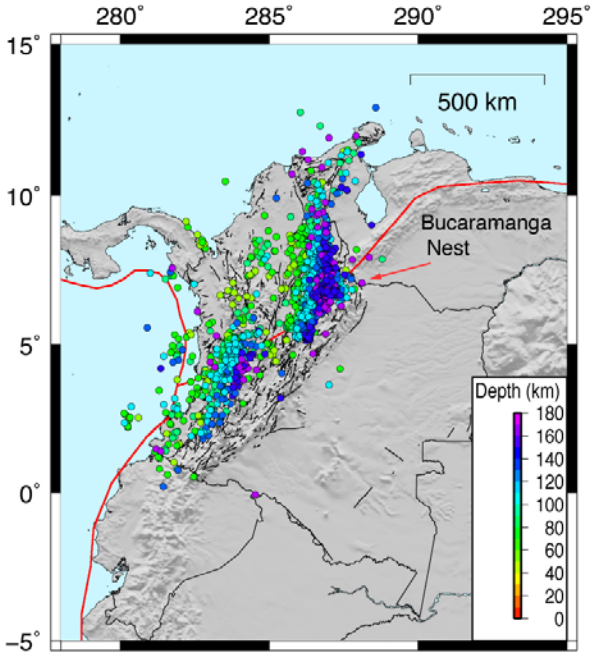
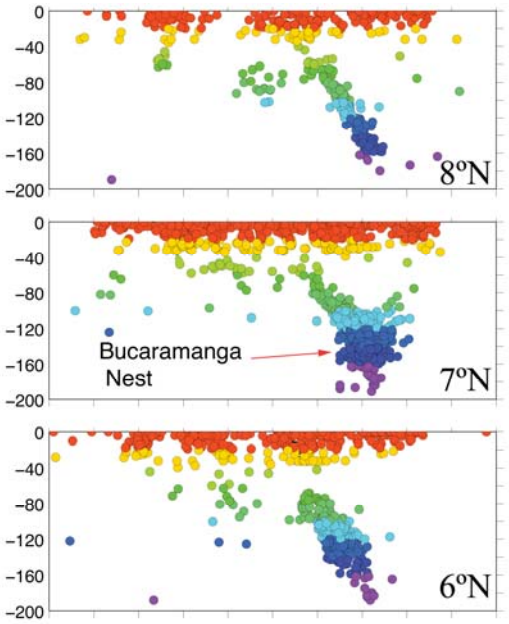
Buscando respuestas del porqué de los terremotos de profundidad intermedia: el Nido de Bucaramanga

Germán A. Prieto
Universidad de los Andes, Bogotá, Colombia





Junio 24, 2011
Programa Anual de Conferencias Divulgativas
Unión Geofísica Mexicana

Terremotos de Profundidad Intermedia

Deep and Intermediate Depth Earthquakes

Depth > 50 – 60 km

25% of global earthquake catalogs

Mechanism is not well constrained

Terremotos de Profundidad Intermedia

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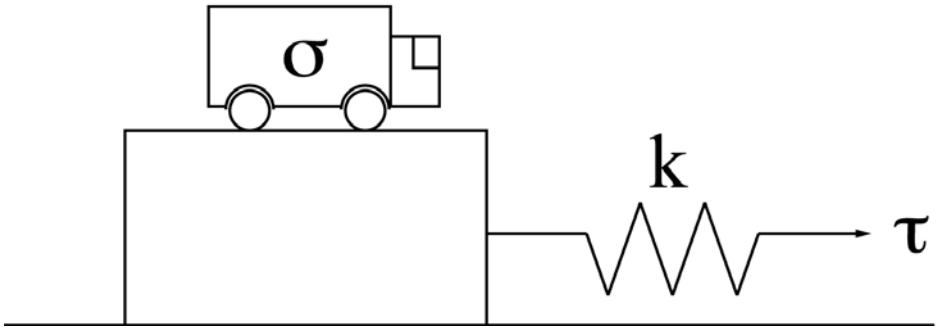
Stick-Slip



After Scholz (1998)

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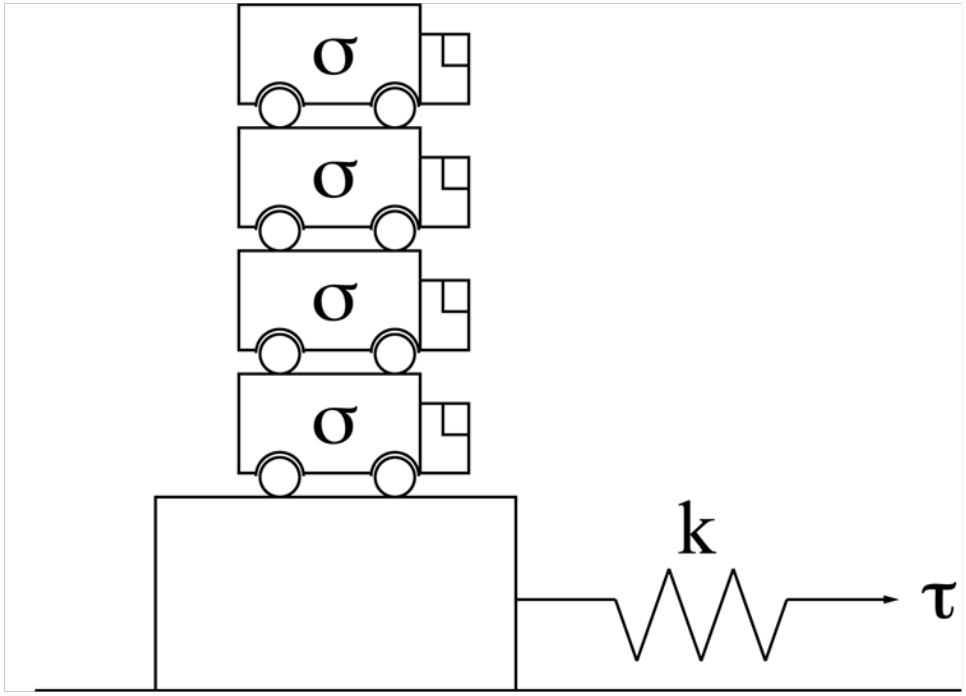

Occur at temperatures and pressures above the point where ordinary fractures ought to occur.

After Scholz (1998)

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Proposed Mechanisms

Dehydration embrittlement

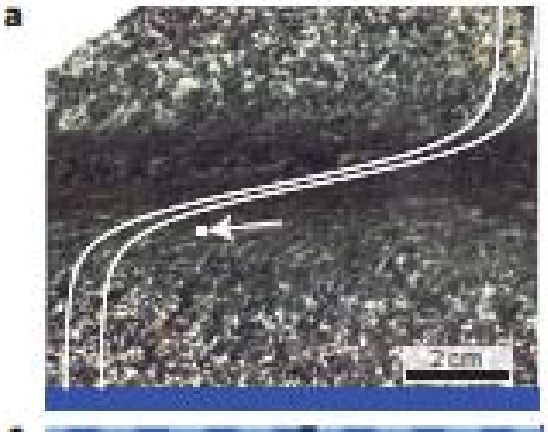
Thermal Shear runaway instability

Phase transformations

….

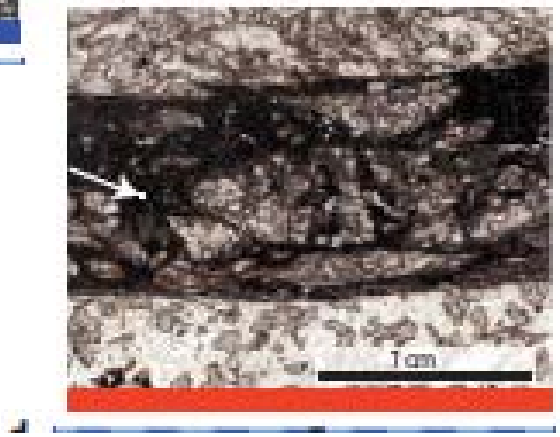
Runaway Instability

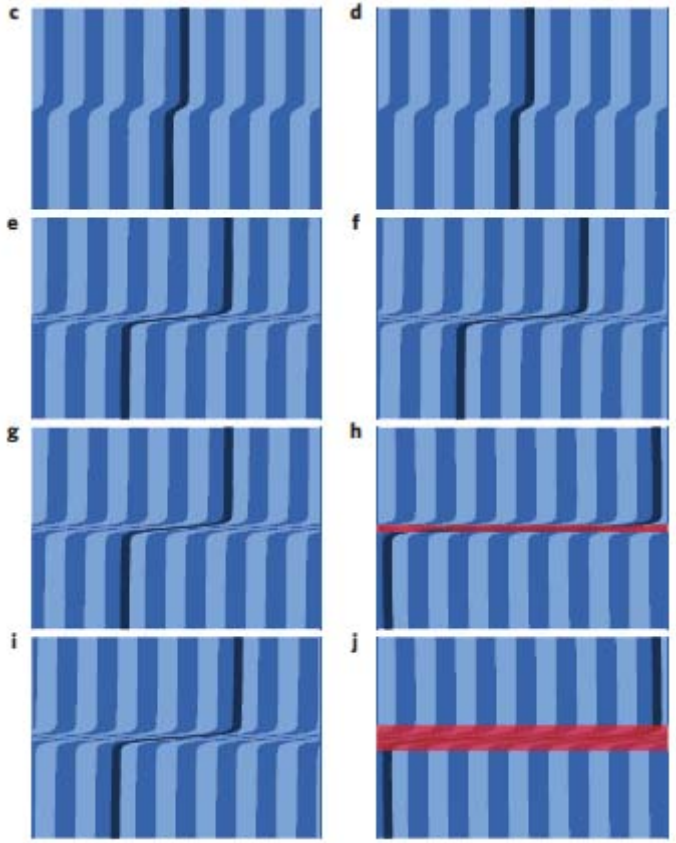
Deep and Intermediate Depth Earthquakes



Shear Zone

Pseudotachylite

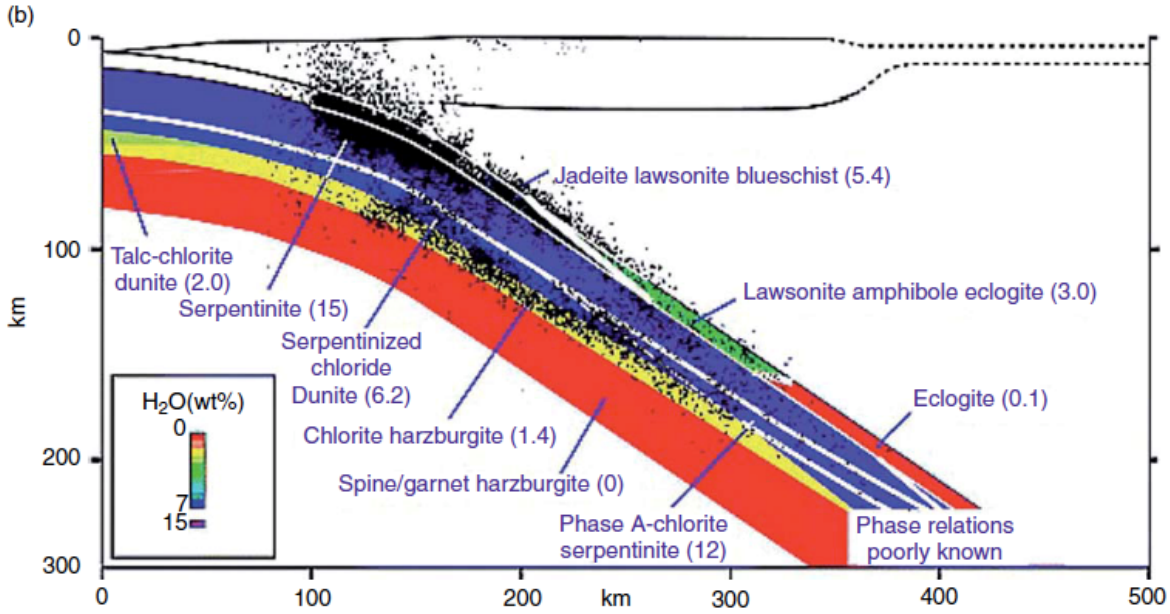




John et al., 2009
Nature Geoscience

“ductile deformation in shear zones leads to heating, thermal softening and weakening of rock”

Dehydration Embrittlement

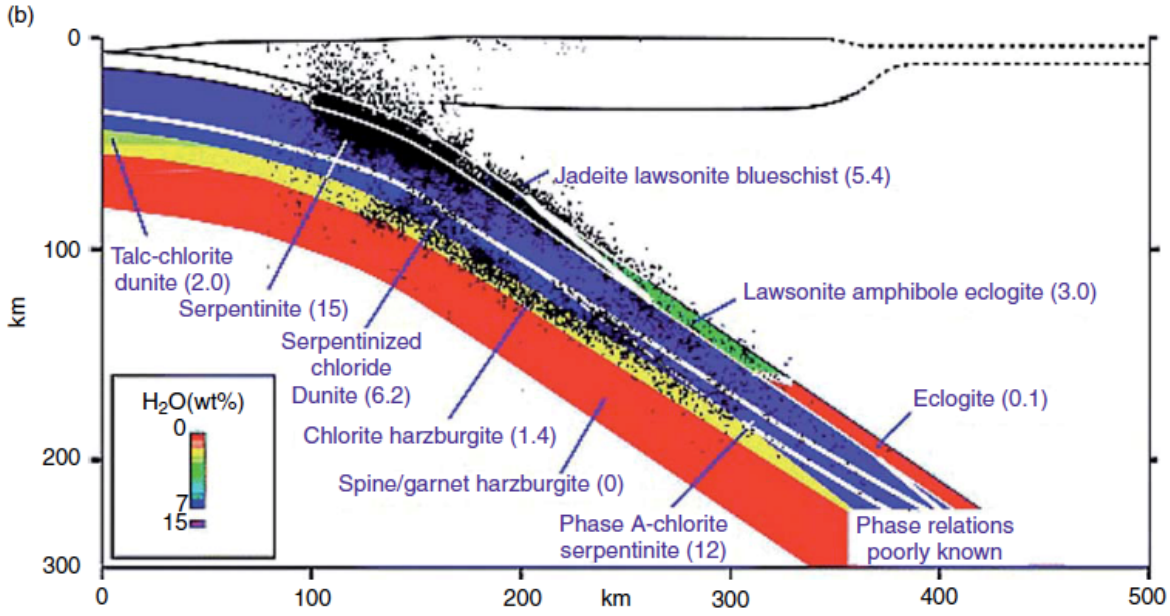


Hacker et al., 2003

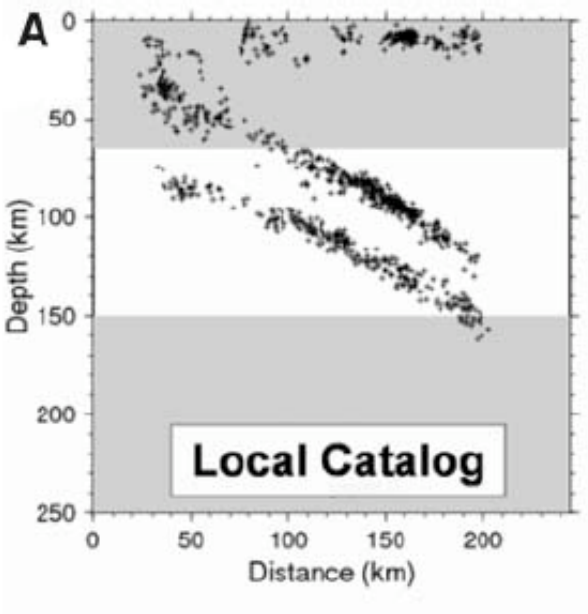
“brittle failure assisted by high fluid pore pressures that counteract high normal stresses due to large pressures”

Dehydration Embrittlement

"intermediate-depth double seismic zones consistent with dewatering of hydrous phases predicted from subduction zone thermal structures" (Houston, 2007)



Hacker et al., 2003



Brudzinski et al., 2007

"brittle failure assisted by high fluid pore pressures that counteract high normal stresses due to large pressures"

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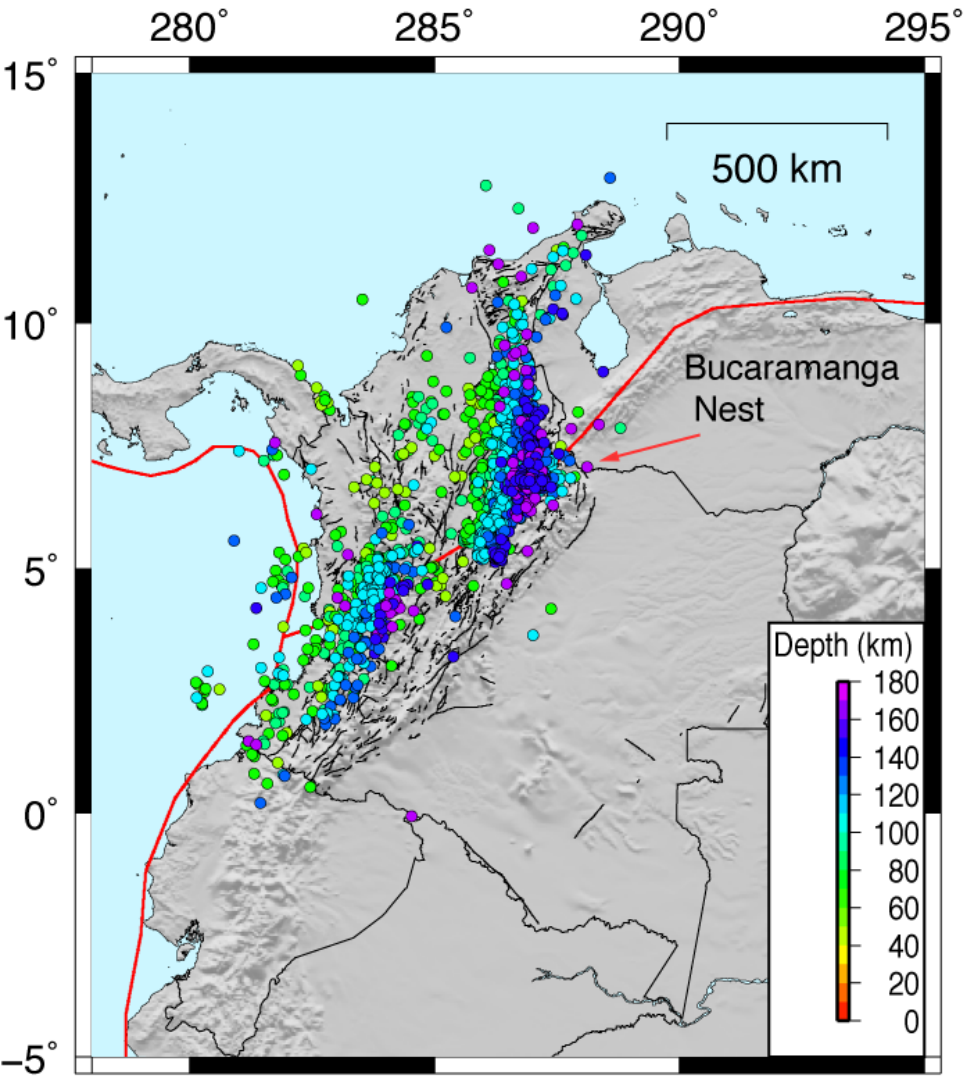
Earthquake Nests

