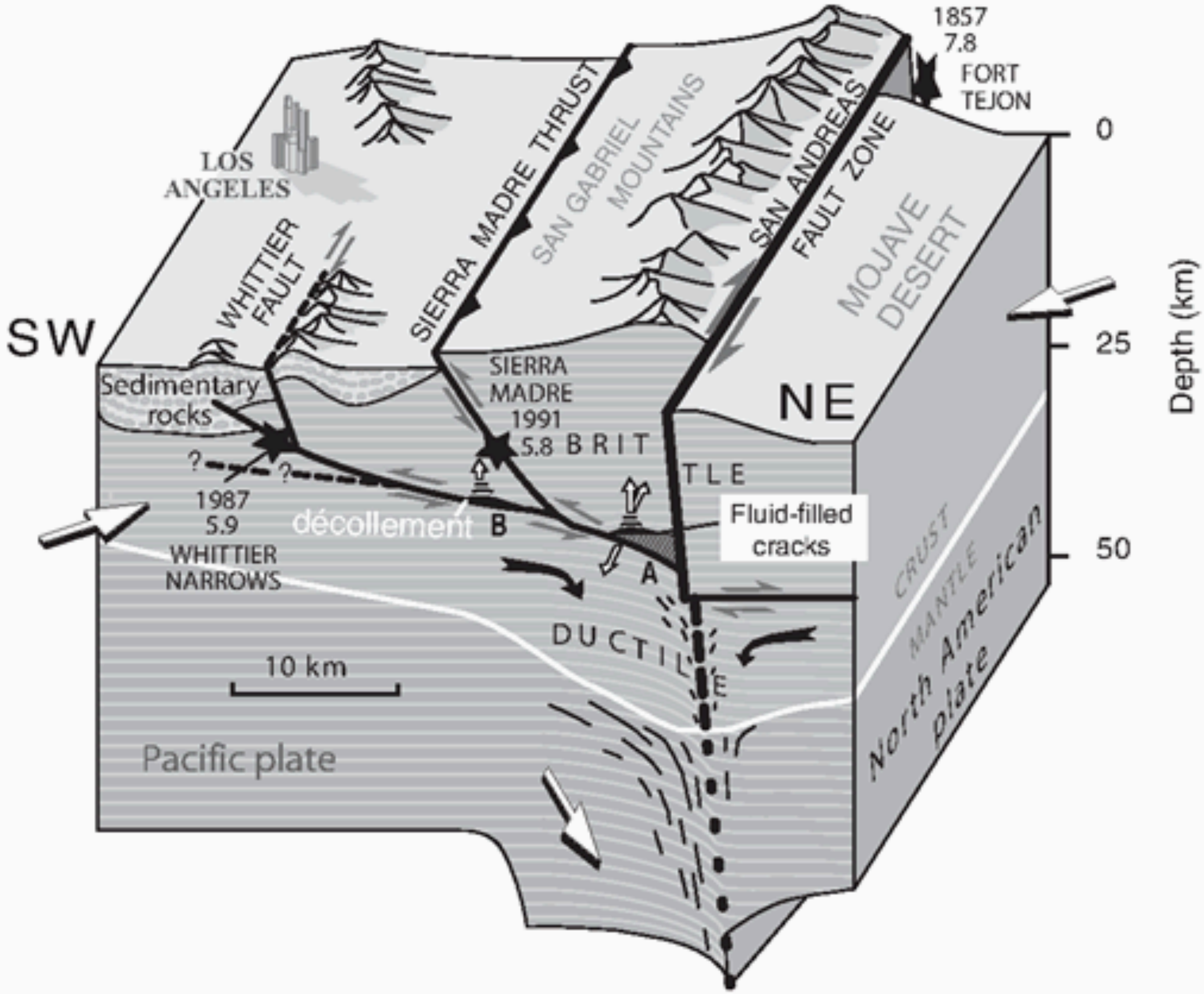
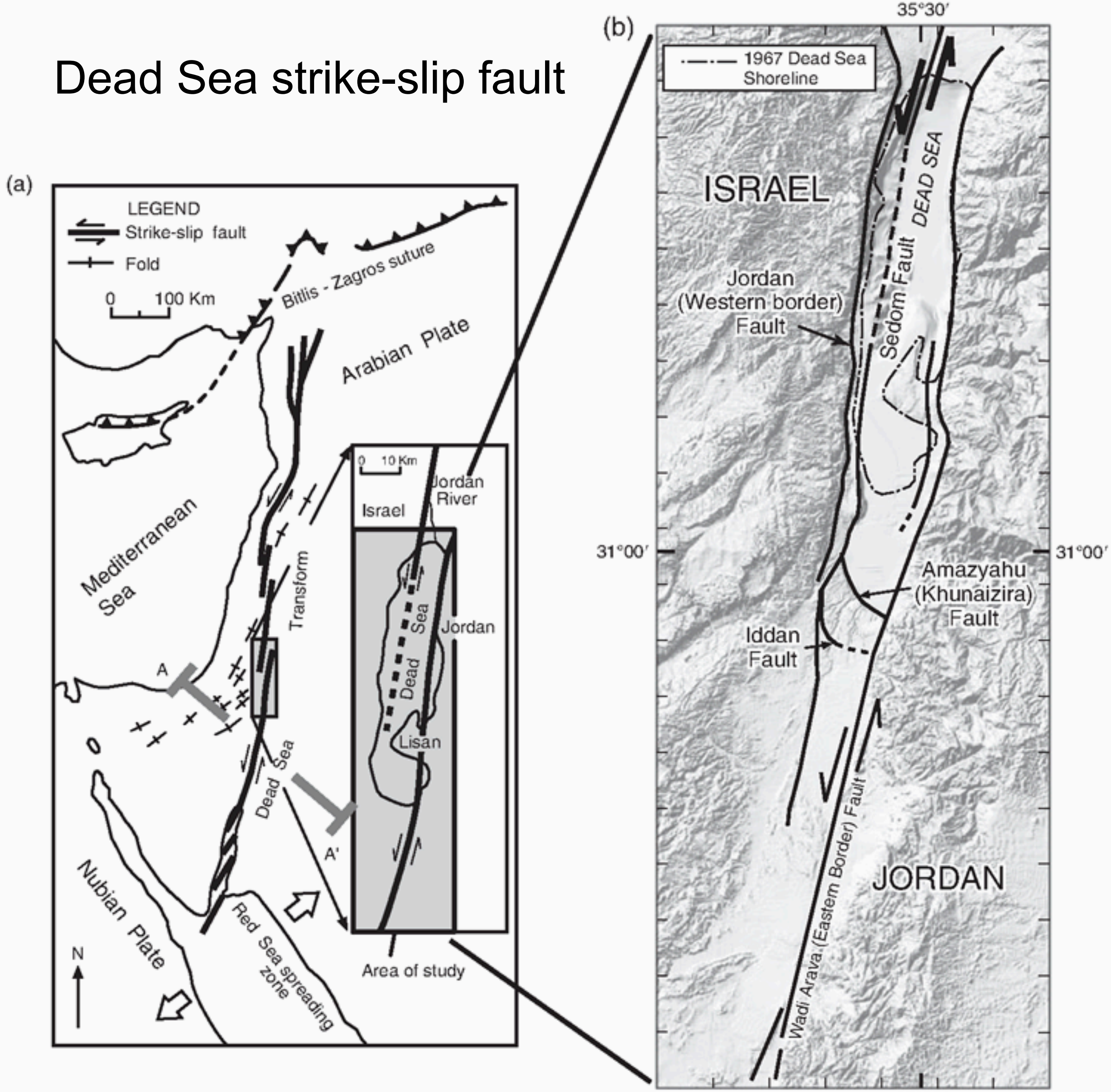
