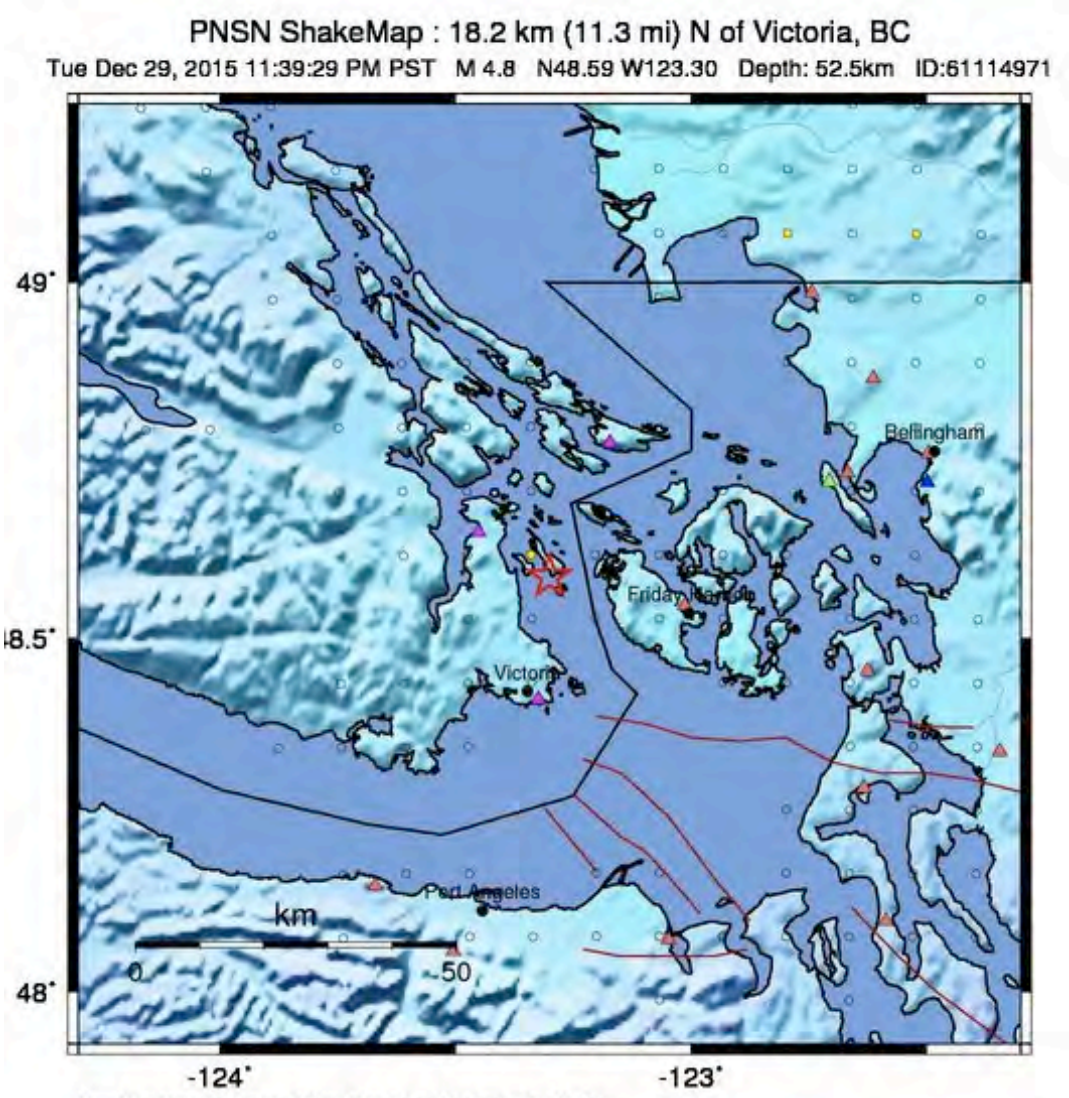
Dec 29 2015 Mag 4.8 Earthquake

Tuesday, 11:39 PM local time

Located 17 km NNE of Victoria
(80 km south of UBC)

"Deep" intraslab earthquake
at 52 km depth

Felt across southern Vancouver Island and Lower Mainland
No significant damage
No casualties



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+

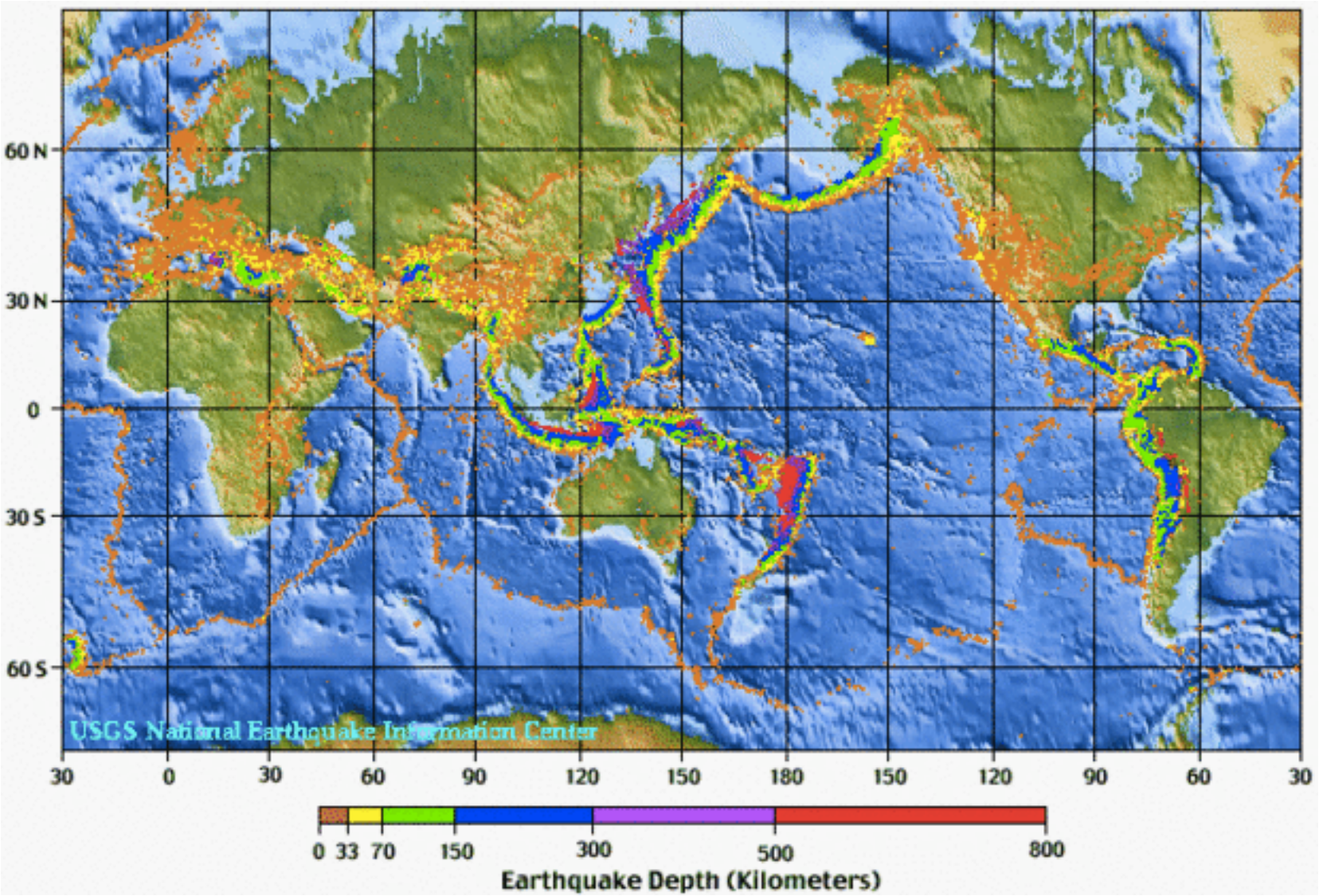
Scale based upon Worden et al. (2011)

Earthquakes occur every day:
http://earthquake.usgs.gov/earthquakes/map/

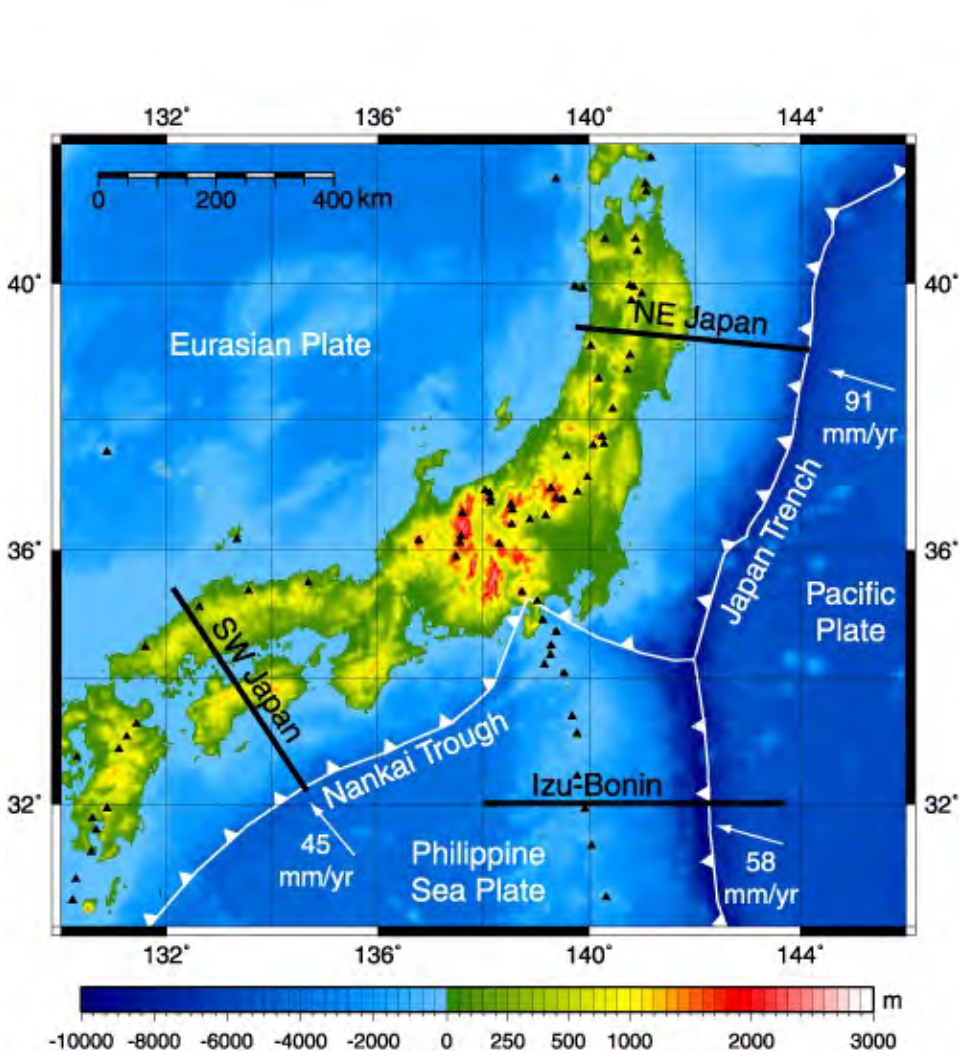
Descriptor	Magnitude	Average Annually
Great	8 and higher	1**
Major	7 - 7.9	15**
Strong	6 - 6.9	134*
Moderate	5 - 5.9	1319*
Light	4 – 4.9	13,000
Minor	3 – 3.9	130,000
Very Minor	2 – 2.9	1,300,000

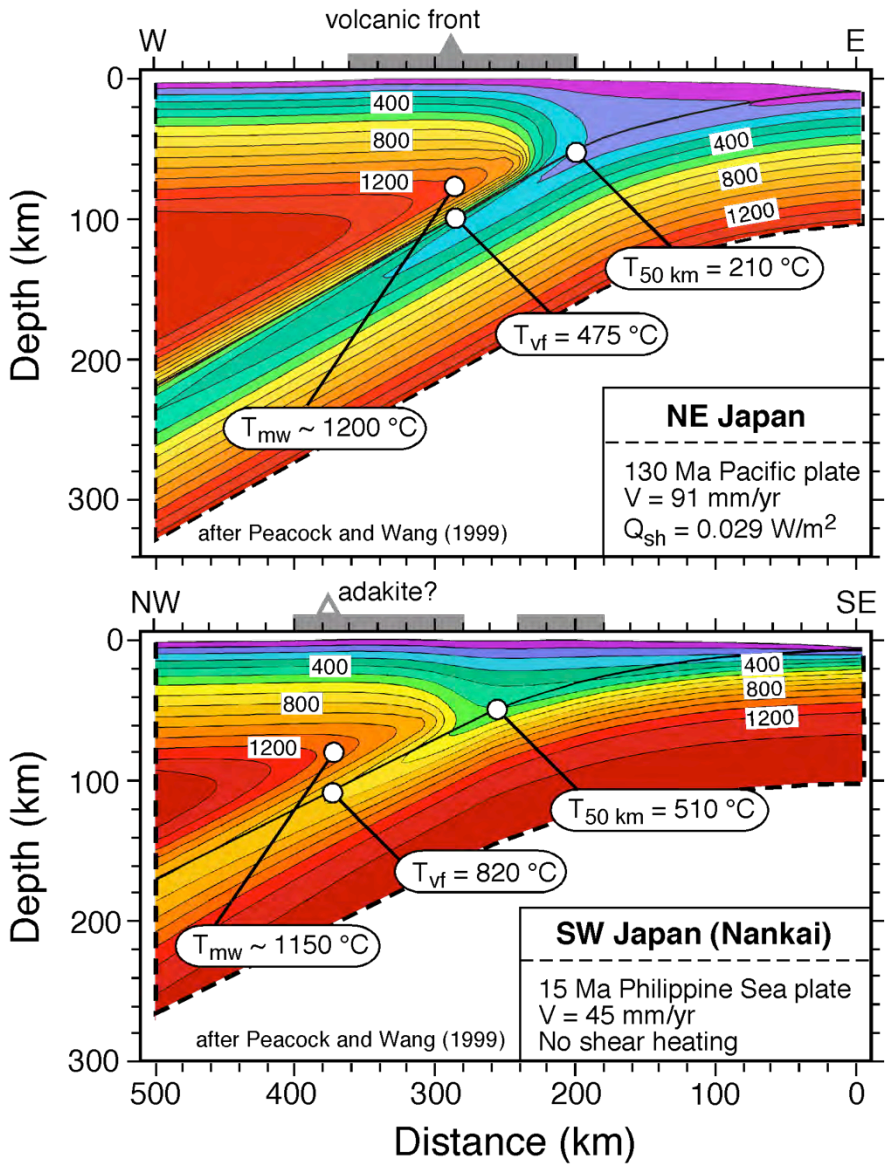
** *Based on observations since 1900*
* *Based on observations since 1990*

Global seismicity 1975-1995



USGS National Earthquake Information Center





after Peacock and Wang (1999, Science)

USA TODAY · FRIDAY, OCTOBER 29, 1999 · 3A

Different sort of quake may hit Northwest

Seattle-Tacoma area at special risk

By Patrick McMahon
USA TODAY

SEATTLE — California and Alaska don't have a monopoly on earthquakes along the West Coast. Authors of a new study are highlighting special hazards in the Pacific Northwest.

In particular, says a study in today's *Science* magazine, the geology beneath Seattle and Vancouver, British Columbia, makes the region especially susceptible to the kind of quake that killed 27 people Sept. 30 in Oaxaca, Mexico.

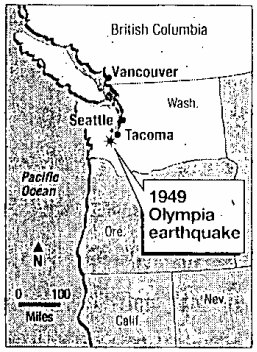
Most Americans are familiar with the shakers, common in California, that rupture the earth's surface along fault lines. The Mexican quake was a less-understood "intraslab" quake, a type that usually occurs on faults deeper in the earth's surface: 30 to 185 miles below ground.

Intraslab earthquakes occur when underground heat and pressure cause minerals to change and to shrink, producing stress along deep underground faults.

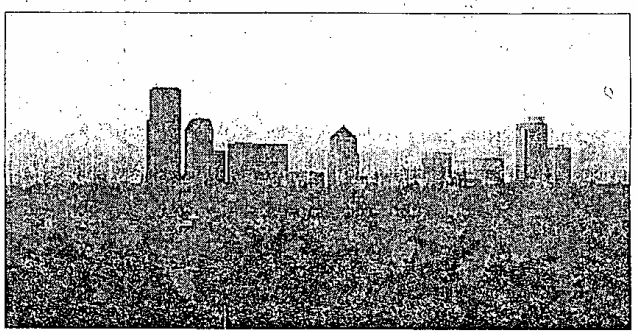
It's long been known that a large earthquake could happen in the Northwest in an offshore trench that runs from British Columbia to northern California. A smaller zone that includes the densely populated Seattle-Tacoma area, as well as Olympia, Wash., and Vancouver, might be in even greater peril from the more frequent intraslab quakes, according to the study's authors.

The Northwest's two worst quakes this century were of this kind. A 7.1-magnitude intraslab quake near Olympia, Wash., in 1949 killed eight people and caused $100 million in property damage. A 6.5-magnitude intraslab quake below Seattle-Tacoma International Airport in 1965 killed seven and caused $50 million in damage.

Simon Peacock, chairman of the geology department at Arizona State University and co-author of the *Science* study, says, "We're starting to realize that we have to worry about a magnitude-7-to-7.5 intraslab earthquake located 31 miles beneath Seattle or Vancouver, as well as a magnitude 8 or 9 out on the coast."



USA TODAY


By Barry Sweet, AP

Seattle: 'We have to worry about a magnitude-7-to-7.5 intraslab earthquake located 31 miles beneath Seattle or Vancouver,' geologist Simon Peacock says.

Peacock, who collaborated with Kelin Wang, a geoscientist at the Geological Survey of Canada's Pacific Geoscience Centre, also says, "The risks posed by intraslab earthquakes have not been fully incorporated into seismic hazard analysis. In the Pacific Northwest, these less easily understood earthquakes occur closer to major population centers than the larger offshore earthquakes. The historic record bears this out."

