Probabilistic Seismic Hazard Assessment: Subduction zone sources and borders

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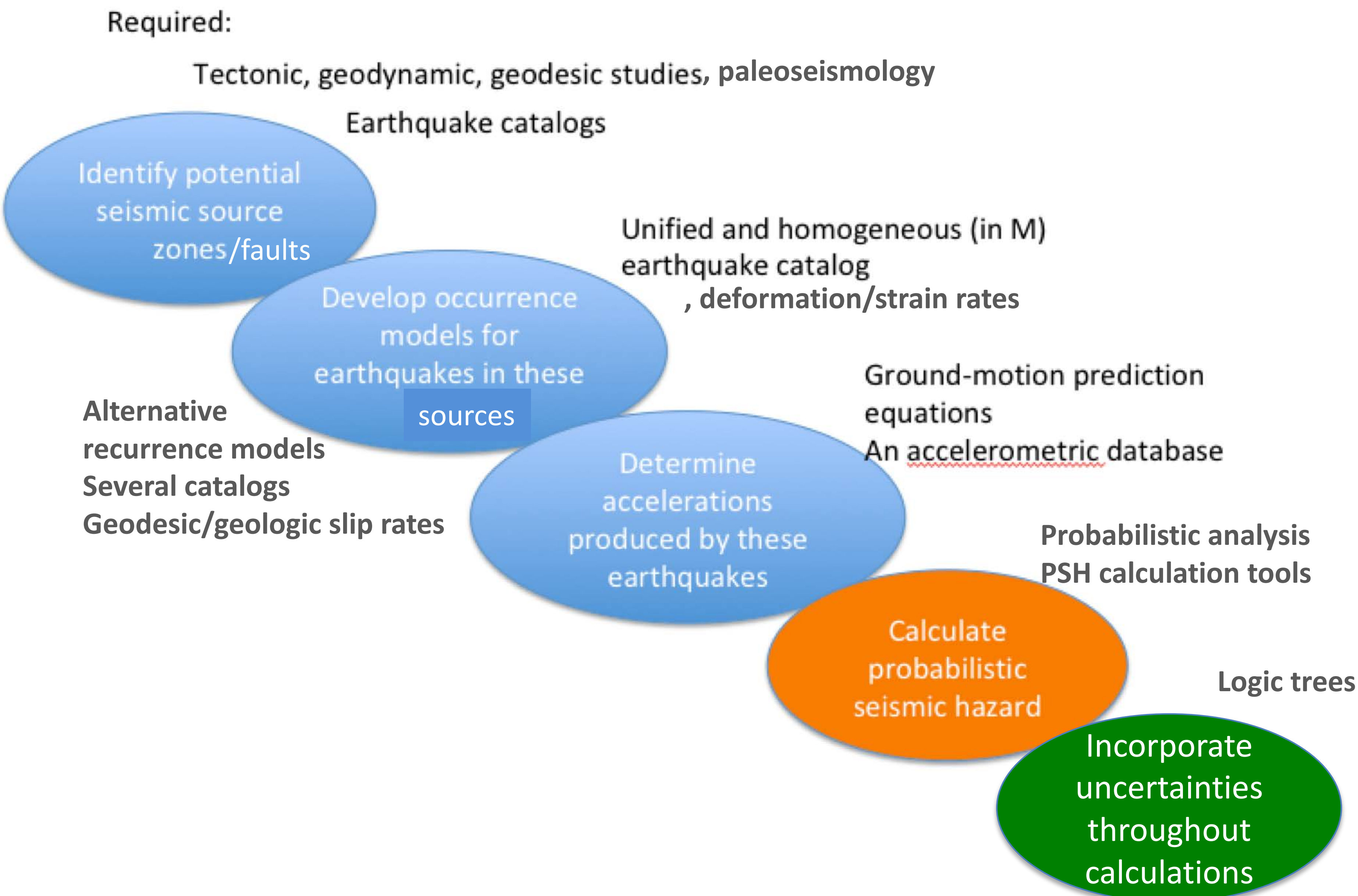
Miami

Main topics

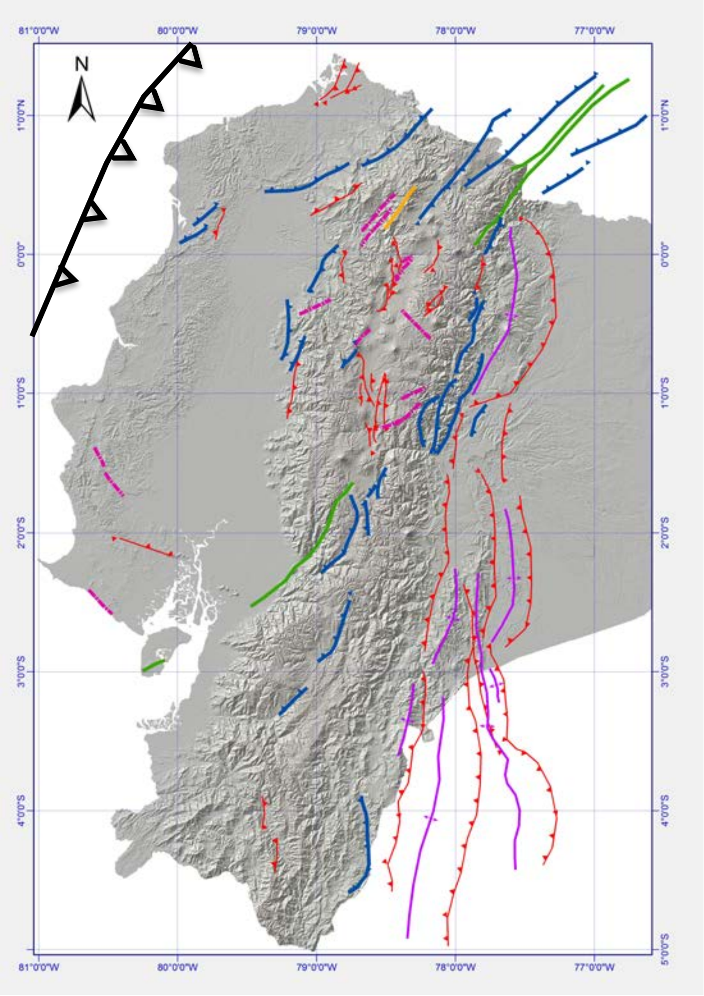
- How to define and parameterize subduction zone sources
- Standardization of Seismic hazard assessment across national boundaries

Estimating probabilistic seismic hazard : main steps



Definition of seismotectonic source zones → subduction

Potentially active faults



Minimum information required for taking into account a fault in the probabilistic hazard calculation :

-Fault plane extension
(surface and depth)
- Fault plane focal mechanism
-Estimate of the maximum magnitude
that can occur on the fault
- Estimate of the mean recurrence interval of magnitudes on this fault

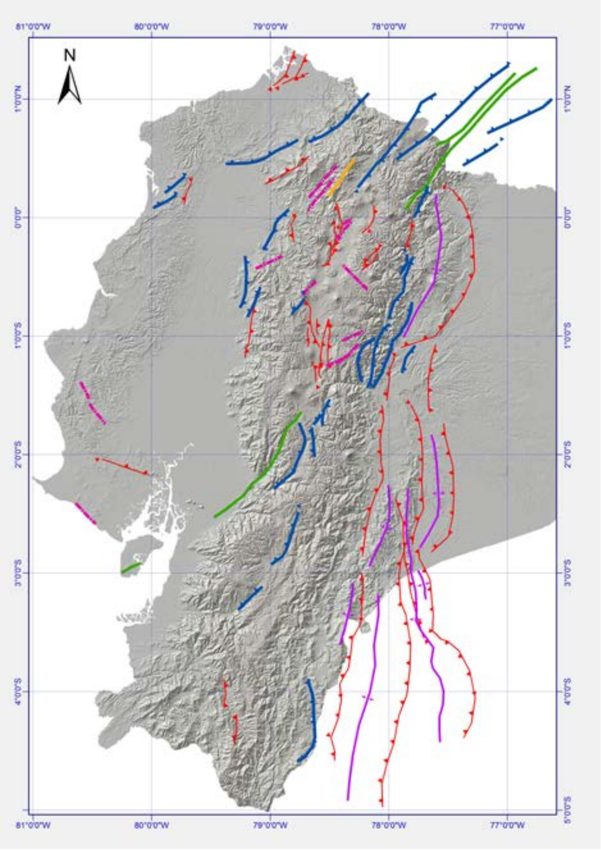
→ In our region, few faults can be taken into account in probabilistic hazard studies

→ Source models are mostly volume sources

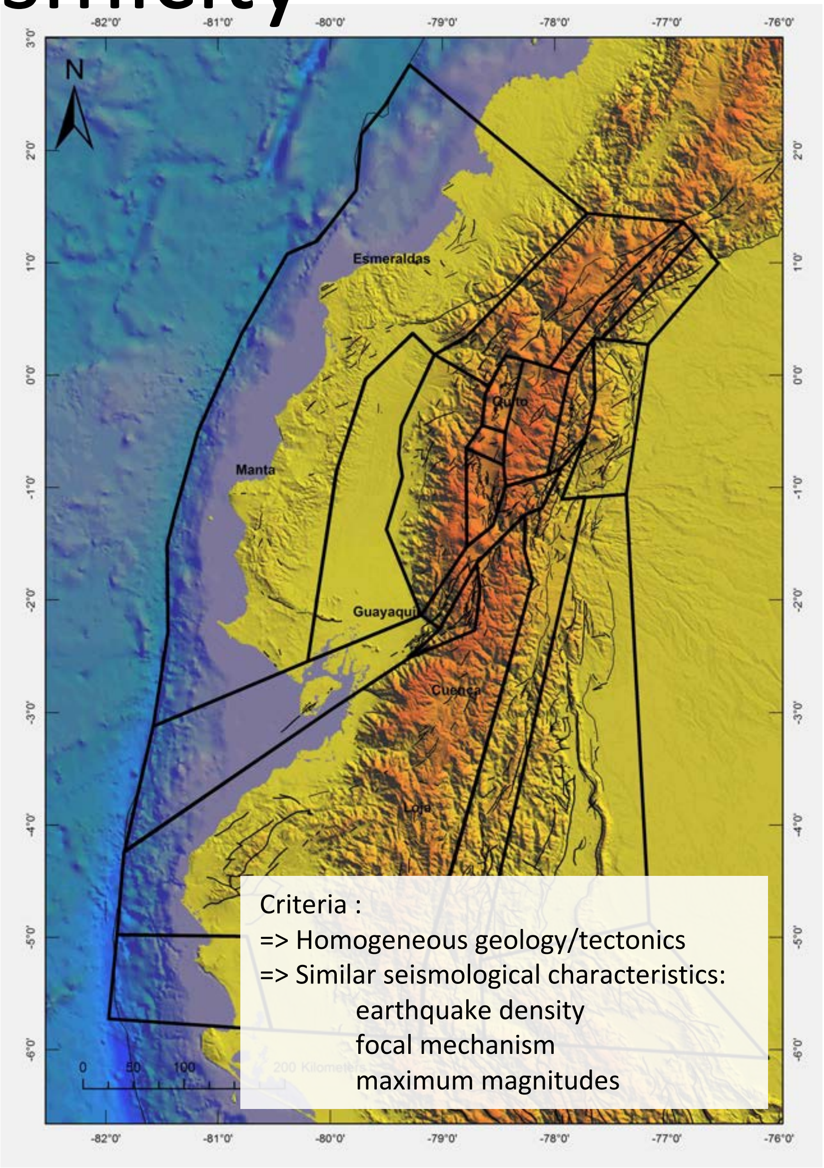
→PSH calculations are being updated as much as faults are better characterized (geodynamics, neotectonic and geodetic studies and paleoseismology)

Definition of seismotectonic source zones: crustal seismicity

Main tectonic structures

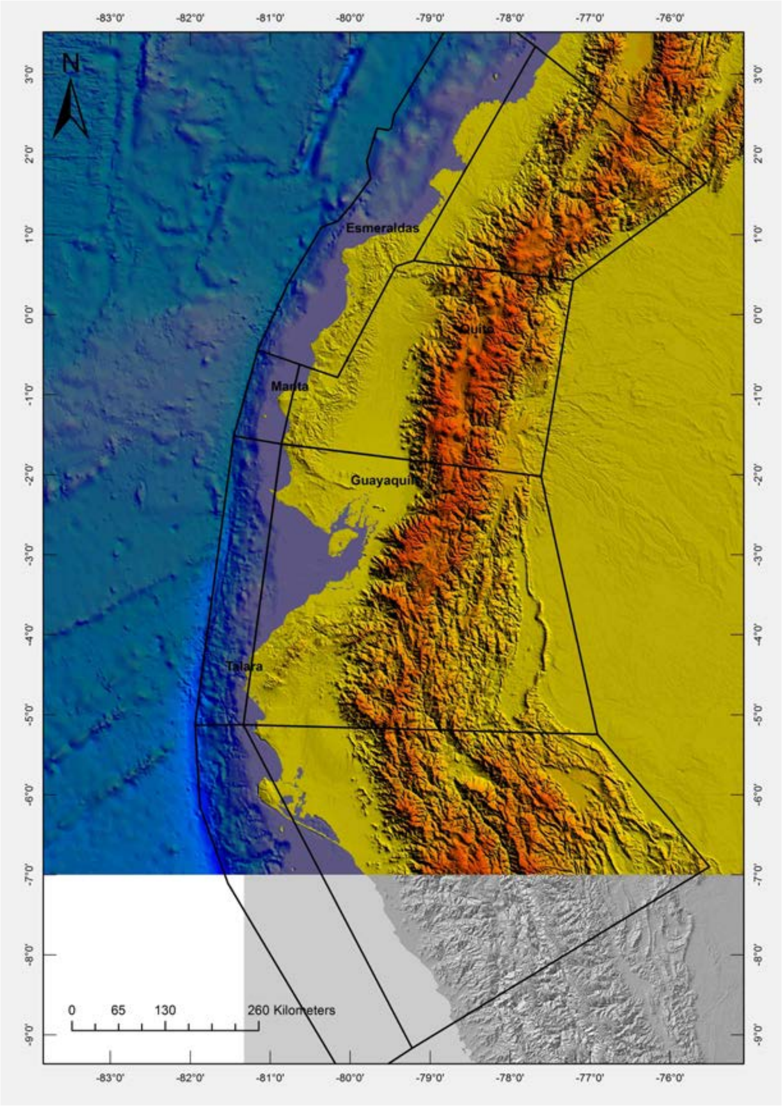


Delineating seismic sources (areas that contain several faults)



Criteria :
=> Homogeneous geology/tectonics
=> Similar seismological characteristics:
earthquake density
focal mechanism
maximum magnitudes

Definition of seismotectonic source zones: subduction



Minimum Criteria:
- Past large earthquakes for which the segments are rather well identified
- Seismicity catalog
- geophysical, geodynamic, oceanographic studies

How important is an accurate modeling of source zones for PSHA

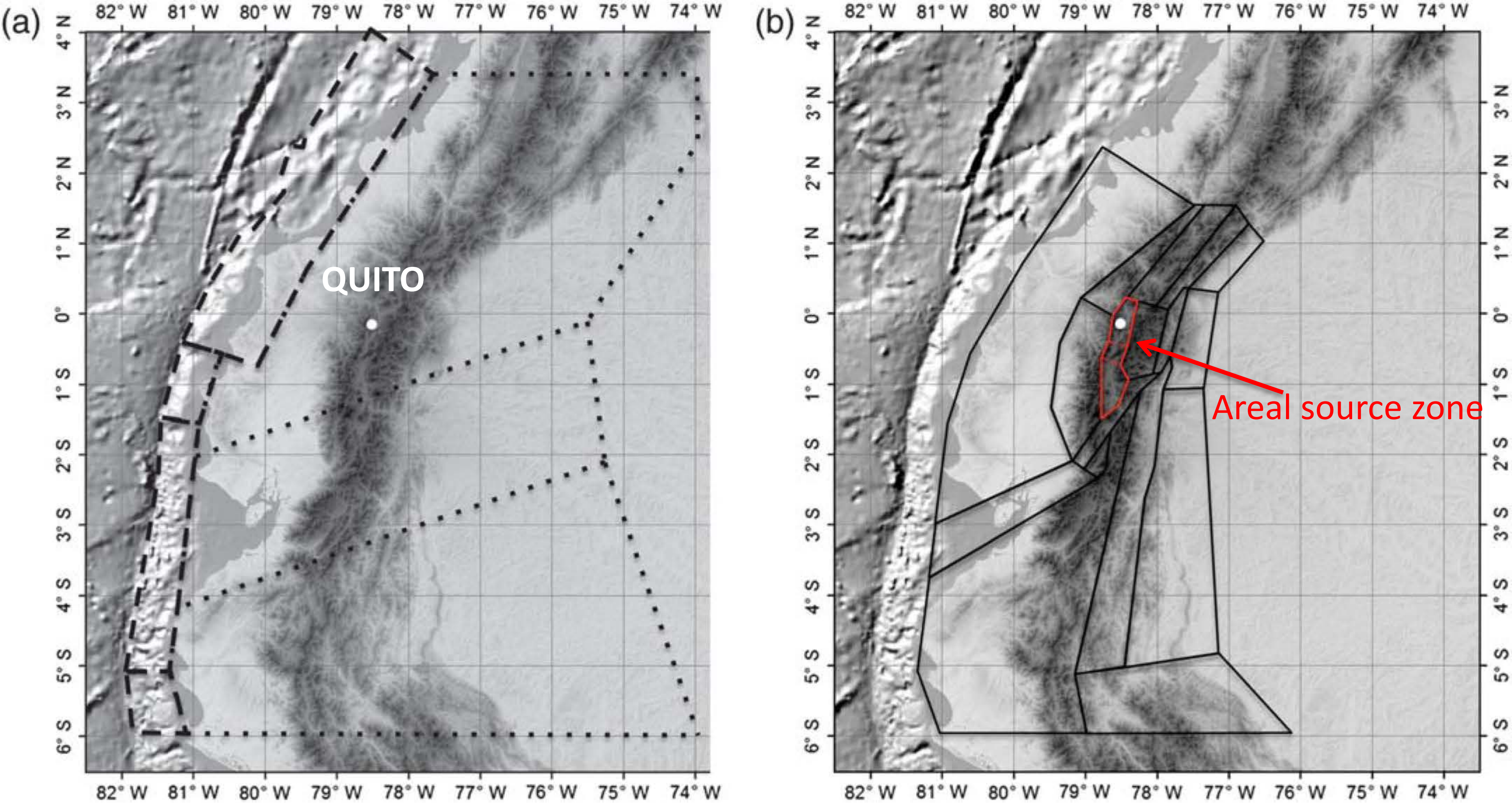
- Source model epistemic uncertainties may be more important than Ground Motion Models uncertainty.
  - The variability (sigma) associated with empirical ground-motion prediction equations has a significant impact on the results of seismic hazard analysis, and in some cases represents the main source of uncertainty.

- How about “area” source modeling? Fault source modeling

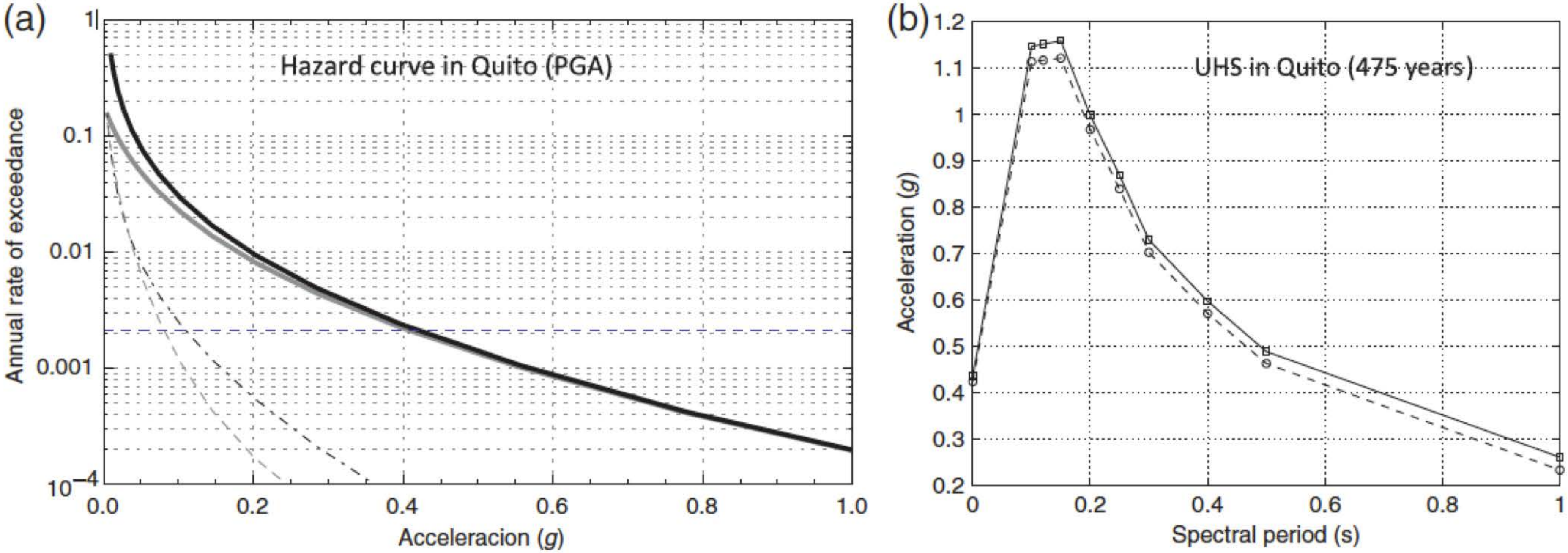
PROBABILISTIC SEISMIC HAZARD IN QUITO: THE LOCAL AREA SOURCE ZONE IS CONTROLLING THE HAZARD

