PROBABILISTIC SEISMIC HAZARD ANALYSIS CASE HISTORIES

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PROBABILISTIC SEISMIC HAZARD CASE HISTORIES

Purpose of Talk

To present a few case histories illustrating the application of probabilistic seismic hazard analysis.

- Regulatory context of studies

- Use of studies for decision-making

- Methods for incorporating earth sciences data and uncertainties

- How expert judgments are included

- Comparisons of probabilistic and deterministic analysis

SOME COMMON APPLICATIONS OF PSHA

Nuclear Power Plants

- Regional studies in EUS (e.g., EPRI, LLNL)
- Site-specific studies in WUS (e.g., Diablo Canyon, Satsop)
- IPEEE evaluations of seismic margins (e.g., Palo Verde, SONGS, WNP-2)

DOE Nuclear and Non-nuclear Facilities

- New facility design (e.g., NPR at INEL, SRS)
- Design review (e.g., Hanford, Rocky Flats, INEL)

Major Bridges and Highway Structures

- Regional studies for design and review (e.g., IDOT, ODOT, ADOT)
- Site-specific design review (e.g., SF Bay, L.A.)

Dams

- Design review (e.g., FERC, commercial owners)
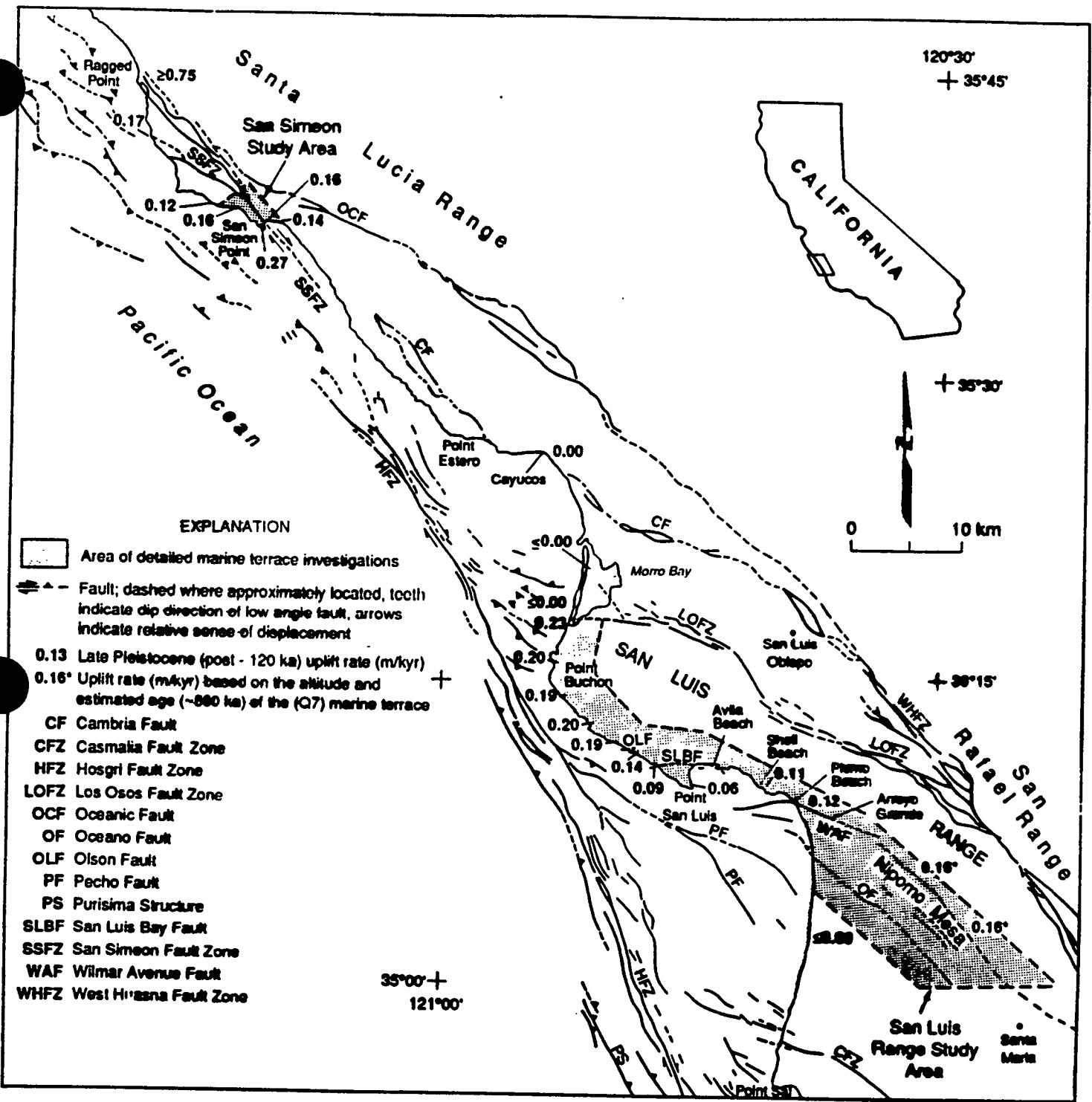- Check on deterministic (e.g., Bureau of Rec., COE)