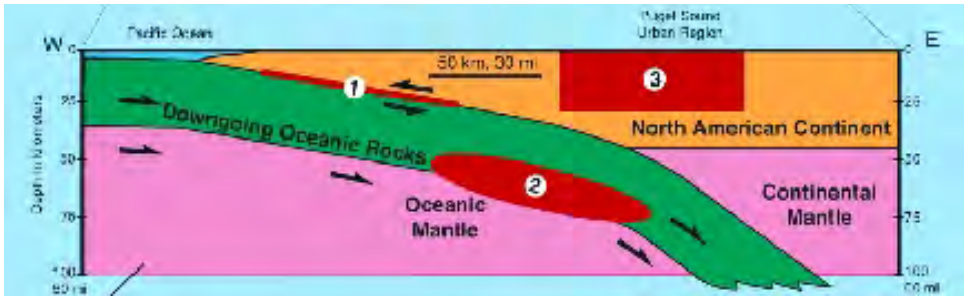
Chris Jonientz-Trisler, a geologist and manager of the Federal Emergency Management Agency's regional earthquake program, says major intraslab quakes "occur roughly every generation or two."

Not all intraslab quakes cause damage: A 5.5-magnitude intraslab quake struck the Olympic Peninsula west of Tacoma on July 2. There were no injuries reported.

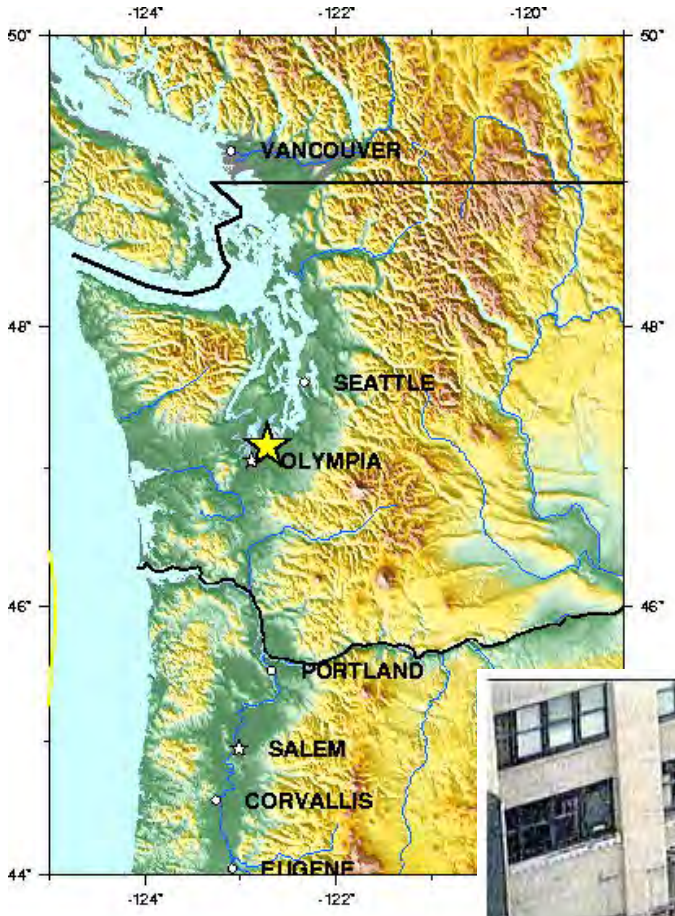
"For a long time, much more attention was focused on California," says University of Washington seismologist Ruth Ludwin. "But now, Seattle has grown so enormously that the economic losses from a large earthquake are much more significant than they were 30 years ago."

'We have to worry about a magnitude-7-to7.5 intraslab earthquake located 31 miles beneath Seattle or Vancouver.'
geologist Simon Peacock says.

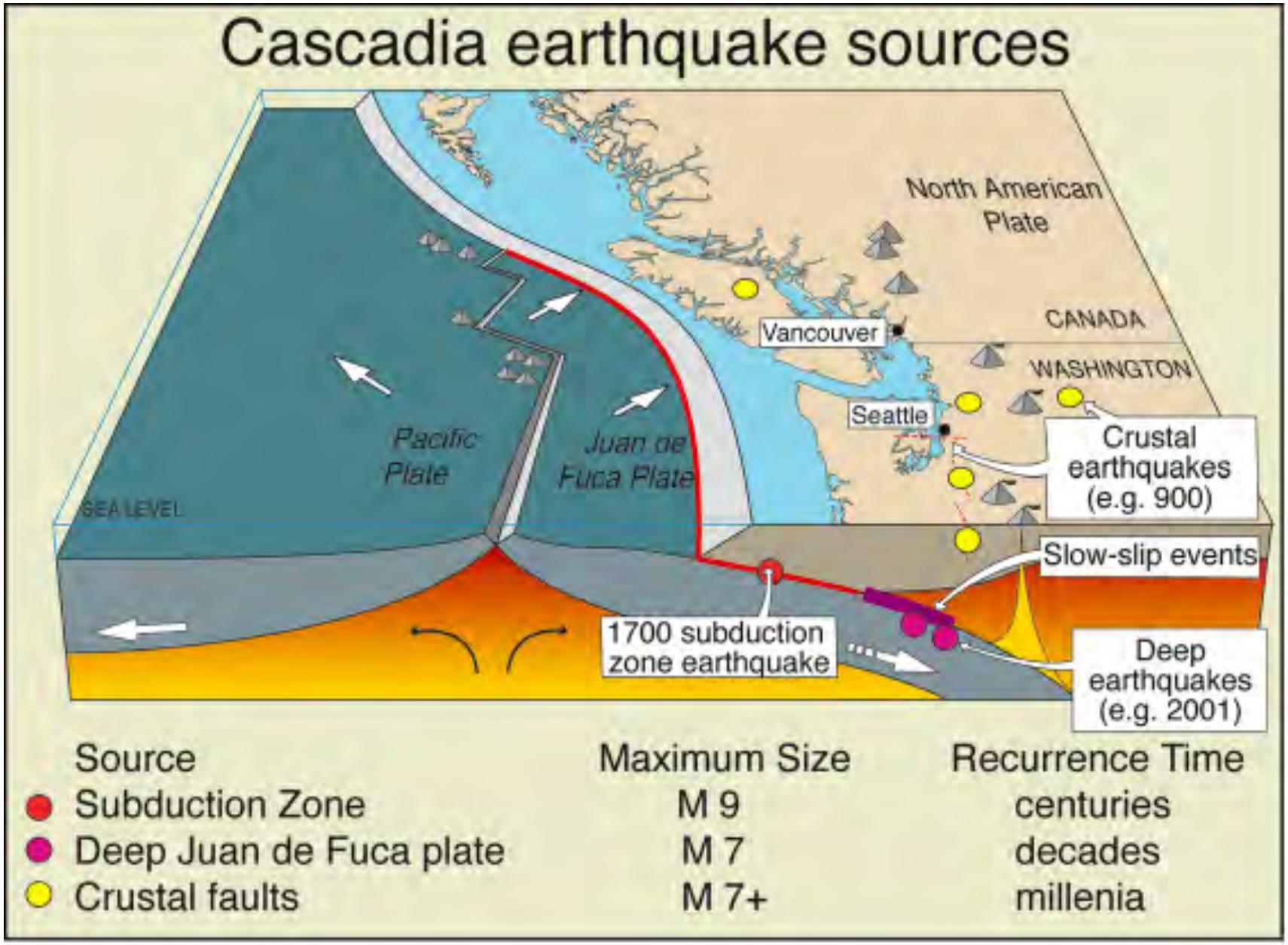
USA Today, Oct. 29, 1999



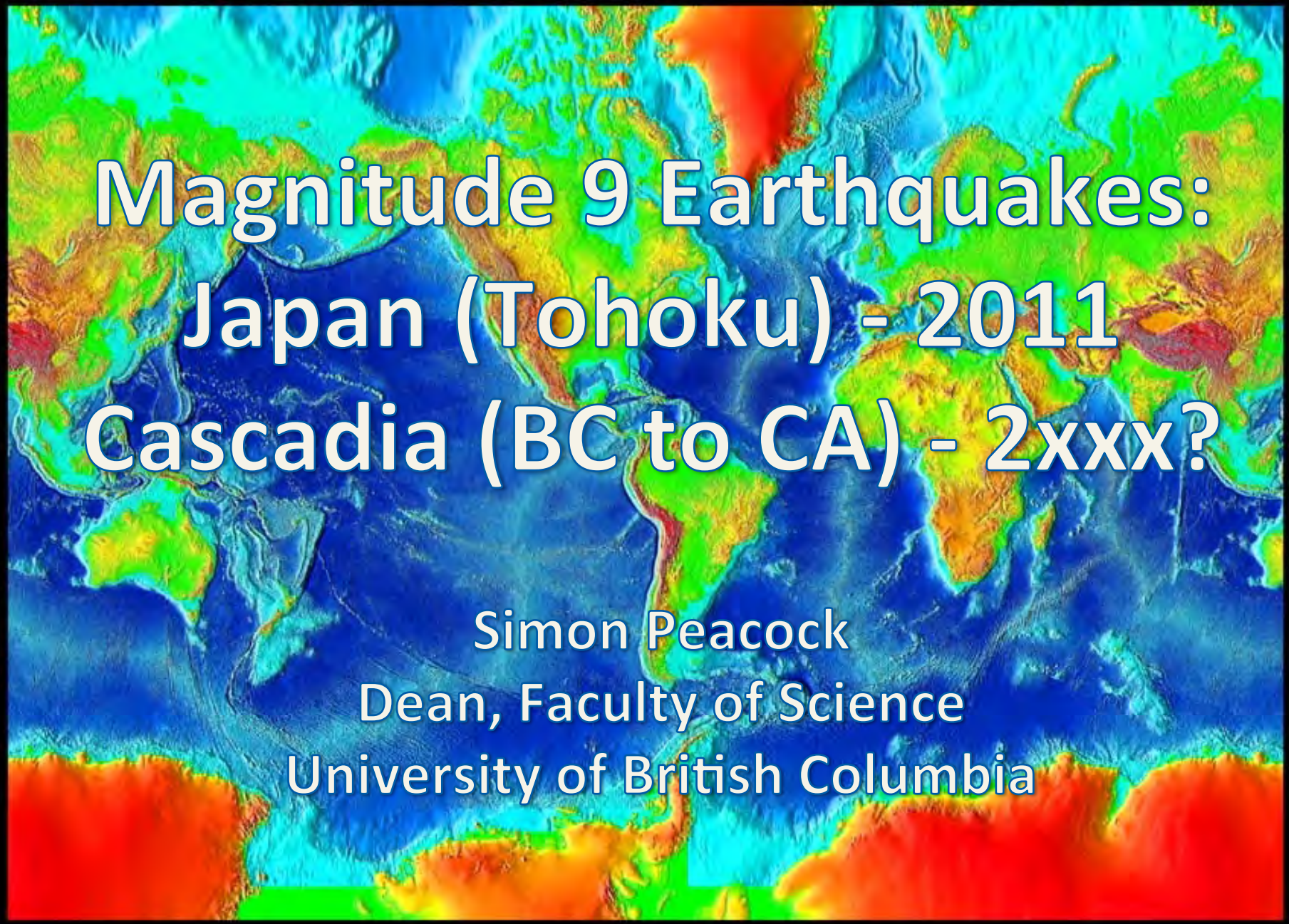
2001 Nisqually (Olympia) Earthquake



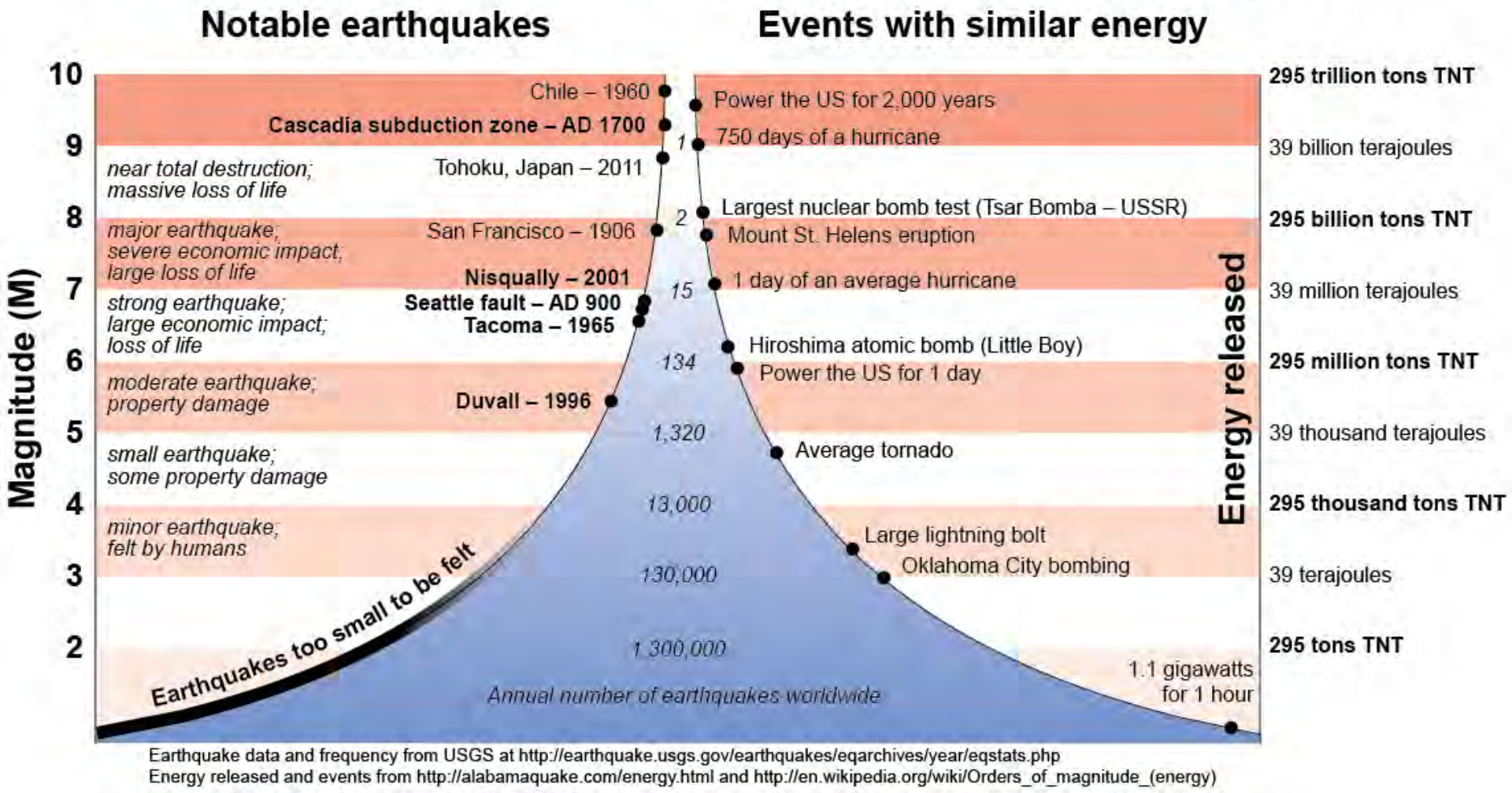
- Feb. 28, 2001, 10:55 AM
- $M_w = 6.8$
- Depth = 52 km
- Located between Tacoma and Olympia
- Up to 40 seconds of local ground shaking
- ~400 injured, 1 death
- $2+ billion damage


Cascadia earthquake sources
North American Plate
CANADA
WASHINGTON
Vancouver
Seattle
Pacific Plate
Juan de Fuca Plate
SEA LEVEL
Crustal earthquakes (e.g. 900)
Slow-slip events
1700 subduction zone earthquake
Deep earthquakes (e.g. 2001)
Source
Maximum Size
Recurrence Time
Subduction Zone
M 9
centuries
Deep Juan de Fuca plate
M 7
decades
Crustal faults
M 7+
millenia

IRIS


Magnitude 9 Earthquakes:
Japan (Tohoku) - 2011
Cascadia (BC to CA) - 2xxx?
Simon Peacock
Dean, Faculty of Science
University of British Columbia

Earthquake energy and frequency



Earthquake data and frequency from USGS at http://earthquake.usgs.gov/earthquakes/eqarchives/year/eqstats.php
Energy released and events from http://alabamaquake.com/energy.html and http://en.wikipedia.org/wiki/Orders_of_magnitude_(energy)

http://www.dnr.wa.gov

March 11, 2011

Imagine you are in Tokyo, working on your computer:

http://www.youtube.com/watch?v=n-FMpNBfna8

And then you turn on your TV:

http://www.youtube.com/watch?v=w3AdFjklR50

, Kisenuma city, Miyagi prefecture, Japan

The tsunami, seen crashing into homes in Natori, Miyagi prefecture. *AP*

Houses were washed away by tsunami in Sendai, Miyagi Prefecture in eastern Japan, after Japan was struck by a magnitude 9.0 earthquake off the northeastern coast.

