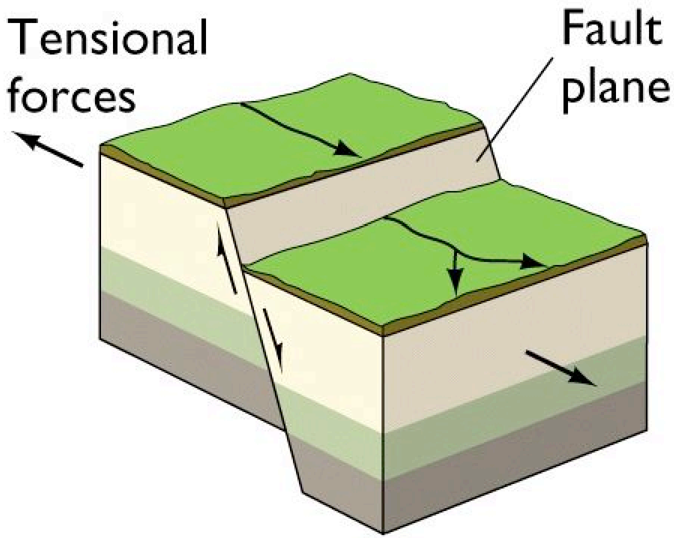
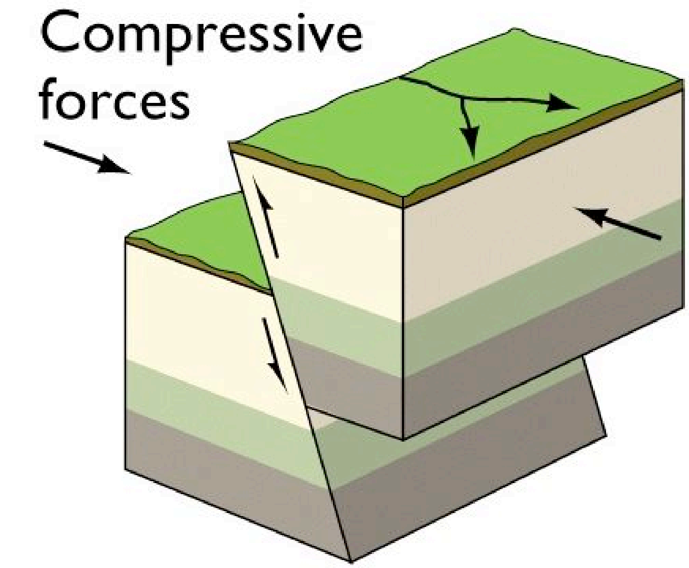
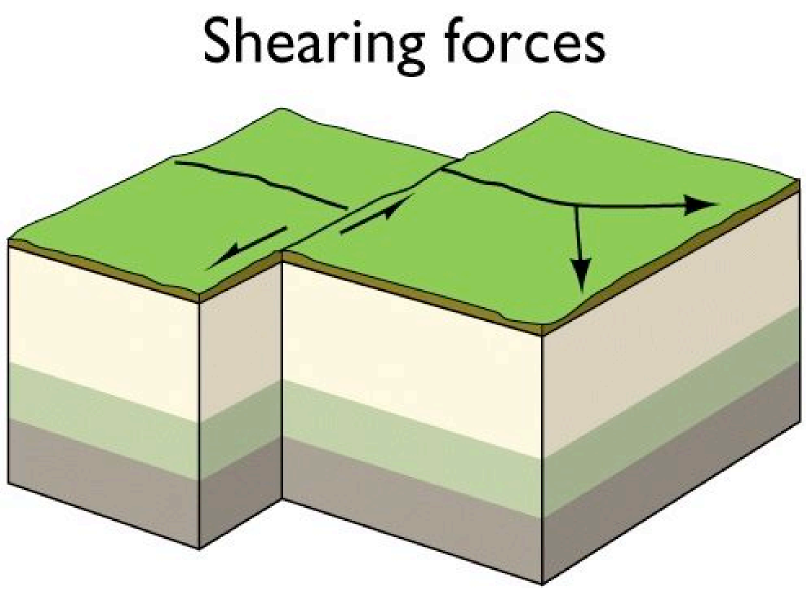
Normal Fault



