Site-Specific Seismic Hazard and Site Response Analyses and Development of Earthquake Ground Motions for the Port of Anchorage Expansion Project

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Introduction

- URS Corporation has performed a site-specific probabilistic seismic hazard analysis (PSHA) and a deterministic seismic hazard analysis (DSHA).
- A site response analysis has been performed to estimate the ground motions at the top of the soil column.
- We have developed Maximum Considered Earthquake (MCE), Contingency Level Earthquake (CLE), and Operating Level Earthquake (OLE) ground motion parameters.

Introduction (cont'd.)

- These three design earthquakes have corresponding exceedance probabilities of 50%, 10%, and 2% in 50 years or return periods of 72, 475, and 2475 years, respectively.
- This study is an update of a 2004 evaluation, which was based on the 1999 USGS National Hazard Maps for Alaska.

Purpose

- The primary objective of this study is to estimate the future levels of ground motions at the site that will be exceeded at a specified probability. Time-independence was assumed.

- Available geologic and seismologic data including inputs used in the USGS Alaska hazard maps (Wesson *et al.*, 1999; 2007) have been used to evaluate and characterize

    1) potential seismic sources,

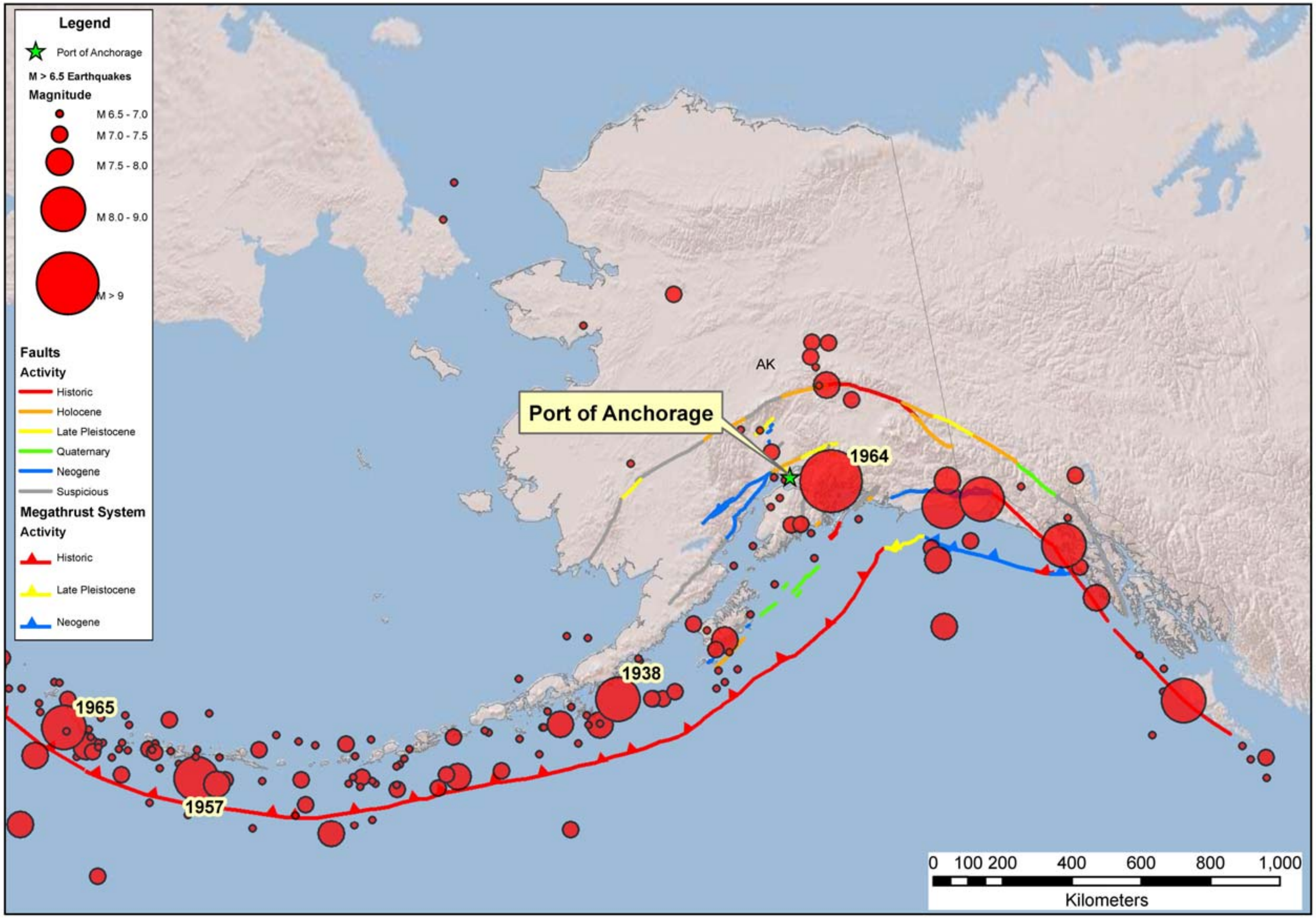
    2) the likelihood of earthquakes of various magnitudes occurring on those sources, and

    3) the likelihood of the earthquakes producing ground motions over a specified level.

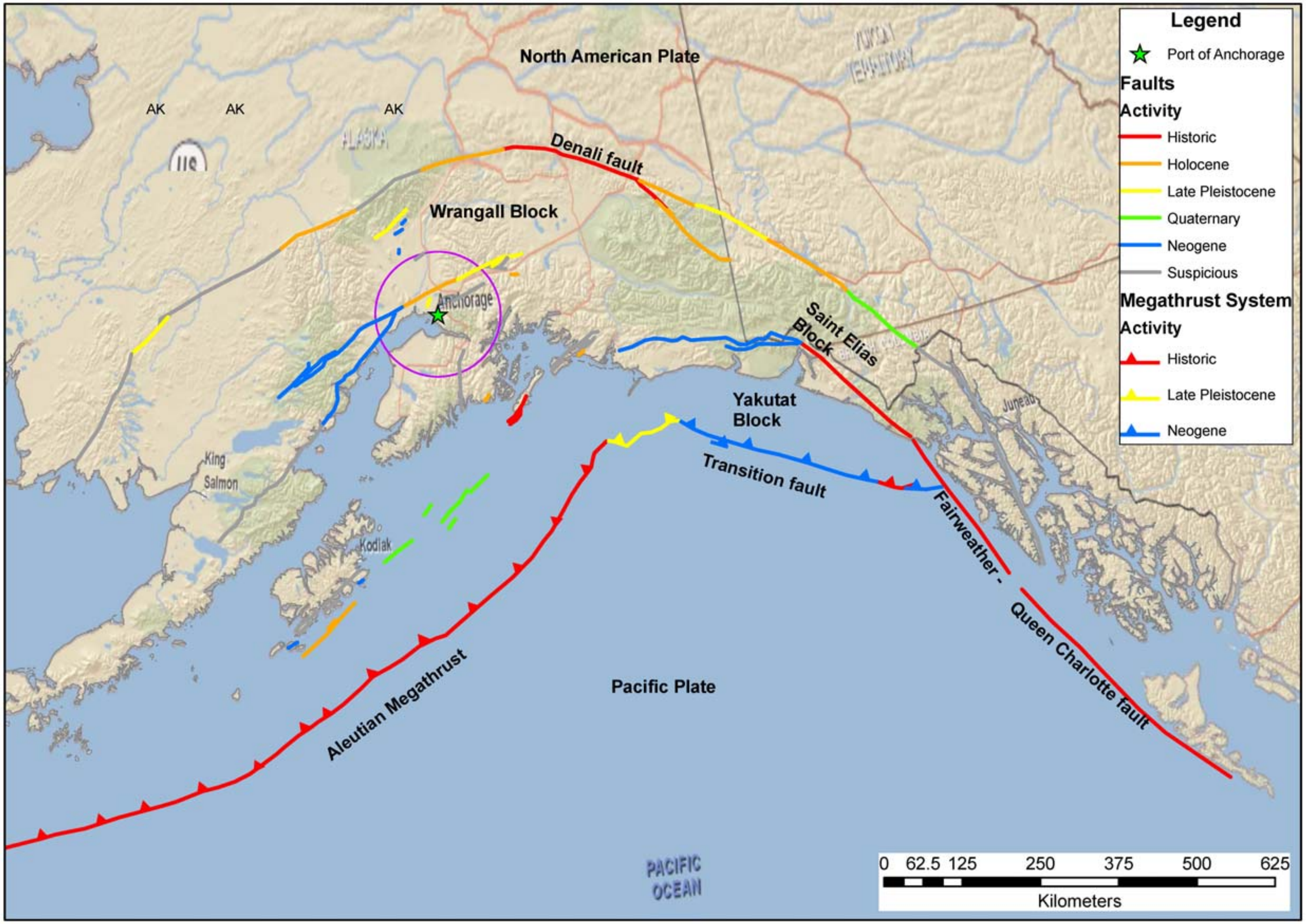
Scope of Work

- Task 1 – Seismic Source Characterization
- Task 2 – Evaluation of Historical and Contemporary Seismicity
- Task 3 – Selection of Attenuation Models
- Task 4 – Probabilistic and Deterministic Seismic Hazard Analyses
- Task 5 – Development of Time Histories
- Task 6 – Site-Specific Response Analysis
- Task 7 – Development of Site-Specific MCE and ODE Spectra and Time Histories
- Task 8 – Interim Memos and Final Report

Aleutian and Alaskan Subduction Zone and Large Historical Earthquakes (M ≥ 6.5), 1898 to 2006



Alaskan Subduction Zone



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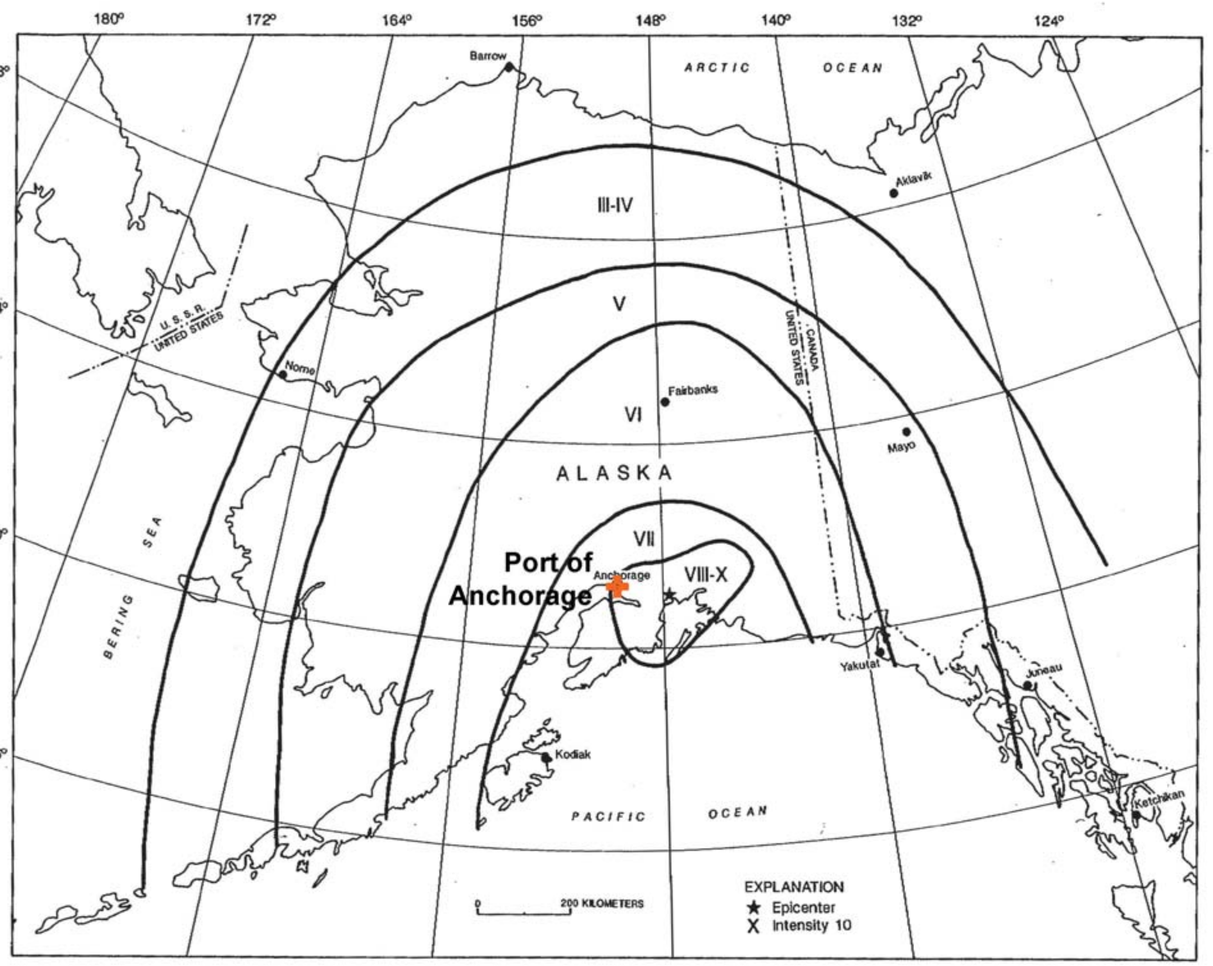
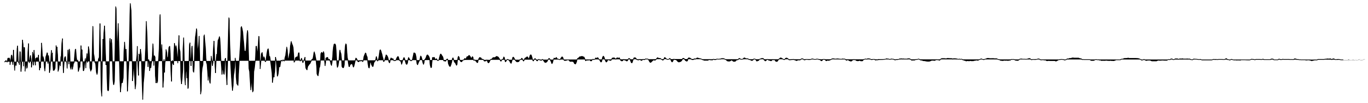
Isoseismal Map of the 28 March 1964 M 9.2 Great Alaskan Earthquake



Source: Stover and Coffman (1993)



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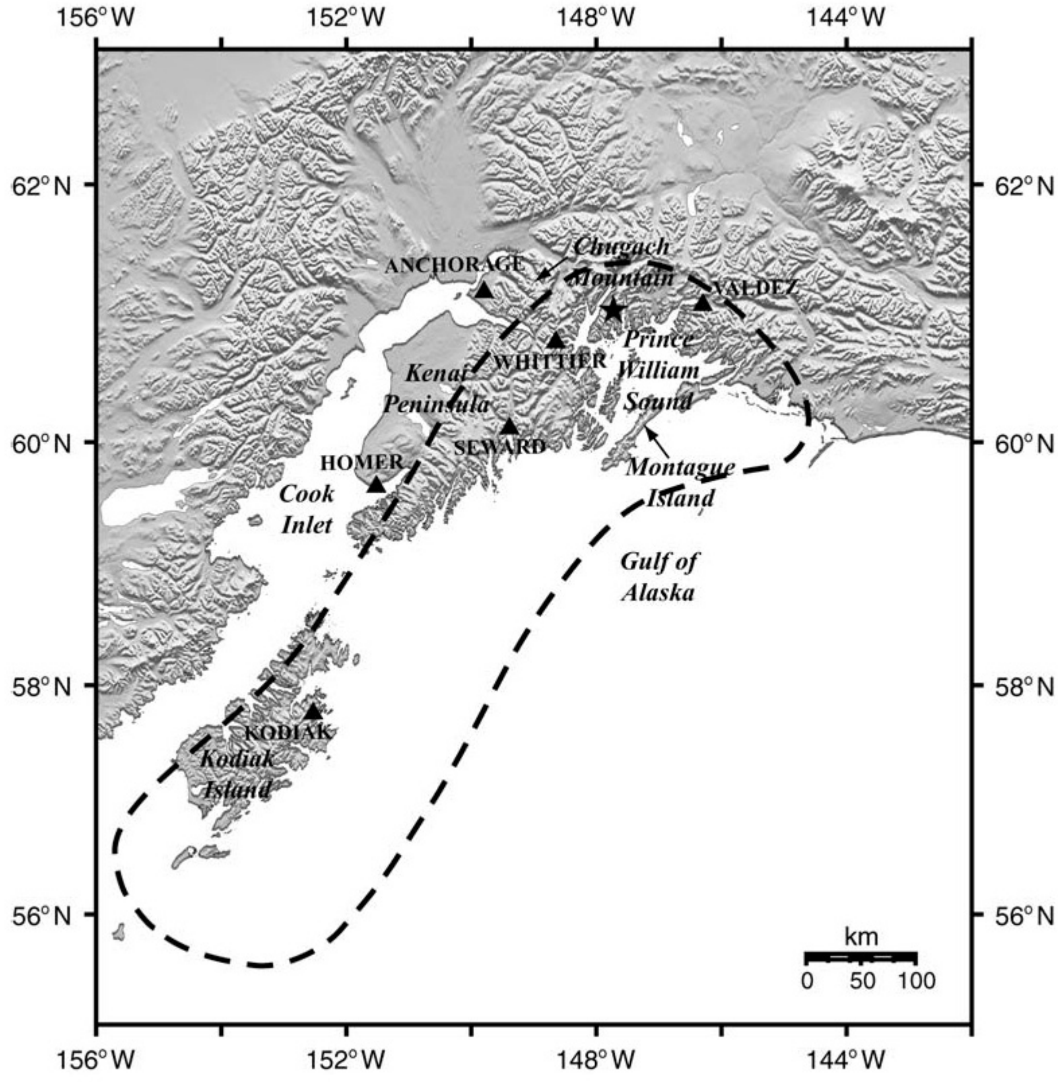
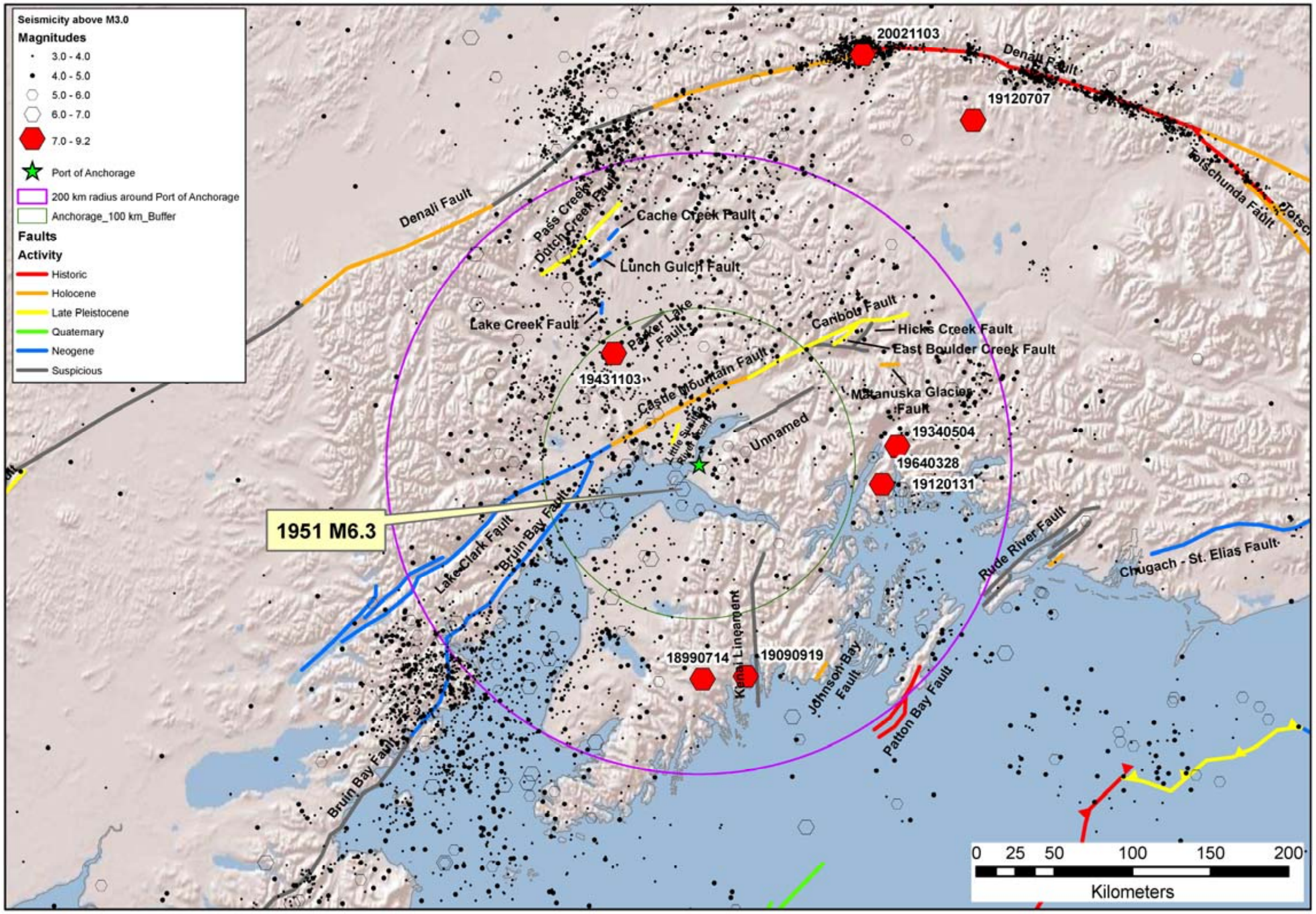
1964 M 9.2 Rupture Area