Hindu-Kush, Vrancea, Bucaramanga

Nido de Bucaramanga – un laboratorio natural

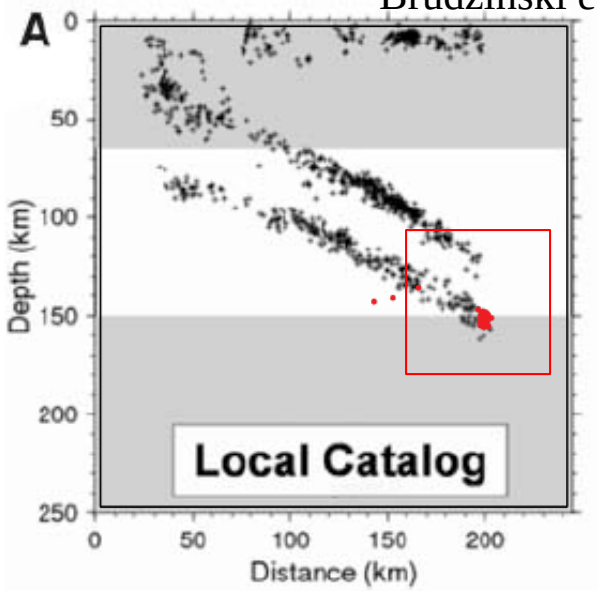


World's greatest concentration of intermediate-depth earthquakes

Isolated from nearby activity

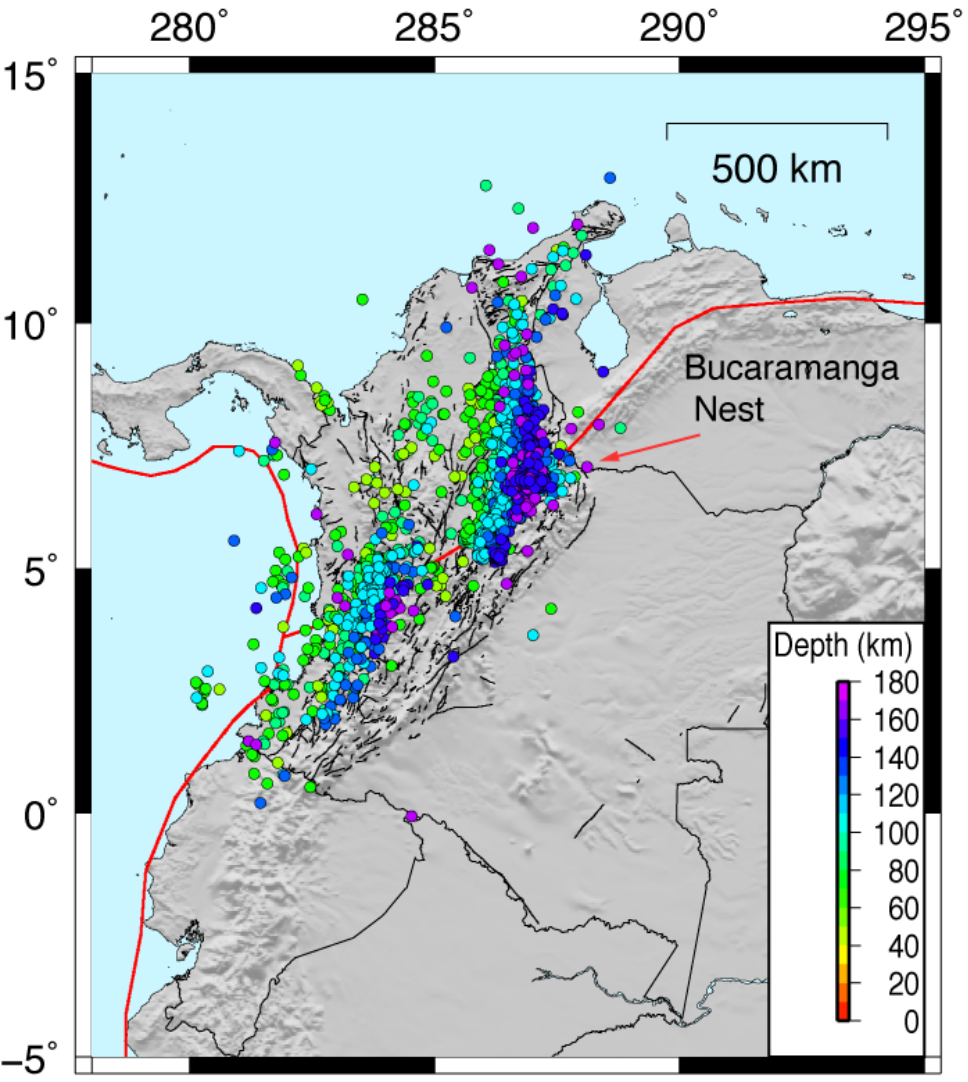
Compact source volume

Brudzinski et al., 2007



>100 EQs

Nido de Bucaramanga – un laboratorio natural



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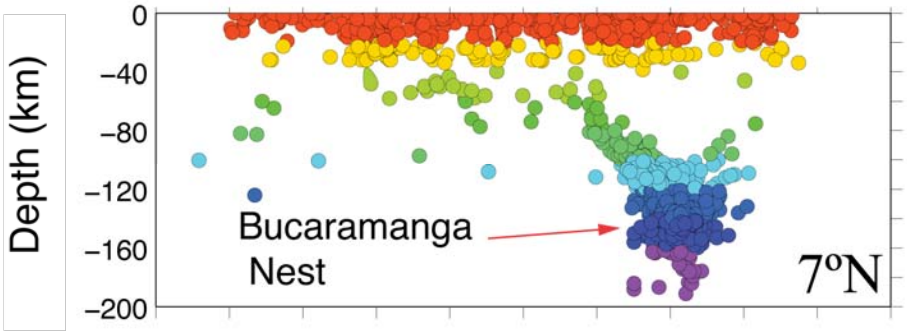
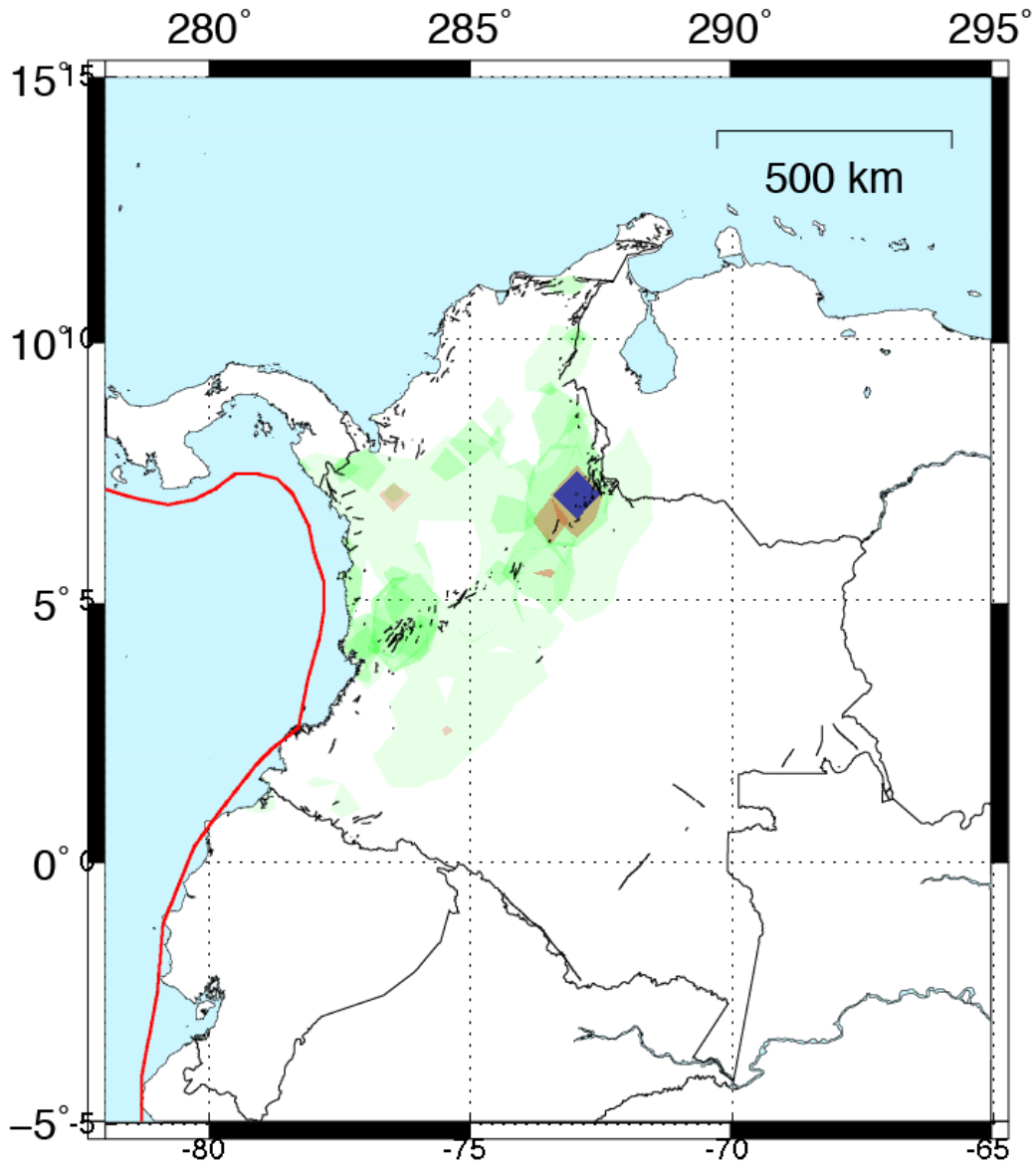


Nido de Bucaramanga – un laboratorio natural



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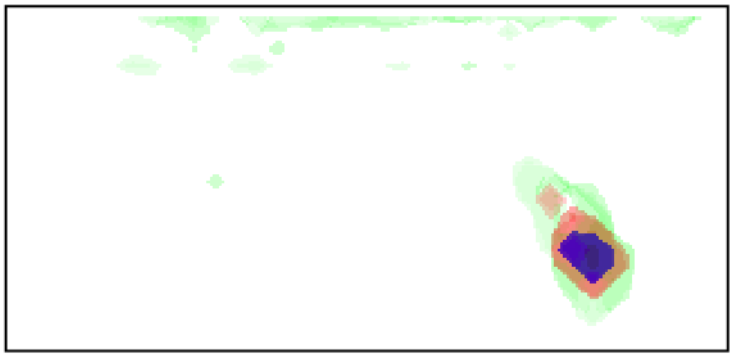
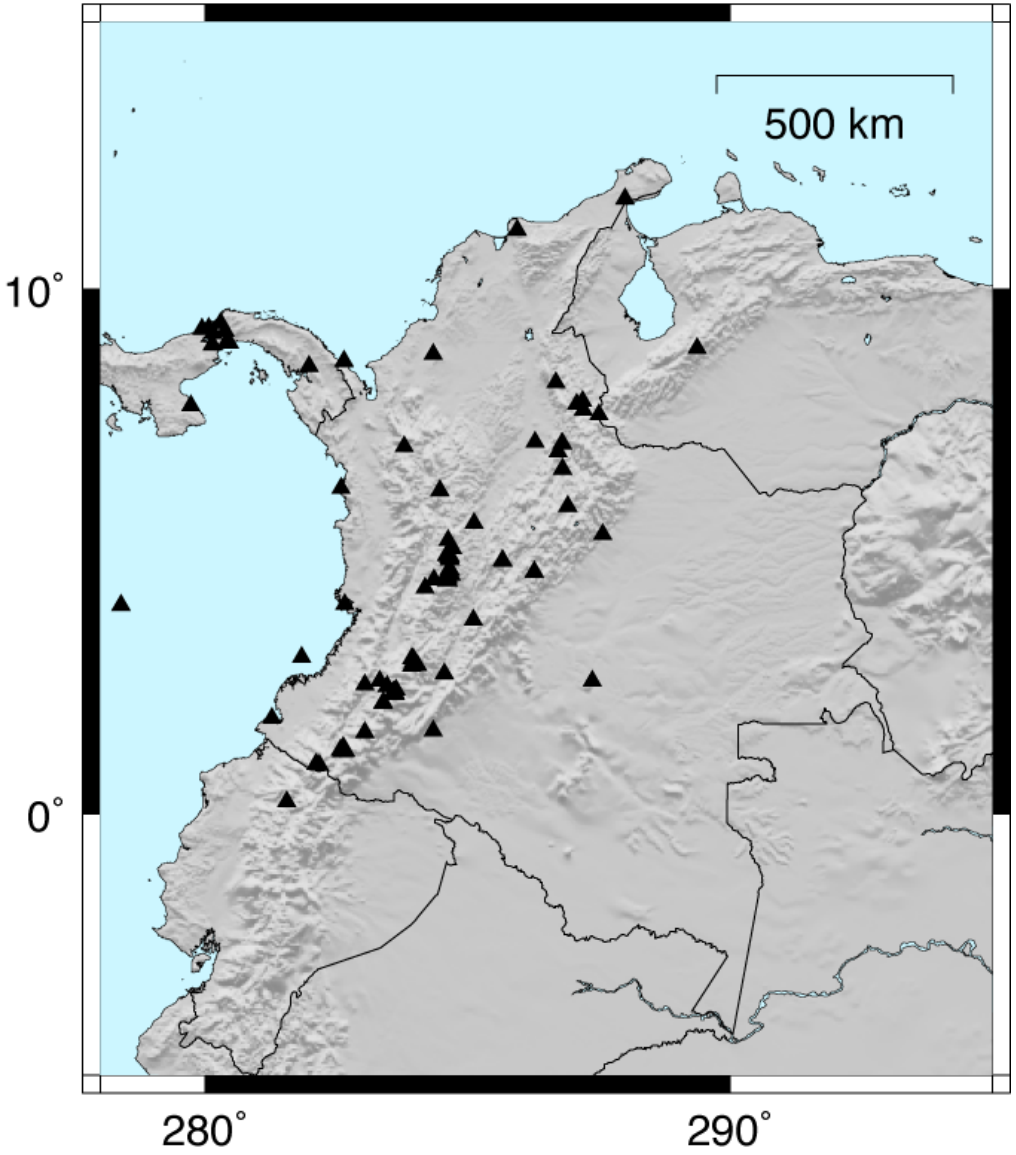


Green 5 Eq/Volume
Red 50 Eq/Volume
Blue 500 Eq/Volume
Black 5000 Eq/Volume

Nido de Bucaramanga – un laboratorio natural



World's greatest concentration of intermediate-depth earthquakes

Isolated from nearby activity

Compact source volume

Colombian network (RSNC)

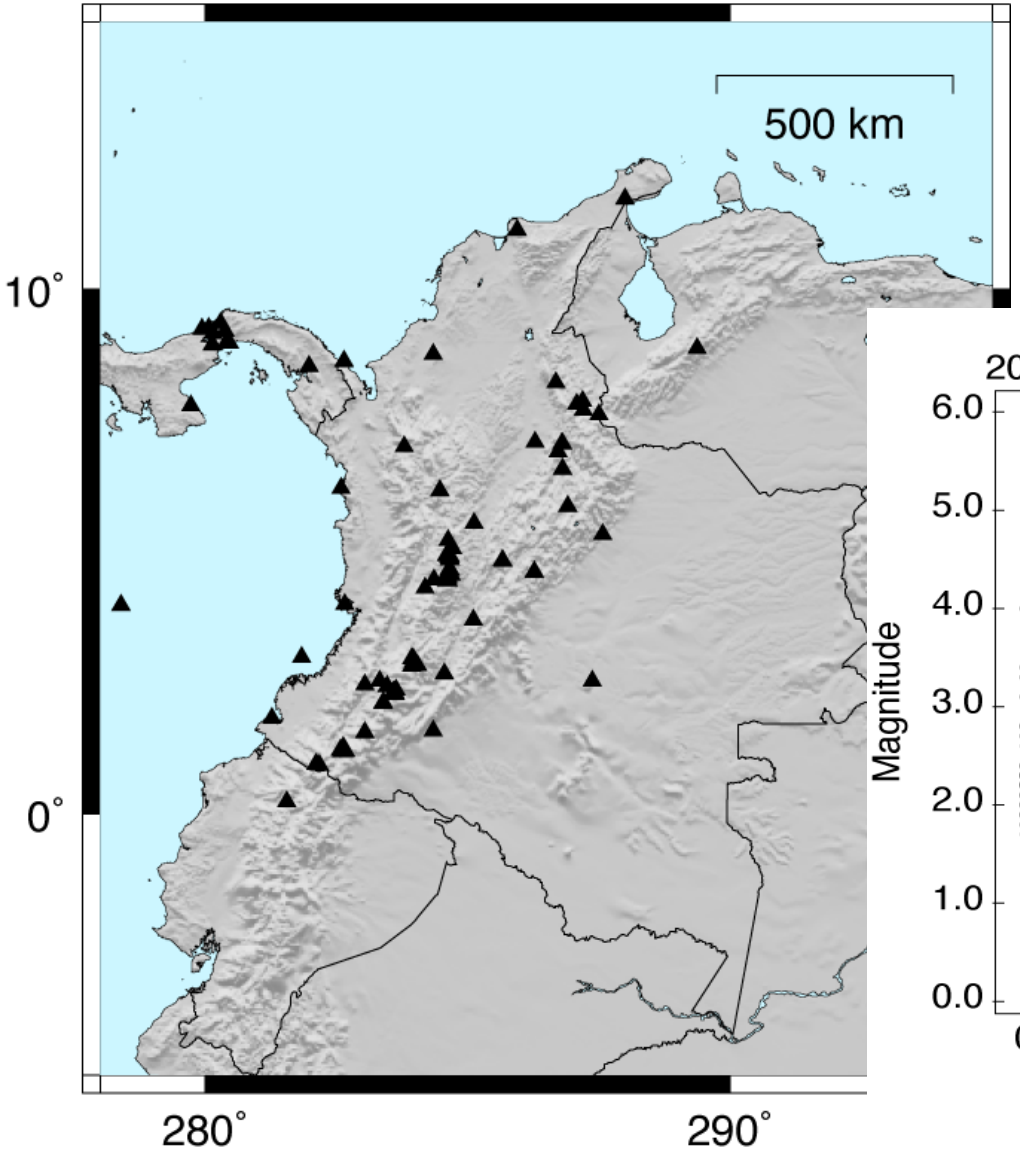
15 B-nest earthquakes per day

1 M_L 4.5 or greater per month.

>60.000 B-Nest EQ (1993-2011)

Broadband and short period

Nido de Bucaramanga – un laboratorio natural



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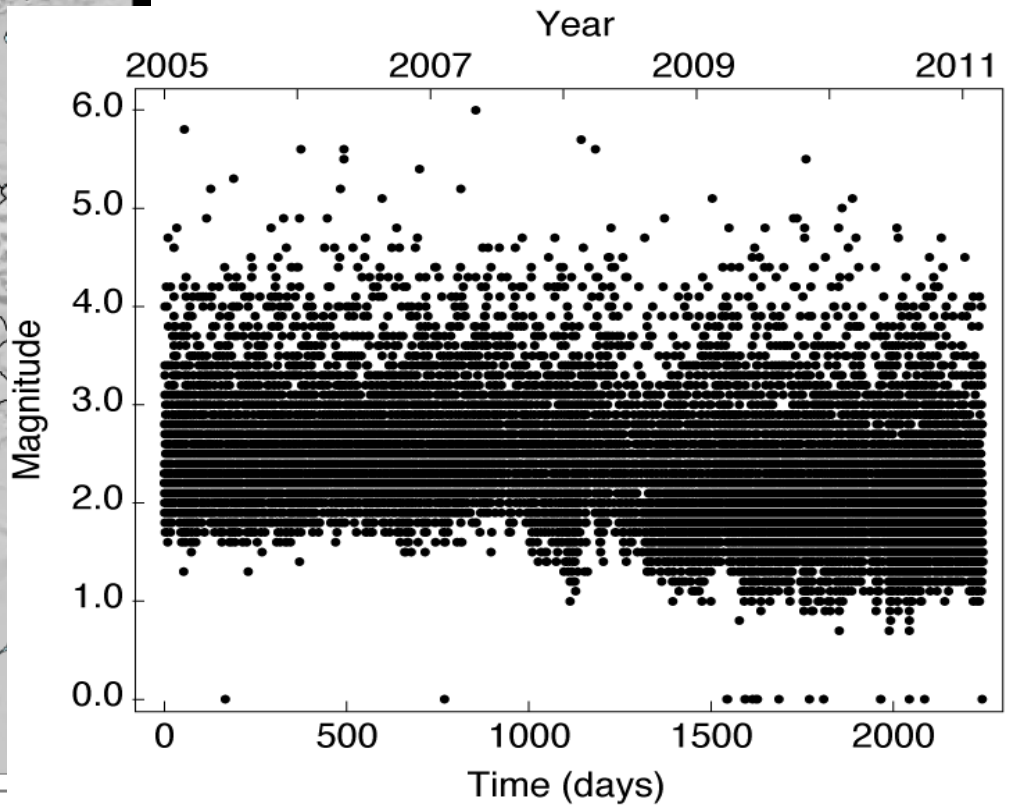


Preguntas Abiertas

Mecanismo de terremotos de profundidad intermedia

Pueden la observación sismológica ayudar a determinar mecanismo?
En qué se parecen y en qué no con los terremotos someros?

Tectónica

Relación con placas tectónicas. Zona de Benioff? Placa Caribe?
Presencia de fluidos?
Existe algún control estructural (explicar concentración).

Física de Terremotos

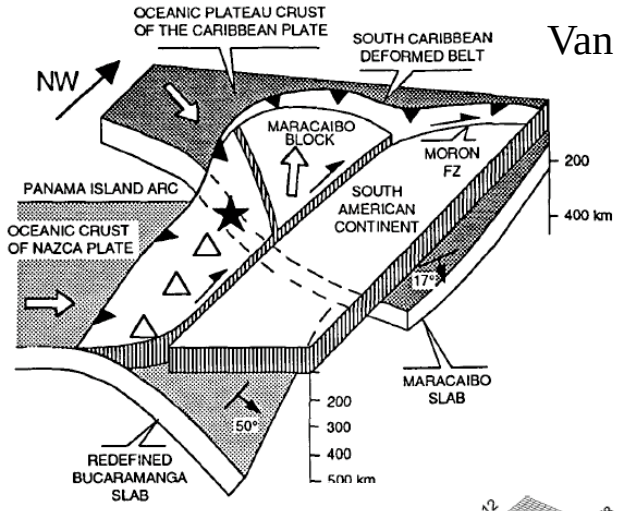
Escalamiento de la fuente? Caida del esfuerzo (Ds) alto? Bajo?
Repetición de eventos? Que tiene que ver con el mecanismo?

Comportamiento Temporal

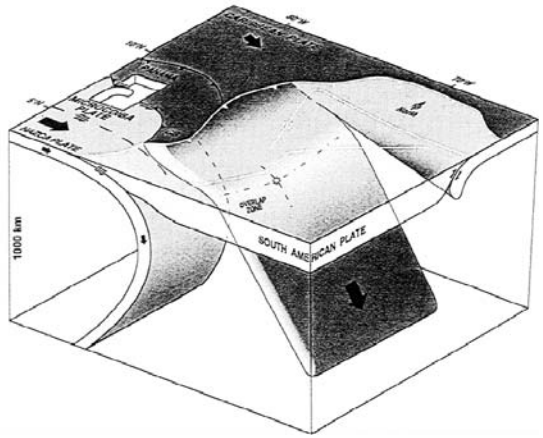
Réplicas, momento sísmico dominado por terremotos pequeños, grandes?
Triggering? Son predecibles?