Subduction source zones

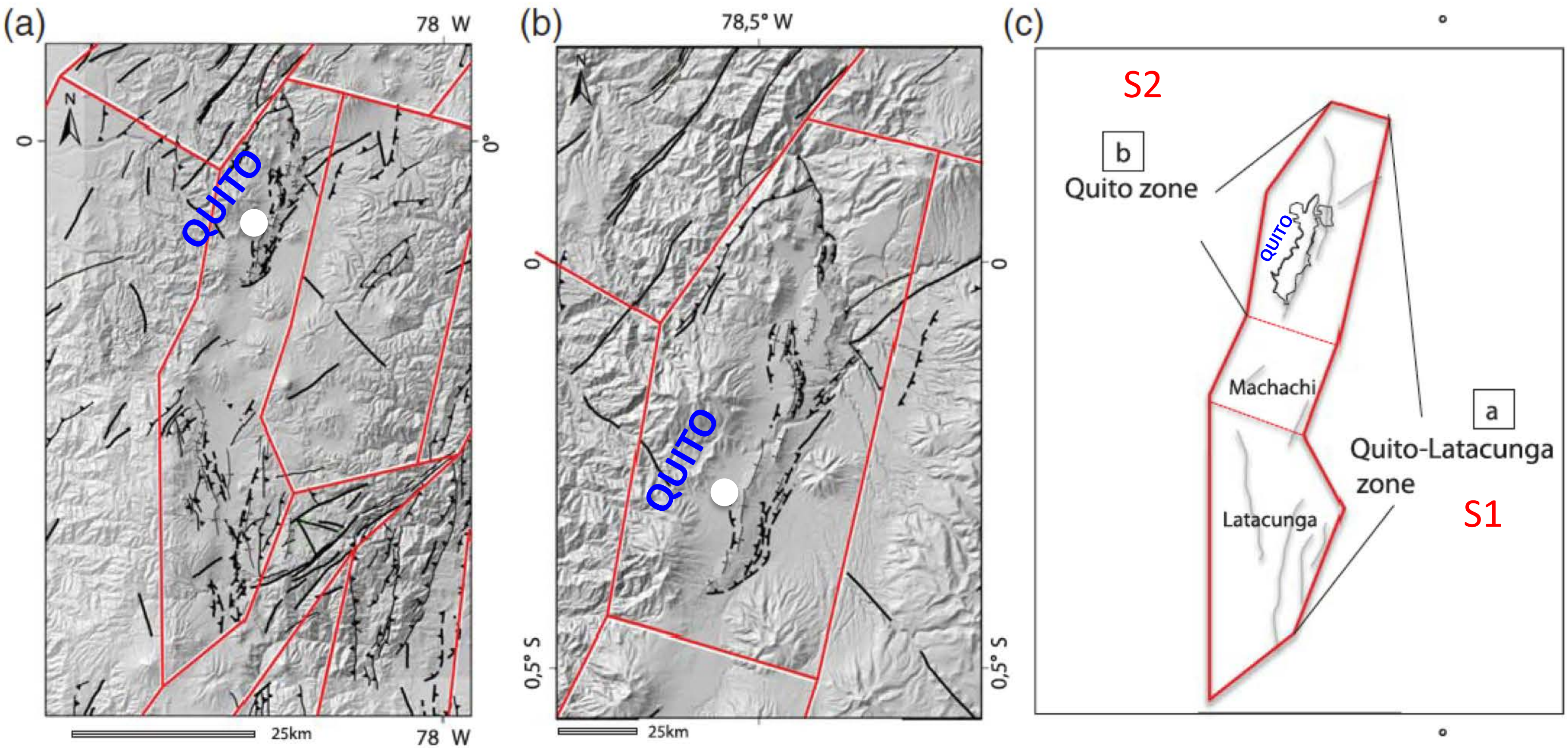
Crustal source zones



PROBABILISTIC SEISMIC HAZARD IN QUITO: THE LOCAL AREA SOURCE ZONE IS CONTROLLING THE HAZARD

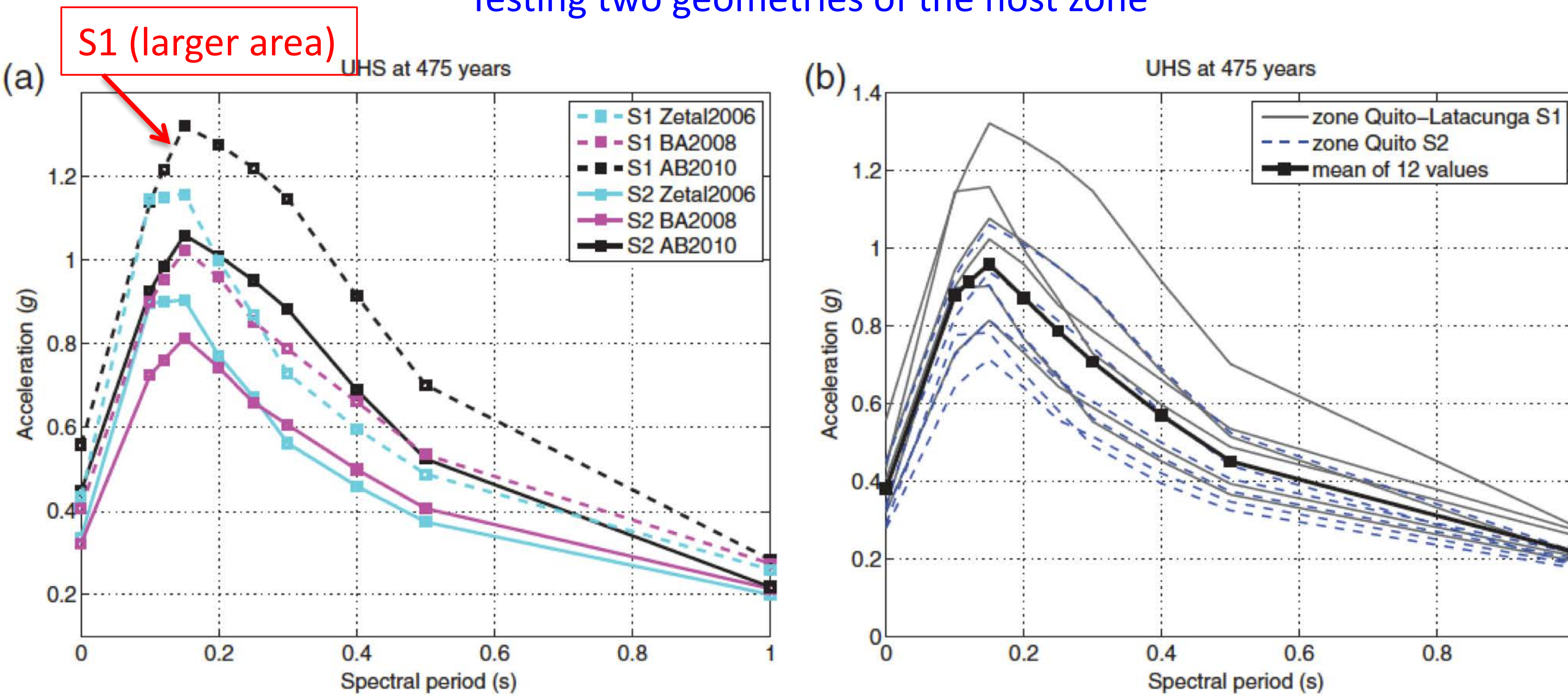


PROBABILISTIC SEISMIC HAZARD IN QUITO: THE LOCAL AREA SOURCE ZONE IS CONTROLLING THE HAZARD

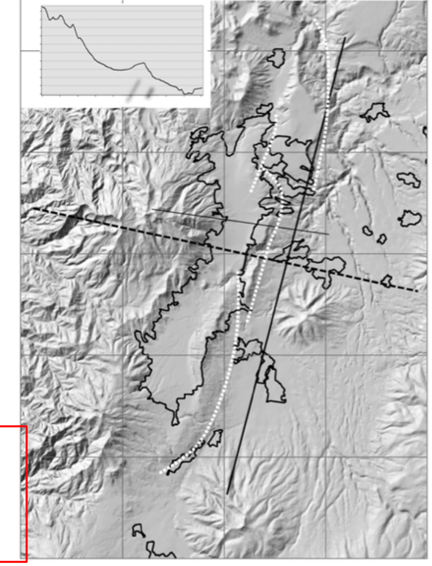


PROBABILISTIC SEISMIC HAZARD IN QUITO: THE LOCAL AREA SOURCE ZONE IS CONTROLLING THE HAZARD

Testing two geometries of the host zone

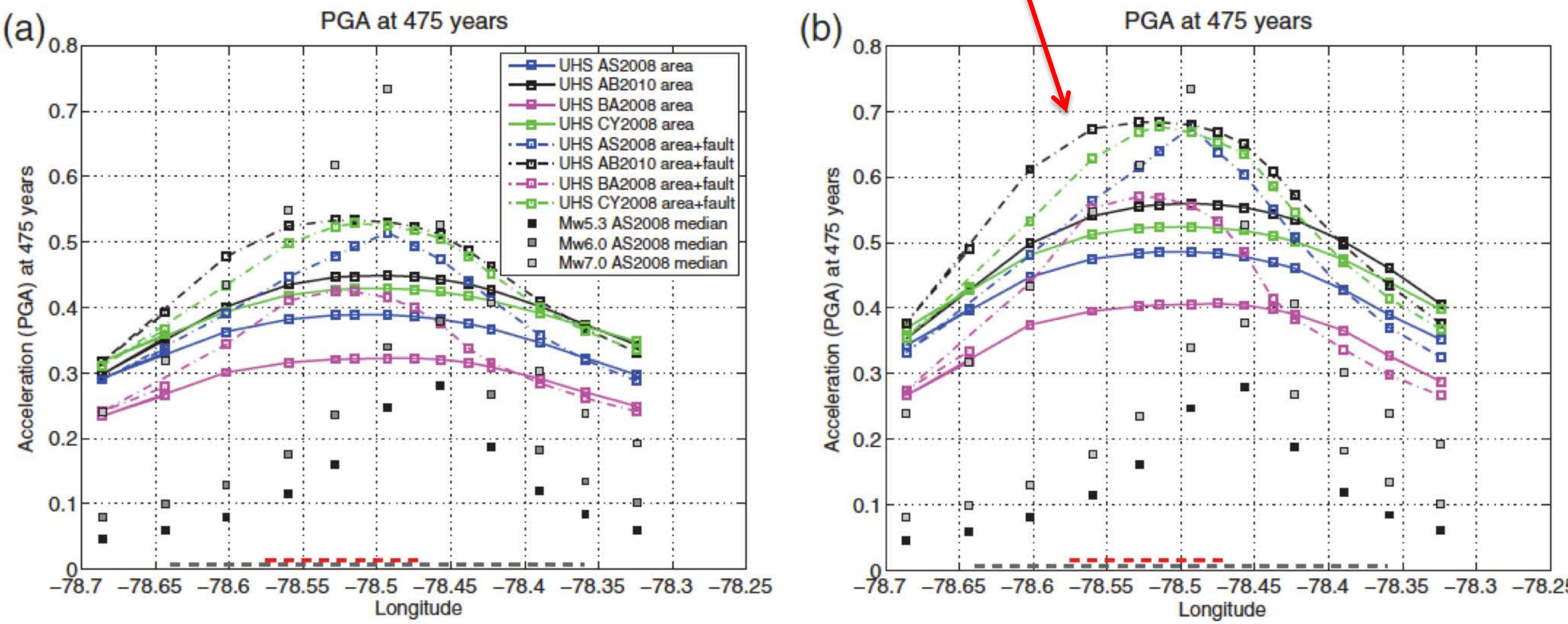


PROBABILISTIC SEISMIC HAZARD IN QUITO: THE LOCAL AREA SOURCE ZONE IS CONTROLLING THE HAZARD



PGA at sites along W-E profile

b value from S1 (larger area)

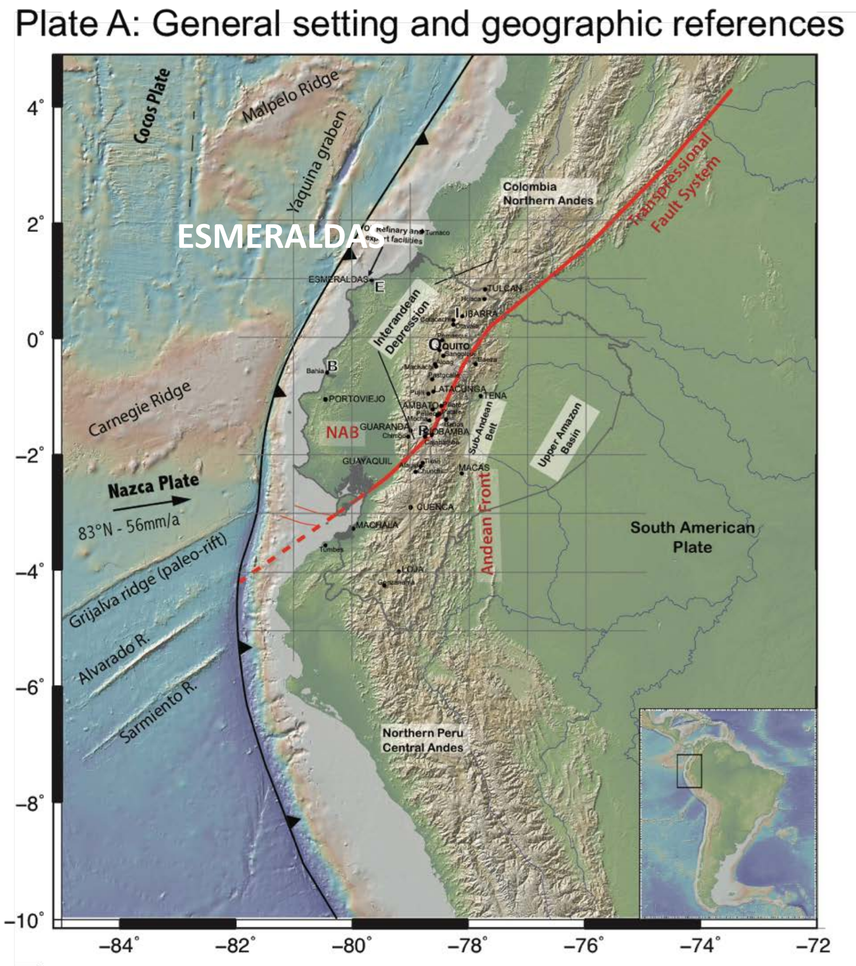


How important is an accurate modeling of source zones for PSHA

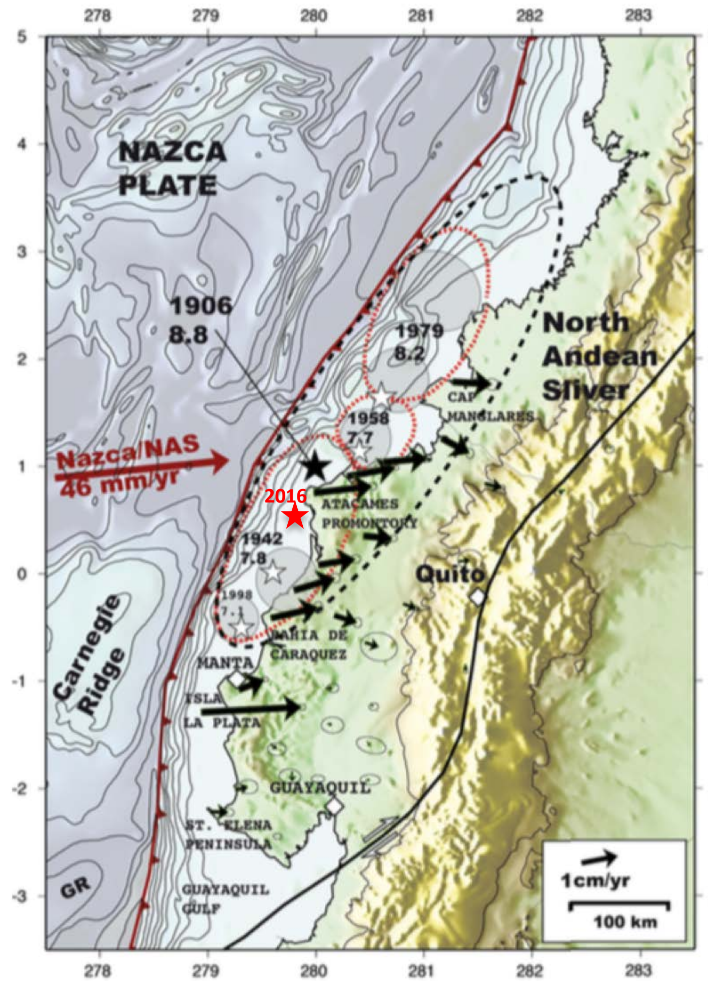
- For Quito, (3 GMPEs are being used for the source variations)
  - If rates for magnitudes 6-7 are extrapolated from historical catalogs with magnitude range from 4.5-6.0, PGA varies from **0.28 – 0.55 g.**
  - Slip rates transformed to frequency-magnitude distribution lead to a greater range: **0.43 – 0.73 g,** if locking is complete.
  - If 50% of the deformation is released aseismically, PGA varies from **0.32–0.58 g**
  - If the Quito fault is modeled as a simple structure and magnitudes 6 – 7 are distributed in the fault, PGA goes from **0.42 – 0.68 g**

- Then, definition and parametrization of source zones need to be carefully made.

The case of the Esmeraldas subduction source zone



Yepes et al. 2016



Chlieh et al. 2014

The case of the Esmeraldas subduction source zone

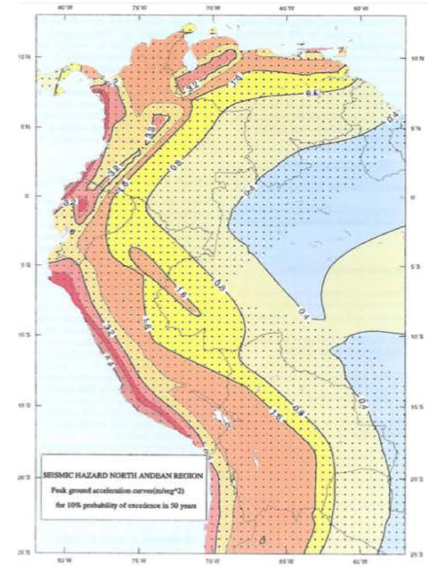
PGA maps
475 yr RT

CERESIS, 1996

CERESIS PGA (1996) 10%/50 yr

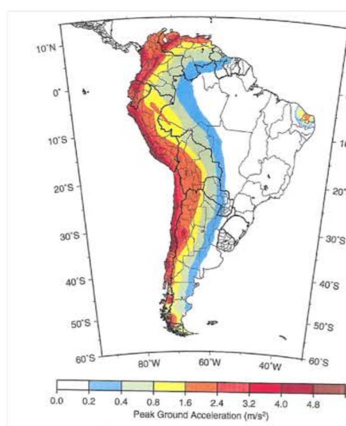
Piloto Project, 1999

PILOTO PGA (1999) 10%/50 yr



PAIGH, 1999

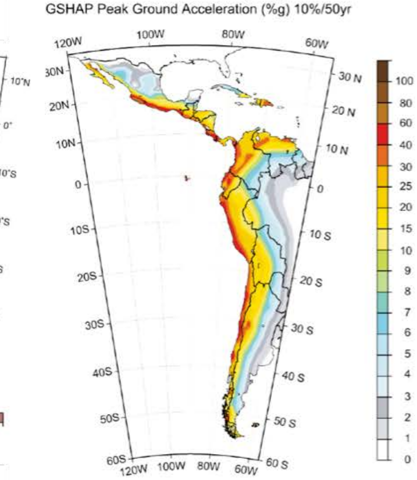
Sheldock&Tanner
PAIGH PGA (1999) 10%/50 yr



GSHAP, 1999

Giardini et al. (1999)
in Tanner&Sheldock (2004)

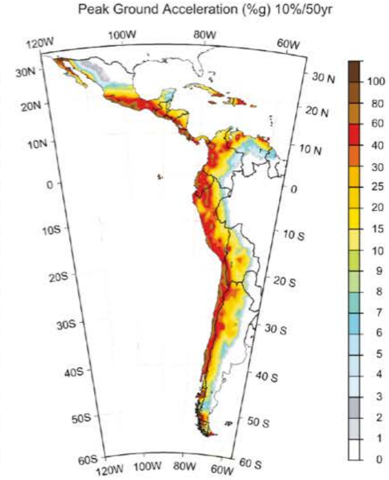
GSHAP Peak Ground Acceleration (%g) 10%/50yr



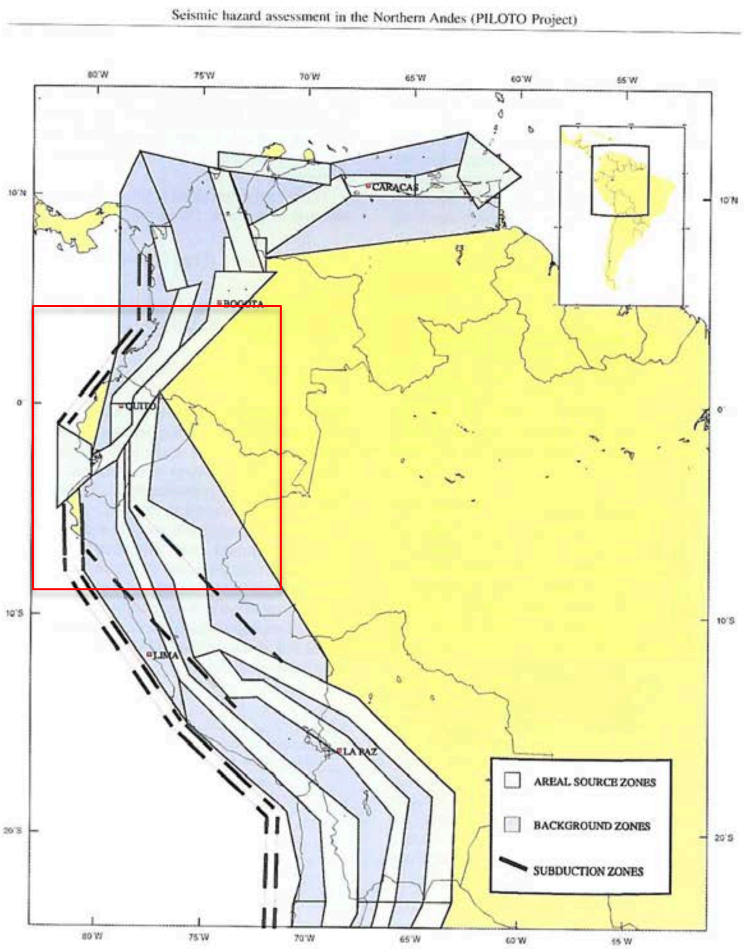
T&S, 2004

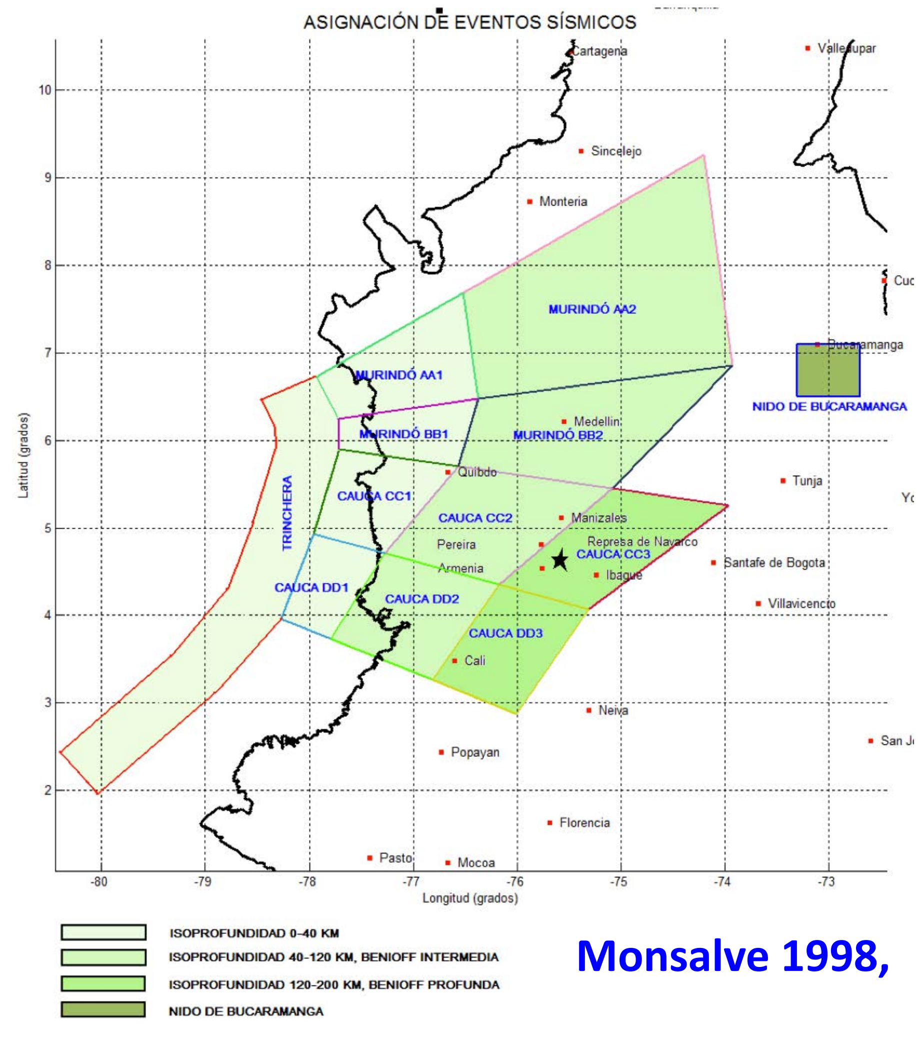
Tanner&Sheldock (2004)