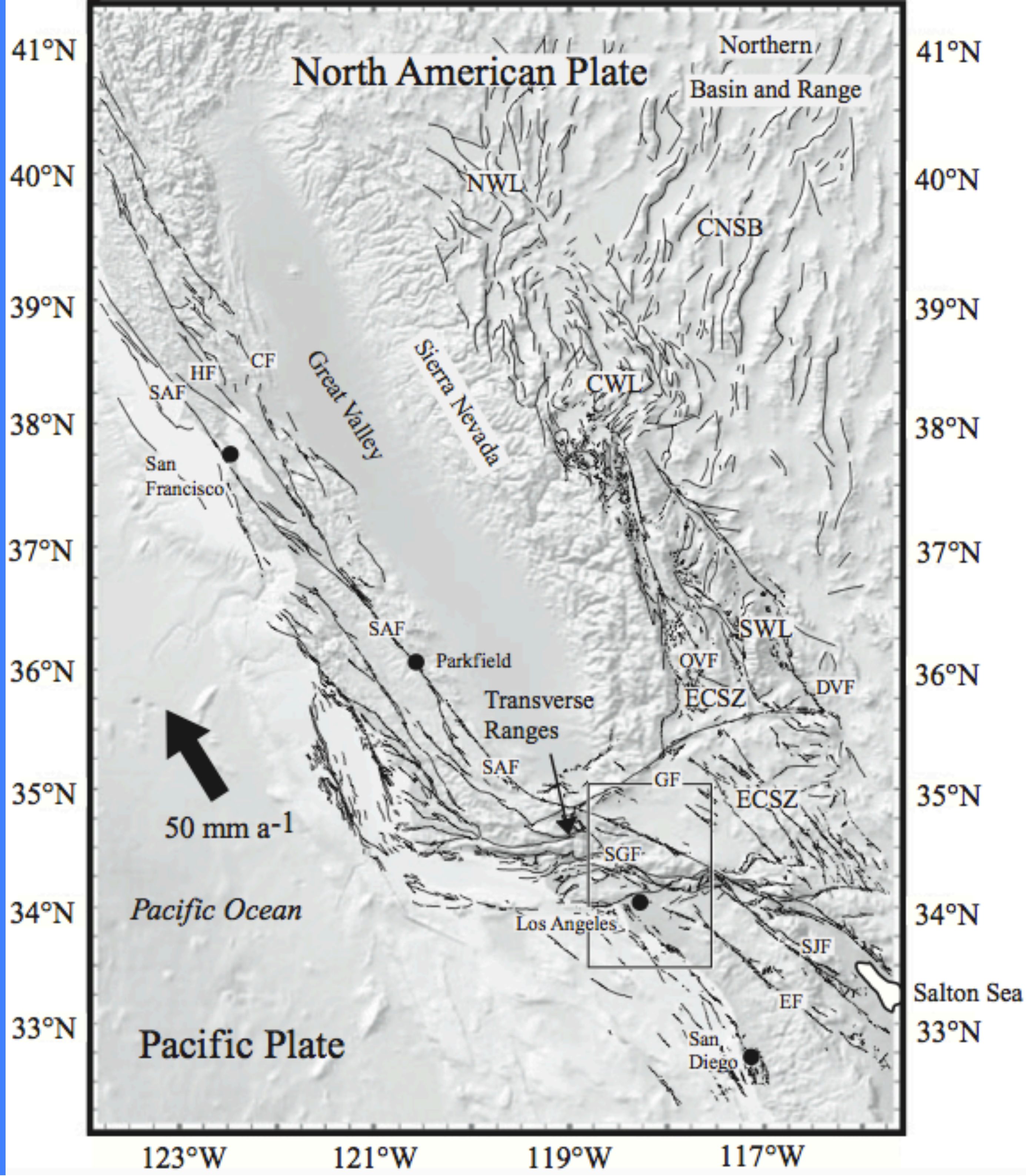