Thrust (reverse) Fault

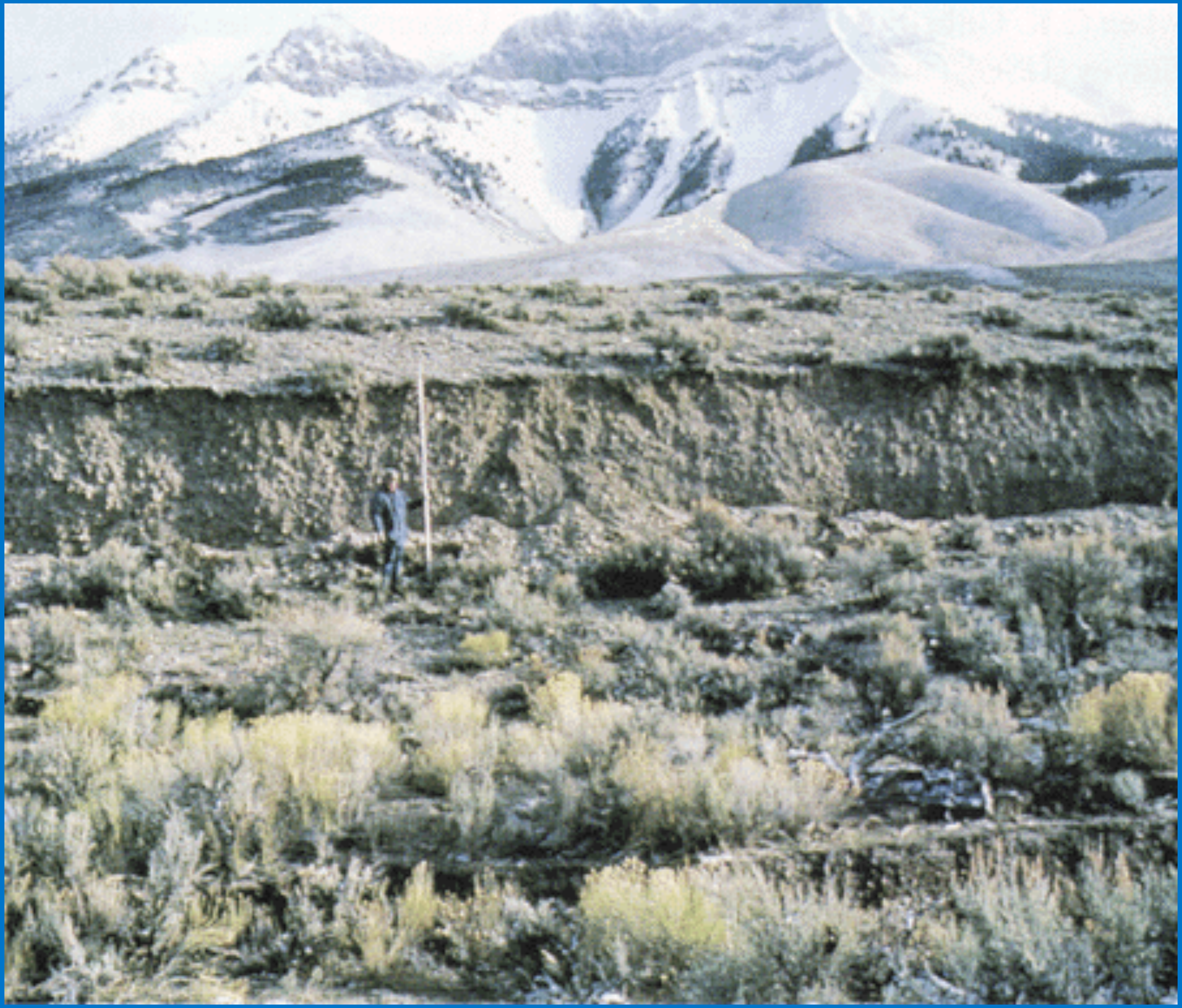


Strike-slip Fault



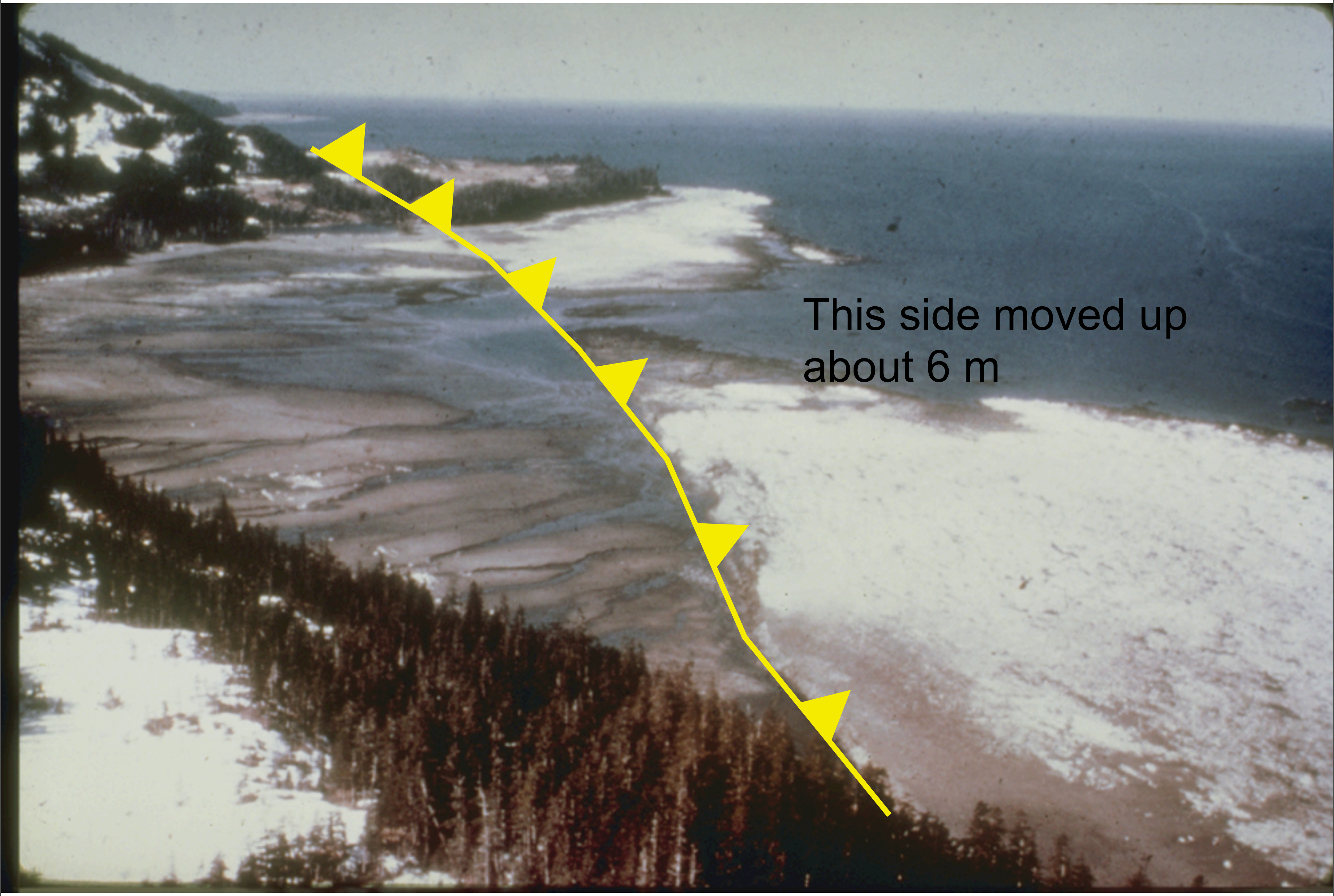
Normal Fault Surface Scarp

Borah Peak, Idaho M 7.3
October 28, 1983



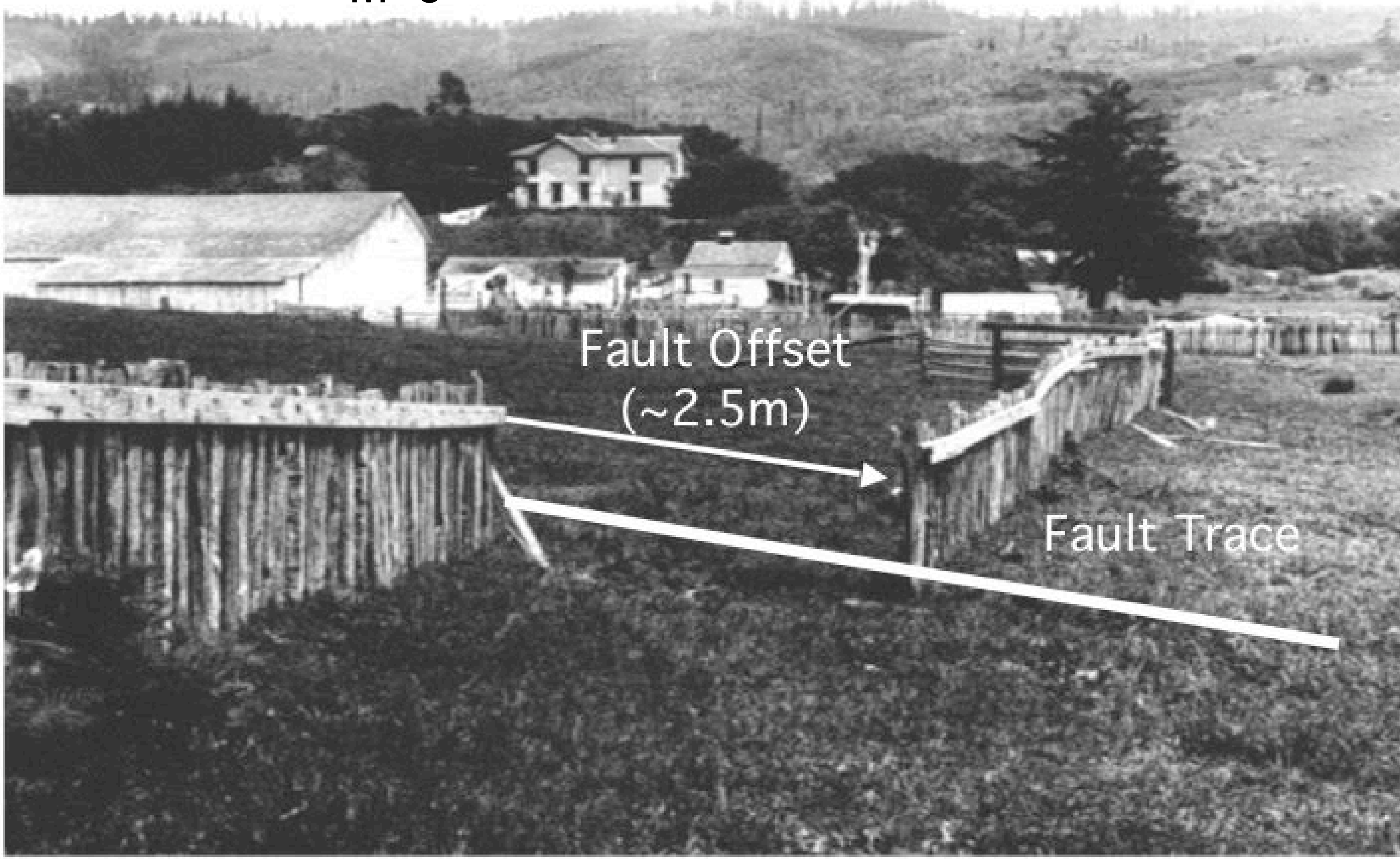
USGS

1964 Alaskan Earthquake (M~9.2)



1906 San Francisco Earthquake

M~8



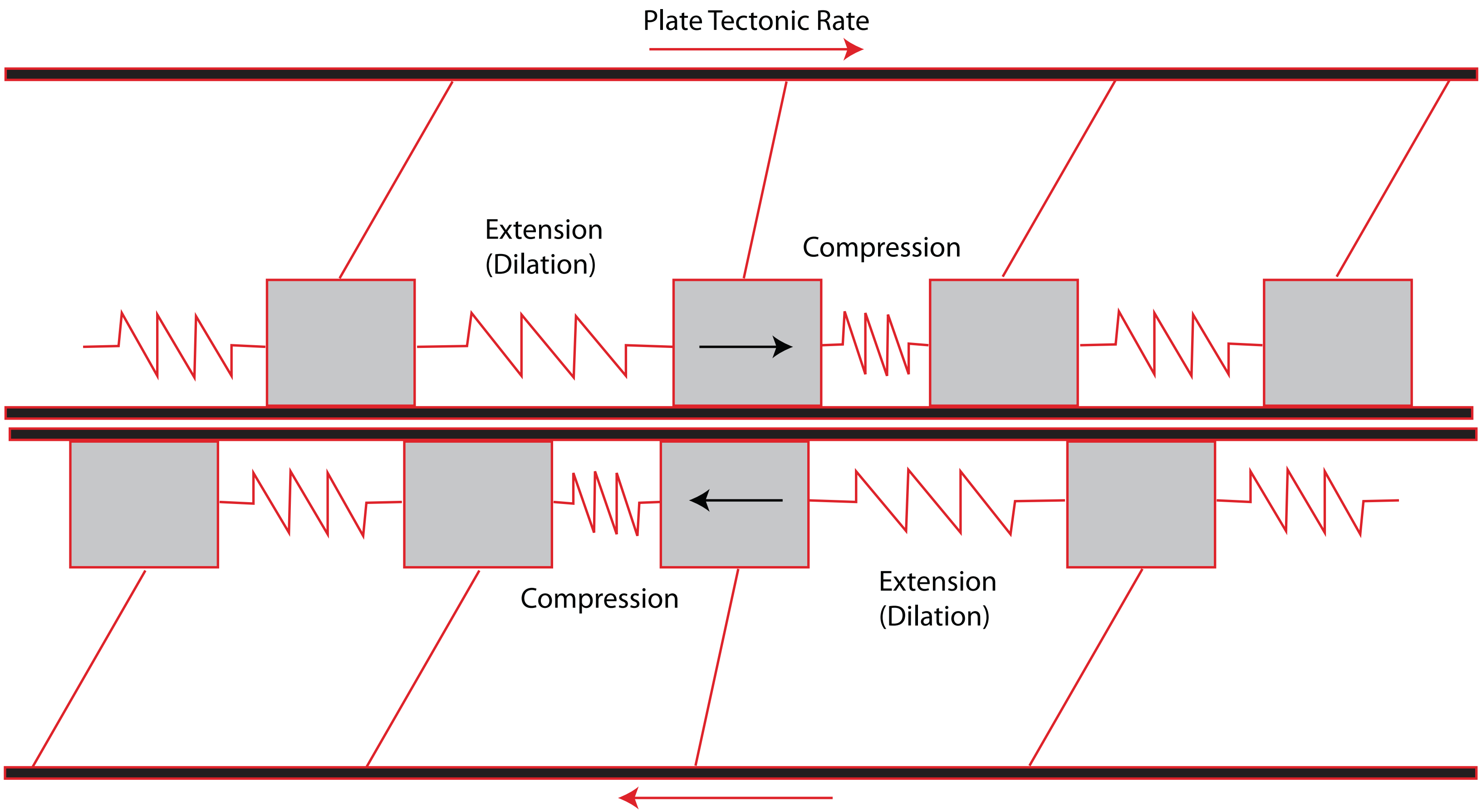


Plate Tectonic Rate
Extension
(Dilation)
Compression
Compression
Extension
(Dilation)

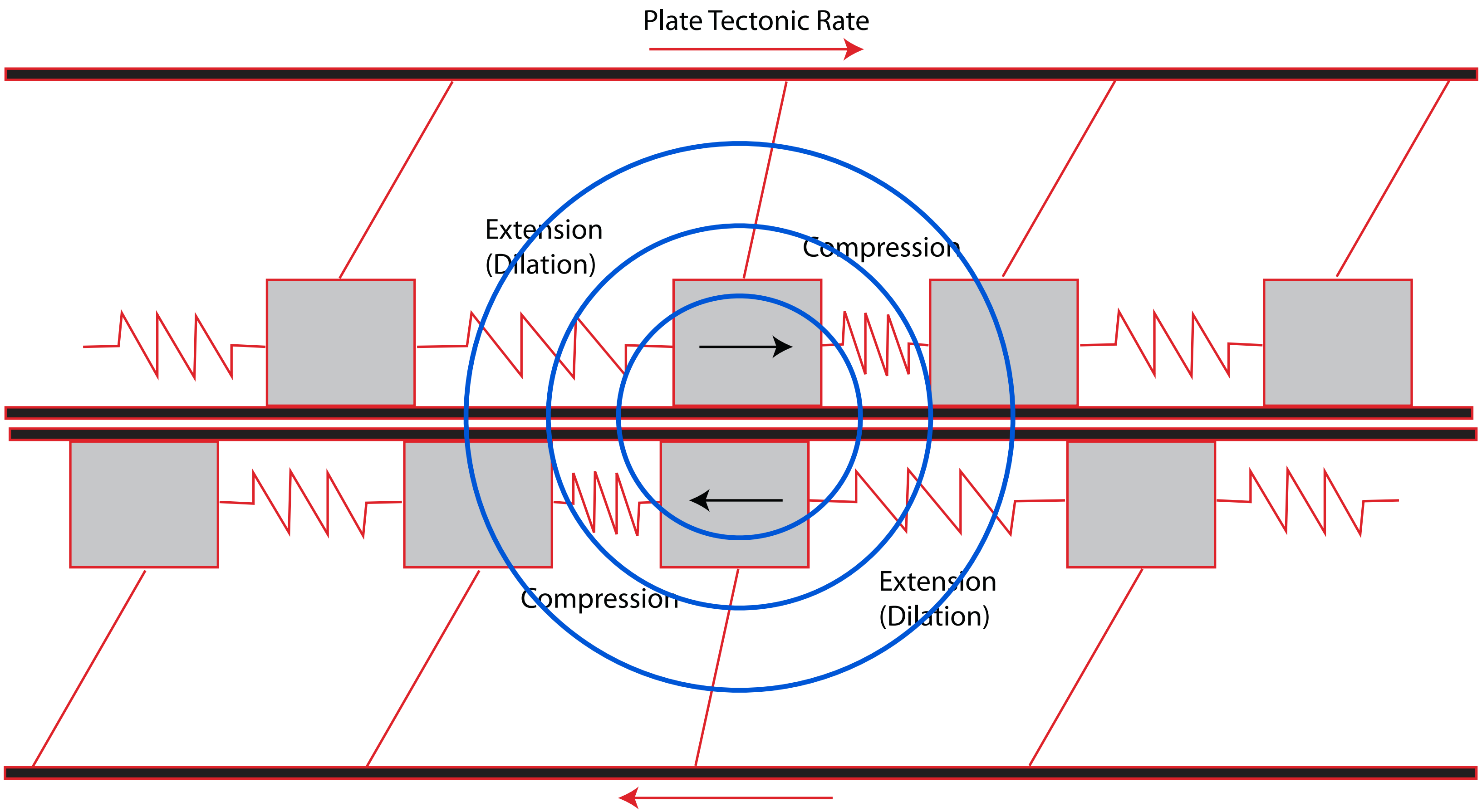


Plate Tectonic Rate
Extension
(Dilation)
Compression
Compression
Extension
(Dilation)

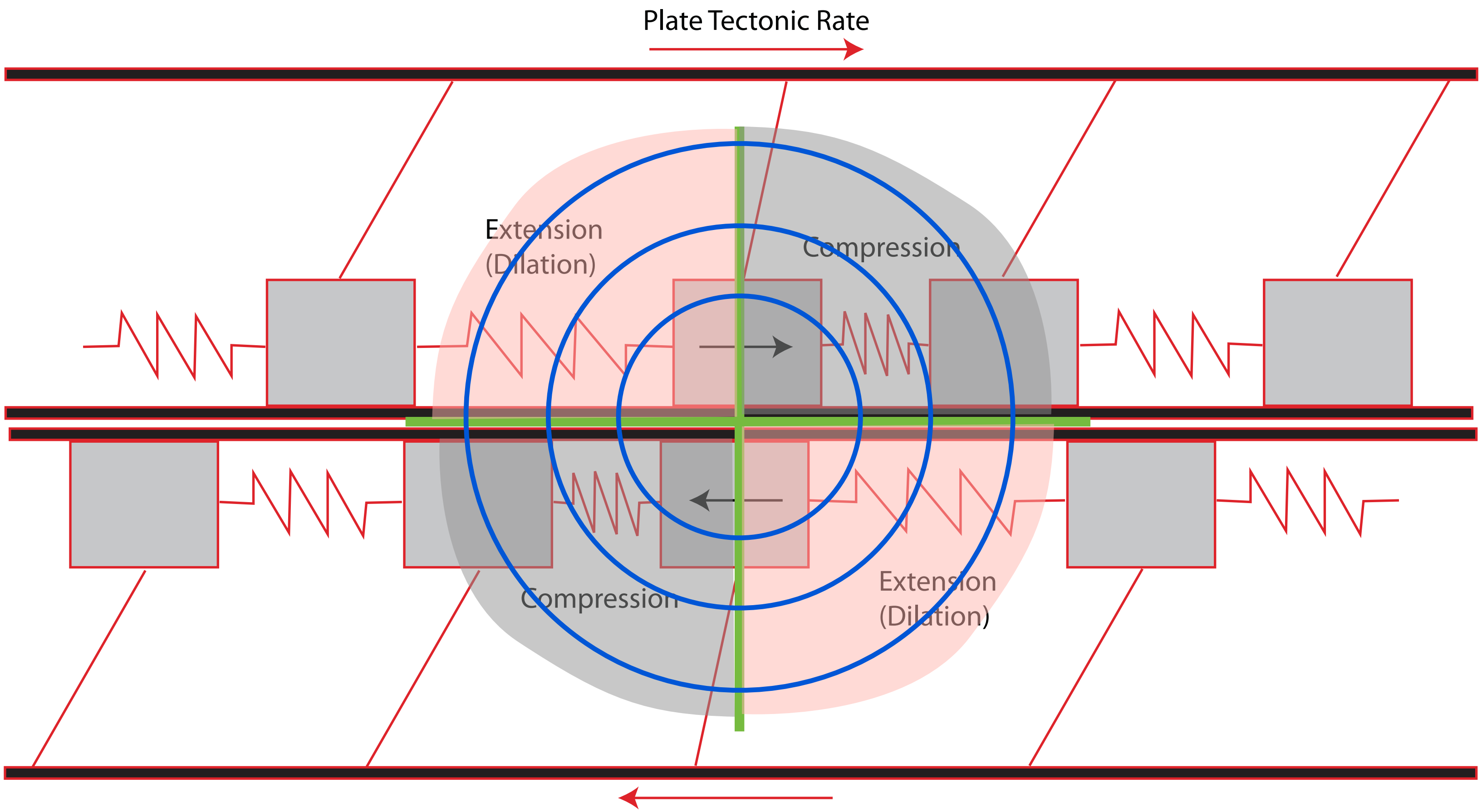
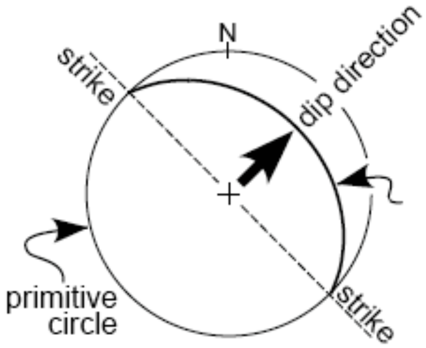
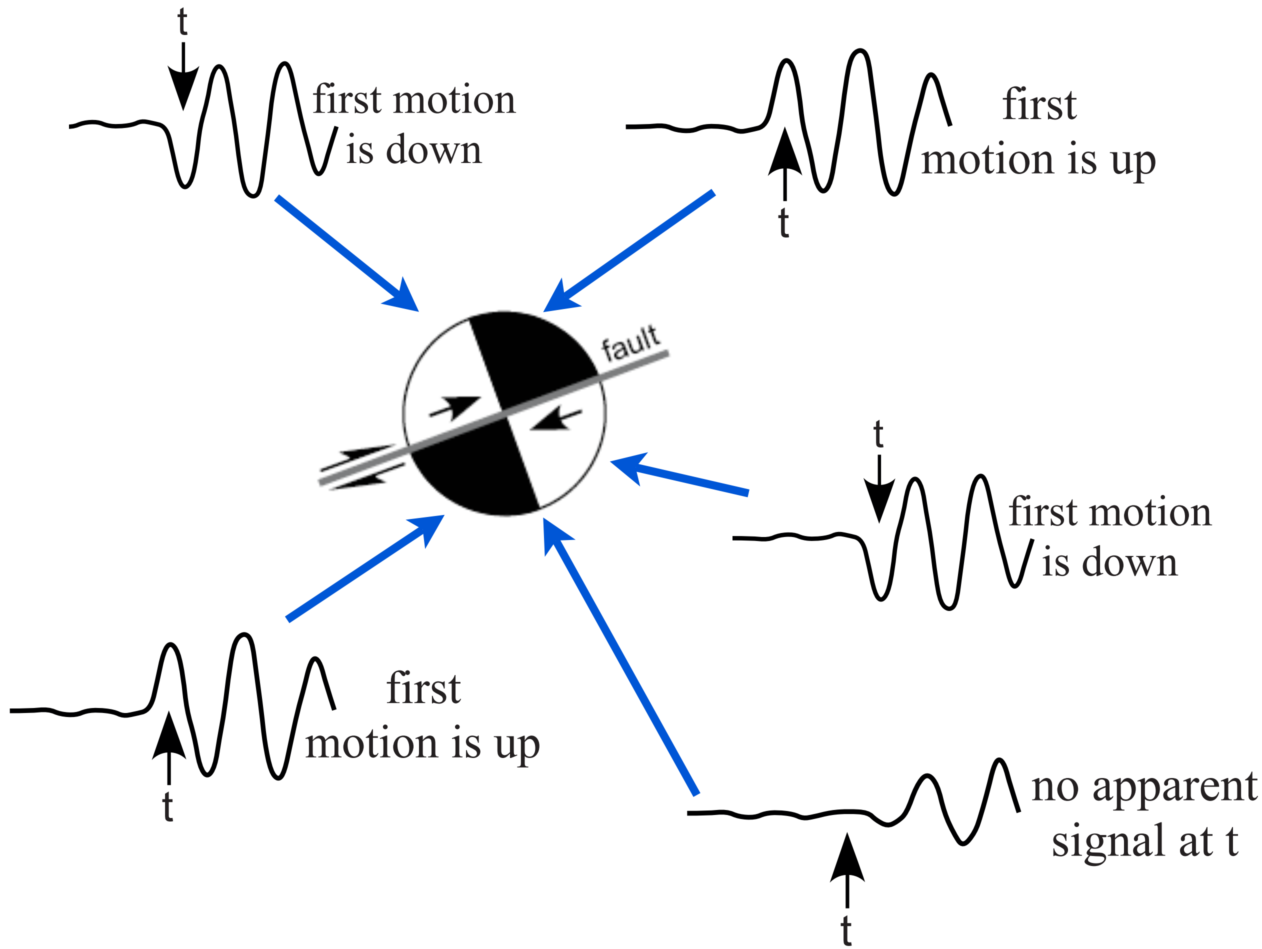
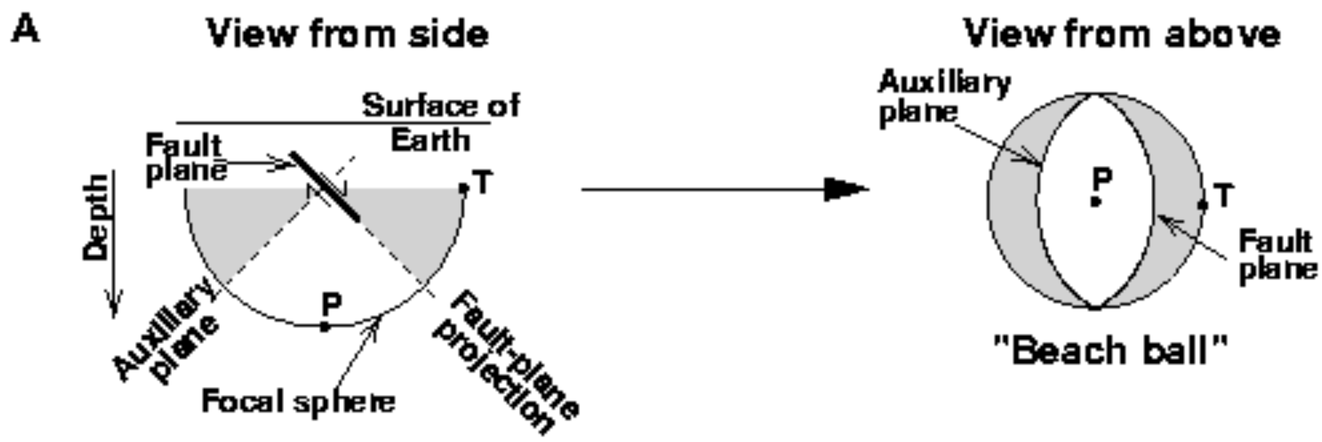