New York Times

Part of houses swallowed by tsunami burn in Sendai, Miyagi Prefecture (state) after Japan was struck by a strong earthquake off its northeastern coast Friday, March 11, 2011. *New York Times*

Tsunami hitting
Sendai airport

Post-tsunami

Fukushima Daiichi nuclear power station dailymail.co.uk

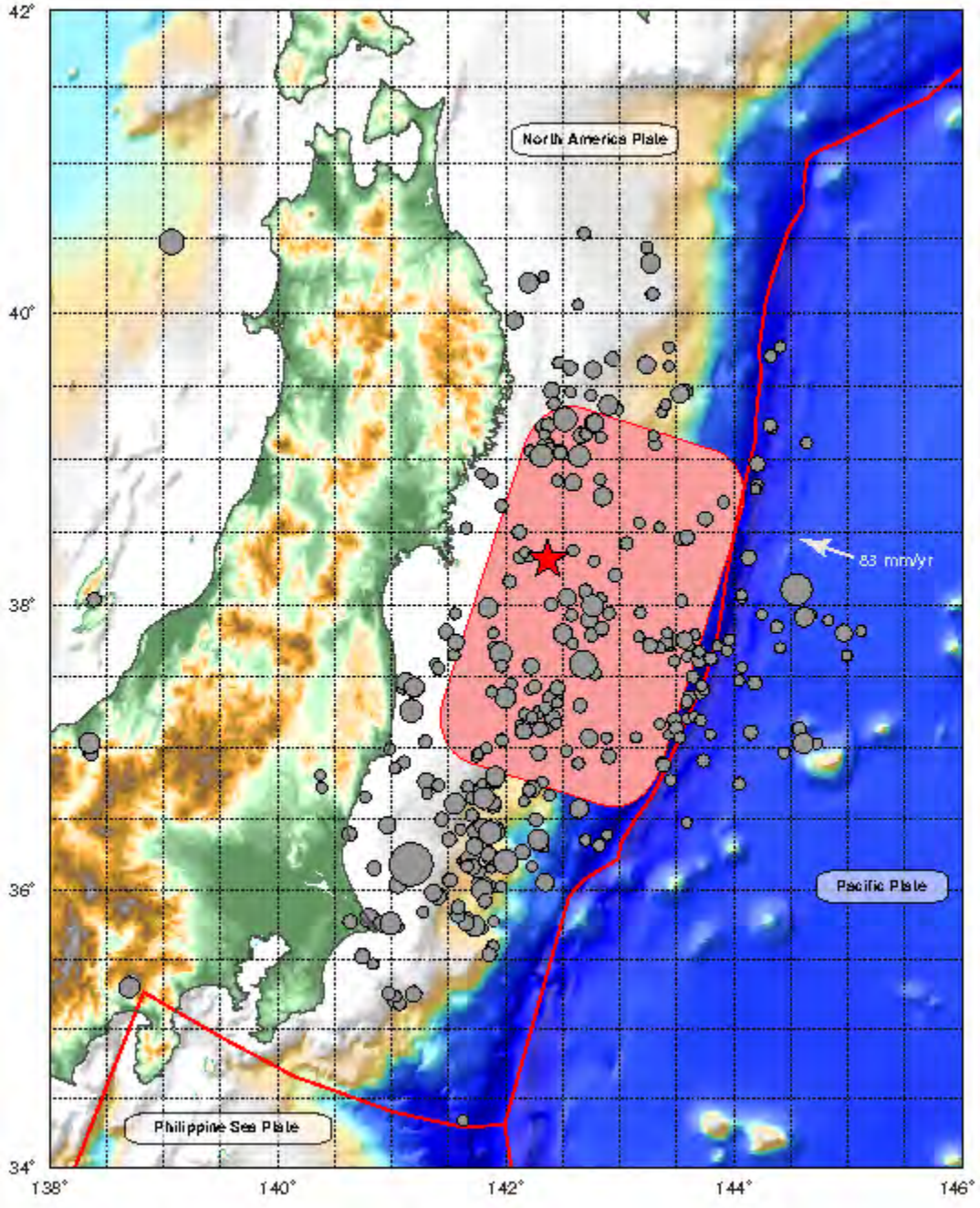
2011 Tohoku Earthquake (NE Japan)

Friday, March 11, 2011 at 2:46 PM local time
Magnitude 9.0 – fourth largest since 1900
Generated powerful tsunami up to 40 meters high

- swept >10 km inland (Sendai plain)
- inundated area >550 km^2

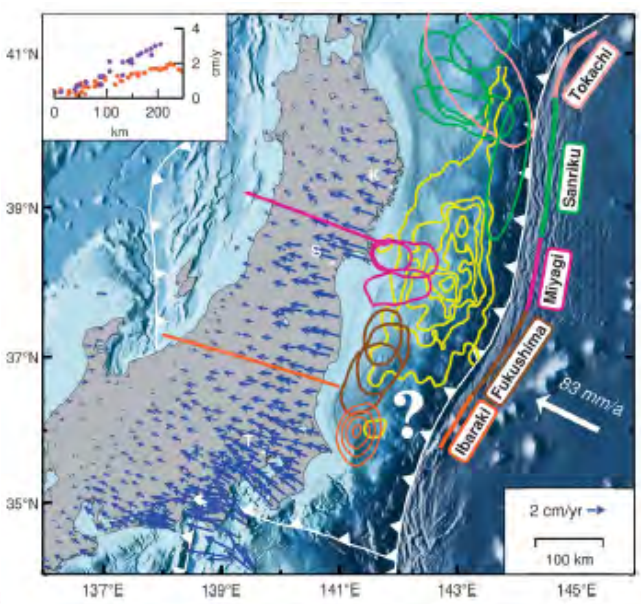
15,894 deaths + 2,572 missing persons + 1,600 evacuation deaths
300,000 evacuees (230,000 still displaced)
125,000+ buildings destroyed; one million damaged
Est. economic cost (World Bank) = US $235 billion
Real-time earthquake warning issued
Fukushima Daiichi nuclear power plant – heavily damaged, partial meltdowns, radioactivity release, clean-up ongoing
Japan – history of devastating earthquakes, tsunamis
- 1923 Great Kanto EQ, M7.9, 143,000 deaths
- excellent building codes, seismic monitoring, plans, etc.

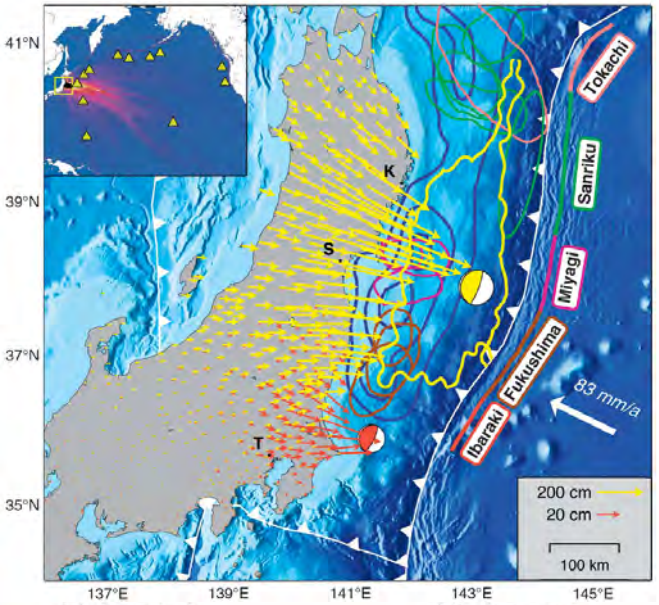
Approximate
Rupture Zone



USGS

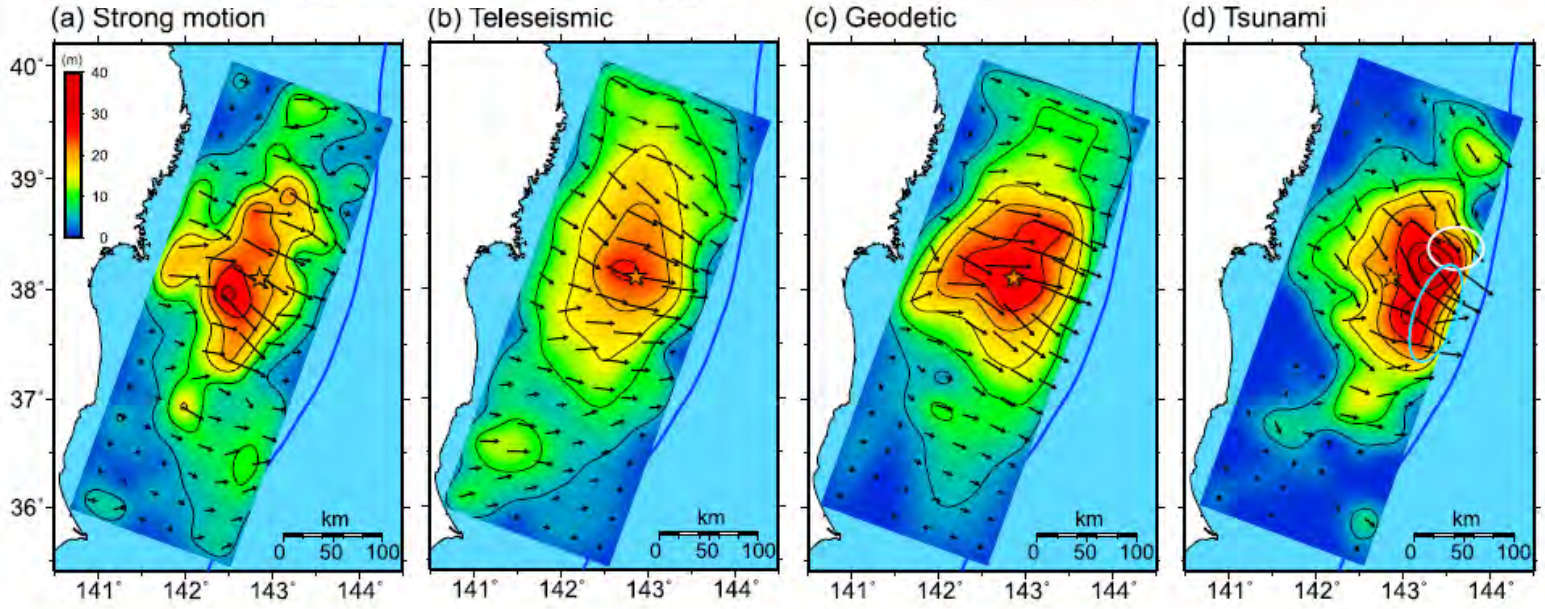
Pre-EQ GPS





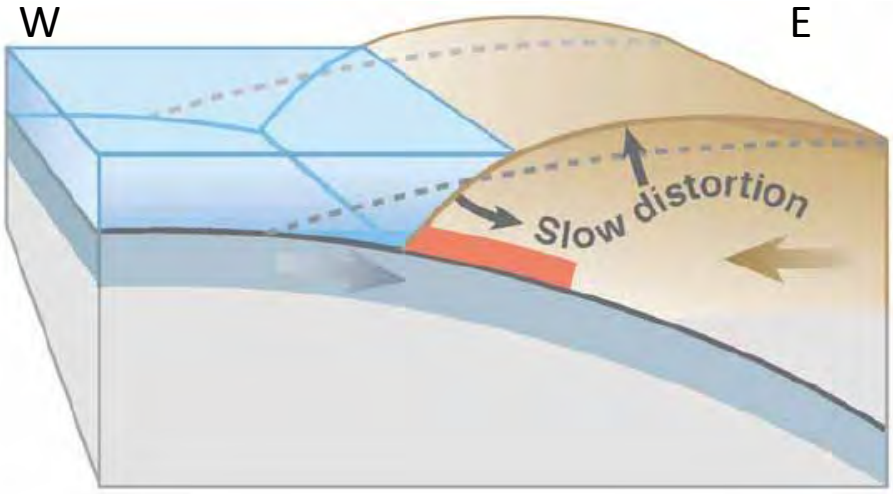
After EQ

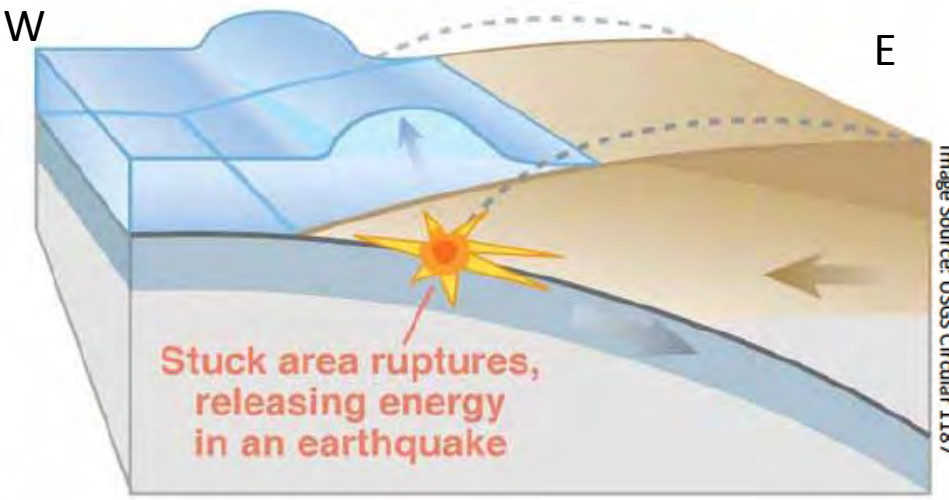
Simons et al. (2011)



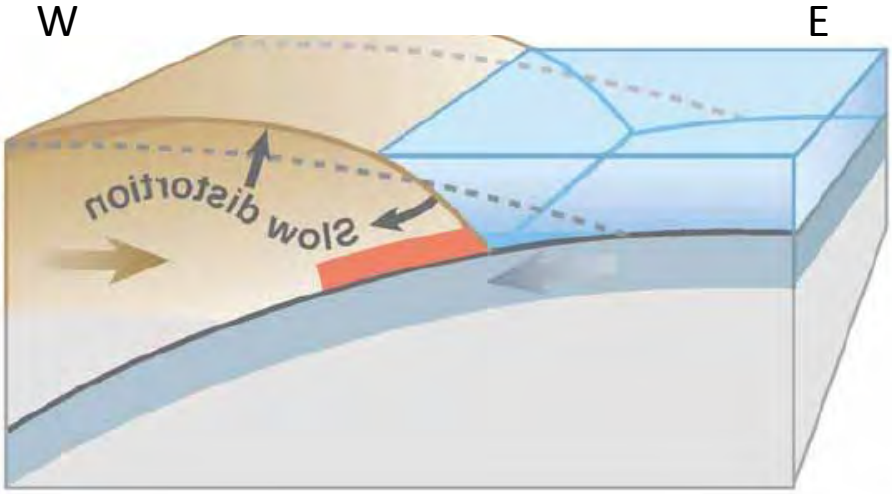
Inferred distribution of slip for the great 11 March 2011 Tohoku Earthquake based on inverting four different data sets (Yokota et al., 2011)