Tectonics

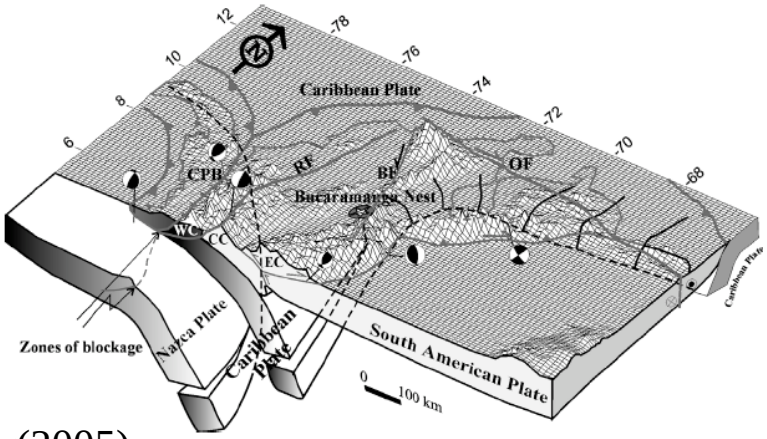
Tectonics



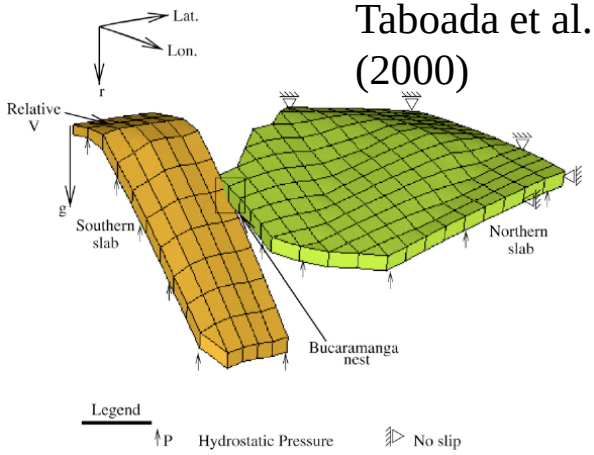
Van der Hilst (1994)



Taboada et al. (2000)



Cortes and Angelier(2005)

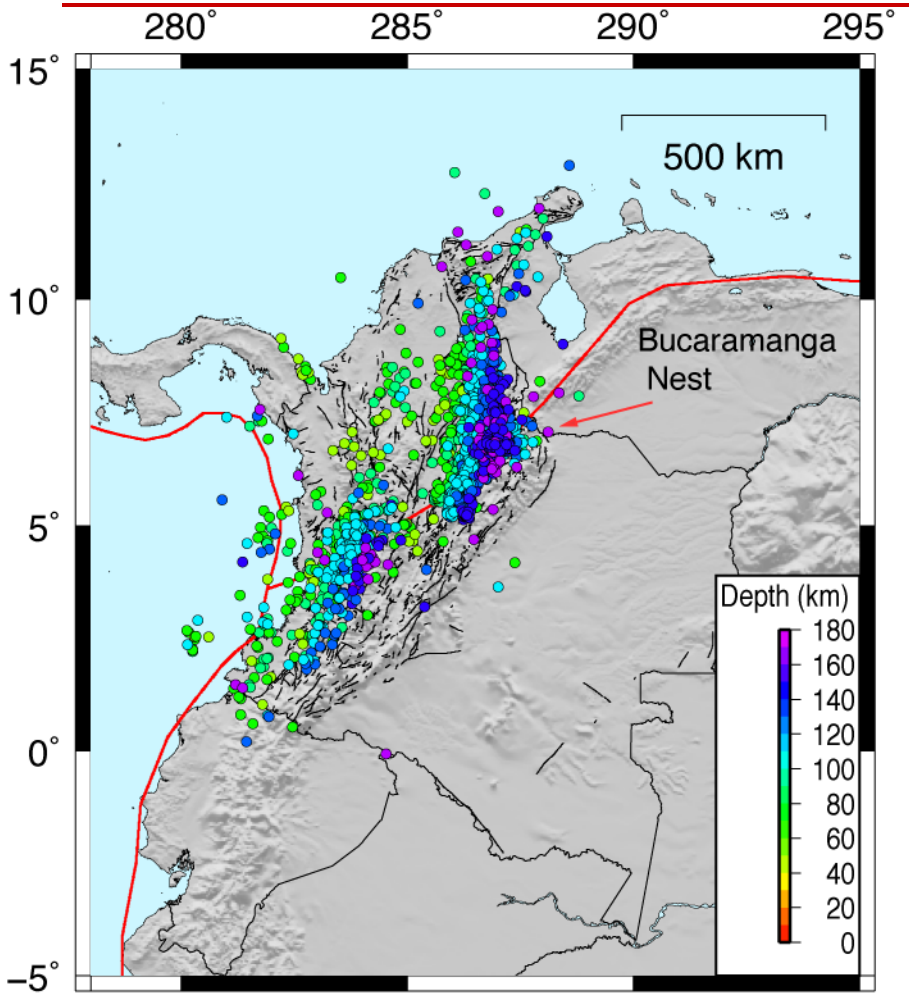


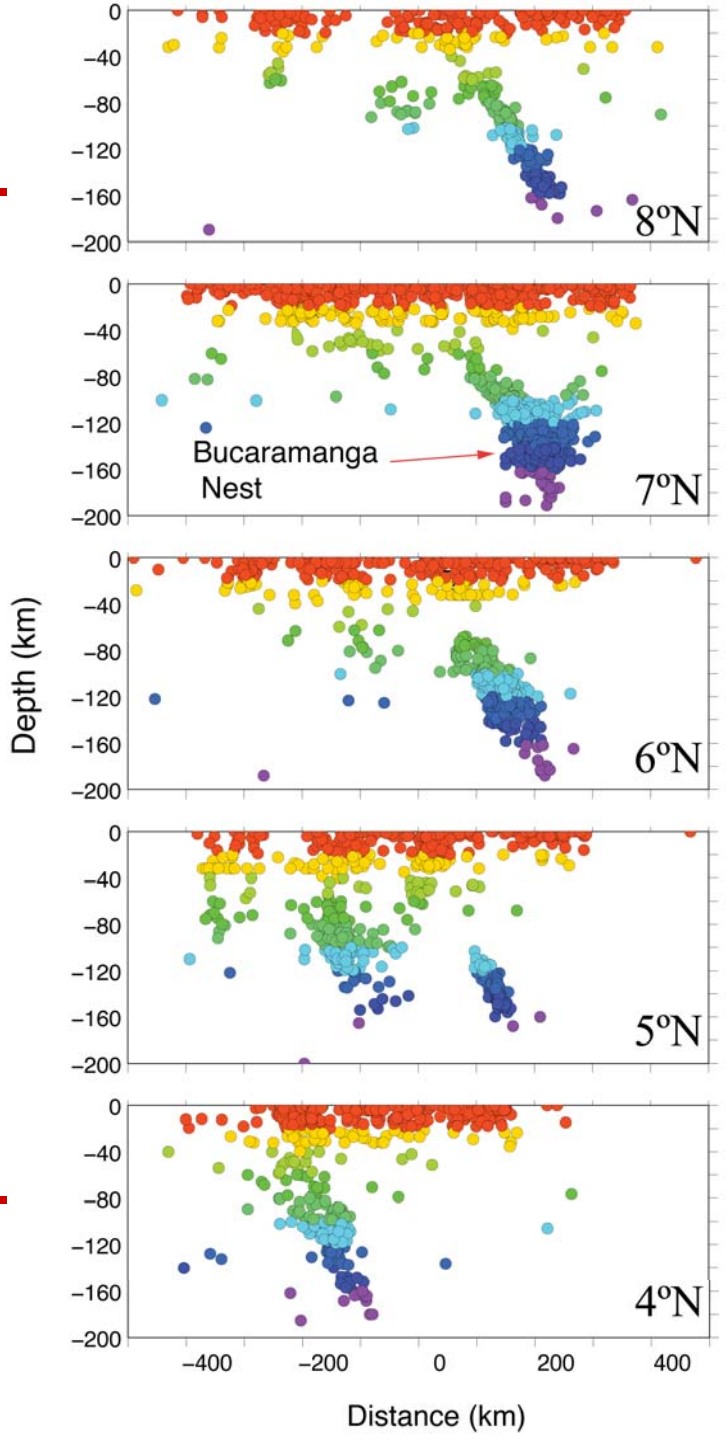
Zafiri et al. (2007)

Caribbean, Nazca or interaction between them?

Strongly variable focal mechanisms observed in close proximity.

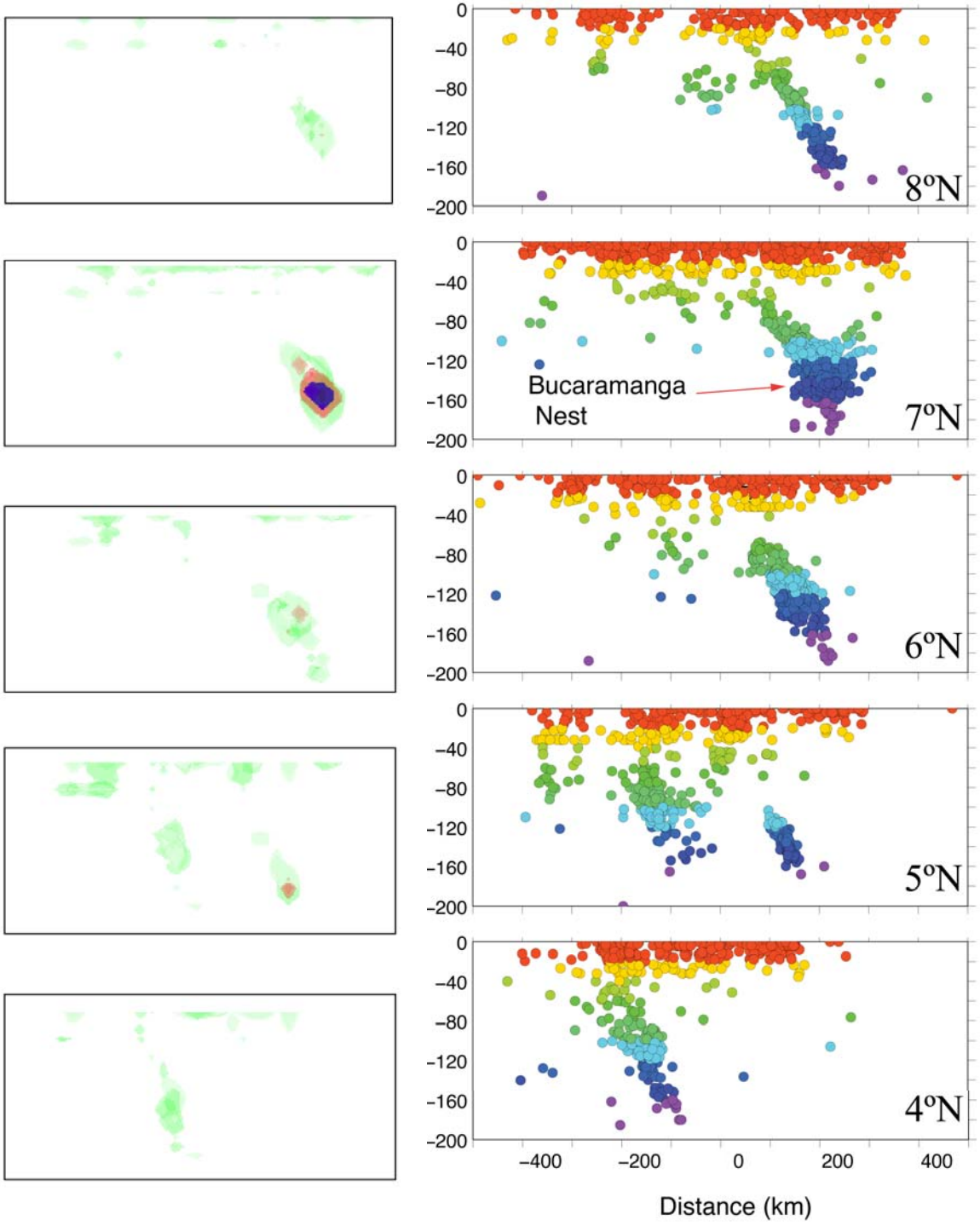
Tectonics – EQ Locations





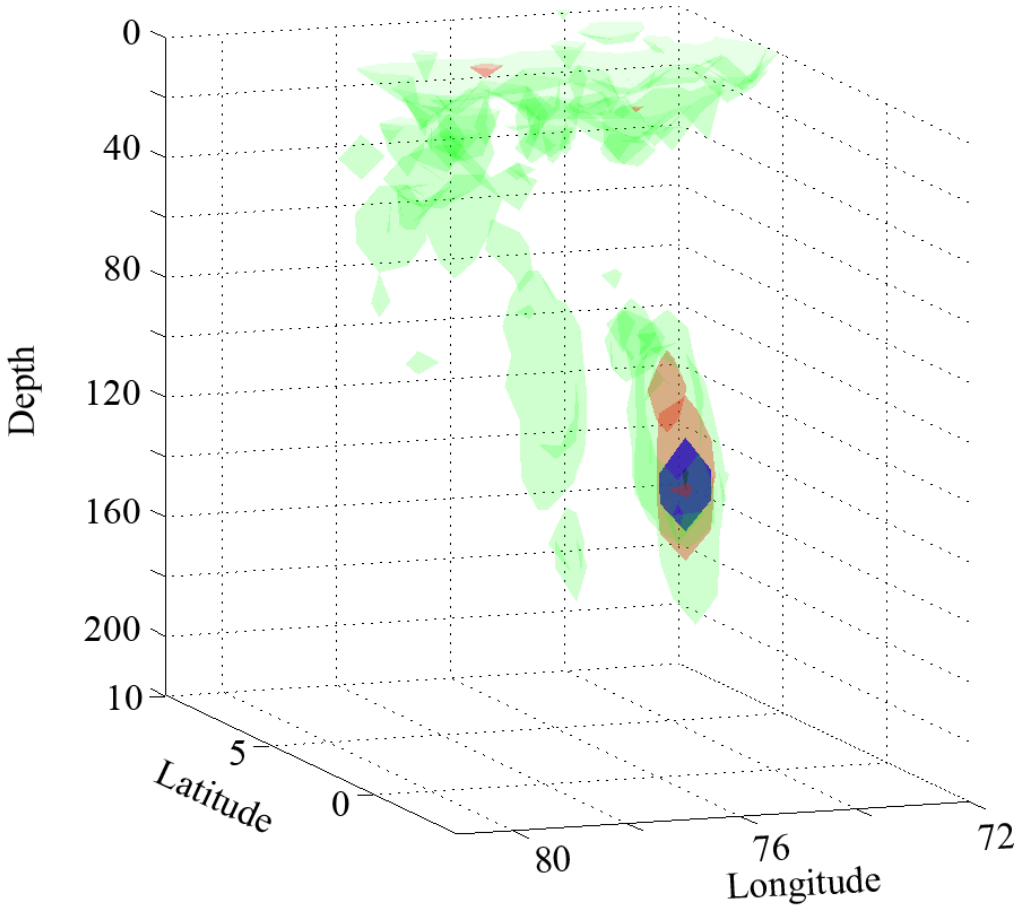
A subducting Caribbean Plate is suggested by earthquake locations

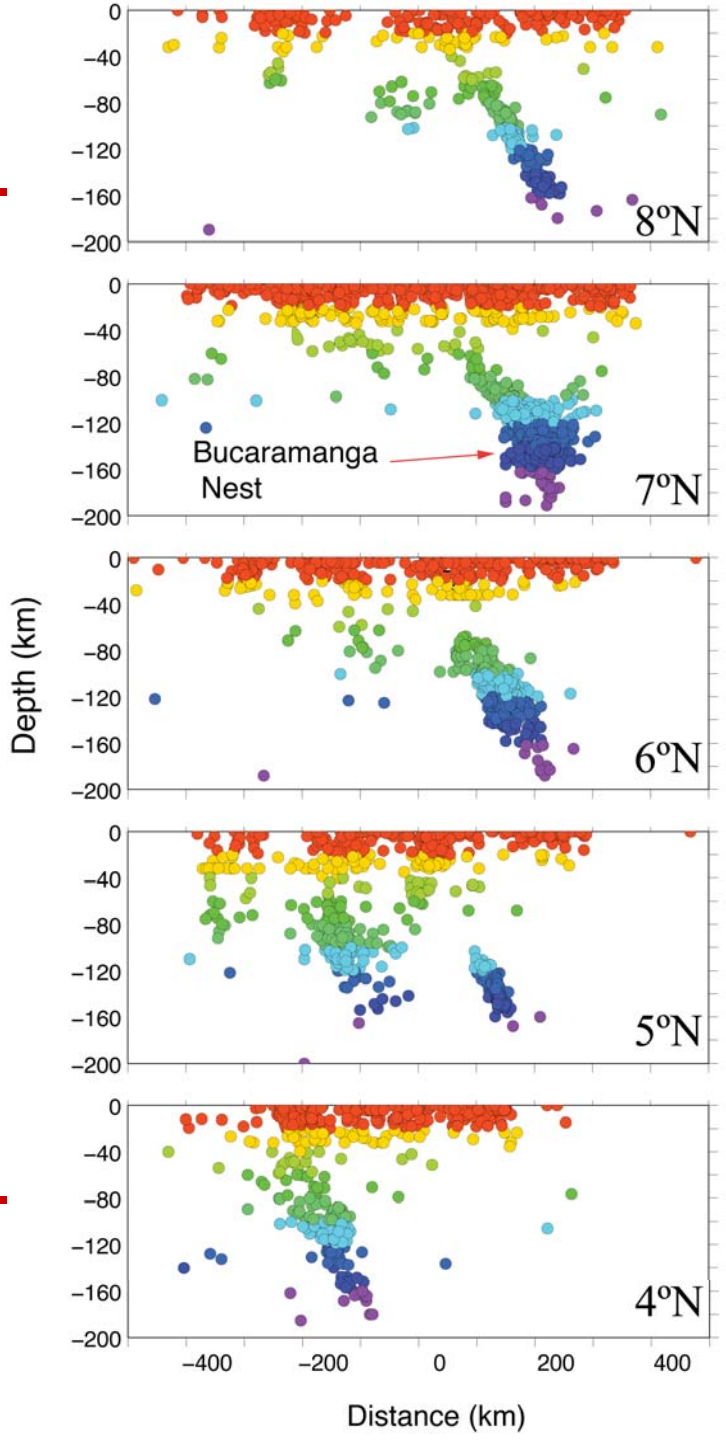
Tectonics – EQ L



A subducting Caril suggested by earthq

Tectonics – EQ Locations





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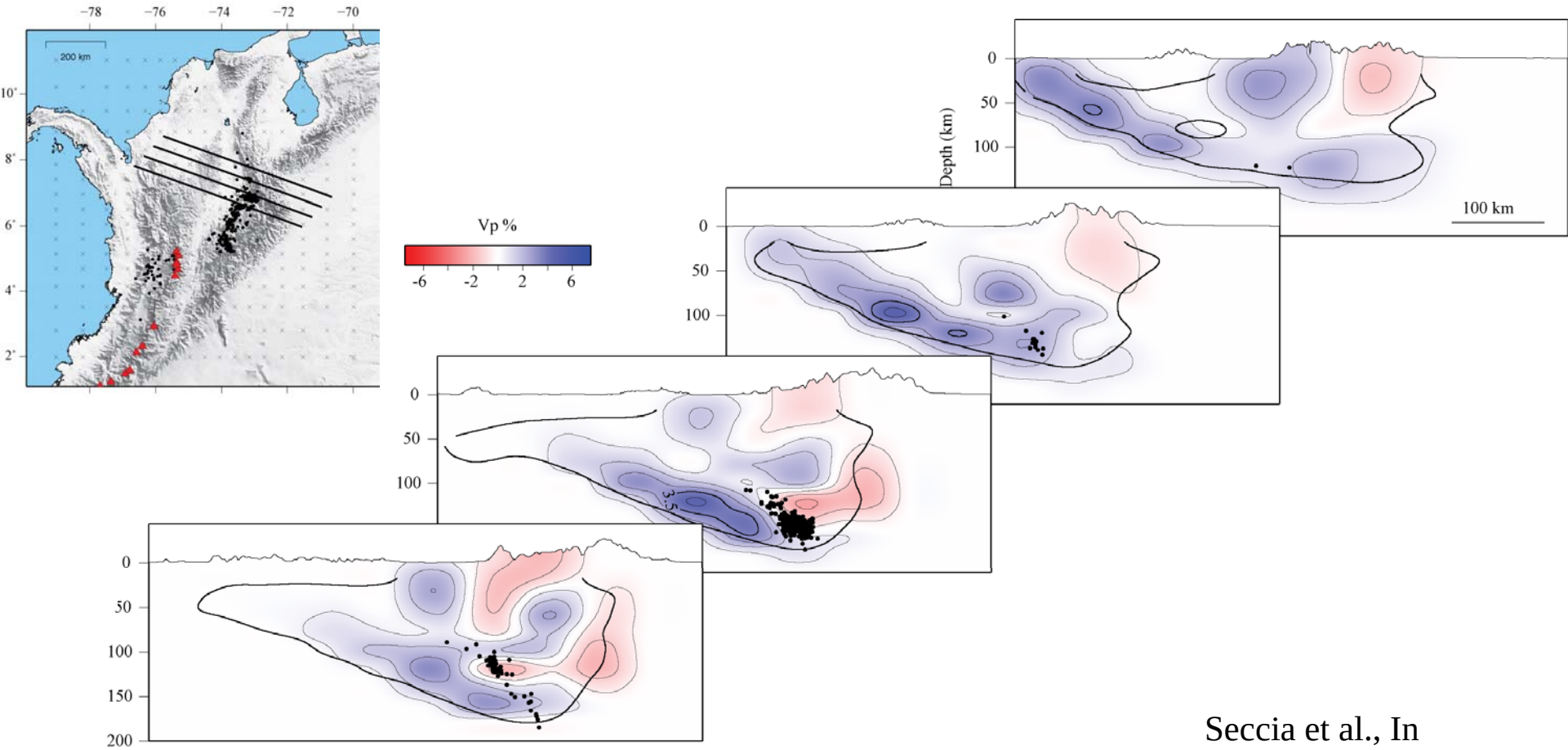
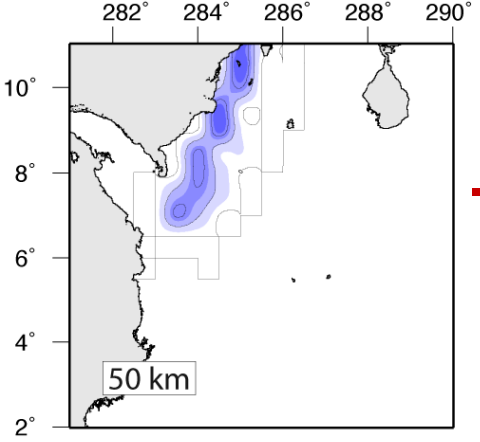
Tectonics - Tomography

