Differences in Source and Ground Motion Characteristics between Shallow and Buried Faulting

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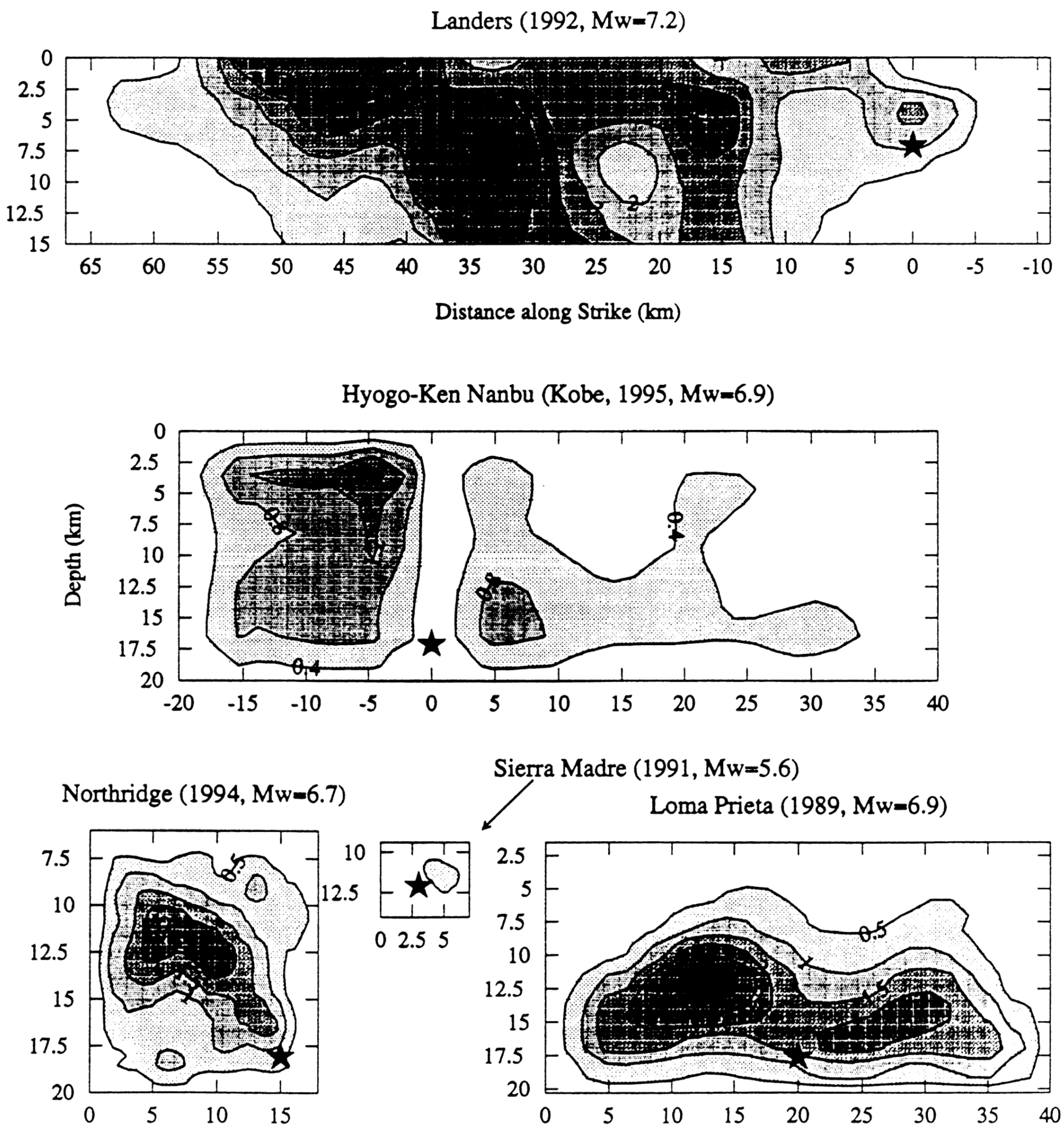
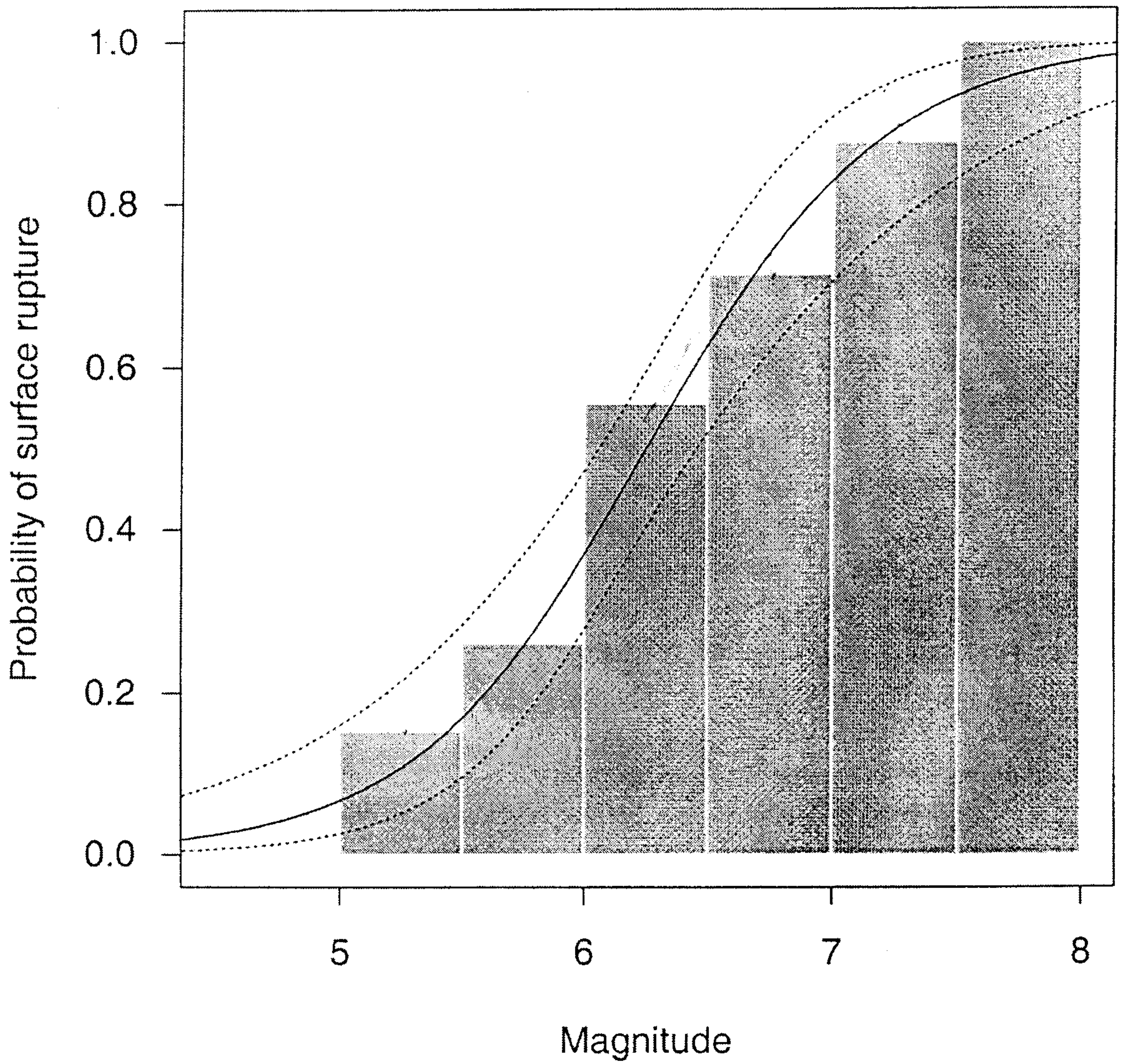
Differences in Source and Ground Motion Characteristics between Shallow and Buried Faulting

