

Update on New Scientific Research of Earthquake Hazards to Seattle

Art Frankel and Craig Weaver

U.S. Geological Survey

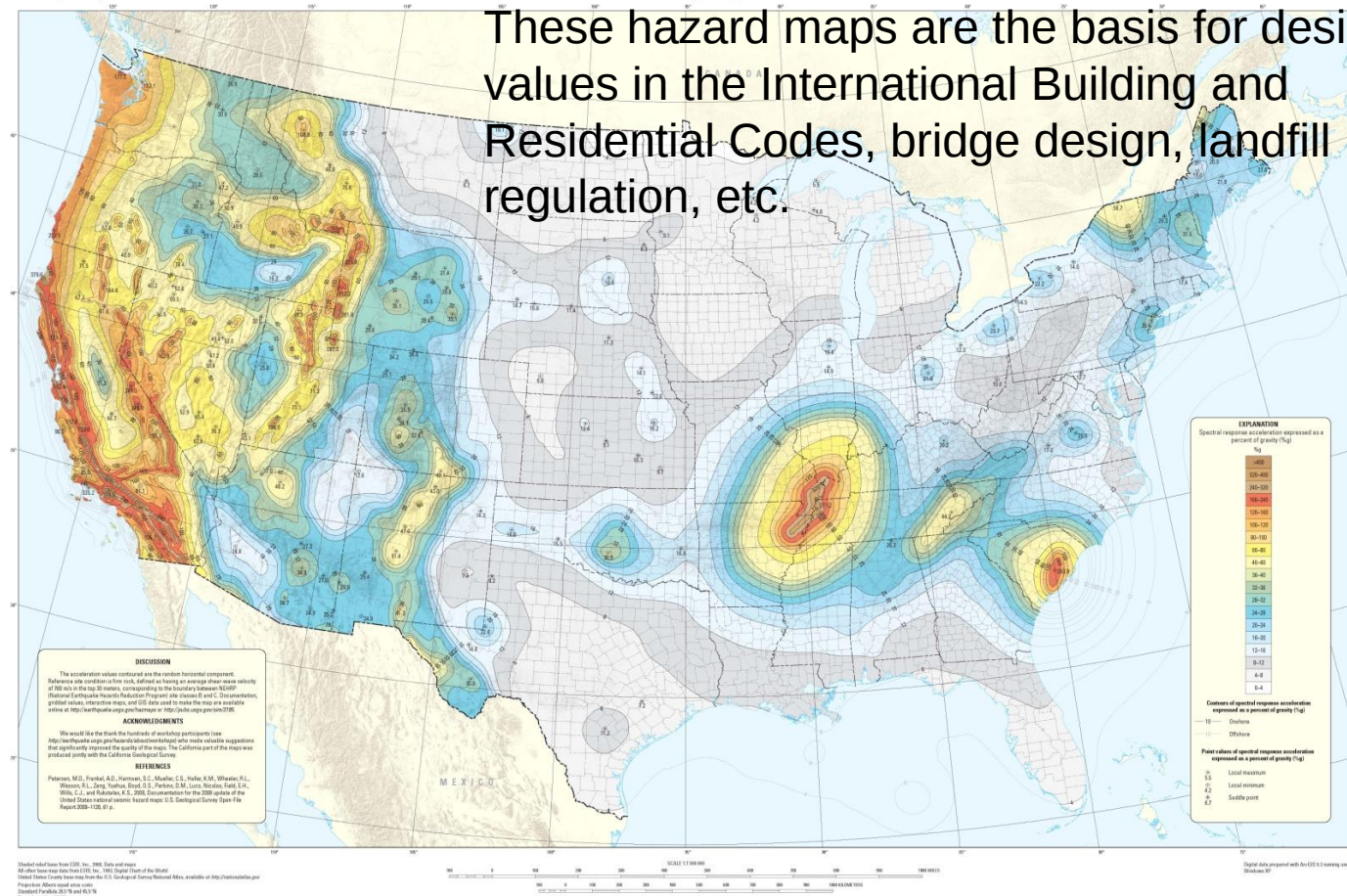
Seattle, WA

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April 9, 2012

Briefing to Seattle City Council

These hazard maps are the basis for design values in the International Building and Residential Codes, bridge design, landfill regulation, etc.



Seismic-Hazard Maps for the Conterminous United States, 2008
Horizontal Spectral Response Acceleration for 0.2-Second Period (5 Percent of Critical Damping)
with 2 Percent Probability of Exceedance in 50 Years

By

Mark D. Petersen,¹ Arthur D. Frankel,¹ Stephen C. Harmsen,¹ Charles S. Mueller,¹ Kathleen M. Haller,¹ Russel L. Wheeler,¹ Robert L. Wesson,¹ Yuehua Zeng,¹ Oliver S. Boyd,¹ David M. Perkins,¹ Nicolas Luco,¹ Edward H. Field,¹ Christopher J. Wills,² and Kenneth S. Rukstales¹

2011

U.S. Geological Survey
Hydrologic Geological Survey, Sacramento, CA

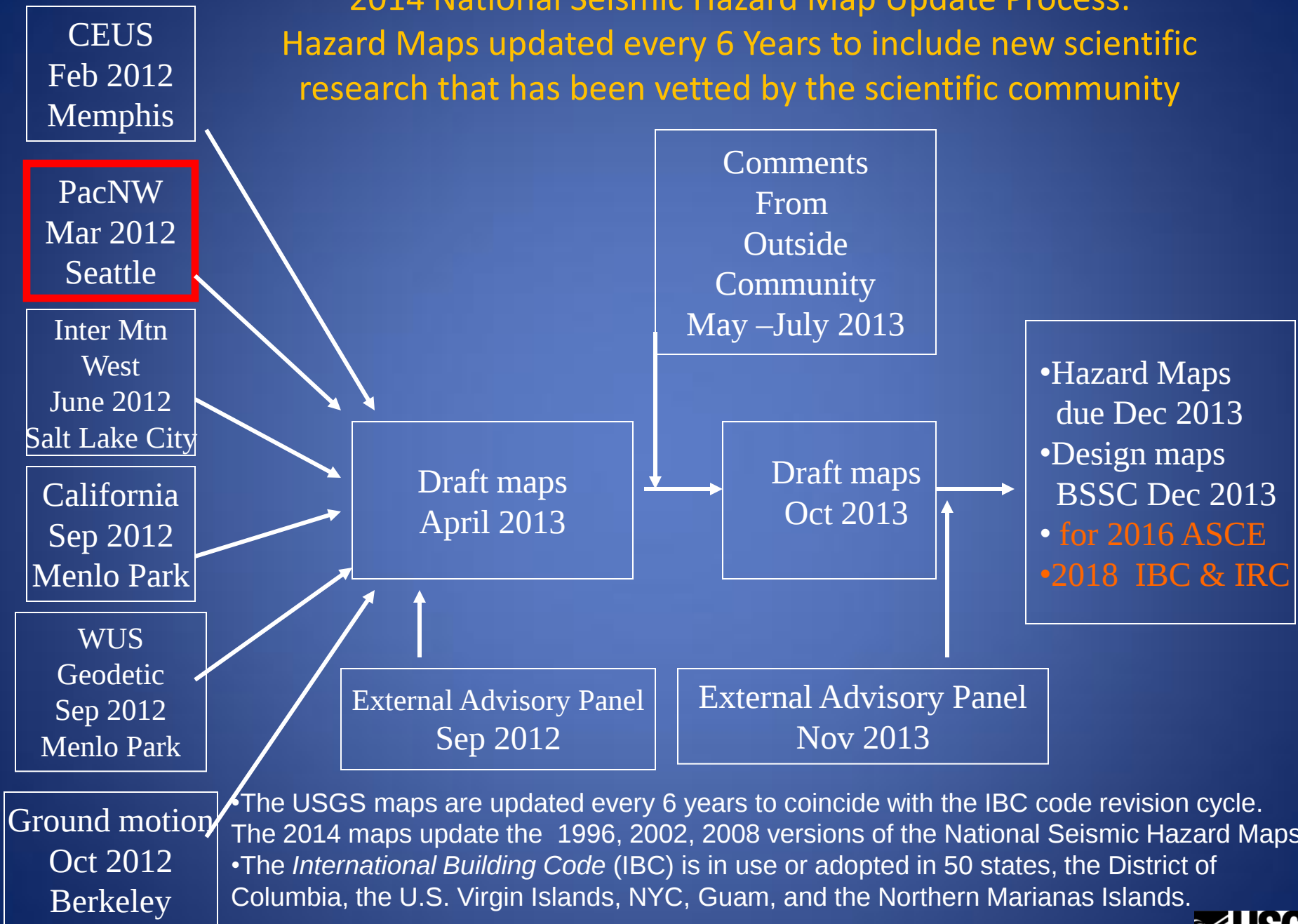
Publishing support provided by:
 Pioneer Publishing Service
 Manuscript prepared for publication by: Drs. 20, 2011
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 (e.g., 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 265

2014 National Seismic Hazard Map Update Process: Hazard Maps updated every 6 Years to include new scientific research that has been vetted by the scientific community

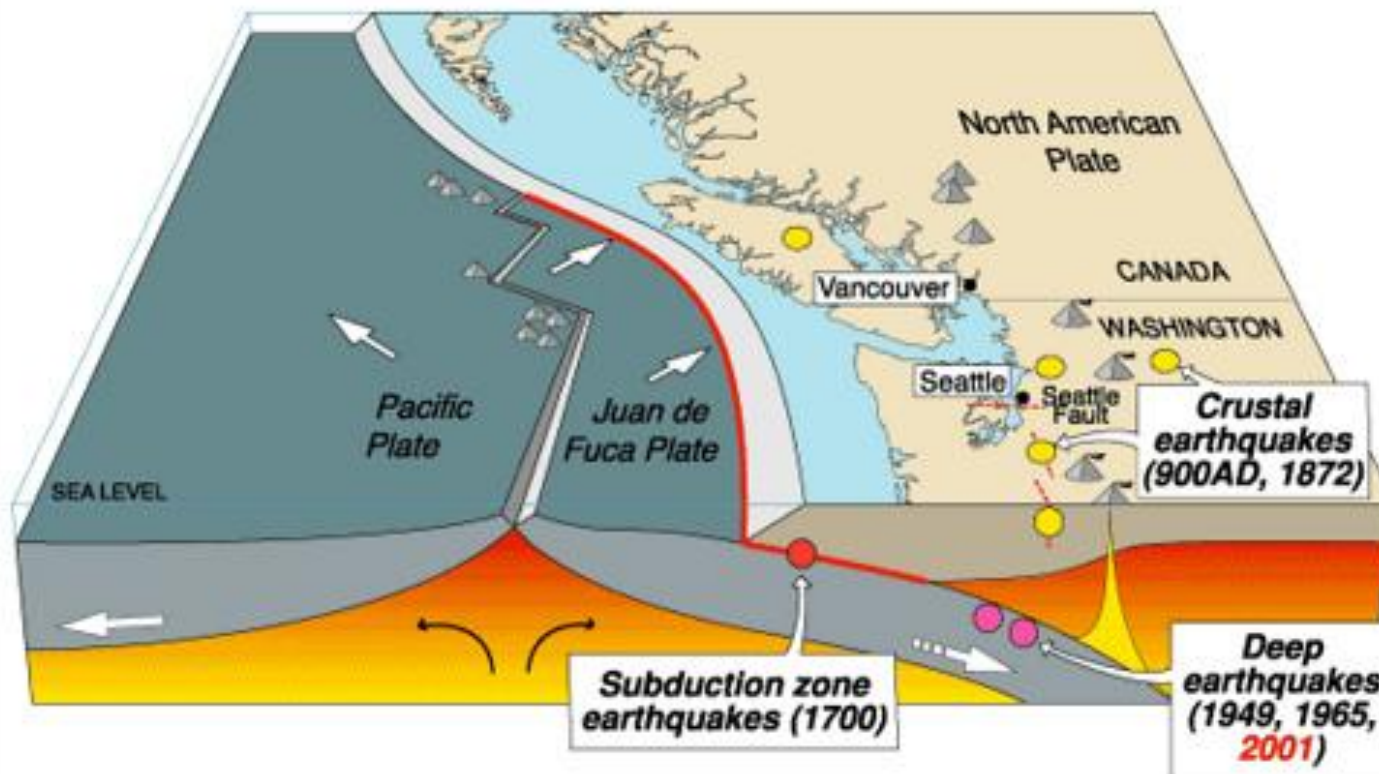


2014 Map update

- Use best available science, need peer-reviewed published information
- Consider alternative models and range of input parameters
- Learn from the past: consider recent large subduction earthquakes (Tohoku, Chile)