Peak Ground Acceleration (%g) 10%/50yr



The case of the Esmeraldas subduction source zone

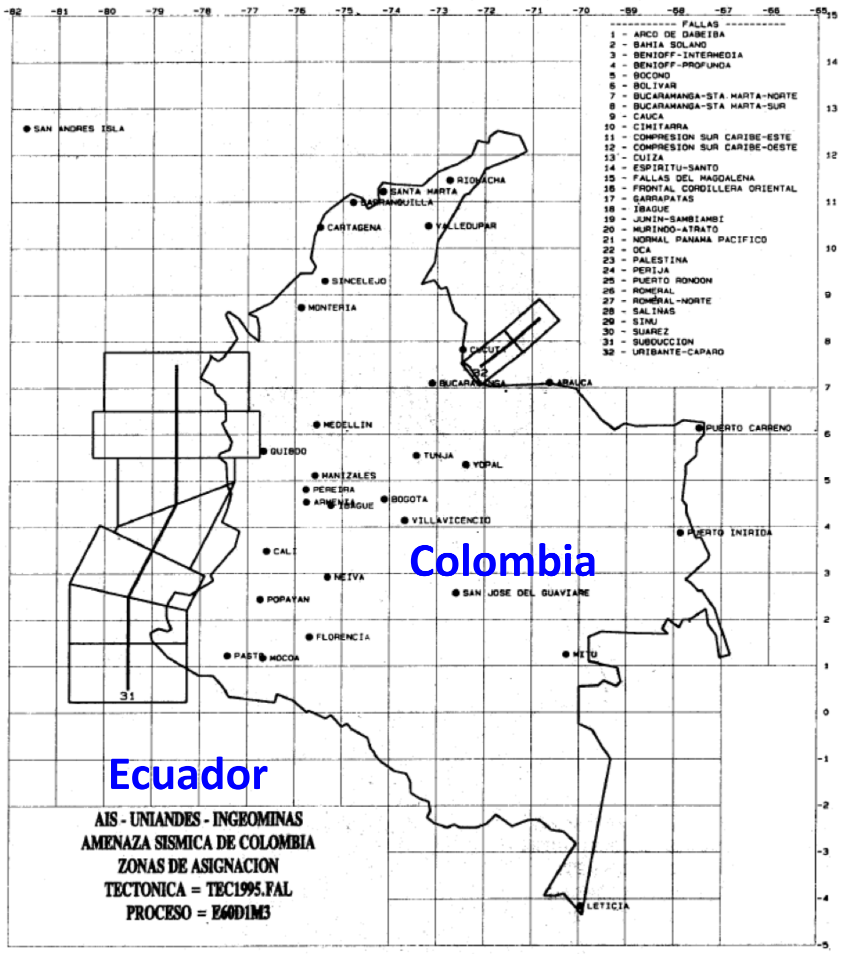




Pilot Project, 1999

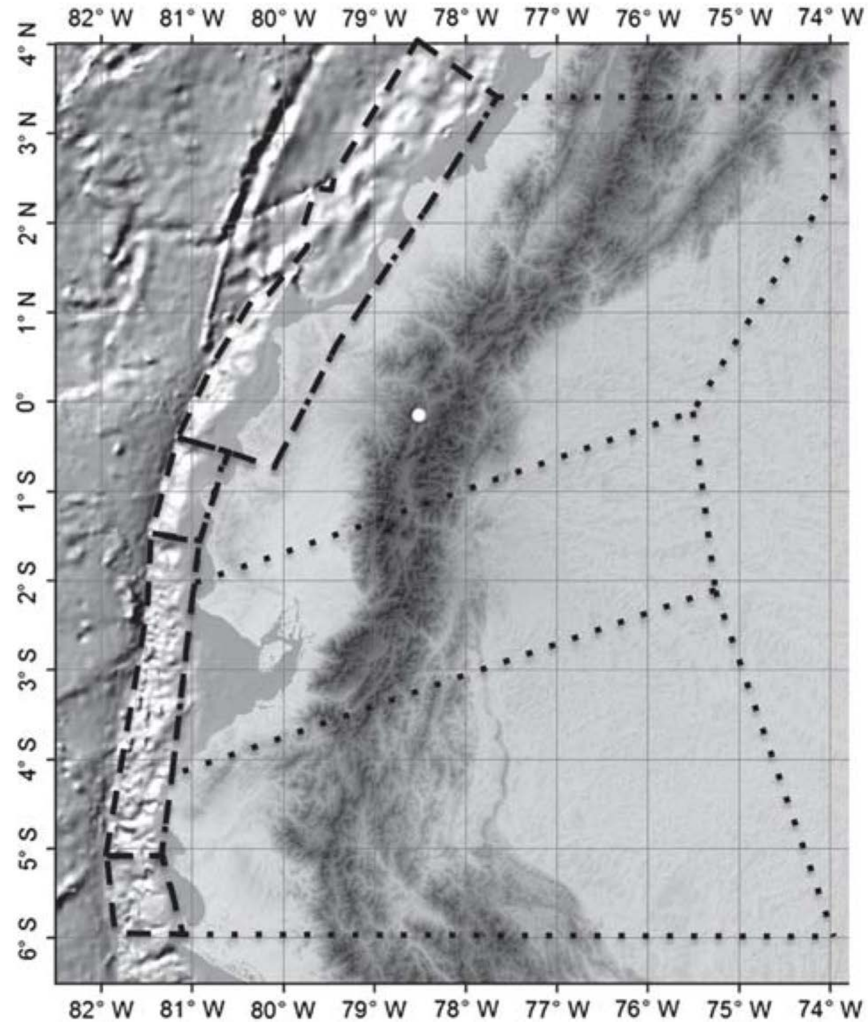
Monsalve 1998,

The case of the Esmeraldas subduction source zone

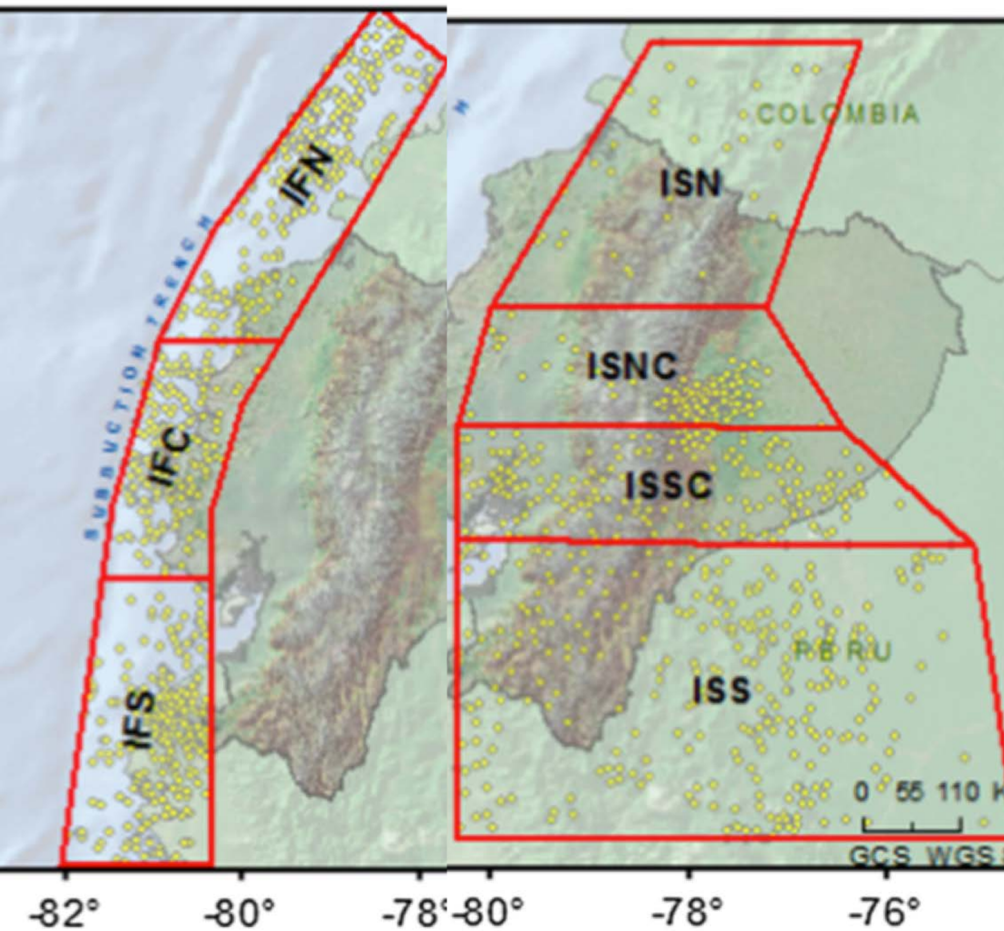


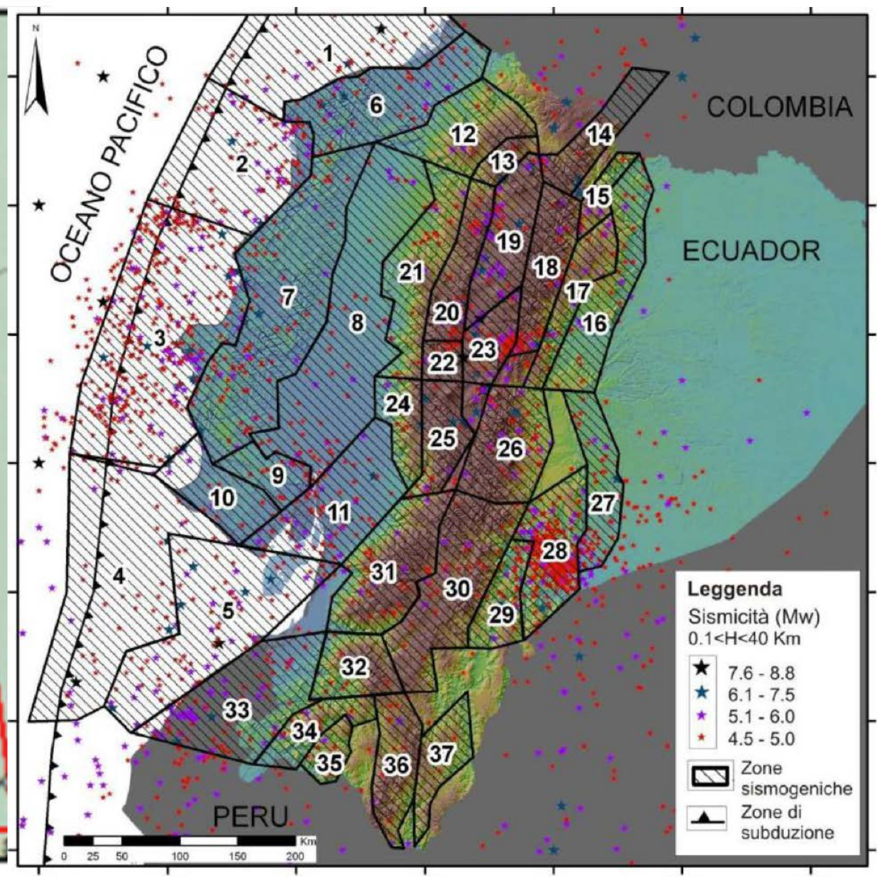
Aso. Ing. Sísmica Colombia 1997

NEC 2011



The case of the Esmeraldas subduction source zone





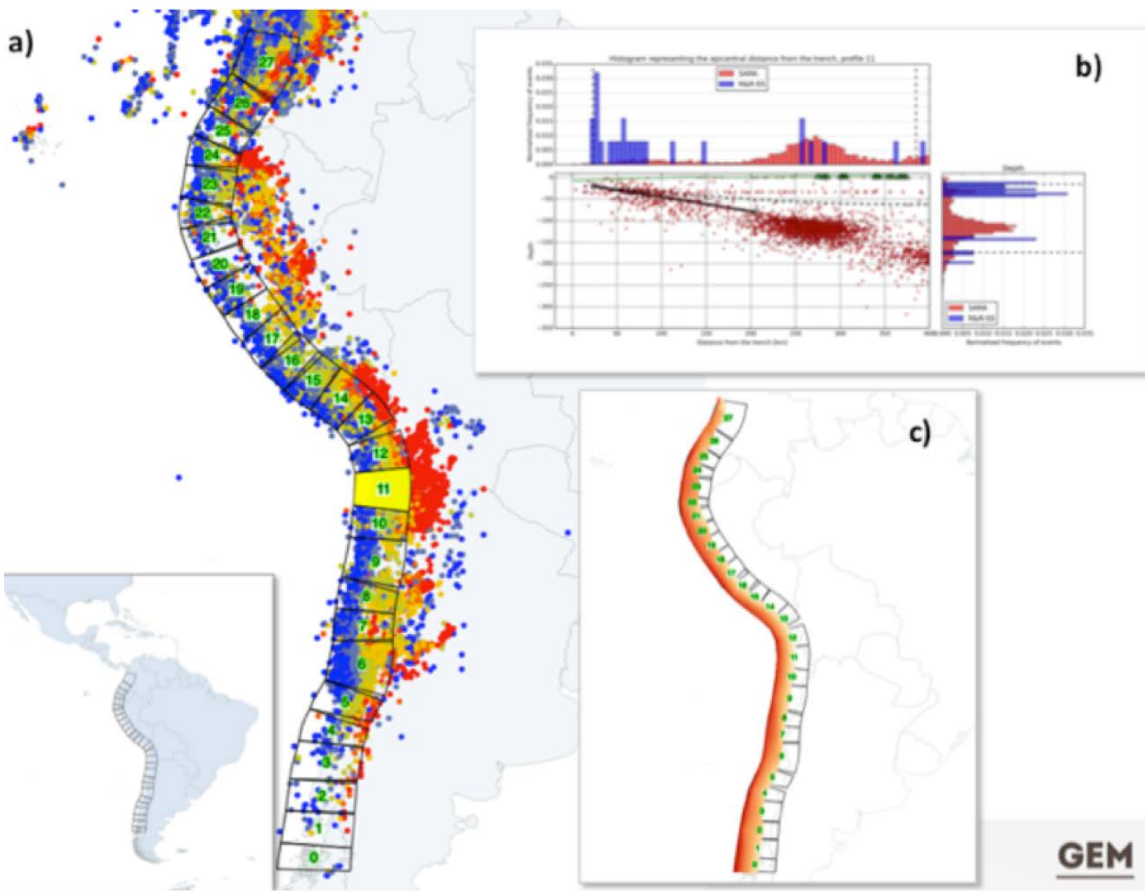
Parra, 2016,

Chunga, Vera, otros,

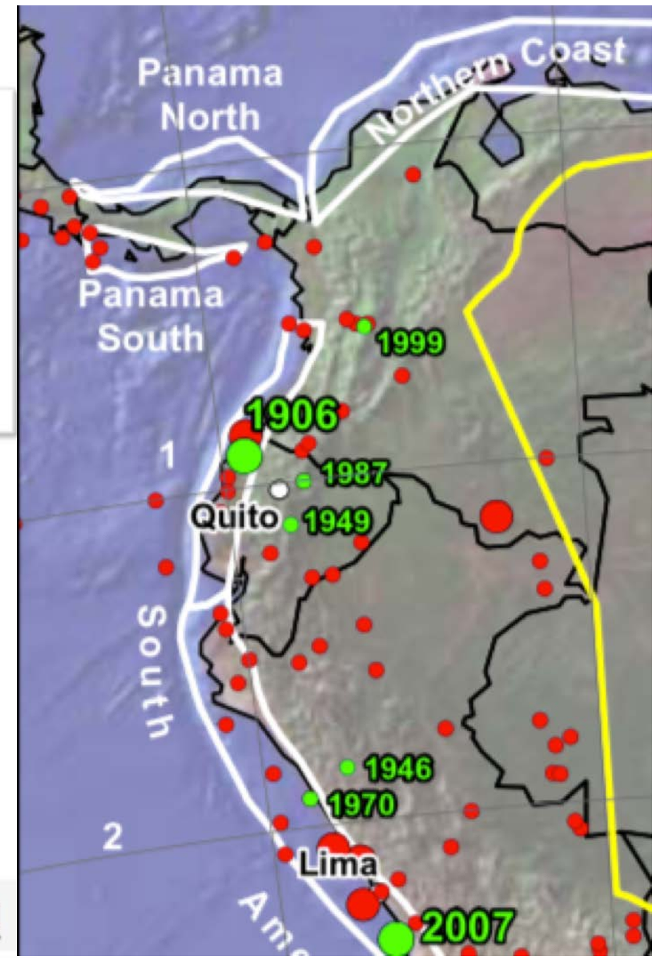
Local Variations

The case of the Esmeraldas subduction source zone

SARA Project 2016



USGS 2018



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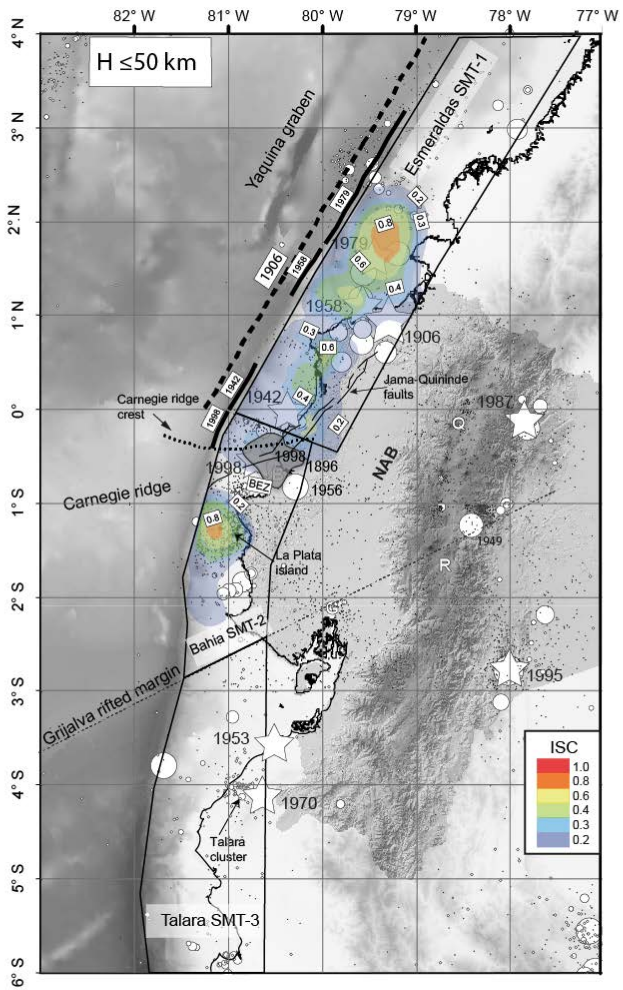
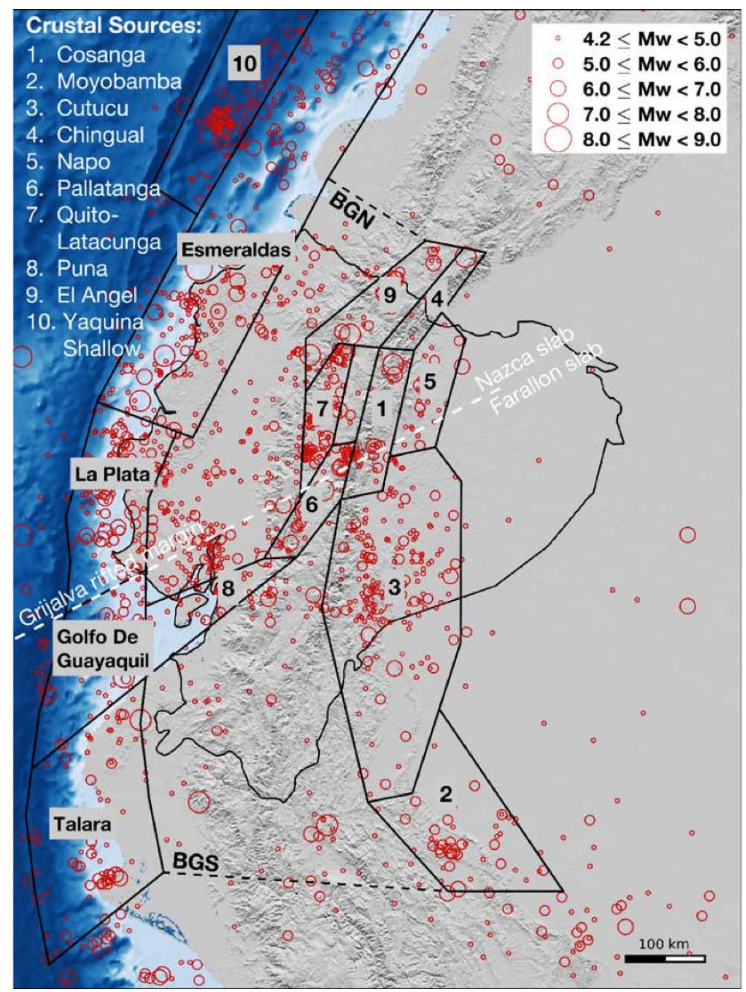
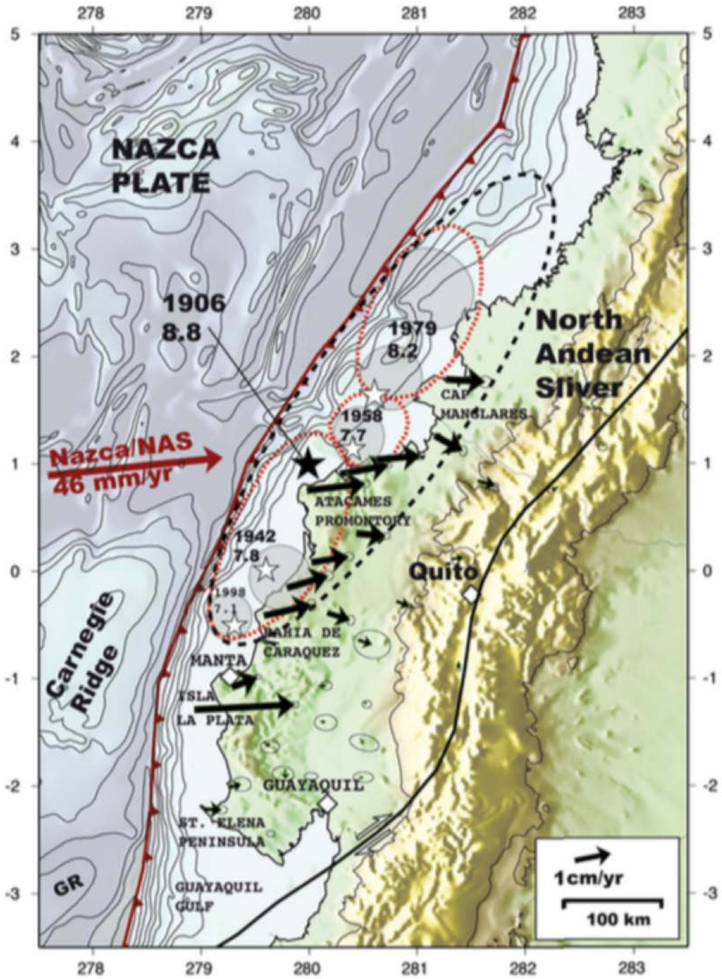
Yepes et al. 2016



