Co-sponsored by
The Department of Ocean, Earth & Atmospheric Sciences
Mitigation and Adaptation Research Institute

Why Price Gouging is Immoral:

Recovering from Disasters

IEPA Guest Speaker:

Dr. Elizabeth Brake

5:30 PM

Wednesday, October 17, 2018

Batten Arts and Letters Building
RM 1012

Free & Open to the Public

IEPA INSTITUTE FOR ETHICS AND PUBLIC AFFAIRS

OLD DOMINION UNIVERSITY

philosophy@odu.edu

Natural Hazards and Disaster

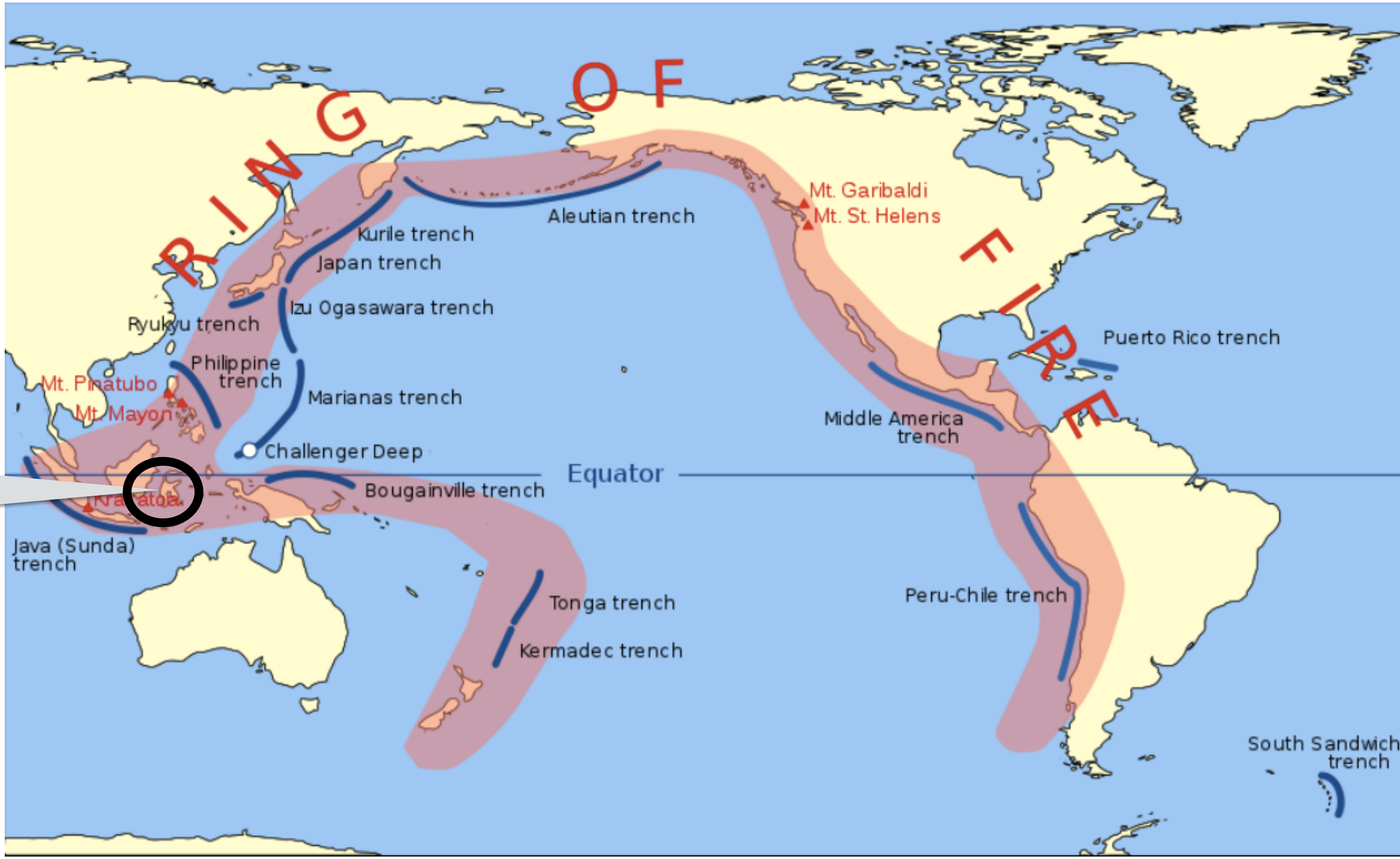
Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Magnitude and Locations
- Cases
- Extreme Events
- Managing Disaster Risk
- Tsunamis

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Most Recent: 28 September 2018

2018 Sulawesi earthquake and tsunami

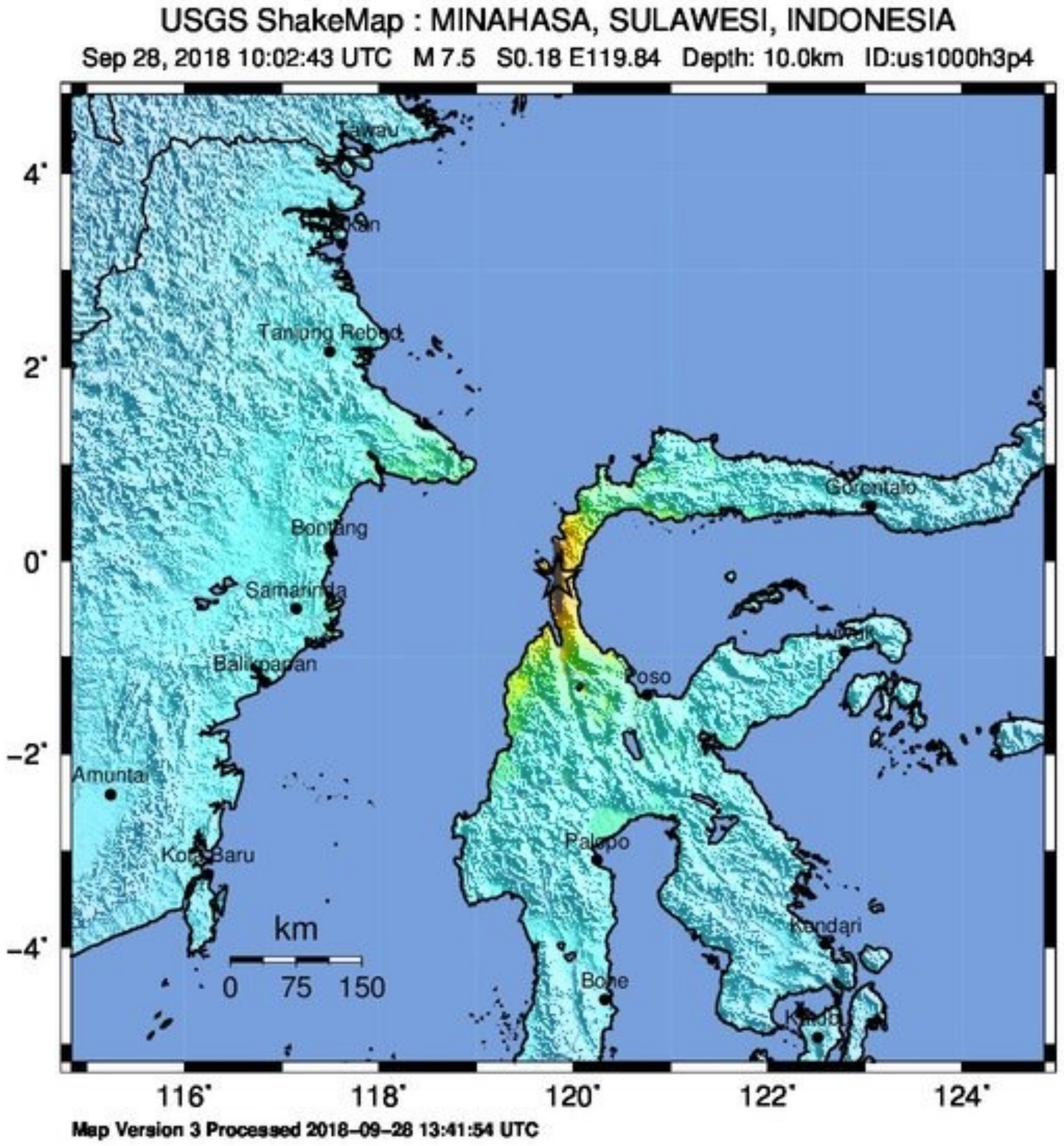


https://en.wikipedia.org/wiki/2018_Sulawesi_earthquake_and_tsunami

Most Recent: 28 September 2018

2018 Sulawesi earthquake and tsunami

UTC time	2018-09-28 10:02:44
ISC event	612780996
USGS-ANSS	ComCat
Local date	28 September 2018
Local time	18:02:44 WITA (Indonesia Central Standard Time)
Magnitude	M_w 7.4[1]
Depth	10.0 km
Epicentre	0.178°S 119.840°E
Fault	Palu-Koro fault
Type	Strike-slip
Max. intensity	IX (*Violent*)
Tsunami	Yes (highest 7 m (23 ft) in Donggala Regency)[2]
Landslides	Yes
Foreshocks	M_w6.1, M5.4, M5.0
Aftershocks	Five M≥5.5
Casualties	• 1,347 dead[3] • 632 injured • 100+ missing • 48,025 evacuated[4]



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

https://en.wikipedia.org/wiki/2018_Sulawesi_earthquake_and_tsunami

Most Recent: 28 September 2018

In Indonesia, Aftershocks And Uncertainty Remain After Deadly Earthquake

October 2, 2018 · 4:27 AM ET

EMILY SULLIVAN

Rescuers assist 15-year old earthquake victim Nurul Istikharah from flood water in her damaged house following earthquakes and tsunami in Palu, Central Sulawesi, Indonesia on Sept. 30.

Casualties (Oct. 2, 2018):

- 1,347 dead (initial: 80)
- 632 injured
- 100+ missing
- 48,025 evacuated

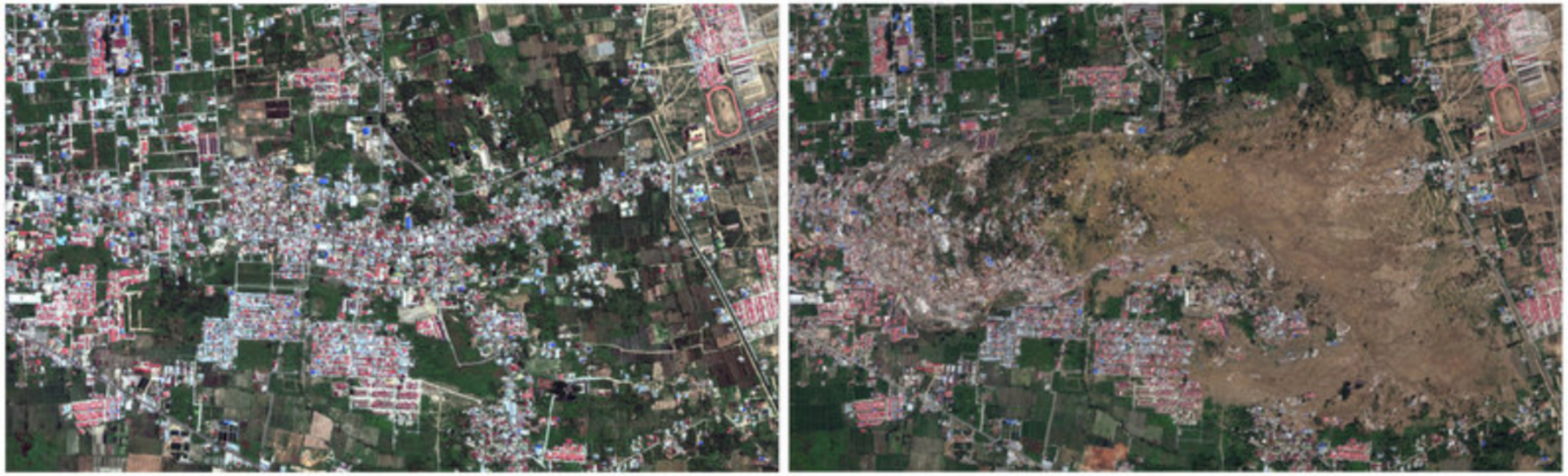
Most Recent: 28 September 2018

The tsunami caught geologists by surprise. Since the earthquake was a strike-slip earthquake, the tsunami was expected to be at a low height, with a maximum height of approximately 2 metres. During a strike-slip earthquake, the movements of the crusts were largely in horizontal motion while most tsunamis occurred in earthquakes with vertical motion. One explanation is that the earthquake triggered underwater landslides, causing the tsunami.

https://en.wikipedia.org/wiki/2018_Sulawesi_earthquake_and_tsunami

A bridge was wrecked at the city of Palu, after an earthquake and tsunami hit the area in Central Sulawesi, Indonesia.

Athit Perawongmetha/Reuters

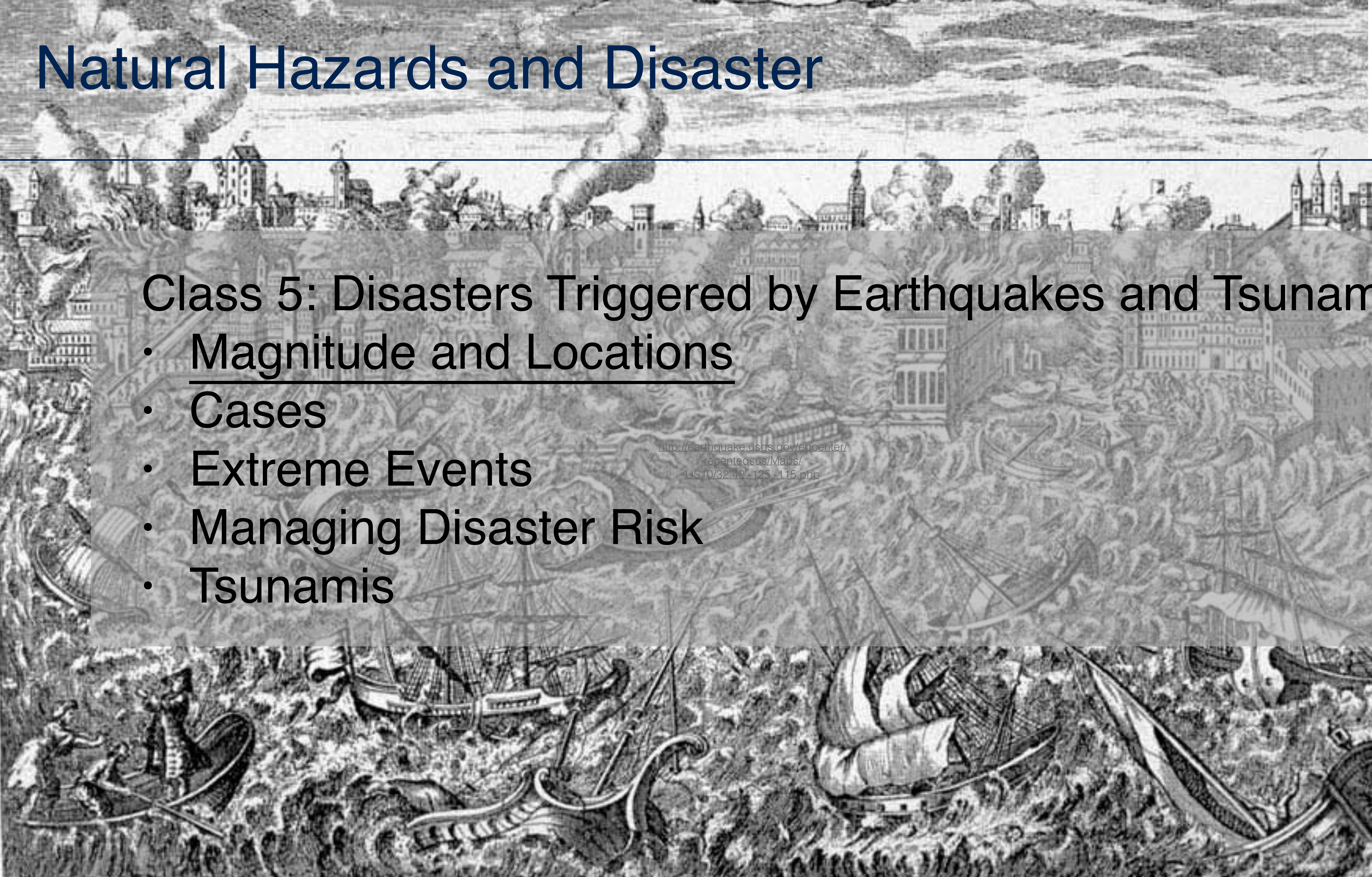


This photo layout of satellite images provided by DigitalGlobe shows the Petobo neighborhood of Palu, Indonesia, on Aug. 17, prior to the earthquake, left, and on Oct. 1, devastated by the subsequent tusnami, right.

DigitalGlobe, a Maxar company via AP

Natural Hazards and Disaster

MITIGATION & ADAPTATION RESEARCH INSTITUTE
MARI
OLD DOMINION UNIVERSITY

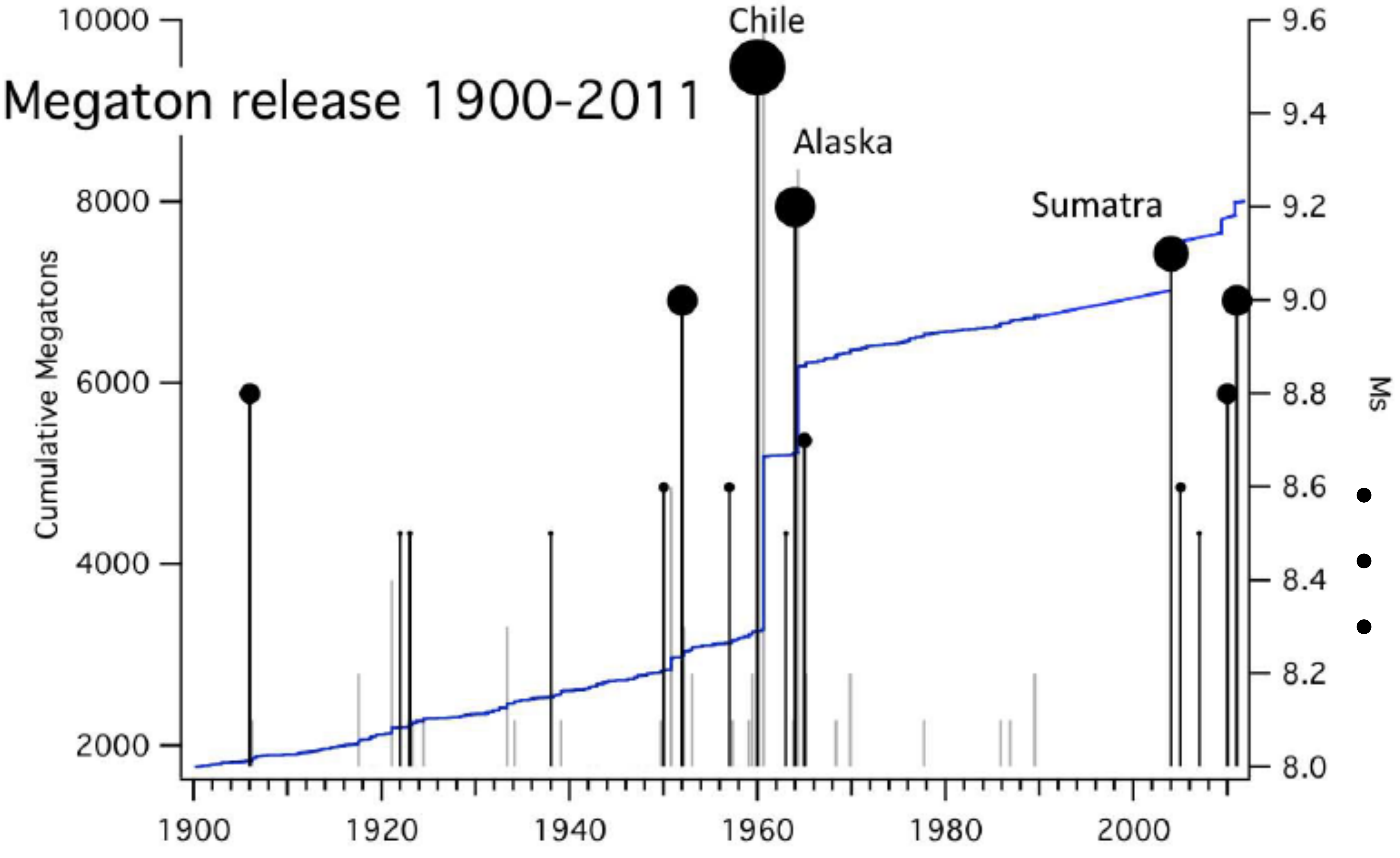


Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Magnitude and Locations
- Cases
- Extreme Events
- Managing Disaster Risk
- Tsunamis

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Magnitude and Location



The total energy of all explosives used in World War II, including the Hiroshima and Nagasaki atom bombs: 3 megatons TNT

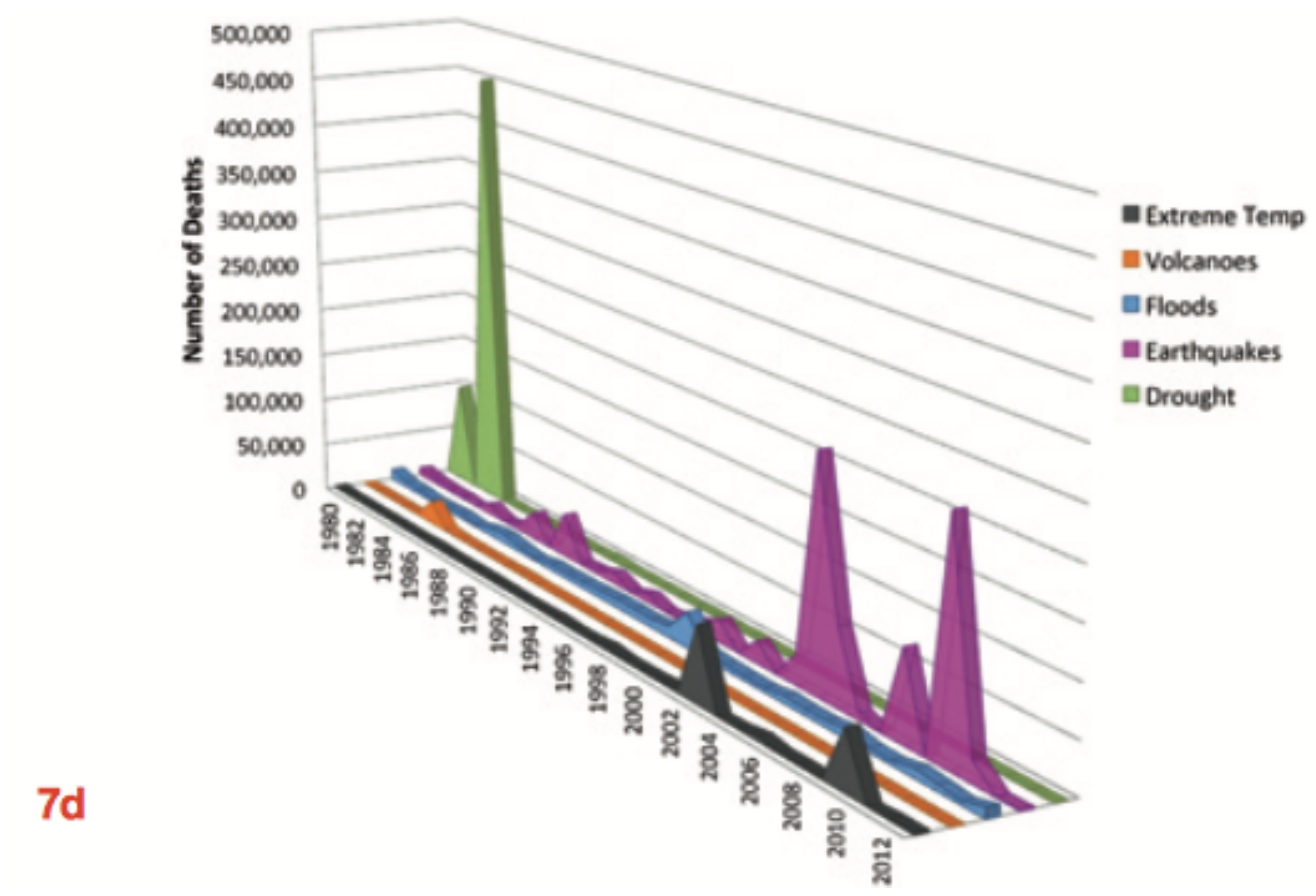
- Average seismic energy: ~0.000010 TerraWatt
- Human energy usage: ~20 TerraWatt,
- Solar energy to earth: ~89,000 TerraWatt

century average ≈ 80 megatons/year:

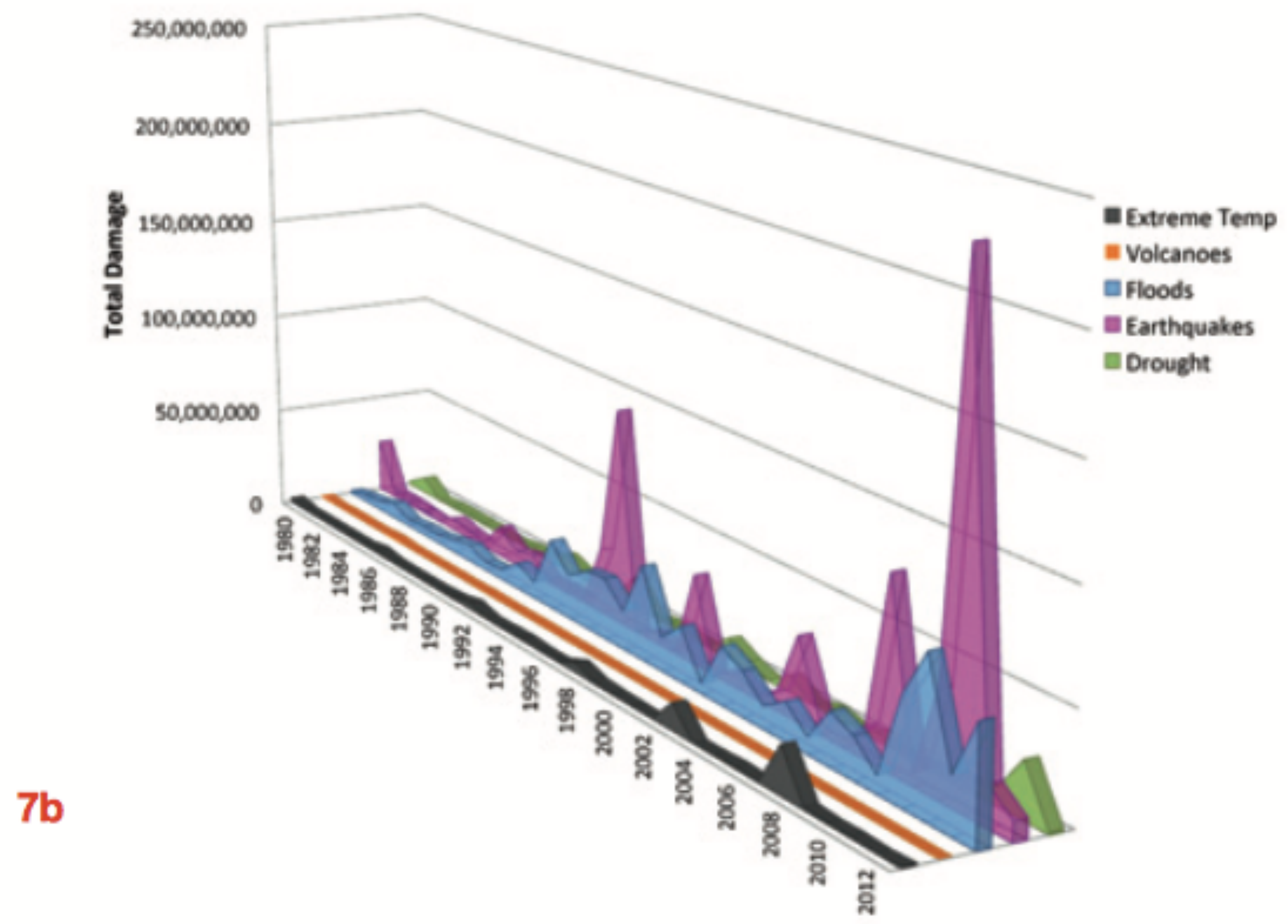
40% from Mw>8.5 earthquakes

3

Magnitude and Location



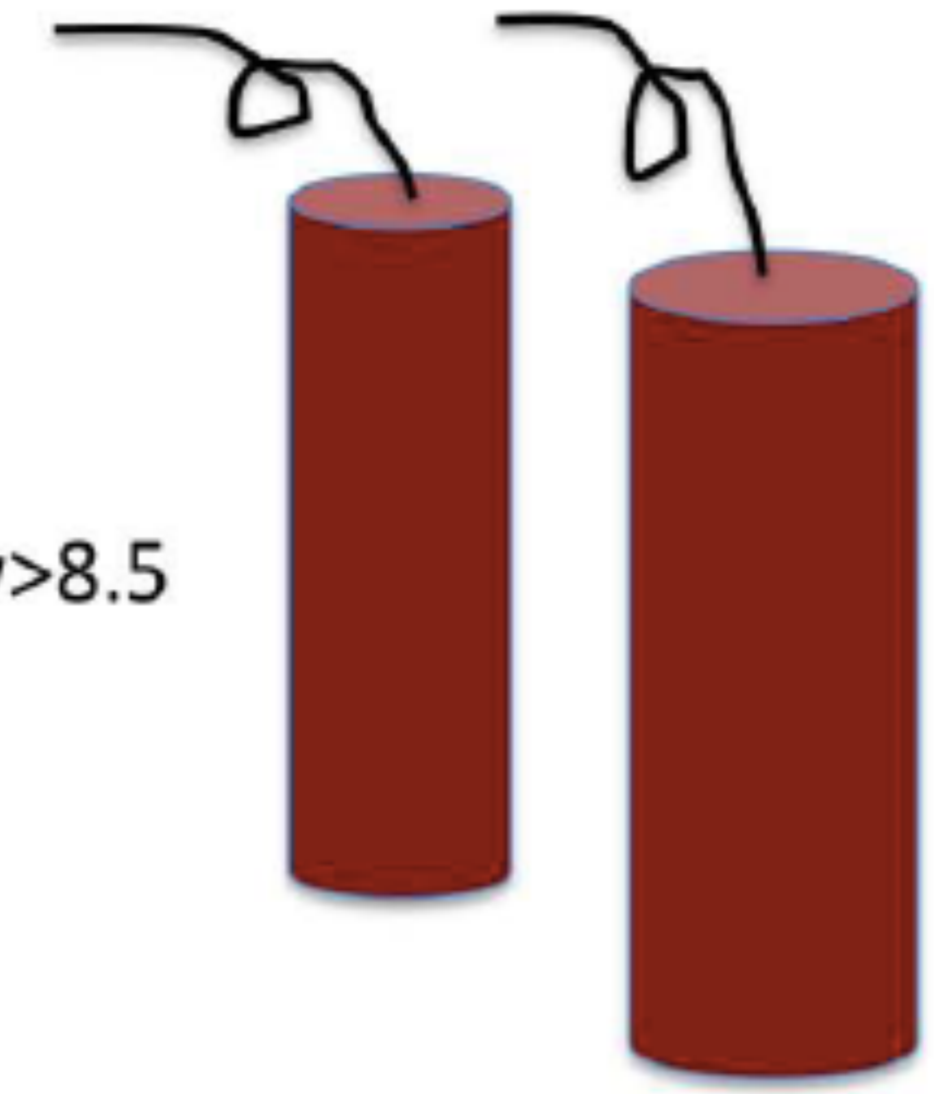
Number of Deaths



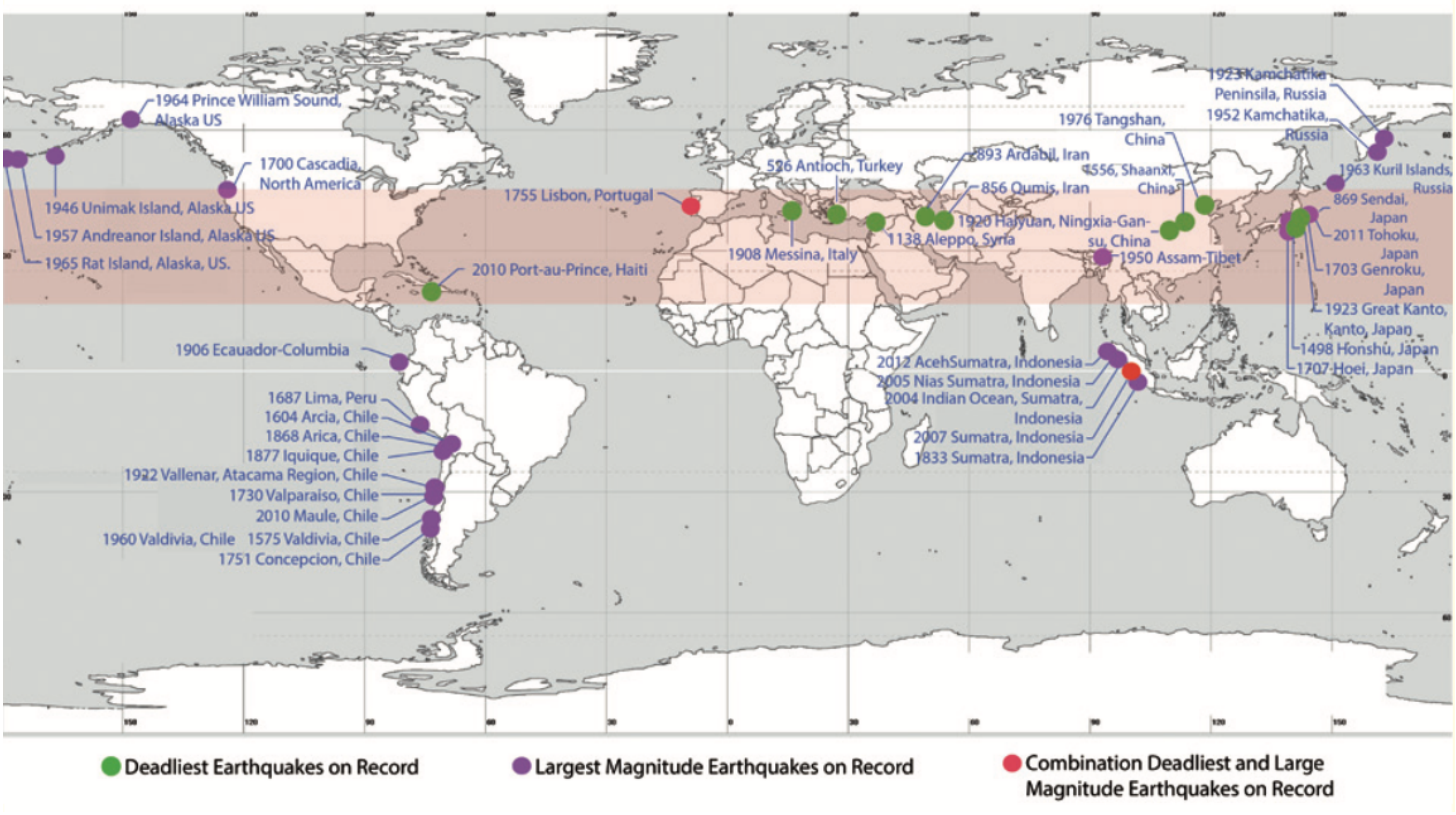
Total Damage

80 Mt/year for 7 billion people is equivalent to
≈11 kg of TNT per person per year
Assuming that a stick of dynamite =1 lb

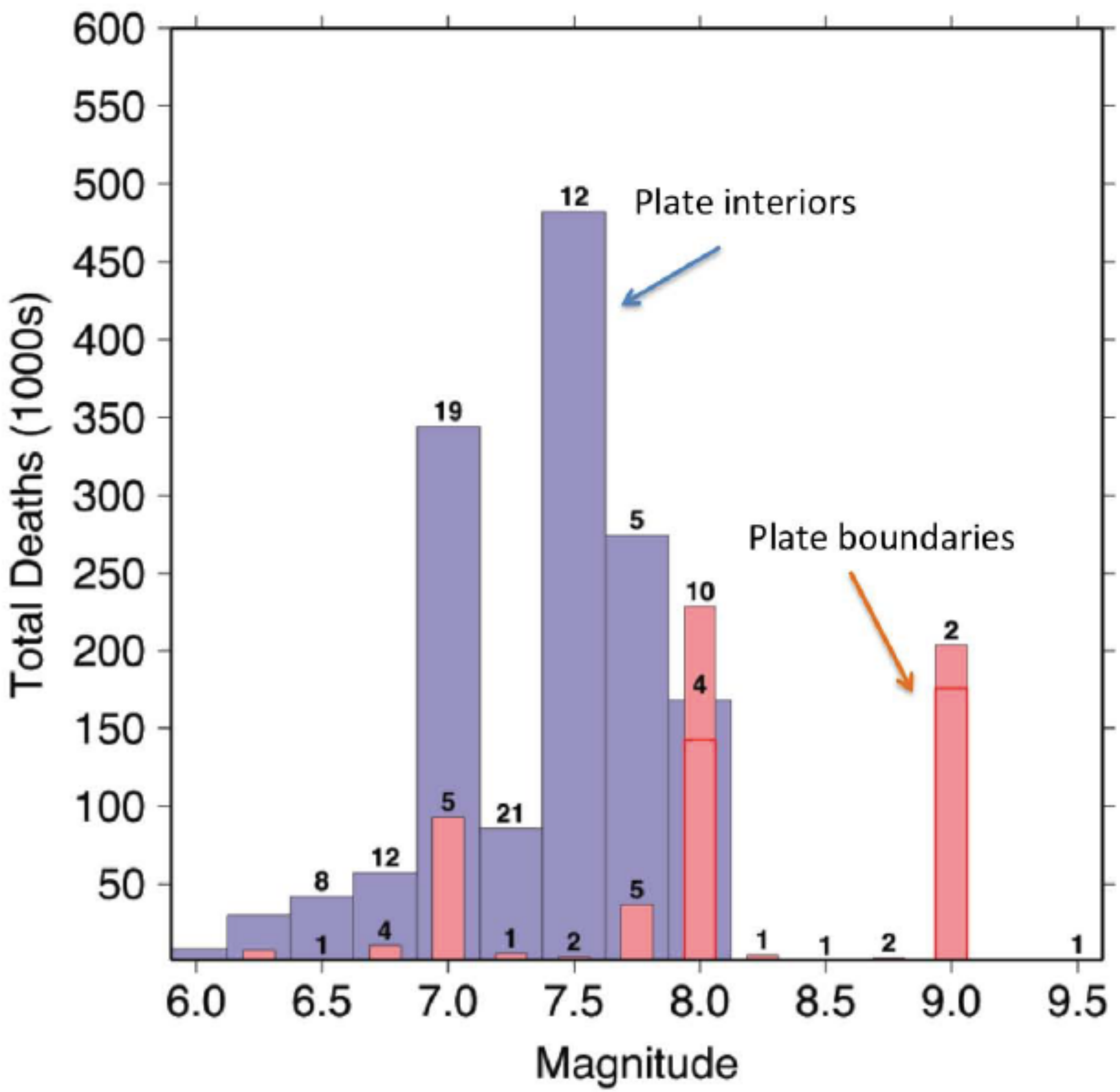
Earthquake energy release is equivalent to 2 sticks of dynamite per person per month



Magnitude and Location



Magnitude and Location

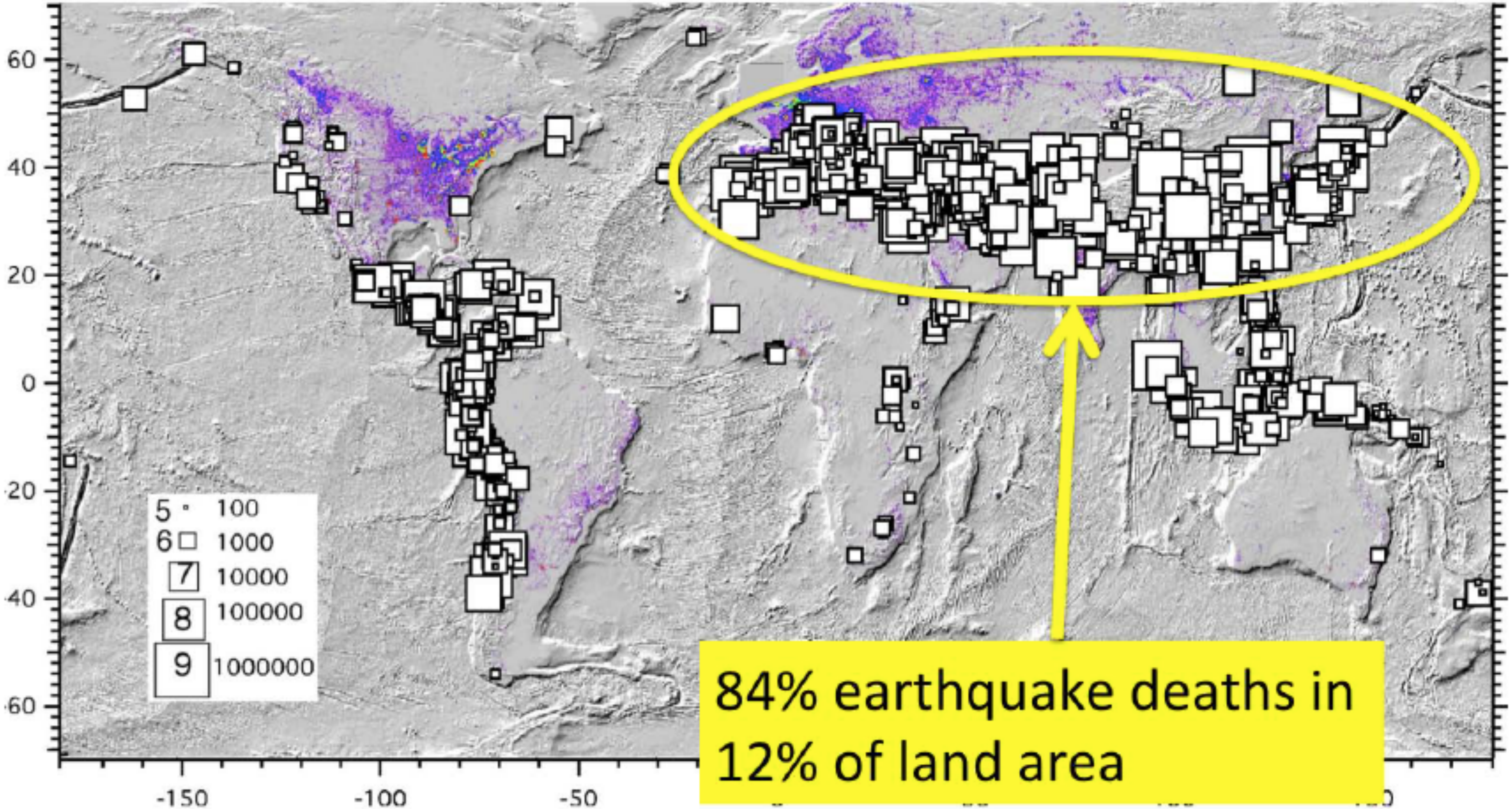


Most deaths from M<7.5 plate interior earthquakes.

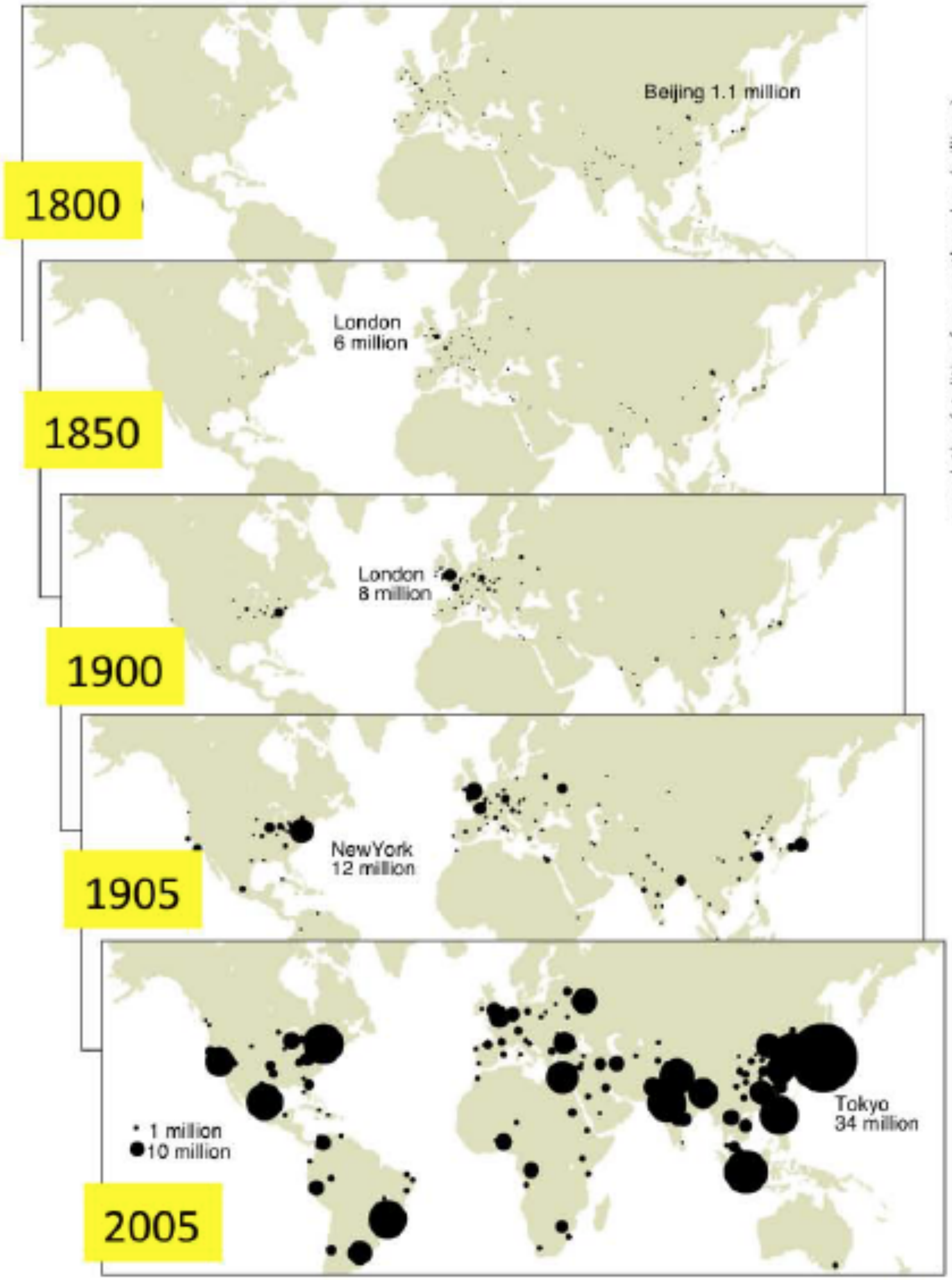
Fewer deaths from much larger plate boundary earthquakes

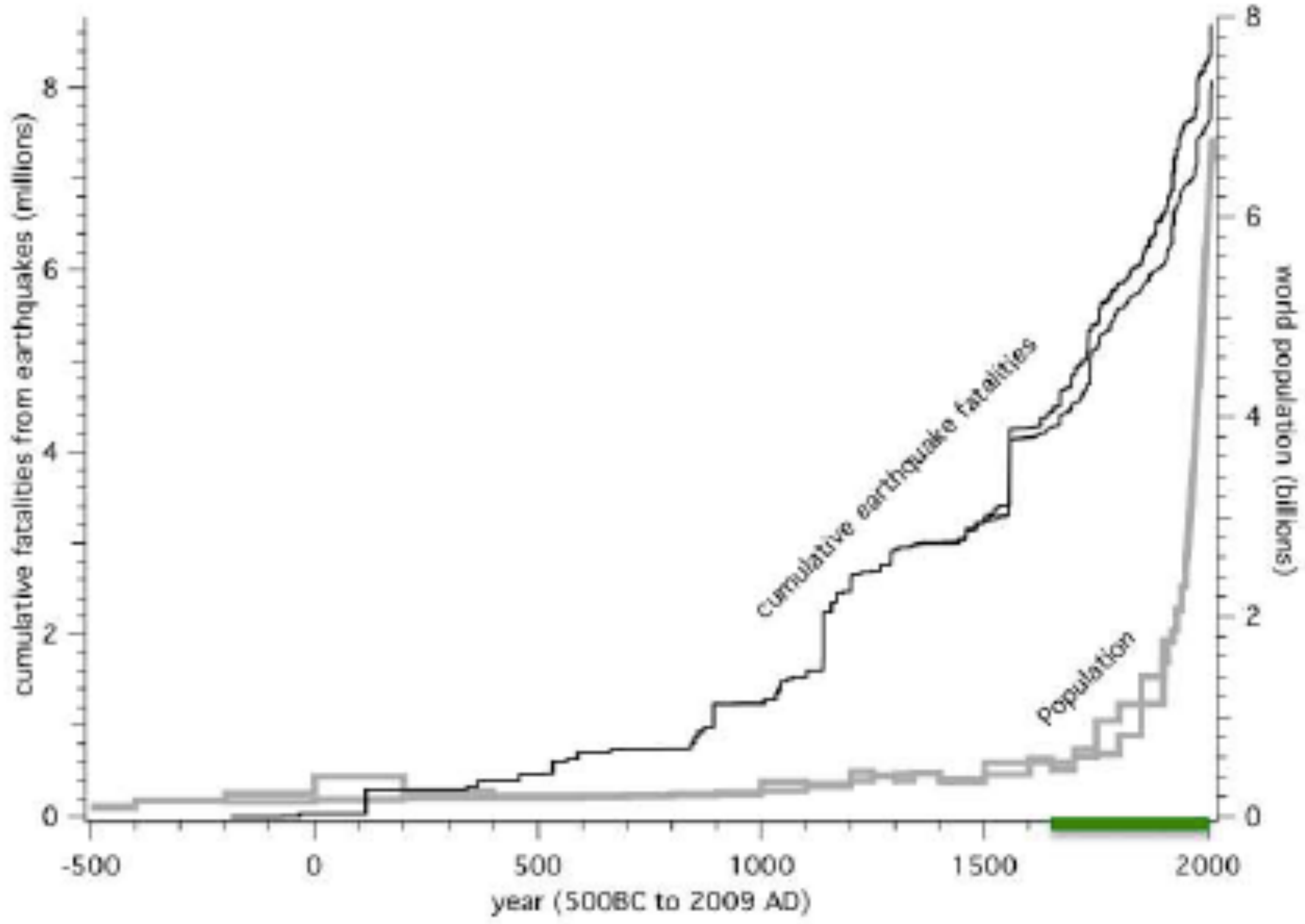
England and Jackson

1000 years of earthquake deaths



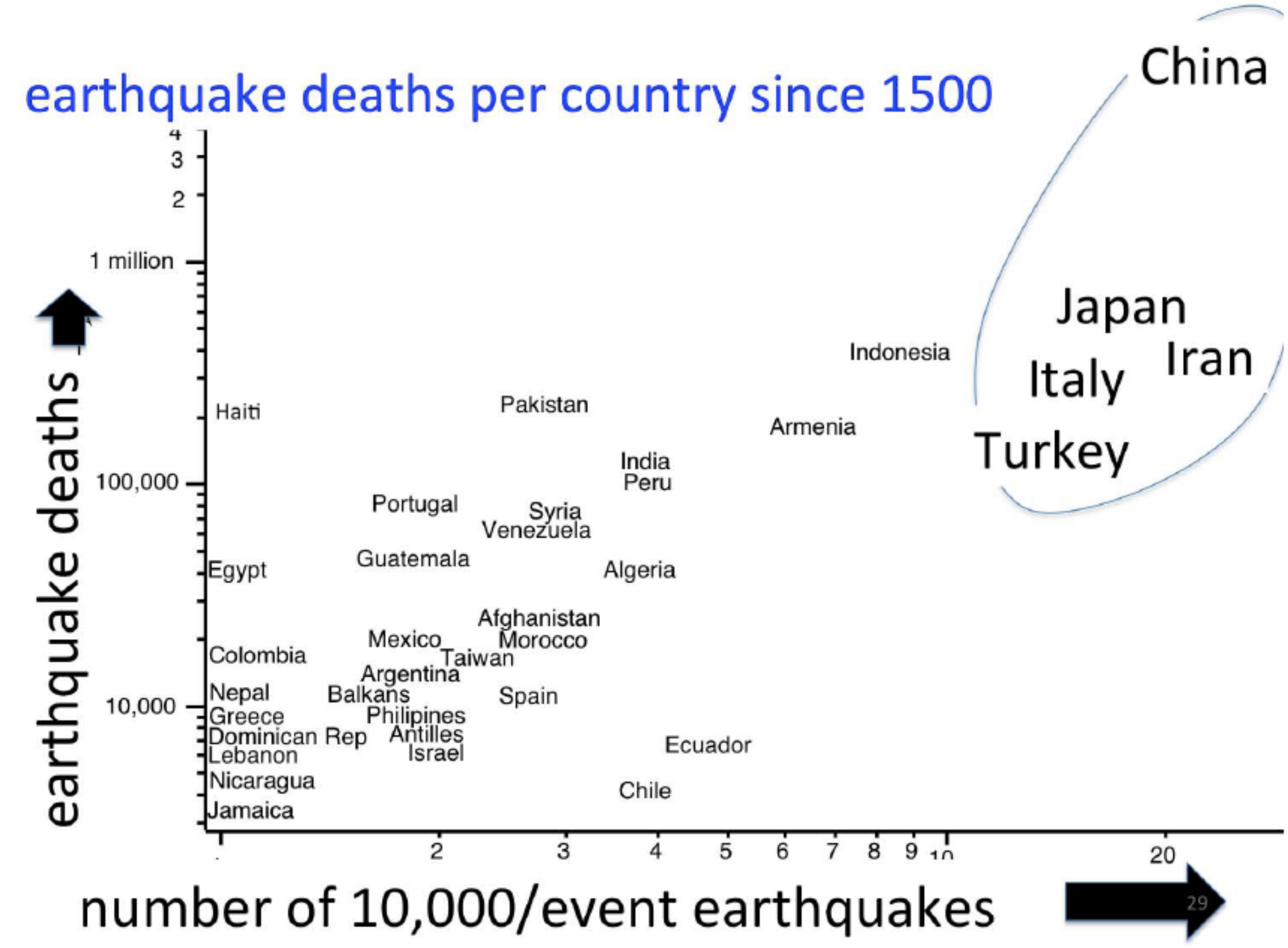
Magnitude and Location





City size exploded after 1800
When cities became no longer
a place to die.

Magnitude and Location



The problem: Too many people in poorly constructed buildings

“Earthquake don’t kill people, buildings do!”