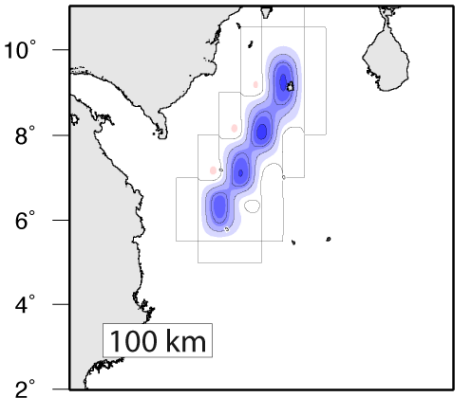


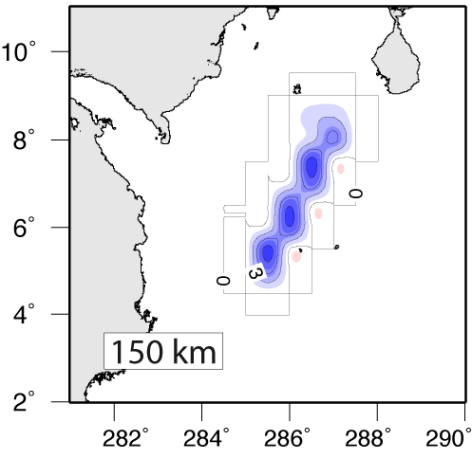
Seccia et al., In preparation (2010)

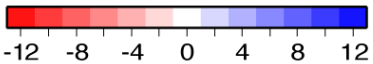
A subducting Caribbean Plate is suggested by tomographic results

Tectonics - Tomography









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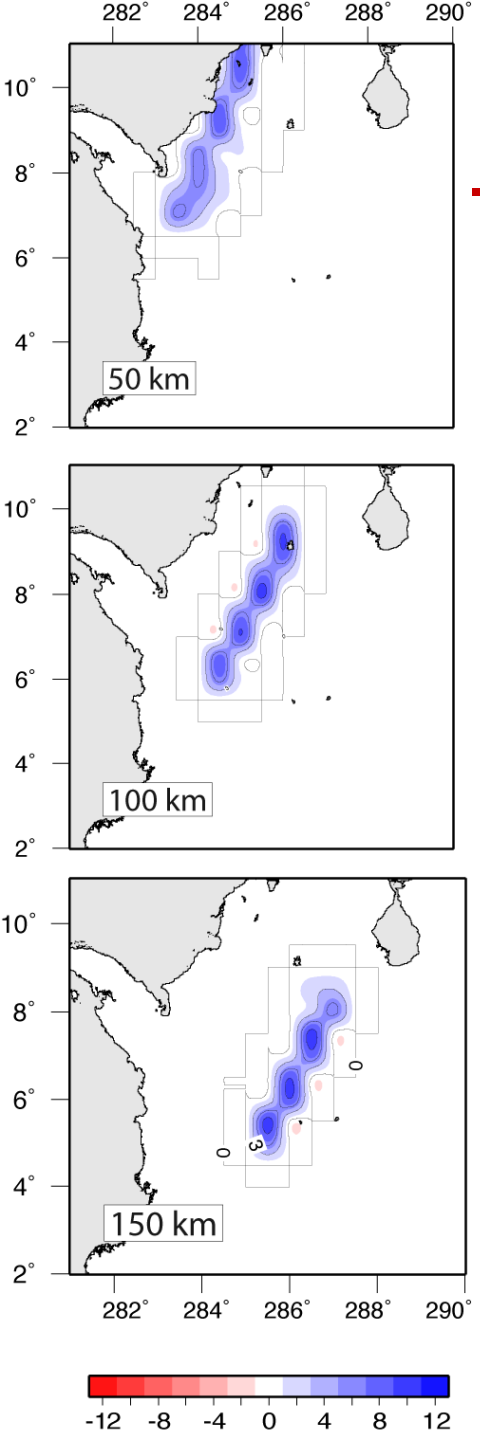

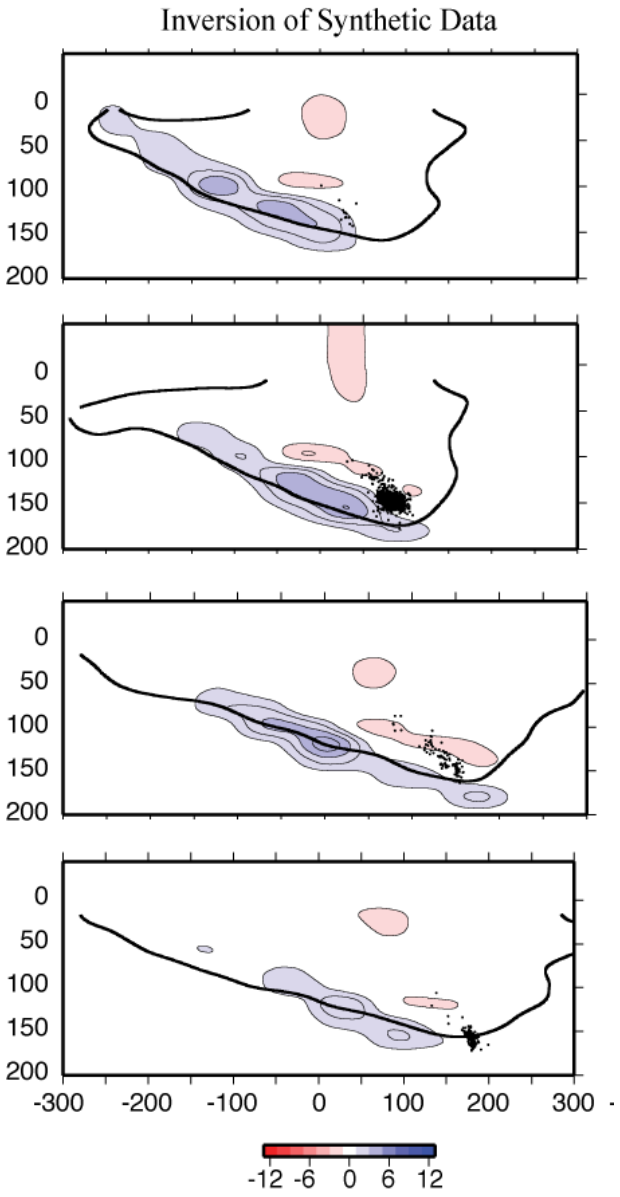

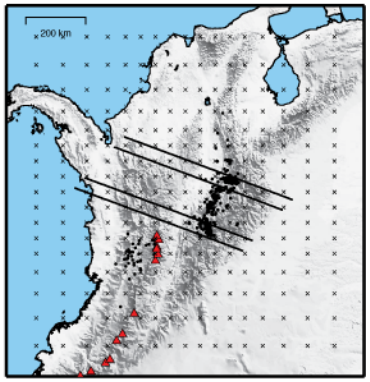

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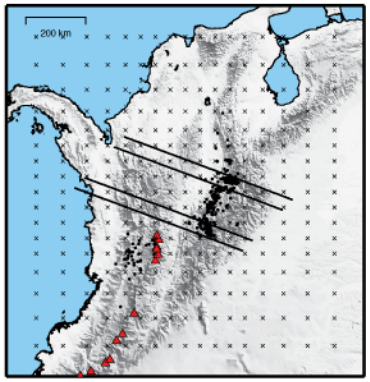

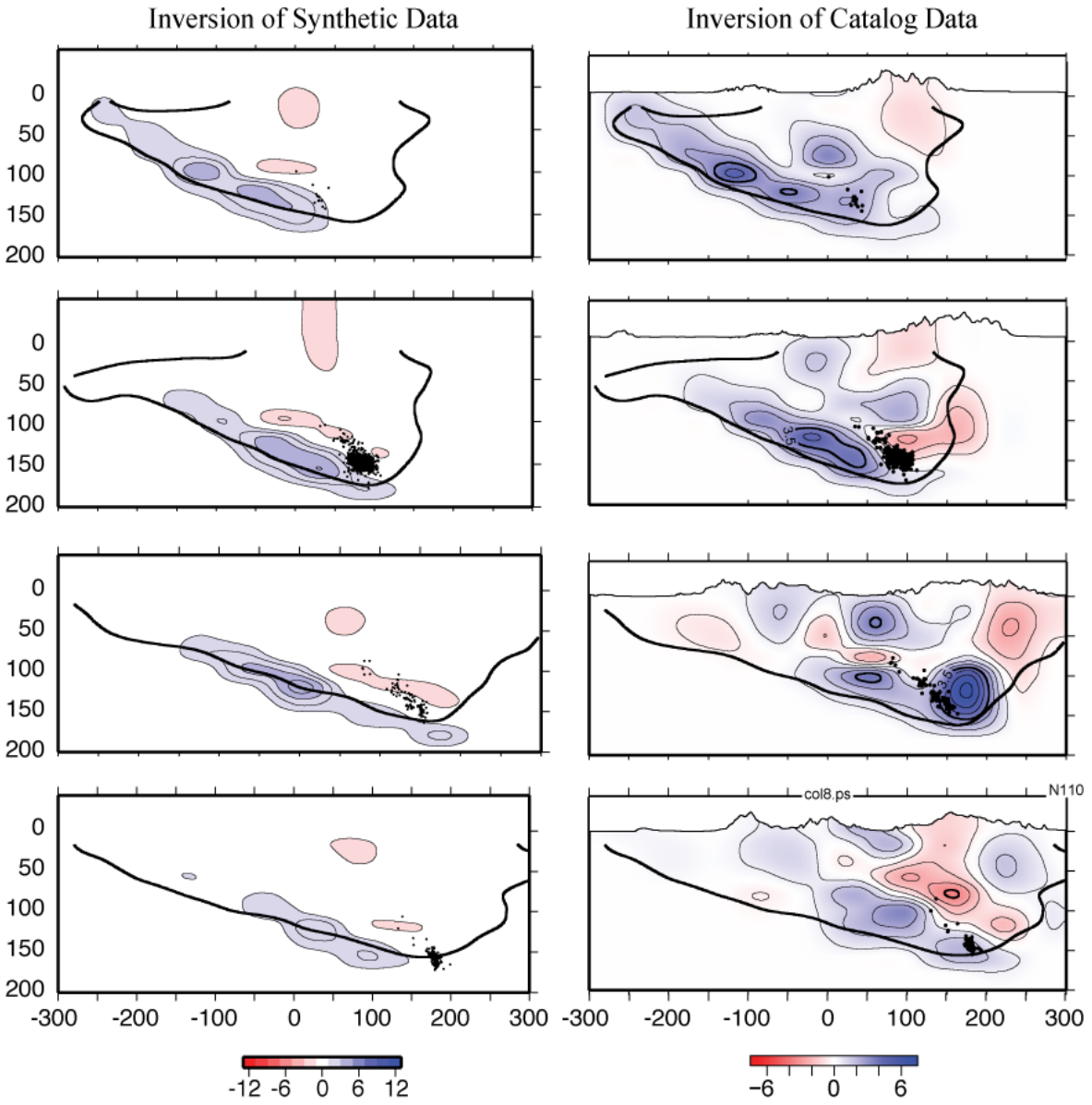

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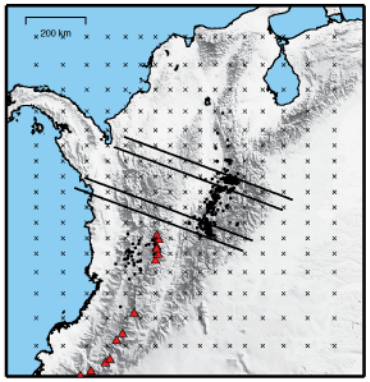
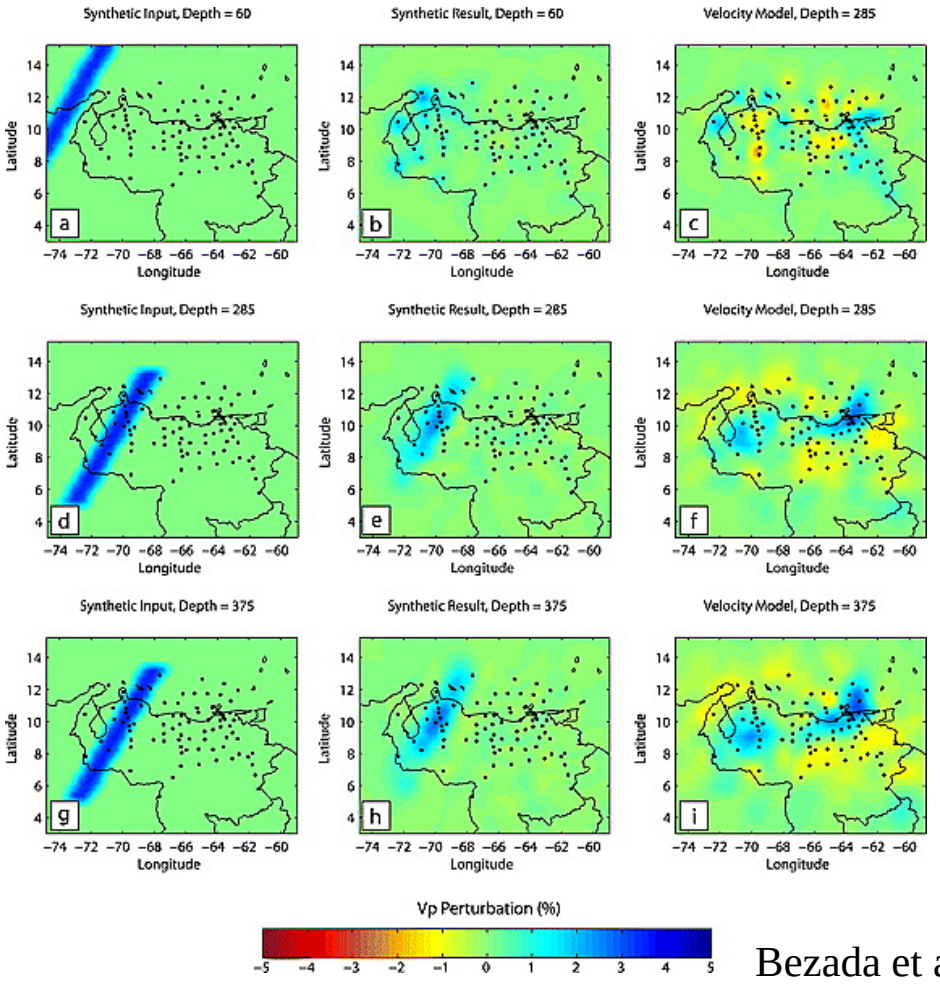
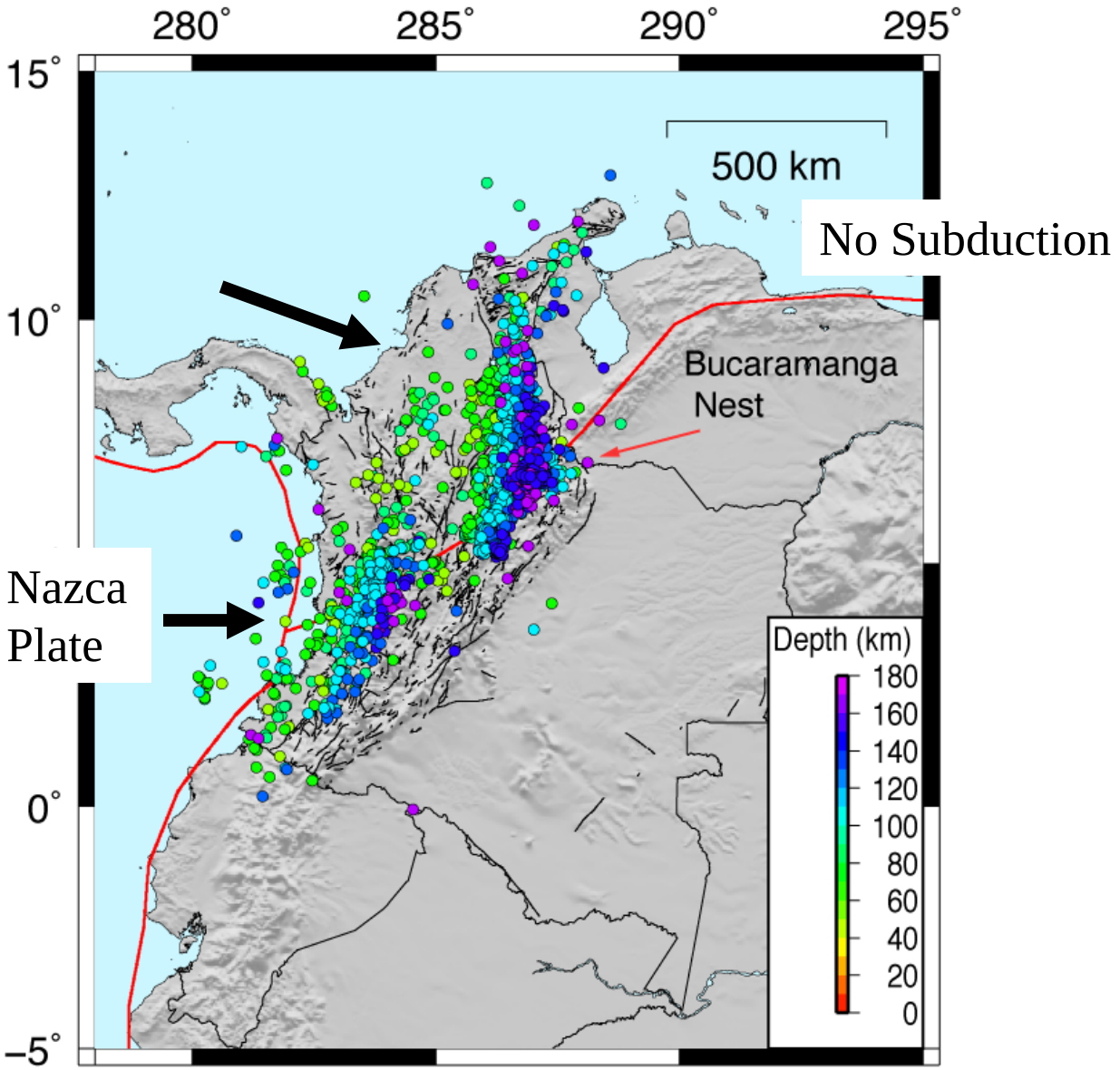




Bezada et al. (2010)

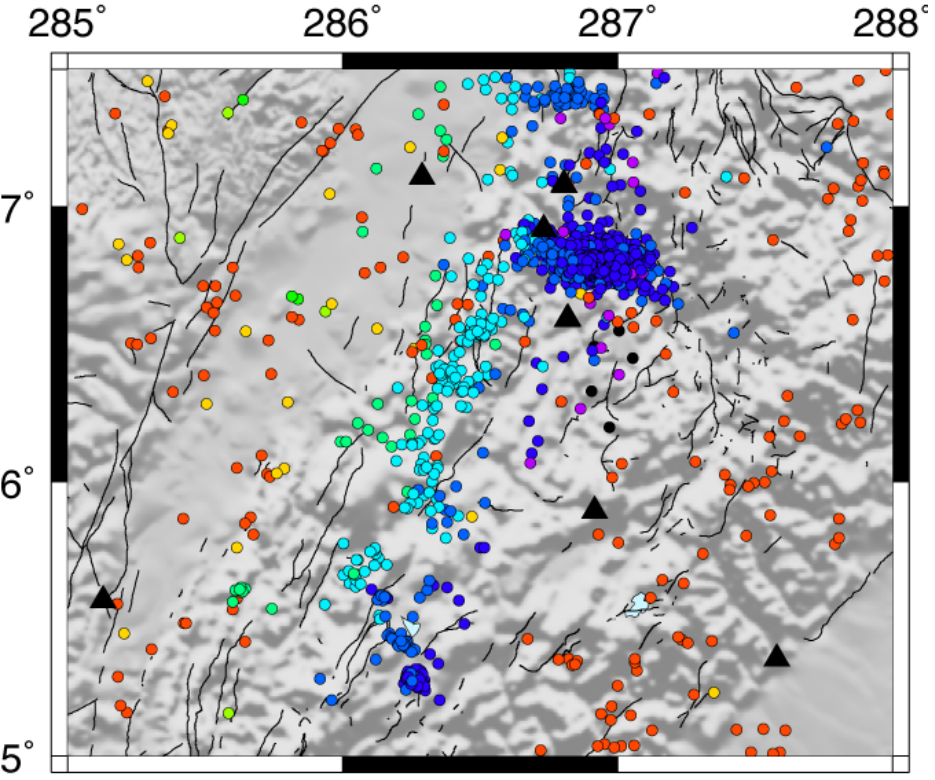
A subducting Caribbean Plate ← tomographic results

Tectonics


280°
285°
290°
295°
15°
10°
0°
−5°
500 km
No Subduction
Bucaramanga
Nest
Nazca
Plate
Depth (km)
180
160
140
120
100
80
60
40
20
0

Earthquake Source Physics

Earthquake Source Physics - Repeating Events



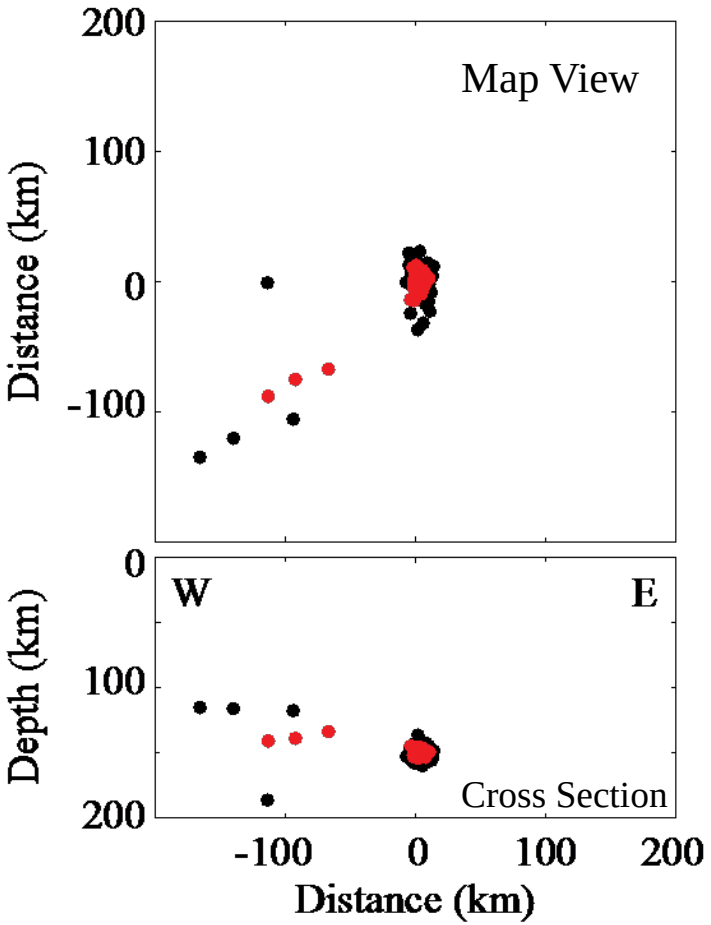
Earthquake Relocations:

Map shows catalog locations of M>3.0 earthquakes.