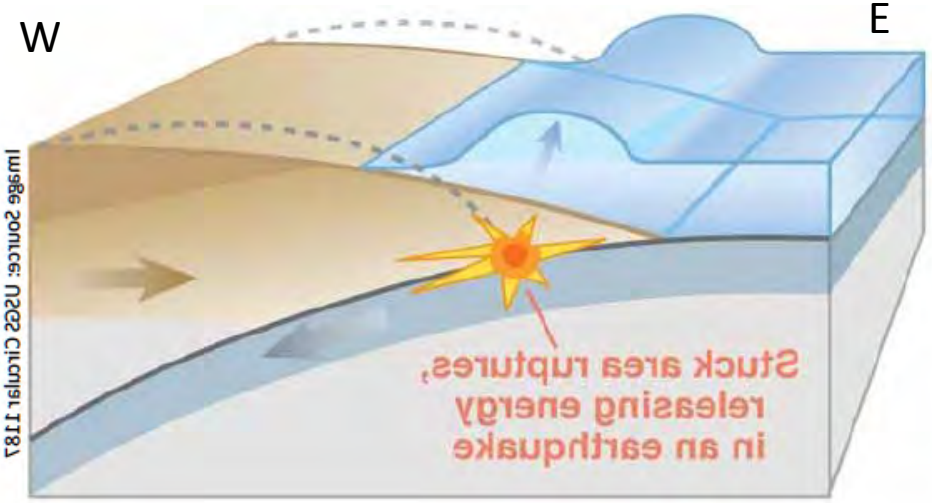
Cascadia

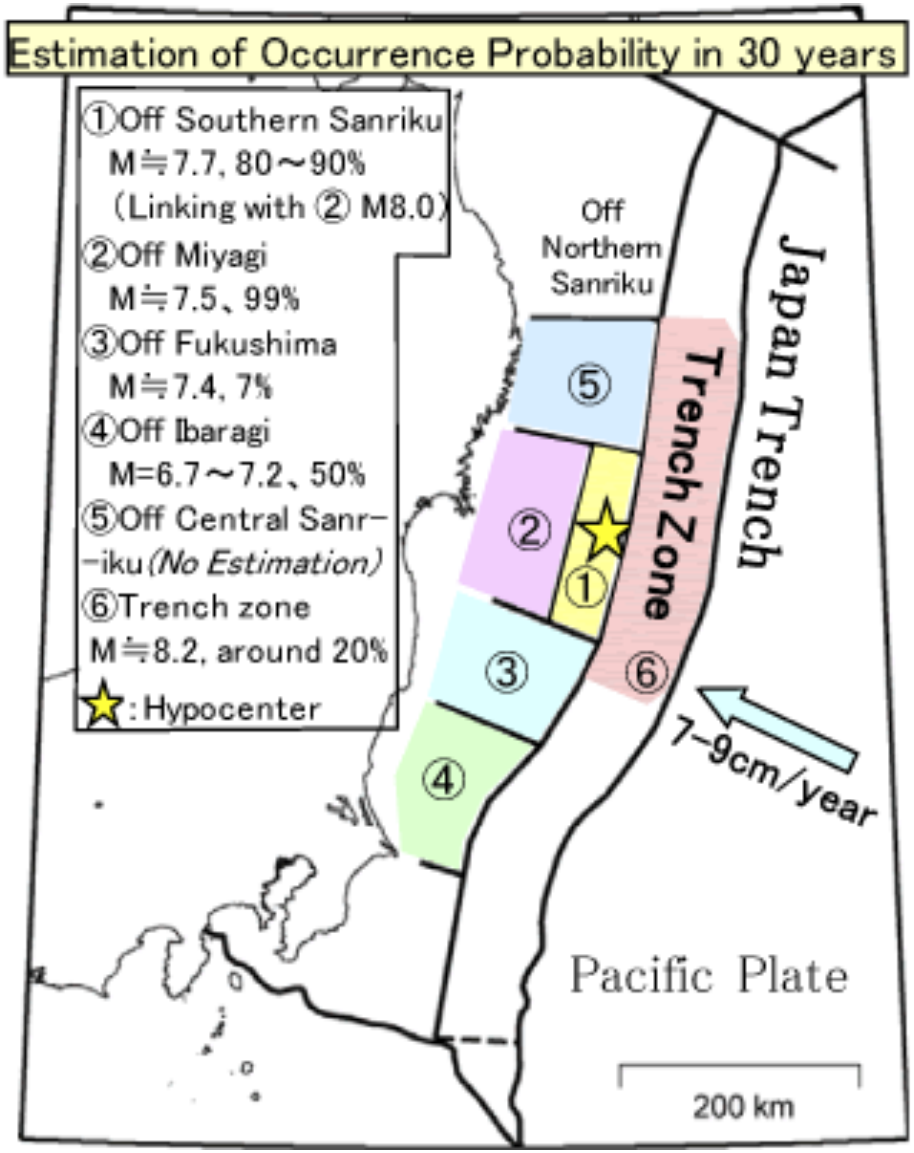


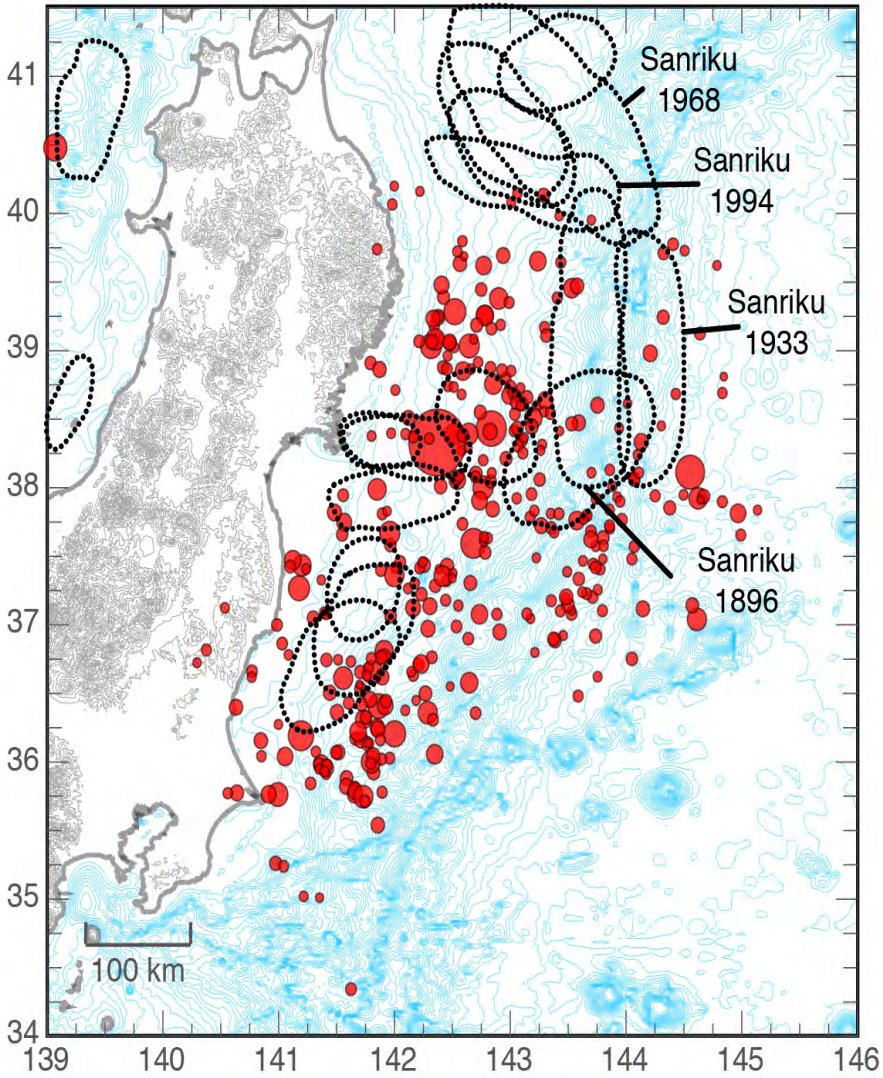


Northeast Japan









Headquarters for Earthquake Research Promotion

http://eqseis.geosc.psu.edu/~cammon/Japan2011EQ/

Red = main shocks and aftershocks of 11 March 2011 earthquake

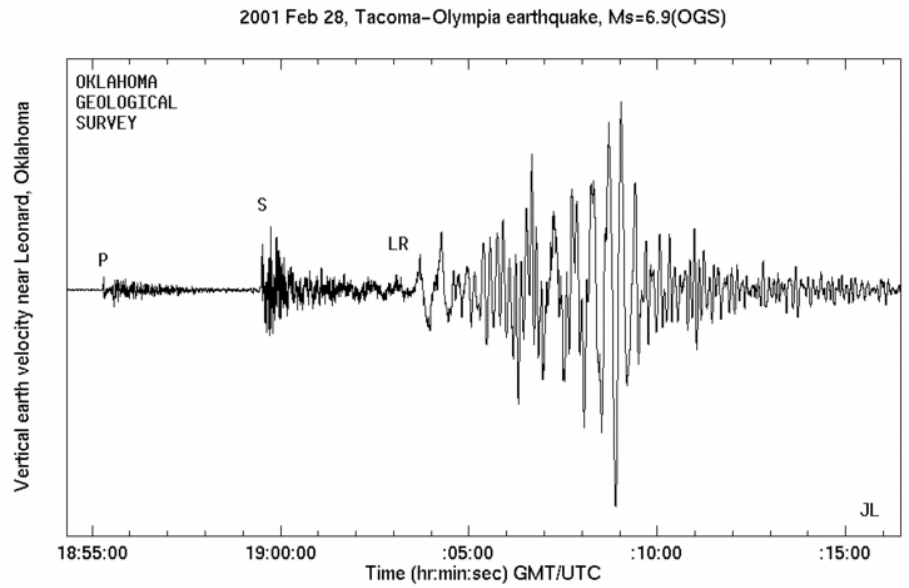
2011 Tohoku Earthquake (NE Japan)

Early alert system saved many thousands of lives

- 80 bullet trains stopped safely
- 98% TV stations broadcast alerts
- 52 million cell phone alerts

BUT - the size of the earthquake and the tsunami were significantly underestimated, both prior to the earthquake and in real time alerts messages.

Lack of independent oversight and regulation of Japanese nuclear power industry



P-waves (~6.4 km/s) travel faster than the S-waves (~3.7 km/s) and surface waves that cause ground shaking. Electrons travel way faster than seismic waves!

Live coverage of Japan parliamentary session in Tokyo, 370 km from epicenter

http://www.youtube.com/watch?feature=player_embedded&v=xYctjv7ouBc

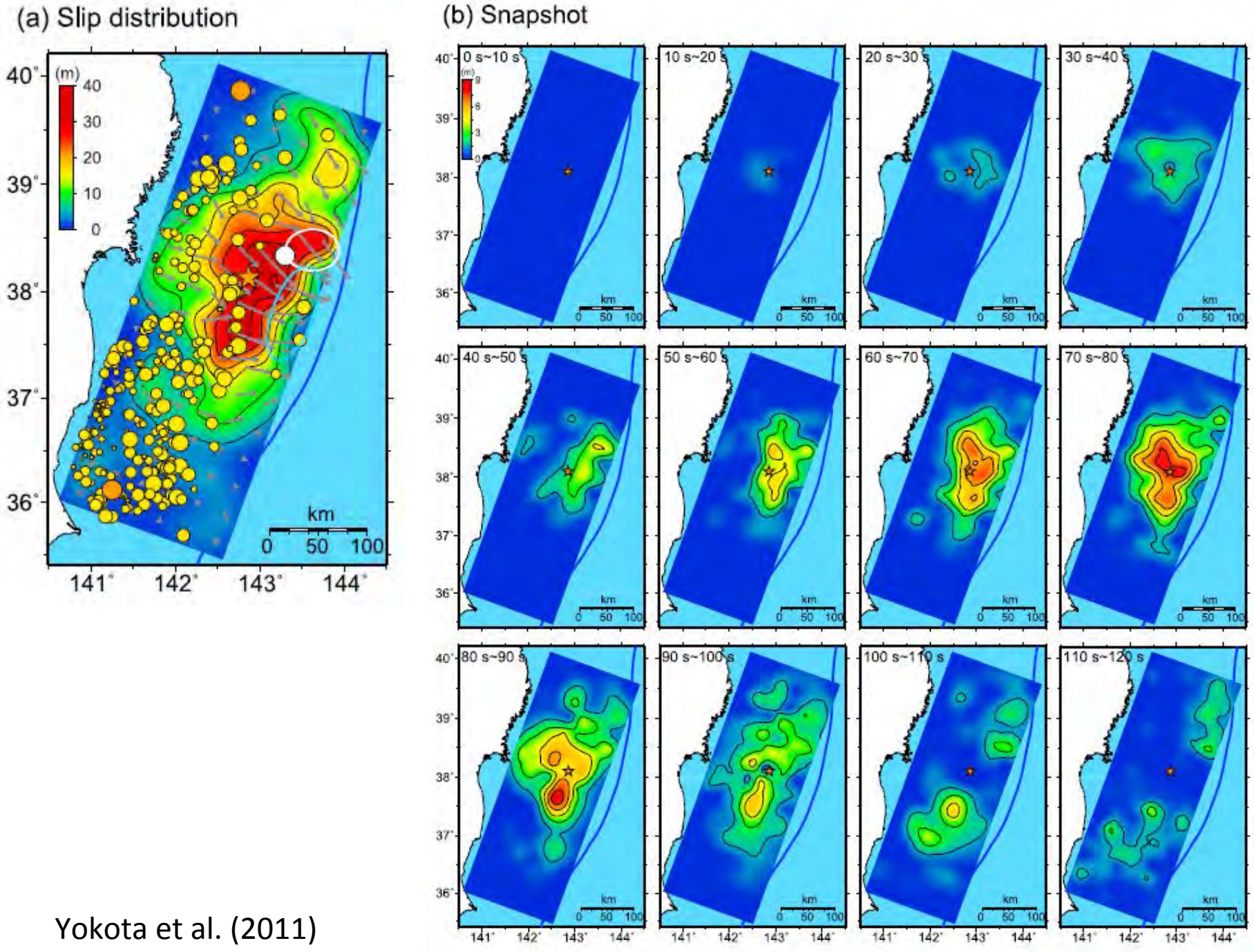
Oct 2007 – Japan turned on first public national earthquake warning system
Operated by the Japan Meteorological Agency (JMA)

Mar 2011 – first true test

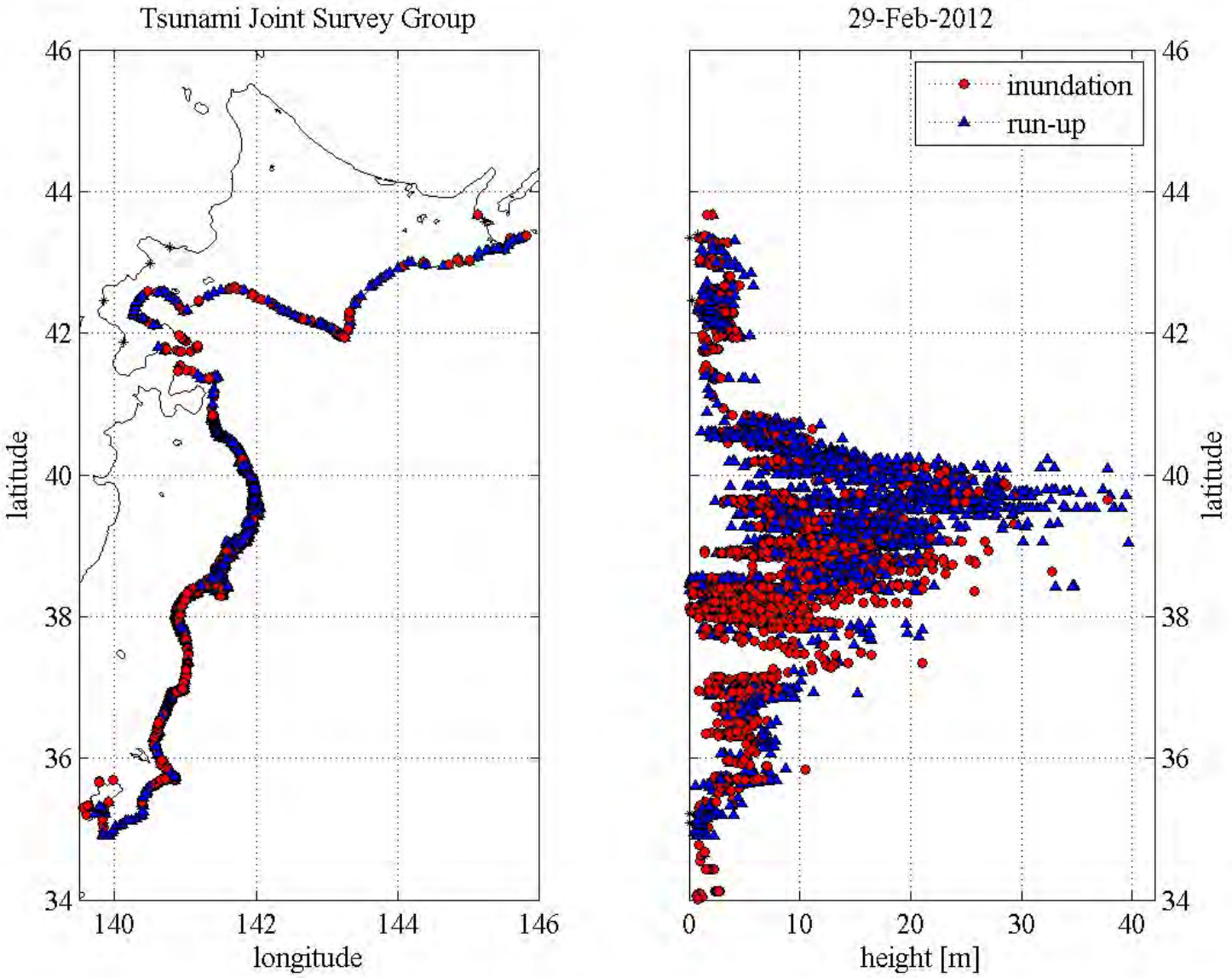
Notes	Update number	**Time since first P-wave detection (sec)**	**Estimated magnitude**	**Estimated maximum shaking intensity (JMA scale)**	Lat	Lon	Depth (km)	Origin time
1st assessment of the event, 5.4 sec after 1st P-wave detection	1	**5.4**	**4.3**	**1**	38.2	142.7	10	14:46:19
	2	**6.5**	**5.9**	**3**	38.2	142.7	10	14:46:19
	3	**7.5**	**6.8**	**4**	38.2	142.7	10	14:46:19
Earthquake warning issued	**4**	**8.6**	**7.2**	**5-lower**	38.2	142.7	10	14:46:19
	5	**9.6**	**6.3**	**4**	38.2	142.7	10	14:46:19
	6	**10.7**	**6.6**	**4**	38.2	142.7	10	14:46:19
	7	**11.0**	**6.6**	**4**	38.2	142.7	10	14:46:19
	8	**15.9**	**7.2**	**4**	38.1	142.9	10	14:46:17
	9	**22.2**	**7.6**	**5-lower**	38.1	142.9	10	14:46:16
	10	**30.0**	**7.7**	**5-lower**	38.1	142.9	10	14:46:16
	11	**45.0**	**7.7**	**5-lower**	38.1	142.9	10	14:46:16
	12	**65.1**	**7.9**	**5-upper**	38.1	142.9	10	14:46:17
	13	**85.0**	**8.0**	**5-upper**	38.1	142.9	10	14:46:17
	14	**105.0**	**8.1**	**6-lower**	38.1	142.9	10	14:46:17
	15	**116.8**	**8.1**	**6-lower**	38.1	142.9	10	14:46:17

Table notes. The first P-wave detection was at 14:46:40.2. All times are JST on March 11, 2011.

http://seismo.berkeley.edu/~rallen/research/WarningsInJapan/



Yokota et al. (2011)



Measured tsunami heights resulting from 11 March 2011 Earthquake.
Japan Society of Civil Engineers Tohoku Earthquake Tsunami Information,
http://www.coastal.jp/tsunami2011/index.php

Grand tsunami monument in Aneyoshi, Miyako

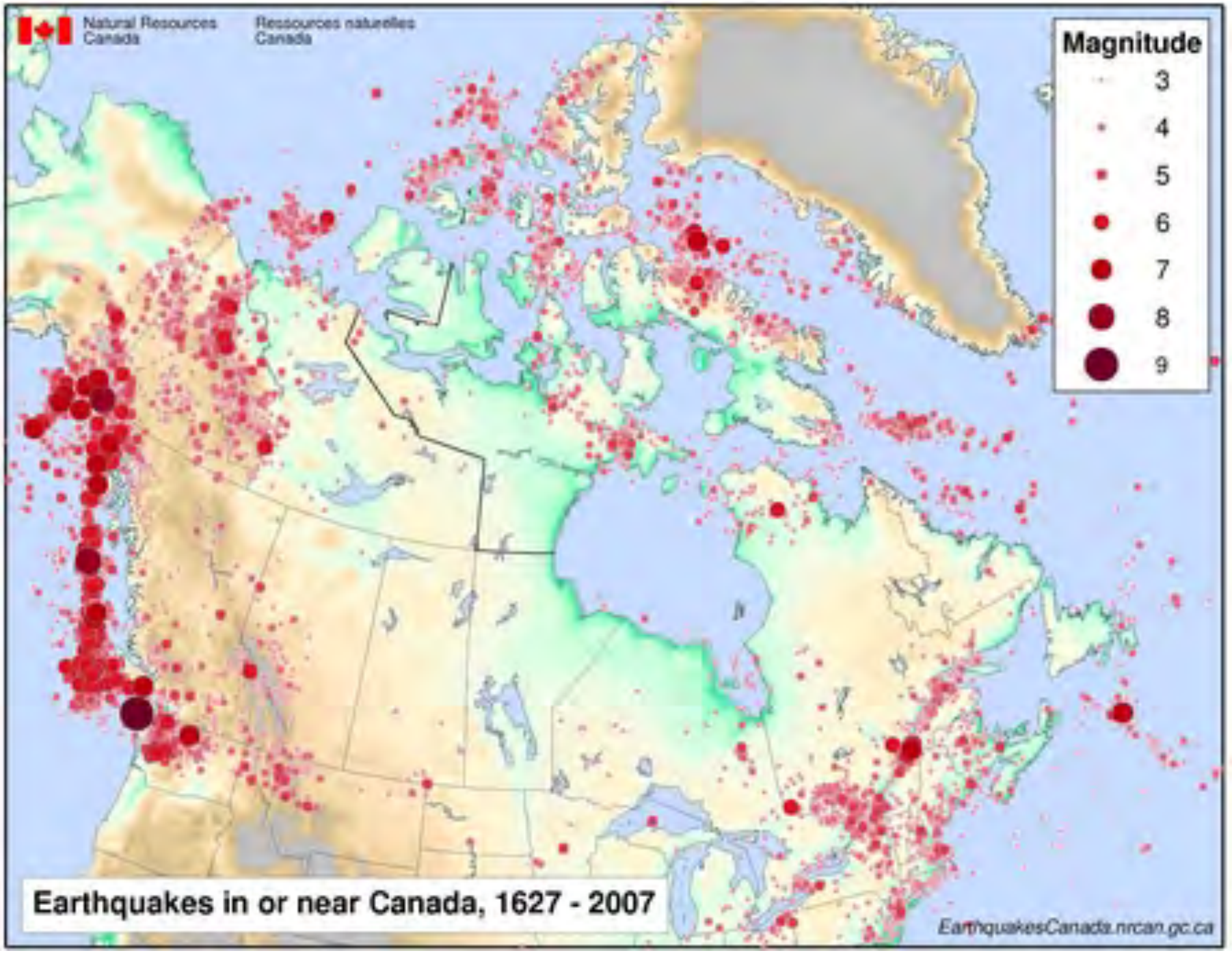
Built after the
13 July 869 AD Sanriku (Jōgan) Earthquake