Natural Hazards and Disaster

Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Magnitude and Locations
- Cases
- Extreme Events
- Managing Disaster Risk
- Tsunamis

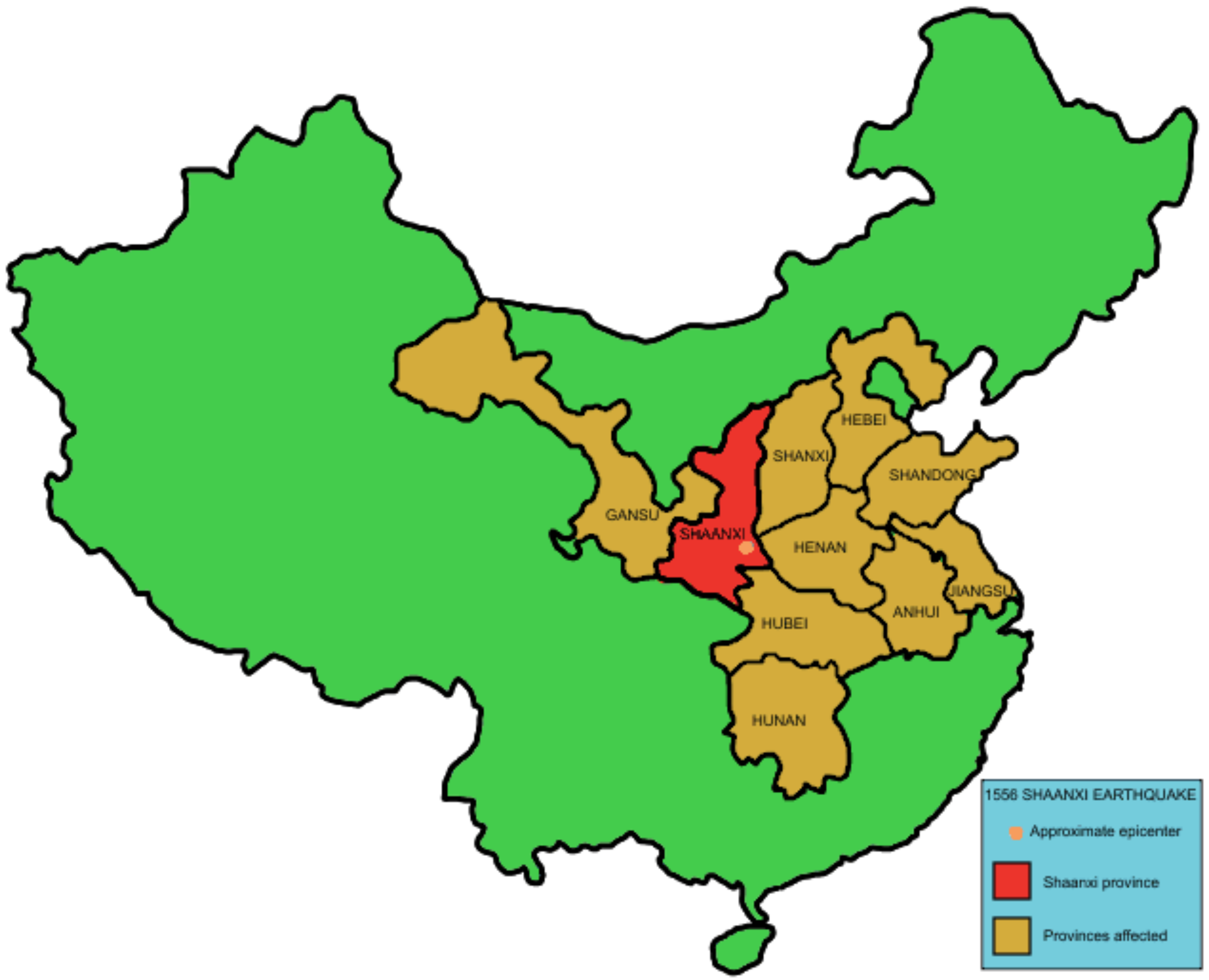
http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Cases

23 January 1556 in Shaanxi, Mw=7.9-8.0, I-XI, Depth unknown
Deaths 820,000-830,000

1556 Shaanxi earthquake or Huaxian earthquake:

- deadliest earthquake on record,
- approximately 830,000 death,
- in some counties 60% of the population killed,
- built infrastructure: mostly yaodongs, artificial caves in loess cliffs,
- epicenter was in the Wei River Valley in Shaanxi Province, near the cities of Huaxian, Weinan and Huayin,
- in Huatian, every single building and home was demolished,
- in certain areas, crevices 20 m deep opened,
- landslides contributed to the death toll.

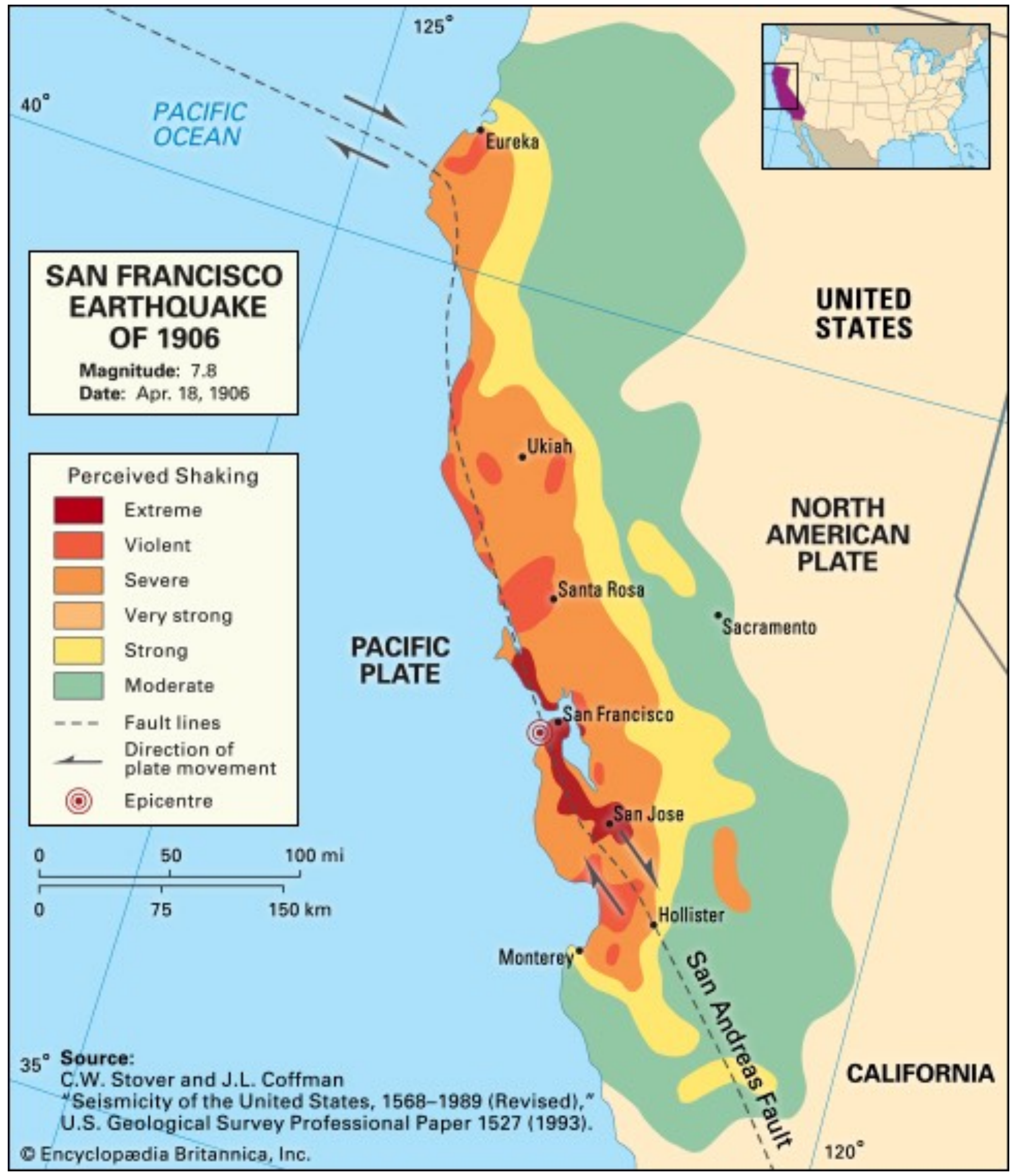


Deadliest earthquake on record

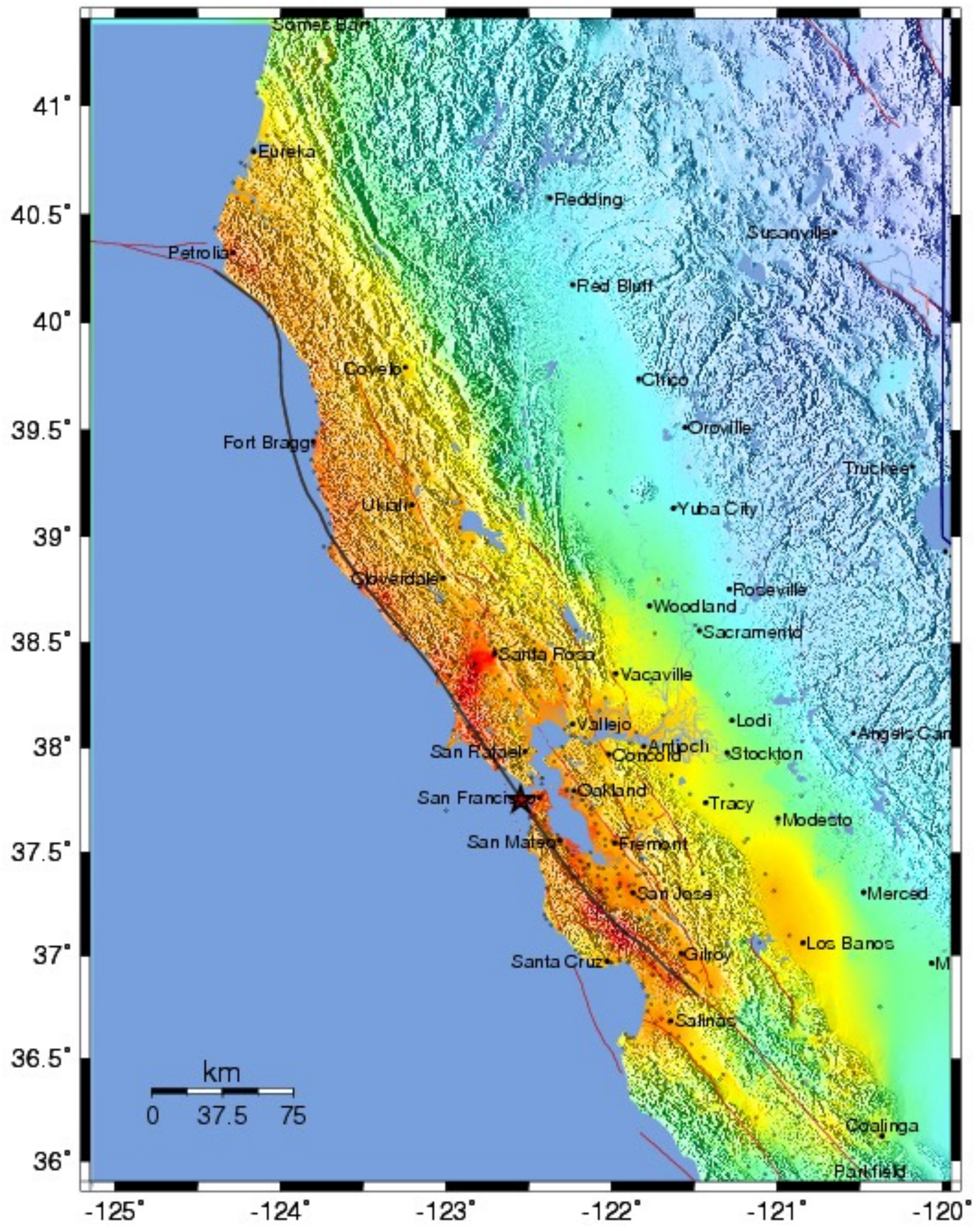
Cases

Apr. 18, 1906 San Francisco, Mw=7.9, I=XI, Depth 8 km, Deaths 700 - 3,000

- San Andreas Fault slipped along a segment about 430 km long,
- Shaking was felt from Los Angeles in the south to Coos Bay, Oregon, in the north.
- Damage was severe in San Francisco and in other towns situated near the fault, including San Jose, Salinas, and Santa Rosa.



1906 Earthquake, M7.8, Depth 10 km, Epicenter N37.75 W122.55

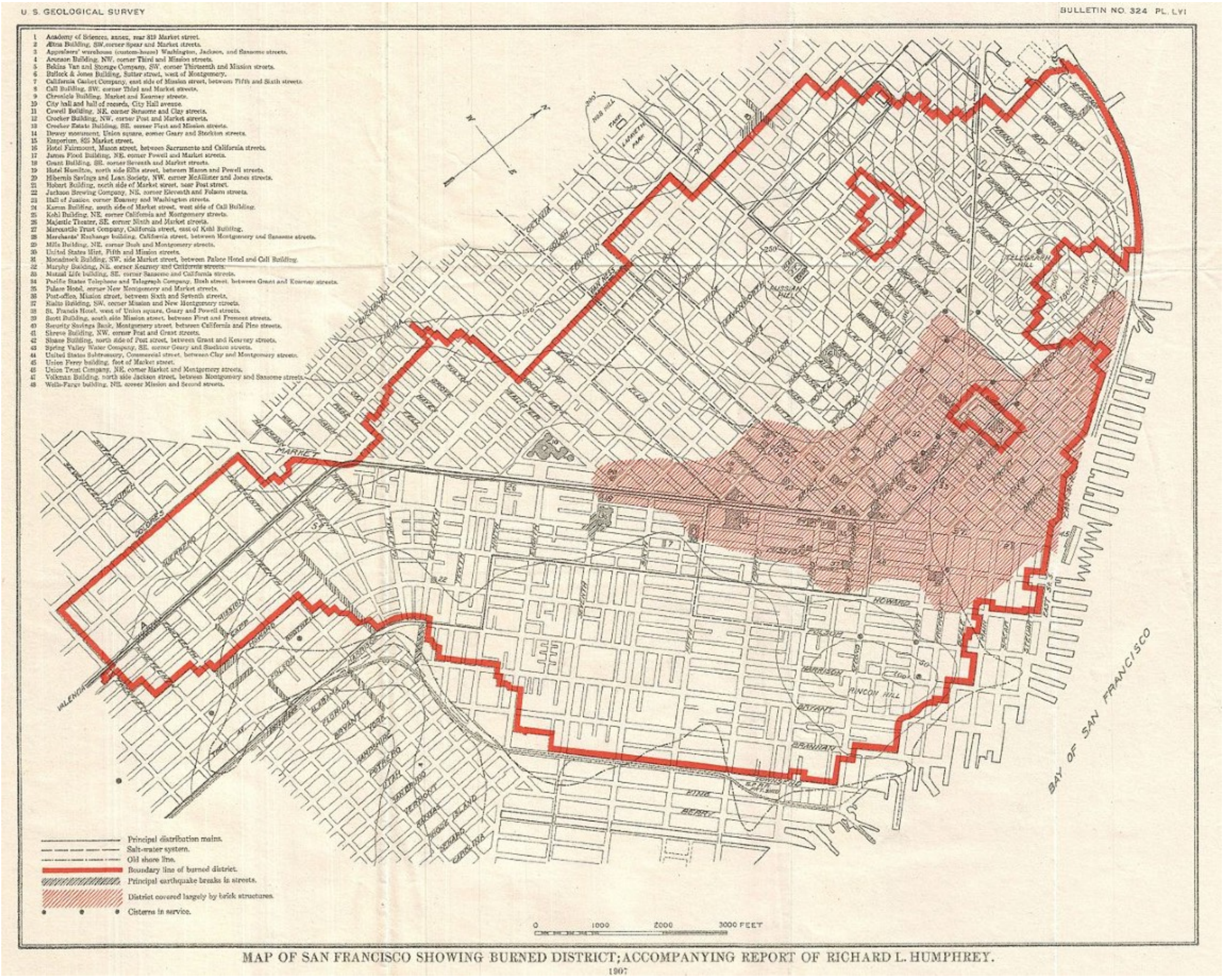


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Cases

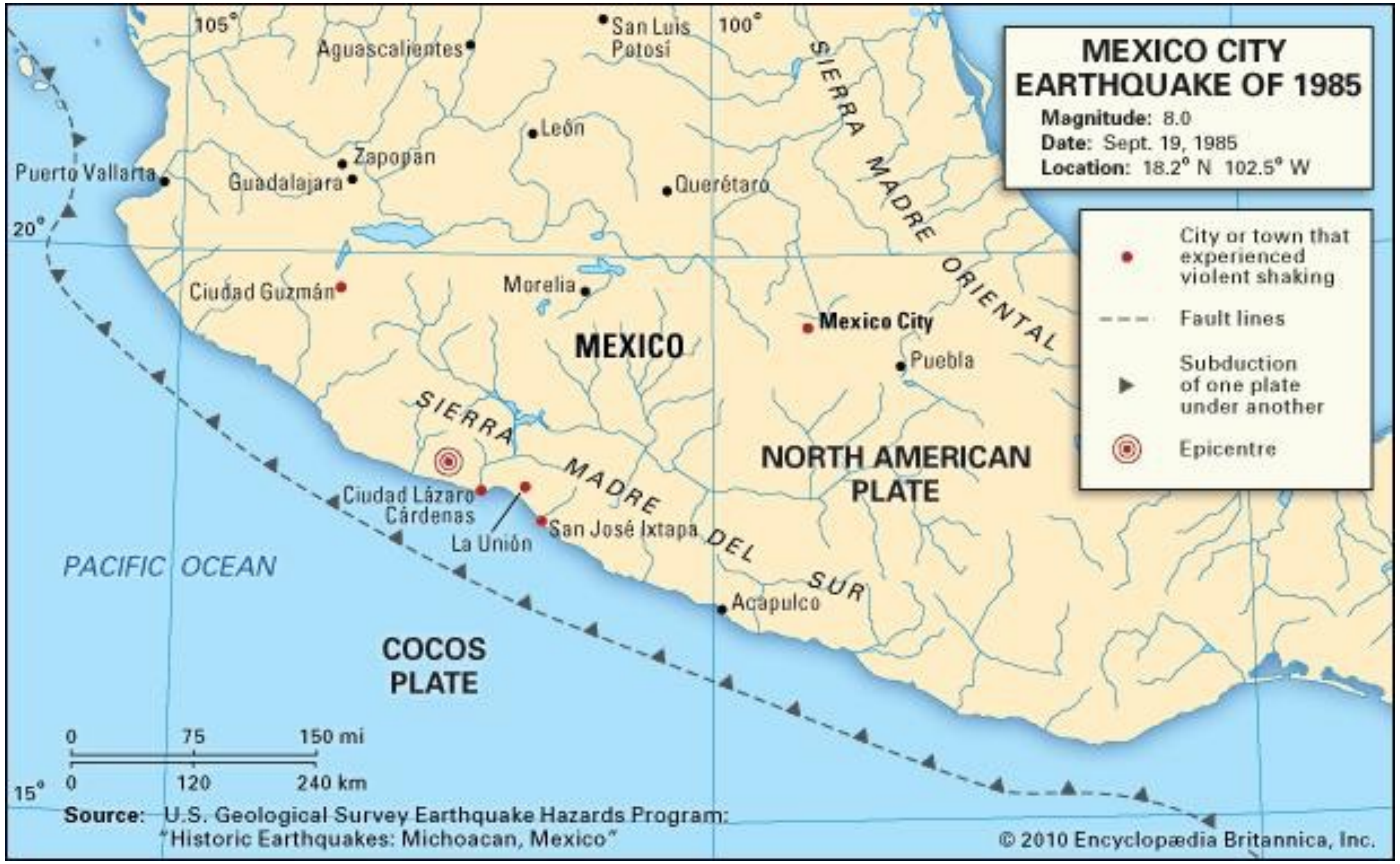
Apr. 18, 1906 San Francisco, Mw=7.9, I=XI,
Depth 8 km, Deaths 700 - 3,000



Sep. 19, 1985 Mexico City, Mw=8.0, I=IX, Depth 20 km, Deaths 10,000 (up to 45,000)

- Central city is constructed on the dry bed of the drained Lake Texcoco.
- There, heaviest shaking because loose lacustrine sediments amplified the shock waves.
- Ground motion there measured five times that of surrounding areas.
- Buildings of 5 to 15 stories were most affected.
- Their eigenperiod resulted in harmonic resonance.
- More than 400 buildings collapsed, and thousands more were damaged.

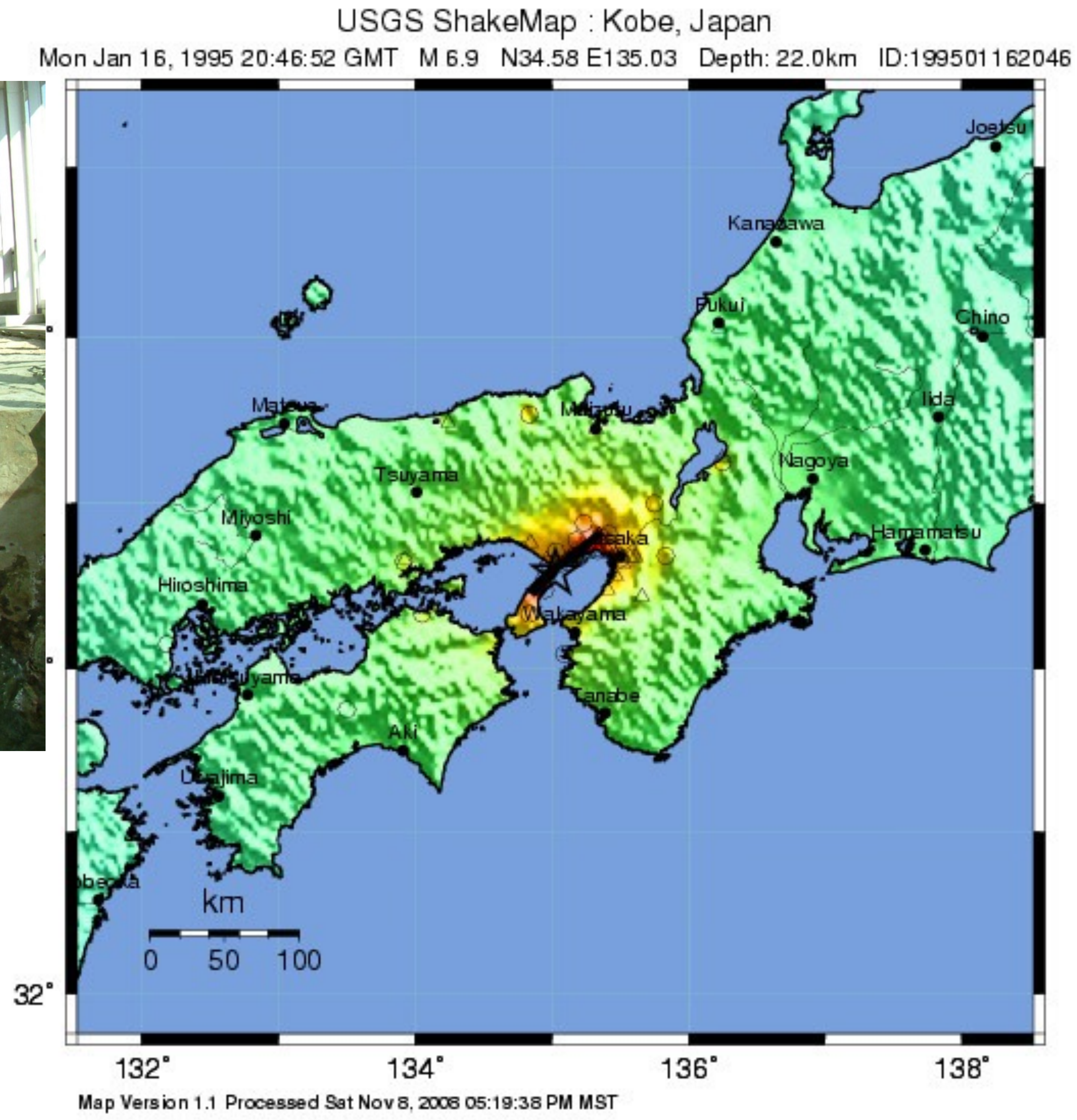


- Soil liquefaction contributed to the extensive damage in the southern part of the city.
- The liquefaction of the soft lake sediments amplified the effect of the surface waves, particularly at periods between 2 and 5 s.

Cases

Jan. 17, 1995, Kobe, Japan, Mw=6.9, I=XI
Depth 17.6 km, Deaths 5,502-6,400,
Damage $200 billion

- Structures damaged beyond repair included nearly 400,000 buildings, numerous elevated road and rail bridges, and 120 of the 150 quays in the port of Kobe.
- Triggered around 300 fires.
- Disruptions of water, electricity and gas supplies were extremely cor

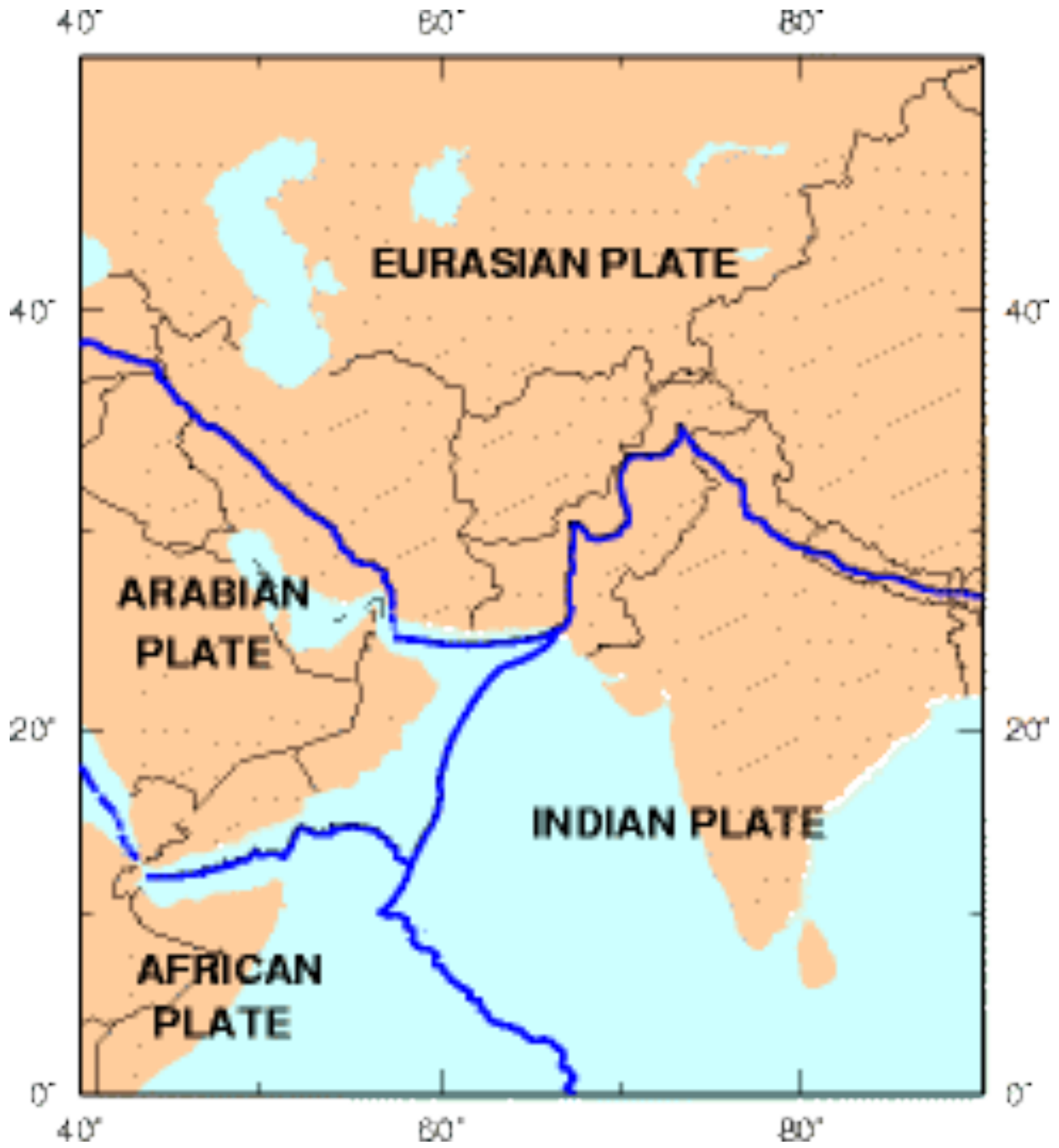


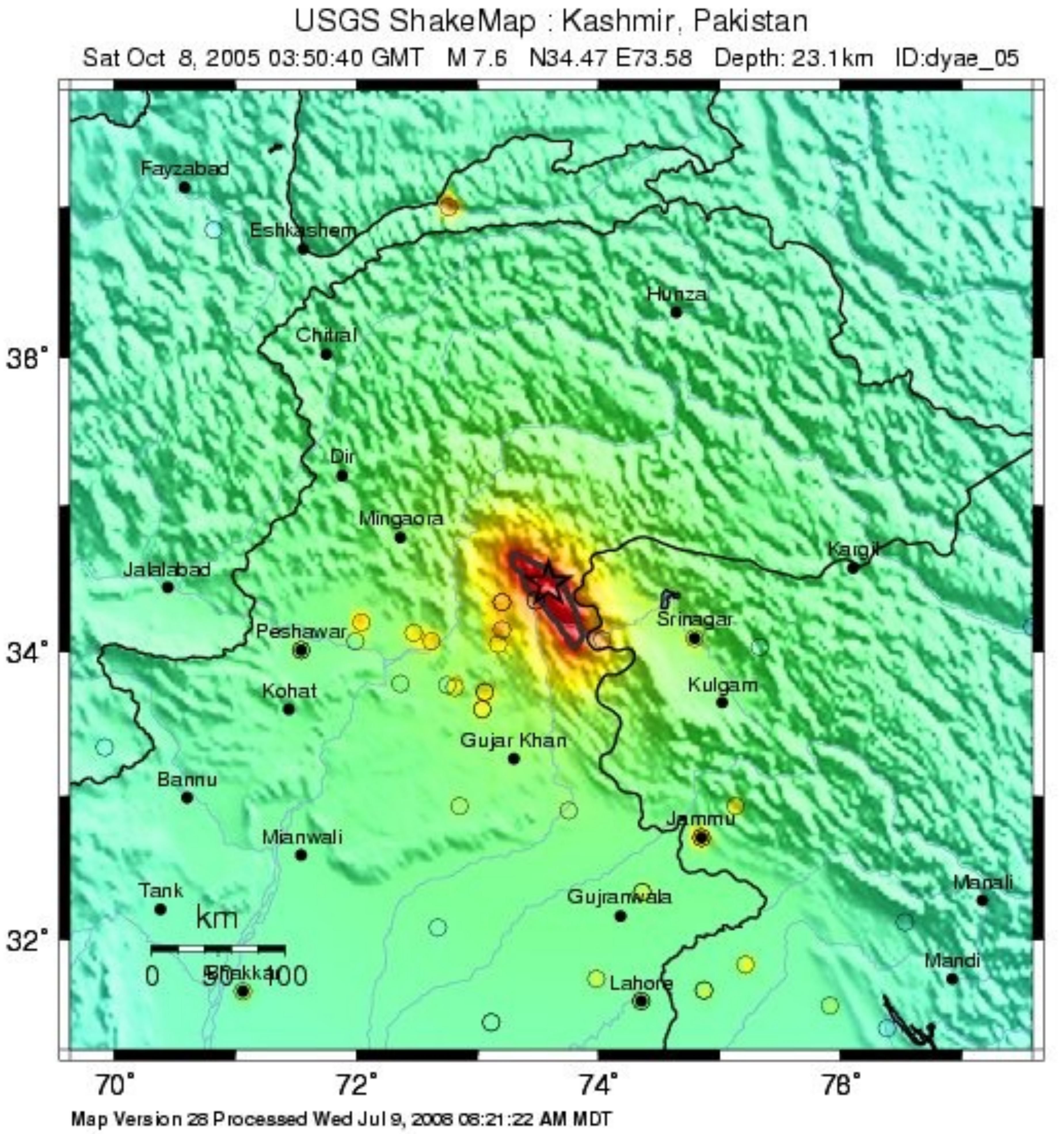
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Cases

Oct. 8, 2005, Azad Kashmir, Mw=7.6, I=VIII, Depth 26 km
Deaths 86,000 to 87,000, Damage $5.2 billion

- The tremors were felt at a distance of up to 620 miles (1,000 km), as far away as Delhi and Punjab in northern India.
- The property loss caused by the quake left an estimated four million area residents homeless.
- The severity of the damage and the high number of fatalities were exacerbated by poor construction in the affected areas.

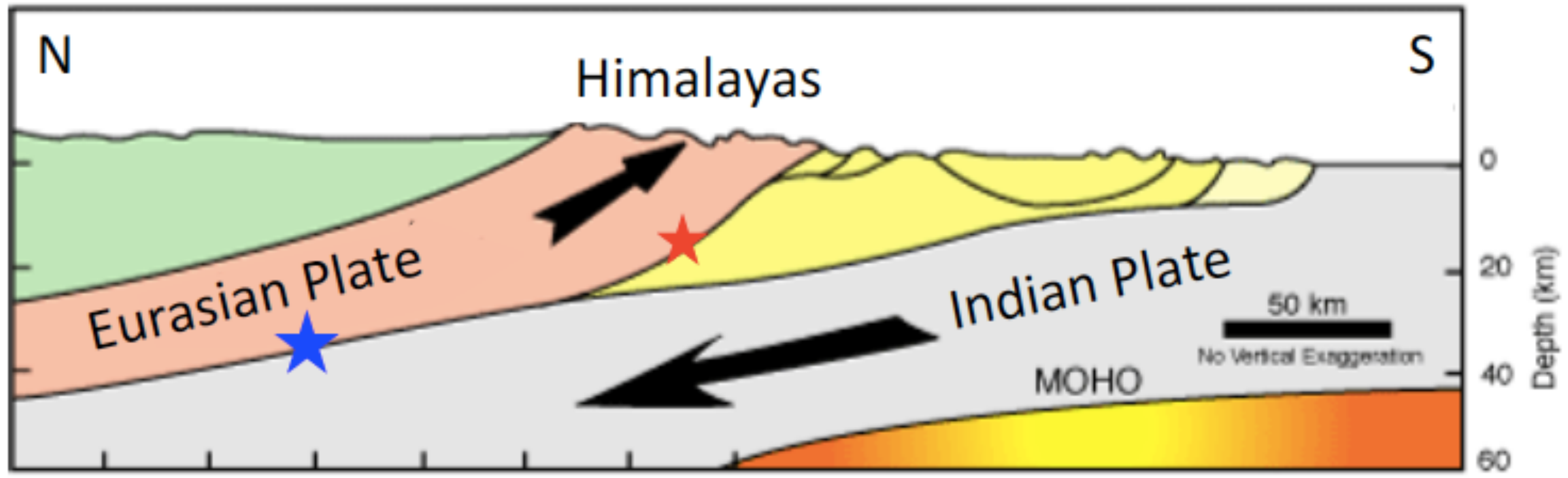




PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

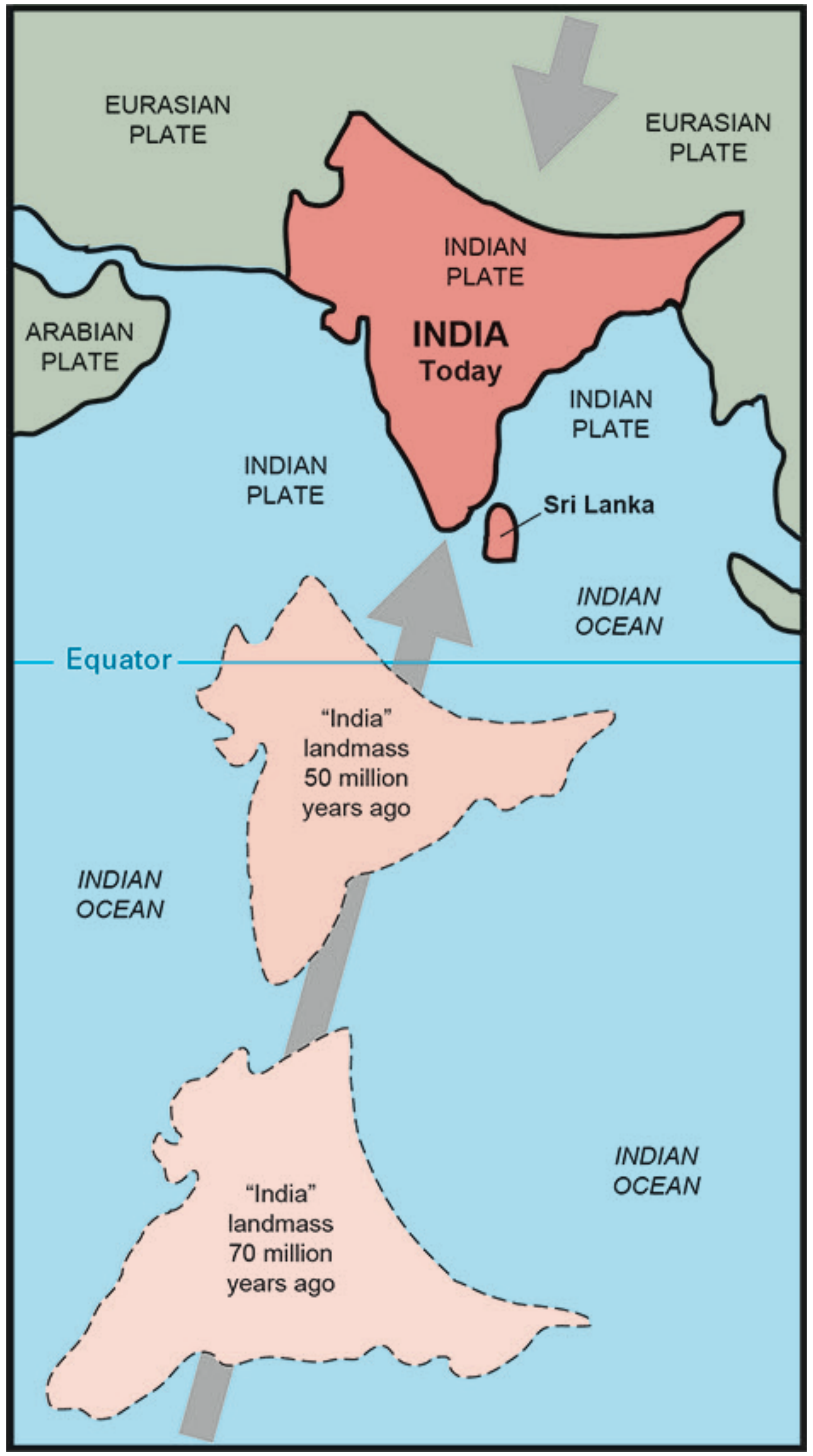
Cases

Oct. 8, 2005, Azad Kashmir, Mw=7.6, I=VIII, Depth 26 km
Death 86,000 to 87,000, Damage $5.2 billion



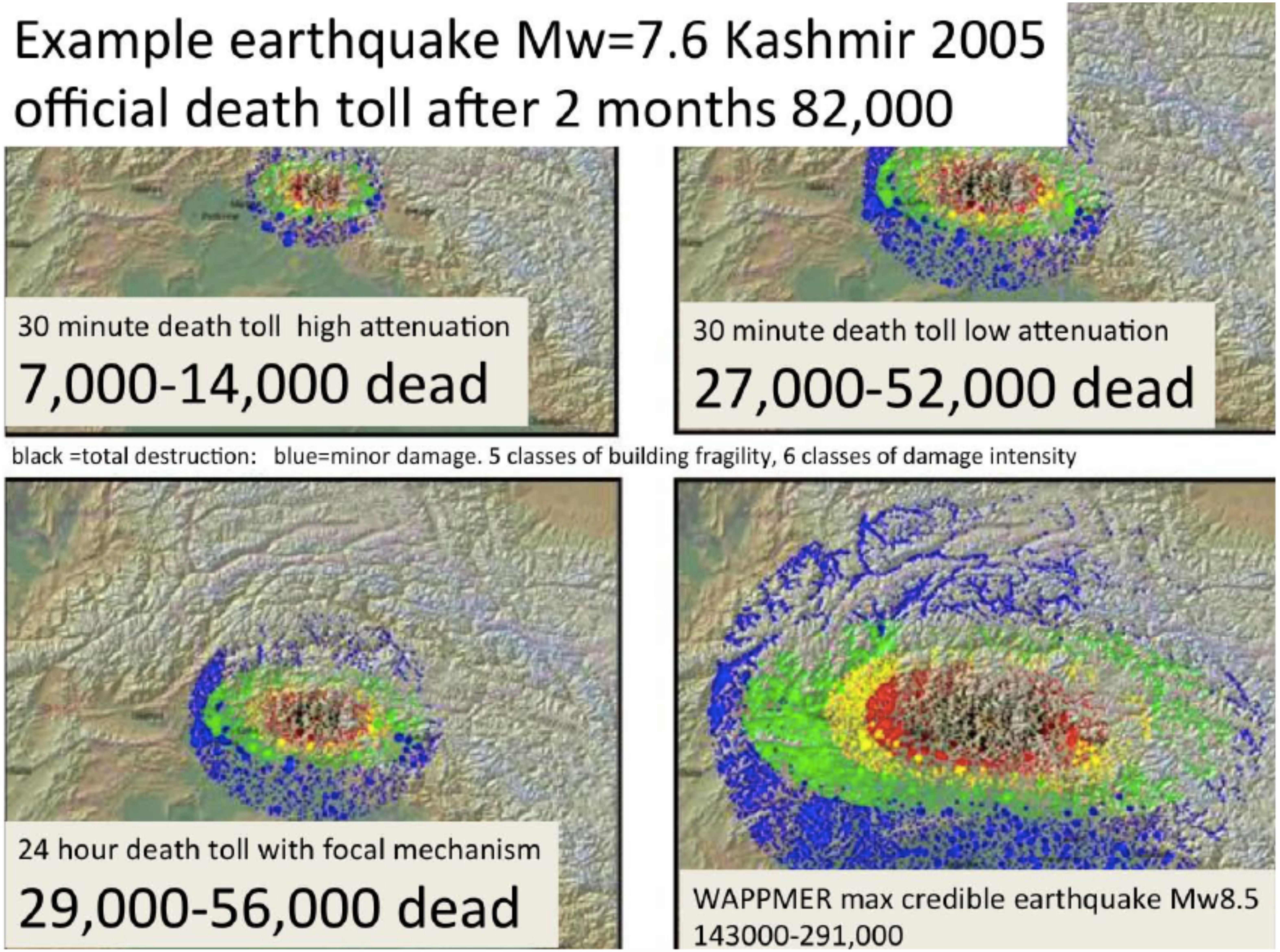
North-South profile of the present Indian-Eurasian plate boundary, with approximate focal depths of the 2005 Kashmir (blue star) and 2015 Nepal (red star) earthquakes.

The Indian Plate's northward migration culminated in continent-continent collision at between 50 and 40 million years ago, causing the uplift of the Himalayas. Epicenters marked by stars on Google Earth image for the 2005 Kashmir (blue) and 2015 Nepal (red) earthquakes.



Cases

Oct. 8, 2005, Azad Kashmir, Mw=7.6, I=VIII, Depth 26 km
Death 86,000 to 87,000, Damage $5.2 billion



Death causes for most earthquakes:

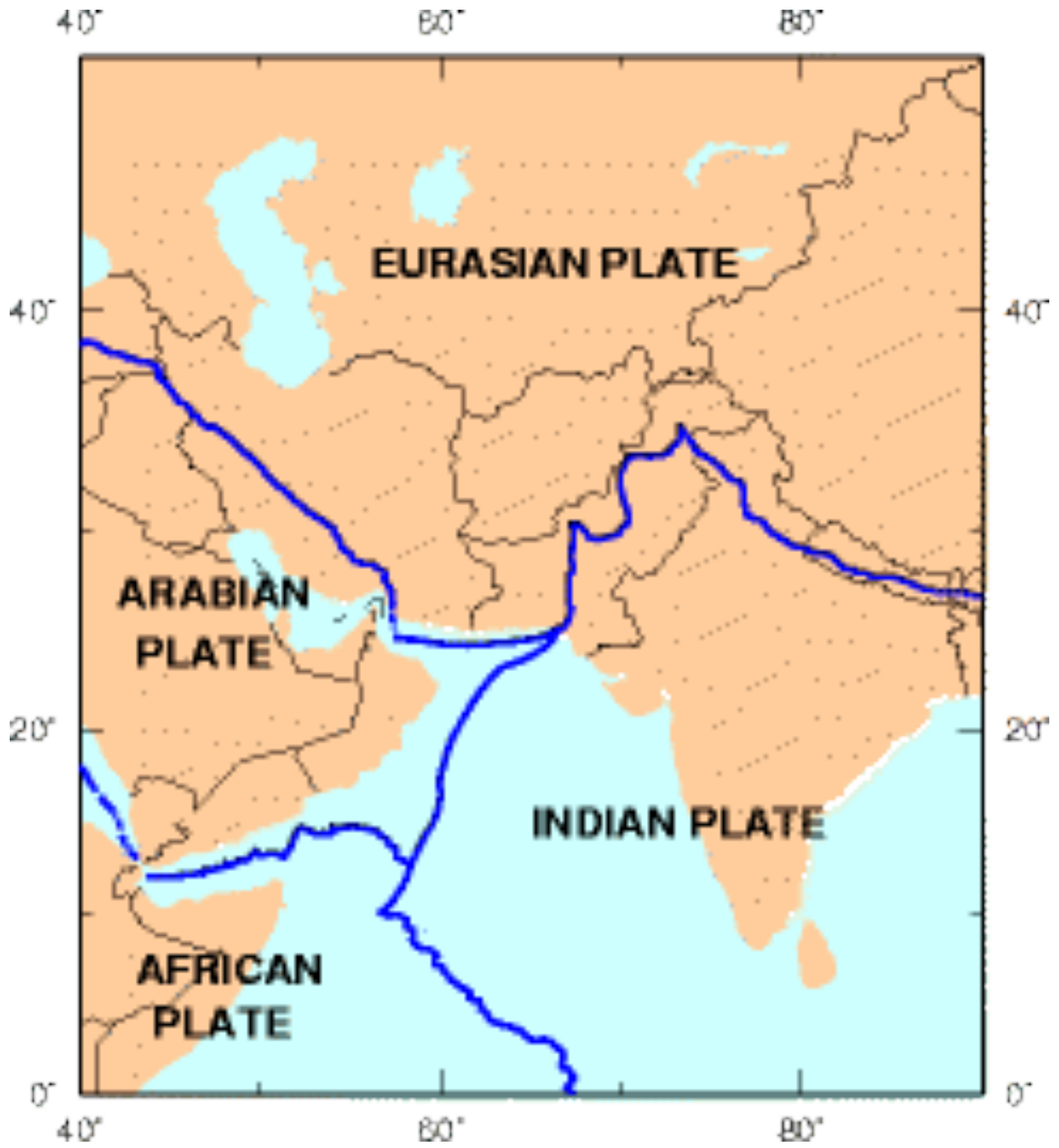
First 2 hours 20% of deaths: asphyxia from dust inhalation or chest compression, hypovolemic shock, or hypothermia.

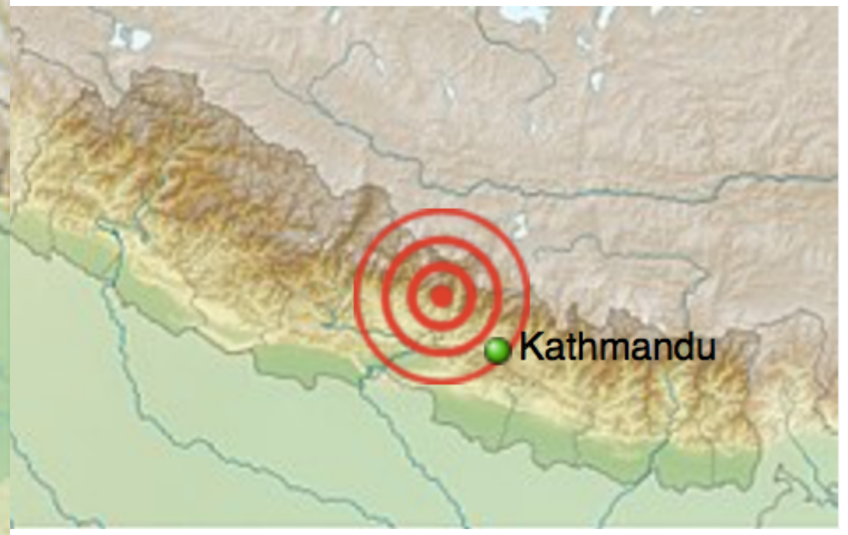
Days 1-3   80% of deaths
Delayed death occurs within days due to dehydration, hypothermia, hyperthermia, crush syndrome, wound infections, or postoperative sepsis.

