Aspectos sismológico de los sismos de septiembre de 2017 (Mw8.2, 7.1)

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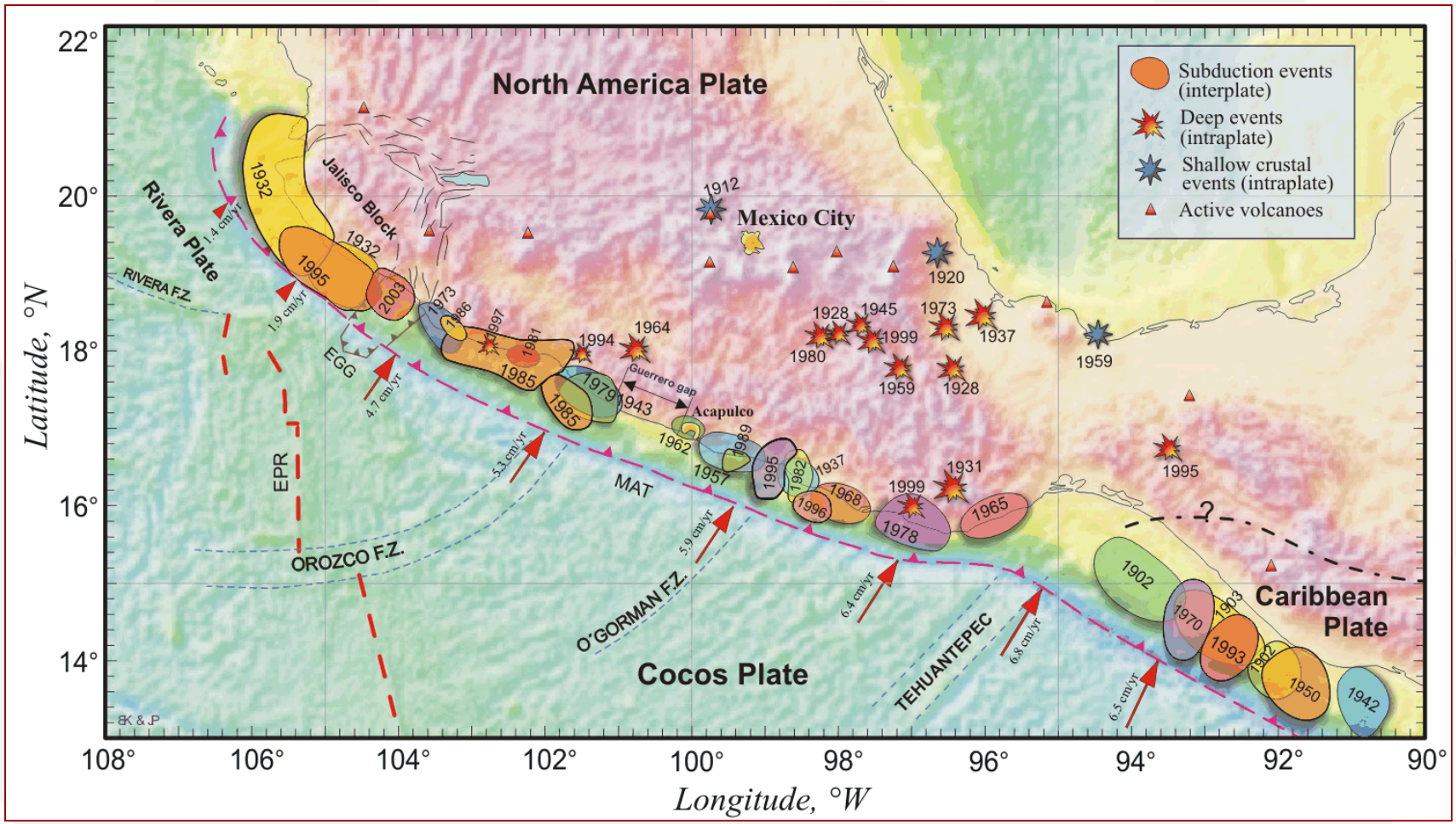

North America Plate
Cocos Plate
Caribbean Plate
Rivera Plate
Jalisco Block
Mexico City
Acapulco
Guerrero gap
RIVERA F.Z.
EGG
EPR
OROZCO F.Z.
MAT
O'GORMAN F.Z.
TEHUANTEPEC
1.4 cm/yr
1.9 cm/yr
4.7 cm/yr
5.3 cm/yr
5.9 cm/yr
6.4 cm/yr
6.8 cm/yr
6.5 cm/yr
Subduction events (interplate)
Deep events (intraplate)
Shallow crustal events (intraplate)
Active volcanoes
Latitude, °N
Longitude, °W
22°
20°
18°
16°
14°
108°
106°
104°
102°
100°
98°
96°
94°
92°
90°

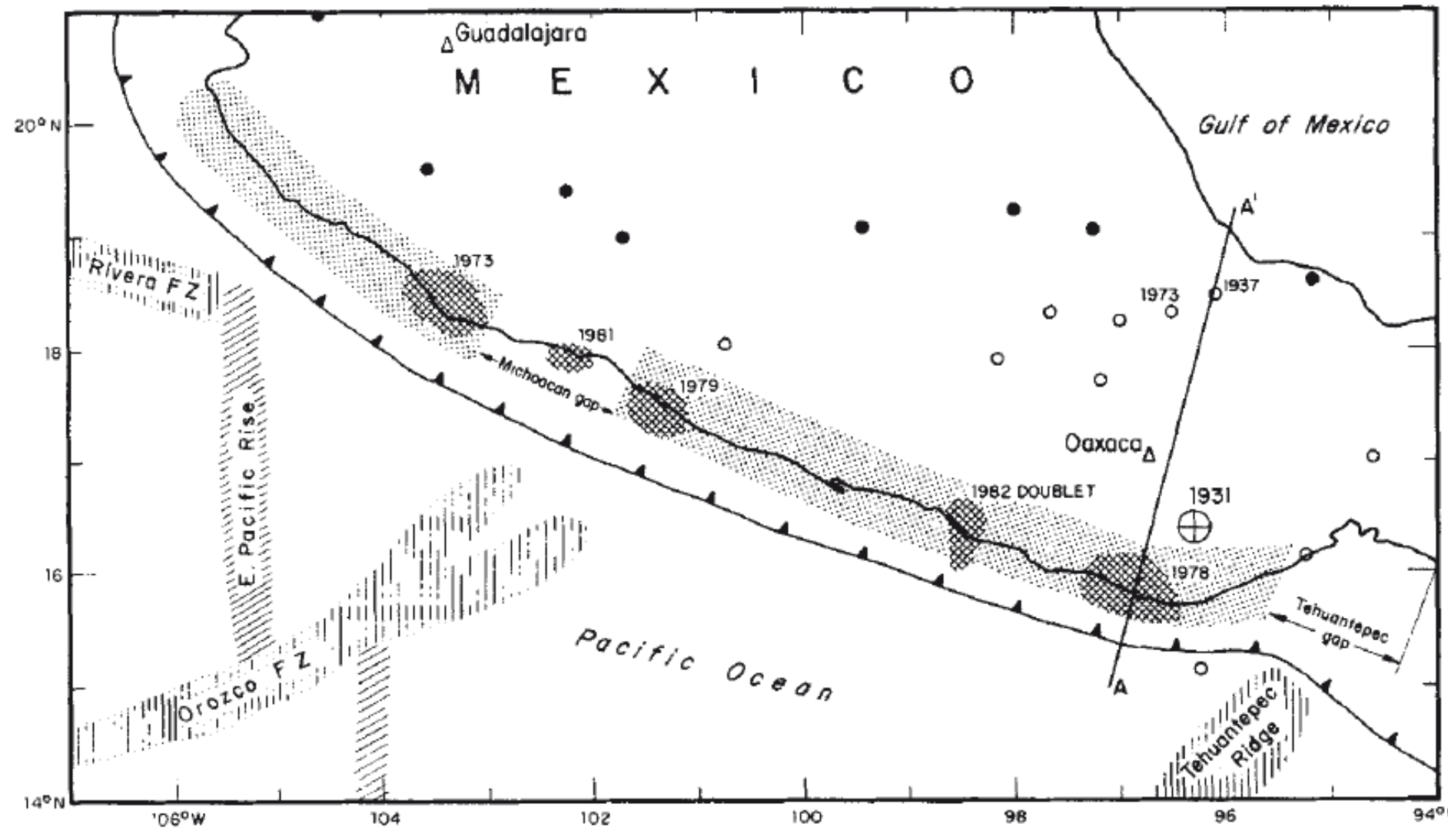
Two extraordinary intraslab earthquakes in Sep 2017 in Mexico

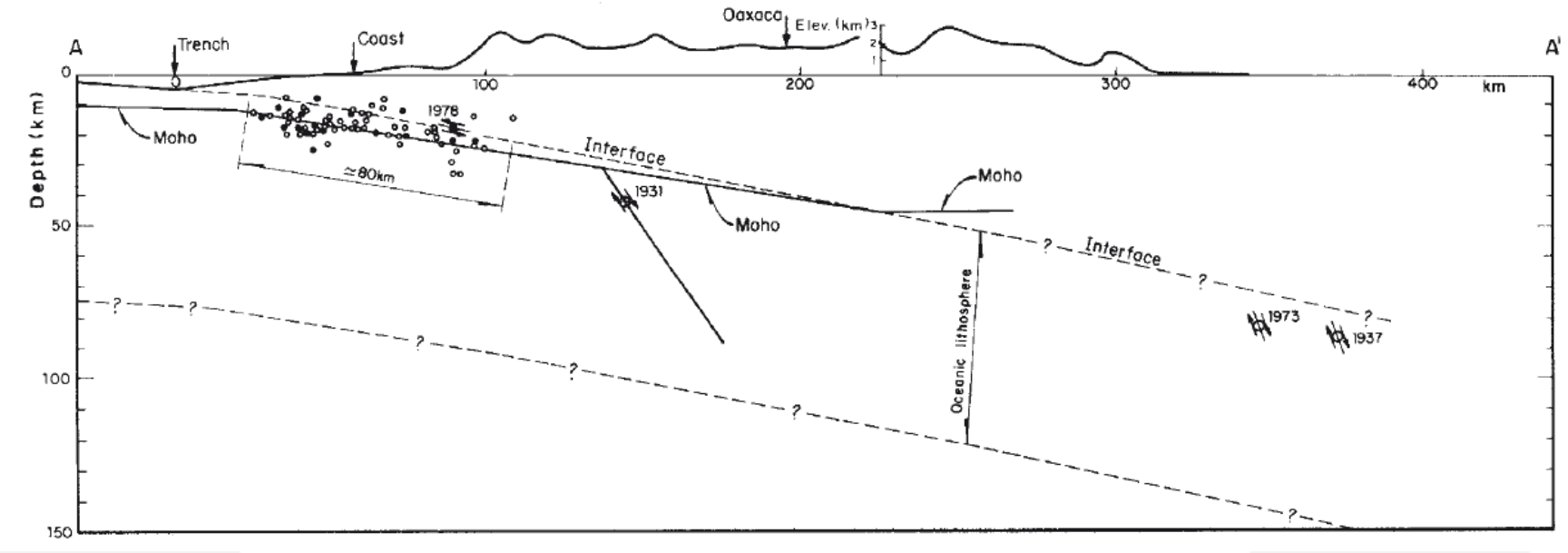
- 8 Sep 2017 (Mw8.2), offshore Tehuantepec, ~700 km from Mexico City (largest recorded earthquake in Mexico ever)

- 19 Sep 2017 (Mw7.1), Morelos-Puebla, 133 km from Mexico City (most damaging intraslab earthquake ever)

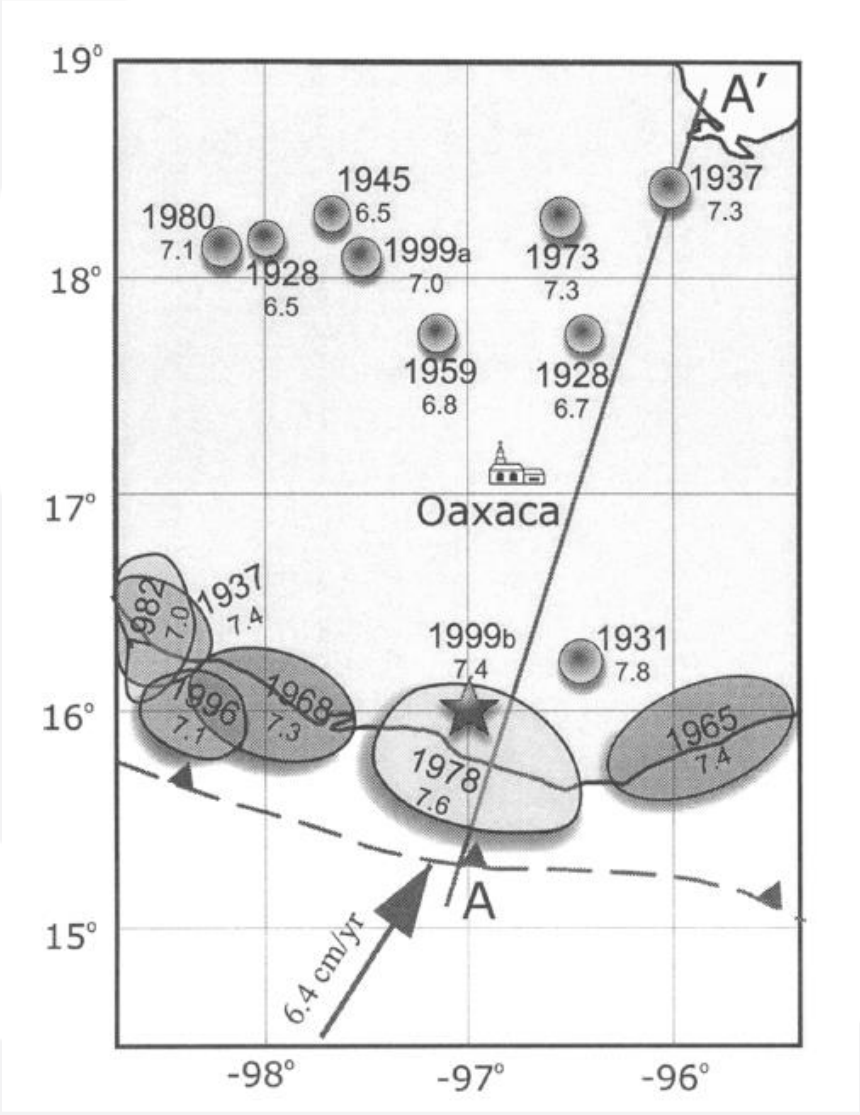
- Historically intraslab earthquakes have caused damage to cities in Mexican altiplano (e.g., 1858, 1931, 1973, 1980).