Plate Tectonic Rate
Extension
(Dilation)
Compression
Compression
Extension
(Dilation)


N
strike
dip direction
great circle
primitive circle
strike


t
first motion is down
first motion is up
t
fault
t
first motion is down
first motion is up
t
no apparent signal at t
t

Schematic diagram of a focal mechanism



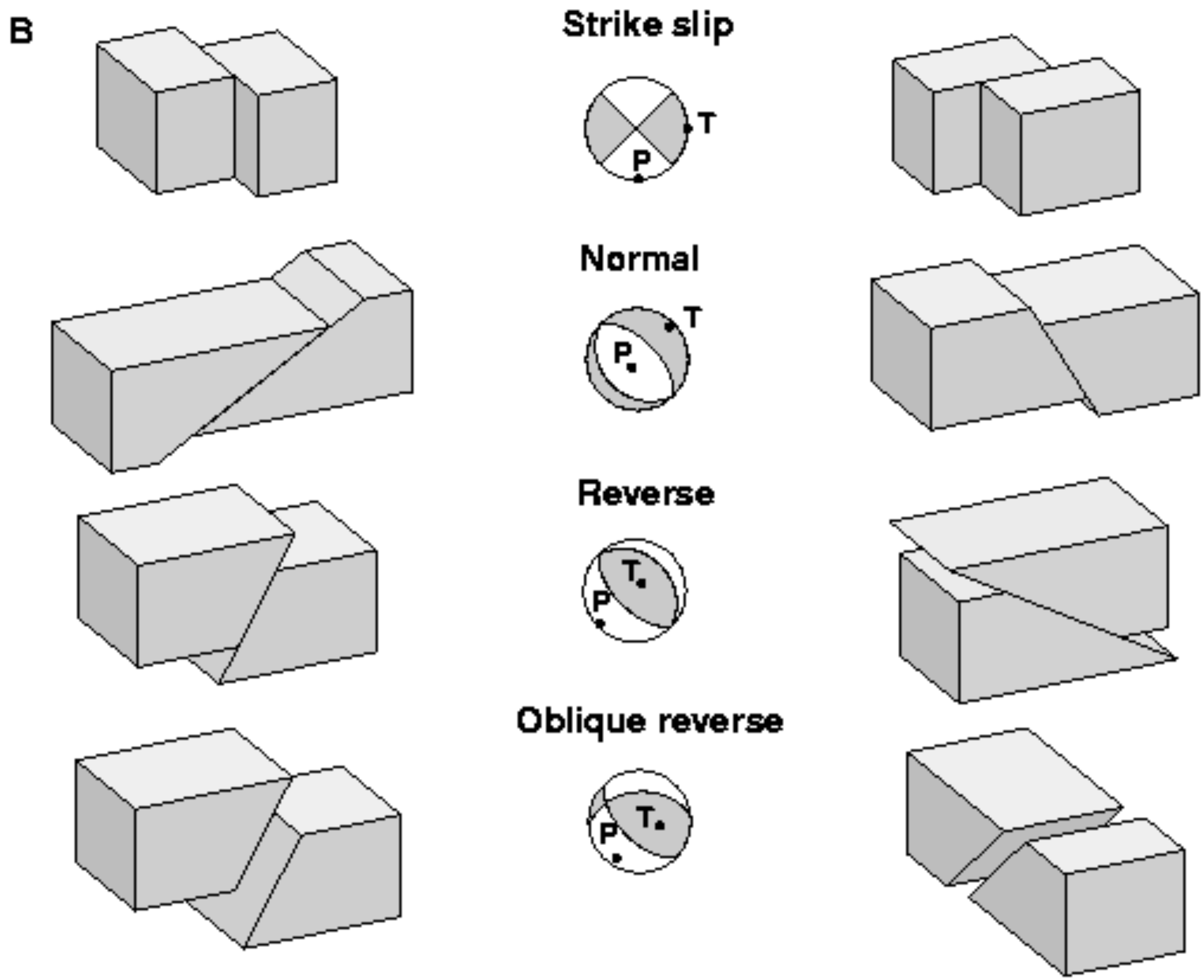

B
Strike slip
T
P
Normal
T
P
Reverse
T
P
Oblique reverse
T
P

Fig. 2. Locations of principal earthquakes and aftershocks. Stars show the hypocenters of the 23 October M_W 6.7 and 3 November M_W 7.9 earthquakes, with double-difference relocated aftershocks shown in green and orange, respectively. Focal mechanisms show the first motion solution for the M_W 6.7 earthquake and the 3 subevents (sub1 to -3) determined for the M_W 7.9 earthquake. Mapped surface rupture shown as heavy magenta line; red lines indicate other faults. The inset cross section shows schematic faults and $M_L \geq 2.5$ aftershocks in the bracketed zone across the Susitna Glacier (SG) thrust, inferred to splay off the Denali (Den) fault. Cross, mainshock.

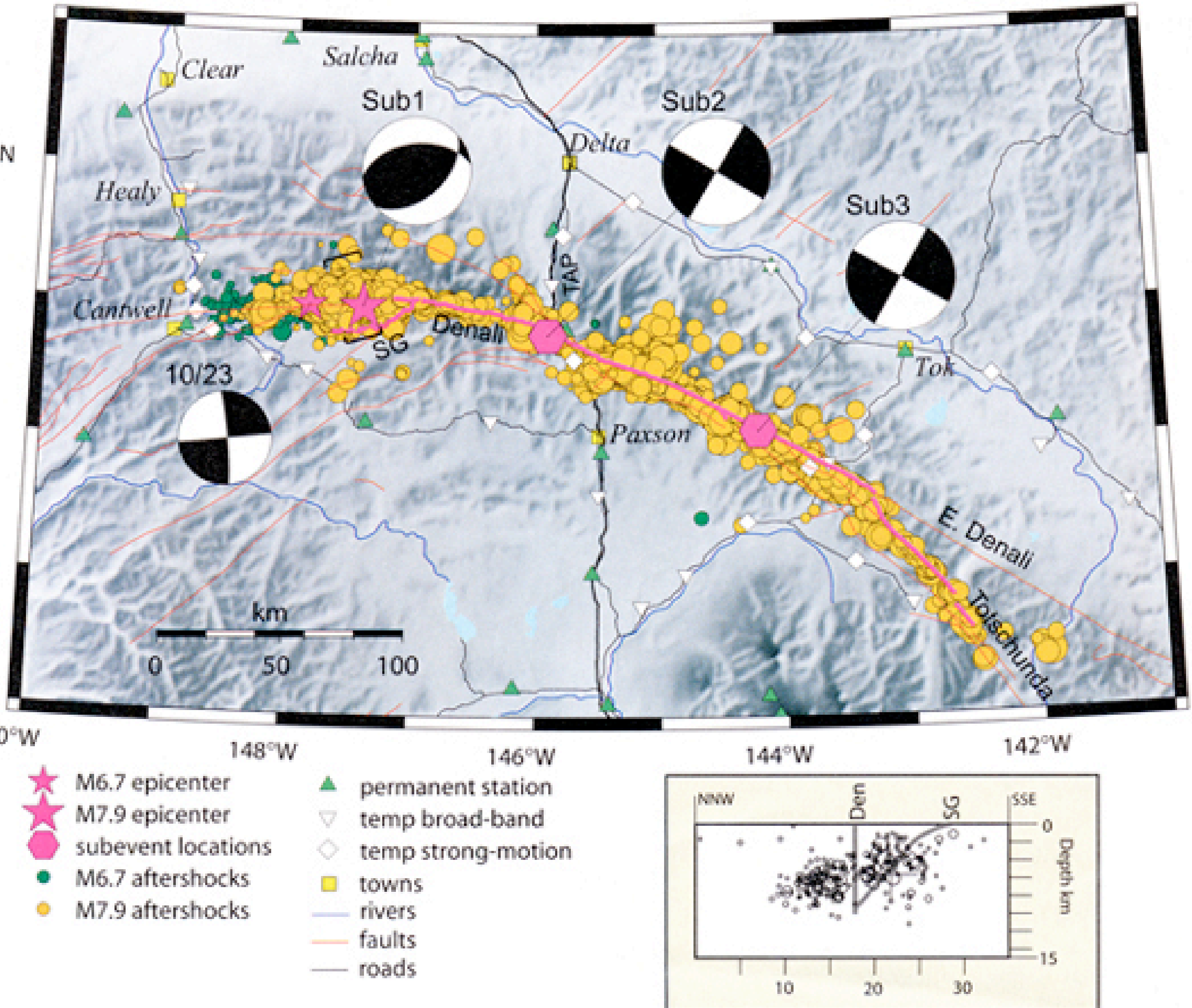
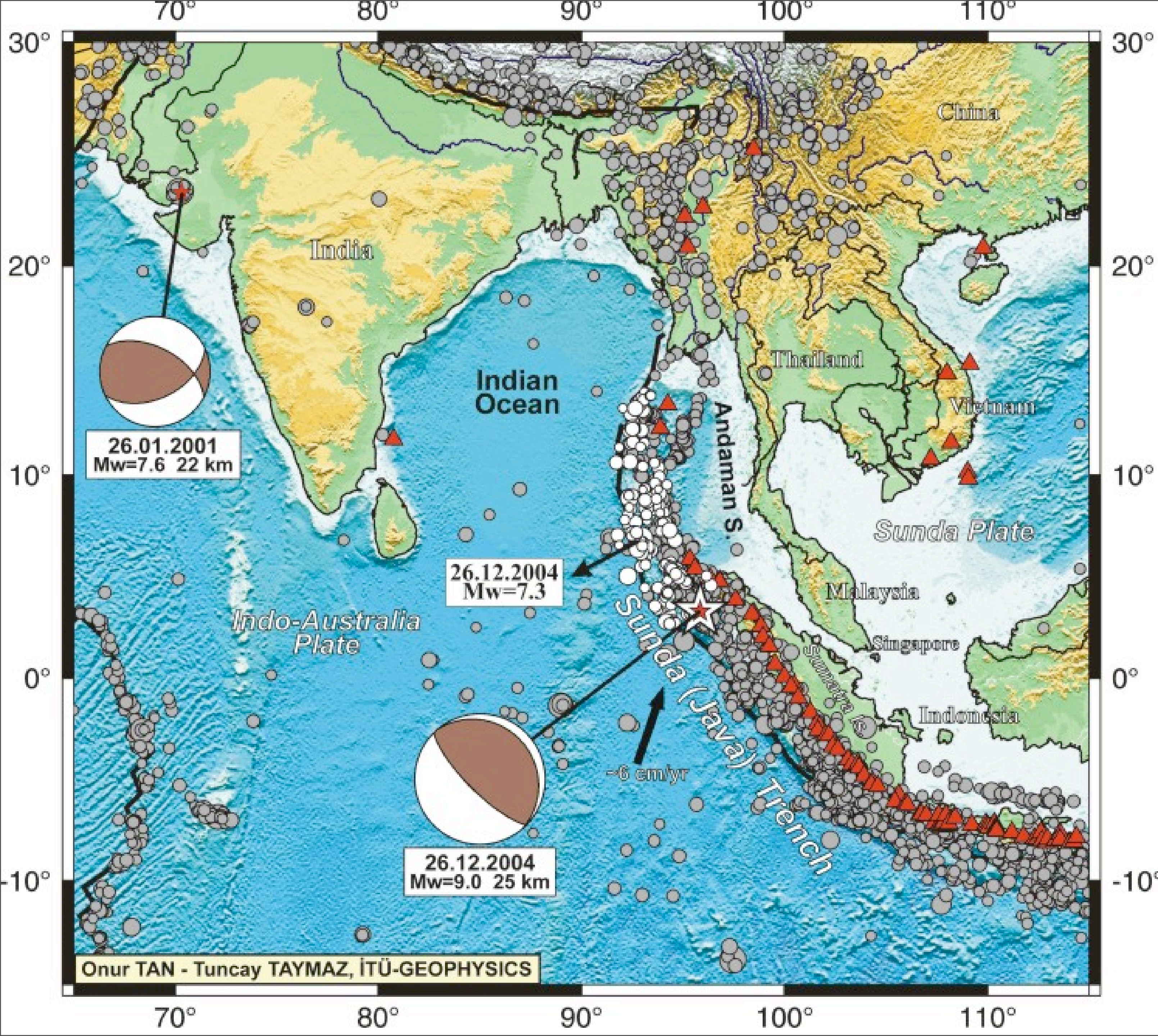


Figure 2 from Donna Eberhart-Phillips, et al., "The 2002 Denali Fault Earthquake, Alaska: A Large Magnitude, Slip-Partitioned Event", Science, Vol. 300 (May 16, 2003), pp. 1113-1118.