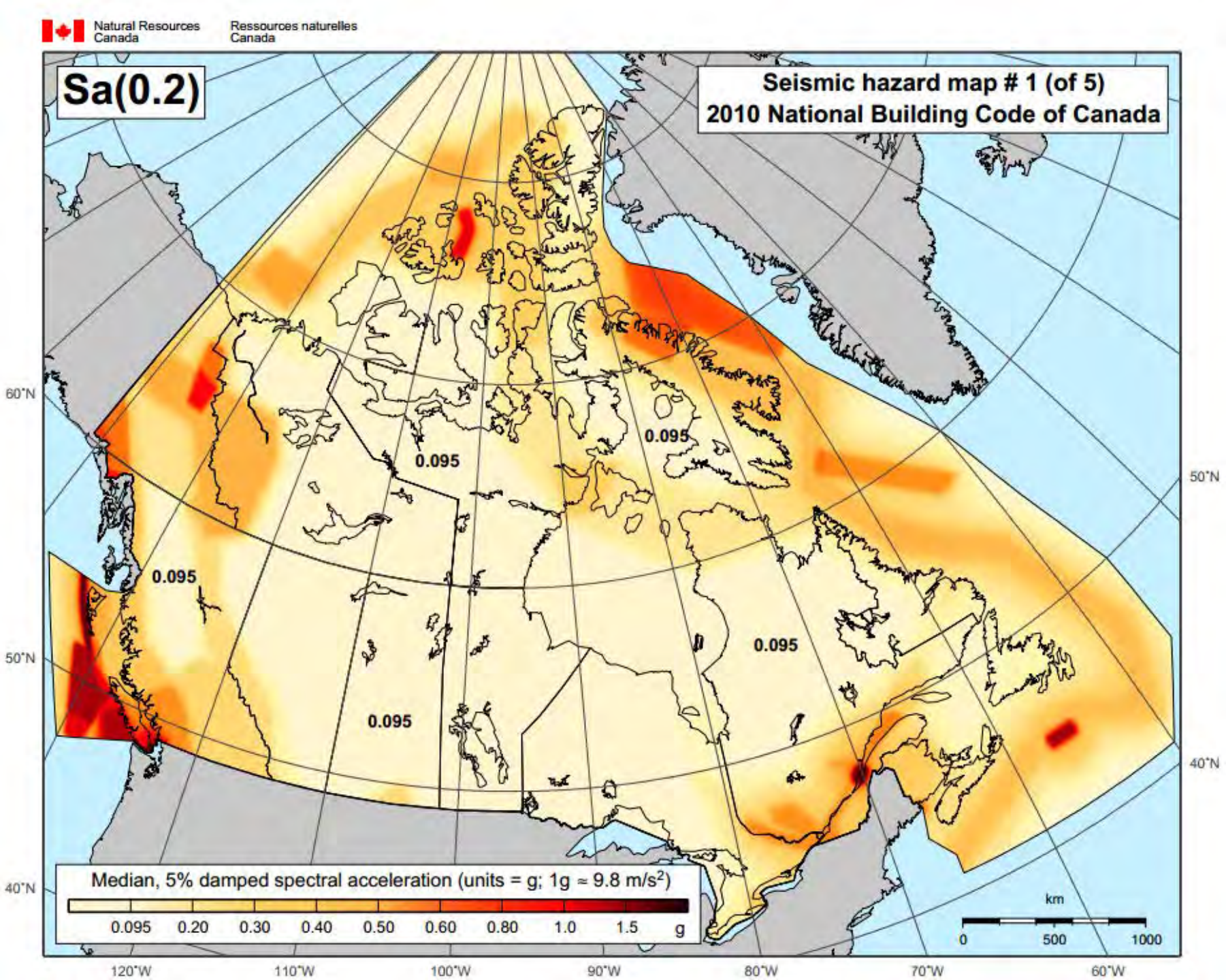
Estimated mag = 8.3+
(Minoura et al., 2002)

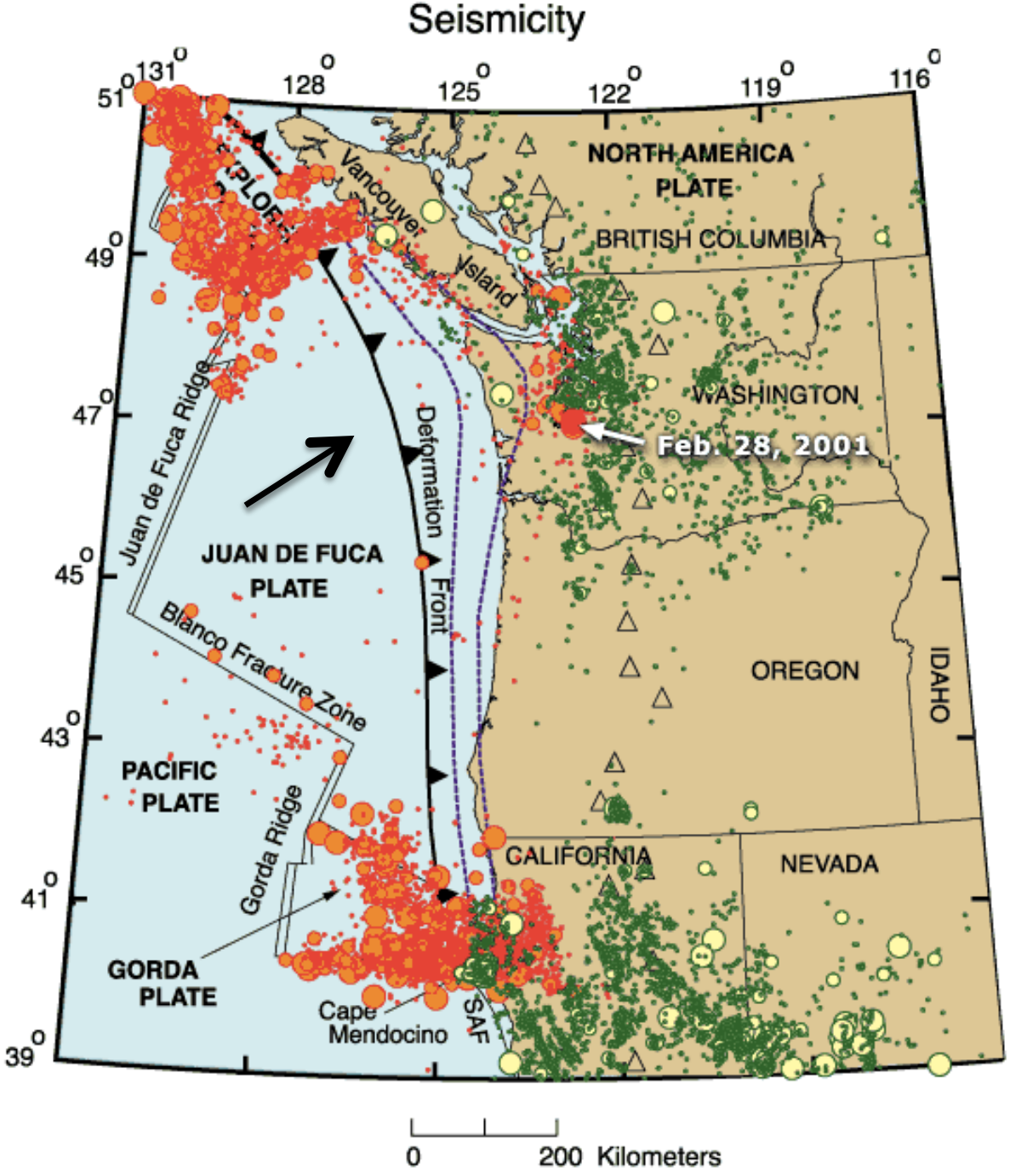
Tsunami reached 38.9 meters above sea level

"A house on a high land brings peace and happiness to your children and grandchildren - Remember the ravages of the great tsunami - Do not build any houses below this point"

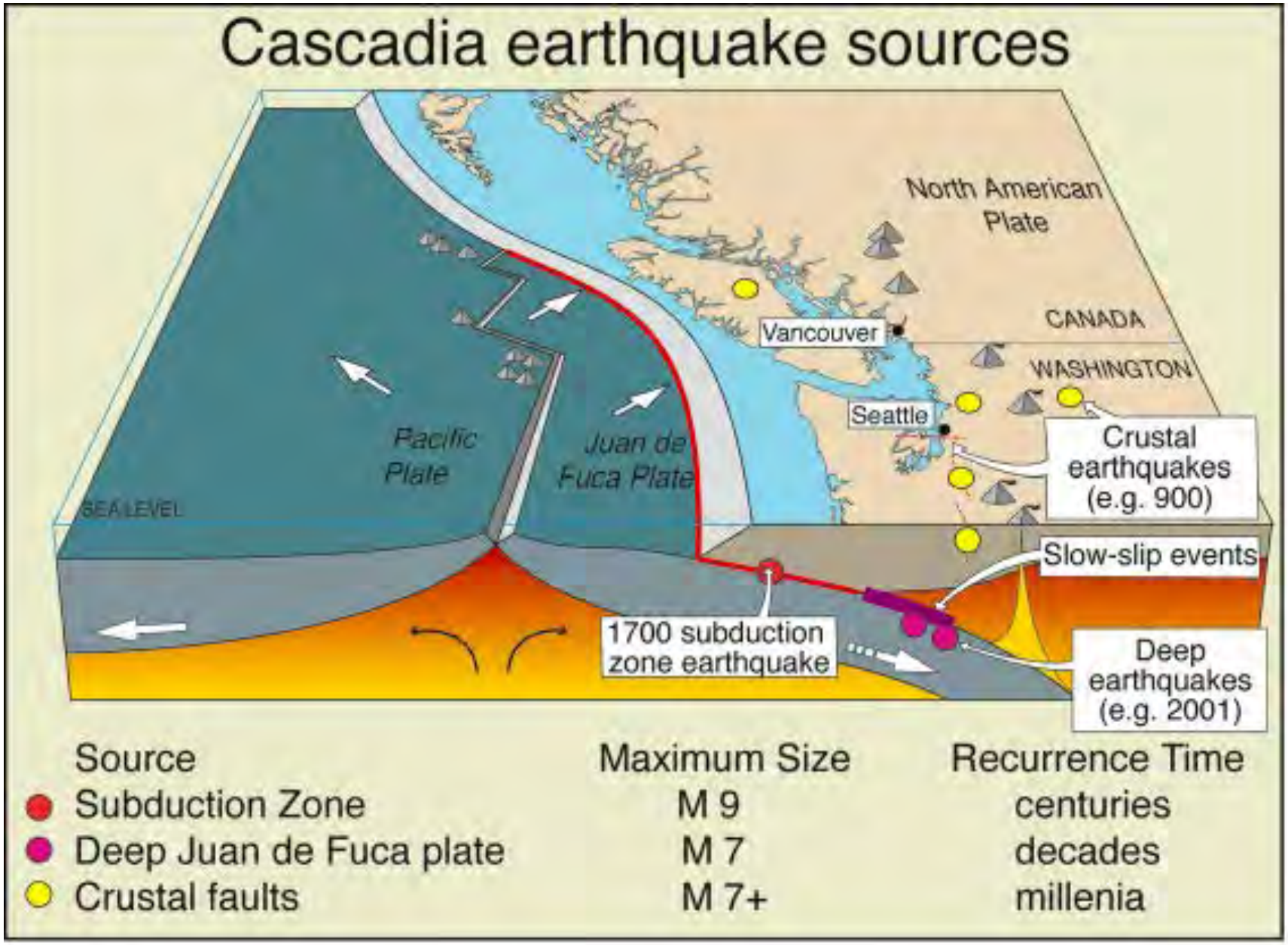
(translation, H. Takagi, Waseda U; Photo – M. Oishi)


Natural Resources Canada
Ressources naturelles Canada
Magnitude
3
4
5
6
7
8
9
Earthquakes in or near Canada, 1627 - 2007
EarthquakesCanada.nrcan.gc.ca

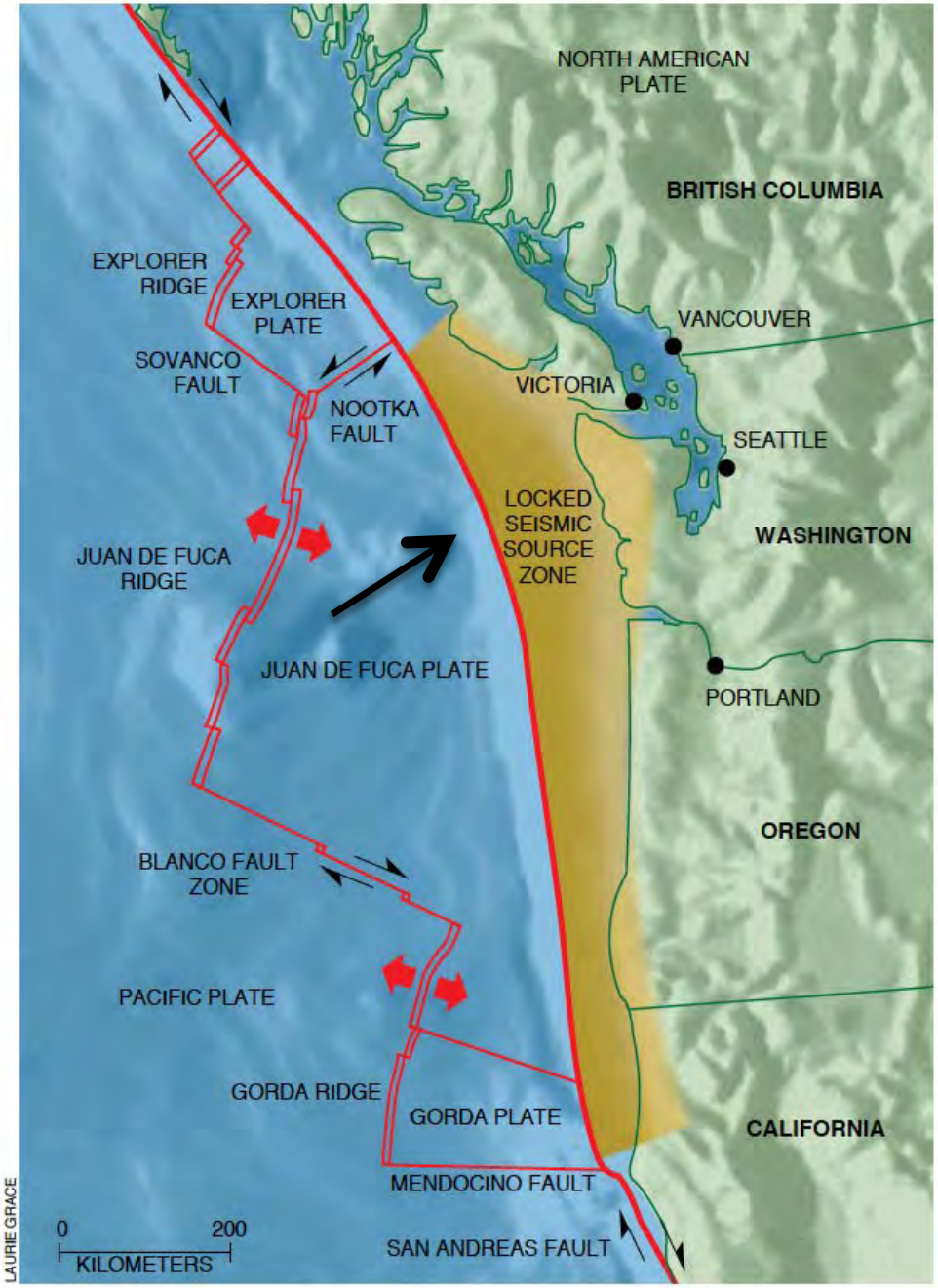

Natural Resources Canada
Ressources naturelles Canada
Sa(0.2)
Seismic hazard map # 1 (of 5)
2010 National Building Code of Canada
0.095
0.095
0.095
0.095
0.095
60°N
50°N
40°N
120°W
110°W
100°W
90°W
80°W
70°W
60°W
Median, 5% damped spectral acceleration (units = g; 1g ≈ 9.8 m/s²)
0.095 0.20 0.30 0.40 0.50 0.60 0.80 1.0 1.5 g
km
0 500 1000



modified from Weaver and Shedlock, 1996


Cascadia earthquake sources
North American Plate
CANADA
Vancouver
WASHINGTON
Seattle
Pacific Plate
Juan de Fuca Plate
SEA LEVEL
Crustal earthquakes (e.g. 900)
Slow-slip events
1700 subduction zone earthquake
Deep earthquakes (e.g. 2001)
Source
Maximum Size
Recurrence Time
Subduction Zone
M 9
centuries
Deep Juan de Fuca plate
M 7
decades
Crustal faults
M 7+
millenia

IRIS



Hyndman (1995)