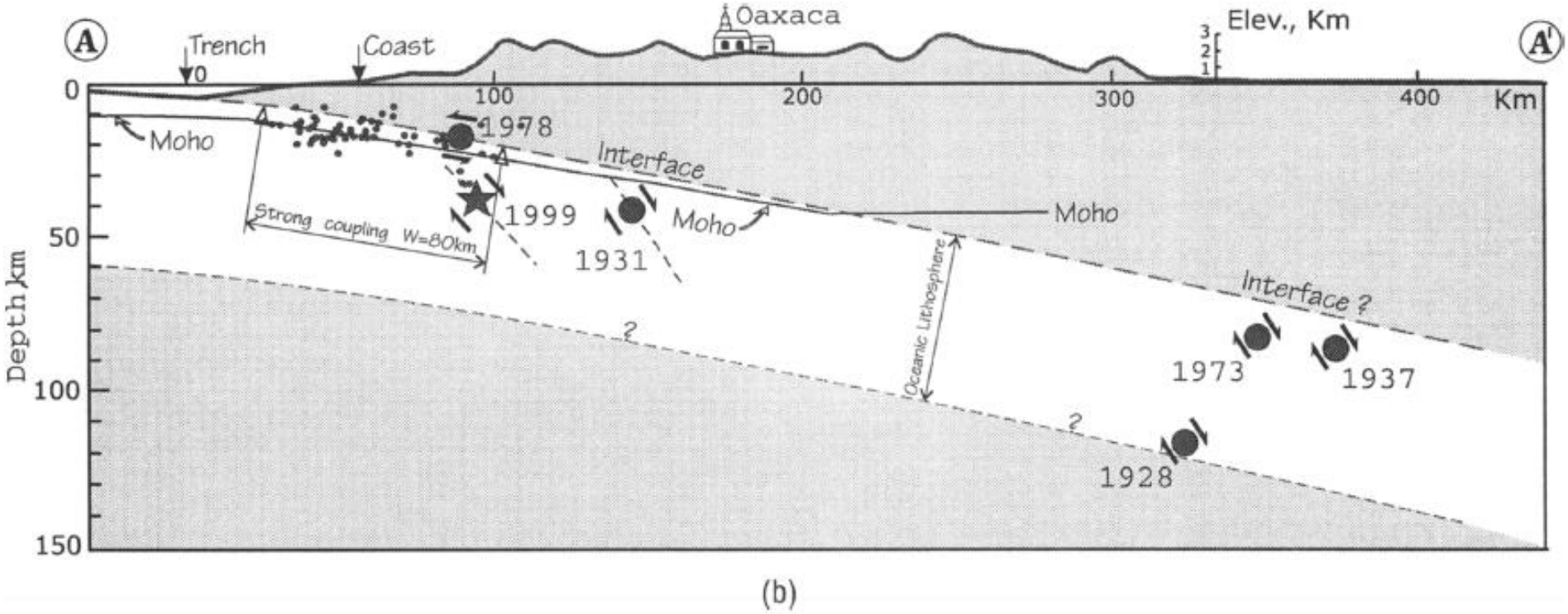
Sismos destructor en Oaxaca:
1931, M~8.0. 14 de enero


Guadalajara
M E X I C O
Gulf of Mexico
20° N
18
16
14°N
106°W
104
102
100
98
96
94°W
Rivera FZ
E. Pacific Rise
Orozco FZ
1973
1981
Michoacan gap
1979
1973
1937
A'
A
Oaxaca
1982 DOUBLET
1931
1978
Tehuantepec gap
Pacific Ocean
Tehuantepec Ridge



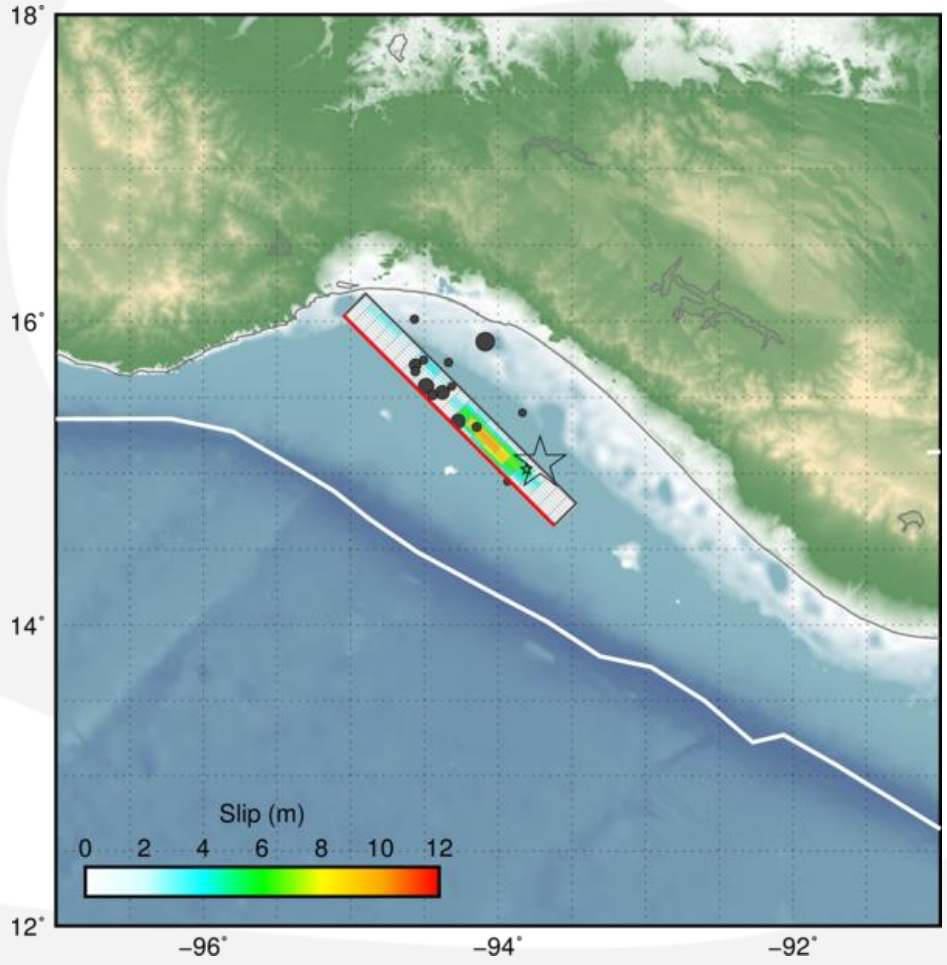
Singh et al., 1985

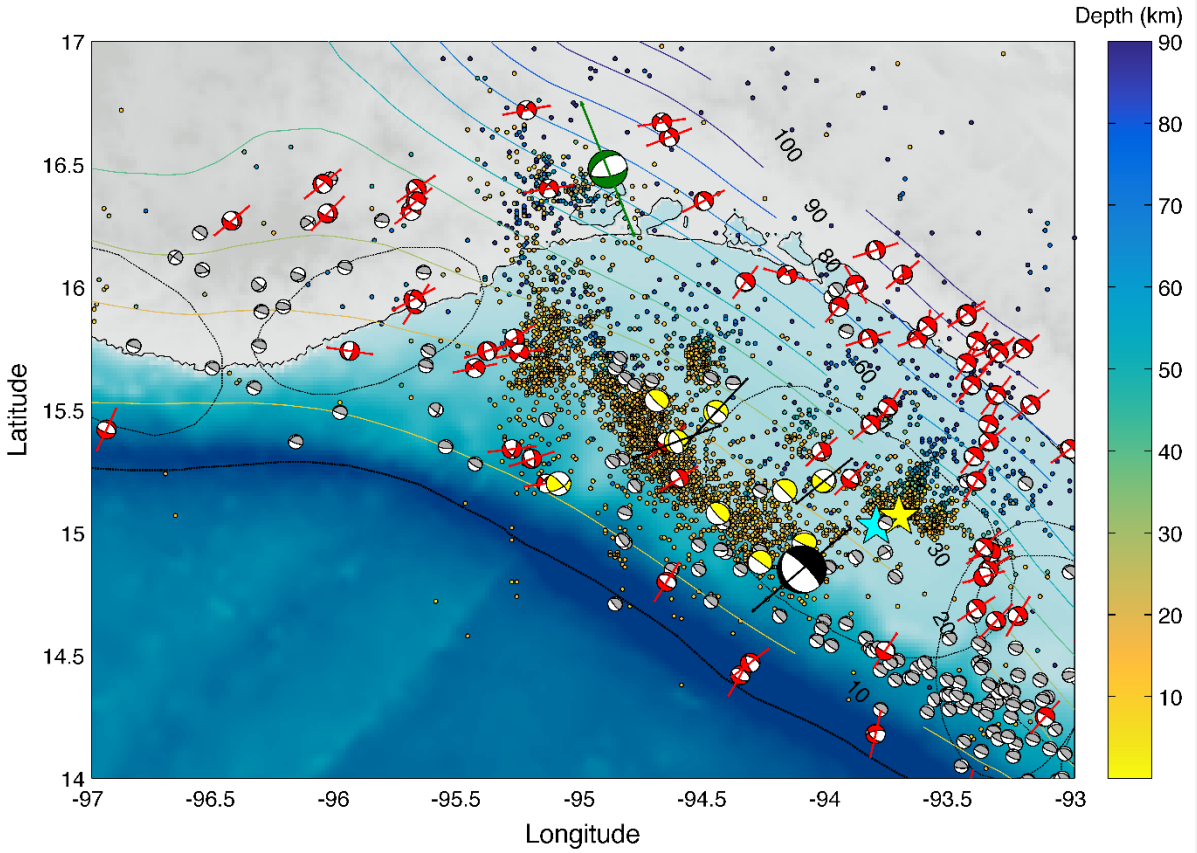

19°
18°
17°
16°
15°
-98°
-97°
-96°
A′
A
1945
6.5
1980
7.1
1928
6.5
1999a
7.0
1973
7.3
1937
7.3
1959
6.8
1928
6.7
Oaxaca
1982
7.0
1937
7.4
1999b
7.4
1931
7.8
1996
7.1
1968
7.3
1978
7.6
1965
7.4
6.4 cm/yr