New research results haven't
substantially changed our
assessment of earthquake hazard
for Seattle

Cascadia earthquake sources



Source	Affected area	Max. Size	Recurrence
● Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
● Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
● Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

Approximate 50 year probabilities

- Cascadia M9: 10-14%
- Seattle Fault $M \geq 6.5$: 5% (from slip rate, GR model; 1000 yr return time) ???
- Deep $M \geq 6.5$: 84% (from 1949, 1965, 2001)
- Random shallow $M \geq 6.5$ in entire Puget Sound area: 15% (mostly from rate of $M \geq 4$ since 1963, $b=0.8$)

Recurrence times for great earthquakes on the Cascadia subduction zone

- Unlike Japan seismic hazard maps, the U.S. national seismic hazard maps use inputs based on evidence of past earthquakes over thousands of years.
- For example, for the Cascadia subduction zone, we use evidence of coastal subsidence and tsunamis over past 5000 years in the inputs to the national maps

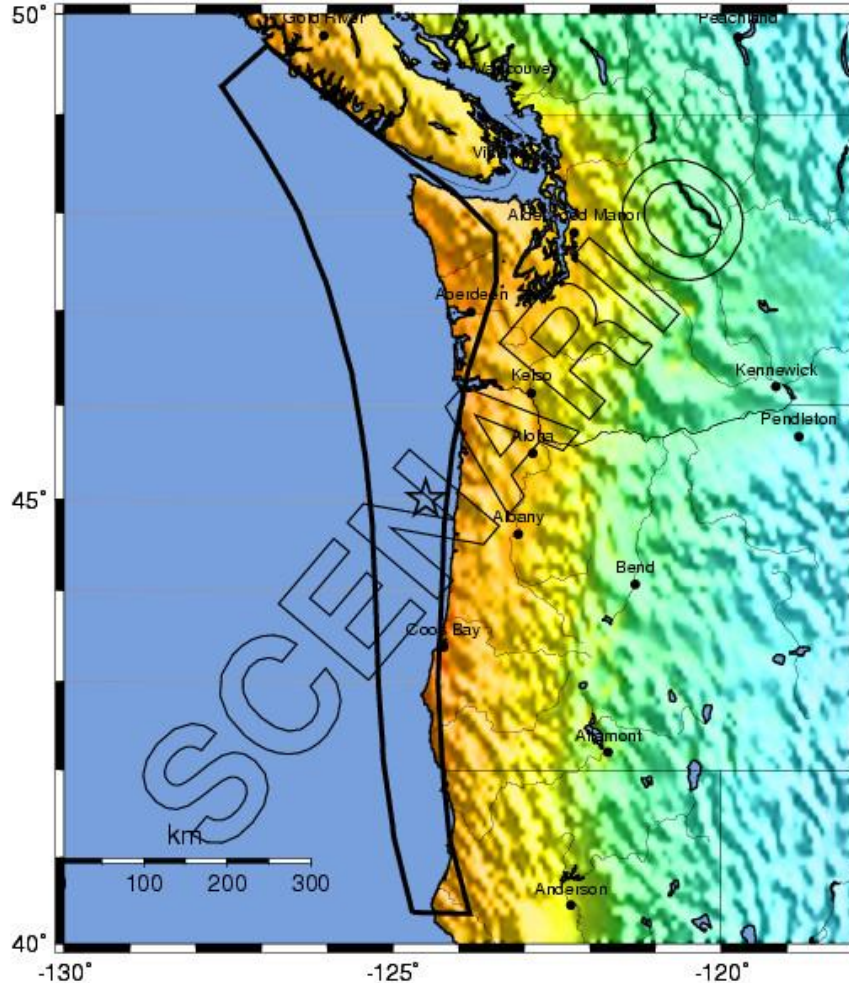
Cascadia Subduction Zone

- Produces similar type of earthquakes as occurred in Tohoku, Japan (2011, M9.0) and Maule, Chile (2010, M8.8)
- How often do M8-9 earthquakes occur on the CSZ? Last one was in 1700; estimate 10-14% chance in 50 years; 25% chance in southern part
- How close will the earthquake get to Seattle?
- How strong will the ground shaking be in Seattle?

-- Earthquake Planning Scenario --

ShakeMap for Casc9.0 Scenario

Scenario Date: JUL 16 2009 09:00:00 PM PST PST M 9.0 N45.00 W124.50 Depth: 10.0km



PLANNING SCENARIO ONLY -- Map Version 3 Processed Tue Sep 29, 2009 03:43:47 PM MDT

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+

Scientific consensus is that these M8.8-9.2 earthquakes occur about every 550 years, on average

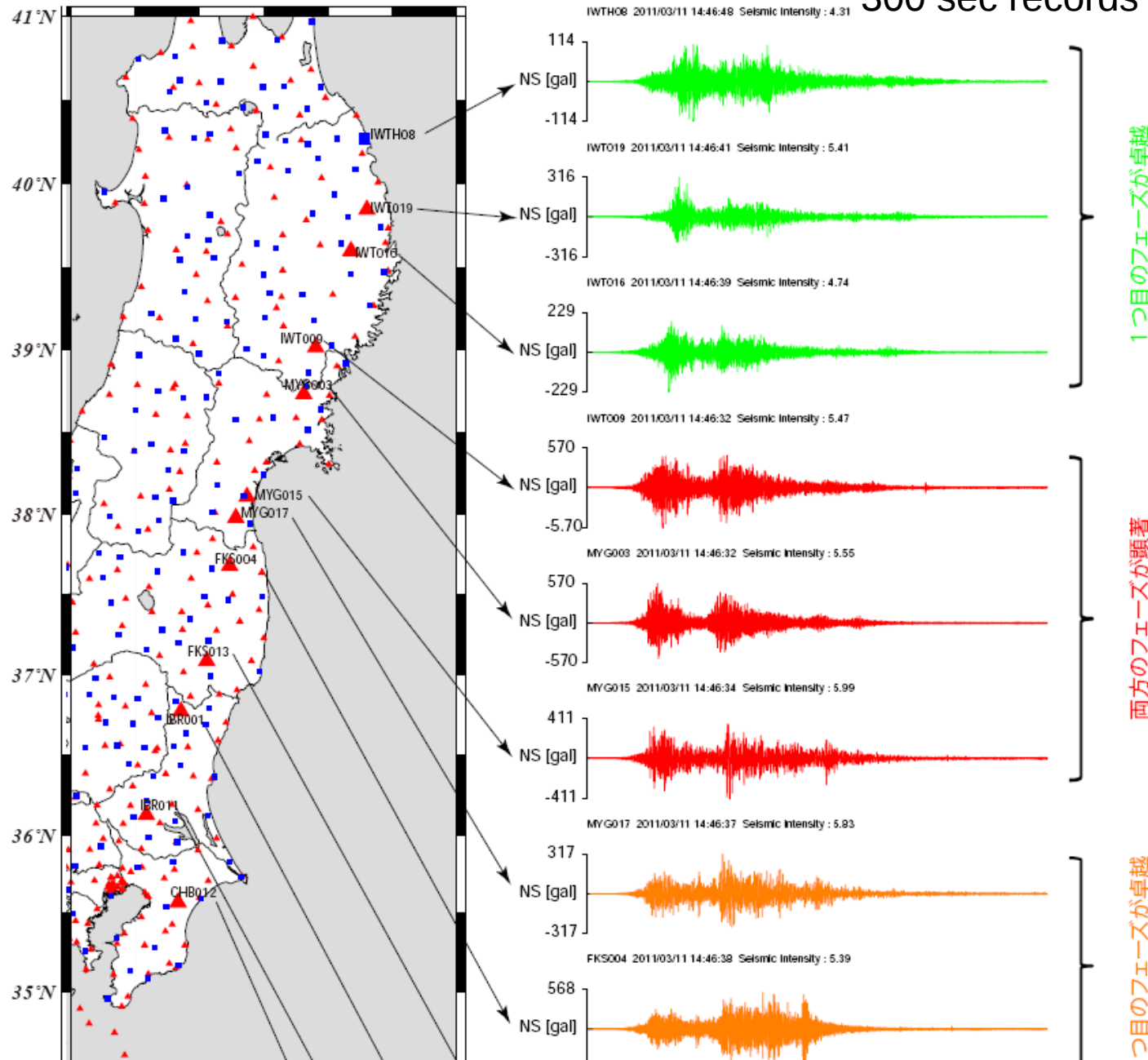
Last one was in 1700

Estimate a 10-14% chance of occurring in the next 50 years

近地強震動波形に見られるフェーズの特徴

防災科学技術研究所資料

300 sec records



Seismograms showing ground accelerations from M9.0 Tohoku earthquake

(figure from NIED)

Offshore and onshore studies indicate that the Cascadia subduction zone sometimes produces M8 earthquakes in its southern portion, in addition to M9 earthquakes that probably rupture the entire length of the subduction zone

Consensus from our workshops is that these M8 earthquakes occur about once in 1000 years, although more research on submarine landslides is needed; they suggest a shorter recurrence time.

