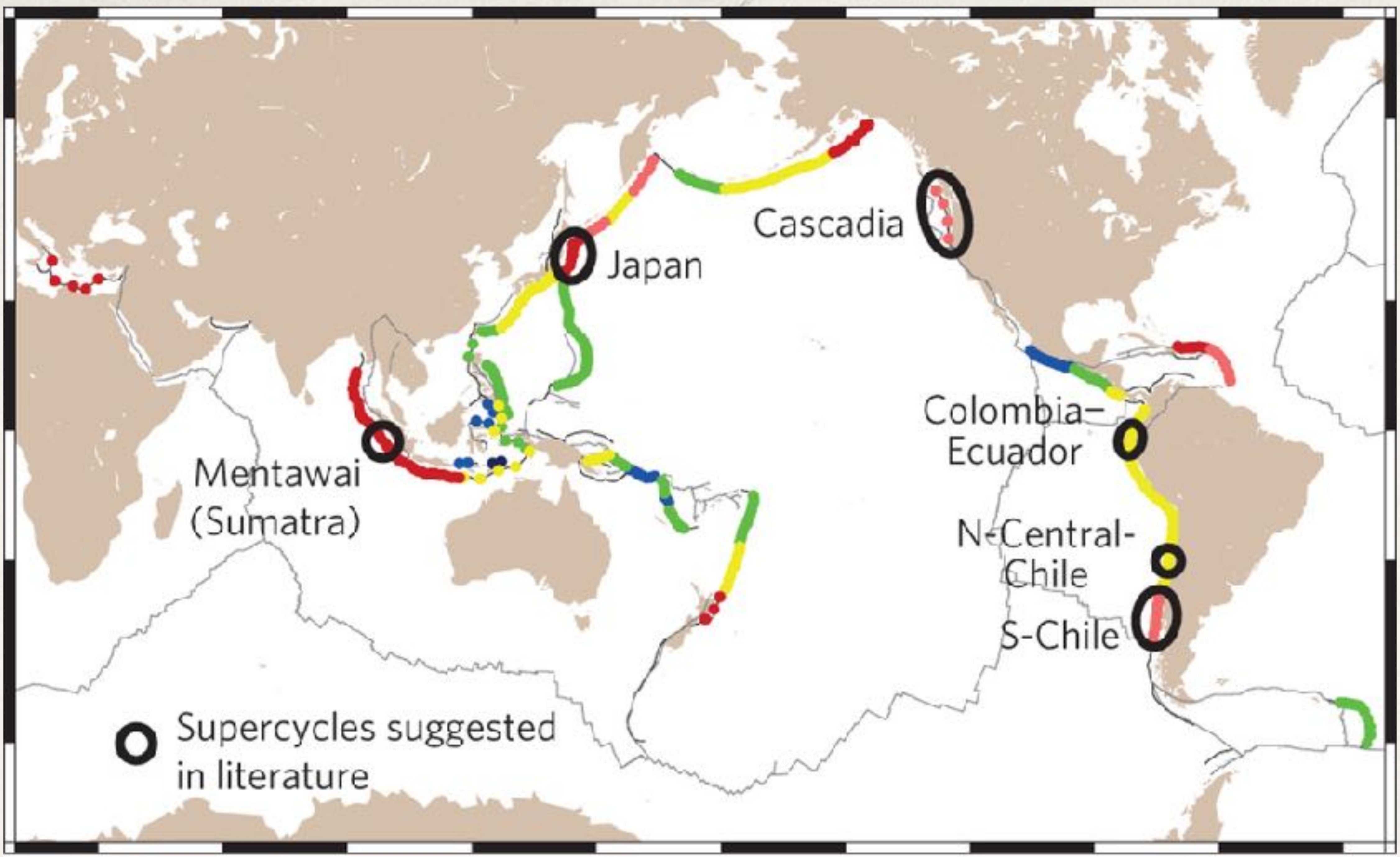


Earthquake Supercycles

GEOPH 677 Final Project Presentation - Rebekah Lee

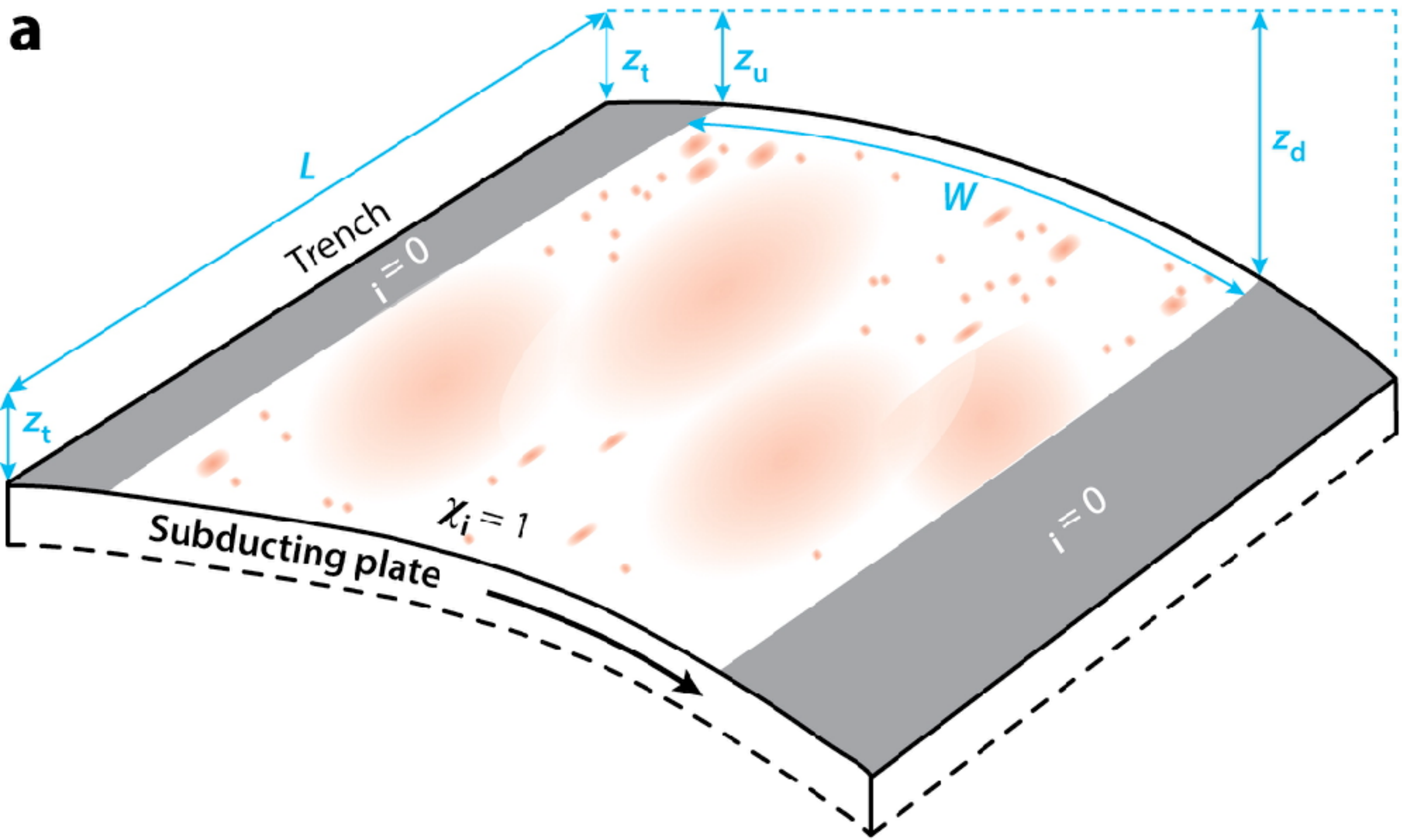
April 25, 2017

Outline

- Simple Earthquake Cycle (review)
- Prehistorical Data Sources
- What determines whether a subduction zone will produce supercycles?