Beauval et al. 2018



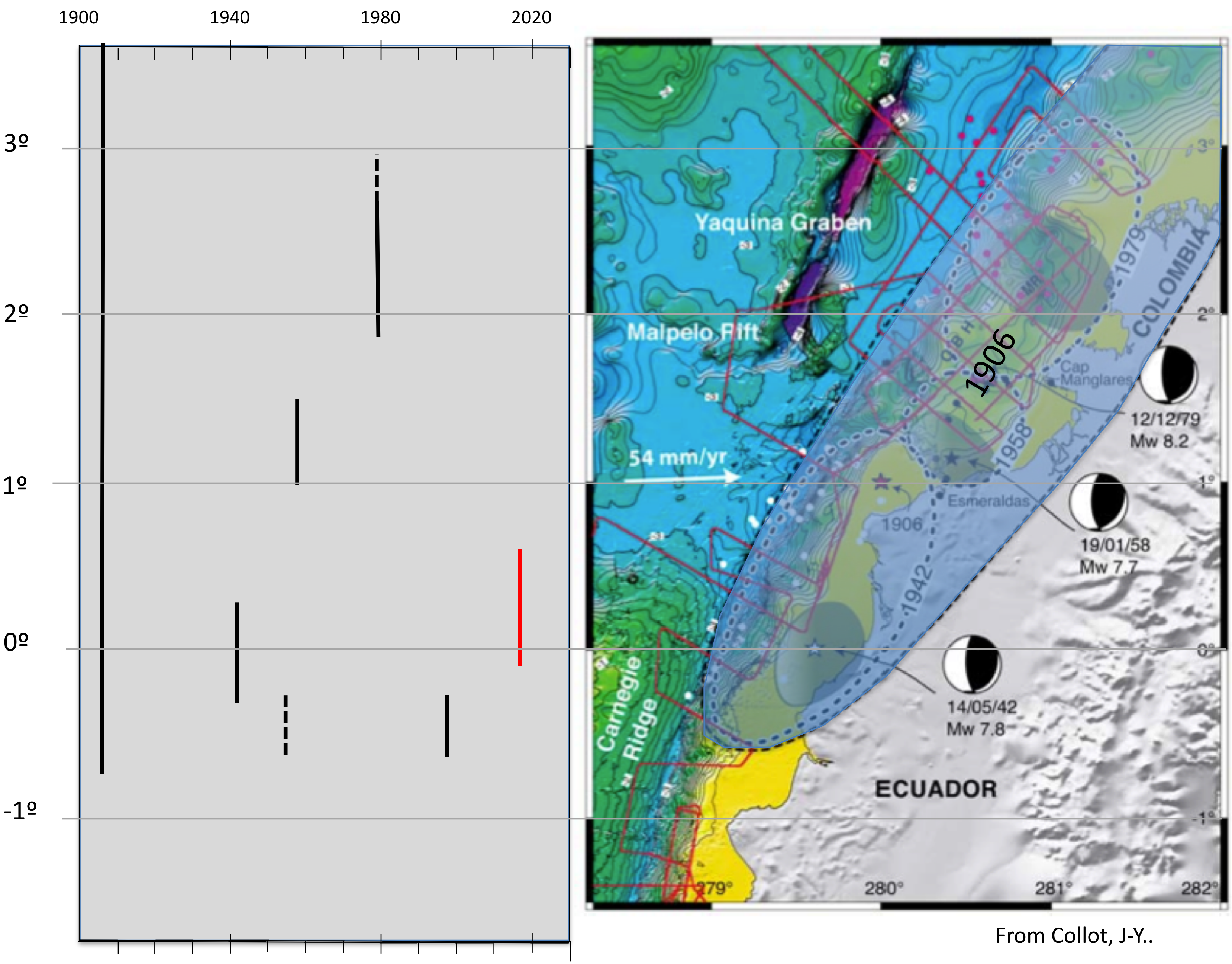
Some issues



Chlieh et al. 2014

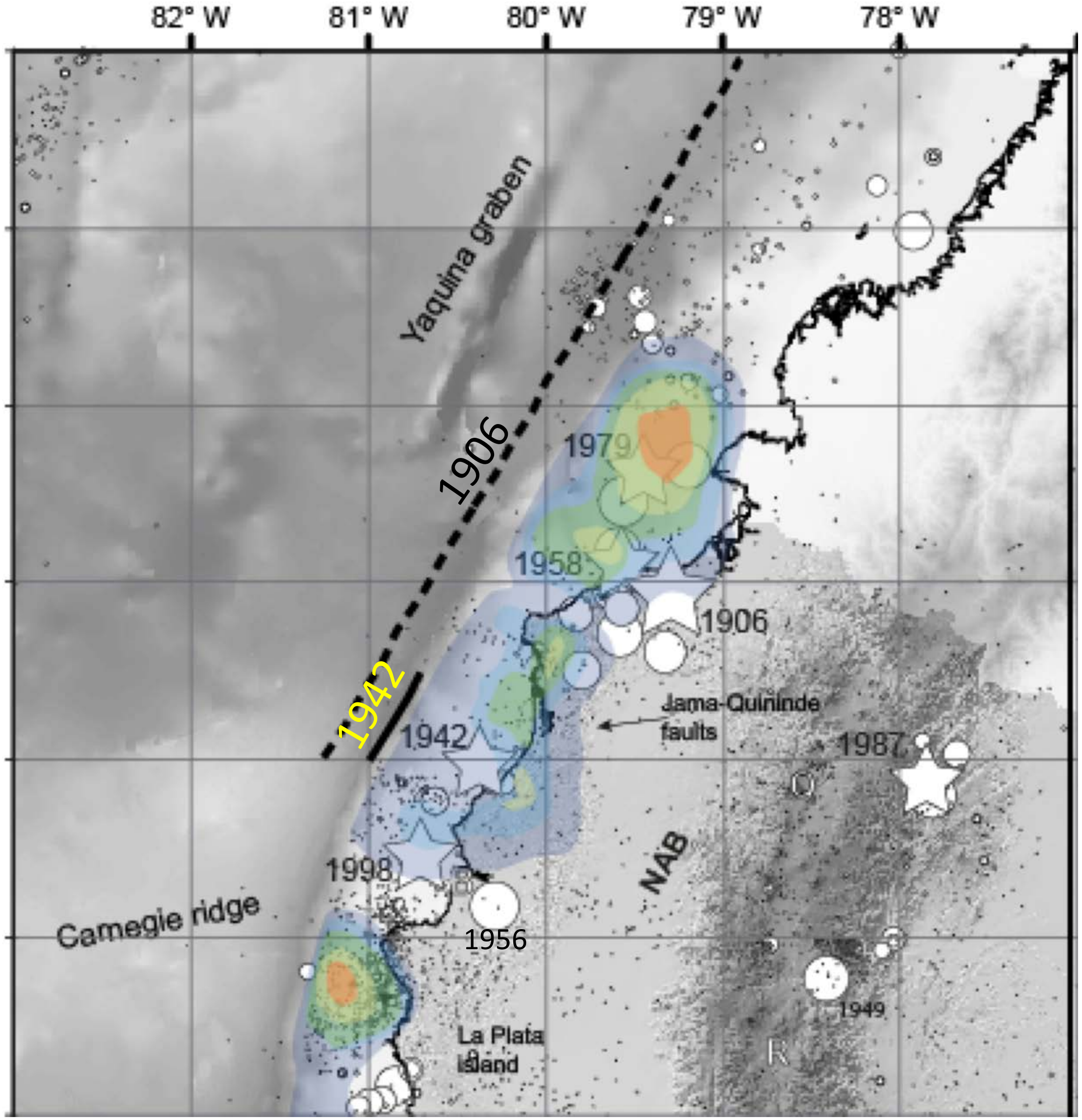
- One single segment?
- Maximum eartquake?
- Dip?
- Depth?
- Northern termination
- Southern termination

RUPTURE LENGTH AT ESMERALDAS SSZ

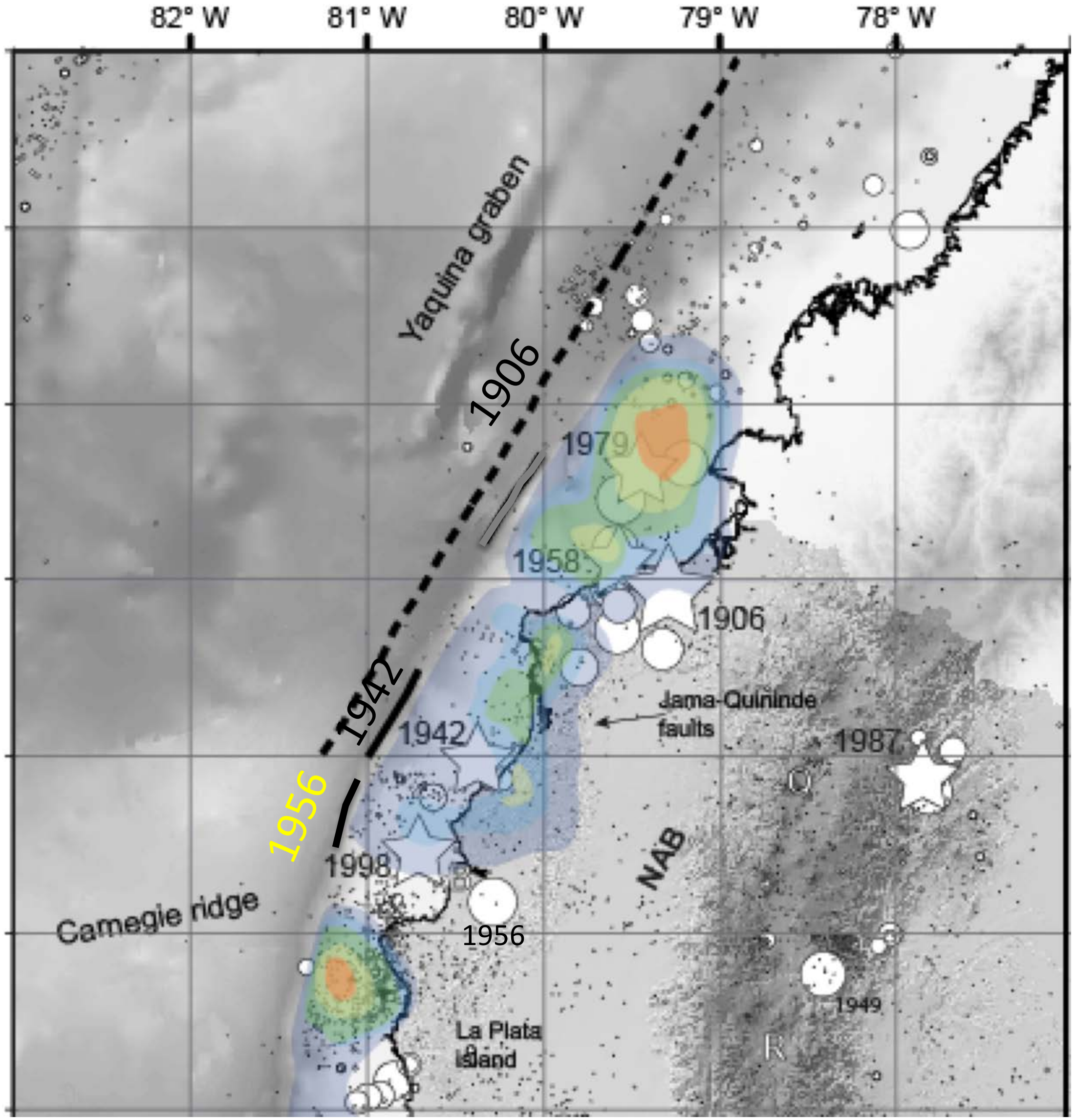


From Collot, J-Y..

Moment balance and the seismic cycle
20th and 21st Centuries



Moment balance and the seismic cycle
20th and 21st Centuries



Moment balance and the seismic cycle
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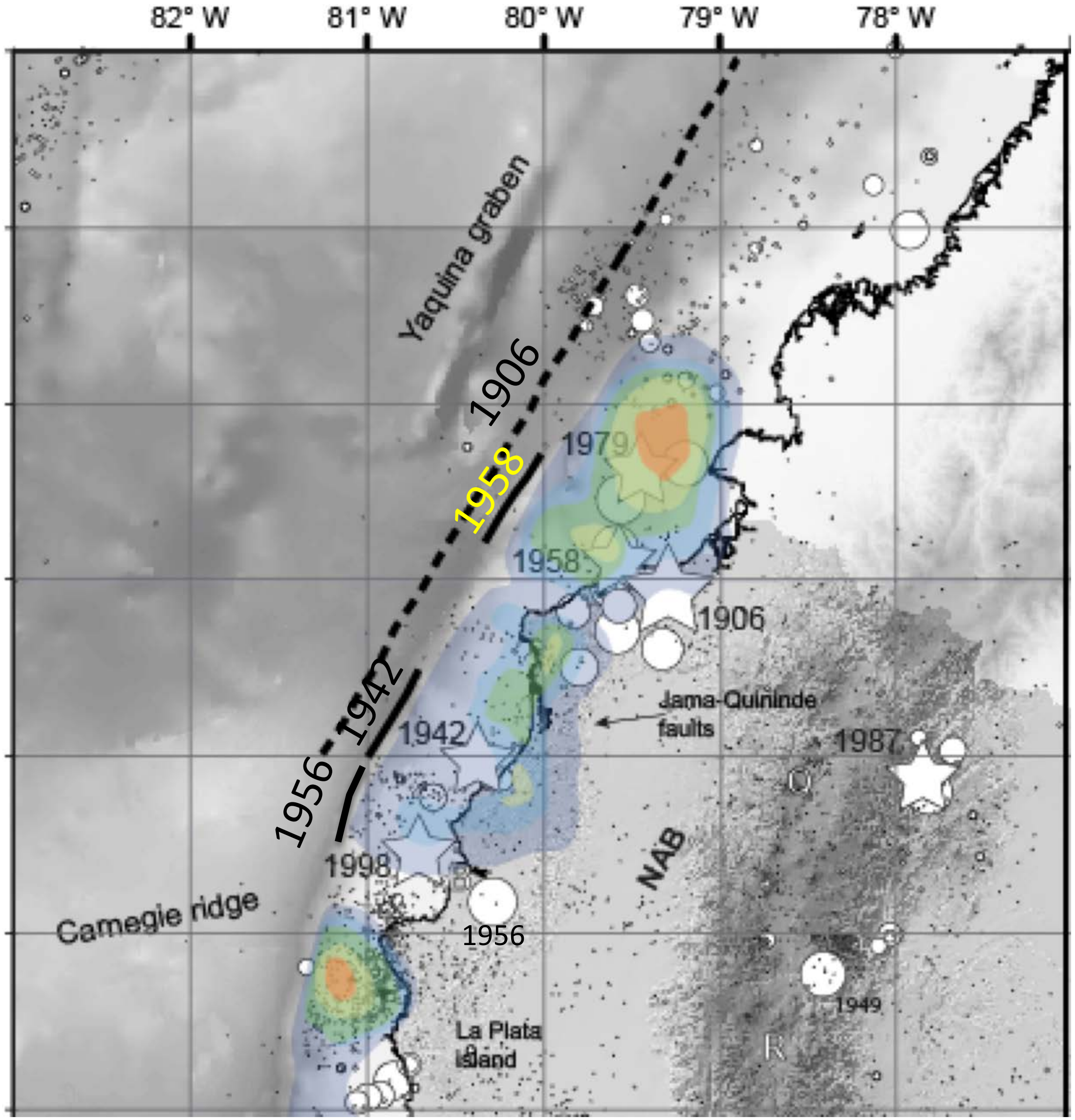

Moment balance and the seismic cycle
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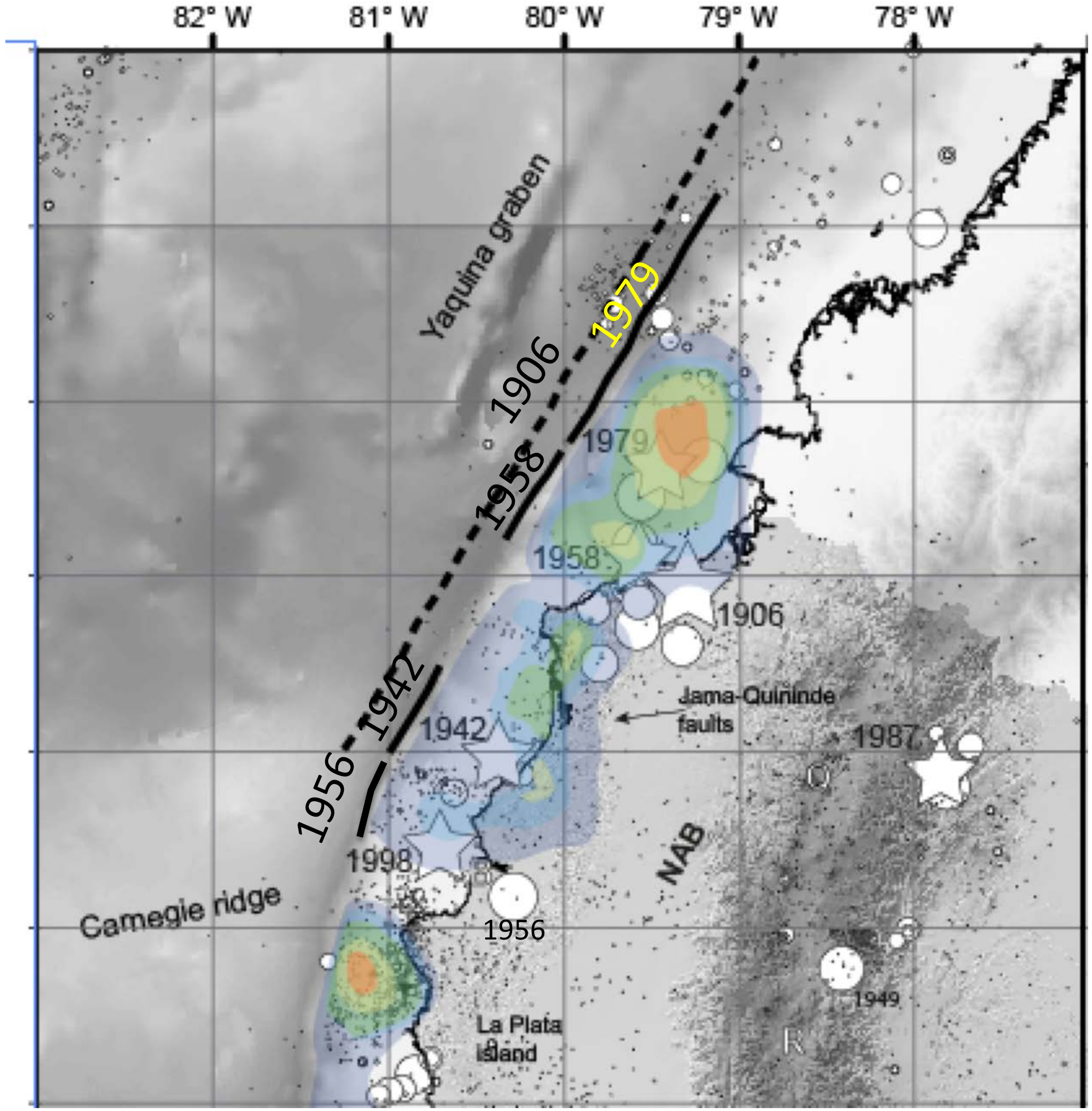
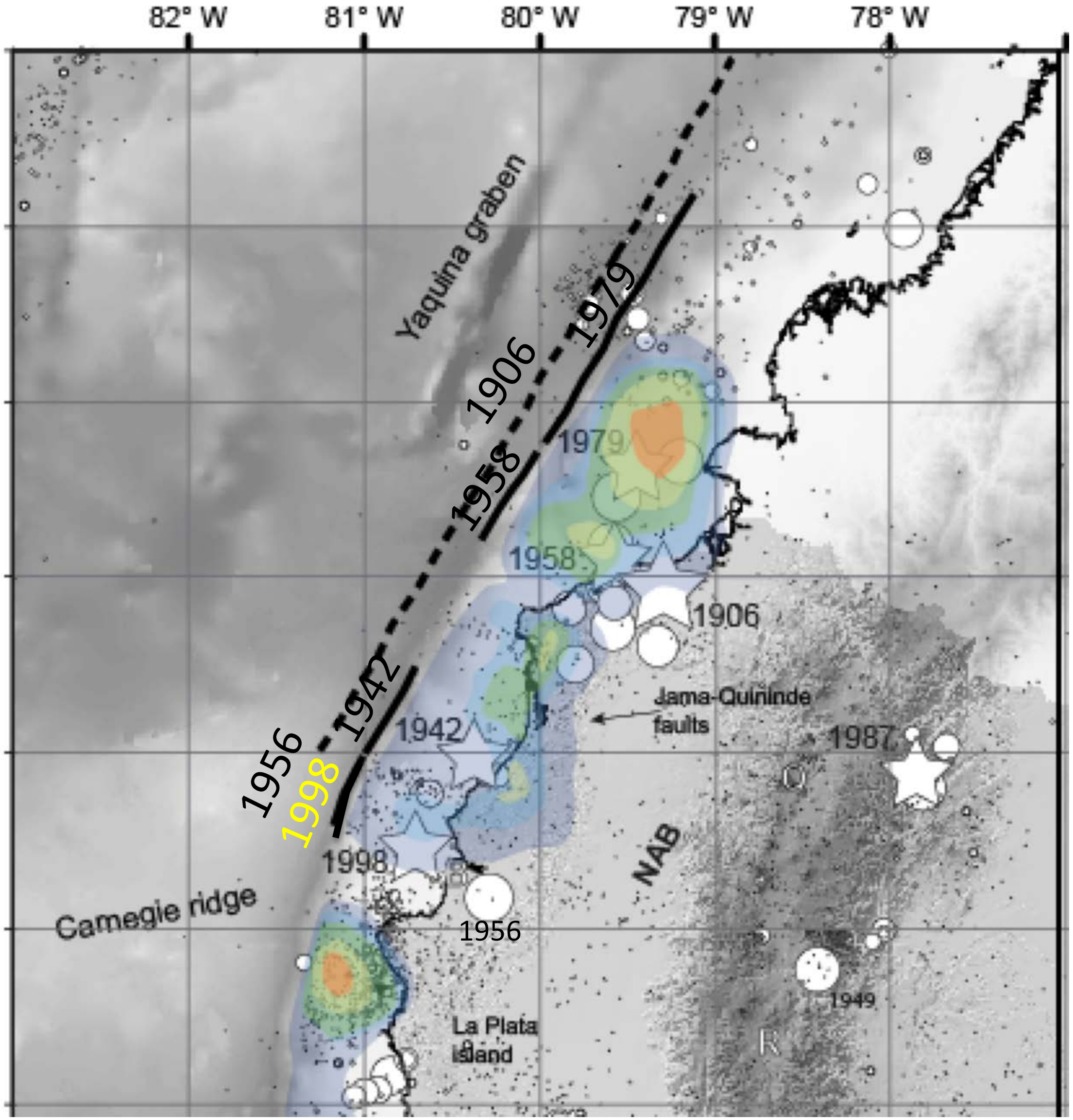
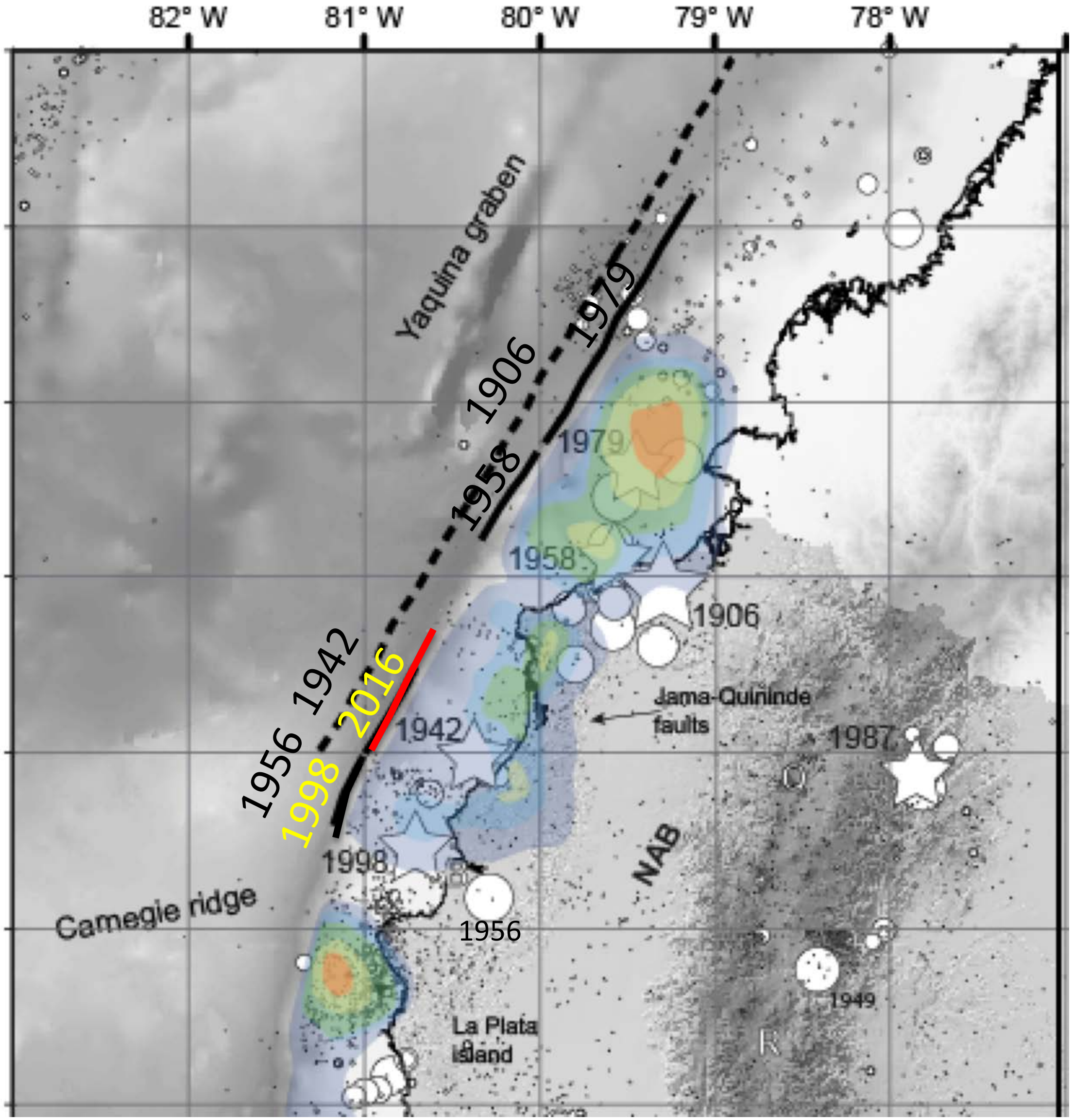