Building Codes
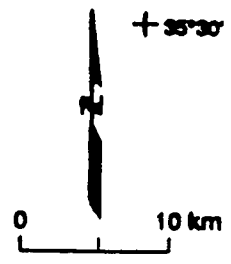
- Federal maps (e.g., USGS maps, BSSC)

Commercial Facilities

- Large building design (e.g., SF, L.A.)
- Large facility review
- Integrated risk assessment (e.g., spatially distributed facilities, other NPH)

DIABLO CANYON NUCLEAR POWER PLANT
LONG TERM SEISMIC PROGRAM

- Purpose: satisfaction of condition on operating license; input to analysis of risk

- Scoping study PSHA to identify significant issues, GSG studies

- Extensive program of data collection; interaction with NRC staff and consultants

- Consensus assessments of uncertainty by large project team; participatory consulting board

- Extensive NRC staff review with consultants

- Both probabilistic and deterministic seismic margin review

120°30'
+ 35°45'

CALIFORNIA

+ 35°30'

Santa Lucia Range

Ragged Point
≥0.75
0.17
SSFZ
San Simeon Study Area
0.16
0.12
OCF
0.16 San Simeon Point
0.14
0.27
SSFZ
CF
HFZ

Pacific Ocean

Point Estero
0.00
Cayucos
CF
≤0.00
Morro Bay
≤0.00
0.23
0.20
LOFZ
San Luis Obispo
Point Buchon
SAN LUIS
0.19
WHFZ
0.20
Avila Beach
0.19 OLF
SLBF
Shell Beach
0.14
Pismo Beach
0.11