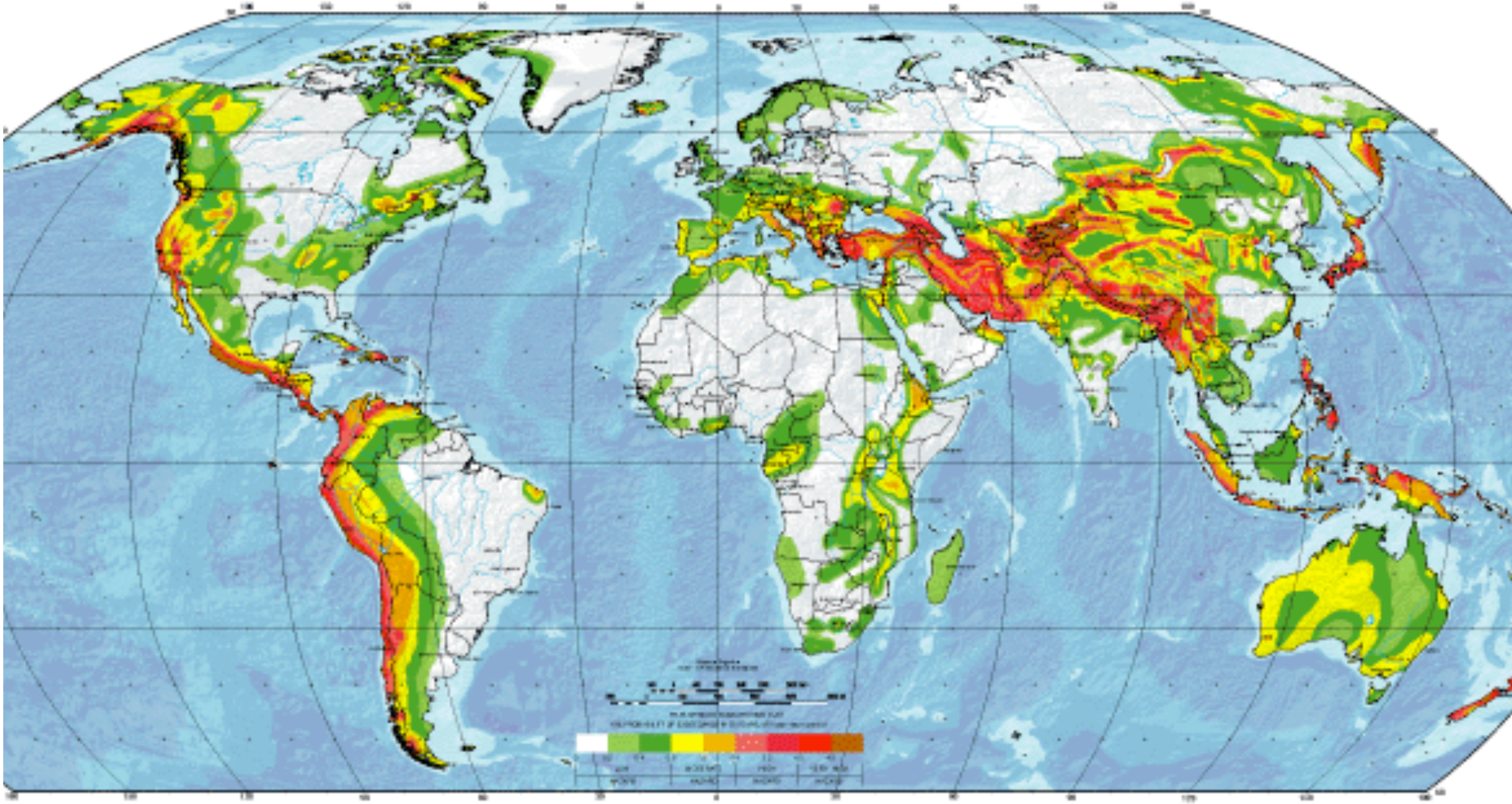


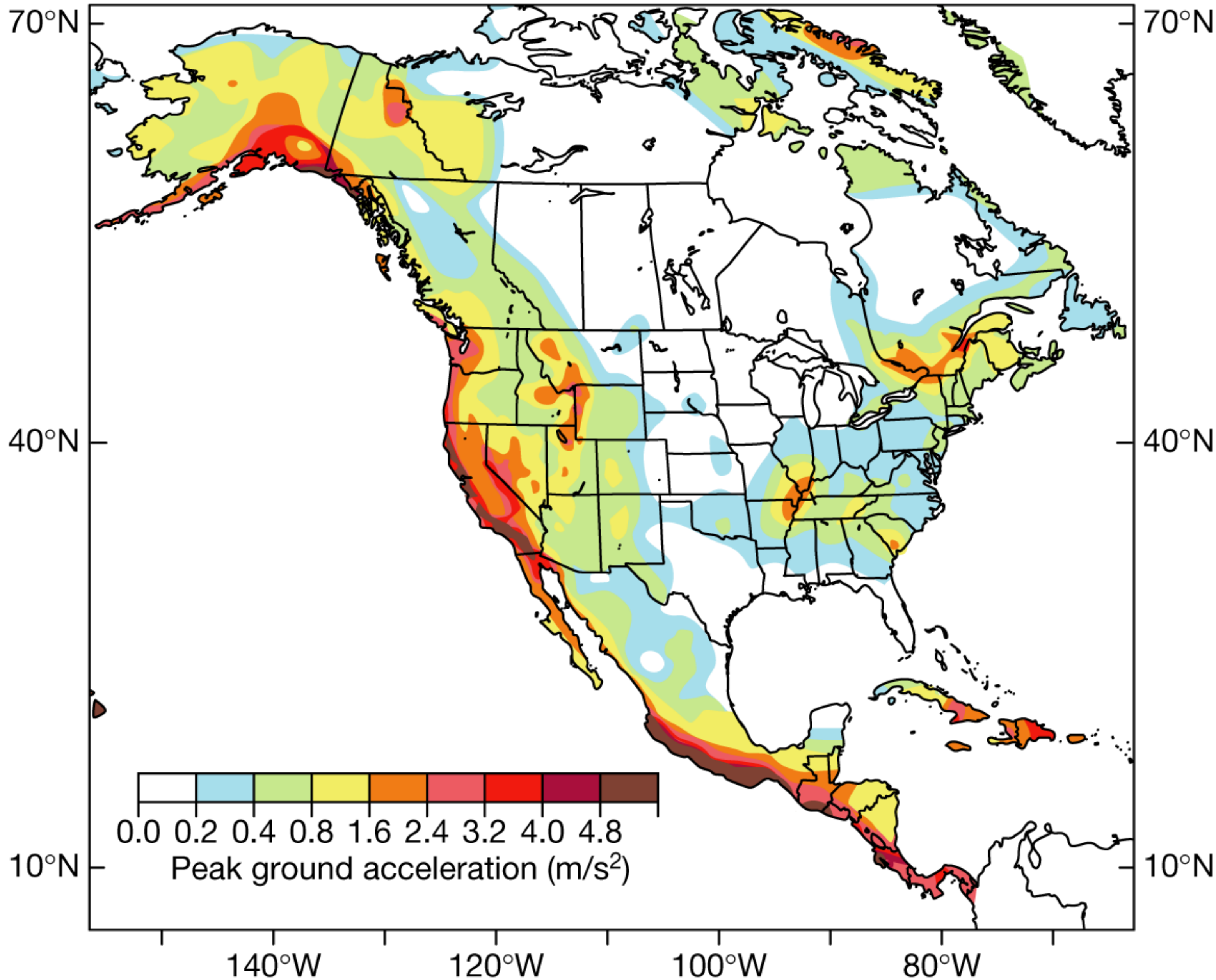
70°
80°
90°
100°
110°
30°
20°
10°
0°
-10°
China
India
Indian Ocean
Andaman S.
Thailand
Vietnam
Sunda Plate
Malaysia
Singapore
Indonesia
26.01.2001
Mw=7.6 22 km
26.12.2004
Mw=7.3
Indo-Australia Plate
Sunda (Java) Trench
~6 cm/yr
26.12.2004
Mw=9.0 25 km
Onur TAN - Tuncay TAYMAZ, İTÜ-GEOPHYSICS

GLOBAL SEISMIC HAZARD MAP

Produced by the Global Seismic Hazard Assessment Program (GSHAP),
a demonstration project of the UN/International Decade of Natural Disaster Reduction, conducted by the International Lithosphere Program.

Global map assembled by D. Giardini, G. Grünthal, K. Shedlock, and P. Zhang
1999





70°N
70°N
40°N
40°N
10°N
10°N
140°W
120°W
100°W
80°W
0.0 0.2 0.4 0.8 1.6 2.4 3.2 4.0 4.8
Peak ground acceleration (m/s²)

Figure 8.30a

What Controls the Level of Shaking?

- **Magnitude**
  - More energy released
- **Distance**
  - Shaking decays with distance
- **Local soils**
  - amplify the shaking

USGS

Earthquake Effects - Ground Shaking

Loma Prieta, CA 1989

USGS

KGO-TV News ABC-7

Earthquake Effects - Ground Shaking

Kobe, Japan 1995

USGS

Figure 8.23b

Figure 8.23c

Earthquake of May 31, 1970, Huaraz, Peru. The magnitude 7.8 earthquake killed 66,794 and caused $250 million in property damage. Several towns were almost totally destroyed. This earthquake, with complicating factors of landslides and floods, was one of the largest disasters ever to occur in the Southern Hemisphere.

Why do buildings/bridges collapse?

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1. Ground shaking produces forces that exceed the strength of the structure — or really, the ability of a structure to deform without breaking. So, strong shaking and weak or rigid structures are the problem here. Wood frame houses are good, masonry houses are bad.

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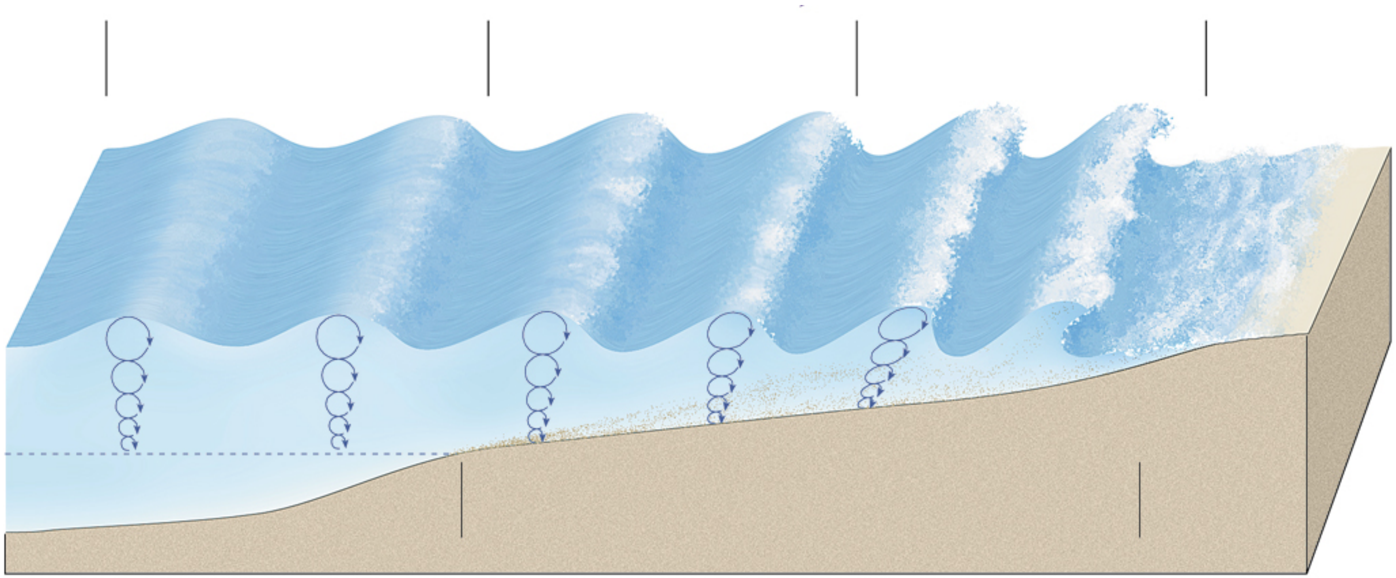
2. Seismic wave frequencies match resonant frequencies of buildings, leading to constructive interference

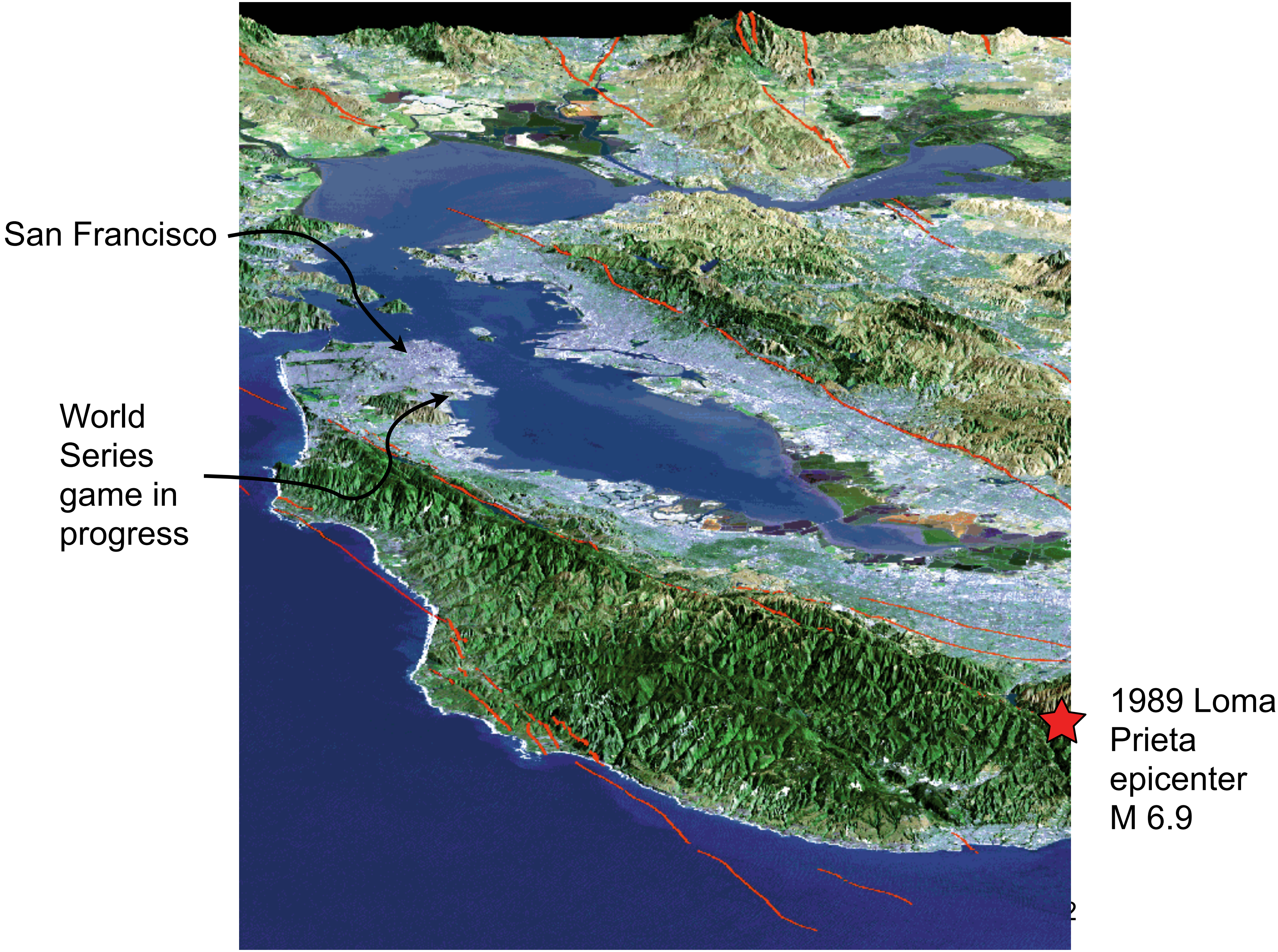
3. Intensity of shaking increases in weak materials.

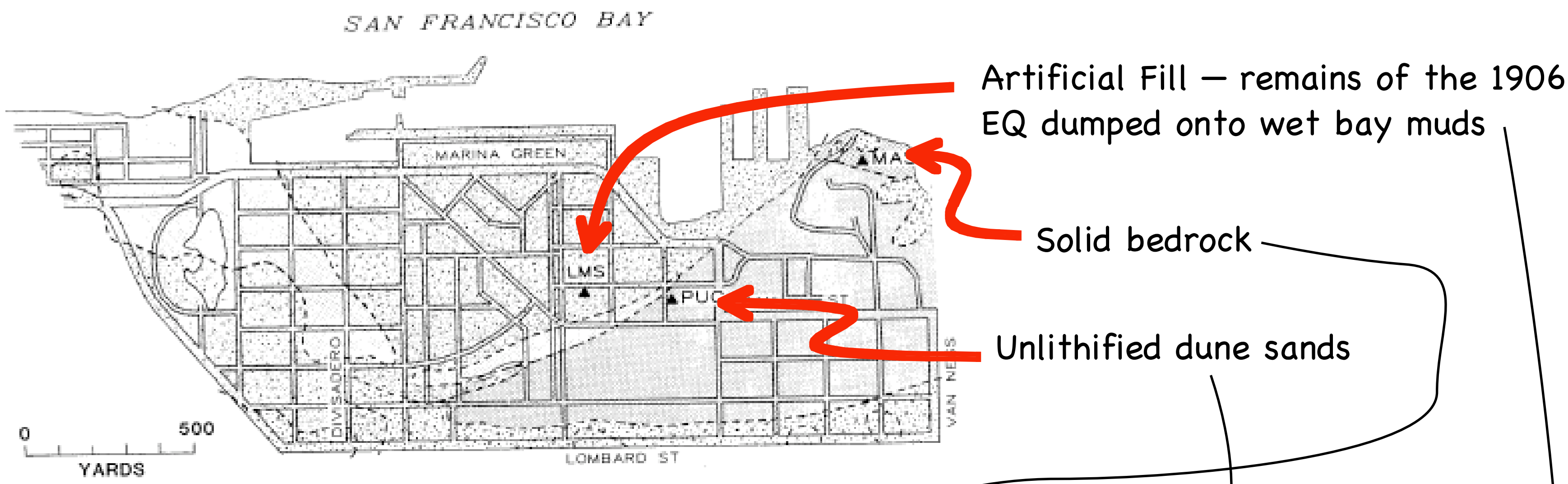
4. Strong shaking can liquefy loose, water-saturated deposits, making them behave as fluids; buildings on liquefied materials are in trouble.

The amplitude of seismic waves is also important and this is a function of magnitude, seismic velocity and focusing effects that concentrate seismic energy.