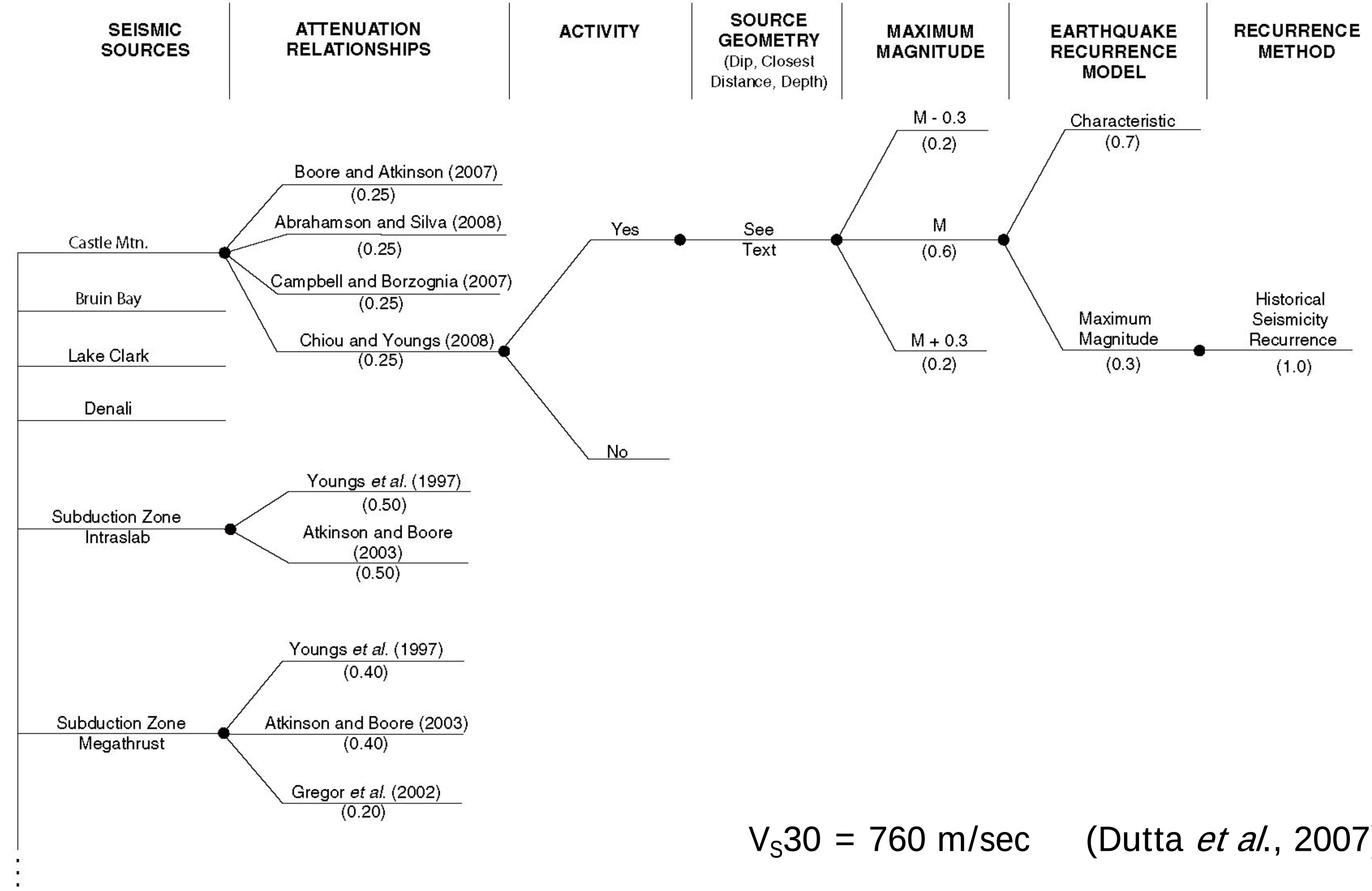


Source: Mavroedis et al., 2008

Historical Seismicity and Significant Earthquakes (M ≥ 3.0) 1898 – 2007

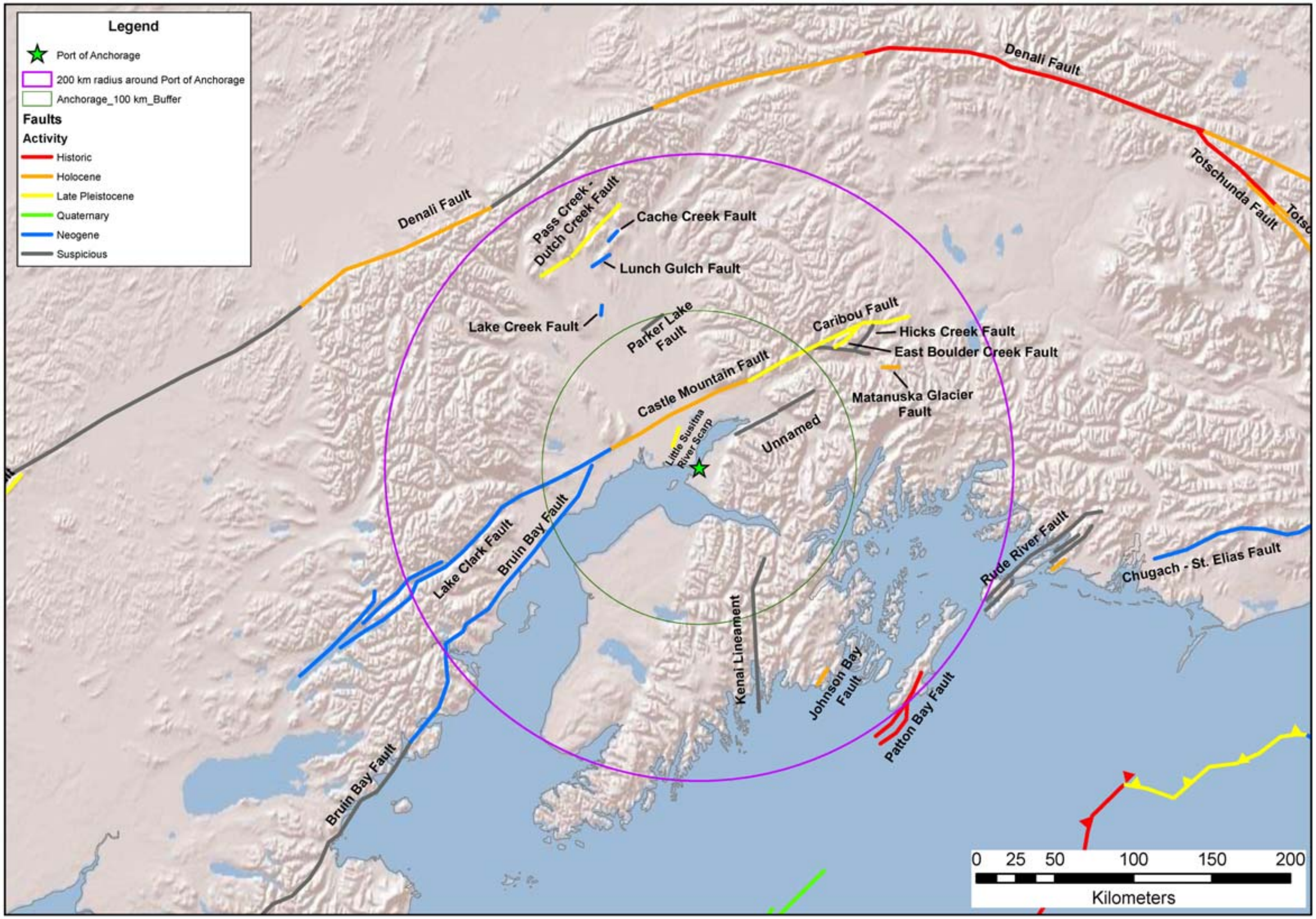


Seismic Hazard Model Logic Tree



V_S30 = 760 m/sec (Dutta *et al.*, 2007)

Neogene and Quaternary Faults Within 200 km of the Port



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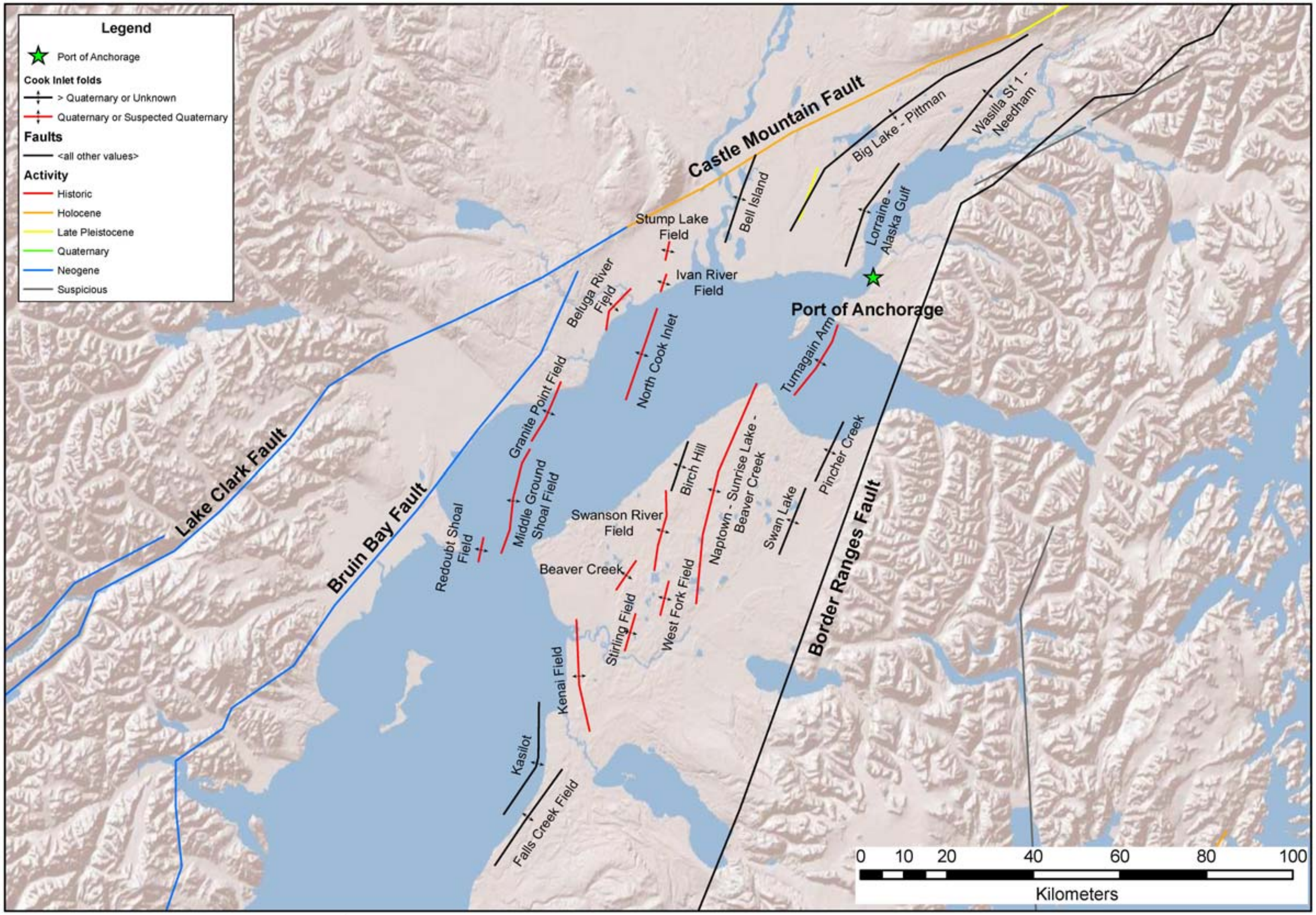
Neogene and Quaternary Faults in the Vicinity of the Port

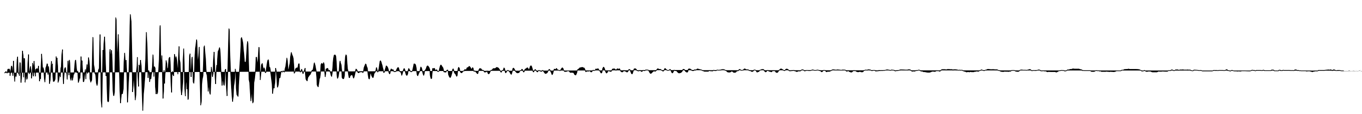


Seismic Source Parameters for Faults in the Vicinity of the Port of Anchorage

FAULT NAME	PROBABILITY OF ACTIVITY	RUPTURE MODEL	SECTION NAME	RUPTURE LENGTH (km)	PREFERRED M_{MAX}[1] (M) ± 0.3	SENSE OF SLIP	DIP (degrees)	RUPTURE DEPTH (km) or DD width	SLIP RATE (mm/yr)	RECURRENCE INTERVAL
Bruin Bay Fault	0.5	Floating (1.0)		N/A	7.0	Reverse	30 NW (0.2) 45 NW (0.6) 60 NW (0.2)	40 (0.2) 28 (0.6) 23 (0.2)	0.01 (0.2) 0.1 (0.6) 1.0 (0.2)	
Castle Mountain – Caribou Fault System	1.0	Unsegmented (0.2)		211	7.7	RL - Reverse	70 N (0.5) 90 (0.5)	20±5	1.9 (0.2) 2.9 (0.6) 3.9 (0.2)	
		Segmented (0.8)	Western	100	7.4	RL - Reverse	70 N (0.5) 90 (0.5)	20±5	1.9 (0.2) 2.9 (0.6) 3.9 (0.2) Slip rate wt: 0.5	600 (0.2) 700 (0.6) 800 (0.2) R.I. wt: (0.5)
			Eastern (plus Caribou)	111	7.4	RL - Reverse	70 N (0.5) 90 (0.5)	20±5	0.1 (0.2) 1.5 (0.6) 2.0 (0.2)	
Denali Fault System	1.0	Unsegmented (0.33)		410	8.1	RL	90 (0.5) 75 SE (0.5)	15±5	1.0 (0.2) 6.4 (0.6) 9.4 (0.2)	
		Segmented (0.34)	Muldrow - Alsek	150	7.6	RL	90 (0.5) 75 SE (0.5)	15±5	6.4 (0.2) 9.4 (0.6) 11 (0.2)	
			Tonozona - Muldrow	122	7.5	RL	90 (0.5) 75 SE (0.5)	15±5	1.0 (0.2) 6.4 (0.6) 9.4 (0.2)	
			Farewell	140	7.5	RL	90 (0.5) 75 SE (0.5)	15±5	1.0 (0.2) 6.4 (0.6) 9.4 (0.2)	
		Floating (0.33)		305	7.9	RL	90 (0.5) 75 SE (0.5)	15±5	1.0 (0.2) 6.4 (0.6) 9.4 (0.2)	

Seismic Source Parameters for Faults in the Vicinity of the Port of Anchorage (cont.)

FAULT NAME	PROBABILITY OF ACTIVITY	RUPTURE MODEL	SECTION NAME	RUPTURE LENGTH (km)	PREFERRED M $_{MAX}$[1] (M) ± 0.3	SENSE OF SLIP	DIP (degrees)	RUPTURE DEPTH (km) or DD width	SLIP RATE (mm/yr)	RECURRENCE INTERVAL
Lake Clark Fault	0.5	Unsegmented (0.1)		247	7.9	RL - Reverse	75 N (0.5) 90 N (0.5)	20±5	0.01 (0.2) 0.1 (0.6) 0.7 (0.2)	
		Segmented (0.3)	West	116	7.5	RL - Reverse	75 N (0.5) 90 N (0.5)	20±5	0.01 (0.2) 0.1 (0.6) 0.7 (0.2)	
			East	131	7.6	RL - Reverse	75 N (0.5) 90 (0.5)	20±5	0.01 (0.2) 0.1 (0.6) 0.7 (0.2)	
		Floating (0.6)		N/A	7.0	RL - Reverse	75 N (0.5) 90 (0.5)	20±5	0.01 (0.2) 0.1 (0.6) 1.0 (0.2)	
Parker Lake Fault	0.5	Unsegmented		16	6.5	RL - Reverse	75 N (0.3) 90 (0.4) 75 S (0.3)	20±5	0.01 (0.2) 0.1 (0.6) 1.0 (0.2)	
Pass Creek – Dutch Creek Fault	1.0	Unsegmented		68	7.2	RL - Reverse	45 N (0.3) 60 N (0.6) 75 N (0.3)	20±5	0.01 (0.2) 0.1 (0.6) 1.0 (0.2)	
Unnamed Fault near Palmer	0.5	Unsegmented		56	7.1	RL - Reverse	75 N (0.5) 90 N (0.5)	20±5	0.01 (0.2) 0.1 (0.6) 1.0 (0.2)	



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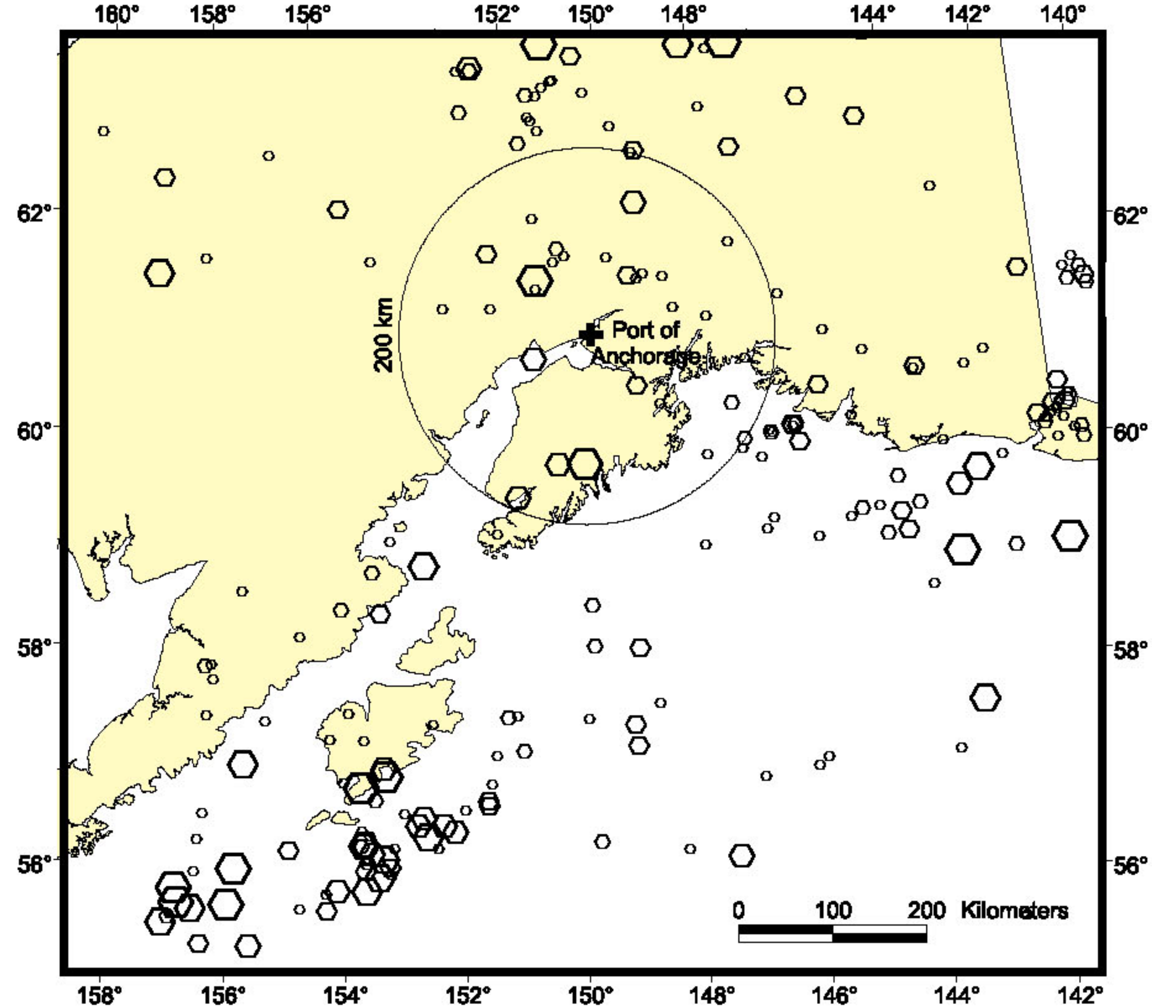
Seismic Source Parameters for Faults in the Vicinity of the Port of Anchorage (cont.)