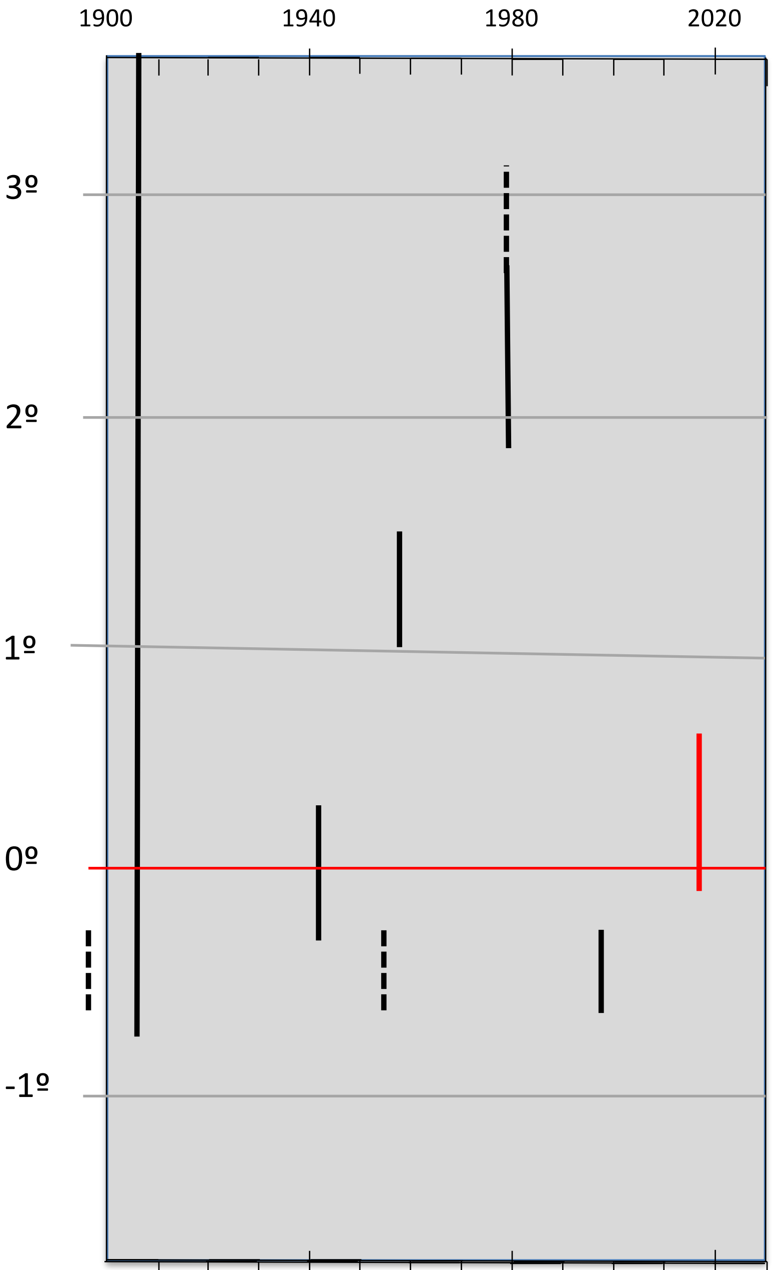
Moment balance and the seismic cycle 20th and 21st Centuries

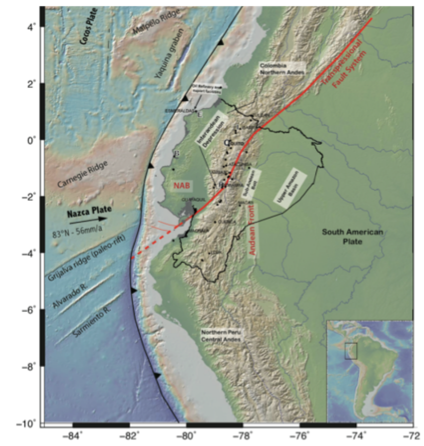


Moment balance and the seismic cycle
20th and 21st Centuries



TOO MANY EARTHQUAKES AT ESSZ





~47 mm/yr of convergence Nazca-NAS

1906-1942 → 36 a → 1.7m

1942-2016 → 74 a → 3.5m

1906-2016 → 110 a → 5.1m

TOTAL SLIP AT INTERFACE ~7m

One single segment?   Maximum earthquake?

nature geoscience

ARTICLES

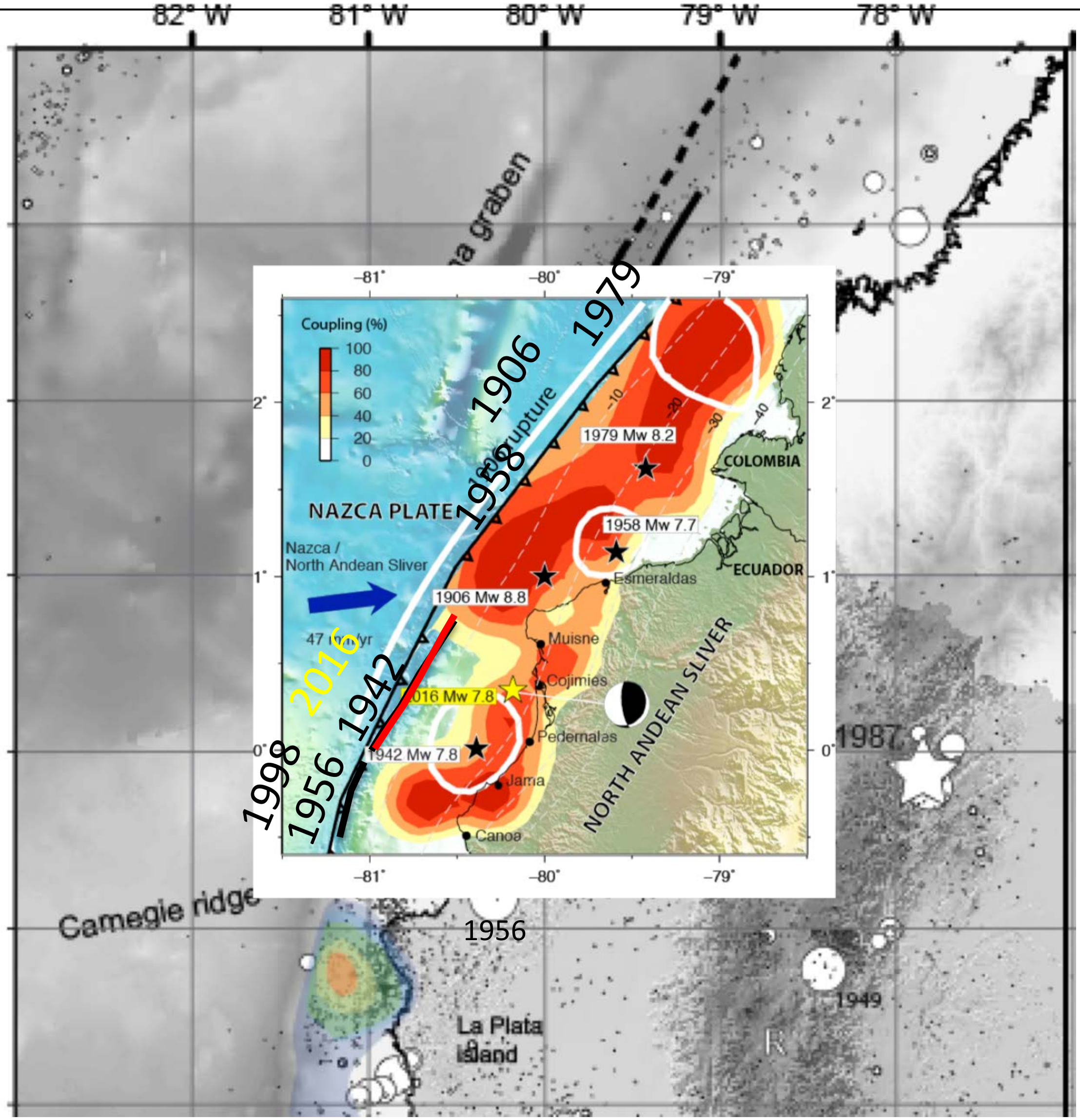
PUBLISHED ONLINE: 26 DECEMBER 2016 | DOI: 10.1038/NGEO2864

Supercycle at the Ecuadorian subduction zone revealed after the 2016 Pedernales earthquake

J.-M. Nocquet[1]*, P. Jarrin[2], M. Vallée[3], P. A. Mothes[2], R. Grandin[3], F. Rolandone[1,4], B. Delouis[1], H. Yepes[2], Y. Font[1], D. Fuentes[2], M. Régnier[1], A. Laurendeau[2], D. Cisneros[5], S. Hernandez[2], A. Sladen[1],

However, we find that coseismic slip in 2016 exceeds the deficit accumulated since 1942. The seismic moment of every large earthquake during the twentieth century further exceeds the moment deficit accumulated since 1906. These results, together with the seismic quiescence before 1906 highlighted by historical records and marine palaeoseismology, argue for an earthquake supercycle at the Ecuador–Colombia margin. This behaviour, which has led to an enhanced seismic hazard for 110 years, is possibly still going on and may apply to other subduction zones that recently experienced a great earthquake.

One single segment? Maximum earthquake?



Nocquet et al. 2016

One single segment? Maximum earthquake?

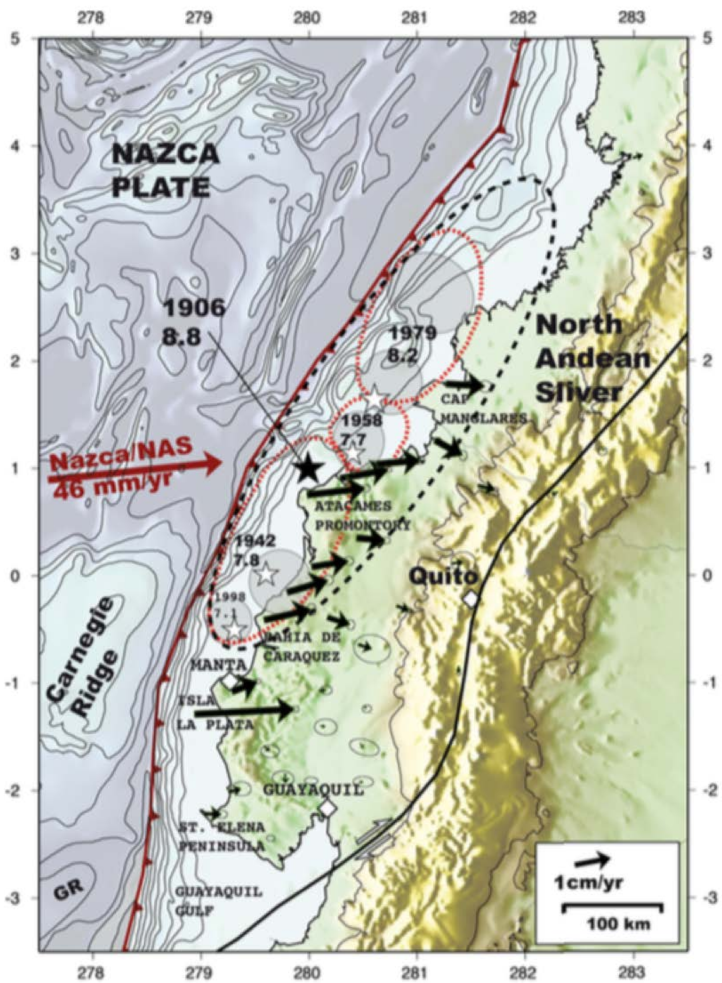
How come ESSZ is not respecting the fundaments of the seismic cycle?

How are we going to incorporate this in PSHA?

Are memory models going to be implemented in SHA?

Well, ESSZ seems to suffer from Alzheimer disease! How many more SSZ present this type of beheavior?

Some issues



Chlieh et al. 2014

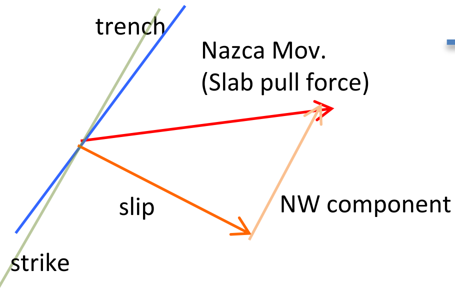
- One single segment?
- Maximum eartquake?
- Dip?
- Depth?
- Northern termination
- Southern termination

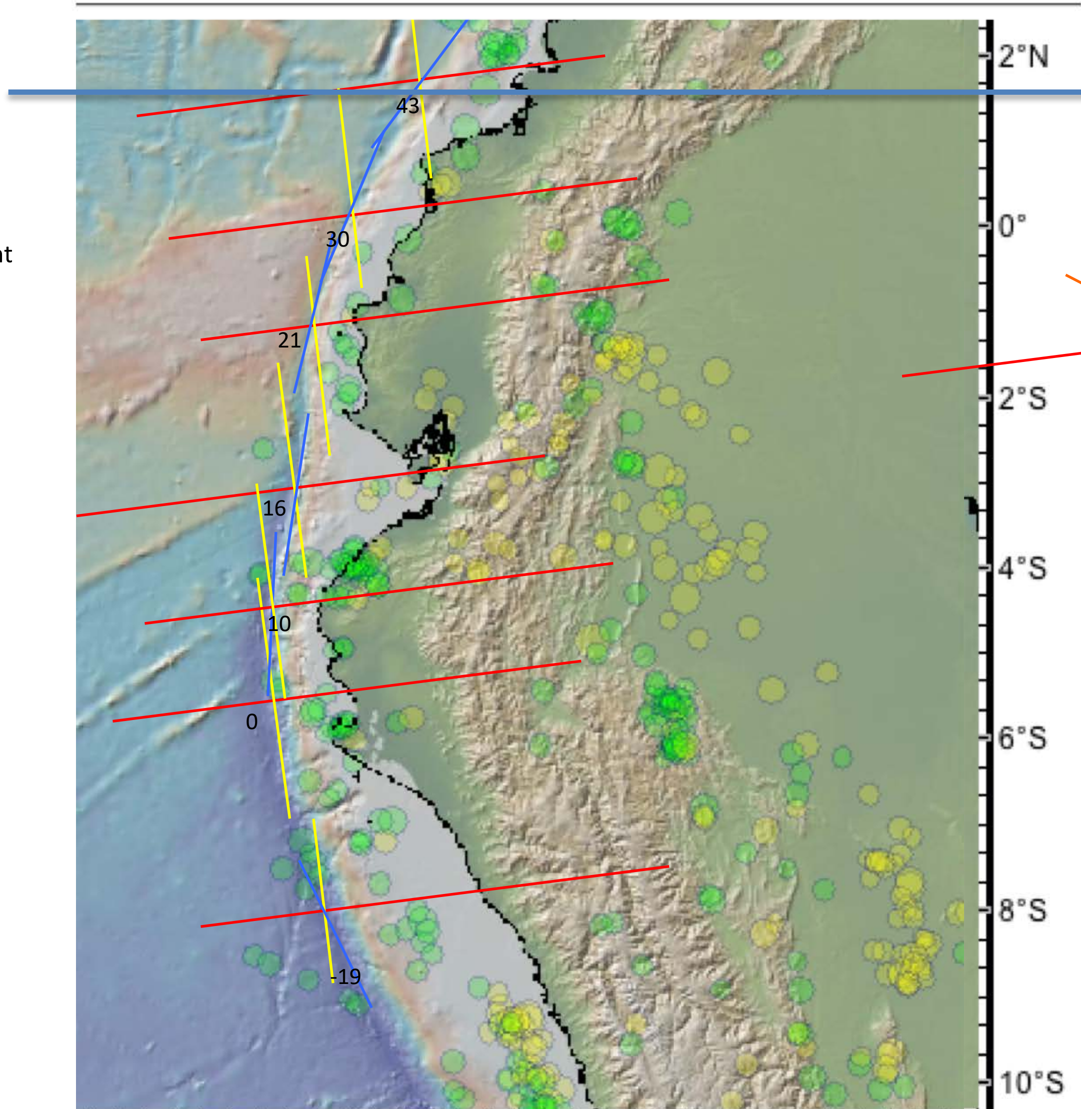
Megathrust interface rupture

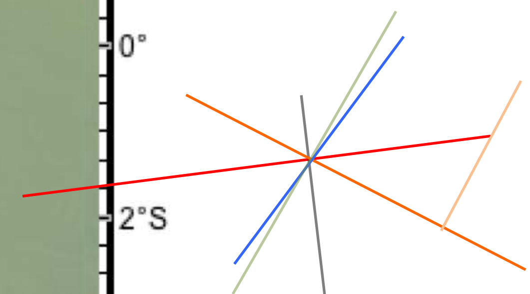
121279A NEAR COAST OF ECUADOR

```
Date: 1979/12/12    Centroid Time:  8: 0: 7.0 GMT
Lat=   2.32  Lon= -78.81
Depth= 19.7    Half duration=22.5
Centroid time minus hypocenter time: 63.7
Moment Tensor: Expo=28  0.785 -0.040 -0.744 0.022 -1.484 -0.229
Mw = 8.1     mb = 6.4     Ms = 7.7   Scalar Moment = 1.69e+28
Fault plane:  strike=30     dip=16    slip=118
Fault plane:  strike=181     dip=76    slip=83
```