Figure 8.14 *Schematic block diagram showing the three-dimensional geometry of active faults of the Los Angeles region (image provided by G. Fuis and modified from Fuis et al., 2001, with permission from the Geological Society of America). Moderate and large earthquakes are shown with black stars, dates, and magnitudes. Small white arrows show block motions in vicinities of bright reflective regions A and B. Large white arrows show relative convergence direction of Pacific and North American plates. Regions A and B are zones of cracks that transport fluids migrating up from depth. A décollement surface ascends from cracked region A at San Andreas Fault, above which brittle upper crust is imbricated along thrust and reverse faults and below which lower crust is flowing toward San Andreas Fault (black arrows), depressing the Moho. Mantle of Pacific plate sinks beneath the San Gabriel Mountains.*

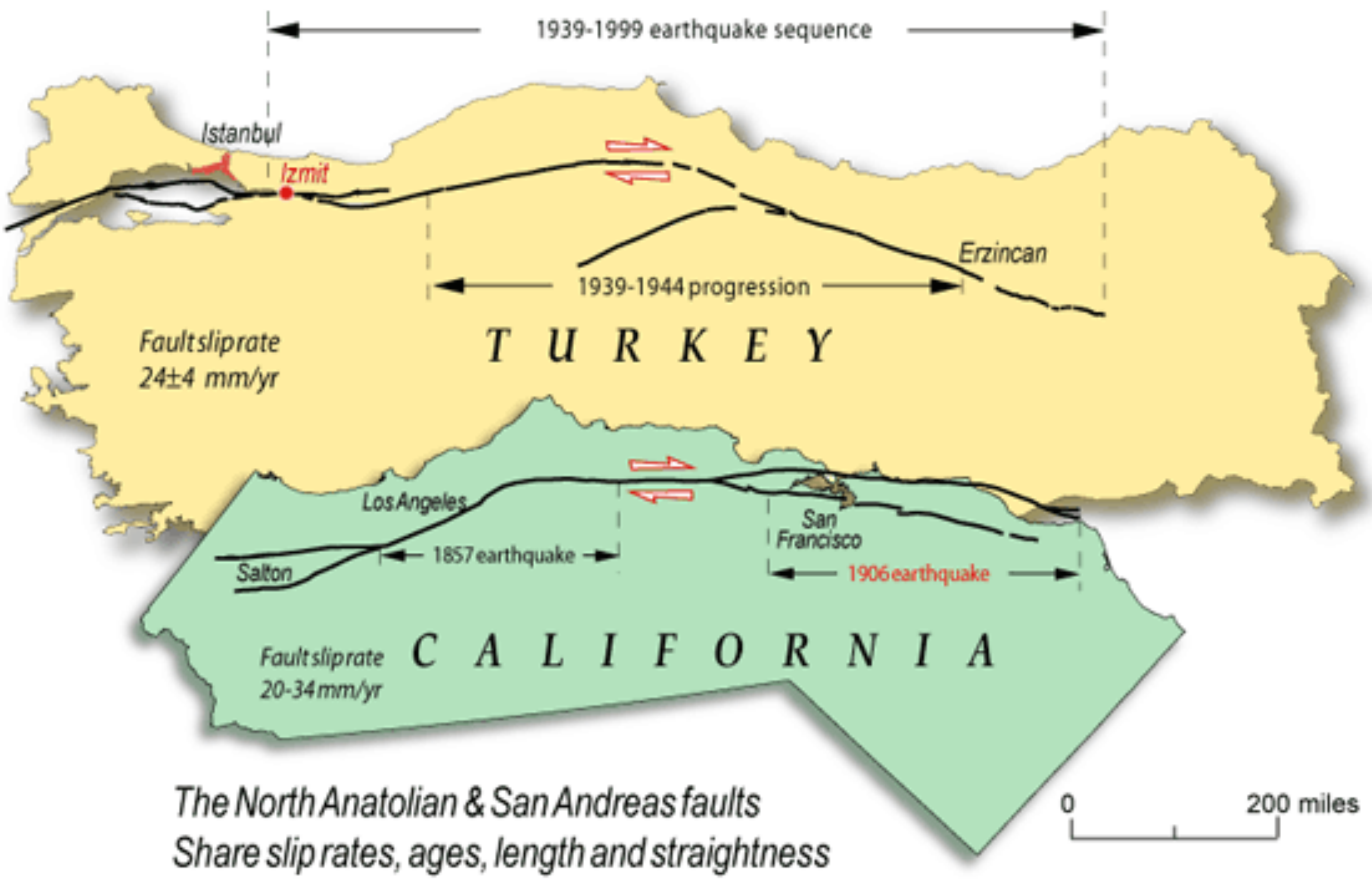
Dead Sea strike-slip fault



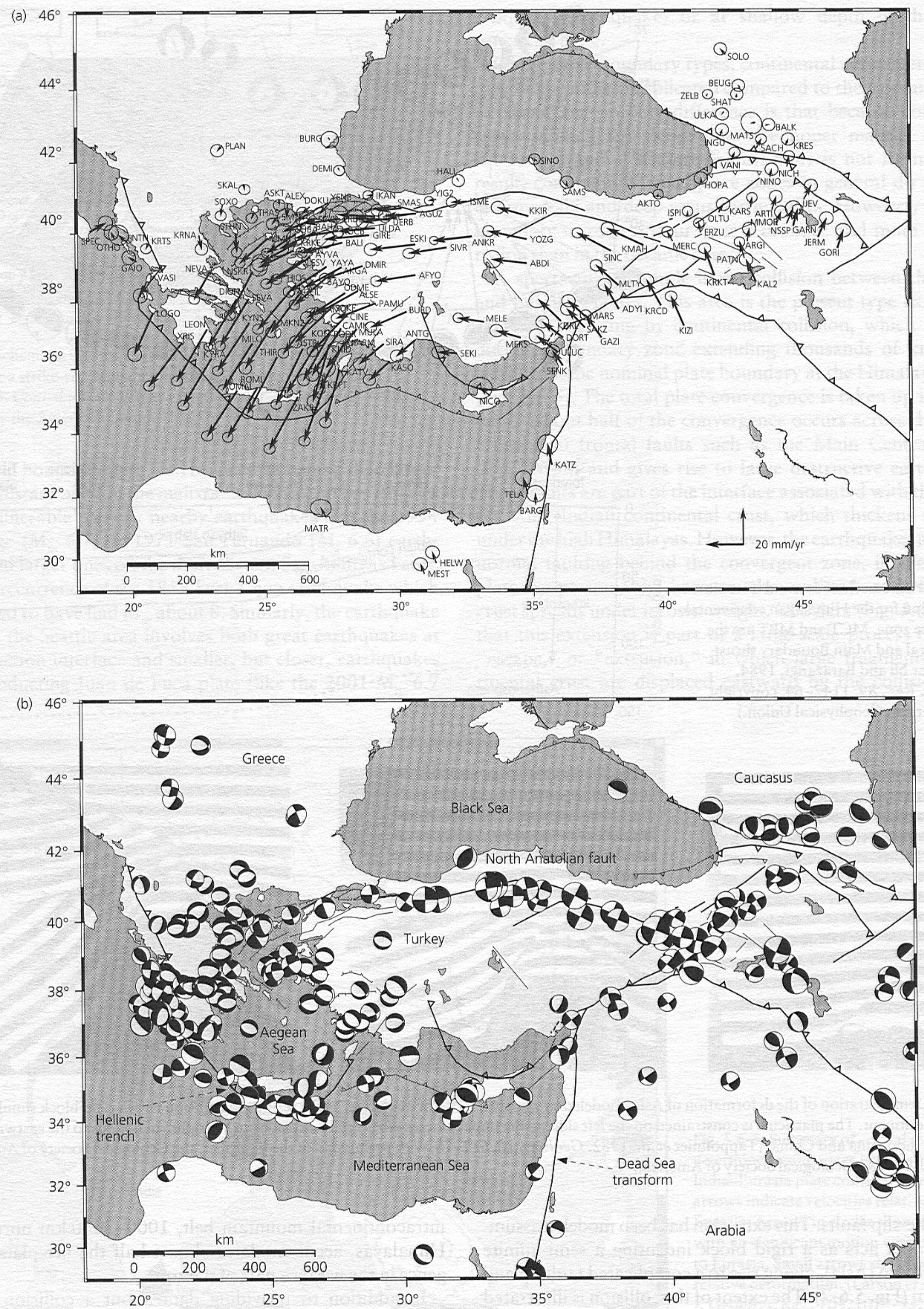
San Andreas Fault System, California



North Anatolian Fault, Turkey

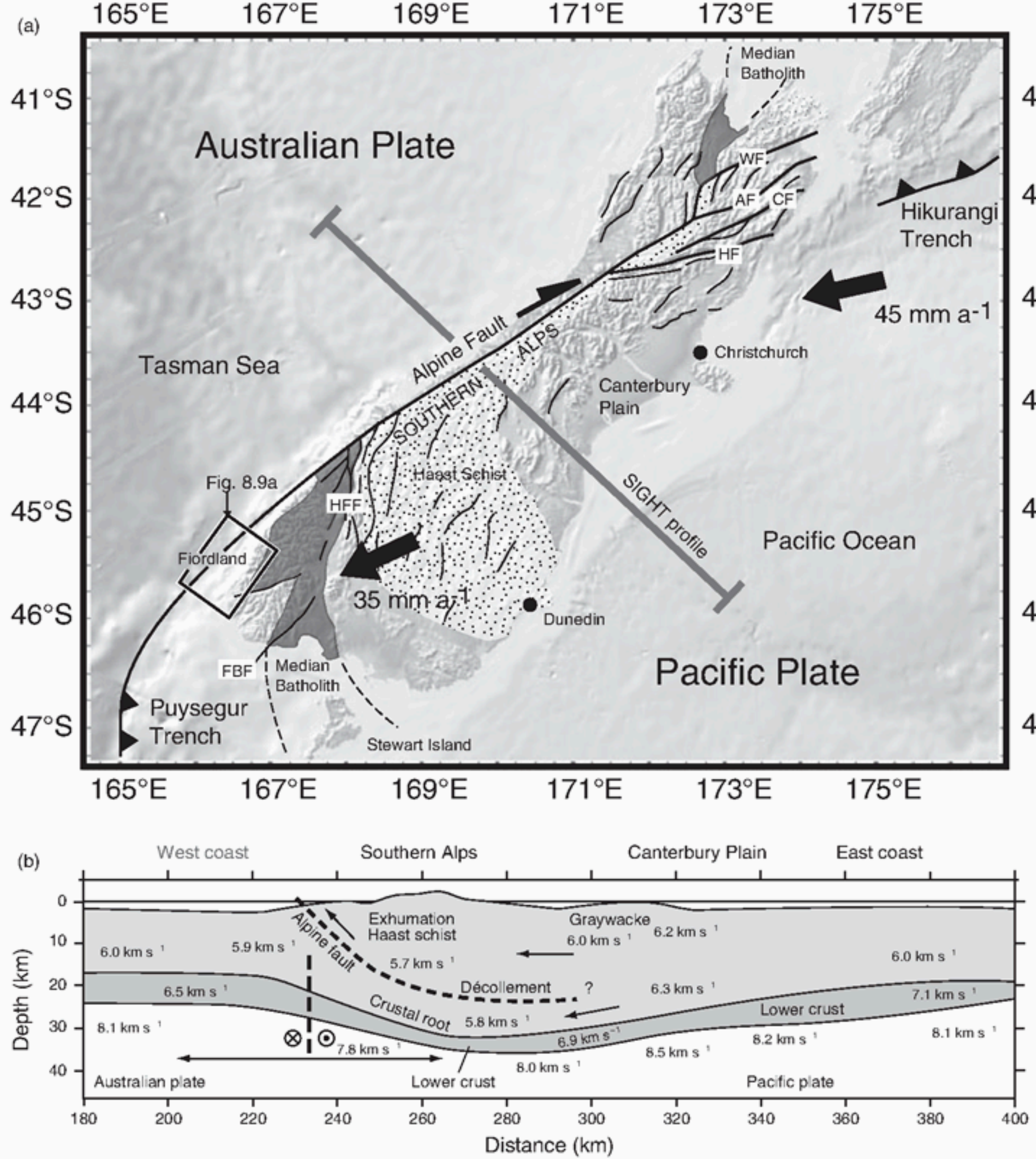


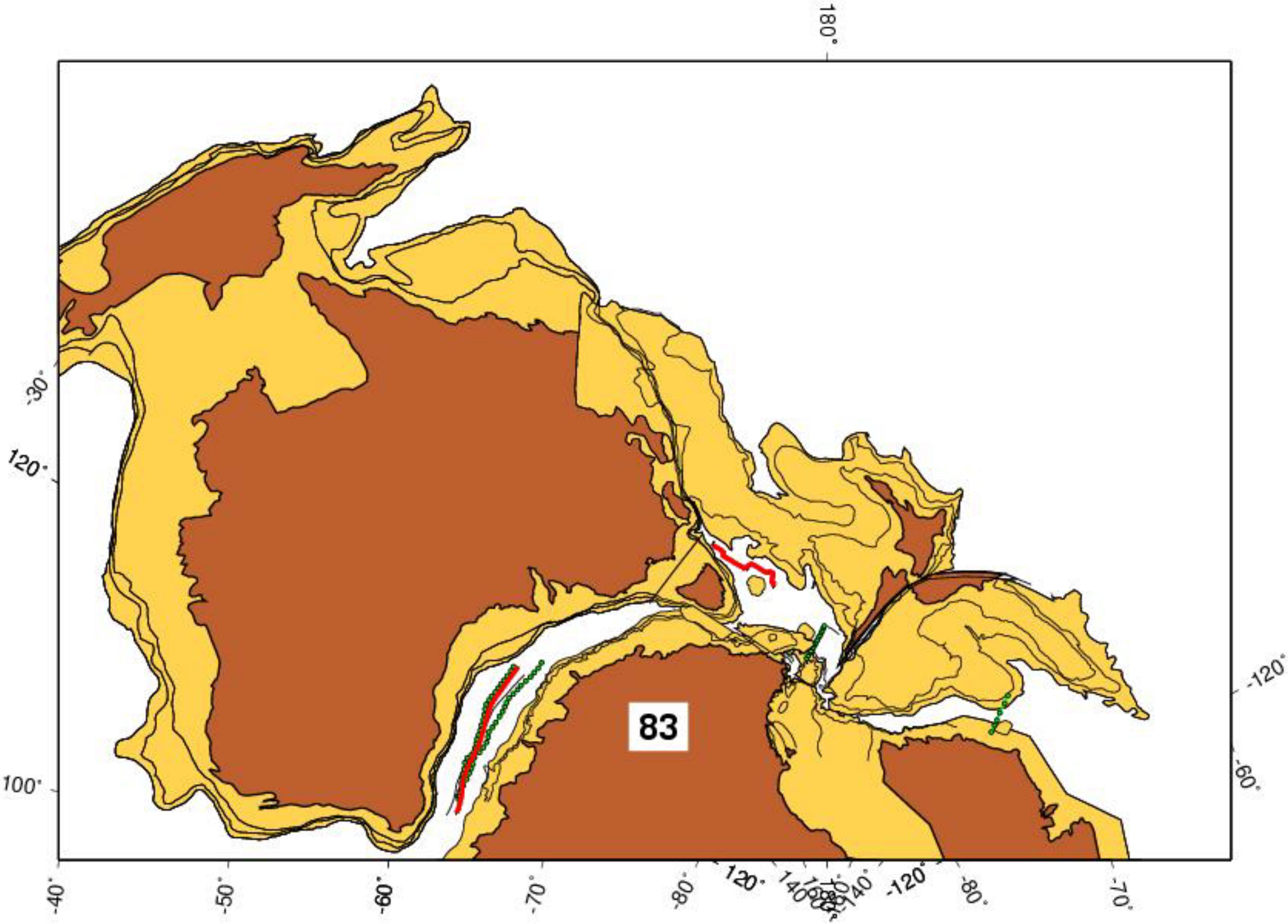
The North Anatolian & San Andreas faults
Share slip rates, ages, length and straightness



(a)
46°
44°
42°
40°
38°
36°
34°
32°
30°
20°
25°
30°
35°
40°
45°
20 mm/yr
km
0
200
400
600
(b)
Greece
Black Sea
Caucasus
North Anatolian fault
Turkey
Aegean Sea
Hellenic trench
Mediterranean Sea
Dead Sea transform
Arabia