FAULT NAME	PROBABILITY OF ACTIVITY	RUPTURE MODEL	SECTION NAME	RUPTURE LENGTH (km)	PREFERRED M_{MAX}[1] (M) ± 0.3	SENSE OF SLIP	DIP (degrees)	RUPTURE DEPTH (km) or DD width	SLIP RATE (mm/yr)	RECURRENCE INTERVAL
COOK INLET – BLIND SOURCES										
Cook Inlet – Middle Ground Shoal + Granite Point	1.0	Unsegmented		44	6.8	Reverse – RL?	45 NW (0.3) 60 NW (0.4) 75 NW (0.3)	20±5	0.39 (0.2) 0.82 (0.6) 2.72 (0.2)	
Cook Inlet – Naptown + Sunrise Lake + Beaver Creek	1.0	Unsegmented		55	7.0	Reverse – RL?	45 NW (0.3) 60 NW (0.4) 75 NW (0.3)	20±5	0.39 (0.2) 0.82 (0.6) 2.72 (0.2)	
Cook Inlet – North Cook Inlet	1.0	Unsegmented		23	6.9	Reverse – RL?	45 NW (0.3) 60 NW (0.4) 75 NW (0.3)	20±5	0.04 (0.2) 0.08 (0.6) 0.27 (0.2)	
Cook Inlet – Ivan River-Lewis River-Beluga River	1.0	Unsegmented		40	6.9	Reverse	45 NW (0.3) 60 NW (0.4) 75 NW (0.3)	20±5	0.04 (0.2) 0.08 (0.6) 0.27 (0.2)	
Cook Inlet – Turnagain Arm	1.0	Unsegmented		22	6.4 (0.5) 6.9 (0.5)	Reverse	45 SE (0.3) 60 SE (0.4) 75 SE (0.3)	20±5	0.04 (0.2) 0.08 (0.6) 0.27 (0.2)	

Crustal Earthquakes (M 4.5 to 7.3, Depth of ≤ 25 km) Used in Recurrence Calculations



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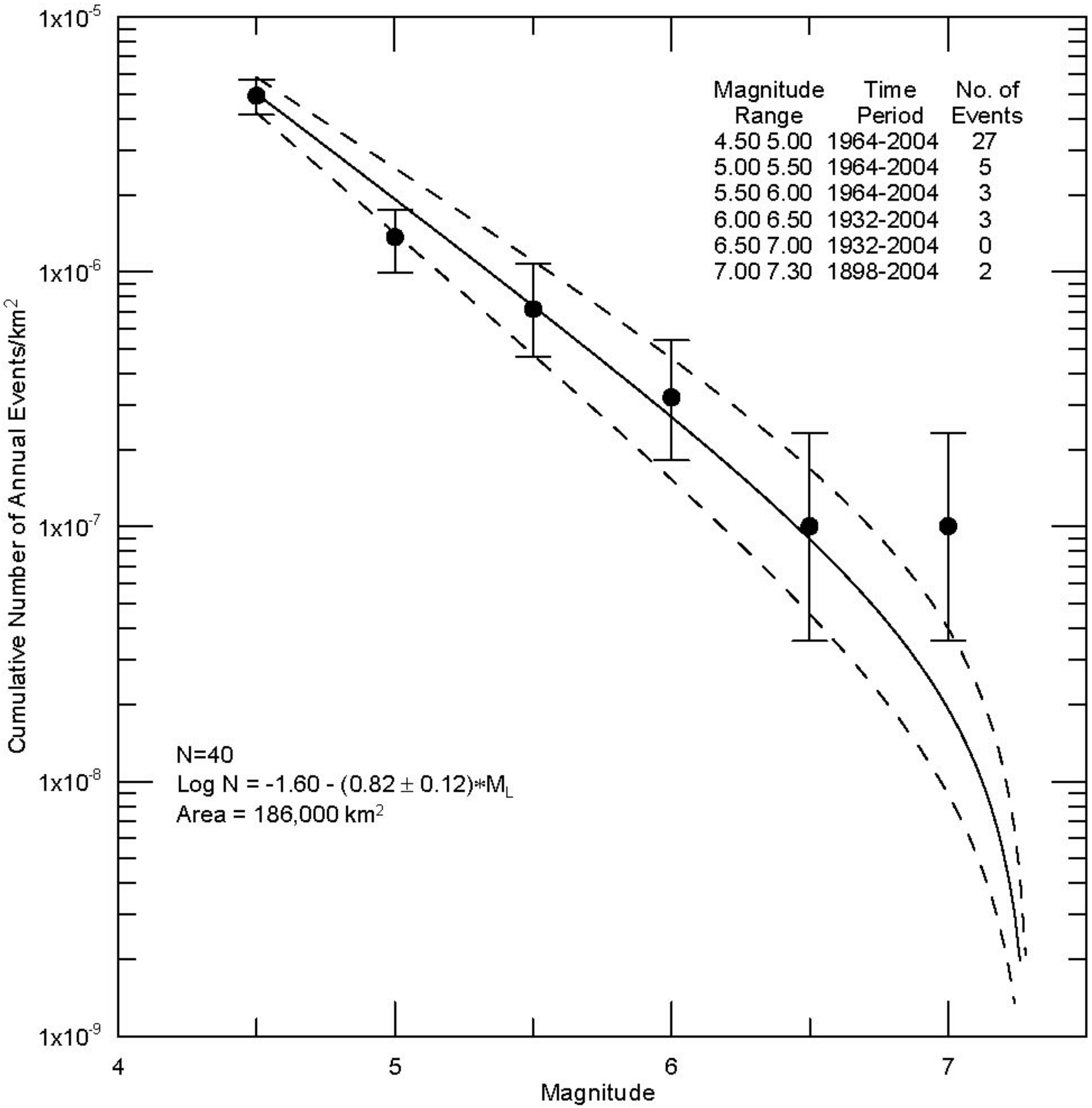
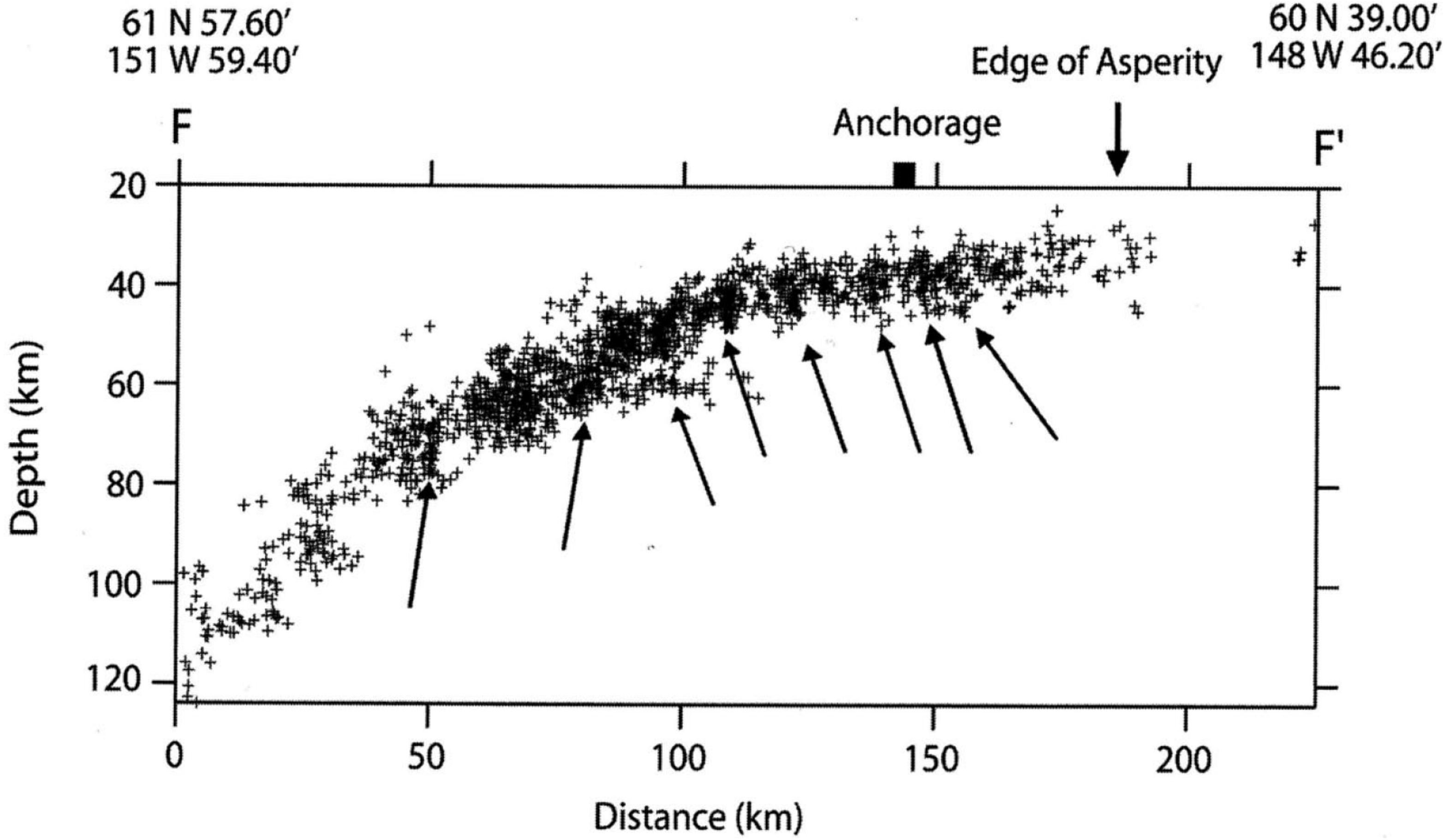
Crustal Background Earthquake Recurrence

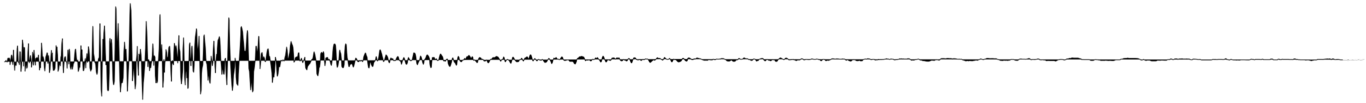
Average Recurrence Intervals
M ≥ 6: 21 yrs
M ≥ 7: 270 yrs



Seismicity Cross-Section Through Alaskan Subduction Zone Near Anchorage



Veilleux and Doser, 2007



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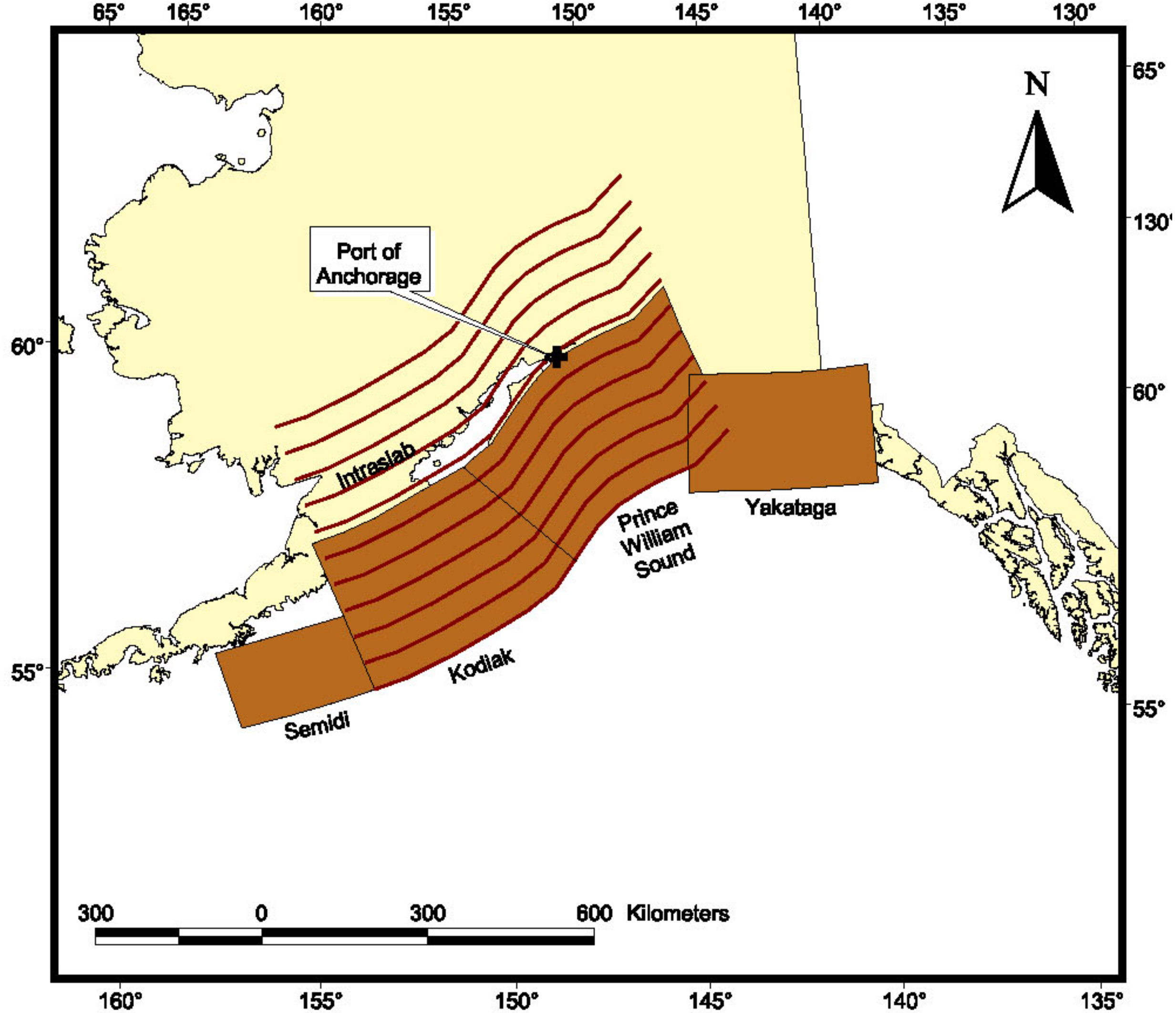
Model of Megathrust and Intraslab Used in the Hazard Analysis



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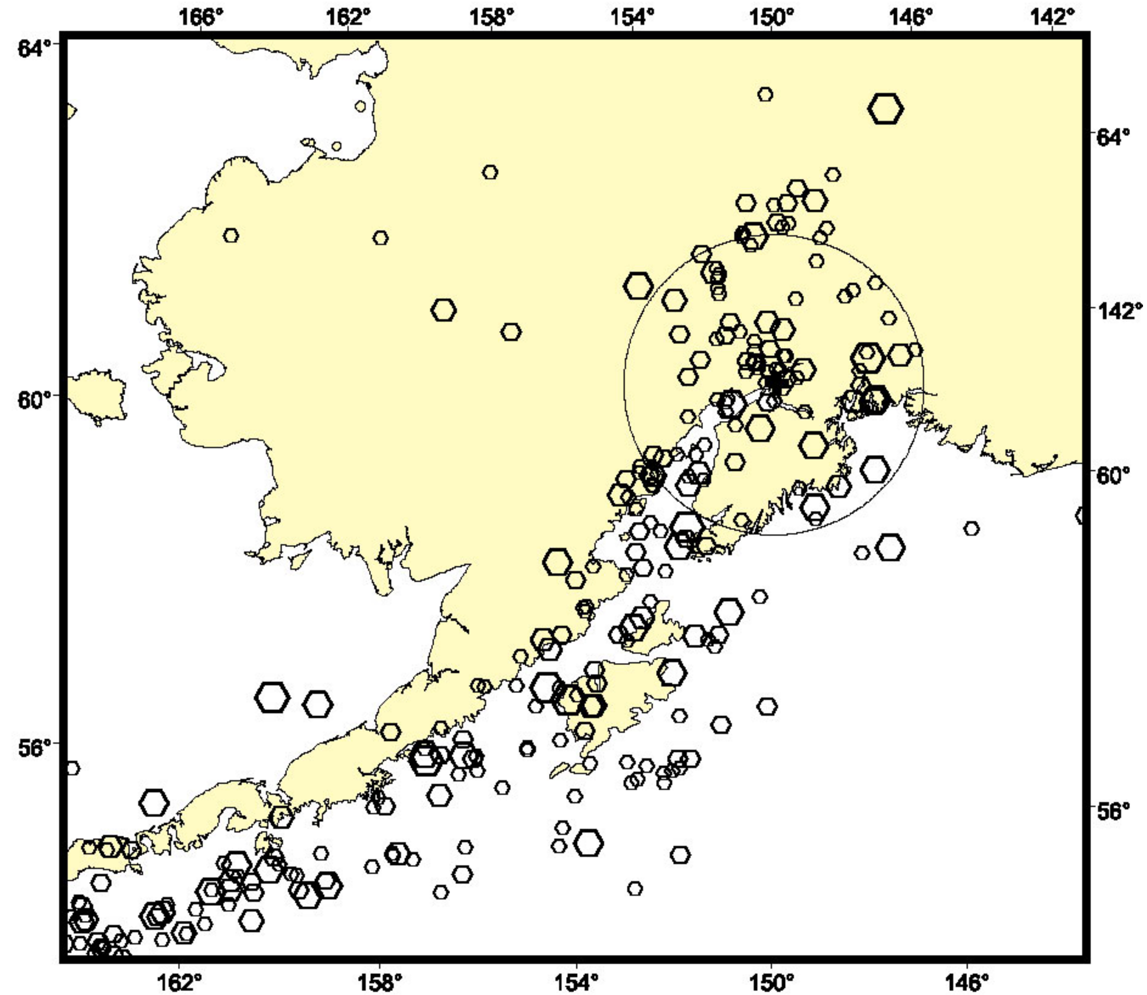
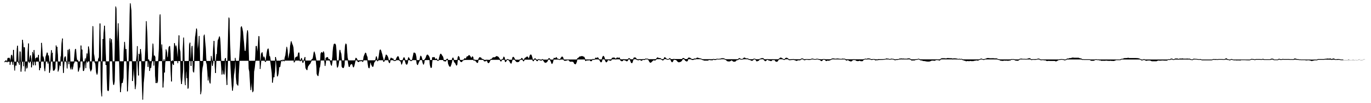
Seismic Source Parameters for the Alaskan Subduction Zone