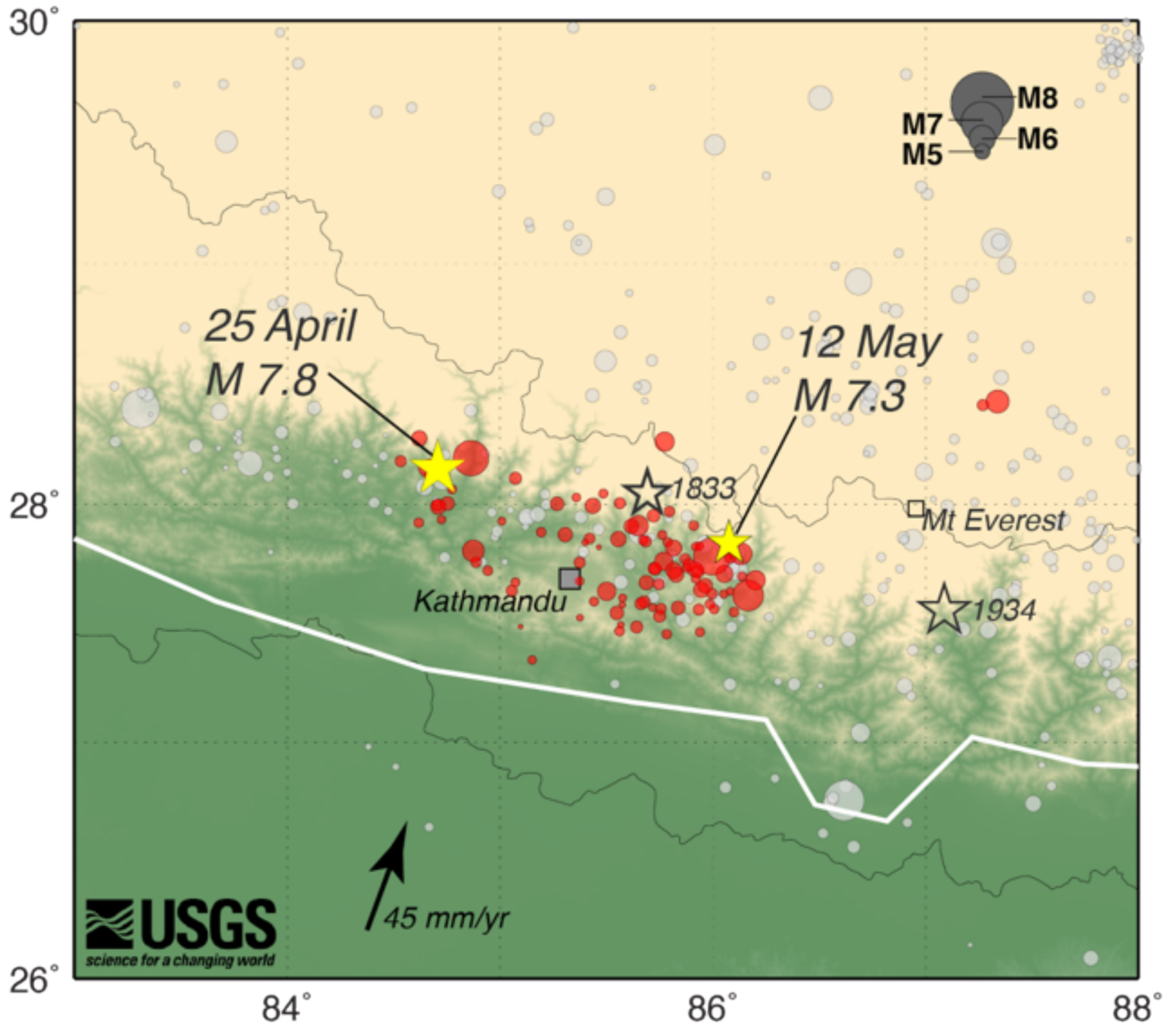
Cases

Oct. 8, 2005, Azad Kashmir, Mw=7.6, I=VIII, Depth 26 km
Death 86,000 to 87,000, Damage $5.2 billion

Apr. 25, 2015, Nepal, Mw=7.8, Depth 15 km
Death: 9,000, Damage: $10 billion (50% of Nepal's GDP)







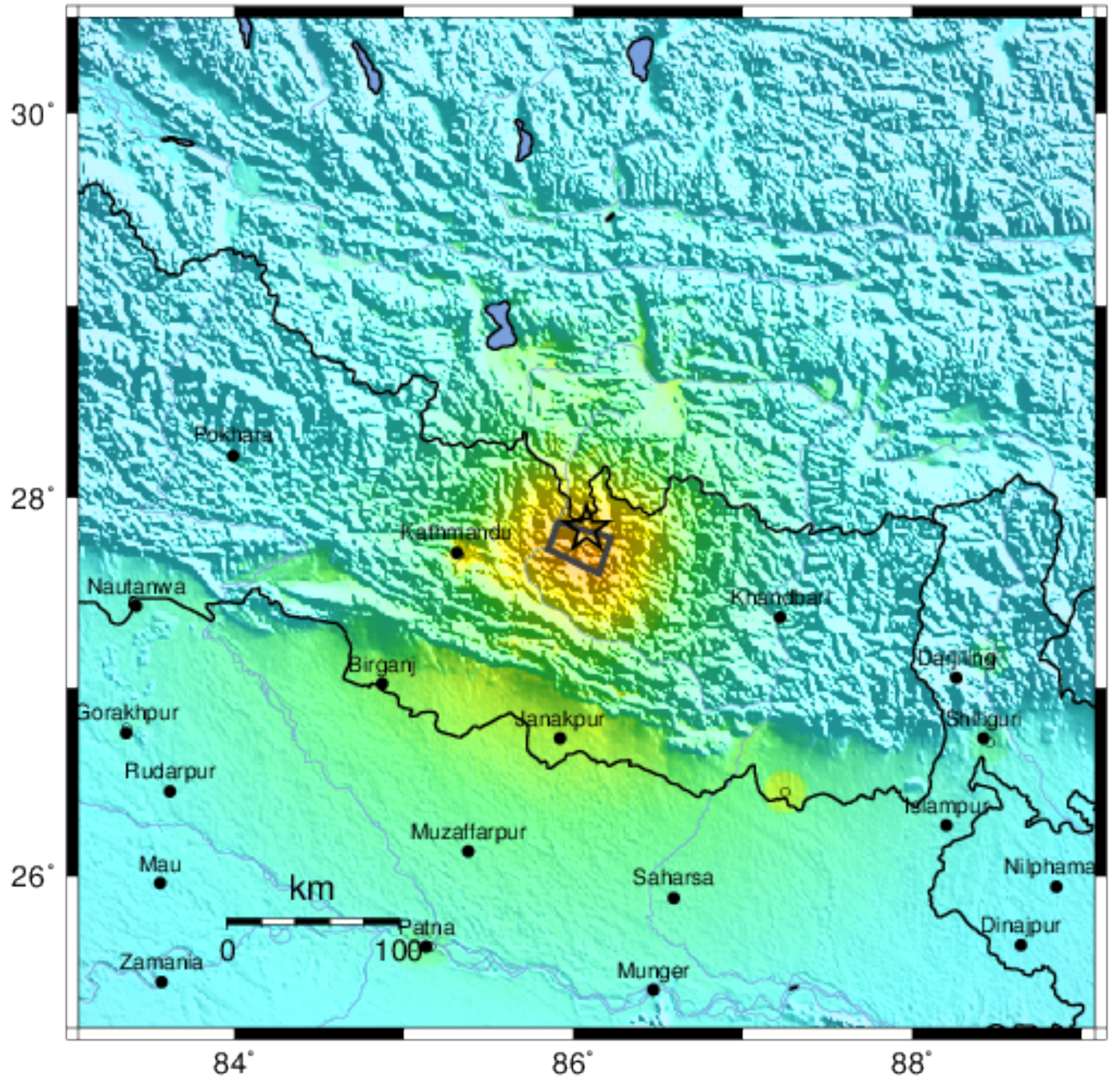
Cases

Oct. 8, 2005, Azad Kashmir, Mw=7.6, I=VIII, Depth 26 km
Death 86,000 to 87,000, Damage $5.2 billion

Apr. 25, 2015, Nepal, Mw=7.8, Depth 15 km
Deaths: 9,000, Damage: $10 billion (50% of Nepal's GDP)

May 12, 2015, Nepal, Mw=7.3, Depth 15 km
Deaths: 218

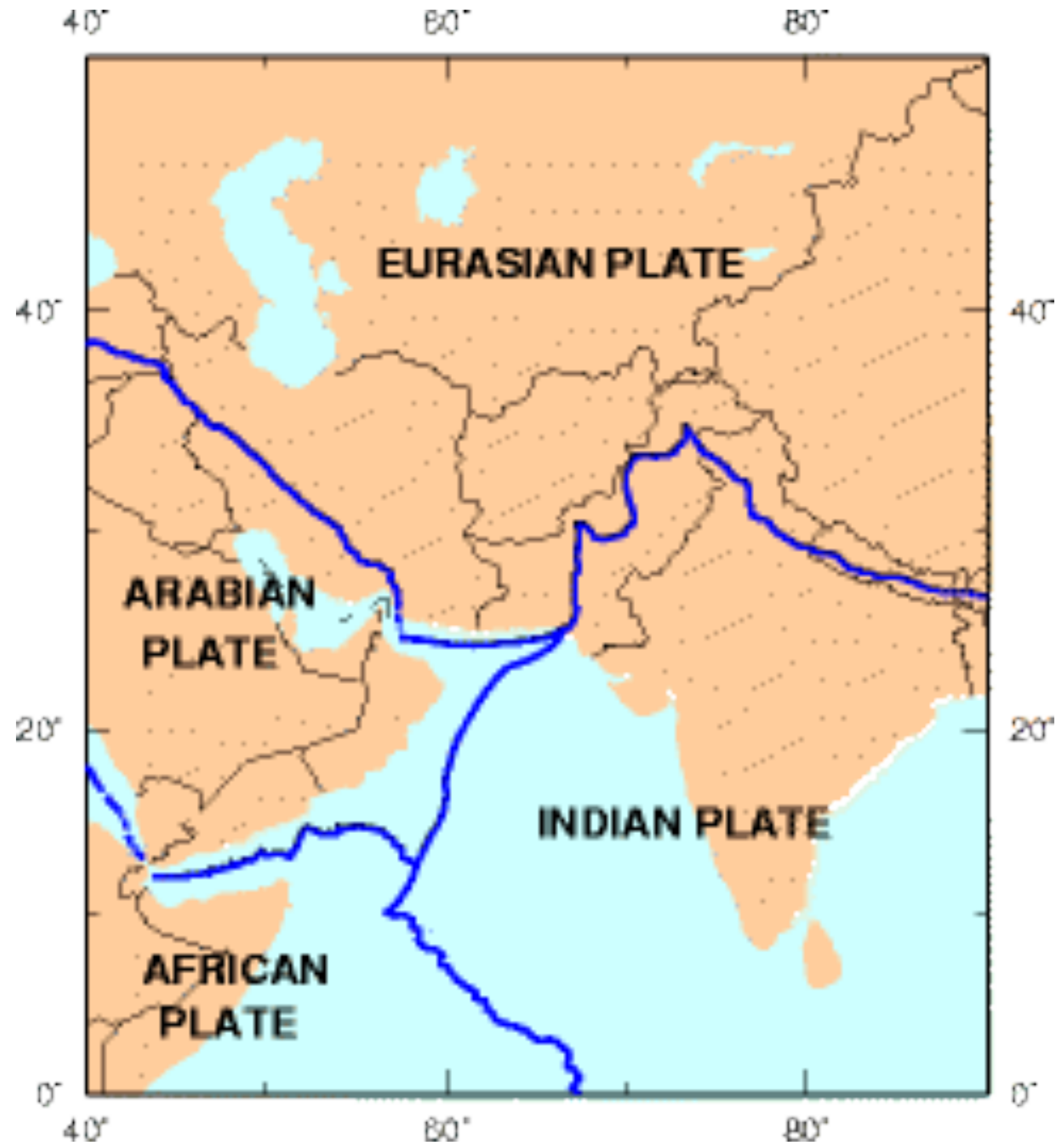
USGS ShakeMap : NEPAL
May 12, 2015 07:05:19 UTC M 7.3 N27.84 E86.08 Depth: 15.0km ID:us20002ejl



Map Version 3 Processed 2015-05-12 09:07:24 UTC

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)



Cases

Oct. 8, 2005, Azad Kashmir, Mw=7.6, I=VIII, Depth 26 km
Death 86,000 to 87,000, Damage $5.2 billion

Apr. 25, 2015, Nepal, Mw=7.8, Depth 15 km
Deaths: 9,000, Damage: $10 billion (50% of Nepal's GDP

May 12, 2015, Nepal, Mw=7.3, Depth 15 km
Deaths: 218

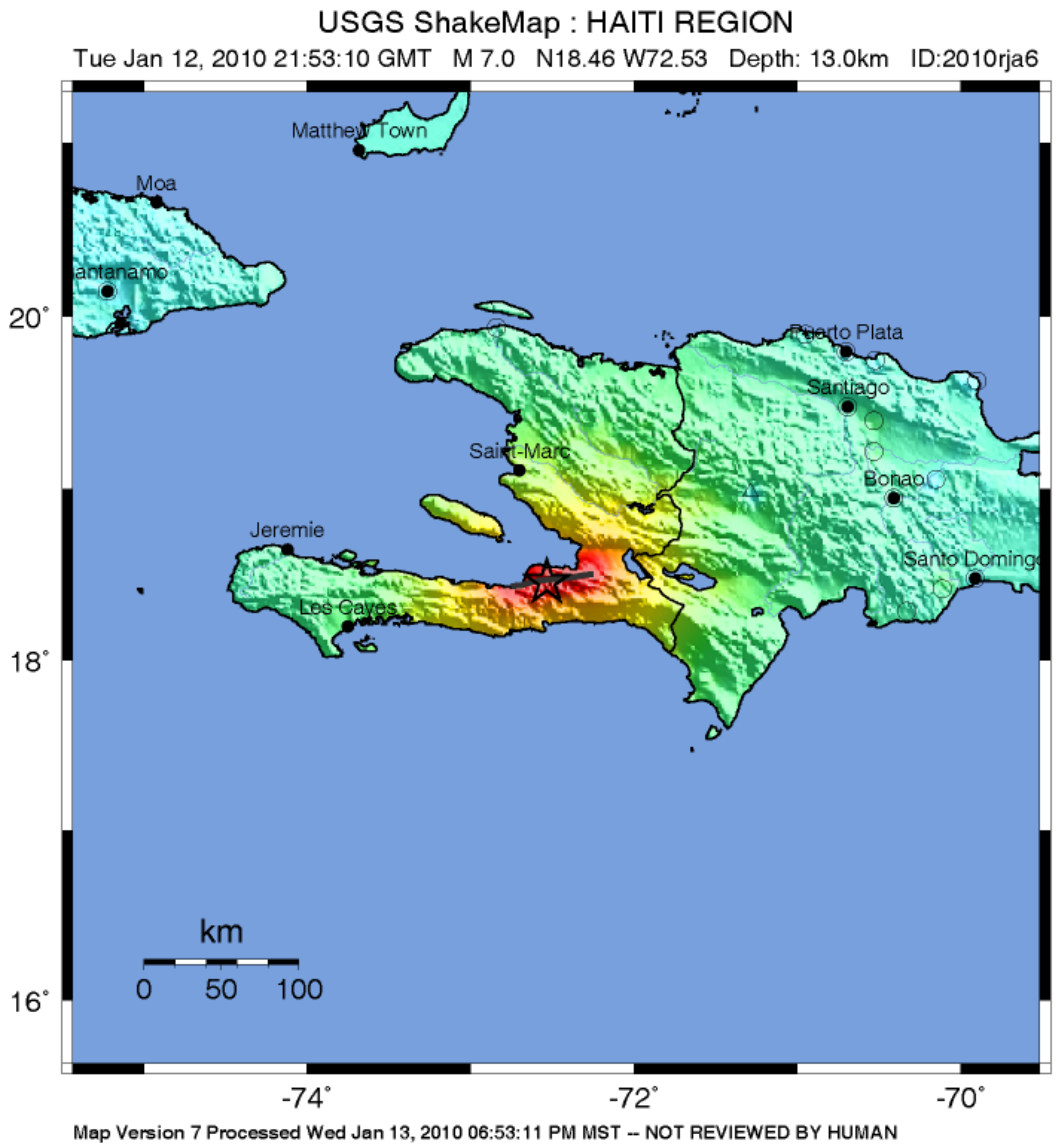
Destruction in Punjab, Pakistan Kashmir, caused by 23 seconds of ground shaking during the October 2005, M_W7.6 earthquake.

Nepalese village near Gorkha destroyed by a landslide that occurred during the April 2015, M_W 7.8 earthquake.

Cases

Jan. 12, 2010, Haiti, Mw=7.0, I=VIII, Depth 13 km
Deaths 80,000 to 315,000

- Generated by contractional deformation along the Léogâne fault,
- A small hidden thrust fault discovered underneath the city of Léogâne. Descends northward at an oblique angle away from the Enriquillo–Plantain Garden (EPG) strike-slip fault system
- Earthquake resulted from the slippage of rock upward across its plane of fracture.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

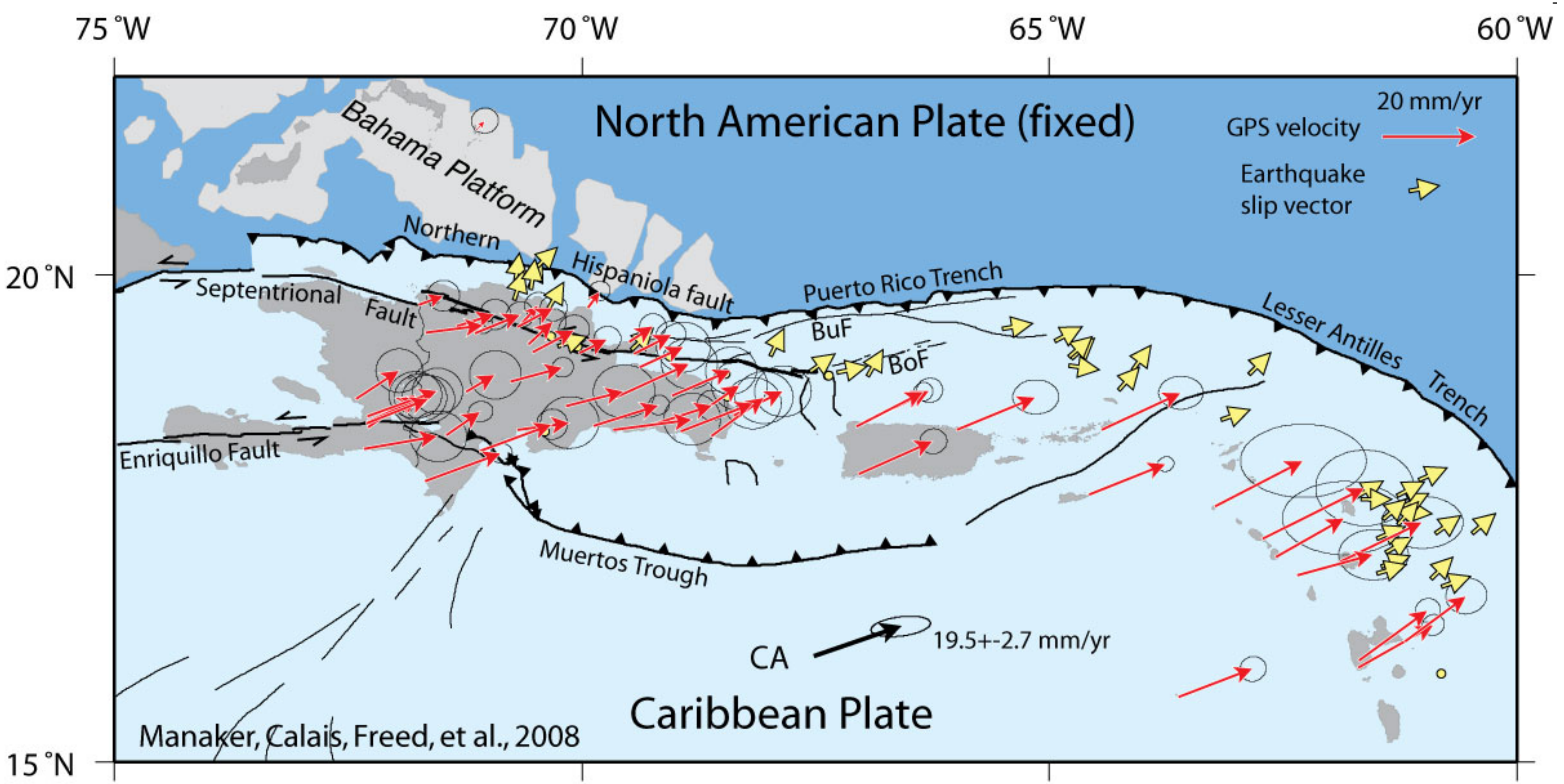
Cases

Jan. 12, 2010, Haiti, Mw=7.0, I=VIII, Depth 13 km
Deaths 80,000 to 315,000

Cases

Jan. 12, 2010, Haiti, Mw=7.0, I=VIII, Depth 13 km
Deaths 80,000 to 315,000

Understanding of Earthquake Preparation Processes Using GPS Geodesy



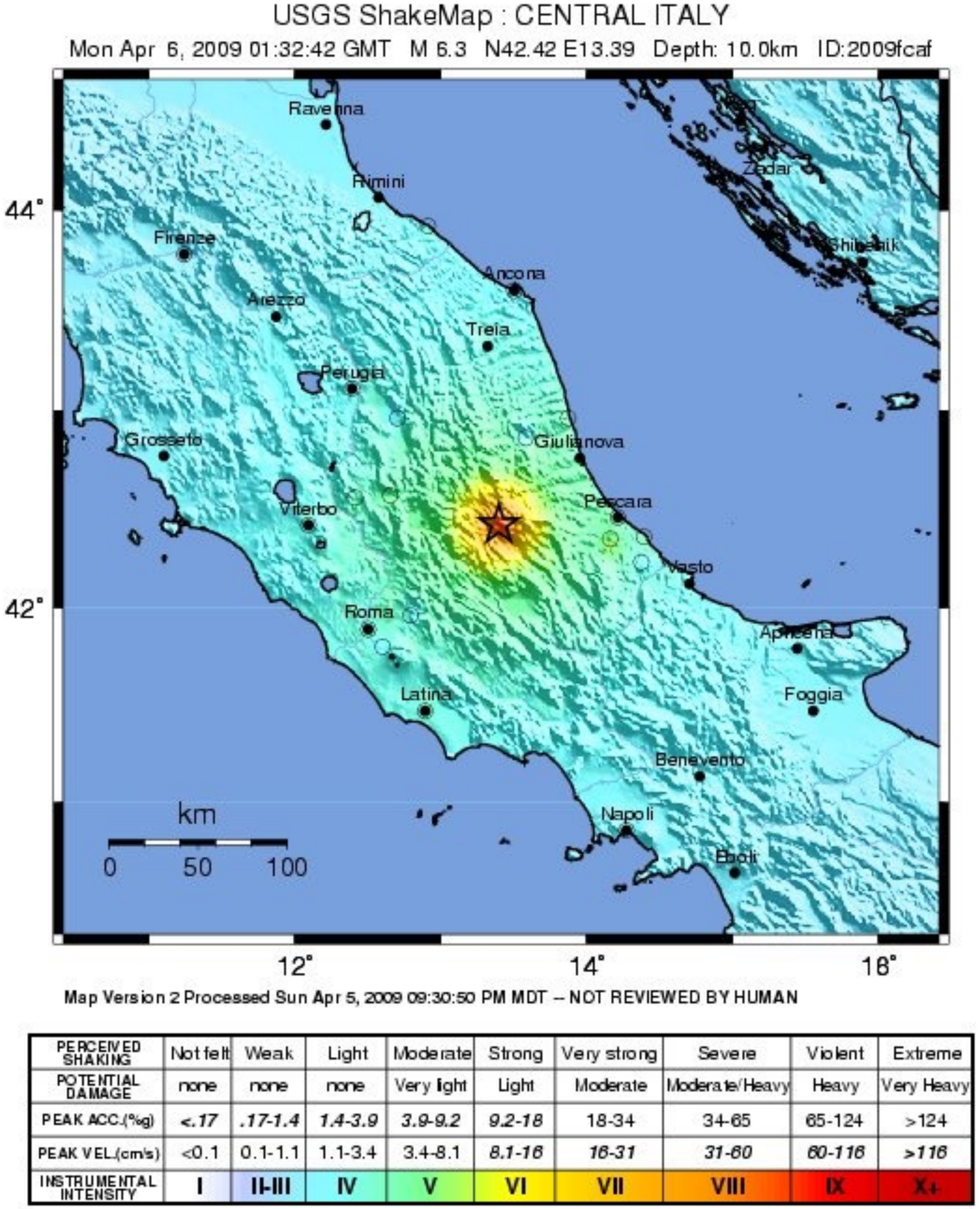
"… the Enriquillo fault in Haiti is currently capable of a Mw7.2 earthquake if the entire elastic strain accumulated since the last major earthquake was released in a single event today" (Manaker et al., 2008)

Ismail-Zadeh, 2011

Cases

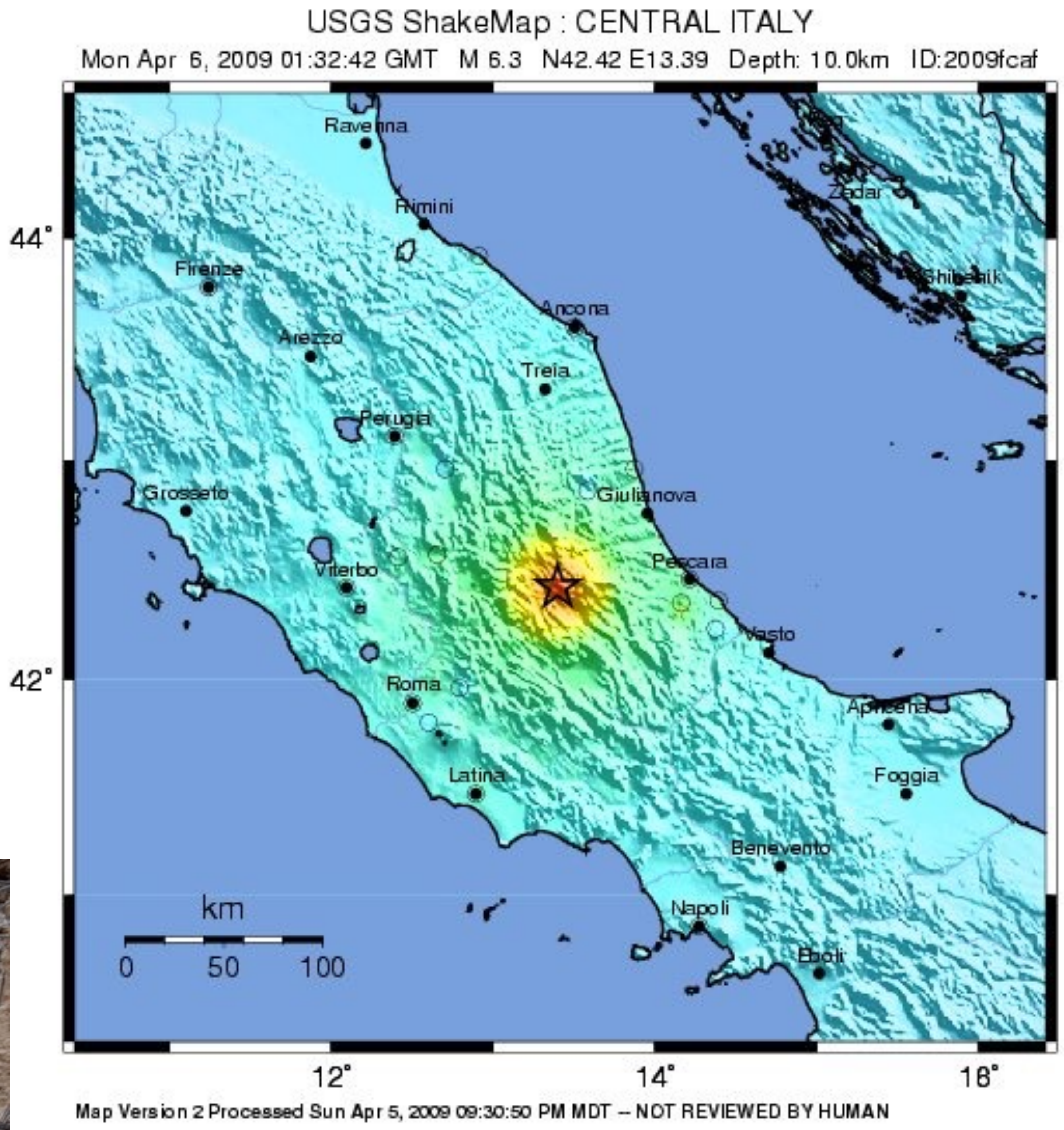
Apr. 6, 2009, L'Aquila M 6.3, I=VIII, Depth 9.5 km
Deaths 309, Damage $16 billion

- Occurred in the region of Abruzzo, in central Italy.
- L'Aquila, the capital of Abruzzo, suffered most damage.
- There were **several thousand foreshocks** and aftershocks since December 2008. More than thirty of which had magnitude greater than 3.5.
- Deadliest earthquake to hit Italy since the 1980 Irpinia earthquake.



Cases

Apr. 6, 2009, L'Aquila M 6.3, I=VIII, Depth 9.5 km
Deaths 309, Damage $16 billion

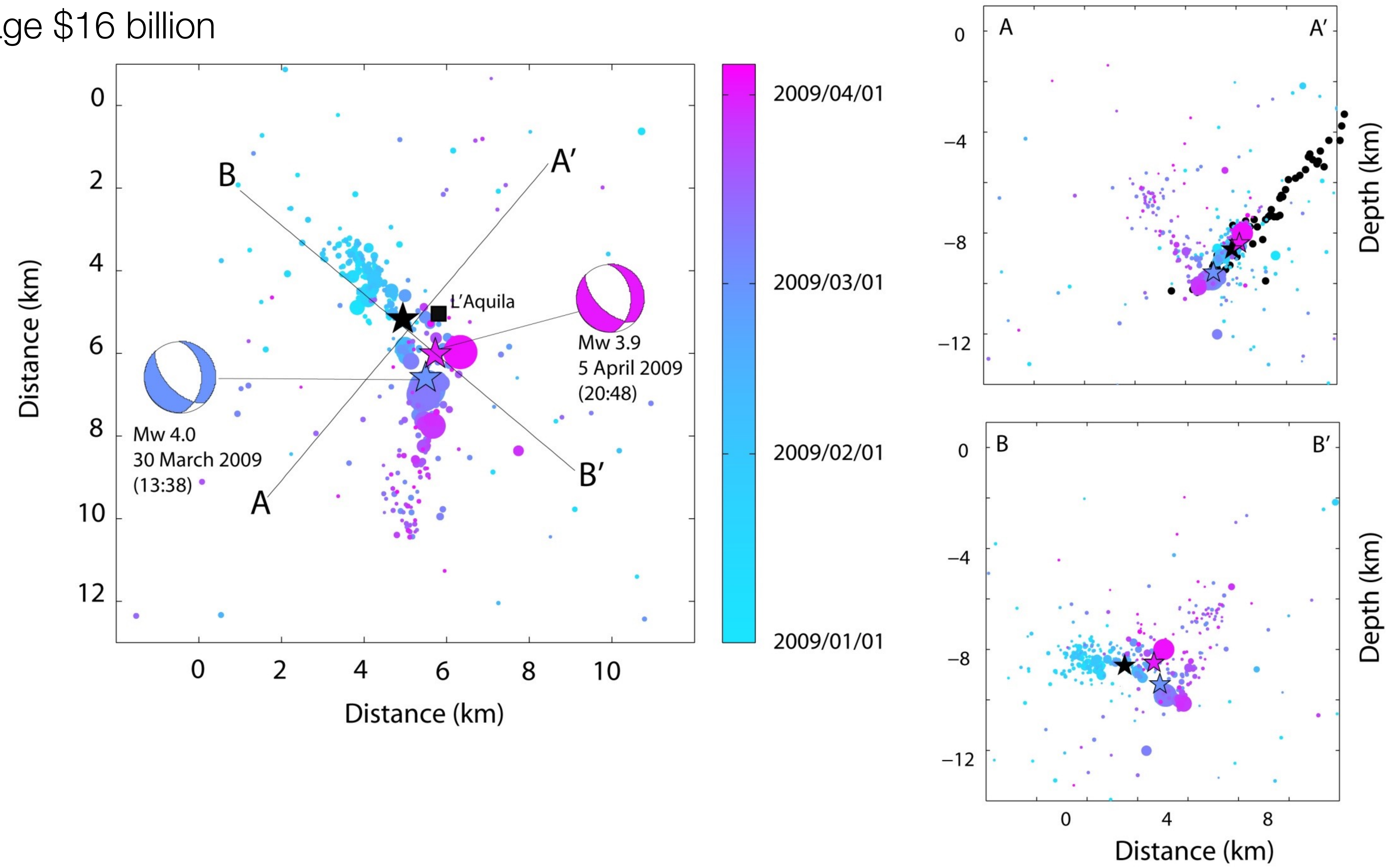


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

- Poor building standards led to the failure of many modern buildings in a known earthquake zone:
- Official at Italy's Civil Protection Agency, Franco Barberi, said that "in California, an earthquake like this one would not have killed a single person".

Cases

Apr. 6, 2009, L'Aquila M 6.3, I=VIII, Depth 9.5 km
Deaths 309, Damage $16 billion



(Chiaraluce et al., 2011)

Cases

Apr. 6, 2009, L’Aquila M 6.3, I=VIII, Depth 9.5 km
Deaths 309, Damage $16 billion

Before the Earthquake:

- The rate of earthquake production increased on March 30th 2009 after a M_L 4.1 earthquake that struck the L’Aquila area
- Preoccupation and panic in population raised
- After a prediction broadcasted by Giuliani, vans mounted with loudspeakers blare warnings to Sulmona residents to flee. Many people do. No earthquake occurs in the prediction window.
- On March 31st the Italian Civil Protection organize in L’Aquila a meeting of the Commissione Grandi Rischi (Major Risks Committee), an expert group that advises the Civil Protection agency on the risks of natural disasters
- Immediately after that meeting, De Bernardinis and Barberi, acting president of the committee, held a press conference in L’Aquila, where De Bernardinis told reporters that “**the scientific community tells us there is no danger, because there is an ongoing discharge of energy. The situation looks favorable**”.

- Subsequently, seven members of the Italian National Commission for the Forecast and Prevention of Major Risks were accused of giving "inexact, incomplete and contradictory" information about the danger of the tremors prior to the main quake.
- On 22 October 2012, six scientists and one ex-government official were convicted of multiple manslaughter for downplaying the likelihood of a major earthquake six days before it took place.
- They were each sentenced to six years' imprisonment.
- On 10 November 2014, the verdict was overturned.

Natural Hazards and Disaster

Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Magnitude and Locations
- Cases
- Extreme Events
- Managing Disaster Risk
- Tsunamis

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Extreme Events

How Big, How Bad, How Often?

20 largest earthquakes (hazards) recorded since 1900

	Mag	Location	Date (UTC)	Time (UTC)	Latitude	Longitude	Death
1.	9.5	Chile Valdivia Earthquake	1960-05-22	19:11	38.14°S	73.41°W	5,700
2.	9.2	Great Alaska Earthquake	1964-03-28	03:36	60.91°N	147.34°W	125
3.	9.1	Sumatra-Andaman Islands Earthquake	2004-12-26	00:58	3.30°N	95.98°E	230,000-300,000
4.	9.1	Tohoku Earthquake	2011-03-11	05:46	38.30°N	142.37°E	15,870
5.	9.0	Kamchatka, Russia	1952-11-04	16:58	52.62°N	159.78°E	1,000
6.	8.8	Chile Maule Earthquake	2010-02-27	06:34	36.12°S	72.90°W	523
7.	8.8	1906 Ecuador–Colombia Earthquake	1906-01-31	15:36	0.96°N	79.37°W	1000
8.	8.7	Rat Islands Earthquake	1965-02-04	05:01	51.25°N	178.72°E	0
9.	8.6	Assam, Tibet	1950-08-15	14:09	28.36°N	96.45°E	1,526
10.	8.6	off West Coast of Northern Sumatra	2012-04-11	08:39	2.33°N	93.06°E	10
11.	8.6	Indonesia Nias Earthquake	2005-03-28	16:10	2.09°N	97.11°E	1,303
12.	8.6	Andreanof Islands, Alaska	1957-03-09	14:23	51.50°N	175.63°W	0
13.	8.6	Unimak Island Earthquake, Alaska	1946-04-01	12:29	53.49°N	162.83°W	165
14.	8.5	Banda Sea	1938-02-01	19:04	5.05°S	131.61°E	0
15.	8.5	Atacama, Chile	1922-11-11	04:33	28.29°S	69.85°W	~100
16.	8.5	Kuril Islands	1963-10-13	05:18	44.87°N	149.48°E	none reported
17.	8.4	Kamchatka, Russia	1923-02-03	16:02	54.49°N	160.47°E	none reported
18.	8.4	Southern Sumatra, Indonesia	2007-09-12	11:10	4.44°S	101.37°E	25
19.	8.4	Peru Earthquake	2001-06-23	20:33	16.27°S	73.64°W	74-145
20.	8.4	Japan Sanriku Japan	1933-03-02	17:31	39.21°N	144.59°E	1522

Extreme Events

Year	Location	Mag.	Int.	Deaths	
1556	Shaanxi, China,	?	IX	830,000	
1693	Sicily		XI	93,000	
1755	Lisbon, Portugal		XI	62,000	a/c
1780	Tabriz, Iran	7.7		200,000	
1812	Caracas, Venezuela	9.6	X	26,000	
1906	San Francisco	7.9	XI	1000	c
1908	Sicily	7.5	XII	110,000	
1920	Gansu, China	8.5		200,000	
1923	Tokyo, Japan	7.9		142,800	
1948	Ashgabat	7.3		176,000	
1970	Chimbote, Peru	7.9		70,000	b
1976	Tangshan, China	7.8	X	240,000	

a: tsunami caused many death
b: landslides caused many death
c: fires caused many death

Extreme Events

Year	Location	Mag.	Int.	Deaths	
1985	Mexico City	8.1	IX	10,000	
1988	Spitak, Armenia	6.8	X	25,000	
1990	Manjil, Iran	7.4		>35,000	
1995	Kobe, Japan	6.9	XI	5,502	c
1999	Izmit, Turkey	7.4	X	17,000	
2001	Bhuj, India	8.0	X	20,000	
2003	Bam, Iran	6.6	IX	26,000	
2004	Aceh, Sumatra	9.1		250,000	a
2005	Azad Kashmir	7.6	VIII	80,000	
2008	Sichuan, China	7.9	IX	69,000	
2010	Haiti	7.0	IX	>80,000	
2011	Japan	9.0	VIII	>16,000	a
2015	Kathmandu, Nepal	7.8	IX	8,300	

a: tsunami caused many death

b: landslides caused many death

c: fires caused many death

Extreme Events

Year	Date (UT)	Region	Deaths	Magnitude
856	December	Greece, Corinth	45,000	?
1290	September 27	China, Chihli	100,000	6.8
1556	January 23	China, Shensi	830,000	8.3
1755	June 7	Northern Persia	40,000	5.9
1755	November 1	Portugal, Lisbon	70,000	8.7
1908	December 28	Italy, Messina	120,000	7.5
1920	December 16	China, Kansu	180,000	8.5
1923	September 1	Japan, Tokyo	143,000	8.2
1960	February 29	Morocco, Agadir	14,000	5.9
1970	May 31	Peru	66,000	7.8
1976	July 27	China, Tangshan	~ 500,000	7.6
1985	September 19	Mexico, Michoacán	9,500	7.9

Wong, 2011

Extreme Events

How Big, How Bad, How Often?

The problems:
- knowledge of rare events is limited
- know better the “why” and “how” but not the “when”
- probability is difficult to assess
- risk assessment is challenged

Assessing impacts: X-ness (Casti, 2012):

$$X = \frac{\delta E}{E}(1 - \frac{U}{U + I})$$

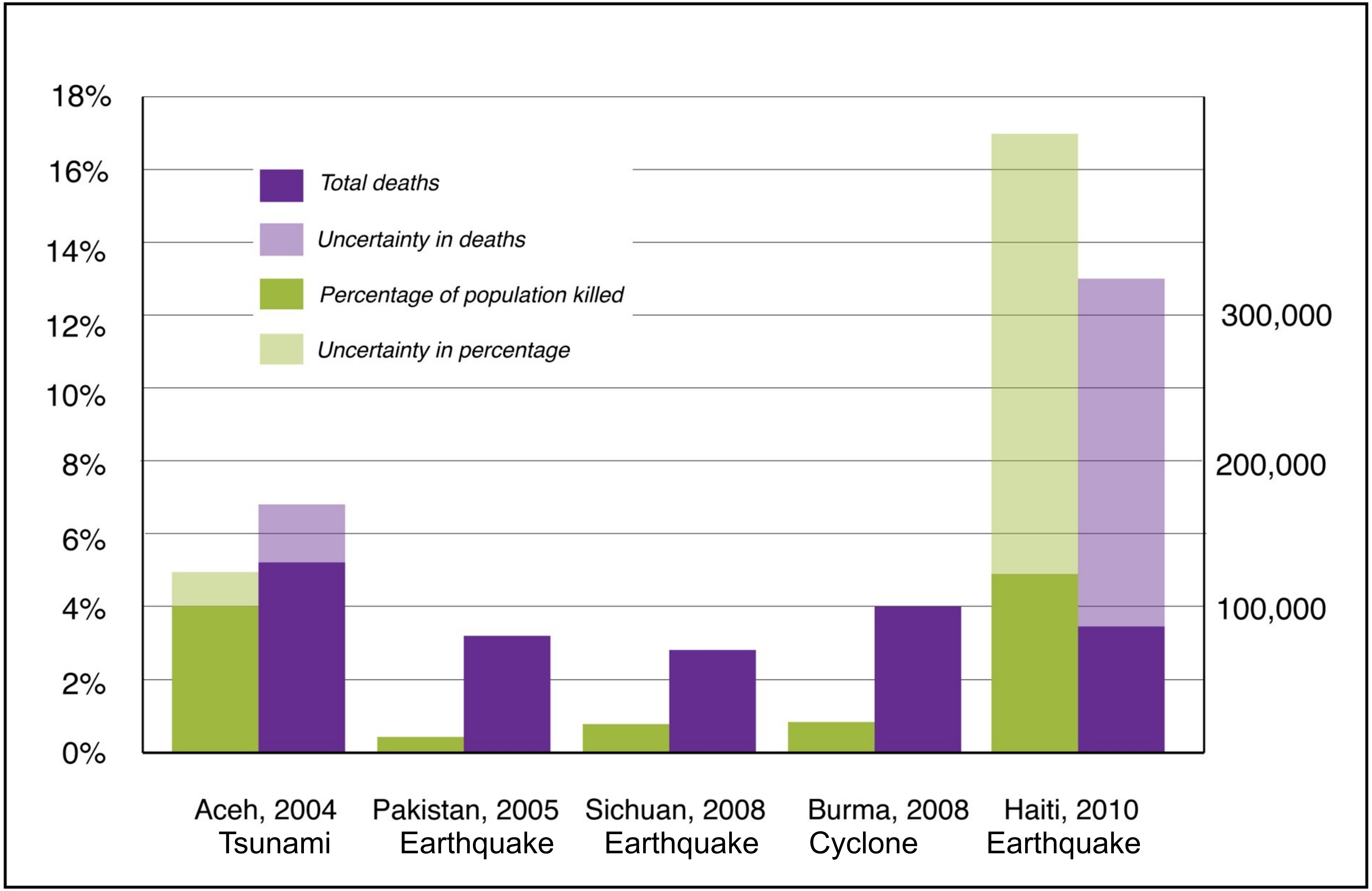
X: X-ness
δE: Impacted ensemble (population, GDP, ...)
U: Unfolding time
I: Impact time

Poisson distribution; Chance that one or more “1 in *N* years” events occur in a century:

N	C in %
10	99.99
100	63.21
500	18.13
1,000	9.516
10,000	0.995
100,000	0.100

In the 20th century we may have been lucky …

Extreme Events



Extreme Events

How Big, How Bad, How Often?

- The 2004 moment magnitude (M) 9.2 Sumatra and 2011 M 9.0 Tohoku, Japan earthquakes can be regarded as “extreme” events because in the past 200 years, less than 10 earthquakes have reached M 9.0 or greater.

- Both earthquakes can also be regarded as extreme events because of the devastating loss of life.

- However, the 2010 M 7.0 Haiti earthquake is also an extreme event because more than 80,000 deaths occurred even though it was of moderate size.

How Big, How Bad, How Often?

Probabilistic Seismic Hazard Analysis (PSHA)

- The objective of PSHA is to answer the questions: How big, how bad, and how often?
- The latter can only be answered if the frequency of earthquake occurrence is an input into the analysis.
- This type of seismic hazard analysis is in contrast to a deterministic (scenario) analysis where the earthquake rates are not considered. Sometimes erroneously called a worse-case scenario analysis.
- Probabilistic hazard can be for ground shaking, tsunami inundation, fault displacement, slope failure, or liquefaction.

How Big, How Bad, How Often?

Probabilistic Seismic Hazard Analysis (PSHA)

- The uncertainties in our knowledge of earthquake behavior need to be adequately included in PSHAs.
- However, even then there is no guarantee that all extreme events will be recognized; there are always unanticipated surprises.
- We must recognize that the results of even the best PSHAs have a limited “guarantee”.
- Although stability is sought in hazard predictions, the record suggests that hazard estimates may only be stable for a decade at best.
- Decisions should be and are based on risk rather than hazard because its the consequence of the hazards that we are concerned about.
- However, even when extreme events and their associated hazards are predicted, decisions to mitigate the impacts from such extreme events are likely put aside because of economic and societal limitations and competing demands.

Extreme Events

- Earthquakes do not kill people, but buildings (corruption, irresponsibility, ignorance …)
- Geohazards cannot be reduced, but vulnerability!
- Reducing predictive uncertainties in geohazard research and enhancing modeling capabilities
- Dealing with multiple and/or sequential events
- Developing a trans-disciplinary link and research
- Developing links to policy-makers, media & insurance
- Enhancing science education and improving awareness on extreme hazards and disaster risk

Ismail-Zadeh, 2011

Natural Hazards and Disaster

Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Magnitude and Locations
- Cases
- Extreme Events
- <u>Managing Disaster Risk</u>
- Tsunamis

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

How large is the risk?

Average cost earthquakes 1999-2011
= $35 billion/yr

≈ $5/person per year
i.e. earthquakes are surprisingly affordable.

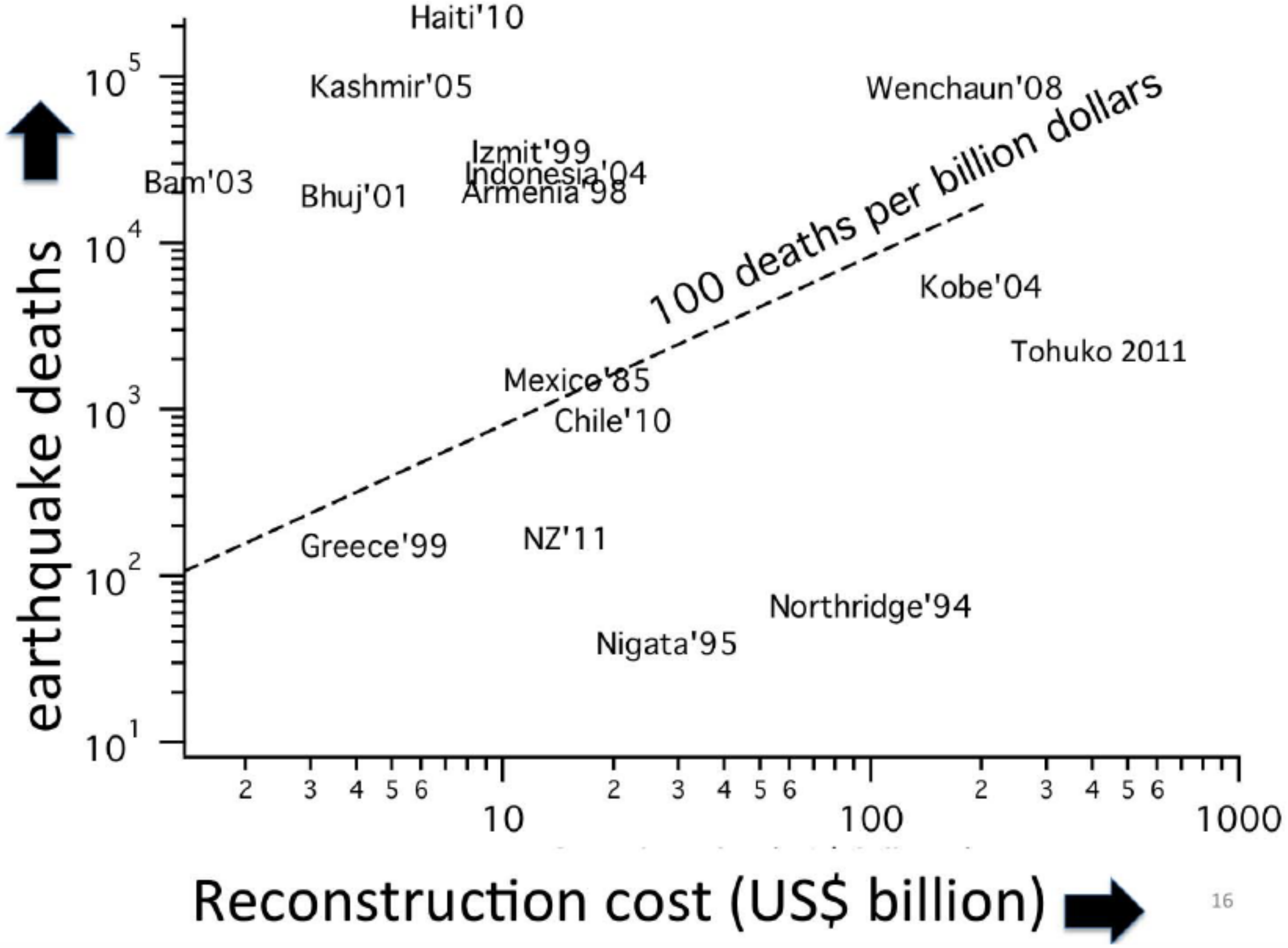
However cost is mostly born by the industrial world
($50/person/year)

17

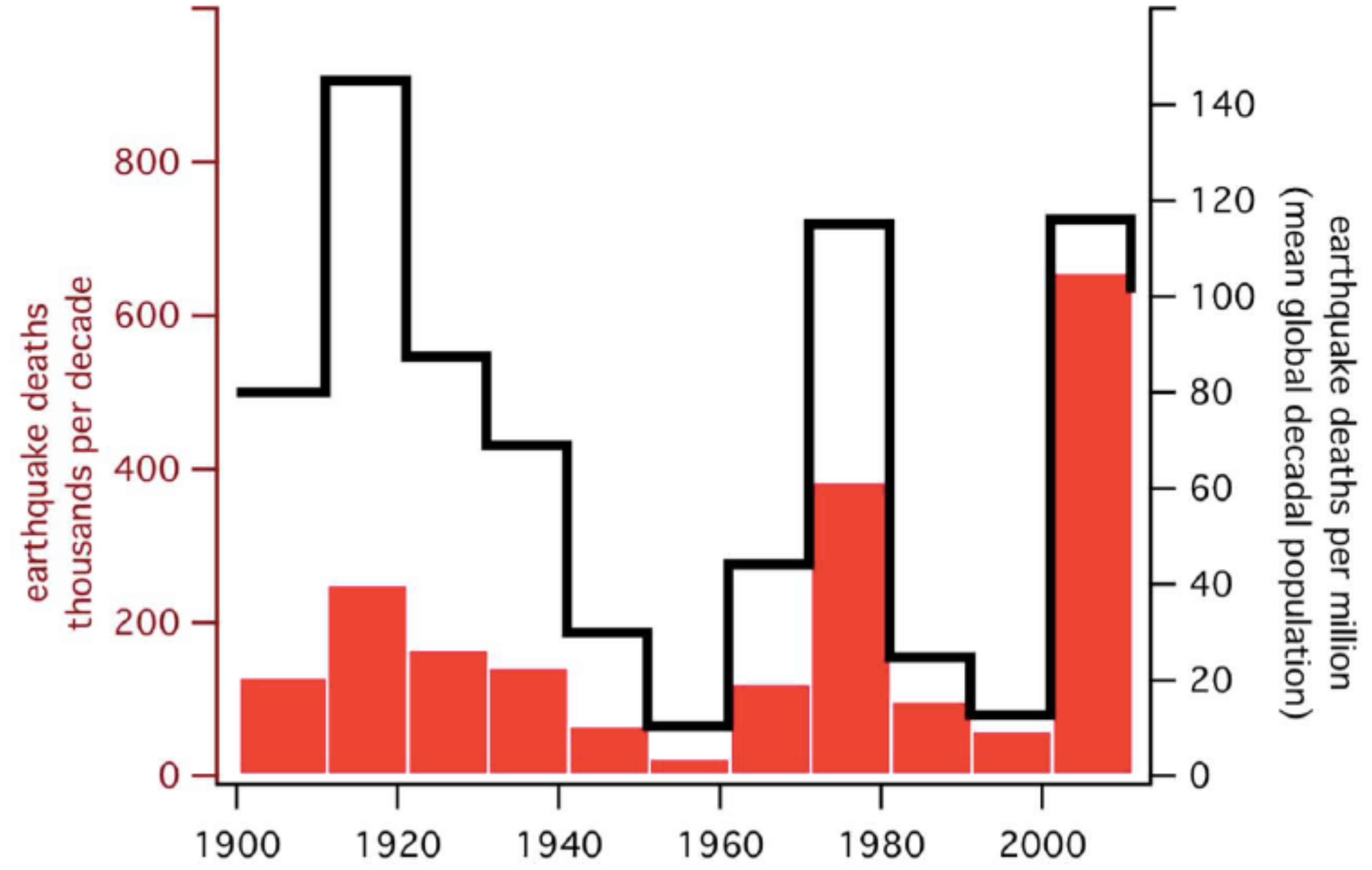
LIFE IS WORTH HOW-MUCH?