Simple Earthquake (EQ) Cycle

- Large and great EQ release elastic strain accumulated during the previous interseismic period at highly locked asperities. (Noquet, 2016)
- This resets the slip and moment deficit
- Reduces local probability of another large EQ ***



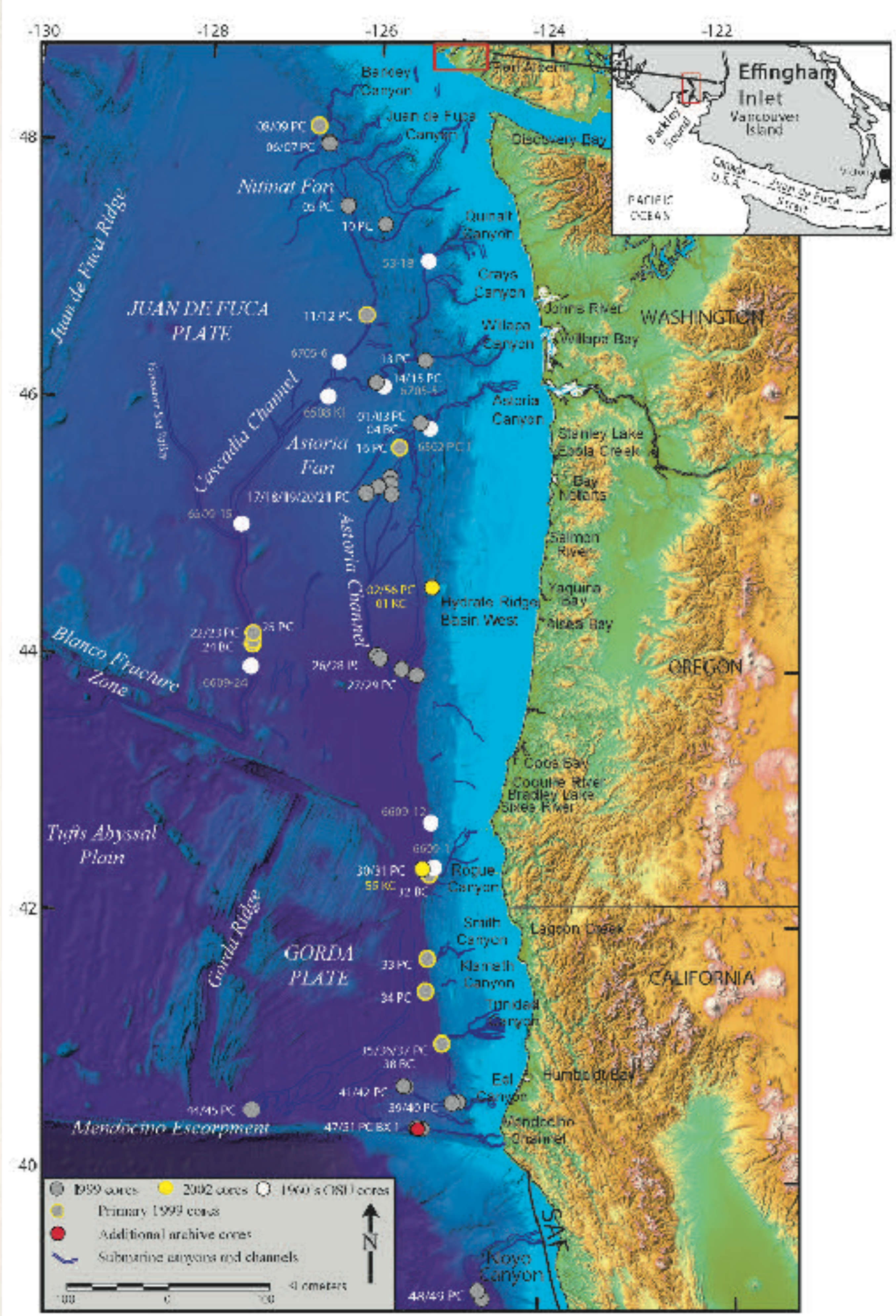
Avouac J-P. 2015.
Annu. Rev. Earth Planet. Sci. 43:233–71

Problem

- 2004 Mw 9.15 Sumatra Andaman and 2011 Mw 9.0 Tohoku, Japan occurred in regions where the maximum expected earthquakes were ~8.4
- This and other observations suggest that some earthquakes can borrow energy from previous seismic cycles —> Supercycles
- Not a long enough time history of data from historical and seismological records

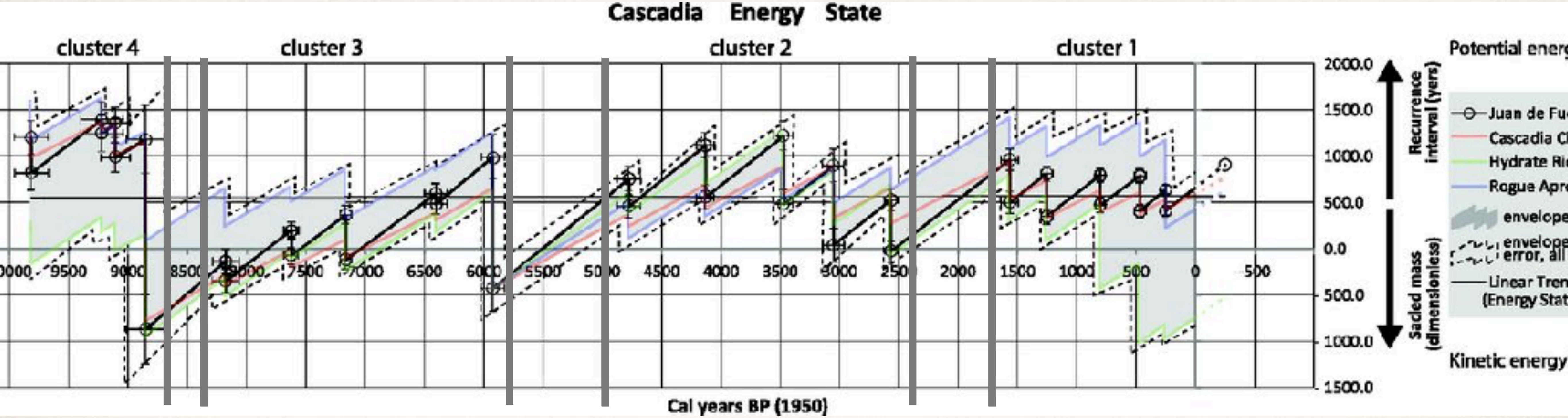
Data Sources

- Tsunami Record
  - eg. Sendai, Japan - 869 and two prior events reached 3 -4 km inland, similar to Tohoku
- Paleoseismic - displacement along Himalayan front
  - Modern EQs haven't ruptured the surface, but there is evidence of ruptures in the past with up to 26 m on surface
- Turbidites- deposits from massive slope failures where rivers have deposited large deltas
  - Cascadia (Goldfinger et al, 2013)


-130
-128
-126
-124
-122
48
46
44
42
40
Effingham
Inlet
Vancouver
Island
Barkley
Sound
PACIFIC
OCEAN
Barkley
Canyon
Juan de Fuca
Canyon
Discovery Bay
Nitinat Fan
Quinault
Canyon
Grays
Canyon
Johns River
WASHINGTON
Willapa
Canyon
Willapa Bay
Juan de Fuca Ridge
JUAN DE FUCA
PLATE
Cascadia Channel
Astoria
Fan
Astoria
Canyon
Stanley Lake
Ecola Creek
Salmon
River
Yaquina
Bay
Alsea Bay
Hydrate Ridge
Basin West
Astoria Channel
Blanco Fracture
Zone
OREGON
Coos Bay
Coquille River
Bradley Lake
Sixes River
Tufts Abyssal
Plain
Rogue
Canyon
Gorda Ridge
Smith
Canyon
Lagoon Creek
GORDA
PLATE
Klamath
Canyon
CALIFORNIA
Trinidad
Canyon
Eel
Canyon
Humboldt Bay
Mendocino
Channel
Mendocino Escarpment
SAF
Noyo
Canyon
08/09 PC
06/07 PC
11/12 PC
6705-6
6509 KI
01/03 PC
15 PC
17/18/19/20/21 PC
02/56 PC
01 KC
22/23 PC
26/28 PC
27/29 PC
30/31 PC
55 KC
33 PC
34 PC
41/42 PC
39/40 PC
47/31 PC BX 1
48/49 PC
1999 cores
2002 cores
1960's OSU cores
Primary 1999 cores
Additional archive cores
Submarine canyons and channels
N
Kilometers
100
0
100