FAULT NAME	PROBABILITY OF ACTIVITY	RUPTURE MODEL	SEGMENT NAME	RUPTURE LENGTH (km)	PREFERRED M_{MAX} (M)	b-Value	DIP (degrees)	RUPTURE DEPTH (km)	SLIP RATE (mm/yr)	RECURRENCE INTERVAL (yrs)
Yakataga	1.0	Unsegmented (1.0)		N/A	7.5 (0.2) 7.8 (0.6) 8.1 (0.2)	0.666	0.0 N (1.0)	15 (1.0)	12.0 (0.2) 15.0 (0.6) 18.0 (0.2)	
1964 Rupture Zone	1.0	Unsegmented (0.5)		N/A	9.1 (0.2) 9.2 (0.6) 9.3 (0.2)	1.000	3.0 N (0.2) 6.0 N (0.6) 9.0 N (0.2)	13-22.		550 (0.2) 650 (0.6) 750 (0.2)
		Segmented (0.5)	Prince William Sound (PA = 0.0)							
			Kodiak Island (PA = 1.0)	N/A	8.2 (0.2) 8.5 (0.6) 8.8 (0.2)	1.000	5.0 N (0.2) 7.0 N (0.6) 9.0 N (0.2)	20-22.8		550 (0.2) 650 (0.6) 750 (0.2)
Semidi	1.0	Unsegmented (1.0)		N/A	7.9 (0.2) 8.2 (0.6) 8.5 (0.2)	0.710	11.5 N (0.2) 12.5 N (0.6) 13.5 N (0.2)	30		550 (0.2) 650 (0.6) 750 (0.2)
Intraslab	1.0				7.25 (0.3) 7.50 (0.4) 7.75 (0.3)	0.84 ± 0.1		30-100		

Intraslab Earthquakes (M 5.0 to 7.5, Depth of 30 to 120 km) Used in Recurrence





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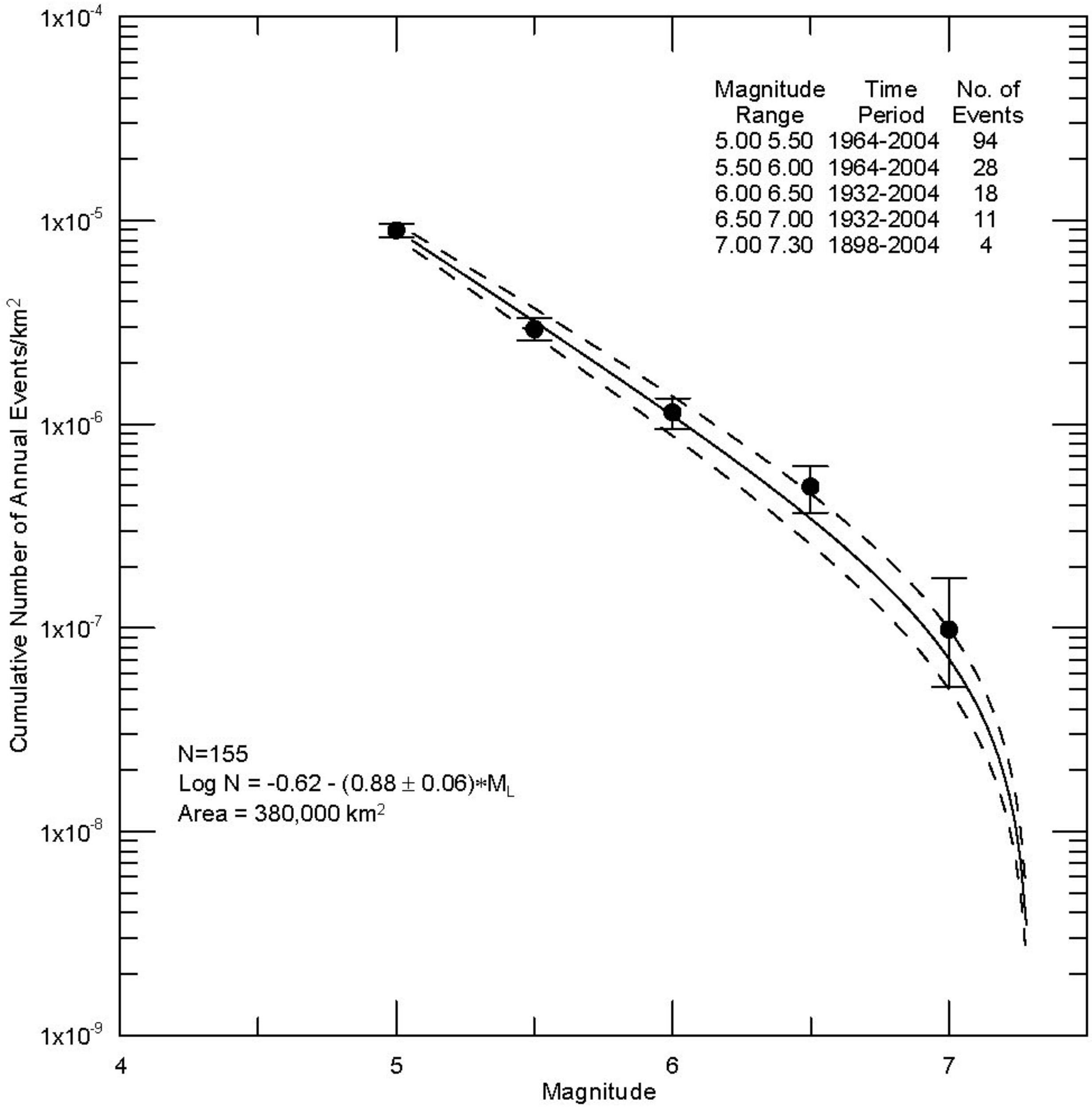
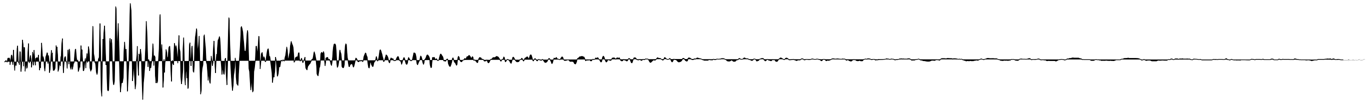
Intraslab Earthquake Recurrence

Average Recurrence Intervals
M ≥ 6: 3 yrs
M ≥ 7: 38 yrs

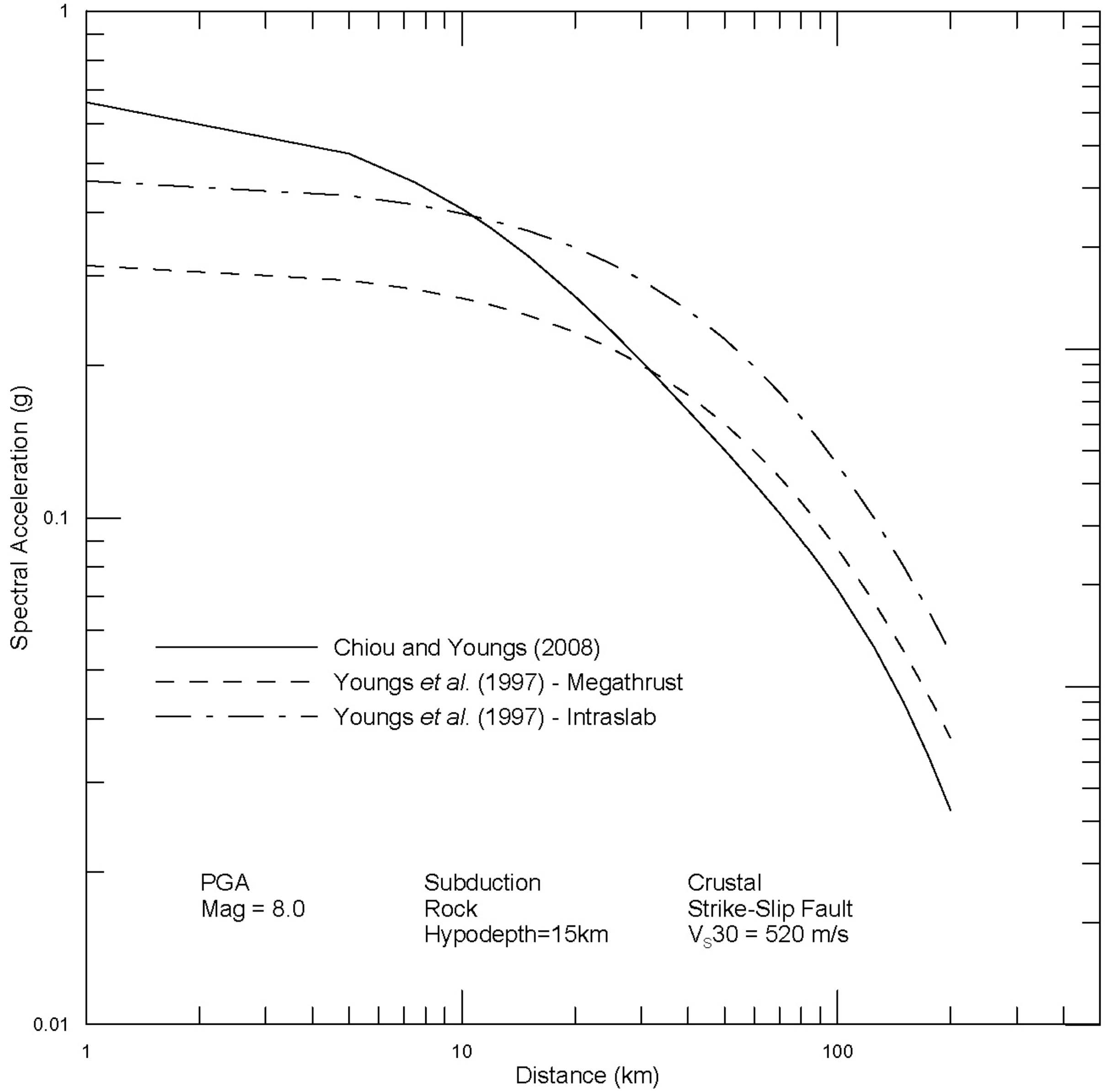




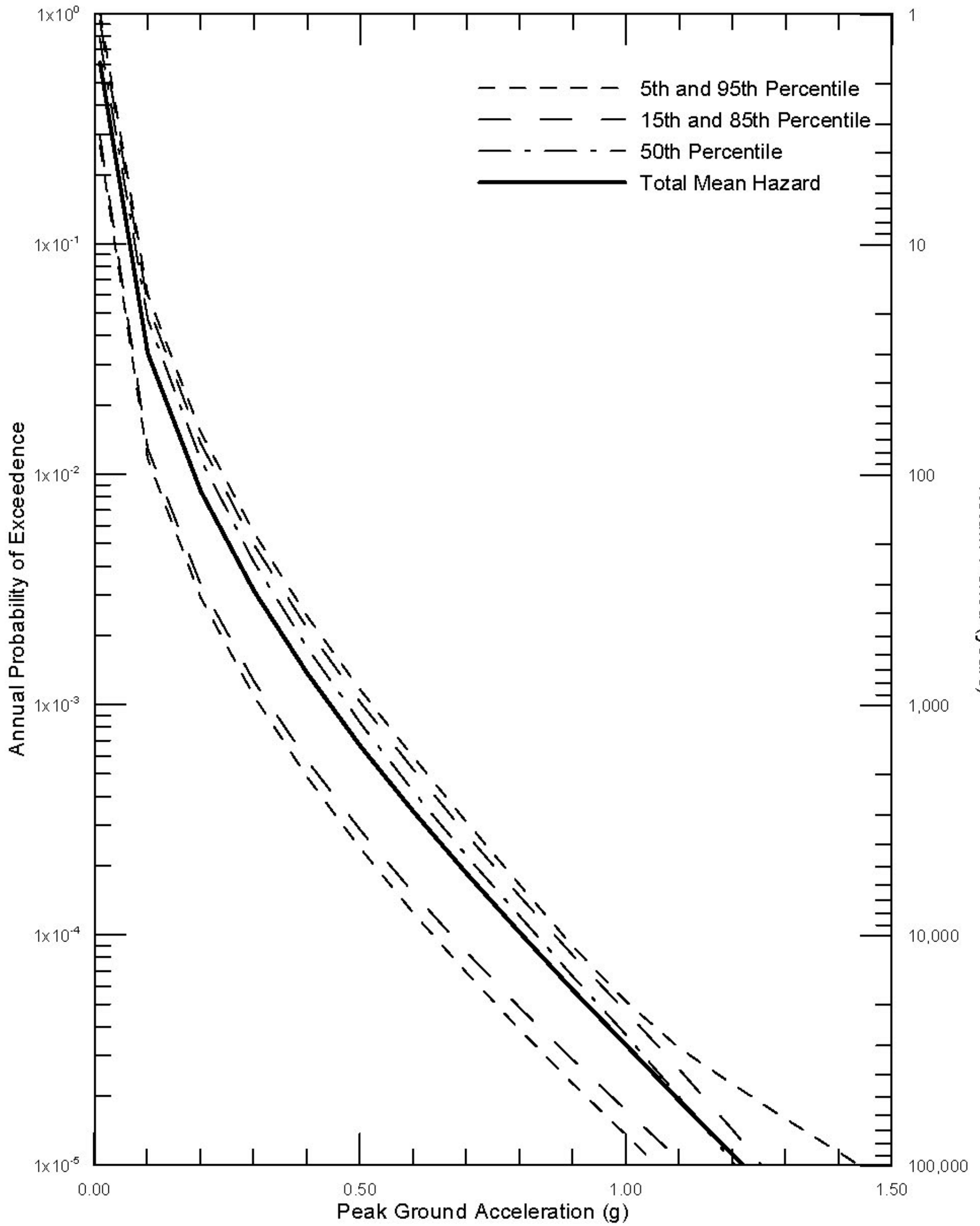
Attenuation Relationships

Crustal (NGA)	Weights
• Chiou and Youngs (2008)	0.25
• Abrahamson and Silva (2008)	0.25
• Campbell and Bozorgnia (2007)	0.25
• Boore and Atkinson (2007)	0.25
Intraslab	
• Youngs et al. (1997)	0.50
• Atkinson and Boore (2003)	0.50
Megathrust	
• Youngs et al. (1997)	(0.4)
• Atkinson and Boore (2003)	(0.4)
• Gregor et al. (2002)	(0.2)

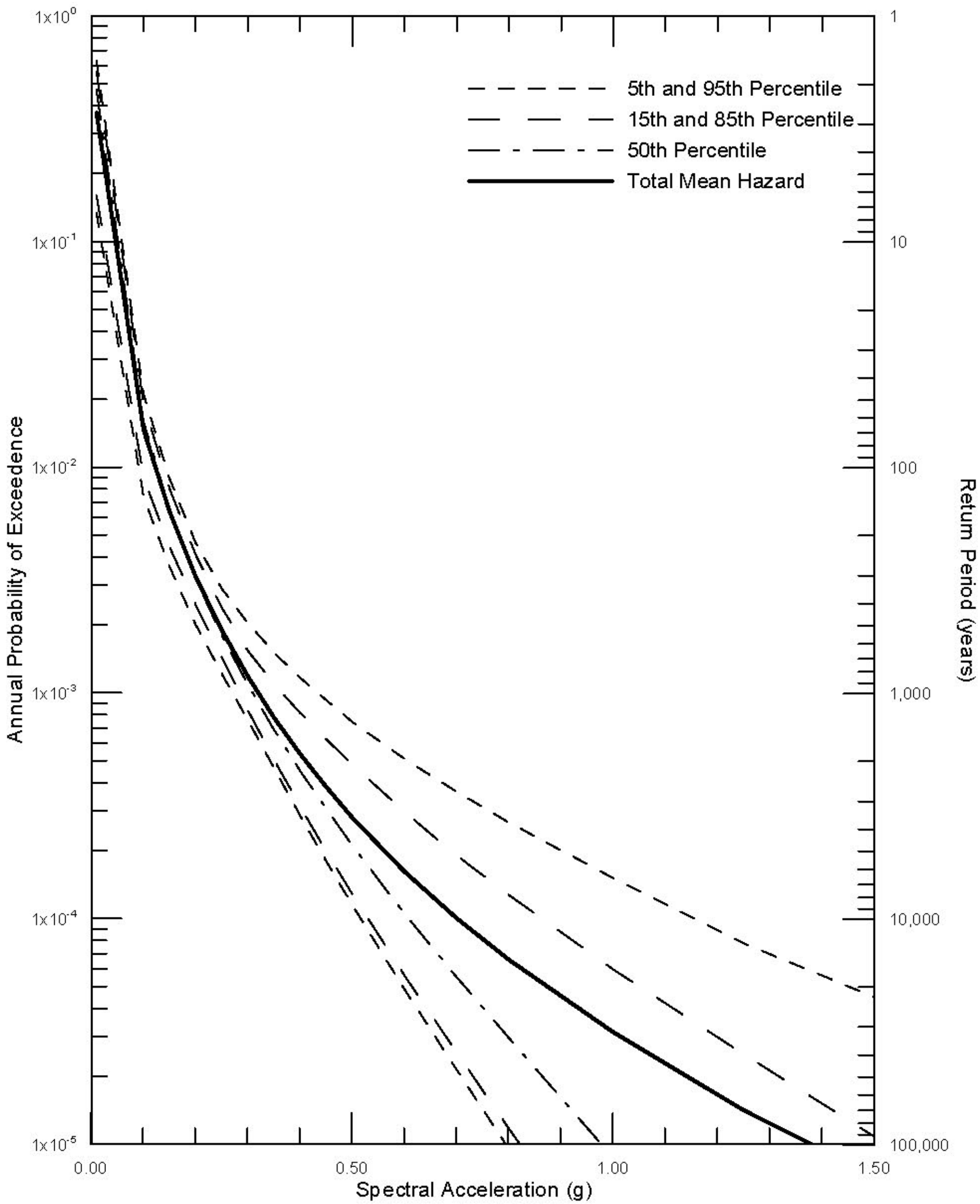
Comparison of Attenuation Models for Different Seismic Source Types

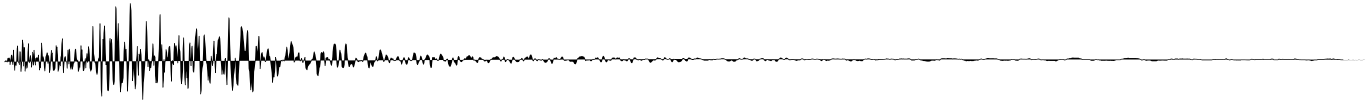


Seismic Hazard Curves for Peak Horizontal Acceleration



Seismic Hazard Curves for 1.0 Sec Horizontal Spectral Acceleration





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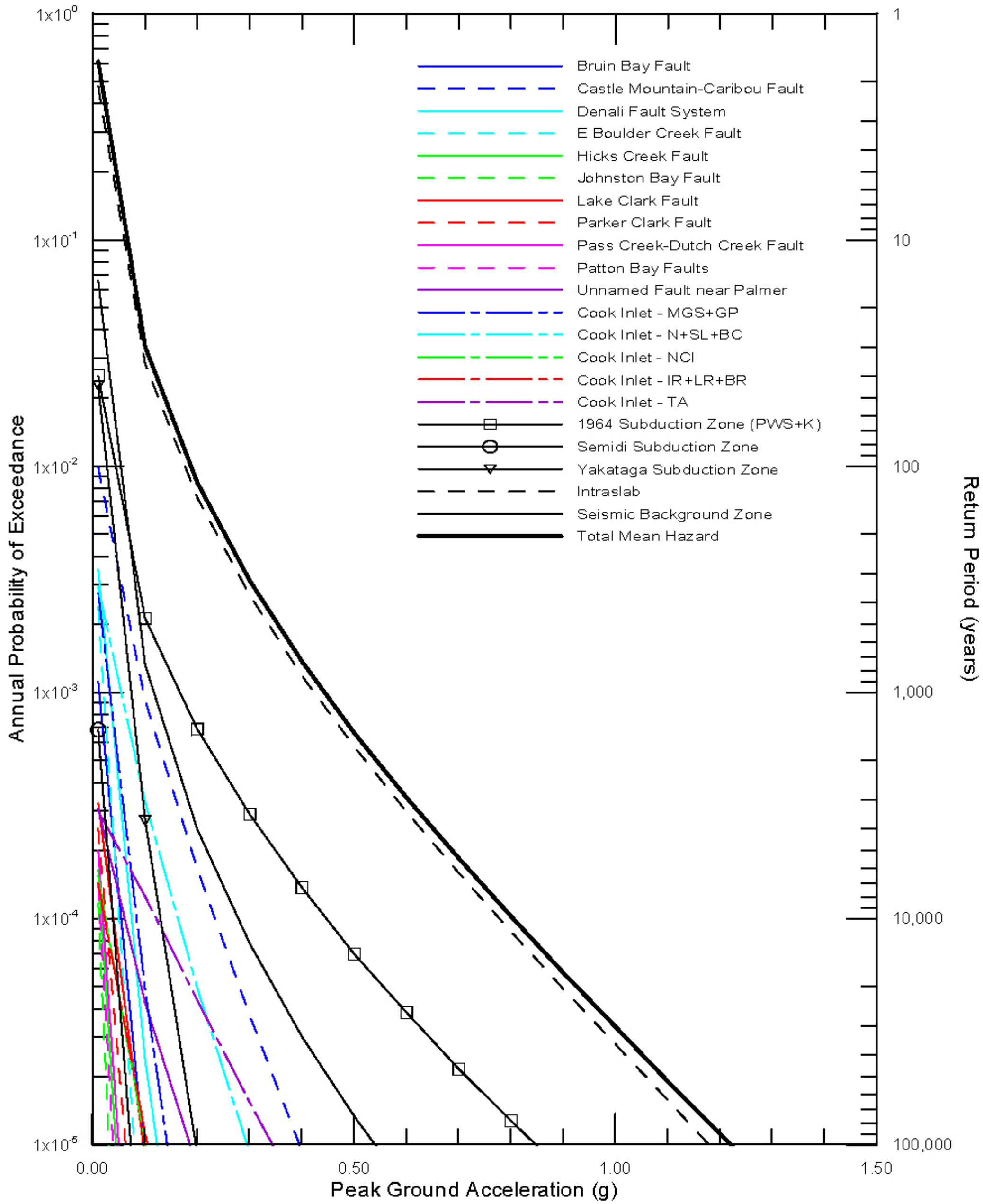
Seismic Source Contributions to Mean Peak Horizontal Acceleration Hazard