0.09 Point San Luis
0.06
LOFZ
0.12 Arroyo Grande
San Rafael Range
RANGE
0.16*
Nipomo Mesa
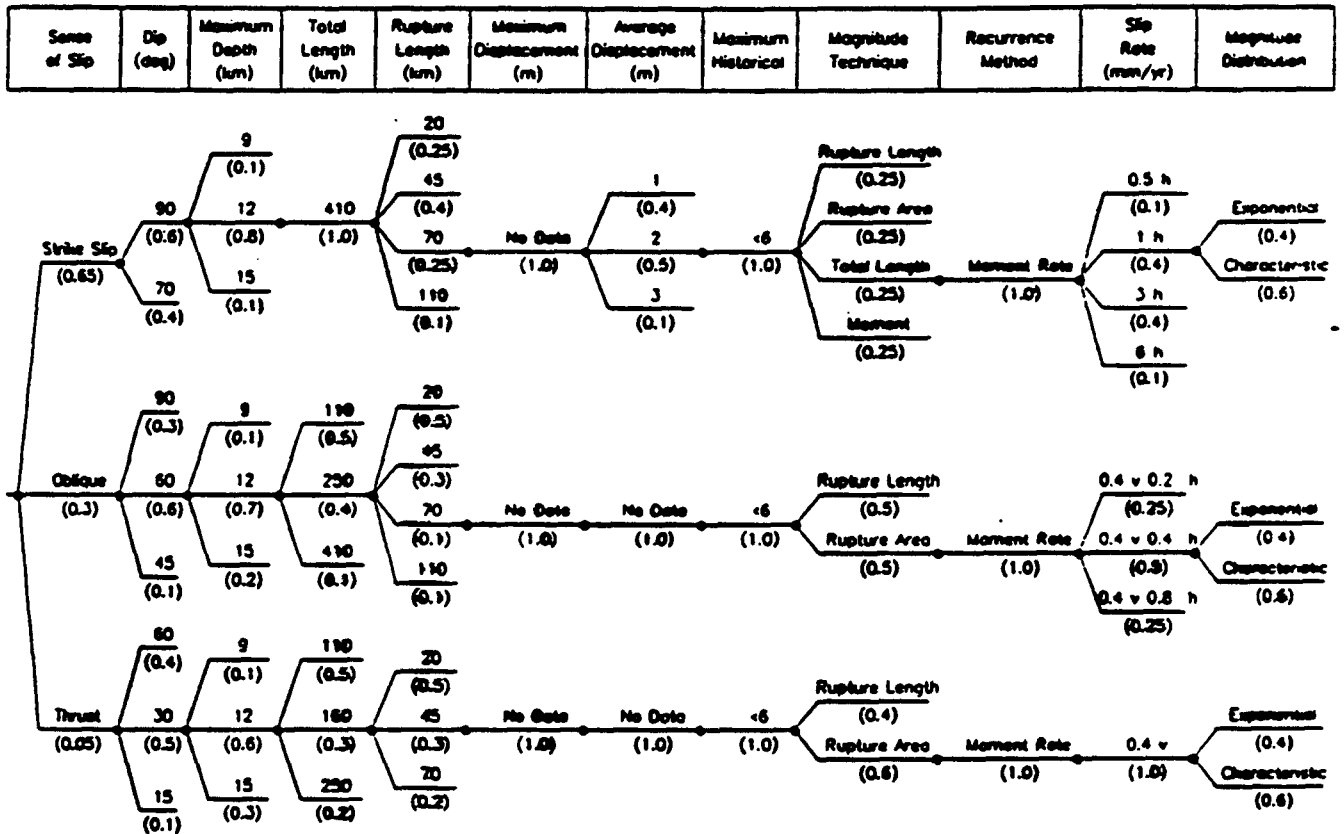0.16*
PF
WAF
PF
OF
≤0.00

0
10 km

+ 35°15'

EXPLANATION

Area of detailed marine terrace investigations

Fault; dashed where approximately located, teeth indicate dip direction of low angle fault, arrows indicate relative sense of displacement

0.13 Late Pleistocene (post - 120 ka) uplift rate (m/kyr)

0.16* Uplift rate (m/kyr) based on the altitude and estimated age (~880 ka) of the (Q7) marine terrace

CF   Cambria Fault
CFZ   Casmalia Fault Zone
HFZ   Hosgri Fault Zone
LOFZ Los Osos Fault Zone
OCF   Oceanic Fault
OF   Oceano Fault
OLF   Olson Fault
PF   Pecho Fault
PS   Purisima Structure
SLBF San Luis Bay Fault
SSFZ San Simeon Fault Zone
WAF   Wilmar Avenue Fault
WHFZ West Huasna Fault Zone

35°00' +
121°00'

San Luis Range Study Area

Santa Maria

HFZ

PS

CFZ

Point Sal

Sense of Slip	Dip (deg)	Maximum Depth (km)	Total Length (km)	Rupture Length (km)	Maximum Displacement (m)	Average Displacement (m)	Maximum Historical	Magnitude Technique	Recurrence Method	Slip Rate (mm/yr)	Magnitude Distribution