We have ***no*** written historical record of past magnitude 9 Cascadia earthquakes

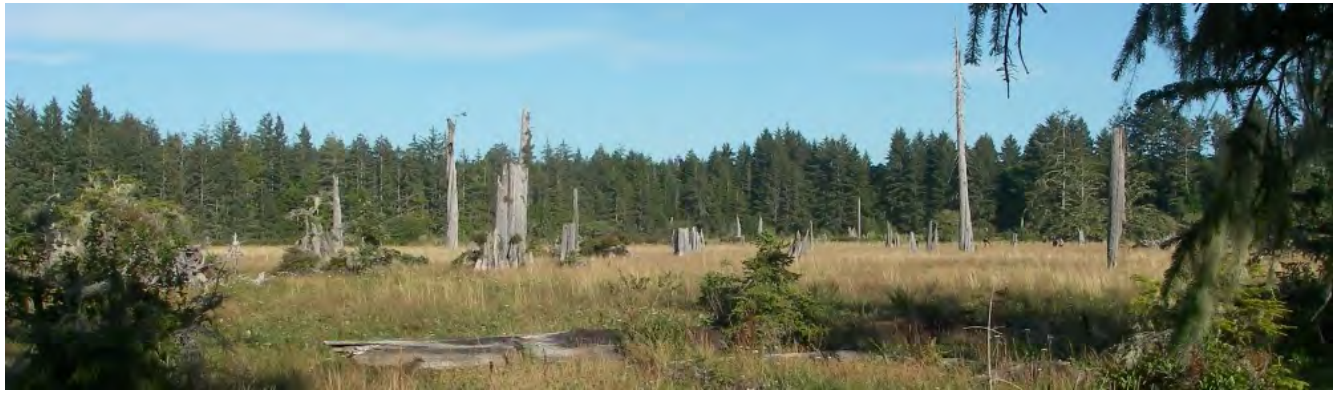
But oral histories of aboriginal groups in the Pacific Northwest tell of entire villages devastated by violent ground shaking and massive floods

"This is the most important story the Huu-ay-aht people have"

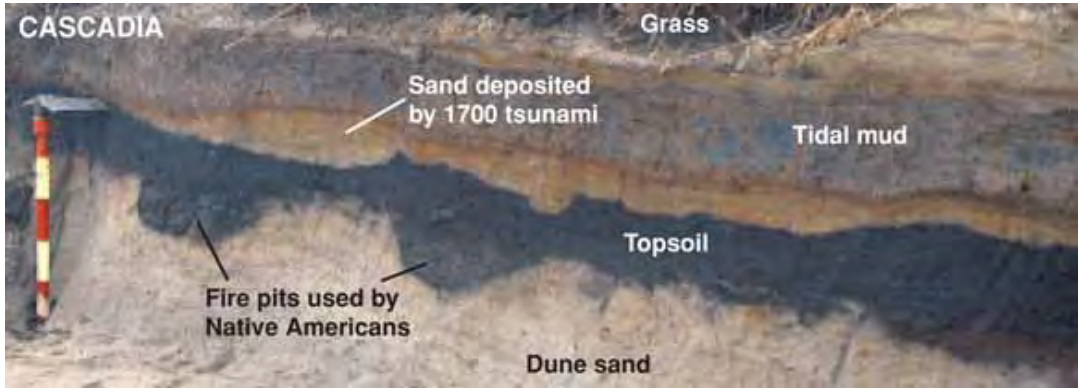
A wall of water estimated at over 50 feet swept through Anacla and other coastal villages drowning thousands of Nuu-chah-nulth-aht

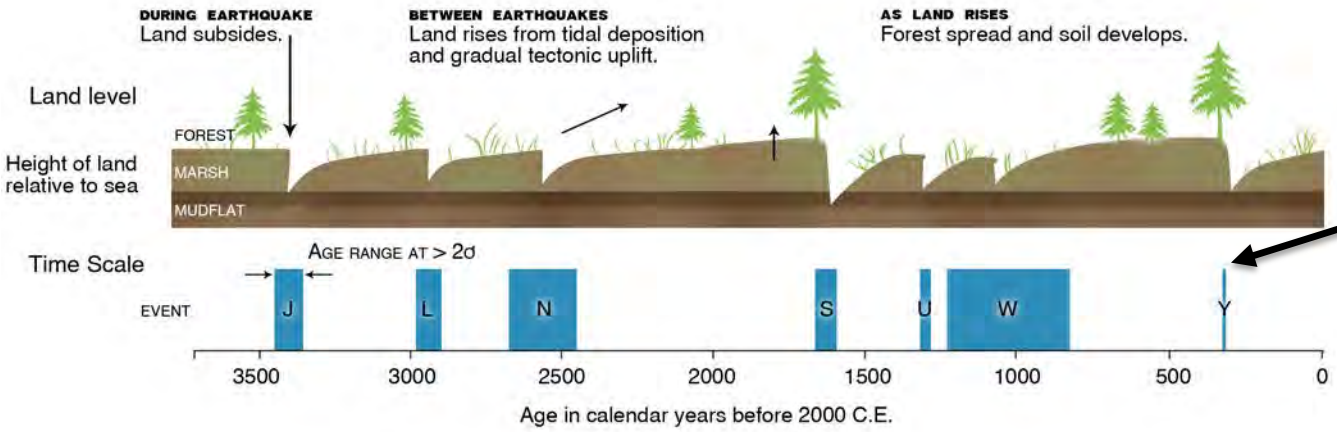
Chief Louis Nookmiis (1880-1964)

Drowned Coastal Forests - Cascadia



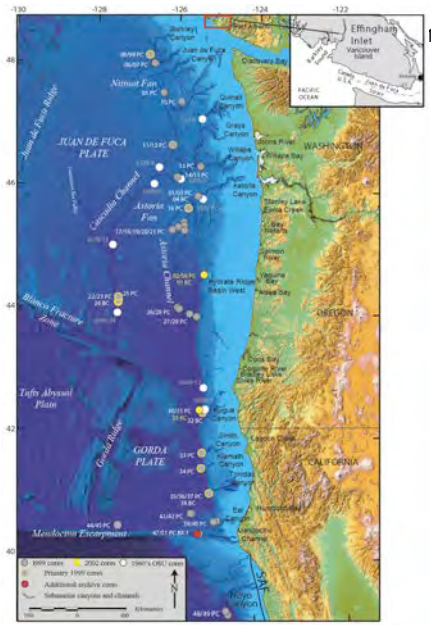
Brian Atwater
U.S. Geological Survey

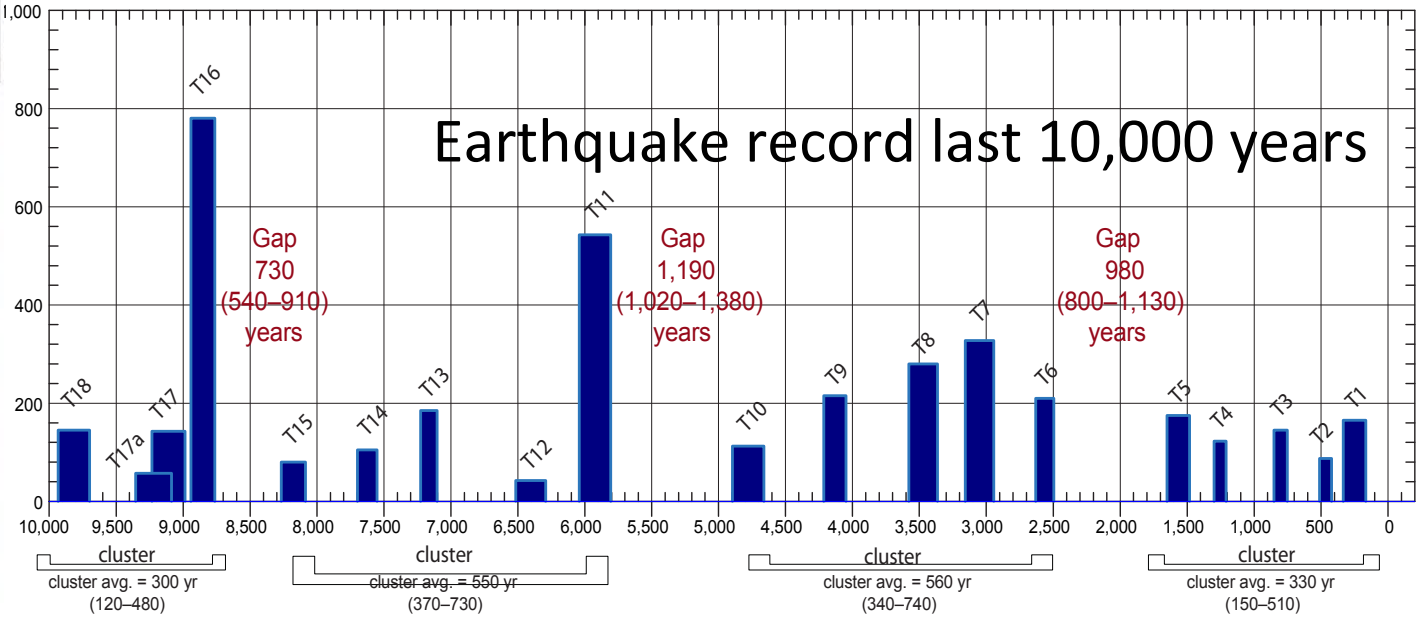




9 PM, Jan 26, 1700 AD based on Japanese tsunami record!

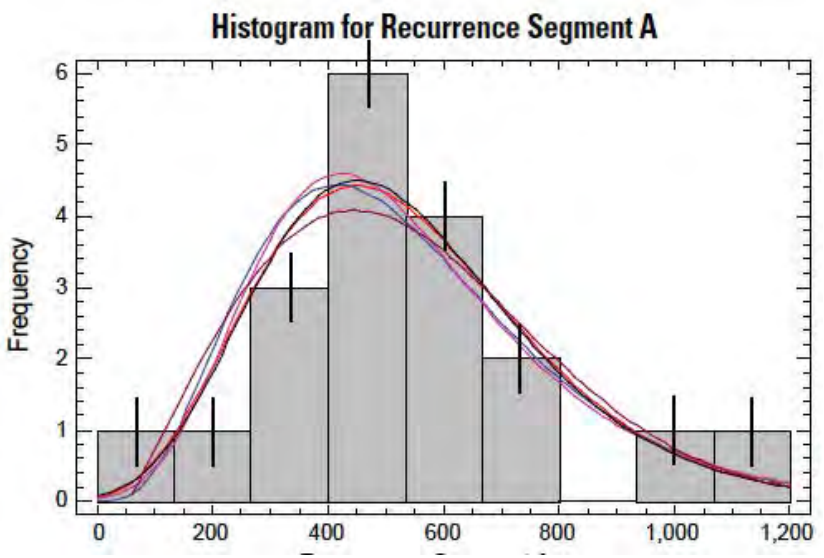
Atwater and Hemphill-Haley (1997)



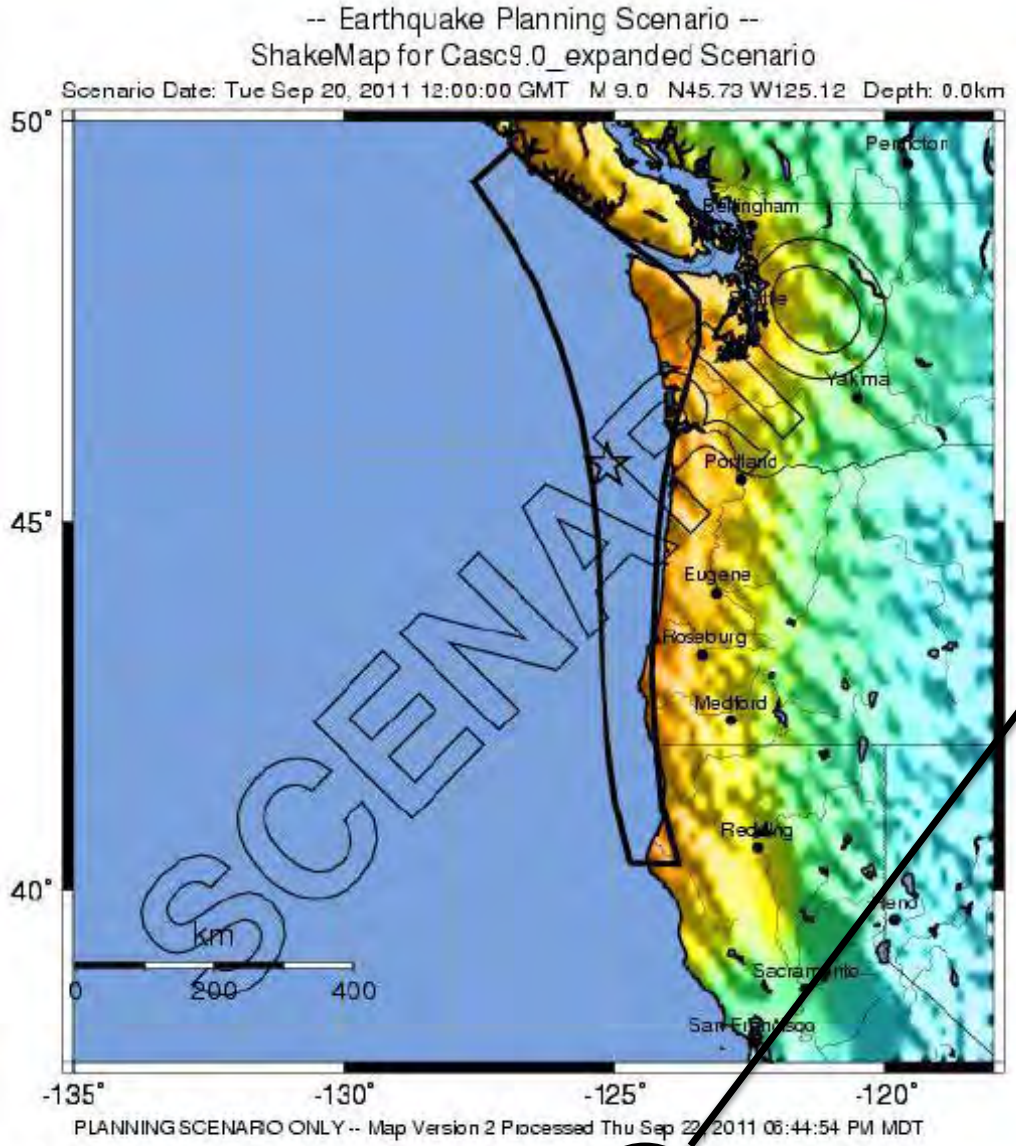


Calibrated years B.P. (1950)

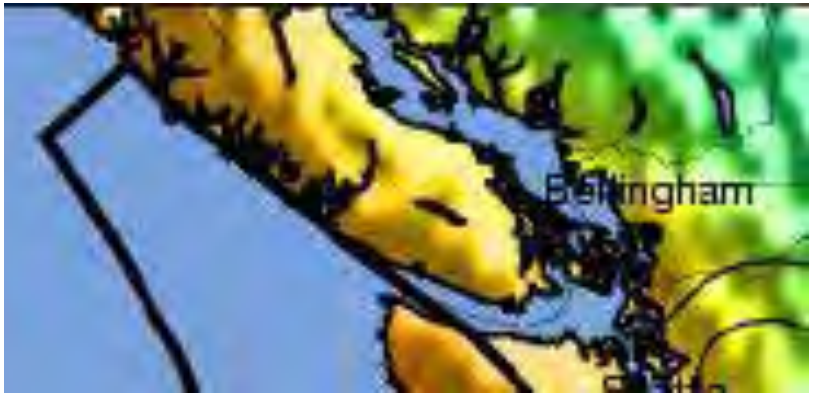
Chris Goldfinger (Oregon State Univ)
Based on offshore submarine landslide record
Nineteen great magnitude ~9 earthquakes in the last 10,000 years
Average recurrence interval **~500 - 530 years**
Recurrence interval ranges from 200 to 800 years, *possible* clusters separated by gaps



Goldfinger et al. (2012)



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+



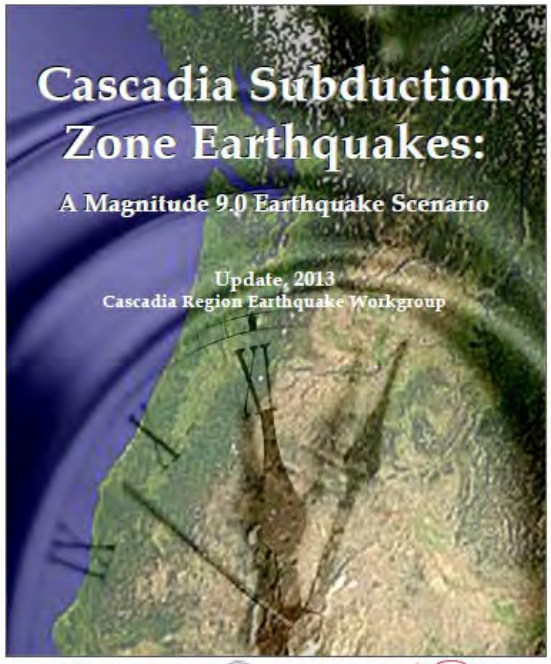
Modified Mercalli *Intensity* Scale VII
"Very Strong" Perceived Shaking
"Moderate" Potential Damage

Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.