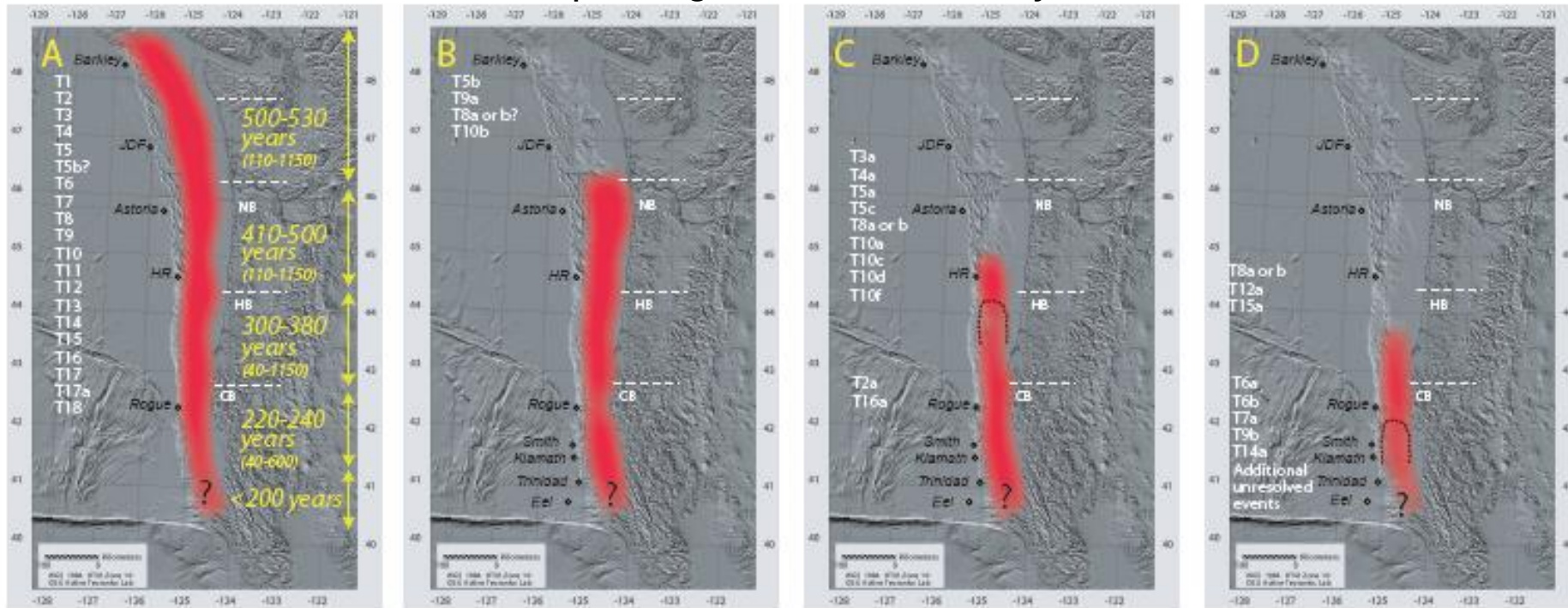


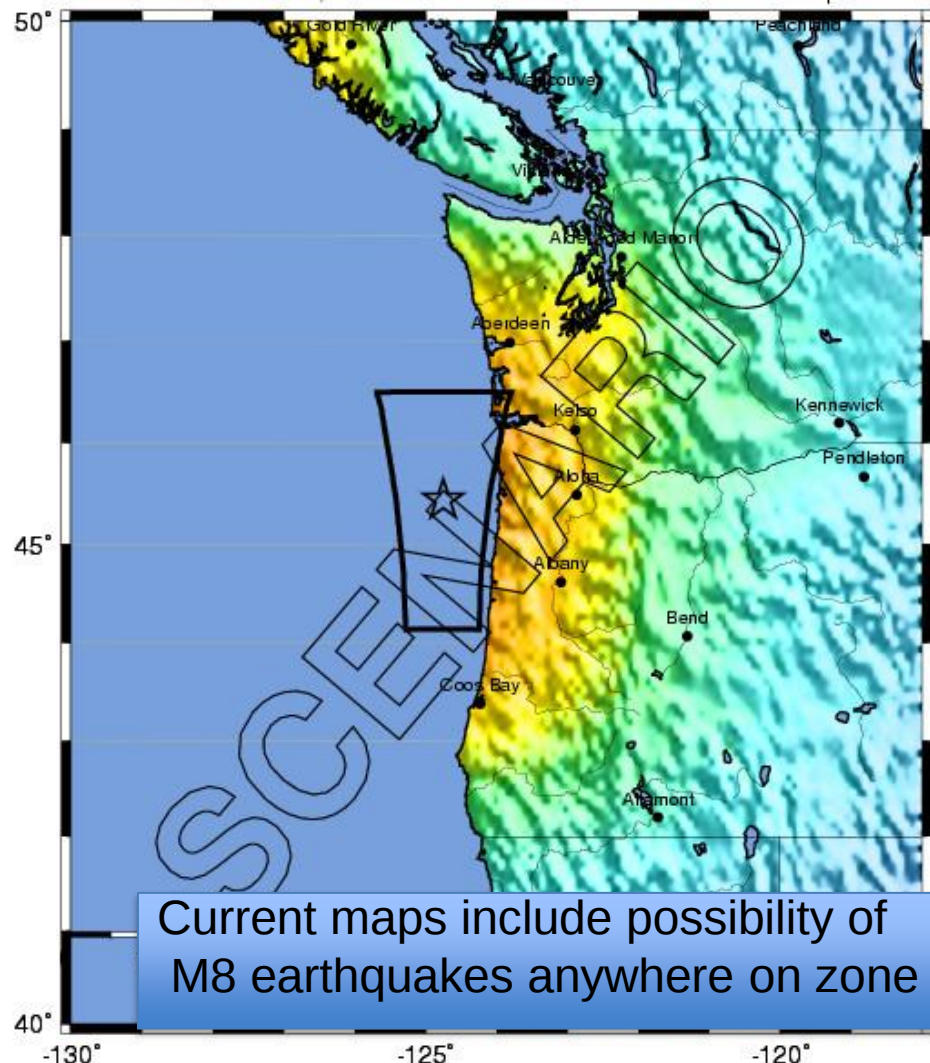
Figure from Goldfinger et al. (in press); great earthquake ruptures inferred from turbidites over past 10,000 years

We convened workshop at OSU on Nov 18-19, 2010 to evaluate turbidite data for constraining recurrence models for CSZ

- 1) Consensus on M9 whole CSZ rupture events with ave. recurr. time of 500-600 yr (or serial M8's in some cases)

-- Earthquake Planning Scenario --
ShakeMap for Casc_North8.3 Scenario

Scenario Date: Thu Jun 4, 2009 12:00:00 GMT M 8.3 N45.44 W124.75 Depth: 0.0km



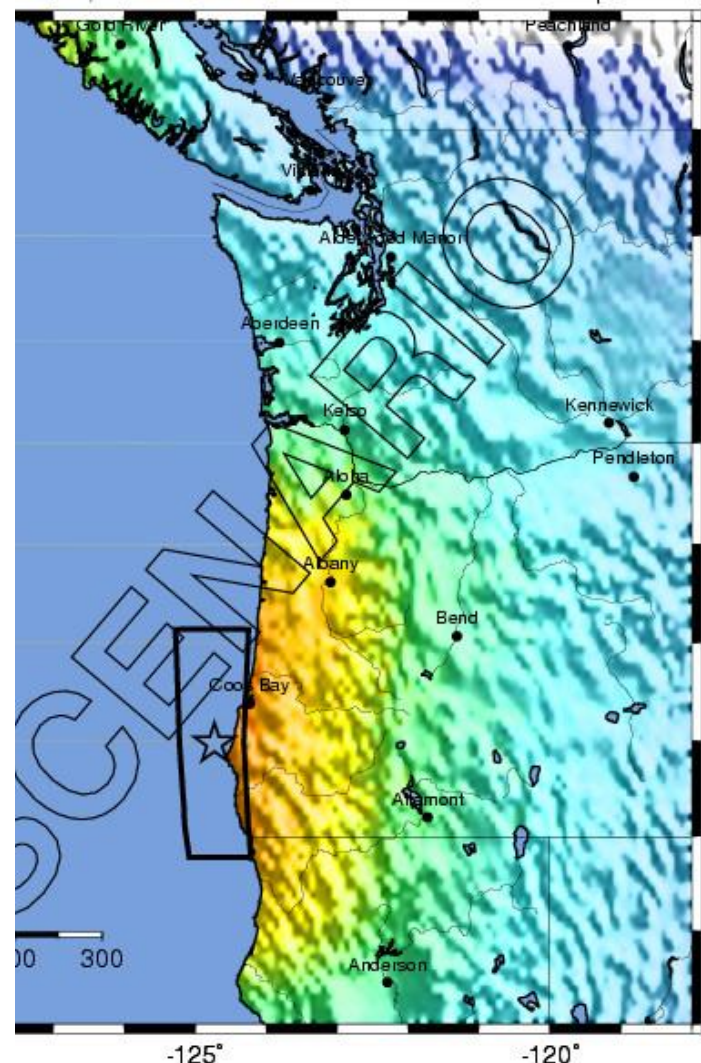
Current maps include possibility of
M8 earthquakes anywhere on zone

PLANNING SCENARIO ONLY -- Map Version 10 Processed Thu Oct 1, 2009 10:09:21 AM MDT

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+

-- Earthquake Planning Scenario --
ShakeMap for Casc_South8.3 Scenario

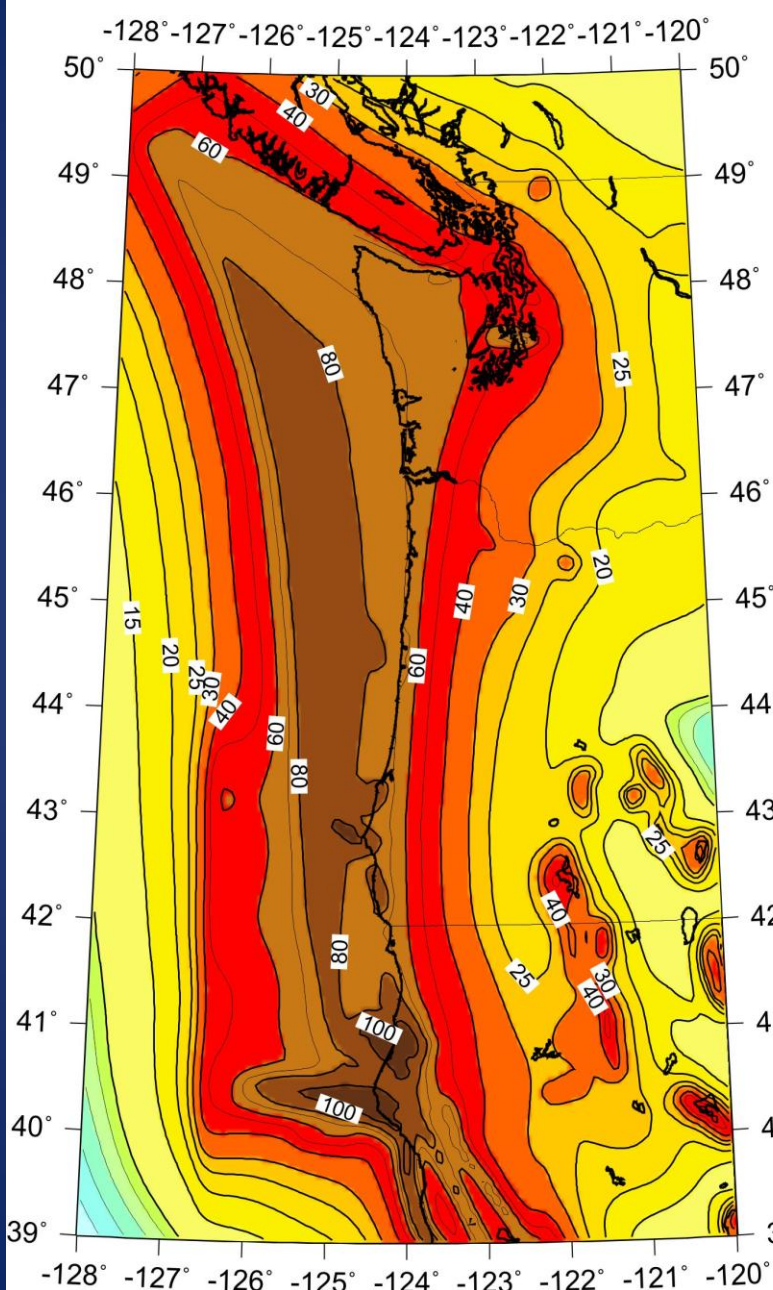
Scenario Date: Thu Jun 4, 2009 12:00:00 GMT M 8.3 N42.97 W124.73 Depth: 0.0km