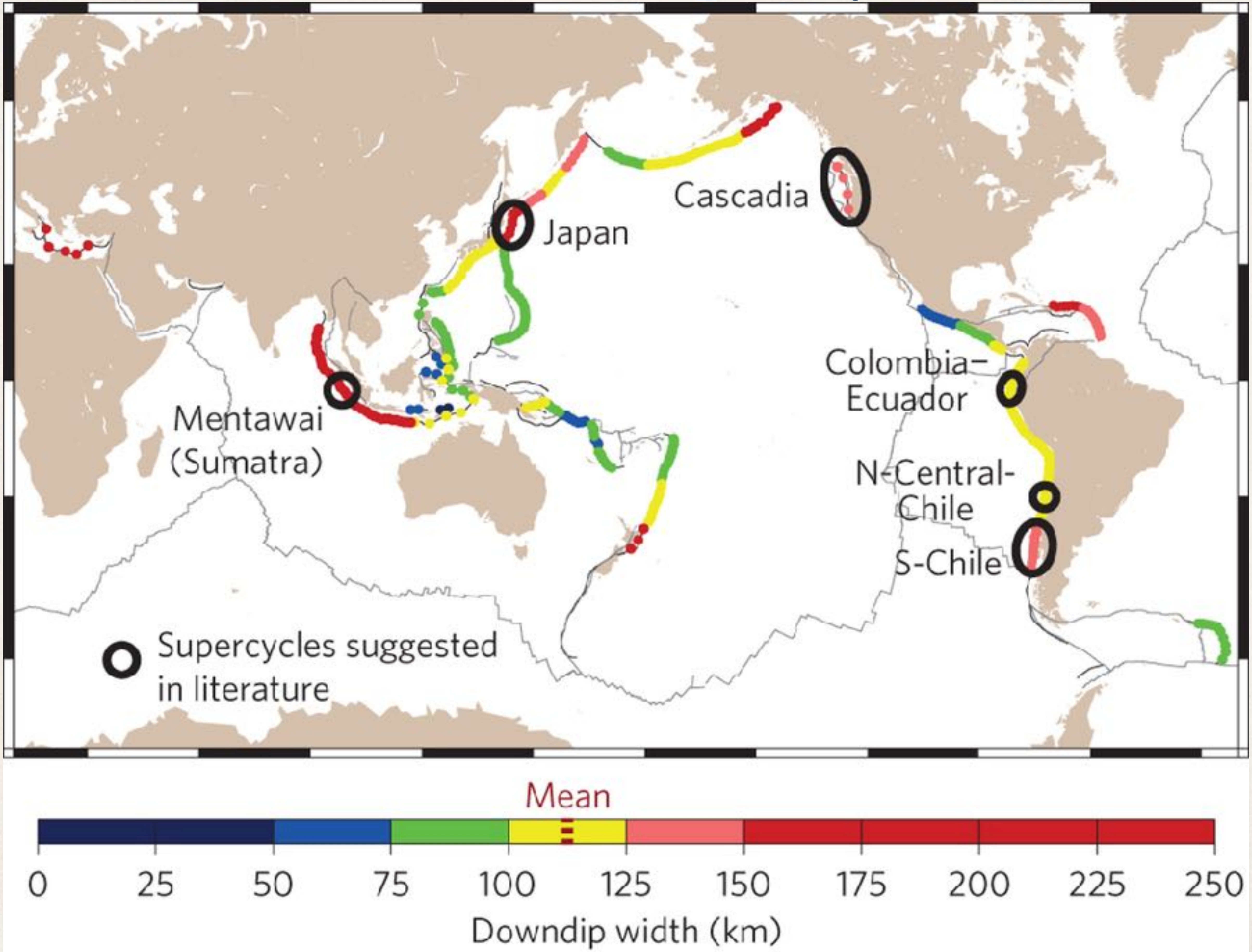
Cascadia Turbidites (Goldfinger, et al, 2013)

- Correlated mass and thickness for same event at different sites
- Modeled coseismic energy release as proportional to mass of turbidites triggered in seismic shaking
- Assumptions:
  - Plate Convergence between EQs increases elastic strain energy in proportion to intervening time
  - zero net energy gain over 10 ky time series



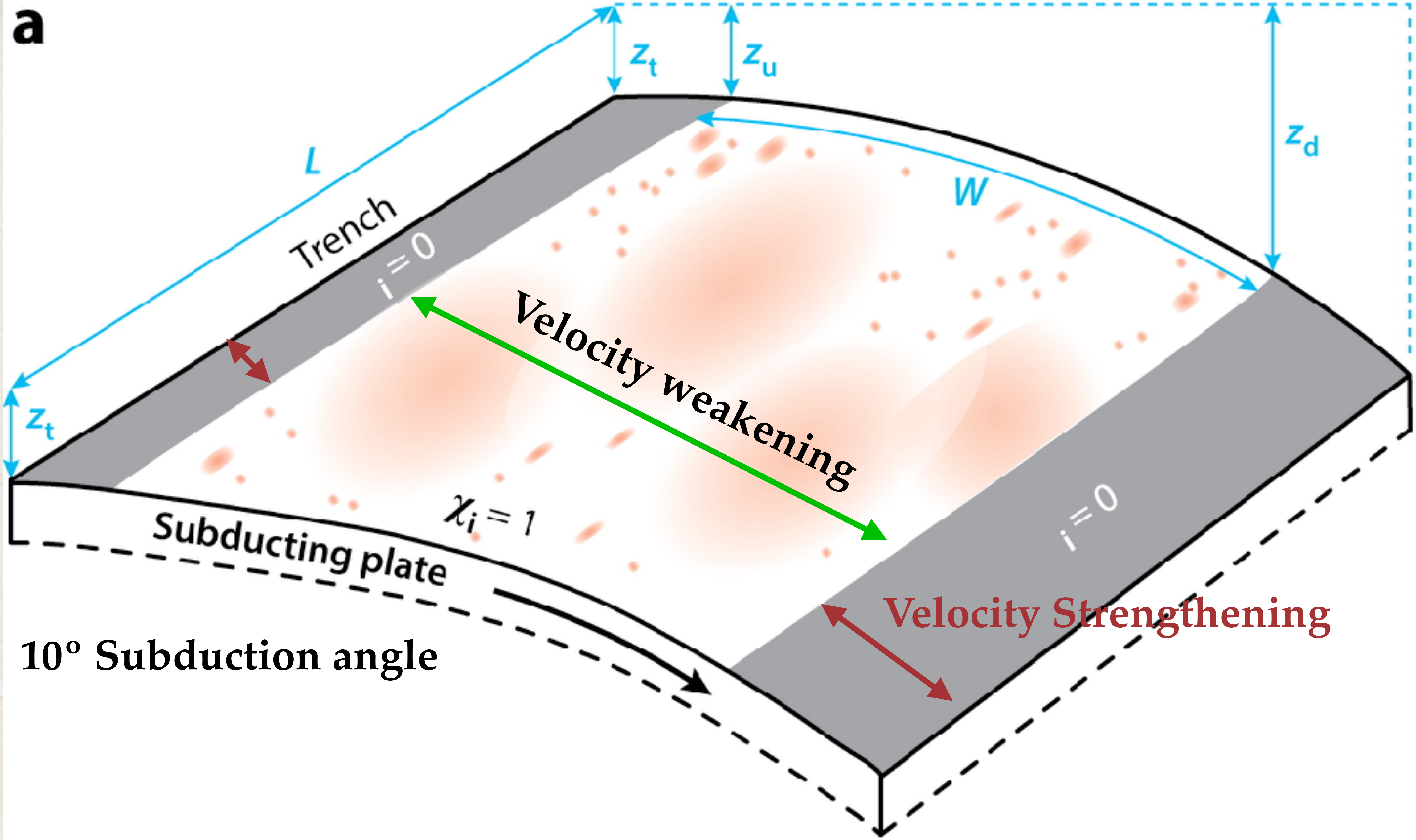
- High Energy States lead to massive event
- Low energy states either result in long gap (cluster 2) or small EQ with net energy gain (cluster 3)

What determines Supercycles?