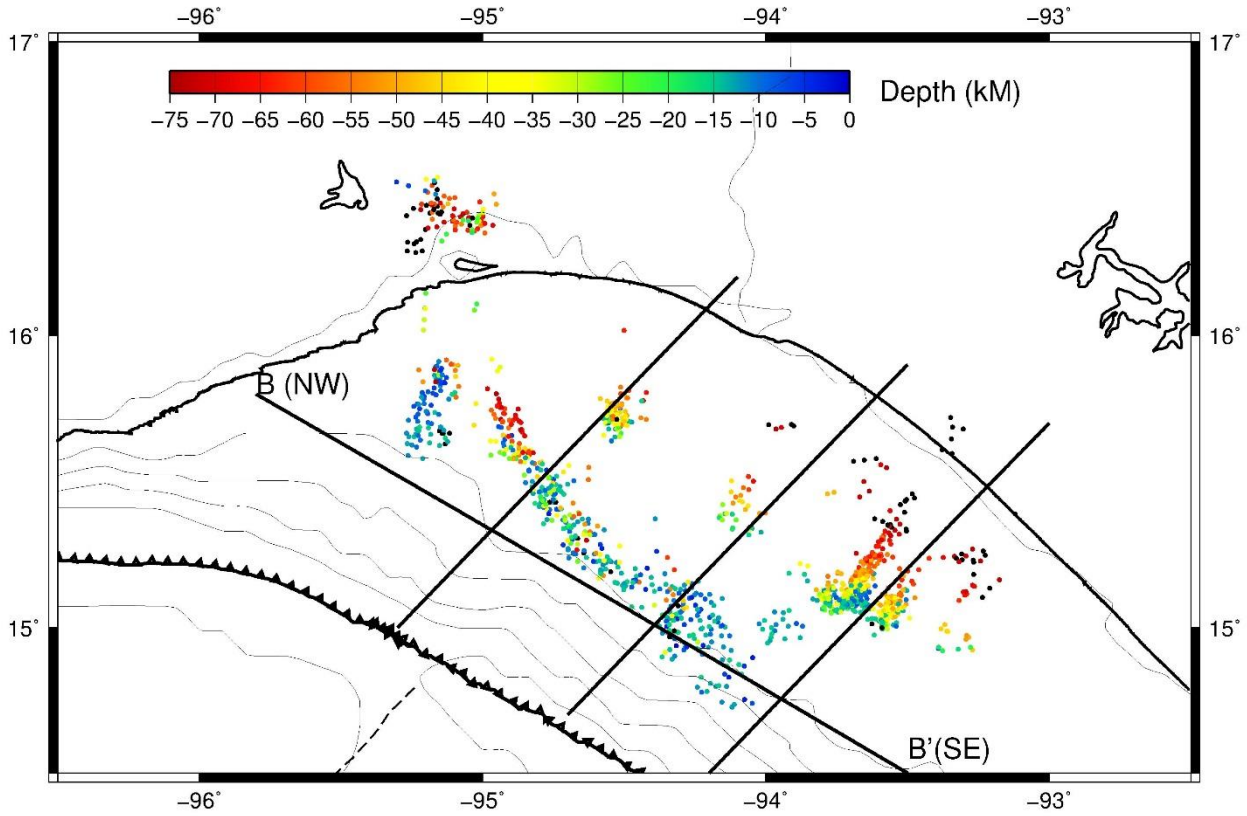


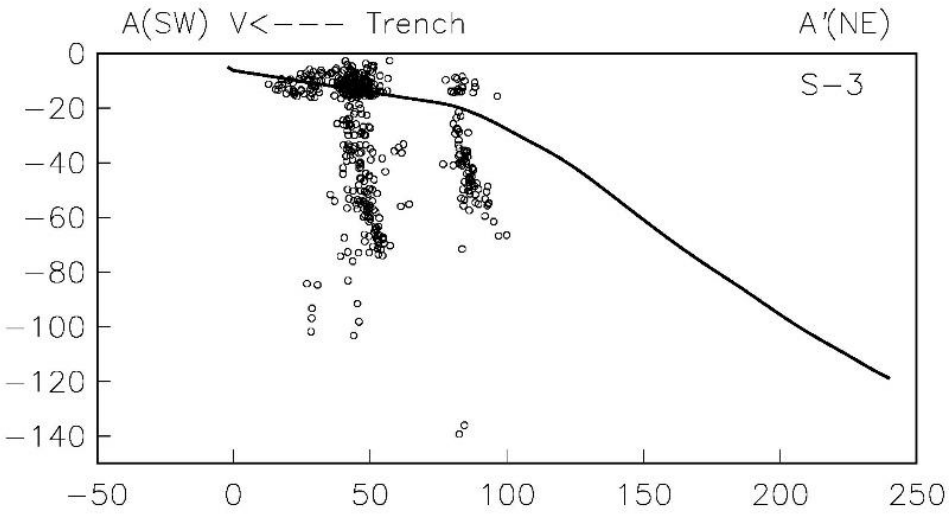
Singh et al., 1999

8 Sep 2017, Mw8.2

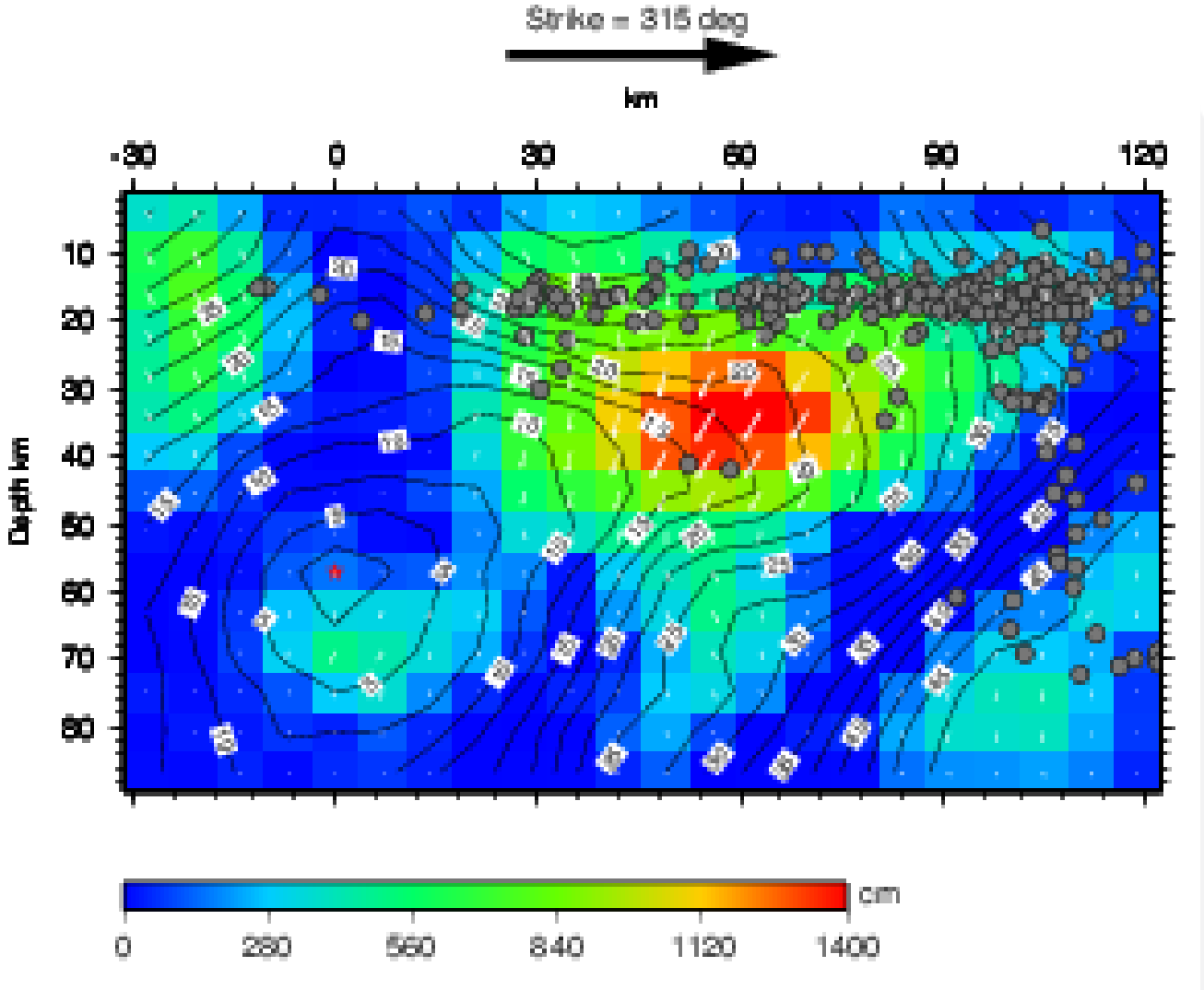


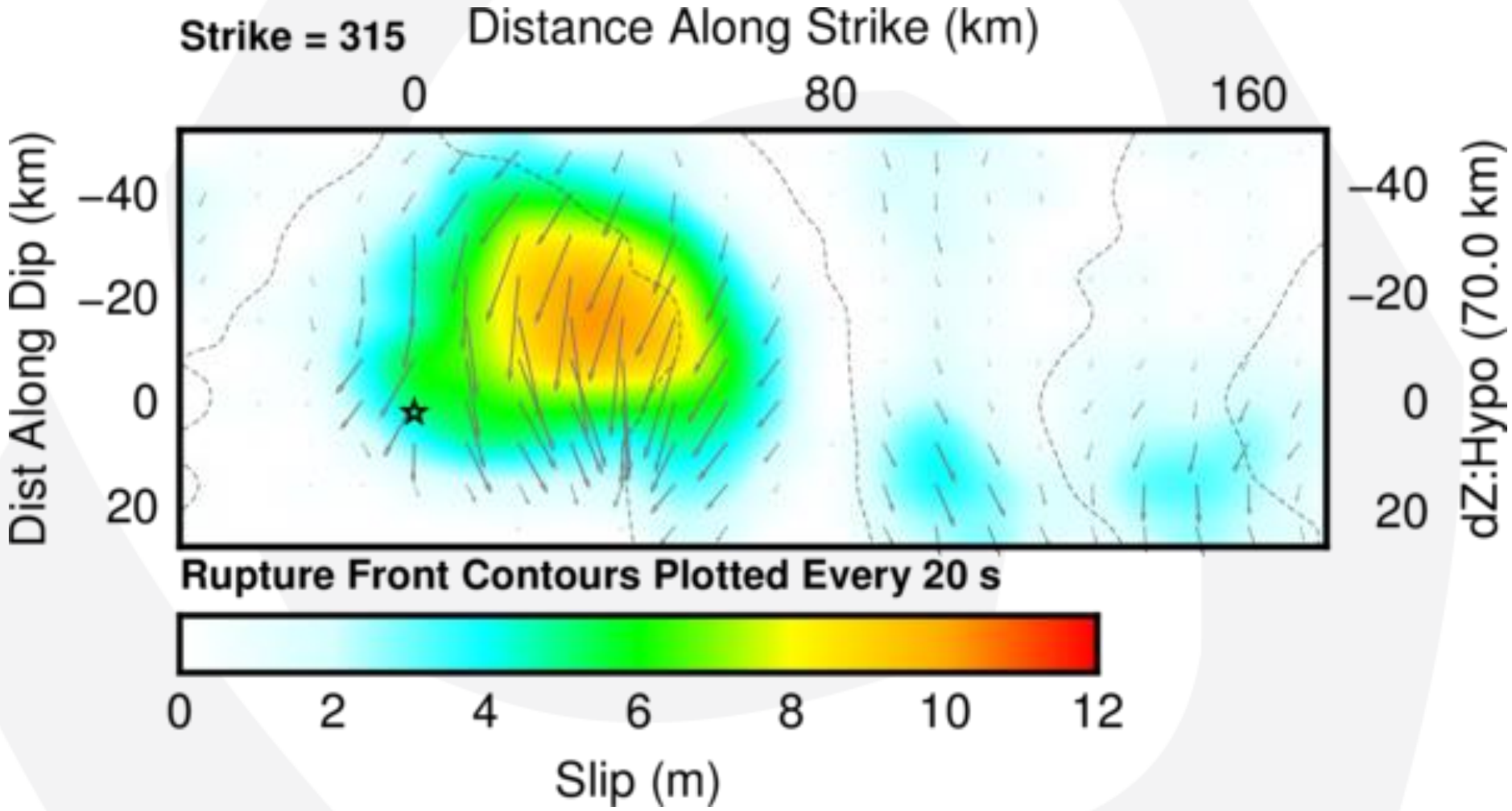

Depth (km)
90
80
70
60
50
40
30
20
10
17
16.5
16
15.5
15
14.5
14
Latitude
-97
-96.5
-96
-95.5
-95
-94.5
-94
-93.5
-93
Longitude
100
90
80
60
30
20
10