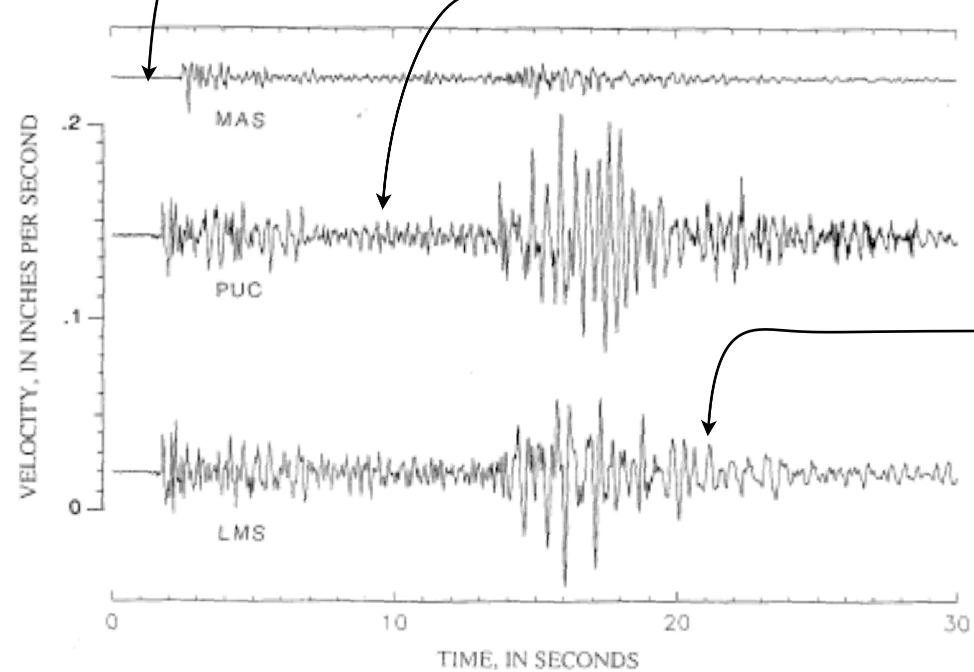
When a waves passes from fast to slow material, the wavelength decreases, and the amplitude increases -- just like a water wave approaching shore.




San Francisco
World Series game in progress
1989 Loma Prieta epicenter M 6.9

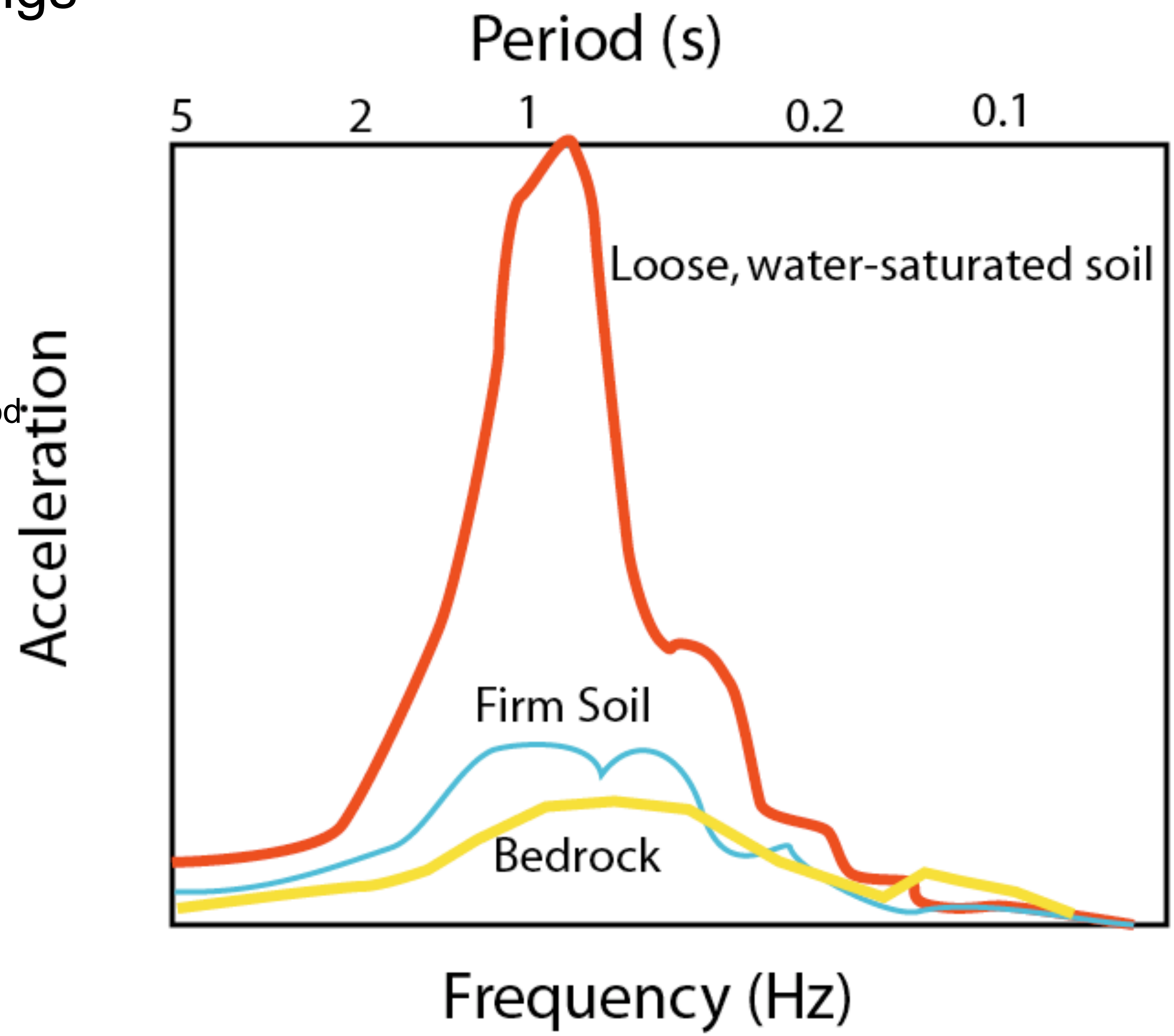


Aftershocks from the 1989 Loma Prieta EQ



Higher accelerations mean larger forces acting on buildings

Building Height	Resonant Period
2 story	.2 sec
10 story	1 sec
20 story	2 sec
30 story	3 sec




was 11 stories
18 stories
Hotel de Carlo

Focusing

The rupture extent and the surrounding topography and Earth structure can focus seismic energy, subjecting some areas to much greater damage.

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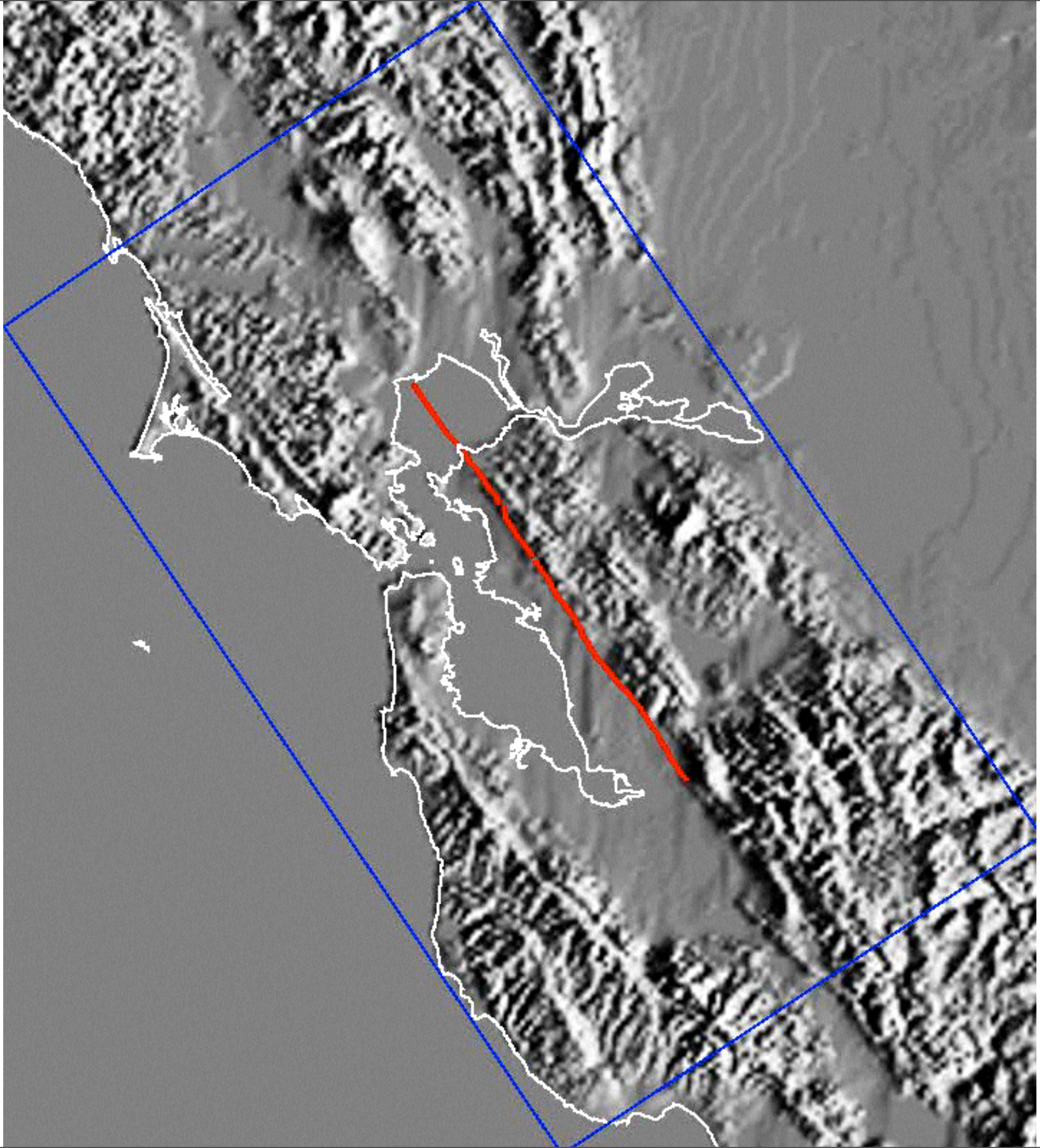
The rupture extent and the surrounding topography and Earth structure can focus seismic energy, subjecting some areas to much greater damage.



Birdseye View of the Ruins of San Francisco.

Supplement to the San Francisco Examiner, May 13, 1906.

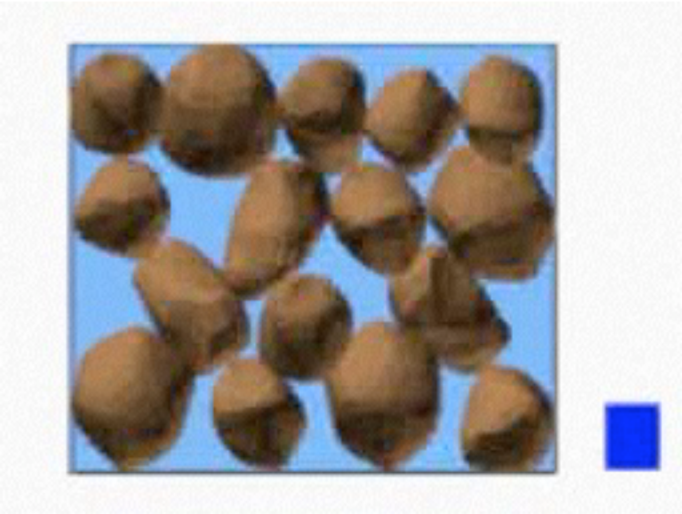
Liquefaction

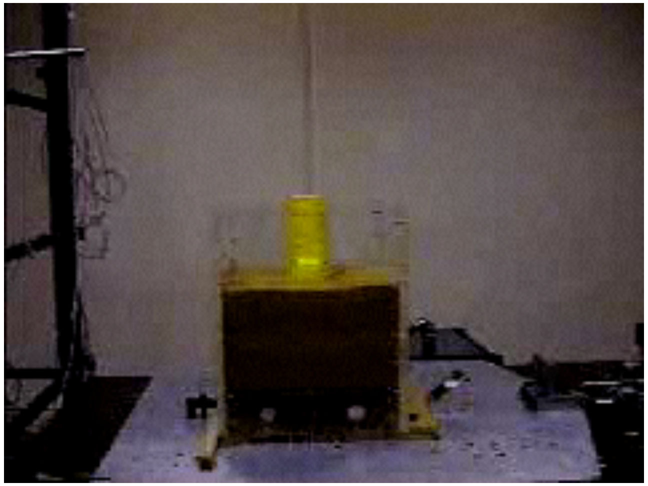
Sand Volcano resulting from liquefaction

When the sand grains are in contact,their weight is supported from grain to grain, and none of their weight is carried by the water.

But if jostled and shaken quickly, the grains loose contact with one another and their weight is carried by the water, so the water pressure shoots up and keeps the grains apart. At this point, the whole mix of sediment and water is a fluid that has no strength.

When the sand grains are in contact,their weight is supported from grain to grain, and none of their weight is carried by the water.





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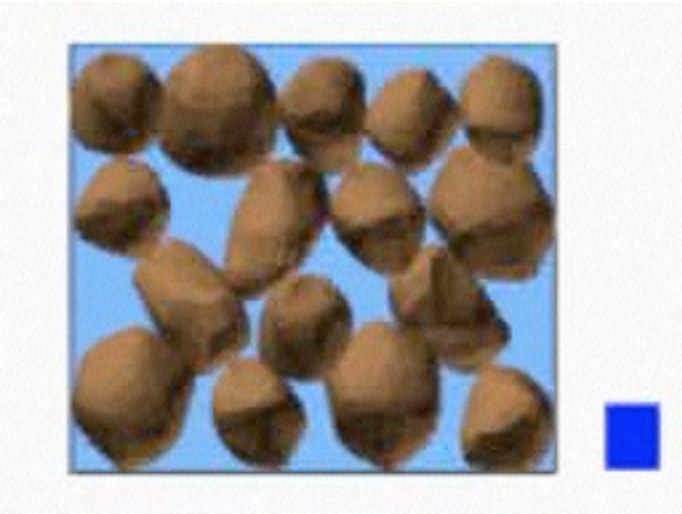