- Shallow faulting – top of shallowest asperity (defined by slip or slip velocity) is shallower than 5 km; there may also be asperities whose tops are deeper than 5 km

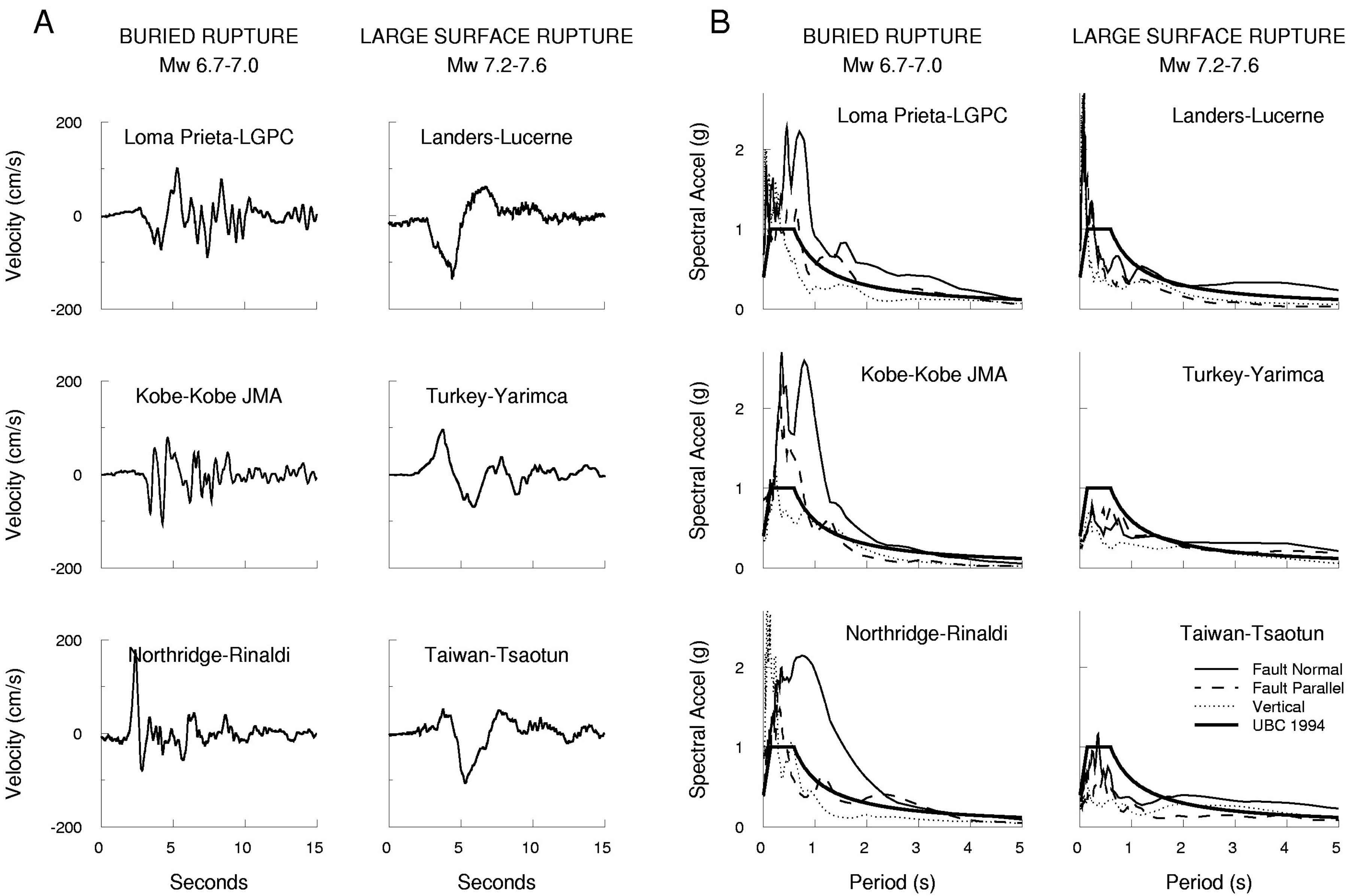
- Buried faulting – tops of all asperities are deeper than 5 km