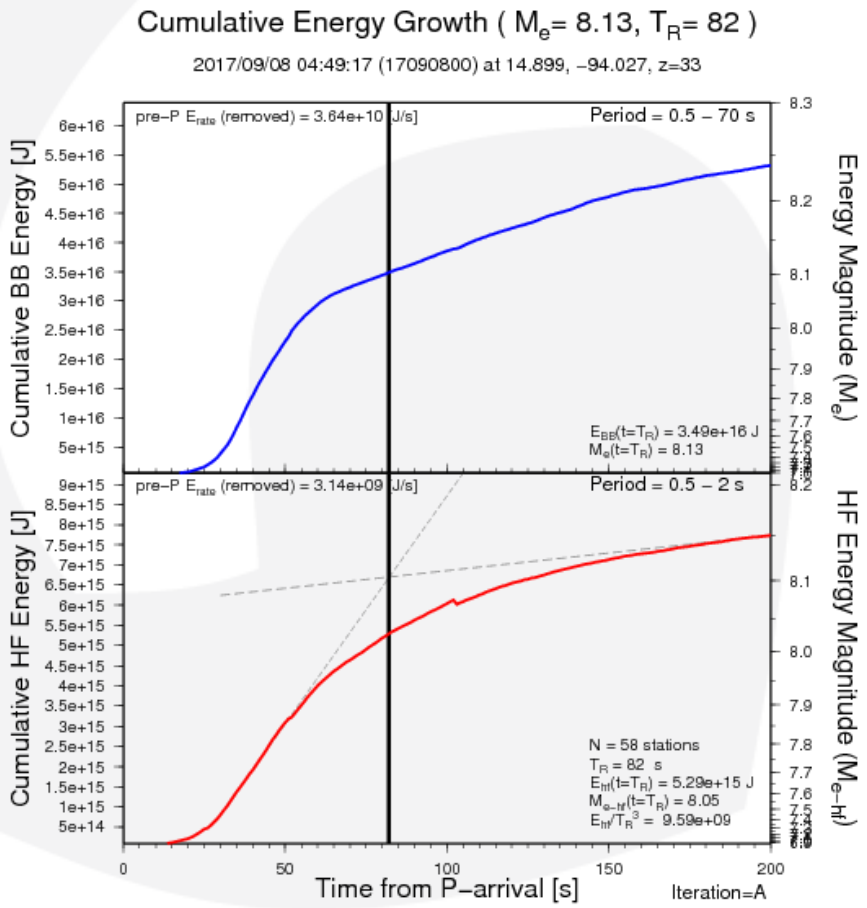

−96˚
−95˚
−94˚
−93˚
17˚
16˚
15˚
Depth (kM)
−75 −70 −65 −60 −55 −50 −45 −40 −35 −30 −25 −20 −15 −10 −5 0
B (NW)
B'(SE)


A(SW) V<--- Trench
A'(NE)
S-3
0
-20
-40
-60
-80
-100
-120
-140
-50
0
50
100
150
200
250

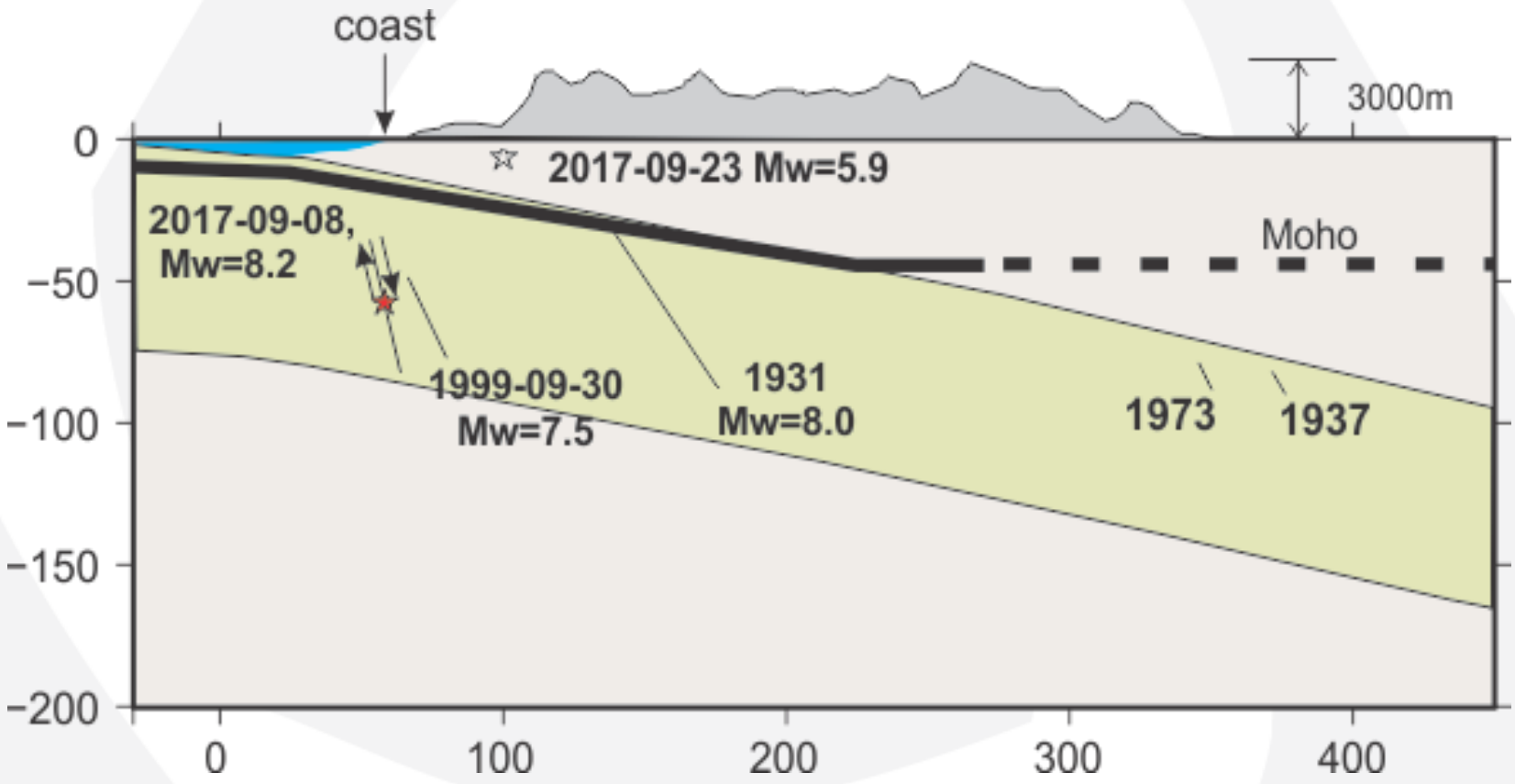
Strong directivity towards Salina Cruz




Strike = 315
Distance Along Strike (km)
0
80
160
Dist Along Dip (km)
−40
−20
0
20
dZ:Hypo (70.0 km)
Rupture Front Contours Plotted Every 20 s
0
2
4
6
8
10
12
Slip (m)

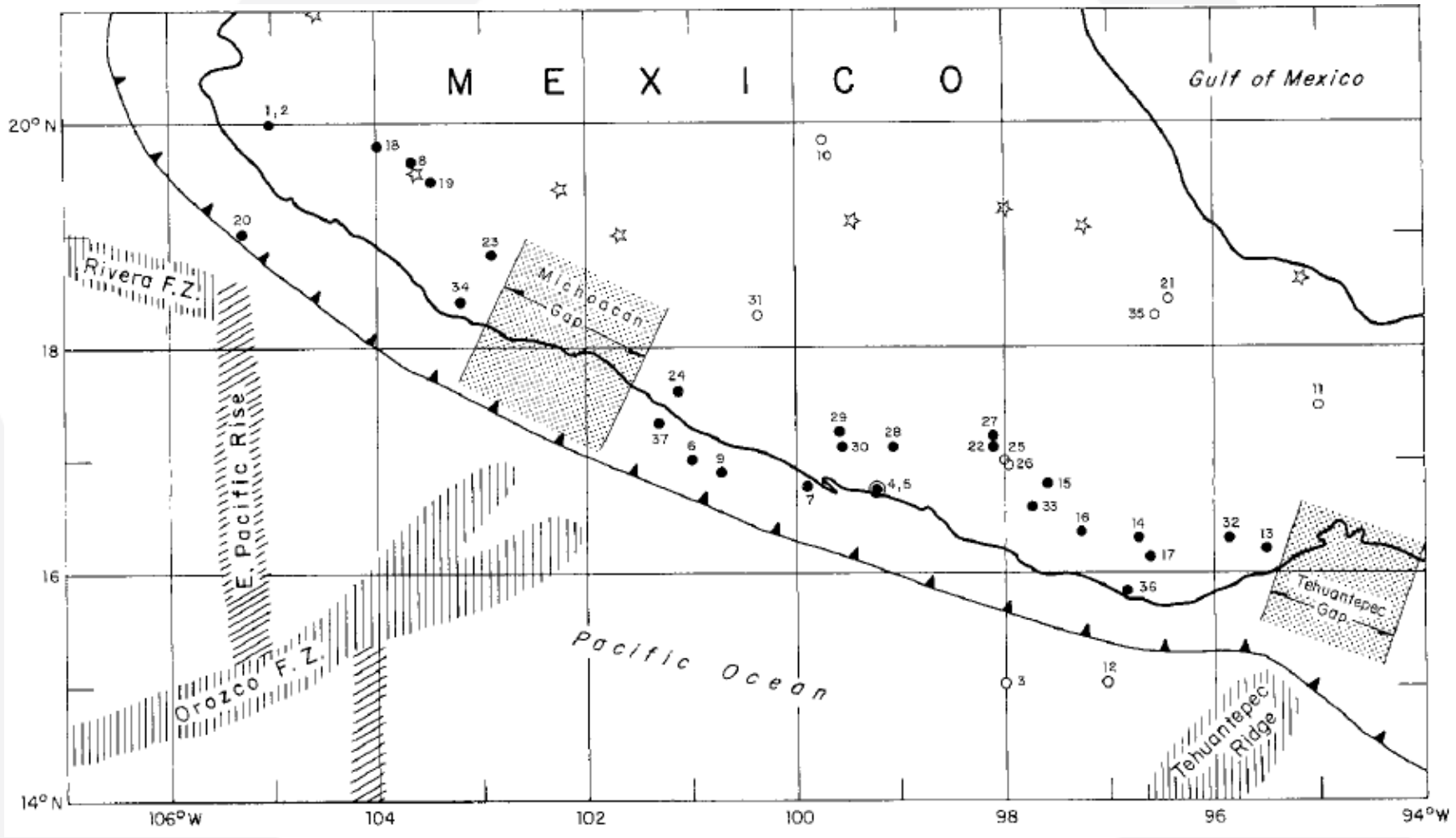

Cumulative Energy Growth (M_e= 8.13, T_R= 82)
2017/09/08 04:49:17 (17090800) at 14.899, -94.027, z=33
pre-P E_{rate} (removed) = 3.64e+10 J/s]
Period = 0.5 – 70 s
$E_{BB}(t=T_R)$ = 3.49e+16 J
$M_e(t=T_R)$ = 8.13
pre-P E_{rate} (removed) = 3.14e+09 J/s]
Period = 0.5 – 2 s
N = 58 stations
T_R = 82 s
$E_{hf}(t=T_R)$ = 5.29e+15 J
$M_{e-hf}(t=T_R)$ = 8.05
E_{hf}/T_R^3 = 9.59e+09
Cumulative BB Energy [J]
Cumulative HF Energy [J]
Energy Magnitude (M_e)
HF Energy Magnitude (M_{e-hf})
Time from P-arrival [s]
Iteration=A

Er/Mo=1.3x10**-5



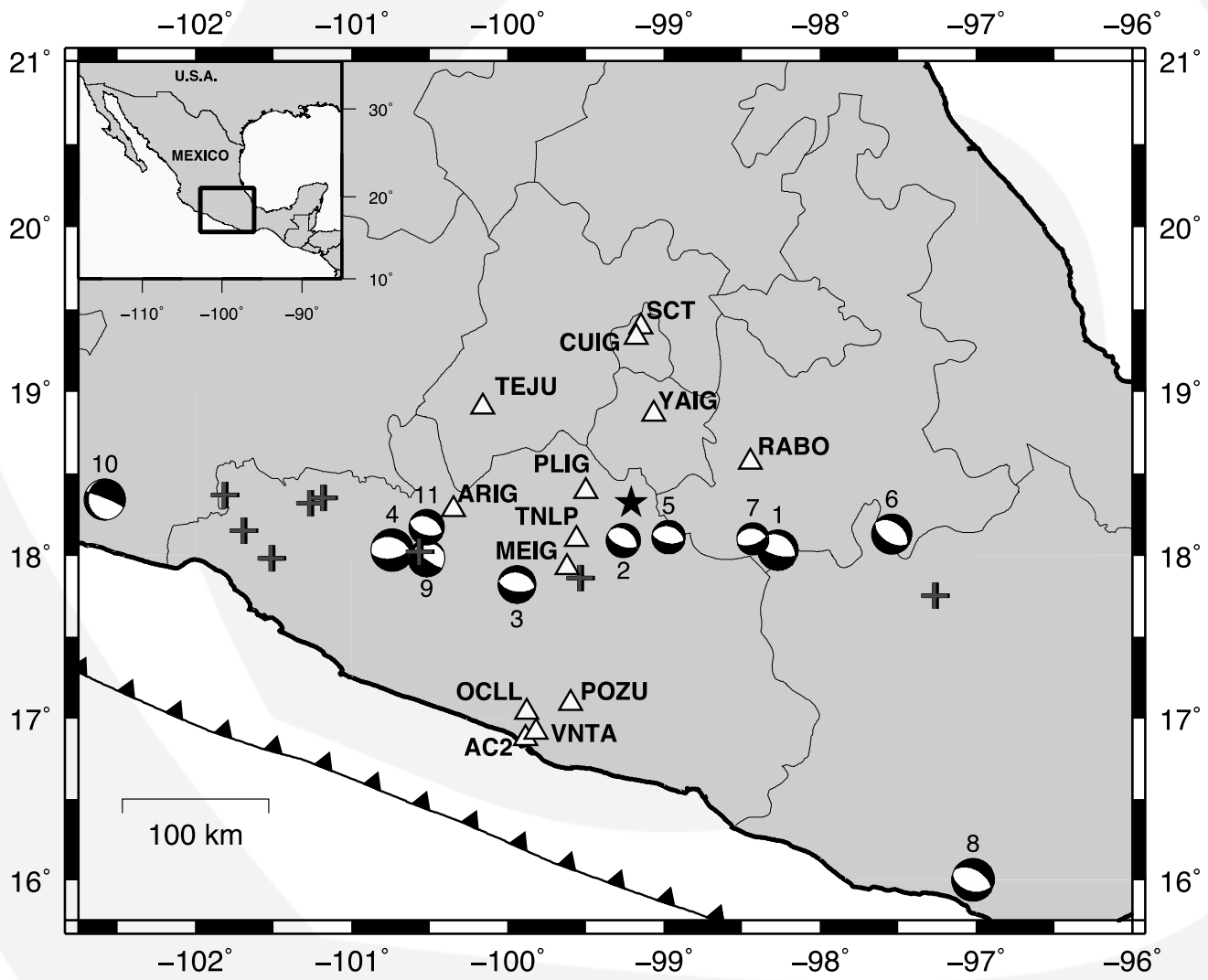
Cartoon, by A. Iglesias

And the seismic gap?