Depth 23.6

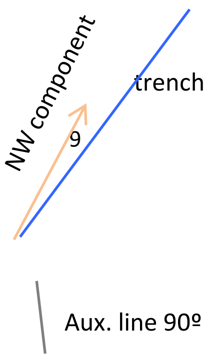




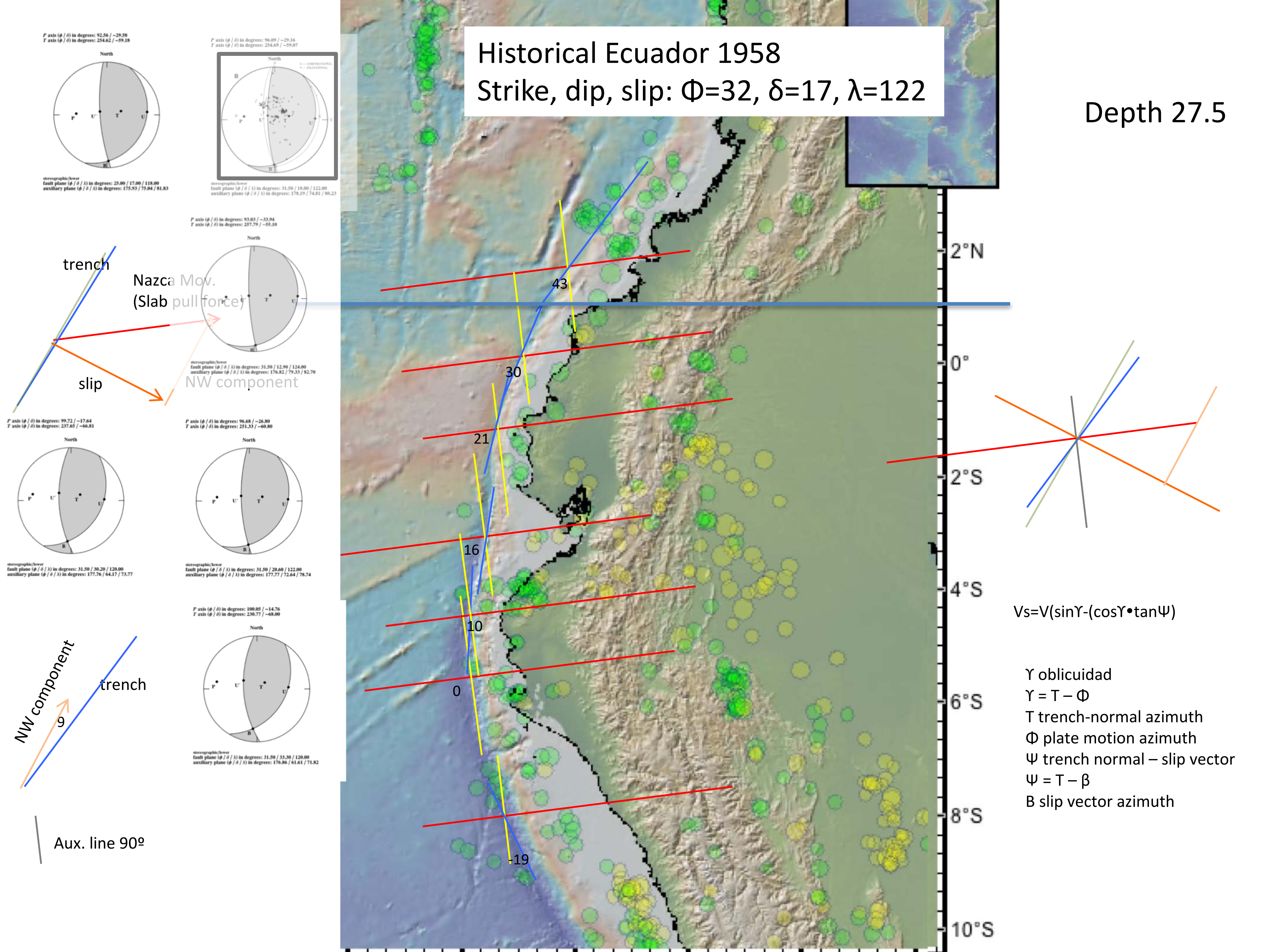


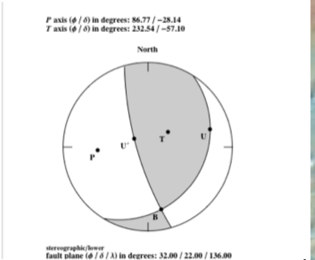
Vs=V(sinϒ-(cosϒ•tanΨ)

ϒ oblicuidad
ϒ = T – Φ
T trench-normal azimuth
Φ plate motion azimuth
Ψ trench normal – slip vector
Ψ = T – β
B slip vector azimuth



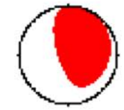
Aux. line 90º


Historical Ecuador 1958
Strike, dip, slip: Φ=32, δ=17, λ=122
Depth 27.5
trench
Nazca Mov.
(Slab pull force)
slip
NW component
NW component
9
trench
Aux. line 90º
43
30
21
16
10
0
-19
2°N
0°
2°S
4°S
6°S
8°S
10°S
Vs=V(sinϒ-(cosϒ•tanΨ)
ϒ oblicuidad
ϒ = T – Φ
T trench-normal azimuth
Φ plate motion azimuth
Ψ trench normal – slip vector
Ψ = T – β
Β slip vector azimuth

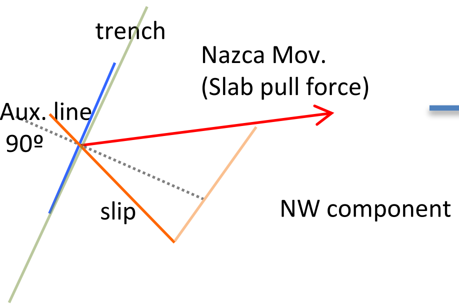


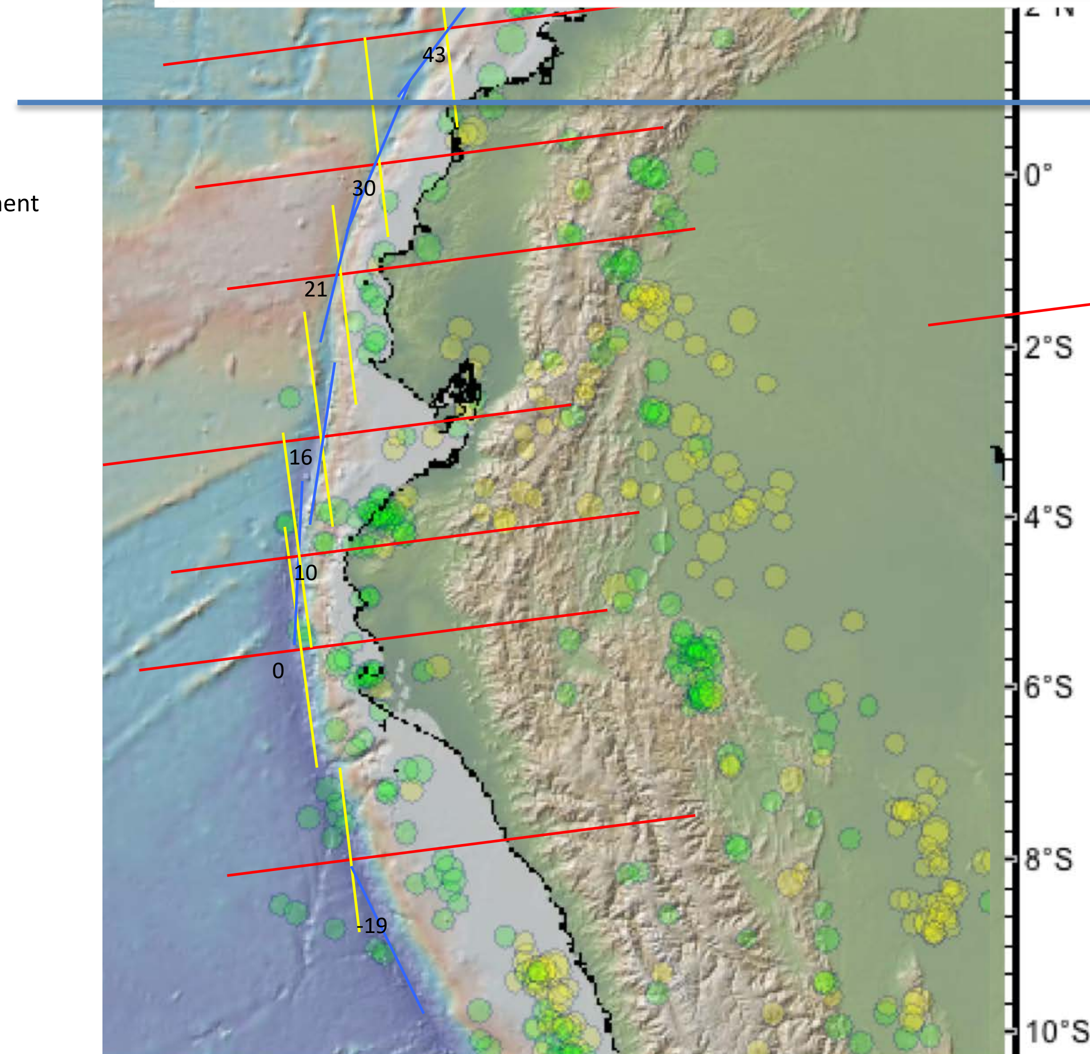
Según McCaffrey, no tan complete decoupling (slip vector paralelo a la normal)

040976A NEAR COAST OF ECUADOR

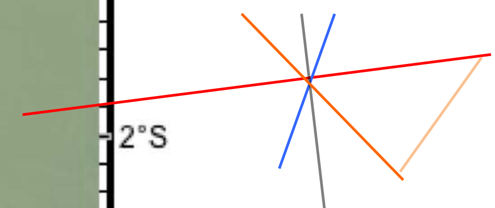


```
Date: 1976/ 4/ 9   Centroid Time:  7: 8:58.3 GMT
Lat=   0.79  Lon= -79.89
Depth= 19.4   Half duration= 5.1
Centroid time minus hypocenter time: 11.3
Moment Tensor: Expo=25  5.880 0.190 -6.070 3.750 -8.540 -1.480
Mw = 6.6     mb = 6.1     Ms = 6.7   Scalar Moment = 1.11e+26
Fault plane:  strike=32     dip=22    slip=136
Fault plane:  strike=164     dip=75    slip=74
```



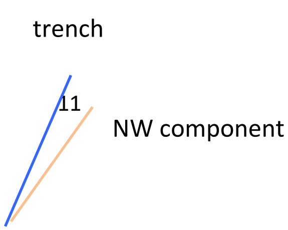


Depth 17.4



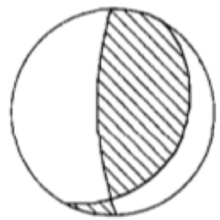
Υ=41º

Vs=V(sinΥ-(cosΥ•tanΨ)



Υ oblicuidad
Υ = T – Φ
T trench-normal azimuth
Φ plate motion azimuth
Ψ trench normal – slip vector
Ψ = T – β
B slip vector azimuth

dip and slip $\phi = 30°$, $\delta = 20°$ and $\lambda = 120°$,

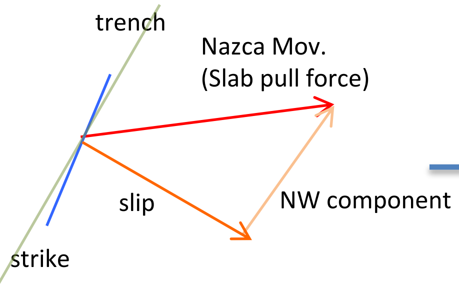


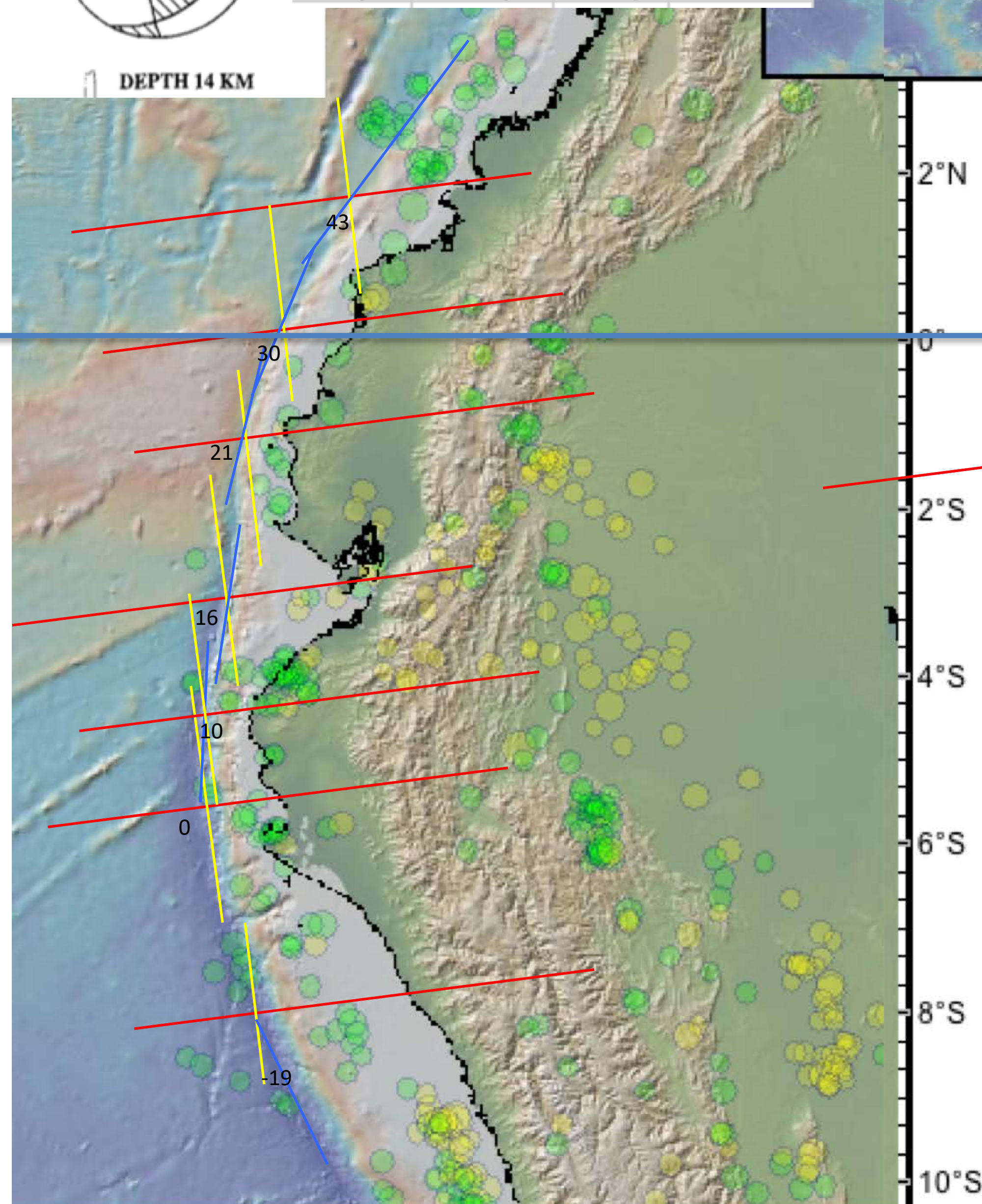
DEPTH 14 KM

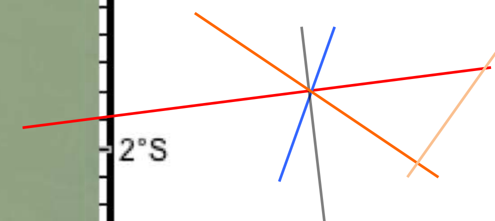
Historical 1942 Ecuador

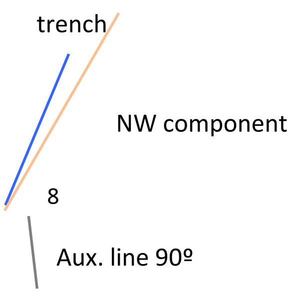
0,01	-80,39	19,7	Mendoza

Depth 20





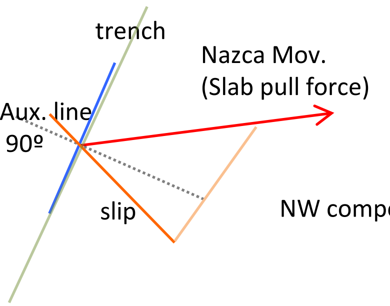


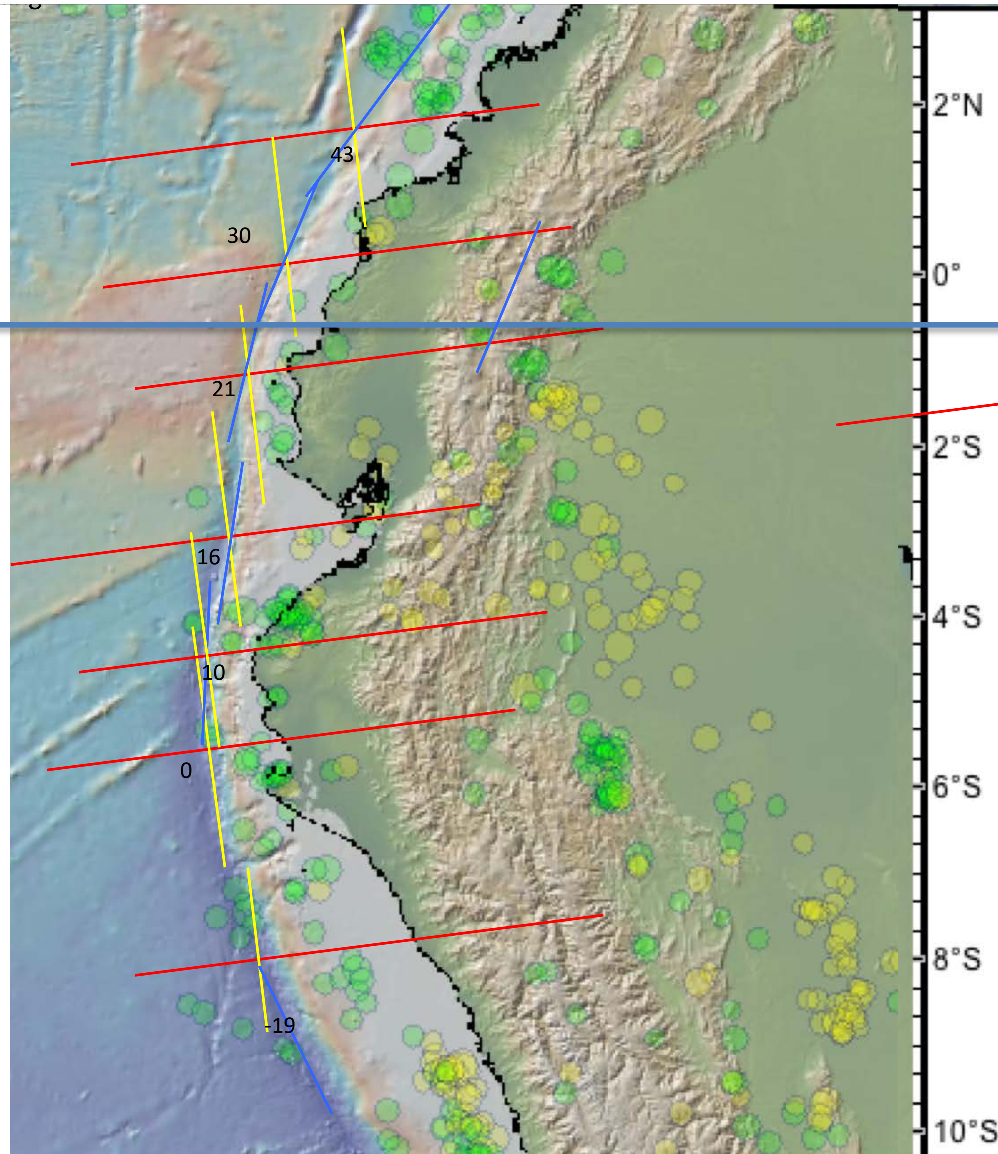


080498H NEAR COAST OF ECUADOR

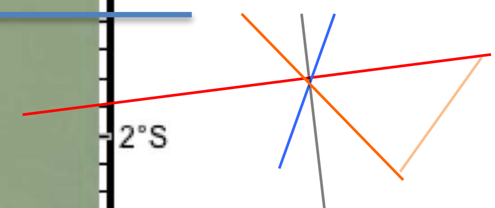
```
Date: 1998/ 8/ 4   Centroid Time: 18:59:29.2 GMT
Lat=  -0.57  Lon= -80.48
Depth= 25.6   Half duration= 8.7
Centroid time minus hypocenter time:  9.1
Moment Tensor: Expo=26  2.593 0.162 -2.755 0.981 -5.671 -0.521
Mw = 7.1     mb = 6.2     Ms = 7.1    Scalar Moment = 6.37e+26
Fault plane:  strike=27     dip=15    slip=124
Fault plane:  strike=172     dip=78    slip=82
```

Según McCaffrey, no tan complet
(slip vector paralelo a la normal



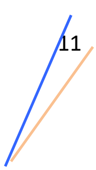


Depth 20



Υ=41º

$V_s = V(\sin\Upsilon - (\cos\Upsilon \cdot \tan\Psi)$



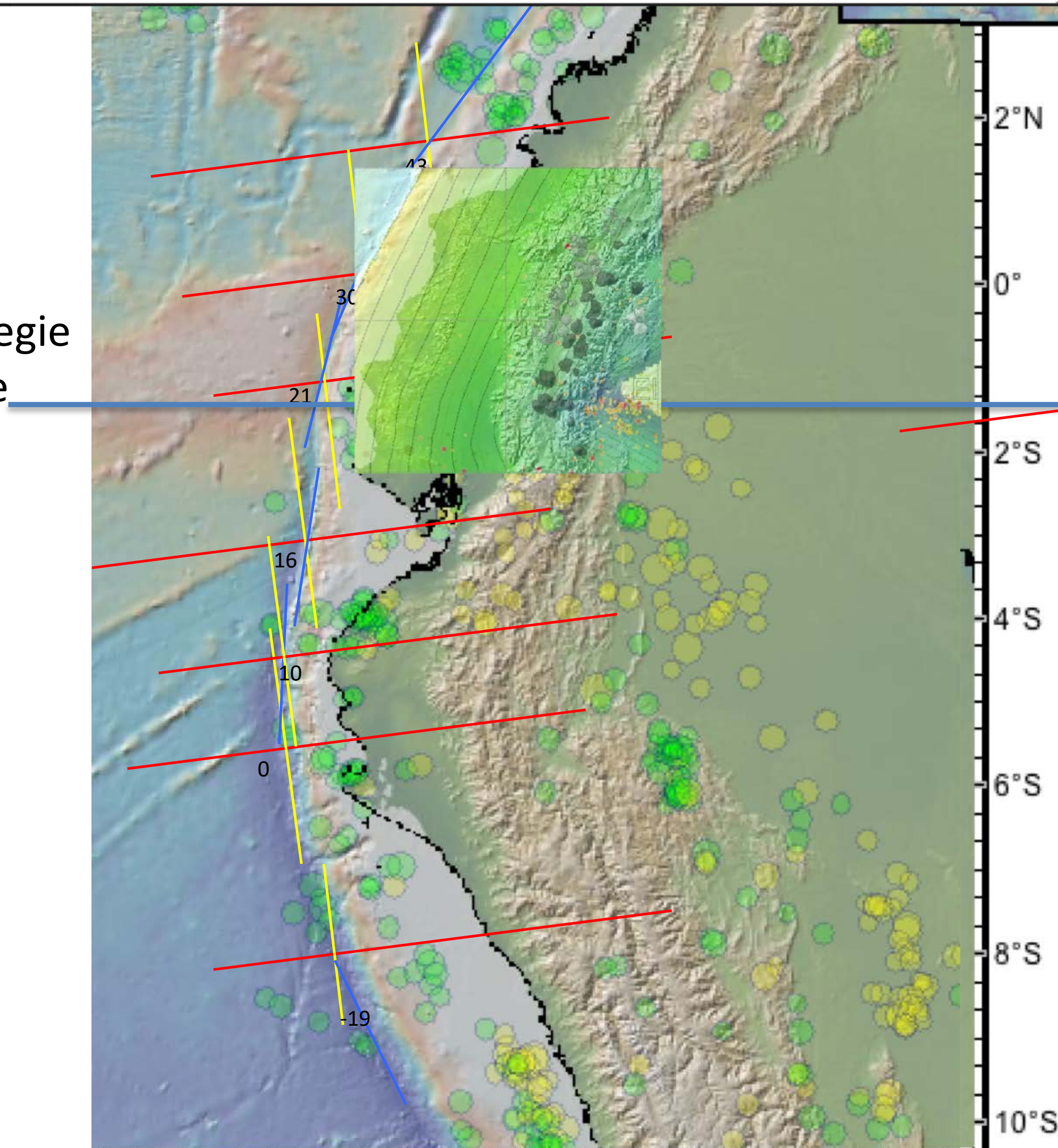
Υ oblicuidad
Υ = T – Φ
T trench-normal azimuth
Φ plate motion azimuth
Ψ trench normal – slip vector
Ψ = T – β
Β slip vector azimuth