From religion $∞ (Life is priceless etc)
9/11 WTC $1.6 million/life
IPCC $6.1 million/life
Jack London "**Life**? Bah! It has no **value**.
Of cheap things it is the cheapest"
The Sea-Wolf 1904

from cost/death regression
1 death = $10 million

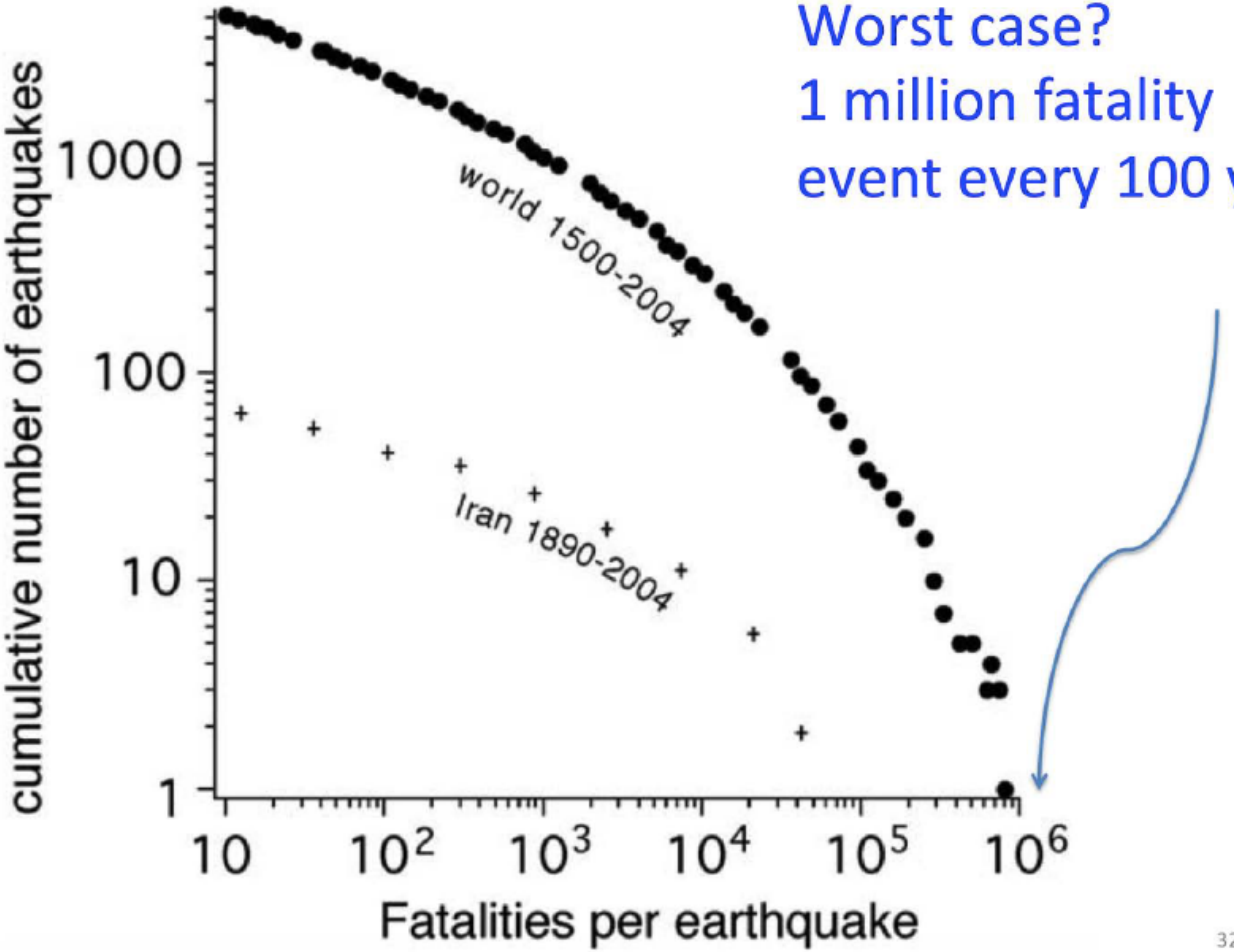


16

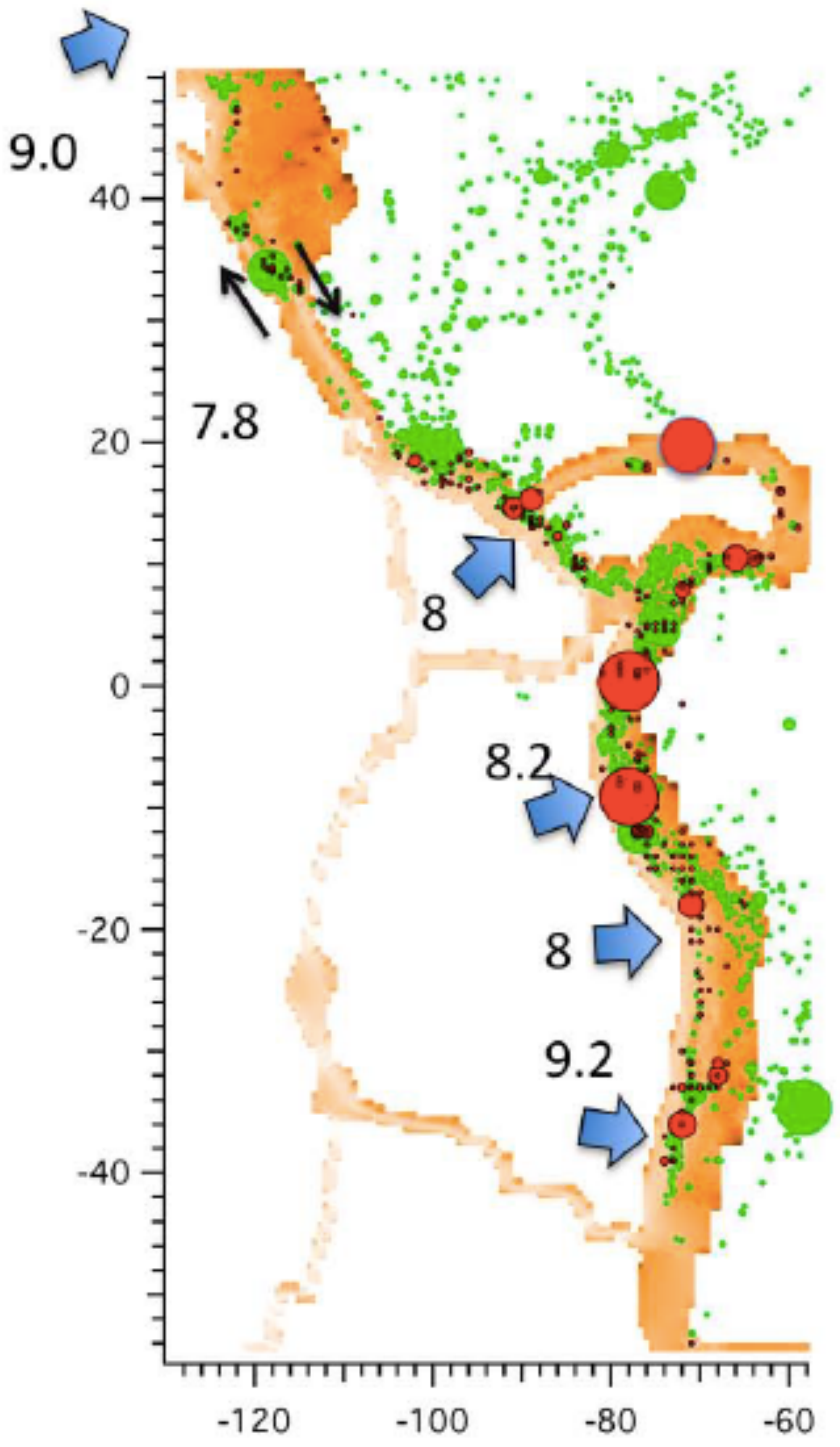


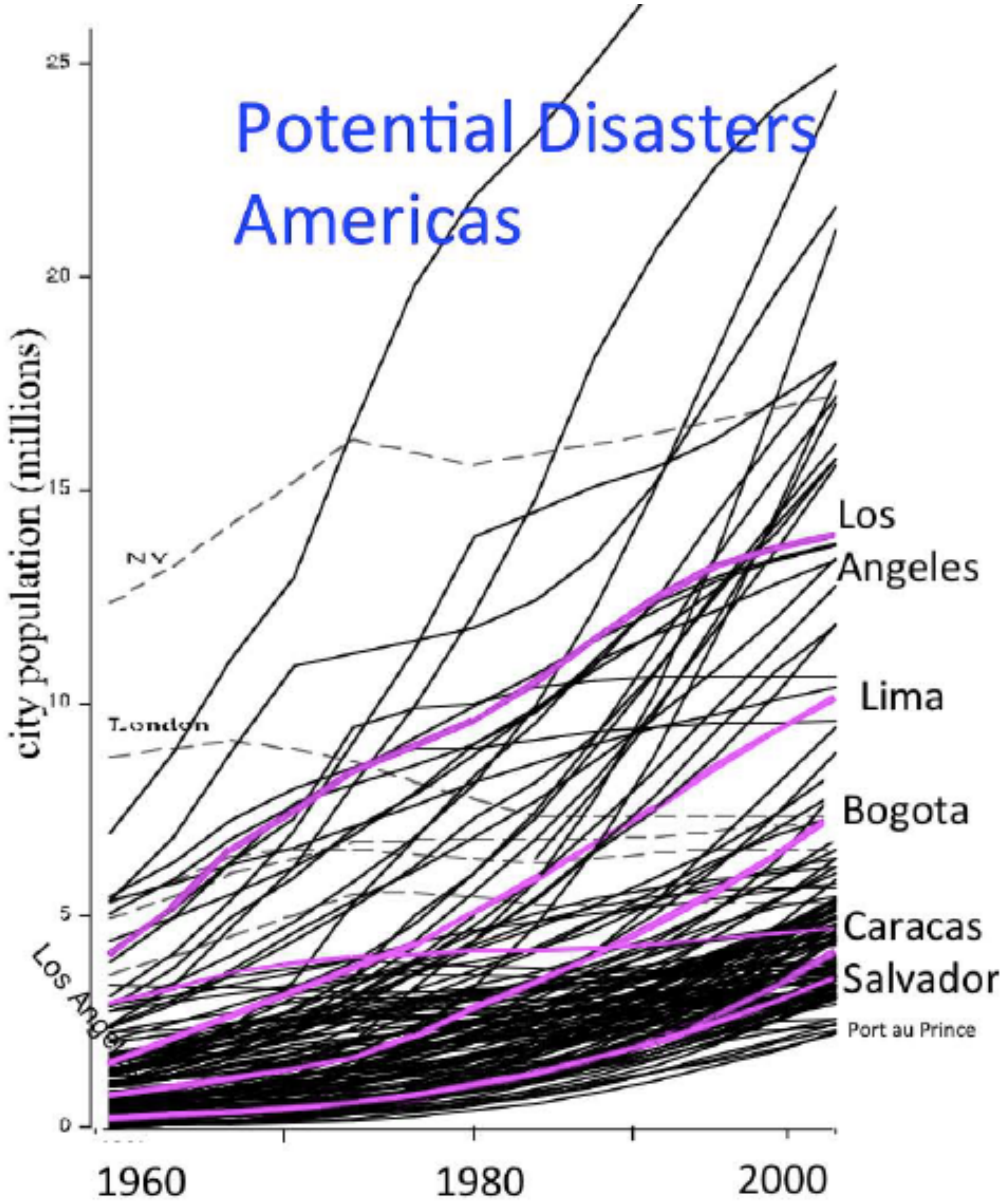
deaths per decade since earthquake resistance implemented

Ten years 600k deaths $400 billion



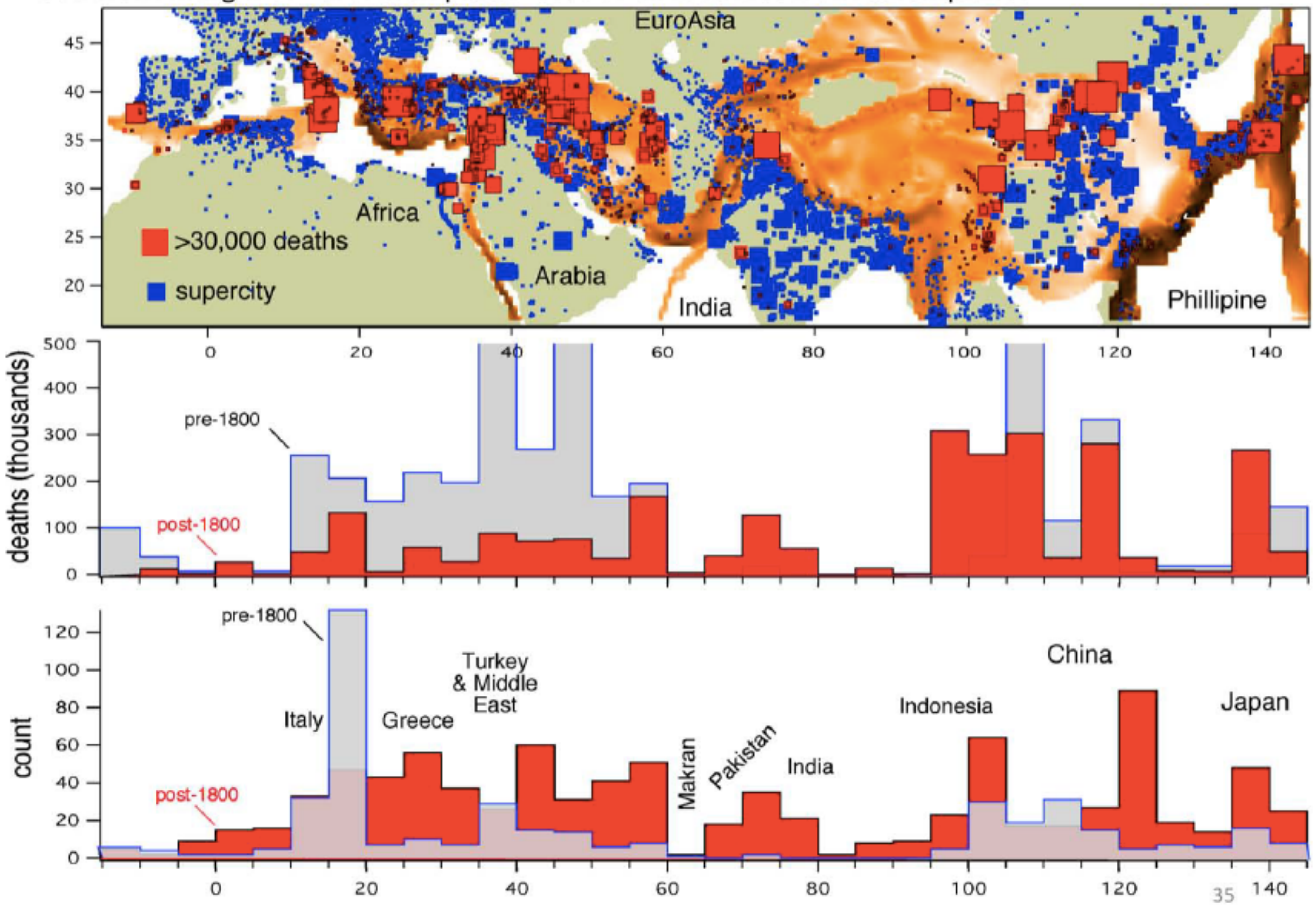
Worst case?
1 million fatality
event every 100 yr



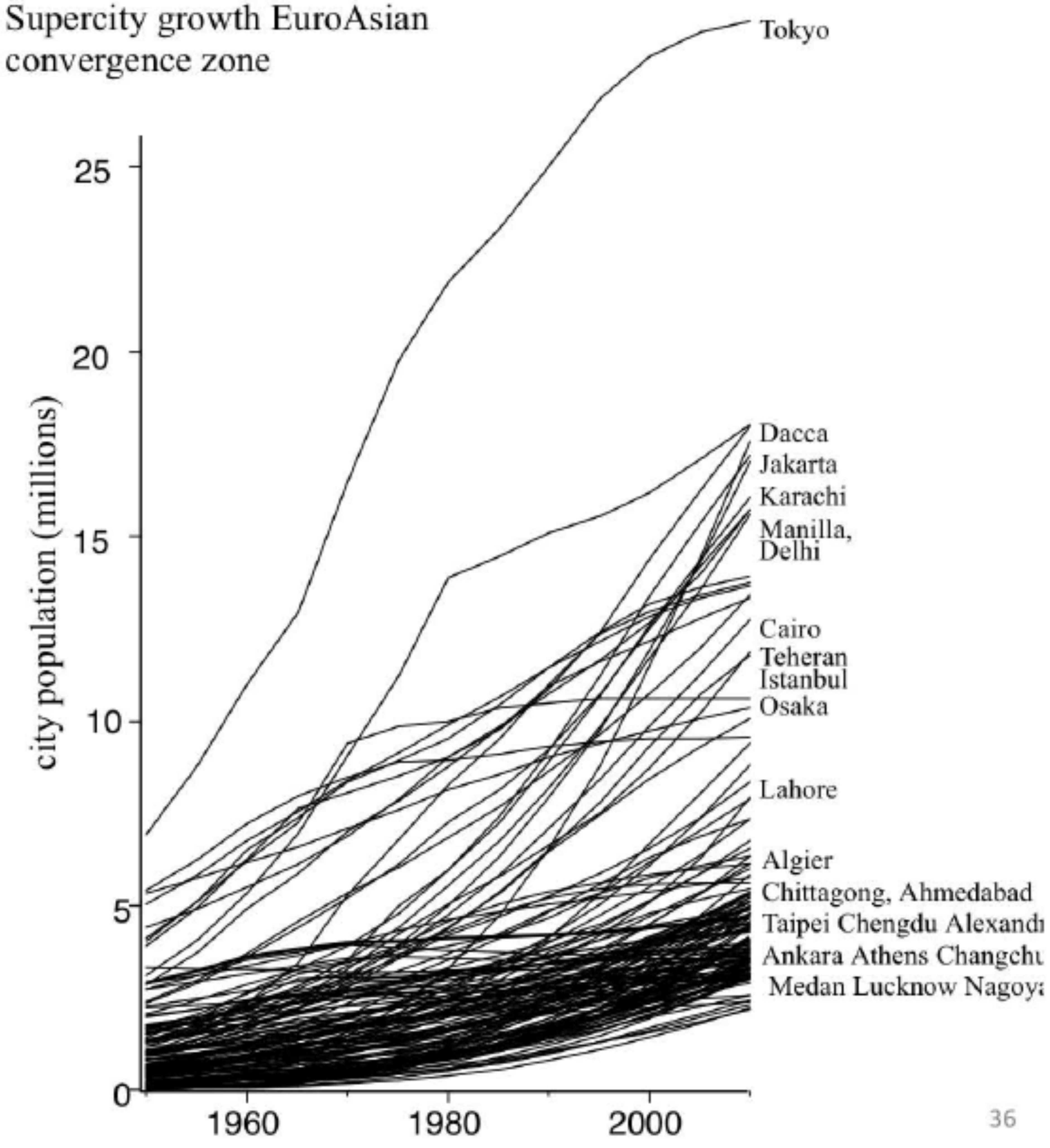


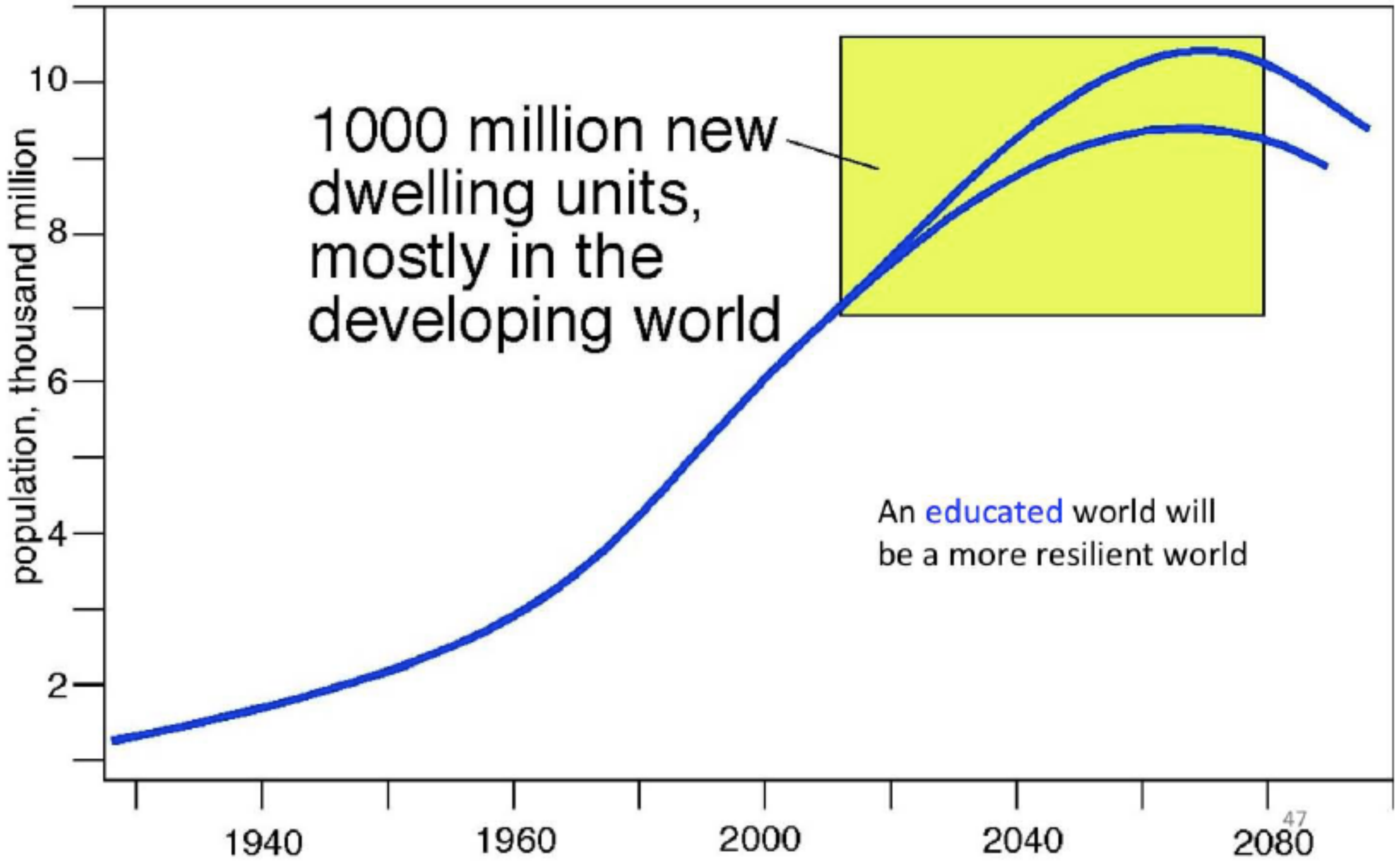
red=fatal earthquakes, green =cities

southern margin of EuroAsian plate: 85% of all fatalities from earthquakes

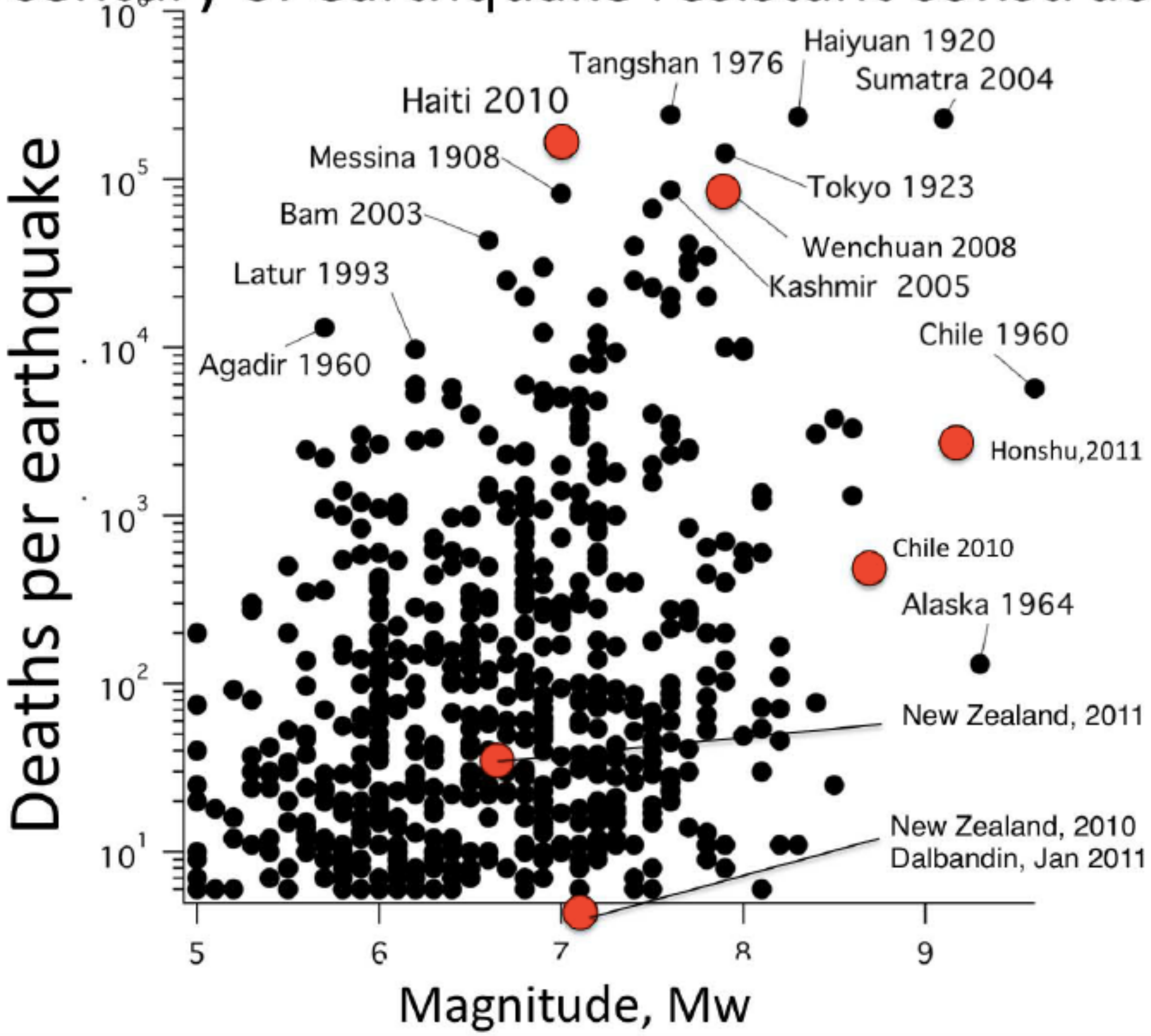


Supercity growth EuroAsian convergence zone

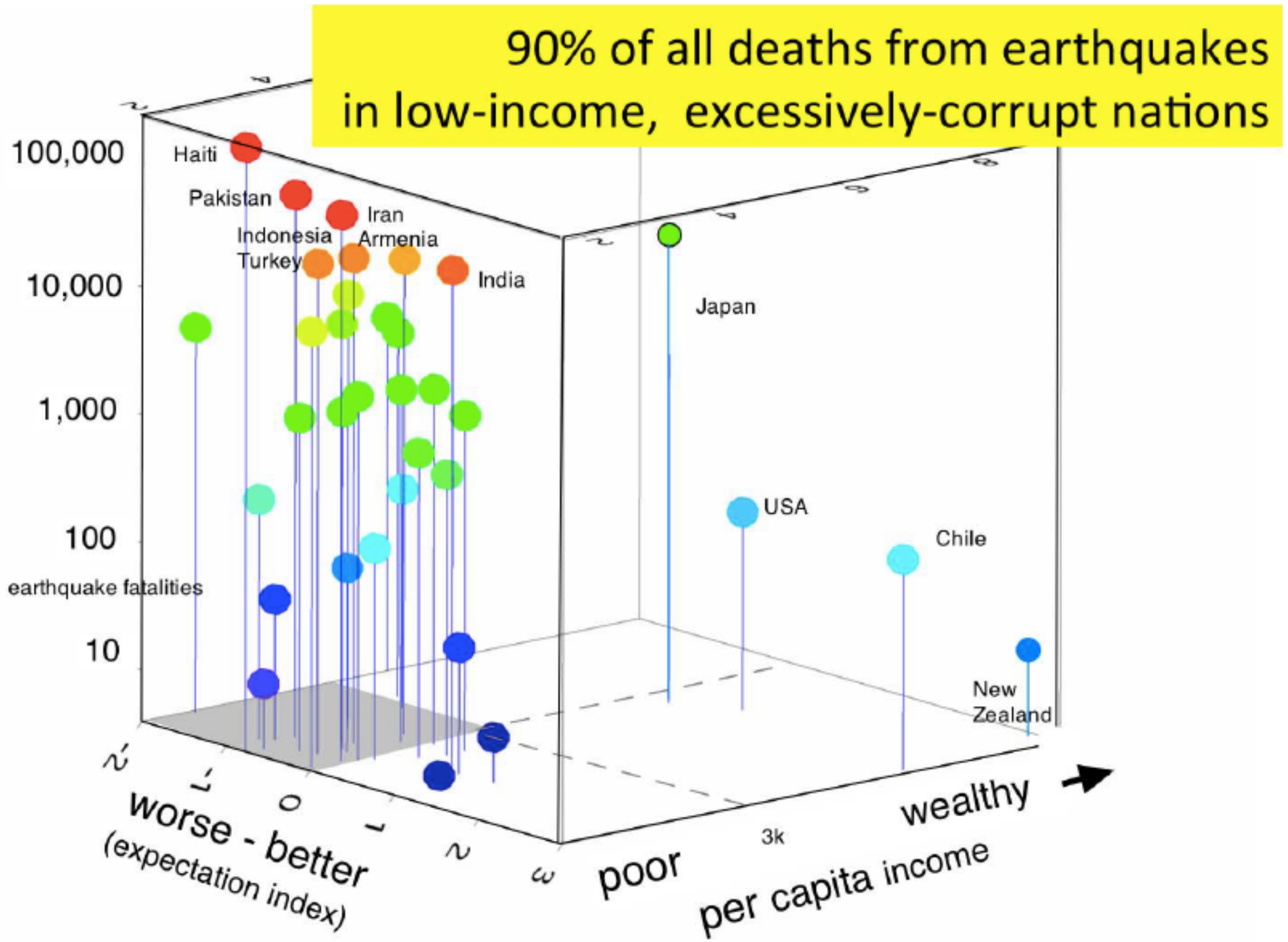



population, thousand million
2
4
6
8
10
1940
1960
2000
2040
2080
1000 million new dwelling units, mostly in the developing world
An educated world will be a more resilient world

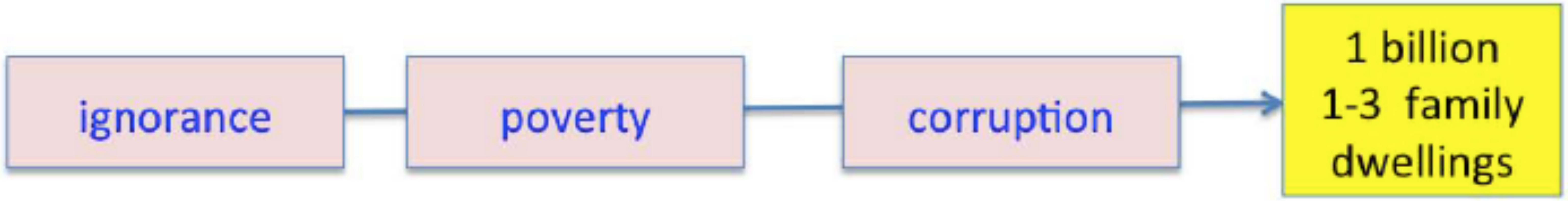
A century of earthquake resistant construction



Corruption and Disasters



future earthquakes will target civilization's weaknesses



The fix........

for ignorance = education

for poverty = education

for corruption = education

Issues with Predictions:

FAILURES

False negative - unpredicted hazard

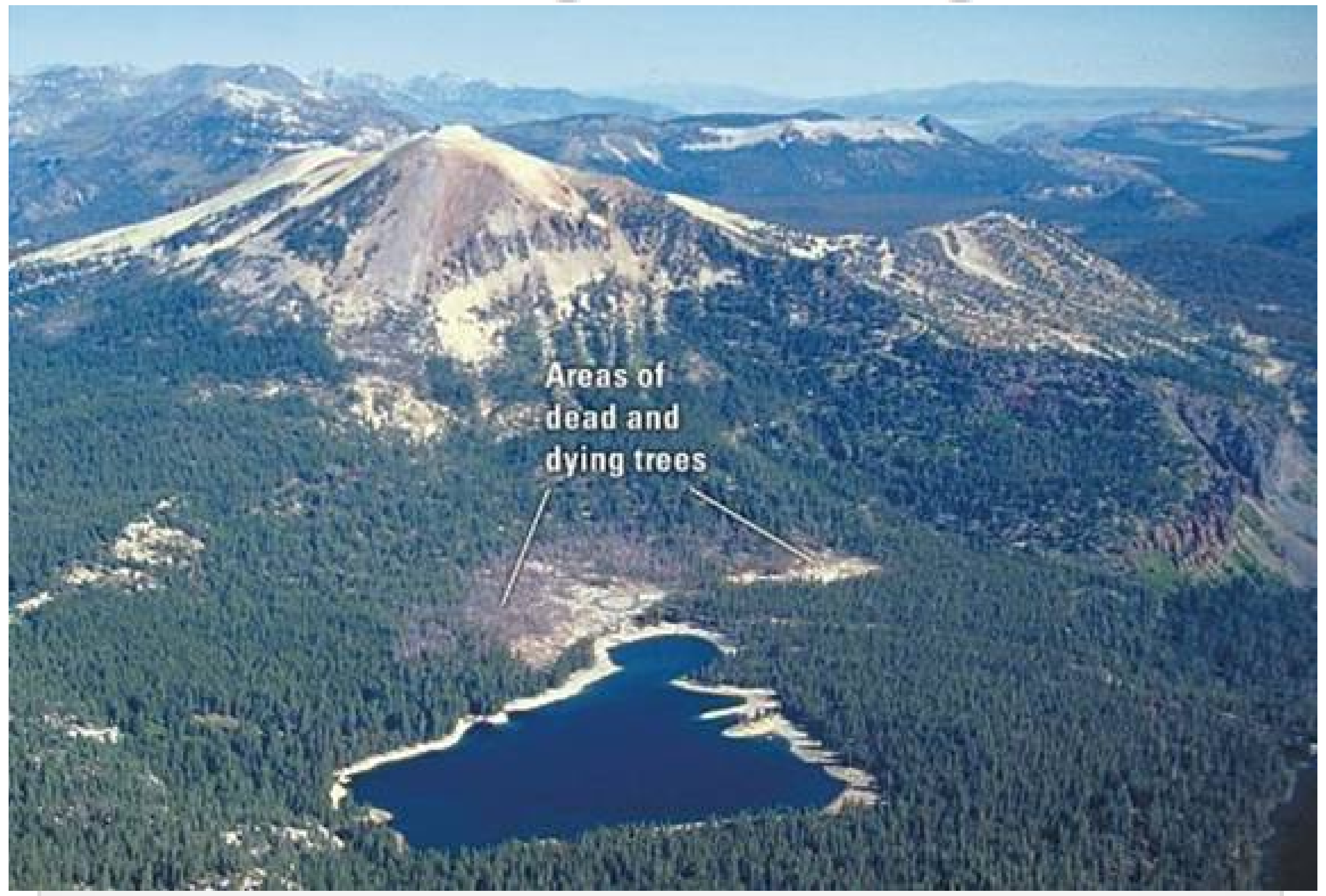
- Loss of life & property

False positive - overpredicted hazard

- Wasted resources, public loses confidence

- Authorities typically ignore, deny, excuse, or minimize failure
- More useful to analyze failures to improve future performance

Perils of prediction: are scientists prepared to warn the public about geologic hazards?



Science News

6/15/91

The town of Mammoth Lakes doesn't look kindly on federal geologists. In this quiet ski-center community nestled at the foot of California's Sierra Nevada range, residents have even coined their own name for the U.S. Geological Survey.

They call it the U.S. Guessing Society.

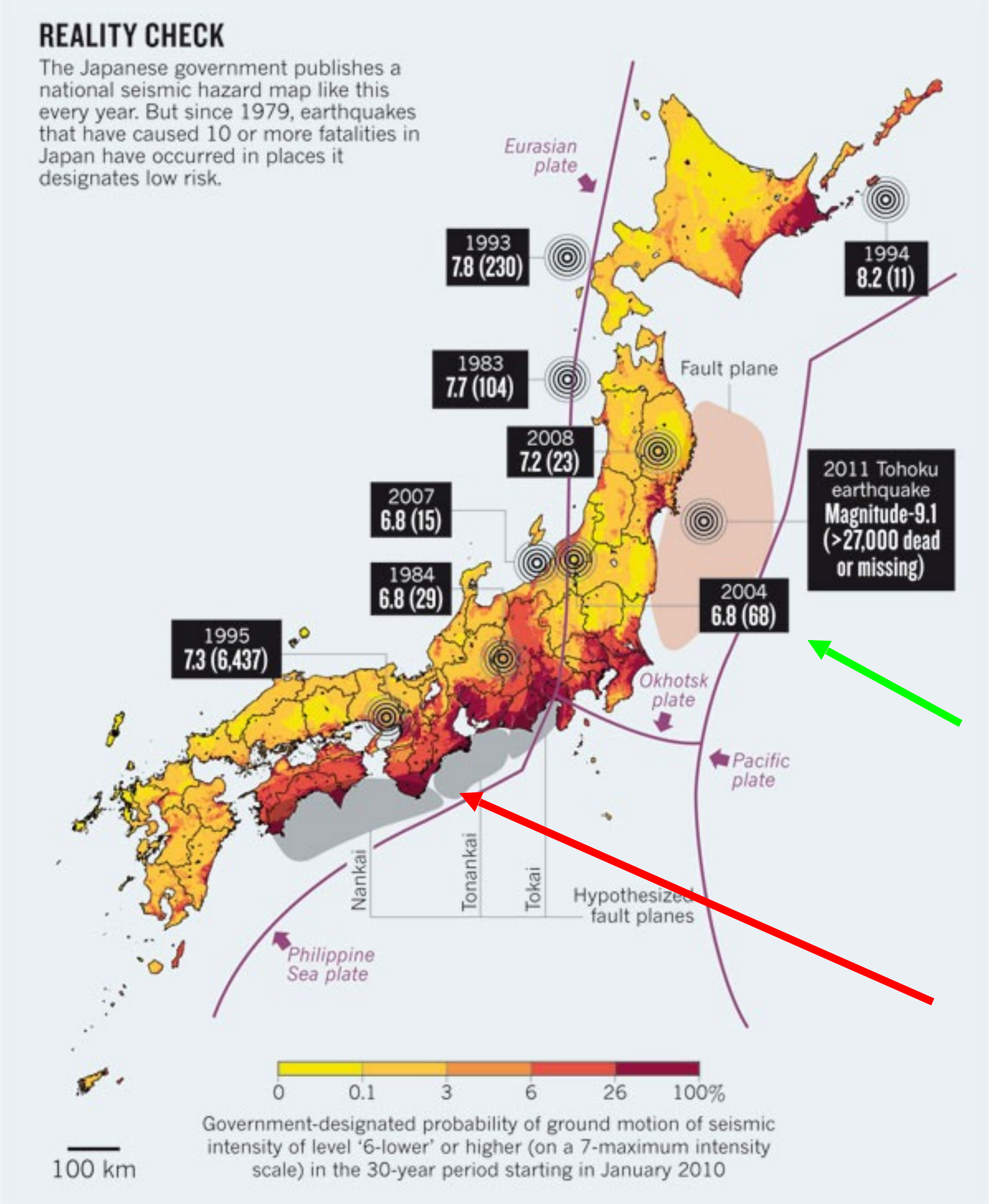
The town's antipathy toward the USGS has stewed for almost a decade, ignited in 1982 by a series of federal announcements and media reports about a potential volcanic eruption, which residents blame for a subsequent nose dive in the local economy. Only recently has the local real estate market climbed back up to its pre-1982 level, they say.

The local economy collapsed, said Glenn Thompson, Mammoth Lakes' town manager. Housing prices fell 40 percent overnight. In the next few years, dozens of businesses closed, new shopping centers stood empty and townspeople left to seek jobs elsewhere. (NYT 9/11/90)

Managing Disaster Risk

Issues with assessments

Mar. 11, 2011, Japan,
Mw=9.0-9.1, I=IX, Depth 29 km
Death >15,900



Japan spent lots of effort on national hazard map, but

2011 M 9.1 Tohoku, 1995 Kobe M 7.3 & others in areas mapped as low hazard

In contrast: map assumed high hazard in Tokai "gap"

Geller 2011

Issues with assessments

Hazard maps fail because of

- bad physics (incorrect description of earthquake processes)
- bad assumptions (mapmakers' choice of poorly known parameters)
- bad data (lacking, incomplete, or underappreciated)
- bad luck (low probability events)

and combinations of these (Tohoku!)

Geller 2011

Natural Hazards and Disaster

Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Magnitude and Locations
- Cases
- Extreme Events
- Managing Disaster Risk
- Tsunamis

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Natural Hazards and Disaster

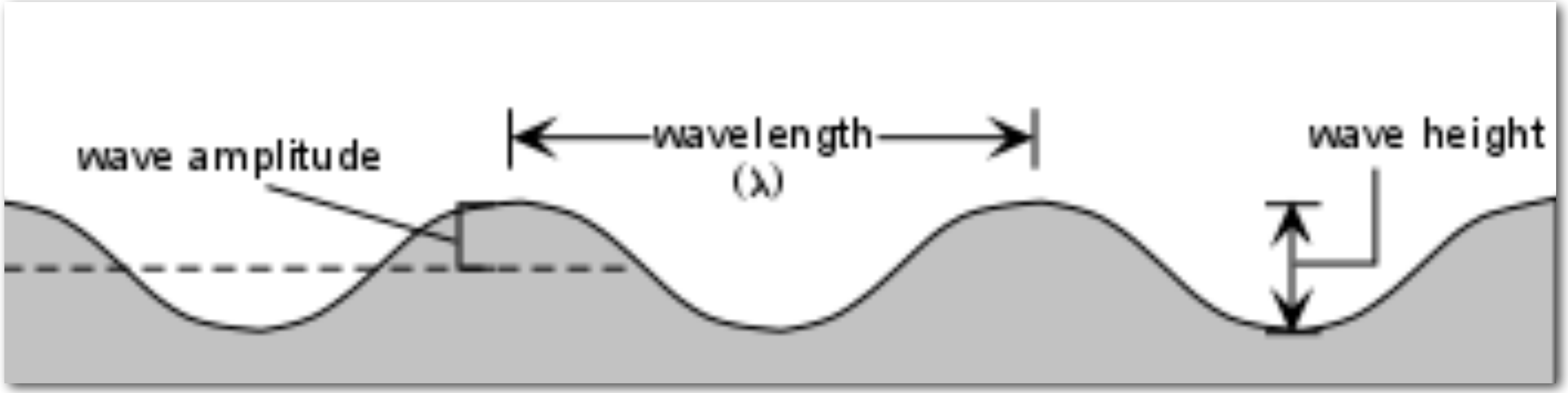
Class 5: Disasters Triggered by Earthquakes and Tsunamis

- <u>Waves</u>
- Tsunamis
- Earthquake Tsunamis
- Landslide Tsunamis
- Tsunami Detection, Prediction and Awareness

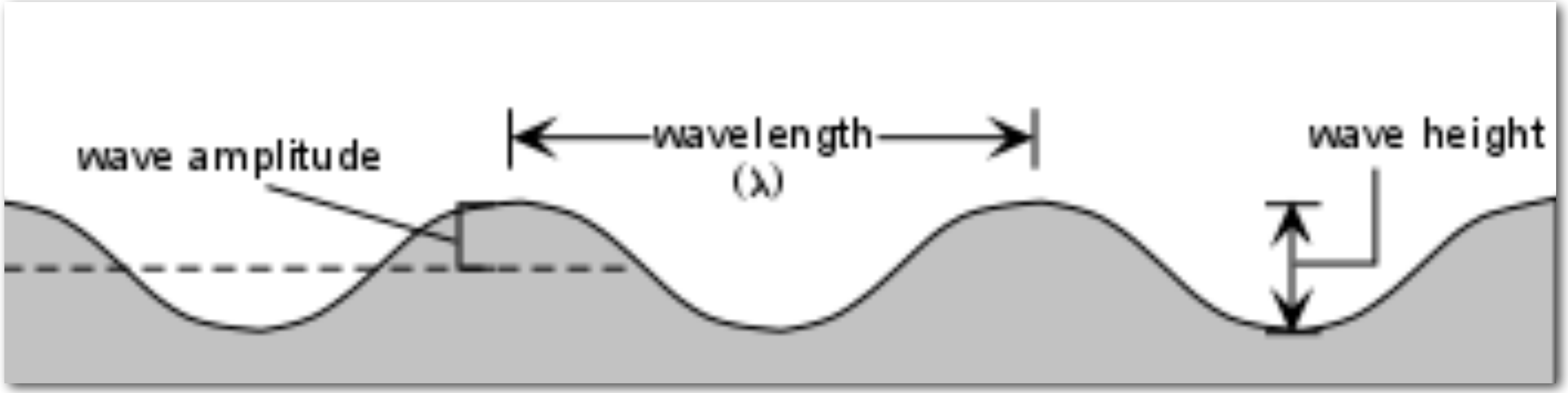
“Harbor Wave” 津波

Katsushika Hokusai (1760–1849)

Waves

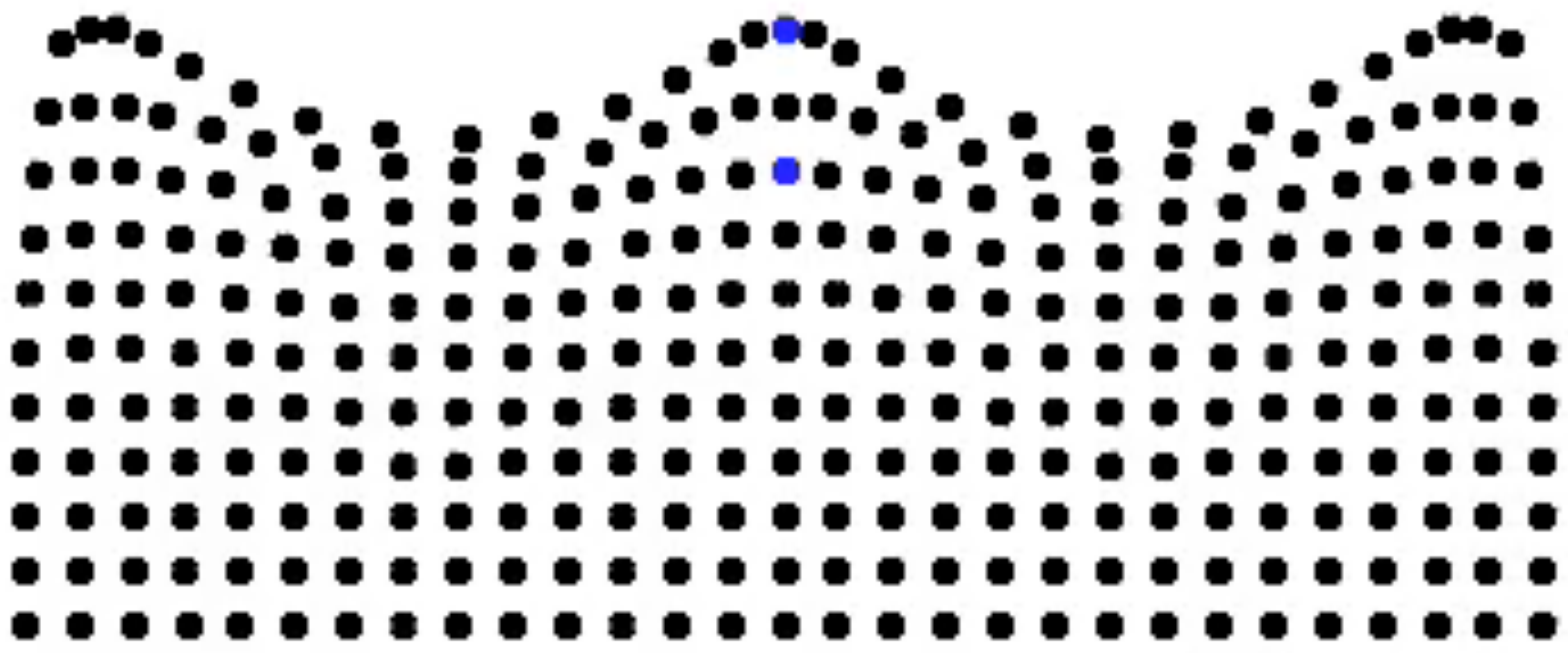


Waves

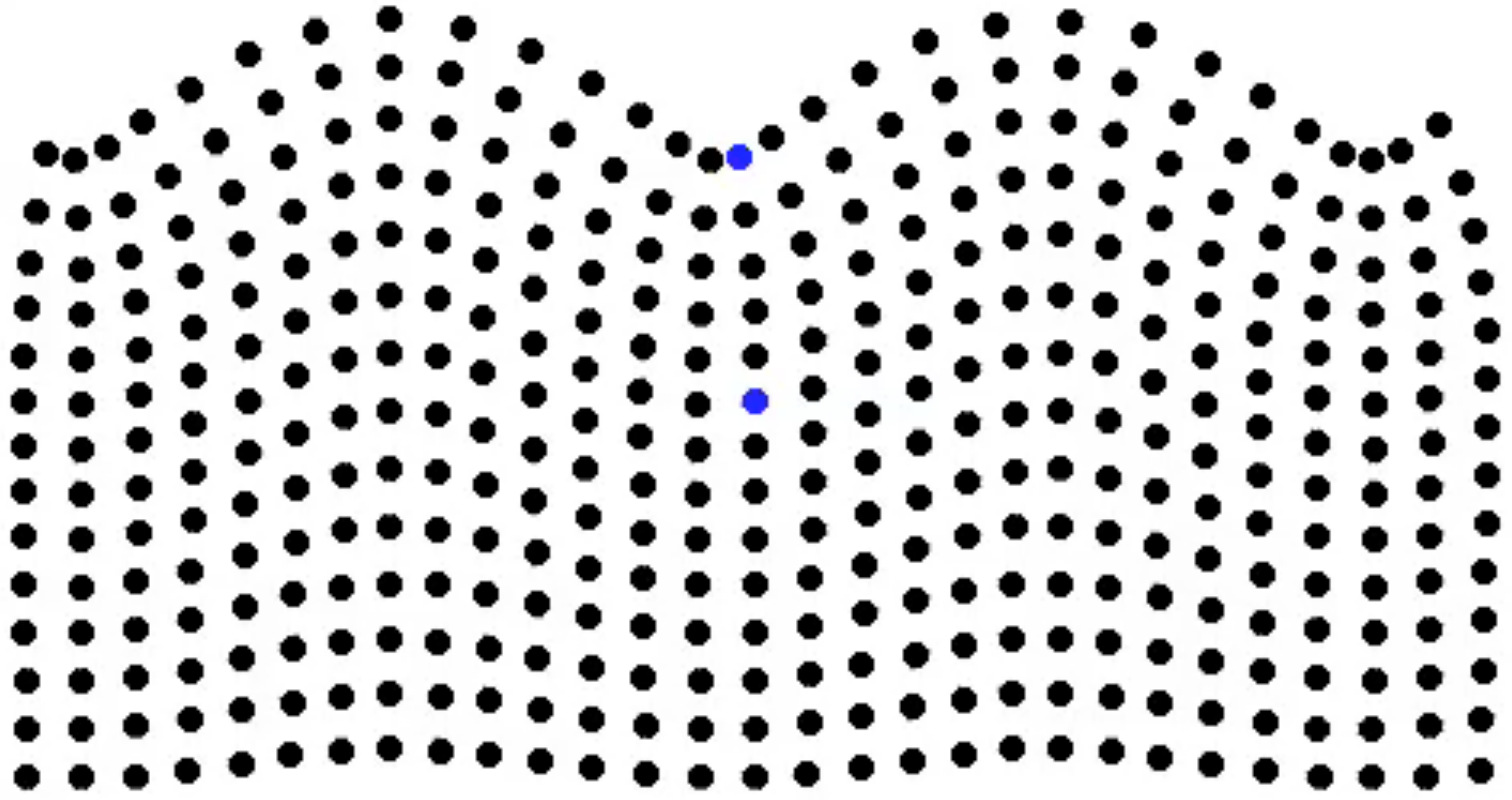


Type	**Wavelength**	**Period**	**Forcing**
wind waves	up to a few 100 m	seconds to minutes	wind
tidal waves	10^2 to 10^4 m	0.5 days, 1 day, 2 weeks, 1 months, 1 year	moon, sun, planets
tsunamis	in open ocean: several 10^2 km	10 to 30 minutes	earthquakes, landslides, volcanic eruptions