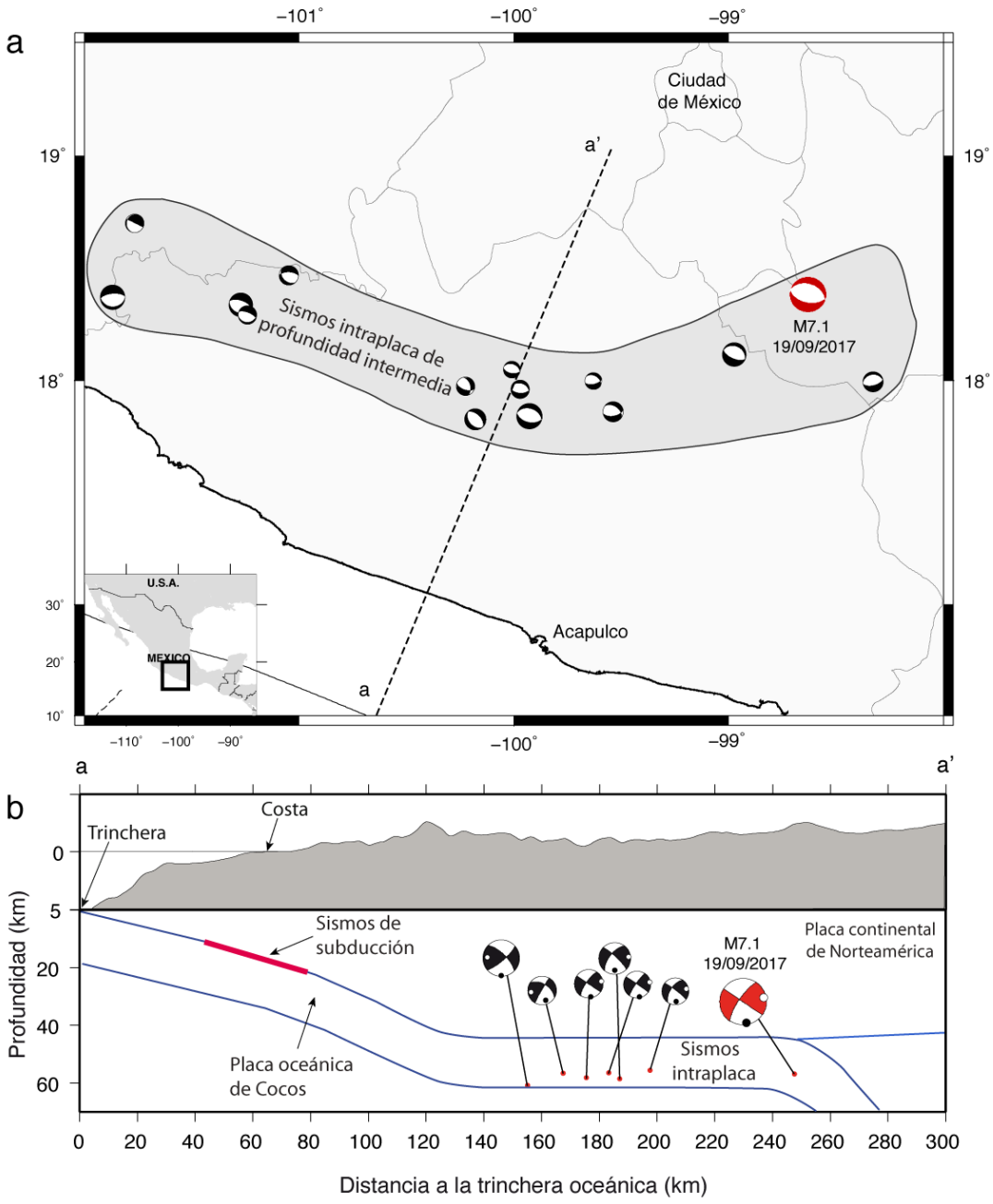


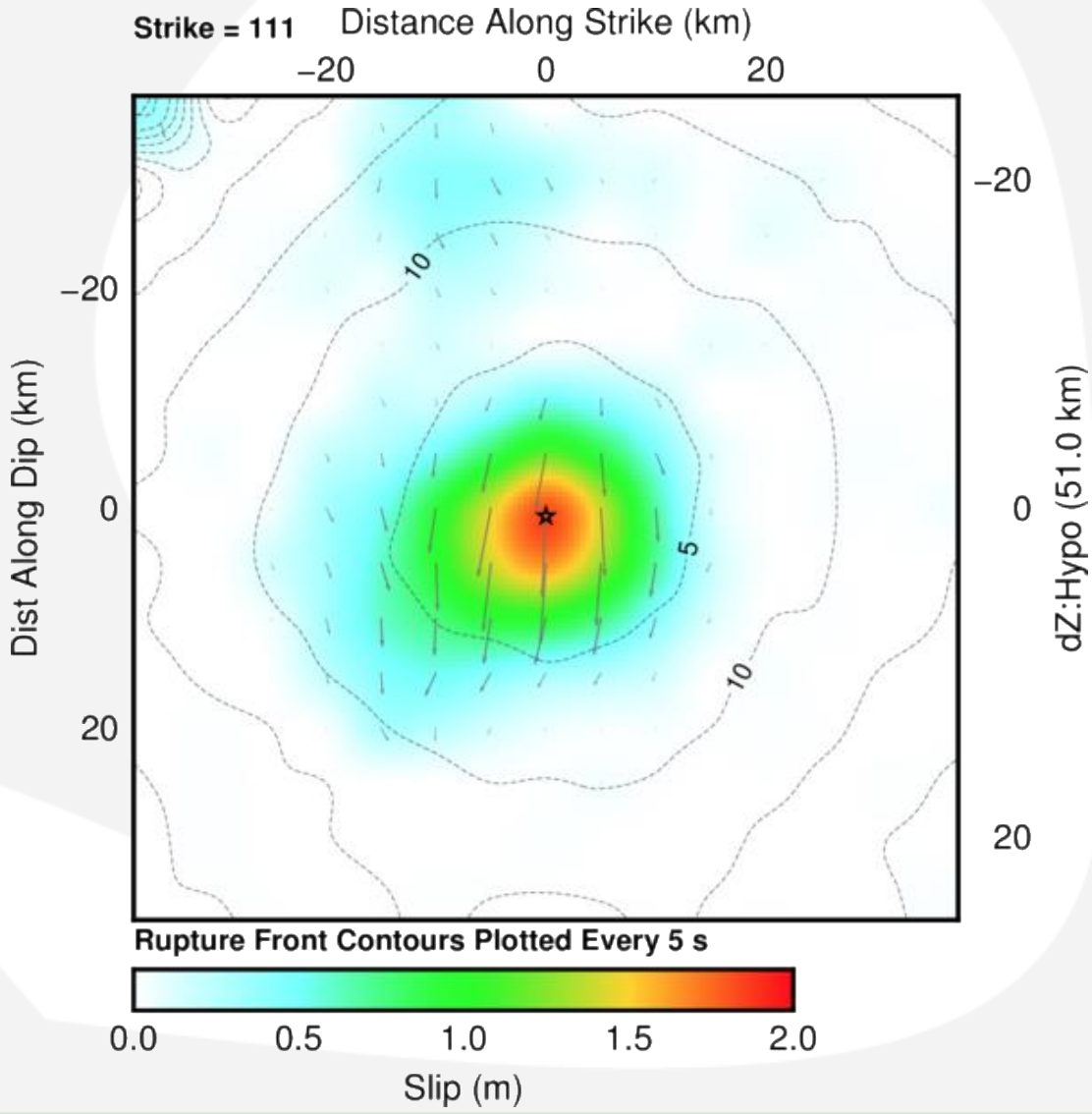
Singh et al., 1981

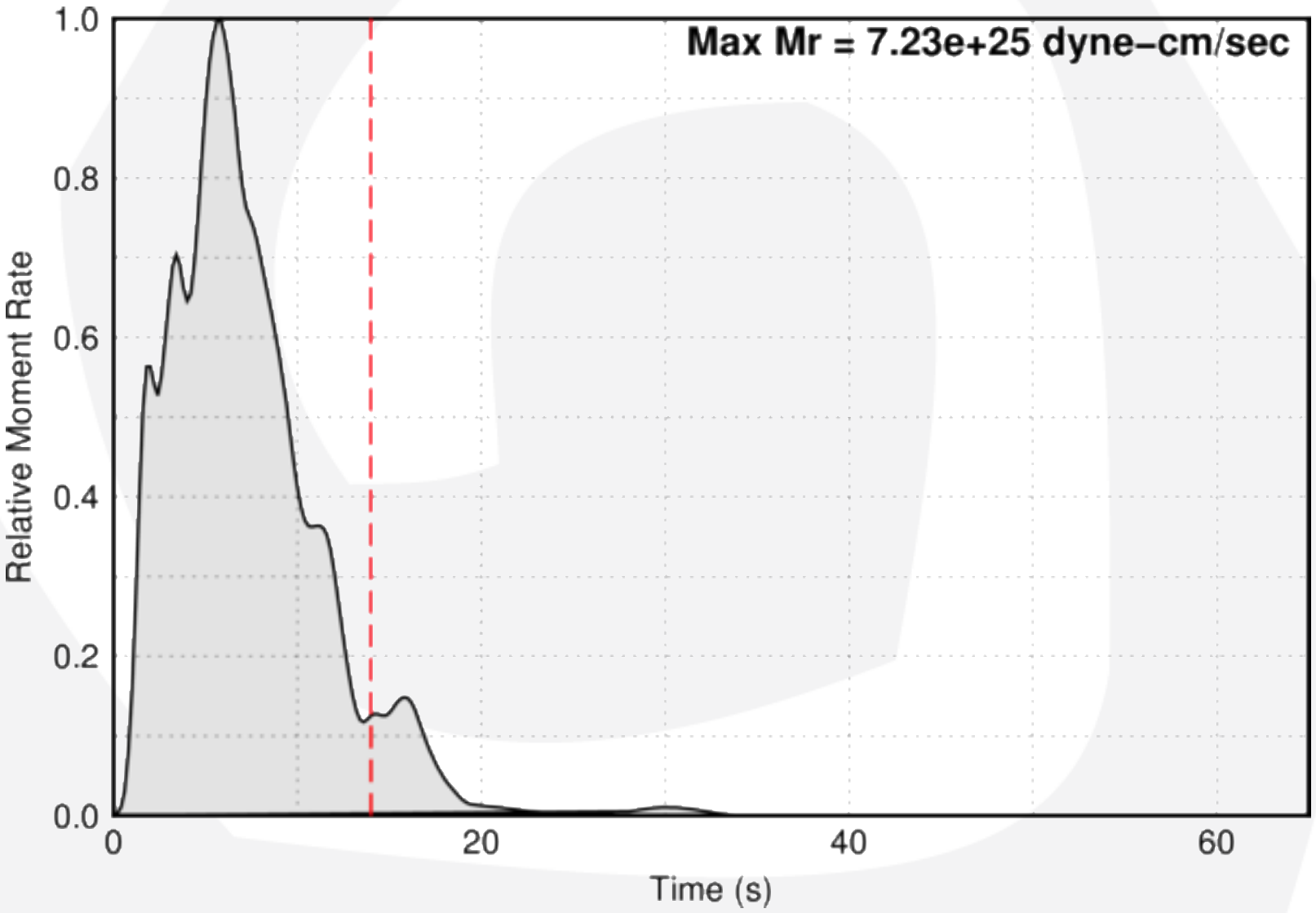
Sismo de 19 de septiembre de 2017 (Mw7.1)

