Solid Earth Dynamics

Bill Menke, Instructor

Lecture 20

Faults and earthquakes

Seismotectonics

Faults and earthquakes

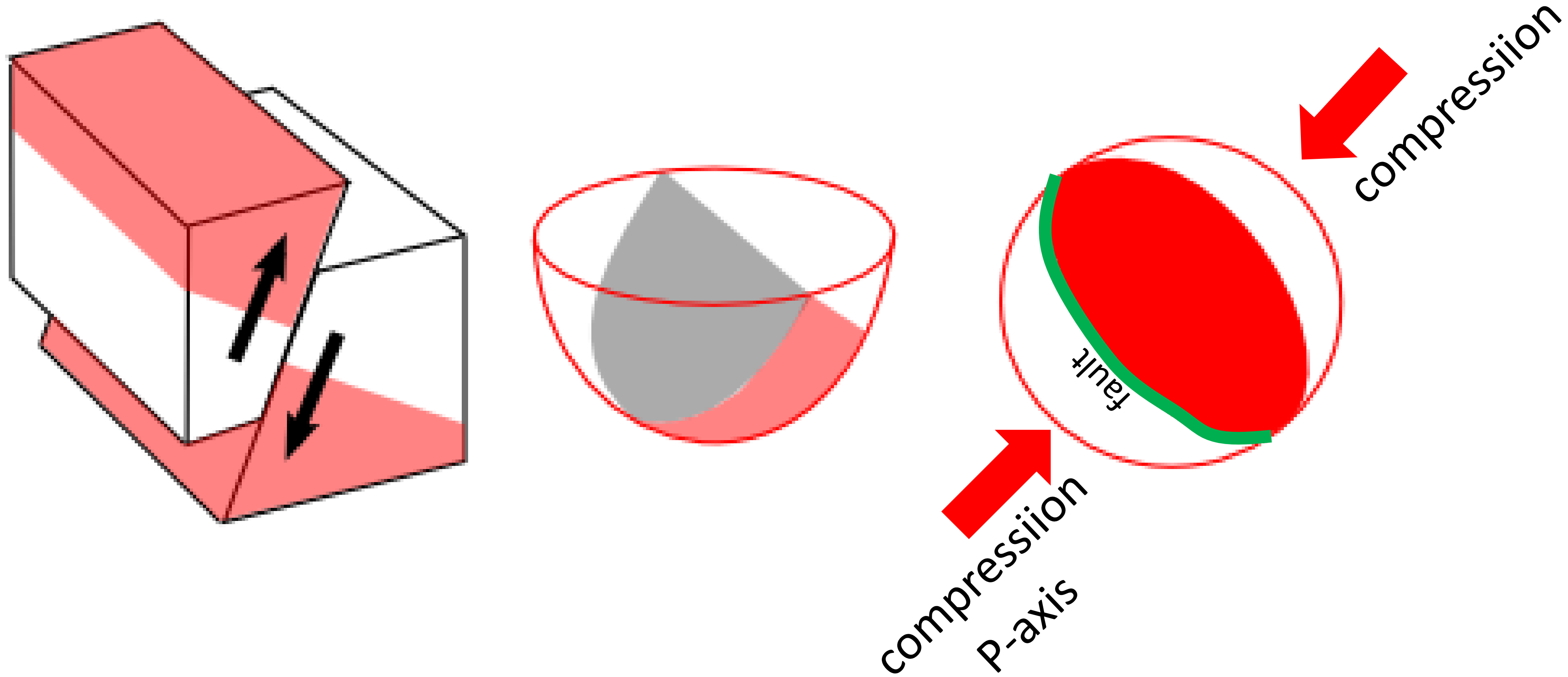
What can be learned from P wave

Angular behavior of P wave: Focal mechanism,
fault is one of two possible
planes

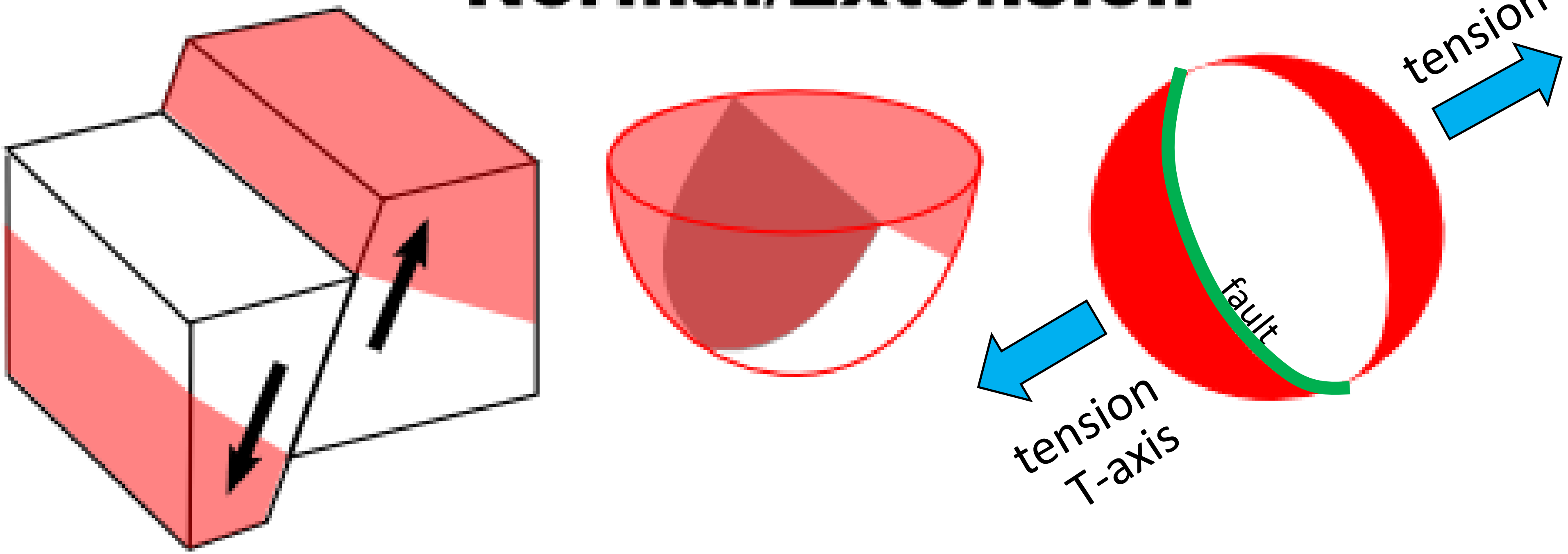
Area under the P wave
(after correcting for distance & focal mechasm):
Moment = slip x area x rigidity

Duration of the P wave: Duration of rupture

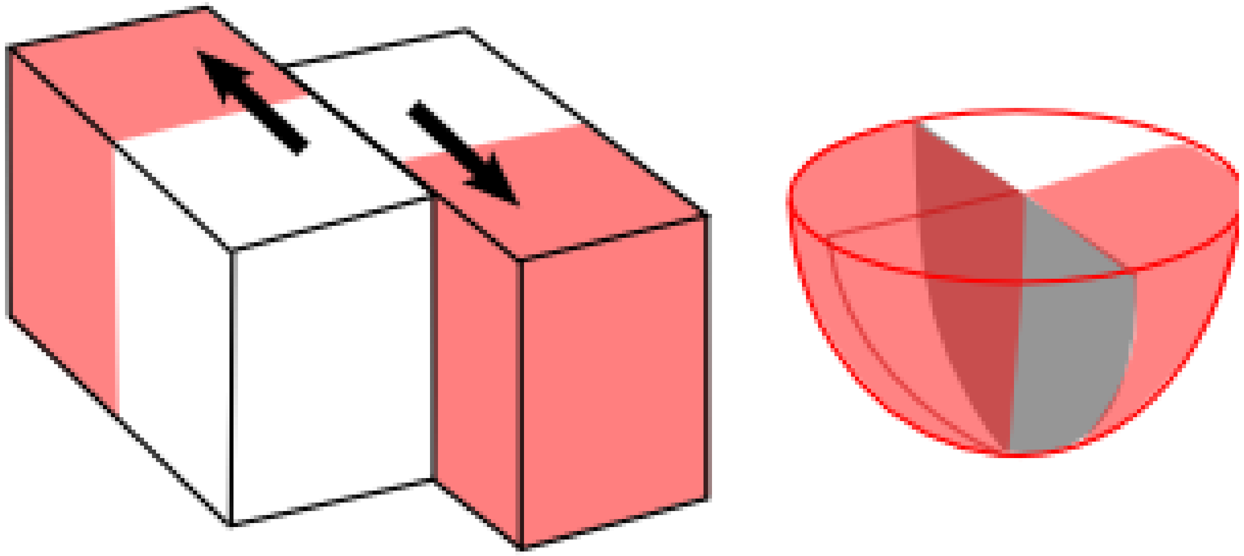
Reverse/Thrust/Compression

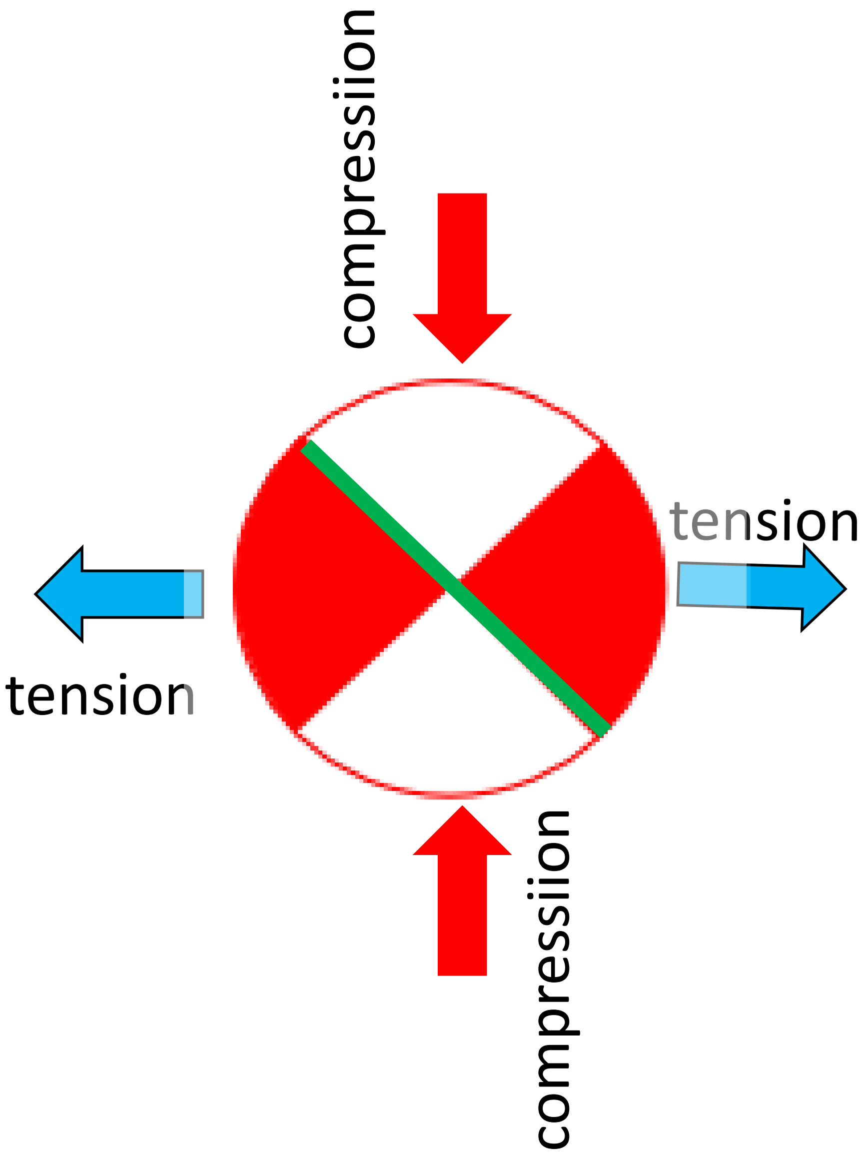


Normal/Extension



Strike-Slip





Moment of a very large earthquake

Rigidity x slip x length x width

$$3 \times 10^{10}\, pa \qquad 1\, m \qquad 10^{5} m \qquad 10^{5} m$$

$$3 \times 10^{20}\, pa\, m^{3}$$

$$\frac{N}{m^{2}} m^{3}$$

$$M_0 = 3 \times 10^{20}\, N\, m$$ (annoyingly big number)

Moment of a very large earthquake

Rigidity x slip x length x width

$3 \times 10^{10}\ pa$ $1\ m$ $10^5 m$ $10^5 m$

typical ratio 1:10^5

$3 \times 10^{20}\ pa\ m^3$

$\frac{N}{m^2} m^3$

$M_0 = 3 \times 10^{20}\ N\ m$ (annoyingly big number)

$$M_0 = 3 \times 10^{20}\ N\ m$$

$$M = (\log_{10} M_0 - 9.05)/1.5$$

$M = 7.6$ Moment magnitude

or colloquially, the magnitude of the earthquake

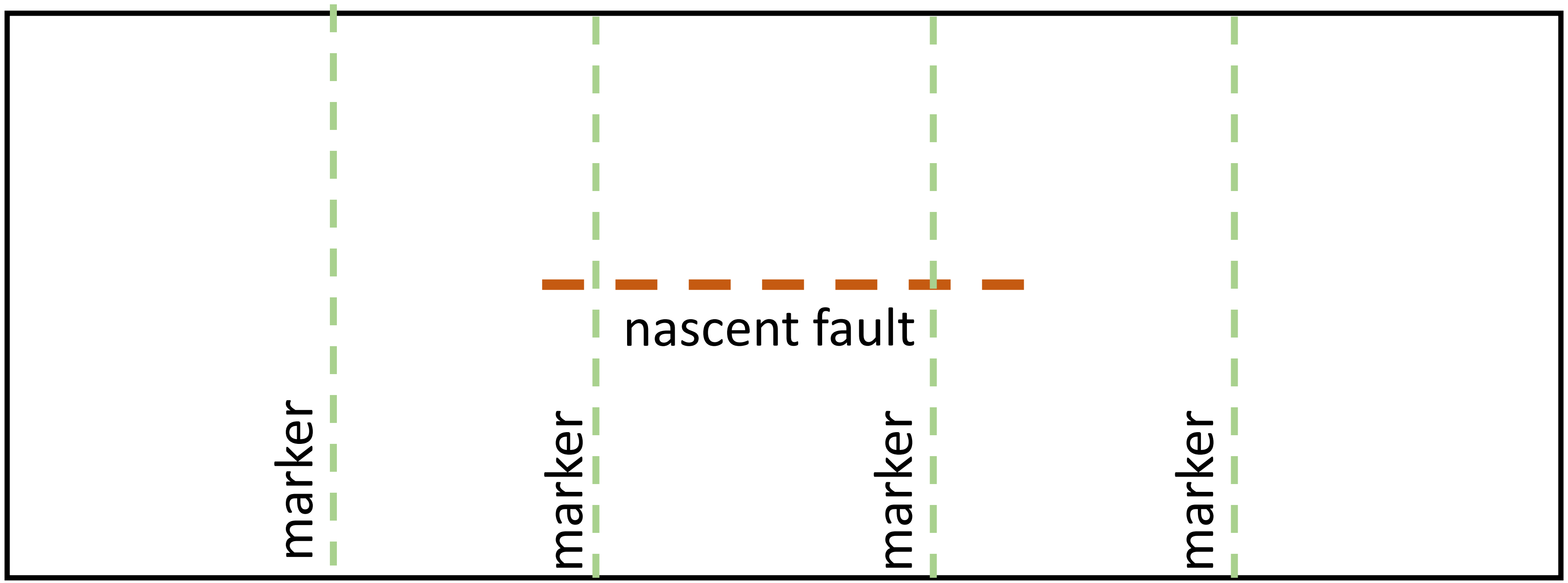
Tiny earthquake
1 millimeter of slip
on a fault 100 m long
magnitude 1.5

Moderate earthquake
1 meter of slip
on a fault 10 km long
magnitude 4.8

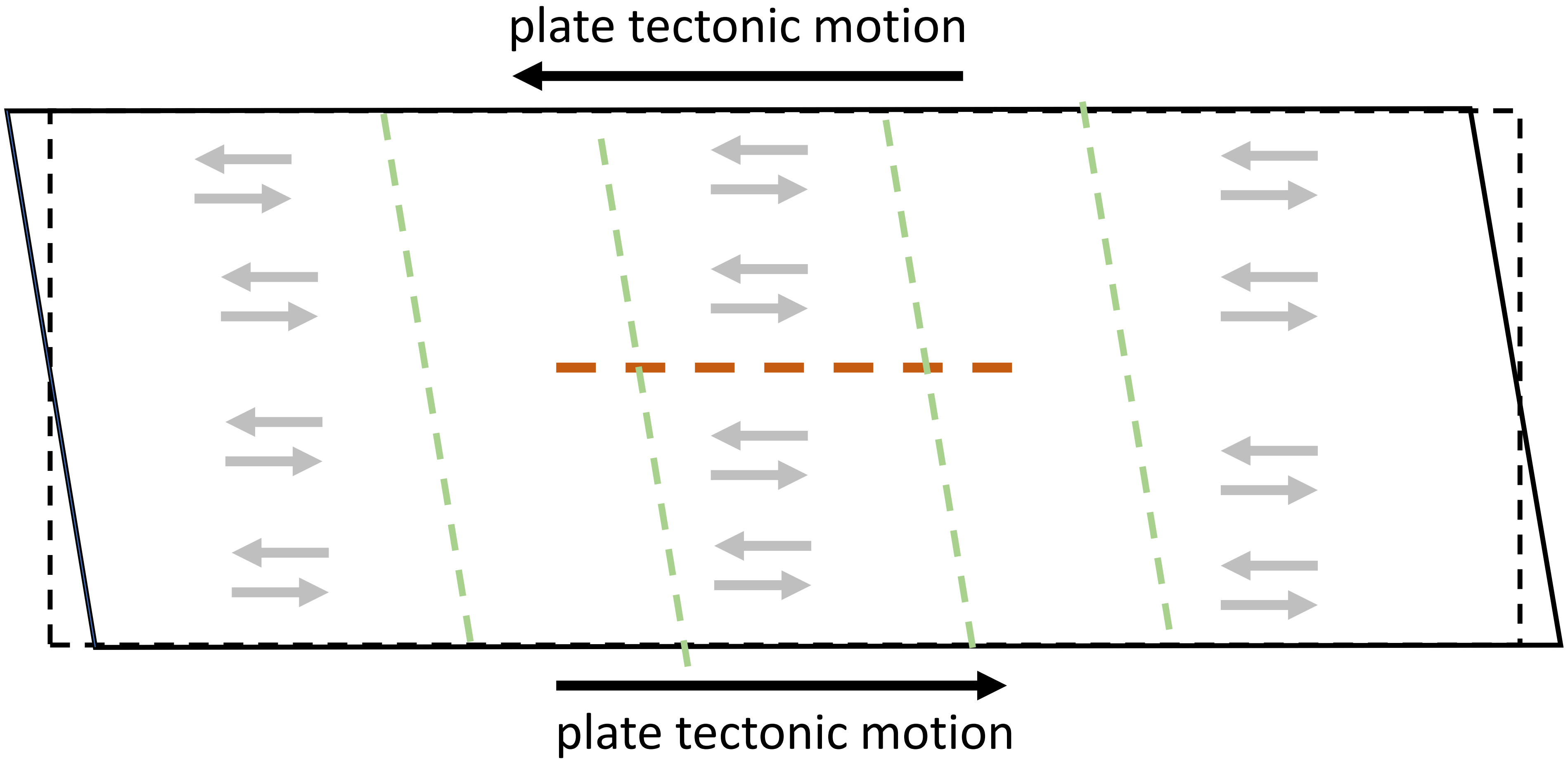
Huge earthquake
100 m of slip
on a fault 1000 km long
magnitude 9.7