What Determines Supercycles?

- Herrendorfer et al, (2015) observed that supercycles suggested to occur in regions where the estimated downdip width of the seismogenic zone is larger than average (>150 km).
- Investigate the link between supercycles and downdip width with 2D numerical modeling.



Avouac J-P. 2015.
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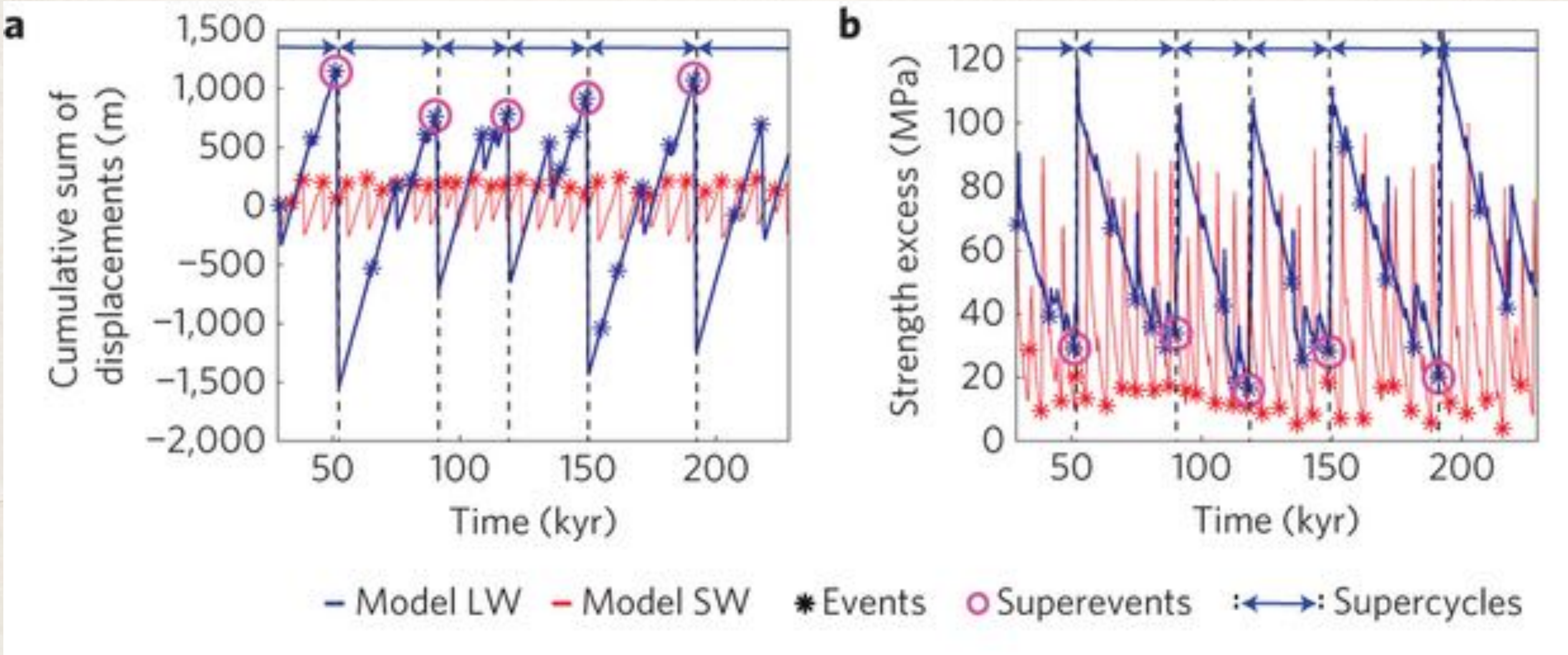
- Visco - elastic wedge
- Conservative finite differences
  - Conservation of mass
  - Conservation of Momentum
  - Assumption of incompressibility (zero divergence)
  - Constitutive relationship connects deviatoric stresses and strain rates

Results of two end models

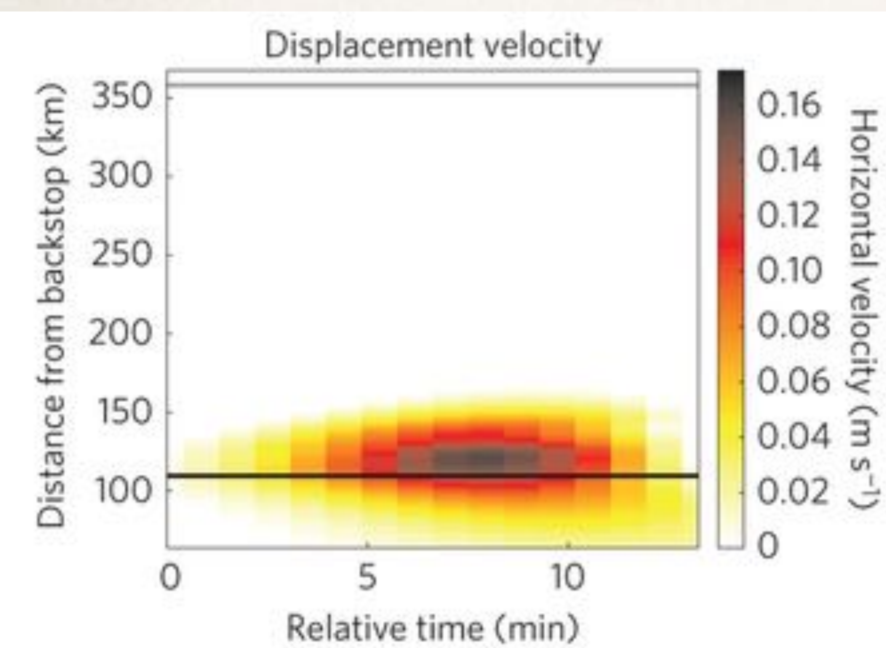
Long width = 248 Km 　　　 Short width = 102 Km



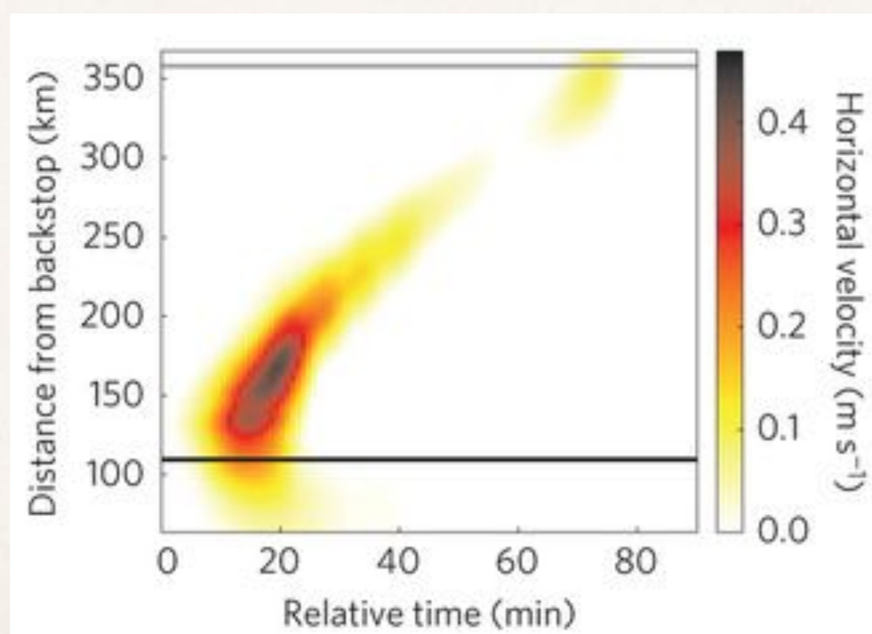
- Long width subduction zones characterized by supercycles that culminate in a Superevent.
- In Supercycles, smaller events only relieve the strain partially but overall excess strength continues to decrease until a low level.