Notes:
Values in parentheses are probabilities
h = horizontal component of slip rate,
v = vertical component of slip rate

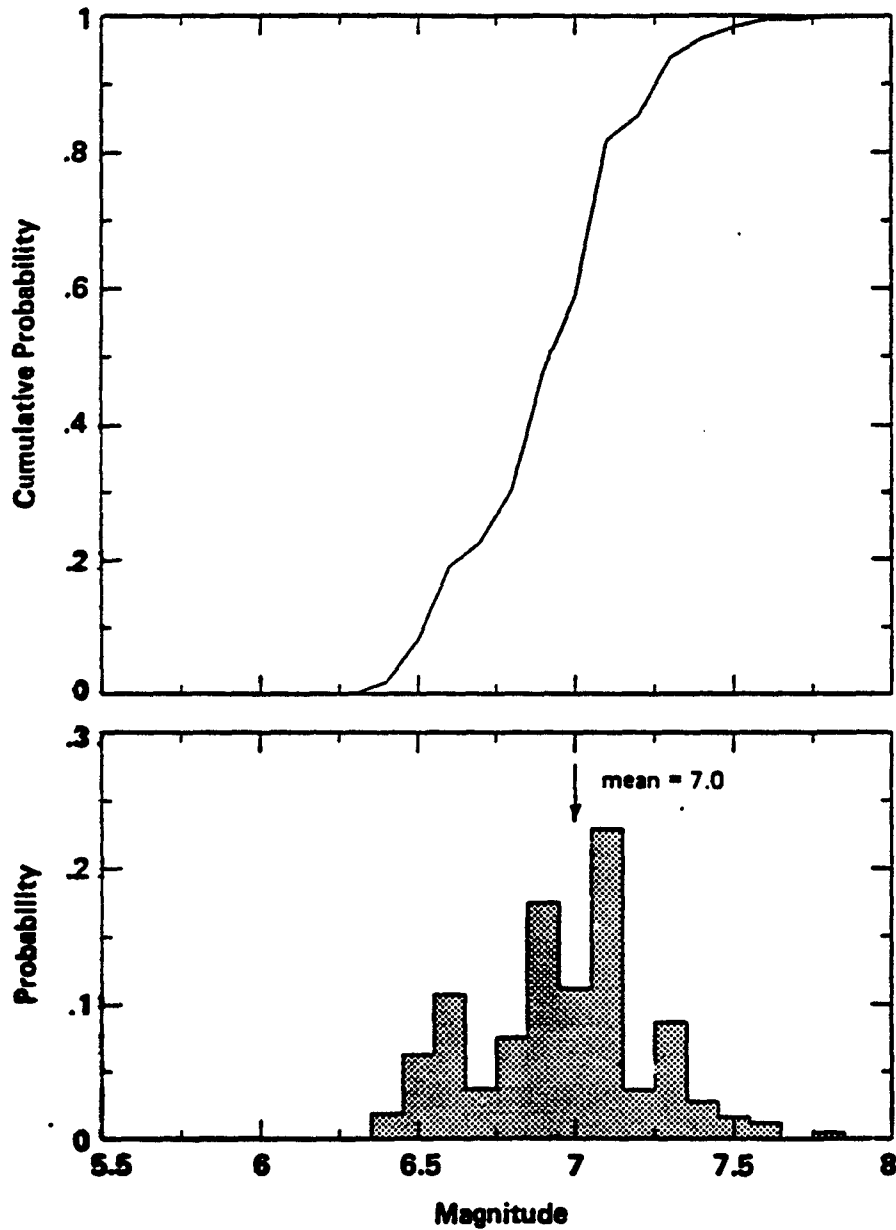**Figure 3-5**
Logic tree for Hosgri fault zone.

Figure 3-9

Maximum magnitude distribution for Hosgri fault zone.