Size of Nest radius from Catalog: ~40 km.

Frohlich suggests a volume of 11 km^3

Bucaramanga Nest Relocations



Catalog

Relocated

Earthquake Relocations:

Double-Difference algorithm

Subset of M>3.5

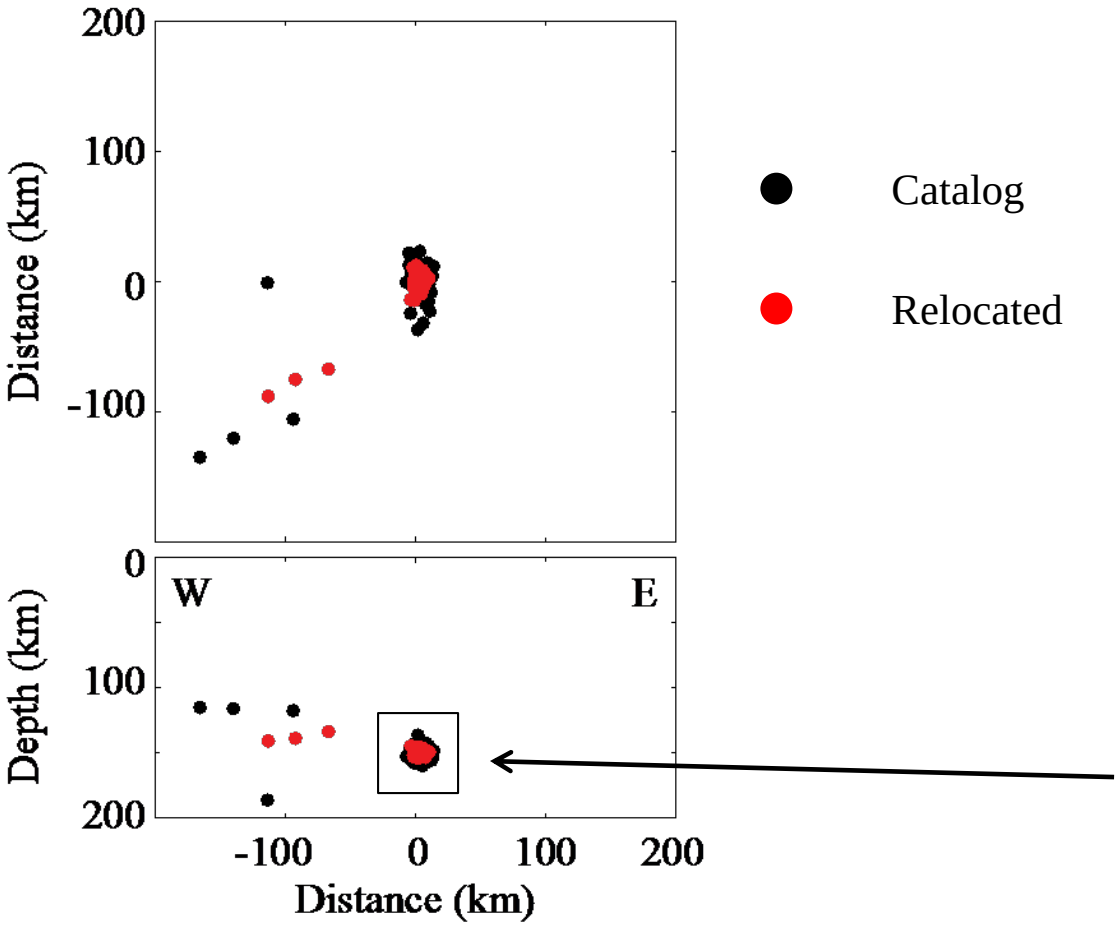
P, S, CC differential t-times

~100 EQs in 2009

Size of Nest radius from Catalog: ~40 km.

Frohlich suggests a 11 km^3

Bucaramanga Nest Relocations



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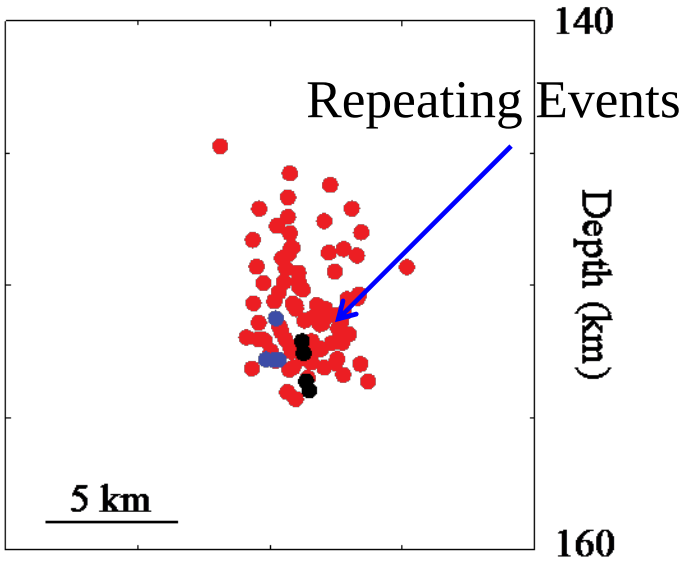
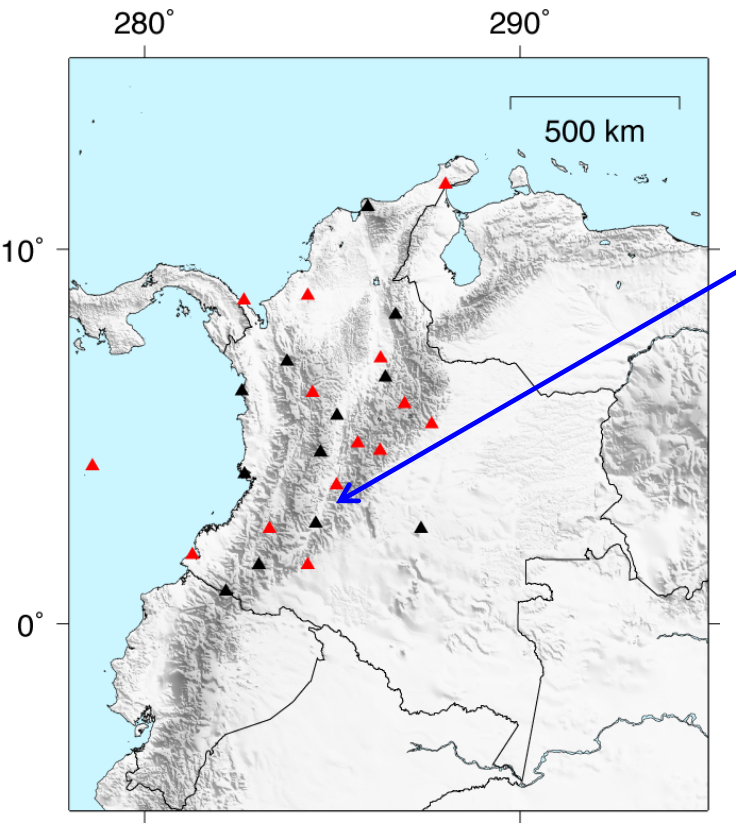


Buca-Nest: Vertical feature, elongated along N-S.

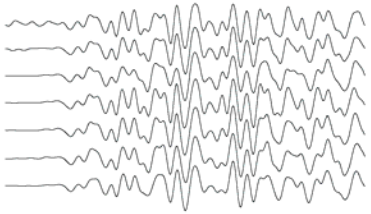
Volume 8 x 10 x 10 km^3

Repeating Events 1



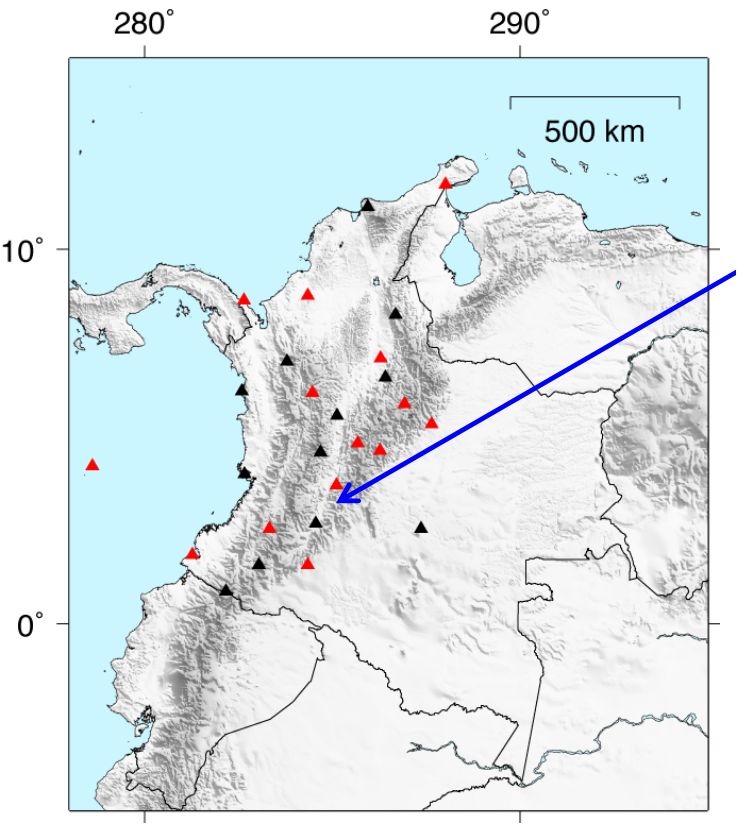
ANIL - HHE

5 sec



Individual Earthquakes
M > 3.5
CC > 0.80

Repeating Events 1



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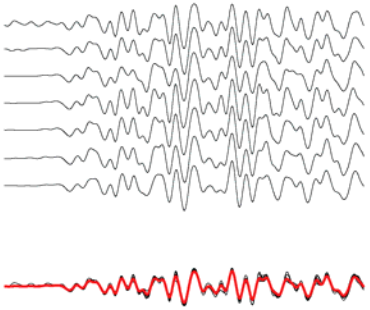
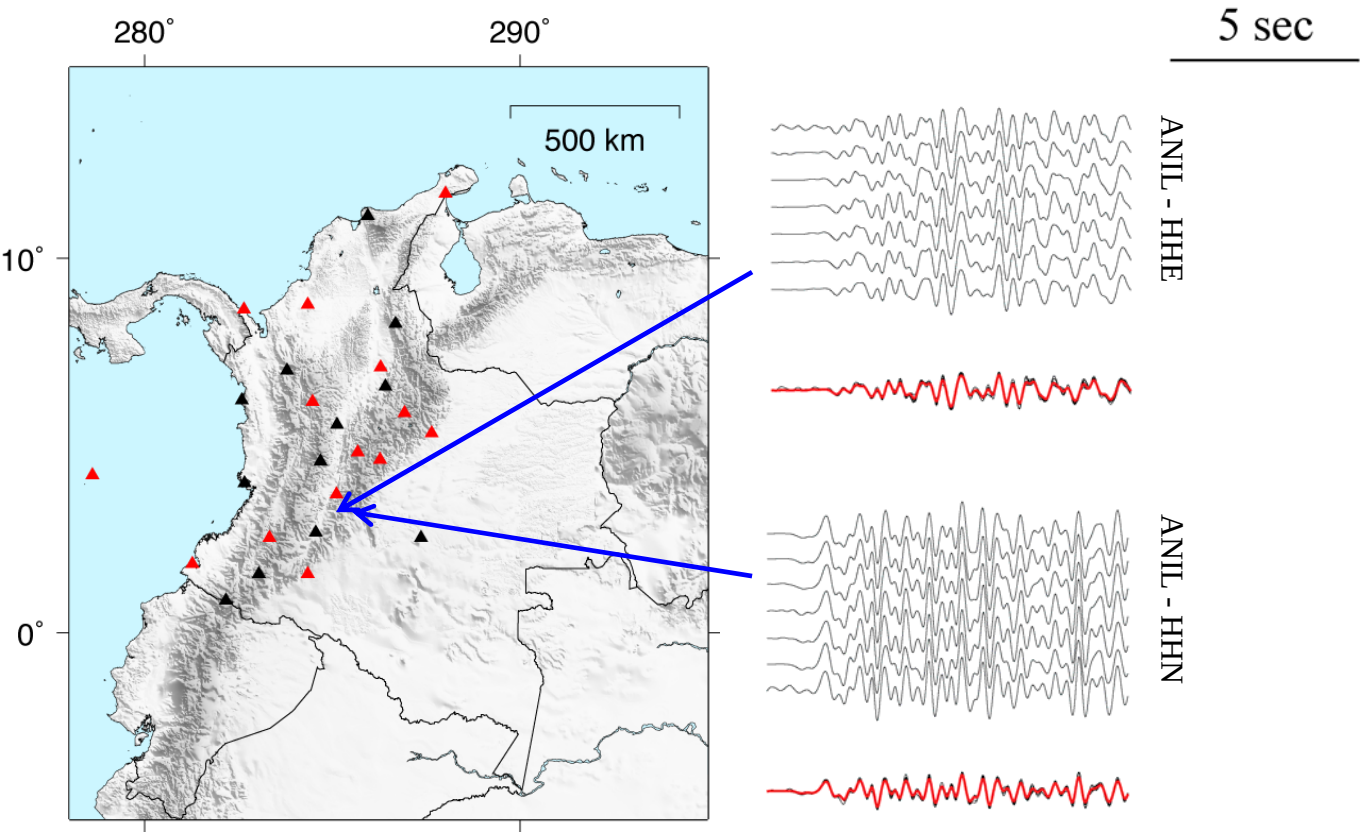


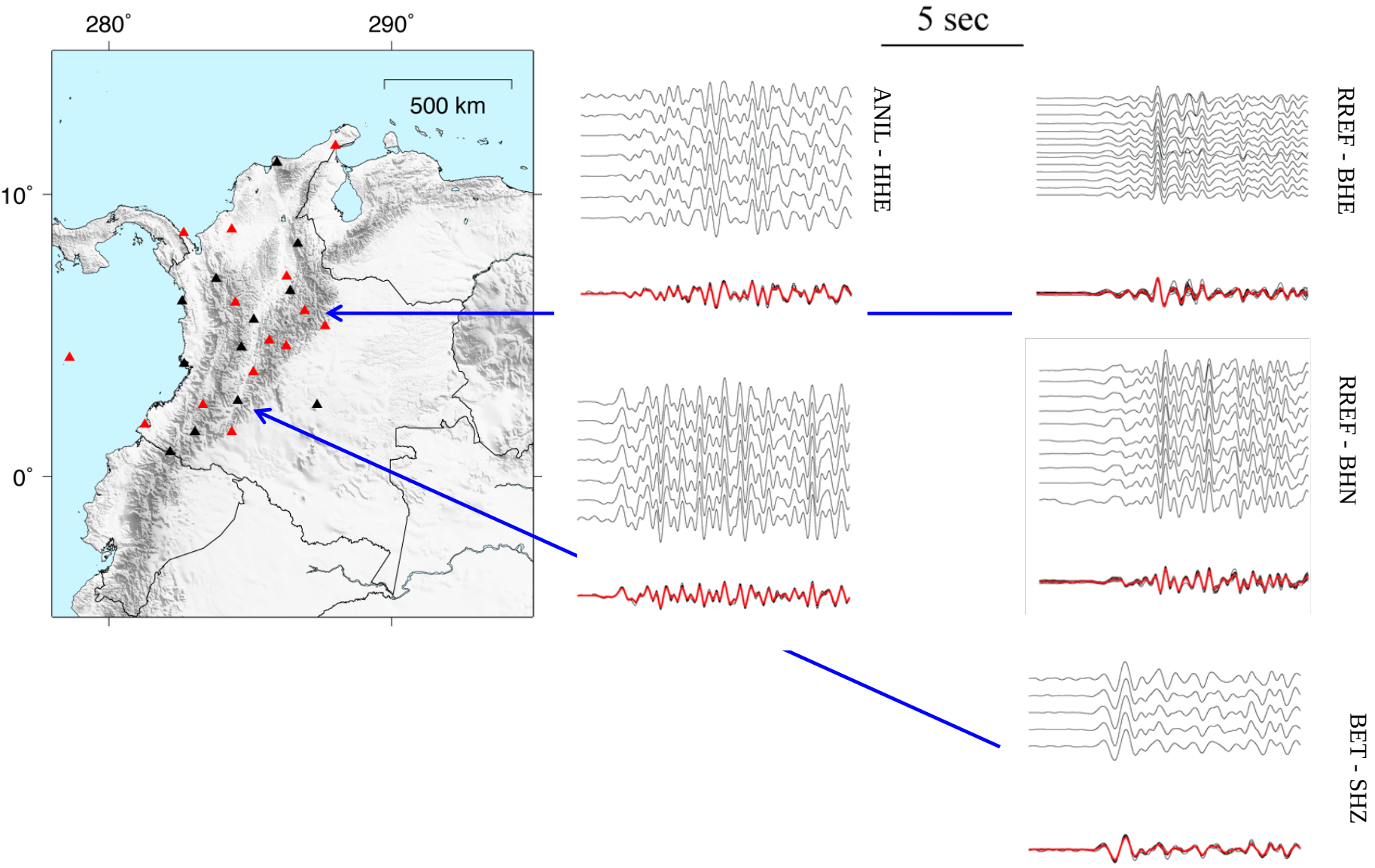
Individual Earthquakes
M > 3.5
CC > 0.80