Large Width Characteristics

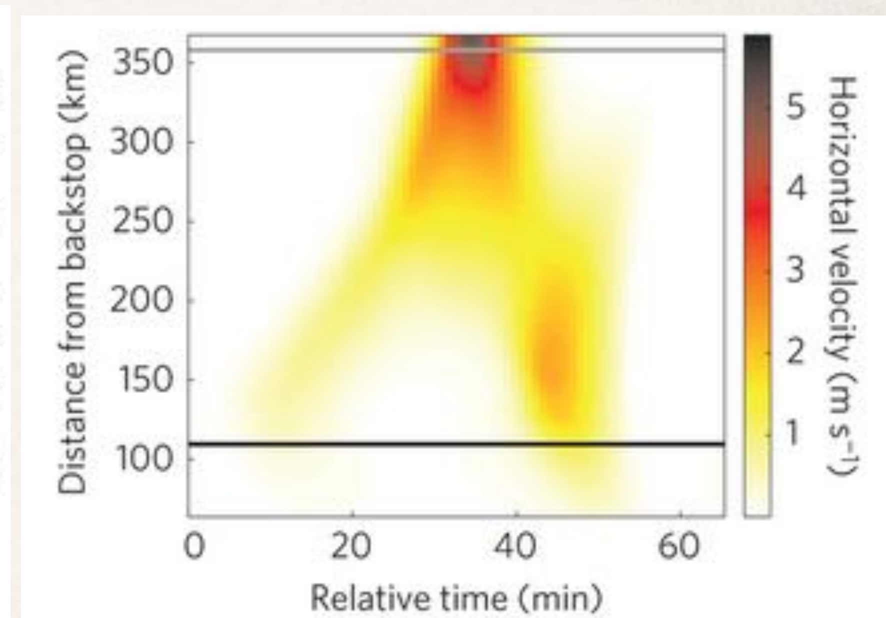
- Characterize events into 3 types:
  1. Subcritical : fail to propagate far from nucleation region
  2. Pulse-like : propagate further but have short local duration
  3. Crack- like : most of the rupture area continues to slip through duration of rupture