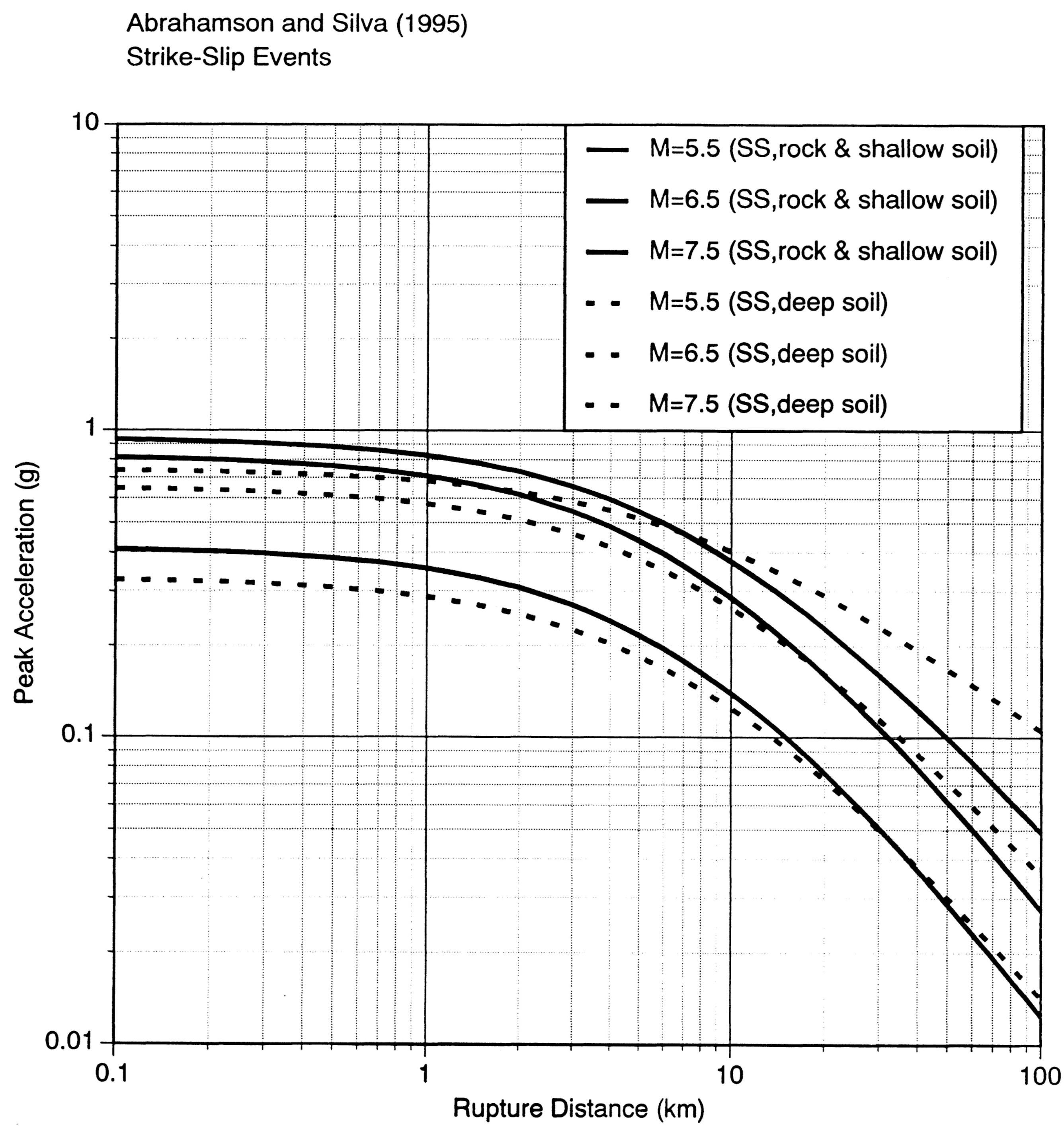
Landers (1992, Mw=7.2)
Distance along Strike (km)
Hyogo-Ken Nanbu (Kobe, 1995, Mw=6.9)
Depth (km)
Sierra Madre (1991, Mw=5.6)
Northridge (1994, Mw=6.7)
Loma Prieta (1989, Mw=6.9)