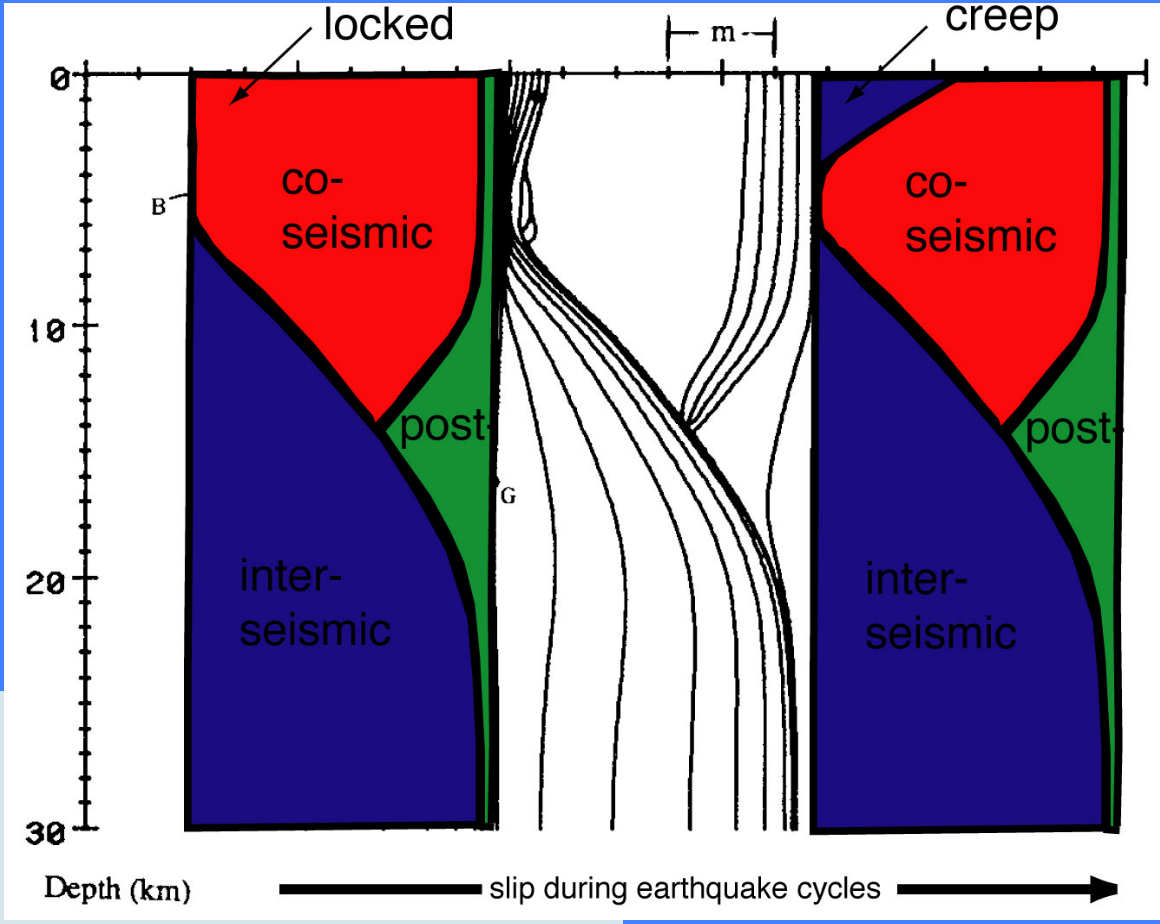
Alpine Fault, New Zealand

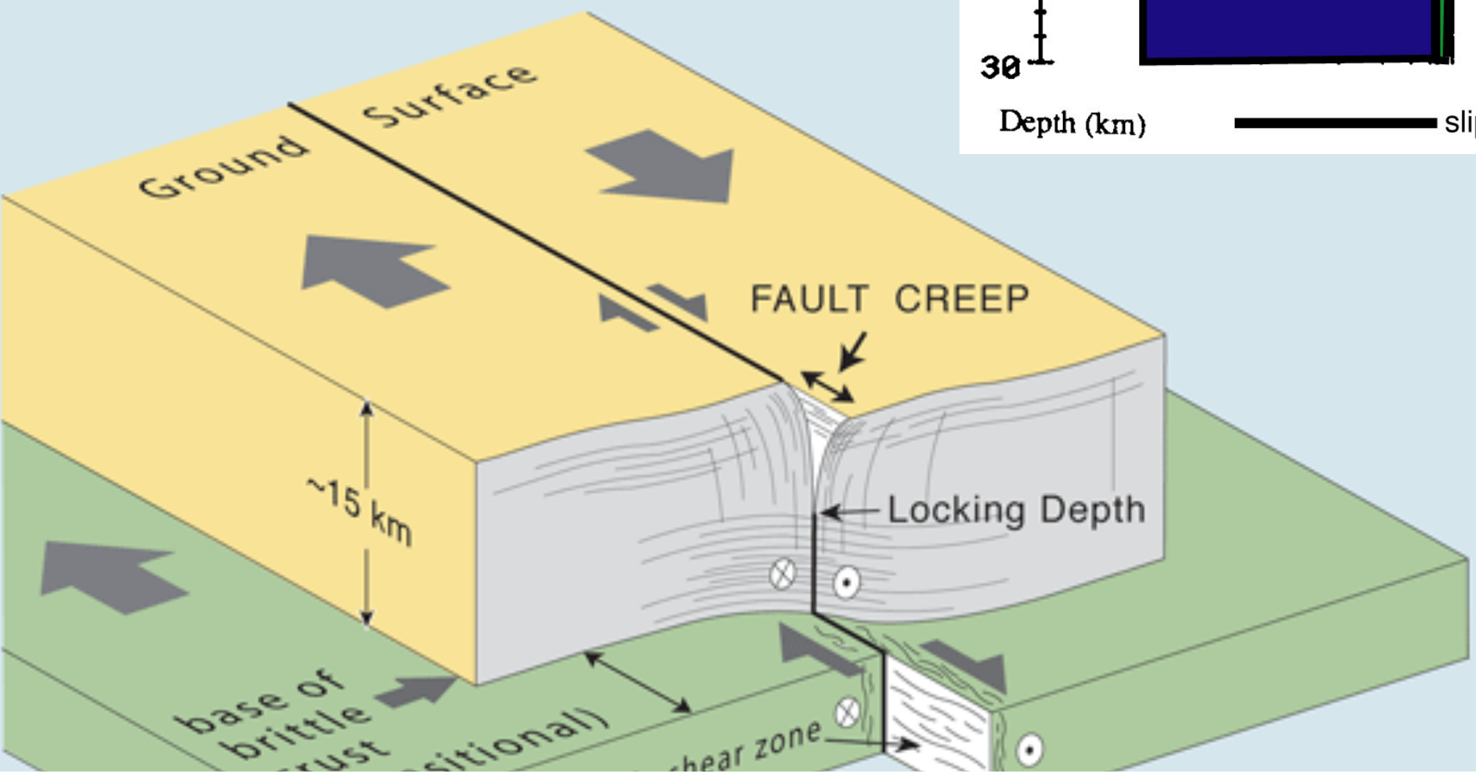


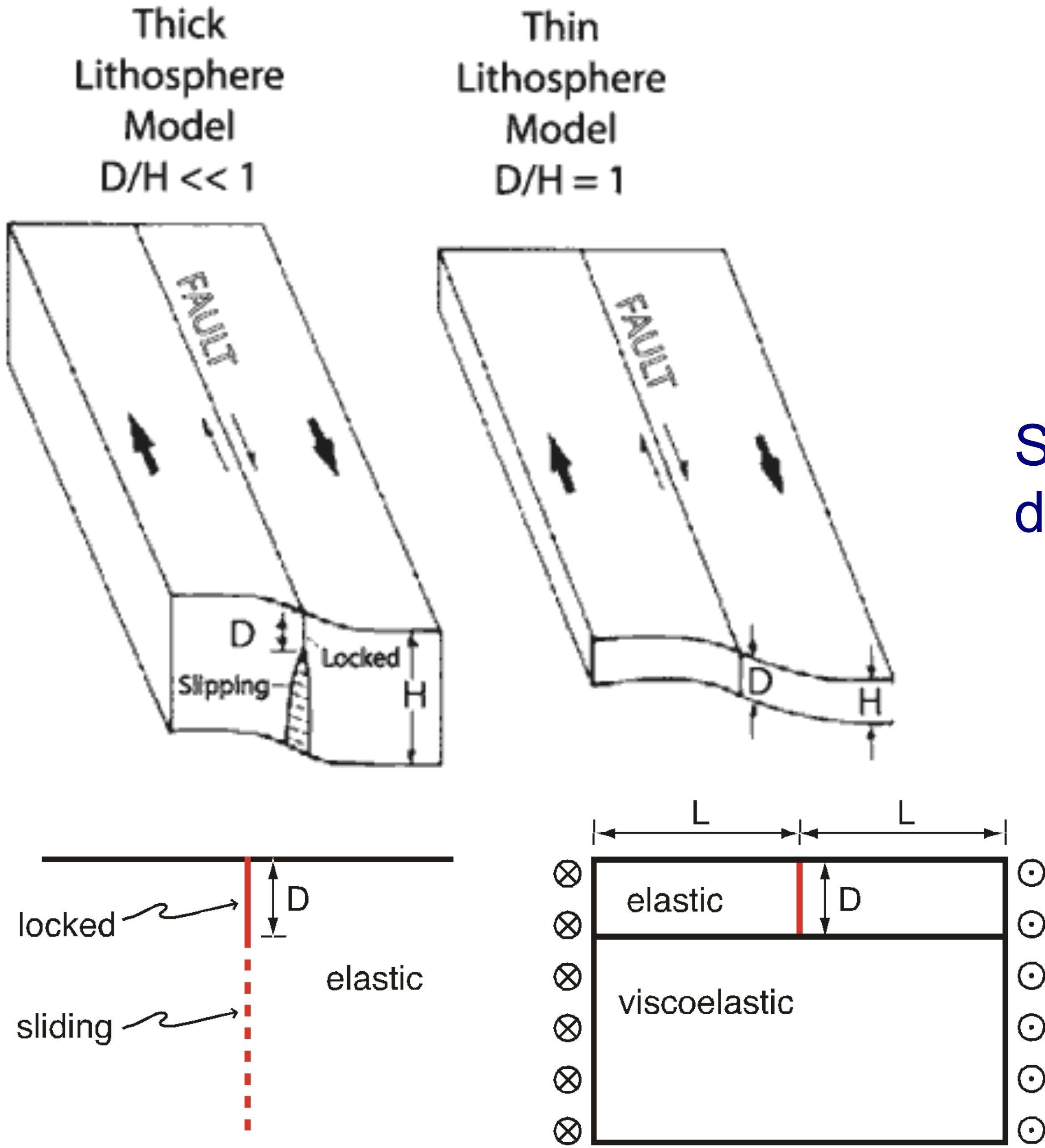

83
180°
-30°
120°
100°
-120°
-60°
-40°
-50°
-60°
-70°
-80°
120°
140°
160°
140°
-120°
-80°
-70°