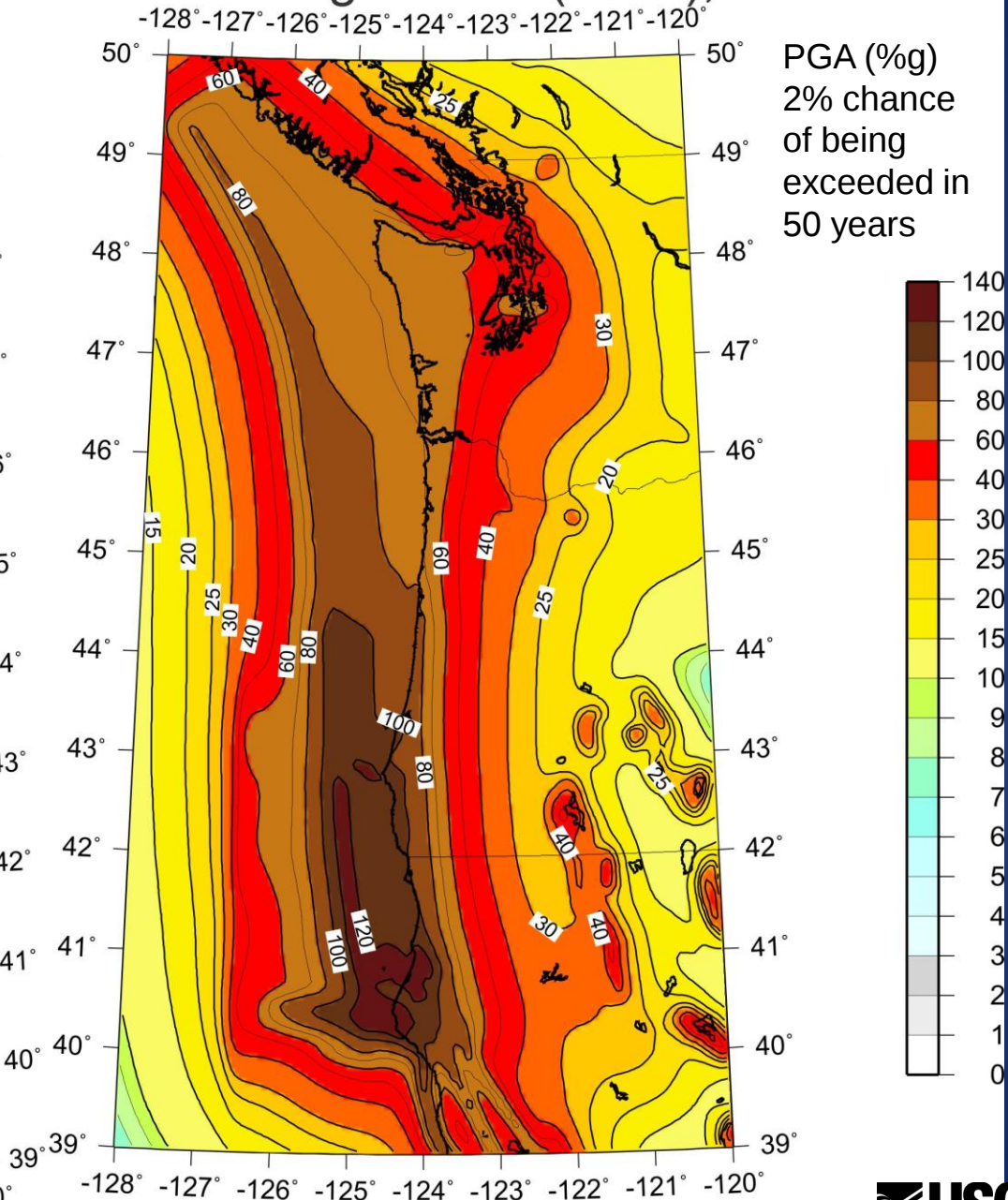
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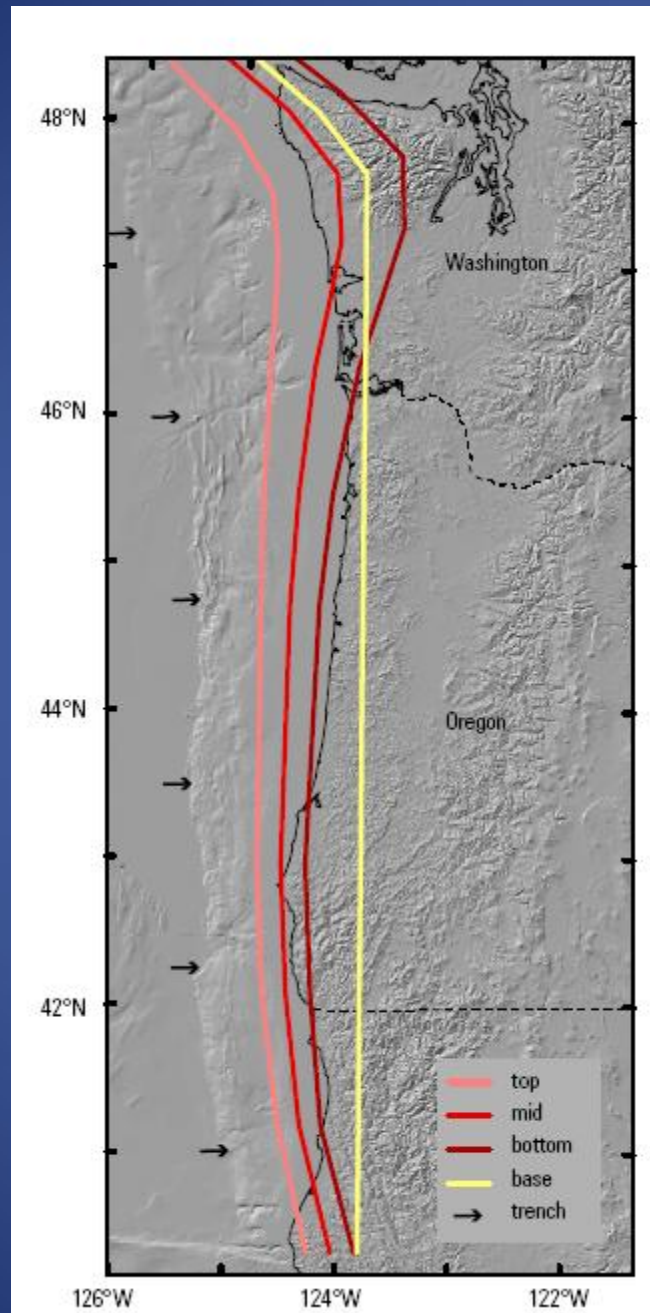
Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
II-III	IV	V	VI	VII	VIII	IX	X+

2008 all sources



with Goldfinger et al. (2012), full wt





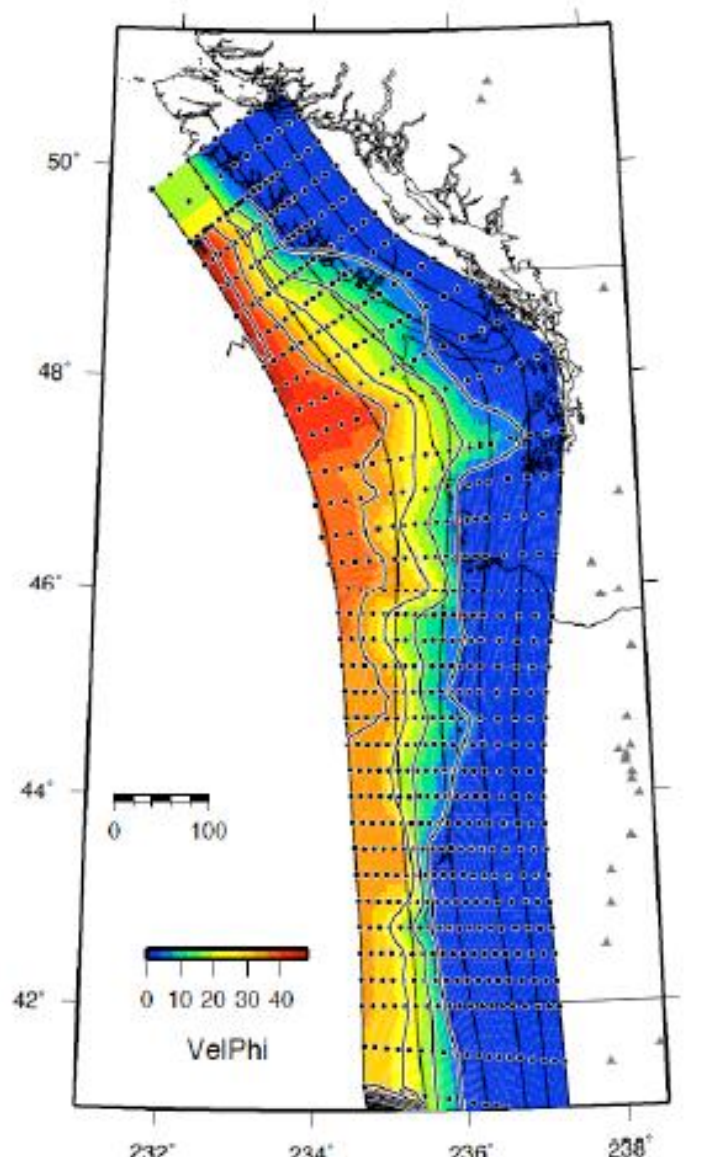
Great earthquakes on
Cascadia Subduction Zone
have been included in NSHM's
since 1996 with rates
based on paleoseismic studies
(e.g., Atwater, 1992)
Included in design values
Of building codes since IBC 2000

How close do these
earthquakes get to Seattle?