Subcritical



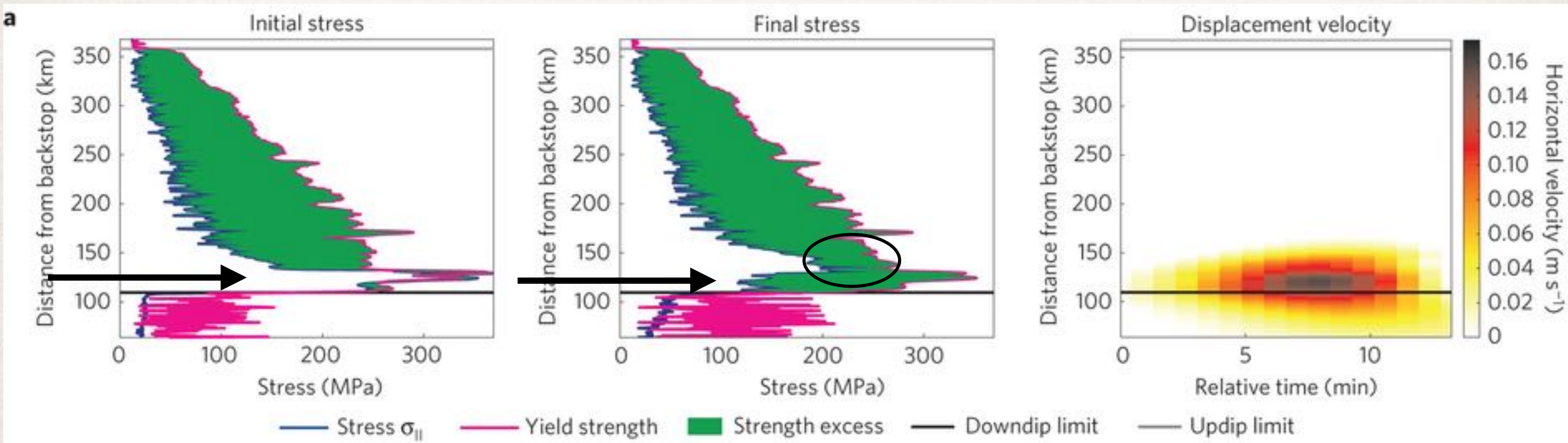
Pulse-like



Crack-like

Large Width Characteristics

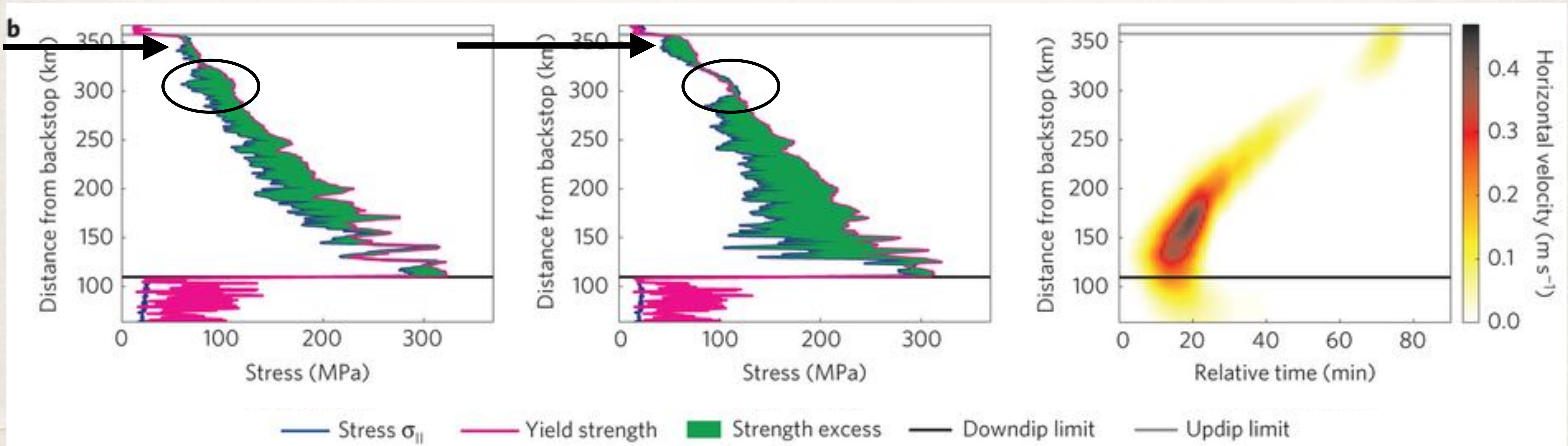
Subcritical Rupture



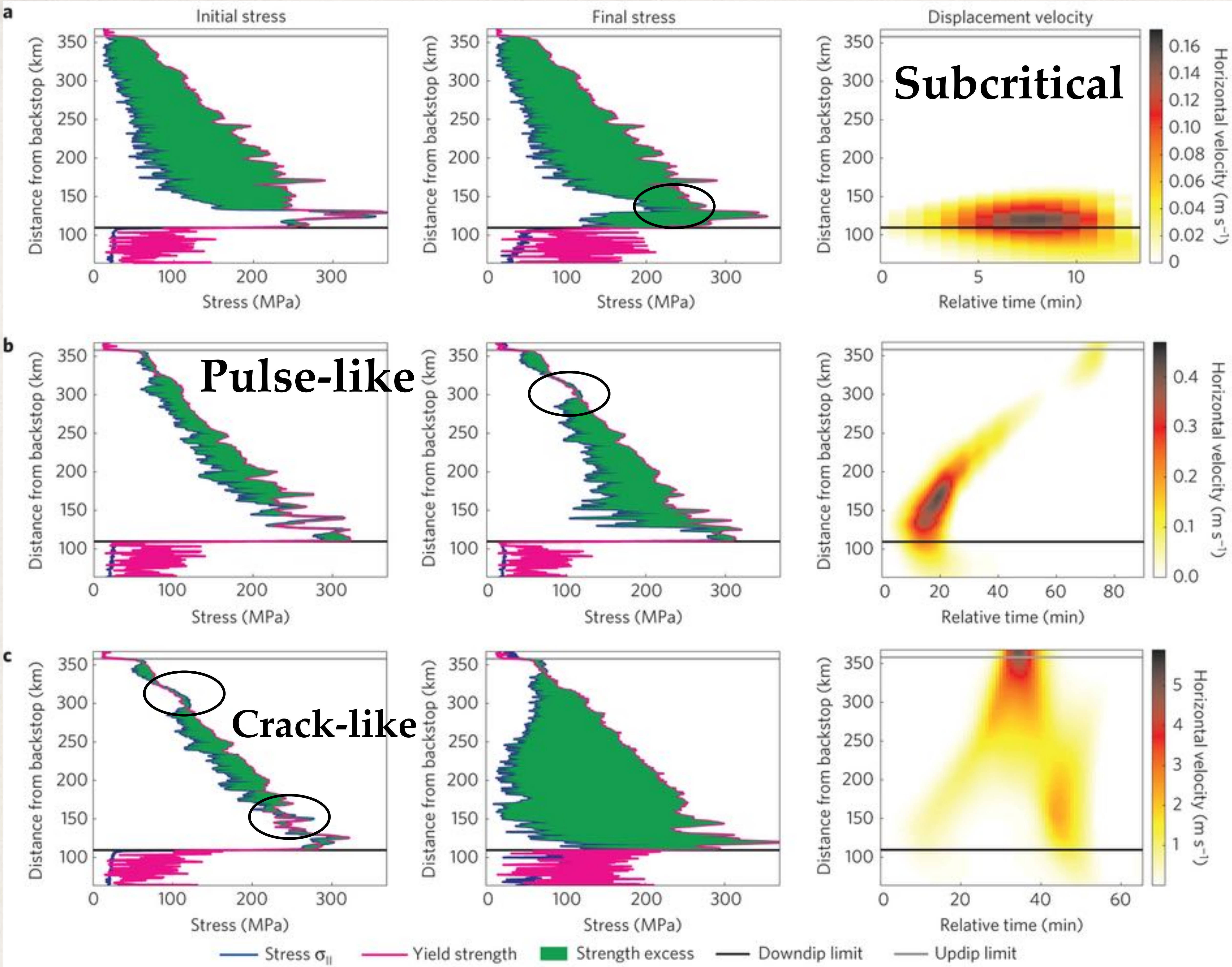
- Subcritical events nucleate close to the downdip limit of the seismogenic zone and transfer stress close to the stopping location

Large Width Characteristics

Pulse-like Rupture



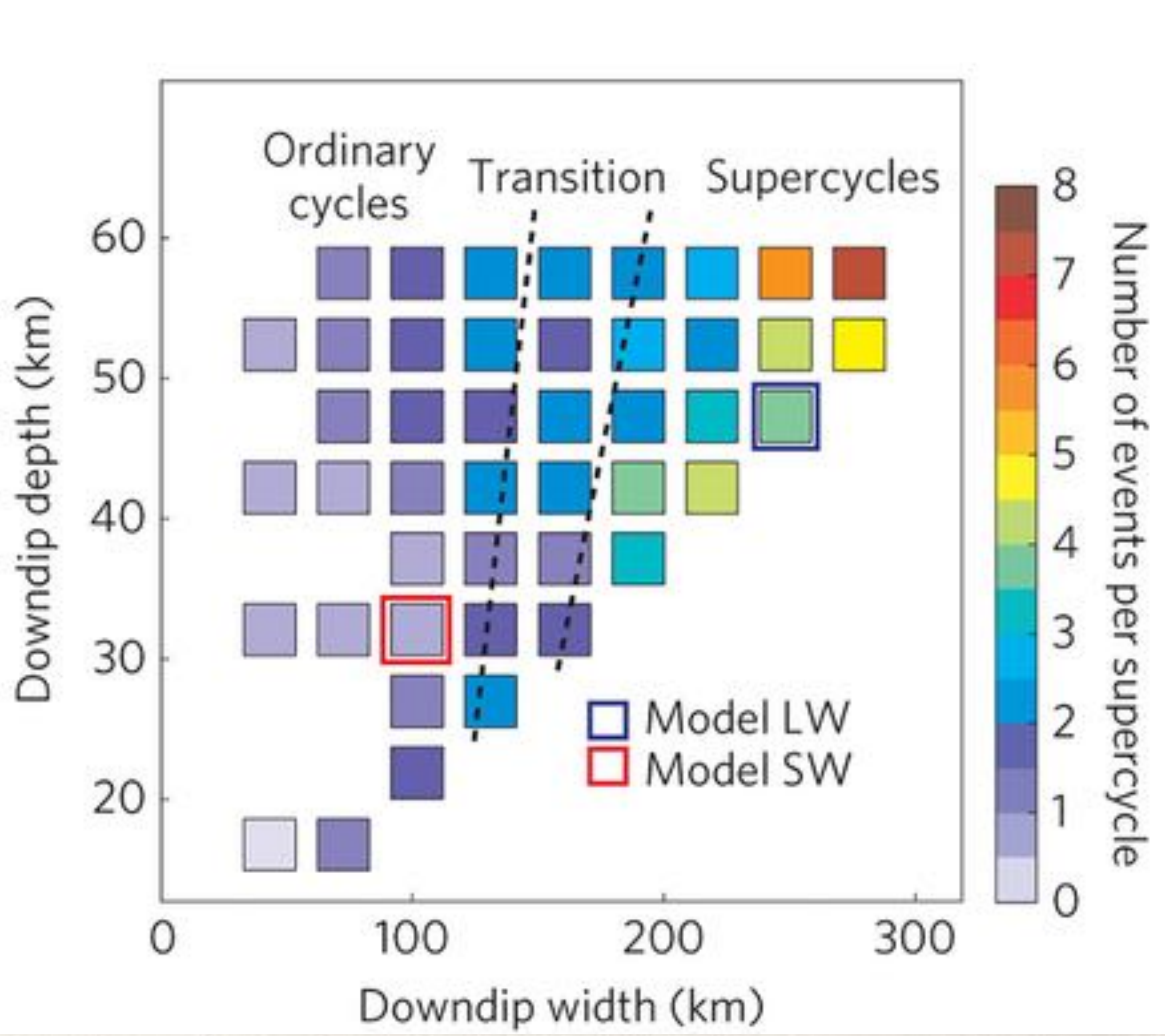
- Pulse-like ruptures nucleate from the downdip limit for short duration and transfer stress updip
- Combined, subcritical and pulse-like ruptures transfer stress towards the center of the seismogenic zone



a
Initial stress
Final stress
Displacement velocity
Subcritical
Horizontal velocity (m s⁻¹)
Distance from backstop (km)
Stress (MPa)
Relative time (min)
b
Pulse-like
c
Crack-like
Stress σ_II
Yield strength
Strength excess
Downdip limit
Updip limit

Downdip Width and Supercycles

- Transition from ordinary cycles to supercycles between 120 and 150 km
- Ordinary cycles dominated by crack-like ruptures in a narrow seismogenic zone
- Supercycles occur in wide seismogenic zone and a sequence of subcritical and pulse-like ruptures prepare the occurrence of crack-like ruptures