WNP-3 SATSOP NUCLEAR POWER PLANT

- Purpose: to answer NRC question to FSAR for licensing; probability of exceeding SSE

- Significant change in perceived hazard due to Cascadia subduction zone; strong diversity in scientific interpretations

- 14 experts elicited in individual interviews; extensive documentation

- Component-level aggregation to examine technical issues

- Used by NRC staff to evaluate 'conservatism' of SSE; little basis for comparing p(exceedance) of WUS sites

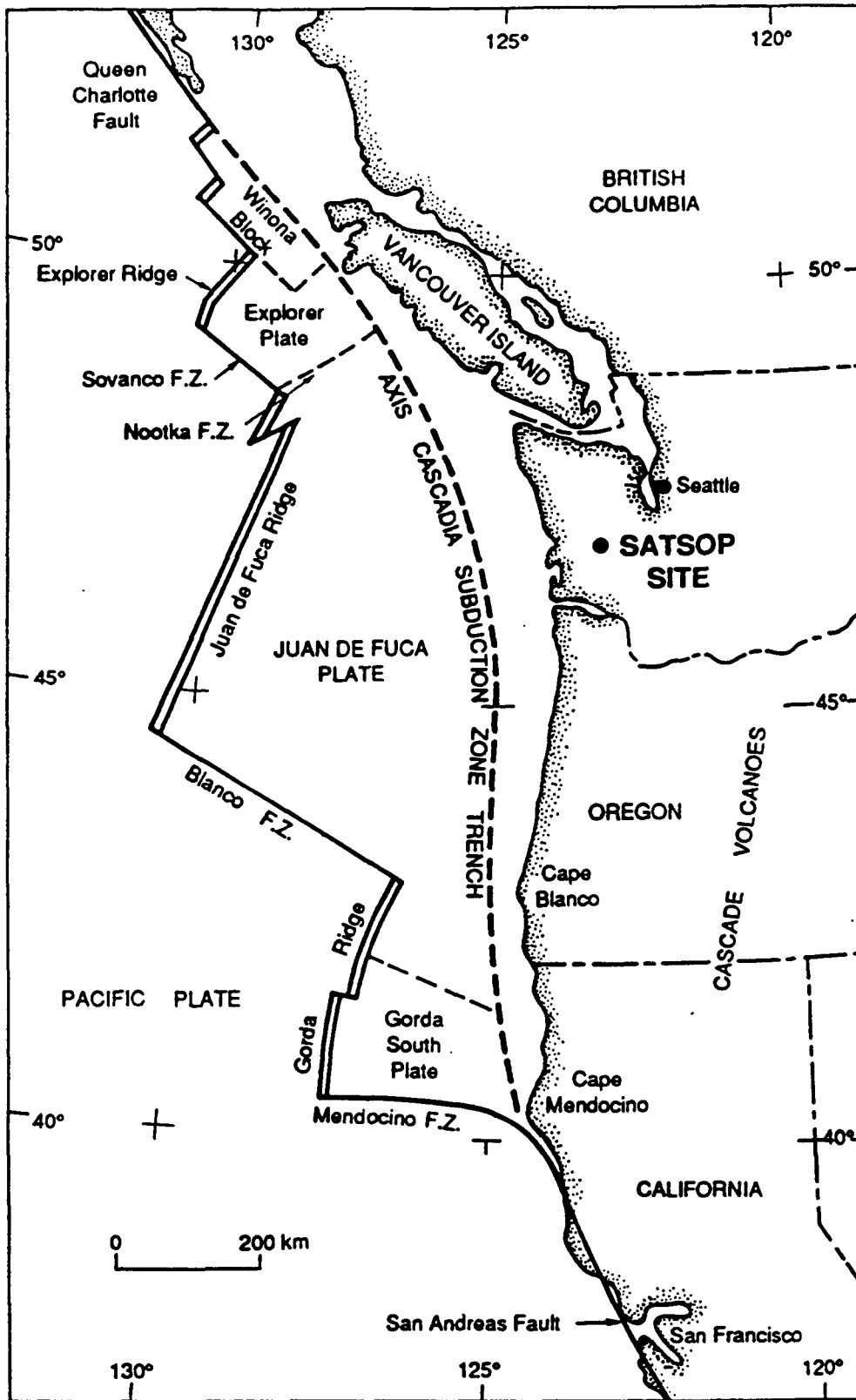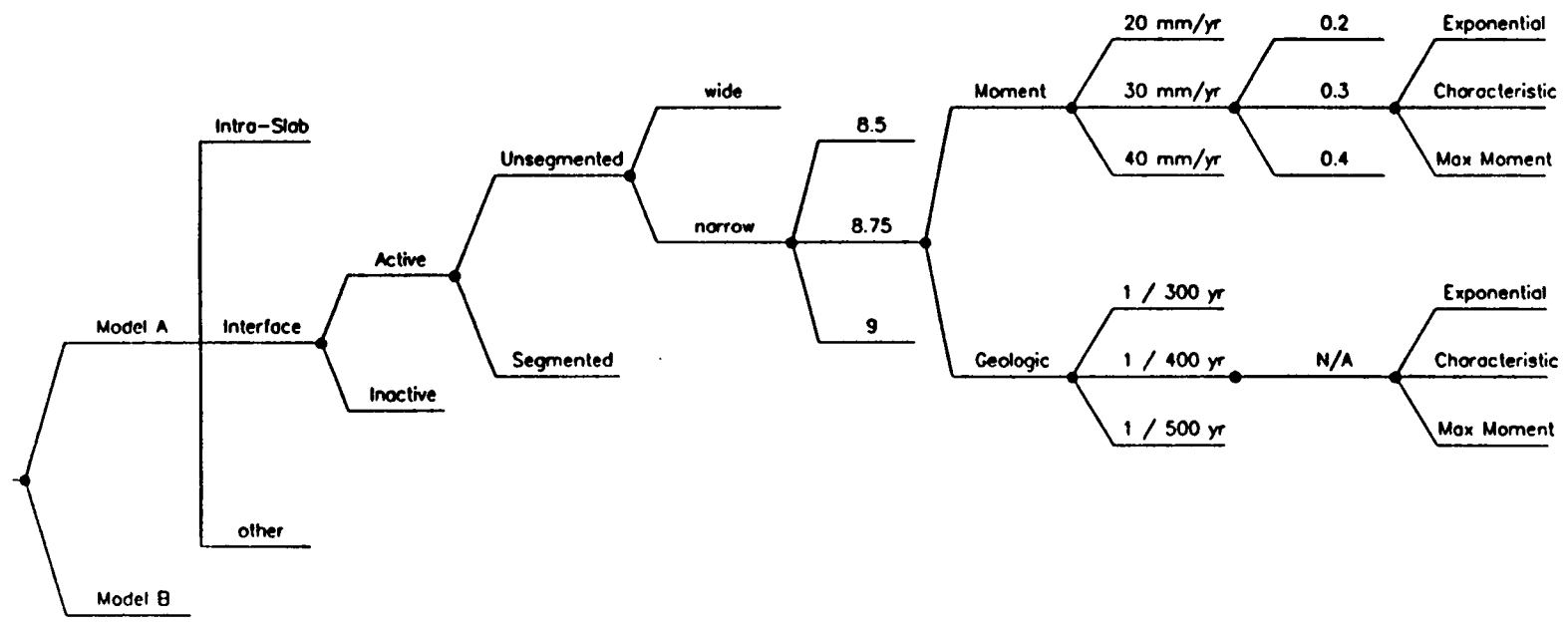- Diversity among experts a significant contributor to total uncertainty

Fig 1

Fig. 3

Oceanic Slab Geometry	Sources	State of Activity	Segmentation	Maximum Extent of Rupture	Maximum Magnitude	Recurrence Method	Convergence or Geologic Rate	Seismic Coupling	Magnitude Distribution