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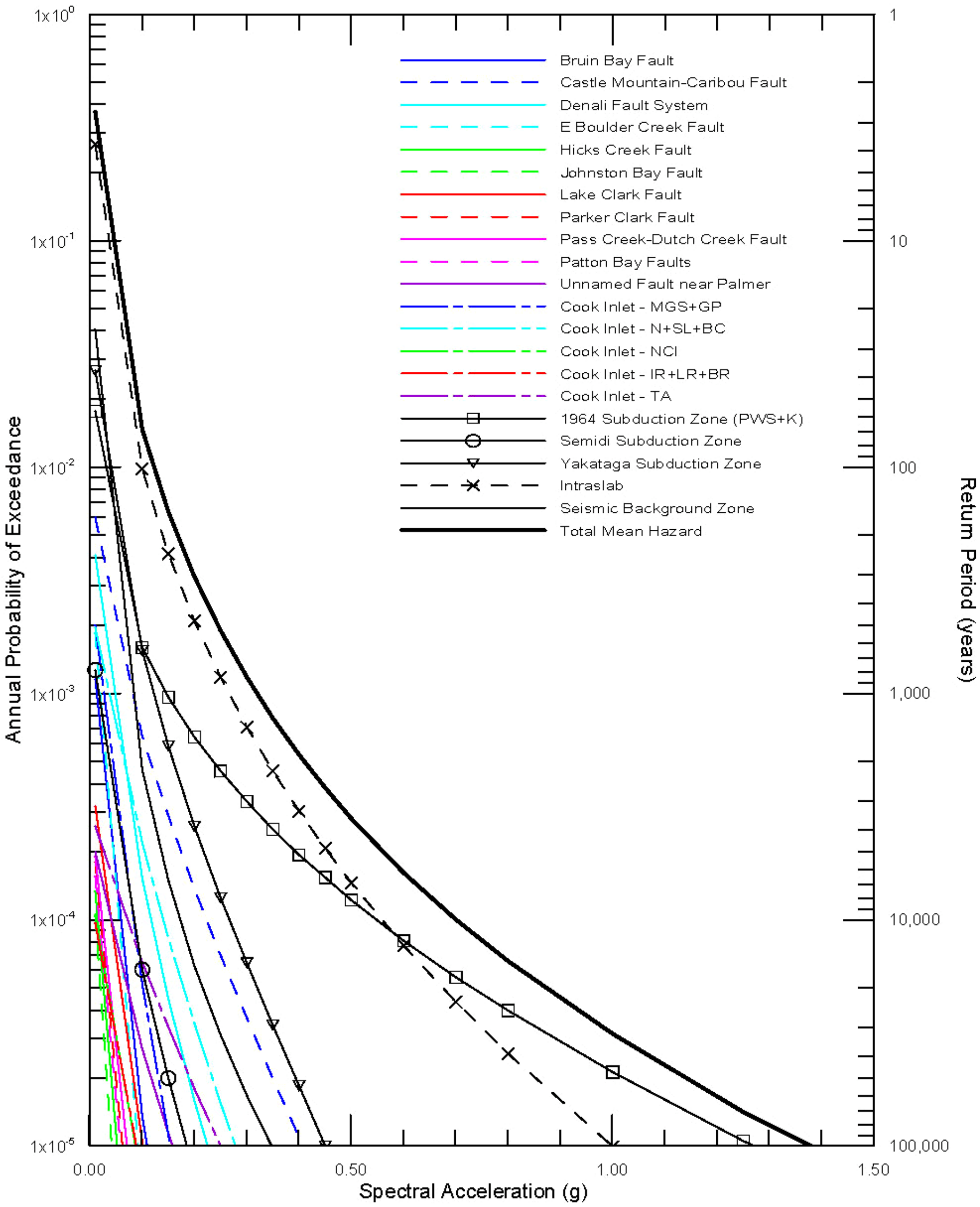
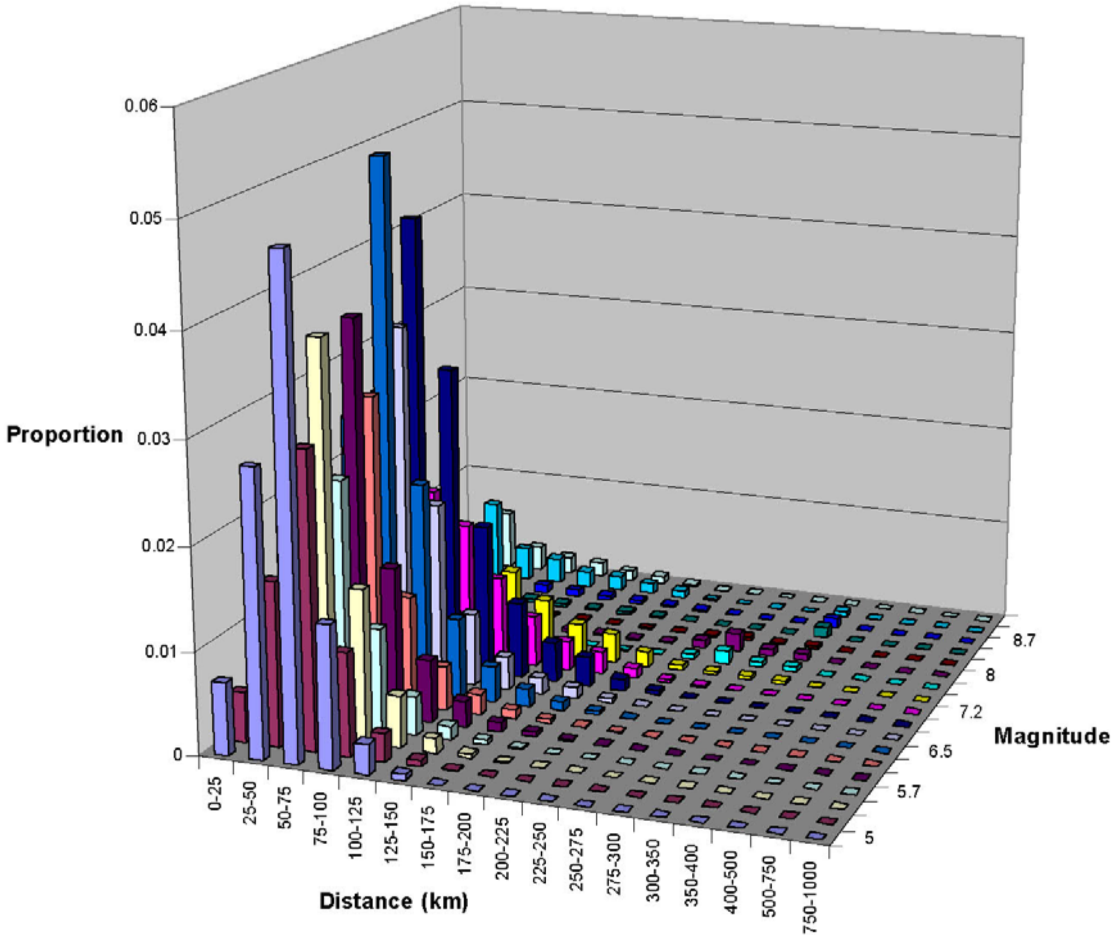
Seismic Source Contributions to Mean 1.0 Sec Horizontal Spectral Acceleration Hazard



Magnitude and Distance Contributions to the Mean Peak Horizontal Acceleration Hazard at 72-Year Return Period



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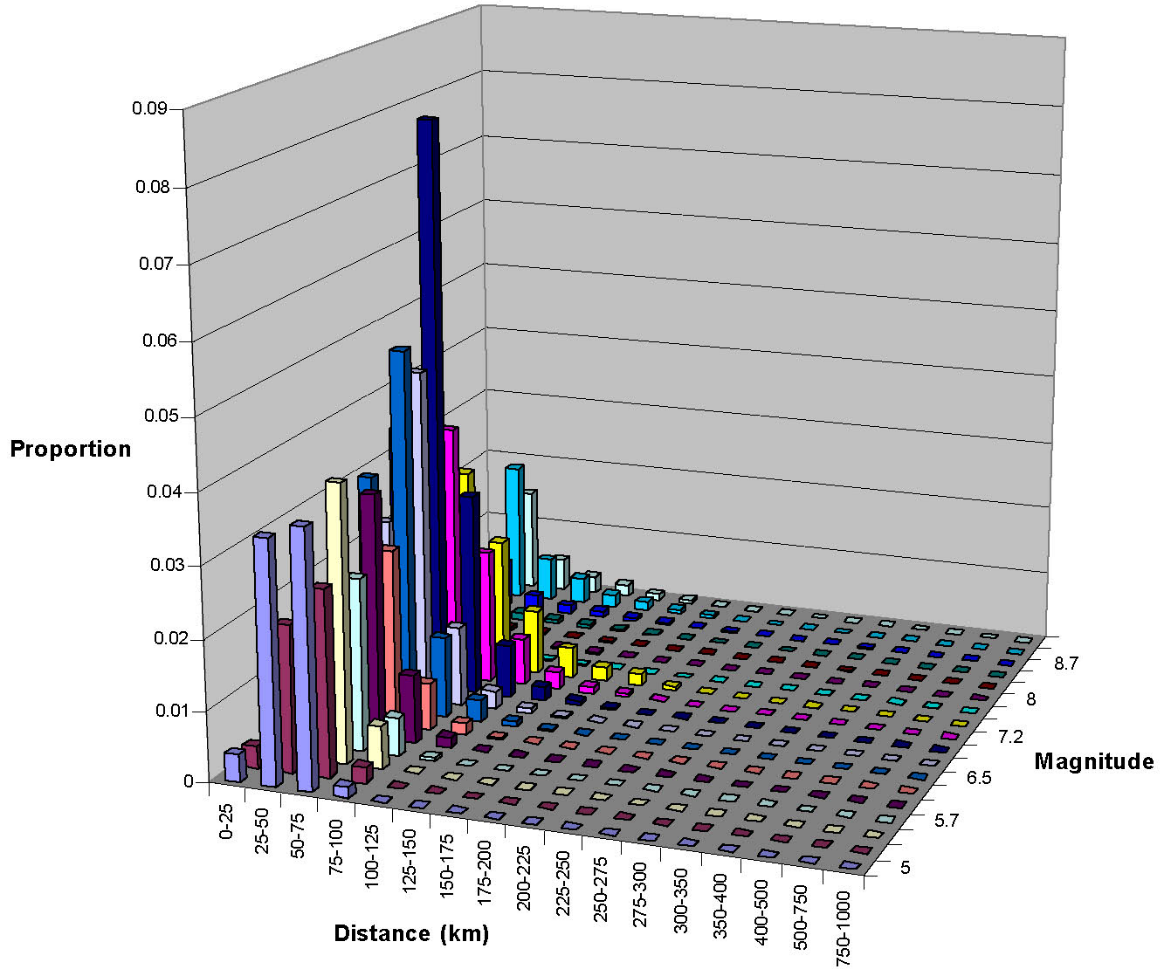
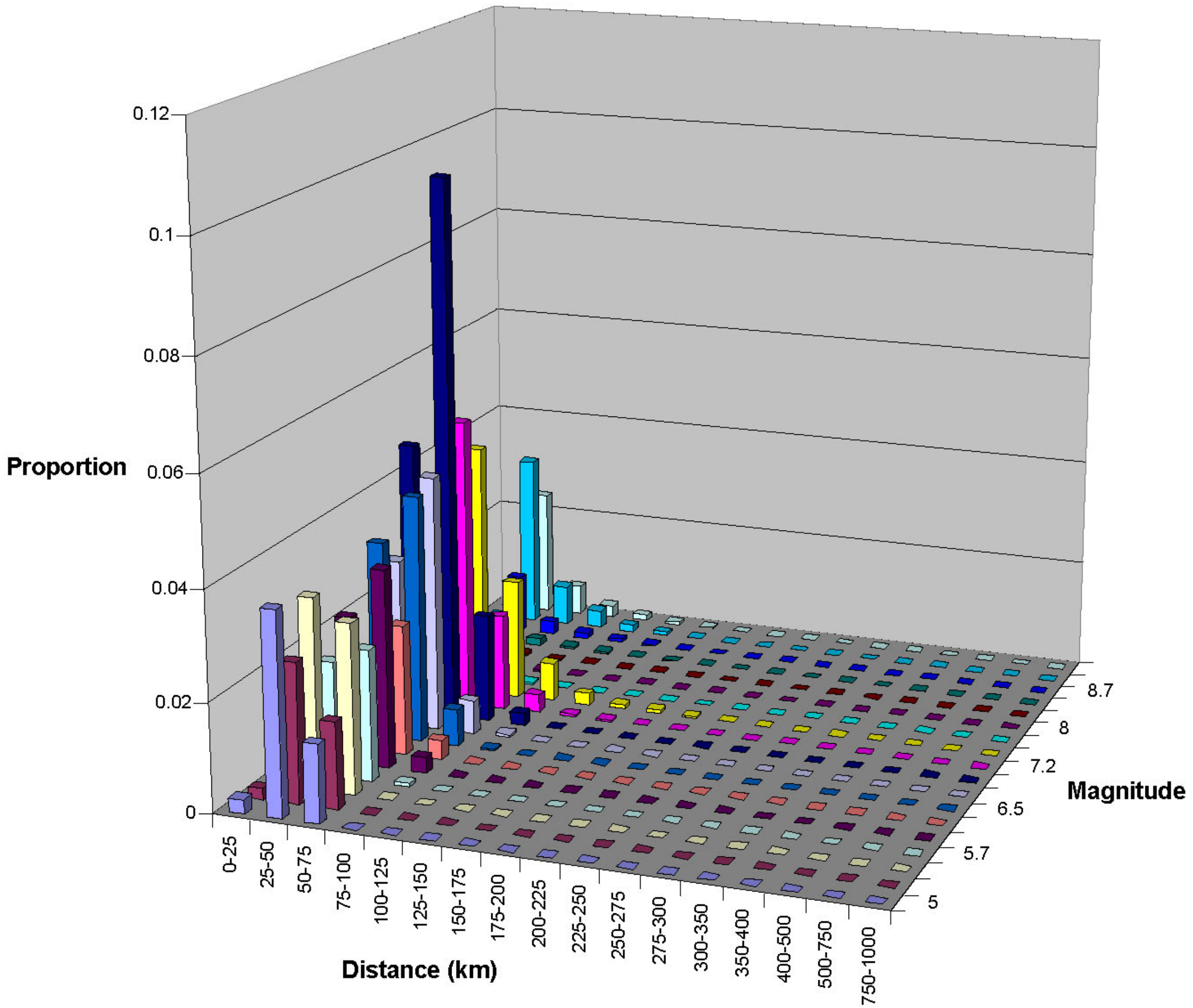
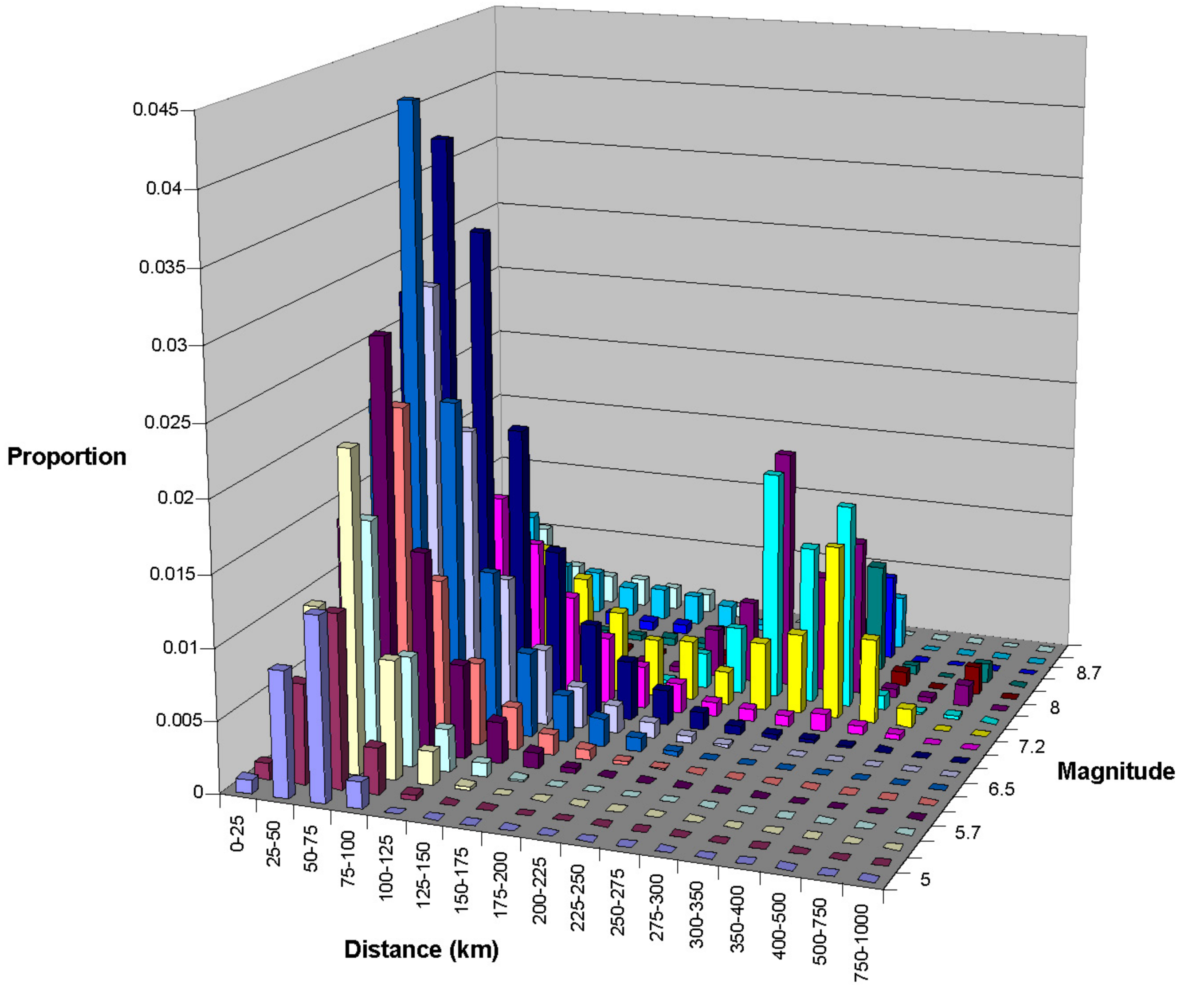
Magnitude and Distance Contributions to the Mean Peak Horizontal Acceleration Hazard at 475-Year Return Period