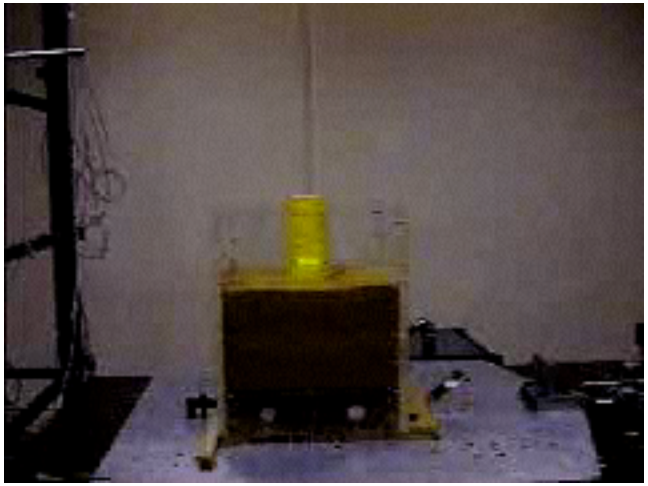

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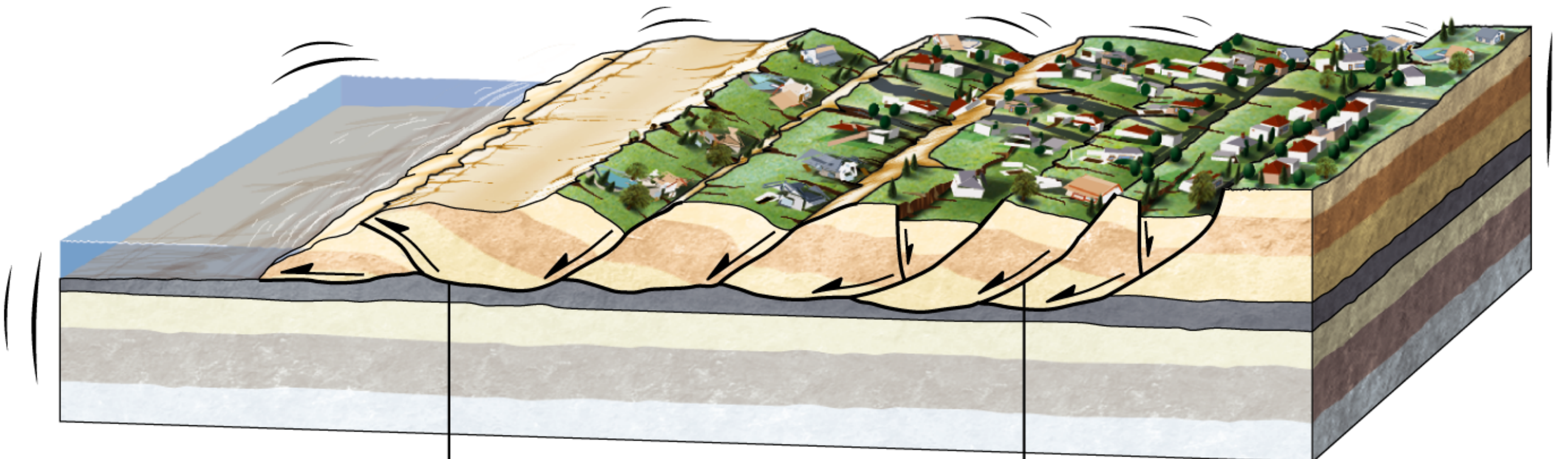
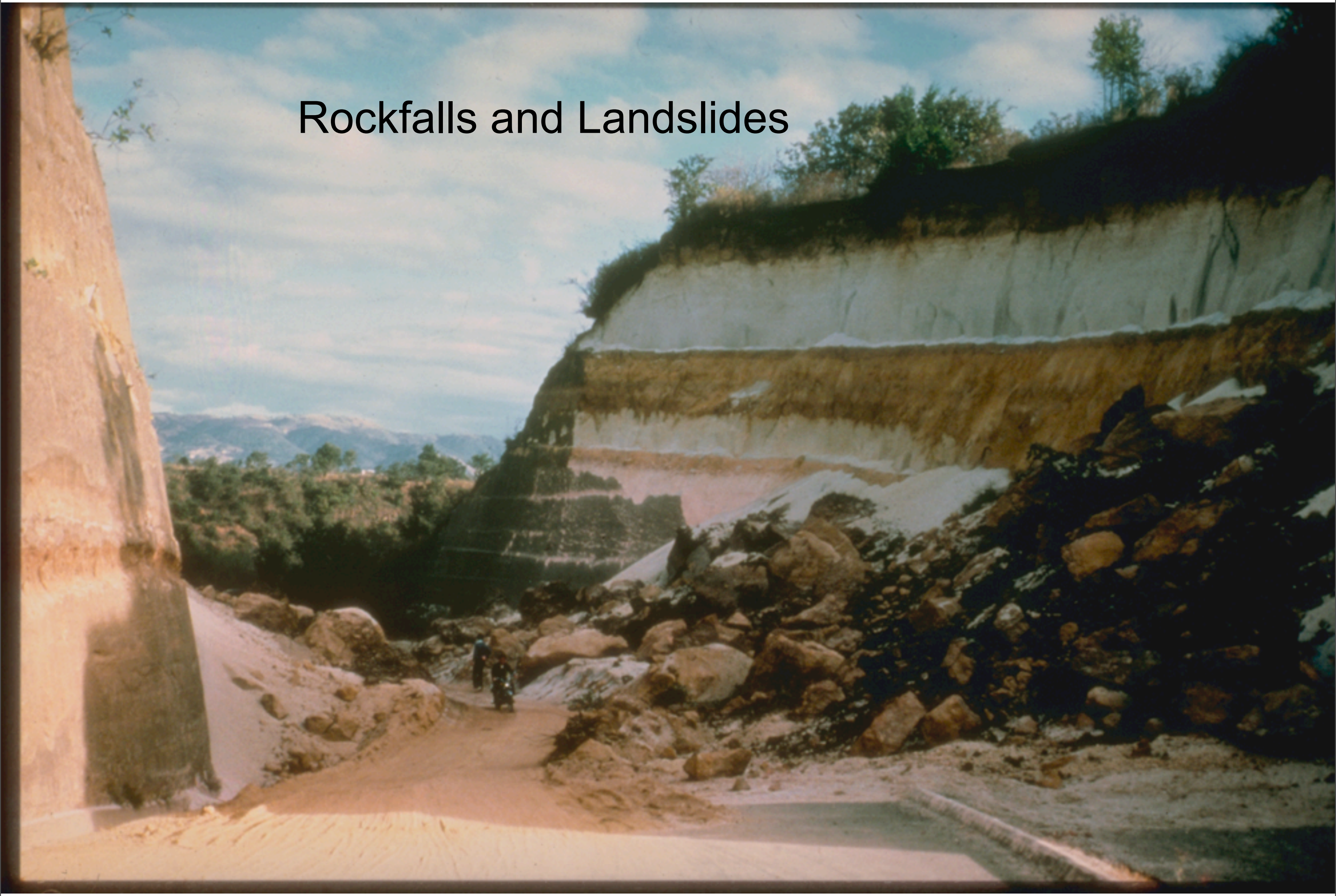


Figure 8.25a

Figure 8.25b

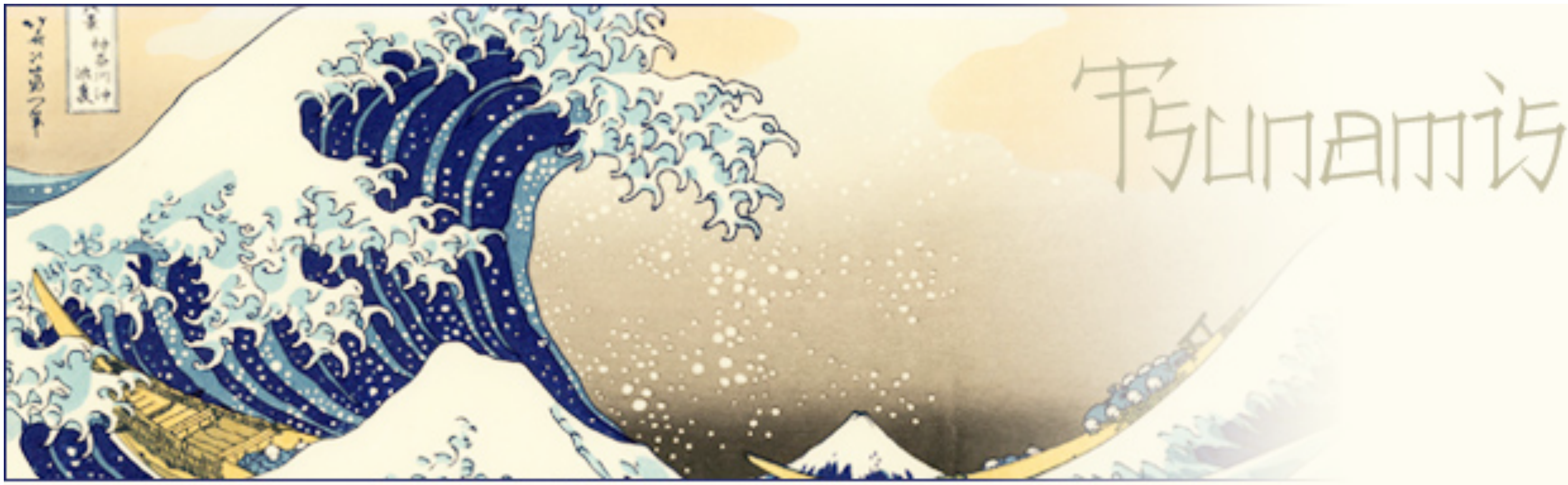

Rockfalls and Landslides

huge landslides from the M 7.9 Denali earthquake

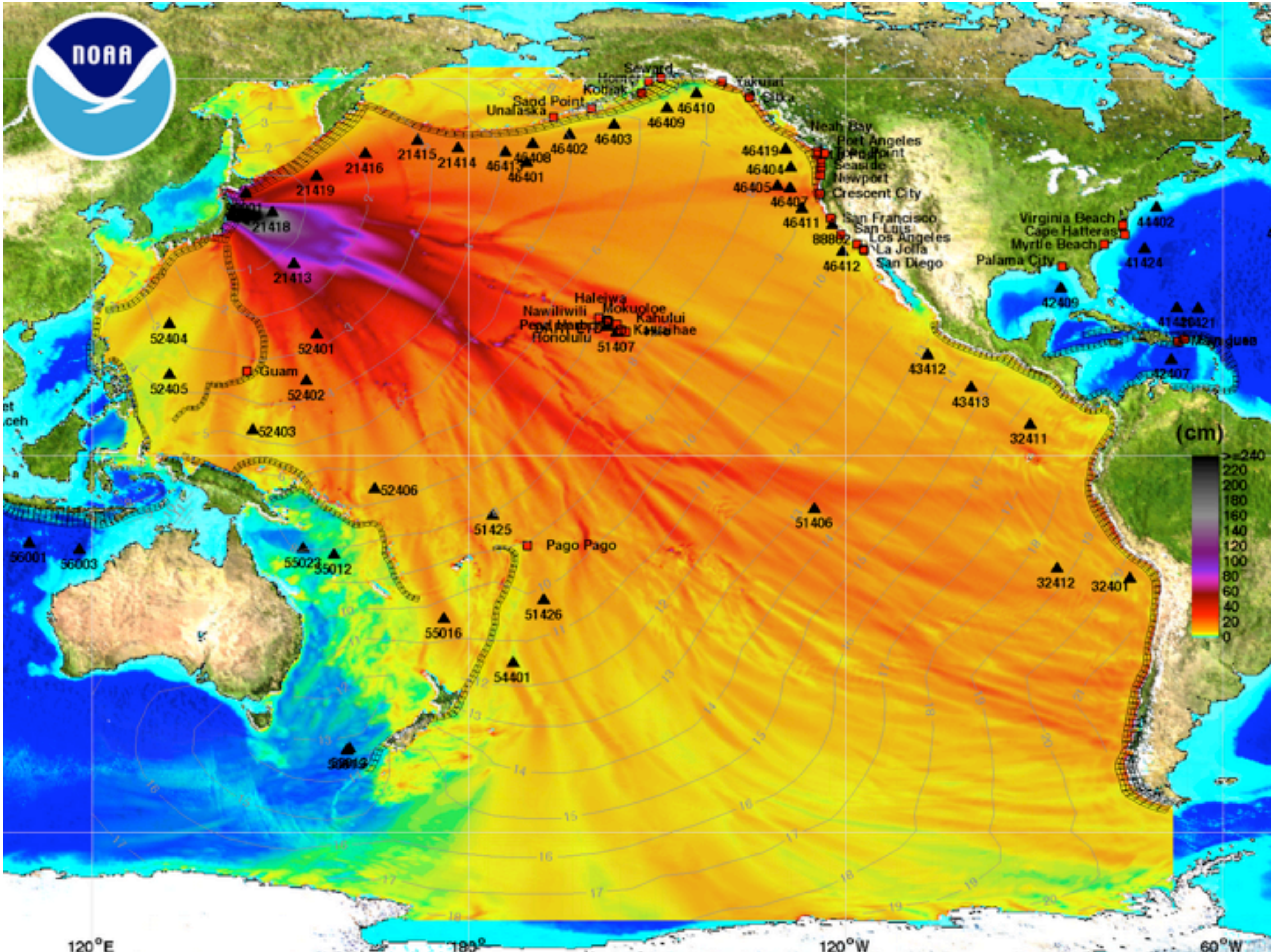
Summary of Seismic Hazards

Building Collapse
- *poor design*
- *strong shaking*
  - *resonance, amplification, topographic focusing*
- *liquefaction*

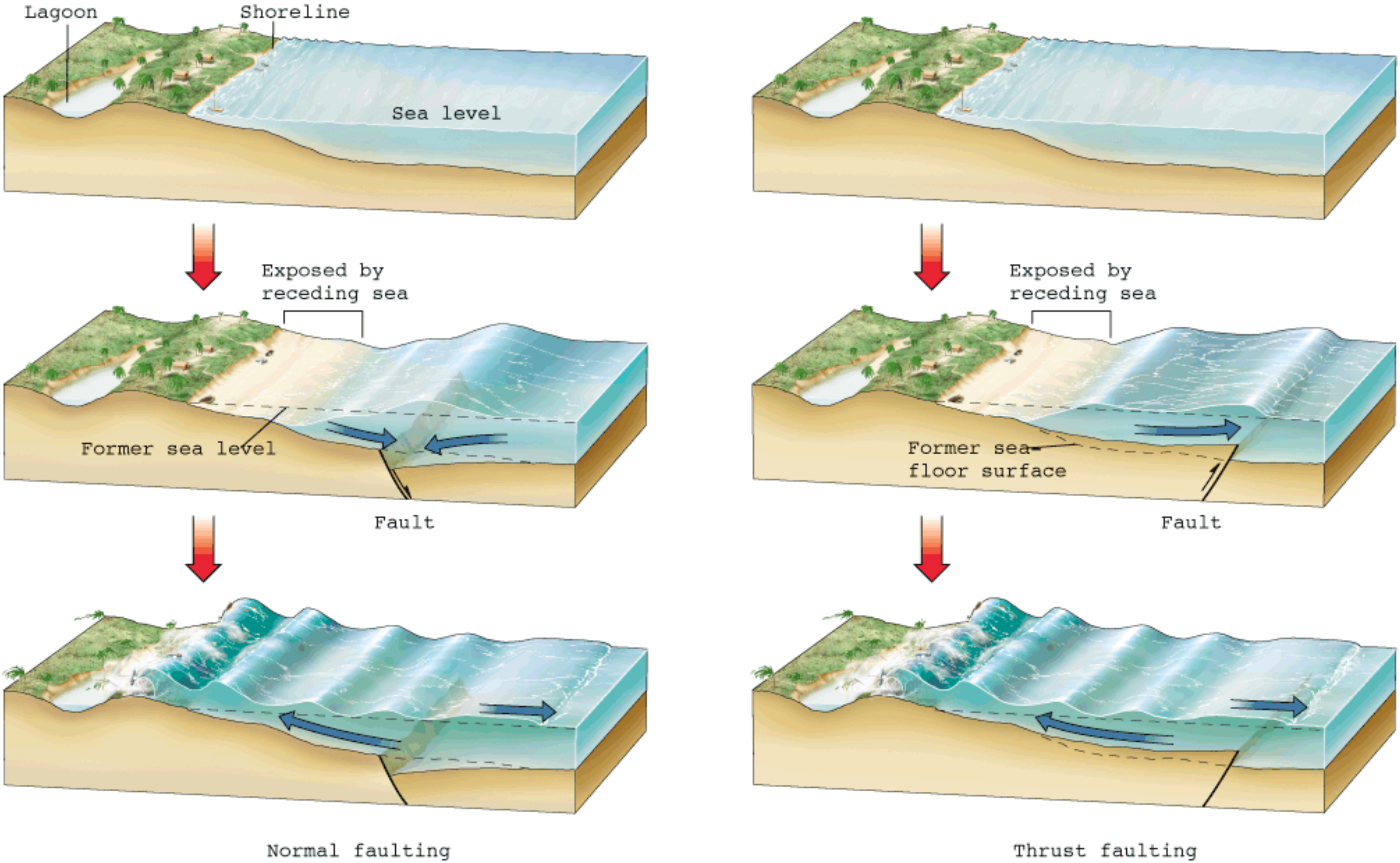
Infrastructure failure — fires, power, sanitation
Landslides, rockfalls
Tsunami



DETAIL FROM *THE GREAT WAVE OFF KANAGAWA* (1820s) BY KATSUSHIKA HOKUSAI


NOAA
Seward
Homer
Kodiak
Sand Point
Unalaska
Yakutat
Sitka
Neah Bay
Port Angeles
Seaside
Newport
Crescent City
San Francisco
San Luis
Los Angeles
La Jolla
San Diego
Virginia Beach
Cape Hatteras
Myrtle Beach
Palama City
Haleiwa
Mokuoloe
Nawiliwili
Kahului
Kawaihae
Honolulu
Guam
Pago Pago
46410
46409
46403
46402
46408
46413
46401
21415
21414
21416
21419
21418
21413
46419
46404
46405
46407
46411
46412
52404
52401
52405
52402
52403
51407
43412
43413
32411
44402
41424
42409
42407
52406
51425
51406
55023
55012
56001
56003
51426
55016
54401
32412
32401
(cm)
>=240
220
200
180
160
140
120
100
80
60
40
20
0
120°E
180°
120°W
60°W

v=√gd; ranges from 350 km/hr in 1000m to 800 km/hr in 5000 m water depth <50 cm amplitude in deep water, 10's of m in shallow water