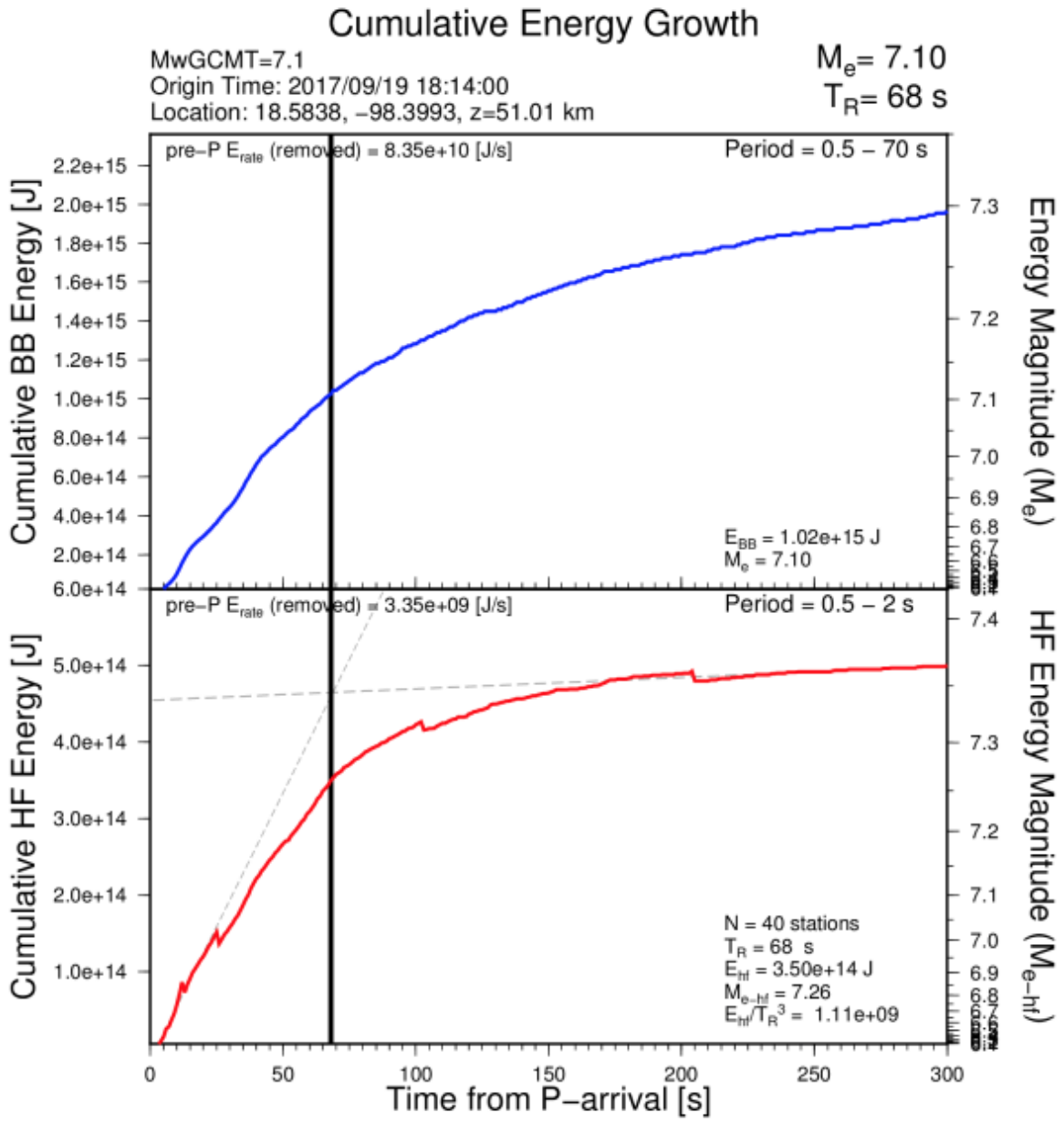

–102°
–101°
–100°
–99°
–98°
–97°
–96°
21°
20°
19°
18°
17°
16°
U.S.A.
MEXICO
30°
20°
10°
–110°
–100°
–90°
SCT
CUIG
TEJU
YAIG
RABO
PLIG
ARIG
TNLP
MEIG
OCLL
POZU
VNTA
AC2
1
2
3
4
5
6
7
8
9
10
11
100 km

Mw7.1, R=127 km

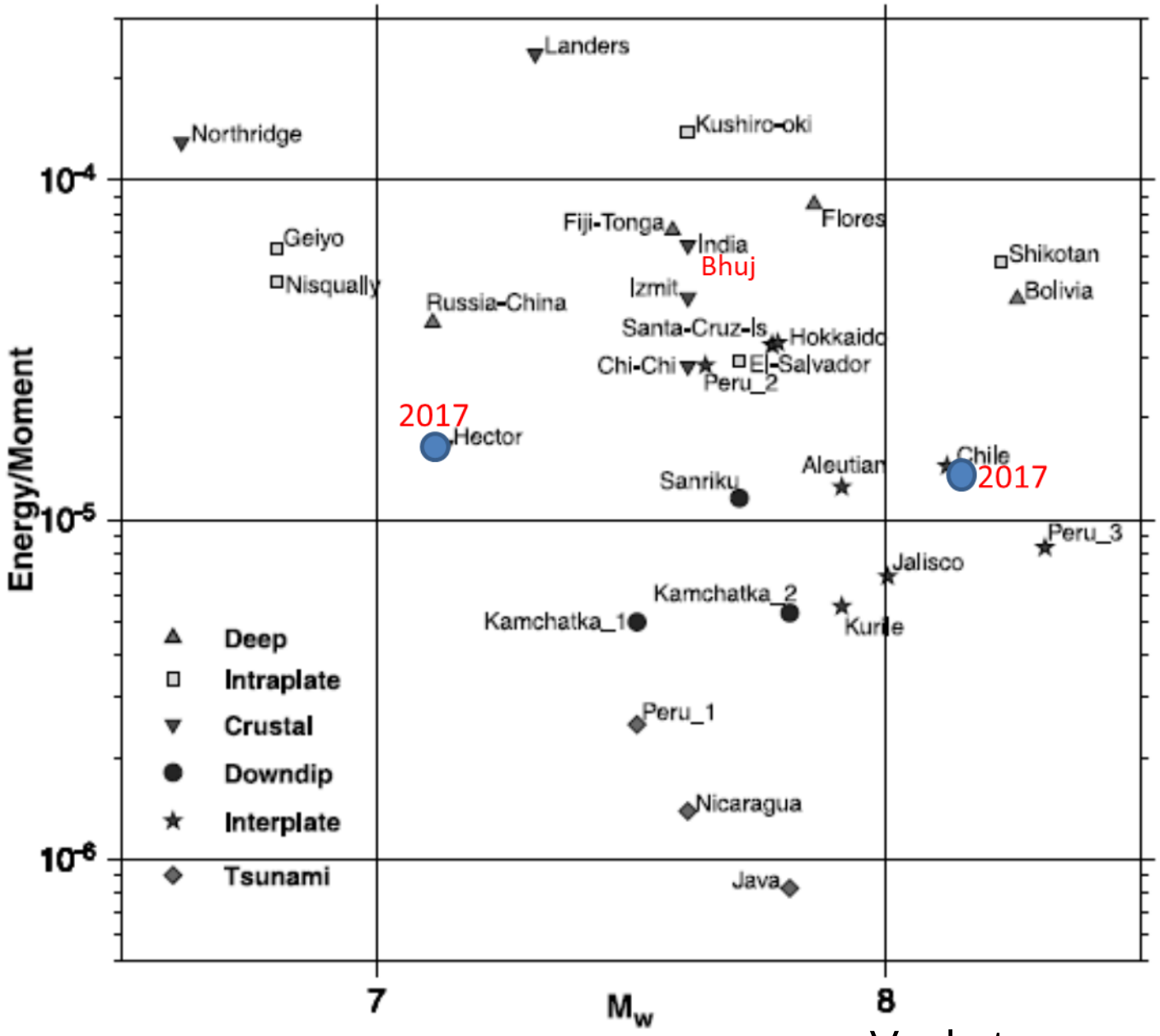

a
−101°
−100°
−99°
Ciudad
de México
a'
19°
Sismos intraplaca de
profundidad intermedia
M7.1
19/09/2017
18°
U.S.A.
MEXICO
30°
20°
10°
Acapulco
a
−110°
−100°
−90°
b
Costa
Trinchera
0
5
Sismos de
subducción
Placa continental
de Norteamérica
M7.1
19/09/2017
20
40
60
Placa oceánica
de Cocos
Sismos
intraplaca
Profundidad (km)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distancia a la trinchera oceánica (km)


Strike = 111
Distance Along Strike (km)
−20
0
20
−20
0
20
Dist Along Dip (km)
dZ:Hypo (51.0 km)
10
5
10
Rupture Front Contours Plotted Every 5 s
0.0
0.5
1.0
1.5
2.0
Slip (m)


Max Mr = 7.23e+25 dyne-cm/sec
Relative Moment Rate
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
Time (s)


Cumulative Energy Growth
MwGCMT=7.1
Origin Time: 2017/09/19 18:14:00
Location: 18.5838, −98.3993, z=51.01 km
M_e= 7.10
T_R= 68 s
pre−P E_{rate} (removed) = 8.35e+10 [J/s]
Period = 0.5 – 70 s
E_{BB} = 1.02e+15 J
M_e = 7.10
pre−P E_{rate} (removed) = 3.35e+09 [J/s]
Period = 0.5 – 2 s
N = 40 stations
T_R = 68 s
E_{hf} = 3.50e+14 J
M_{e-hf} = 7.26
E_{hf}/T_R^3 = 1.11e+09
Cumulative BB Energy [J]
Cumulative HF Energy [J]
Energy Magnitude (M_e)
HF Energy Magnitude (M_{e-hf})
Time from P−arrival [s]

Er/Mo=1.6e-5



Venkataraman & Kanamori, 2004

- 19 Sep 2017 (Mw7.1) intraslab earthquake produced highest PGA recorded at CU in Mexico City, twice that recorded during the interplate 1985 (Mw8.0) Michoacán earthquake.

- These two earthquakes are extreme examples of their type, so far, in terms of ground motion and destruction to the city.

Table 1. Twenty earthquakes with largest recorded A_{max}* at CU in the period 1964–2012, listed in descending order+. Local earthquakes are excluded

Date	Lat. (°)	Long. (°)	H (km)	M_w	R (km)	A_{max} (gal)	$A_{max}^{HF\#}$ (gal)	Type$
19/09/1985	18.14	−102.71	22	8.0	395	29.8	5.4	T
24/10/1980	18.03	−98.27	65	7.0	184	24.4	17.6	IS
11/12/2011	17.82	−99.94	57	6.4	194	19.2	17.0	IS
14/03/1979	17.46	−101.46	25	7.4	319	18.3	5.6	T
06/07/1964	18.03	−100.77	55	7.3	221	17.1	13.6	IS
21/09/1985	17.62	−101.82	22	7.5	338	13.9	5.9	T
02/08/1968	16.25	−98.08	16	7.3	360	13.0	3.5	T
21/07/2000	18.11	−98.97	50	5.8	145	12.8	8.4	IS
20/03/2012	16.25	−98.53	20	7.3	348	12.0	3.4	T
25/04/1989	16.58	−99.48	17	6.9	307	11.9	2.2	T
15/06/1999	18.13	−97.54	60	6.9	225	11.6	8.3	IS
07/06/1976	17.41	−100.68	57	6.4	265	10.7	4.1	IS
14/09/1995	16.48	−98.76	22	7.3	319	10.3	3.3	T
07/06/1982	16.25	−98.34	6	6.9	352	9.9	4.4	T
07/06/1982	16.32	−98.45	19	6.9	342	9.7	2.3	T
22/05/2009	18.10	−98.43	46	5.8	160	8.6	5.9	IS
03/02/1968	16.37	−98.40	33	5.6	339	8.6	3.1	T
30/09/1999	16.00	−97.02	40	7.4	433	7.8	6.6	IS
29/11/1978	16.03	−96.67	23	7.8	452	6.4	1.4	T
23/08/1965	16.28	−96.02	12	7.5	475	6.1	1.9	T

*$A_{max} = [(A_n^2 + A_e^2)/2]^{1/2}$.
+Intraslab earthquake of 28 August 1973 (M_w7.0, $R = 311$ km) is not listed because it was not recorded at CU, probably due to instrumental malfunction. The estimated A_{max} is 9.3 gal (see text).
#A_{max}^{HF}: high-frequency A_{max}, computed from the two band-pass filtered (2.5–8.5 Hz) horizontal components.
$T: Interplate, IS: Intraslab normal fault.