Earthquake: Releases shear stress near the fault

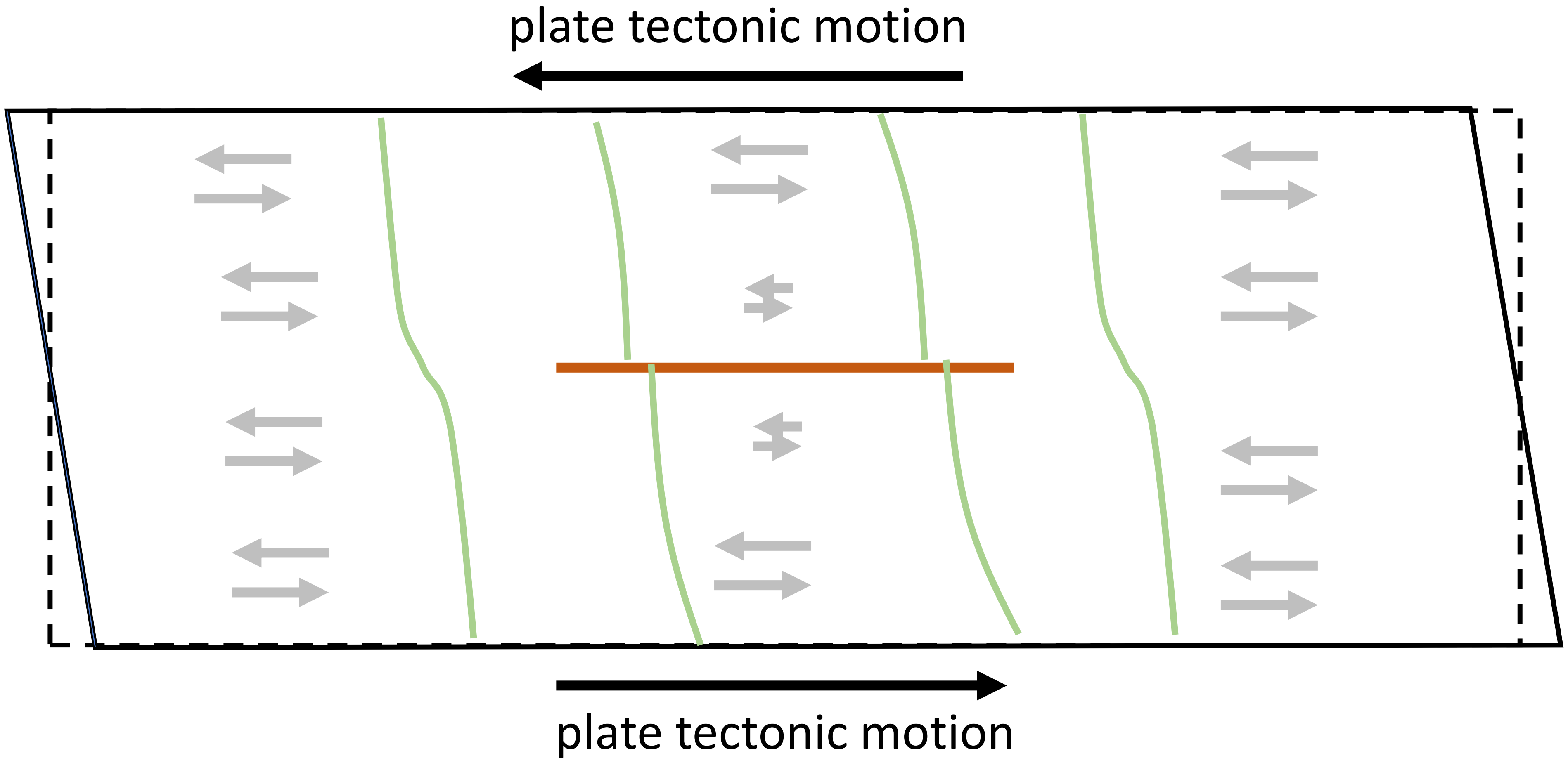
no slip, no stress



no slip, stress



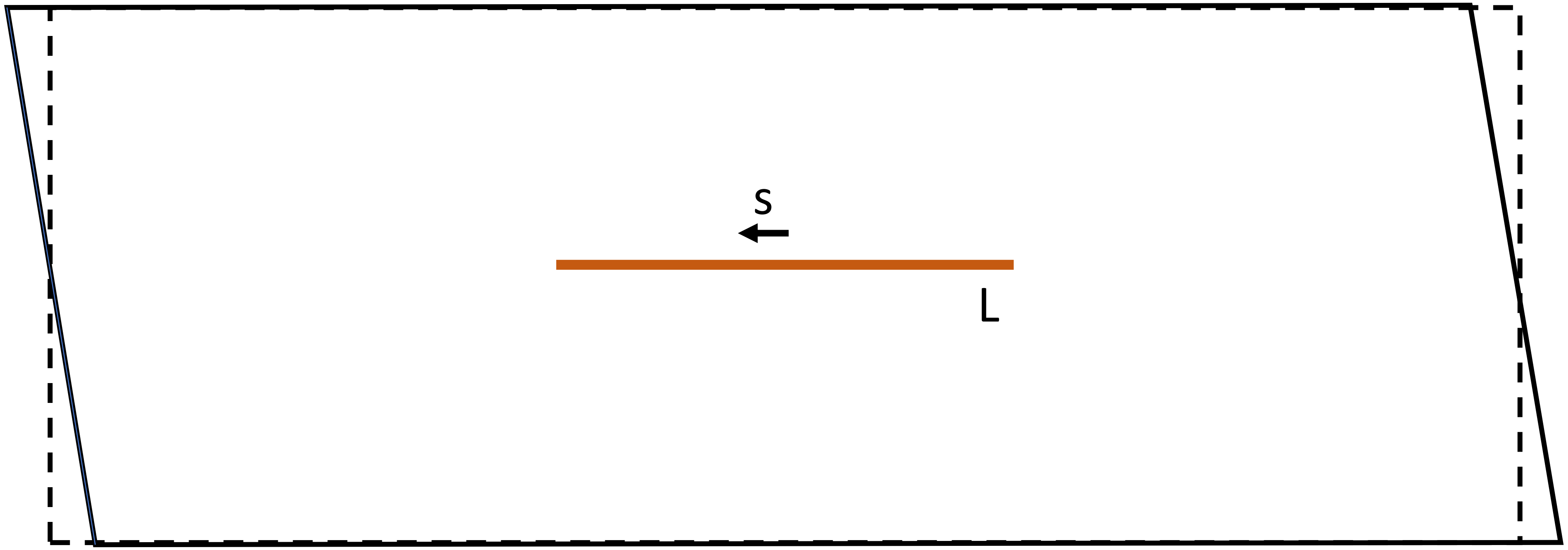
slip, reduced stress



(roughly)

drop in strain: s/L

drop in shear stress: $\mu s/L$

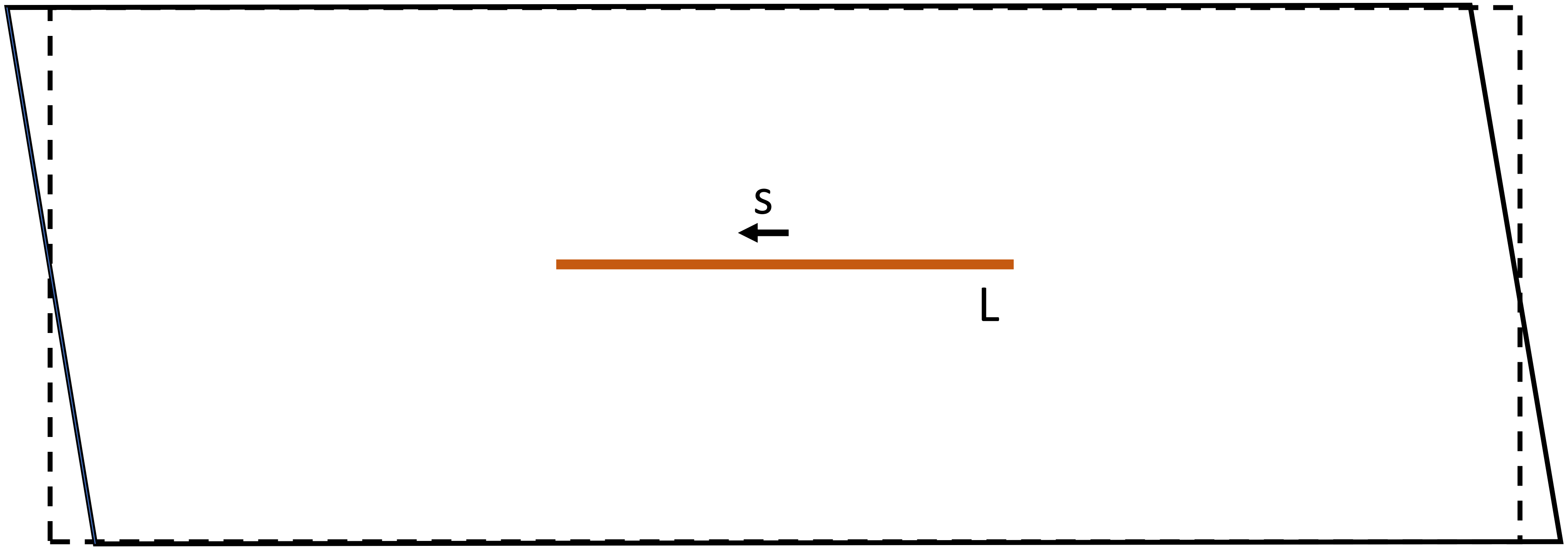


(roughly)

drop in shear stress: $\mu s/L$

$$M_0 \approx \mu sLW \approx \mu sL^2 \quad (\text{if } L \approx W)$$

$$L \approx T/V_r$$

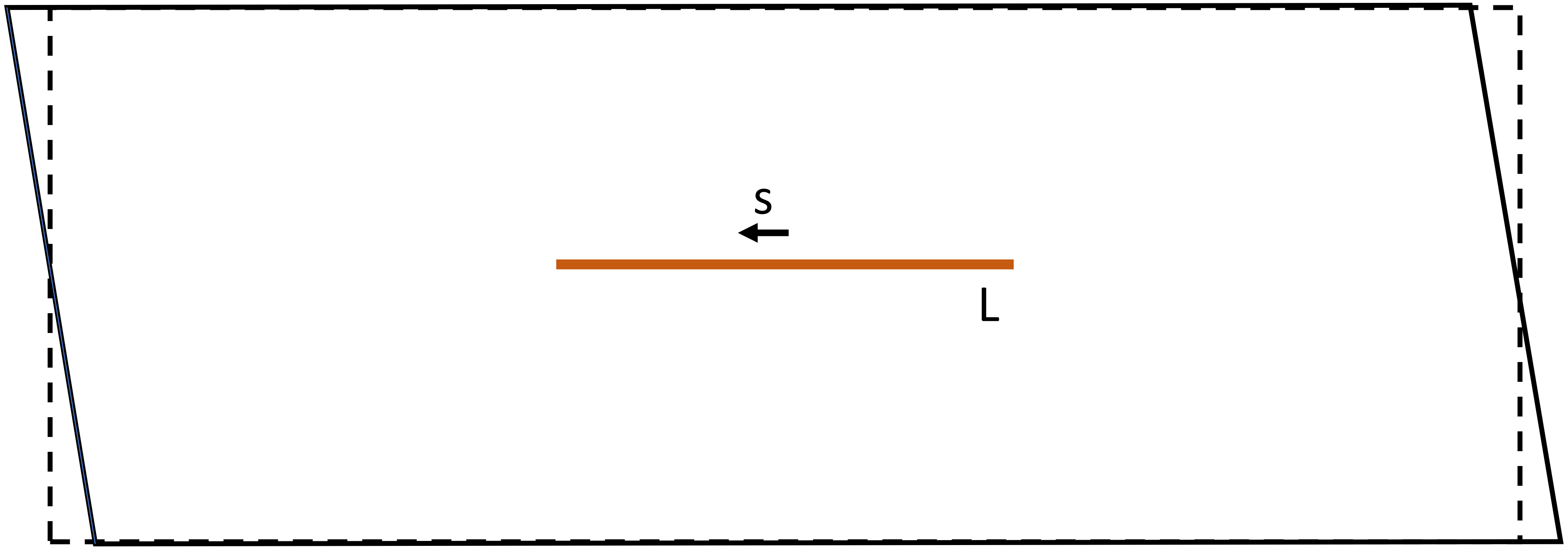


(roughly)

drop in shear stress: $\mu s/L$

$$\mu s \approx \frac{M_0}{L^2}$$

$$L \approx T/V_r$$

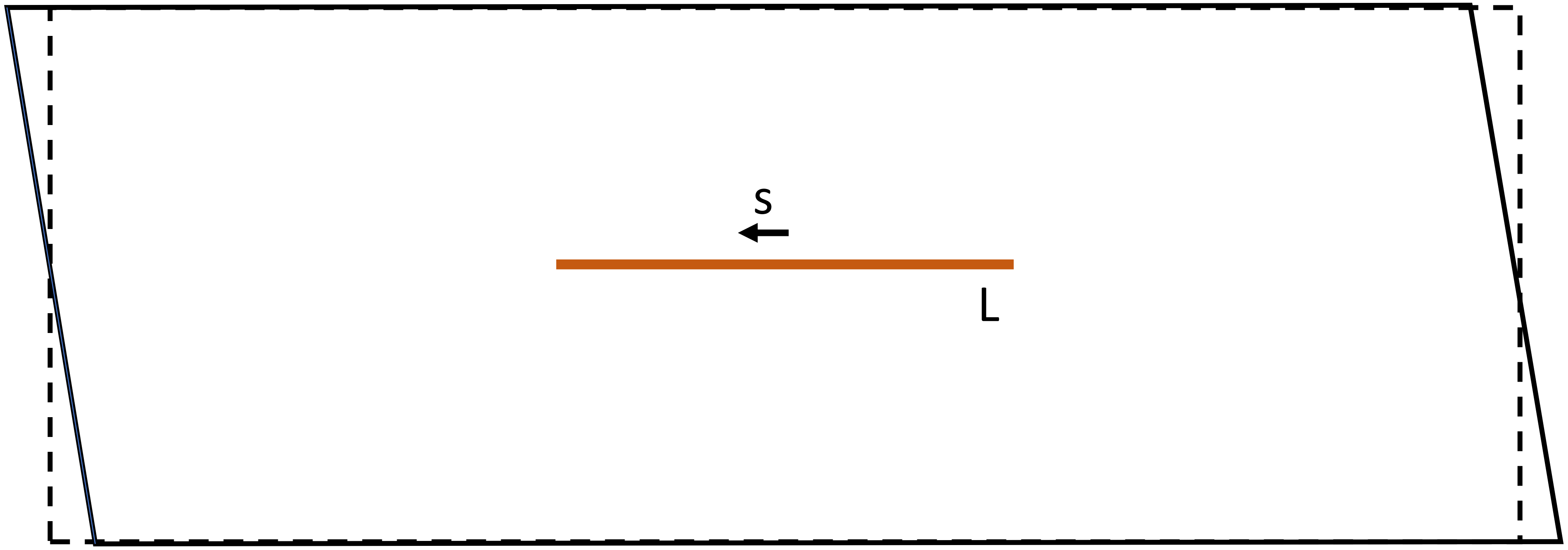


(roughly)

drop in shear stress: $\mu s/L$

$$\frac{\mu s}{L} \approx \frac{M_0}{L^3}$$

$$L \approx T/V_r$$

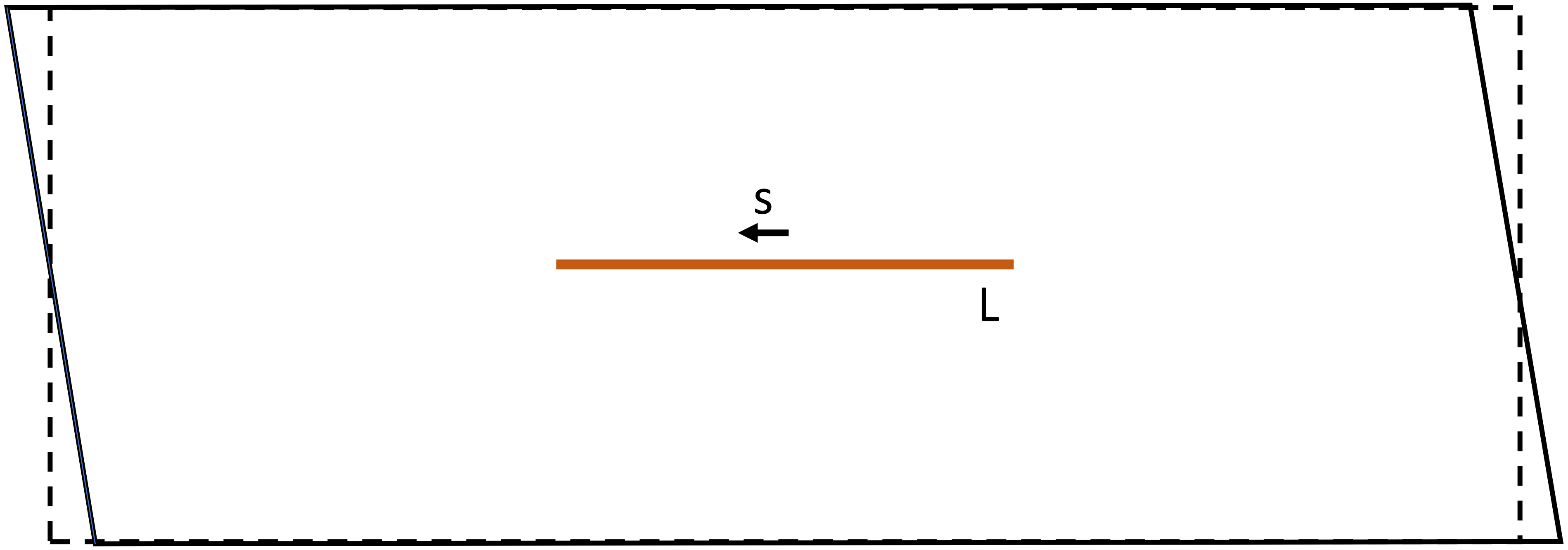


(roughly)

drop in shear stress: $\mu s/L$

$$\frac{\mu s}{L} \approx \frac{M_0}{(T/V_r)^3} \approx \frac{M_0}{(T/\beta)^3} \quad (\text{if } V_r \approx \beta)$$

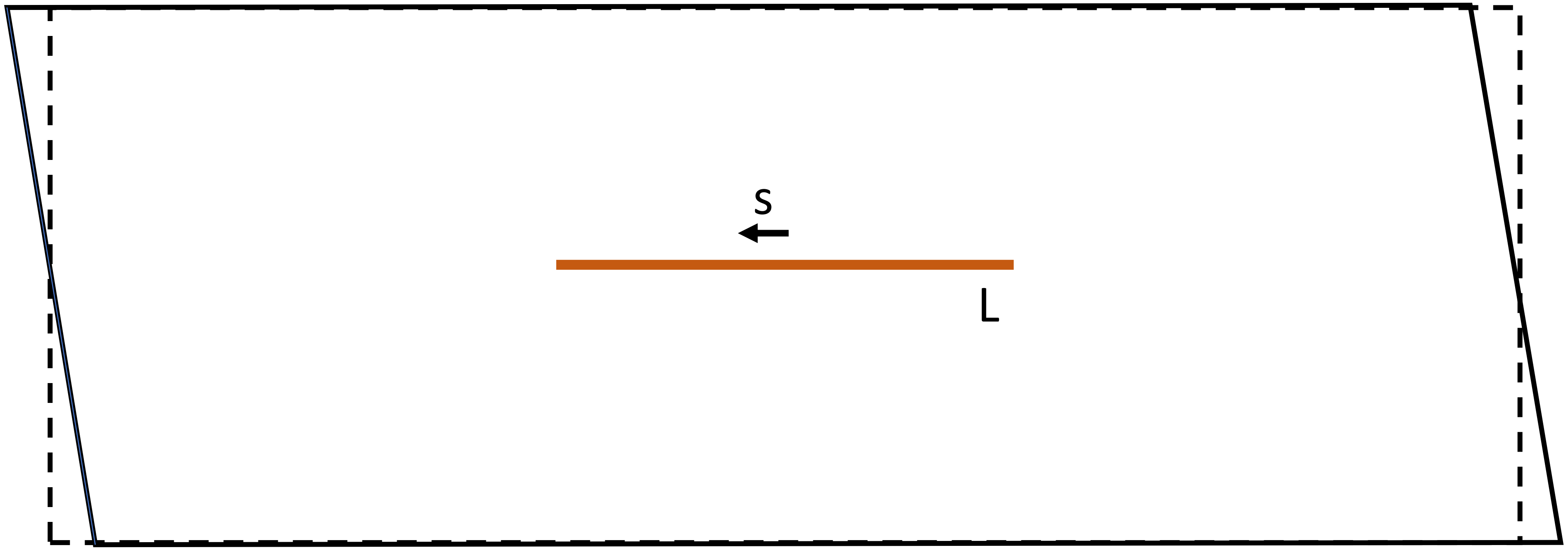
$L \approx T/V_r$

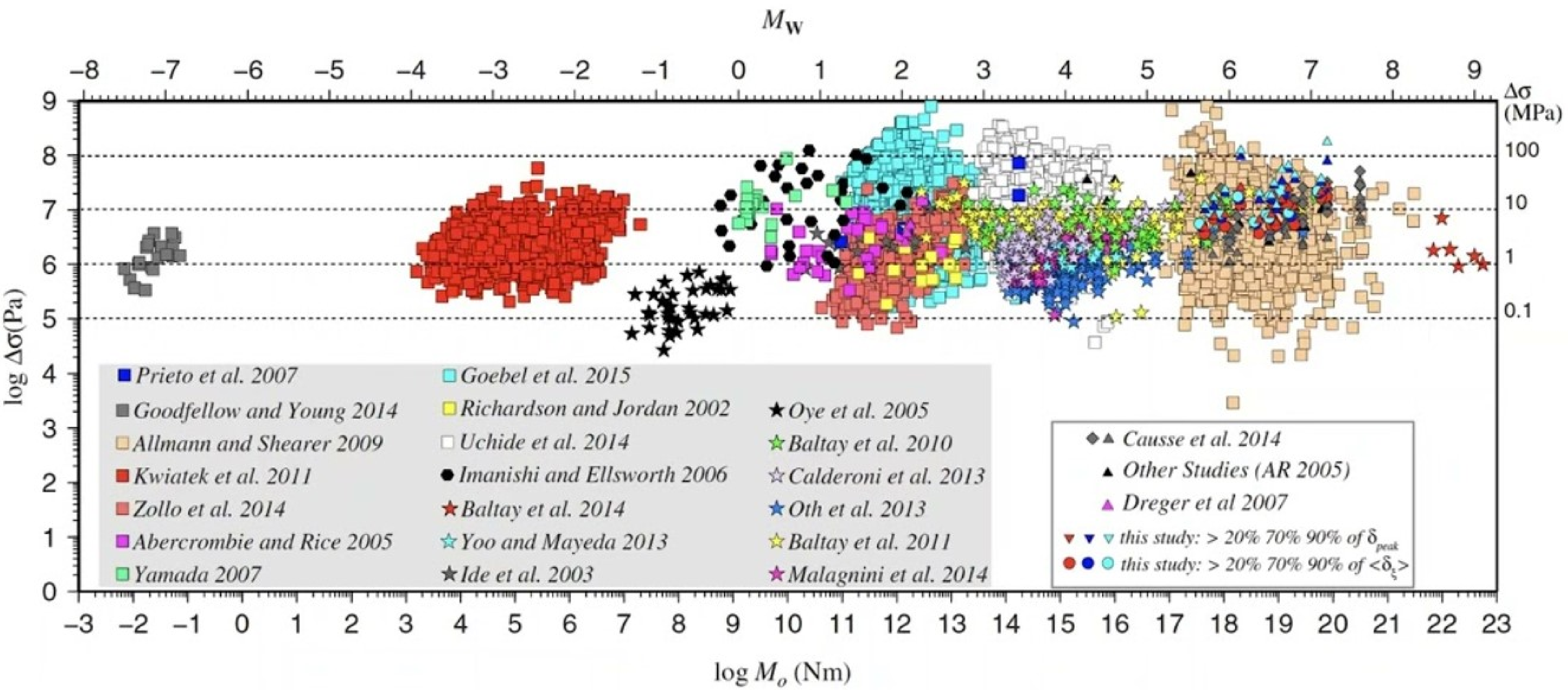


(roughly)