Strike-slip fault: top to bottom

Tse and Rice, 1987
Lapusta et al., 2001





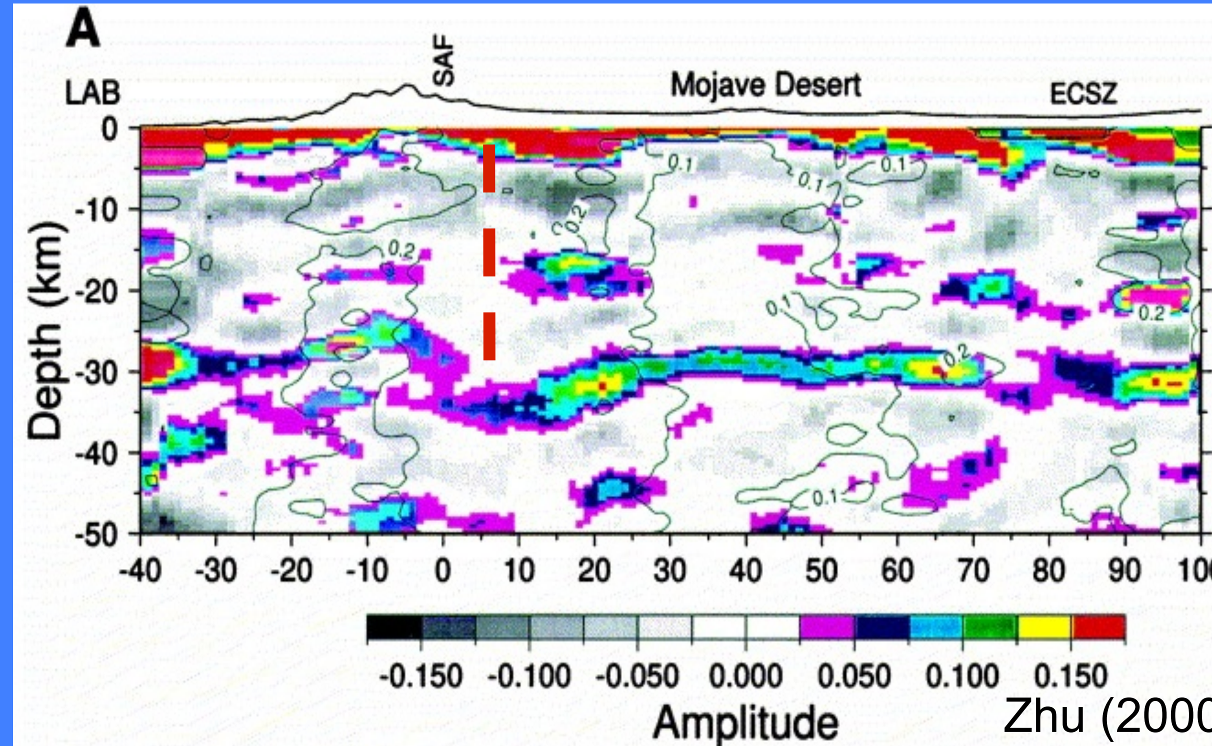


Same pattern of interseismic deformation

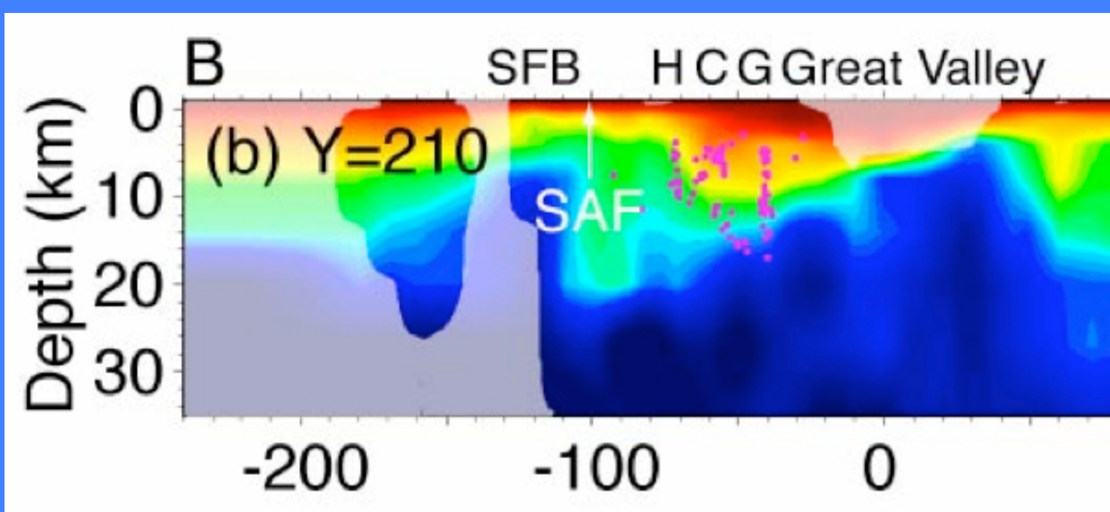
Savage and Burford, 1973
Turcotte and Spence, 1974

Elsasser, 1969
Savage and Prescott, 1978

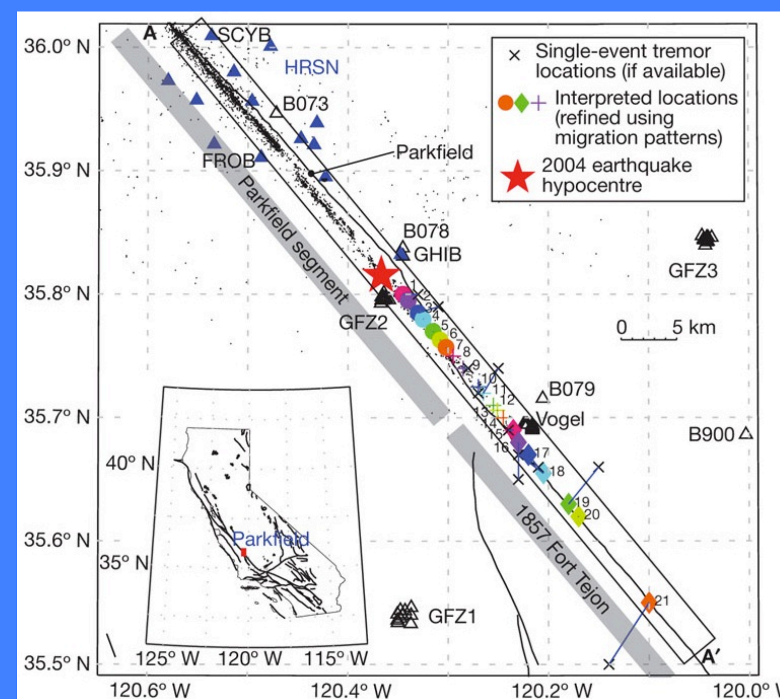
Mylonite zone (Ontario, Canada)



Zhu (2000)