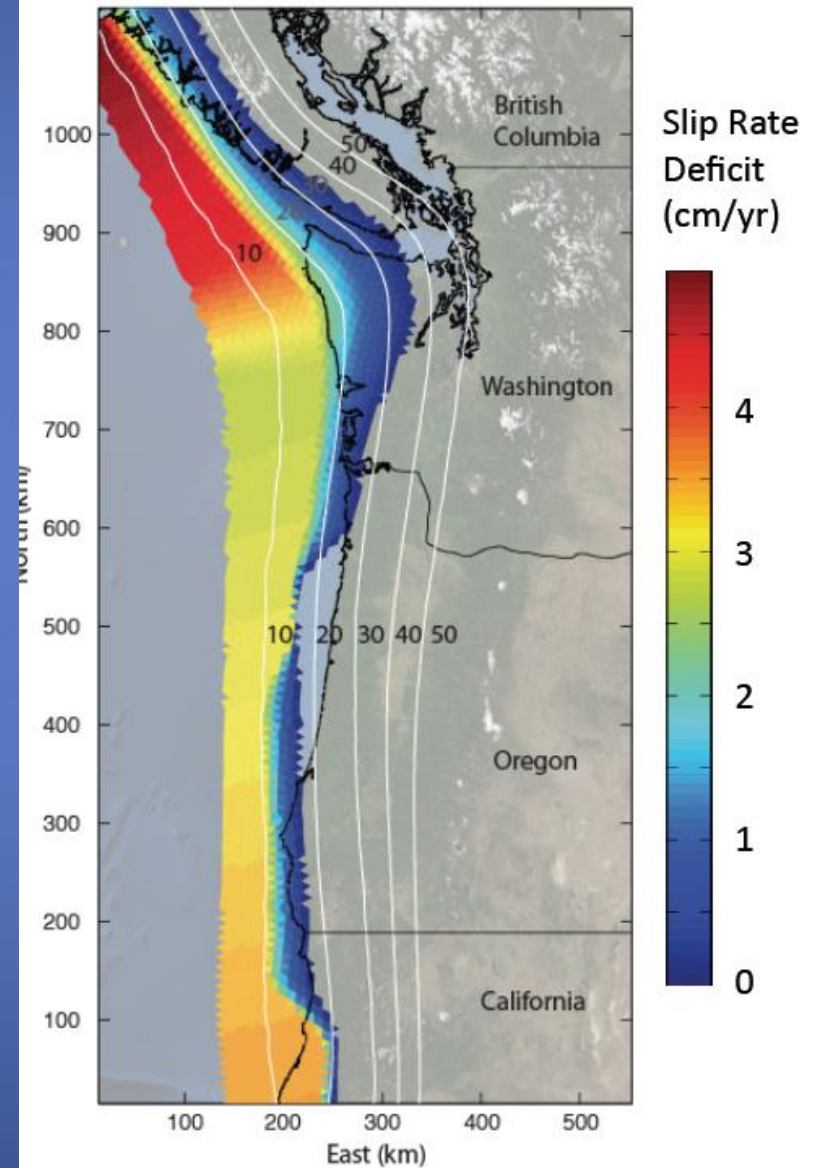
Figure shows different models for
eastern edge of rupture used in
2002 and 2008 maps; we already
accounted for possibility they may
get within about 80 km of Seattle

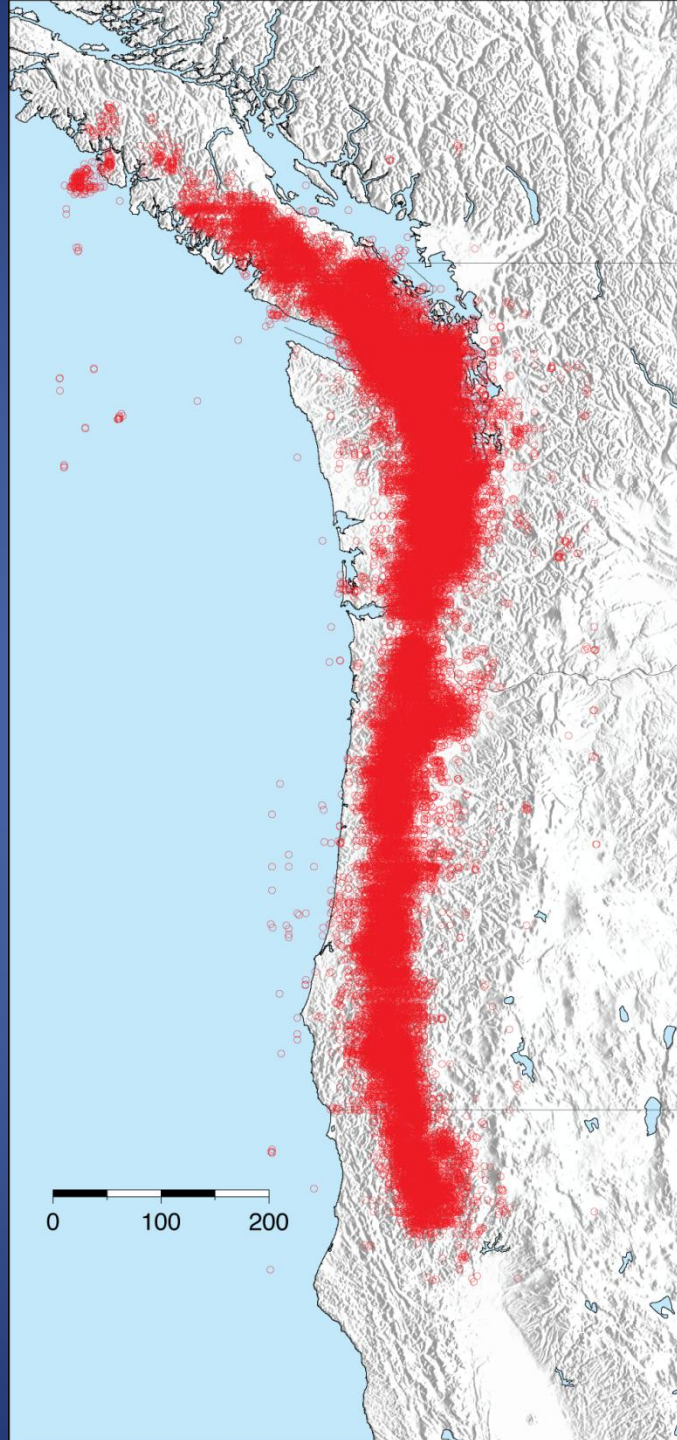
How close will subduction zone earthquakes get to Seattle?
Use GPS measurements to estimate where the fault is locked

McCaffrey and King (2011)



Schmidt et al. (2011)





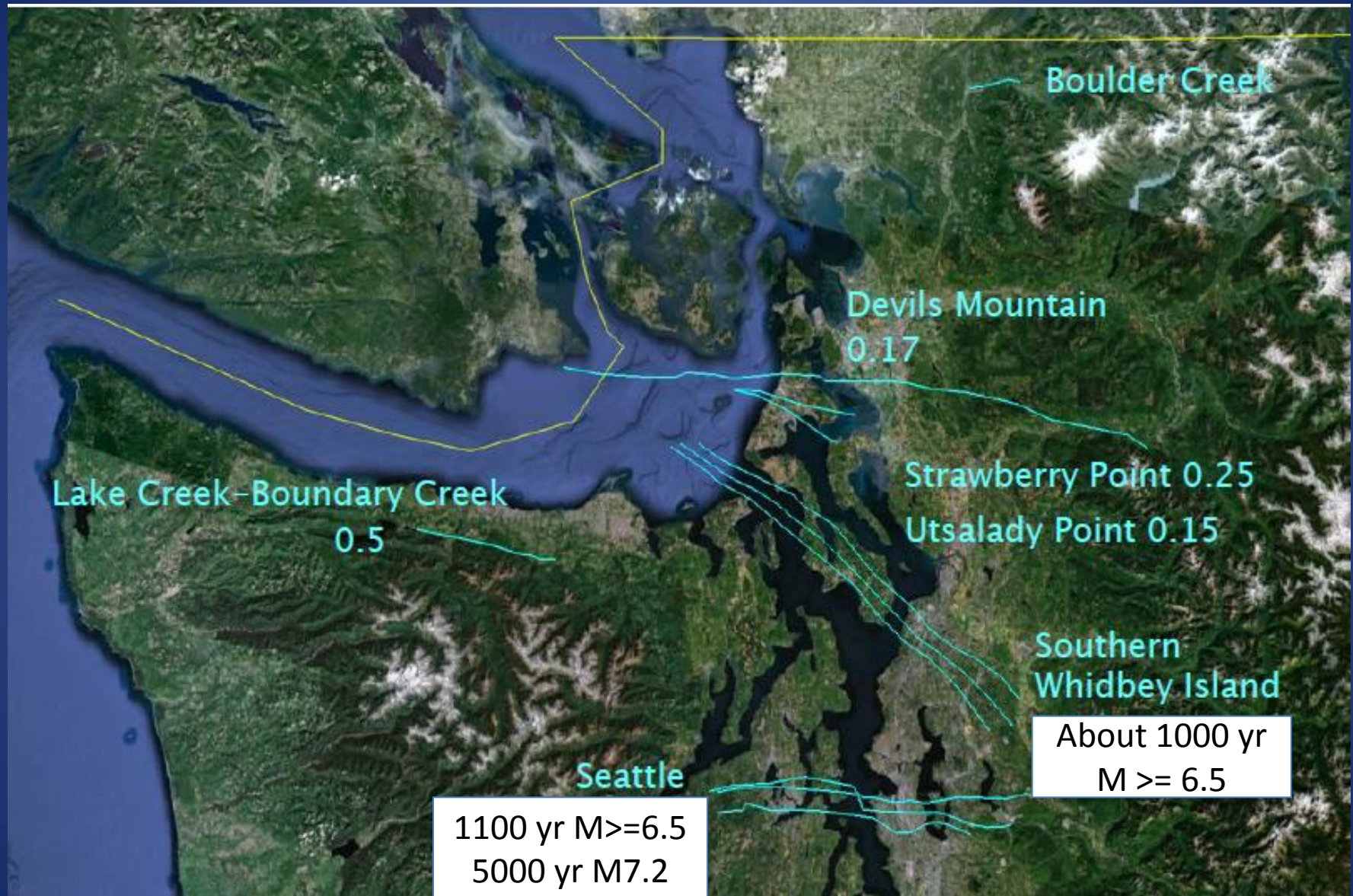
Nonvolcanic tremor locations
From Aaron Wech, UW

Indicates deep portion of fault
where slow slip occurs
releasing strain

Top of zone is possible
location of eastern edge
of great earthquakes

Already considered in 2002
And 2008 hazard maps

Crustal faults in NW Washington used
in the current hazard maps (with slip rates in mm/yr)