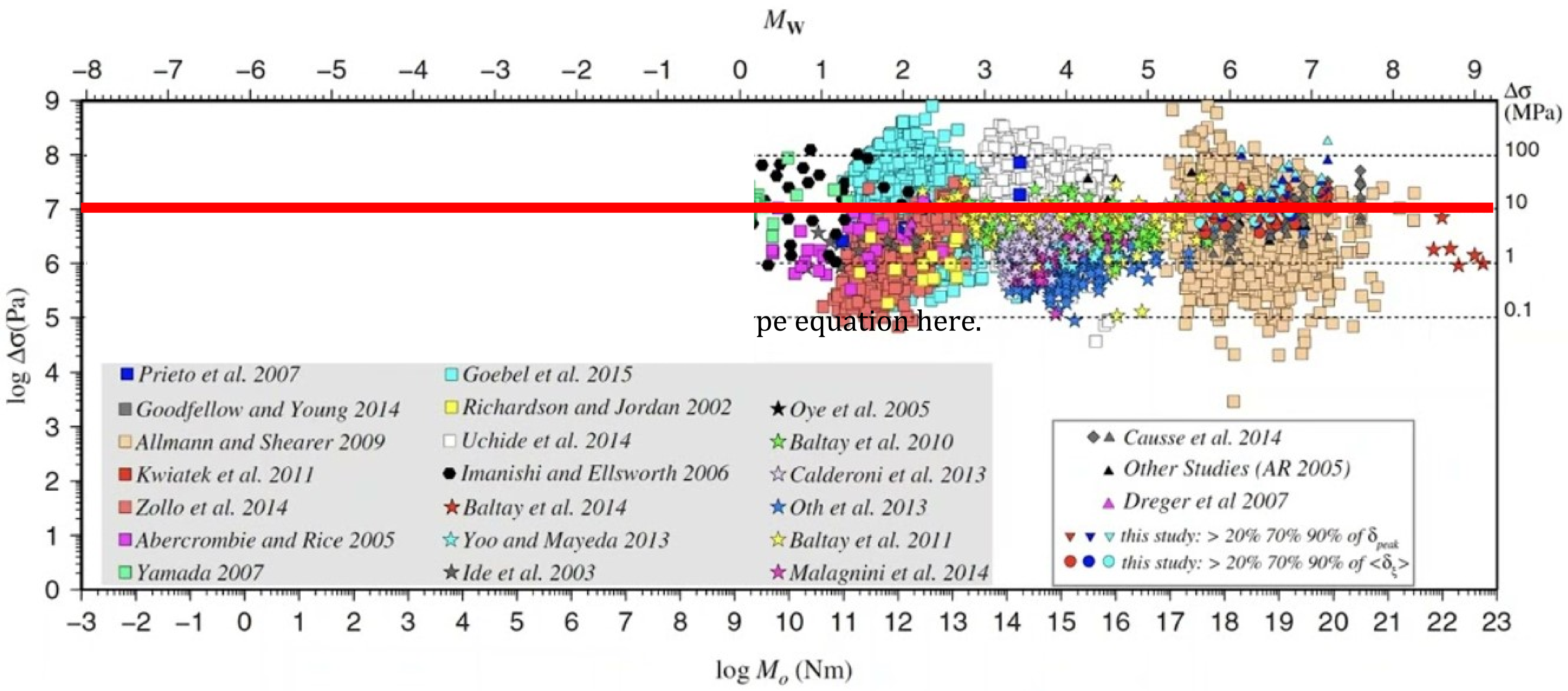
drop in shear stress can be measured seismologically

$$\Delta\sigma \approx \frac{M_0}{(T/\beta)^3}$$





M_W
$\Delta\sigma$ (MPa)
log $\Delta\sigma$(Pa)
log M_o (Nm)
Prieto et al. 2007
Goodfellow and Young 2014
Allmann and Shearer 2009
Kwiatek et al. 2011
Zollo et al. 2014
Abercrombie and Rice 2005
Yamada 2007
Goebel et al. 2015
Richardson and Jordan 2002
Uchide et al. 2014
Imanishi and Ellsworth 2006
Baltay et al. 2014
Yoo and Mayeda 2013
Ide et al. 2003
Oye et al. 2005
Baltay et al. 2010
Calderoni et al. 2013
Oth et al. 2013
Baltay et al. 2011
Malagnini et al. 2014
Causse et al. 2014
Other Studies (AR 2005)
Dreger et al 2007
this study: > 20% 70% 90% of δ_{peak}
this study: > 20% 70% 90% of $\langle\delta_\xi\rangle$



1×10^7 Pa $\approx$ 100 atm

(relatively low stress, relatively constant with earthquake size)

Another interesting tidbit

earthquake is releasing stress from plate tectonic motion that has *already happened*

and GPS measusrements show that plate tectonic motions
(away from the plate edges)

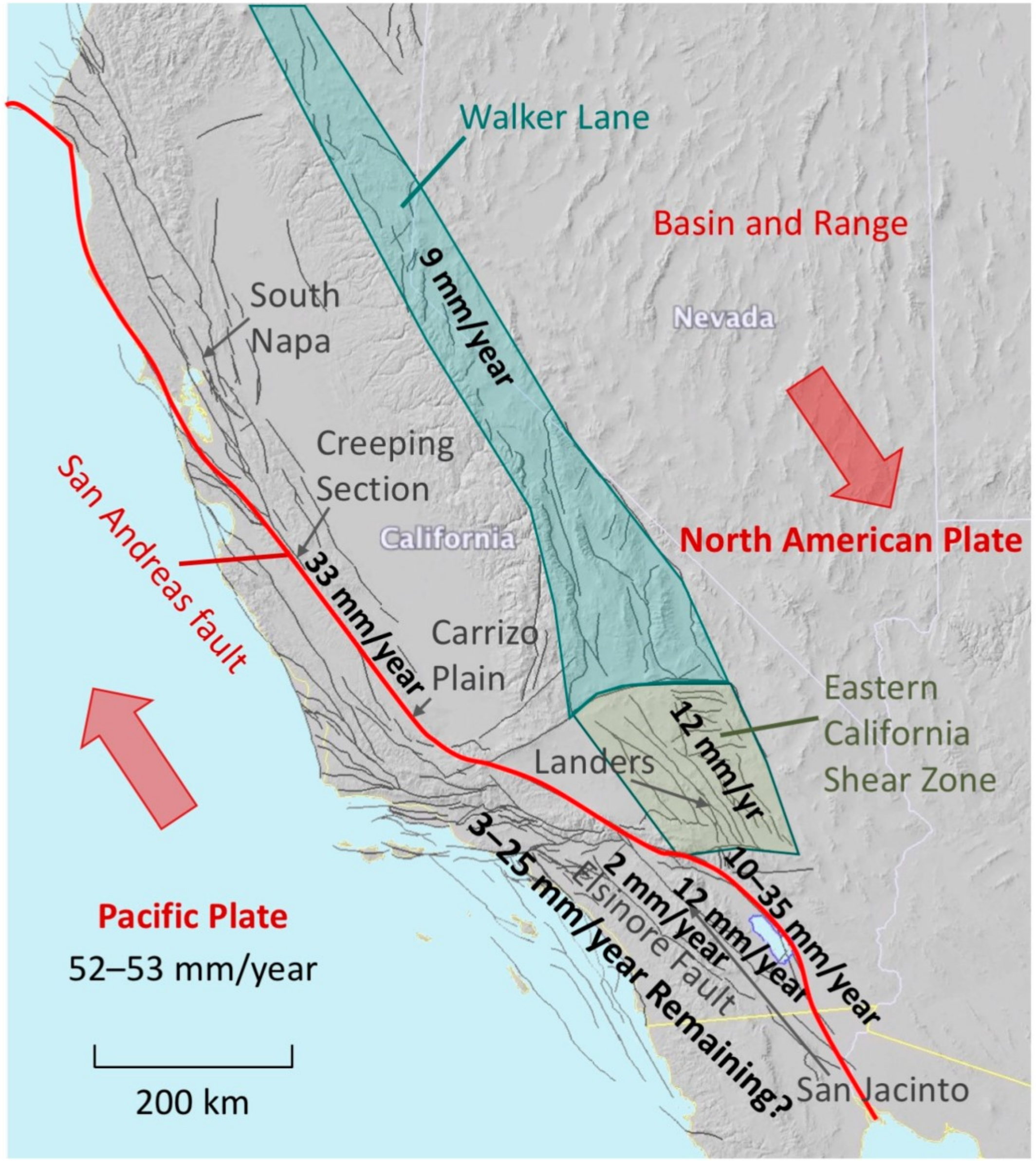
are occurring at a near-constant rate

Mean Recurrence Time of Earthquakes

typical slip for the fault in question

divided by

rate of plate motion



northern San Andreas Fault (SAF)

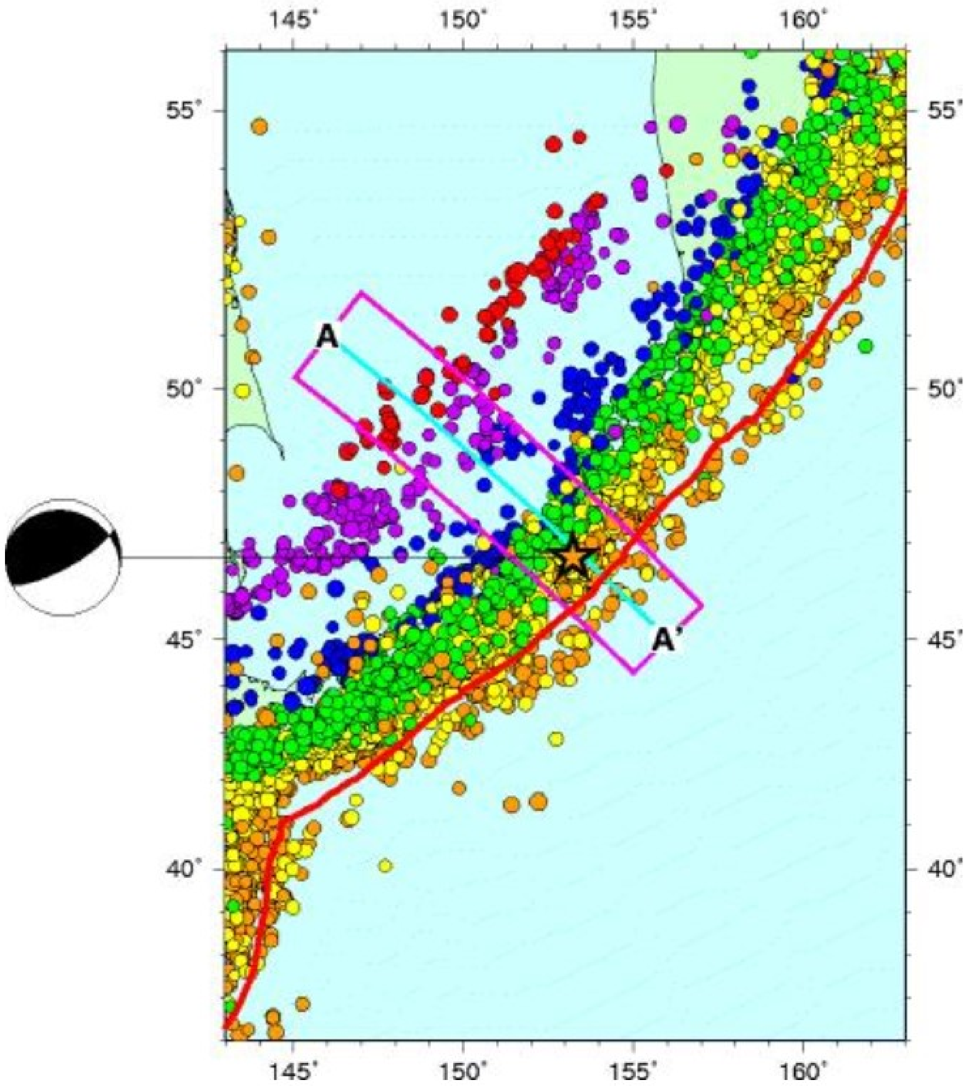
North-American Pacific 52 mm/yr
but some accommodated east of SAF
about 33 for SAF

1906 Magntude 7.7 earthquake
maximum slip 9.7 m
but average is less, say 5 m
(= 5000 mm)

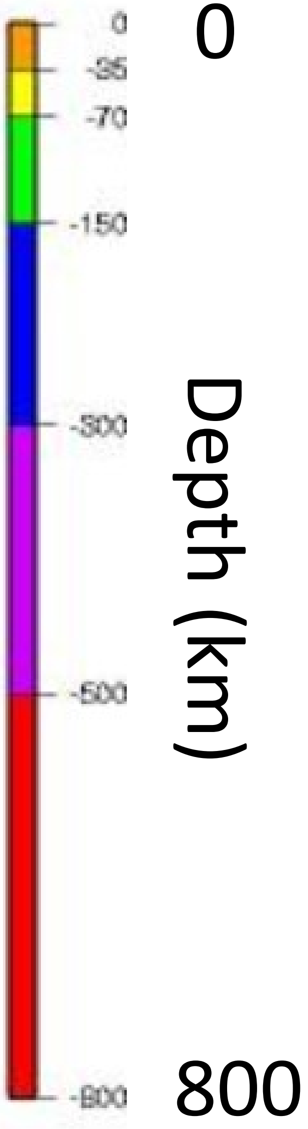
Recurrence time
5000/33 = 151 years

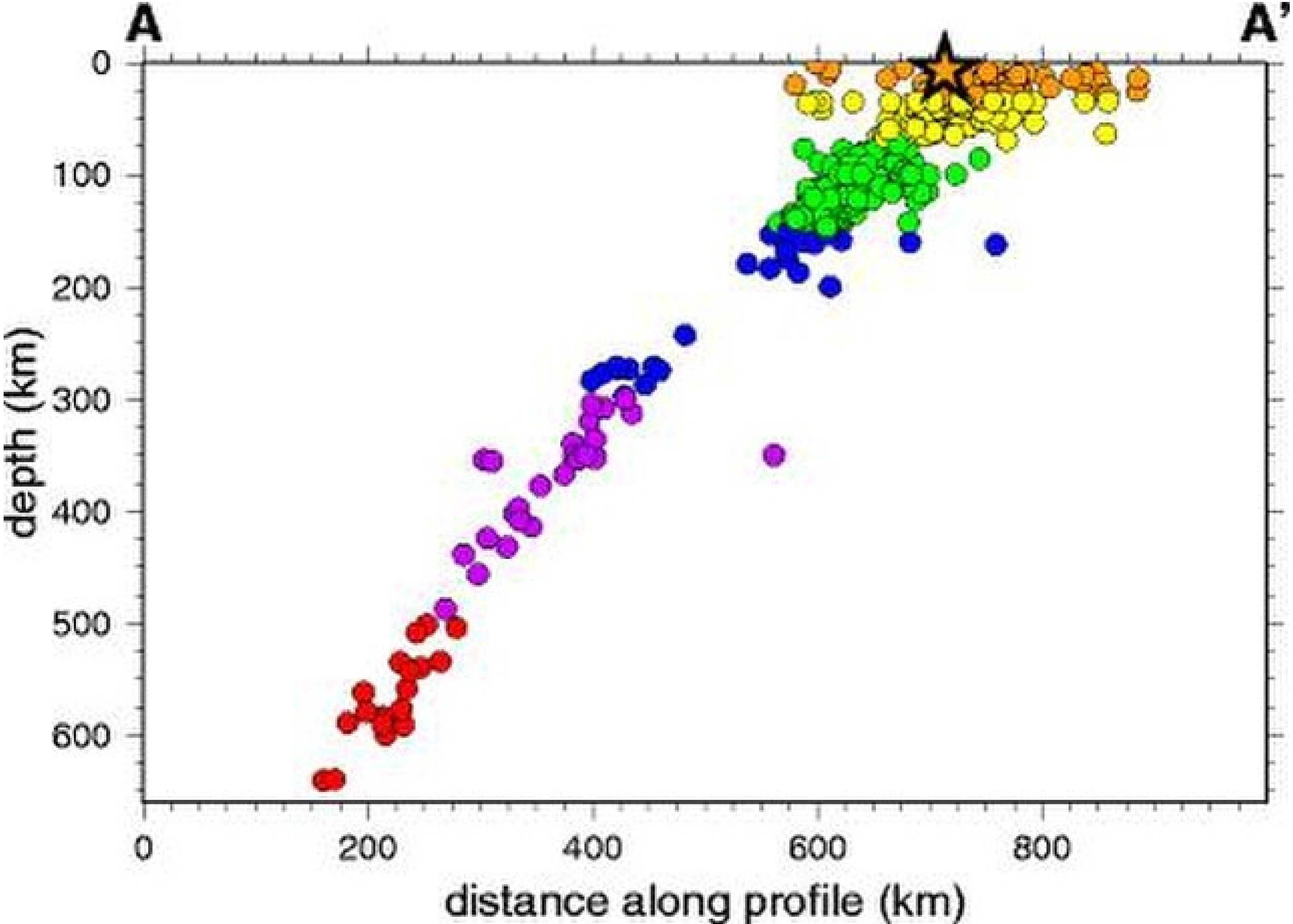
Seismotectonics

subduction zones

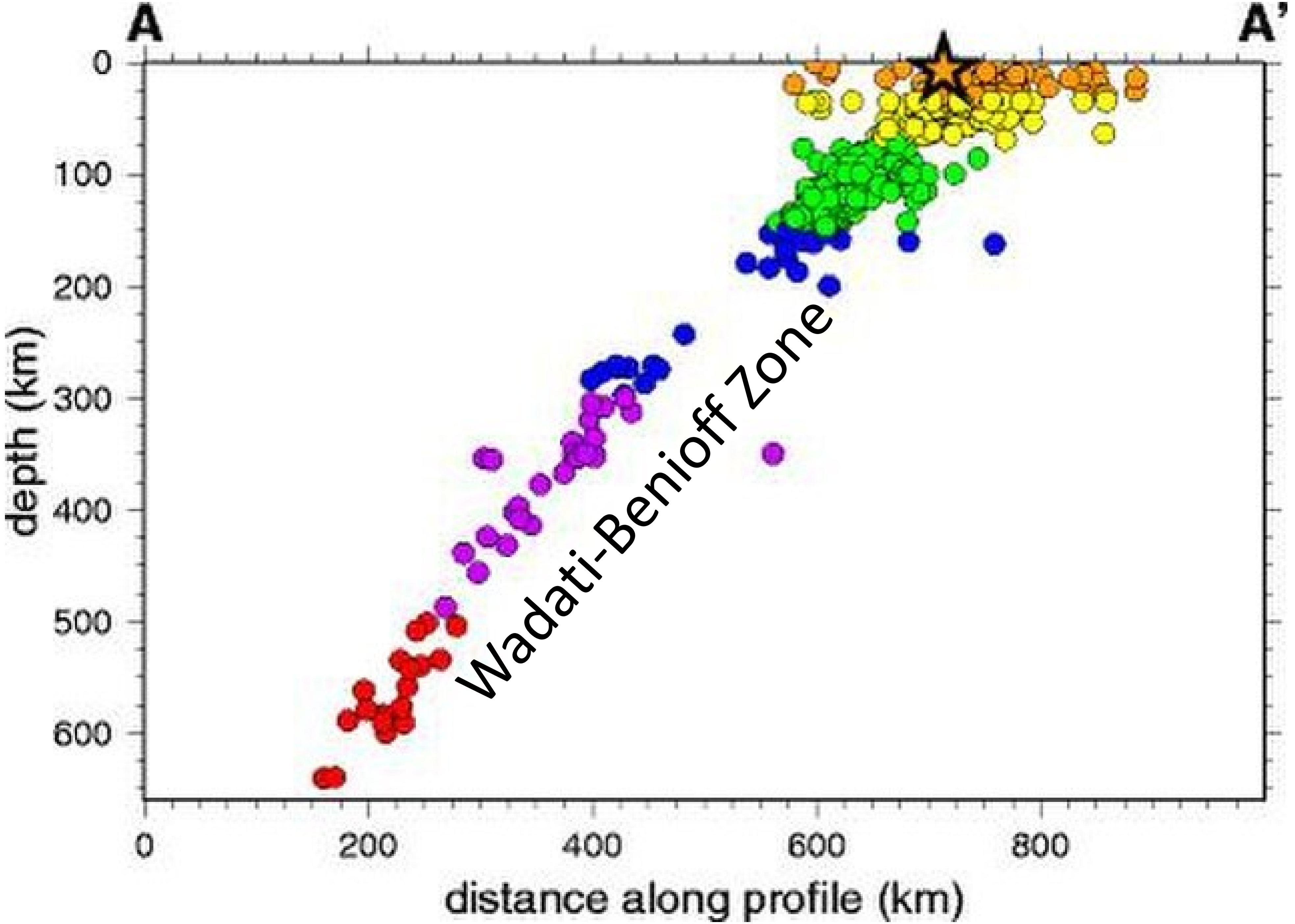


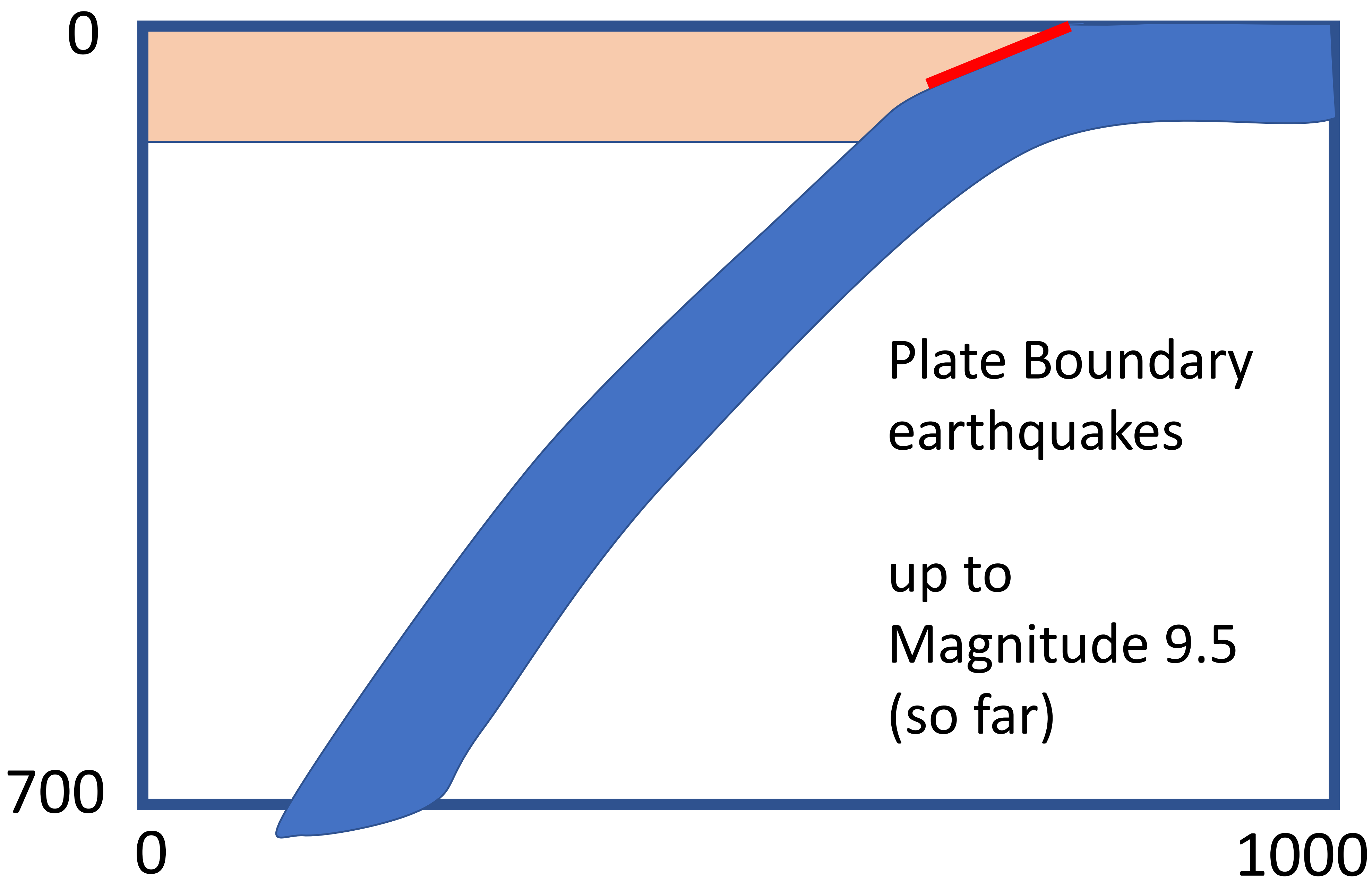
No higher resolution available.