Magnitude and Distance Contributions to the Mean Peak Horizontal Acceleration Hazard at 2,475-Year Return Period



Magnitude and Distance Contributions to the Mean 1.0 Sec Horizontal Spectral Acceleration Hazard at 72-Year Return Period



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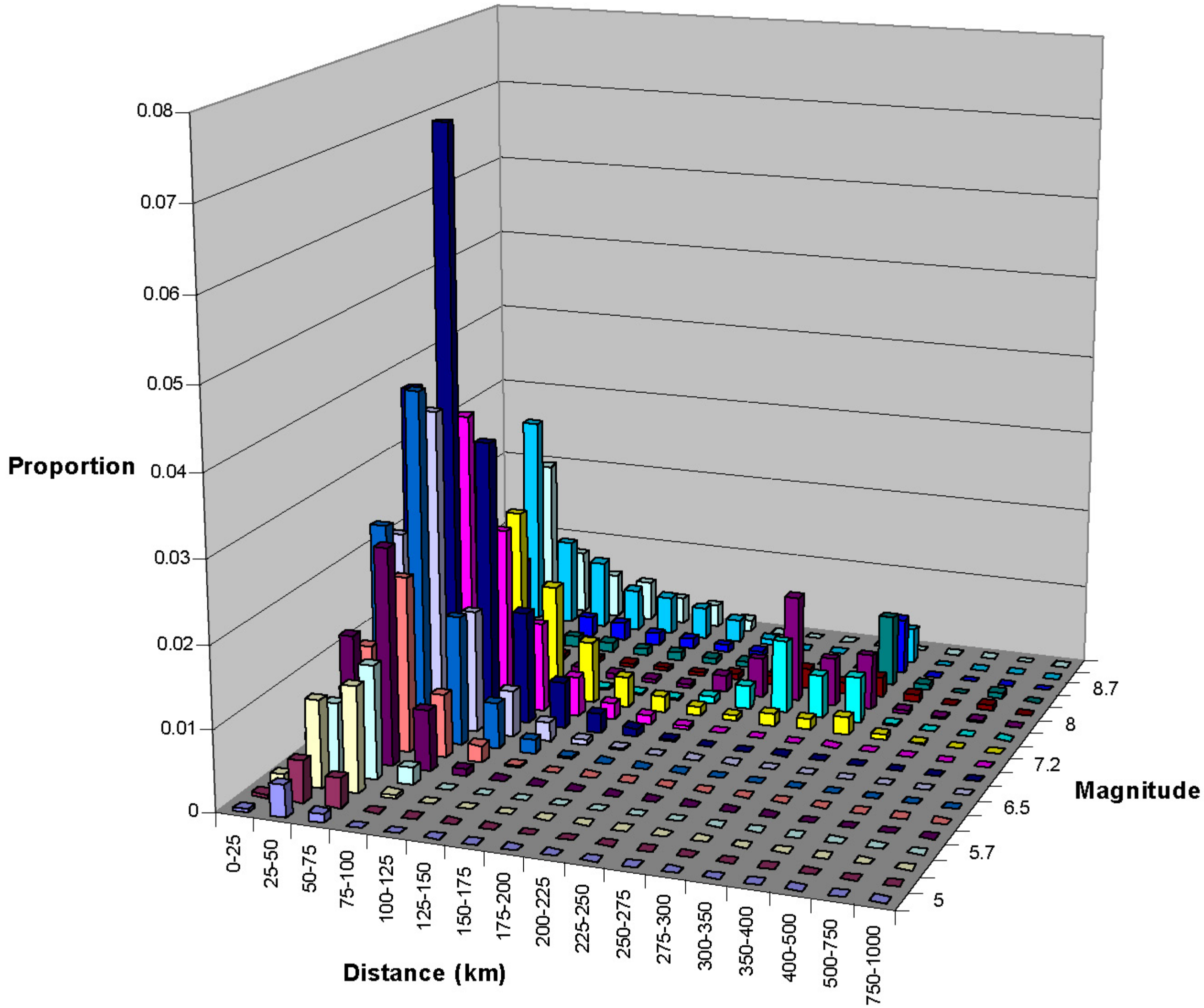
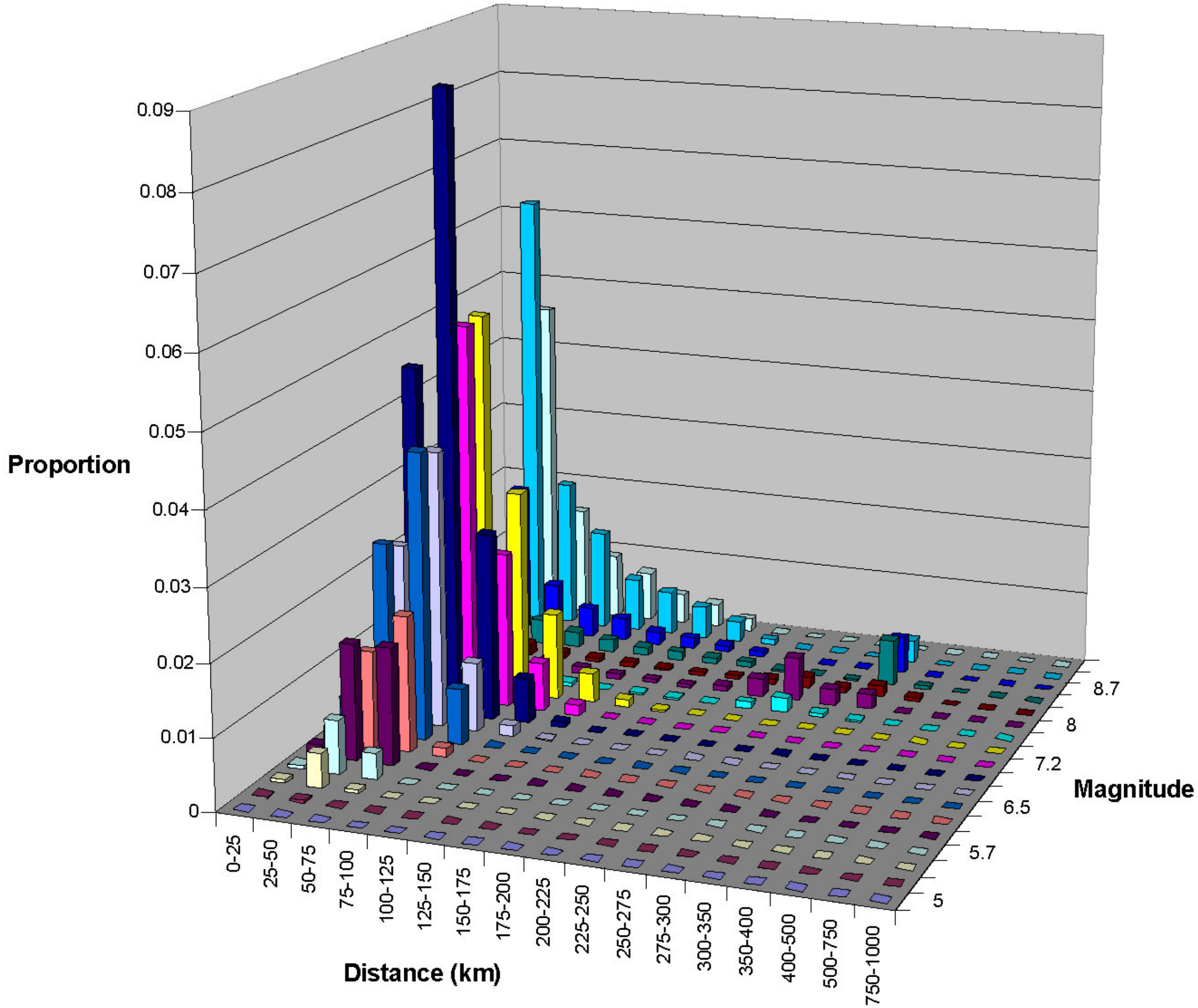
Magnitude and Distance Contributions to the Mean 1.0 Sec Horizontal Spectral Acceleration Hazard at 475-Year Return Period



Magnitude and Distance Contributions to the Mean 1.0 Sec Horizontal Spectral Acceleration Hazard at 2,475-Year Return Period



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Site-Specific Probabilistic Spectral Accelerations

Return Period	PGA (g)	0.3 Sec SA (g)	2.0 Sec SA (g)
72	0.16	0.26	0.10
475	0.34	0.59	0.24
2,475	0.58	1.02	0.44

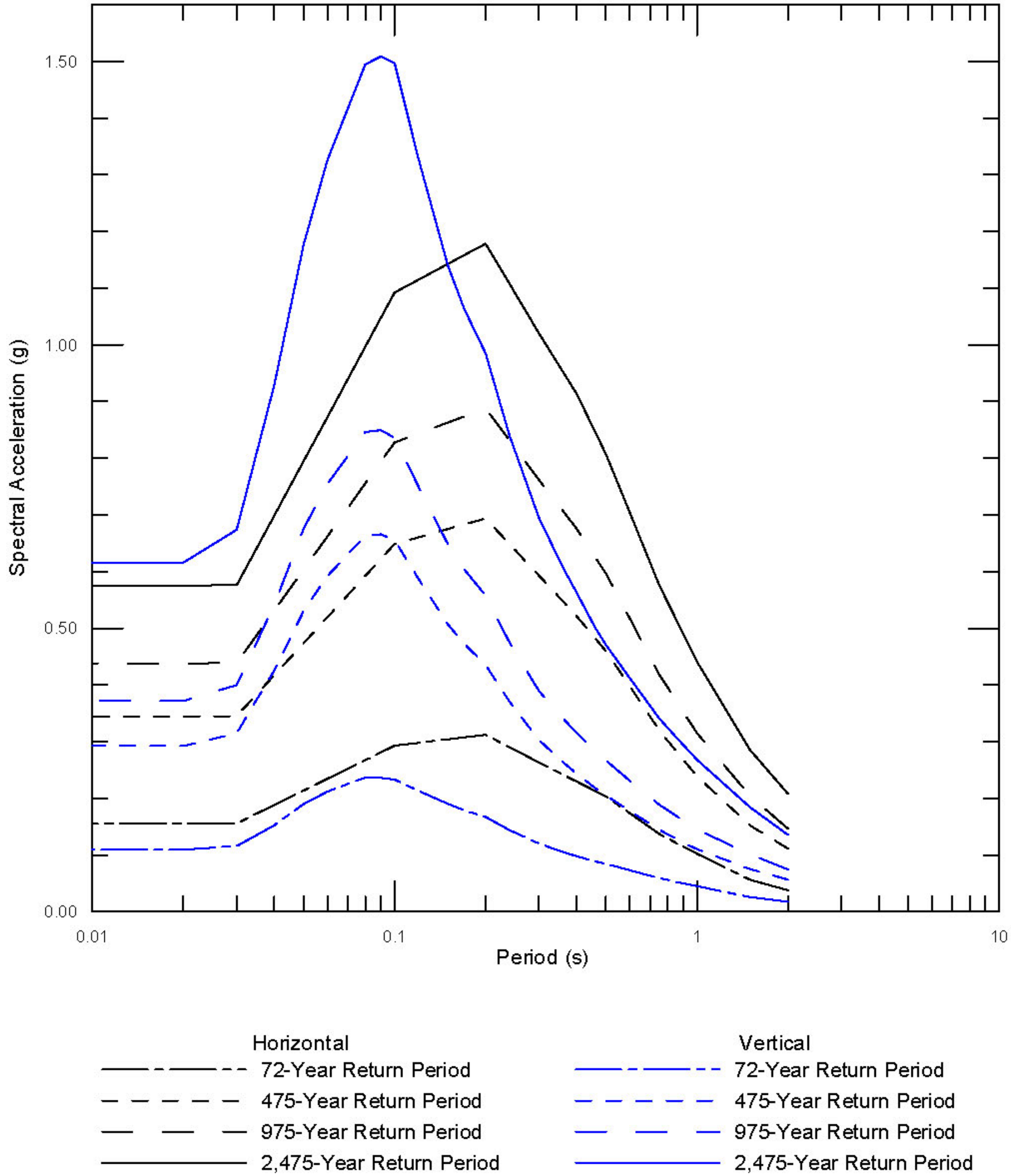
Comparison of Site-Specific Versus 2007 USGS Map Values 2% in 50 Years

SA	Site-Specific	2007 USGS	% Change
PGA	0.58	0.69	-16%
0.2 sec	1.18	1.55	-24%
1.0 sec	0.44	0.52	-15%

Controlling Earthquakes (Modes)

Return Period (yrs)	0.3 Sec SA			0.75 Sec SA			2.0 Sec SA		
	72	**475**	**2,475**	**72**	**475**	**2,475**	**72**	**475**	**2475**
M*	6.1	6.3	6.6	6.2	6.6	7.1	6.8	7.0	7.5
D*	45	49	53	52.5	52.5	52.5	160	108	50
ε*	1.45	1.85	1.90	0.7	1.6	1.65	1.10	1.65	1.35

5%-Damped Uniform Hazard Spectra



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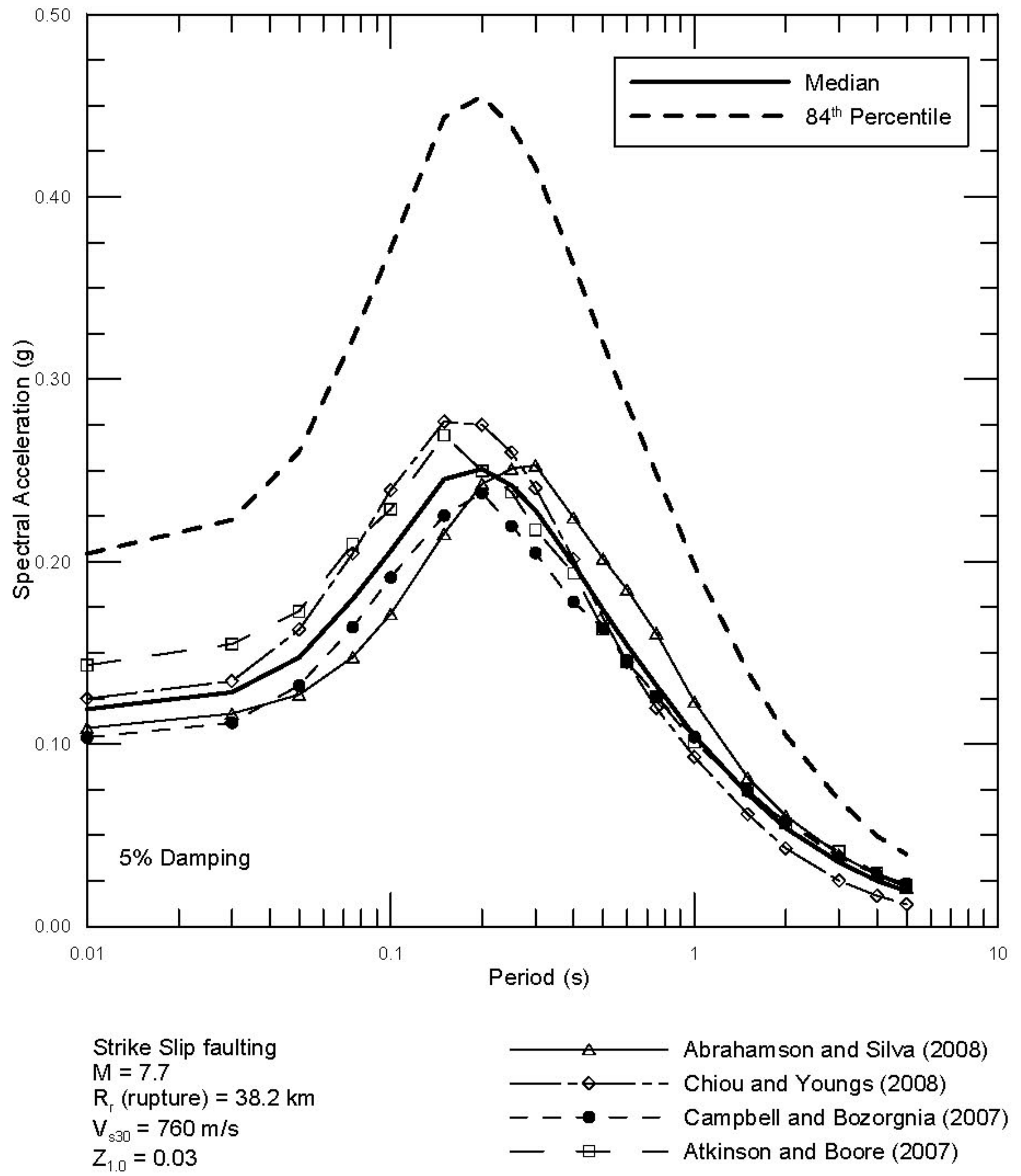
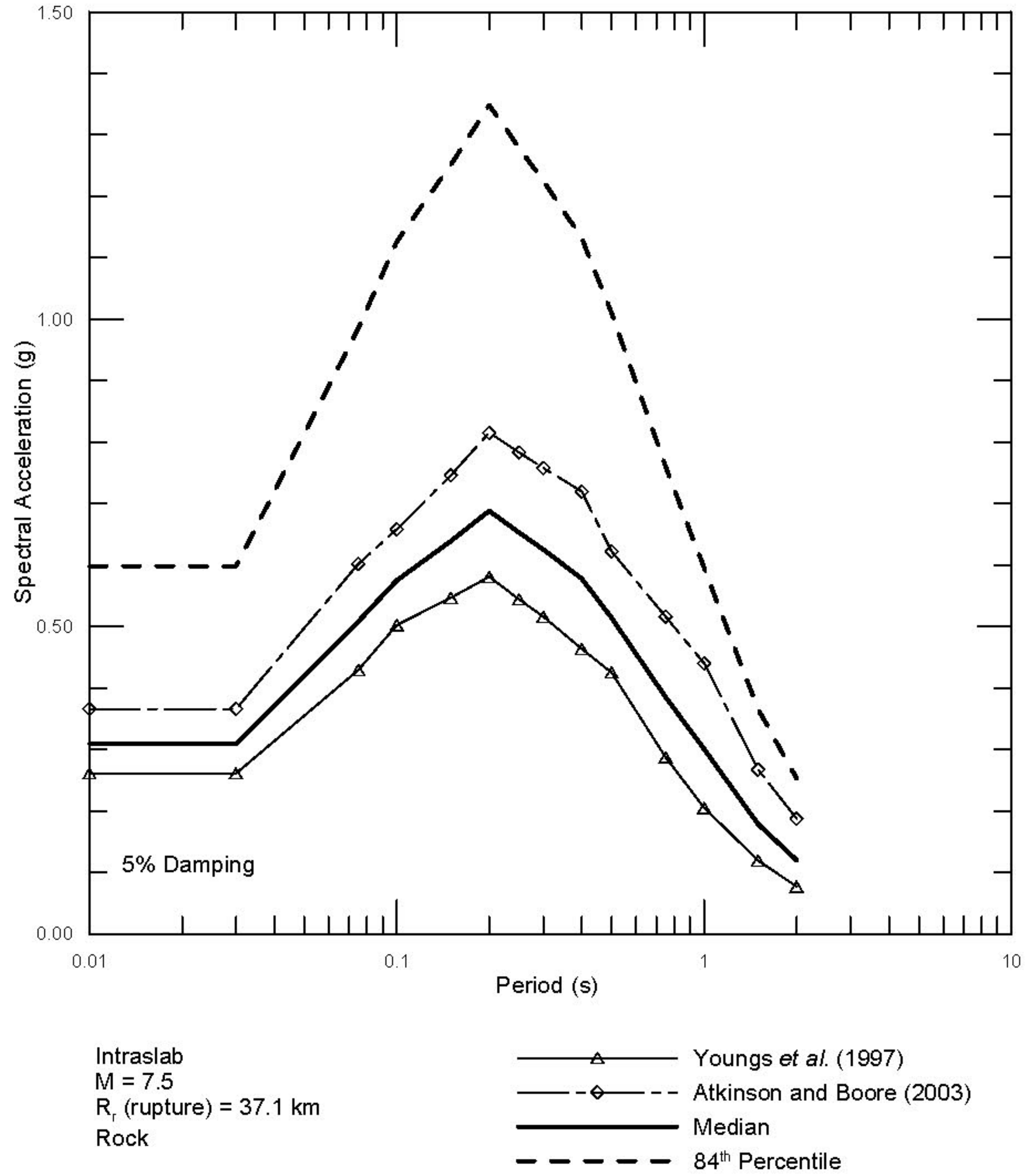
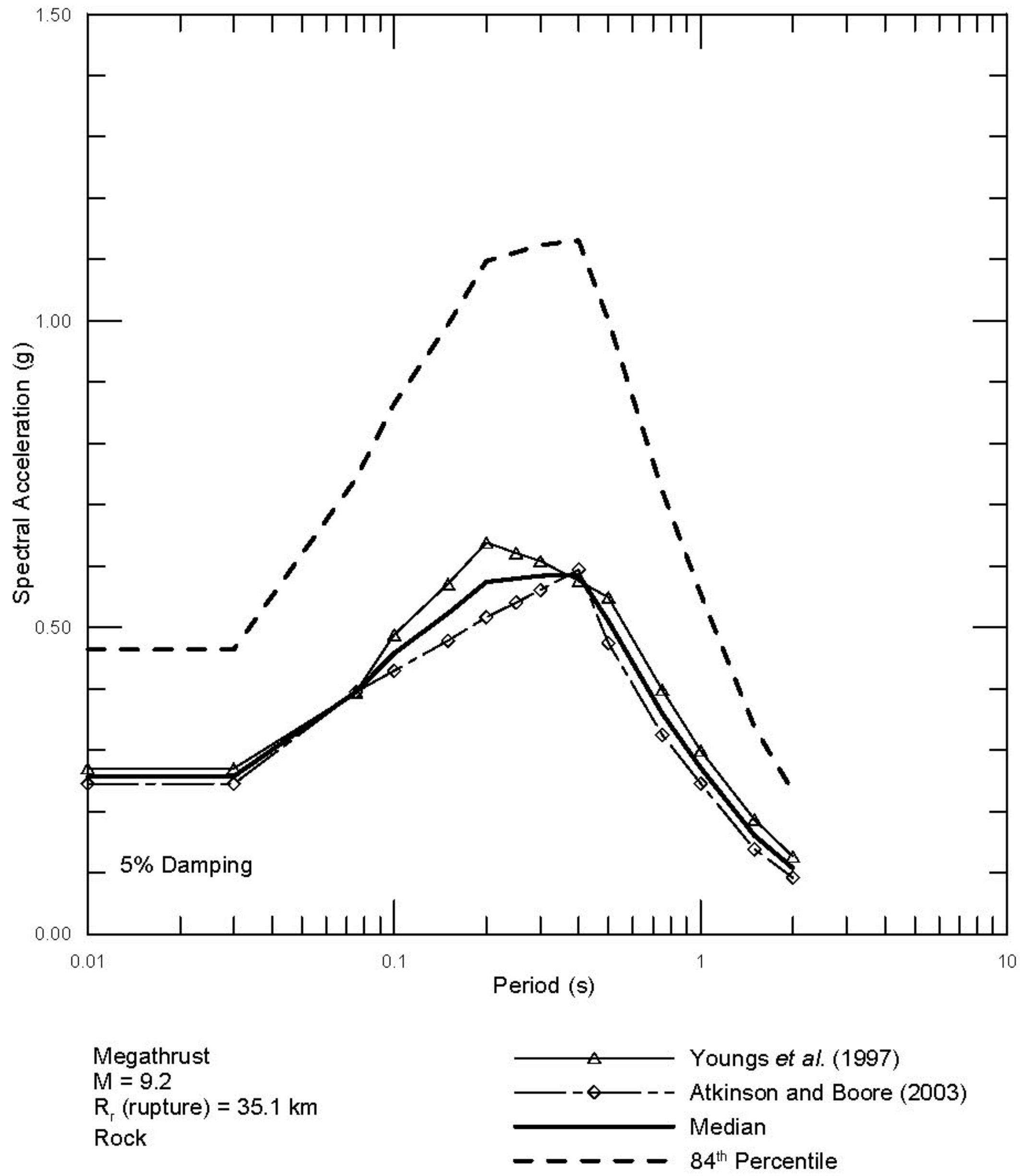
Median and 84th Horizontal Acceleration Response Spectra for the M 7.7 Castle Mountain Fault Maximum Earthquake