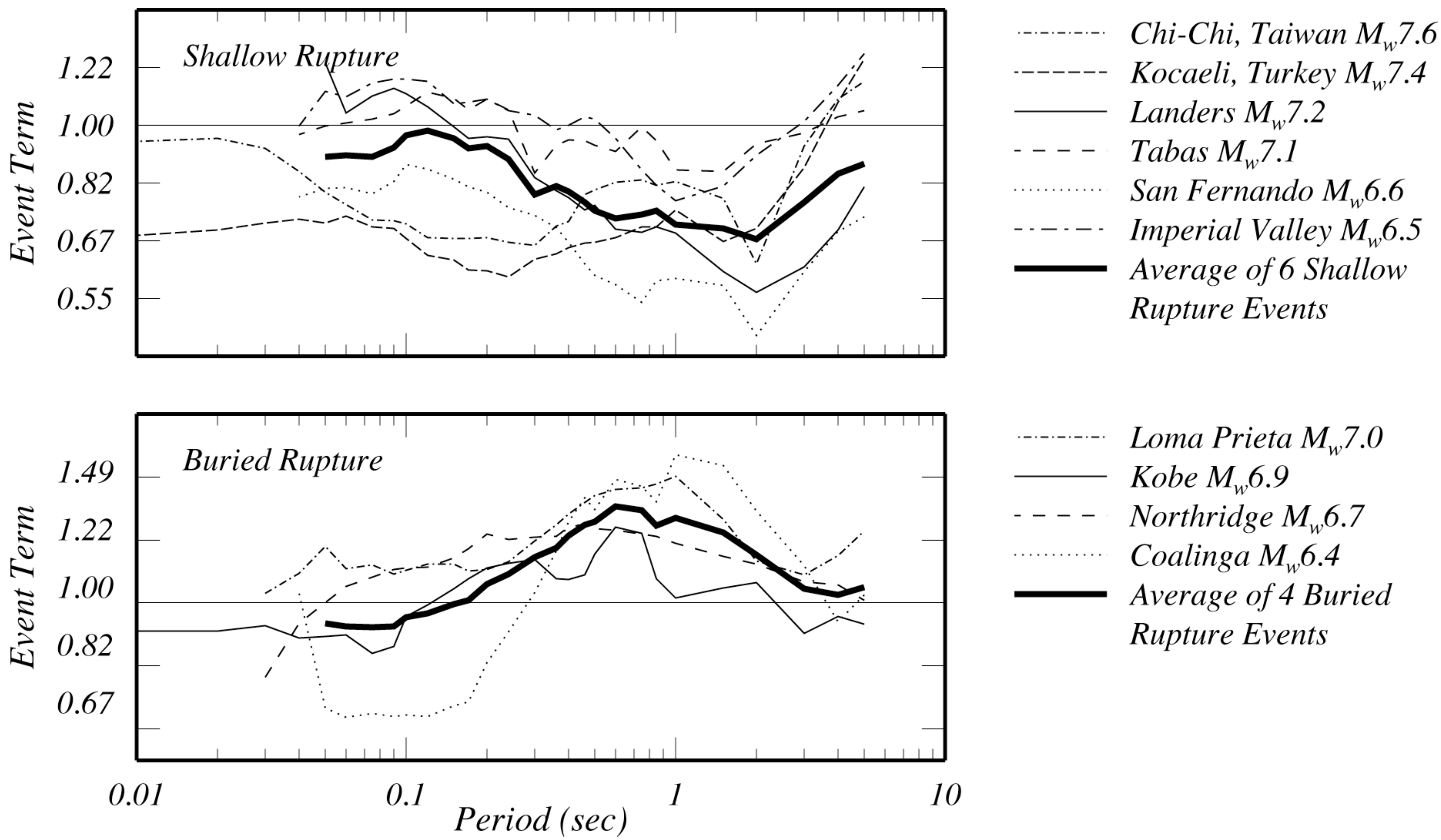


Probability of surface rupture
1.0
0.8
0.6
0.4
0.2
0.0
5
6
7
8
Magnitude

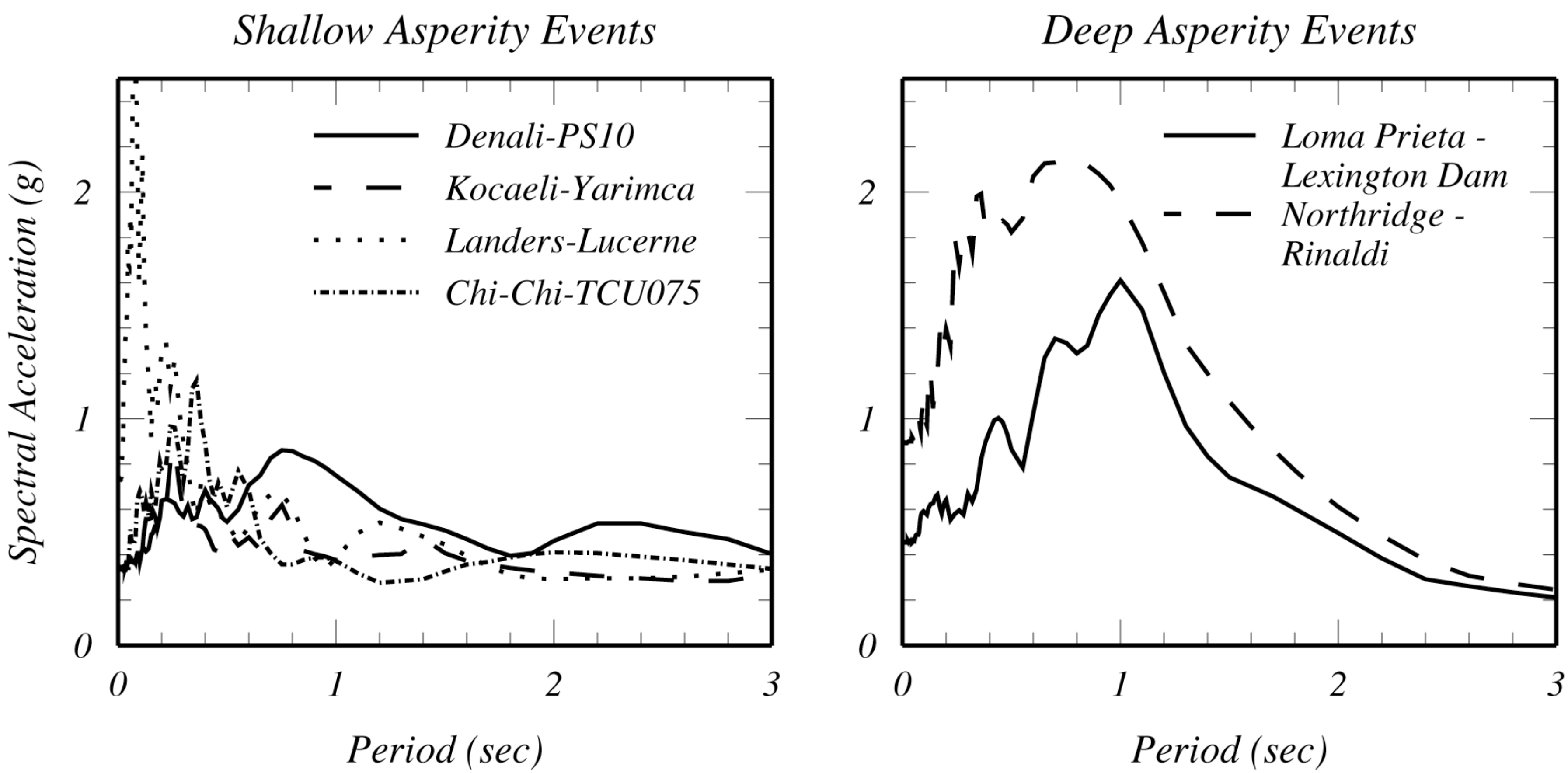


A
BURIED RUPTURE
Mw 6.7-7.0
LARGE SURFACE RUPTURE
Mw 7.2-7.6
Loma Prieta-LGPC
Landers-Lucerne
Kobe-Kobe JMA
Turkey-Yarimca
Northridge-Rinaldi
Taiwan-Tsaotun
Velocity (cm/s)
200
0
-200
0
5
10
15
Seconds
B
BURIED RUPTURE
Mw 6.7-7.0
LARGE SURFACE RUPTURE
Mw 7.2-7.6
Loma Prieta-LGPC
Landers-Lucerne
Kobe-Kobe JMA
Turkey-Yarimca
Northridge-Rinaldi
Taiwan-Tsaotun
Spectral Accel (g)
2
1
0
0
1
2
3
4
5
Period (s)
Fault Normal
Fault Parallel
Vertical
UBC 1994