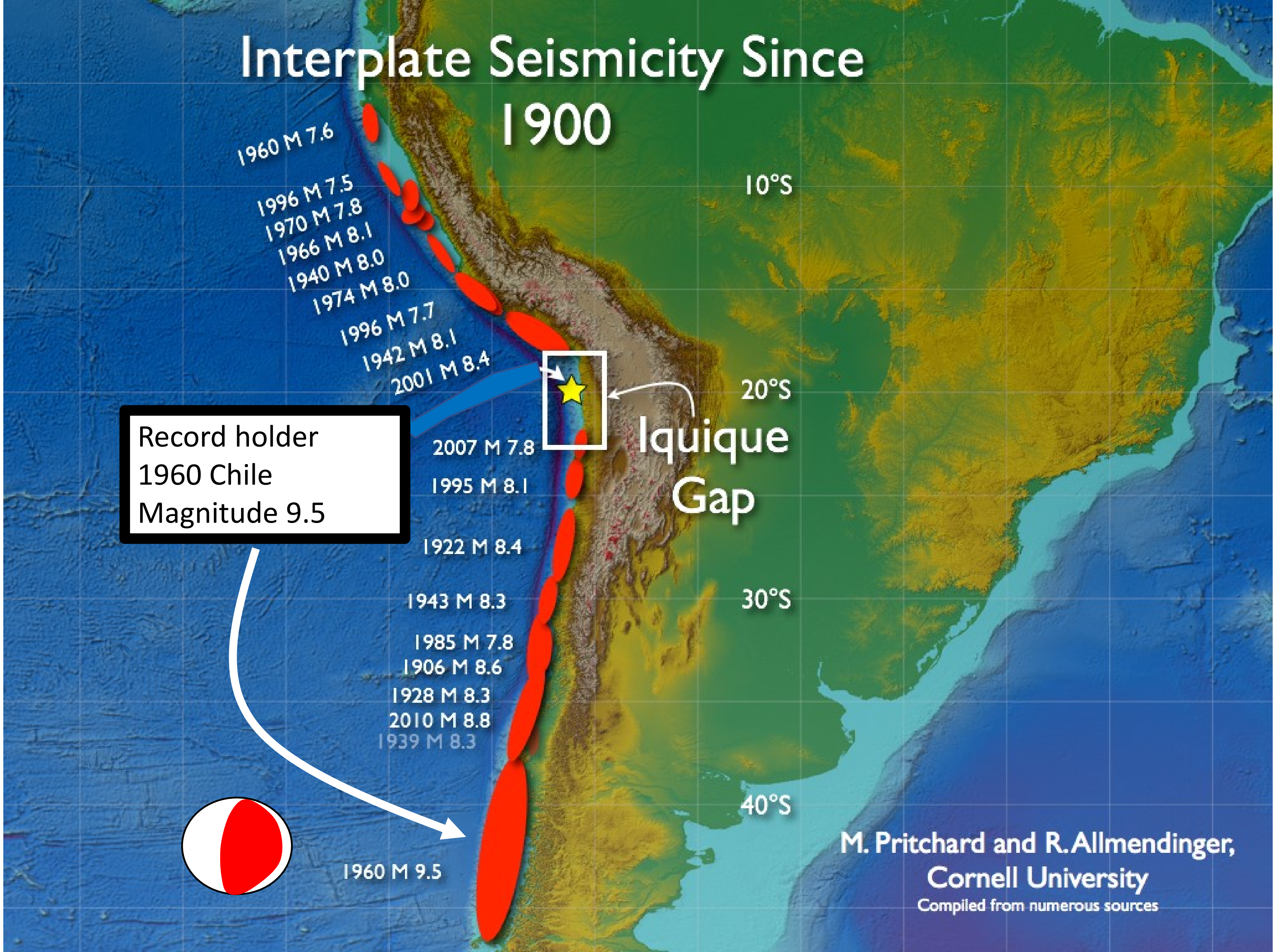


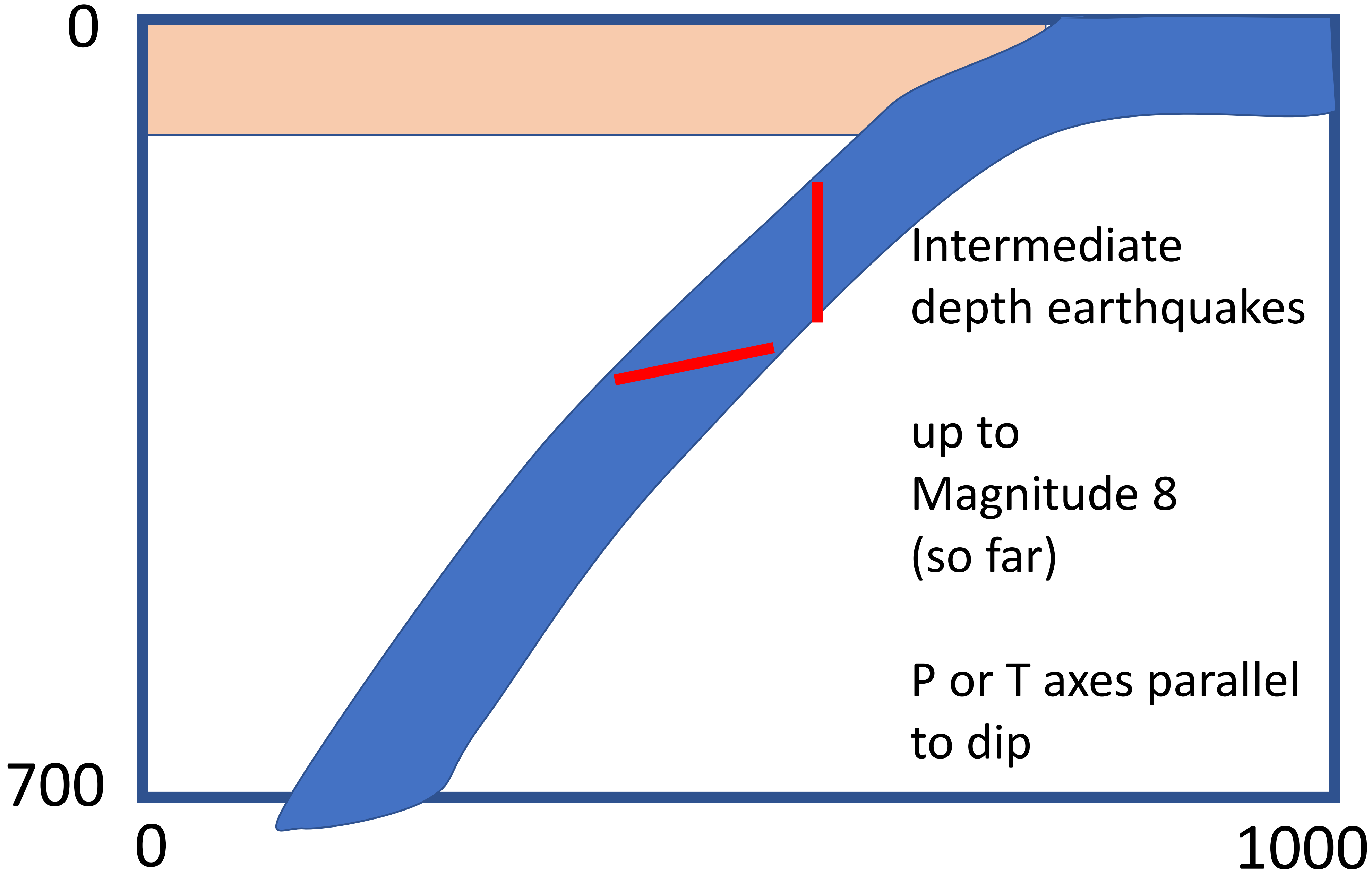


A
A’
0
100
200
300
400
500
600
depth (km)
0
200
400
600
800
distance along profile (km)


A
A'
Wadati-Benioff Zone
depth (km)
0
100
200
300
400
500
600
0
200
400
600
800
distance along profile (km)


0
700
0
1000
Plate Boundary
earthquakes
up to
Magnitude 9.5
(so far)

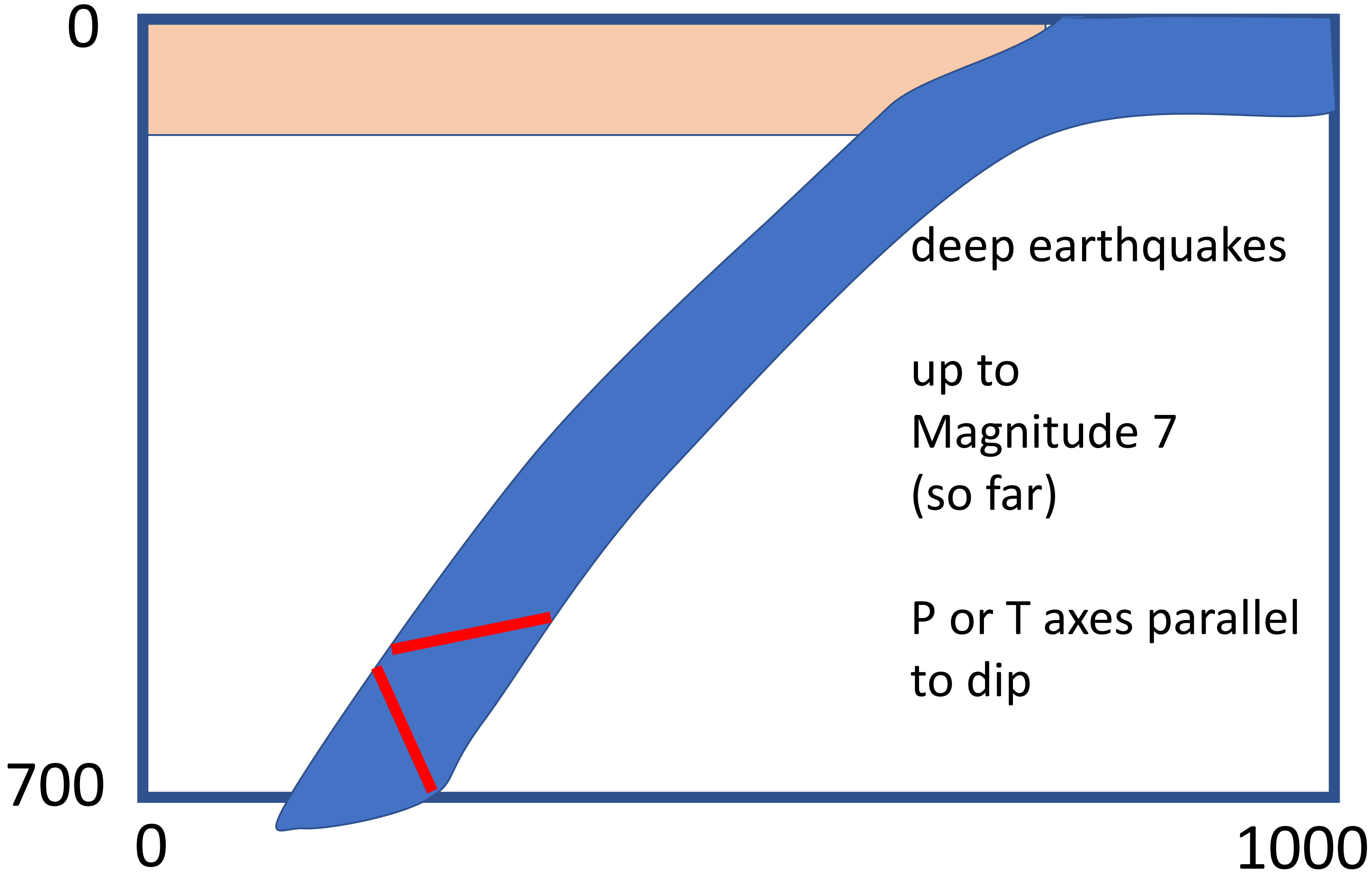

Interplate Seismicity Since 1900
10°S
20°S
30°S
40°S
1960 M 7.6
1996 M 7.5
1970 M 7.8
1966 M 8.1
1940 M 8.0
1974 M 8.0
1996 M 7.7
1942 M 8.1
2001 M 8.4
Record holder
1960 Chile
Magnitude 9.5
2007 M 7.8
1995 M 8.1
1922 M 8.4
1943 M 8.3
1985 M 7.8
1906 M 8.6
1928 M 8.3
2010 M 8.8
1939 M 8.3
1960 M 9.5
Iquique
Gap
M. Pritchard and R. Allmendinger,
Cornell University
Compiled from numerous sources

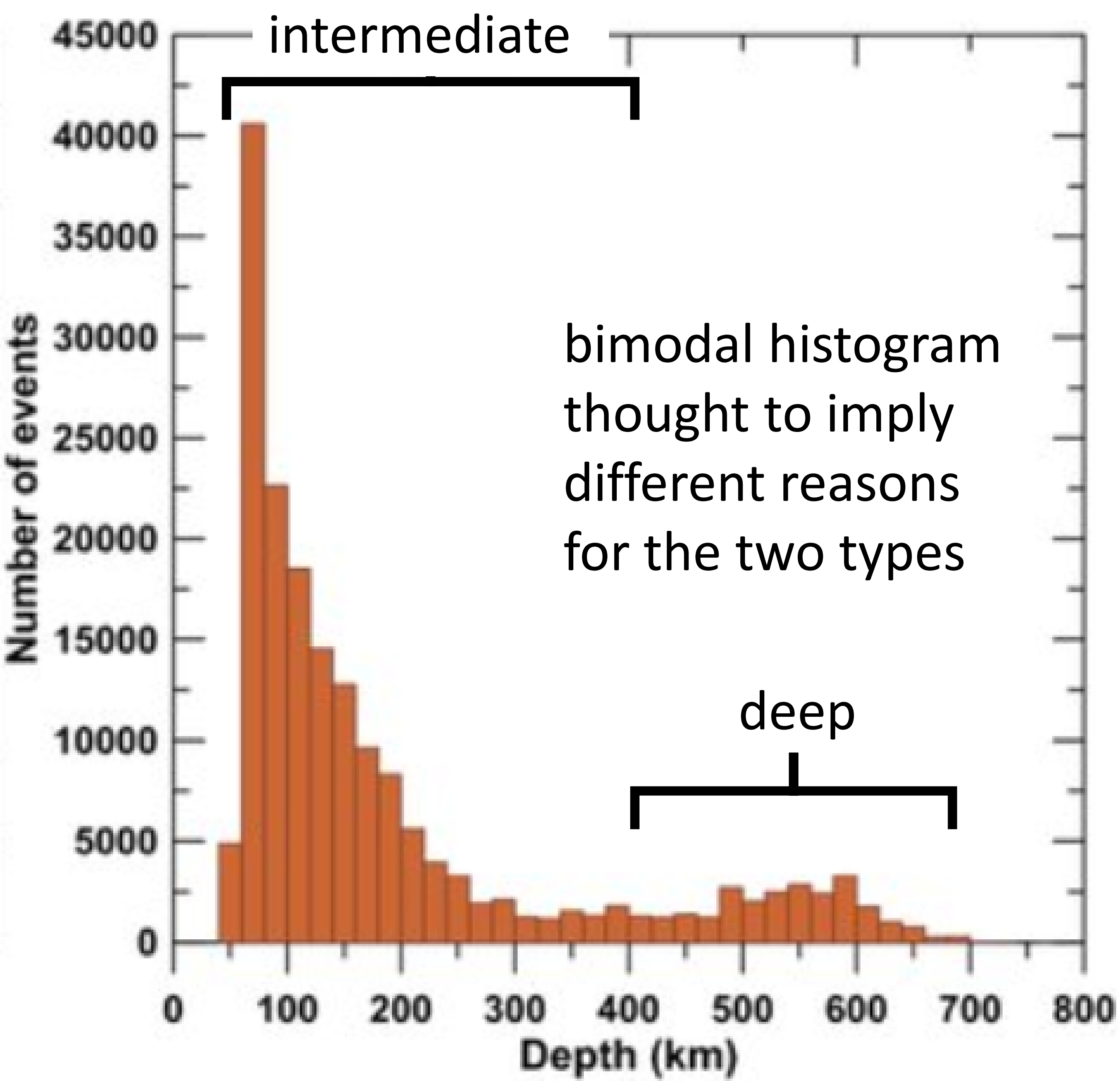


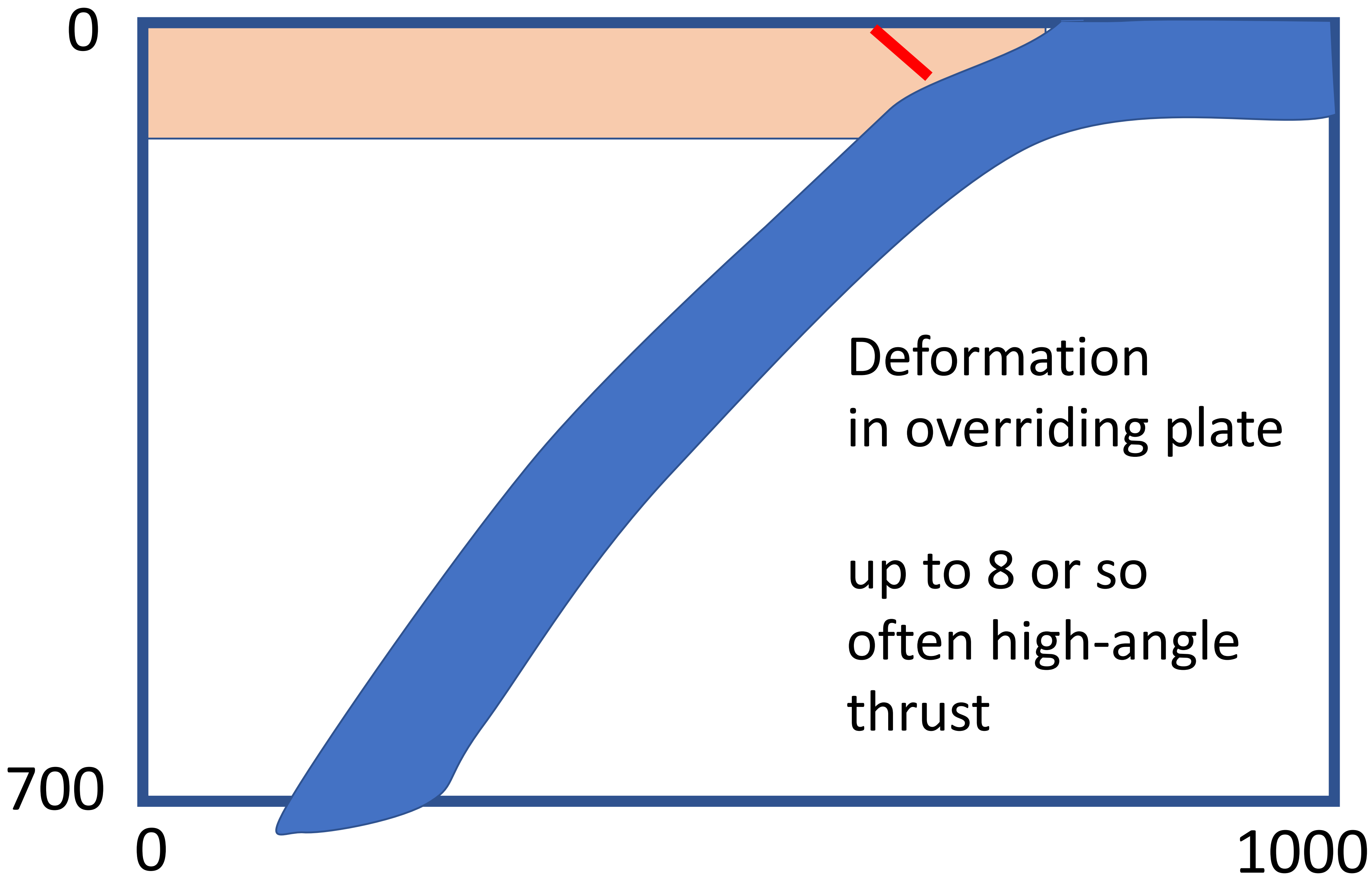
Intermediate depth earthquakes

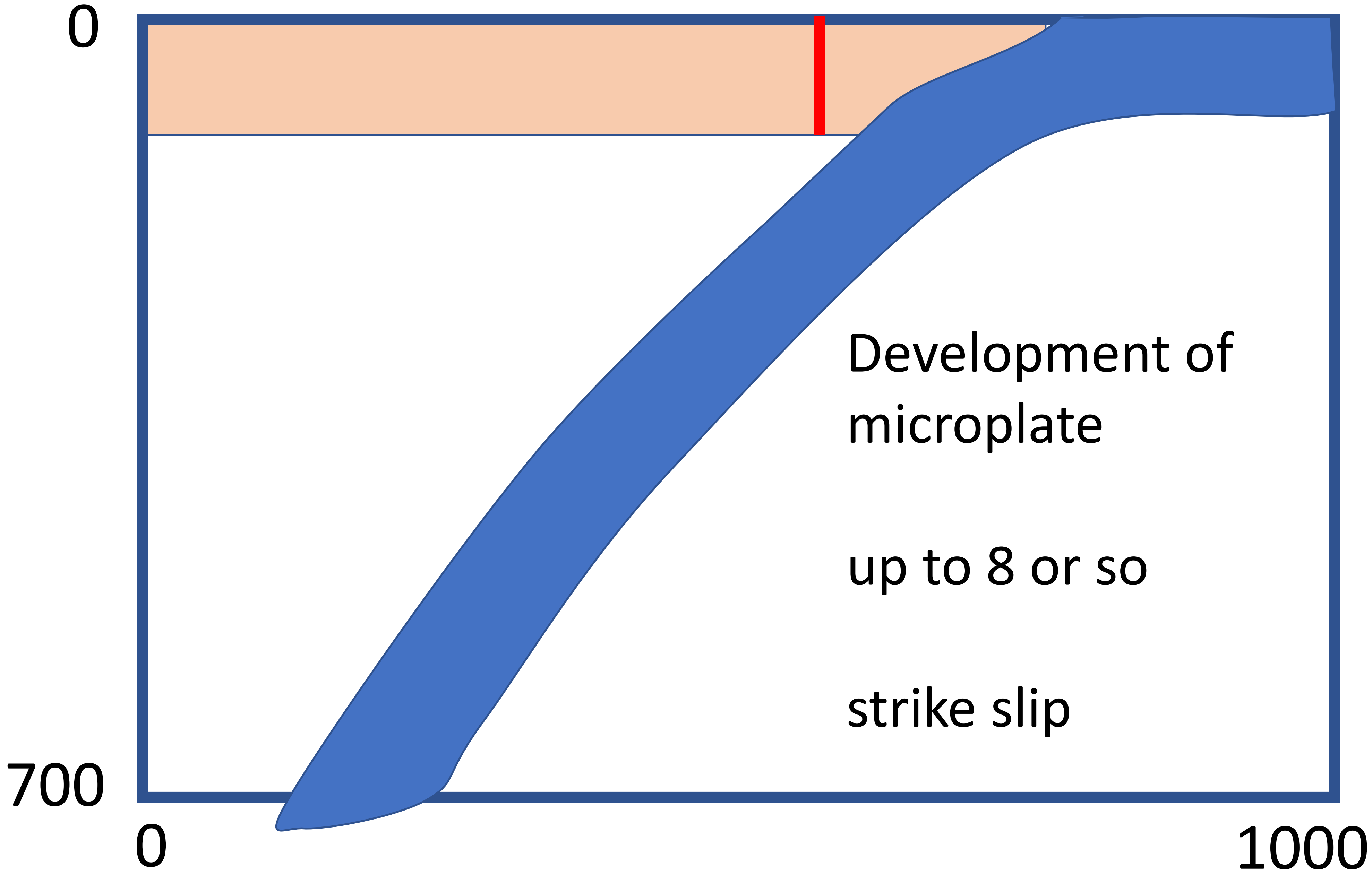
up to Magnitude 8 (so far)