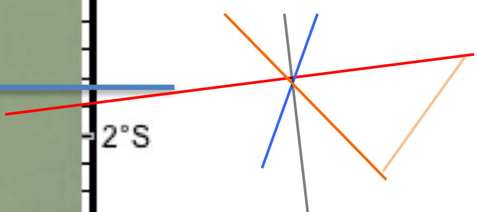
200501242323A NEAR COAST OF ECUADOR

```
Date: 2005/ 1/24   Centroid Time: 23:23:30.8 GMT
Lat=  -1.53  Lon= -80.95
Depth= 16.0   Half duration= 2.7
Centroid time minus hypocenter time:  4.7
Moment Tensor: Expo=25  0.855 0.052 -0.907 0.110 -1.520 -0.020
Mw = 6.1     mb = 5.5     Ms = 5.7    Scalar Moment = 1.76e+25
Fault plane:  strike=6     dip=15    slip=100
Fault plane:  strike=177     dip=75    slip=87
```

Depth 15

Carnegie Ridge



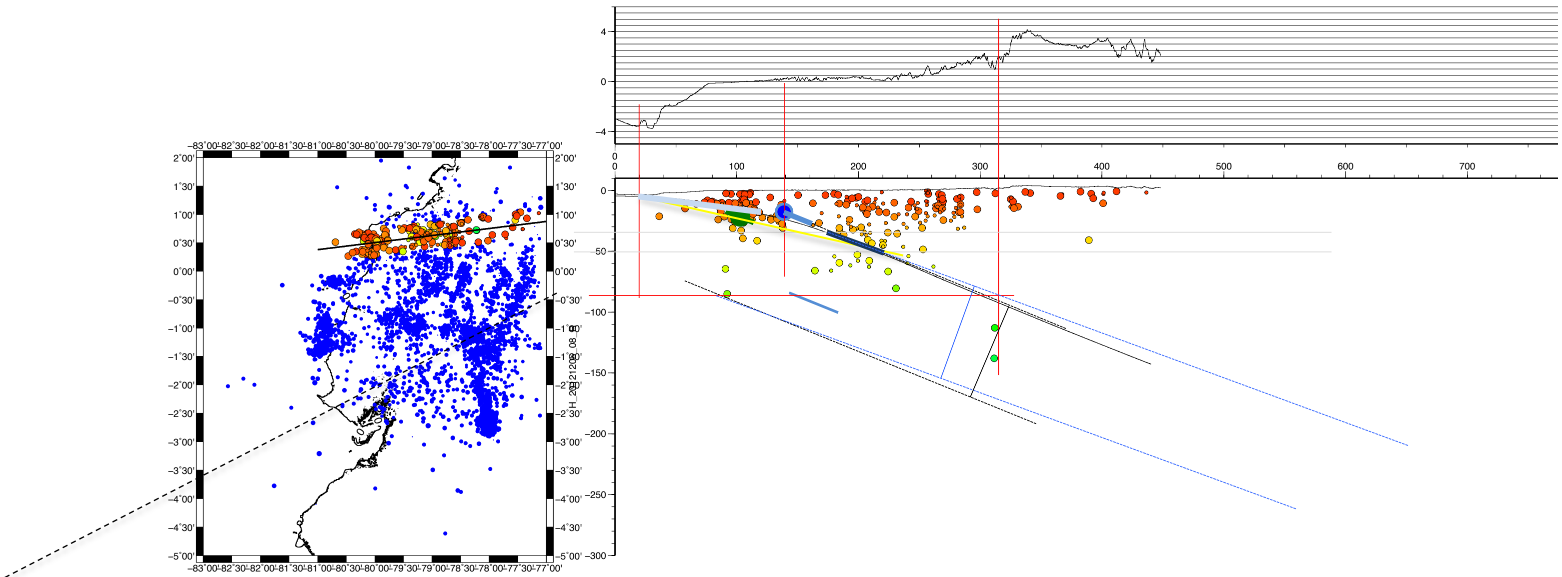


Vs=V(sinϒ-(cosϒ•tanΨ)

ϒ oblicuidad
ϒ = T – Φ
T trench-normal azimuth
Φ plate motion azimuth
Ψ trench normal – slip vector
Ψ = T – β
B slip vector azimuth