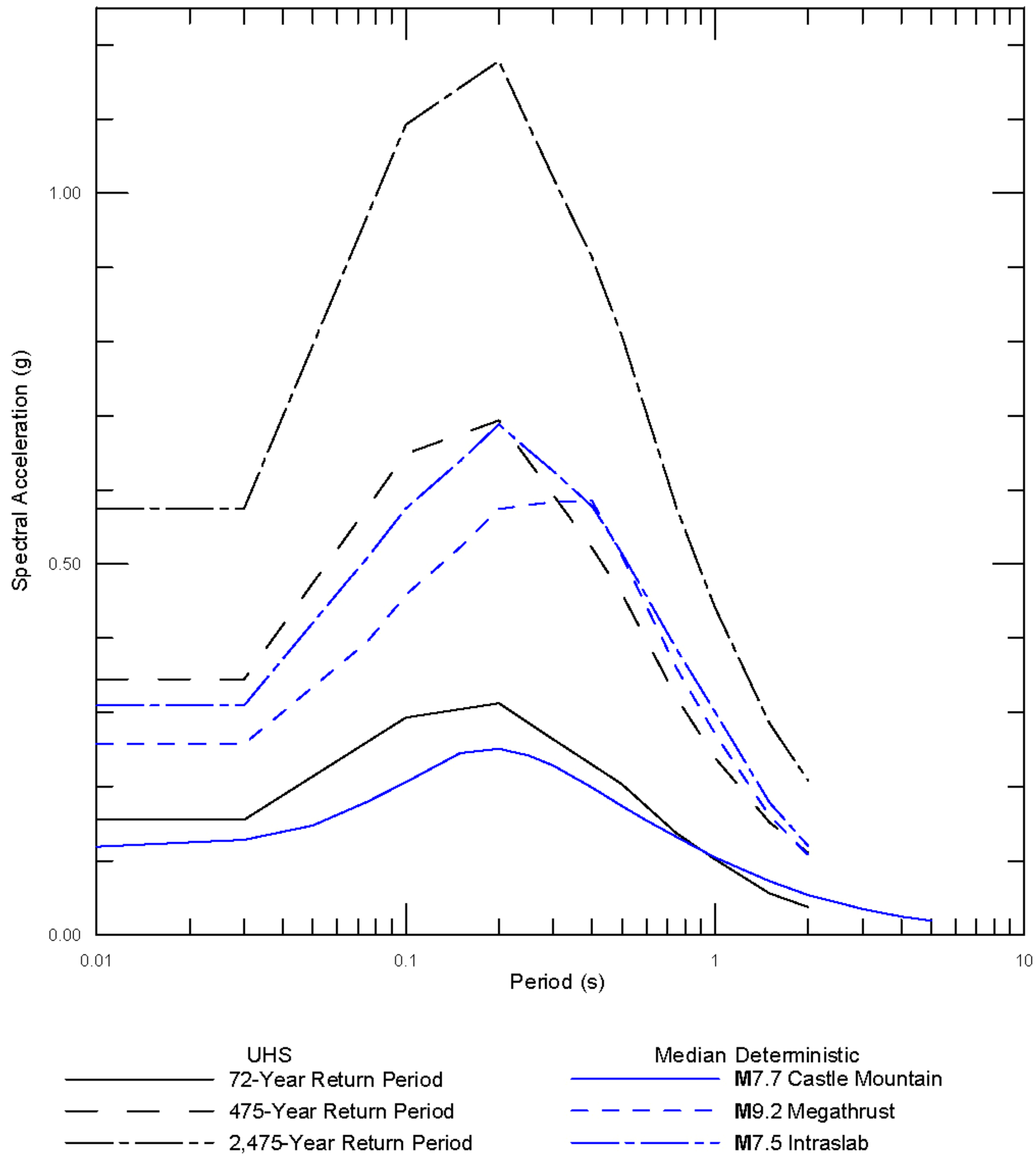
Median and 84th Horizontal Acceleration Response Spectra for the M 7.5 Intraslab Maximum Earthquake



Median and 84th Horizontal Acceleration Response Spectra for the M 9.2 Megathrust Maximum Earthquake



Comparison of UHS and Deterministic Scenario Spectra



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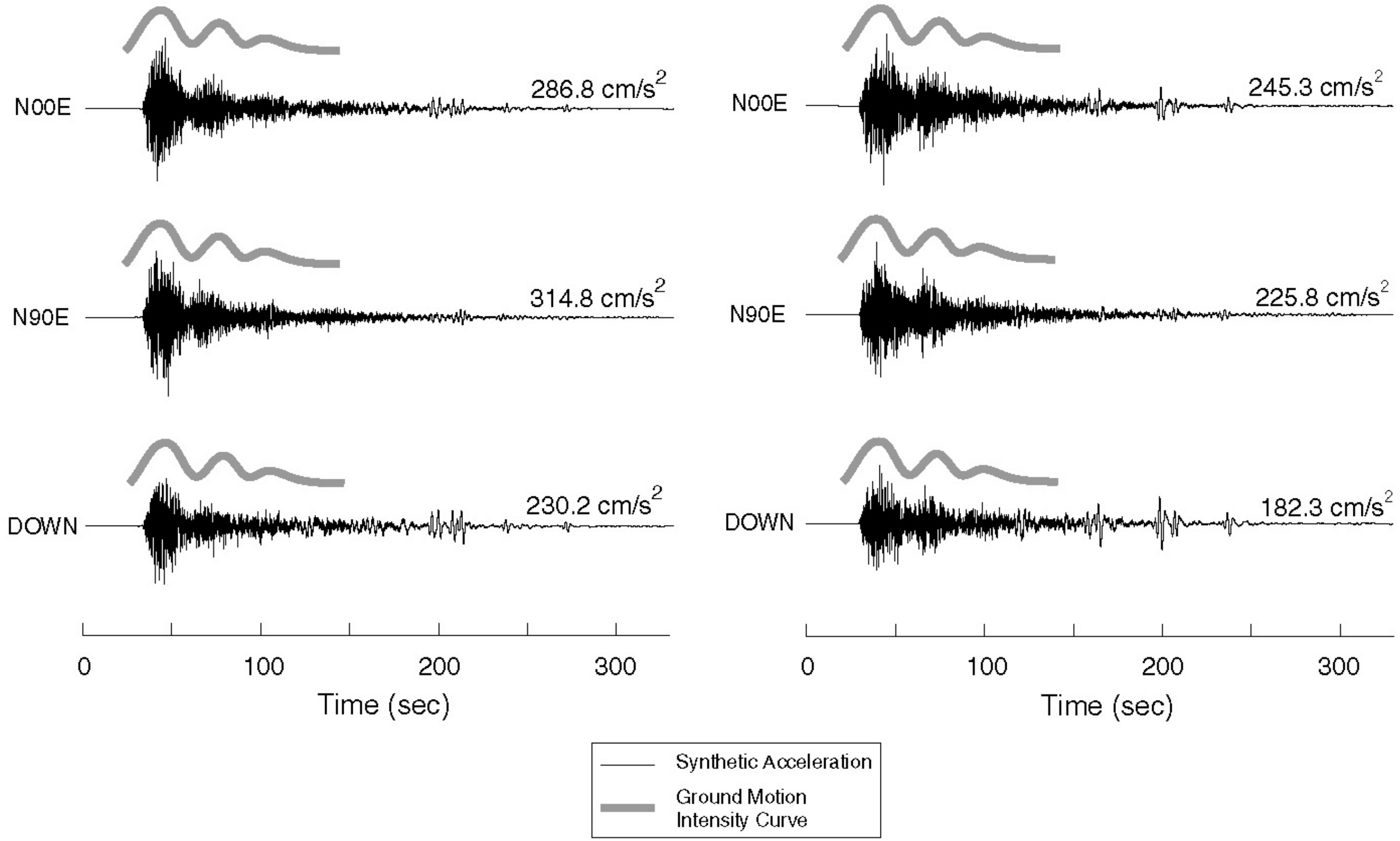
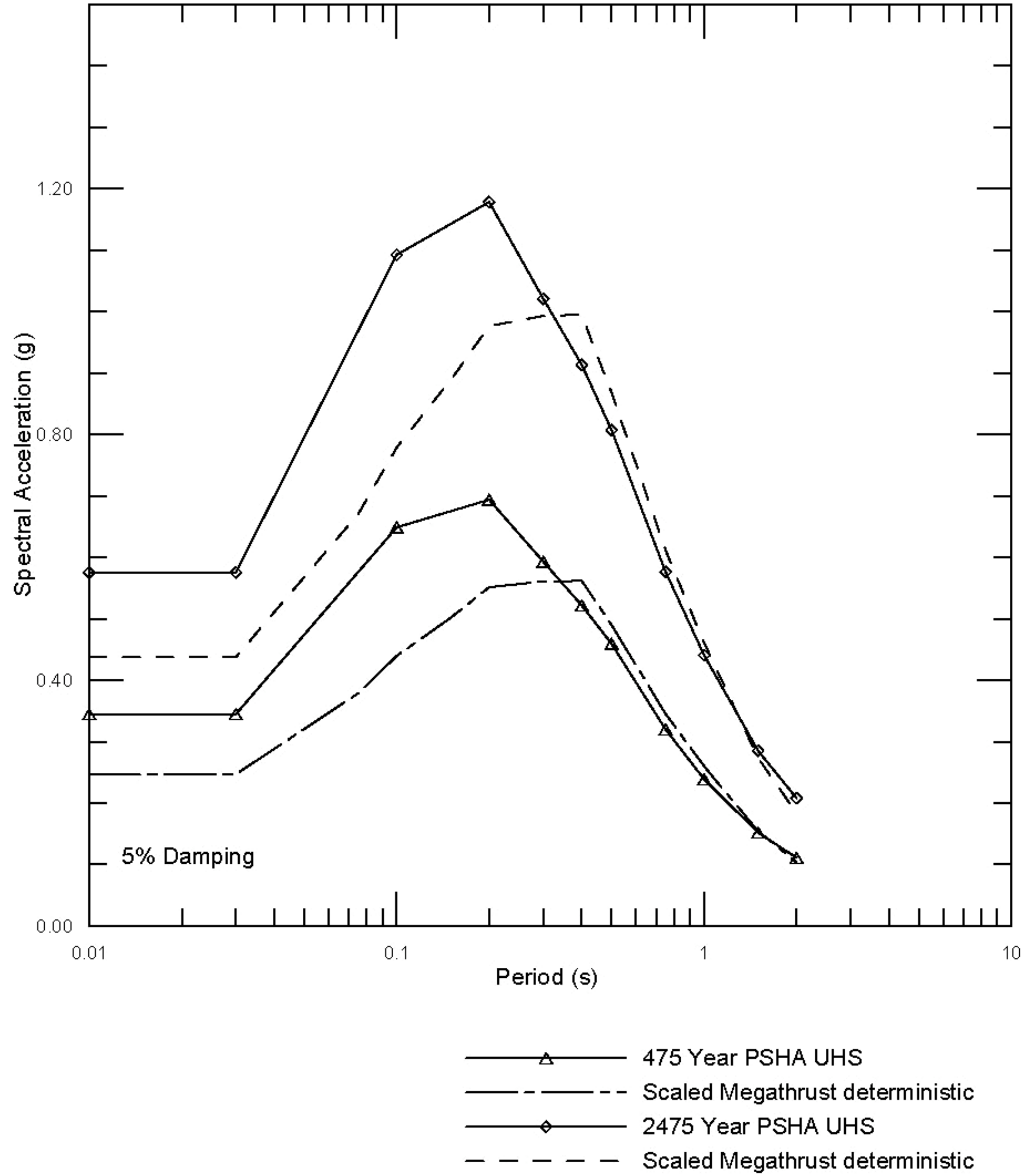
Synthetic Acceleration Time Histories for Anchorage



Source: Mavroedis et al., 2008

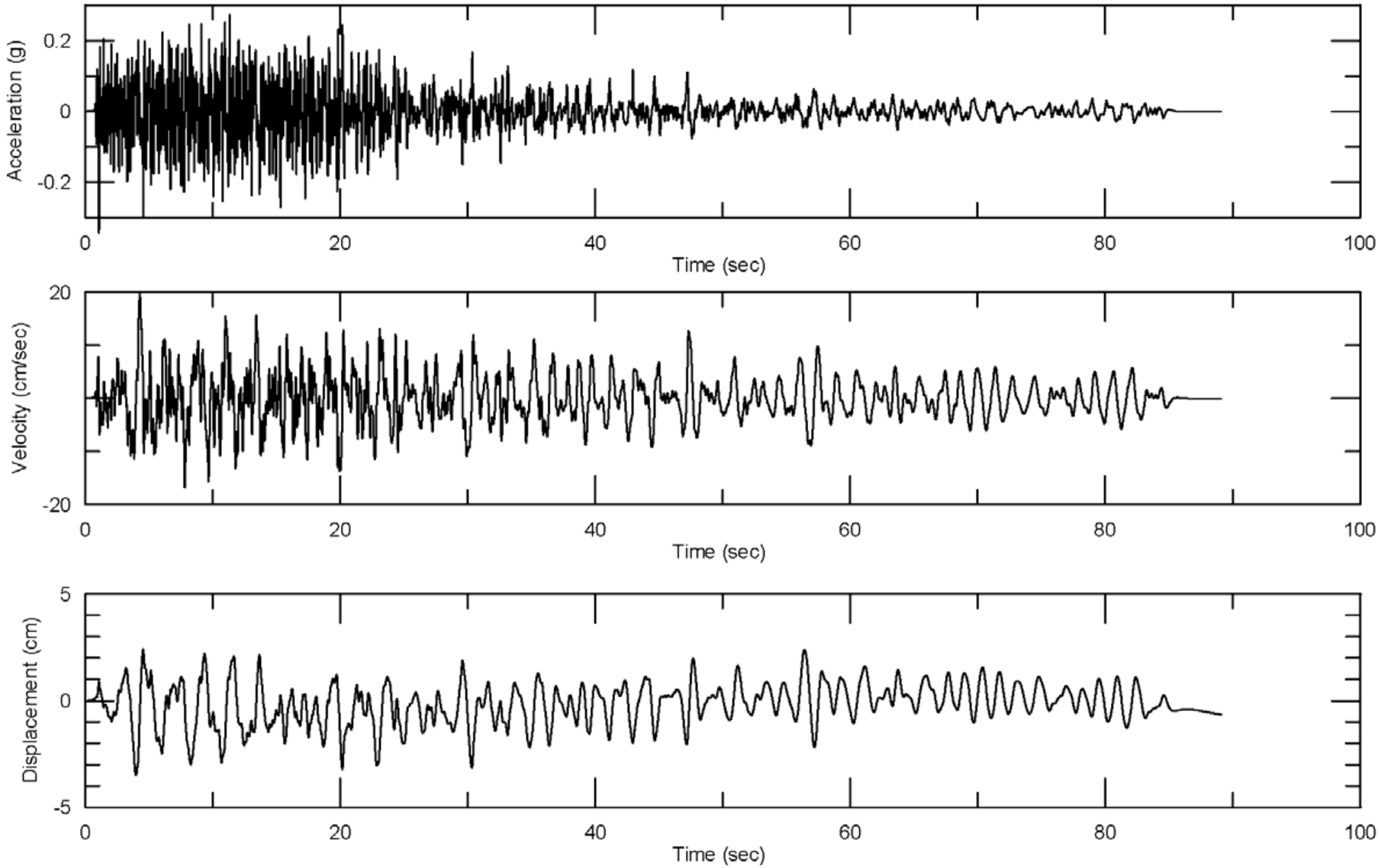
UHS and Scaled Megathrust Spectra



Summary of Seed Time Histories

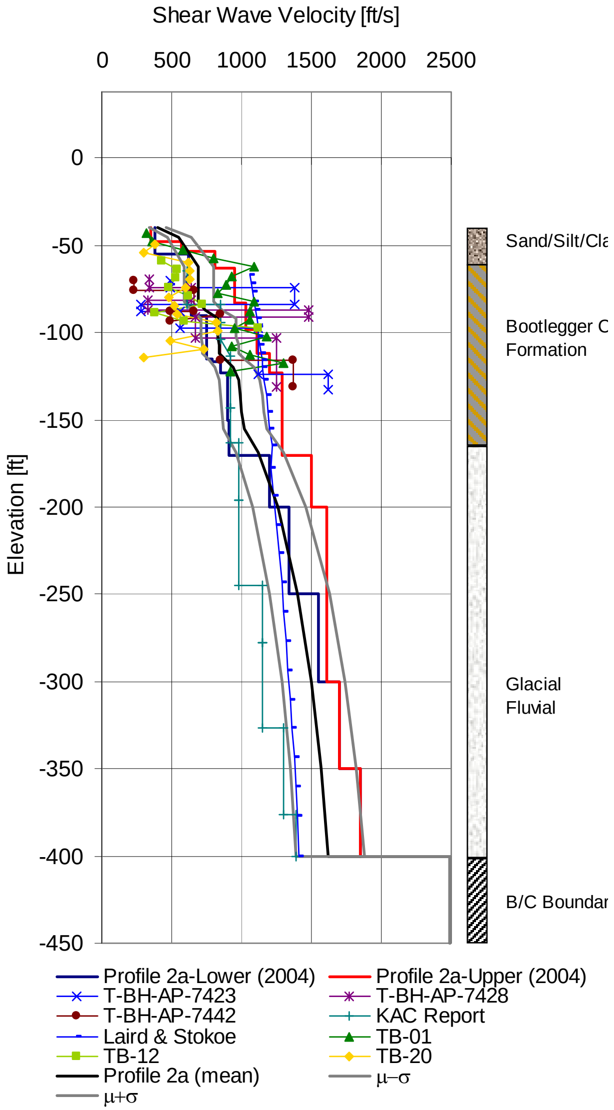
Name of Station	NEHRP Category Based on Vs30	Event Name	Date	Magnitude (M)	Hypocentral Distance (km)	PGA (g)
Olympia	D (623 ft/sec)	Puget Sound	April 29, 1965	6.5	84.9	H1(176): 0.137
Zarate	?	Peru Coast	January 5, 1974	6.3	73	H1(000): 0.142
Unio	B?	Michoacan, Mexico	May 22, 1997	6.6	107	H1(000): 0.048
Olympia	D (623 ft/sec)	Western Washington	April 13, 1949	7.1	74.7	H1(356): 0.165
Cale	B?	Michoacan, Mexico	January 11, 1997	7.1	36.9	H1(180): 0.357
PCEP	C (1445 ft/sec)	Nisqually, WA	February 28, 2001	6.8	62	H1(090): 0.204 H2(000): 0.213
Synthetic ALL005	B	Cascadia	--	9.0		0.217
Synthetic ALL009	B	Cascadia	--	9.0		0.290