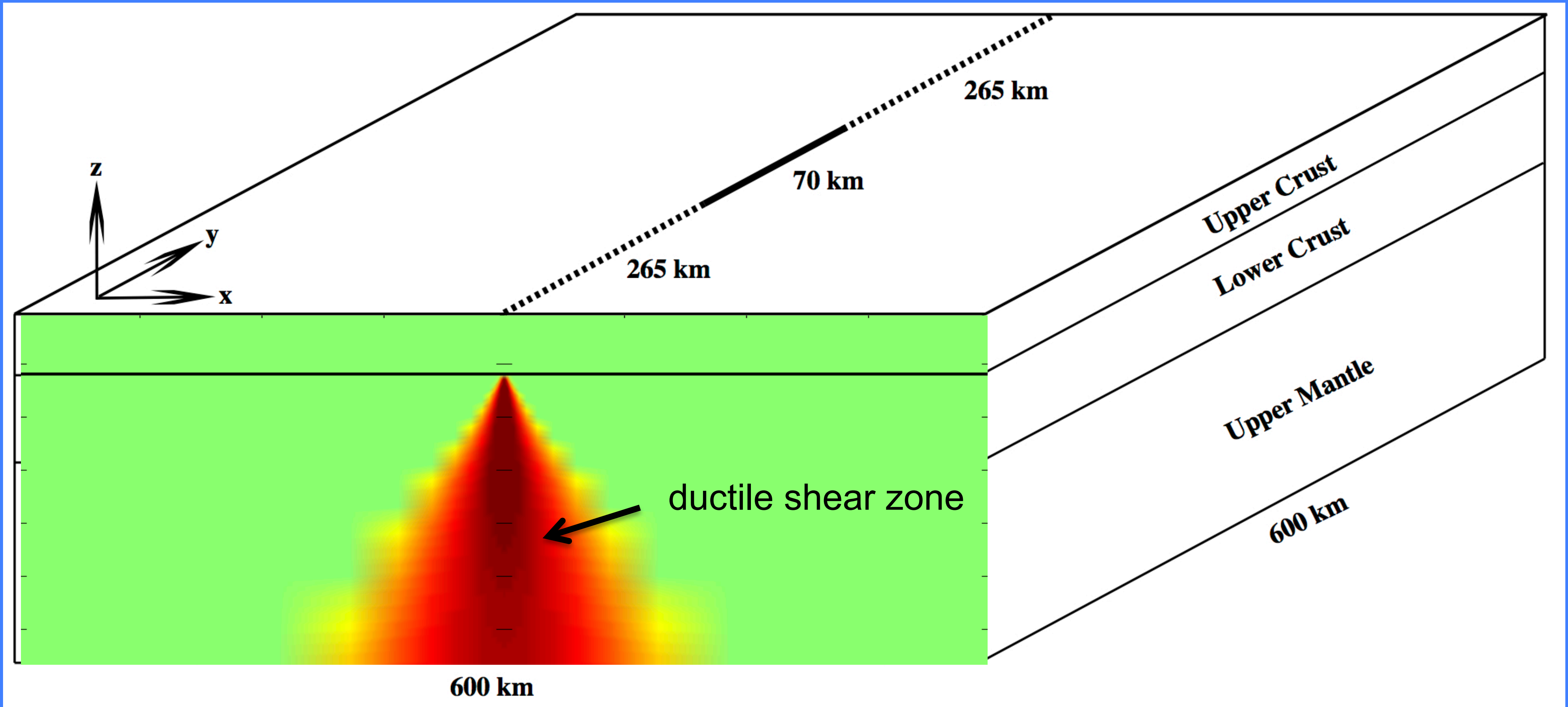


Thurber et al. (2006)



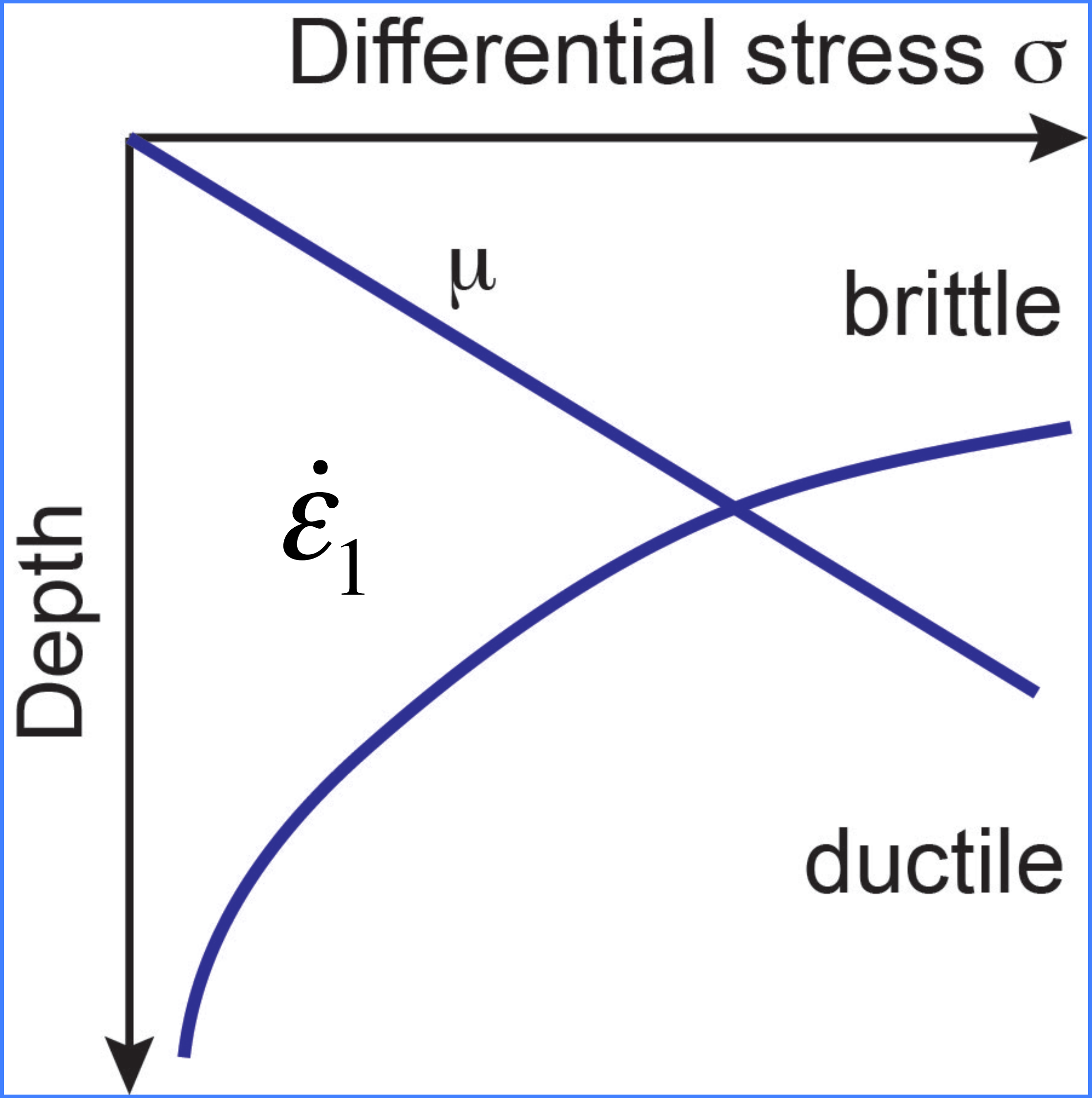
Shelly (2010)