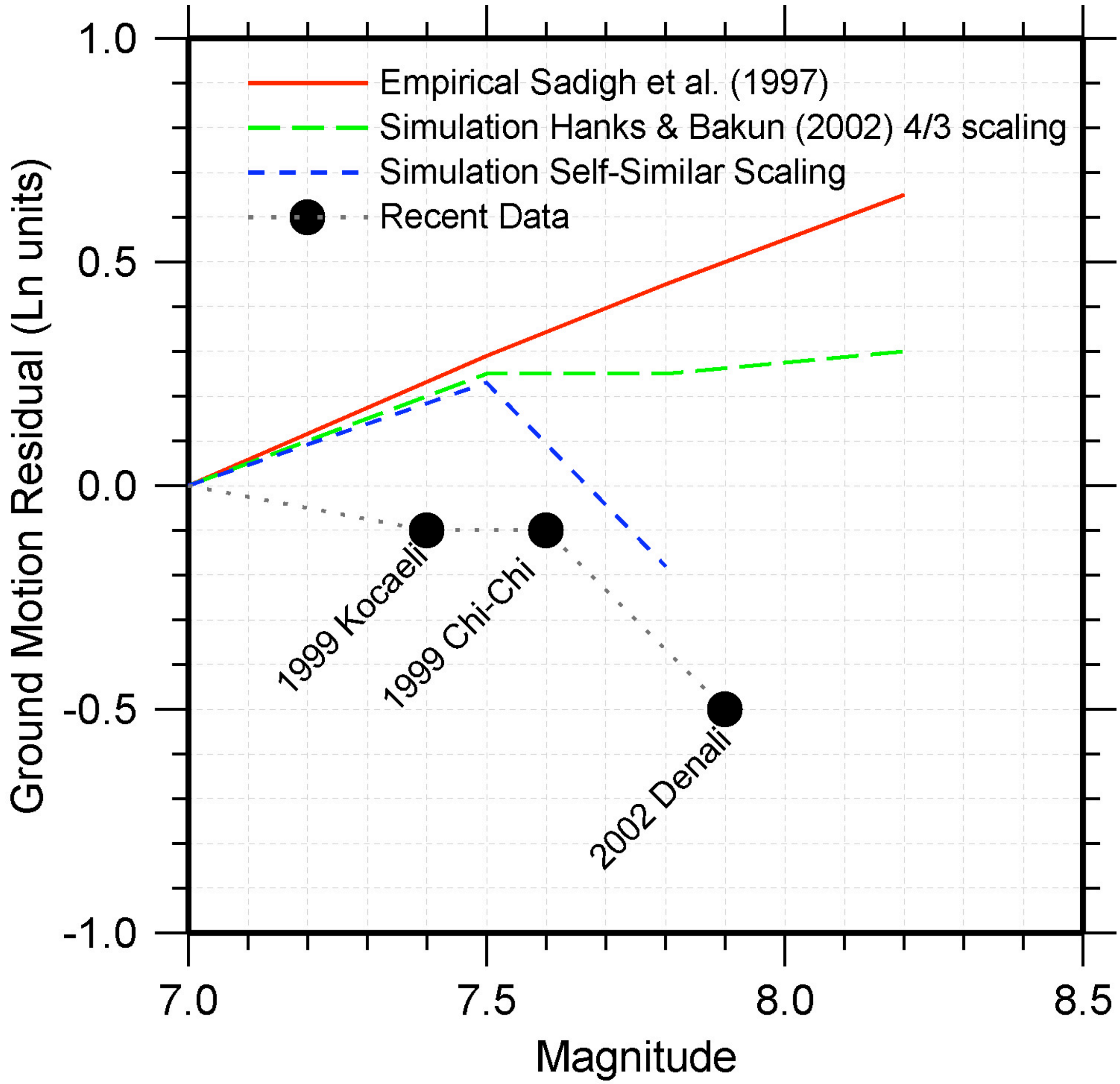

Abrahamson and Silva (1995)
Strike-Slip Events
M=5.5 (SS,rock & shallow soil)
M=6.5 (SS,rock & shallow soil)
M=7.5 (SS,rock & shallow soil)
M=5.5 (SS,deep soil)
M=6.5 (SS,deep soil)
M=7.5 (SS,deep soil)
Peak Acceleration (g)
10
1
0.1
0.01
0.1
1
10
100
Rupture Distance (km)



Shallow Rupture
Buried Rupture
Event Term
1.22
1.00
0.82
0.67
0.55
1.49
1.22
1.00
0.82
0.67
0.01
0.1
1
10
Period (sec)
Chi-Chi, Taiwan M_w7.6
Kocaeli, Turkey M_w7.4
Landers M_w7.2
Tabas M_w7.1
San Fernando M_w6.6
Imperial Valley M_w6.5
Average of 6 Shallow Rupture Events
Loma Prieta M_w7.0
Kobe M_w6.9
Northridge M_w6.7
Coalinga M_w6.4
Average of 4 Buried Rupture Events



Shallow Asperity Events
Deep Asperity Events
Spectral Acceleration (g)
Period (sec)
Period (sec)
Denali-PS10
Kocaeli-Yarimca
Landers-Lucerne
Chi-Chi-TCU075
Loma Prieta - Lexington Dam
Northridge - Rinaldi
0
1
2
3



Empirical Sadigh et al. (1997)
Simulation Hanks & Bakun (2002) 4/3 scaling
Simulation Self-Similar Scaling
Recent Data
1999 Kocaeli
1999 Chi-Chi
2002 Denali
Ground Motion Residual (Ln units)
Magnitude
1.0
0.5
0.0
-0.5
-1.0
7.0
7.5
8.0
8.5

Paleo Ground Motion from Analysis of Precariously Balanced Rocks

Brune, Anooshepoor, Purvance, Anderson, et al

Balanced rocks appear to be inconsistent with calculated seismic hazard levels

- Limitations of the ergodic assumption?
- Variability in ground motion level too high?
- Median ground motion level to high?

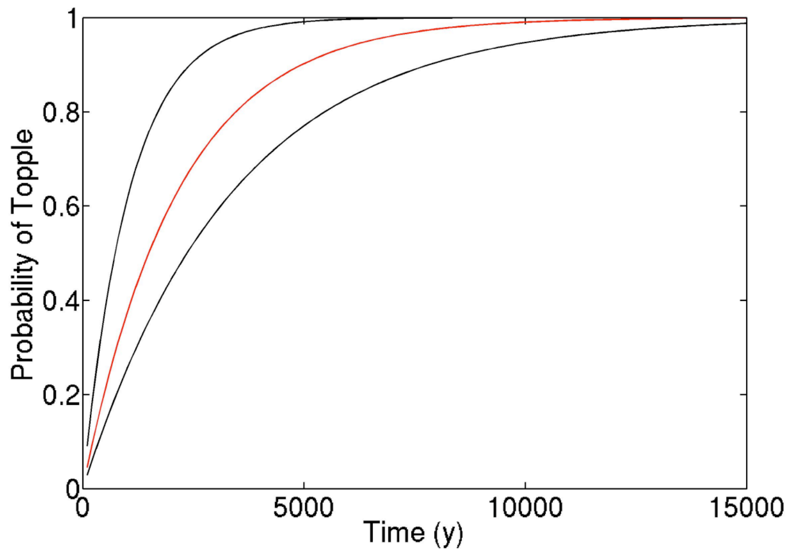
Vector Valued Seismic Hazard for Paleo Ground Motion