Megathrust interface rupture

1976

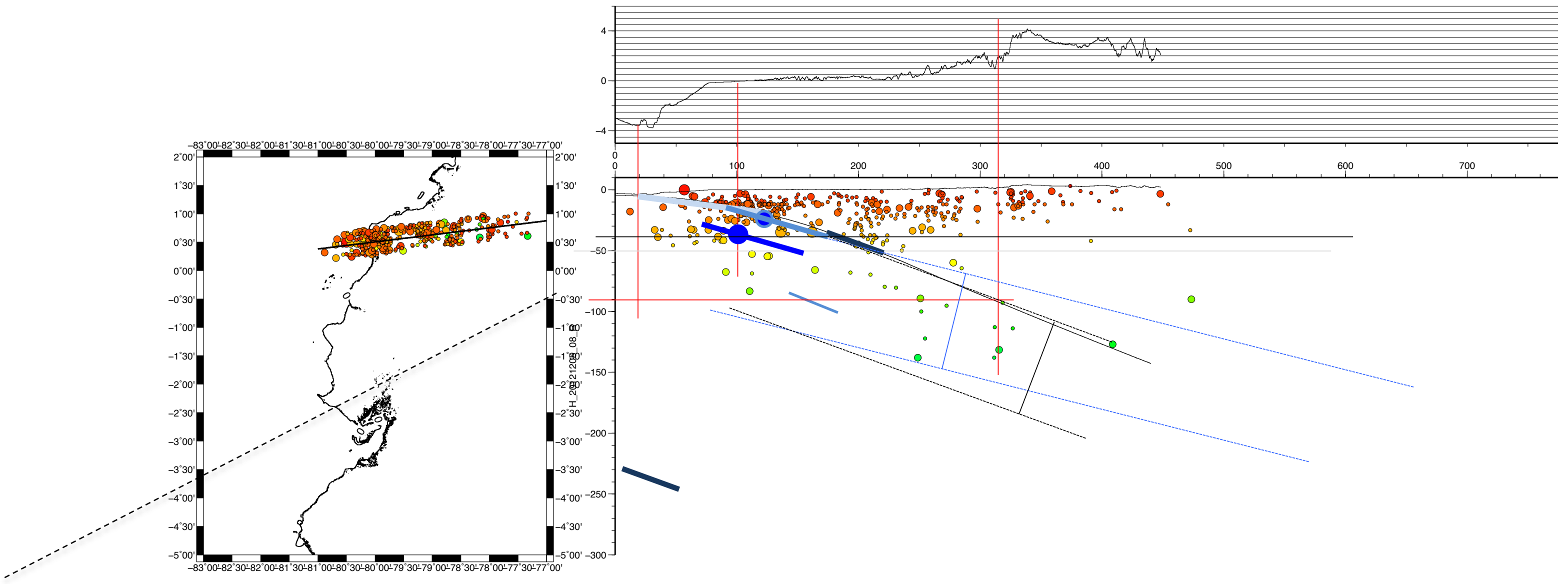


25º

22º

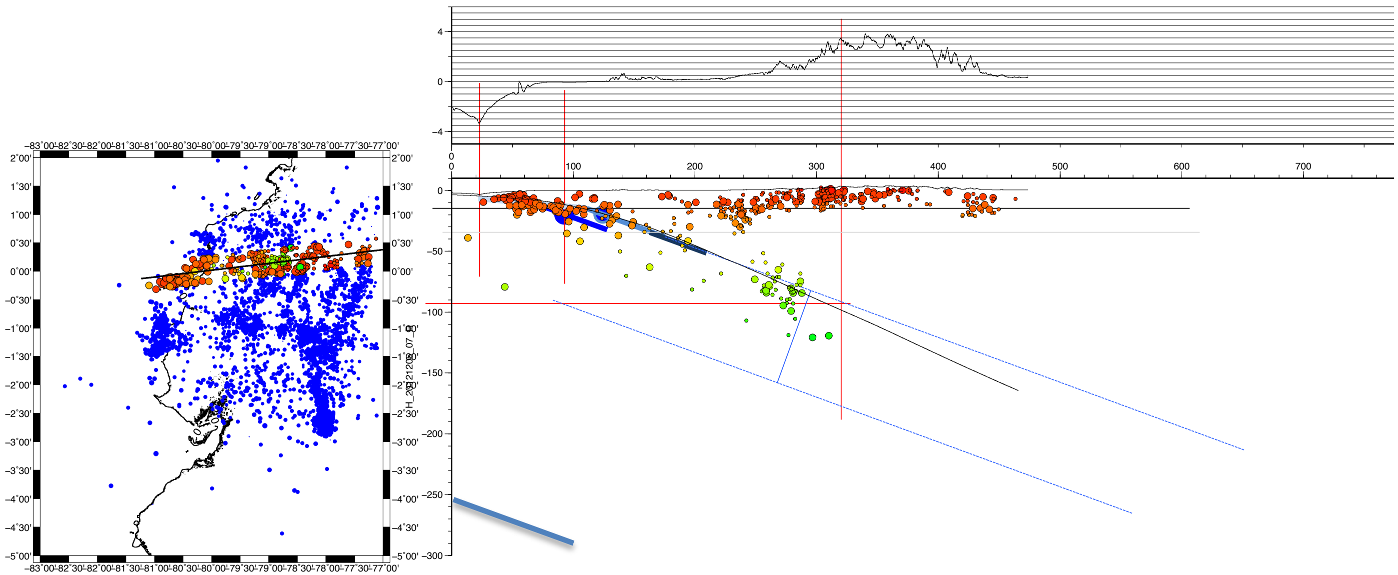
Megathrust interface rupture

1979



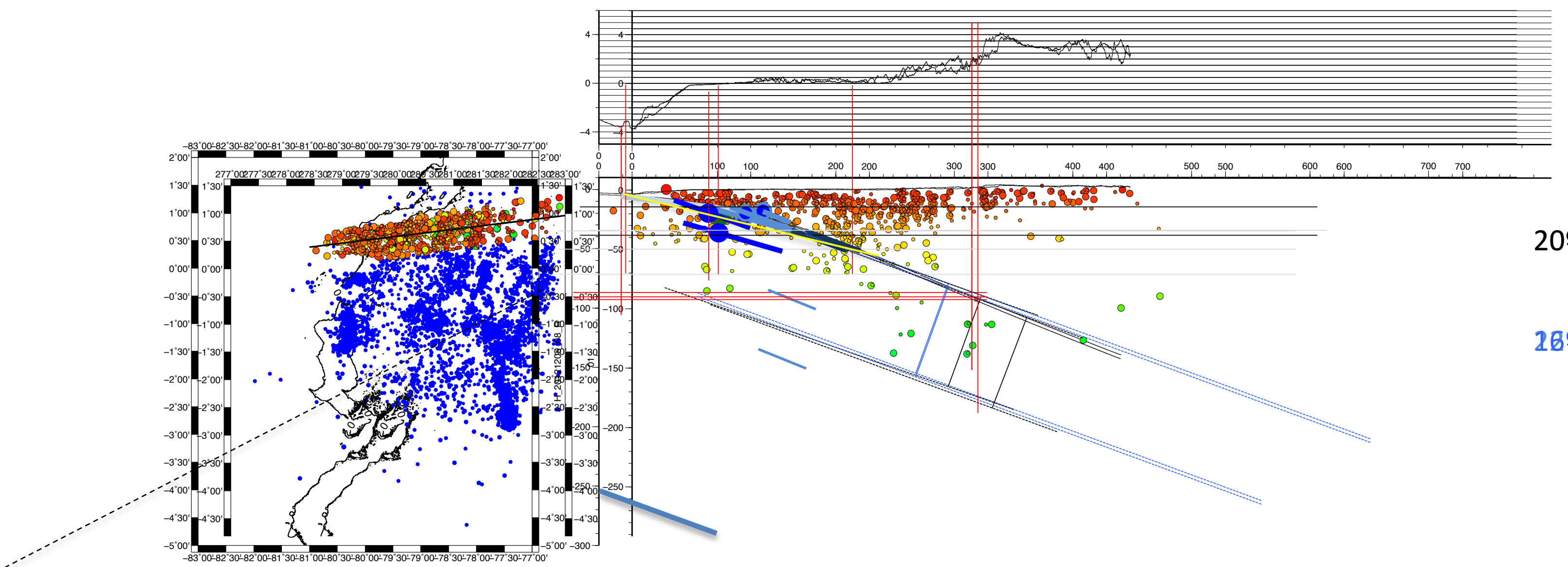
Megathrust interface rupture

1942



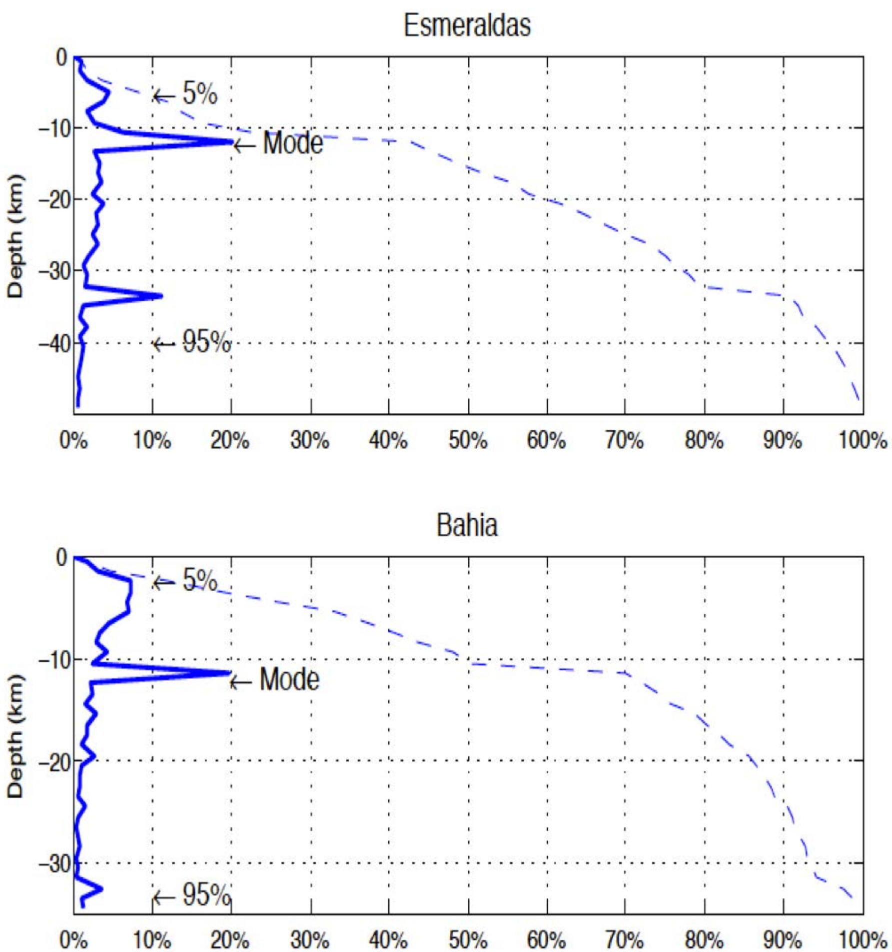
Megathrust interface rupture

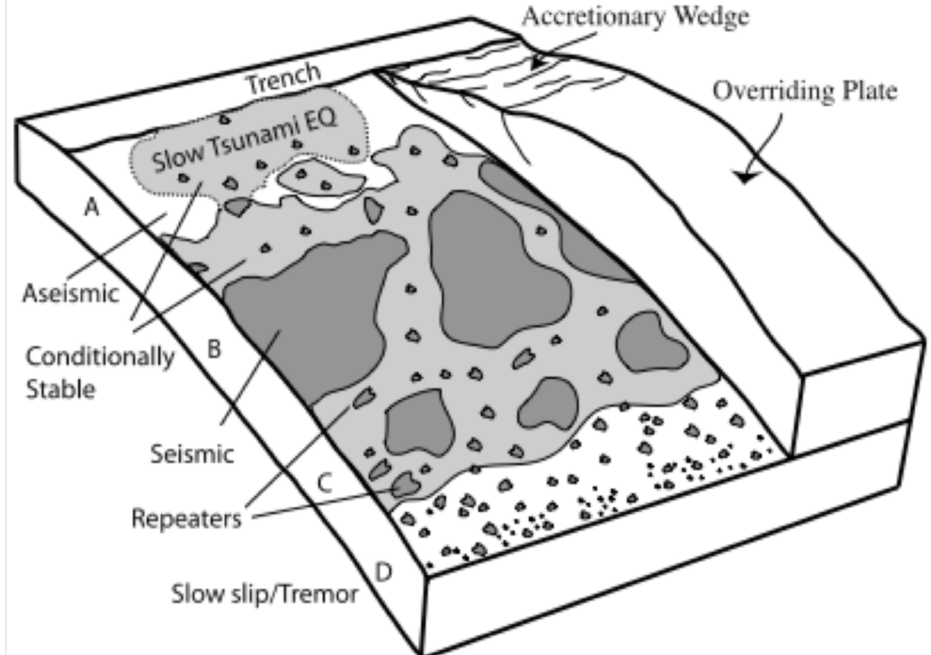
ALL



Megathrust interface rupture

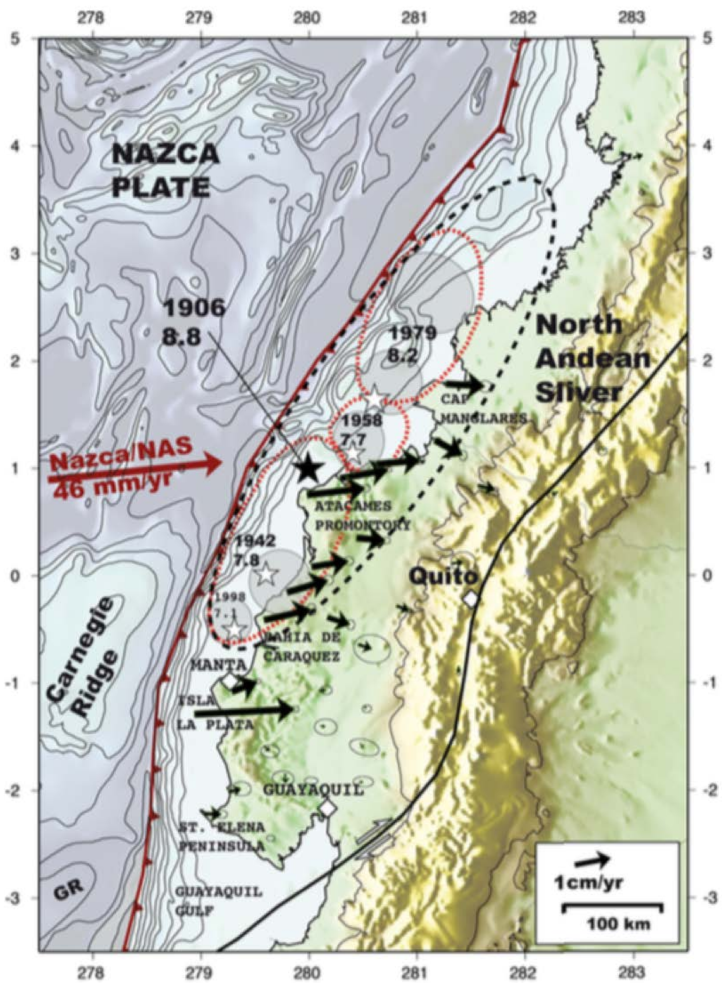
Depth Distribution





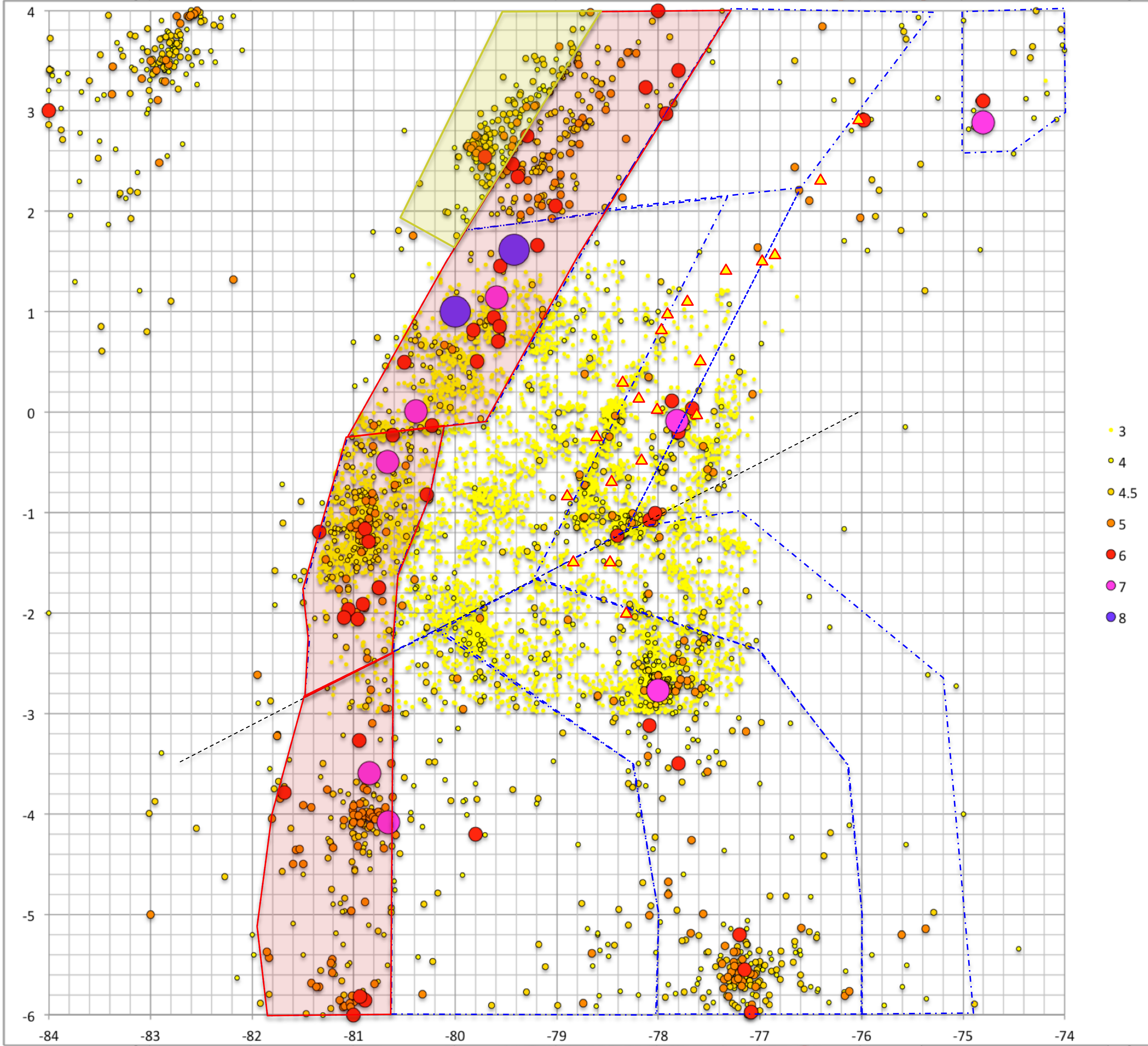
From Lay, T, 2012

Some issues



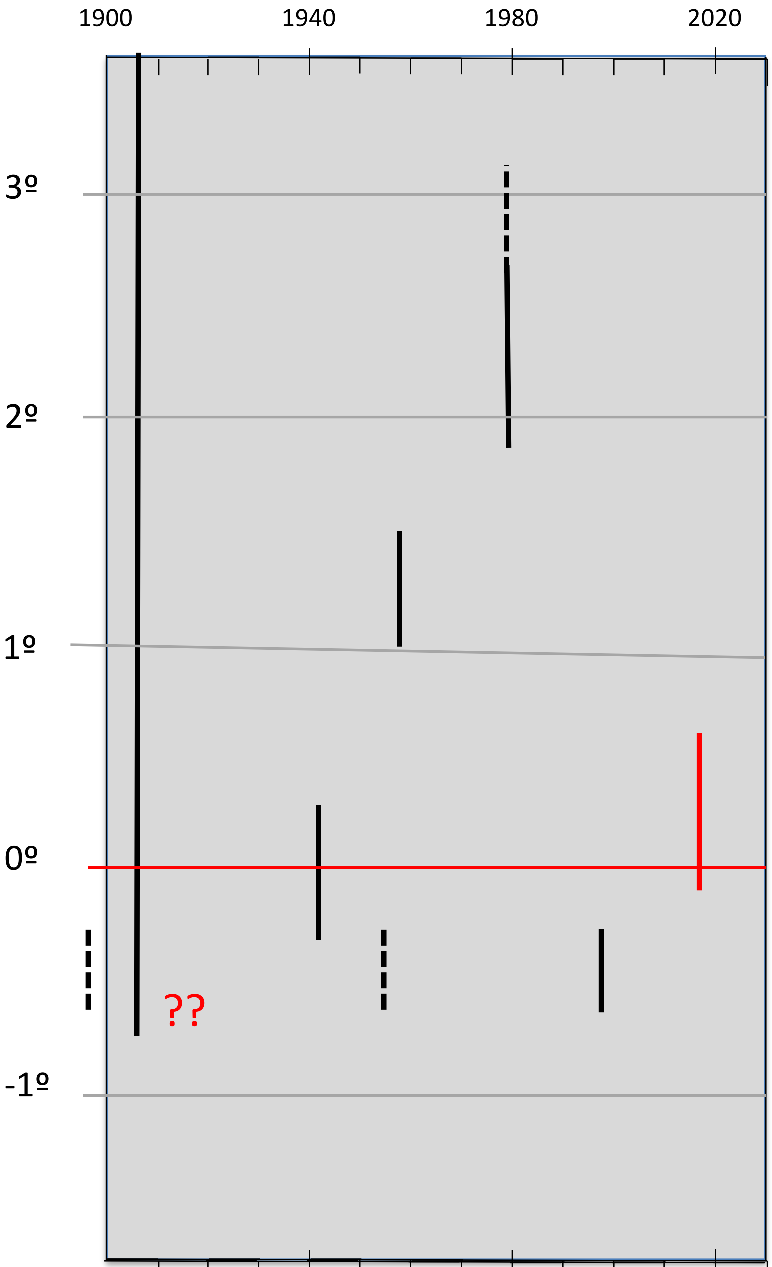
Chlieh et al. 2014

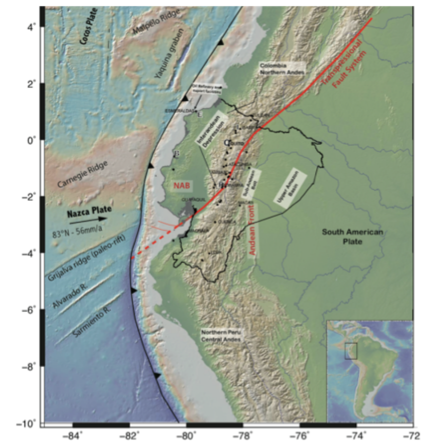
- One single segment?
- Maximum eartquake?
- Dip?
- Depth?
- Northern termination
- Southern termination



4
3
2
1
0
-1
-2
-3
-4
-5
-6
-84
-83
-82
-81
-80
-79
-78
-77
-76
-75
-74
3
4
4.5
5
6
7
8

TOO MANY EARTHQUAKES AT ESSZ





~47 mm/yr of convergence Nazca-NAS

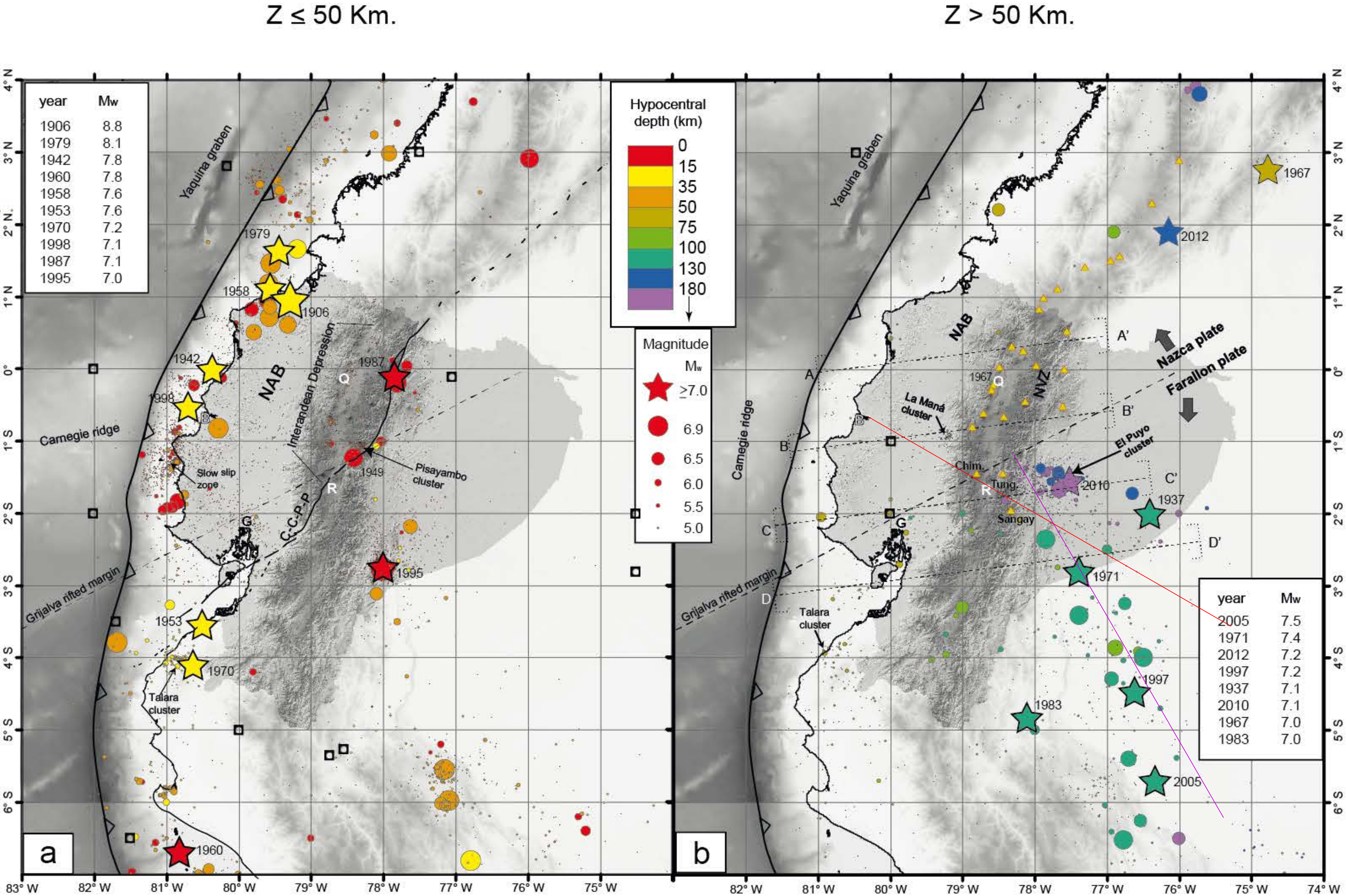
1906-1942 → 36 a → 1.7m

1942-2016 → 74 a → 3.5m

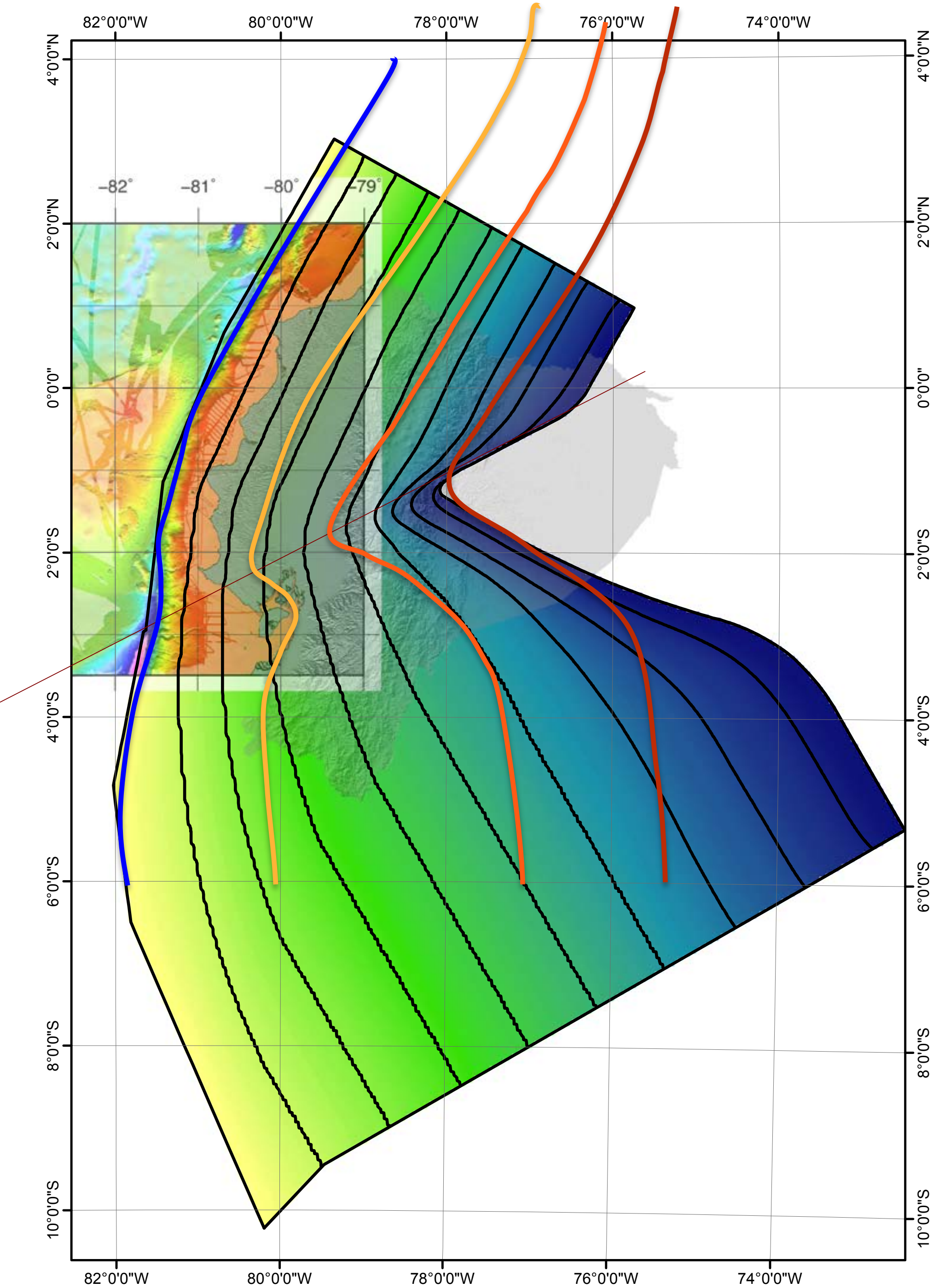
1906-2016 → 110 a → 5.1m

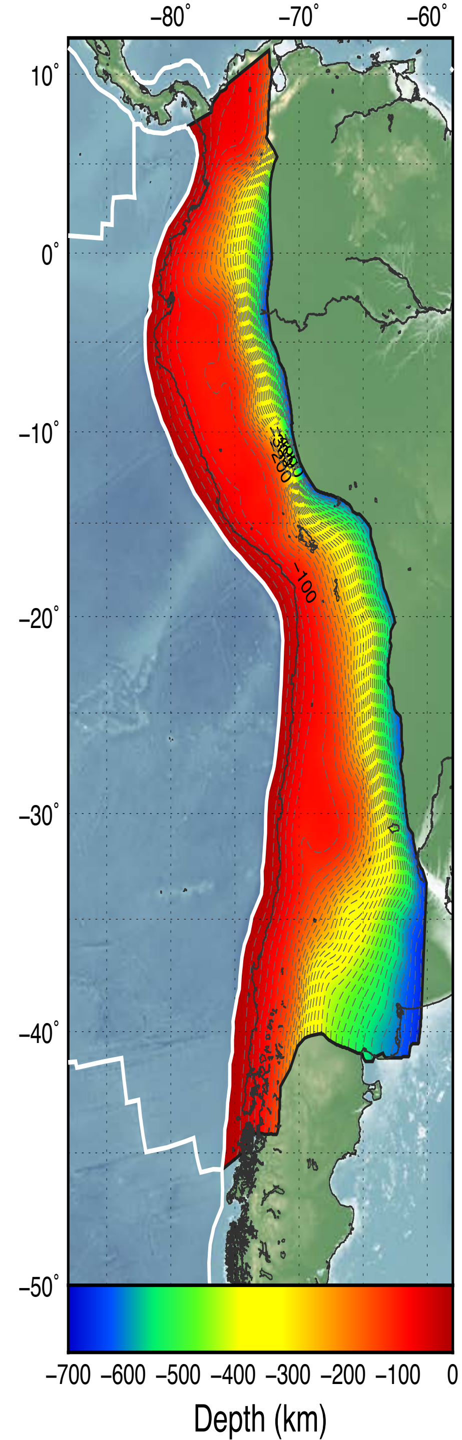
TOTAL SLIP AT INTERFACE ~7m

F2

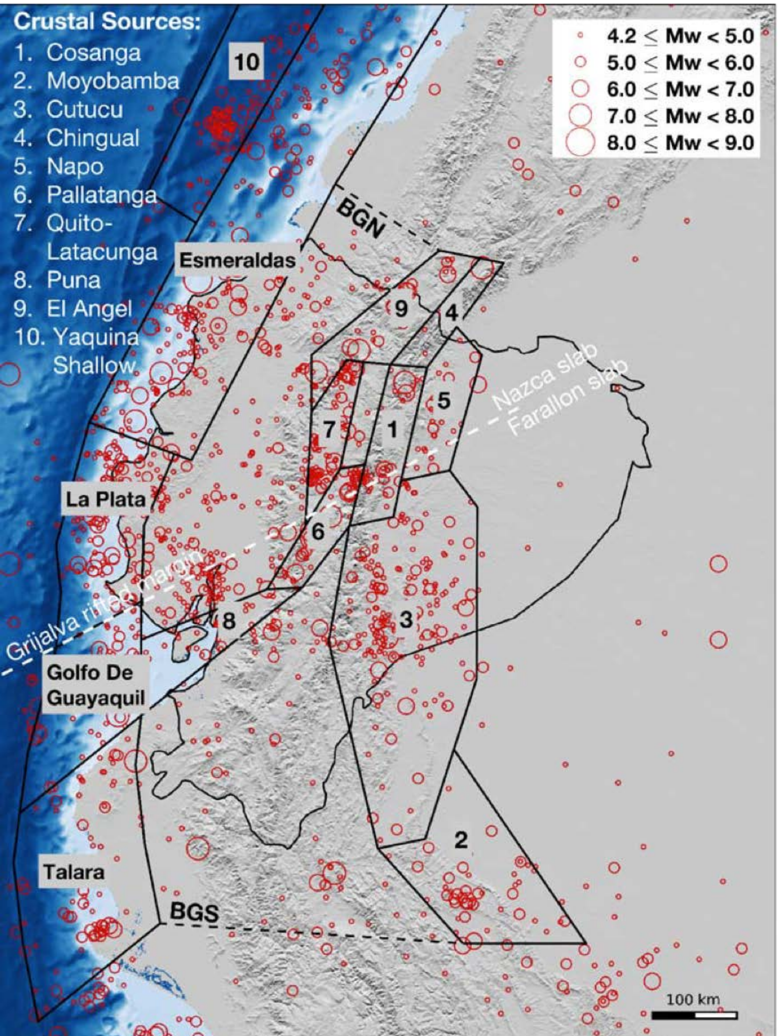


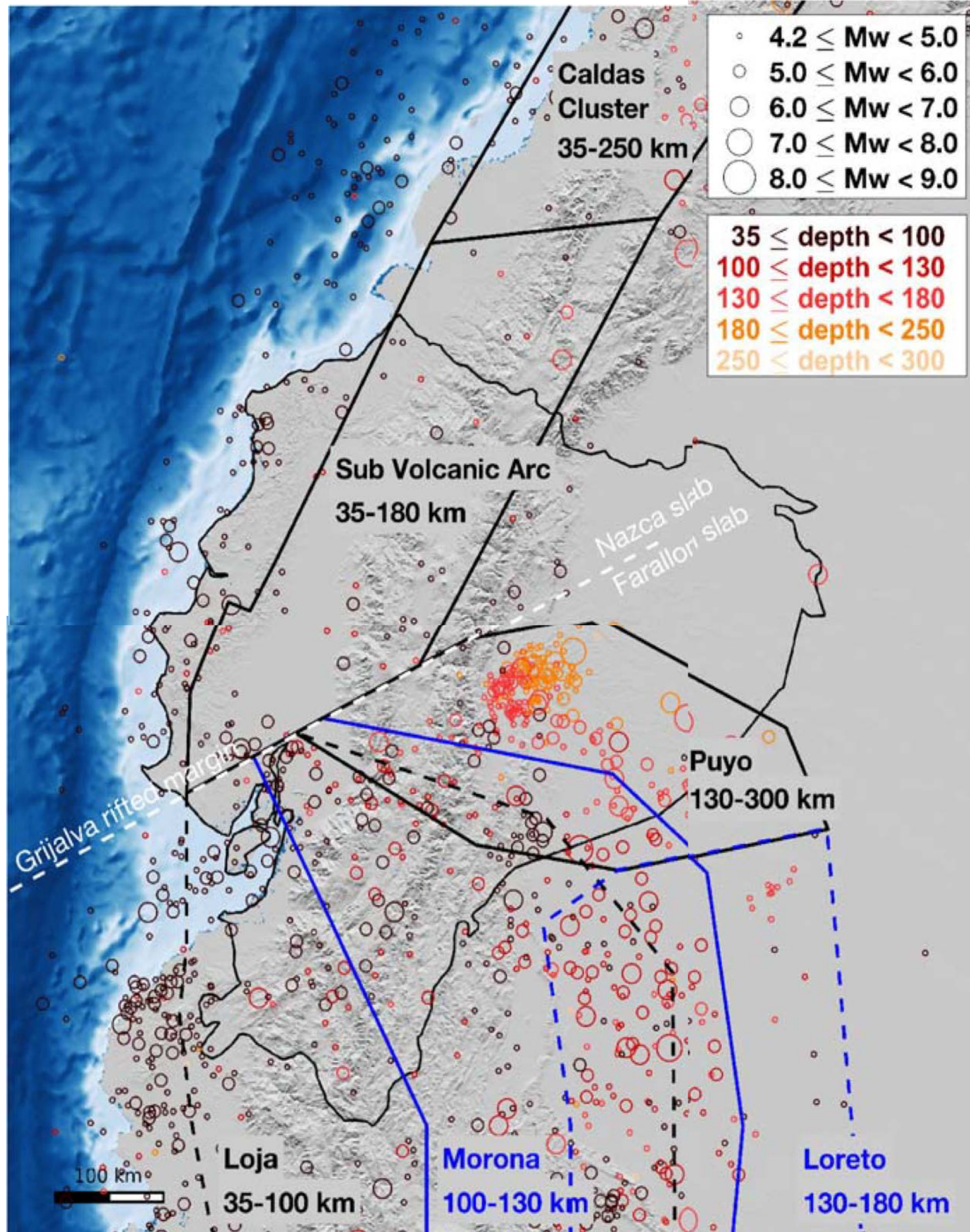
Z ≤ 50 Km.
Z > 50 Km.
year Mw
1906 8.8
1979 8.1
1942 7.8
1960 7.8
1958 7.6
1953 7.6
1970 7.2
1998 7.1
1987 7.1
1995 7.0
Hypocentral depth (km)
0
15
35
50
75
100
130
180
Magnitude
Mw
≥7.0
6.9
6.5
6.0
5.5
5.0
Yaquina graben
Carnegie ridge
Grijalva rifted margin
NAB
Interandean Depression
Pisayambo cluster
Slow slip zone
Talara cluster
C-C-P-P
La Maná cluster
El Puyo cluster
Nazca plate
Farallon plate
NVZ
Chim.
Tung.
Sangay
year Mw
2005 7.5
1971 7.4
2012 7.2
1997 7.2
1937 7.1
2010 7.1
1967 7.0
1983 7.0
a
b





SAM
SLAB2
Heyes G.


Crustal Sources:
1. Cosanga
2. Moyobamba
3. Cutucu
4. Chingual
5. Napo
6. Pallatanga
7. Quito-Latacunga
8. Puna
9. El Angel
10. Yaquina Shallow
4.2 ≤ Mw < 5.0
5.0 ≤ Mw < 6.0
6.0 ≤ Mw < 7.0
7.0 ≤ Mw < 8.0
8.0 ≤ Mw < 9.0
10
BGN
Esmeraldas
9
4
5
7
1
Nazca slab
Farallon slab
La Plata
6
Grijalva rifted margin
8
3
Golfo De Guayaquil
2
Talara
BGS
100 km


Caldas Cluster
35-250 km
4.2 ≤ Mw < 5.0
5.0 ≤ Mw < 6.0
6.0 ≤ Mw < 7.0
7.0 ≤ Mw < 8.0
8.0 ≤ Mw < 9.0
35 ≤ depth < 100
100 ≤ depth < 130
130 ≤ depth < 180
180 ≤ depth < 250
250 ≤ depth < 300
Sub Volcanic Arc
35-180 km
Nazca slab
Farallon slab
Puyo
130-300 km
Grijalva rifted margin
100 km
Loja
35-100 km
Morona
100-130 km
Loreto
130-180 km

Gracias