Tree branches:

Model A
- Intra-Slab
- Interface
  - Active
    - Unsegmented
      - wide
      - narrow — 8.5
    - Segmented — 8.75 — 9
  - Inactive
- other

Moment — 20 mm/yr, 30 mm/yr, 40 mm/yr — 0.2, 0.3, 0.4 — Exponential, Characteristic, Max Moment

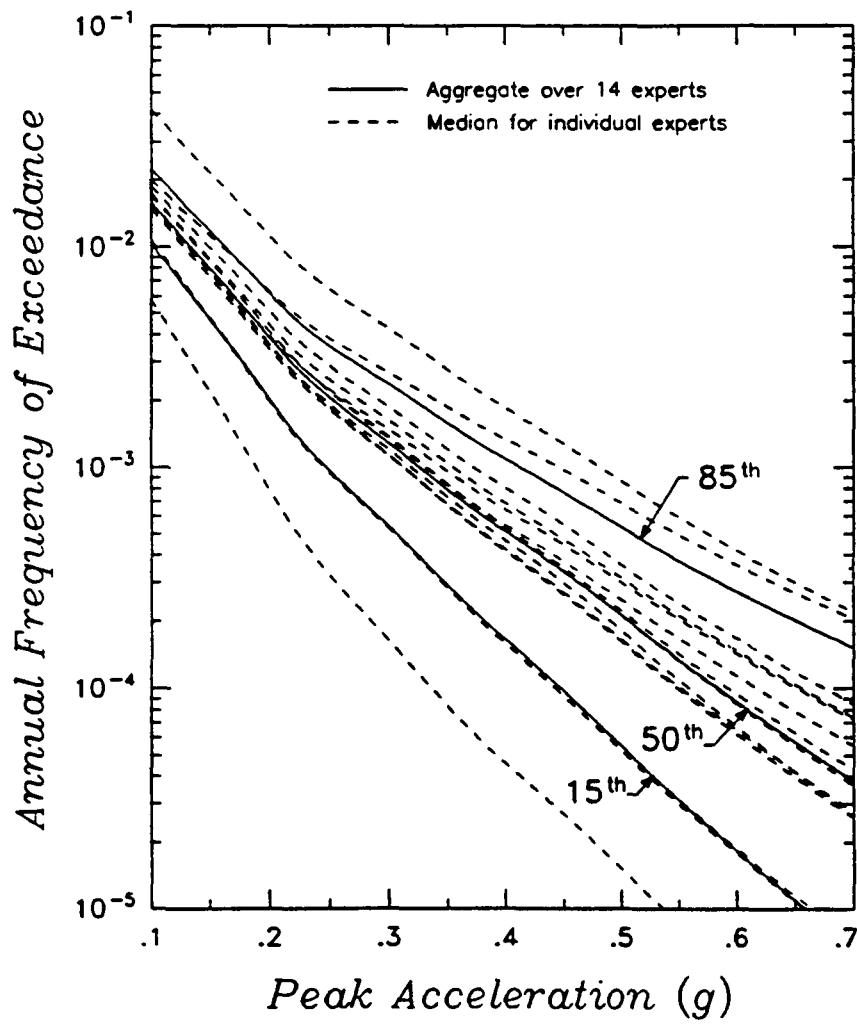Geologic — 1 / 300 yr, 1 / 400 yr, 1 / 500 yr — N/A — Exponential, Characteristic, Max Moment