Stack

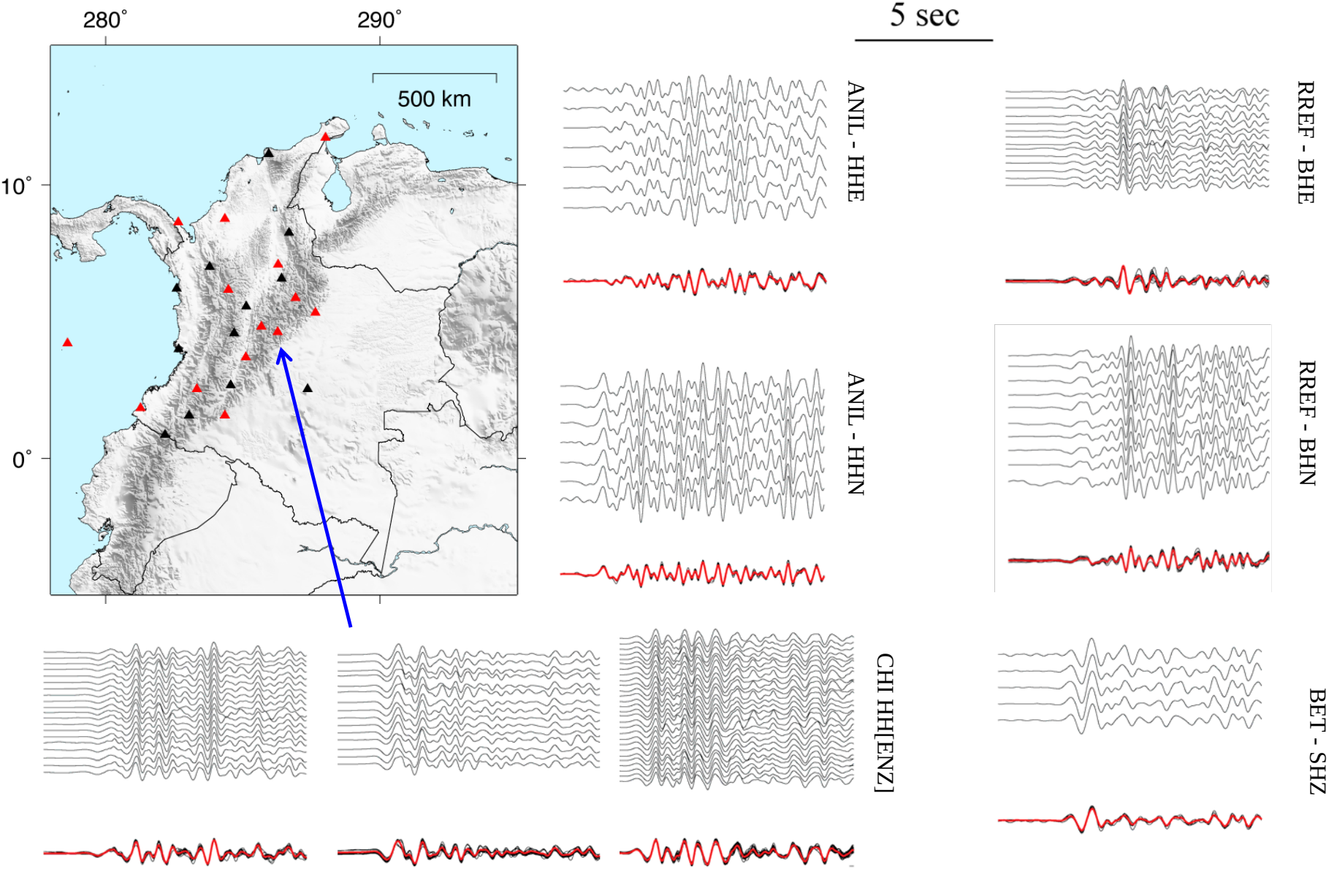
Repeating Events 1



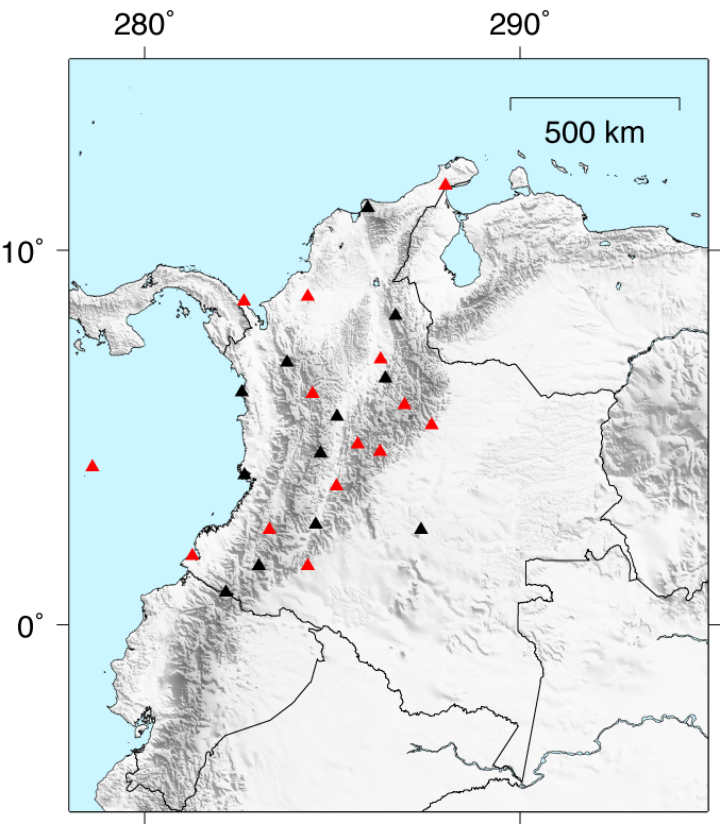
Repeating Events 1

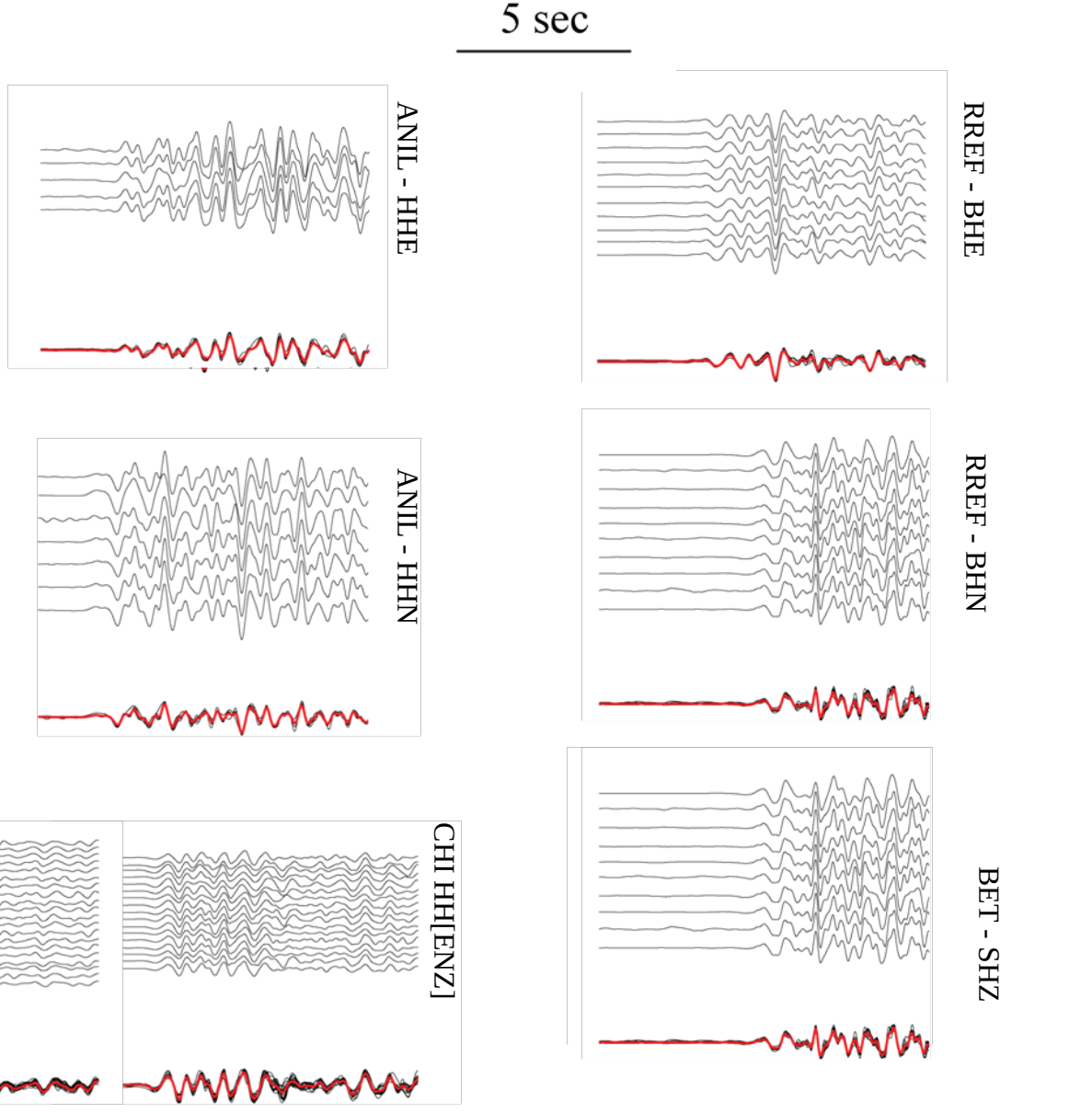


Repeating Events 1

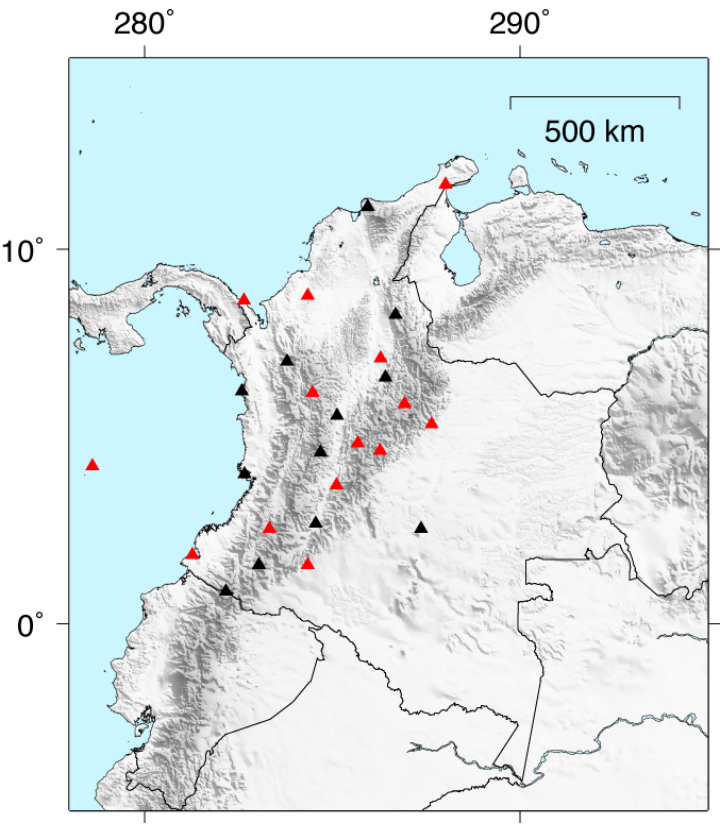


Repeating Events 2



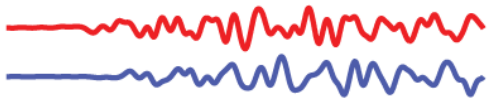


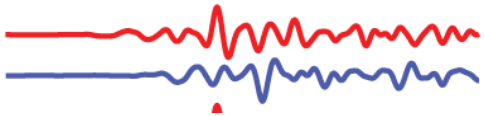
Reversed Polarity Events?

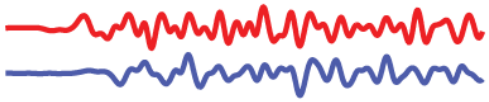


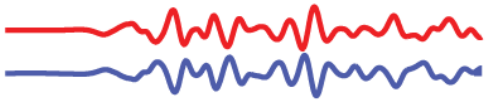
5 sec

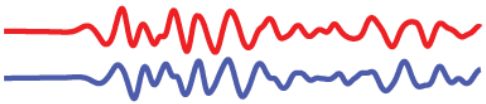
Repeat 1 Repeat 2



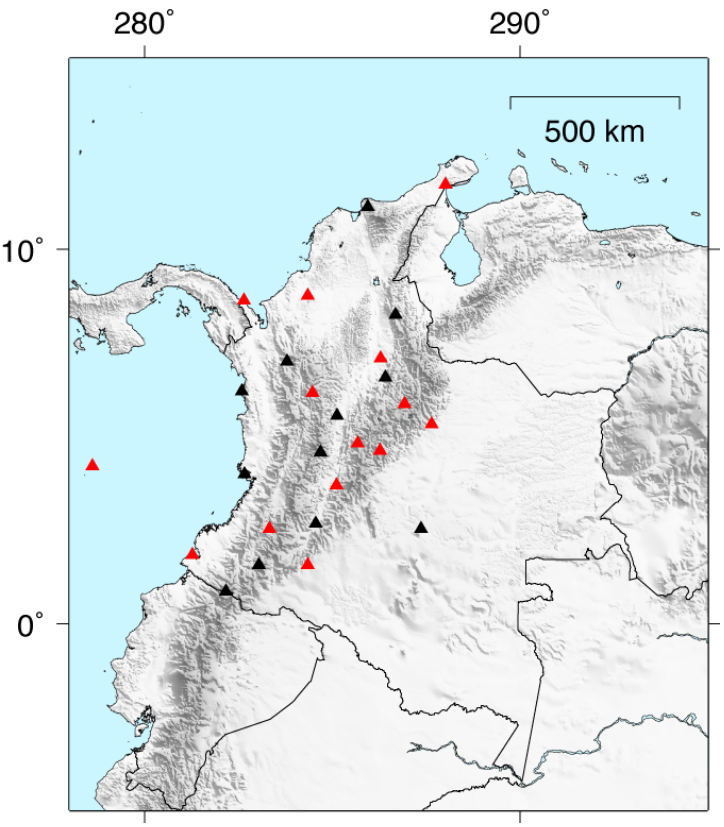






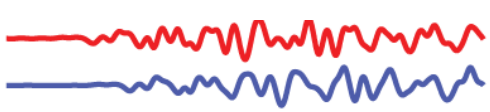
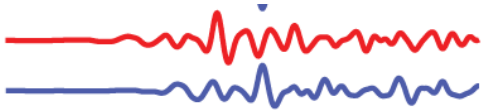
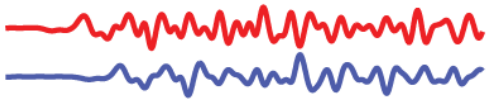


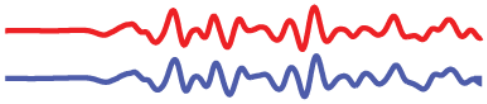
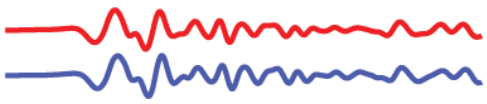
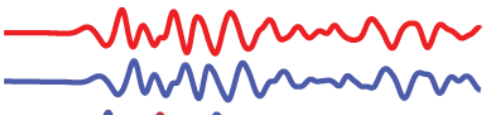
Reversed Polarity Events?



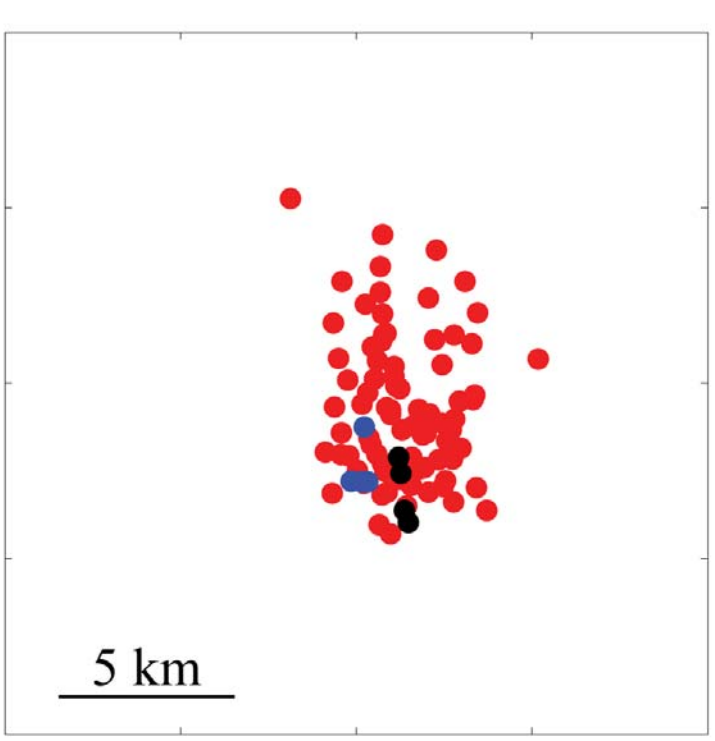
5 sec

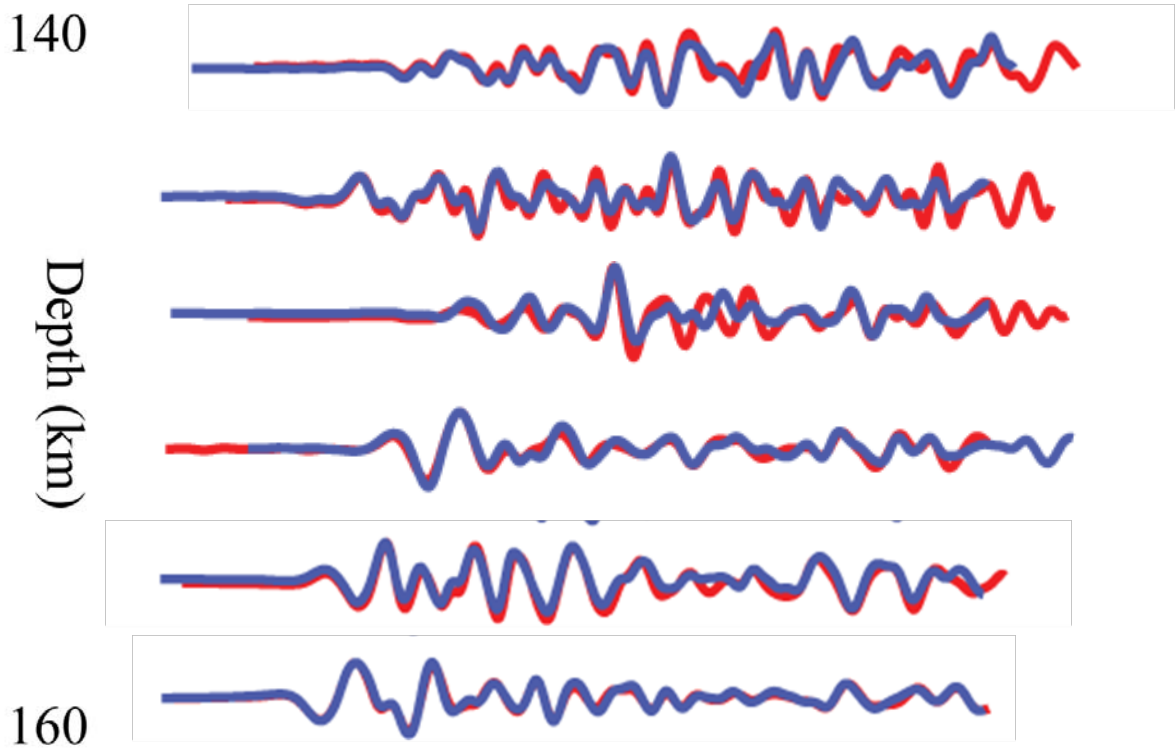
Inverted Repeat 2

Reversed Polarity Events

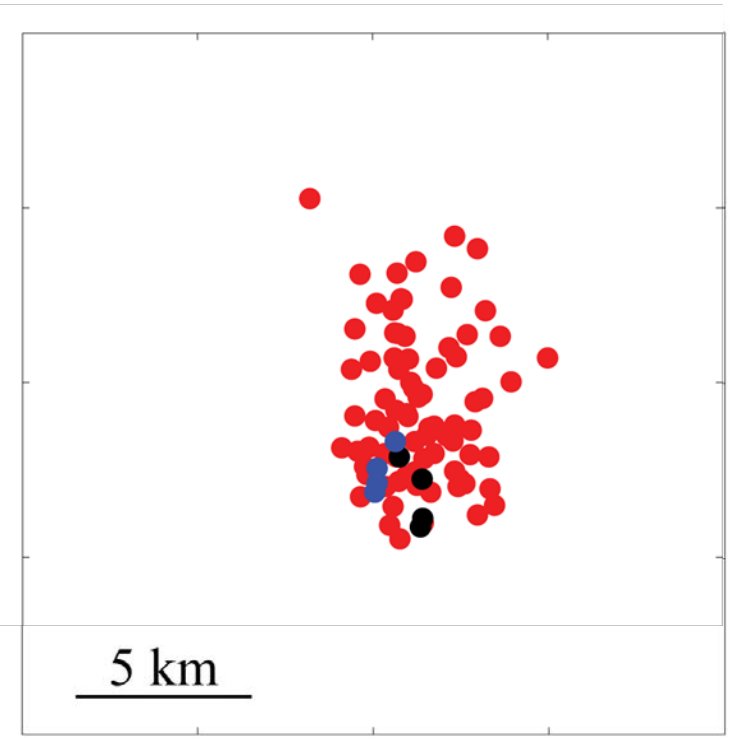


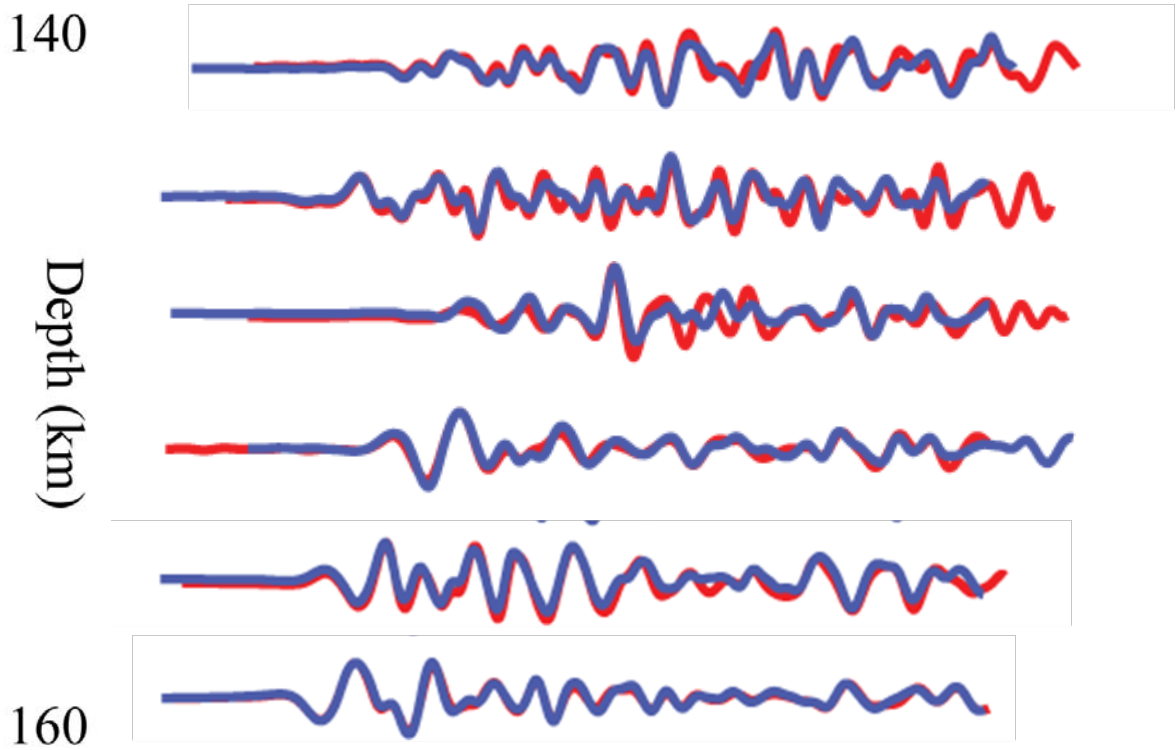


Bucaramanga Nest: Large number of repeating events

Large number of repeating and reversed polarity earthquakes

Reversed Polarity Events





Using relative arrivals for reverse Polarity events.