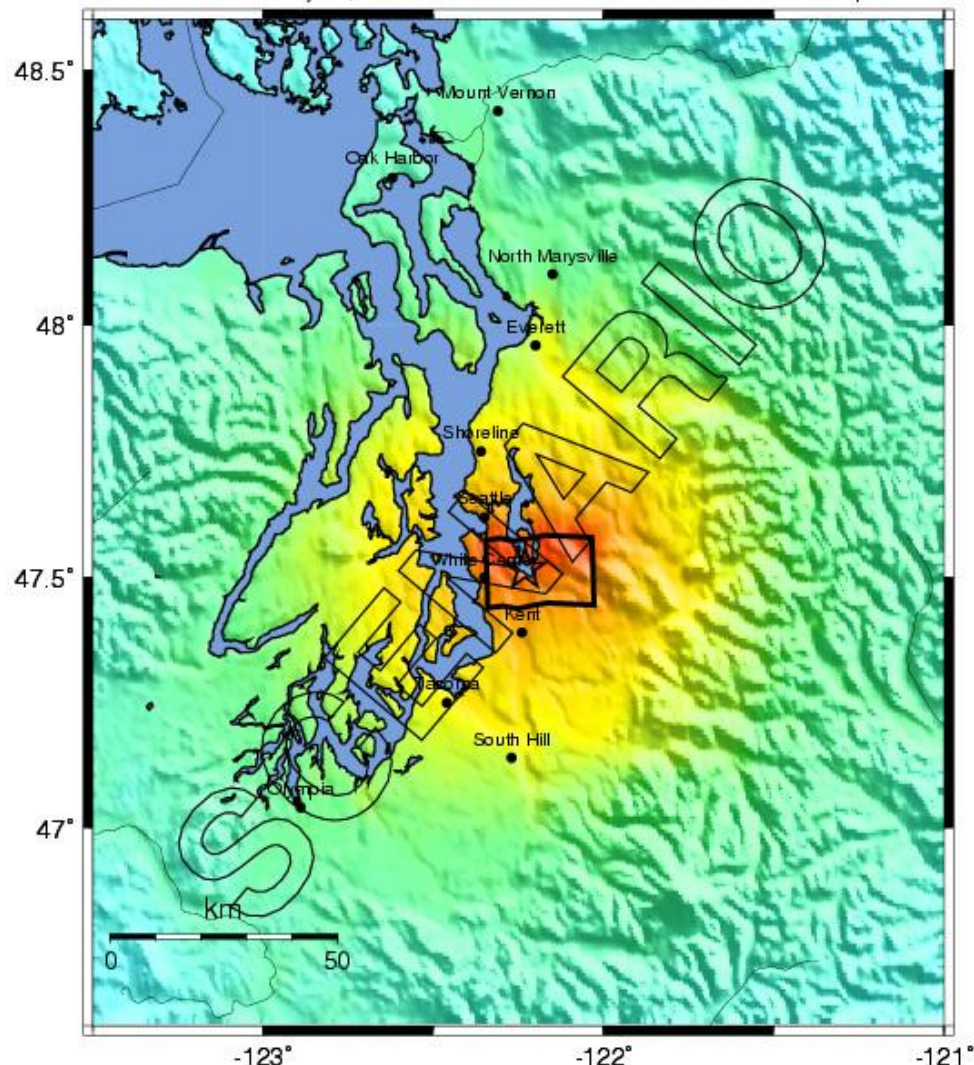


Faults near Seattle

- Seattle fault: no changes, estimate 5% chance in 50 years of $M \geq 6.5$
- Southern Whidbey Island fault
- Will add Tacoma fault to national seismic hazard maps
- Also can have M6 earthquakes on faults that haven't been identified or mapped

-- Earthquake Planning Scenario --
ShakeMap for SeattleM6.7 Scenario

Scenario Date: Sun May 15, 2011 12:00:00 GMT M 6.7 N47.52 W122.23 Depth: 0.0km



PLANNING SCENARIO ONLY -- Map Version 3 Processed Thu May 19, 2011 03:57:50 PM MDT

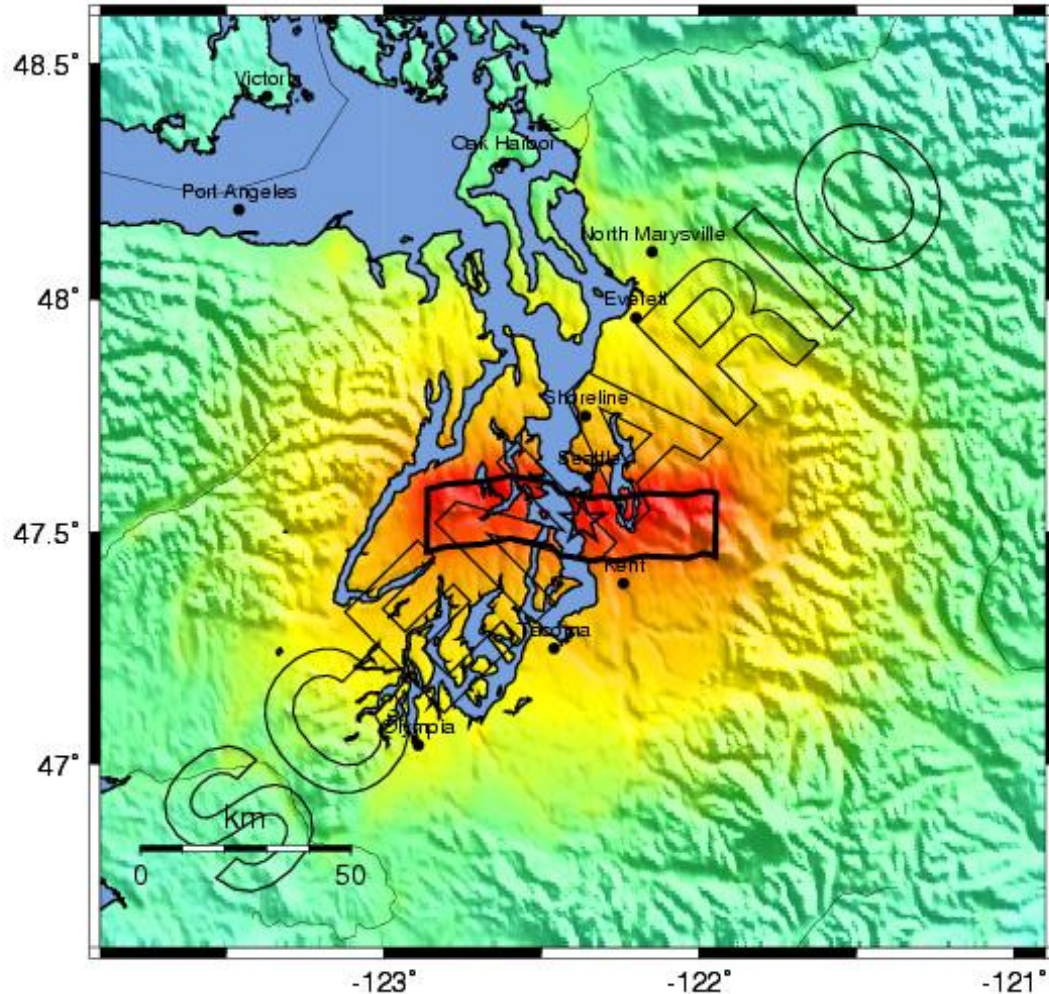
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16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

Scenario maps done for
Washington Emergency
Management Division

This scenario is for a
M6.7 on the Seattle fault

-- Earthquake Planning Scenario --
ShakeMap for SeattleM7.2 Scenario

Scenario Date: Wed Apr 20, 2011 12:00:00 GMT M 7.2 N47.52 W122.37 Depth: 0.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Mon Apr 25, 2011 03:37:50 PM MDT

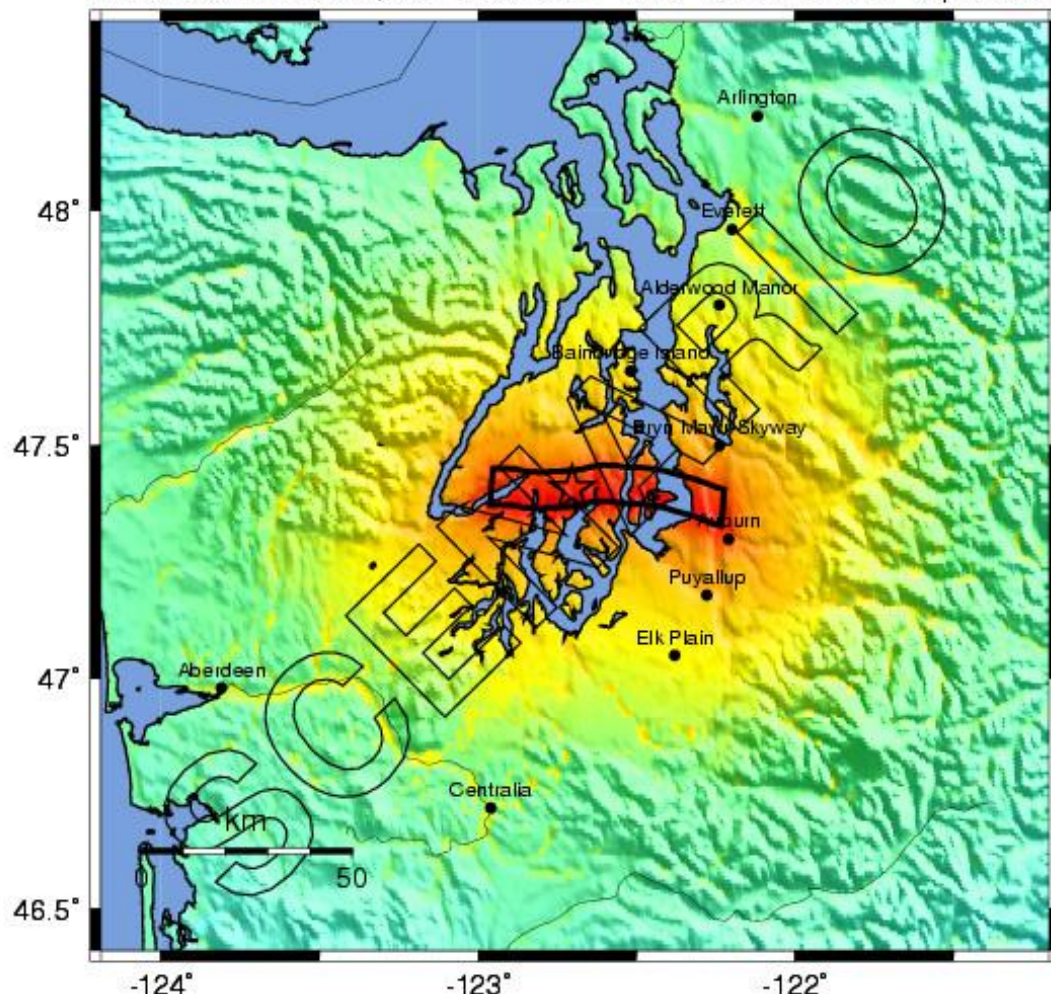
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC. (%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL. (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16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