Waves



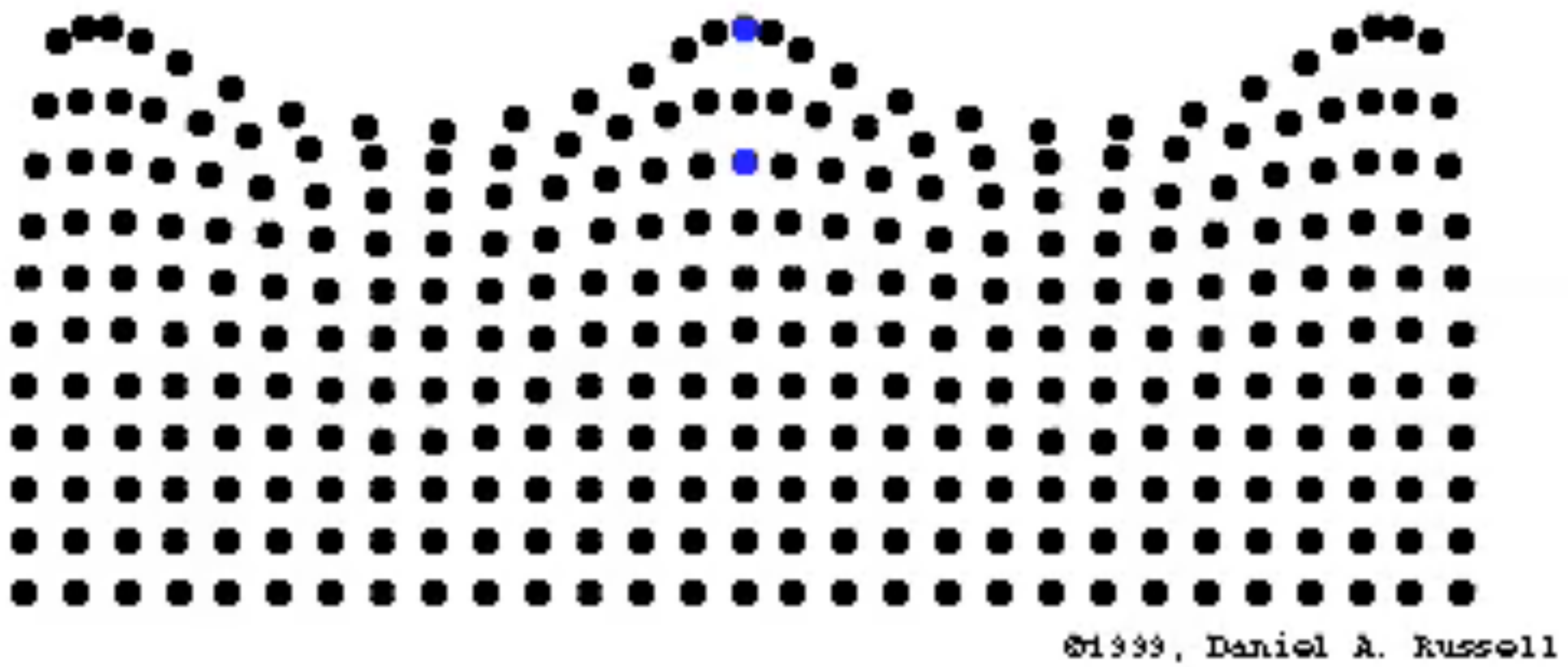
©1999, Daniel A. Russell

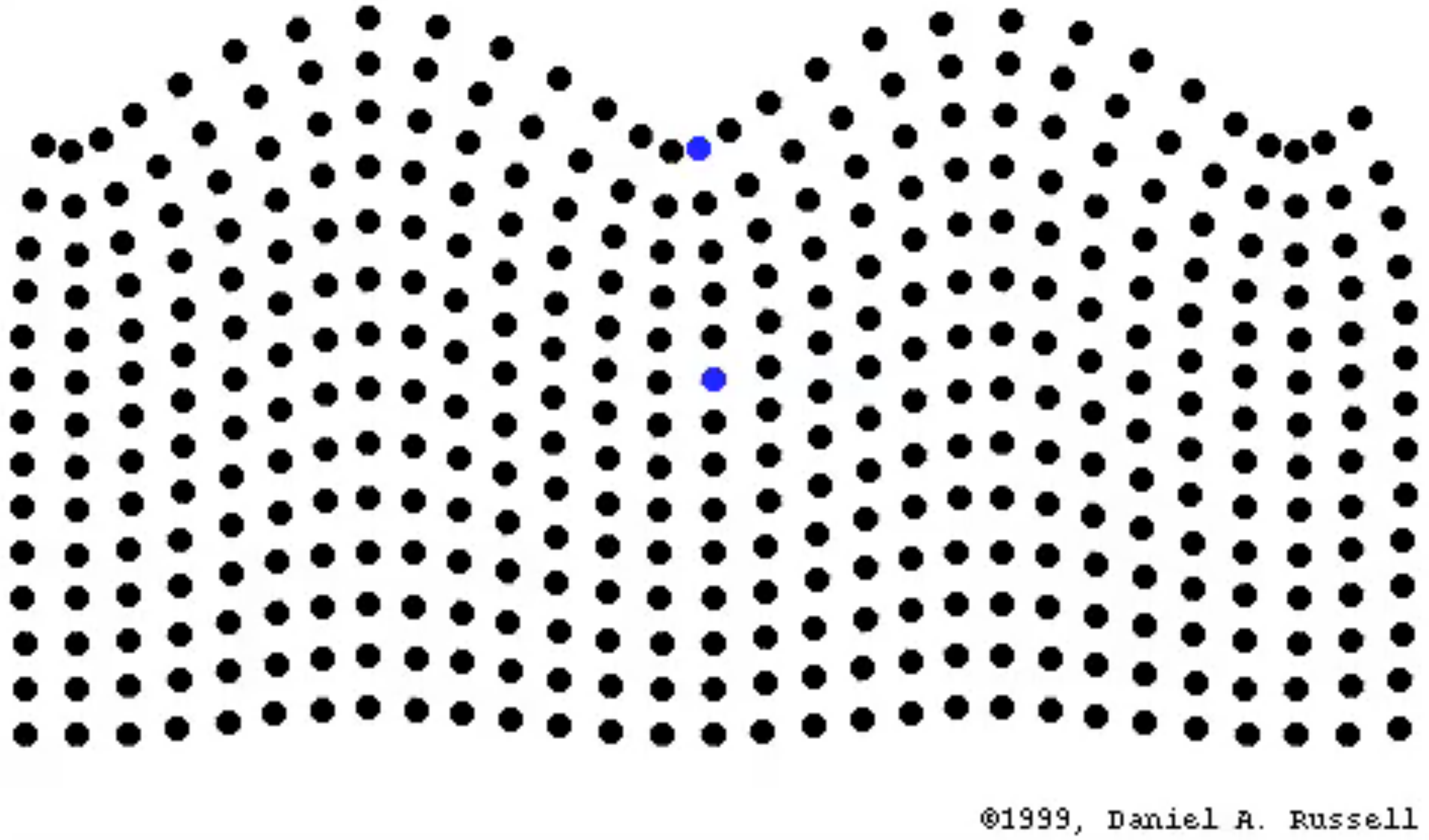


©1999, Daniel A. Russell

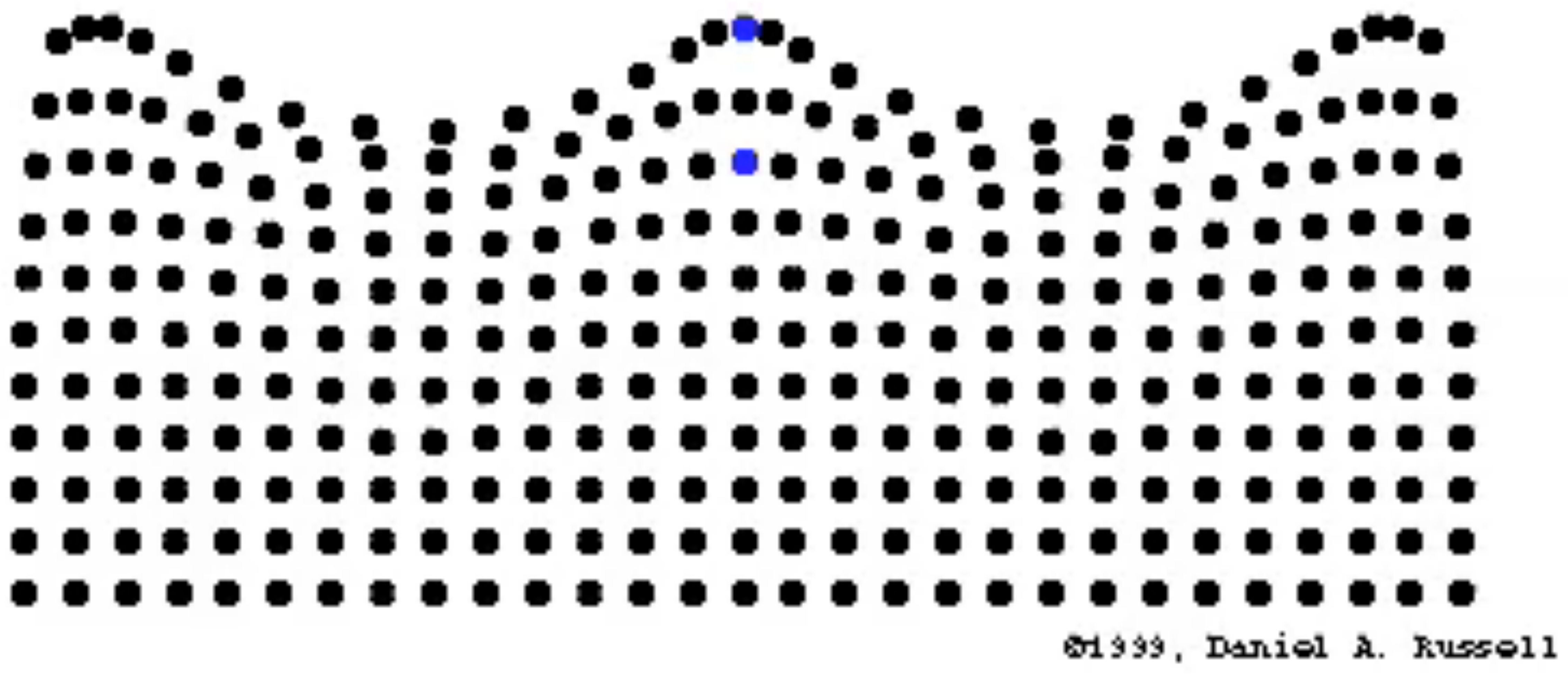
Waves

Water waves only affect the uppermost part of the water …

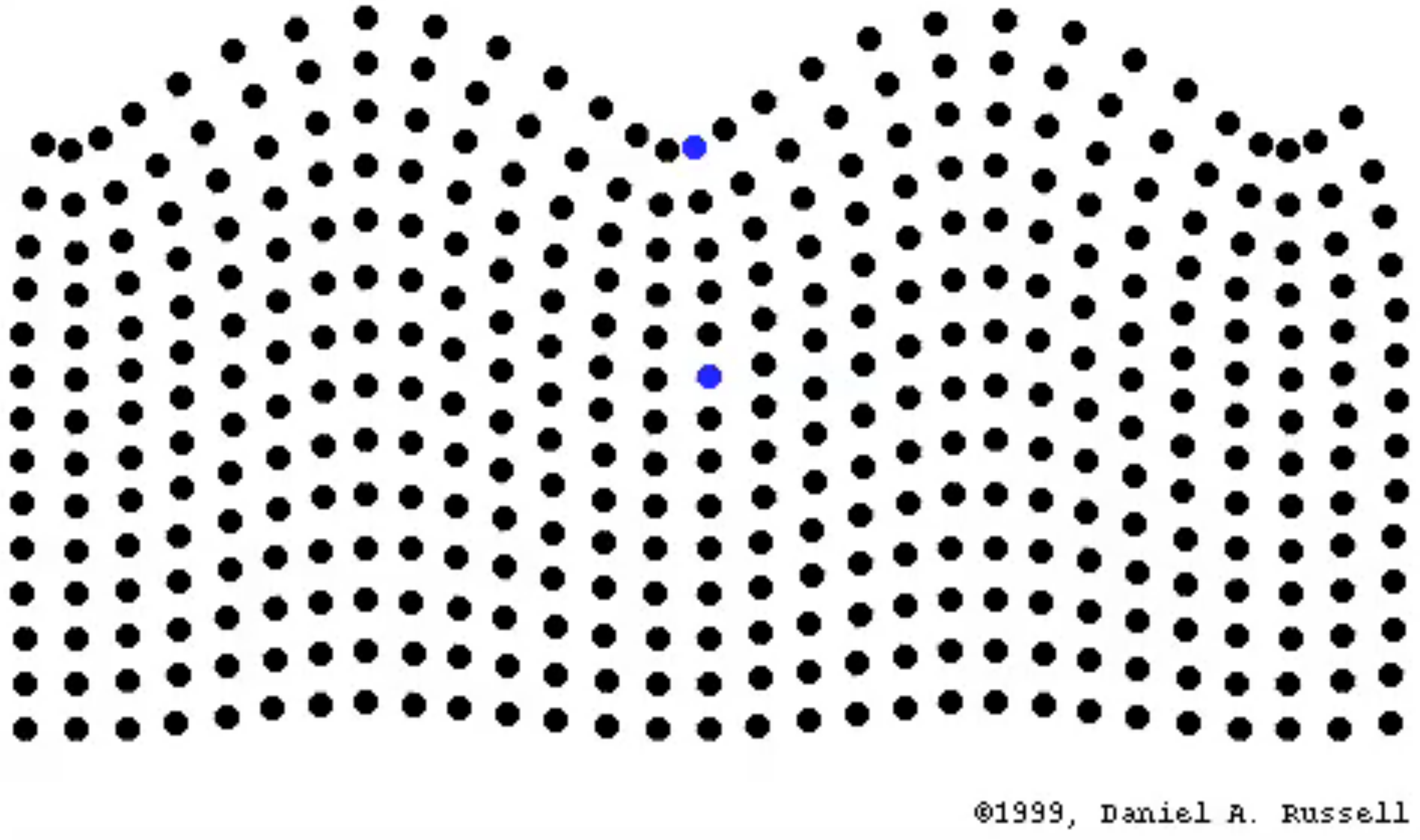




Water waves only affect the uppermost part of the water …

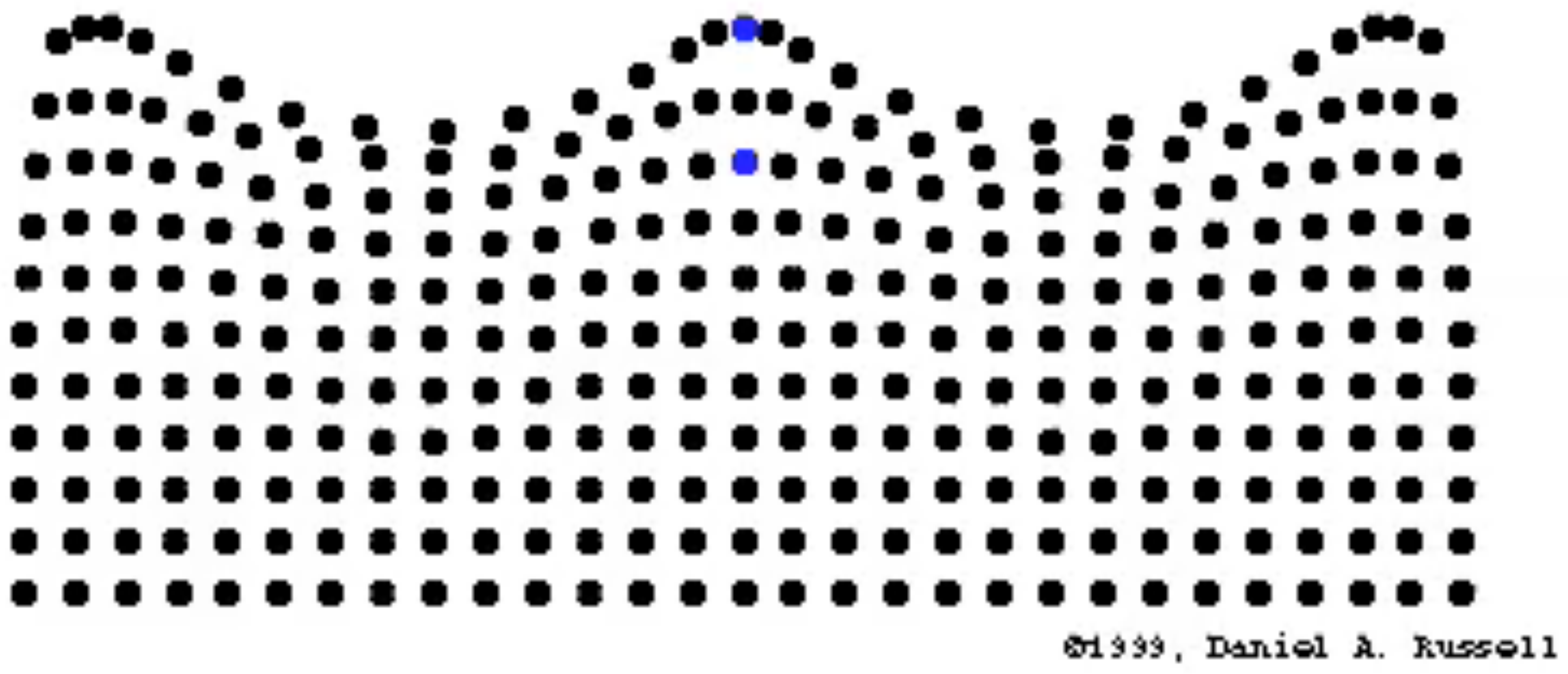


… unlike ground surface waves that can affect a deeper section of rock

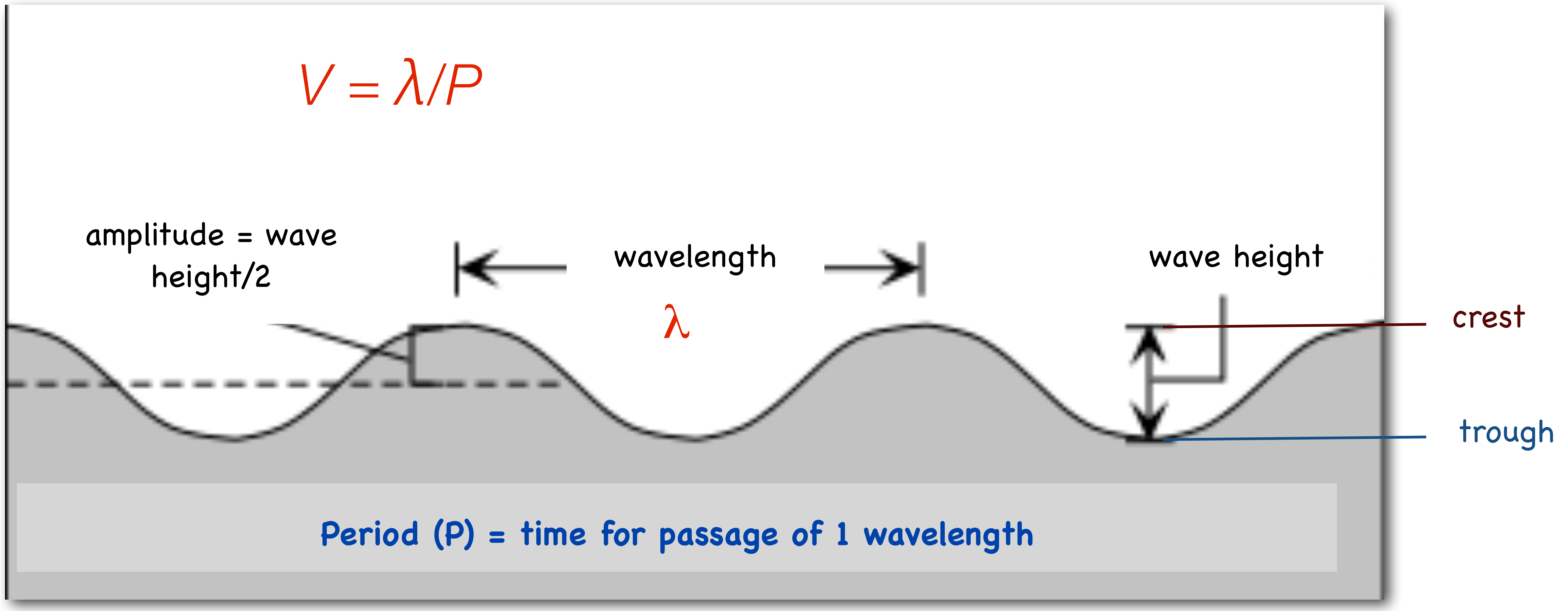


Waves

Water waves only affect the uppermost part of the water …

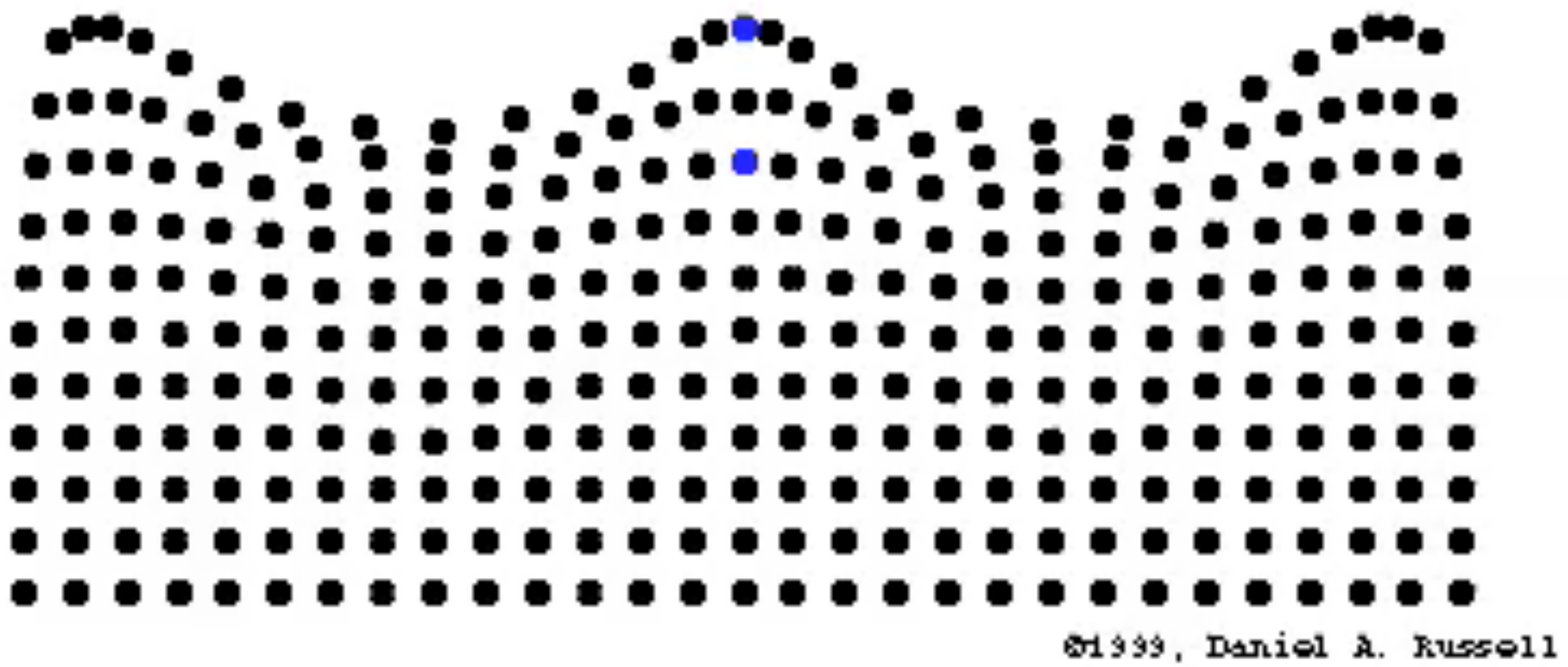


Velocity *V* is wavelength dependent

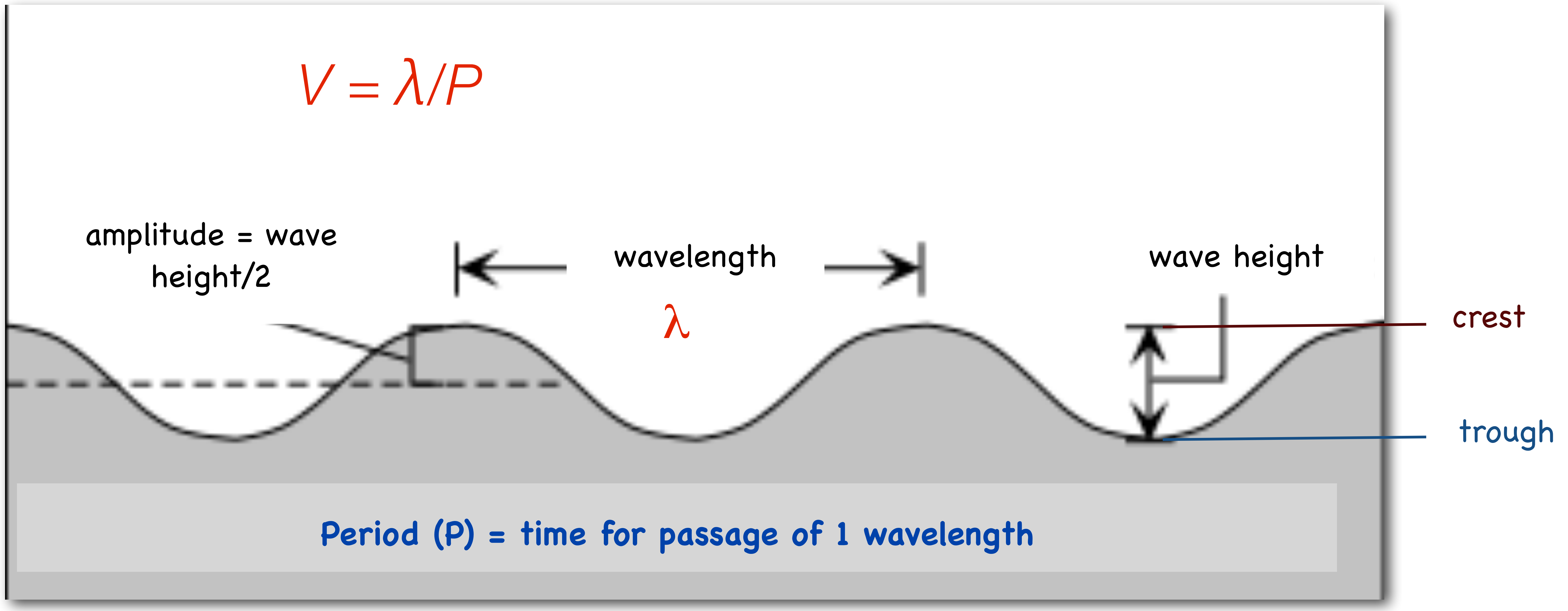


Waves

Water waves only affect the uppermost part of the water …

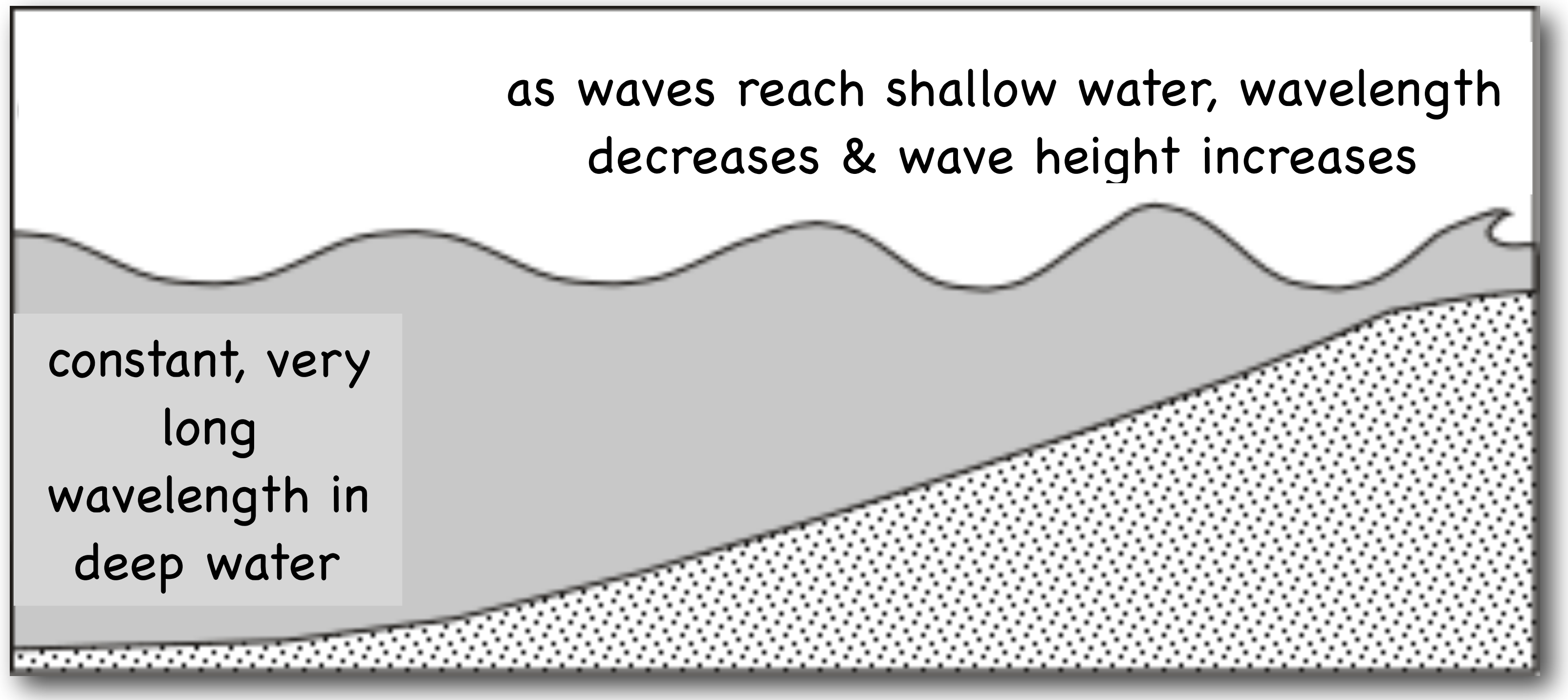


Velocity V is wavelength dependent



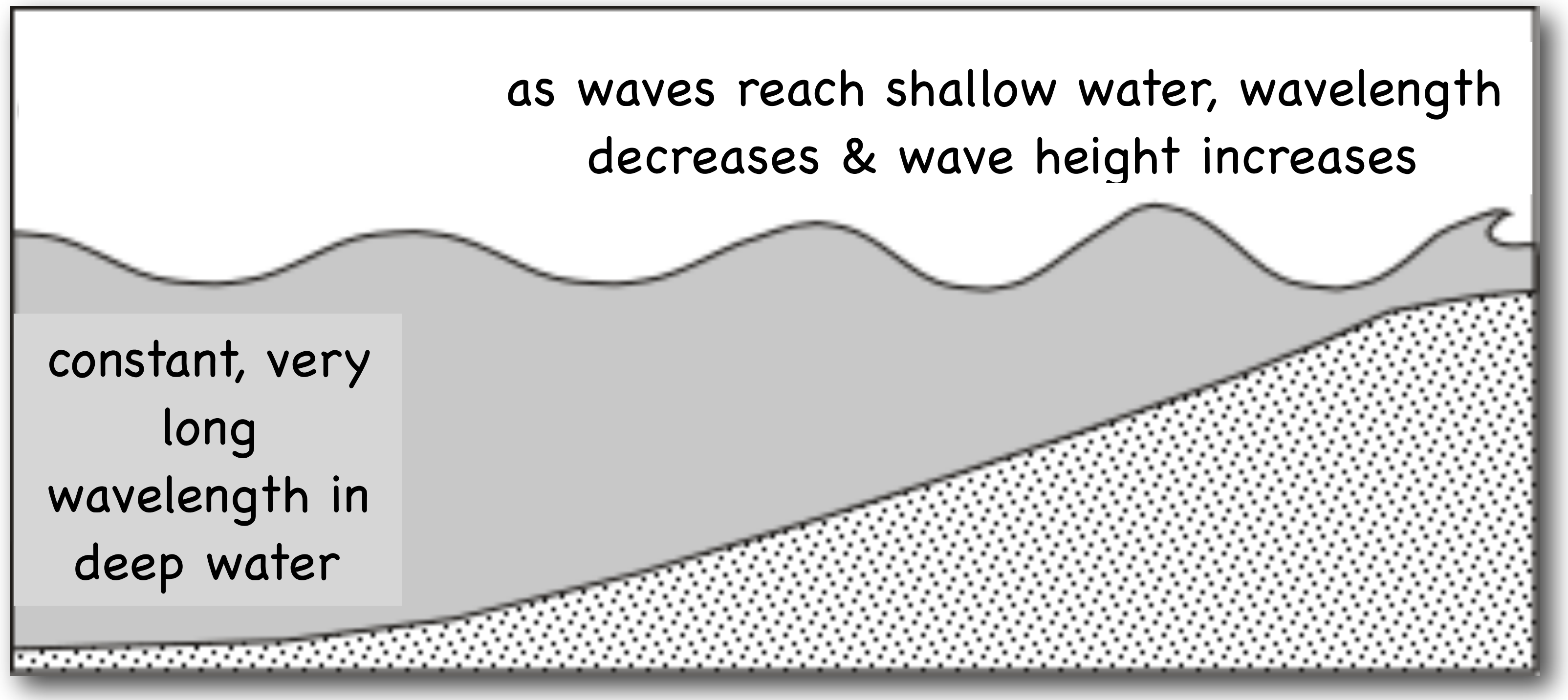
Waves

Waves

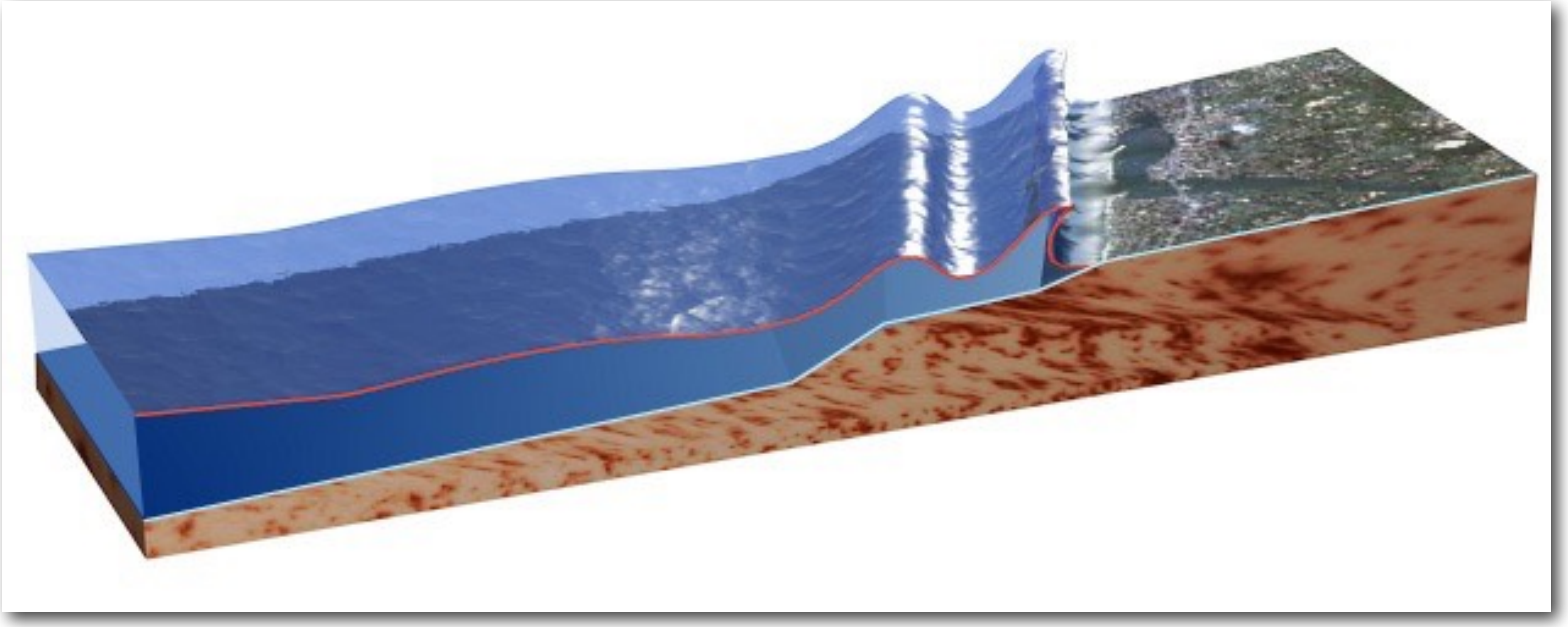


http://www.tulane.edu/~sanelson/images/tsunami_wave.gif

Waves

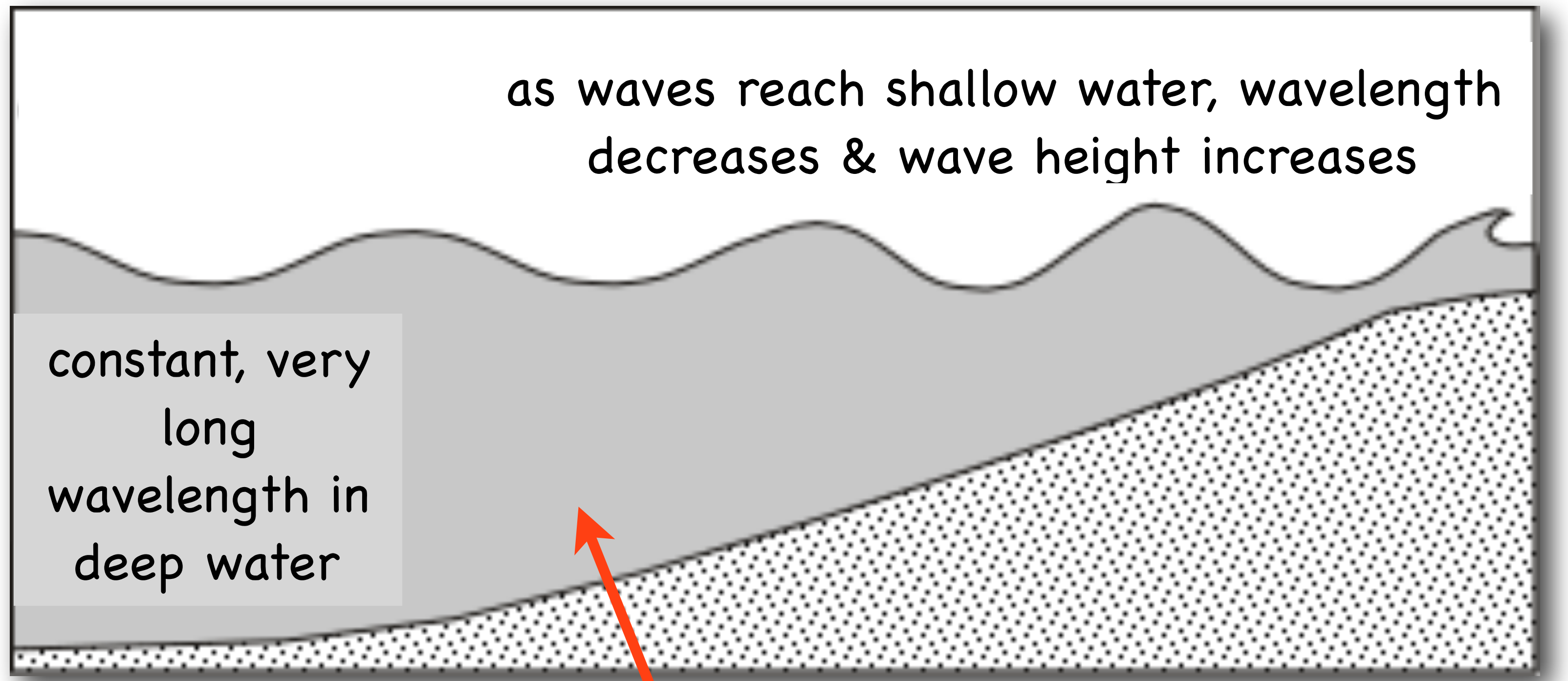


http://www.tulane.edu/~sanelson/images/tsunami_wave.gif

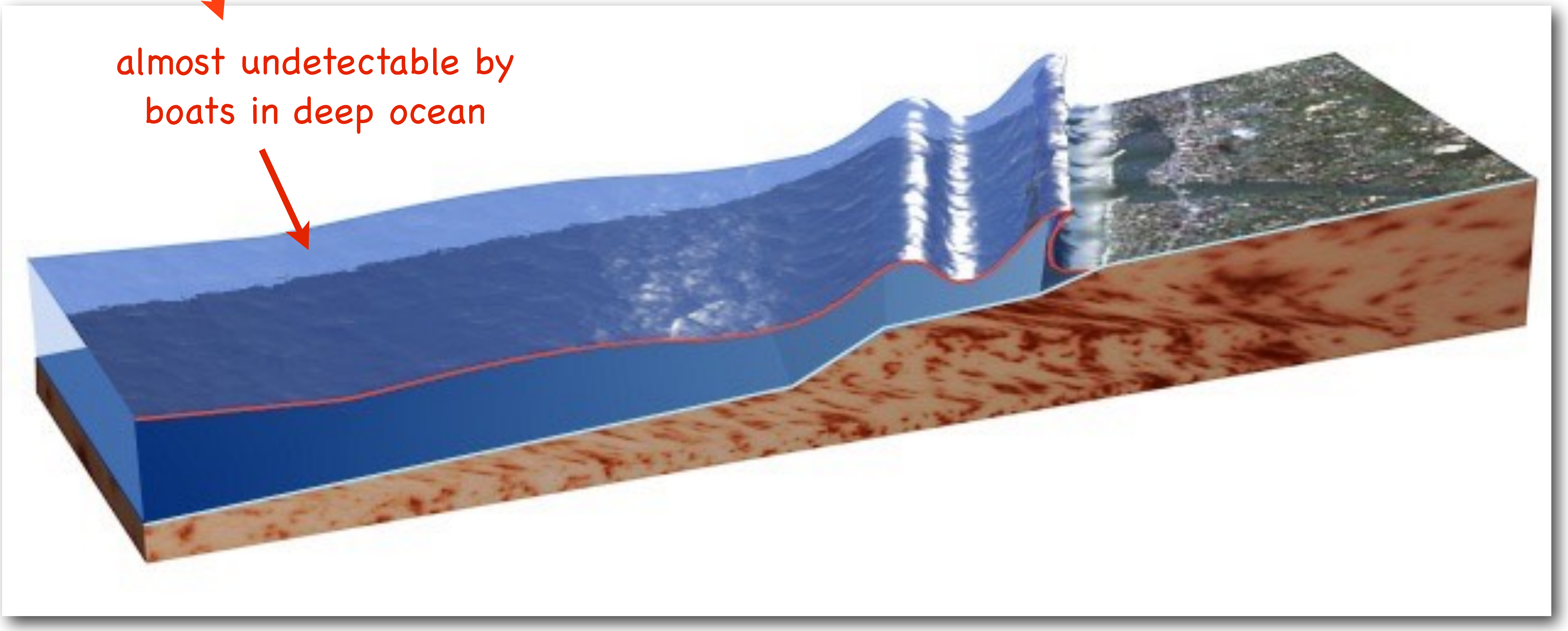


http://isaac.exploratorium.edu/~pauld/summer_institute/cset/Tsunamishore.jpg

Waves

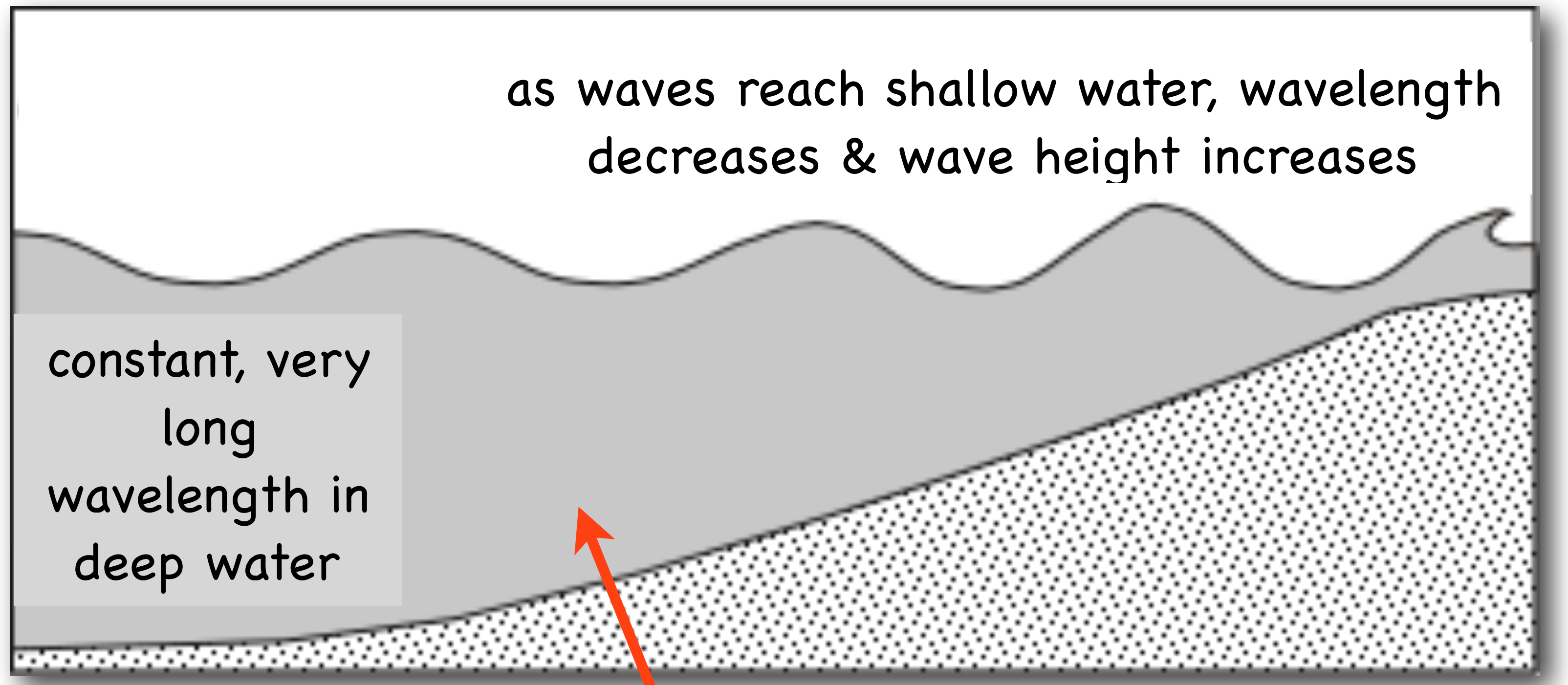


http://www.tulane.edu/~sanelson/images/tsunami_wave.gif

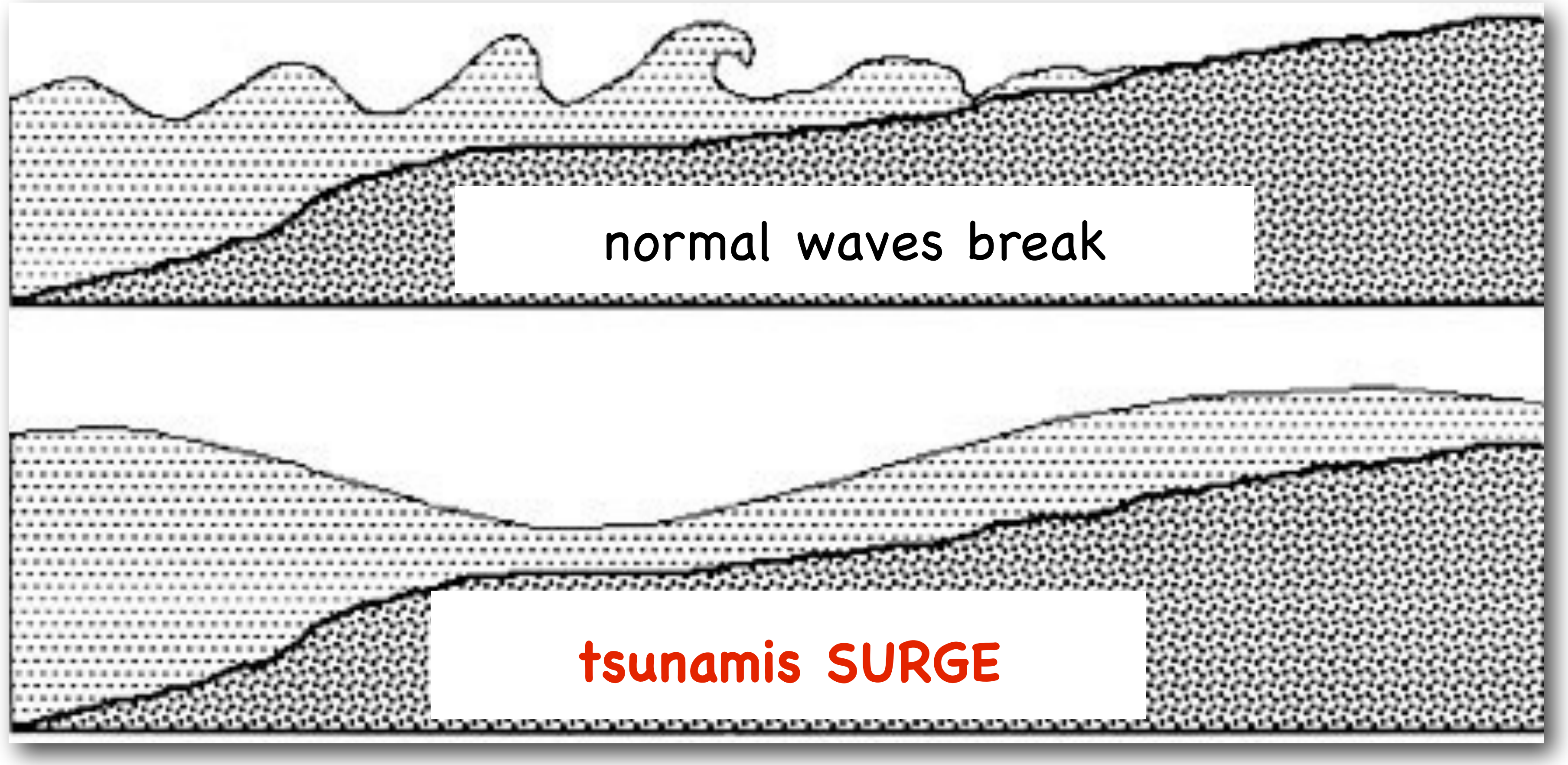


http://isaac.exploratorium.edu/~pauld/summer_institute/cset/Tsunamishore.jpg

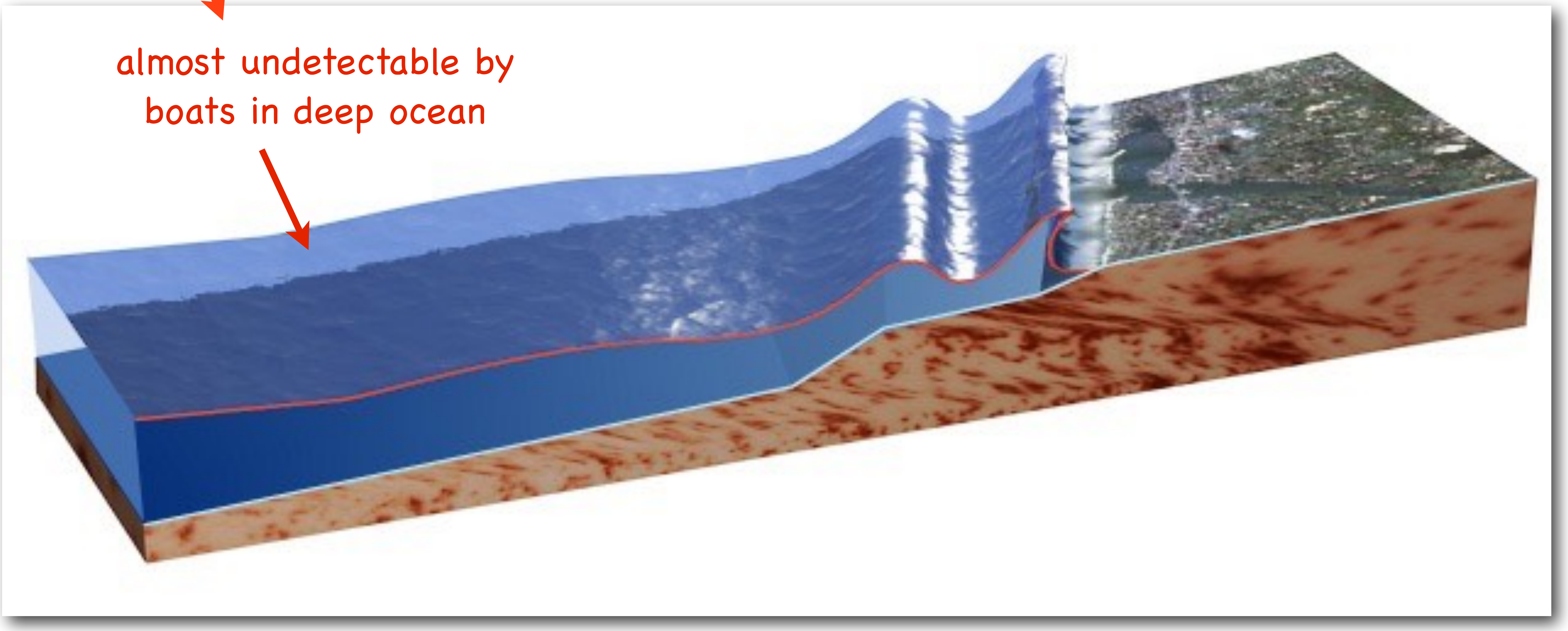
Waves



http://www.tulane.edu/~sanelson/images/tsunami_wave.gif

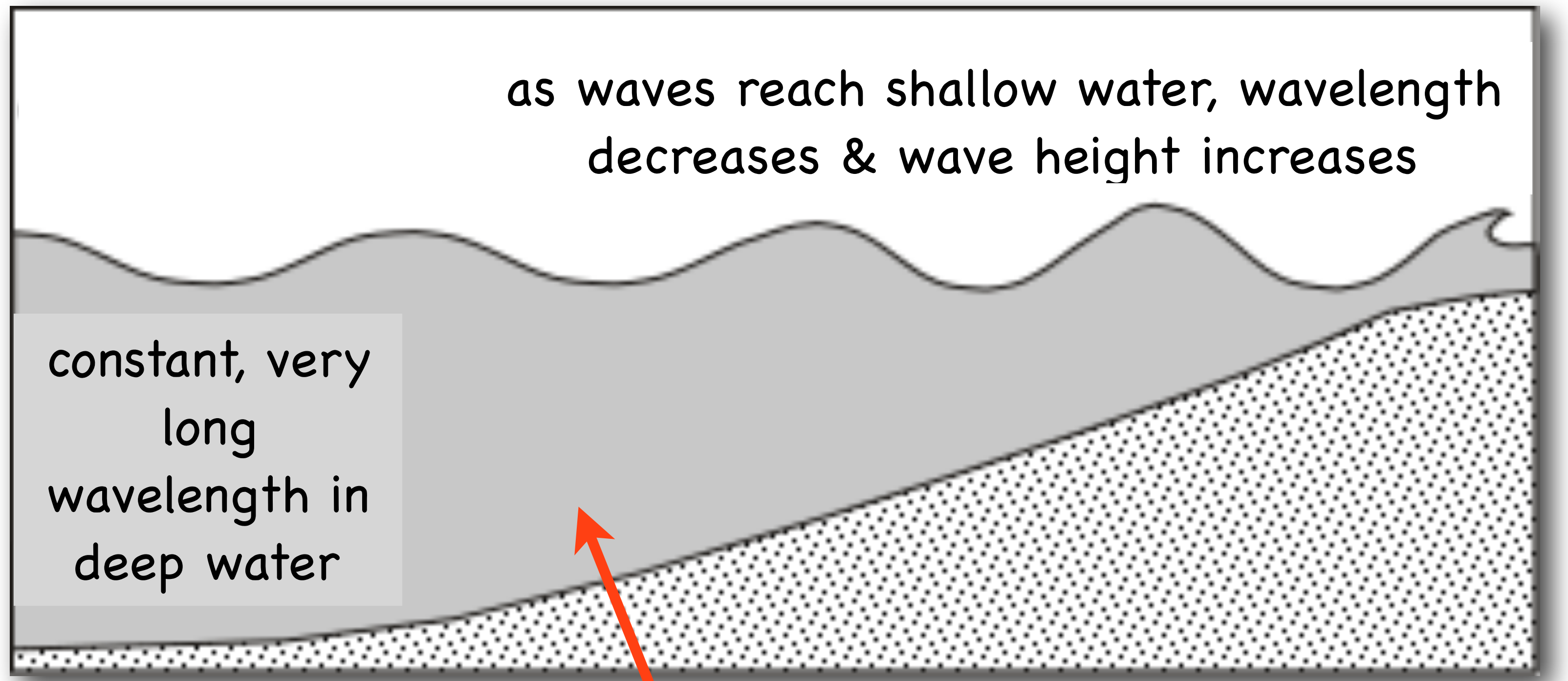


almost undetectable by boats in deep ocean

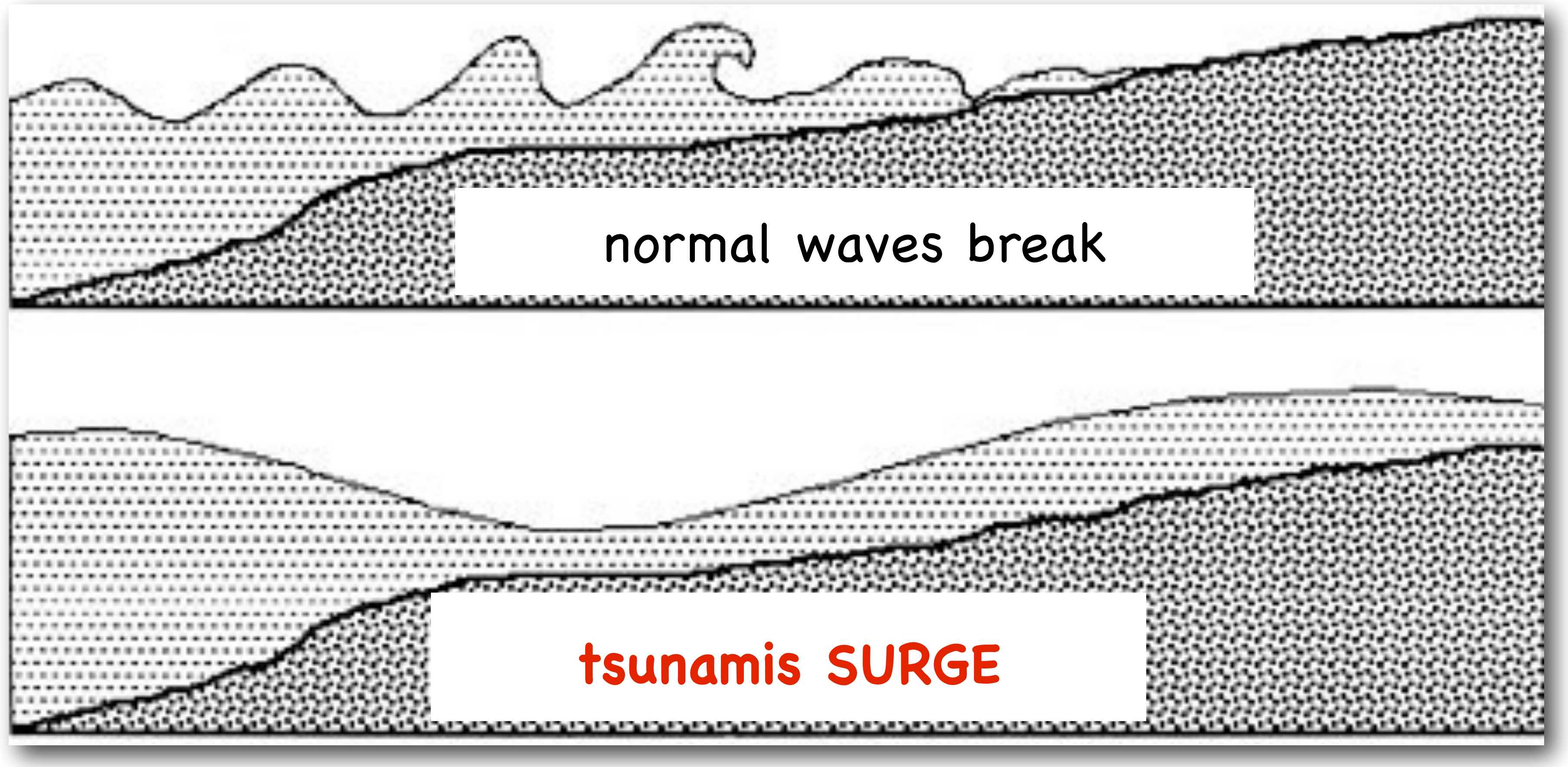


http://isaac.exploratorium.edu/~pauld/summer_institute/cset/Tsunamishore.jpg

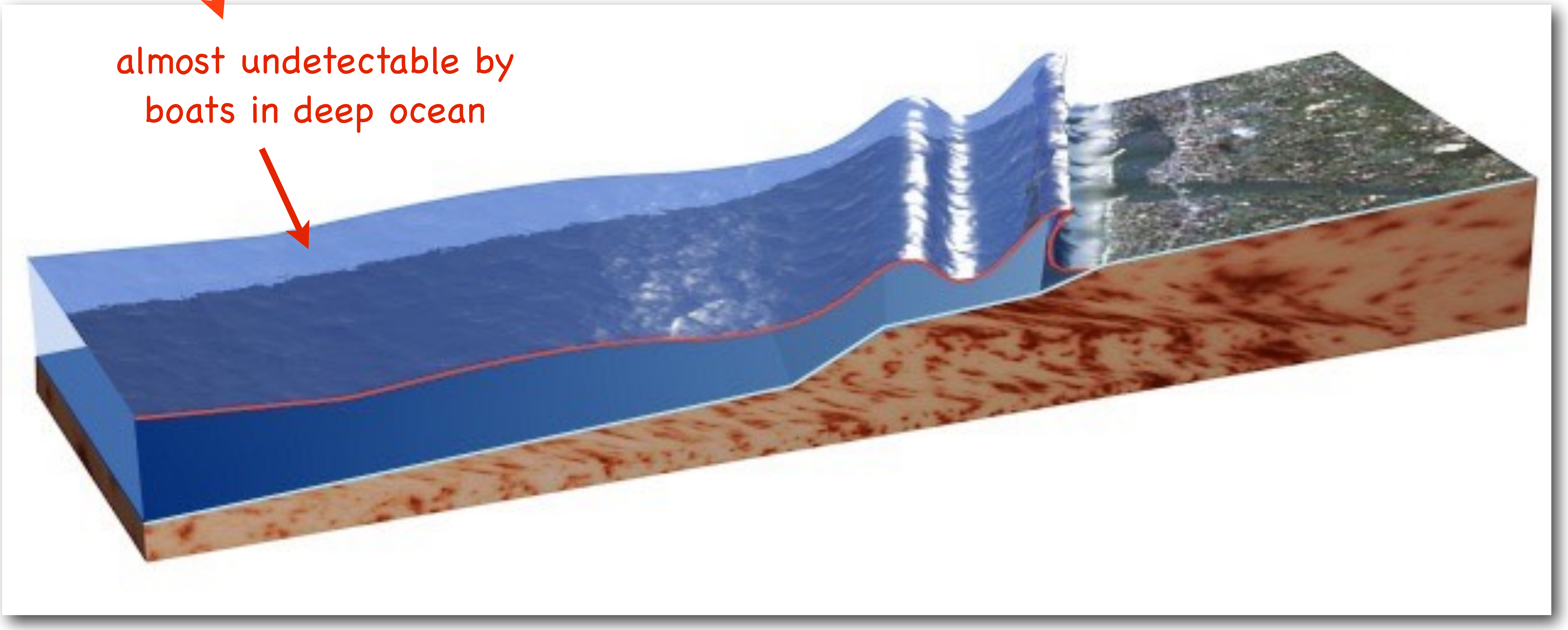
Waves



http://www.tulane.edu/~sanelson/images/tsunami_wave.gif

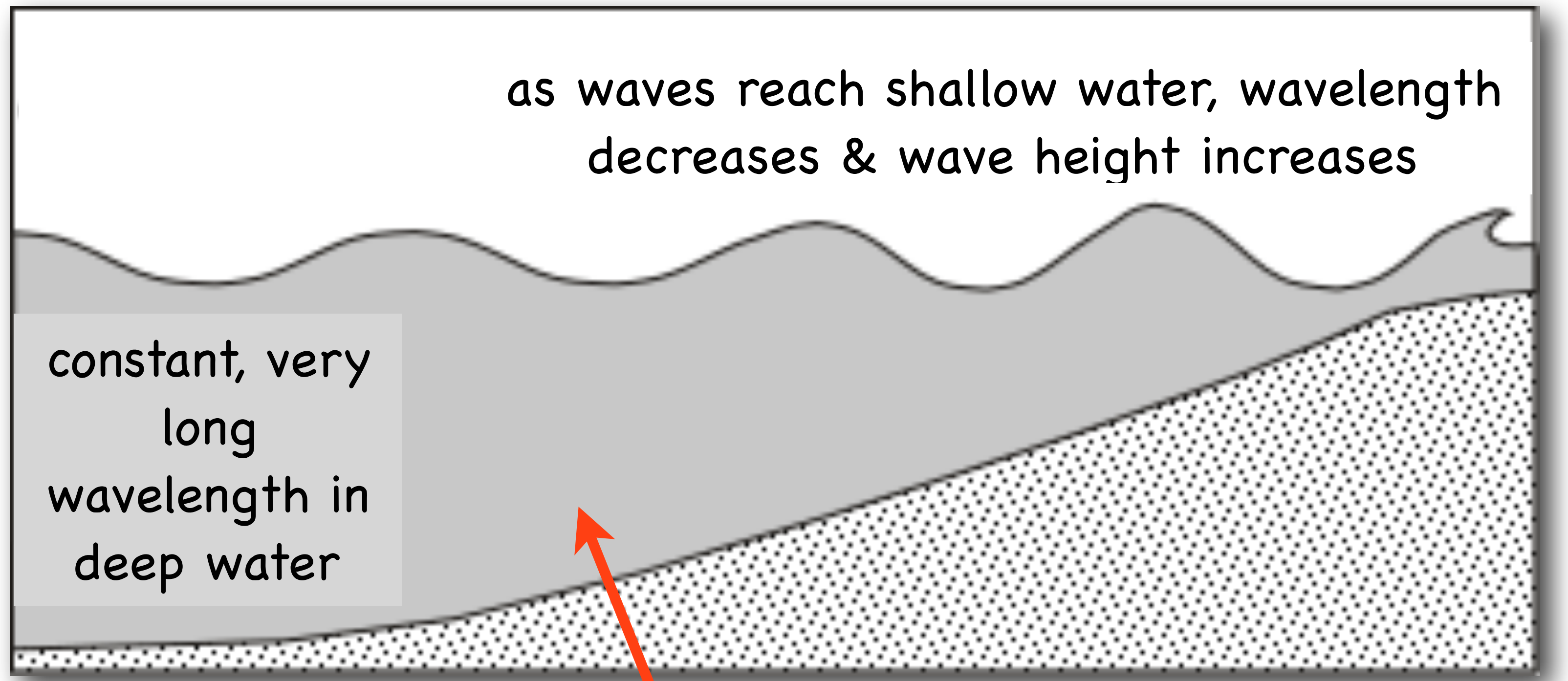


http://www.northcoastjournal.com/media/issues/032008/SCI-tsunami-wave-break-surge.jpg