Large number of repeating and reversed polarity earthquakes

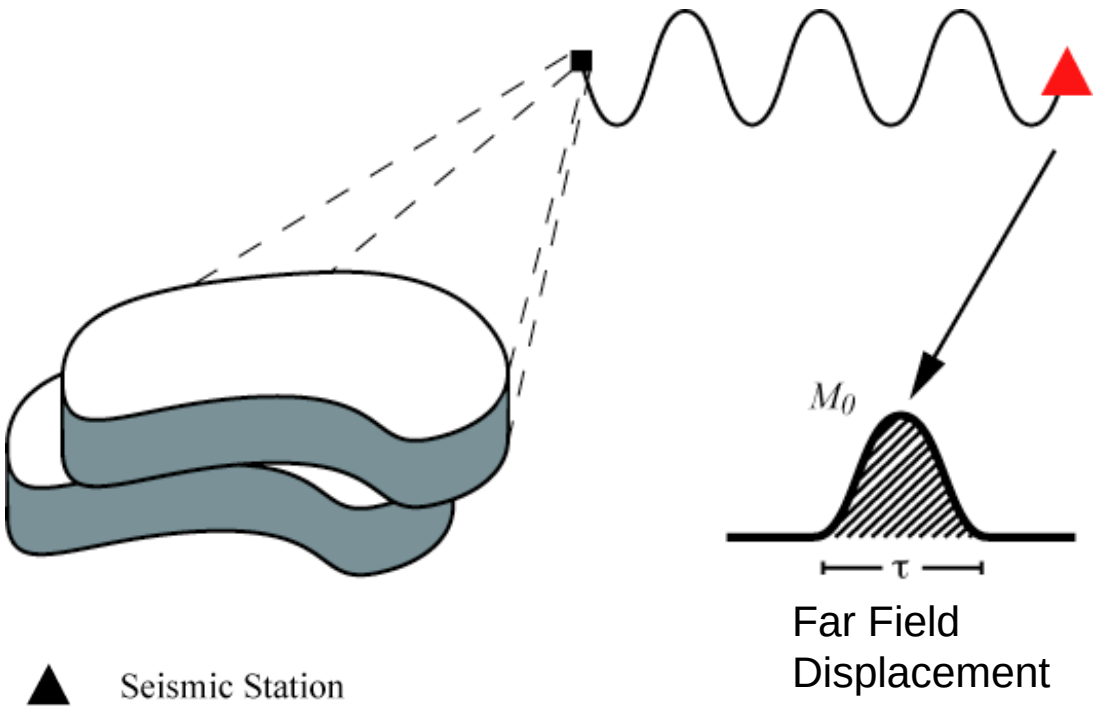
Repeating events with reversed polarity in close proximity

Earthquake Source Physics - Source Scaling

Earthquake Basics

Static measure

$M_0 \propto$ Area $\times$ Displacement



Ignoring attenuation and other wave propagation effects:

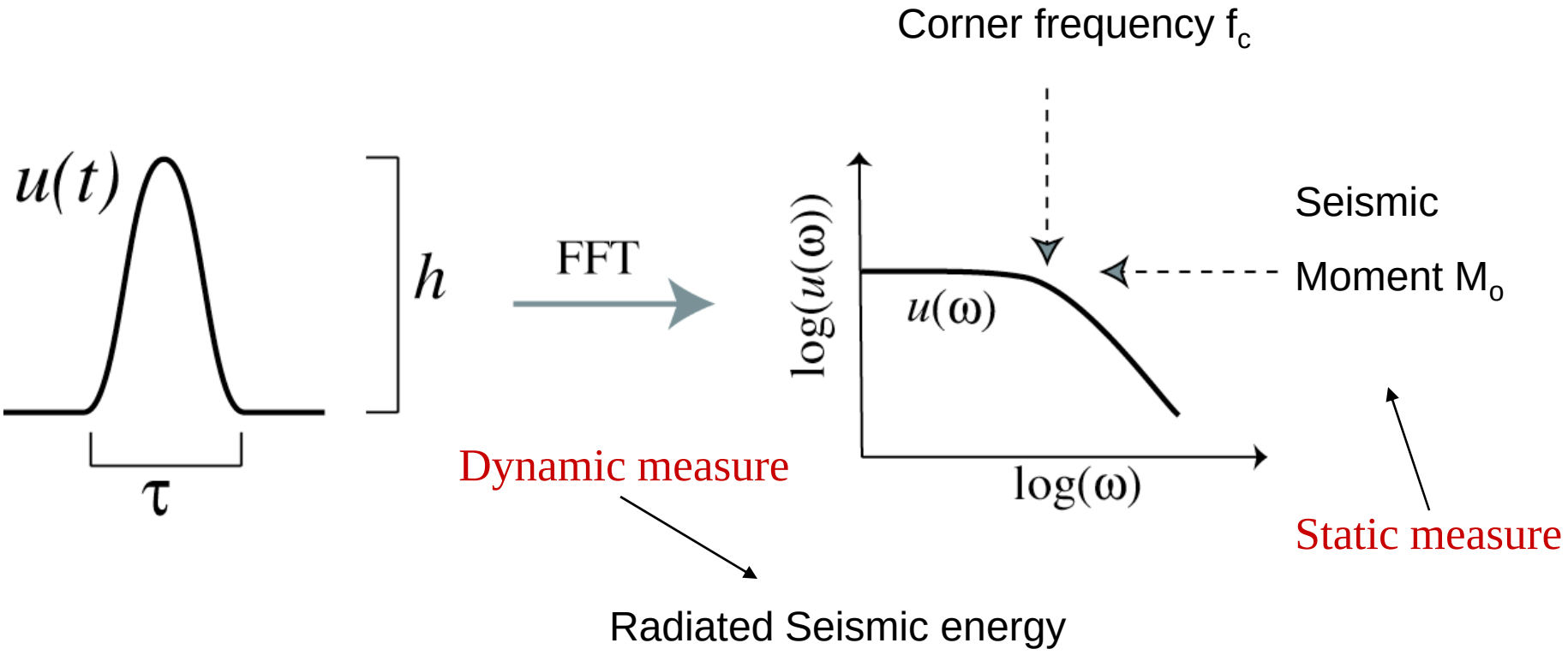
• In the far-field a displacement pulse is recorded.

Area under displacement pulse is related to **seismic moment M_0**, a measure of event size

Basic Source Parameters

Time Series

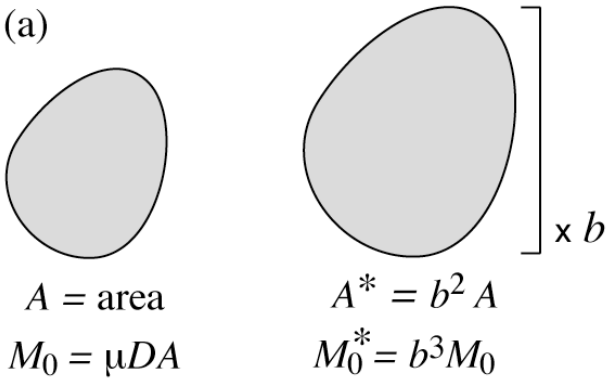
Spectrum



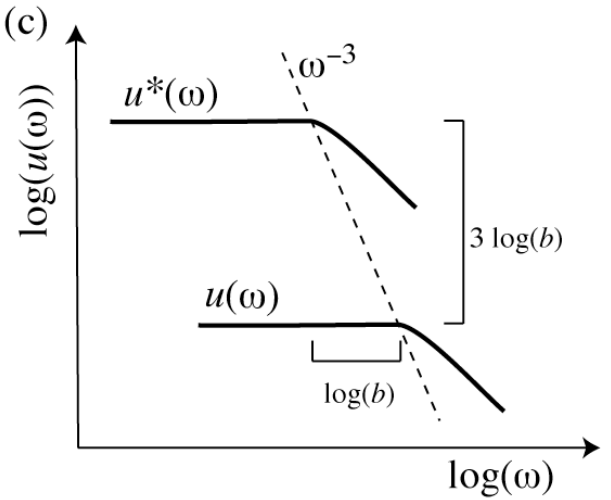
Area under displacement pulse is related to **seismic moment** M_0, a measure of event size

Integrated velocity squared is related to **radiated energy** E_S, another measure of event size

Earthquake Scaling



All the terms **scale with** earthquake **size** (Aki, 1967)



Prieto et al. 2004

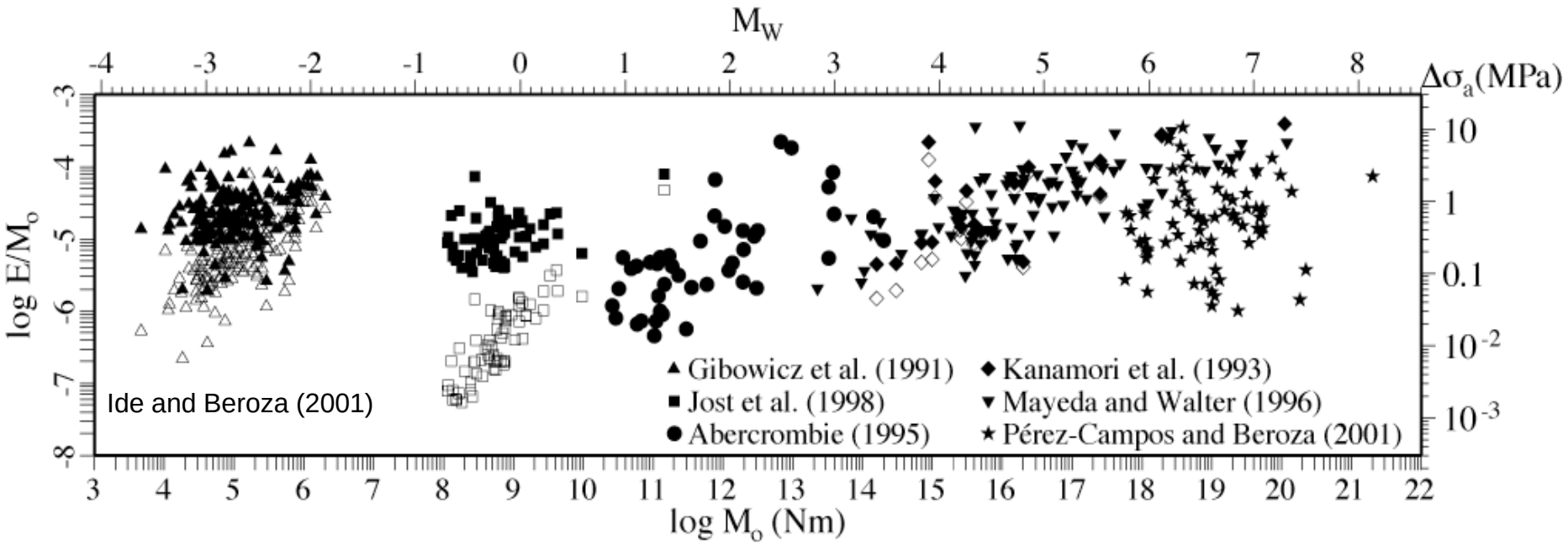
Earthquake Self-similarity

Still debated, but some data suggest that shallow earthquakes are self-similar.

Earthquake Scaling

$$\sigma_a = \mu E_s / M_0$$

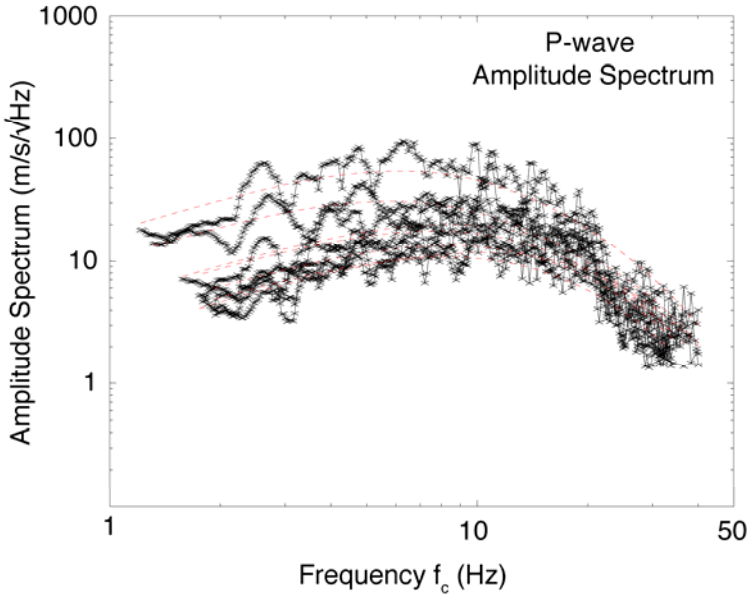
radiated energy per unit fault area and displacement

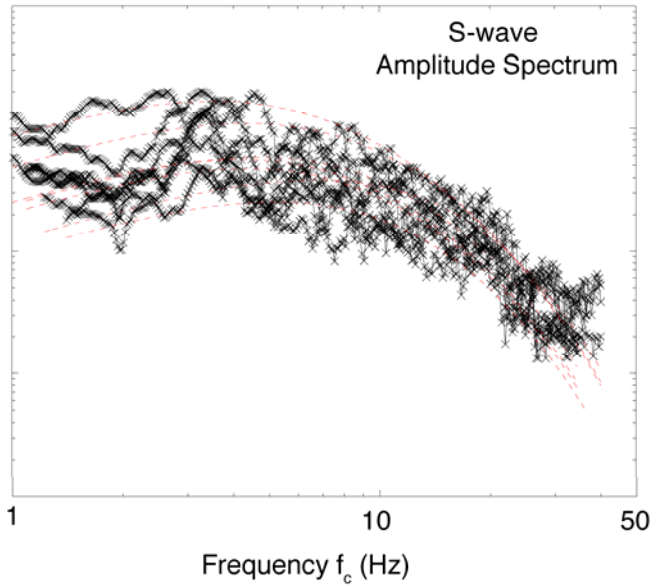


What about intermediate-depth earthquakes?

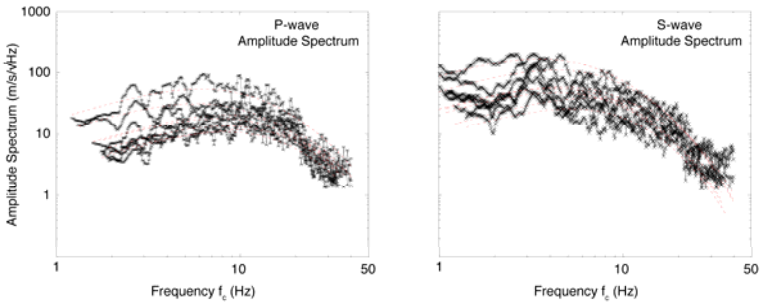
Does this tell us something about rupture mechanism?