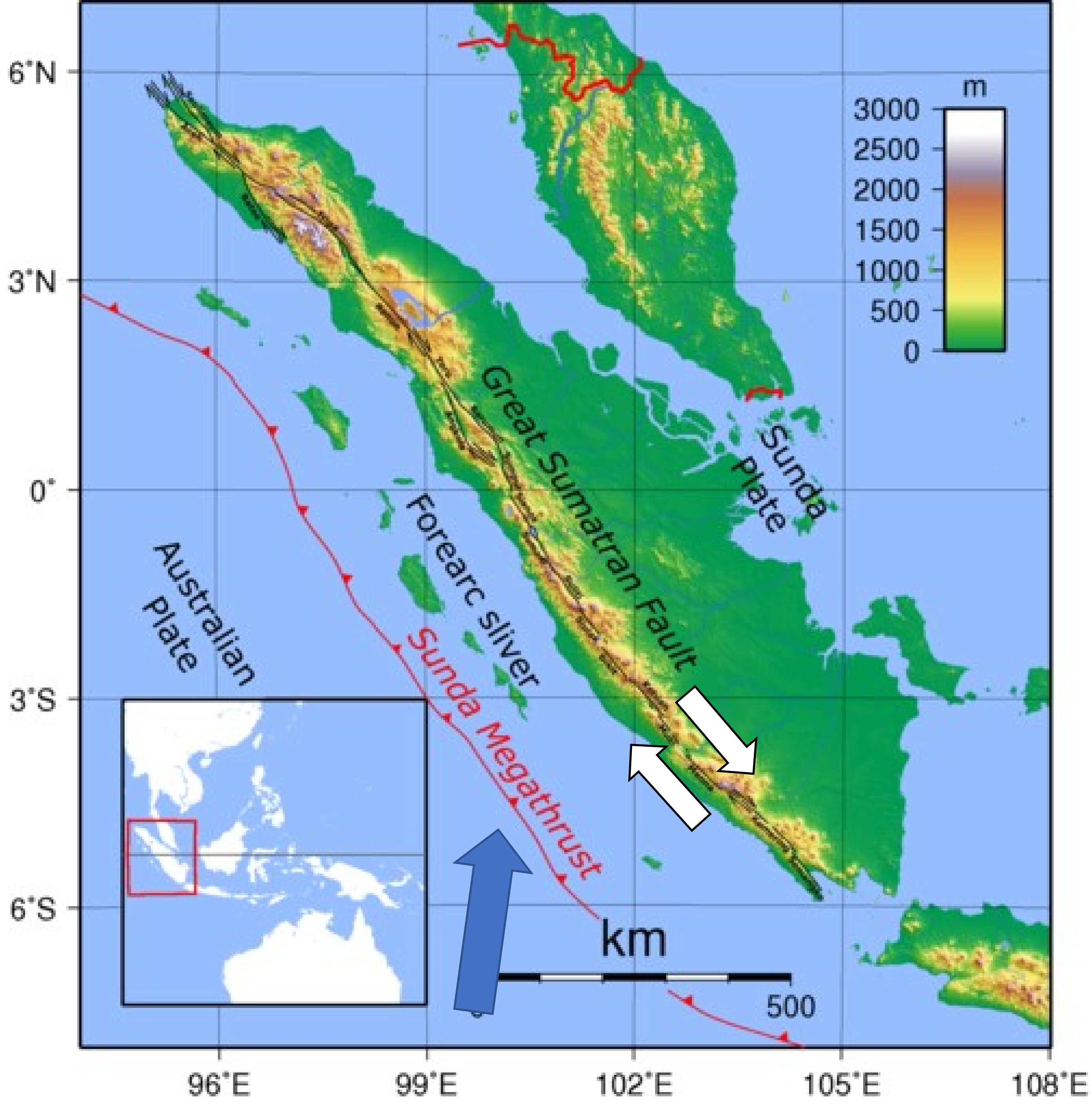
P or T axes parallel to dip


0
700
0
1000
deep earthquakes
up to
Magnitude 7
(so far)
P or T axes parallel
to dip

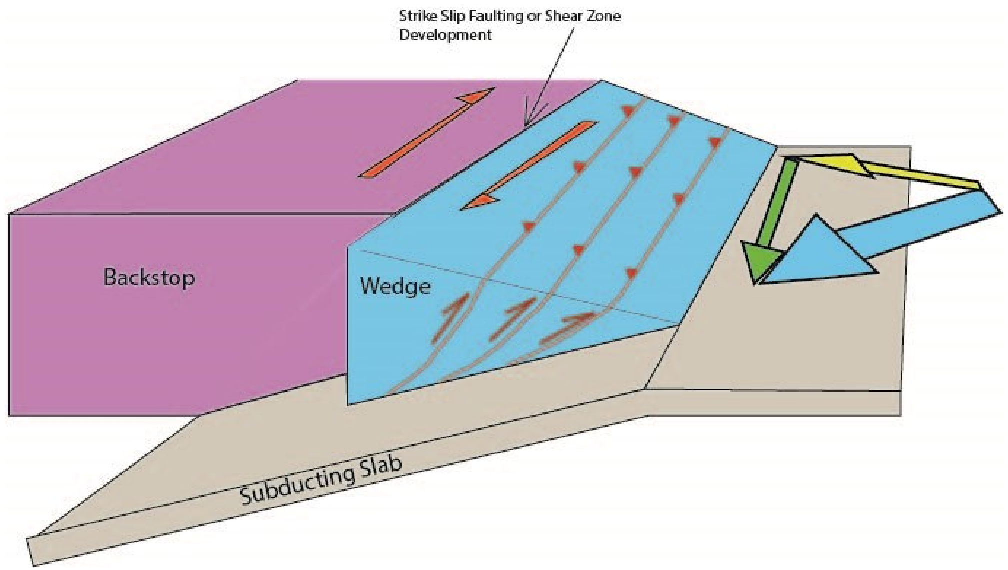

intermediate
bimodal histogram
thought to imply
different reasons
for the two types
deep
Number of events
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
Depth (km)

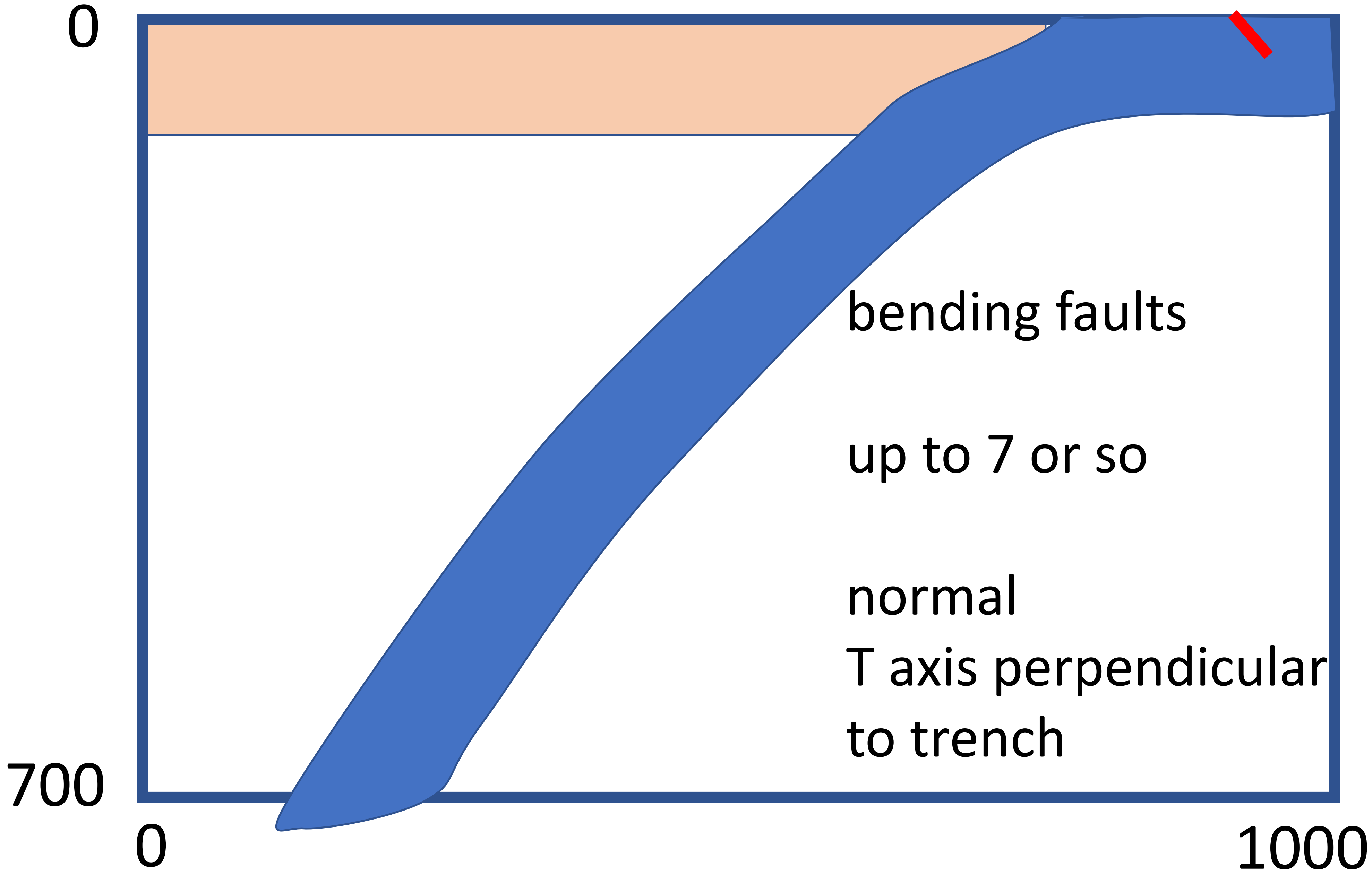

0
700
0
1000
Deformation
in overriding plate
up to 8 or so
often high-angle
thrust


0
700
0
1000
Development of microplate
up to 8 or so
strike slip

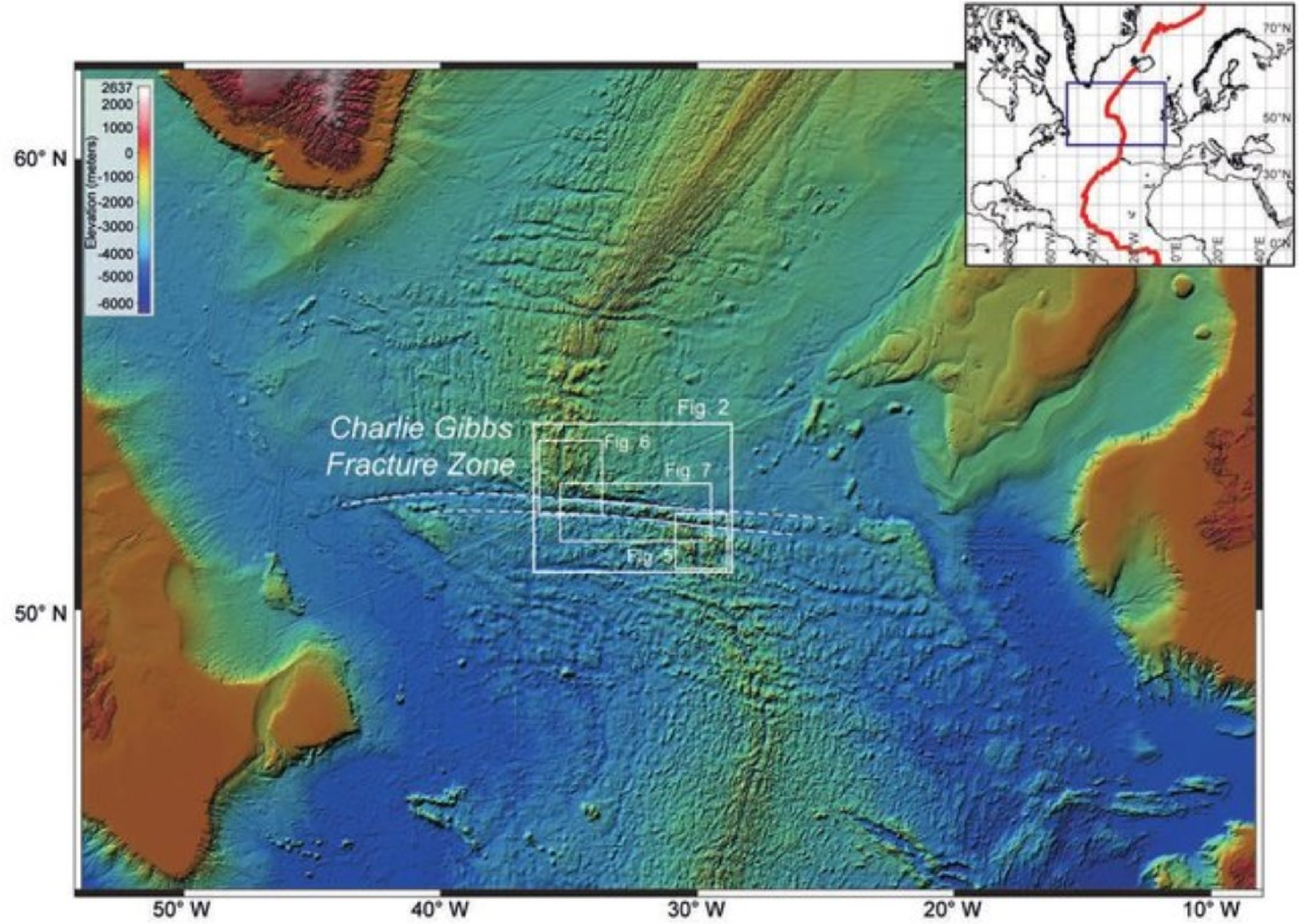


accommodates oblique subduction (strain partitioning)