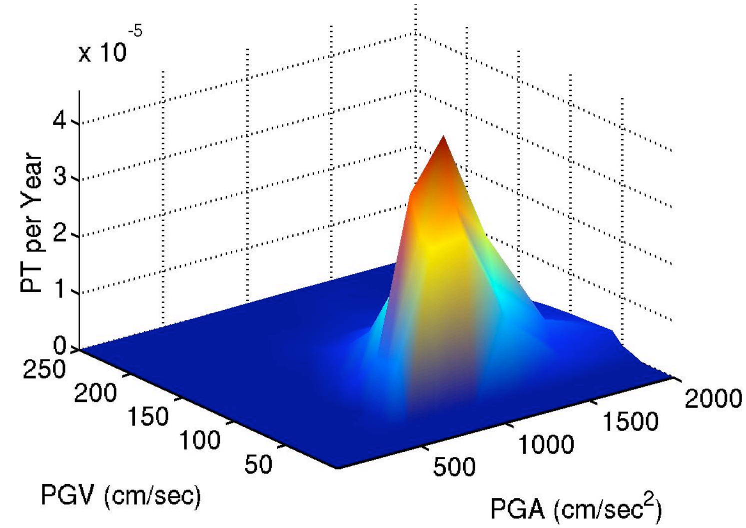
Toppling of rocks depends on both peak acceleration PGA and peak velocity PGV

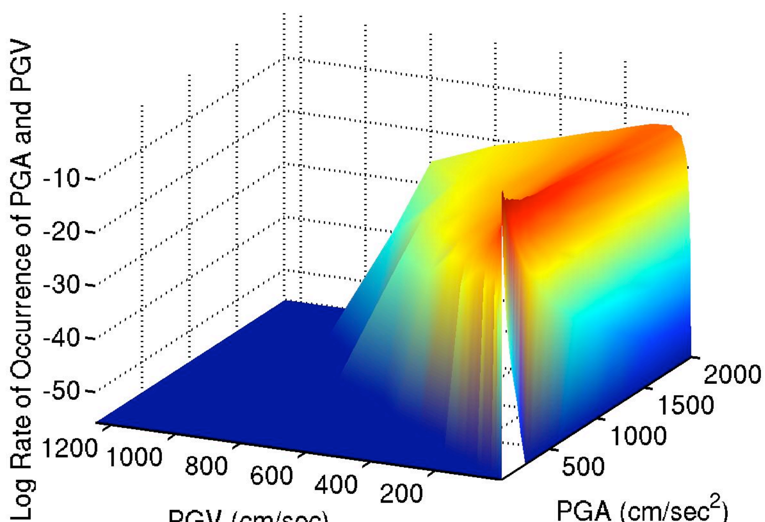
- Thio: Hazard surface for PGA and PGV
- Purvance: Fragility surface for PGA and PGV
- Combine to give probability of toppling as a function of return period
- Results incompatible with balanced rocks?