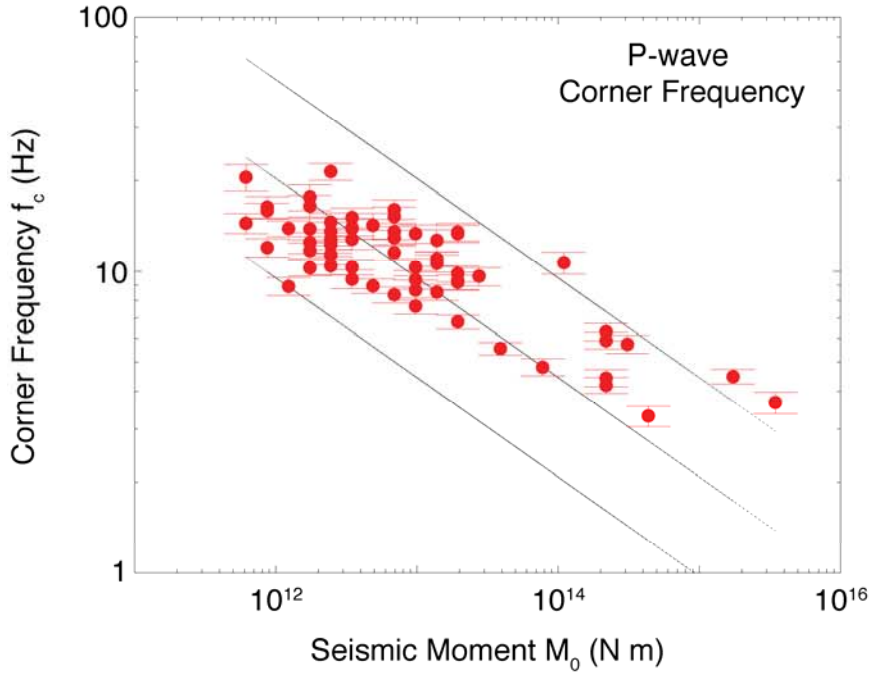
Source Physics and Source Scaling

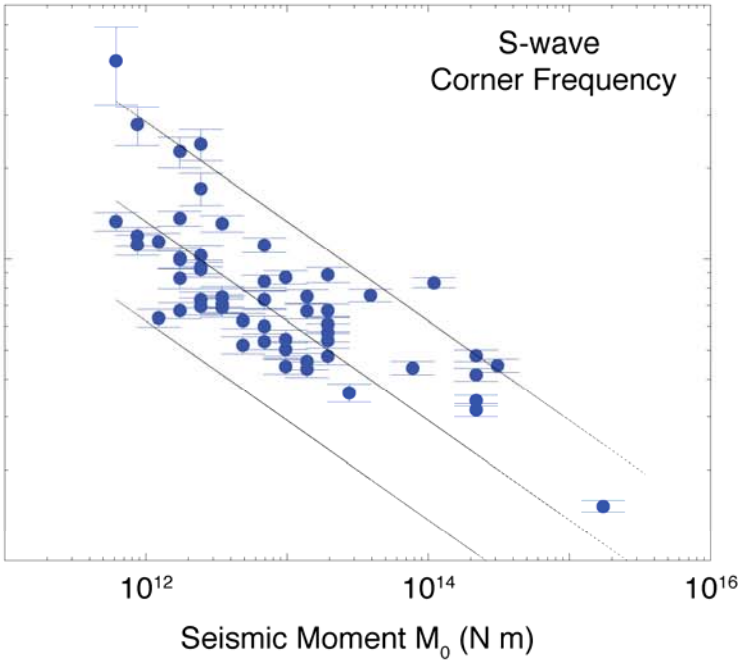




Source Physics and Source Scaling

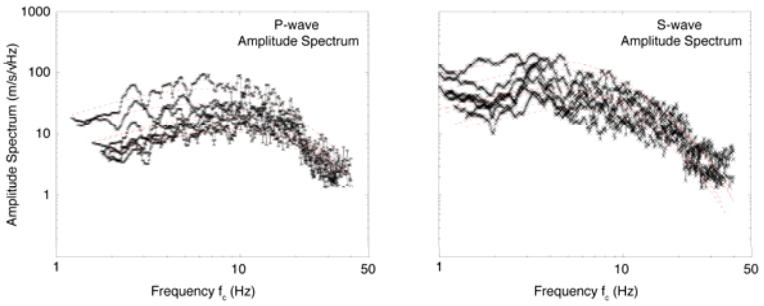


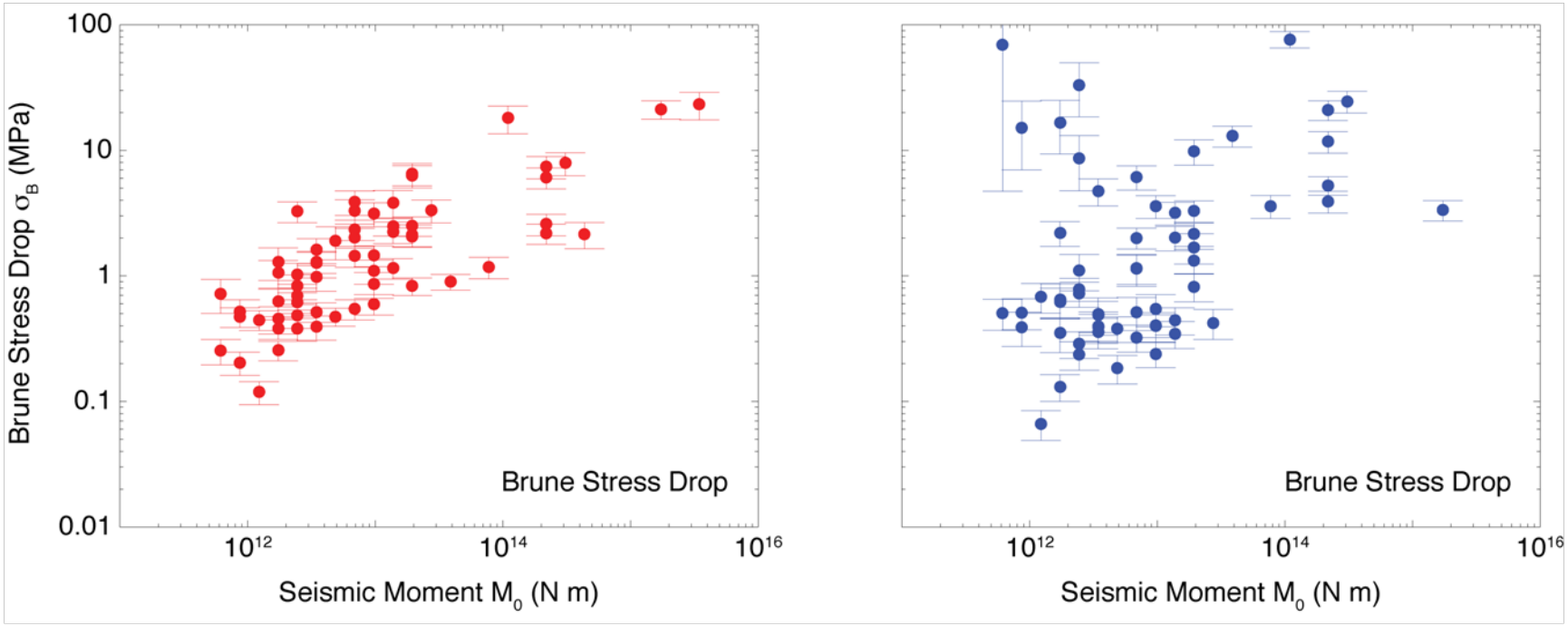




Self-similarity predicts $M_o - f_c^{-3}$ scaling

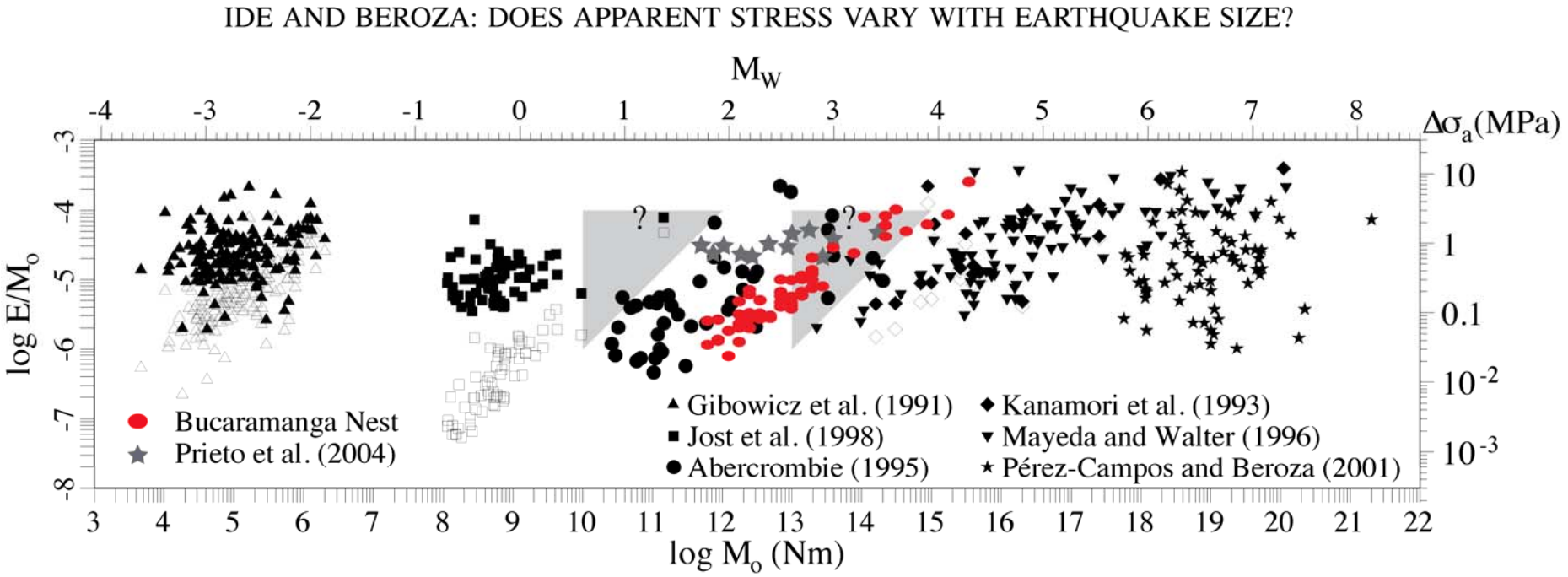
Source Physics and Source Scaling





Self-similarity predicts constant stress drop

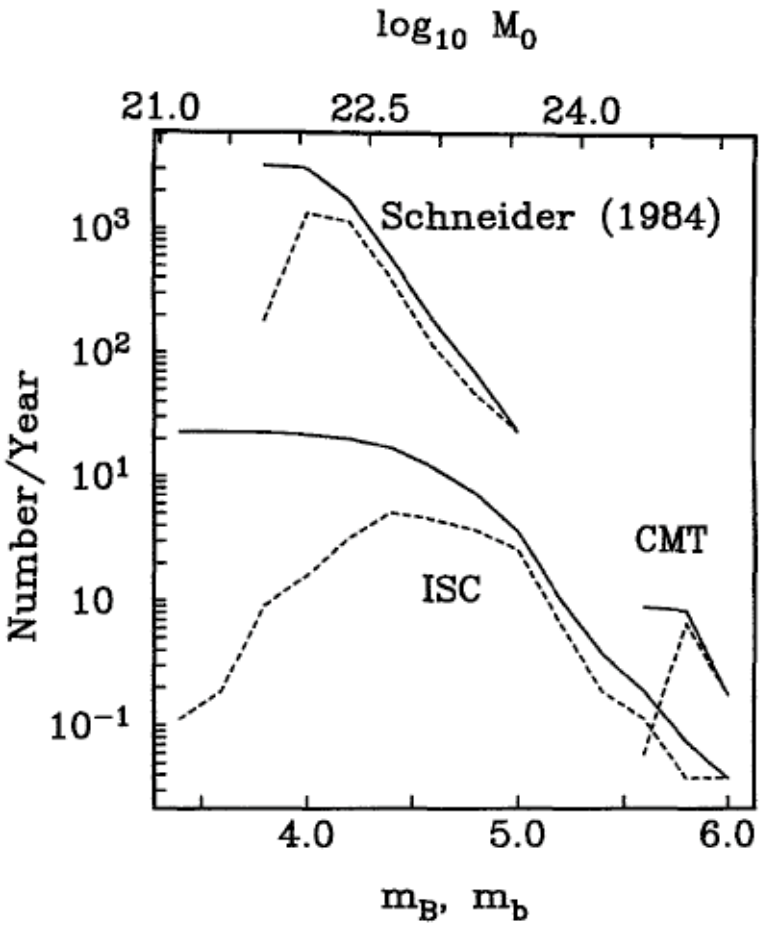
Source Physics and Source Scaling



Bucaramanga Nest earthquake do not follow self-similarity
Another feature different from shallow earthquakes

Temporal Behavior

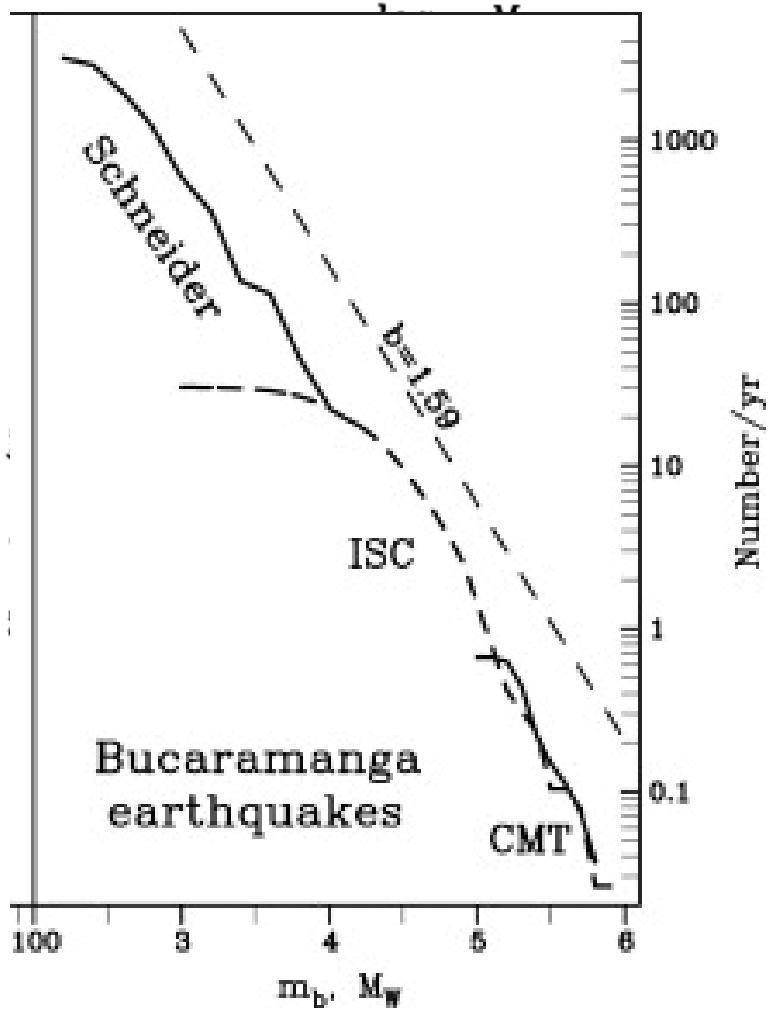
Temporal Behavior

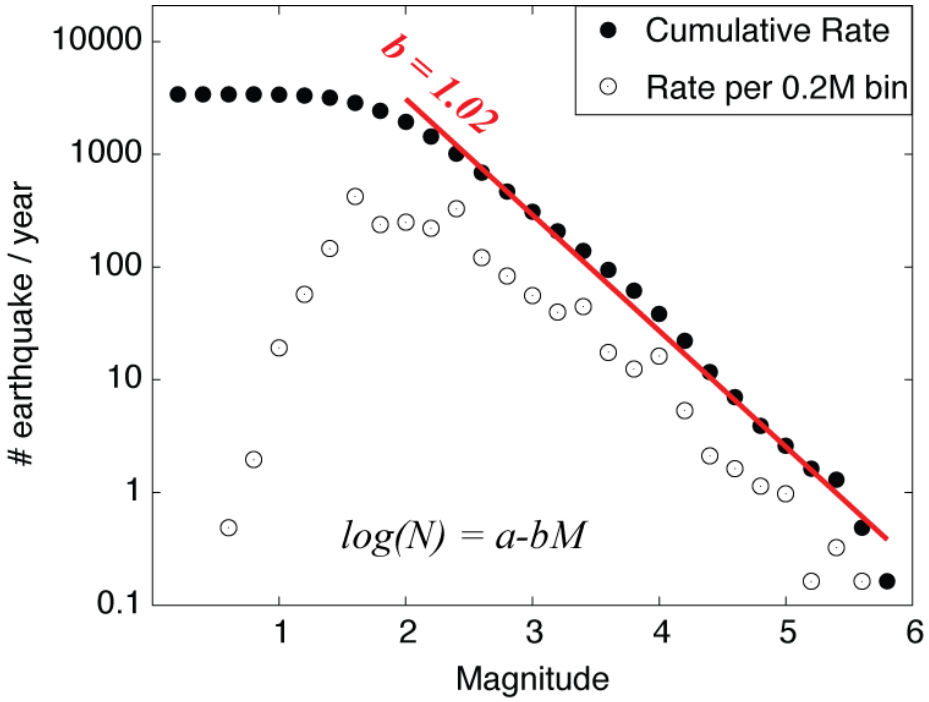


Frohlich et al. (1995), using global and temporal deployment suggest a large b-value, meaning seismic moment release dominated by small earthquakes.

b-value = 1.6 – 2.0
Frohlich and Nakamura (2009)

Temporal Behavior – b-value



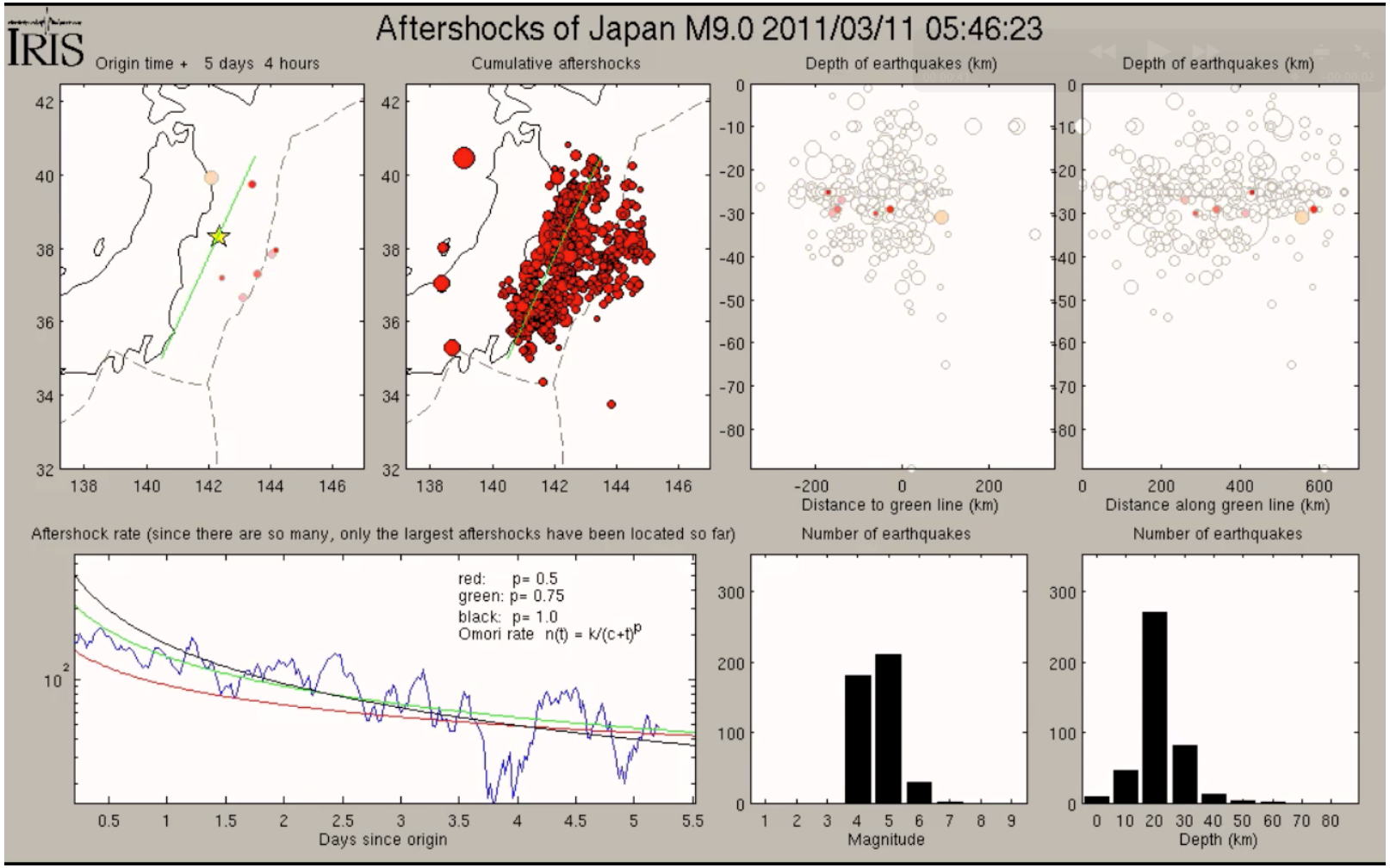


b-value = 1.6

Frohlich and Nakamura (2009)

Local network suggests b-value similar to shallow earthquakes

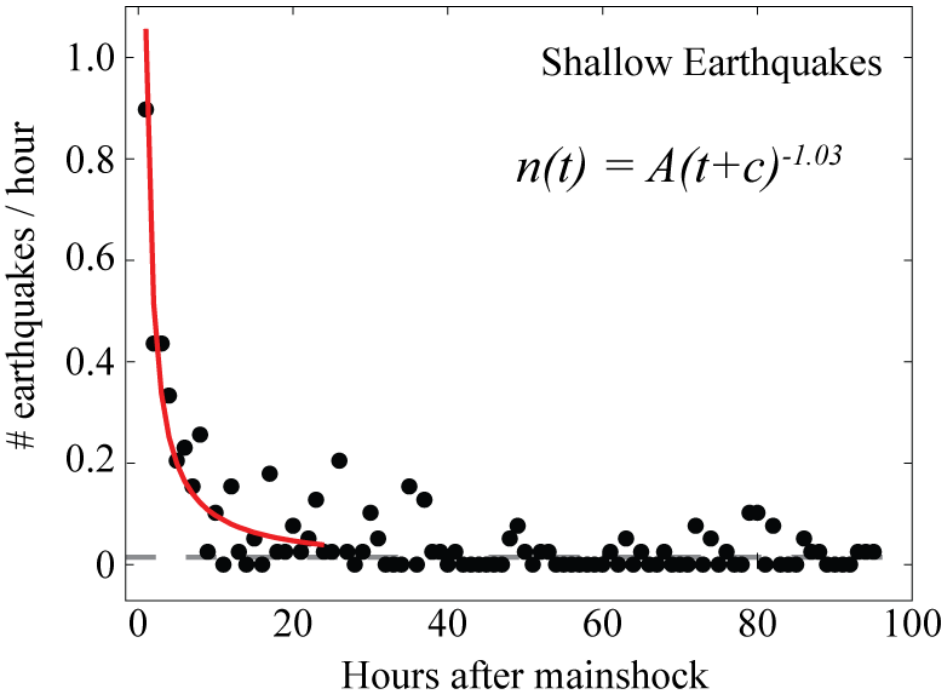
Temporal Behavior - Aftershocks



For shallow earthquakes, clear aftershock sequences develop
Deep earthquakes have few aftershocks (or none)

Temporal Behavior - Aftershocks

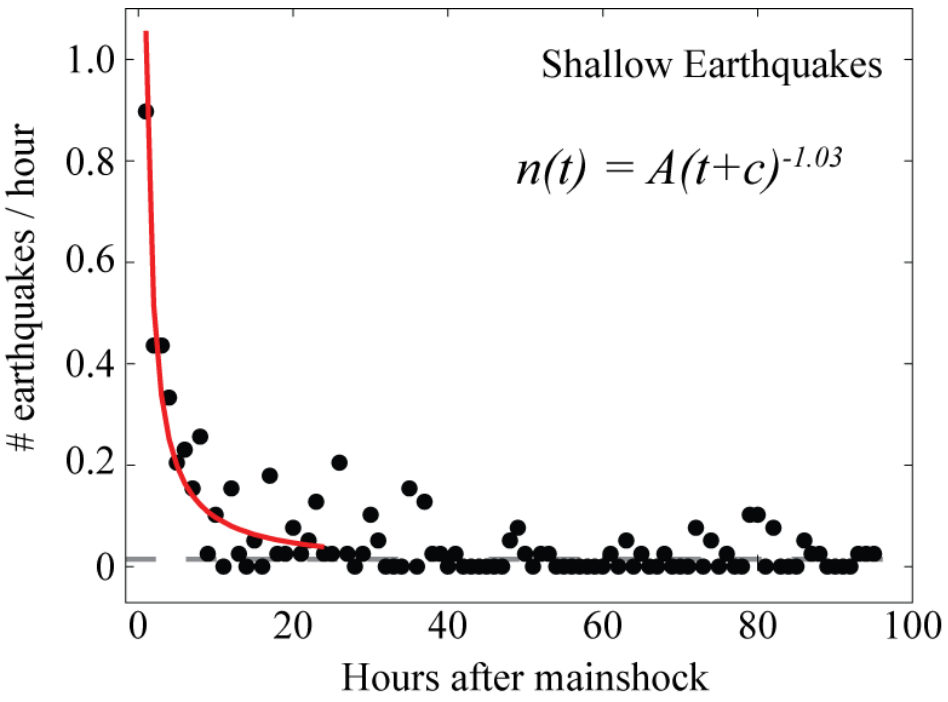
Shallow

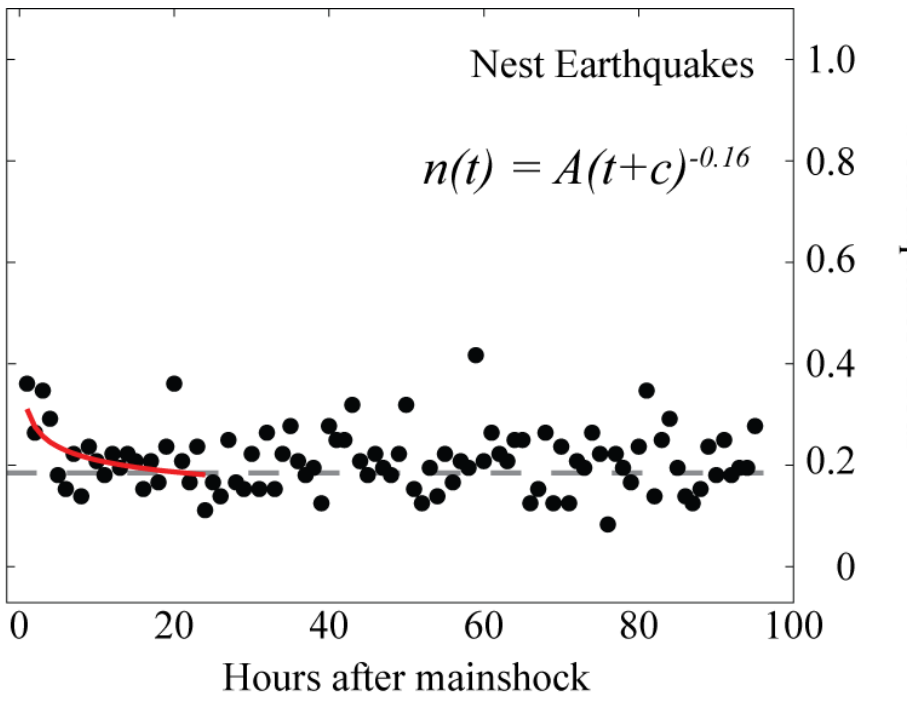


No evidence for aftershock sequence using local catalog

Temporal Behavior - Aftershocks

Nest EQs





No evidence for aftershock sequence using local catalog

Conclusiones

Resultados preliminares sugieren:

Nido de Bucaramanga relacionado con subducción de placa Caribe

Nido de Bucaramanga muestra lineamientos en eventos relocalizados

Gran número de repeticiones y cambios de polarización.

Escalamiento de la fuento no auto-similar

Conclusiones

Resultados preliminares sugieren:

Nido de Bucaramanga relacionado con subducción de placa Caribe

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Gran número de repeticiones y cambios de polarización.

Escalamiento de la fuento no auto-similar

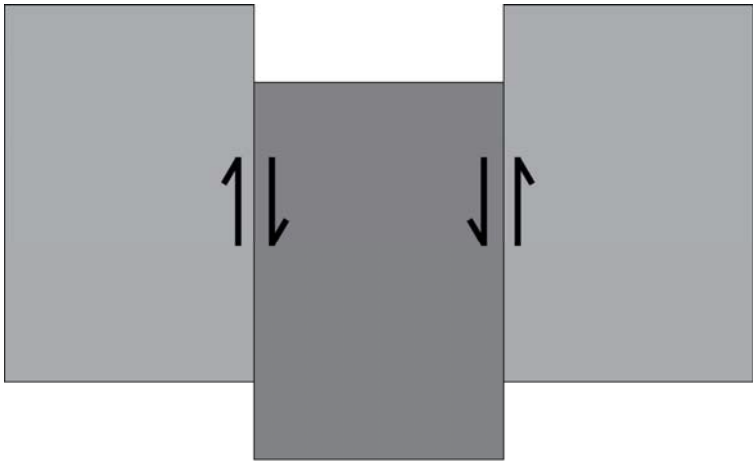
Cuál es el mecanismo para eventos con polaridad invertida?

Extruding block model

Tenemos que mejorar localización

asignar falla → eventos repetidos

inversión polaridad



Gracias!