Earthquake Effects - Tsunamis

1957 Aleutian Tsunami

USGS

Photograph Credit: Henry Helbush. Source: National Geophysical Data Center

Earthquake Effects - Tsunamis

1957 Aleutian Tsunami

USGS

Photograph Credit: Henry Helbush. Source: National Geophysical Data Center

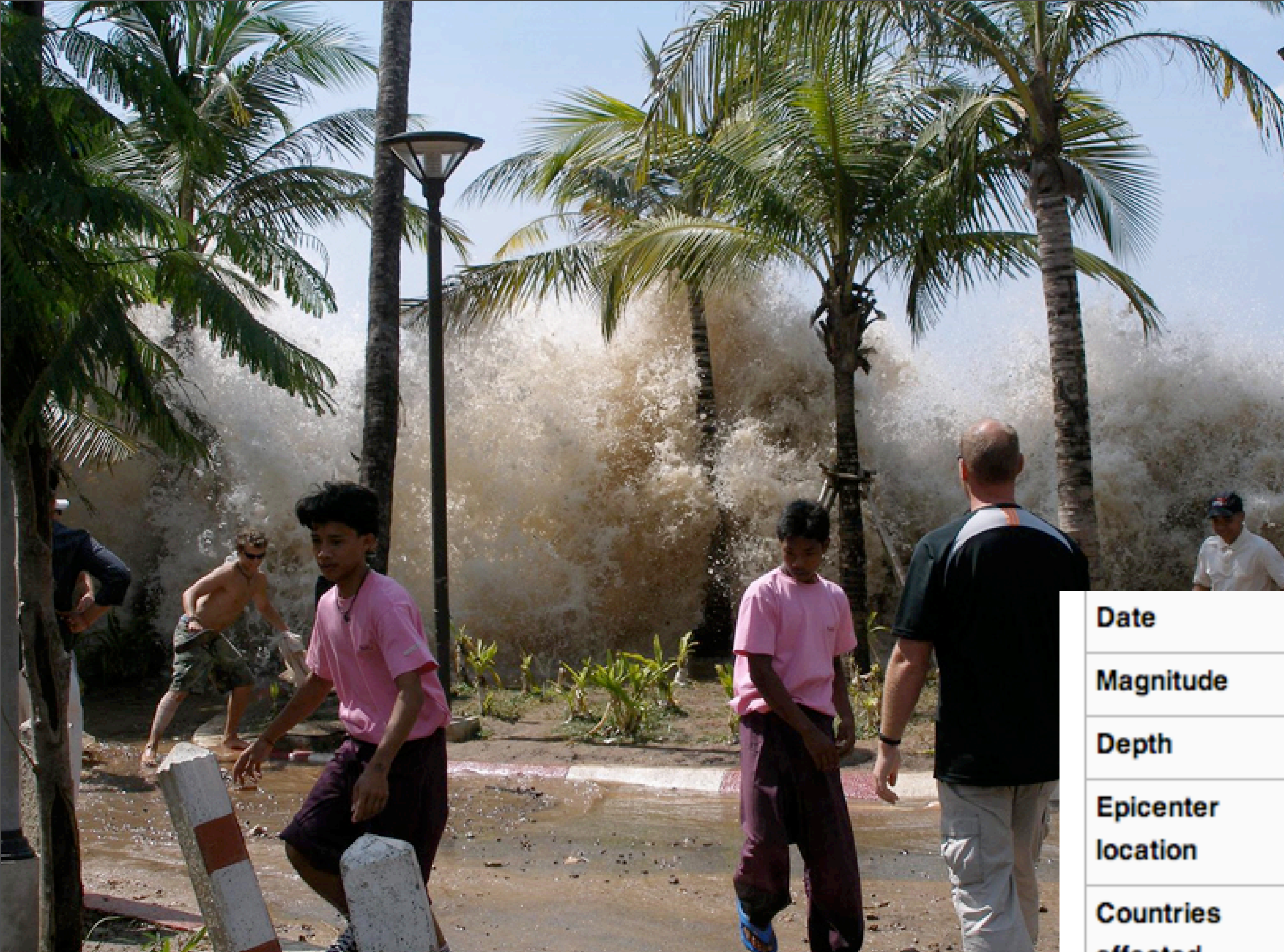
Earthquake Effects - Tsunamis

1957 Aleutian Tsunami

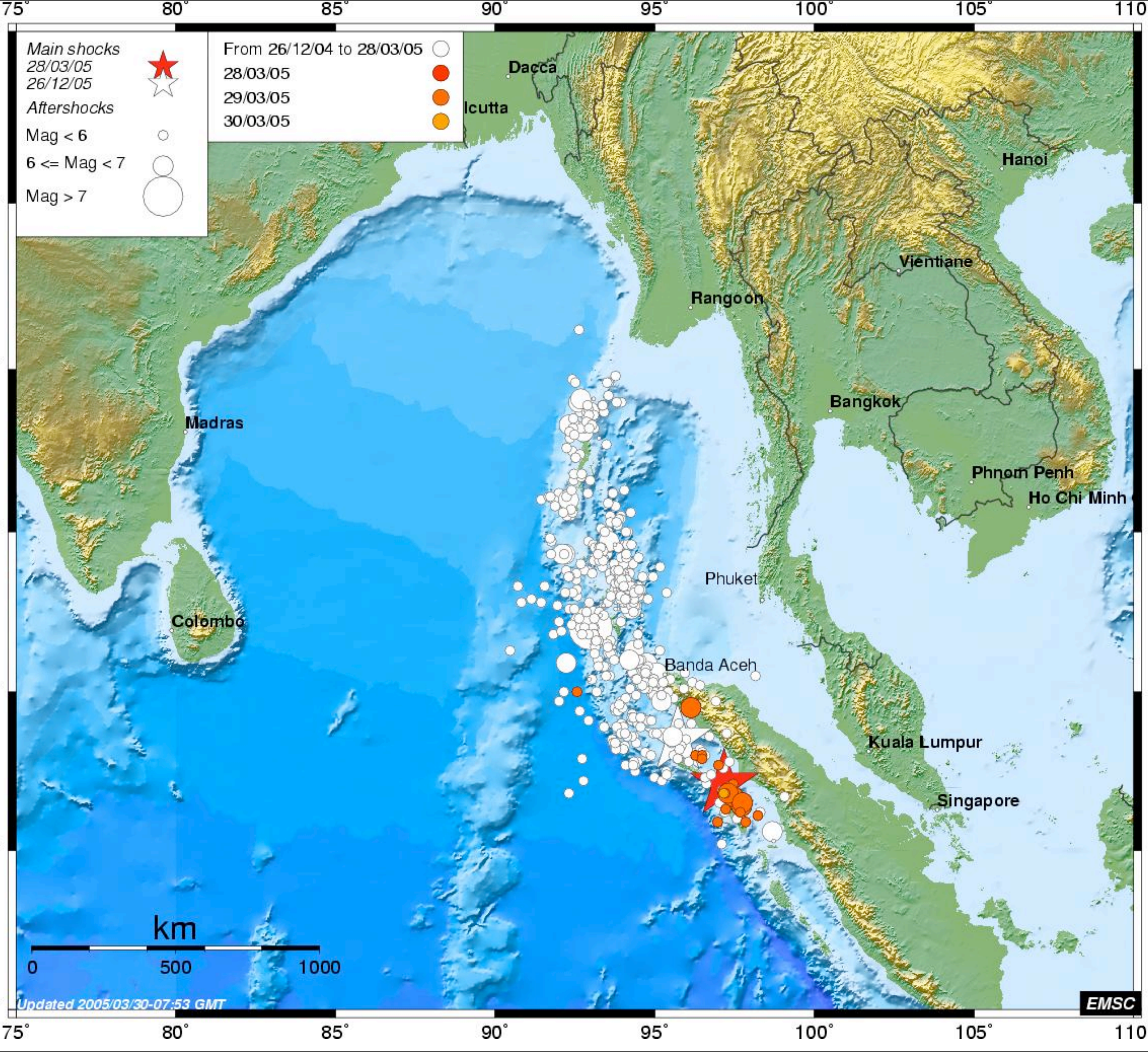
Photograph Credit: Henry Helbush. Source: National Geophysical Data Center