2017/09/19

H~51 km

R = 133 km

A_{max} = 59 cm/s^2

Singh et al., 2014

Table 2
Ten Intraslab Earthquakes with Largest Recorded A_{max} at CU in the Period 1964–2013, Listed in Descending Order*

Event Number	Date (yyyy/mm/dd)	Latitude (°)	Longitude (°)	H (km)	m_b	M_w	R (km)	A_{max} (gal)†	V_{max} (cm/s)†
1	1980/10/24	18.03	−98.27	65	6.3	7.0	184	24.4	3.24
2	2013/06/16	18.09	−99.26	56	5.9	5.9	148	19.5	2.21
3	2011/12/11	17.82	−99.94	57	6.2	6.5	194	19.2	1.40
4	1964/07/06	18.03	−100.74	55	6.5	7.3	221	17.1	1.82
5	2000/07/21	18.11	−98.97	50	5.4	5.8	145	12.8	0.82
6	1999/06/15	18.13	−97.54	60	6.4	6.9	225	11.6	1.84
7	2009/05/22	18.10	−98.43	46	5.8	5.6	160	8.6	0.66
8	1999/09/30	16.00	−97.02	47	6.5	7.4	433	7.8	2.32
9	1994/12/10	17.98	−100.52	50	6.5	6.4	212	5.8	0.91
10	1997/01/11	18.34	−102.58	40	6.5	7.1	378	5.1	1.99

*The intraslab earthquake of 28 August 1973 (M_w 7.0, R = 311 km) is not listed because it was not recorded at CU, probably due to instrumental malfunction. The estimated A_{max} is 9.3 gal (Singh *et al.*, 2013). Local earthquakes are excluded.
†$A_{max} = [(A_n^2 + A_e^2)/2]^{1/2}$; $V_{max} = [(V_n^2 + V_e^2)/2]^{1/2}$

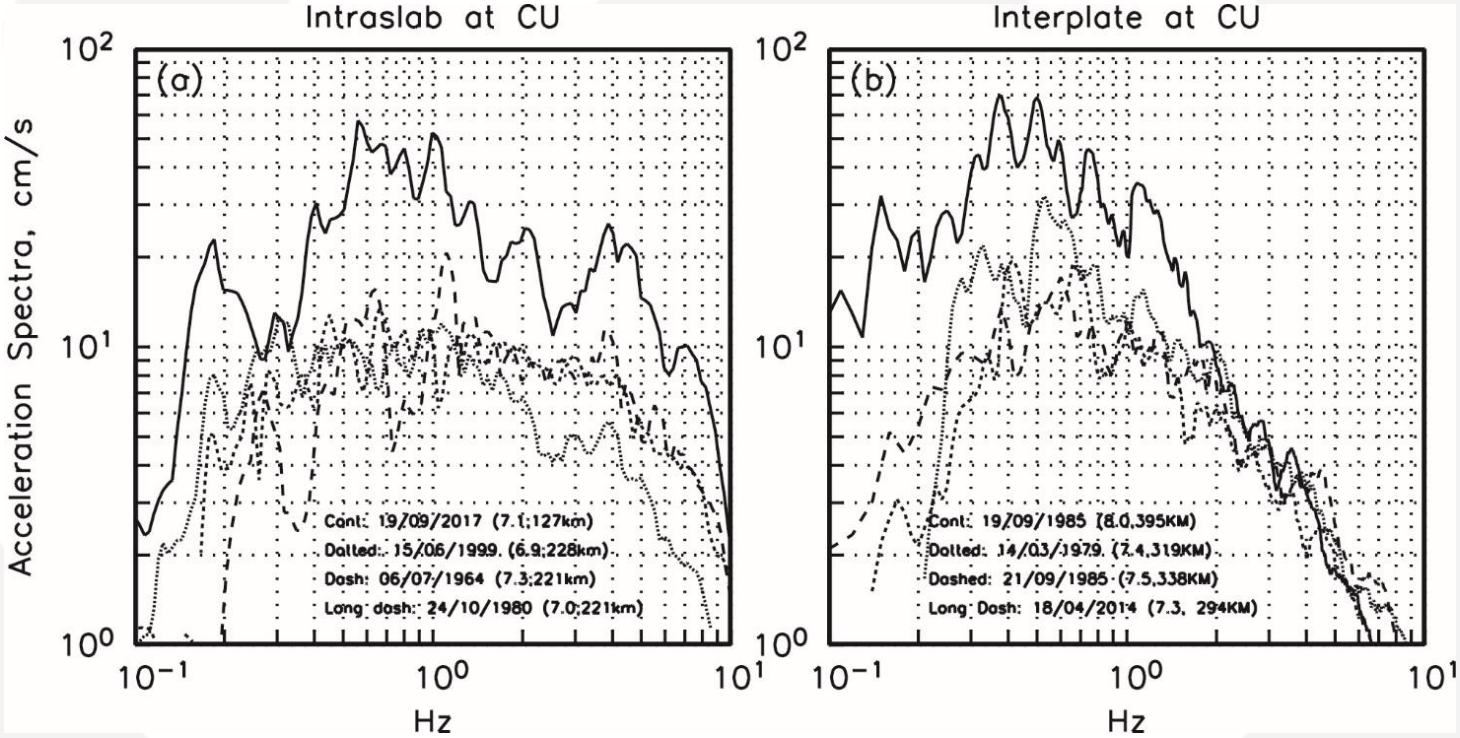
2017/09/19 H~51 km R = 133 km A_{max} = 59 cm/s^2 V_{max} = 8.9 cm/s

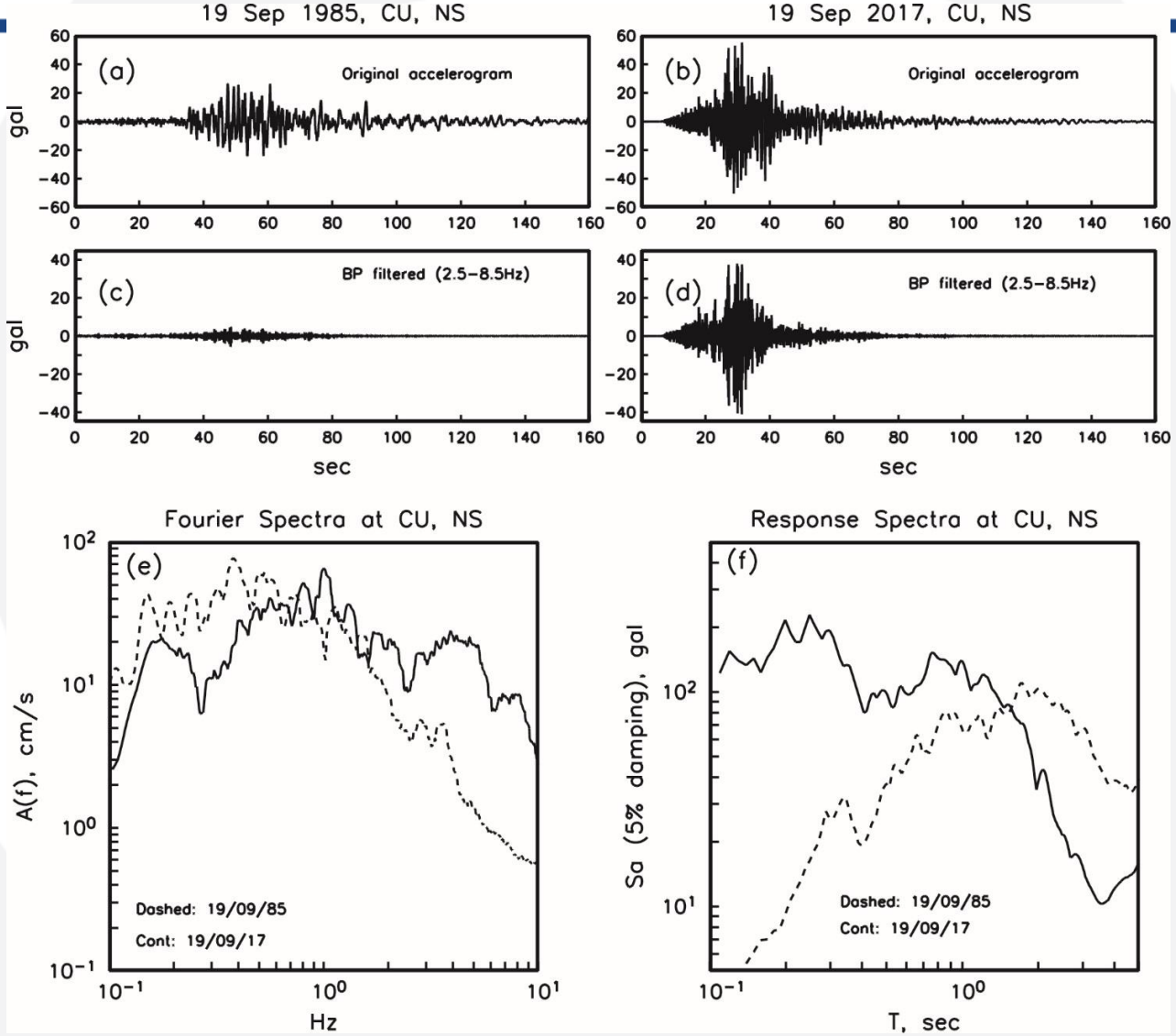
Singh et al., 2014

Sismos Intraslab *vs* Interplaca

	Intraslab	Interplaca
H	≥ 40 km	~15-25 km
Δσ	30 Mpa	7 Mpa
R a CU	≥ 120 km	≥300 km

→ el espectro enriquecido en CU en altas frecuencias durante sismos intraslab

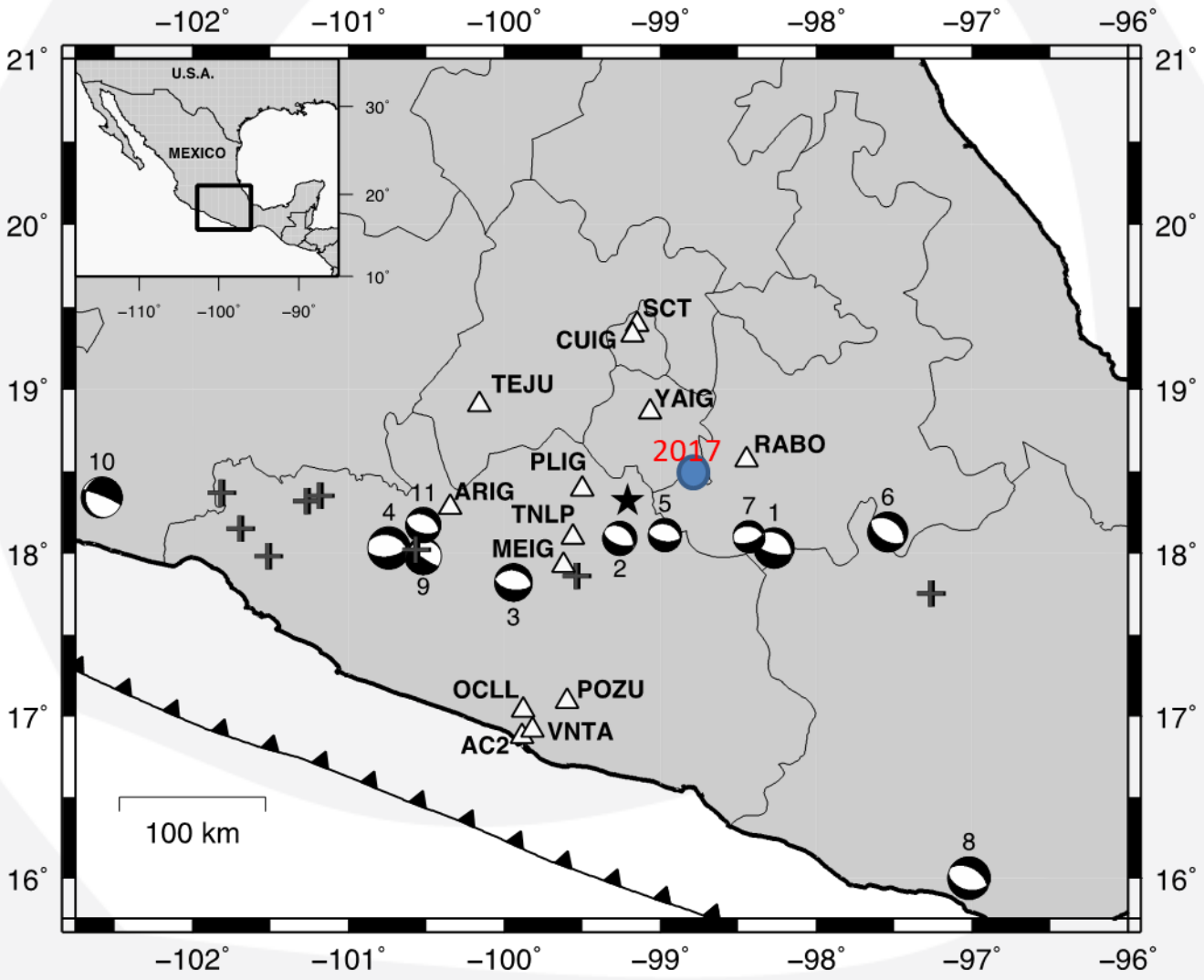

Intraslab at CU
Interplate at CU
(a)
(b)
Acceleration Spectra, cm/s
Hz
Hz
Cont: 19/09/2017 (7.1;127km)
Dotted: 15/06/1999. (6.9;228km)
Dash: 06/07/1964 (7.3;221km)
Long dash: 24/10/1980 (7.0;221km)
Cont: 19/09/1985 (8.0,395KM)
Dotted: 14/03/1979. (7.4,319KM)
Doshed: 21/09/1985 (7.5,338KM)
Long Dash: 18/04/2014 (7.3, 294KM)