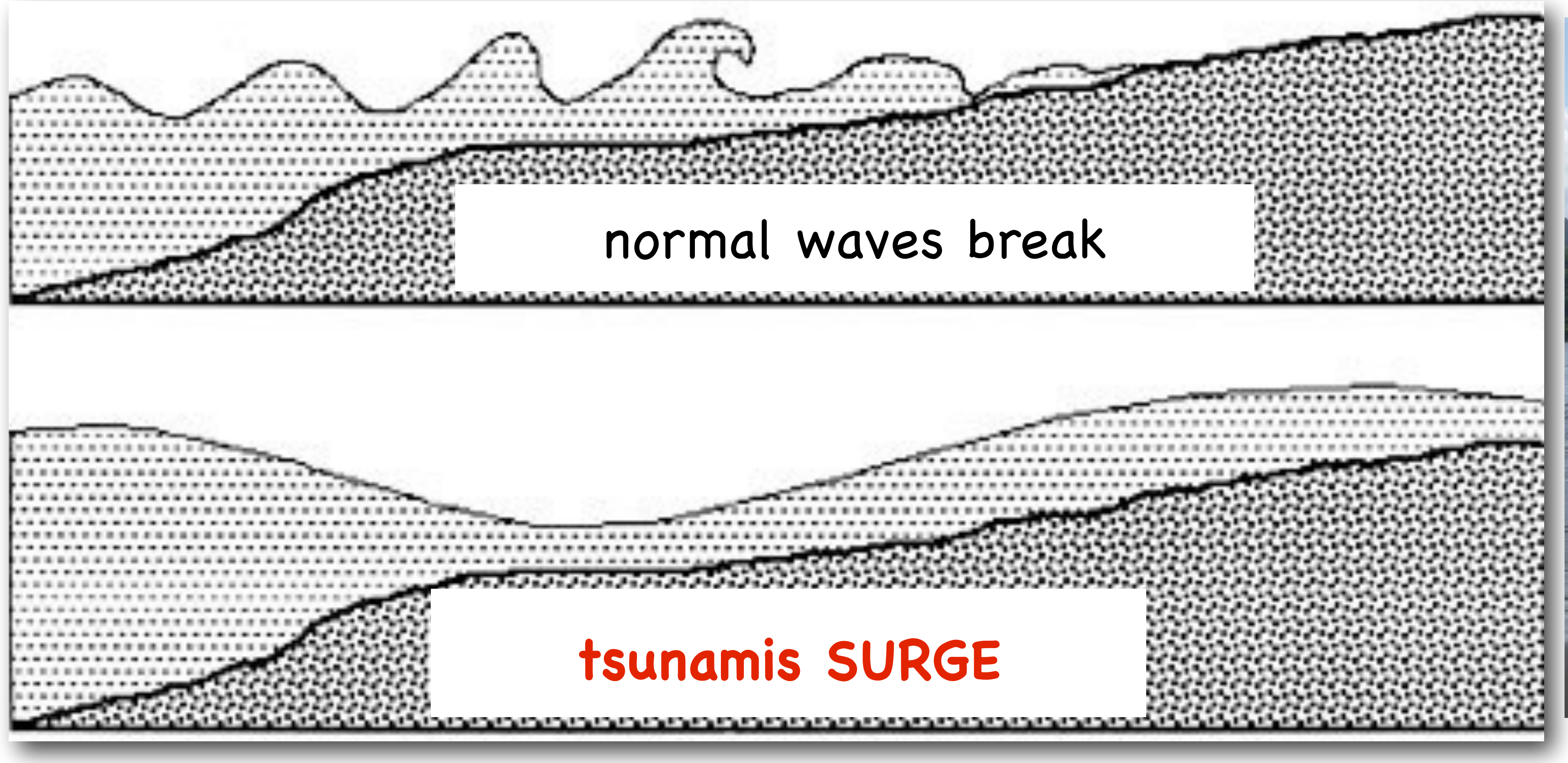


http://isaac.exploratorium.edu/~pauld/summer_institute/cset/Tsunamishore.jpg

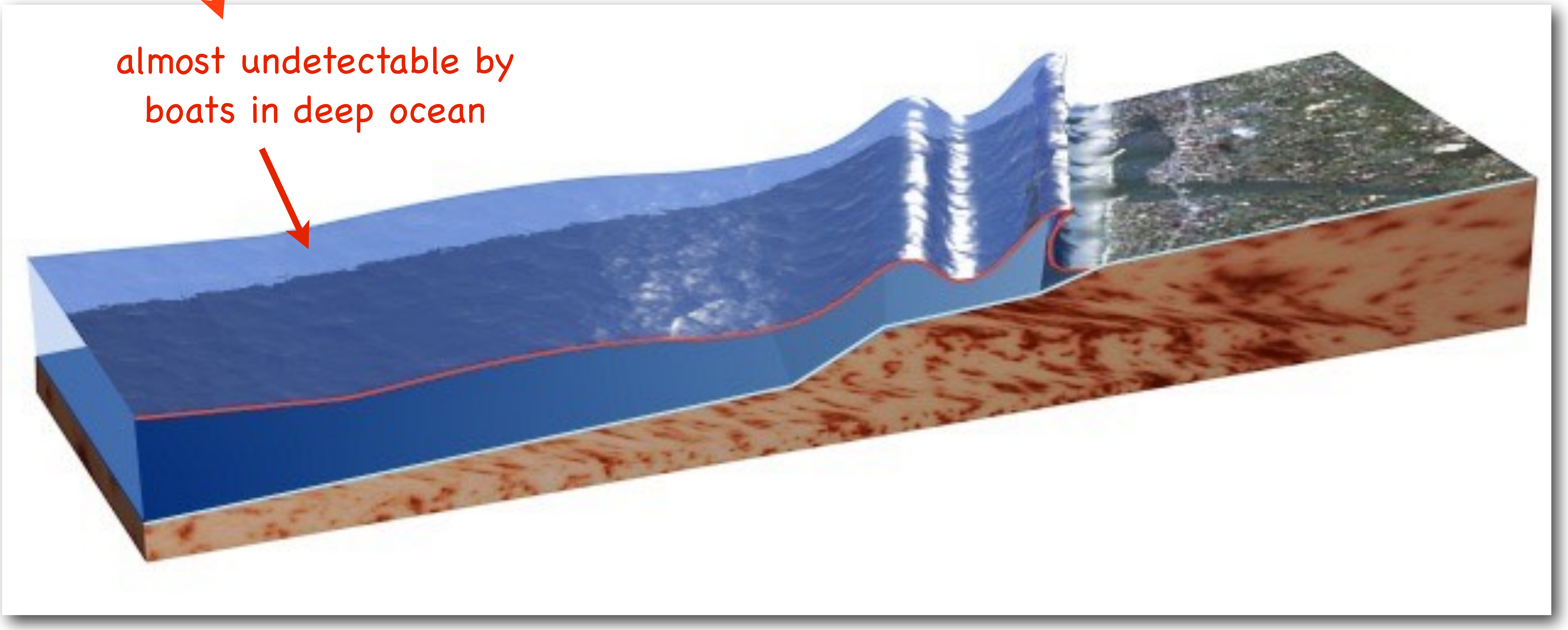
Waves



http://www.tulane.edu/~sanelson/images/tsunami_wave.gif

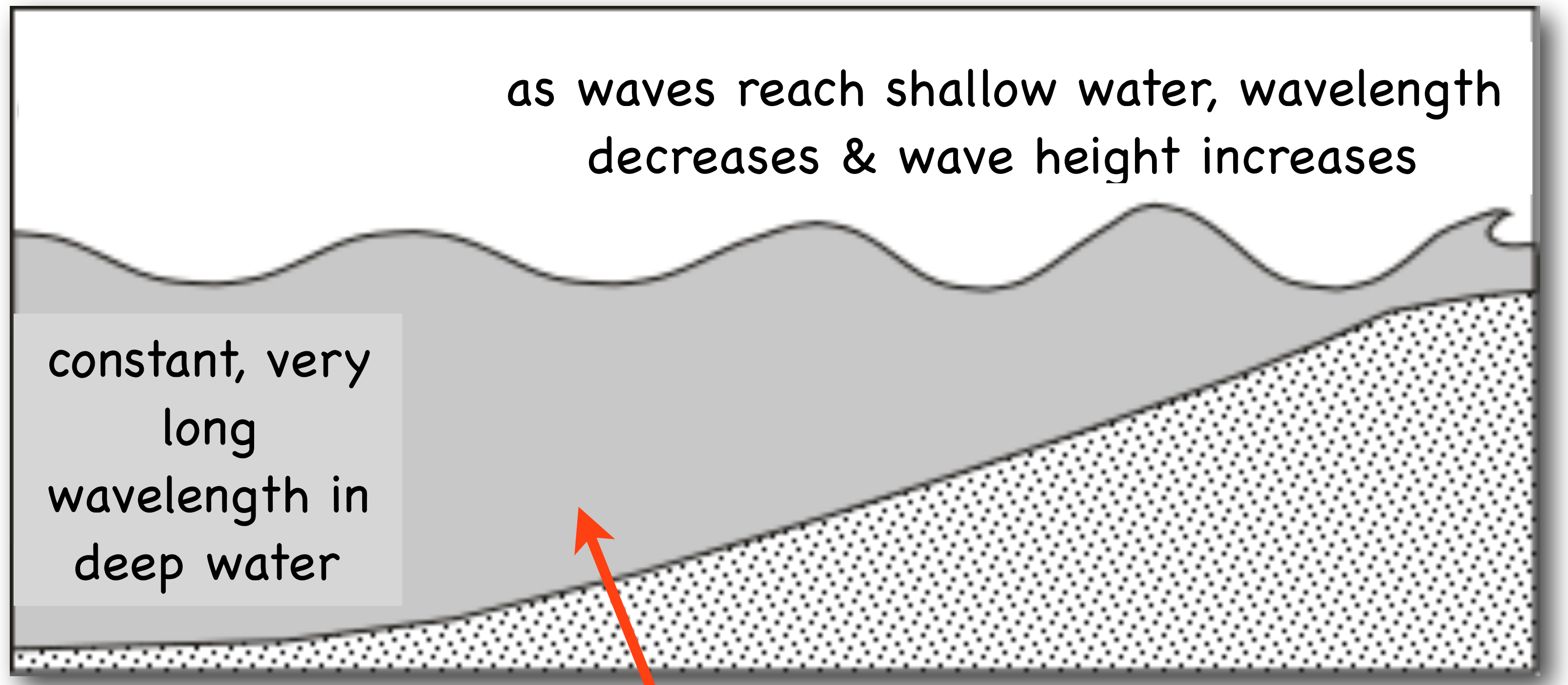


http://www.northcoastjournal.com/media/issues/032008/SCI-tsunami-wave-break-surge.jpg

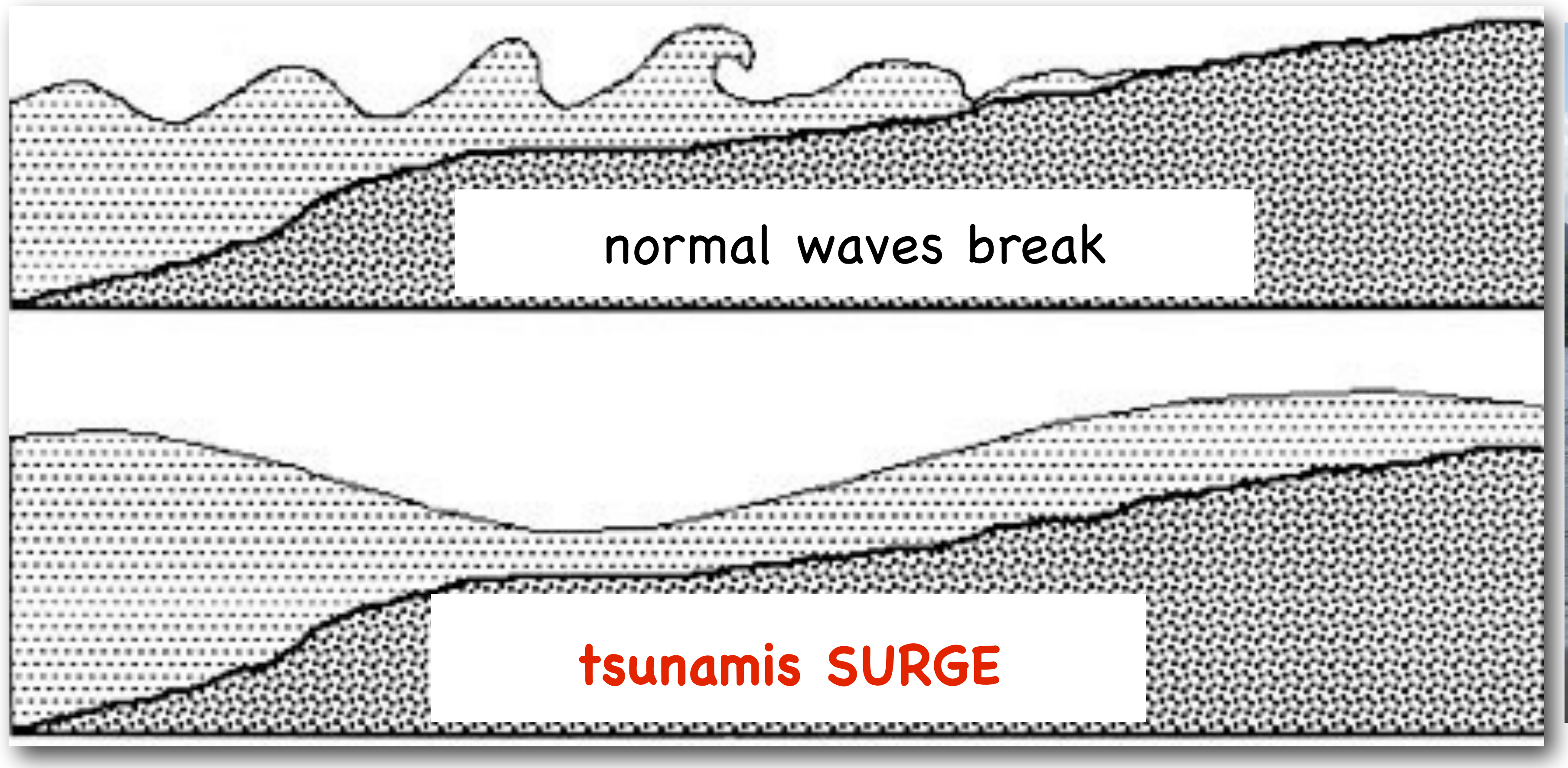


http://isaac.exploratorium.edu/~pauld/summer_institute/cset/Tsunamishore.jpg

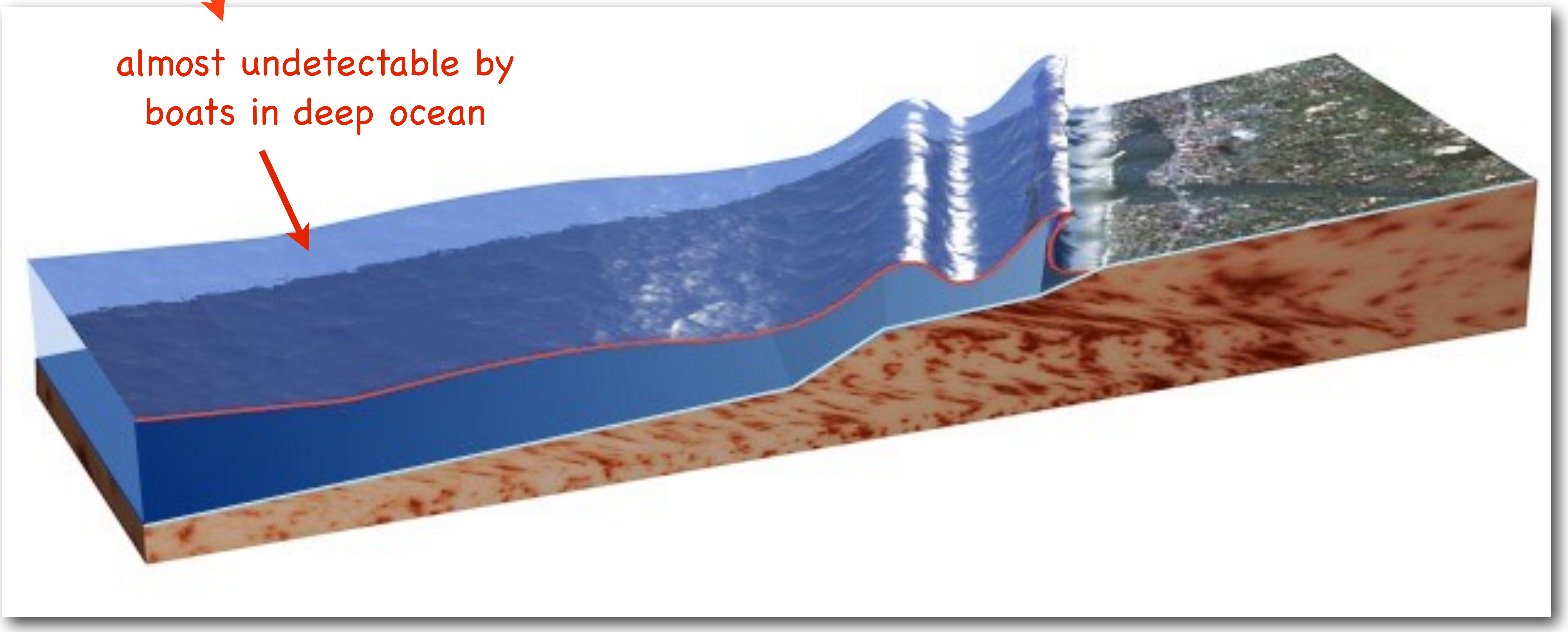
Waves



http://www.tulane.edu/~sanelson/images/tsunami_wave.gif

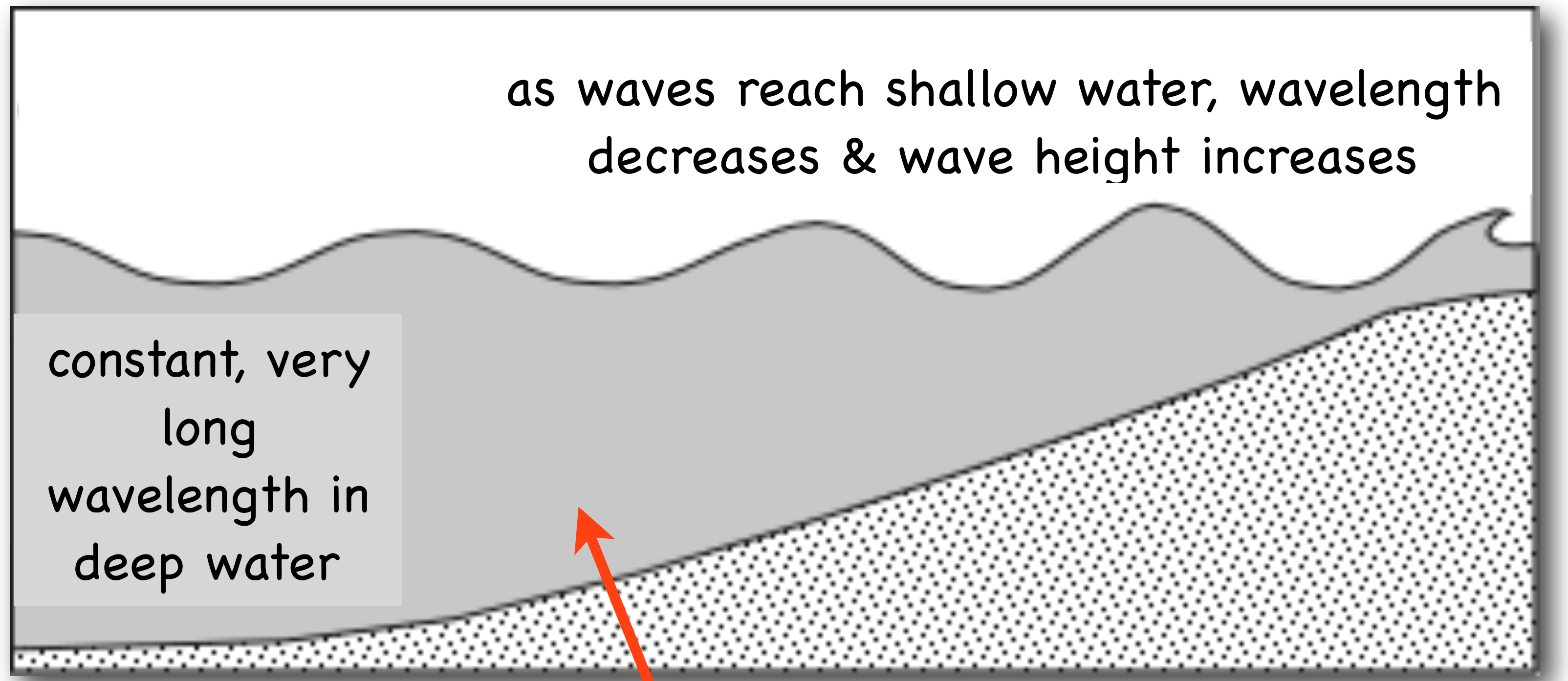


http://www.northcoastjournal.com/media/issues/032008/SCI-tsunami-wave-break-surge.jpg

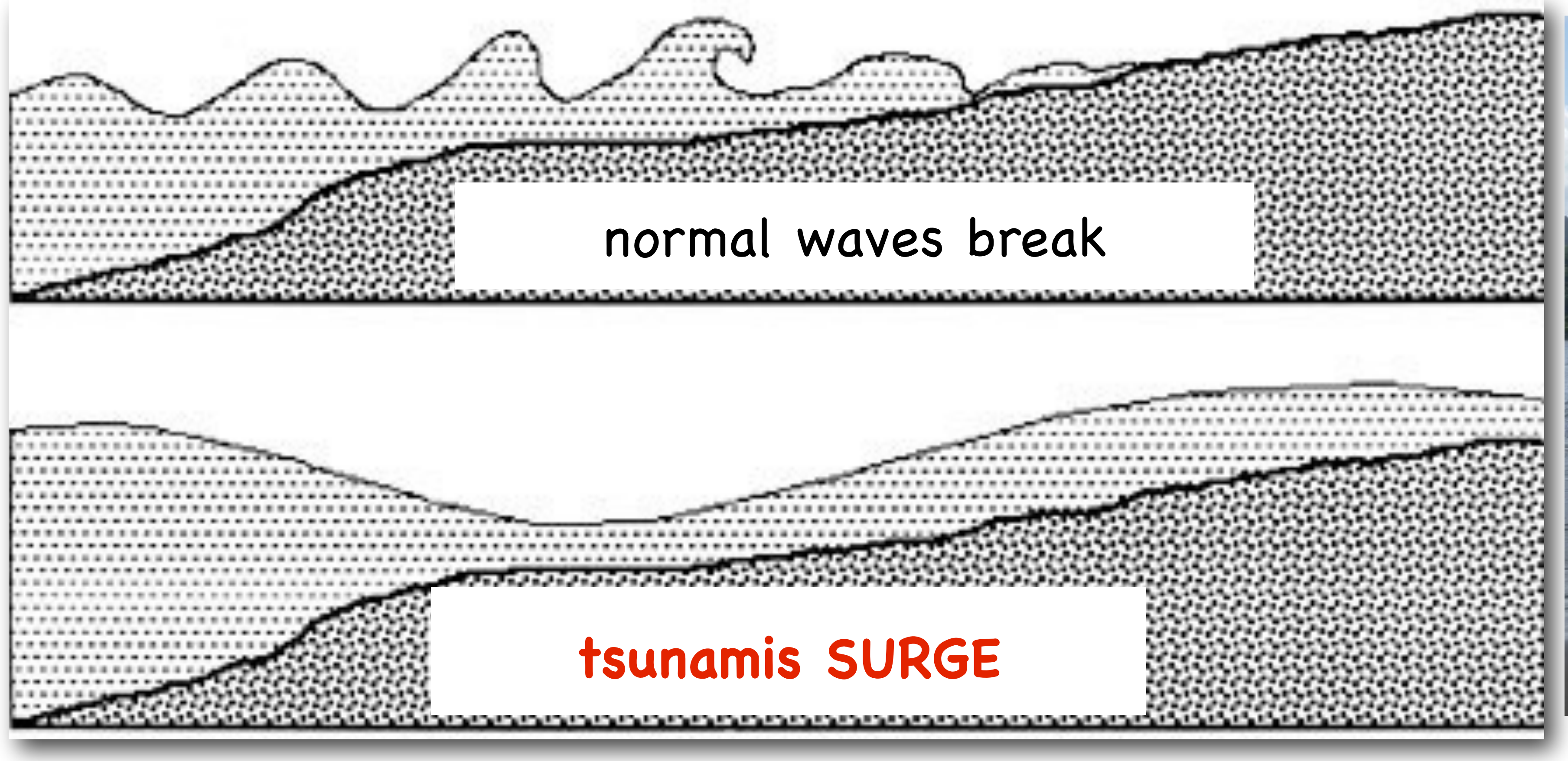


http://isaac.exploratorium.edu/~pauld/summer_institute/cset/Tsunamishore.jpg

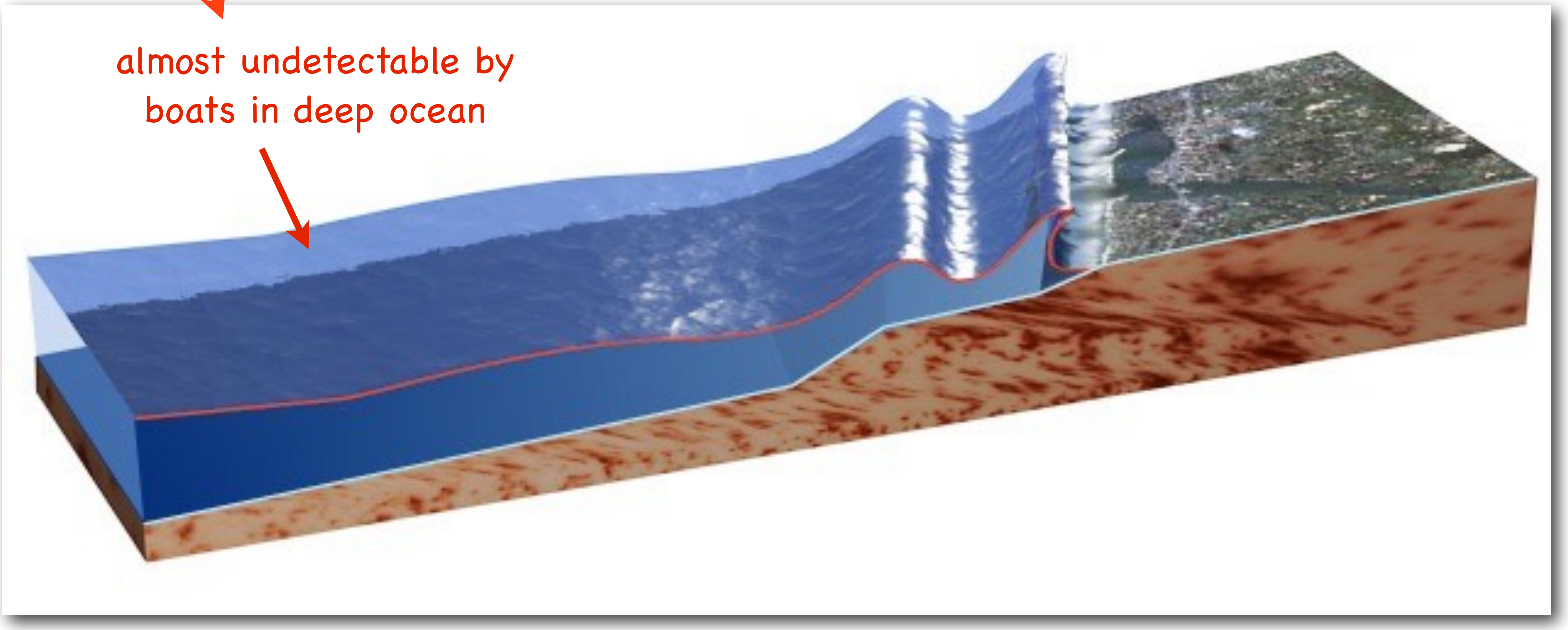
Waves



http://www.tulane.edu/~sanelson/images/tsunami_wave.gif



http://www.northcoastjournal.com/media/issues/032008/SCI-tsunami-wave-break-surge.jpg



http://isaac.exploratorium.edu/~pauld/summer_institute/cset/Tsunamishore.jpg

Natural Hazards and Disaster

Class 5: Disasters Triggered by Earthquakes and Tsunamis

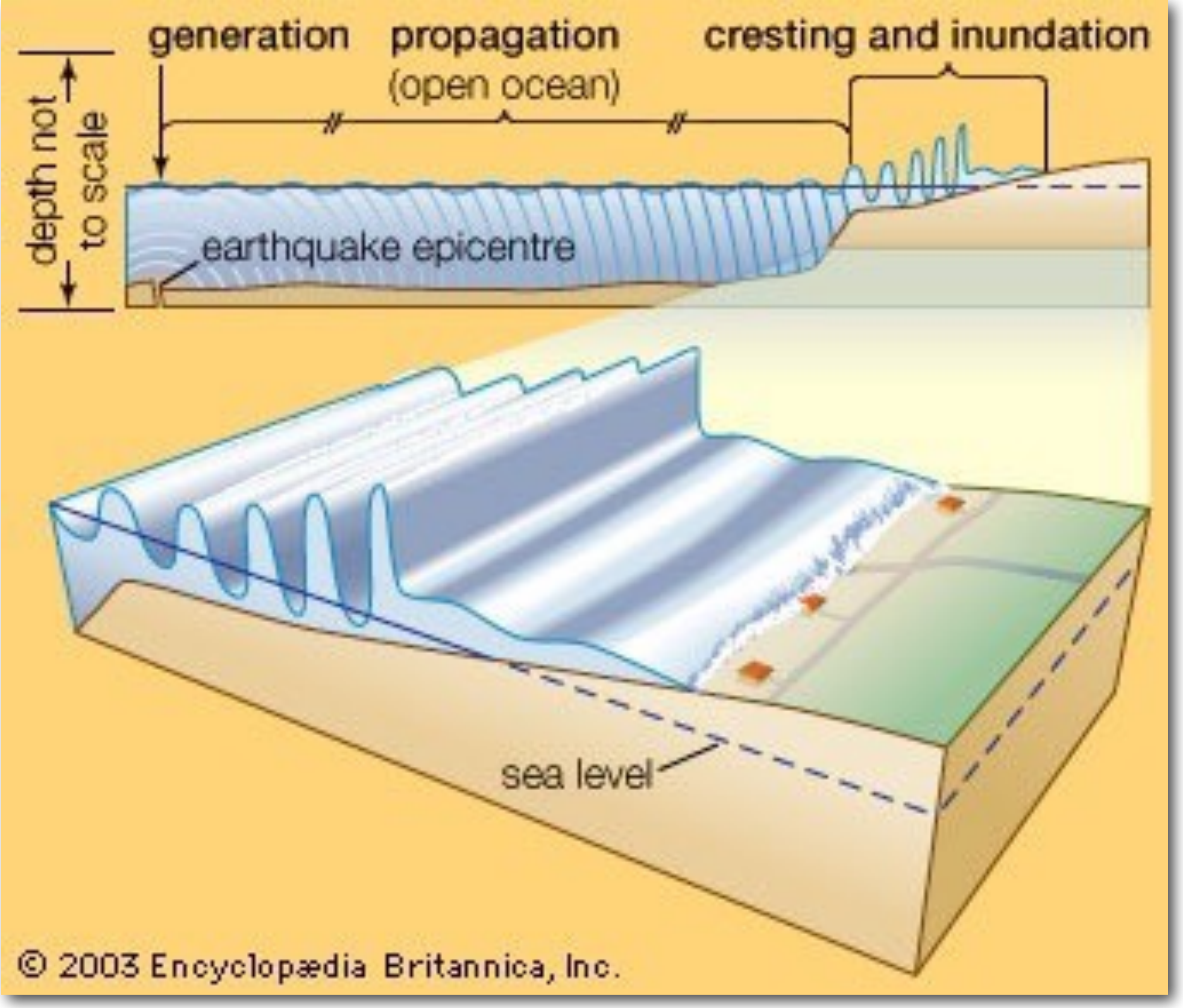
- Waves
- Tsunamis
- Earthquake Tsunamis
- Landslide Tsunamis
- Tsunami Detection, Prediction and Awareness

“Harbor Wave”

津波

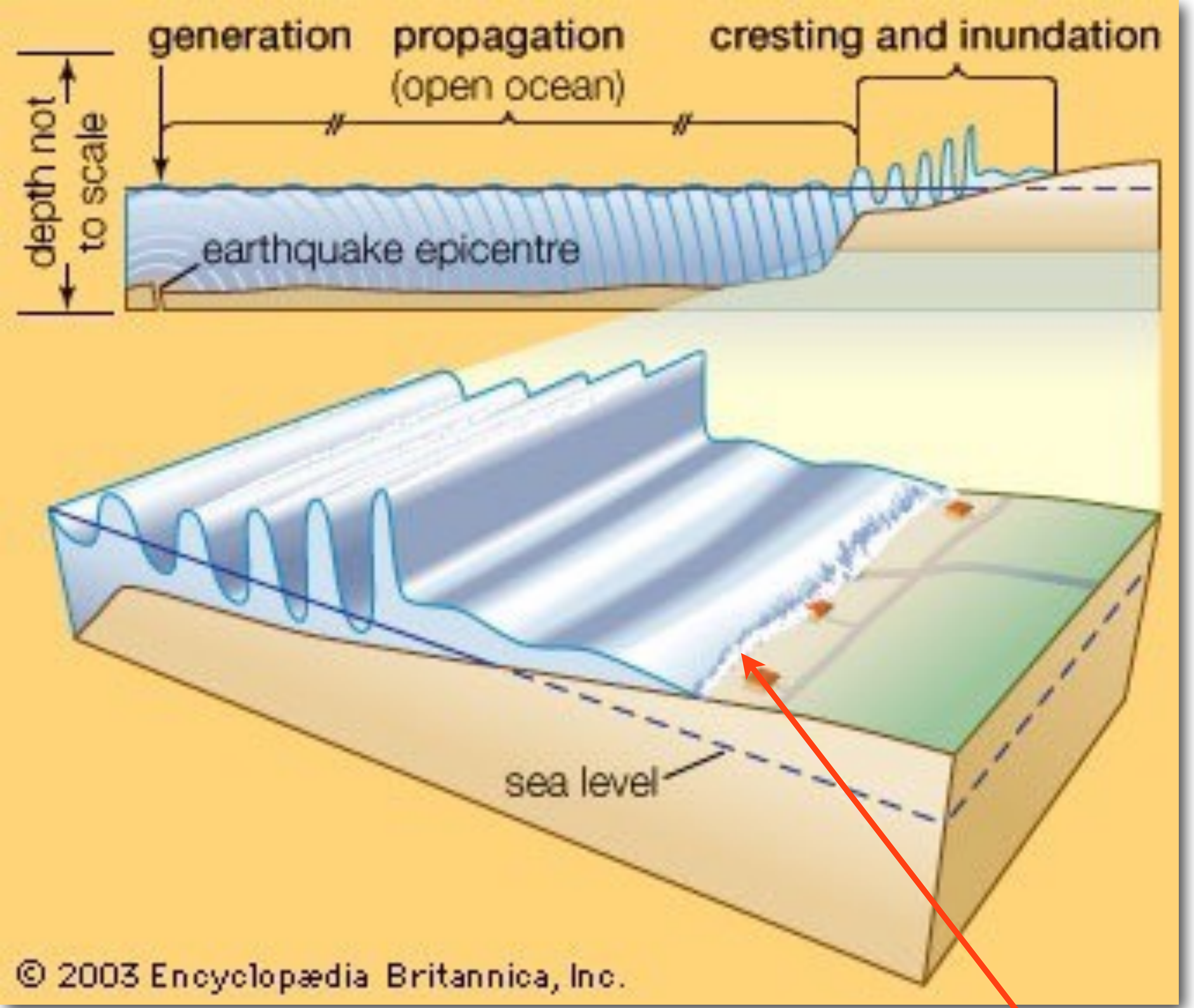
Katsushika Hokusai (1760–1849)

Tsunamis



wave height is greatly
exaggerated in this image!

Tsunamis



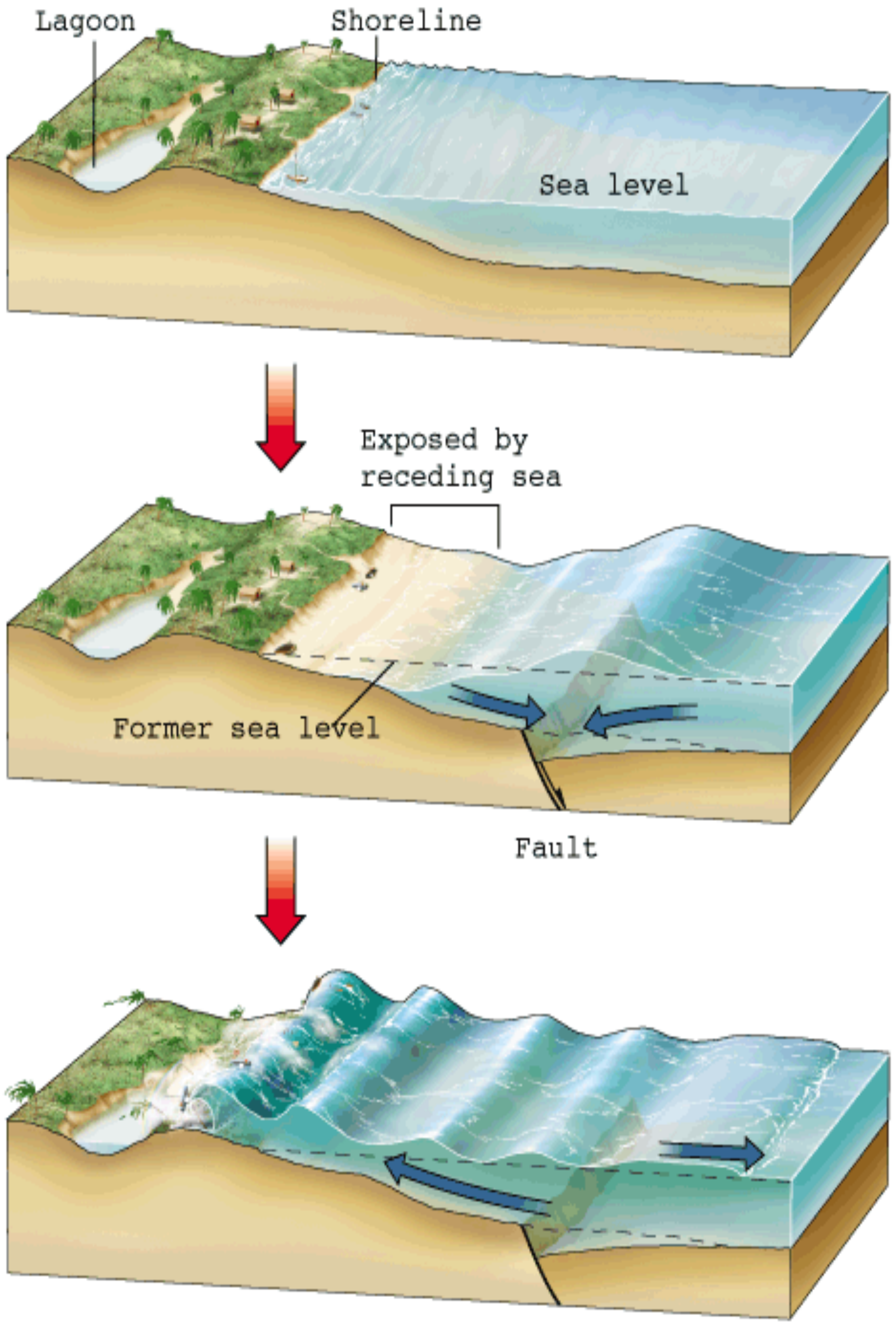
wave height is greatly exaggerated in this image!

tsunami surge

http://www.erh.noaa.gov/okx/tsunamipic.jpg

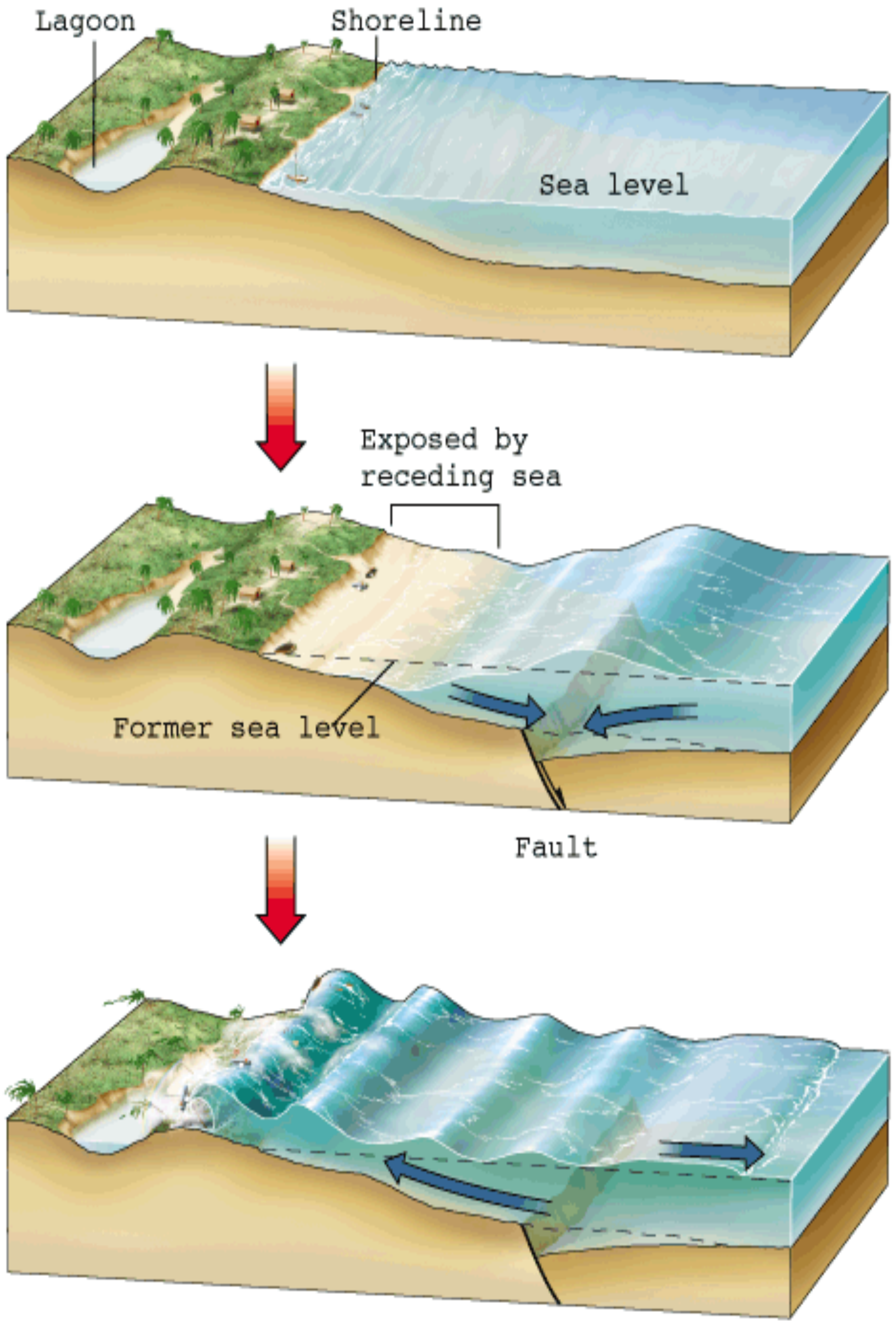
surge front

Tsunamis



source: Pearson.com earthscience publications

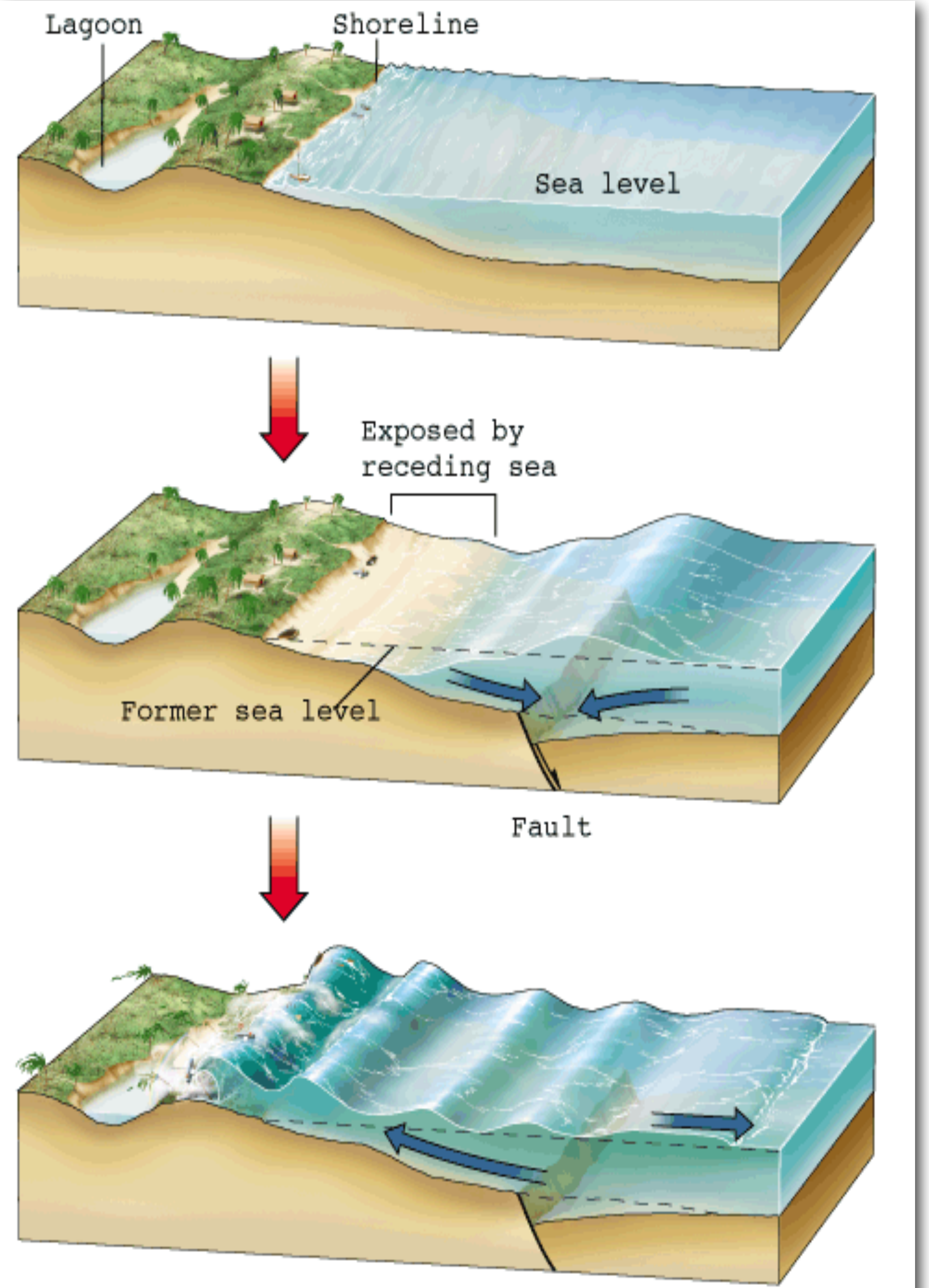
Tsunamis



source: Pearson.com earthscience publications

first indication of approaching tsunami
may be rapidly receding ocean

Tsunamis



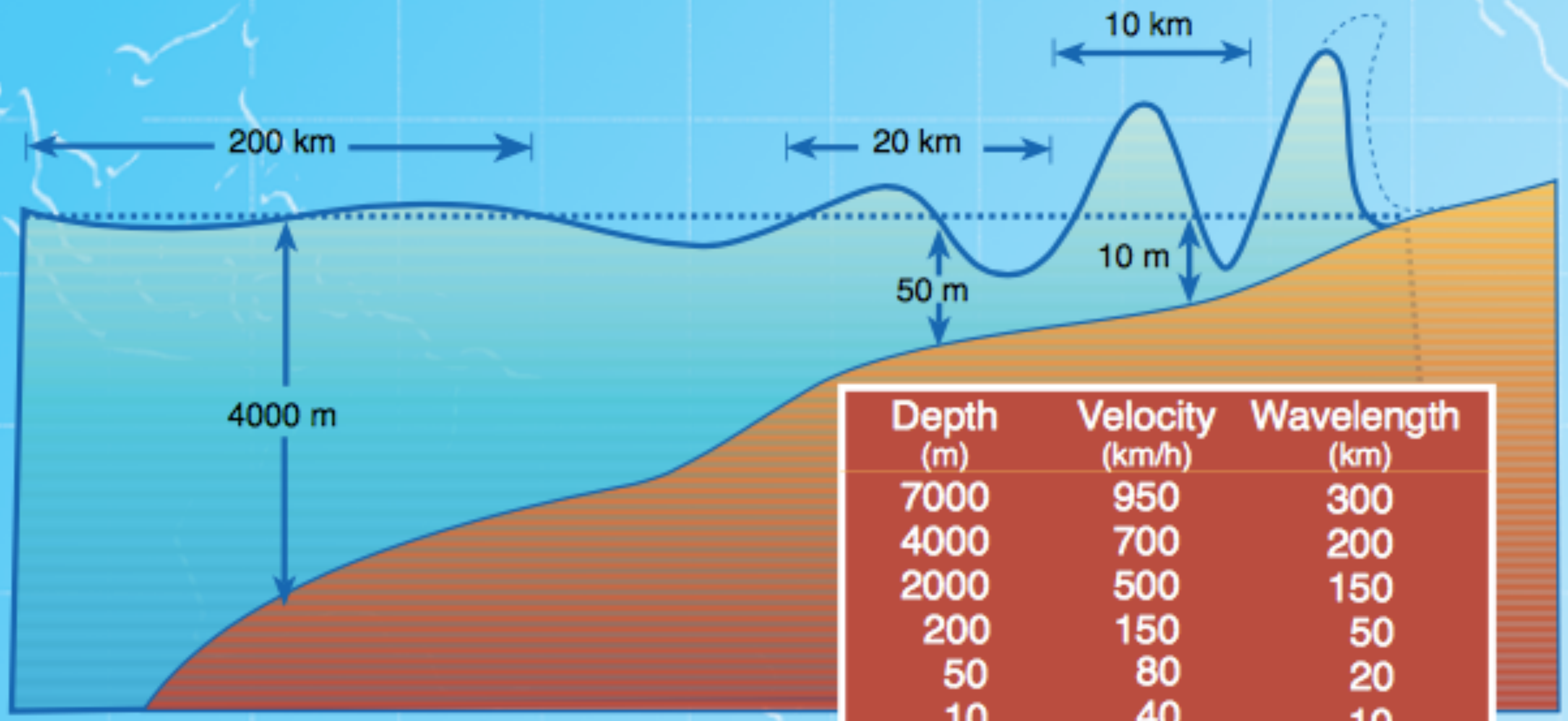
source: Pearson.com earthscience publications

first indication of approaching tsunami may be rapidly receding ocean

a tsunami will have more than one destructive surge until waves lose energy

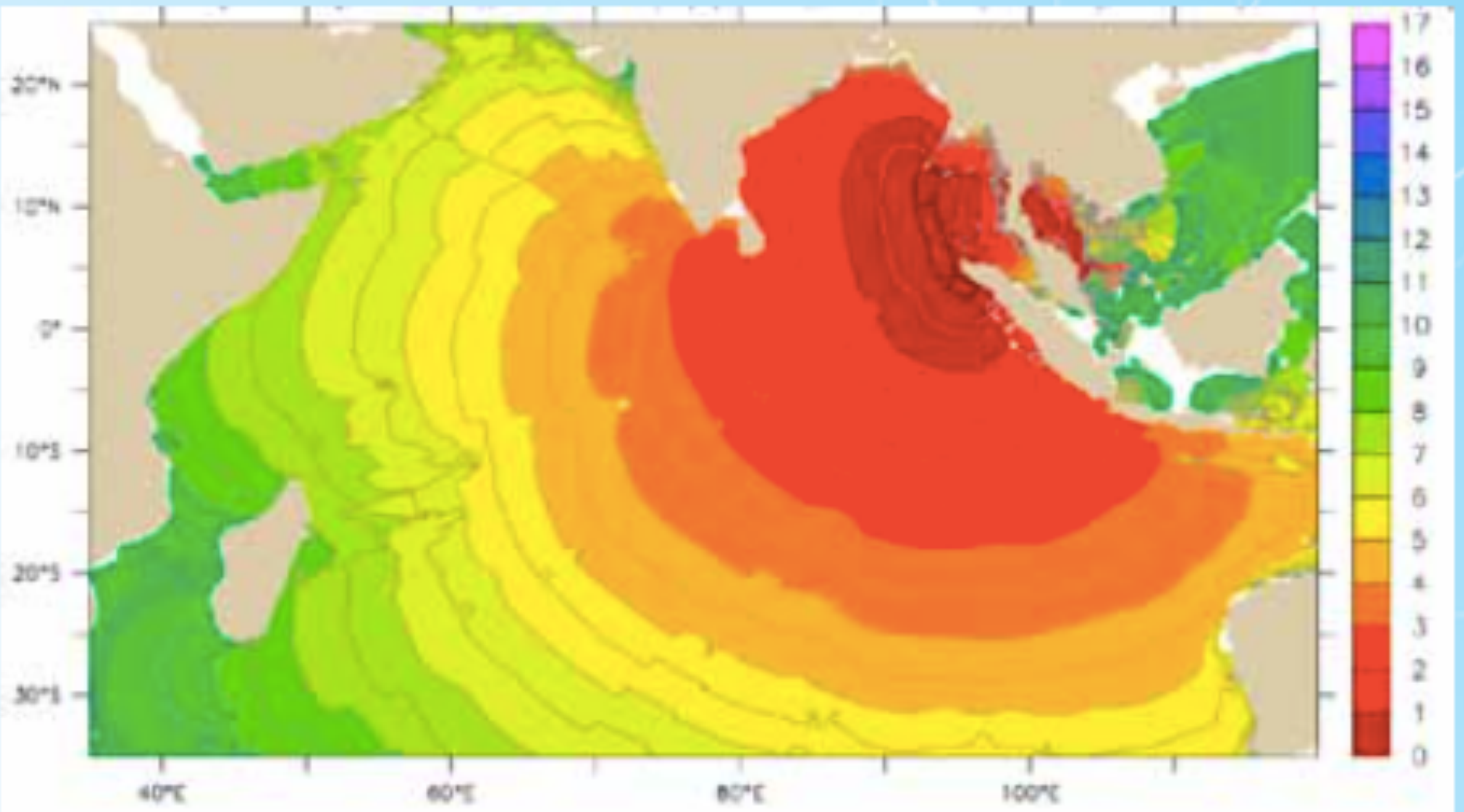
Tsunamis

Tsunami Speed is reduced in shallow water as wave height increases rapidly.