Scenario for M7.2
earthquake on
Seattle fault,

Similar to earthquake
that occurred
1100 years ago

-- Earthquake Planning Scenario --
ShakeMap for Tacoma7.1 Scenario

Scenario Date: Thu Jun 4, 2009 12:00:00 GMT M 7.1 N47.41 W122.70 Depth: 0.0km



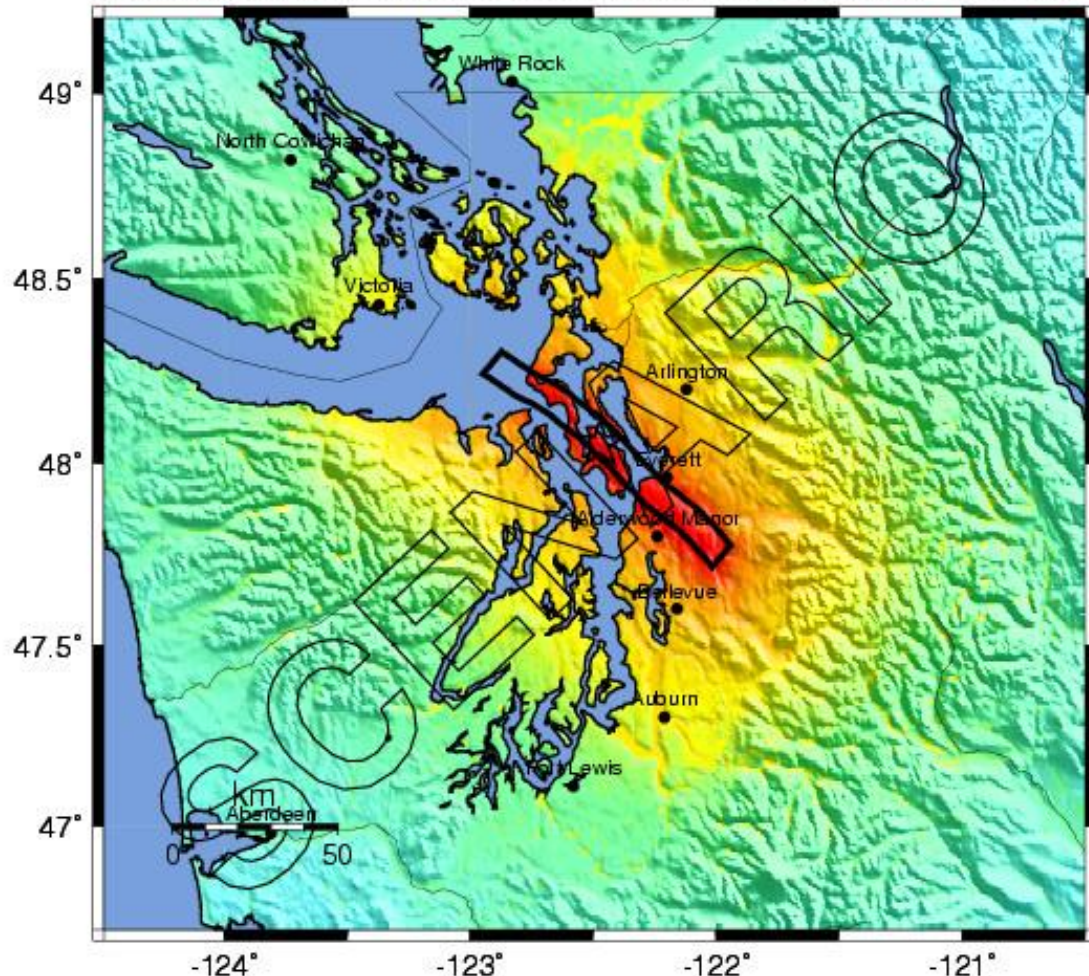
PLANNING SCENARIO ONLY -- Map Version 1 Processed Thu Jun 4, 2009 03:09:25 PM MDT

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+

Scenario for M7.1
Earthquake on
Tacoma fault

-- Earthquake Planning Scenario --
ShakeMap for Swif7.4 Scenario

Scenario Date: Mon Apr 27, 2009 12:00:00 GMT M 7.4 N48.05 W122.47 Depth: 0.0km

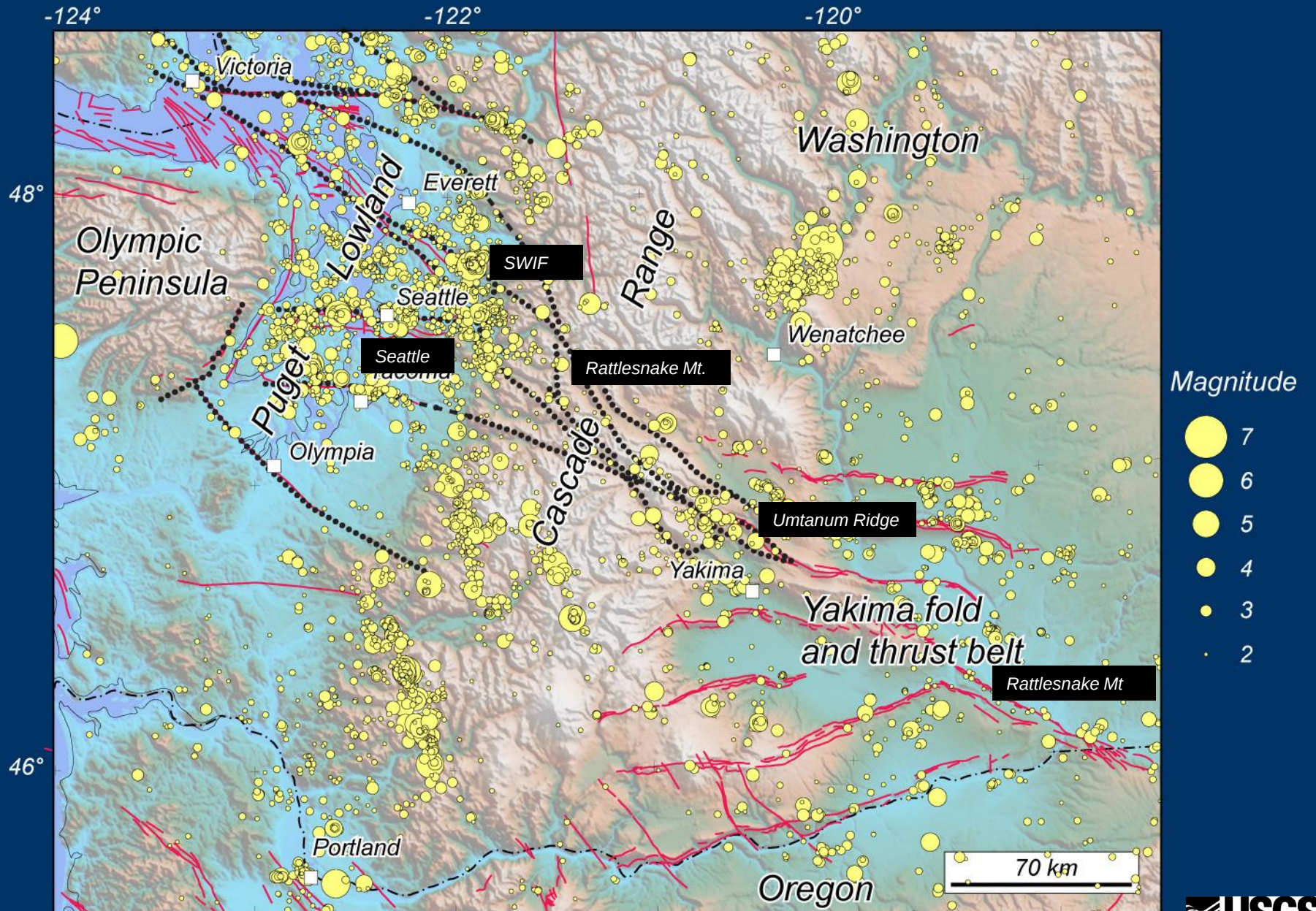


PLANNING SCENARIO ONLY -- Map Version 10 Processed Thu May 7, 2009 03:50:25 AM MDT

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+

Scenario for
M7.4 on Southern
Whidbey Island fault

The Seattle fault is a splay off the SWIF system in new models



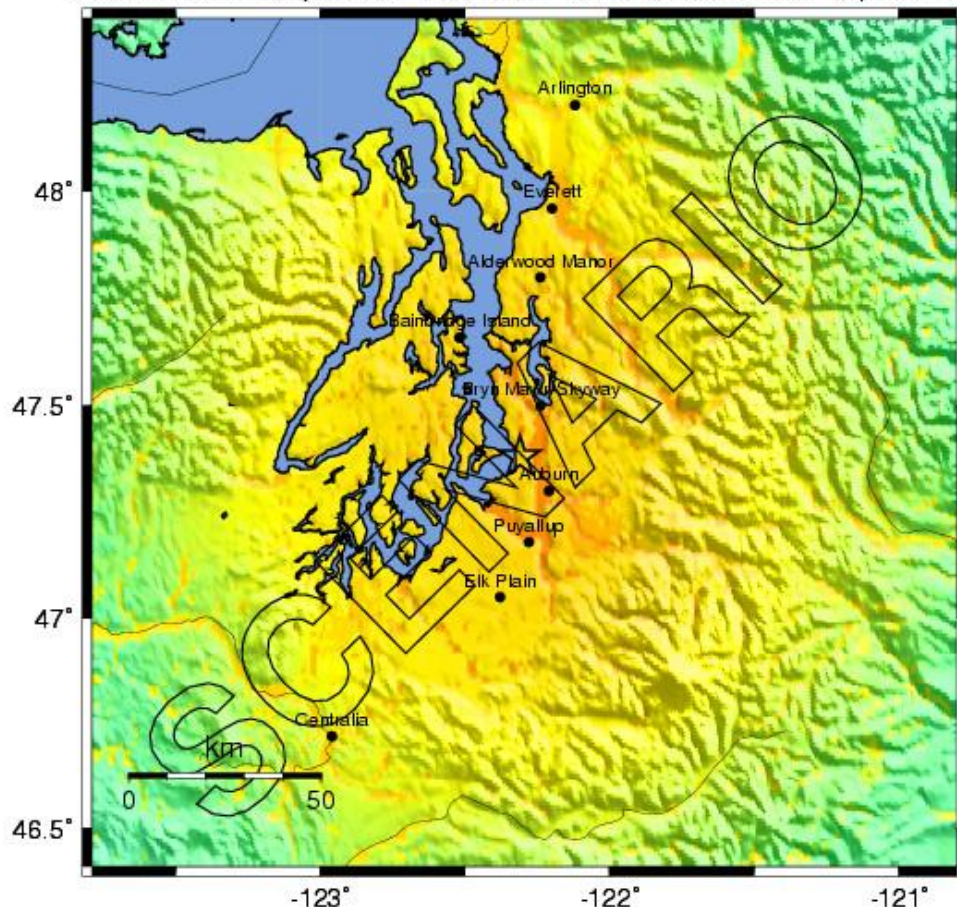
Deep earthquakes like 2001 Nisqually and 1949 and 1965 earthquakes