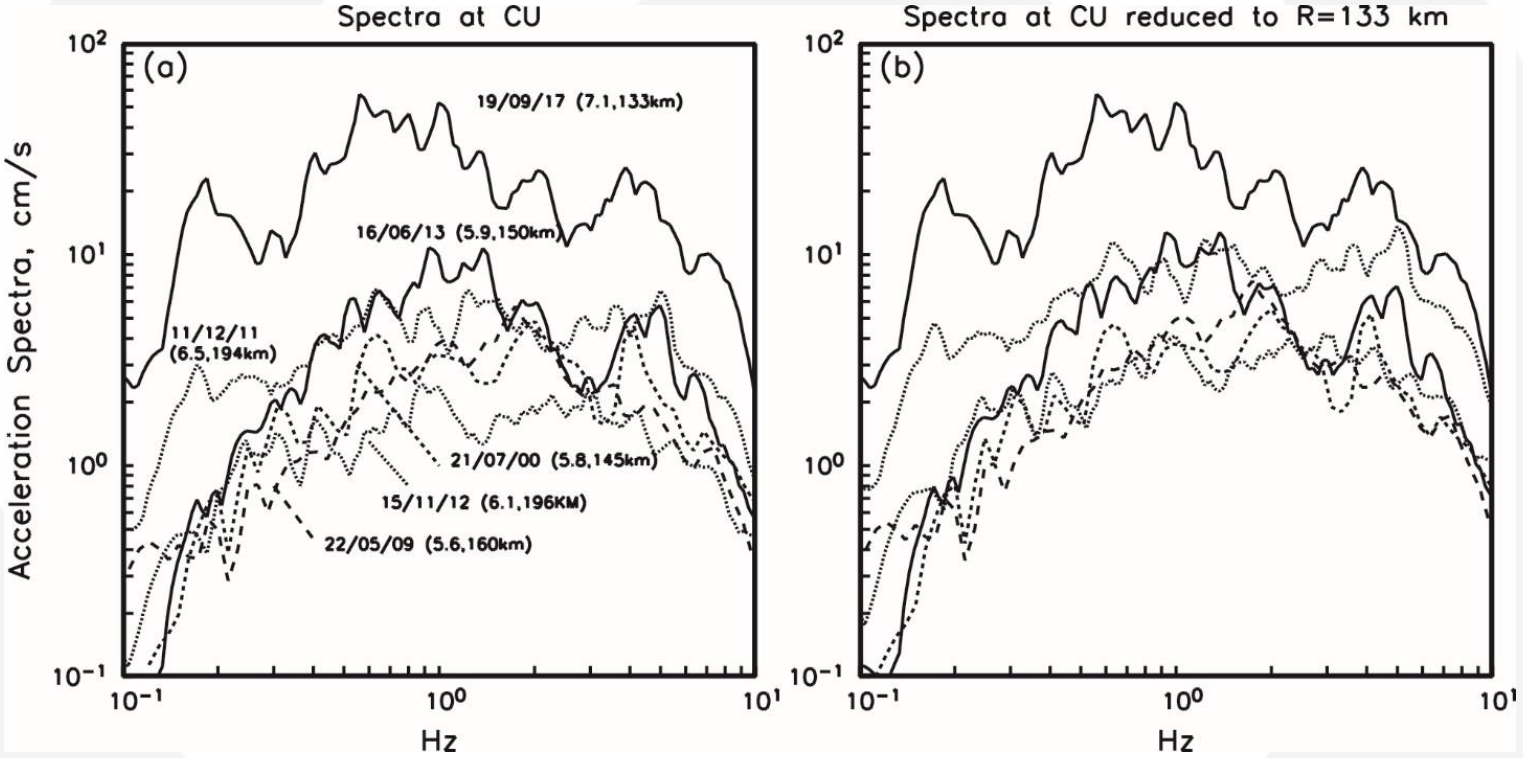

19 Sep 1985, CU, NS
19 Sep 2017, CU, NS
(a)
Original accelerogram
(b)
Original accelerogram
(c)
BP filtered (2.5–8.5Hz)
(d)
BP filtered (2.5–8.5Hz)
gal
sec
Fourier Spectra at CU, NS
Response Spectra at CU, NS
(e)
(f)
A(f), cm/s
Sa (5% damping), gal
Hz
T, sec
Dashed: 19/09/85
Cont: 19/09/17

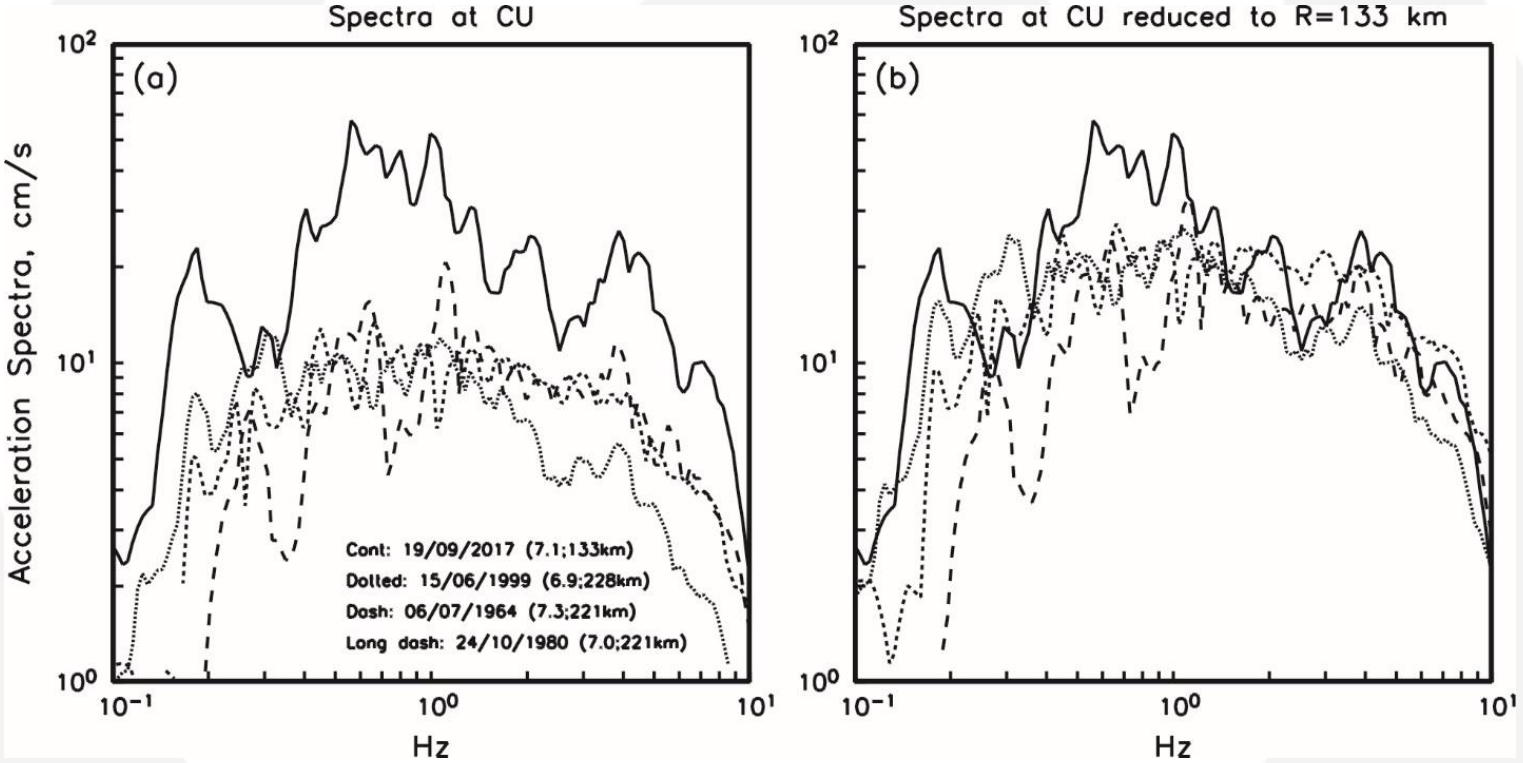
¿Mw, R esperado?

¿Sismo Anómalamente energético?

Mw7.1, R=127 km

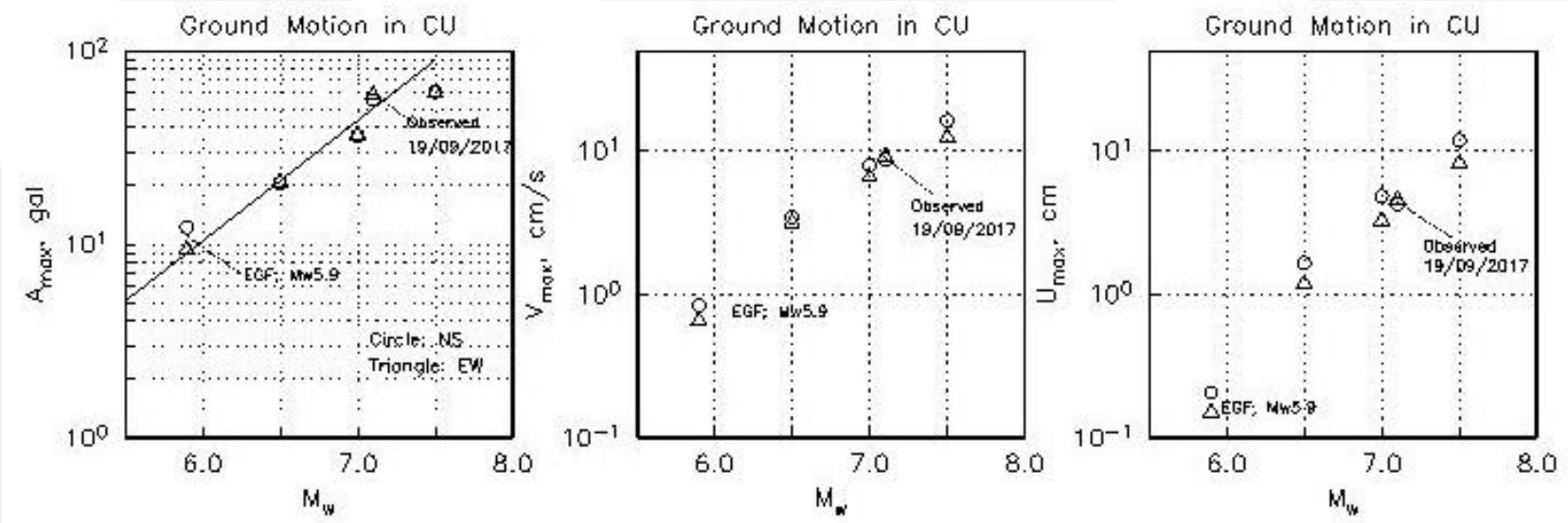

U.S.A.
MEXICO
SCT
CUIG
TEJU
YAIG
2017
RABO
PLIG
ARIG
TNLP
MEIG
OCLL
POZU
VNTA
AC2
100 km
1
2
3
4
5
6
7
8
9
10
11


Spectra at CU
(a)
19/09/17 (7.1,133km)
16/06/13 (5.9,150km)
11/12/11 (6.5,194km)
21/07/00 (5.8,145km)
15/11/12 (6.1,196KM)
22/05/09 (5.6,160km)
Acceleration Spectra, cm/s
Hz
Spectra at CU reduced to R=133 km
(b)
Hz


Spectra at CU
(a)
Acceleration Spectra, cm/s
10^2
10^1
10^0
10^{-1}
10^0
10^1
Hz
Cont: 19/09/2017 (7.1;133km)
Dotted: 15/06/1999 (6.9;228km)
Dash: 06/07/1964 (7.3;221km)
Long dash: 24/10/1980 (7.0;221km)
Spectra at CU reduced to R=133 km
(b)
10^2
10^1
10^0
10^{-1}
10^0
10^1
Hz

Prediction of ground motion at CU for Mw7 intraslab earthquake at 150 km.

EGF: 21/07/2000, Mw5.8



Modified from Iglesias et al., 2002

Conclusions

Chiapas Mw8.2 intraslab earthquake

Nearly vertical normal fault, severing the subducting Cocos plate

Large slip (upto 15 m) about 60 km from the hypocenter

Directivity towards Salina Cruz (probably the cause of damage in Juchitan area)

Large number of aftershocks

Can similar large intraslab earthquake occur near the coast elsewhere along the Mexican subduction zone?

Implication for Tehuantepec seismic gap? Strongly or weakly coupled interface?

Conclusions

Morelos-Puebla Mw7.1 intraslab earthquake

Mw and R expected (more or less)

Largest PGA at CU (twice that recorded in 1985)

At CU the earthquake seems unusually energetic (0.4<f<1.0), Directivity? (No clear eveidence from modelling), Er/Mo ~ 1.3X 10e-5 is not unusual

Fourier spectra of intraslab and interplate earthquakes at CU differ and, hence, also the damage pattern in Mexico City

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How close to Mexico City can such earthquakes occur?

Gracias