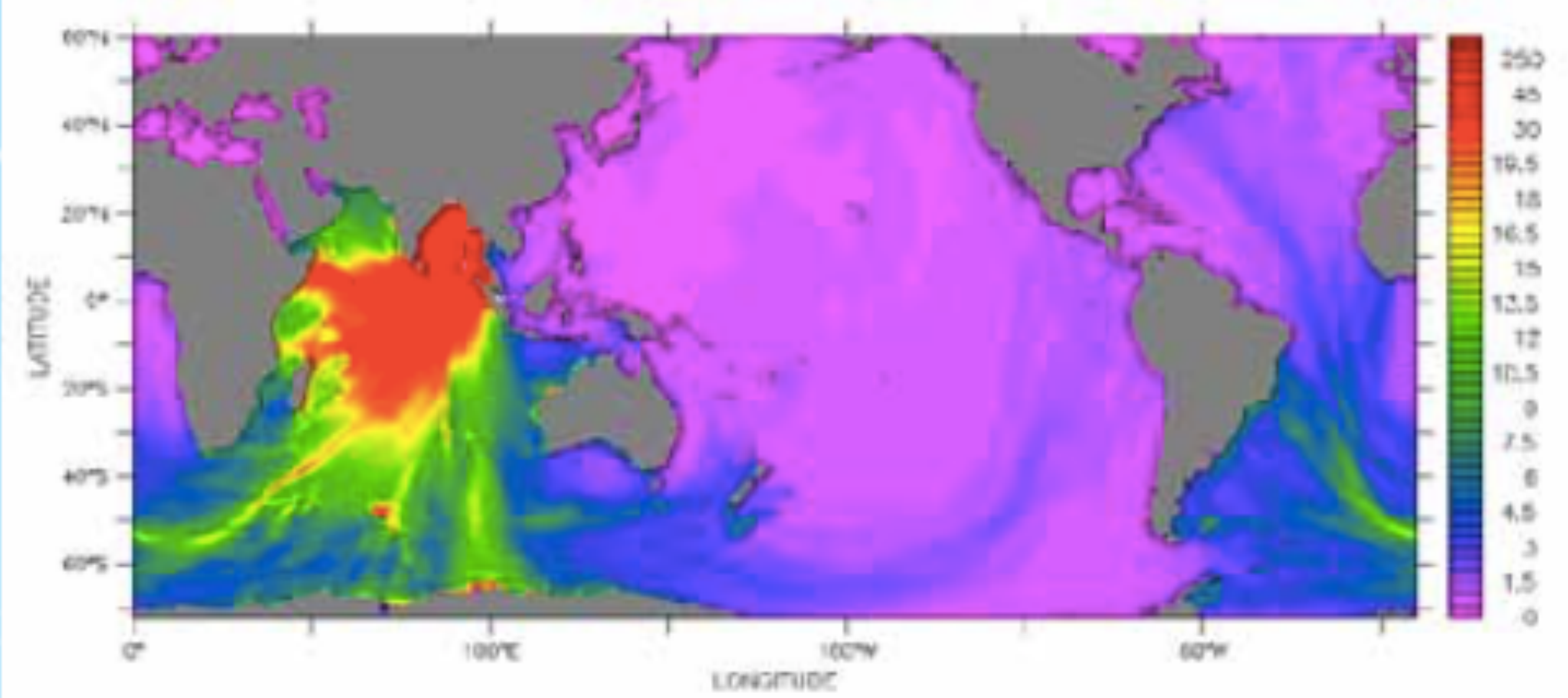


Depth (m)	Velocity (km/h)	Wavelength (km)
7000	950	300
4000	700	200
2000	500	150
200	150	50
50	80	20
10	40	10

In the open ocean a tsunami is less than a few tens of centimeters (1 ft) high at the surface, but its wave height increases rapidly in shallow water. Tsunami wave energy extends from the surface to the bottom in even the deepest waters. As the tsunami attacks the coastline, the wave energy is compressed into a much shorter distance and a much shallower depth, creating destructive, life-threatening waves. As shown in this figure, tsunamis are a series of waves that can be destructive for hours. Although not depicted, the 1st wave may not be the largest.



Calculated tsunami travel times for the December 26, 2004 earthquake off western Sumatra. Each concentric curve represents 30 minutes of tsunami travel time. Destructive tsunami hit Indonesia in 15 minutes, Sri Lanka in two hours, and Kenya nine hours after the earthquake (NOAA PMEL).



Maximum calculated global wave heights (cm) from the December 26, 2004 Indian Ocean tsunami. Waves were recorded on sea level gauges in Antarctica, and along the coasts of South and North America and Canada in both the Pacific and Atlantic Oceans (NOAA PMEL).

http://unesdoc.unesco.org/images/0014/001486/148609e.pdf

Natural Hazards and Disaster

Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Waves
- Tsunamis
- <u>Earthquake Tsunamis</u>
- Landslide Tsunamis
- Tsunami Detection, Prediction and Awareness

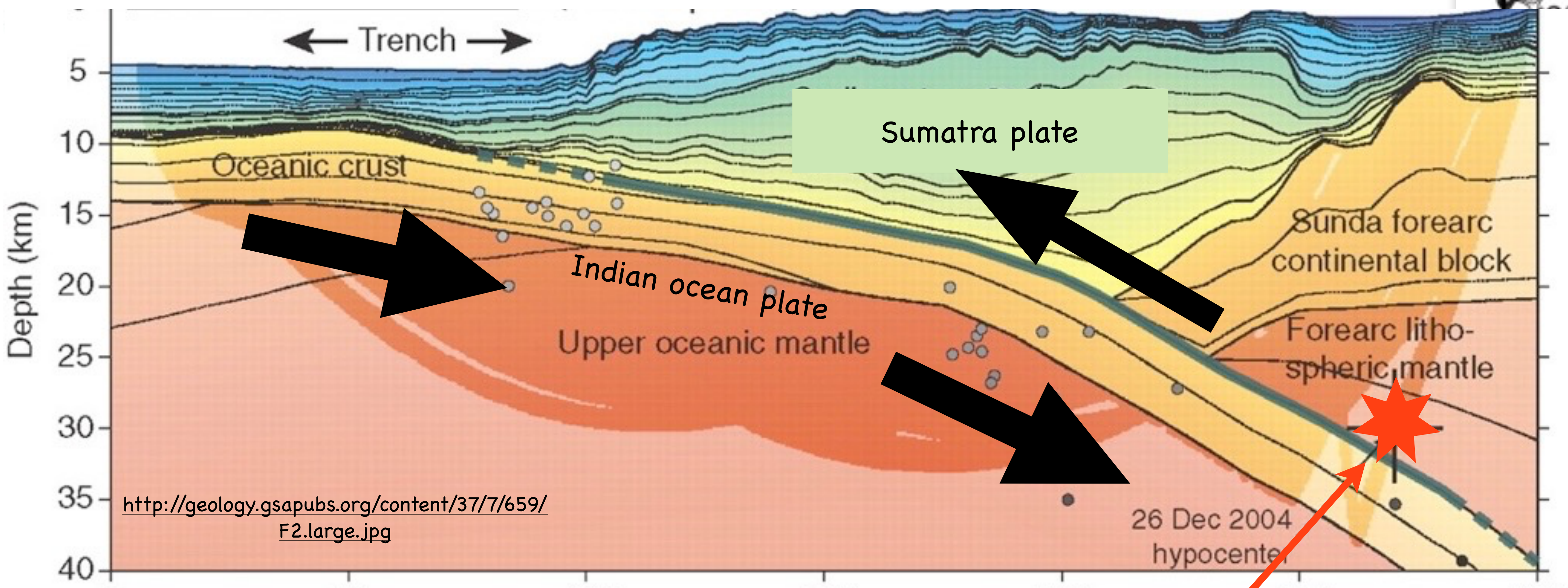
“Harbor Wave”

津波

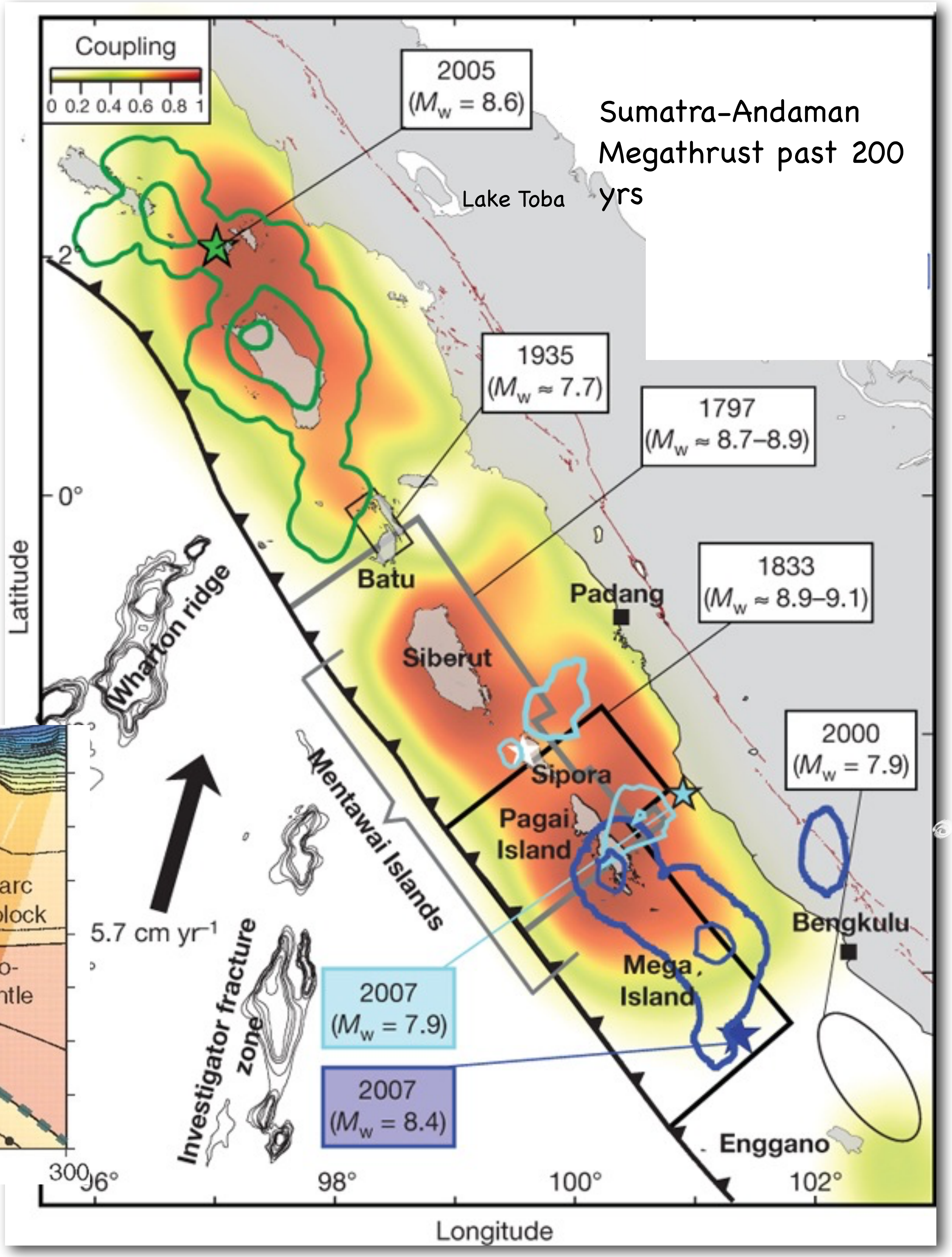
Katsushika Hokusai (1760–1849)

Earthquake Tsunamis

- Sumatra-Andaman Megathrust
- Sumatra plate thrusts over the subducting Indian Ocean plate.



Dec 26, 2004 hypocenter
Mw 9.2 earthquake



http://www.nature.com/nature/journal/v456/n7222/images/nature07572-f1.2.jpg

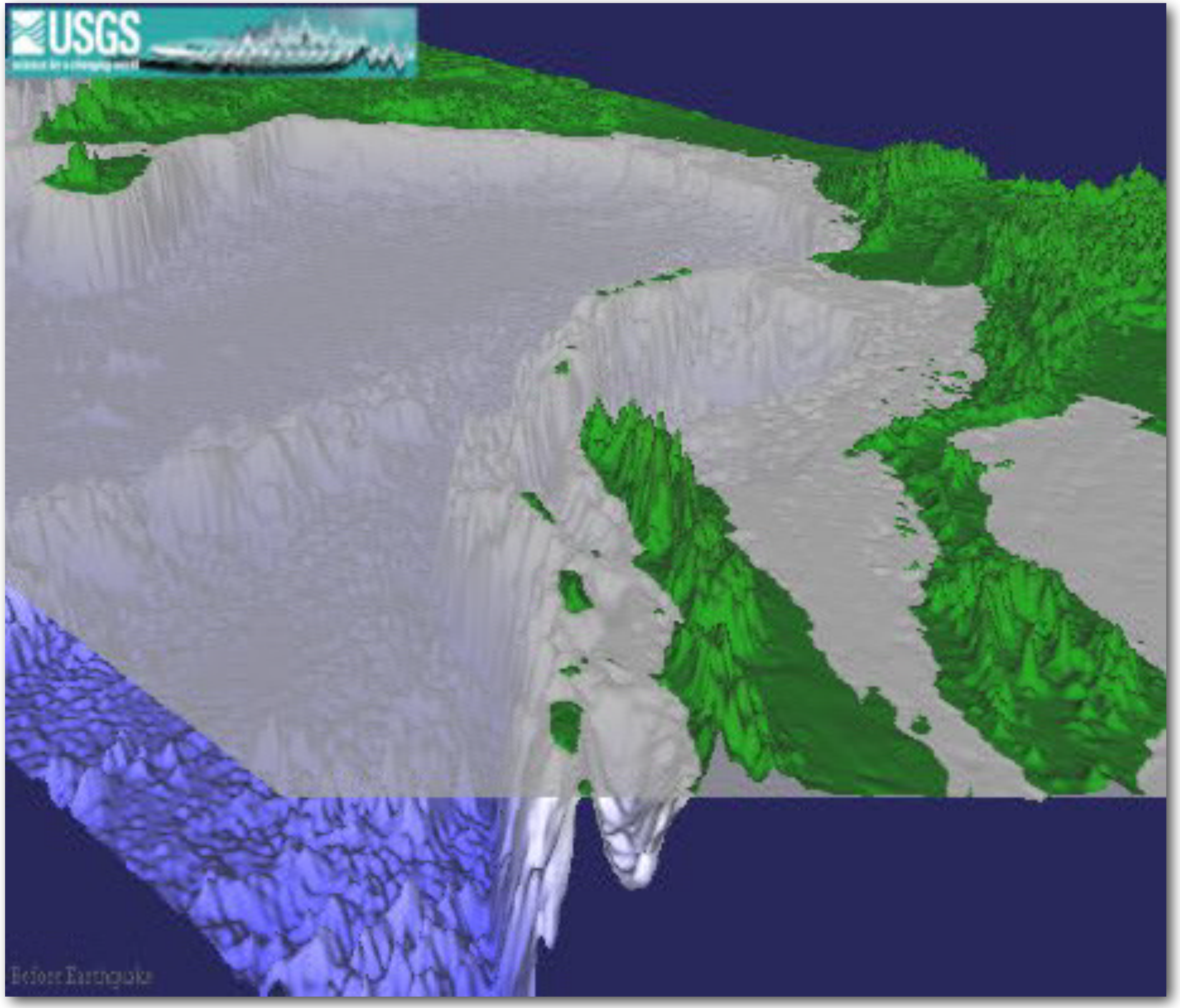
Site of numerous large magnitude earthquakes in historical times

Earthquake Tsunamis

December 26, 2004

Sudden thrust upward of Sumatra plate generated an initial upwards pressure wave 4m to 8m high in the ocean...

...resulting in a wave that spread out and across the Indian Ocean

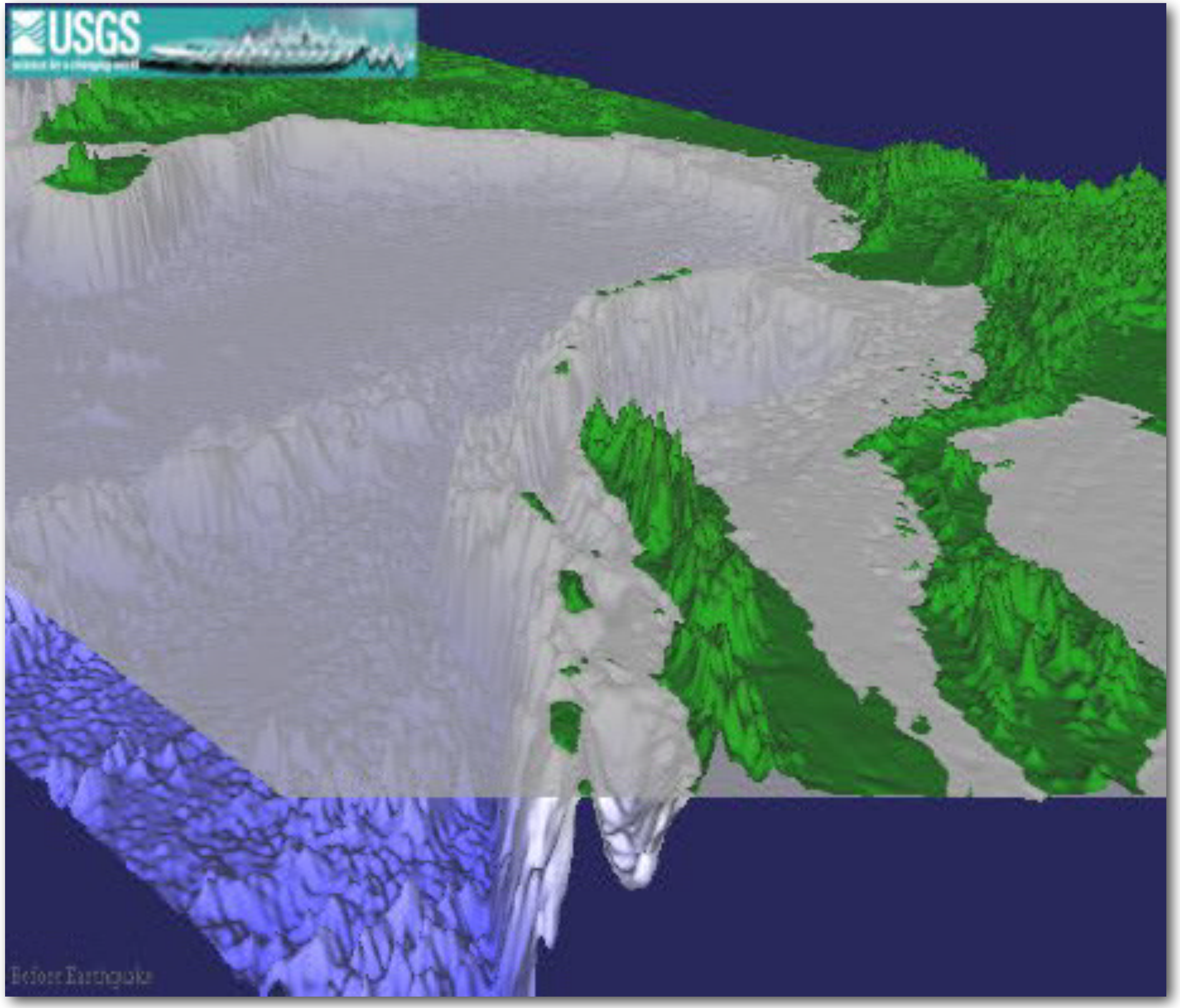


Earthquake Tsunamis

December 26, 2004

Sudden thrust upward of Sumatra plate generated an initial upwards pressure wave 4m to 8m high in the ocean...

...resulting in a wave that spread out and across the Indian Ocean

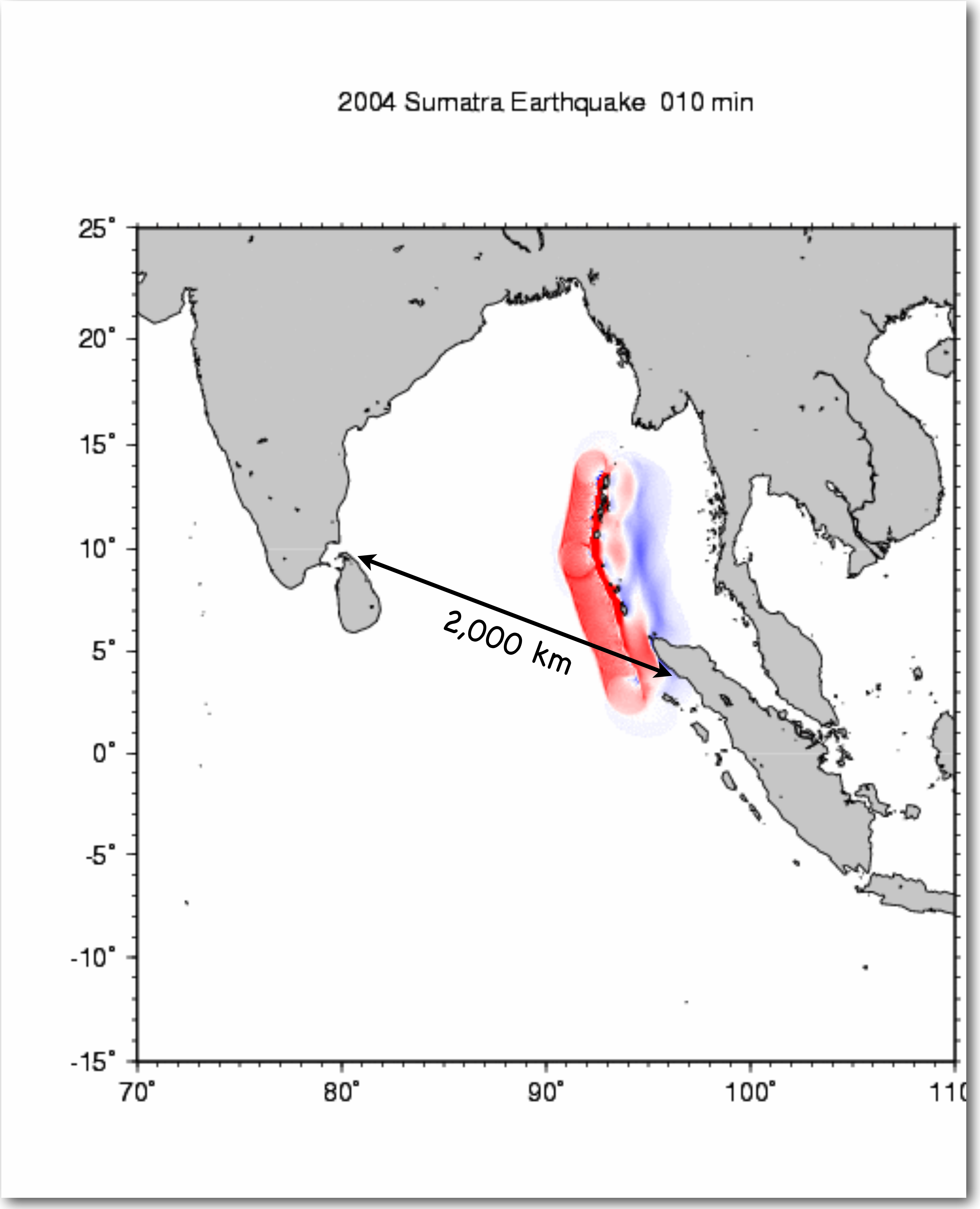


Earthquake Tsunamis

December 26, 2004

Sudden thrust upward of Sumatra plate generated an initial upwards pressure wave 4m to 8m high in the ocean...

...resulting in a wave that spread out and across the Indian Ocean

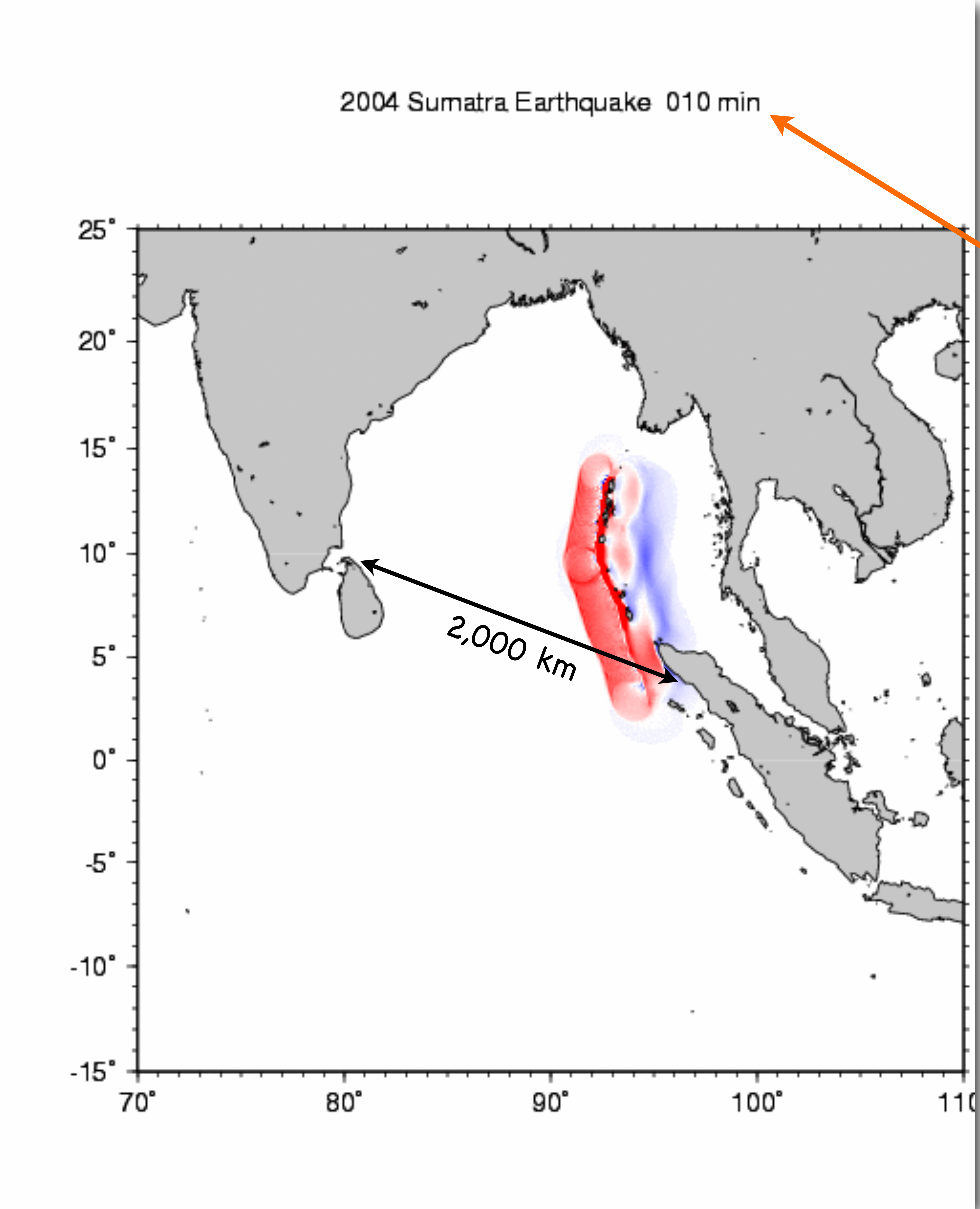


Earthquake Tsunamis

December 26, 2004

Sudden thrust upward of Sumatra plate generated an initial upwards pressure wave 4m to 8m high in the ocean...

...resulting in a wave that spread out and across the Indian Ocean



note: time is in minutes!

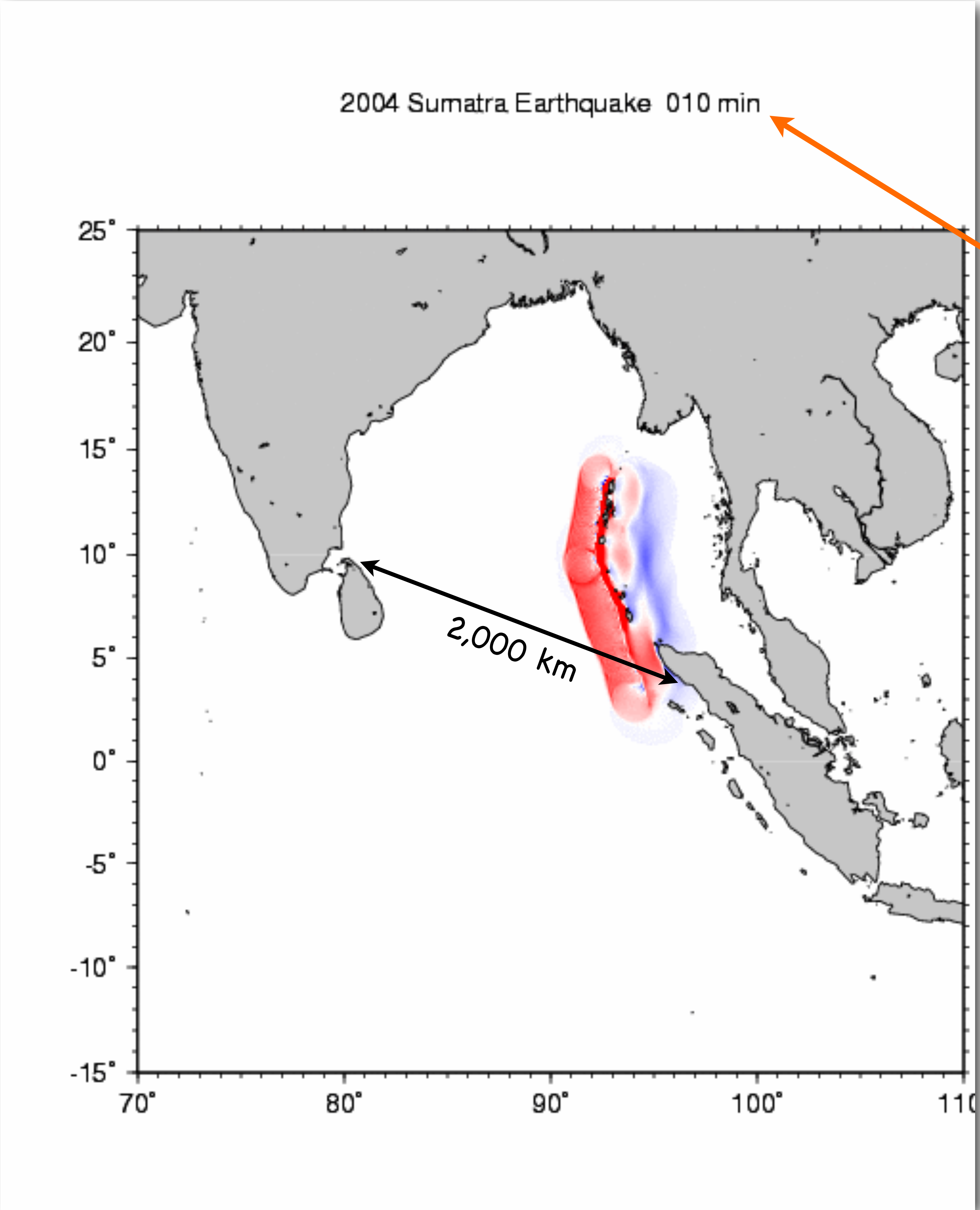
Earthquake Tsunamis

December 26, 2004

Sudden thrust upward of Sumatra plate generated an initial upwards pressure wave 4m to 8m high in the ocean...

...resulting in a wave that spread out and across the Indian Ocean

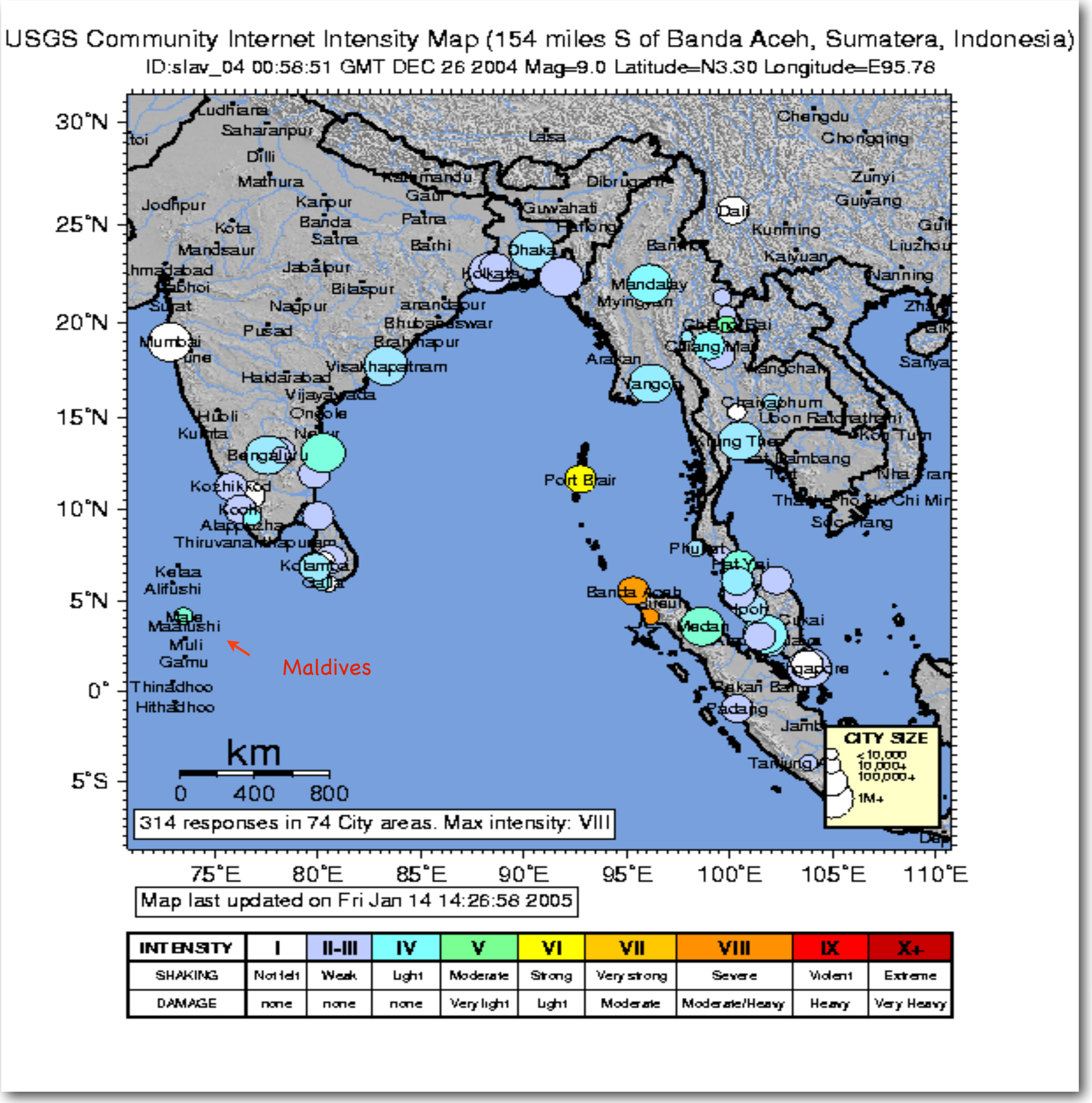
In the open ocean, tsunamis travel at a speed of >200 m/s (>720 km/h)



note: time is in minutes!

Earthquake Tsunamis

Damage from December 2004 tsunami

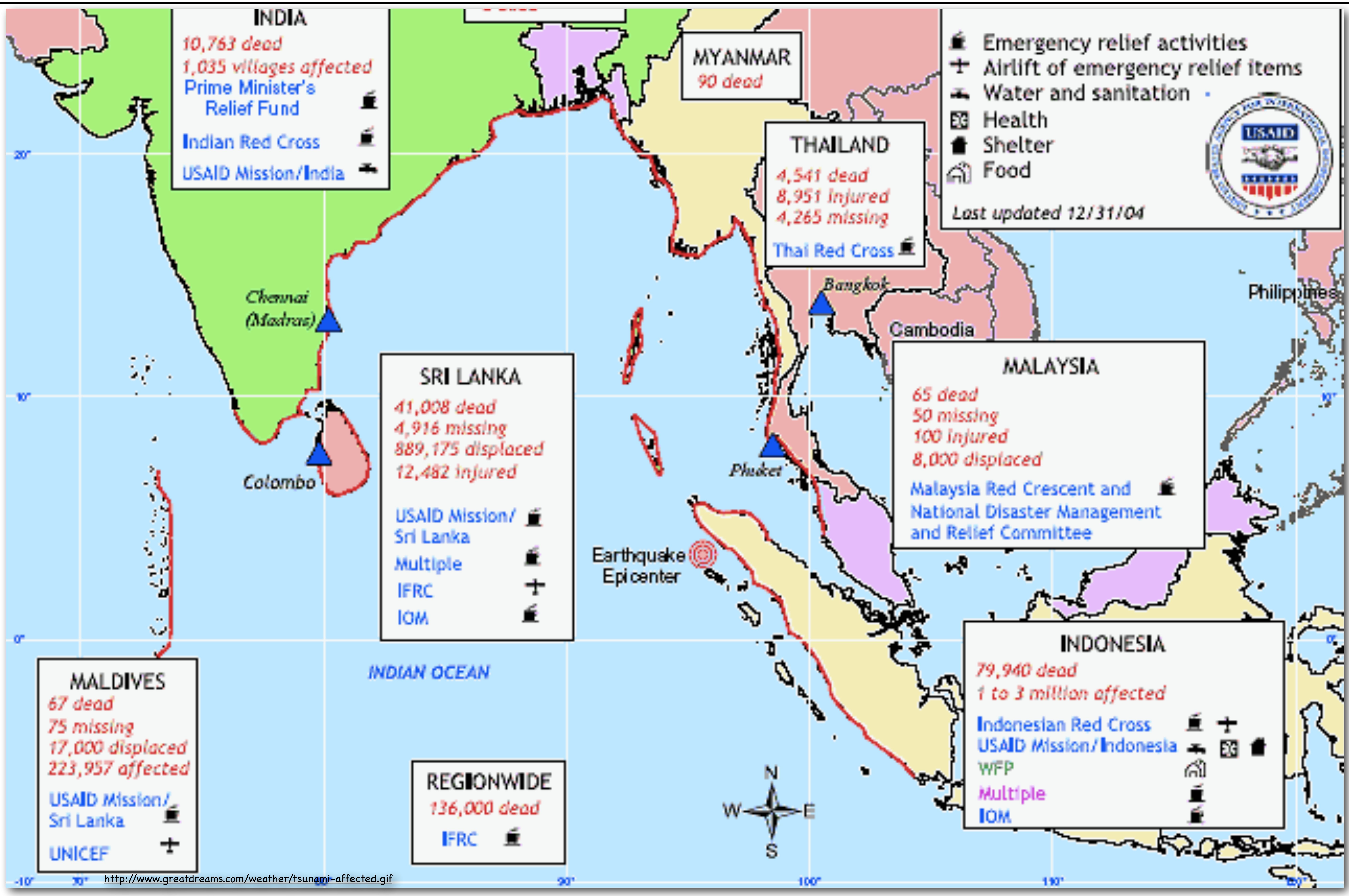


Banda Aceh

http://img.photobucket.com/albums/v199/pekar/banda_aceh_tsunami.jpg

almost total destruction in some areas

Earthquake Tsunamis



280,000 killed, millions made homeless

Natural Hazards and Disaster

Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Waves
- Tsunamis
- Earthquake Tsunamis
- <u>Landslide Tsunamis</u>
- Tsunami Detection, Prediction and Awareness

"Harbor Wave" 津波

Katsushika Hokusai (1760–1849)

Why are submarine landslide tsunamis extreme?

- The landslides
  - May occur "anywhere" on the continental margins, also on very gentle slopes
  - Have extreme volumes, velocities, and travel distances
  - "Unpredictable" ⇒ Unprepared ⇒ Extreme consequences

The 8200 BP Storegga slide
Volume: 2400 km^3
Max speed: 35 m/s
Run-out distance: 150 (800) km

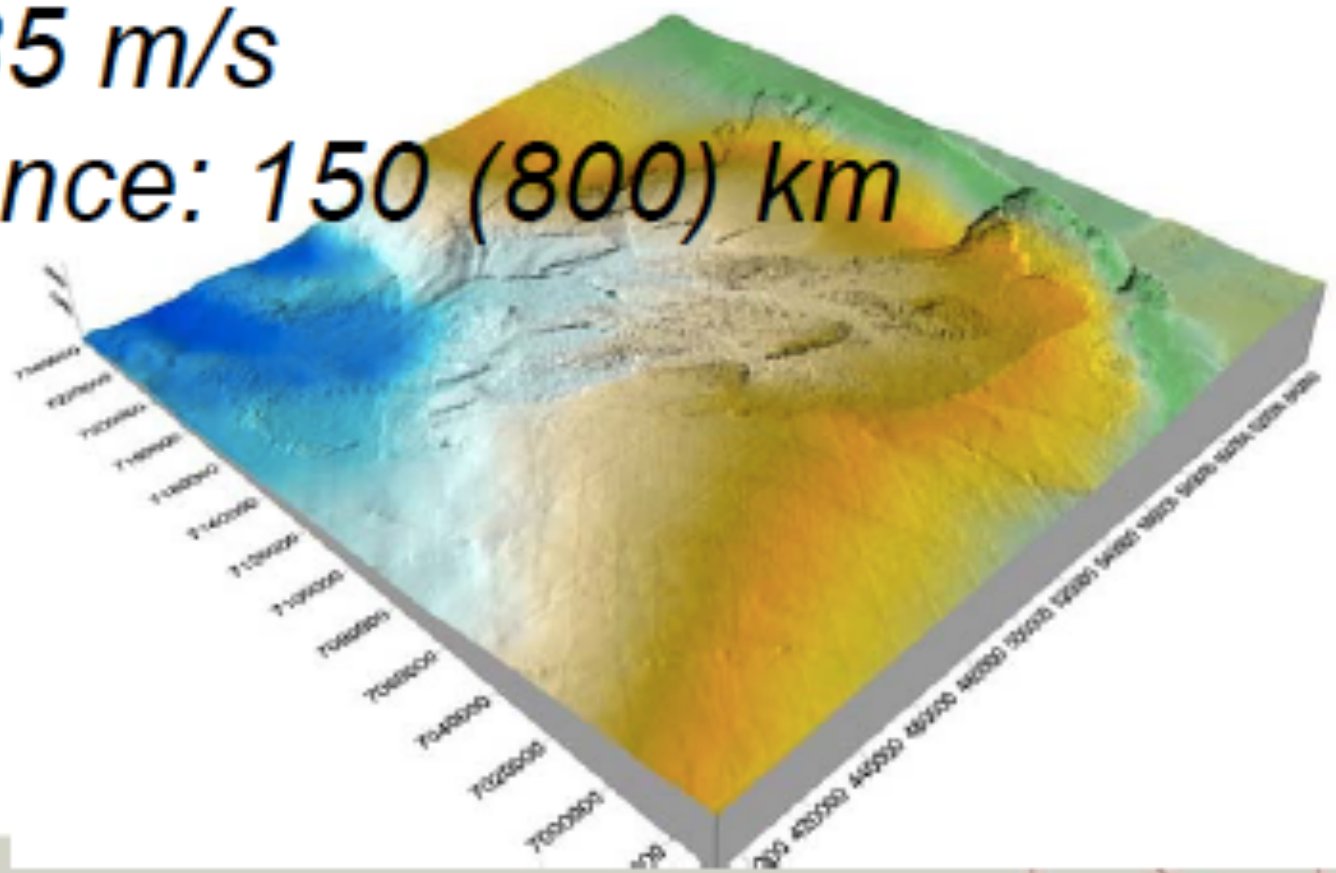
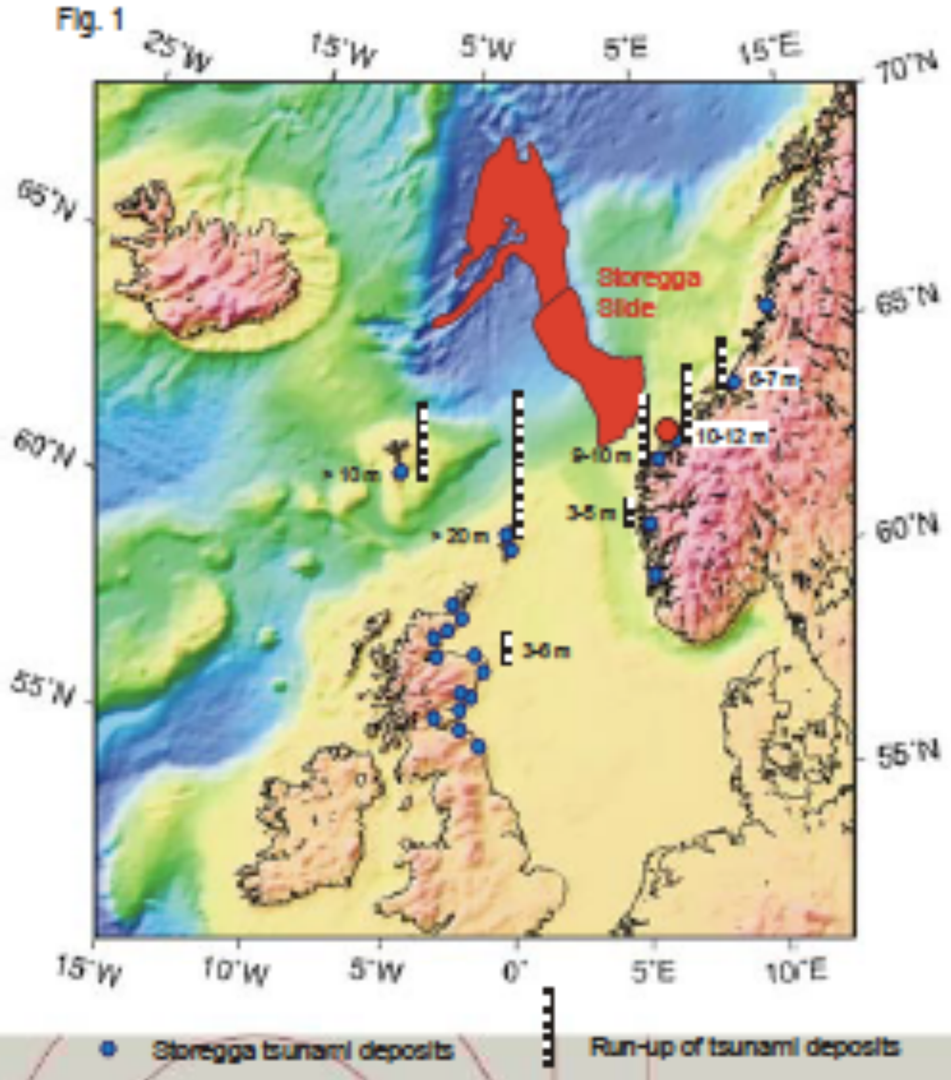