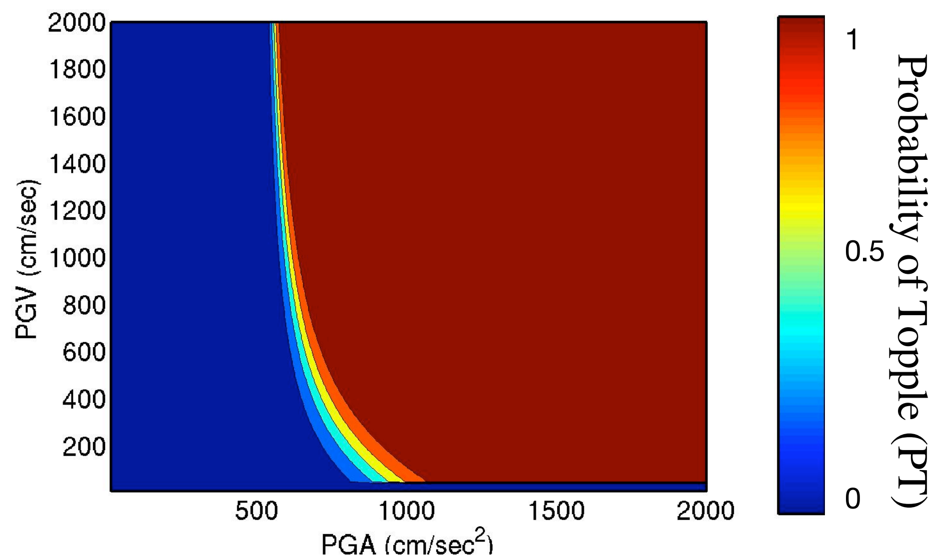
Pedley-1

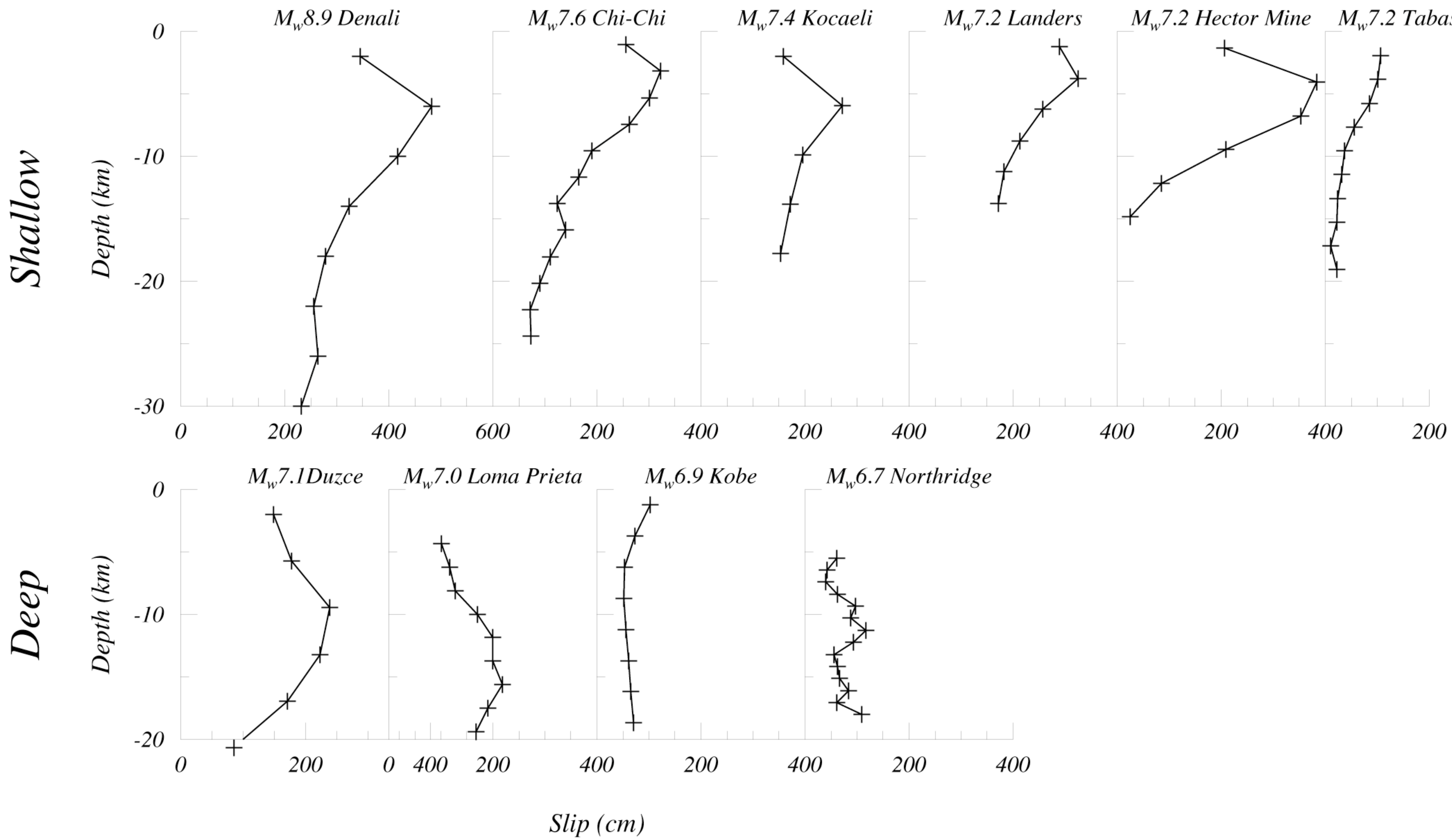
Alpha 0.4, R 51



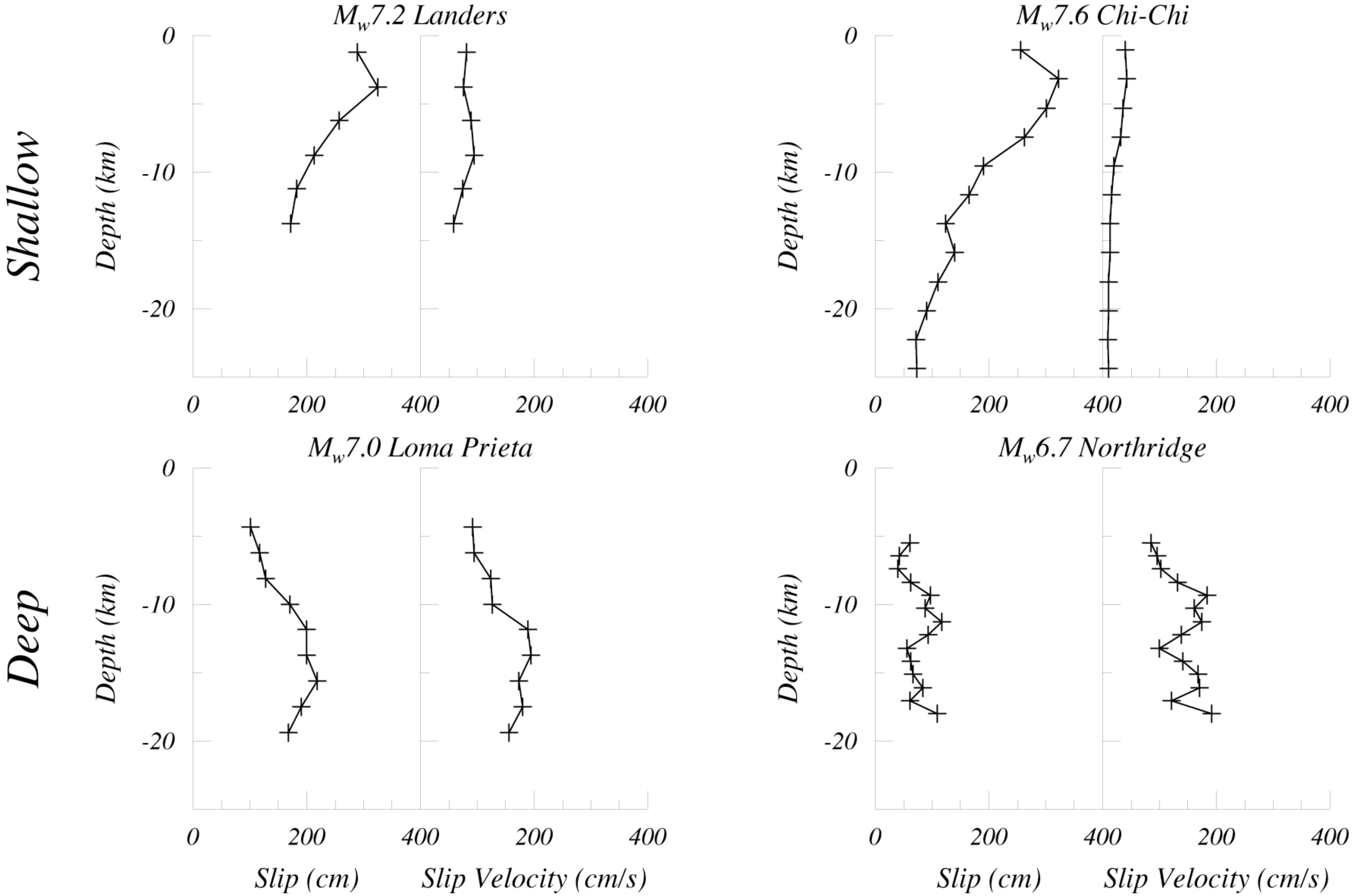








Shallow
Deep
Depth (km)
Slip (cm)
M_w8.9 Denali
M_w7.6 Chi-Chi
M_w7.4 Kocaeli
M_w7.2 Landers
M_w7.2 Hector Mine
M_w7.2 Tabas
M_w7.1Duzce
M_w7.0 Loma Prieta
M_w6.9 Kobe
M_w6.7 Northridge
0
-10
-20
-30
0
200
400
600