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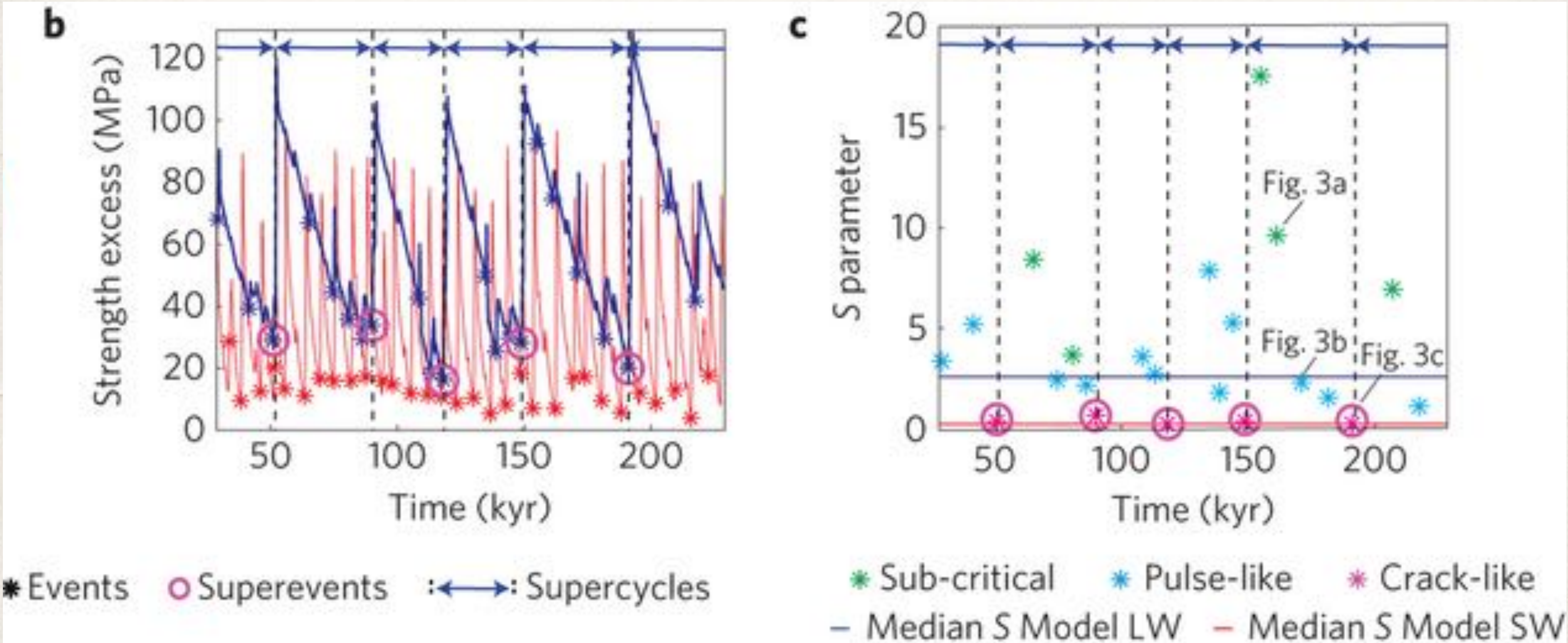
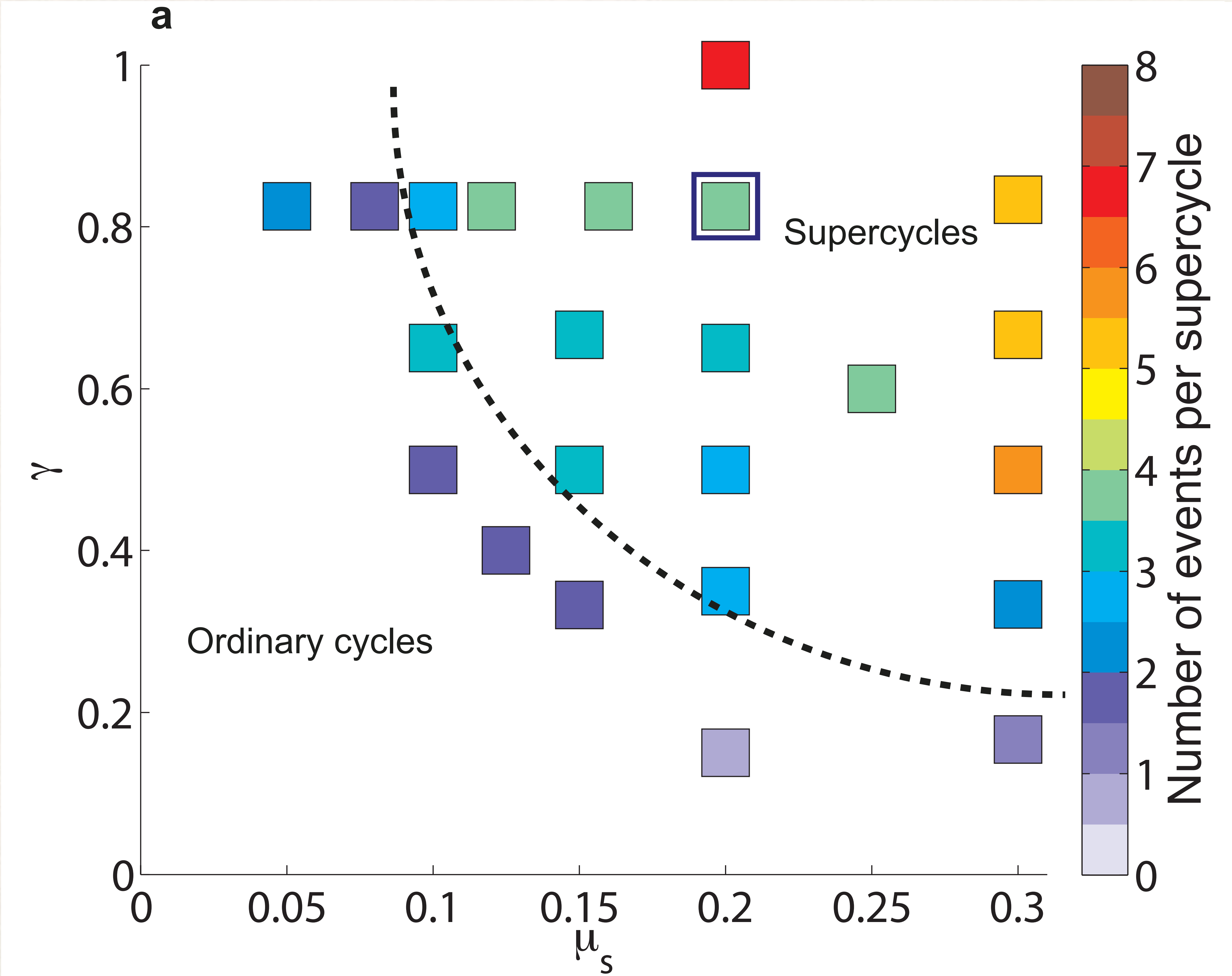
S Parameter