- No change in our understanding of these
- Given 30 year recurrence time, highly likely to have another one of these in the next 50 years
- At workshop we debated possibility of having deep M6-7 earthquake under Portland; this is included in current maps

-- Earthquake Planning Scenario --

ShakeMap for Seatac7.2 Scenario

Scenario Date: Thu May 14, 2009 12:00:00 GMT M 7.2 N47.38 W122.31 Depth: 52.0km



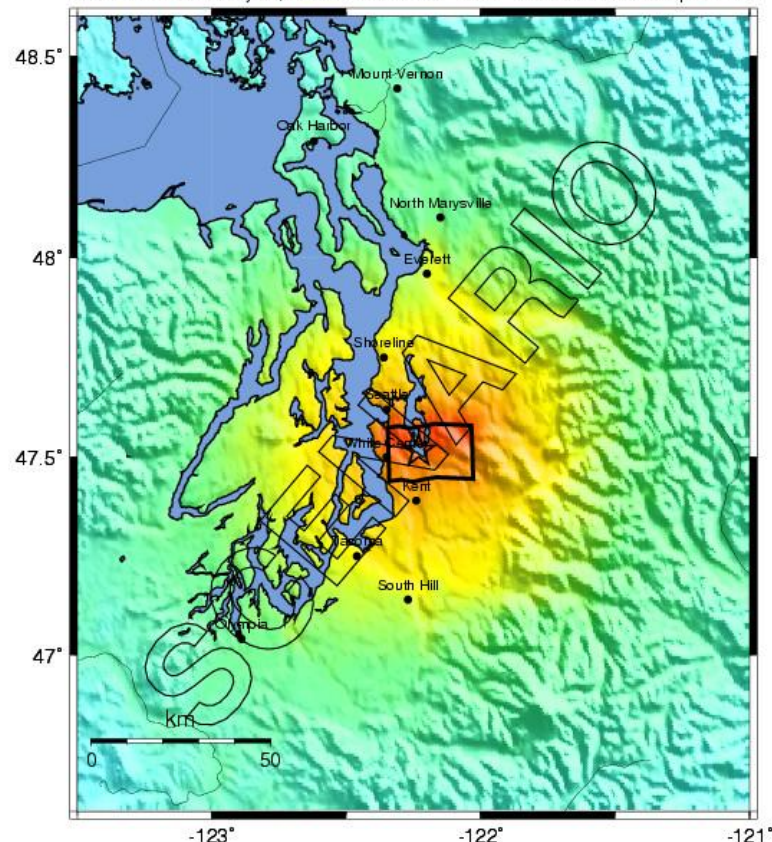
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PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC (%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>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+

-- Earthquake Planning Scenario --

ShakeMap for SeattleM6.7 Scenario

Scenario Date: Sun May 15, 2011 12:00:00 GMT M 6.7 N47.52 W122.23 Depth: 0.0km



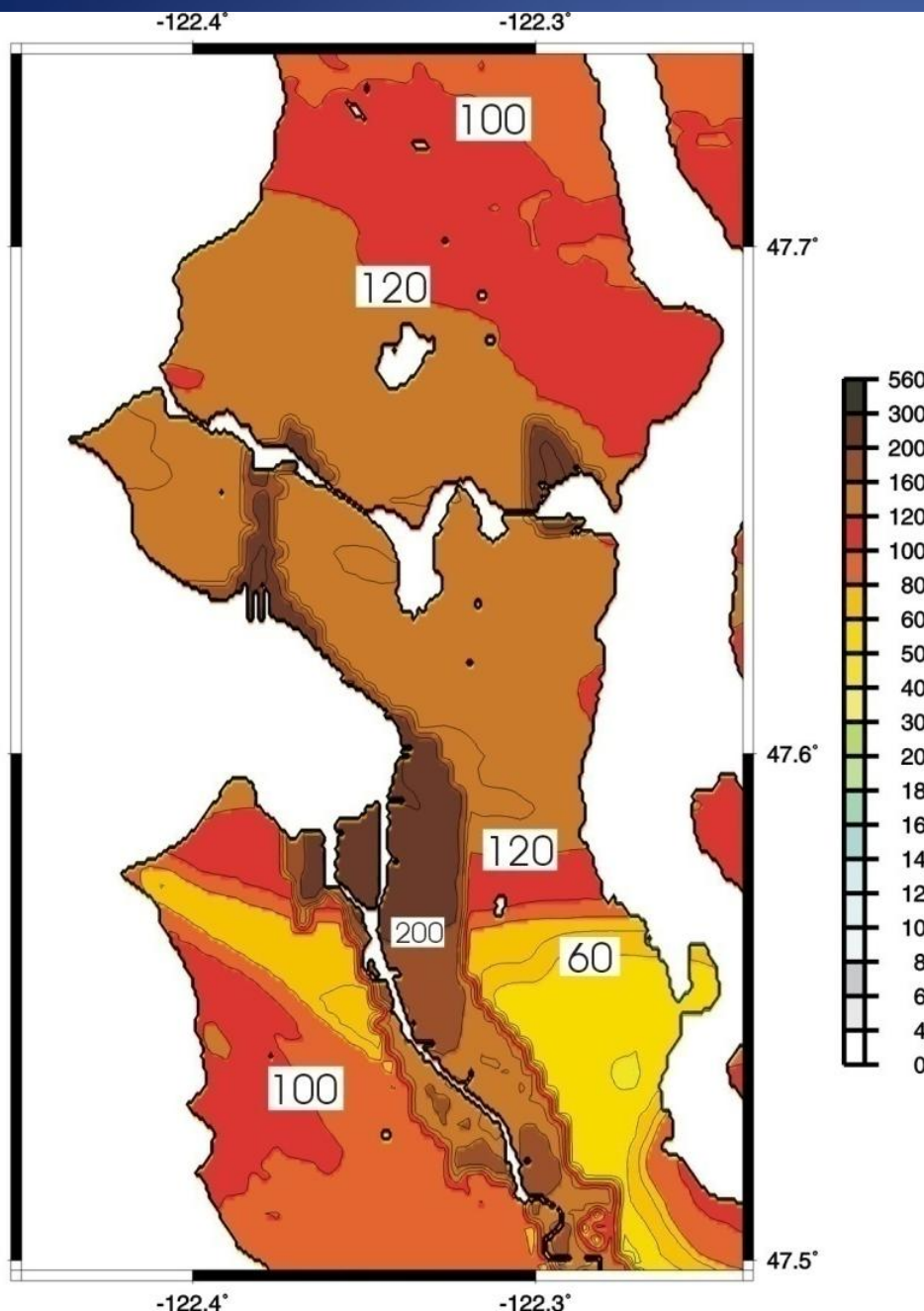
PLANNING SCENARIO ONLY -- Map Version 3 Processed Thu May 19, 2011 03:57:50 PM MDT

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+

Scenario map for M6.7 earthquake on Seattle fault

Scenario map for M7.2 deep earthquake under SeaTac

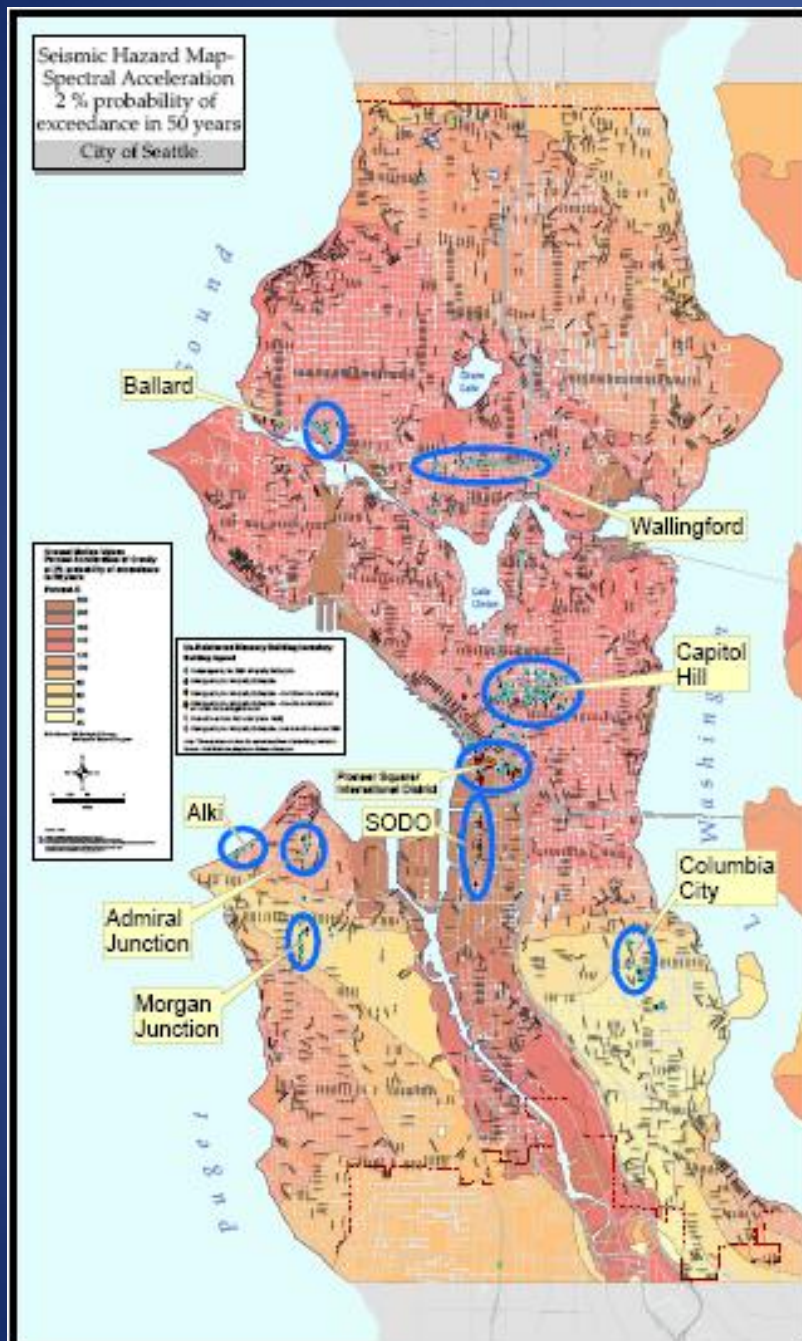
1 Hz S.A. (%g) with 2% Chance of Being Exceeded in 50 Years; this is the period that would most affect a 10 story building



Seattle urban
seismic hazard map
with soil conditions, basin effects,
and rupture directivity

Combines results of 3D simulations
of 541 scenarios (Seattle fault,
Cascadia subduction zone, random
shallow and deep earthquakes)

USGS Open-File Report
2007-1175



Unreinforced Masonry Building locations in Seattle plotted on USGS urban seismic hazard map showing spectral accelerations with 2% probability of exceedance in 50 years.

Urban seismic hazard maps useful for screening purposes and as check for site-specific studies; most site-specific studies do not consider basin effects or directivity effects

Need to get basin amplification terms into the building code for tall buildings

**Map from City of Seattle
Unreinforced Masonry Building
Seismic Hazards Study, 2007**