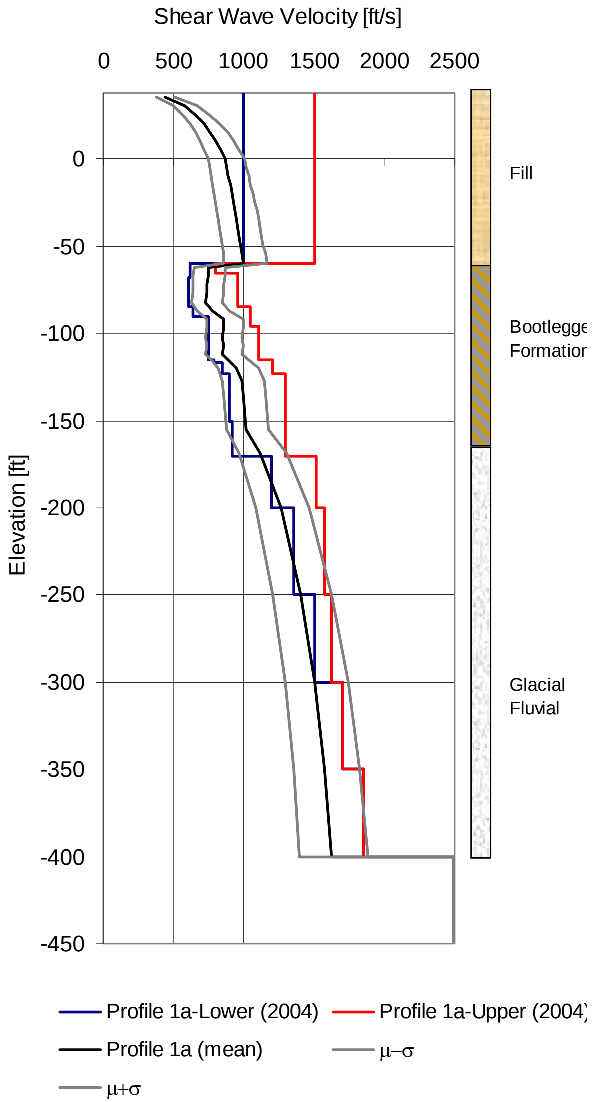
Time Histories Spectrally Matched to Horizontal 475-Year Return Period Target UHS, Intraslab Event (M = 7.1, D = 74.7 km) 1949 Western Washington Earthquake, Olympia

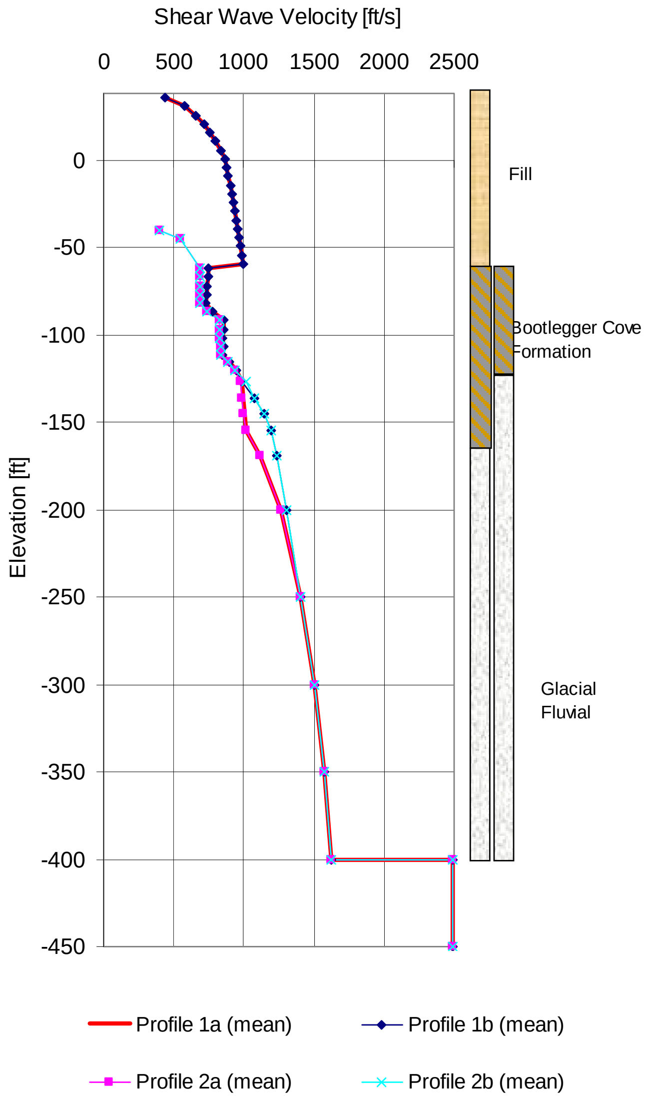


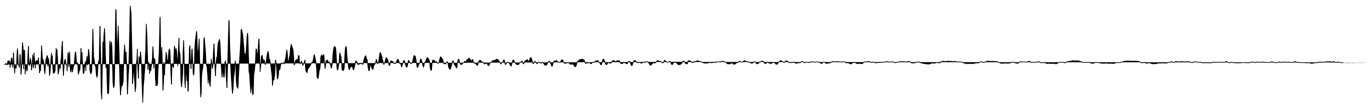
Site Response Analysis

Updated V_S – 4 Profiles



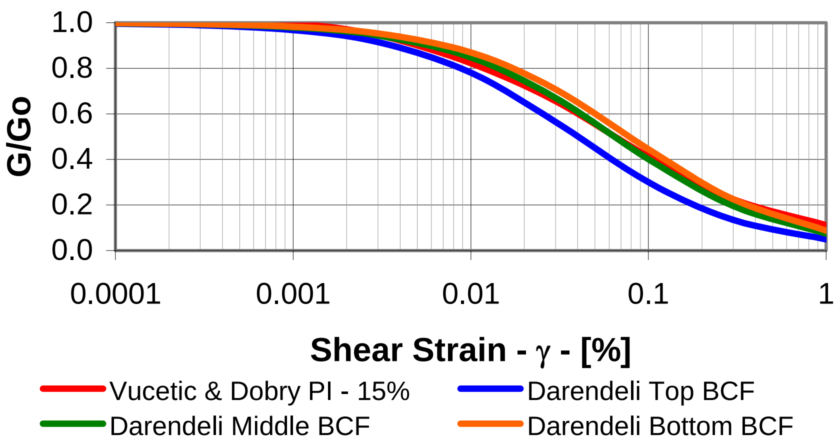


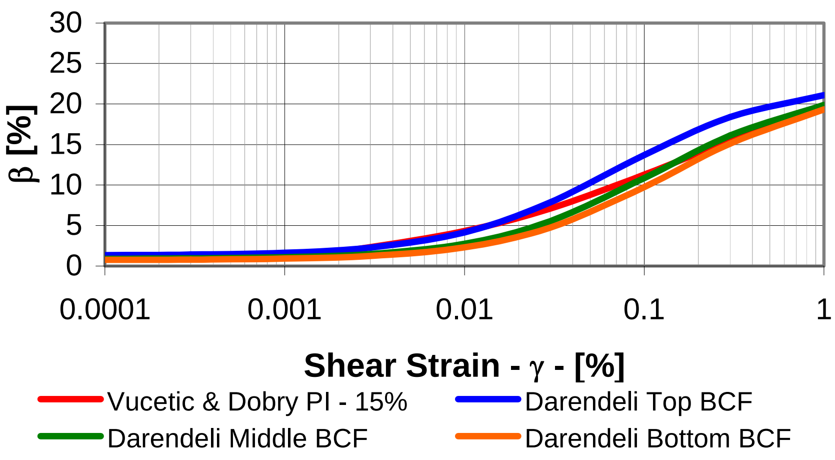




Updated Shear Modulus Reduction and Damping Curves

Bootlegger Cove Formation without the fill





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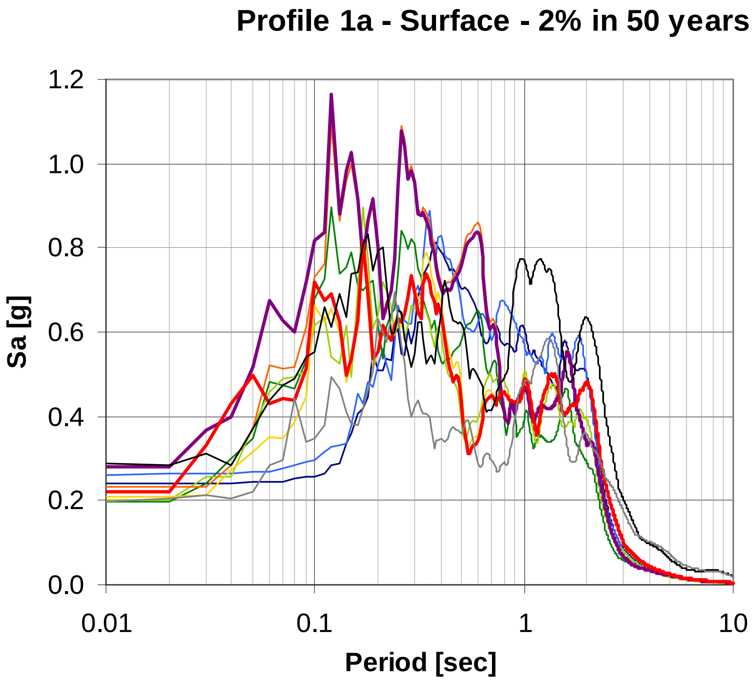
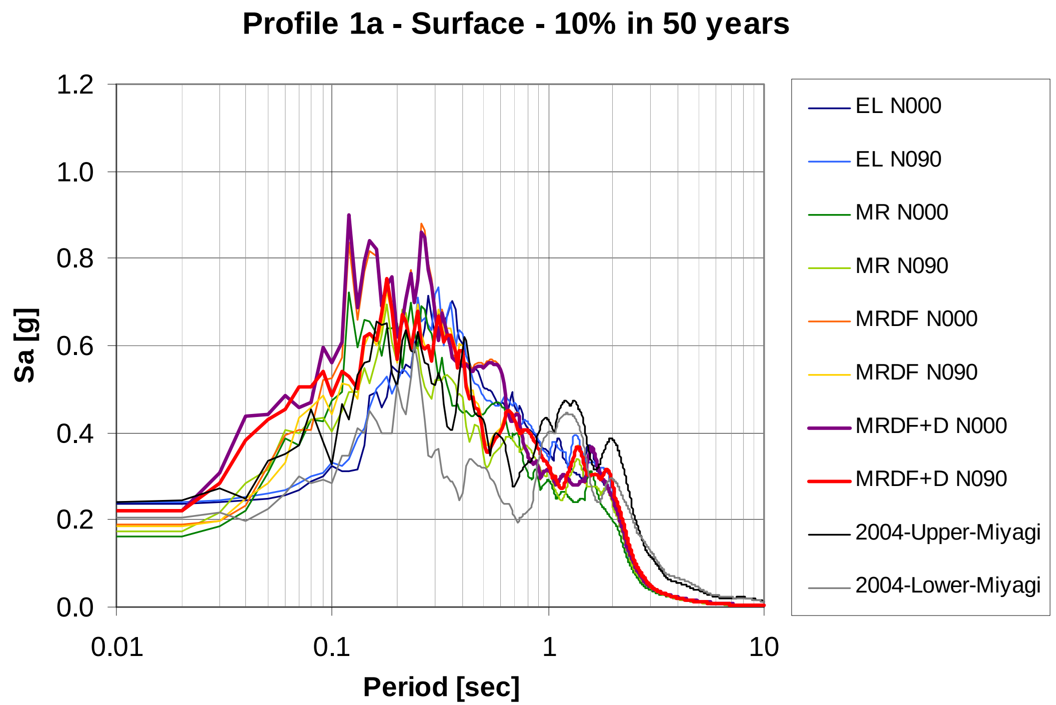
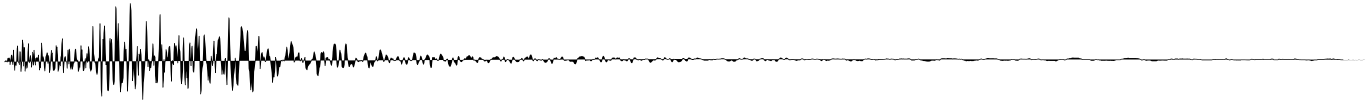
Typical Results: Different Models







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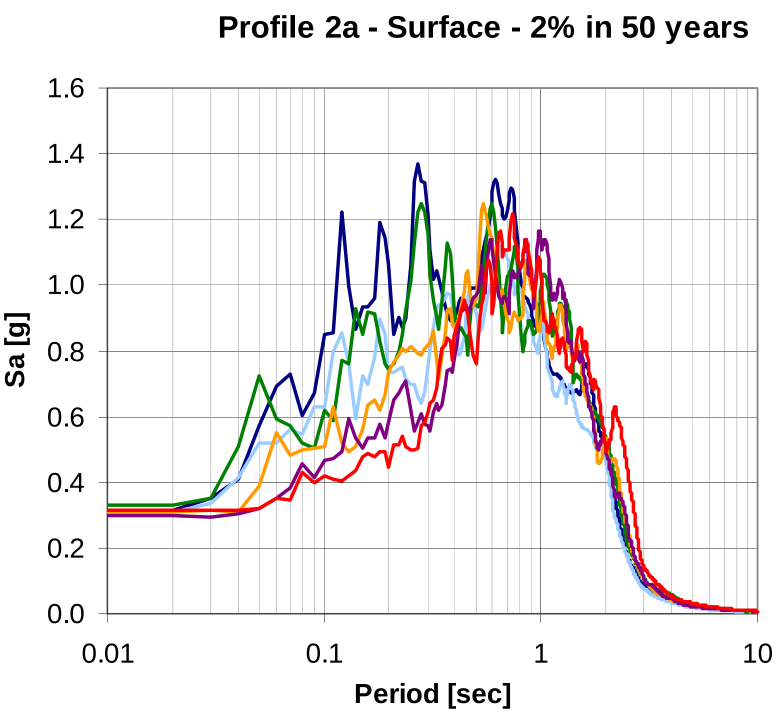
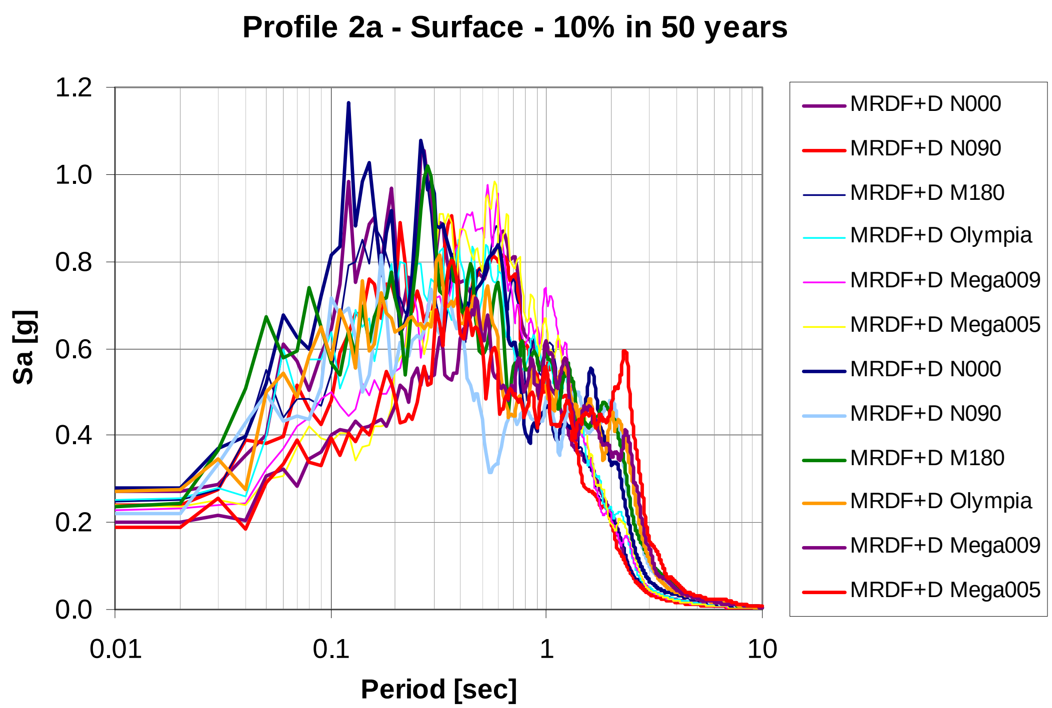
Typical Results: All Motions





Conclusions

- The probabilistic hazard at the Port is expectedly moderate to high with a 2,475-year return period mean PGA of 0.58 g.
- The controlling seismic source at the Port is the Wadati-Benioff zone with a significant contribution from the 1964 megathrust at long periods (> 2 sec).
- The site-specific ground motions for the Port are about 20% lower than the USGS National Hazard Maps. The use of more recent attenuation relationships probably account for this difference.

Conclusions (cont'd.)

- The Castle Mountain fault is not a significant contributor relative to the subduction zone in large part due to the lower ground motions resulting from the NGA models.

- The site response analysis indicates that at higher levels of ground motions e.g., 2% and 10% in 50 years, there is deamplification of ground motions due to nonlinear soil response and the impedance contrast between the Bootlegger Cove Formation and the overlying fill.

- At lower levels of ground motions, there is some amplification e.g., 50% in 50 years.