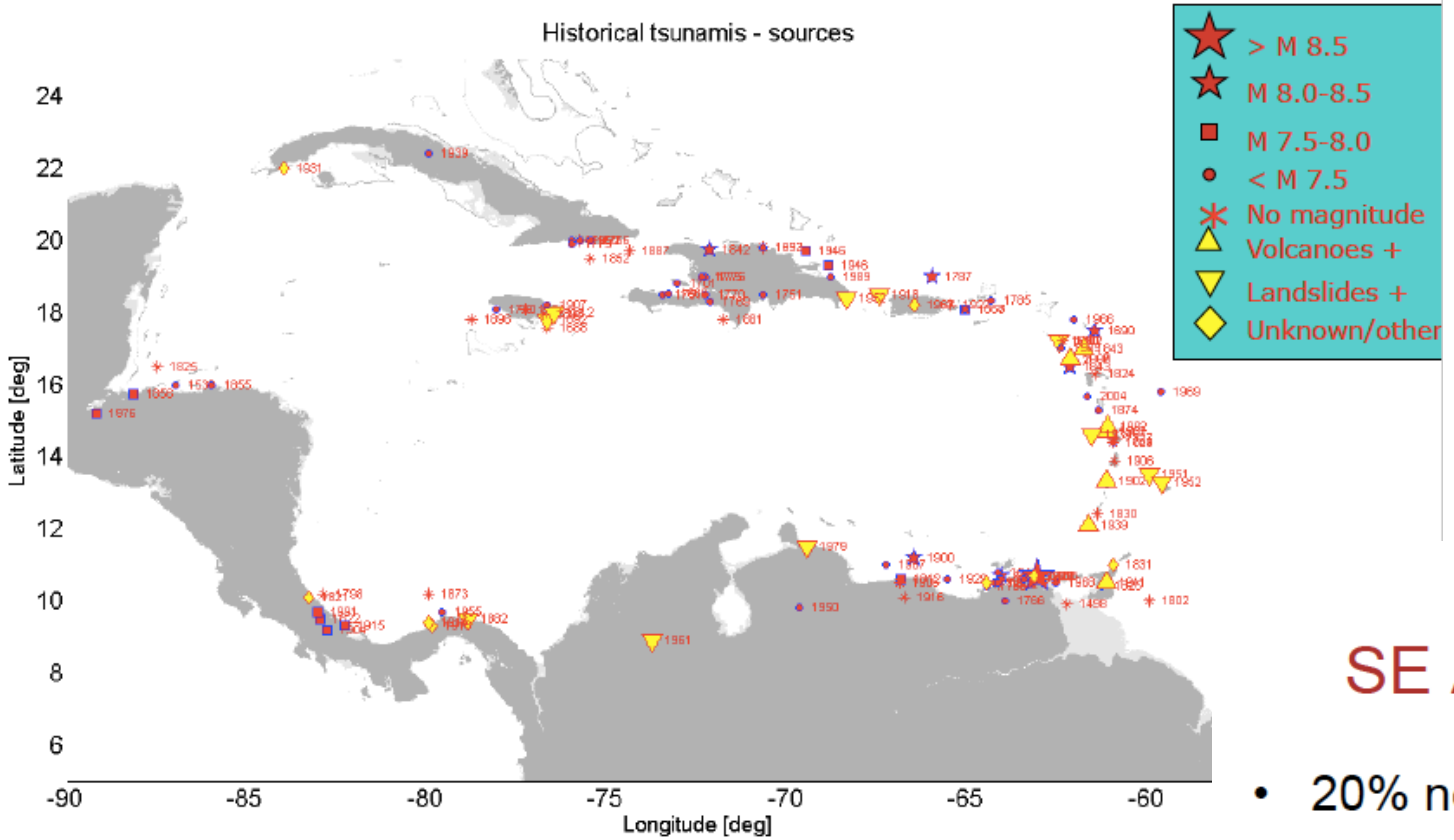
Fig. 1



http://www.geohazcop.org/workshops/Sant_Feliu_2011/

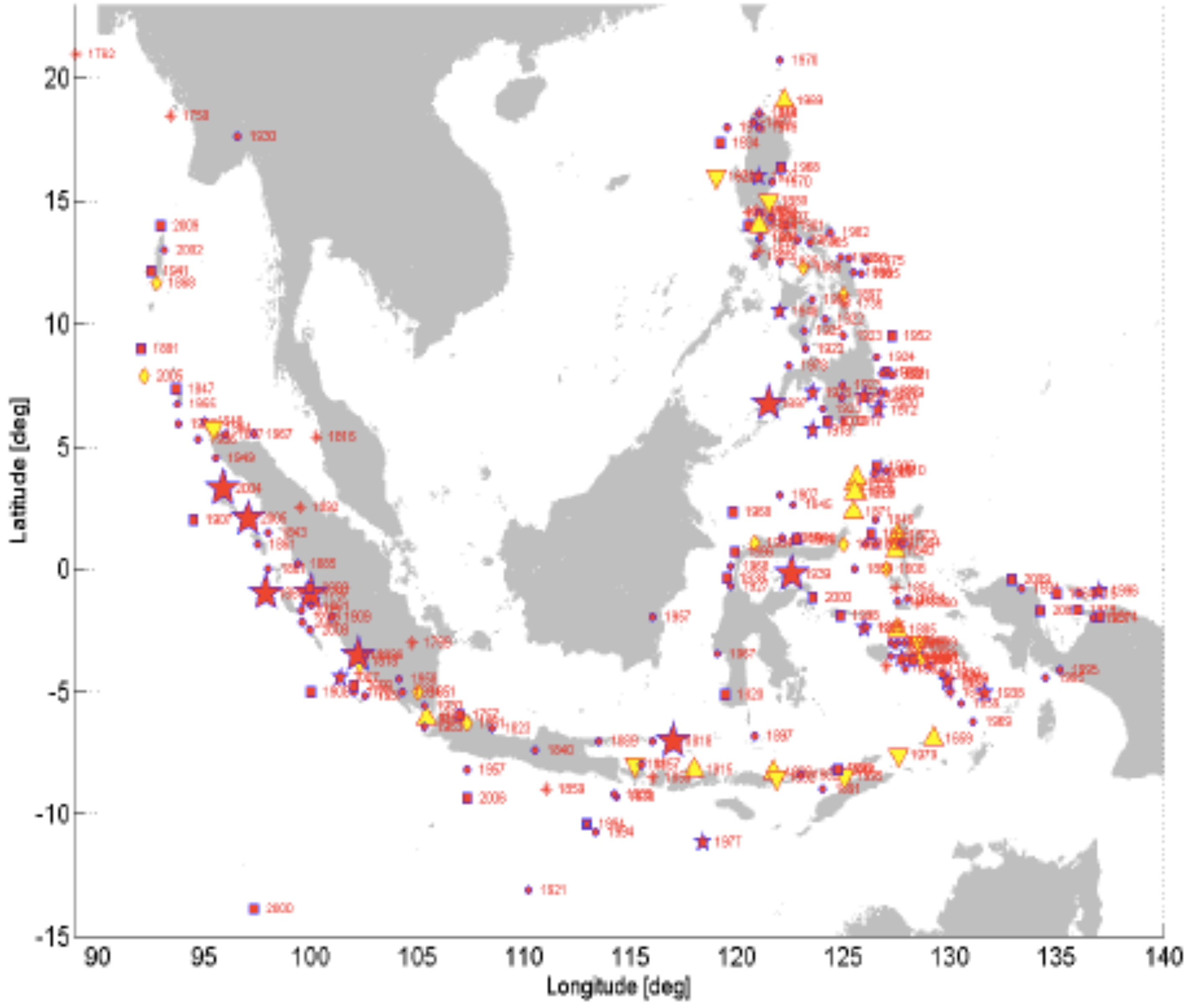
Landslide Tsunamis

Source location for all recorded tsunamis in the Caribbean – first data from year 1498



SE Asia

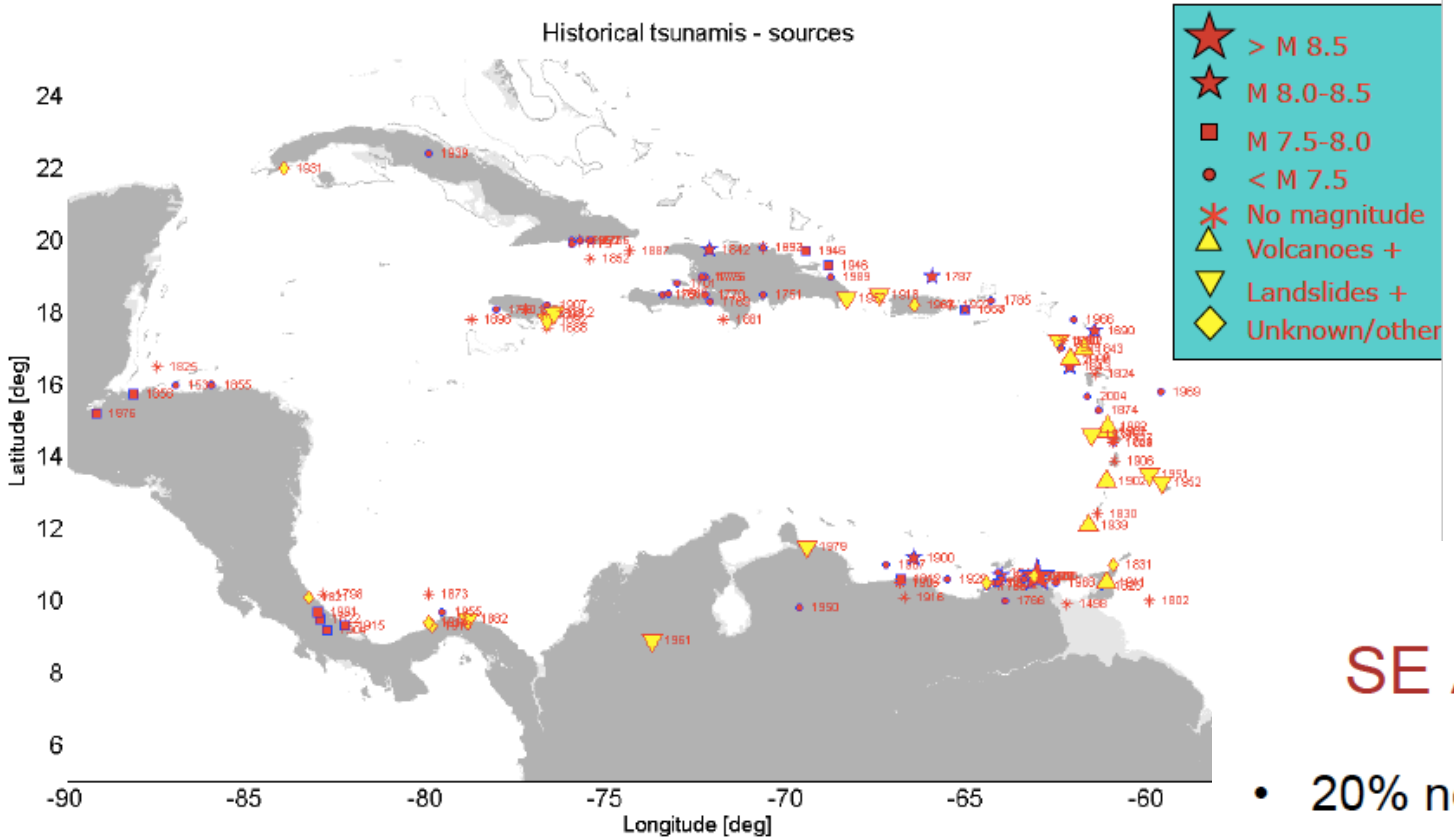
- 20% non-seismic
- ca. 2/3 are volcanic
- and 1/3 landslides, also combined with earthquakes

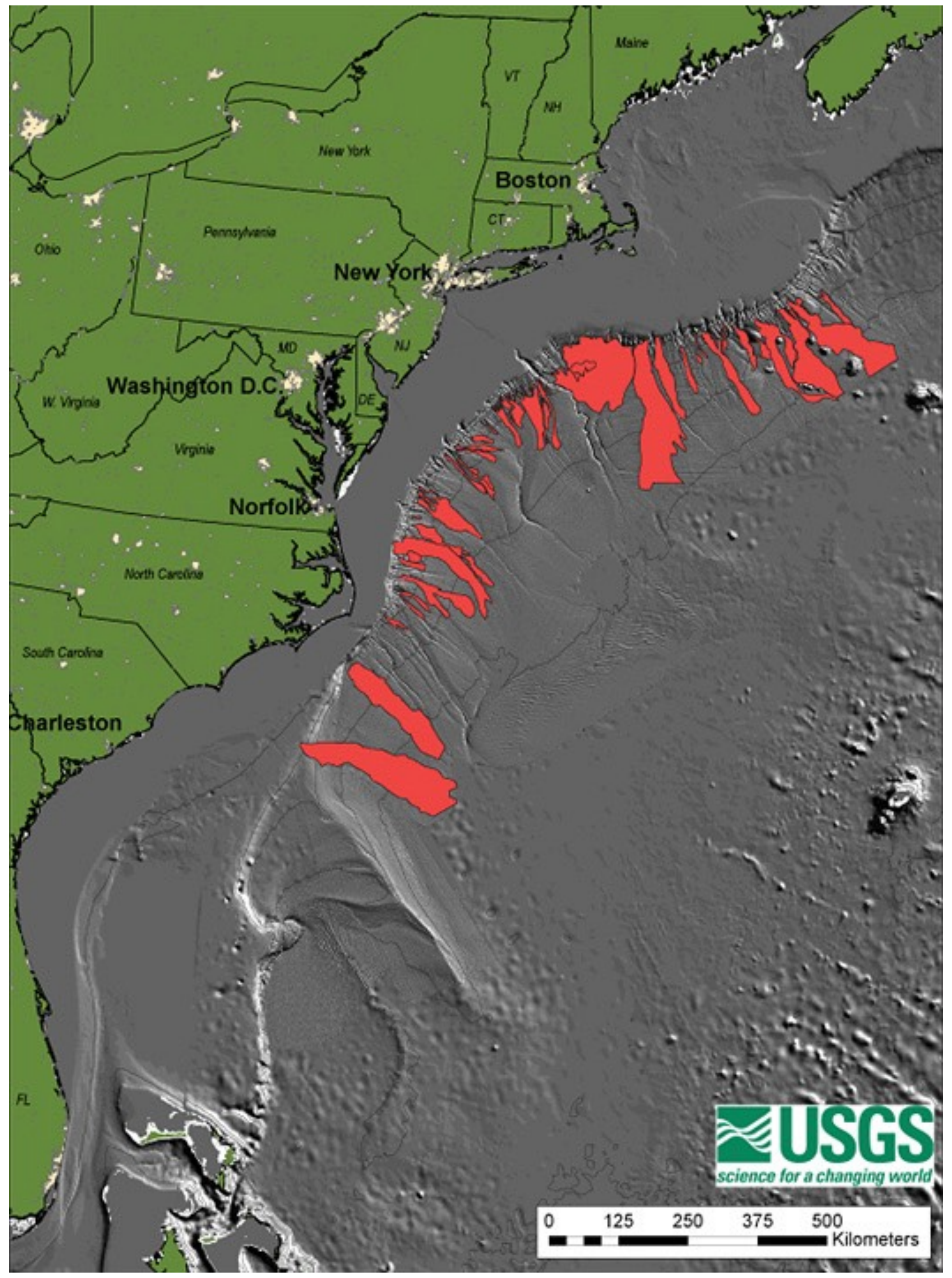


http://www.geohazcop.org/workshops/Sant_Feliu_2011/

Landslide Tsunamis

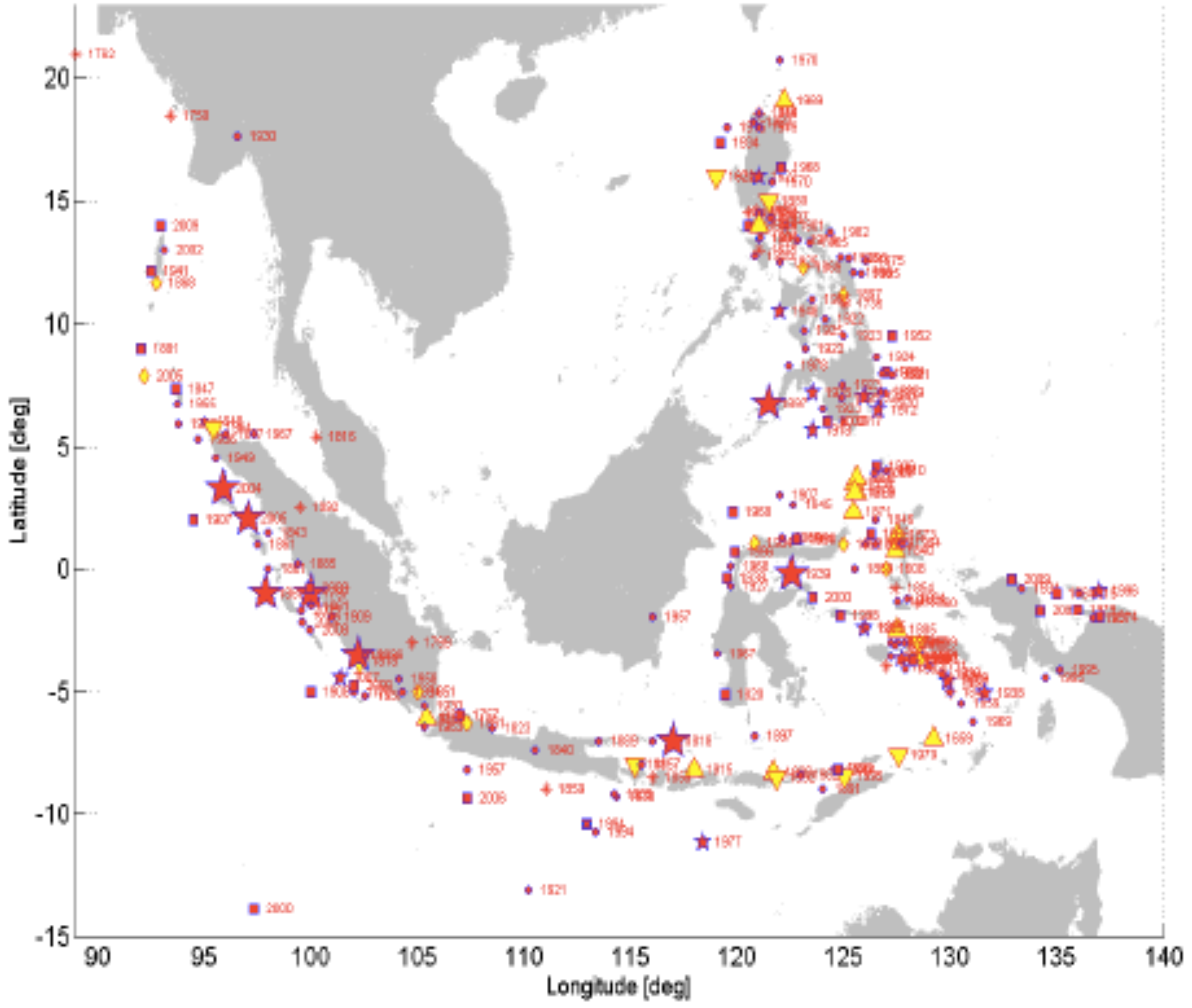
Source location for all recorded tsunamis in the Caribbean – first data from year 1498





SE Asia

- 20% non-seismic
- ca. 2/3 are volcanic
- and 1/3 landslides, also combined with earthquakes



http://www.geohazcop.org/workshops/Sant_Feliu_2011/

What about La Cumbre Vieja volcano, La Palma?

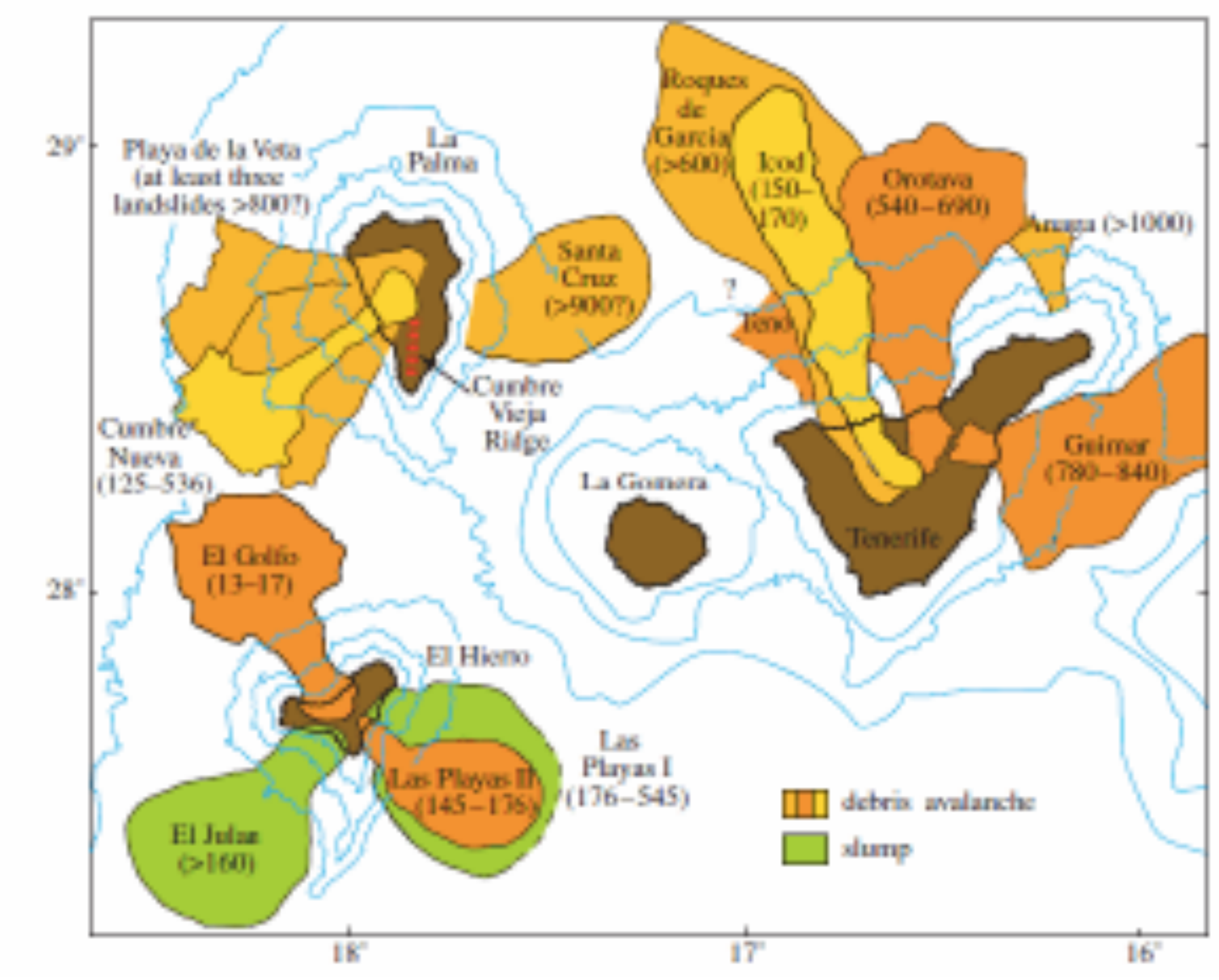
Ward & Day 2001: Great danger to US East Coast

Wynn & Masson 2003: Danger greatly overestimated - slide volume likely much smaller

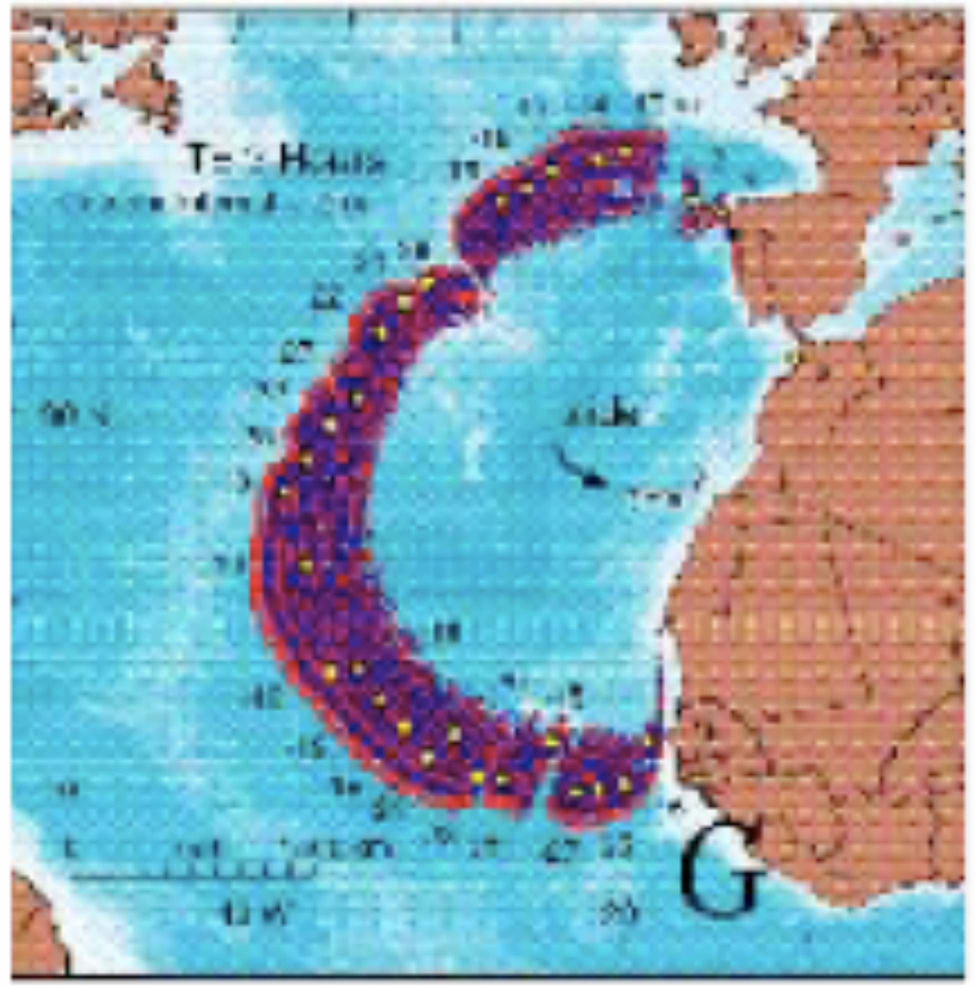
Gisler, Weaver & Gittings 2006: Even with maximal slide, danger to US minimal

Løvholt, Pedersen & Gisler 2008: Maximal slide constitutes some danger to US East coast, severe danger to shores of Europe and Africa

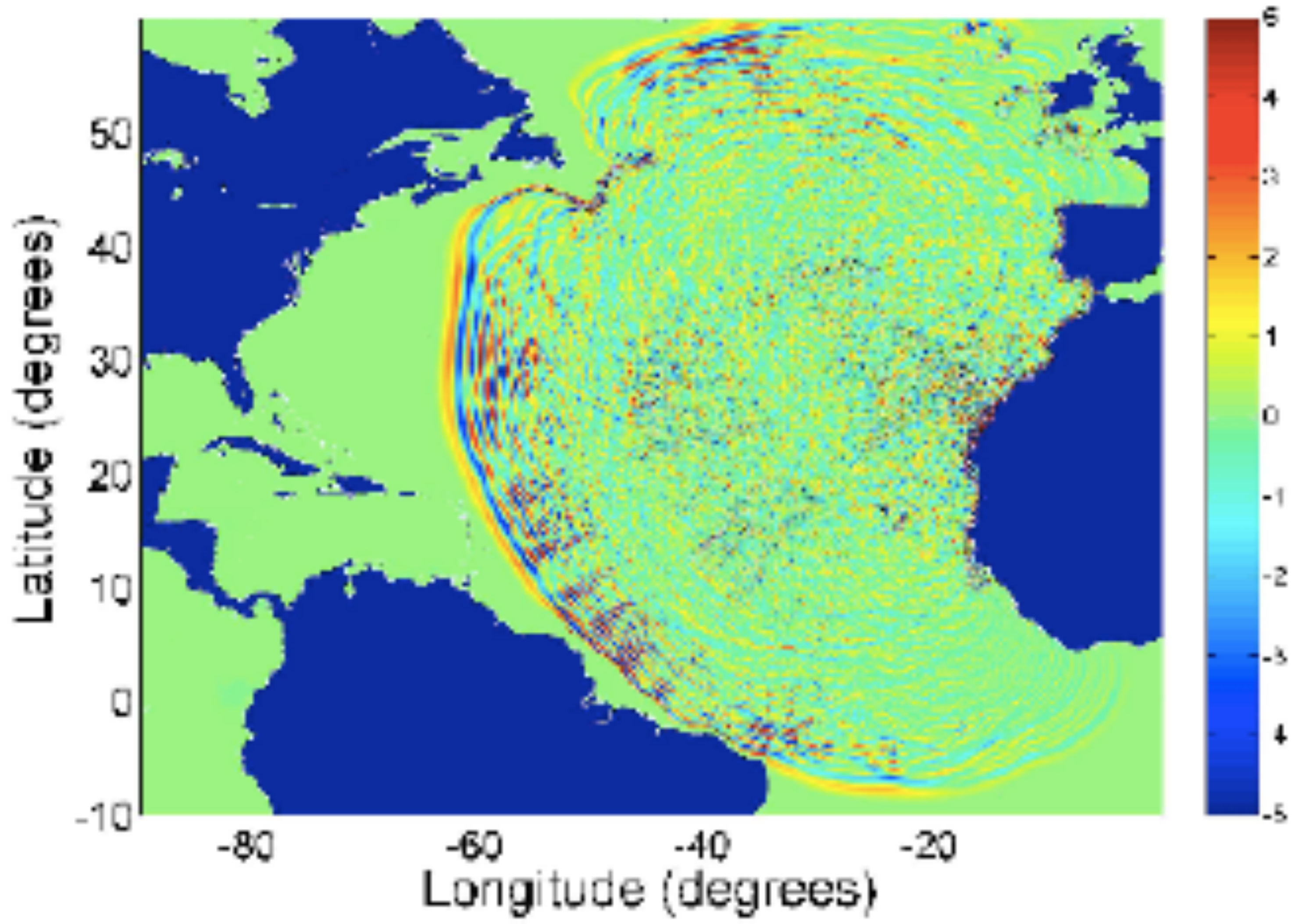
- **Need to look closer at realistic slide scenarios for La Palma**



BGS 2009



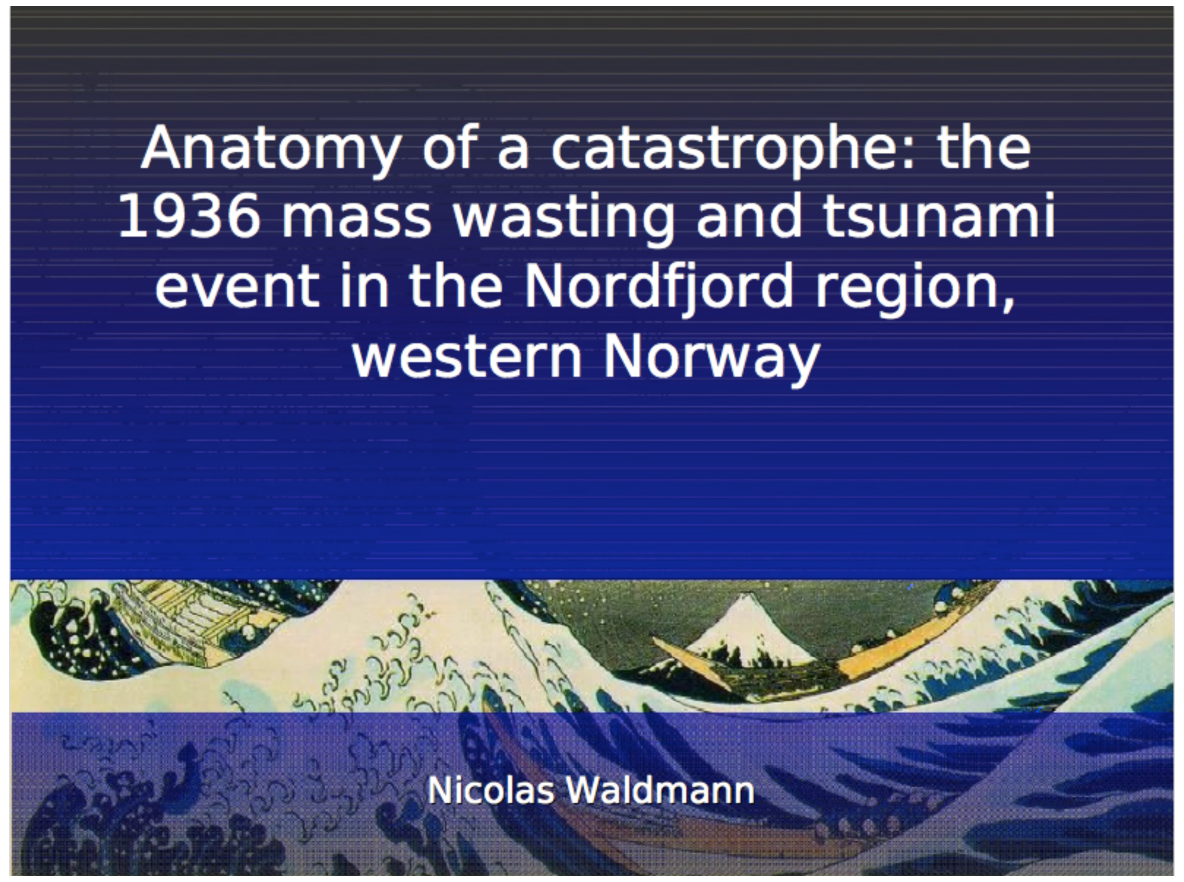
Ward & Day 2001

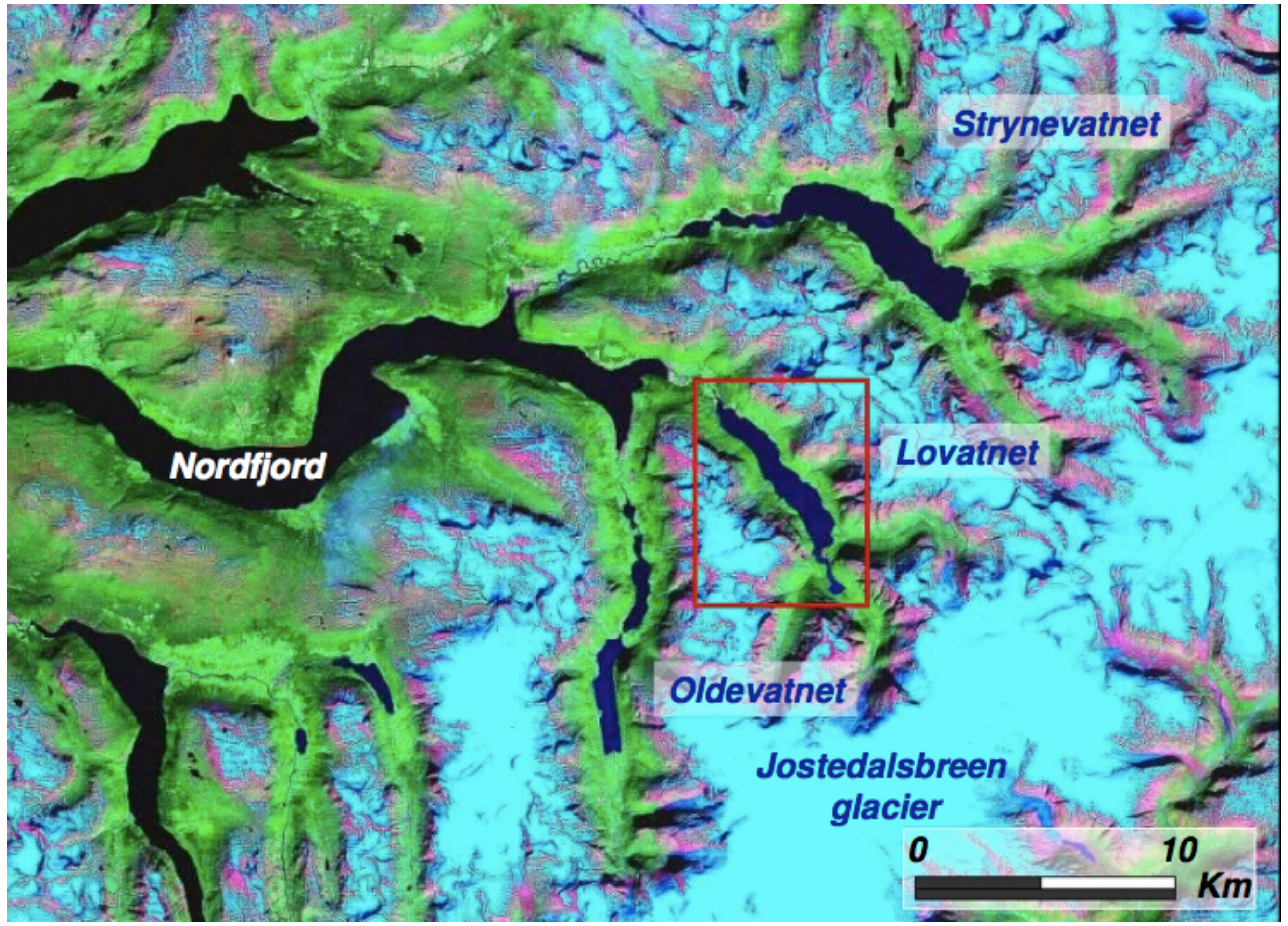


Løvholt, Pedersen & Gisler 2008

http://www.geohazcop.org/workshops/Sant_Feliu_2011/

Landslide Tsunamis

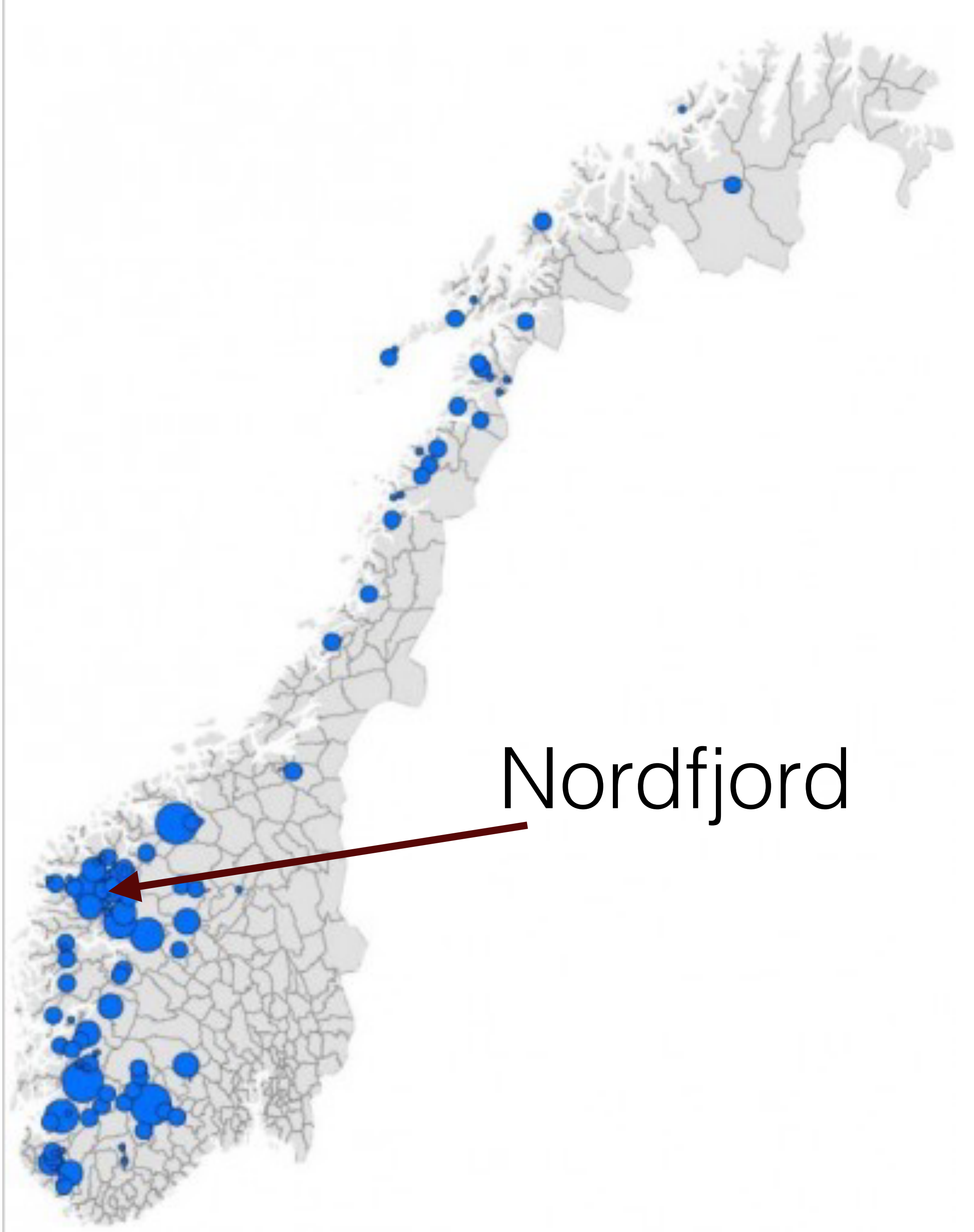




20th century rock fall records in Lovatnet

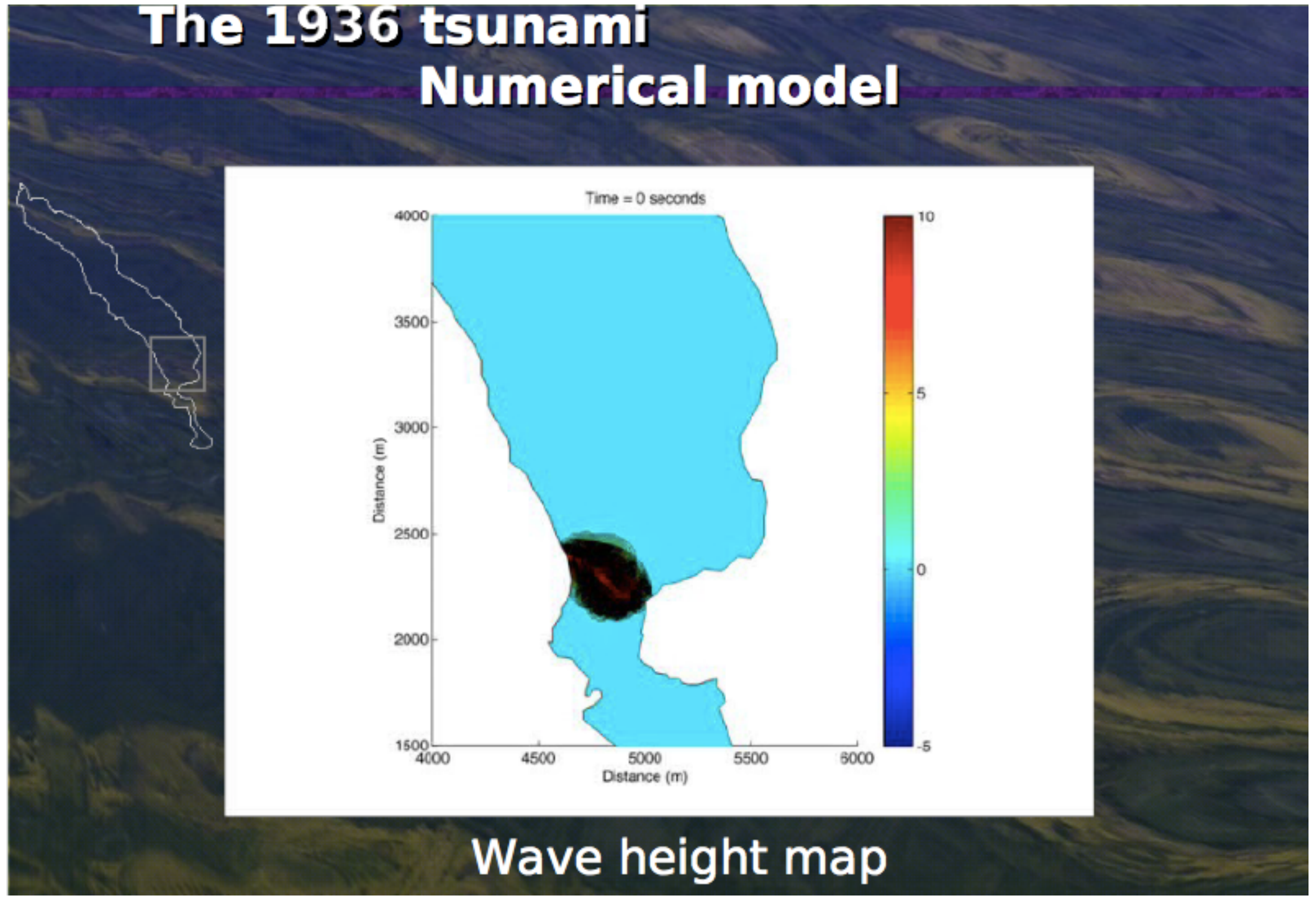
Date	Volume rock (m³)	Fallout (m asl)	Maximum run-up (m)	No. of casualties
15.01.1905	50,000	500	40.5	61
20.09.1905	ca. 15,000	400	>15	0
13.09.1936	1 million	800	74.2	74
21.09.1936	ca. 100,000	800	ca. 40	0
06.10.1936	?	800	?	0
11.11.1936	>1 million	800	>74	0
22.06.1950	ca. 1 million	800	ca. 15	0

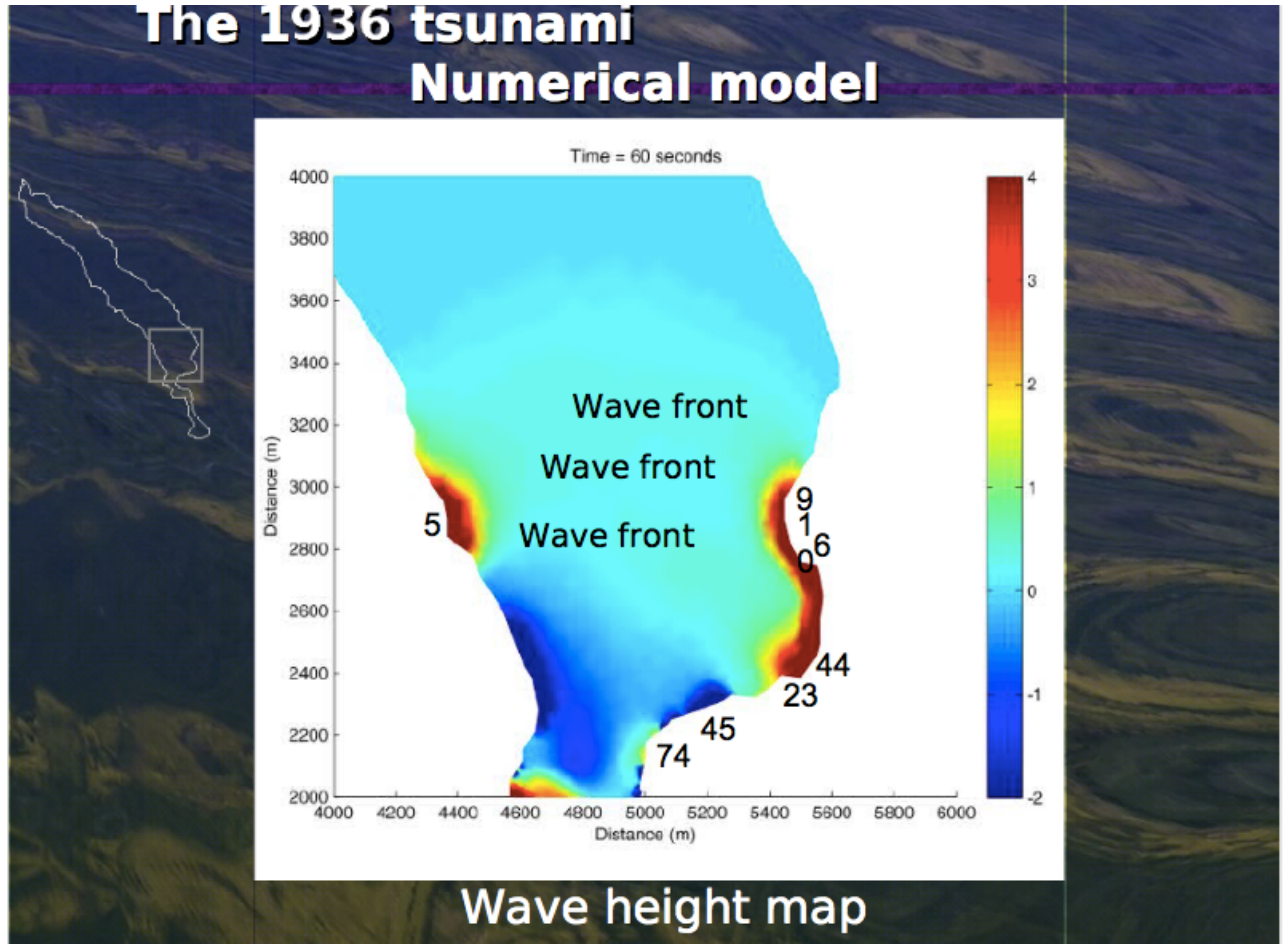
Based on Grimstad and Nesdal (1991)



Location of 100 most tsunami-threatened lakes

http://theforeigner.no/pages/columns/just-when-you-thought-it-was-safe-to-go-back-into-the-fjord/

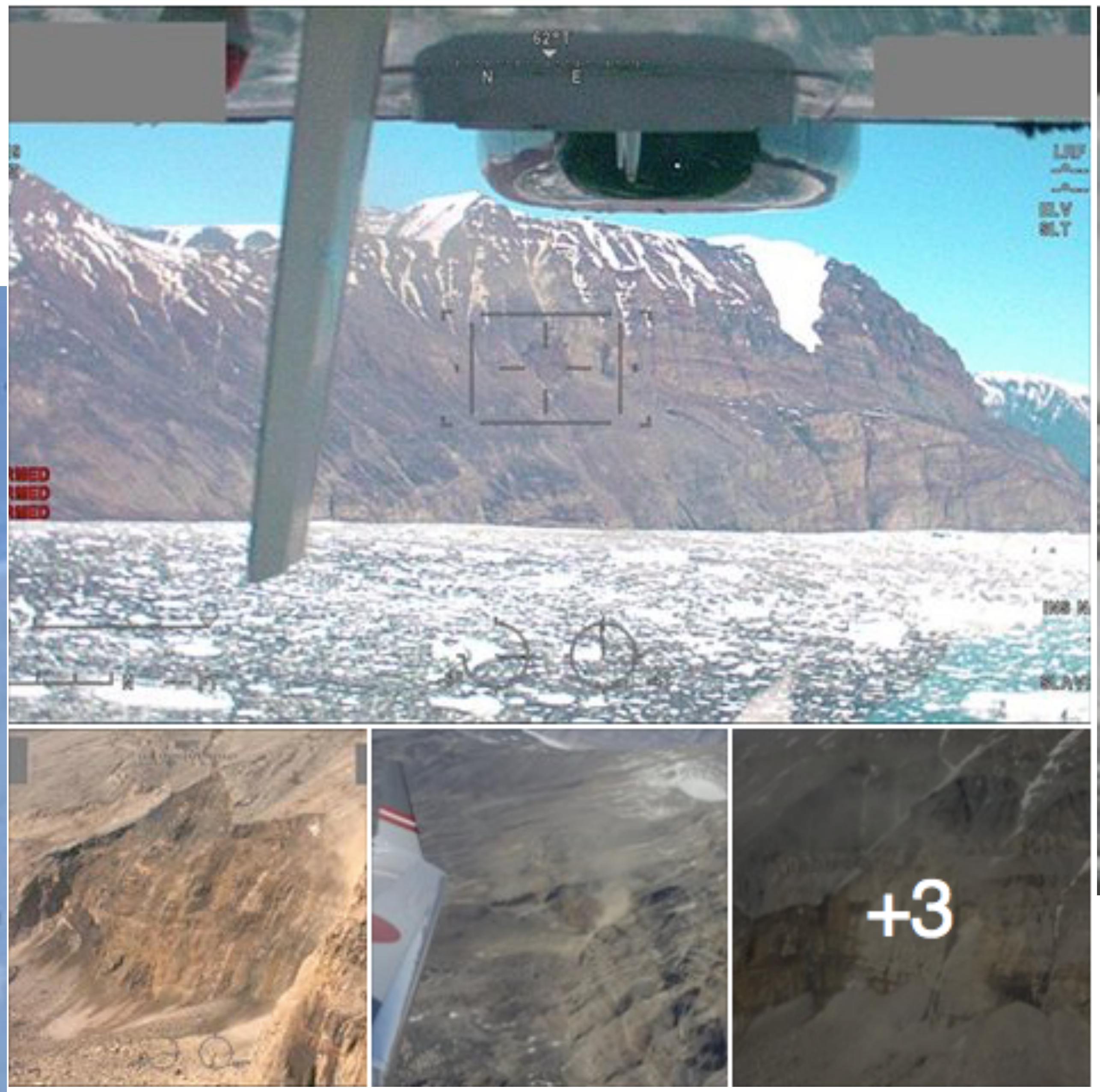


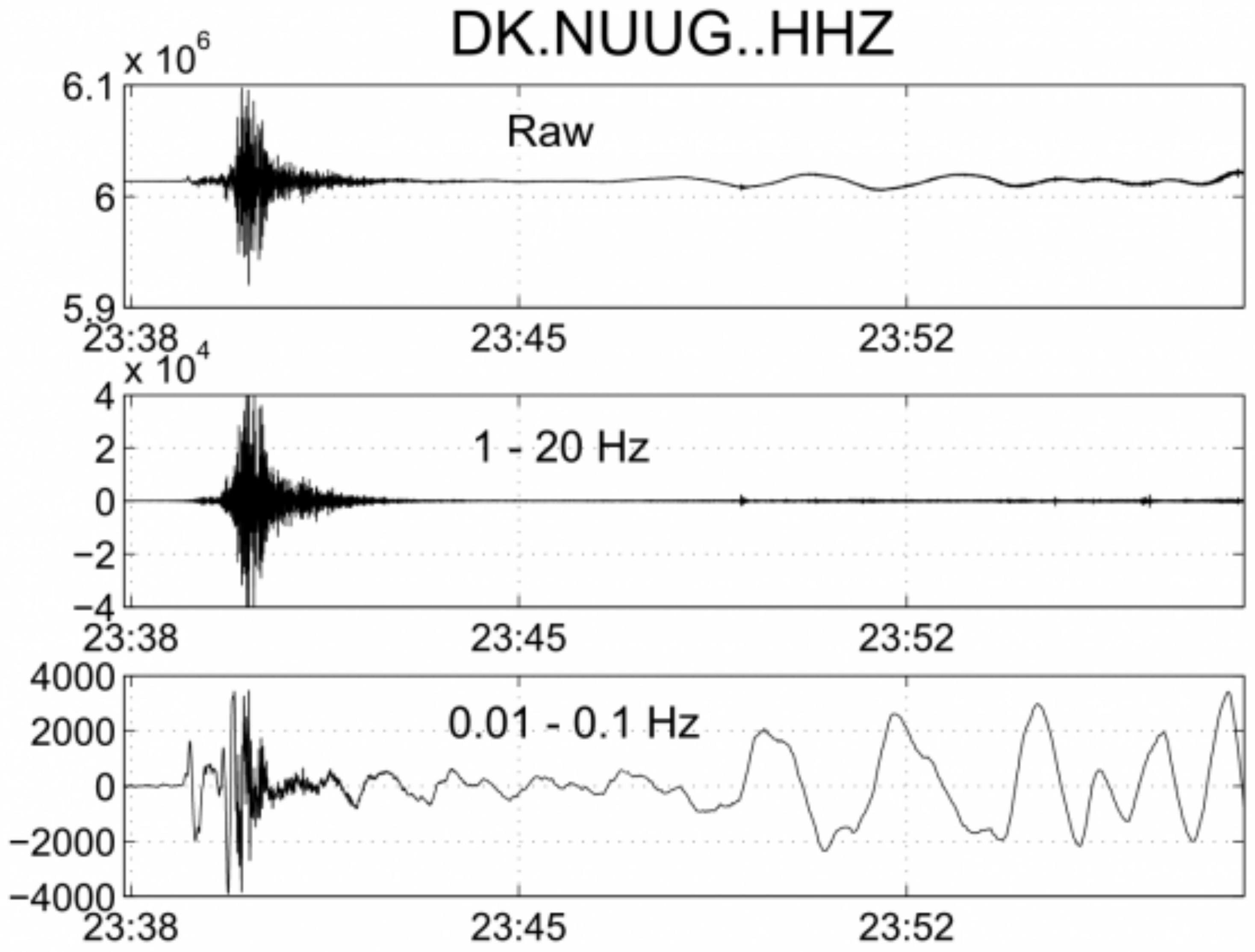


http://www.academia.edu/446006/Anatomy_of_a_catastrophe_the_1936_mass_wasting_and_tsunami_event_in_the_Nordfjord_region_western_Norway

Landslide Tsunamis

Greenland, June 17 2017





The tsunami hit the village of Nuugaatsiaq just after 23:00 local time on June 17 (01:00 UTC on June 18), sweeping away 11 houses and leaving 4 people dead and 9 injured, 2 of them seriously.

http://www.johnenglander.net/sea-level-rise-blog/tsunami-caused-by-greenland-landslide/
https://watchers.news/2017/06/21/greenland-landslide-tsunami-june-2017/

Natural Hazards and Disaster

Class 5: Disasters Triggered by Earthquakes and Tsunamis

- Waves
- Tsunamis
- Earthquake Tsunamis
- Landslide Tsunamis
- (Tsunami Detection, Prediction and Awareness)

"Harbor Wave"

津波

Katsushika Hokusai (1760–1849)

See Class 6