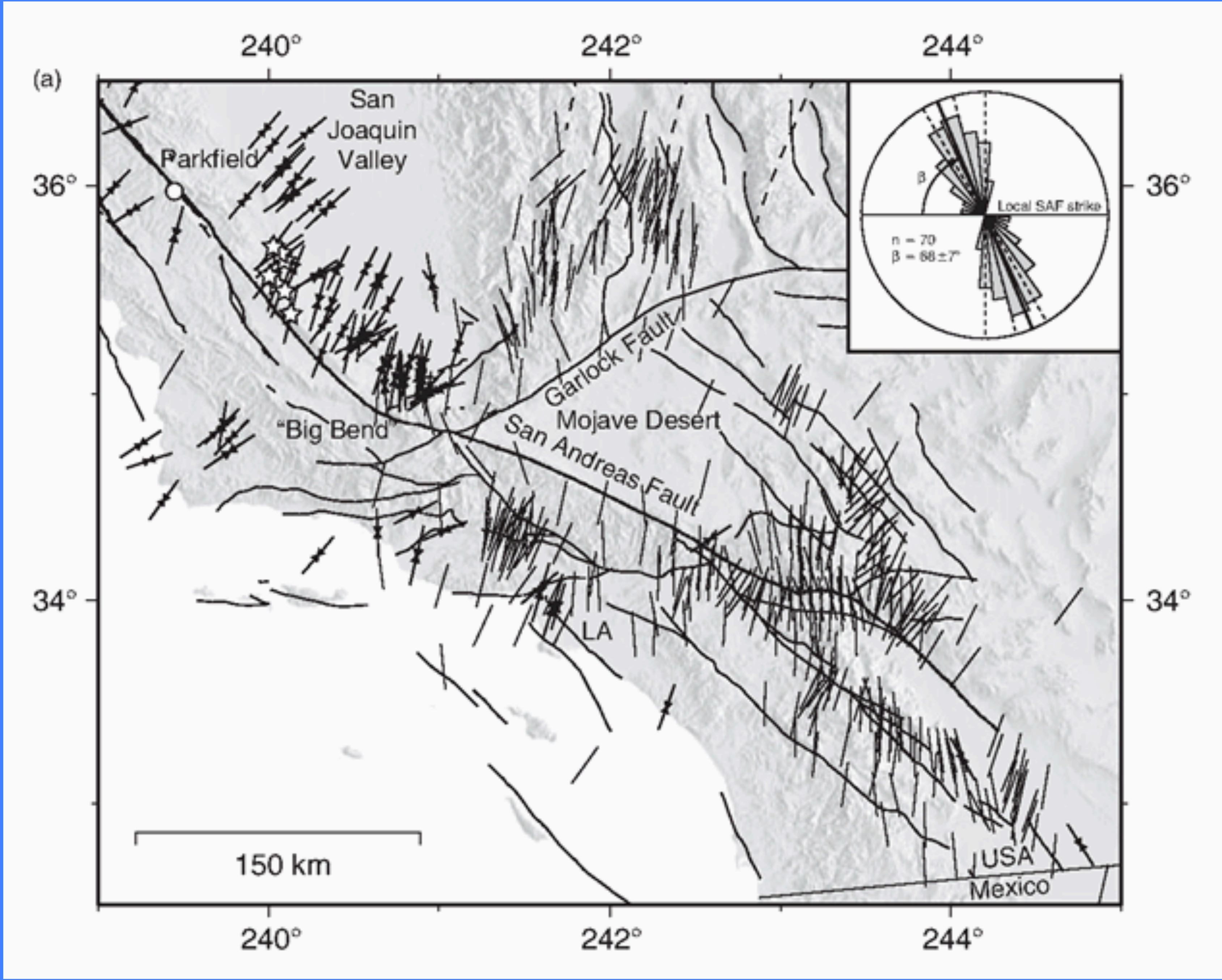
Strain localization in the ductile substrate



Takeuchi and Fialko, 2012; 2013

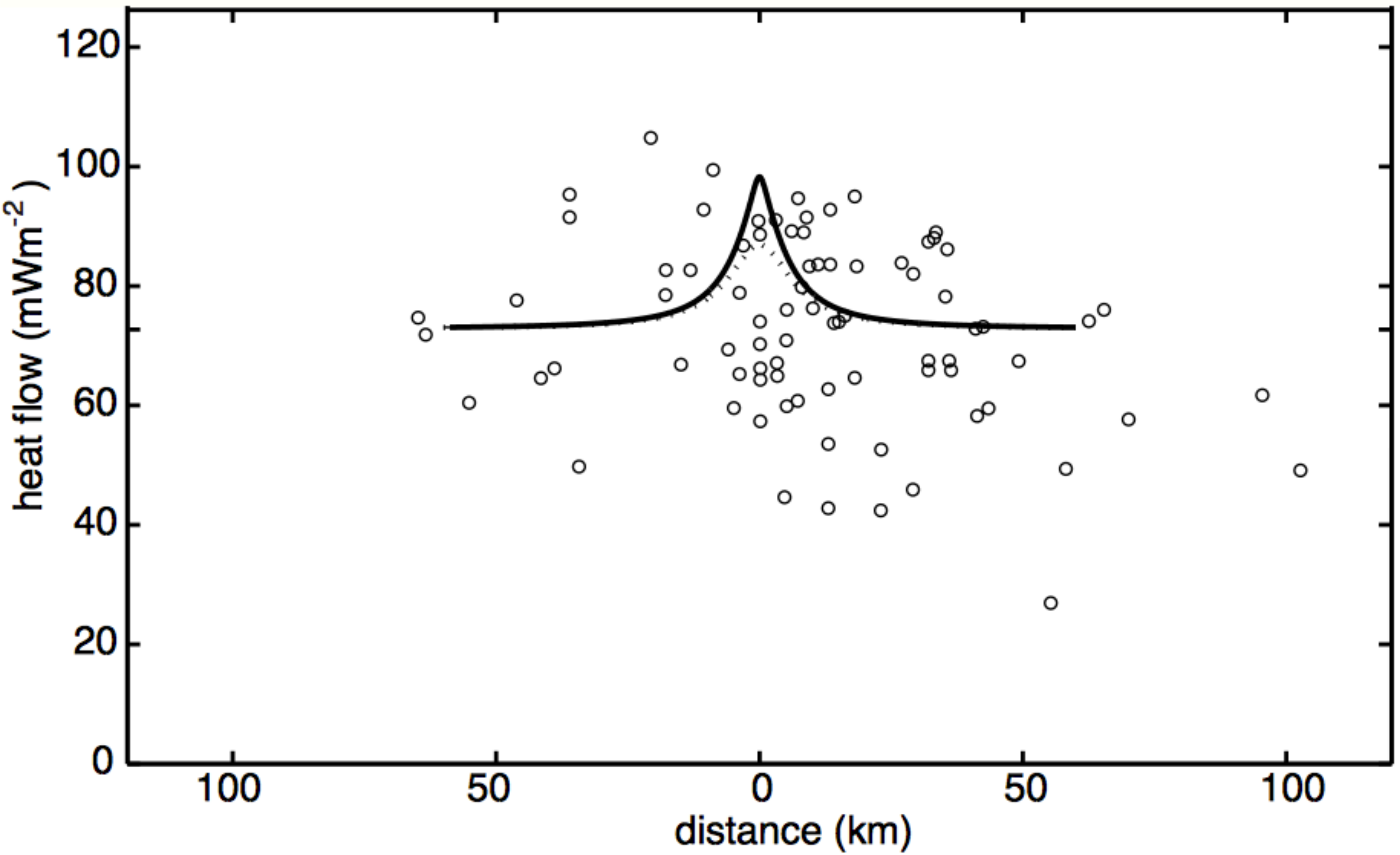
How strong are mature continental transform faults?





(a)
240°
242°
244°
36°
34°
San
Joaquin
Valley
Parkfield
Garlock Fault
Mojave Desert
"Big Bend"
San Andreas Fault
LA
150 km
USA
Mexico
β
Local SAF strike
n = 70
β = 68±7°

“Heat flow paradox” of the San Andreas Fault



Mature faults appear to be weak (much weaker than predicted by the Byerlee's law)

Possible explanation: low friction during rapid slip (i.e., during earthquakes)