Shallow
Deep
M_w7.2 Landers
M_w7.6 Chi-Chi
M_w7.0 Loma Prieta
M_w6.7 Northridge
Depth (km)
0
-10
-20
0
200
400
Slip (cm)
Slip Velocity (cm/s)

Variations in Slip Along Strike

(Note: The slip and slip velocity were averaged along strike)

- Are there some places along strike where the ground motions from large earthquakes may be strong, e.g. due to a local deep asperity?
- Does a large surface faulting earthquake begin as a subsurface earthquake and then evolve along strike into a surface faulting earthquake?

  e.g. Chi-Chi: South to North
- Do some multi-segment earthquakes contain both surface and subsurface faulting segments?

  e.g. Kobe: Nojima; Suma/Suwayama

Variations In Slip With Depth

- According to the Characteristic Earthquake model, all surface faulting earthquakes on a given fault have the same surface slip
  - Do they also all have the same subsurface slip?
- Do smaller buried earthquakes (with no surface rupture) also occur on that fault?
  - If not, then surface faults always produce surface faulting and weak ground motions
  - If so, then surface faults may also produce subsurface faulting and strong ground motions

Comparison of Dynamic Rupture Parameters of Shallow and Buried Faulting Earthquakes

Defined surface rupture

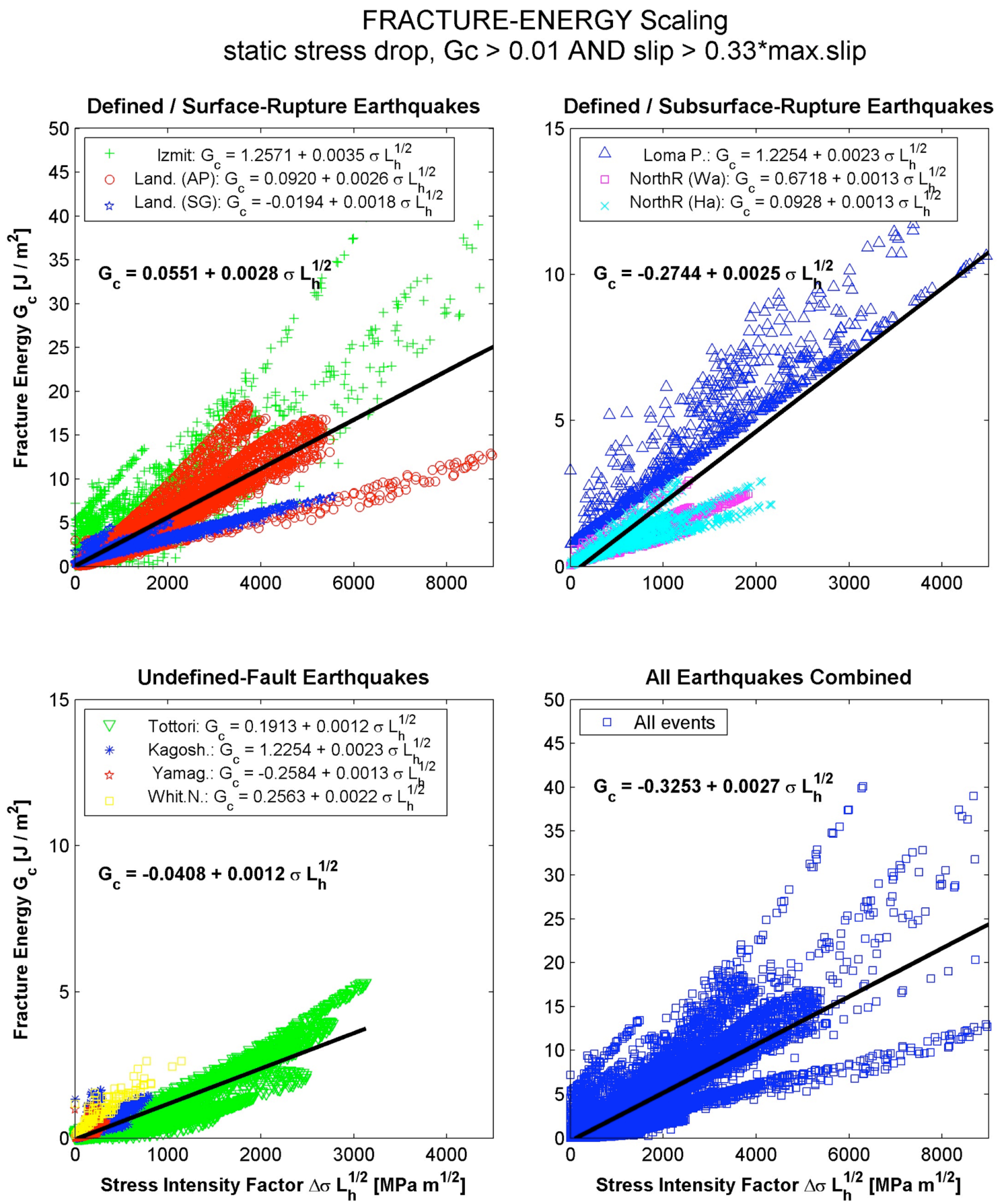
(1)	Izmit	Dalguer
(2)	Kobe	Song
(3)	Landers	Song
(4)	Landers	Pitarka

Defined subsurface rupture

(5)	Northridge	Guatteri
(6)	Northridge	Guatteri
(7)	Loma Prieta	Song

Undefined rupture

(8)	Tottori	Dalguer
(9)	Kagoshima	Dalguer
(10)	Yamaguchi	Dalguer
(11)	Whittier N.	Song



DYNAMIC SOURCE PARAMETERS

Fracture-Energy Scaling

Fracture Energy Scaling Based on STATIC STRESS DROP

Fracture Energy and Stress Intensity Factor

- Large for defined surface faulting events
- Small for defined subsurface and undefined faults

- Large fracture energy events may produce mainly long period seismic radiation
- This is consistent with surface faulting events producing weak high frequency ground motions

Features of Rupture in the Shallow Part of Fault (0 – 5 km depth)

- Controlled by velocity strengthening
- Larger slip weakening distance Dc
- Larger fracture energy i.e.much energy absorbed from the crack tip
- Lower rupture velocity
- Lower slip velocity
- Lower ground motions than buried faulting events

Implications for Seismic Hazards

- Need separate ground motion models for shallow and buried faulting
- These models might each have lower aleatory variability, and the shallow faulting model will have much lower median values
- Need criteria for predicting surface and/or subsurface faulting
- Ground motion amplitudes from shallow faulting earthquakes may have been overestimated in current seismic hazard estimates