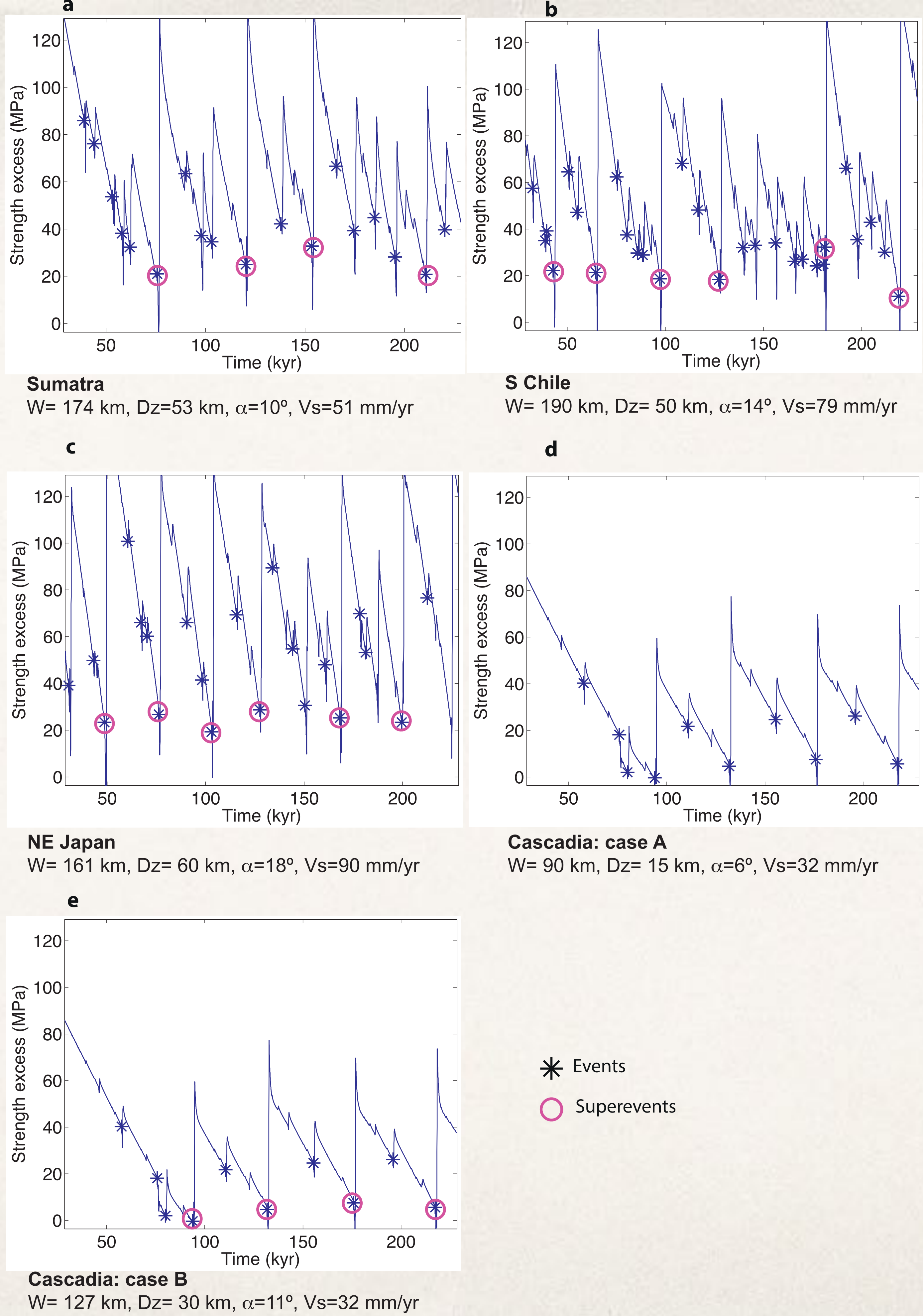


- S parameter: initial stress excess/stress drop

Influence of Relative friction drop and static Friction



Supercycle case studies

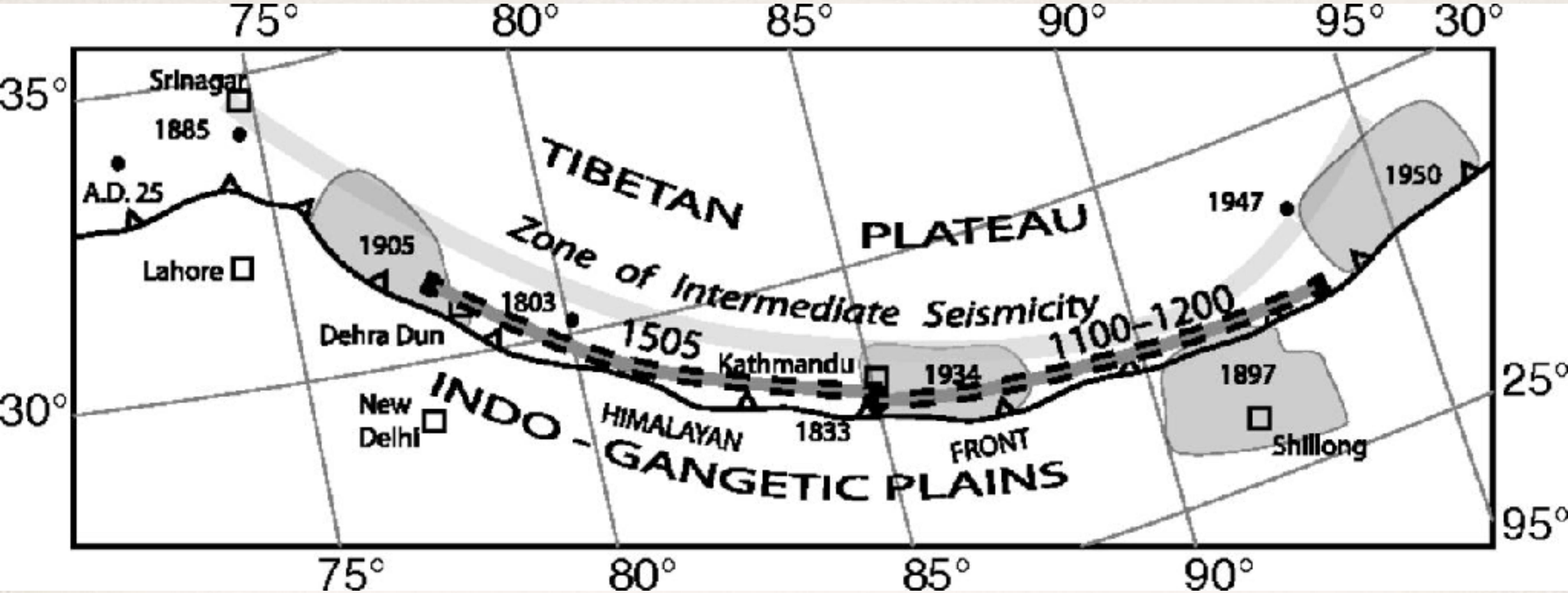


Material Parameters

Parameter	Symbol	Unit	Wedge	Seis. zone	Aseis. zone	Rigid body	Sticky air
Min. viscosity	η_{min}	Pa·s	$5{\cdot}10^{21*}$	$1.7{\cdot}10^{14*}$	$1.7{\cdot}10^{14*}$	$1.7{\cdot}10^{22*}$	$3.3{\cdot}10^{13*}$
Max. viscosity	η_{max}	Pa·s	$5{\cdot}10^{21*}$	$5{\cdot}10^{21*}$	$5{\cdot}10^{21*}$	$1.7{\cdot}10^{22*}$	$3.3{\cdot}10^{13*}$
Shear modulus	G	GPa	9.2^*	9.2^*	9.2^*	$2.95{\cdot}10^{9*}$	9.2^*
Density	ρ	kg·m^{-3}	2900	2900	2900	2900	2.9
Static friction	μ_s	-	-	0.2	0.002	-	-
Dynamic friction	μ_d	-	-	0.035	0.157	-	-
Char. velocity	V_c	m·s^{-1}	-	0.16	0.031	-	-
Cohesion	C	MPa	-	11.1	11.1	-	-

Global downdip width estimates

Subduction zone segment	ref. 5 W (km)	ref. 6-7 W (km)	Average W (km)
Andaman	243	159	201
Sumatra	174	159	166.5
Java	188	173	180.5
Philippines	81	79	80
S-Ryukyu	73	116	94.5
N-Ryukyu	122	116	119
Nankai	132*	116	124
Marianas	93	85	89
IzuBonin	104	85	94.5
Japan	161	162	161.5
S-Kuril	102	148	125
N-Kuril	95	137	116
Kamchatka	110	150	130
Ws-Aleutians	72	108	90
C-Aleutians	75	139	107
E-Aleutians	72	130	101
W-Alaska	91	151	121
E-Alaska	180	151	165.5
Mexico	74	73	73.5
Costa Rica	103	83	93
Cocos	138	83	110.5
Colombia	101	128	114.5
N-Peru	118	128	123
S-Peru	79	133	106
N-Chile	105	143.5	124.25
S-Chile	190*	105	147.5
Antilles	168	120	144
Sandwich	131	68	99.5
S-Kermadec	117	119	118
N-Kermadec	112	119	115.5
S-Tonga	80	101	90.5
N-Tonga	98	101	99.5
S-New Hebrides	83	70	76.5
D'Entrecasteaux	72	70	71
N-NewHebrides	100	70	85
Salomon Islands	87	62	74.5
Bougainville	97	62	79.5
New Britain	121	101	111
Hikurangi	178		178
Cotobato	52		52
Flores	57		57
W-Aegean	179		179
Cascadia	127*		127
Timor	110		110
Seram	76		76
Halmahera	79		79
Sangihe	104		104
Sulawesi	62		62
Manila	98		98
Mean Value	**112**	**113**	**111**



75°
80°
85°
90°
95°
30°
35°
30°
25°
95°
Srinagar
1885
A.D. 25
Lahore
1905
TIBETAN
PLATEAU
Zone of Intermediate Seismicity
1803
Dehra Dun
1505
1100–1200
1947
1950
Kathmandu
1934
1897
New Delhi
INDO - GANGETIC PLAINS
HIMALAYAN
1833
FRONT
Shillong