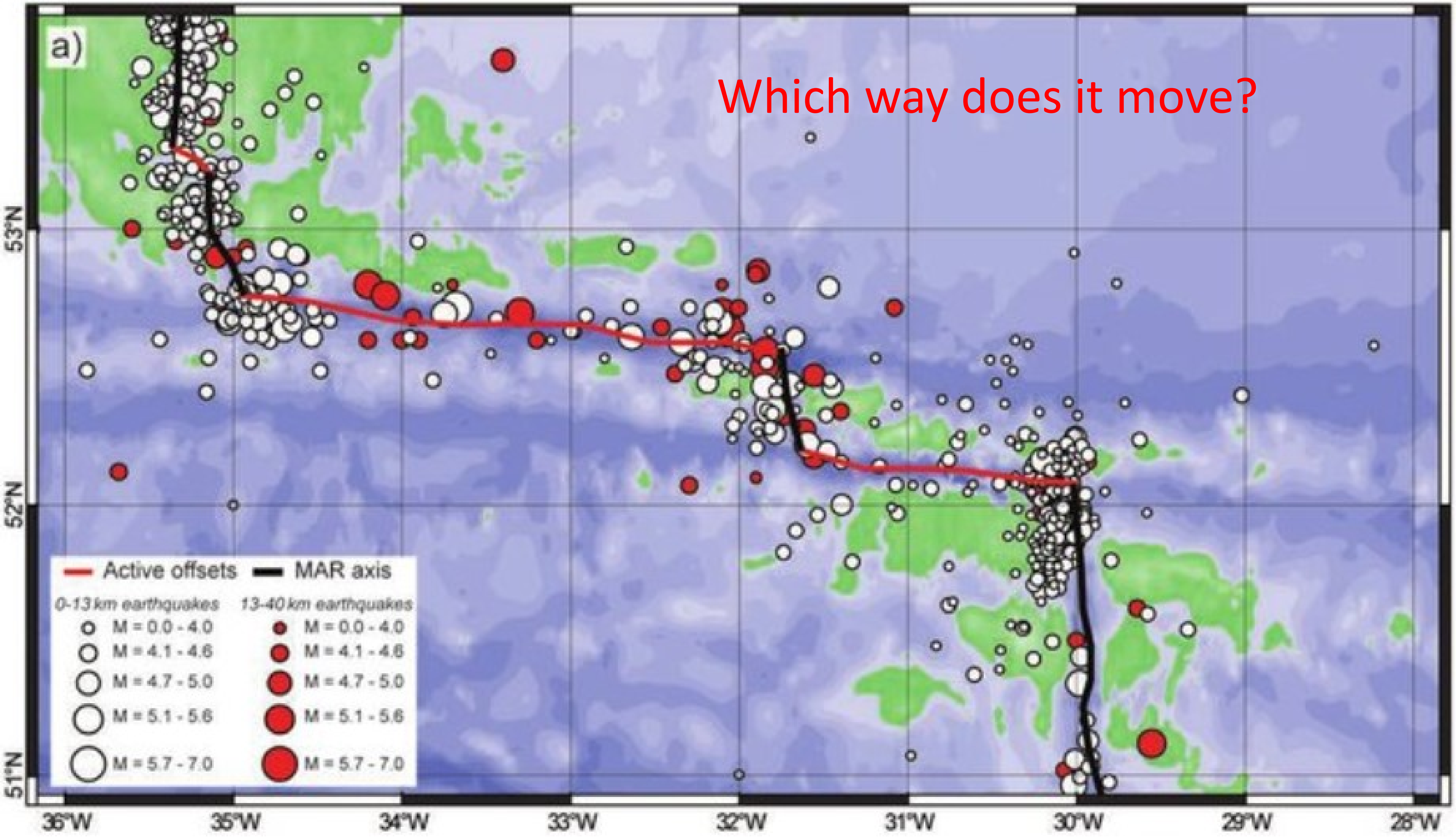



0
700
0
1000
bending faults
up to 7 or so
normal
T axis perpendicular
to trench

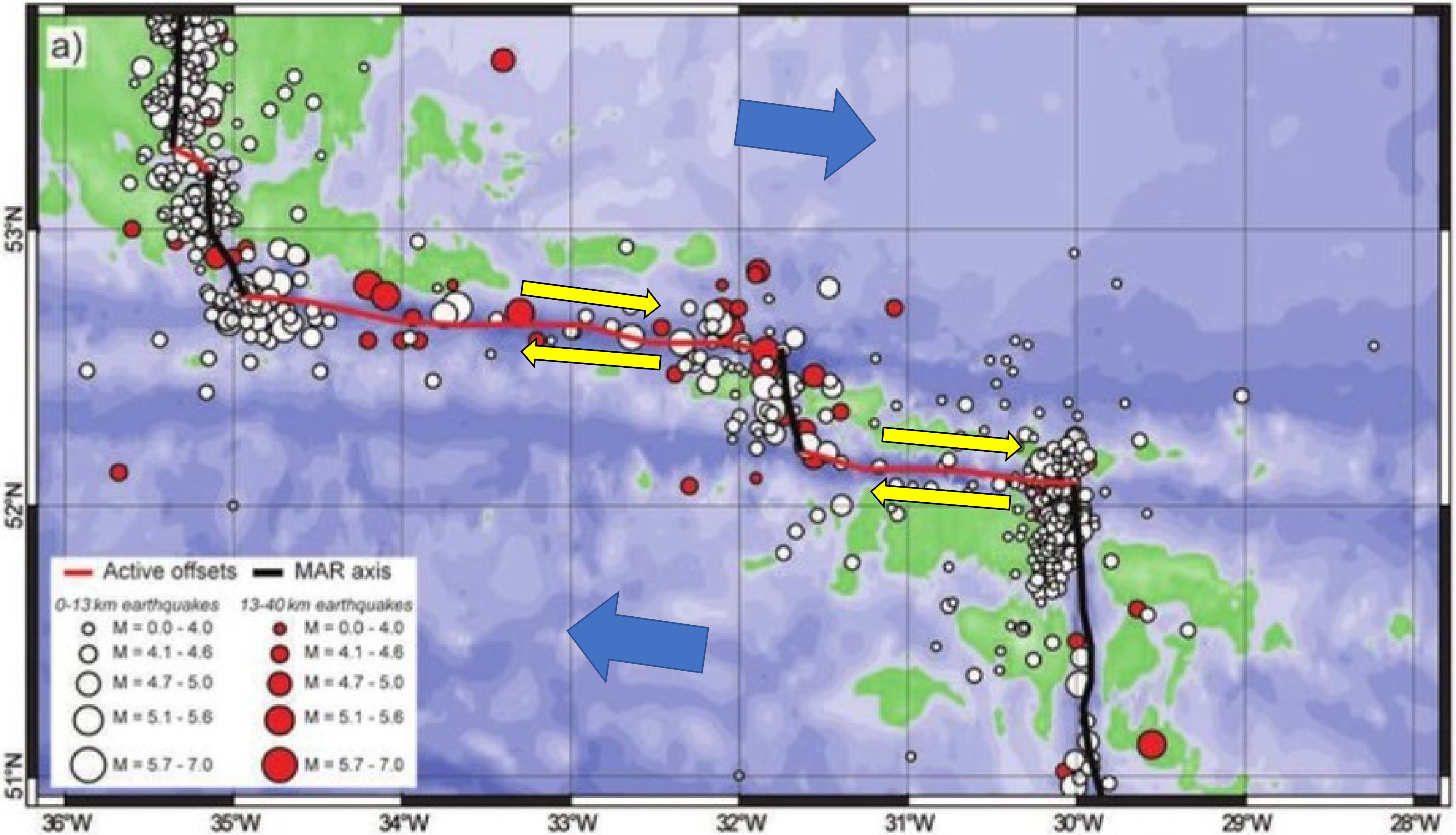
oceanic ridge - transform

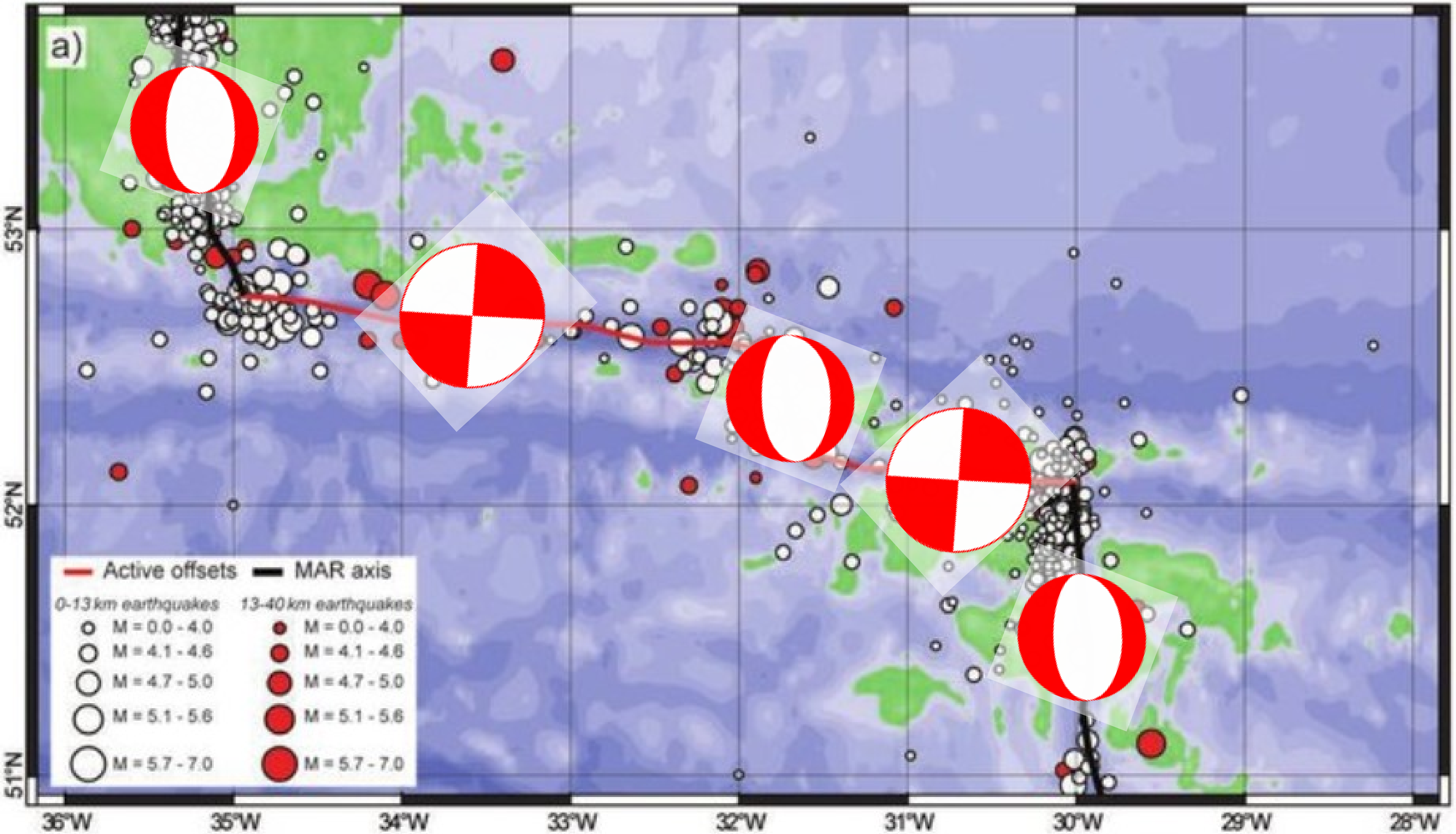


2637
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
Elevation (meters)
60° N
50° N
50° W
40° W
30° W
20° W
10° W
Charlie Gibbs
Fracture Zone
Fig. 2
Fig. 6
Fig. 7
Fig. 5
70°N
50°N
30°N

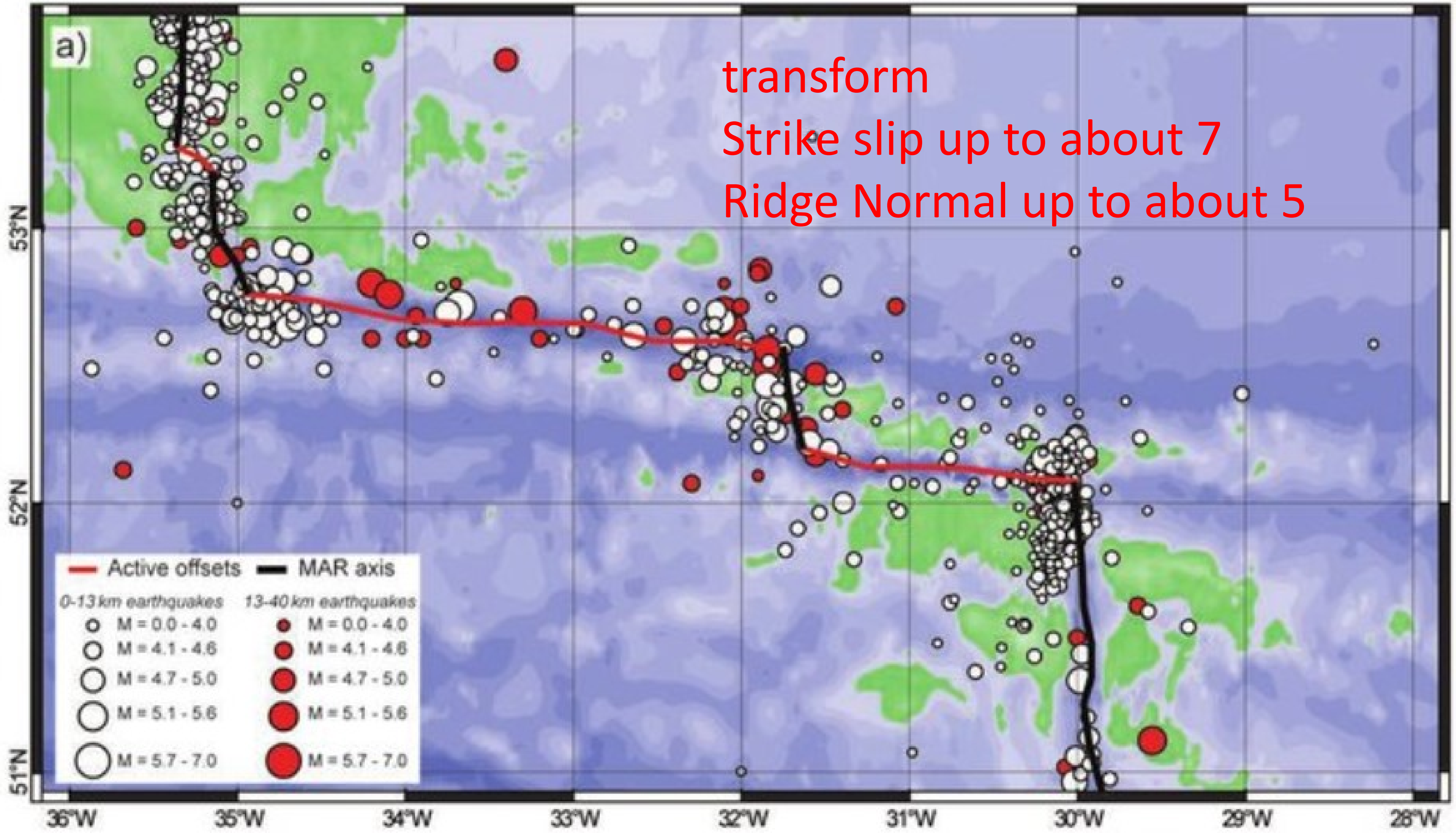


a)
Which way does it move?
Active offsets
MAR axis
0-13 km earthquakes
13-40 km earthquakes
M = 0.0 - 4.0
M = 4.1 - 4.6
M = 4.7 - 5.0
M = 5.1 - 5.6
M = 5.7 - 7.0
53°N
52°N
51°N
36°W
35°W
34°W
33°W
32°W
31°W
30°W
29°W
28°W


a)
Active offsets
MAR axis
0-13 km earthquakes
13-40 km earthquakes
M = 0.0 - 4.0
M = 4.1 - 4.6
M = 4.7 - 5.0
M = 5.1 - 5.6
M = 5.7 - 7.0
53°N
52°N
51°N
36°W
35°W
34°W
33°W
32°W
31°W
30°W
29°W
28°W

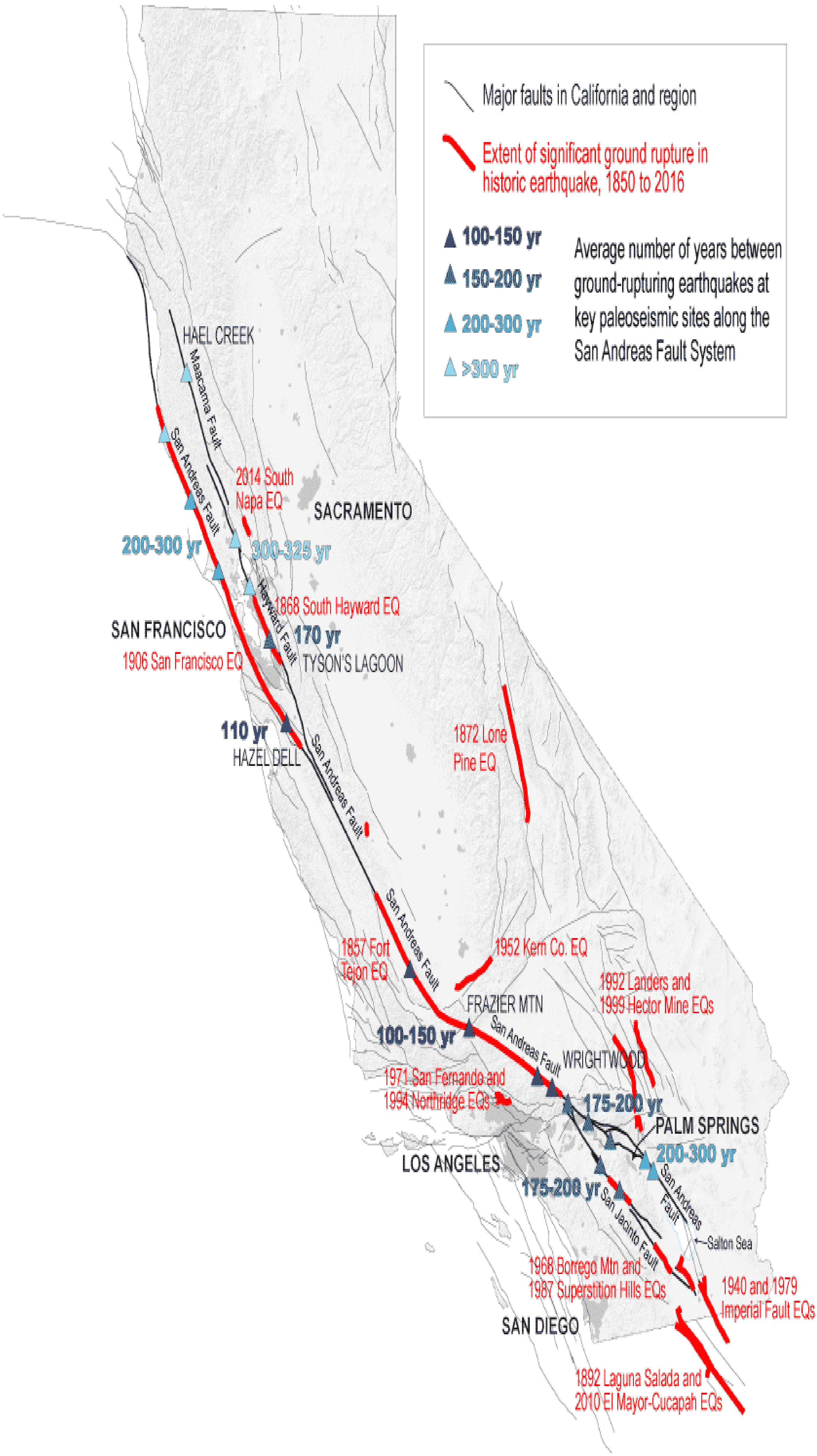


a)
53°N
52°N
51°N
36°W
35°W
34°W
33°W
32°W
31°W
30°W
29°W
28°W
Active offsets
MAR axis
0-13 km earthquakes
13-40 km earthquakes
M = 0.0 - 4.0
M = 4.1 - 4.6
M = 4.7 - 5.0
M = 5.1 - 5.6
M = 5.7 - 7.0

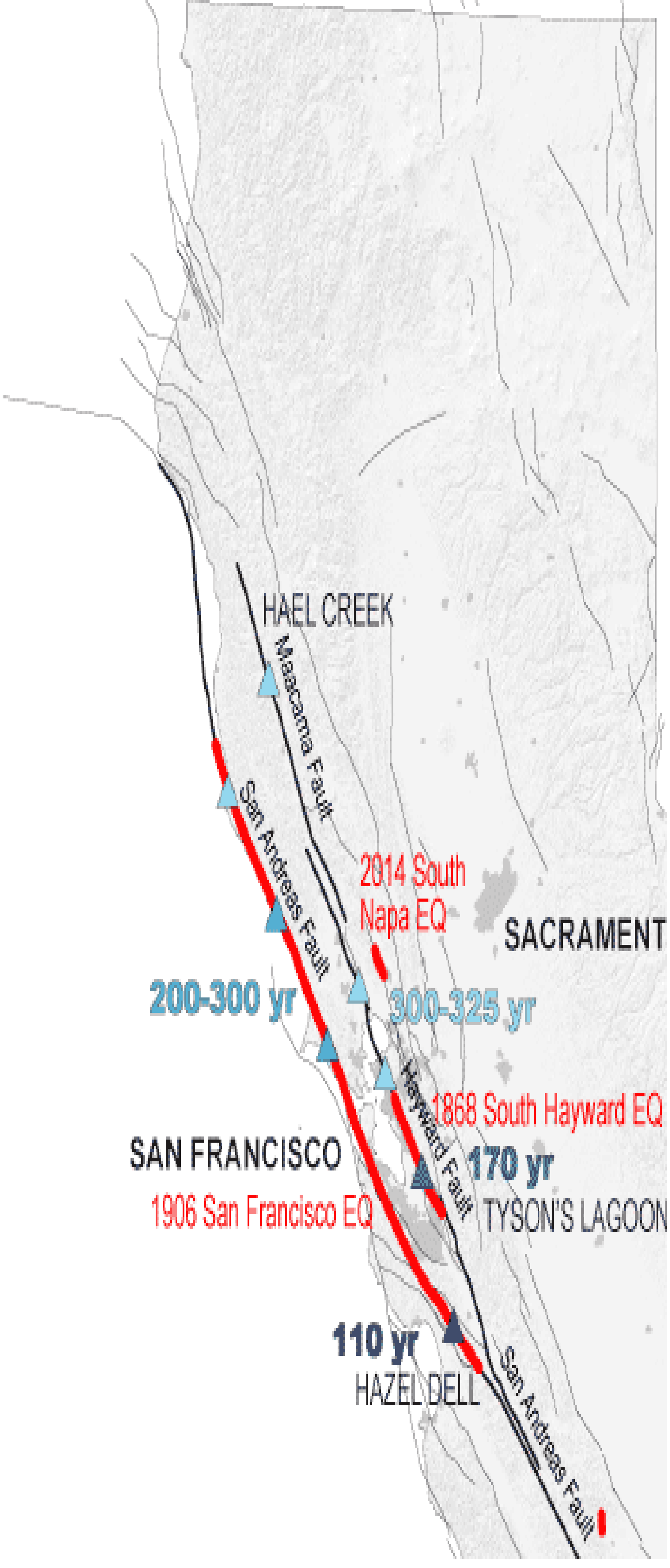

a)
transform
Strike slip up to about 7
Ridge Normal up to about 5
Active offsets
MAR axis
0-13 km earthquakes
13-40 km earthquakes
M = 0.0 - 4.0
M = 4.1 - 4.6
M = 4.7 - 5.0
M = 5.1 - 5.6
M = 5.7 - 7.0
53°N
52°N
51°N
36°W
35°W
34°W
33°W
32°W
31°W
30°W
29°W
28°W

continental transform


California's
San Andreas Fault
Crescent City
Eureka
Garberville
Point Delgada
Point Arena
Ukiah
Santa Rosa
Point Reyes
San Francisco
Daly City
San Jose
Santa Cruz
Hollister
San Juan Bautista
Monterey
Parkfield
San Luis Obispo
Simmler
Carrizo Plain
Soda Lake Rd
Frazier Park
Palmdale
Santa Barbara
San Bernardino
Desert Hot Springs
Los Angeles
Palm Springs
San Andreas Fault
Brawley
San Diego
Map copyright © 2006 David K. Lynch



Major faults in California and region
Extent of significant ground rupture in historic earthquake, 1850 to 2016
100-150 yr
150-200 yr
200-300 yr
>300 yr
Average number of years between ground-rupturing earthquakes at key paleoseismic sites along the San Andreas Fault System
HAEL CREEK
Maacama Fault
San Andreas Fault
2014 South Napa EQ
SACRAMENTO
200-300 yr
300-325 yr
1868 South Hayward EQ
Hayward Fault
SAN FRANCISCO
170 yr
TYSON'S LAGOON
1906 San Francisco EQ
110 yr
HAZEL DELL
1872 Lone Pine EQ
1857 Fort Tejon EQ
1952 Kern Co. EQ
1992 Landers and 1999 Hector Mine EQs
FRAZIER MTN
100-150 yr
WRIGHTWOOD
1971 San Fernando and 1994 Northridge EQs
175-200 yr
PALM SPRINGS
200-300 yr
LOS ANGELES
175-200 yr
San Jacinto Fault
Salton Sea
1968 Borrego Mtn and 1987 Superstition Hills EQs
1940 and 1979 Imperial Fault EQs
SAN DIEGO
1892 Laguna Salada and 2010 El Mayor-Cucapah EQs