USGS M9.0 planning scenario from *CREW (2103)*

Times Colonist

Essential infrastructure will be heavily damaged by ground shaking, rockslides

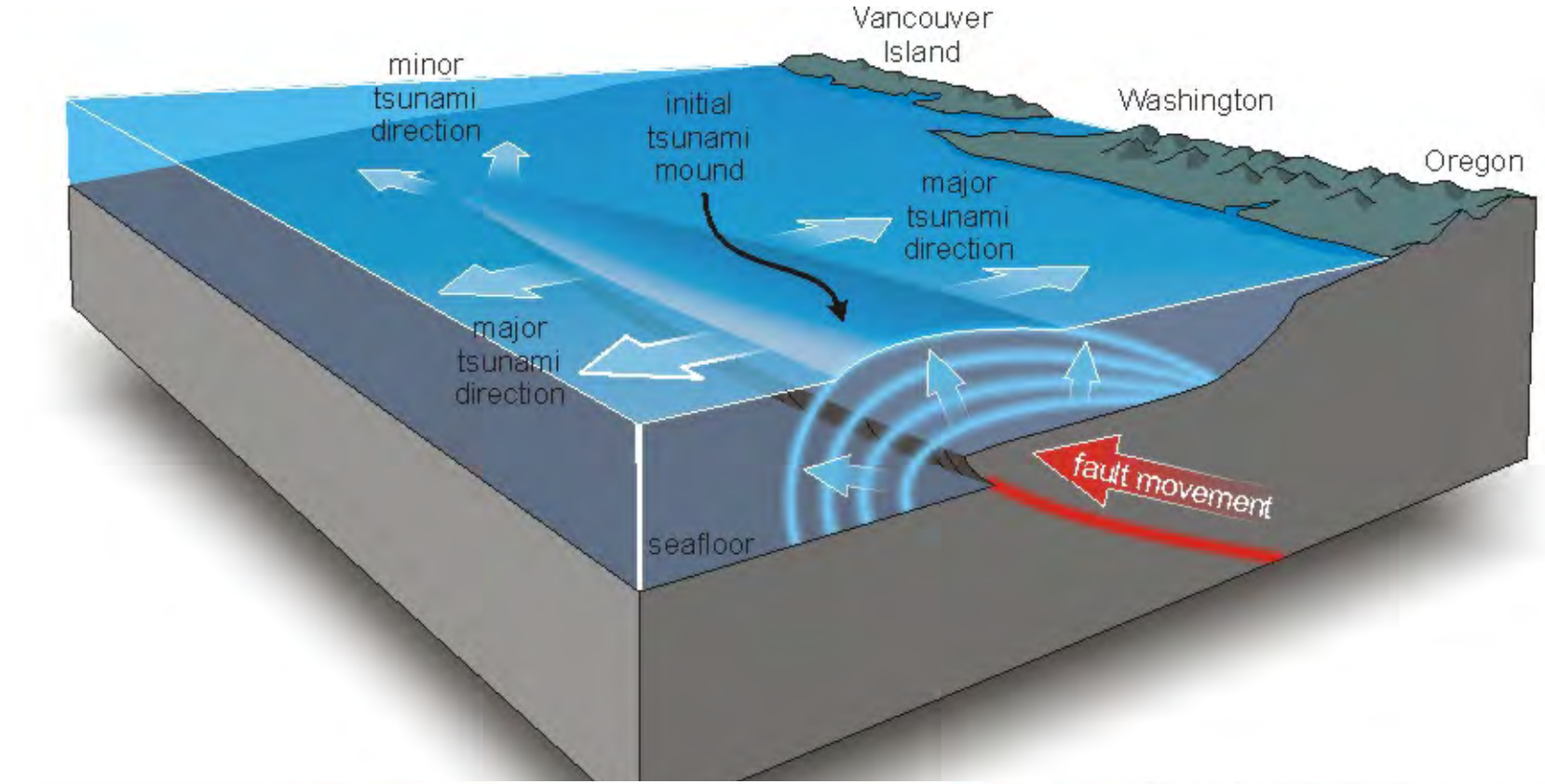


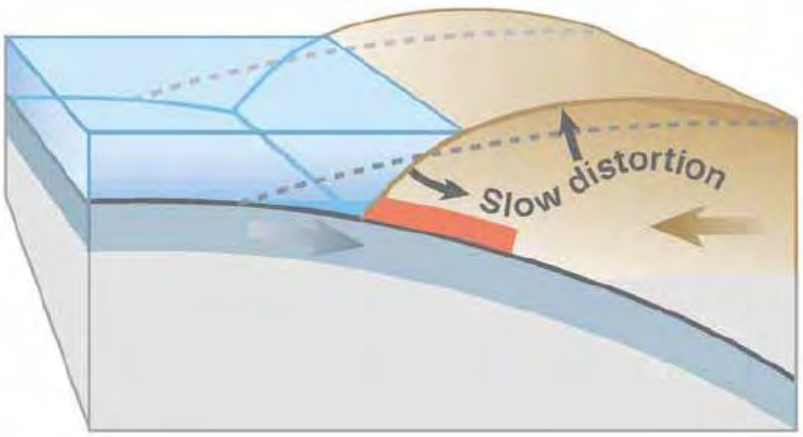
Cascadia Region Earthquake Group, 2013
www.crew.org

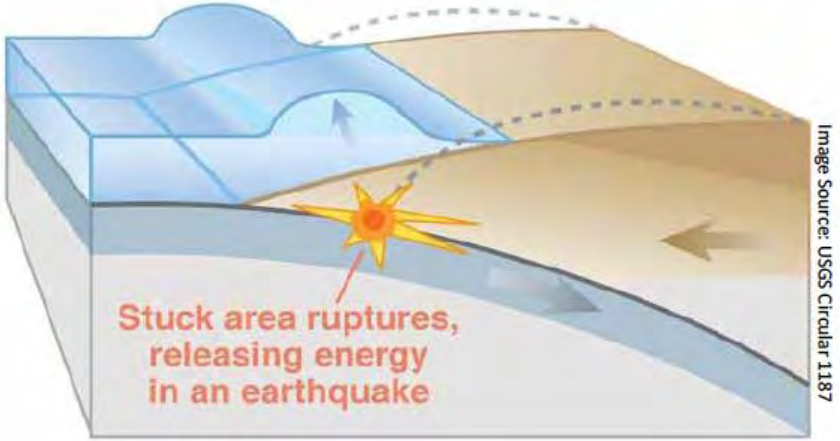
- Transportation networks:
  - bridges, roads, railways
- Airports
- Ports, shipping channels
- Electricity, natural gas, liquid fuels
- Water systems – fire fighting, drinking
- Communication networks
- Critical facilities - hospitals, fire stations

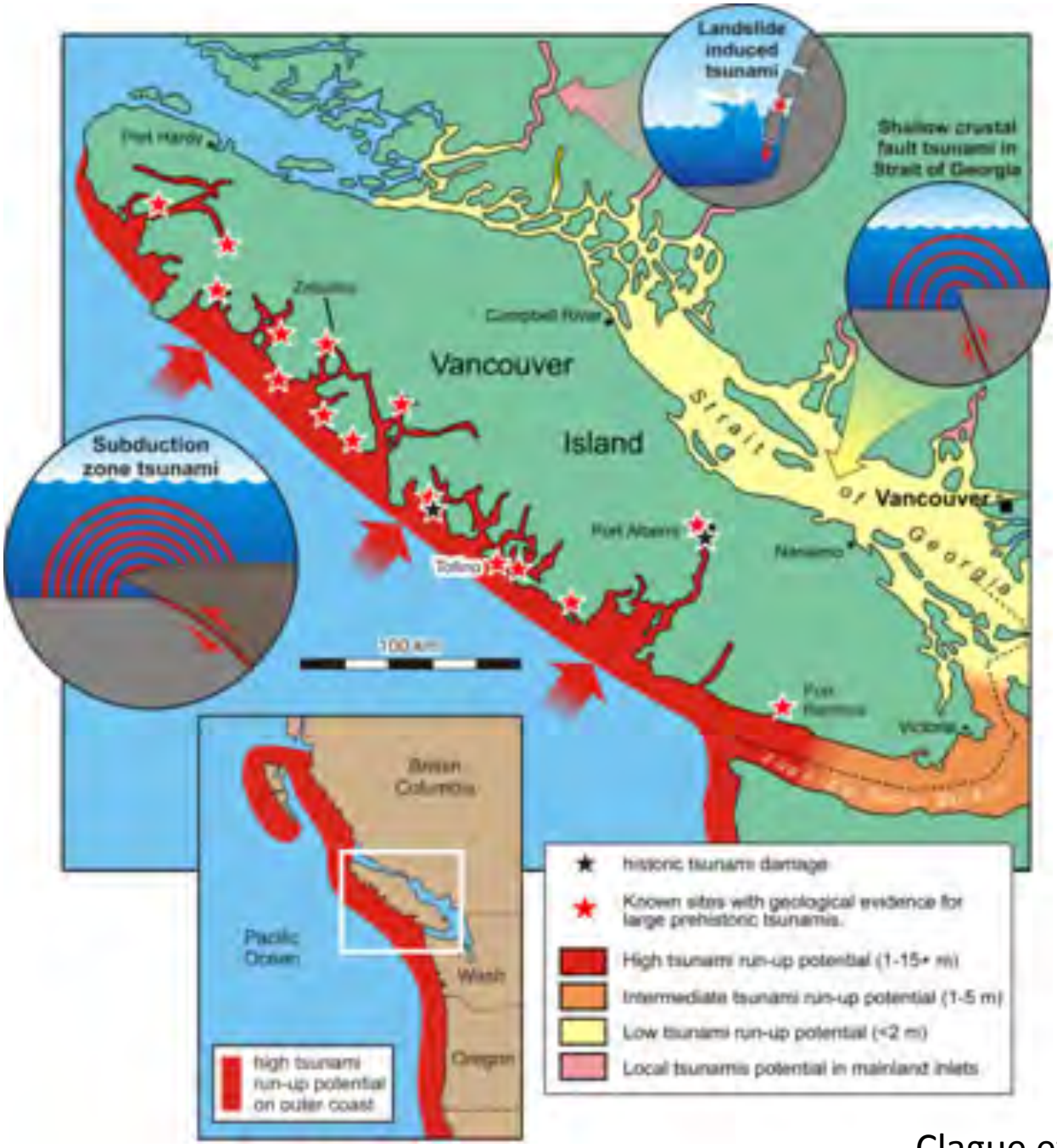
Tsunami will inundate low-lying areas along the west coast of Vancouver Island, Washington, Oregon, Calif

Tsunami from Cascadia subduction zone





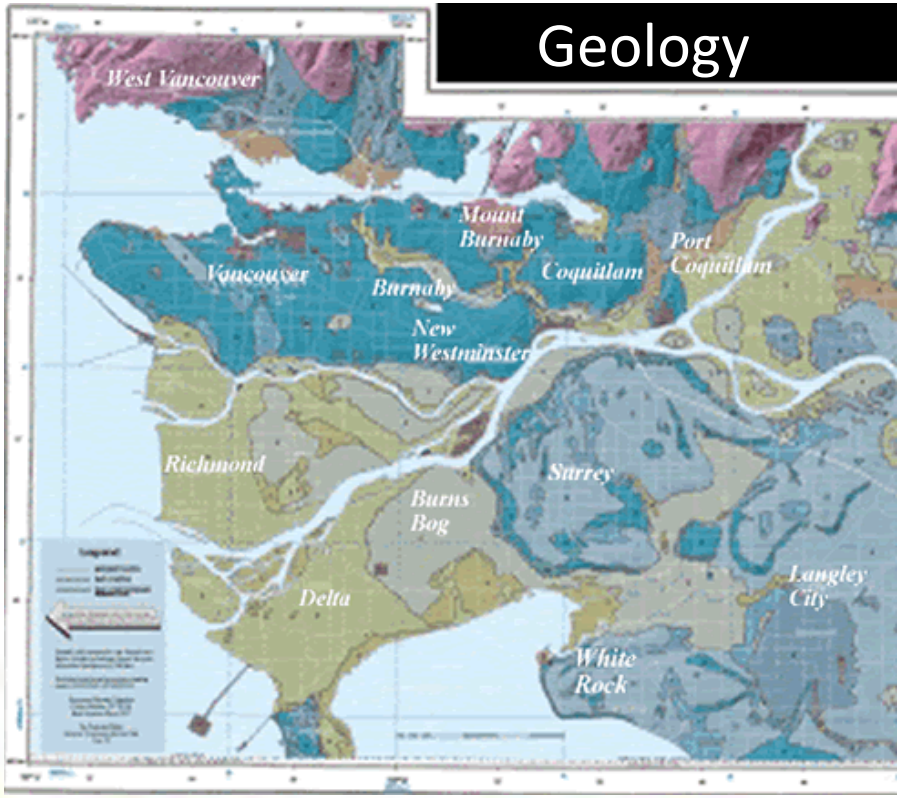


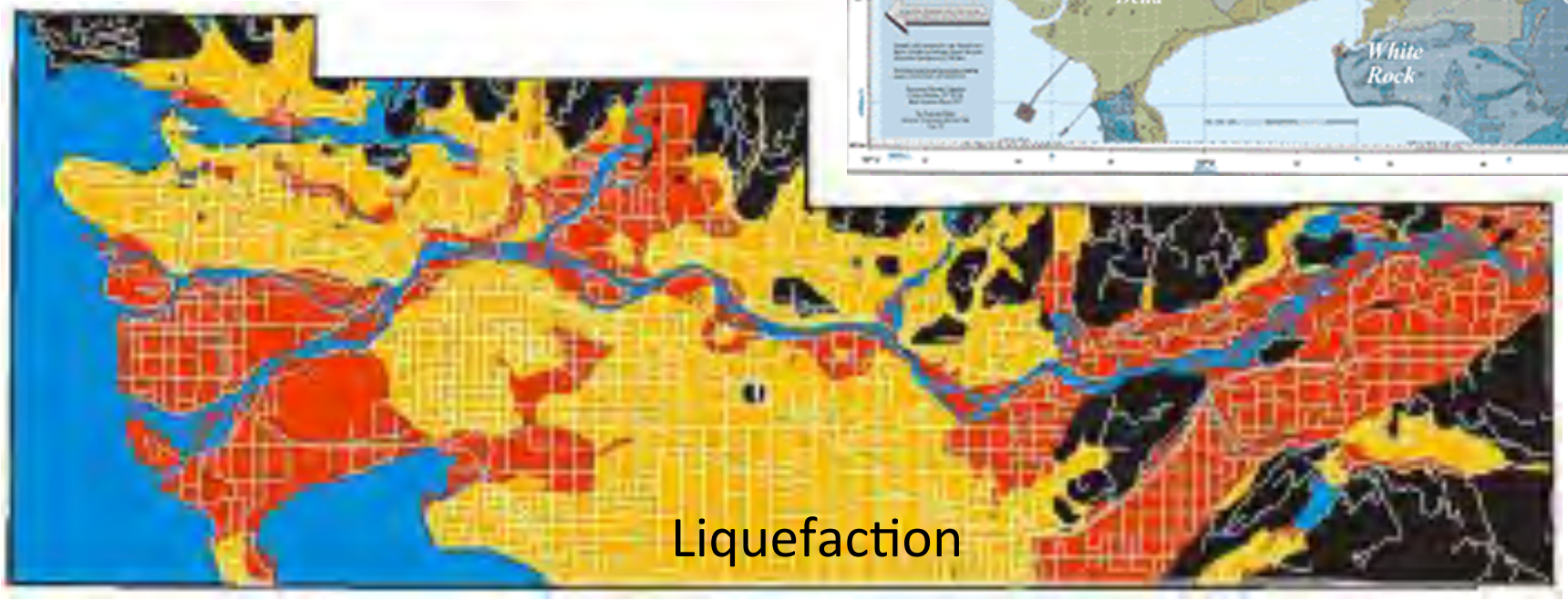


Clague et al. (2006)

Ground shaking depends on earthquake magnitude, distance from epicenter and *local geology*

Unconsolidated soil (muds, sands)
→ amplified shaking and liquefaction:
- Richmond, Delta
- False Creek





Geomap Vancouver

Ground Shaking in Vancouver caused by Magnitude 9 Cascadia Earthquake

Expect 3 to 4 minutes of very strong lateral shaking, with many aftershocks occurring for months afterward

What will happen to my home or workplace during an earthquake?

- When was the building built?
  - First comprehensive seismic building code in Canada - 1953
  - Major upgrades to seismic building codes in 1970, 1985, 2005
  - Our seismic codes continue to be strengthened as we learn more
- Where is building located?
  - Loose soil – more shaking
- What is the building made of?
  - Unreinforced concrete or brick buildings perform poorly
  - Wood frame homes should perform well (except chimneys and glass)
- How long and how violently does the ground shake?