Figure 8.28a

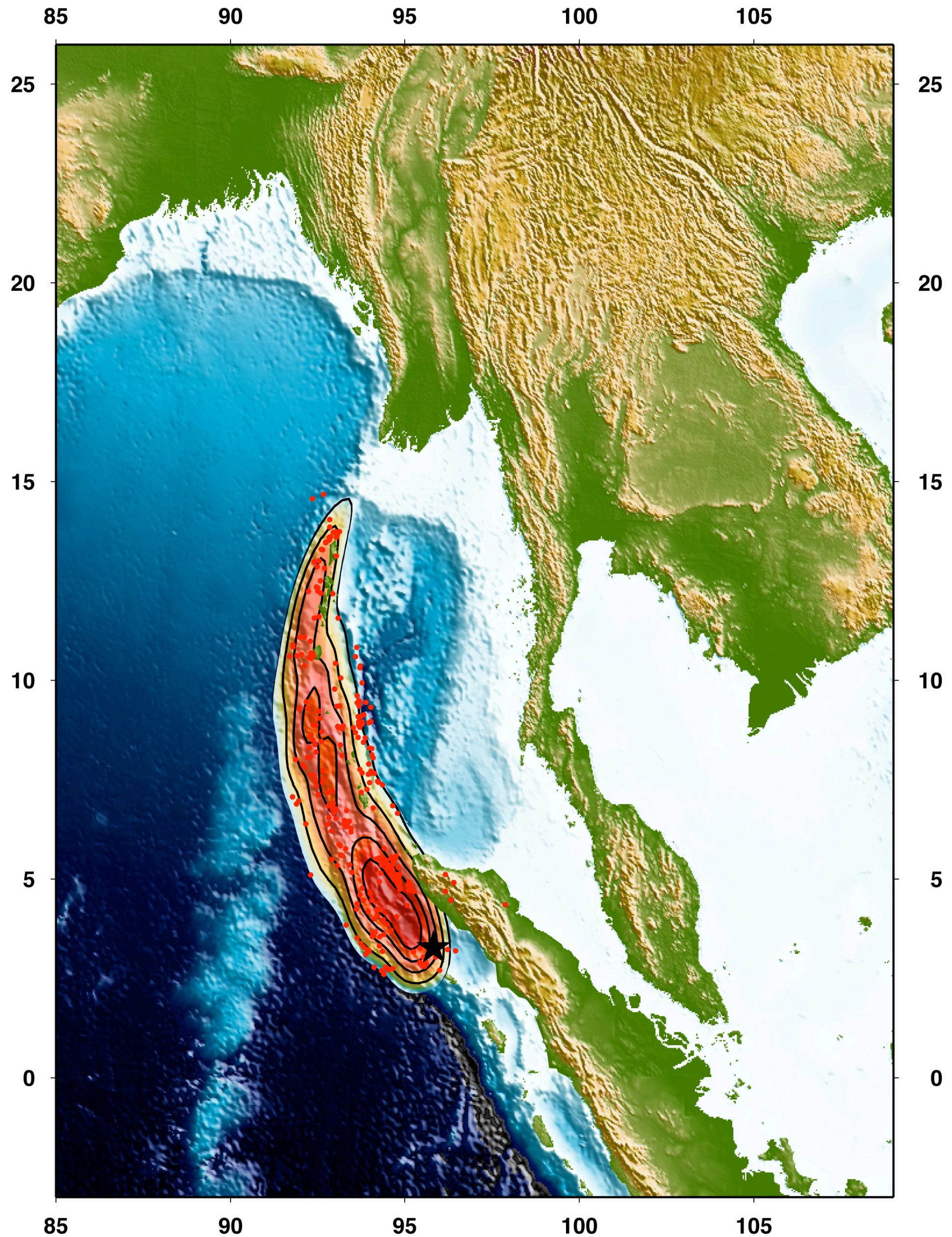
Figure 8.28b

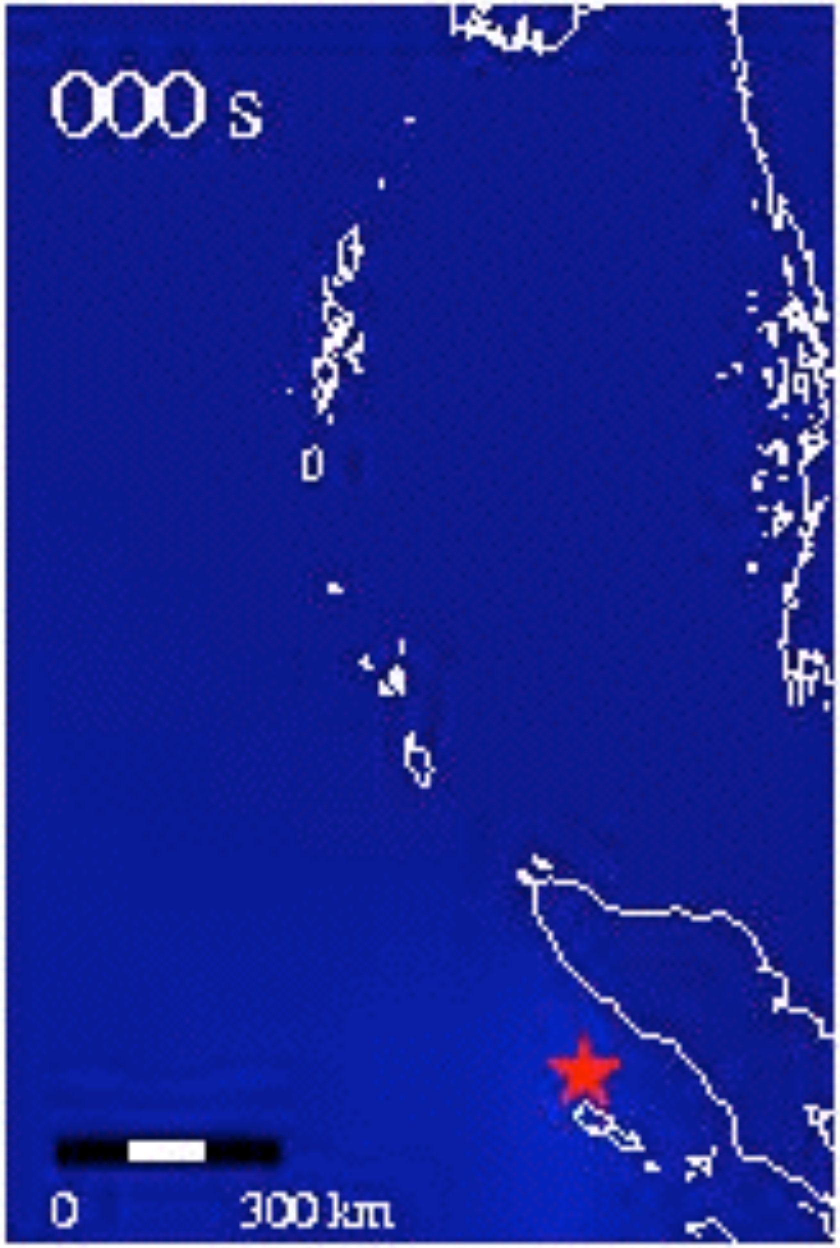


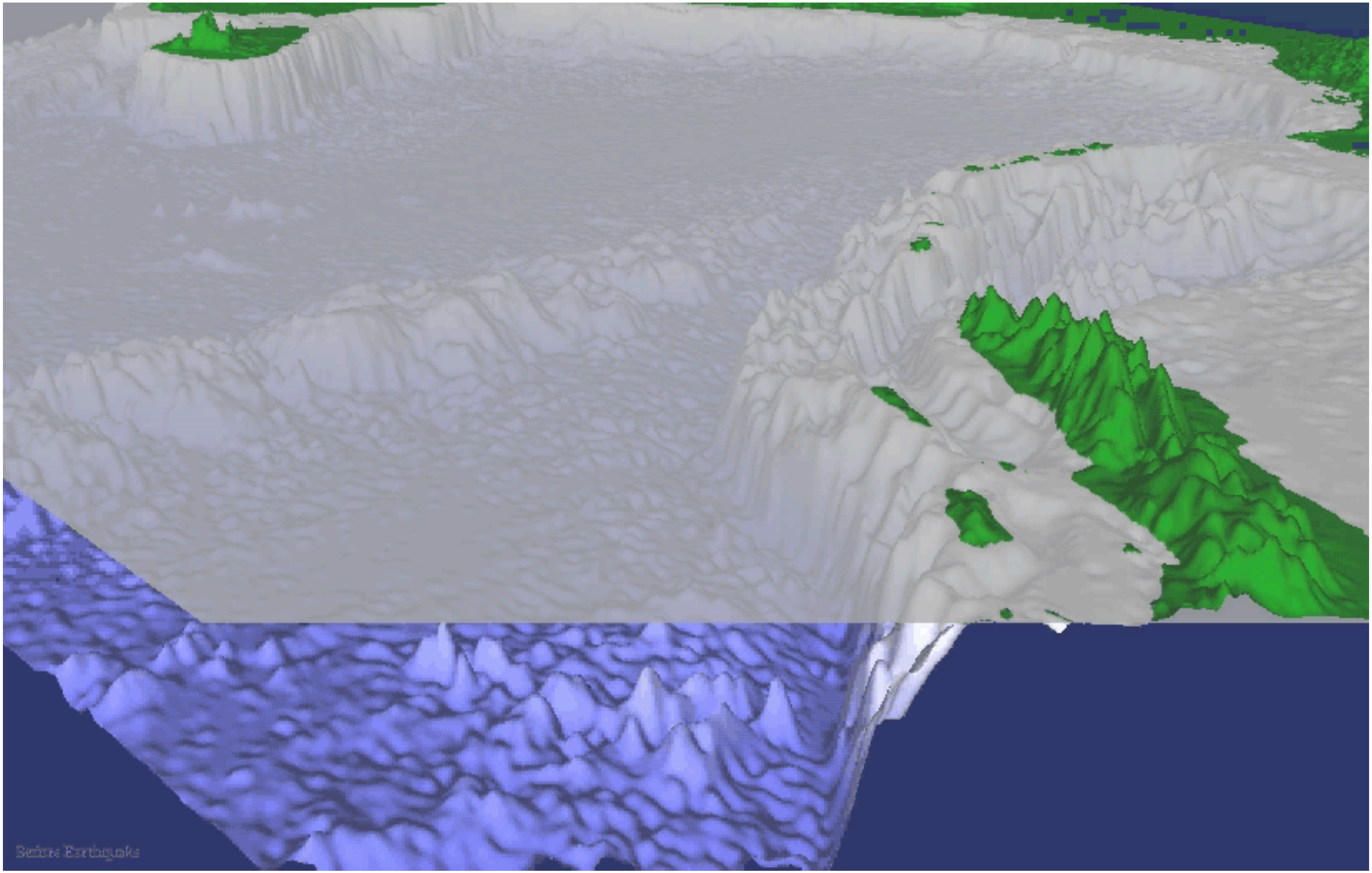
Date	December 26, 2004
Magnitude	9.3 M_w
Depth	30 km (18.6 mi)
Epicenter location	3.316° N 95.854° E
Countries affected	Indonesia (mainly i Aceh) Sri Lanka India (mostly in Tamil Nadu) Thailand
Casualties	229,866

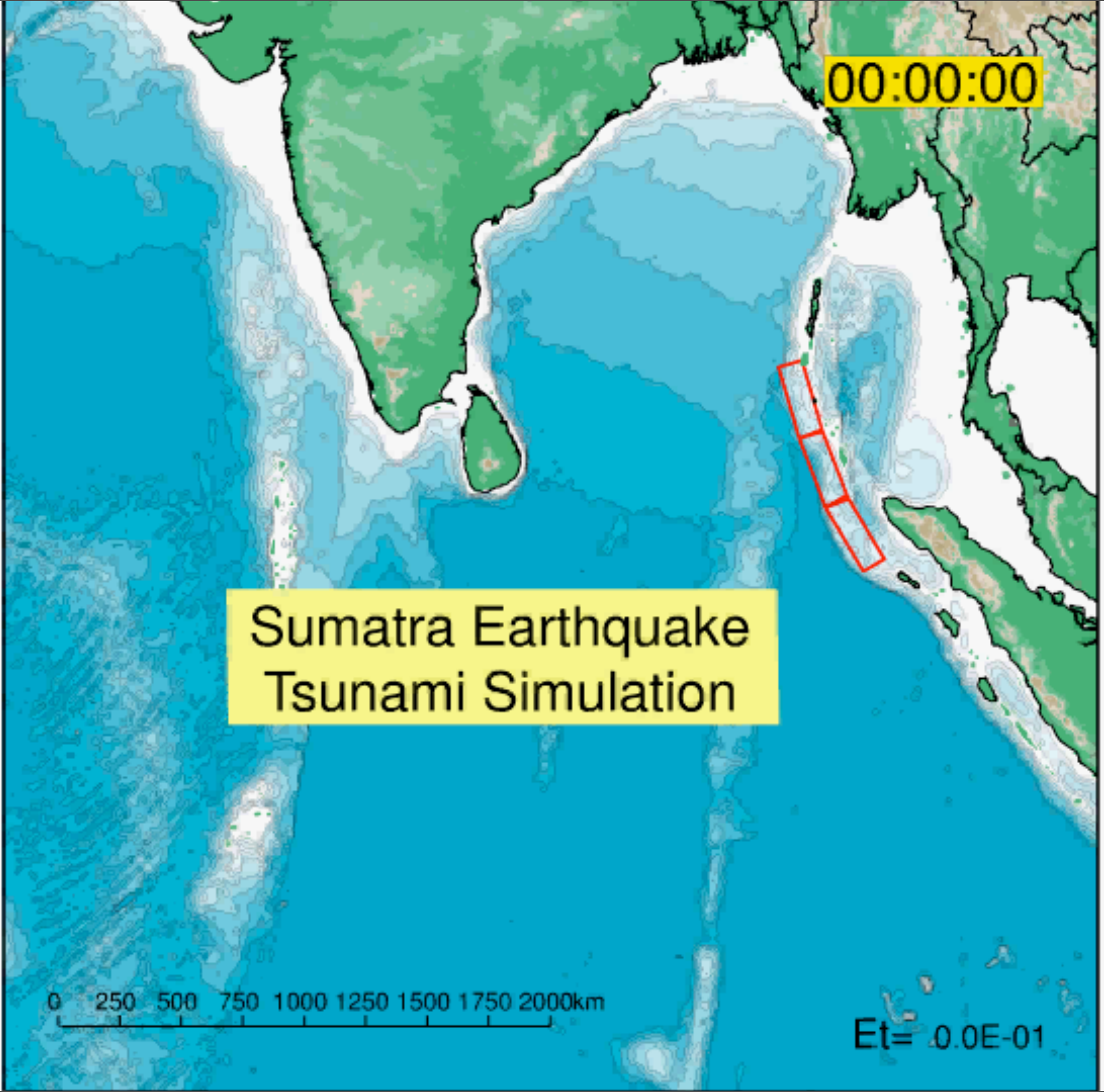


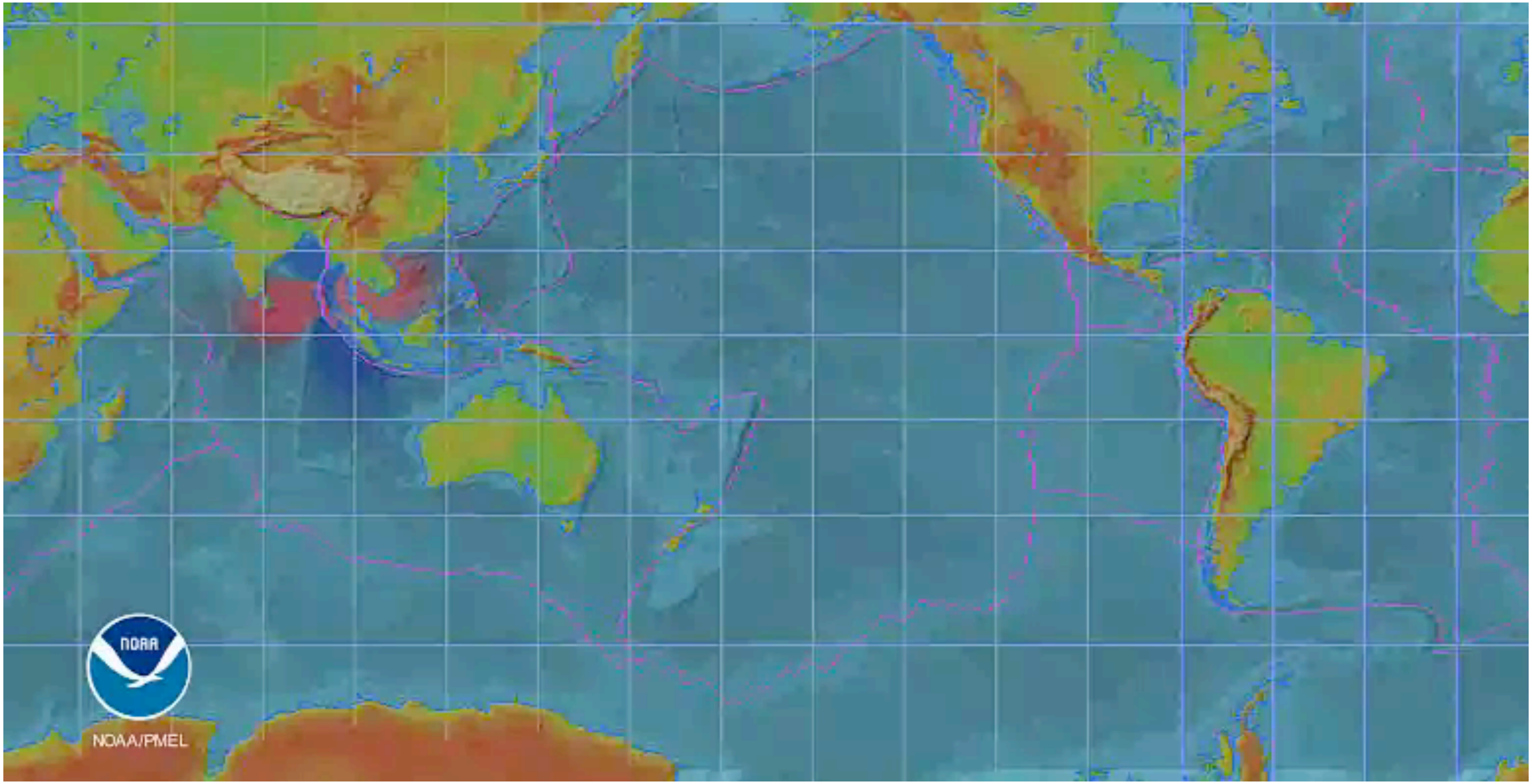
Main shocks
28/03/05
26/12/05
Aftershocks
Mag < 6
6 <= Mag < 7
Mag > 7
From 26/12/04 to 28/03/05
28/03/05
29/03/05
30/03/05
Dacca
lcutta
Hanoi
Vientiane
Rangoon
Bangkok
Madras
Phnom Penh
Ho Chi Minh
Colombo
Phuket
Banda Aceh
Kuala Lumpur
Singapore
km
0
500
1000
Updated 2005/03/30-07:53 GMT
EMSC
75°
80°
85°
90°
95°
100°
105°
110°
25°
20°
15°
10°
5°
0°
-5°

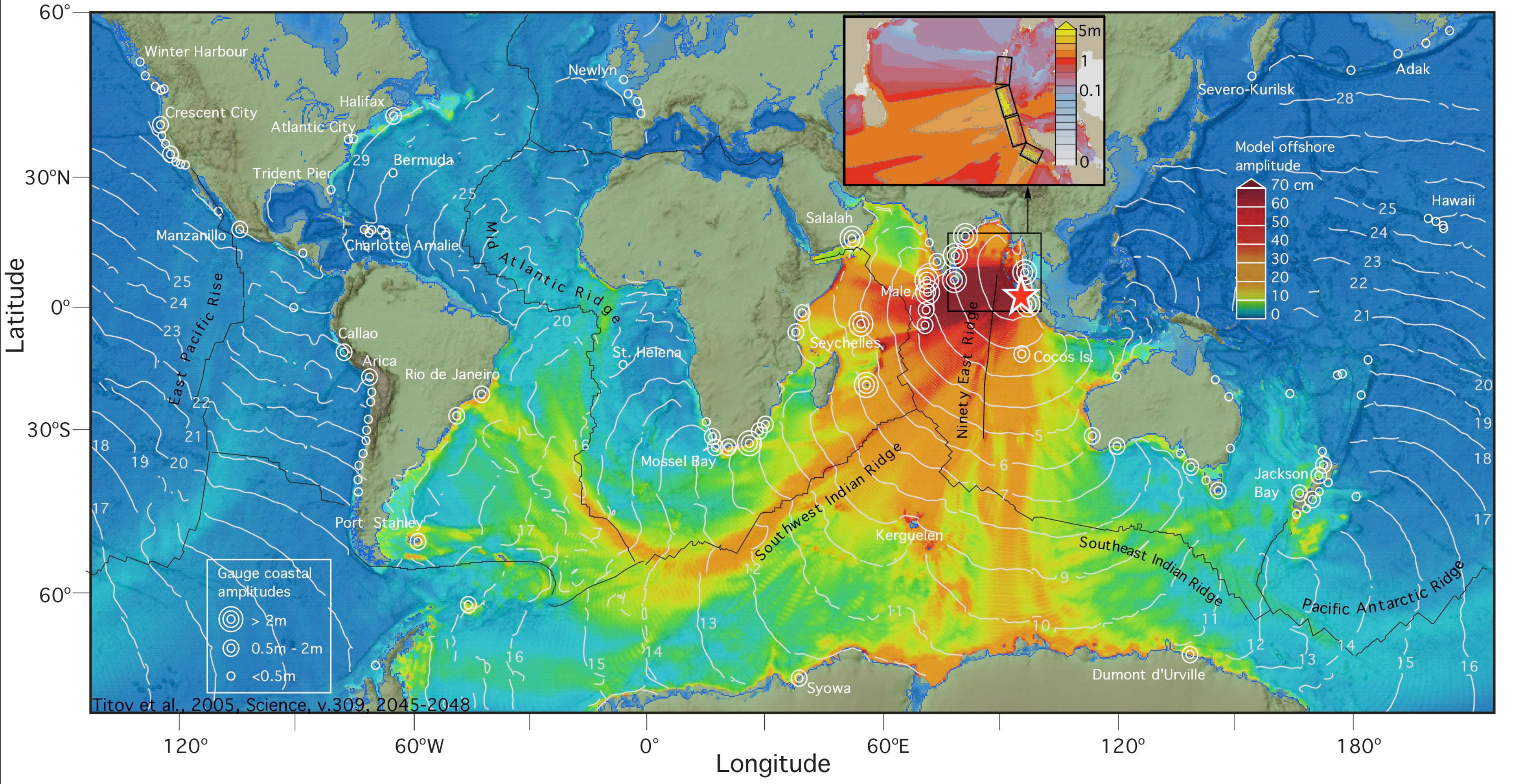

85
90
95
100
105
25
20
15
10
5
0


000 s
0
300 km


Before Earthquake


00:00:00
Sumatra Earthquake
Tsunami Simulation
0 250 500 750 1000 1250 1500 1750 2000km
Et= 0.0E-01


NOAA/PMEL



Winter Harbour
Crescent City
Halifax
Atlantic City
Newlyn
Bermuda
Trident Pier
Manzanillo
Charlotte Amalie
Mid Atlantic Ridge
East Pacific Rise
Callao
Arica
Rio de Janeiro
St. Helena
Salalah
Male
Seychelles
Ninety East Ridge
Cocos Is.
Mossel Bay
Southwest Indian Ridge
Kerguelen
Port Stanley
Southeast Indian Ridge
Pacific Antarctic Ridge
Syowa
Dumont d'Urville
Jackson Bay
Severo-Kurilsk
Adak
Hawaii
Model offshore amplitude
70 cm
60
50
40
30
20
10
0
5m
1
0.1
0
Gauge coastal amplitudes
> 2m
0.5m - 2m
<0.5m
Titov et al., 2005, Science, v.309, 2045-2048
60°
30°N
0°
30°S
60°
Latitude
120°
60°W
0°
60°E
120°
180°
Longitude