HAEL CREEK
Maacama Fault
San Andreas Fault
2014 South
Napa EQ
SACRAMENT
200-300 yr
300-325 yr
Hayward Fault
1868 South Hayward EQ
SAN FRANCISCO
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1906 San Francisco EQ
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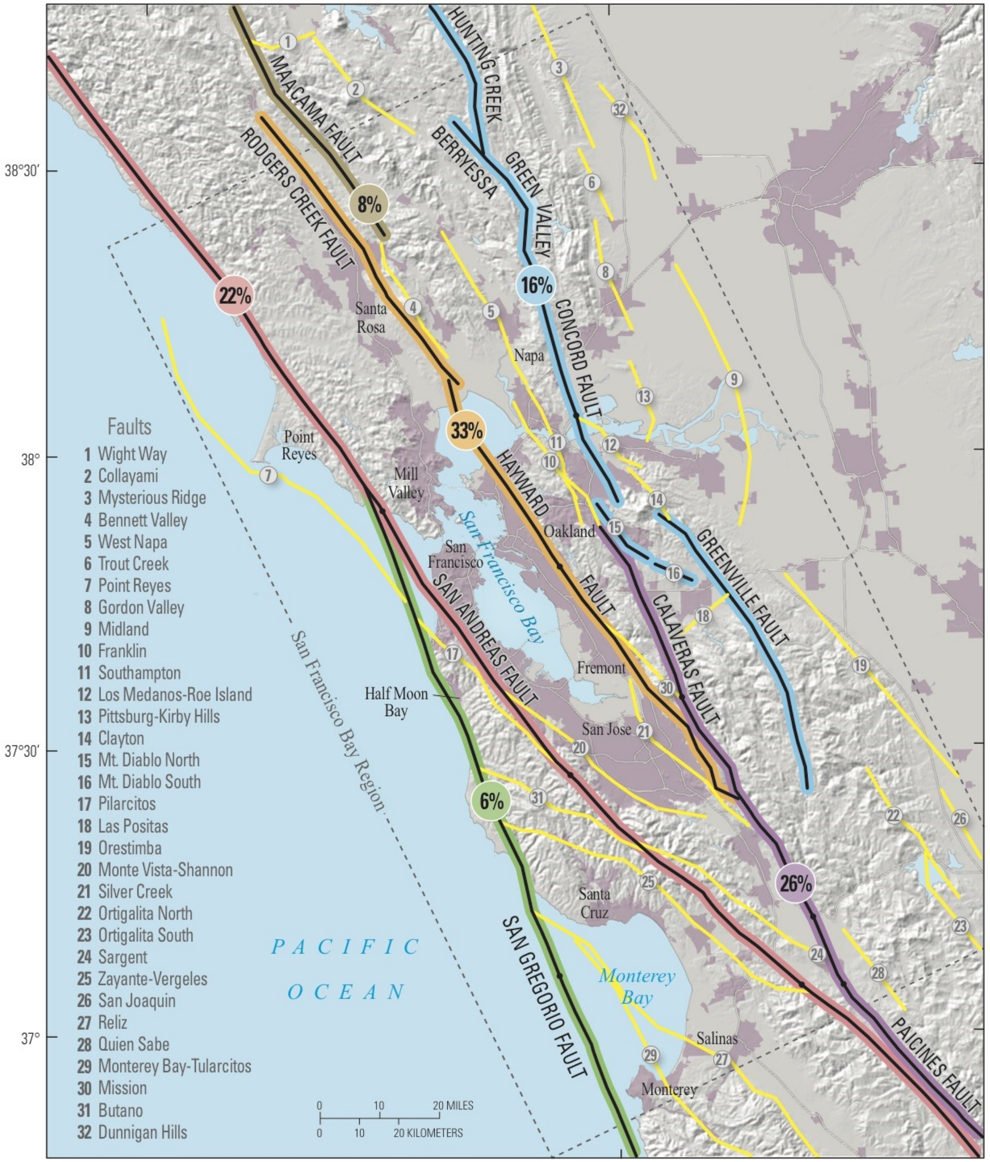
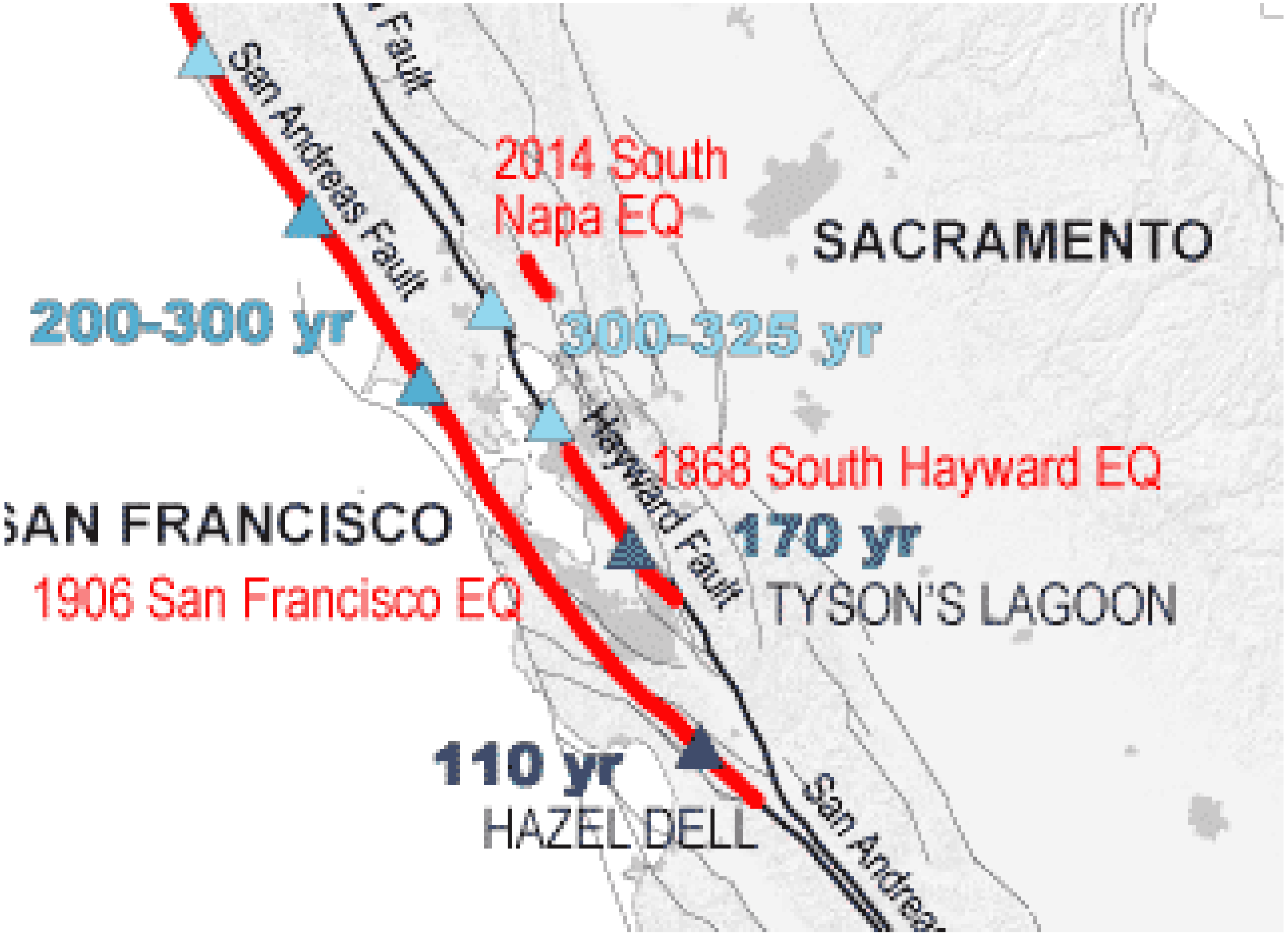
110 yr
HAZEL DELL
San Andreas Fault

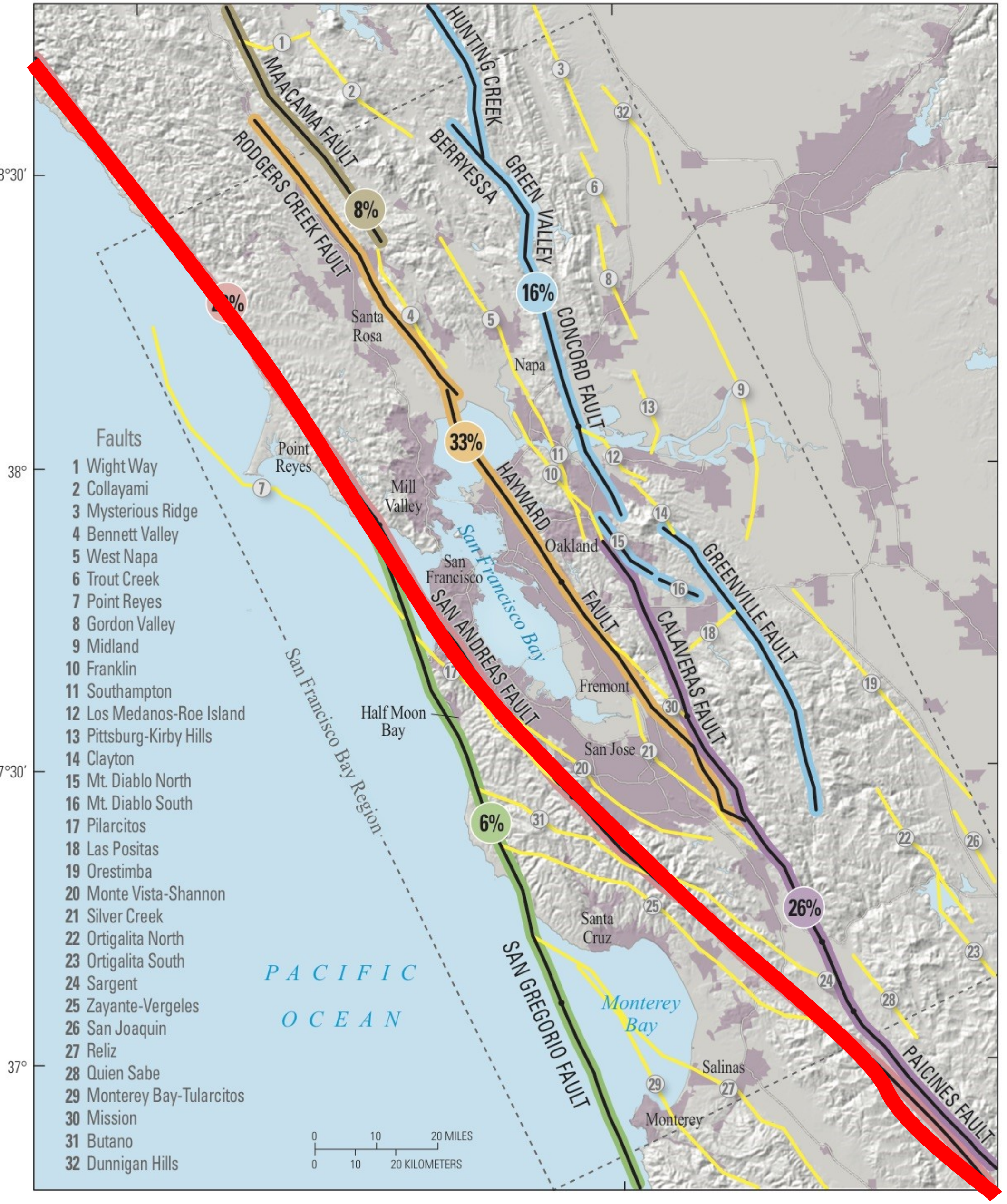
1857 Fort
Tejon EQ
San Andreas Fault
1952 Kern Co. EQ
FRAZIER MTN
100-150 yr
San Andreas Fault
1992 Landers and
1999 Hector Mine EQs
WRIGHTWOOD
1971 San Fernando and
1994 Northridge EQs
175-200 yr
PALM SPRINGS
200-300 yr
LOS ANGELES
175-200 yr
San Andreas
Fault
San Jacinto Fault
Salton Sea
1968 Borrego Mtn and
1987 Superstition Hills EQs
1940 and 1979
Imperial Fault EQs
SAN DIEGO
1892 Laguna Salada and
2010 El Mayor-Cucapah EQs



38°30'
38°
37°30'
37°
Faults
1 Wight Way
2 Collayami
3 Mysterious Ridge
4 Bennett Valley
5 West Napa
6 Trout Creek
7 Point Reyes
8 Gordon Valley
9 Midland
10 Franklin
11 Southampton
12 Los Medanos-Roe Island
13 Pittsburg-Kirby Hills
14 Clayton
15 Mt. Diablo North
16 Mt. Diablo South
17 Pilarcitos
18 Las Positas
19 Orestimba
20 Monte Vista-Shannon
21 Silver Creek
22 Ortigalita North
23 Ortigalita South
24 Sargent
25 Zayante-Vergeles
26 San Joaquin
27 Reliz
28 Quien Sabe
29 Monterey Bay-Tularcitos
30 Mission
31 Butano
32 Dunnigan Hills
MAACAMA FAULT
RODGERS CREEK FAULT
HUNTING CREEK
BERRYESSA
GREEN VALLEY
CONCORD FAULT
HAYWARD FAULT
GREENVILLE FAULT
CALAVERAS FAULT
SAN ANDREAS FAULT
SAN GREGORIO FAULT
PAICINES FAULT
8%
22%
16%
33%
6%
26%
Santa Rosa
Napa
Point Reyes
Mill Valley
San Francisco
Oakland
San Francisco Bay
Fremont
Half Moon Bay
San Jose
Santa Cruz
Monterey Bay
Salinas
Monterey
San Francisco Bay Region
PACIFIC OCEAN
0 10 20 MILES
0 10 20 KILOMETERS



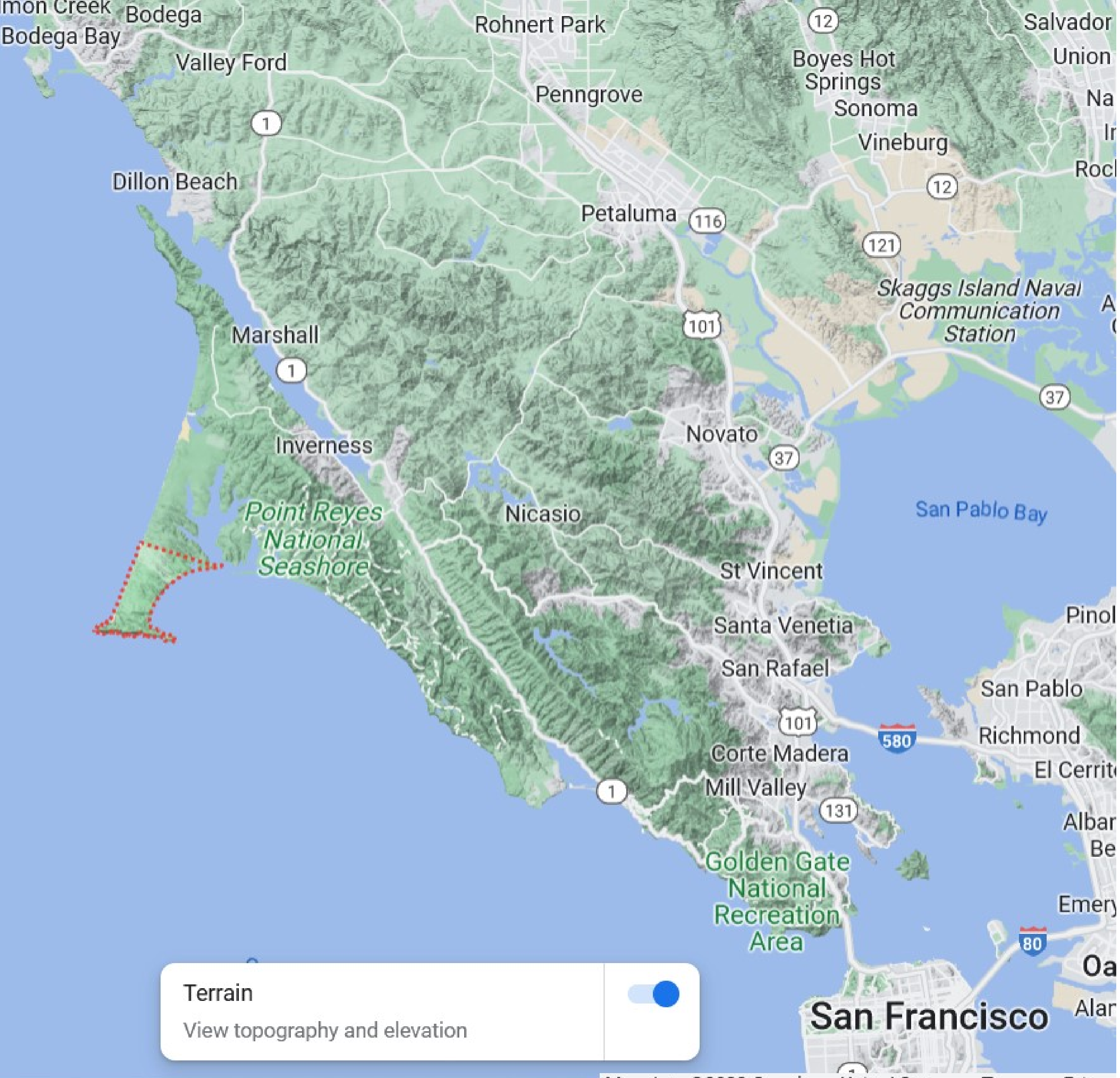
San Andreas Fault
2014 South Napa EQ
SACRAMENTO
200-300 yr
300-325 yr
Hayward Fault
1868 South Hayward EQ
SAN FRANCISCO
170 yr
TYSON'S LAGOON
1906 San Francisco EQ
110 yr
HAZEL DELL
San Andreas

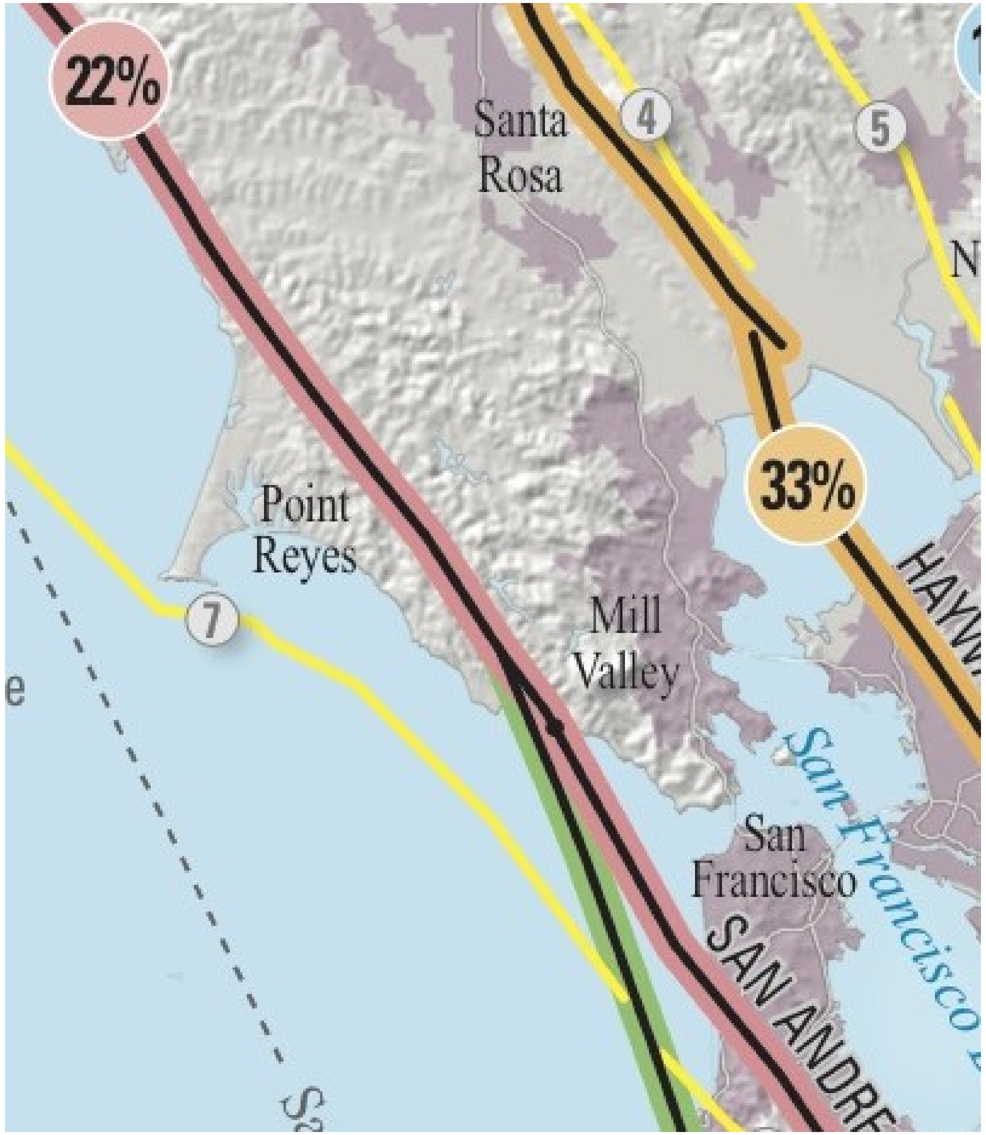


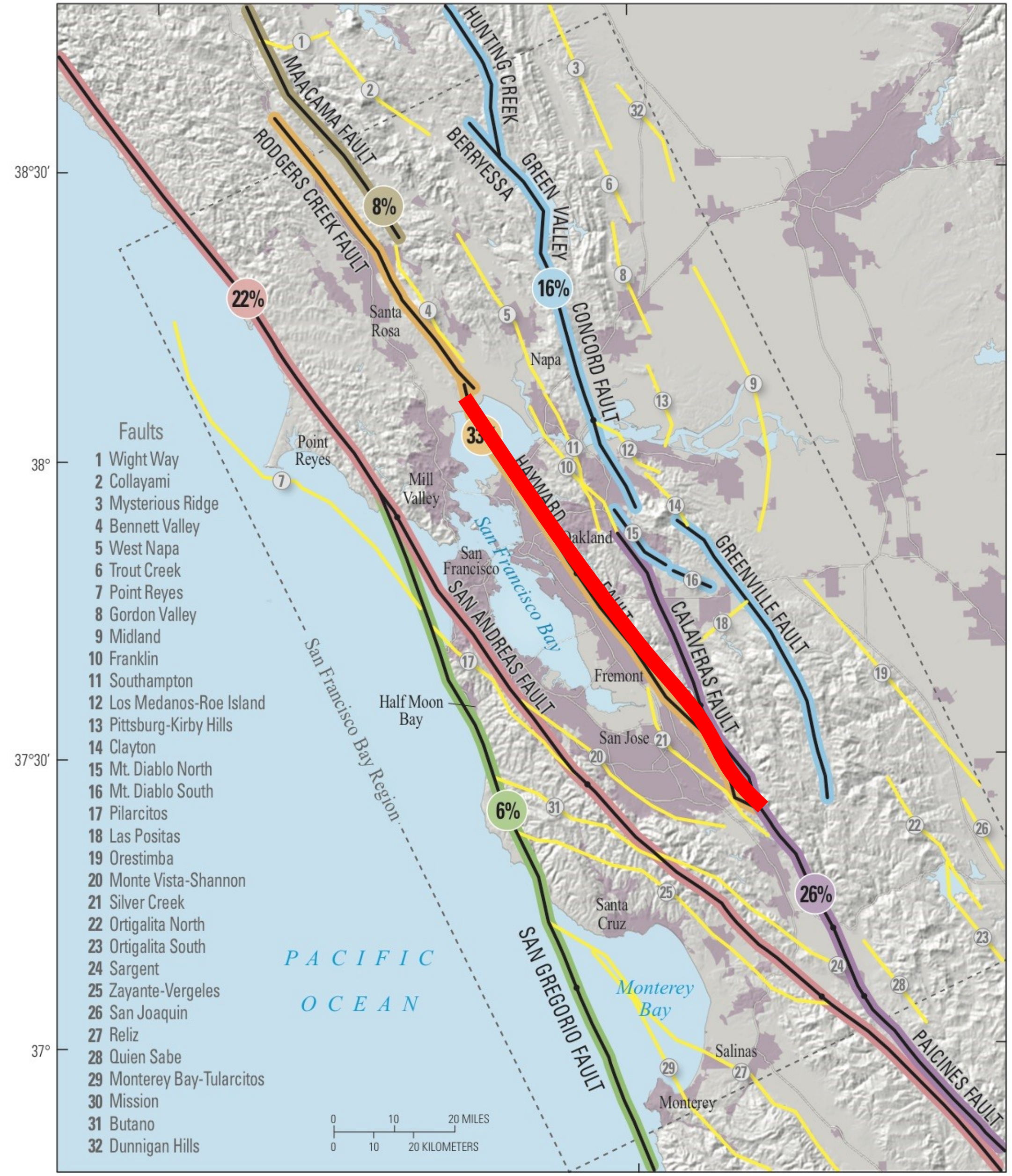
San Andreas Fault

strike slip

eqs up to about magnitude 8


Bodega
Bodega Bay
Rohnert Park
Salvador
Union
Valley Ford
Boyes Hot Springs
Penngrove
Sonoma
Vineburg
Dillon Beach
Petaluma
Skaggs Island Naval Communication Station
Marshall
Novato
Inverness
San Pablo Bay
Point Reyes National Seashore
Nicasio
St Vincent
Santa Venetia
San Rafael
San Pablo
Richmond
Corte Madera
Mill Valley
Golden Gate National Recreation Area
San Francisco
Terrain
View topography and elevation