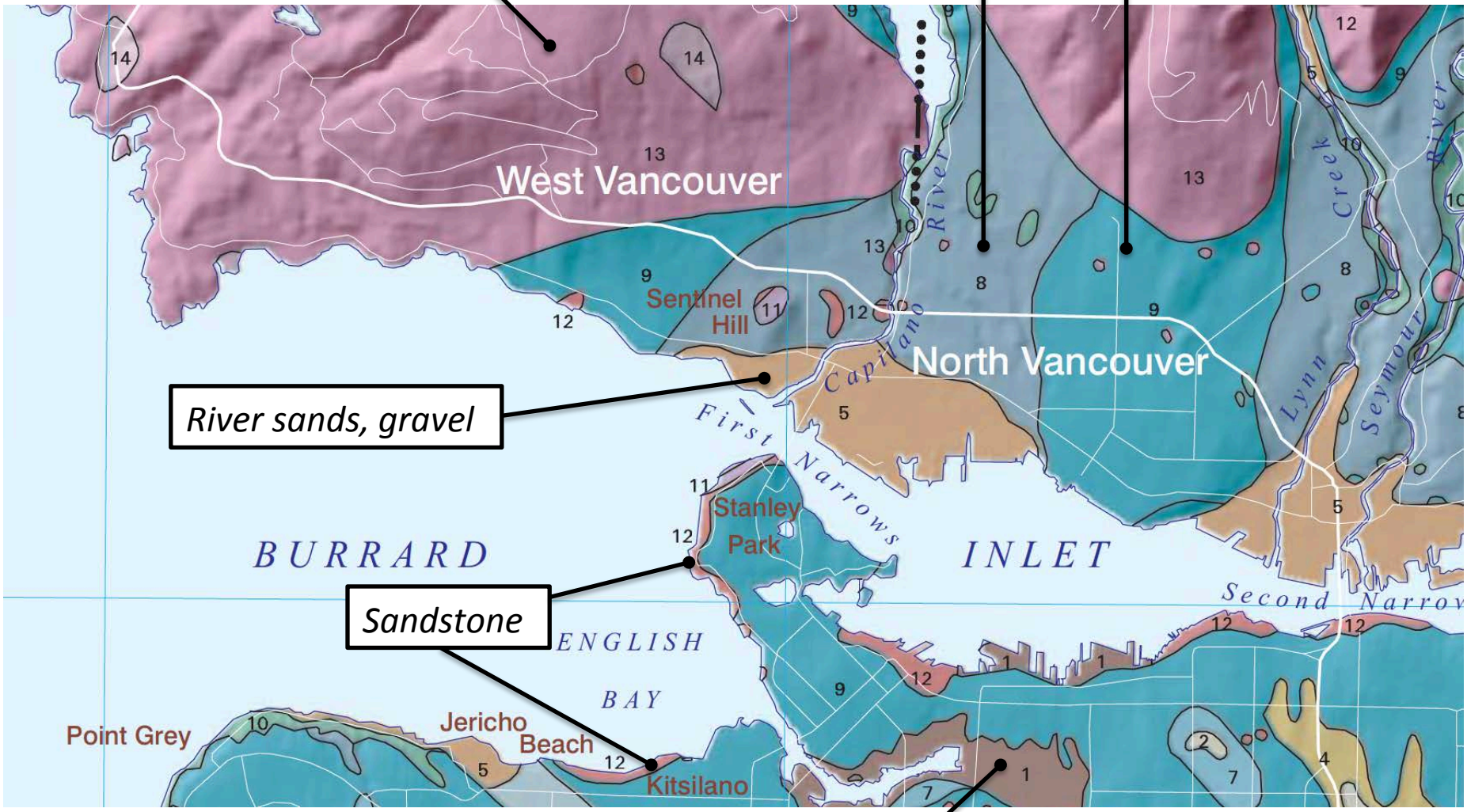
Estimated ground motions

Probabilistic

Deterministic

MMI Scale	Perceived Shaking	Damage Potential
V	Light felt by some	Pictures move
VI	Moderate *felt by all*	Objects fall to ground
VII	Strong *difficulty standing*	Non-structural damage
VIII	Very strong *difficulty driving*	Moderate structural damage
IX	Violent *general panic*	Heavy structural damage
X	Very violent *general panic*	Extreme structural damage

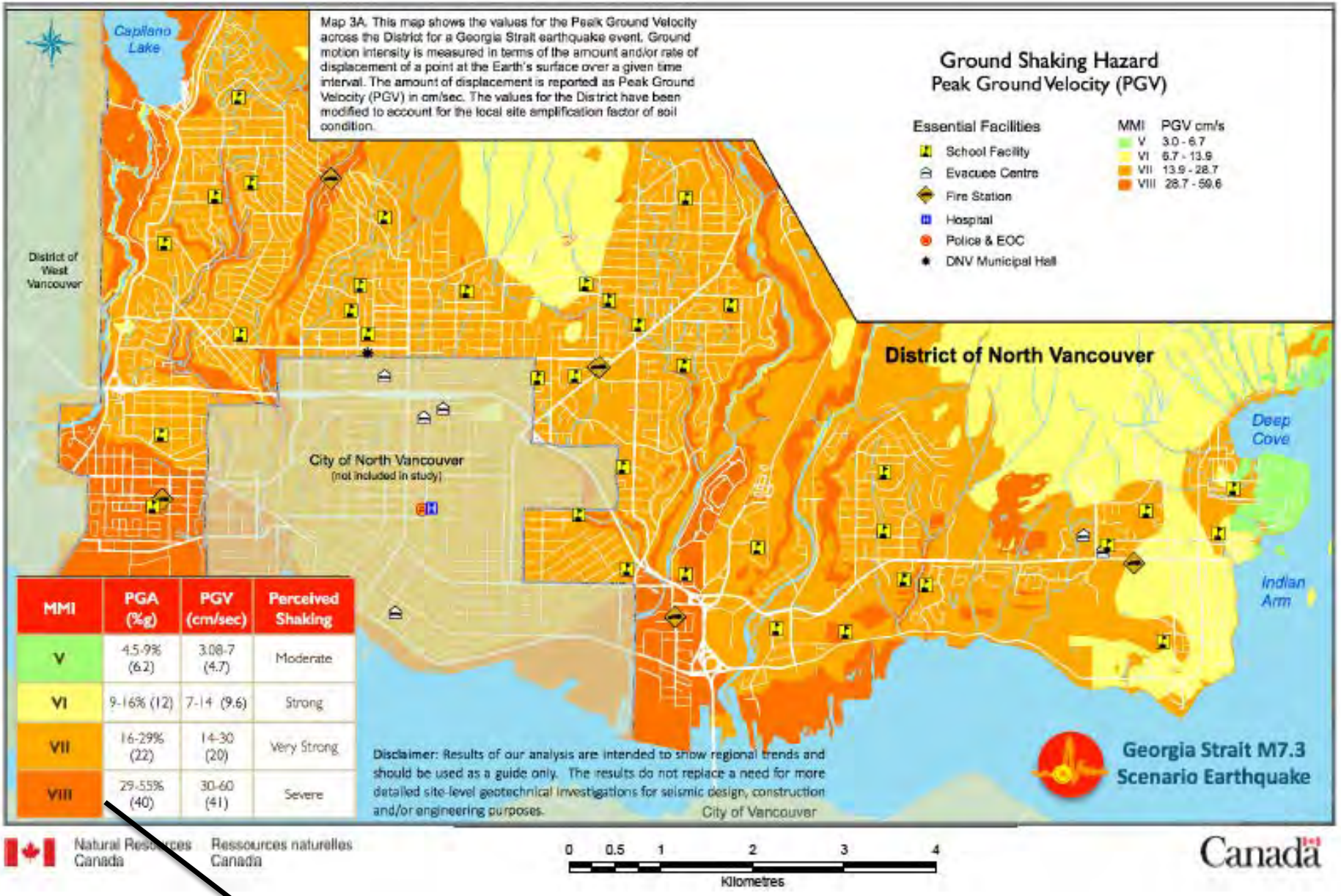
Journeay et al. (2015) A profile of earthquake risk for the District of North Vancouver, British Columbia. *Geol. Surv. Canada Open File 7677*



Geological Survey Canada (1998) GeoScape

Ground Shaking Hazard

Journeay et al. (2015)



MMI	PGA (%g)	PGV (cm/sec)	Perceived Shaking
V	4.5-9% (6.2)	3.08-7 (4.7)	Moderate
VI	9-16% (12)	7-14 (9.6)	Strong
VII	16-29% (22)	14-30 (20)	Very Strong
VIII	29-55% (40)	30-60 (41)	Severe

Deep orange = severe shaking, PGA = 29-55 %g, PGV = 30-60 cm/s

1. Plan and prepare

Assess and reduce risk

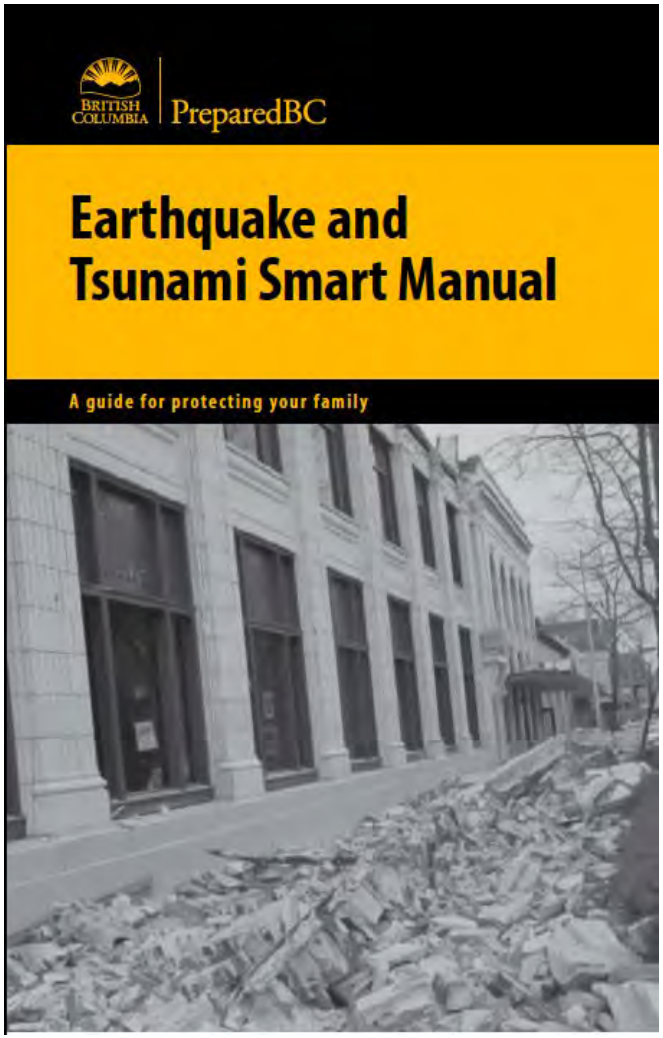
Emergency management planning, practise
"*The worst time to be exchanging business cards is during a crisis.*" - *Marcia McNutt*

Harden infrastructure
- Strict building codes
- Retrofit or rebuild critical infrastructure
  - Hospitals, fire stations
  - Bridges (disaster relief)
  - Airport
- Steady investment in all public buildings
  - Schools, community centres, …

Develop, deploy early warning systems

Educate public → personal preparation
- Secure your home, communication plan, disaster supplies

Next Shakeout BC – **October 20, 2016**



British Columbia government
http://www2.gov.bc.ca

Basic Emergency Supply Kit

- First Aid kit and medications
- Battery-powered or hand crank radio tuned to Environment Canada weather
- Battery-powered or hand crank flashlight with extra batteries
- Whistle to signal for help
- Cell phone with chargers, inverter or solar charger
- Local maps (identify a family meeting place) and some cash in small bills
- At least a three-day supply of non-perishable food. Manual can opener for cans
- Garbage bags, moist towelettes and plastic ties for personal sanitation
- Water, four litres per person per day for at least three days, for drinking and sanitation
- Dust mask to help filter contaminated air
- Seasonal clothing and footwear

2. Survive

DROP down onto your hands and knees

Get under sturdy desk or table

Crouch against interior wall

~~Triangle of life~~ – no!

~~Doorway~~ – no!

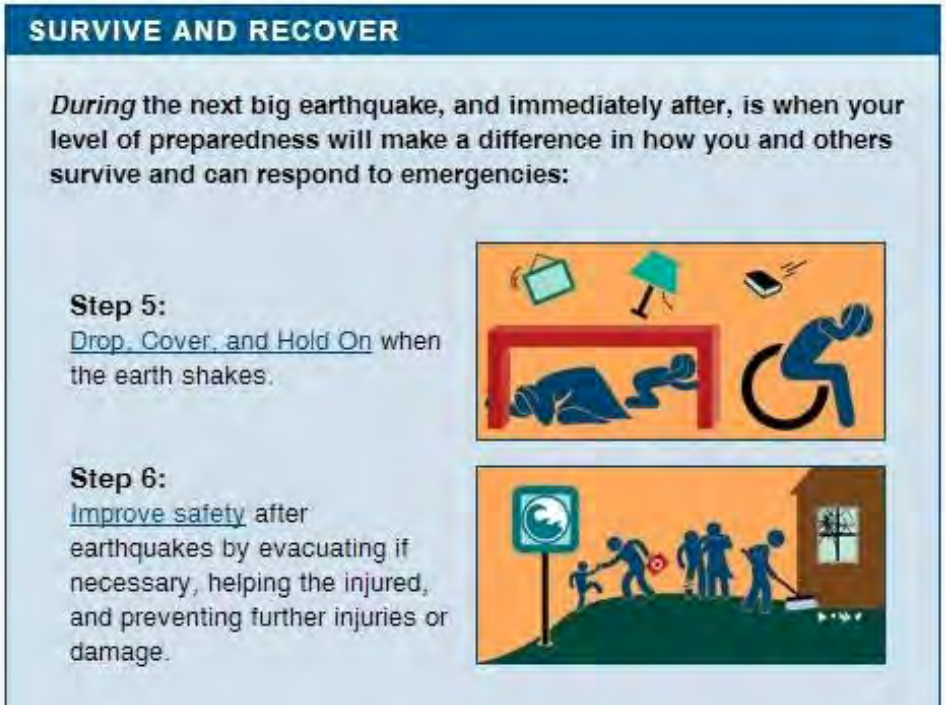
COVER your head and neck

HOLD ON

Wait until shaking stops to get out

Turn off gas, water

West coast tsunami – seek high ground



3. Respond and recover

Search and rescue

Help the injured, get hospitals functioning

Relief supplies

- Get airport and highways open

Restore essential services

- Water, electricity, sewer
- Telecommunications

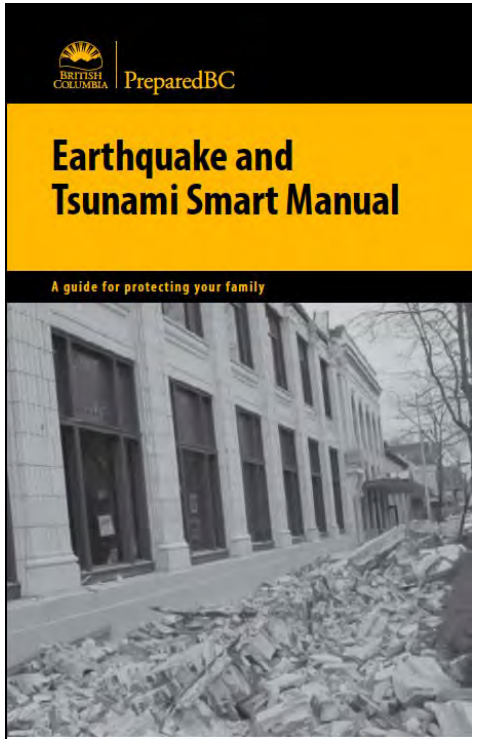
Debris removal

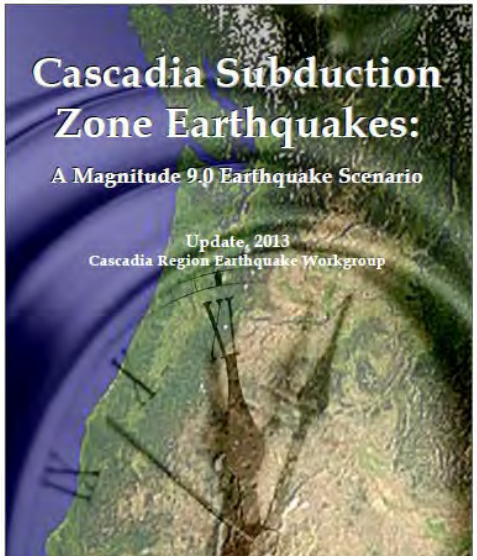
Get our city up and running

- Reconnect and rebuild our communities
- Minimize economic disruption

Next Shakeout BC – **October 20, 2016**

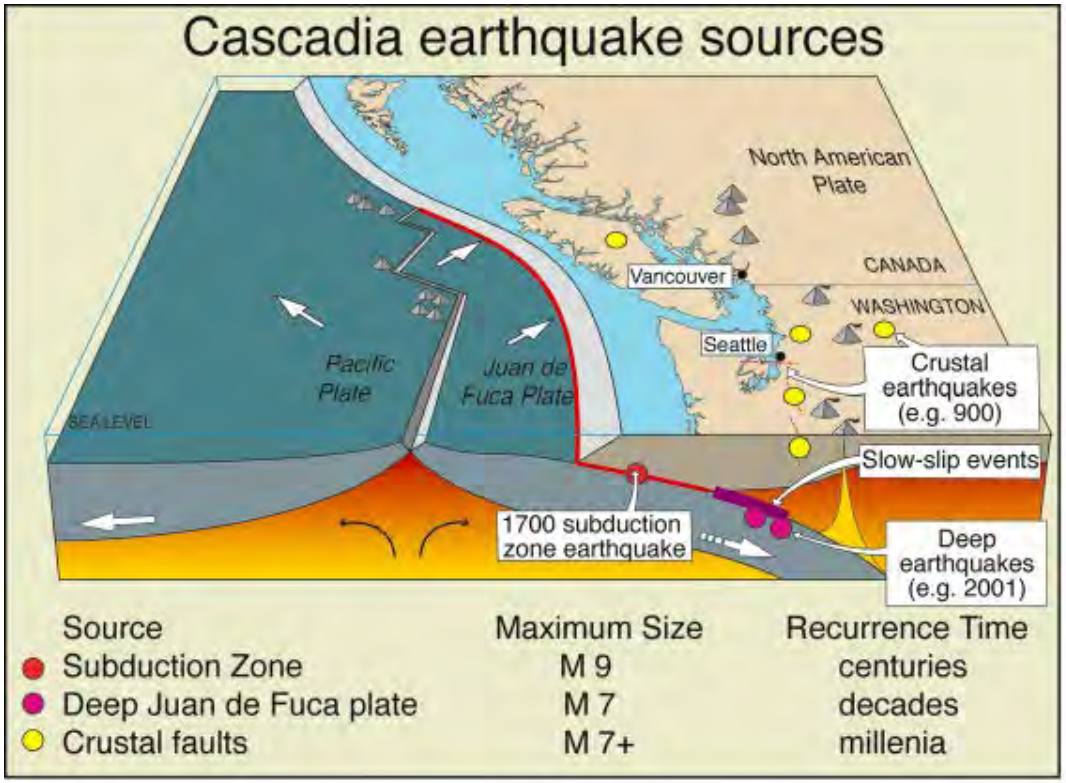
Resources





Wealth of information on the web on how to best prepare for an earthquake :

Government of Canada - *http://www.getprepared.gc.ca*
Government of British Columbia - *http://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/preparedbc/know-the-risks/earthquakes*
Shakeout BC – *www.shakeoutbc.ca* next BC wide event October 20, 2016
City of Vancouver - *http://vancouver.ca/home-property-development/earthquake.aspx*
UBC -*http://riskmanagement.ubc.ca/emergency-mgt/emergency-procedures/earthquake*
Cascadia Region Earthquake Workgroup - *www.crew.org*


Cascadia earthquake sources
North American Plate
CANADA
Vancouver
WASHINGTON
Seattle
Pacific Plate
Juan de Fuca Plate
SEA LEVEL
Crustal earthquakes (e.g. 900)
Slow-slip events
1700 subduction zone earthquake
Deep earthquakes (e.g. 2001)
Source
Maximum Size
Recurrence Time
Subduction Zone
M 9
centuries
Deep Juan de Fuca plate
M 7
decades
Crustal faults
M 7+
millenia

The End