22%
Santa Rosa
33%
Point Reyes
Mill Valley
San Francisco
San Francisco
SAN ANDRE

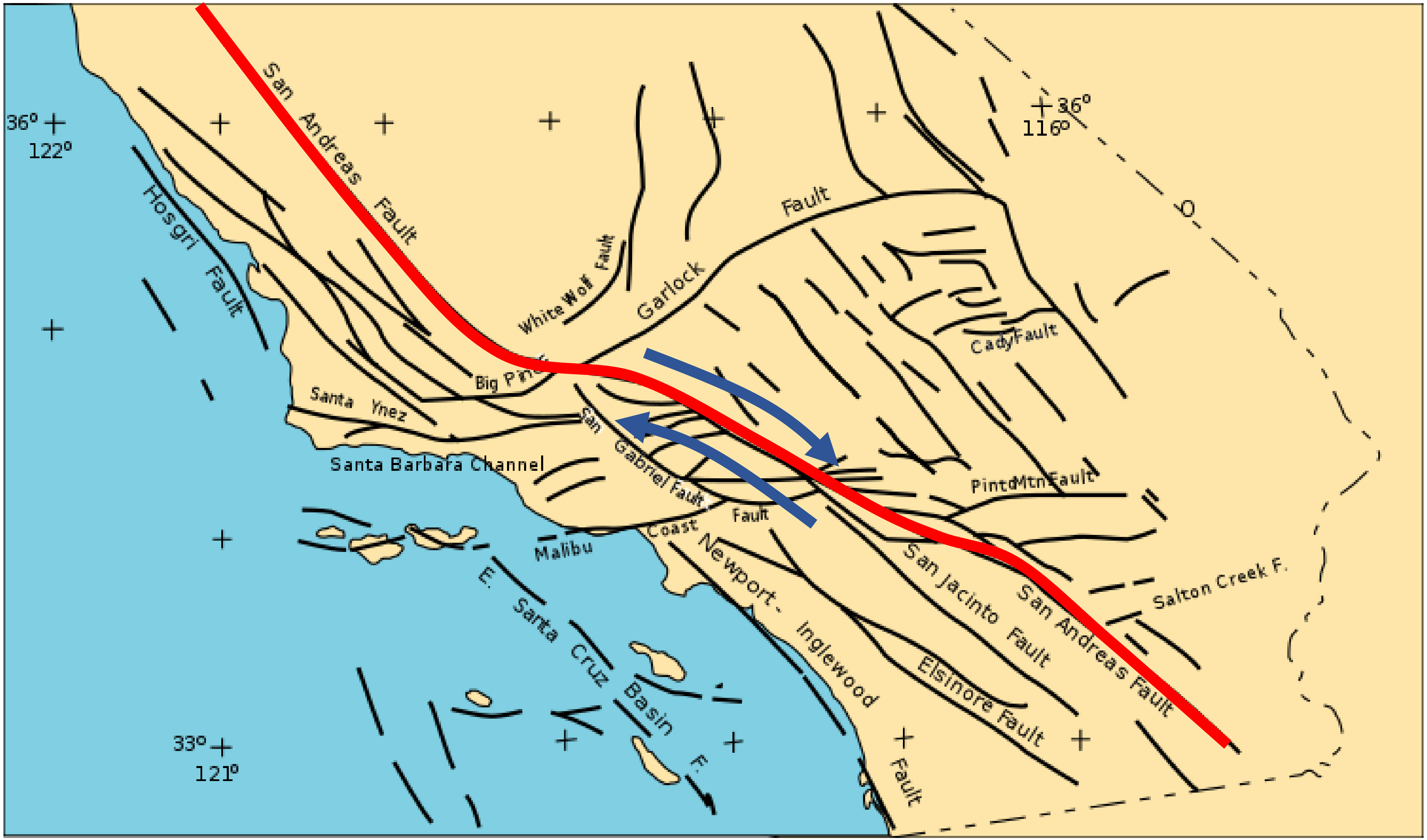


Hayward Fault

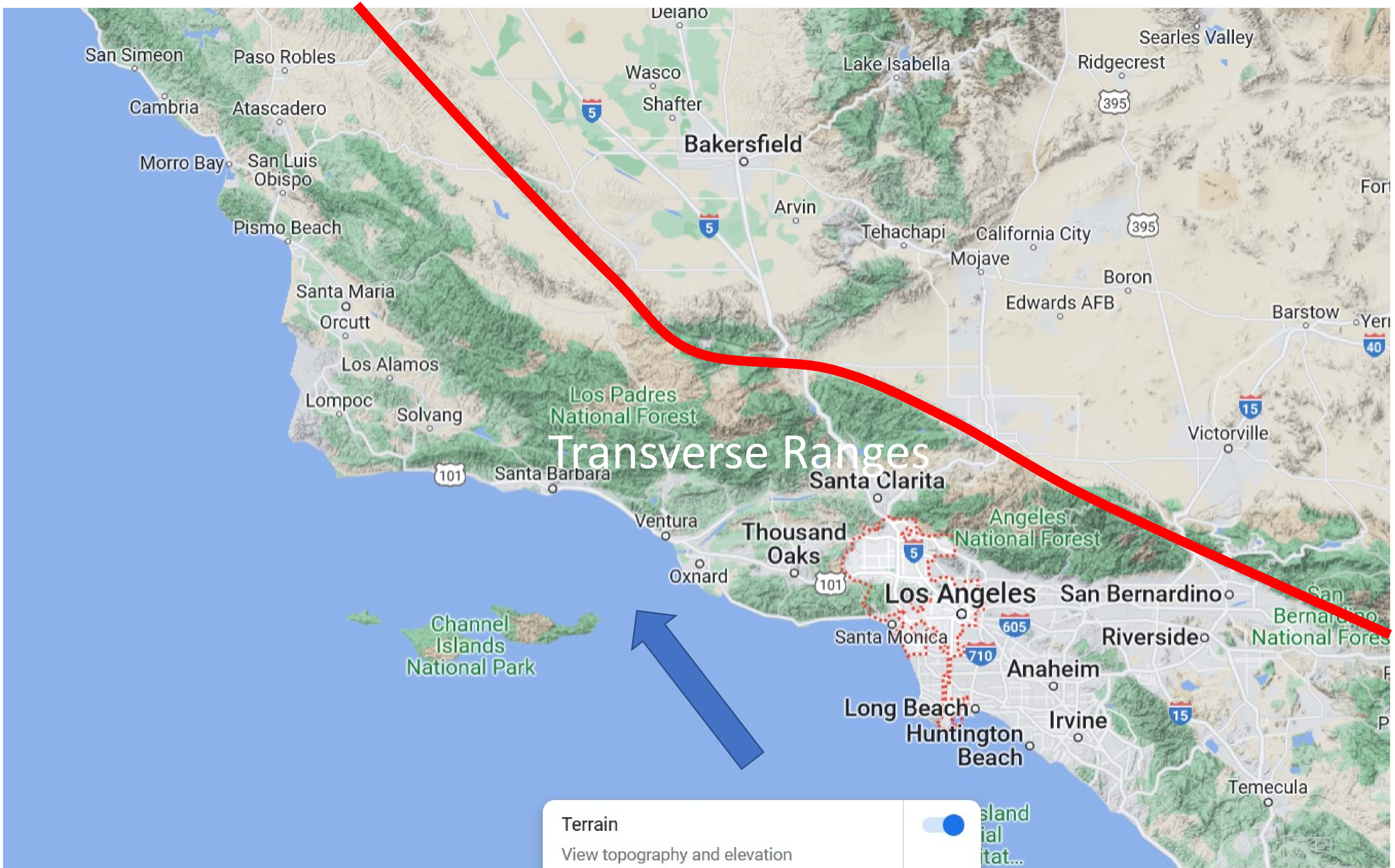
strike slip

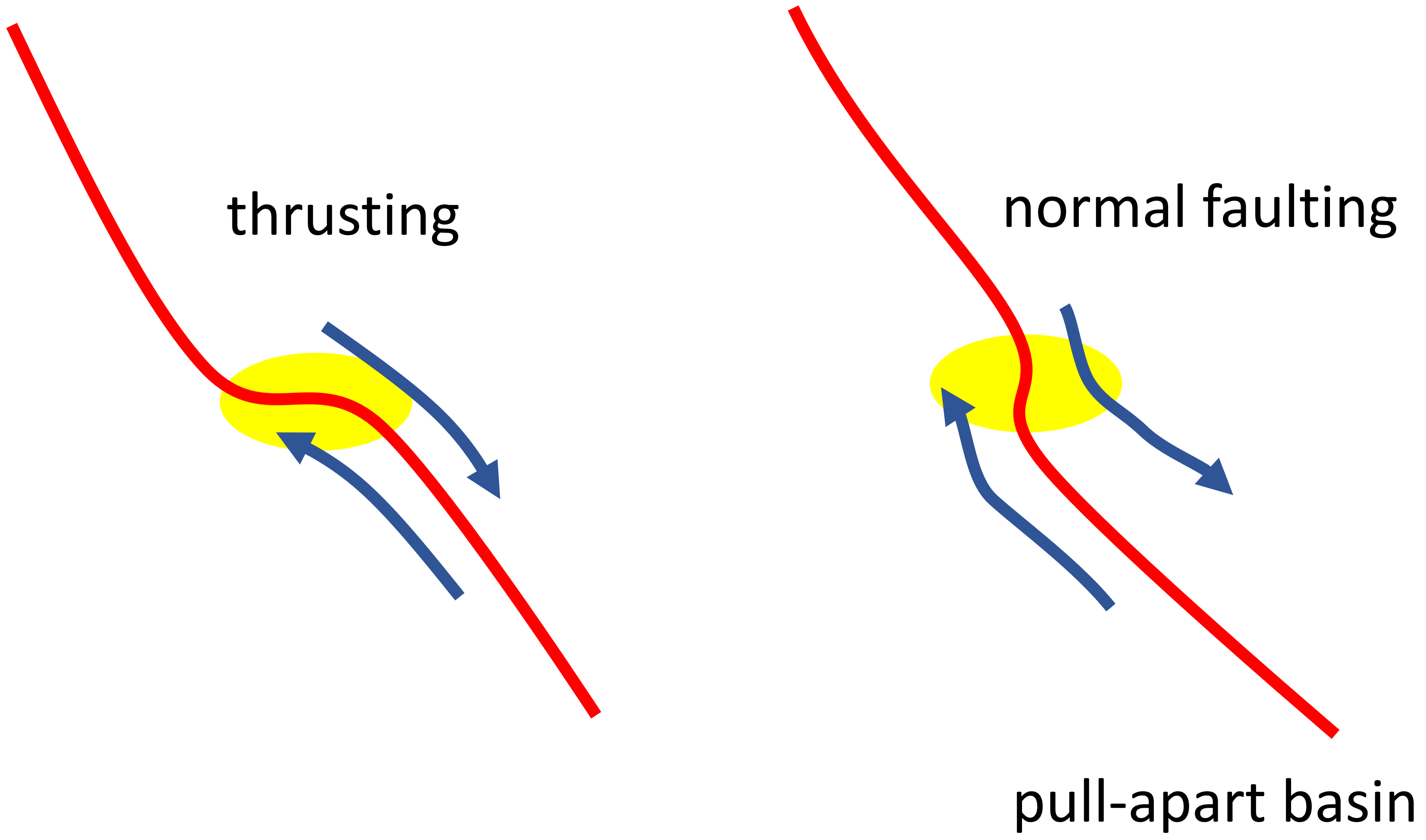
eqs up to about magnitude 7

36°
122°
36°
116°
33°
121°
San Andreas Fault
Hosgri Fault
White Wolf Fault
Garlock Fault
Big Pine F.
Santa Ynez
Santa Barbara Channel
San Gabriel Fault
Cady Fault
Pinto Mtn Fault
Fault
Coast
Malibu
E. Santa Cruz Basin F.
Newport-Inglewood Fault
San Jacinto Fault
San Andreas Fault
Elsinore Fault
Salton Creek F.

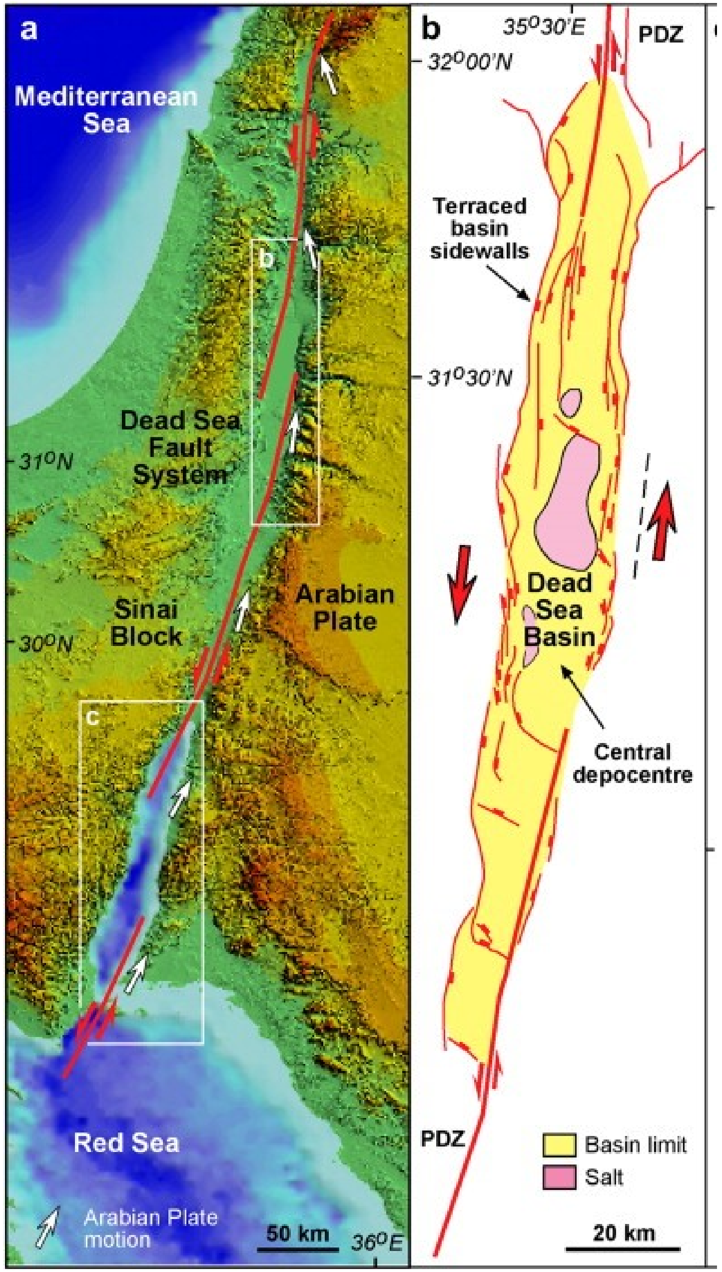


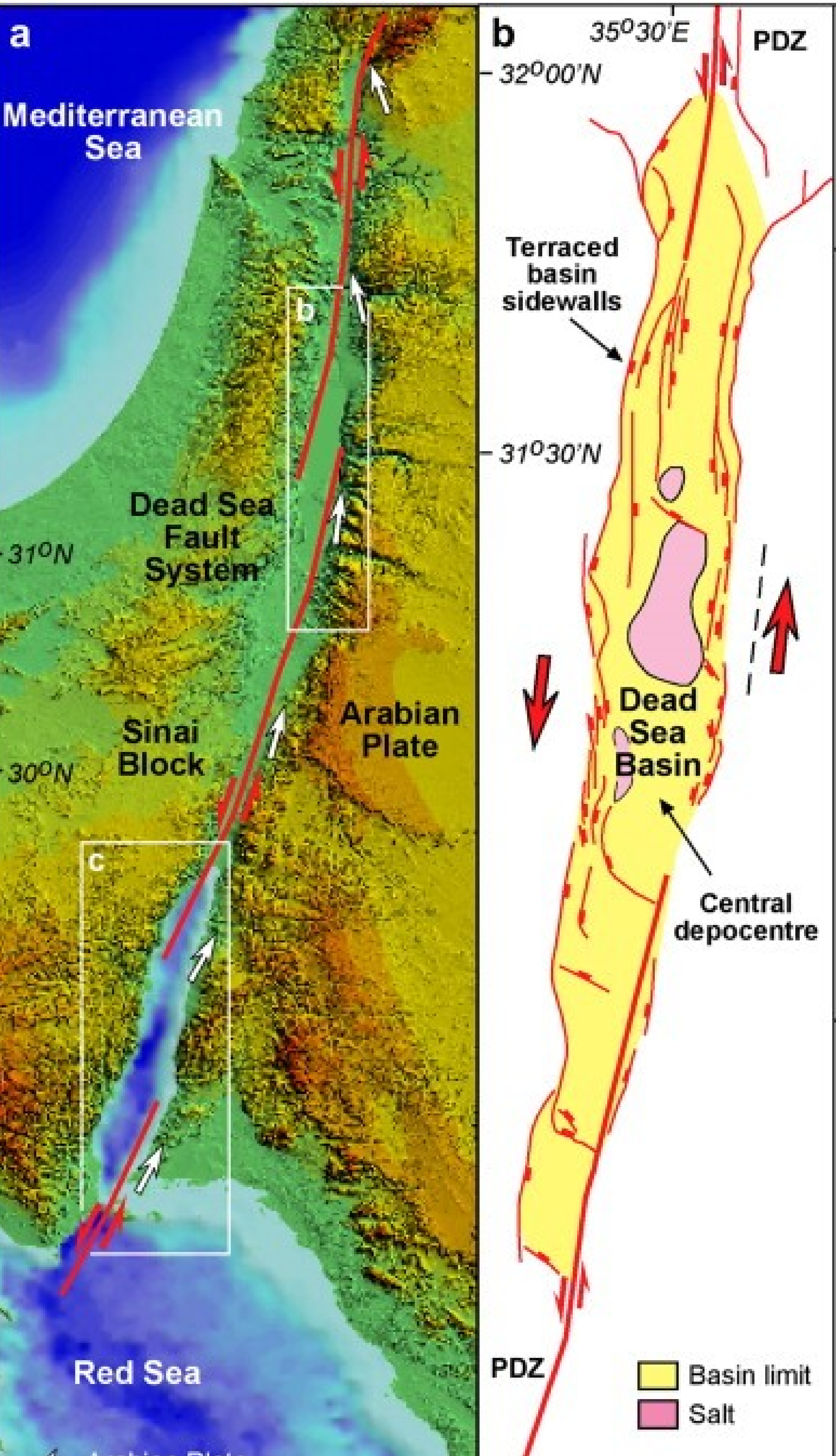
San Andreas Fault
Hosgri Fault
White Wolf Fault
Garlock Fault
Big Pine
Santa Ynez
Santa Barbara Channel
San Gabriel Fault
Cady Fault
Pinto Mtn Fault
Coast Fault
Malibu
Newport - Inglewood Fault
San Jacinto Fault
Elsinore Fault
Salton Creek F.
E. Santa Cruz Basin F.
36°
122°
116°
33°
121°


Transverse Ranges
Delano
San Simeon
Paso Robles
Cambria
Atascadero
Morro Bay
San Luis Obispo
Pismo Beach
Santa Maria
Orcutt
Los Alamos
Lompoc
Solvang
Wasco
Shafter
Bakersfield
Arvin
Lake Isabella
Searles Valley
Ridgecrest
Tehachapi
California City
Mojave
Boron
Edwards AFB
Barstow
Victorville
Los Padres National Forest
Santa Barbara
Santa Clarita
Ventura
Oxnard
Thousand Oaks
Angeles National Forest
Los Angeles
San Bernardino
Santa Monica
Riverside
San Bernardino National Forest
Anaheim
Long Beach
Huntington Beach
Irvine
Temecula
Channel Islands National Park
Terrain
View topography and elevation
5
101
395
15
40
605
710


thrusting
normal faulting
pull-apart basin


Tel Aviv-Yafo
WEST BANK
Jerusalem
ort Said
بور سعيد
GAZA STRIP
Be'er Sheva
Jordan
Israel
Suez
السويس
Wadi Musa
وادي موسى
Aqaba
العقبة
Haql
حقل
Gulf of Suez
Dahab
دهب
El Tor
الطور
Sharm
El-Sheikh
شرم الشيخ
Sharma
شرما
Al Muwaileh
المويلح
Tabuk
تبوك


a
Mediterranean Sea
Dead Sea Fault System
Sinai Block
Arabian Plate
Red Sea
31ºN
30ºN
36ºE
50 km
Arabian Plate motion
b
c
35º30'E
32º00'N
31º30'N
PDZ
Terraced basin sidewalls
Dead Sea Basin
Central depocentre
Basin limit
Salt
20 km


a
Mediterranean Sea
Dead Sea Fault System
Sinai Block
Arabian Plate
Red Sea
31ºN
30ºN
b
c
b
35º30'E
32º00'N
31º30'N
PDZ
Terraced basin sidewalls
Dead Sea Basin
Central depocentre
PDZ
Basin limit
Salt

The **1927 Jericho earthquake** was a devastating event that shook Mandatory Palestine and Transjordan on July 11 at 15:04 local time. The epicenter of the earthquake was in the northern area of the Dead Sea. The cities of Jerusalem, Jericho, Ramle, Tiberias, and Nablus were heavily damaged and at least 287 were estimated to have been killed.

Earthquake [edit]

Vered and Striem (1977) located the earthquake epicenter to be near the

1927 Jericho earthquake M=6.3