Model B

Fig 14
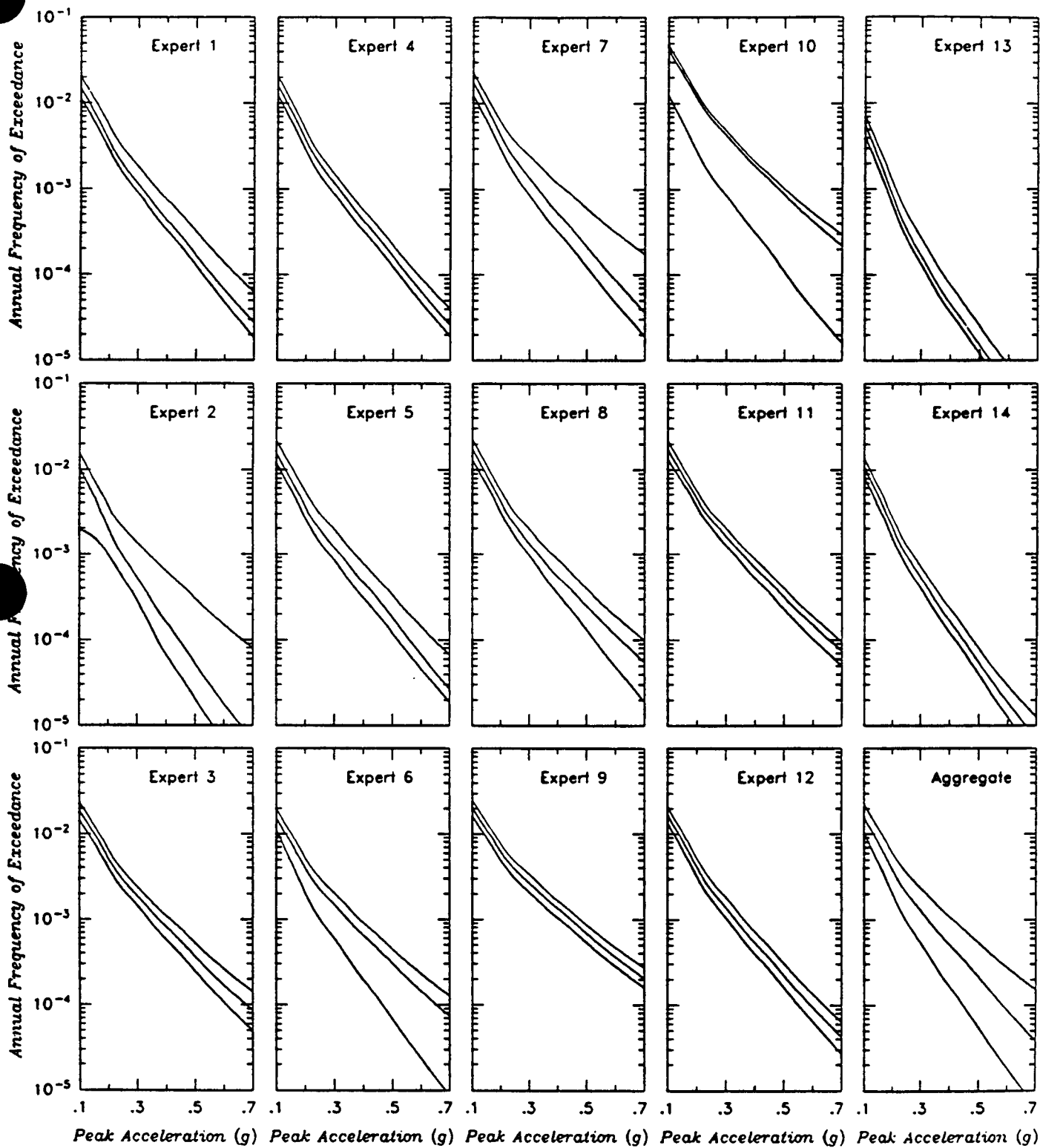
Fig 13

SAN FRANCISCO BAY AREA BRIDGES

- Purpose: define ground motion levels for design review of Caltrans bridges

- Site-specific assessments to be used for decisions regarding seismic retrofit

- Incorporation of fault-specific paleoseismic studies, tectonic models, recurrence models, seismicity

- Carried out by project team with consulting board review

- Selection of design through comparison of probabilistic and deterministic results

──── ─ ── Active faults

──── ─ ── Other faults considered
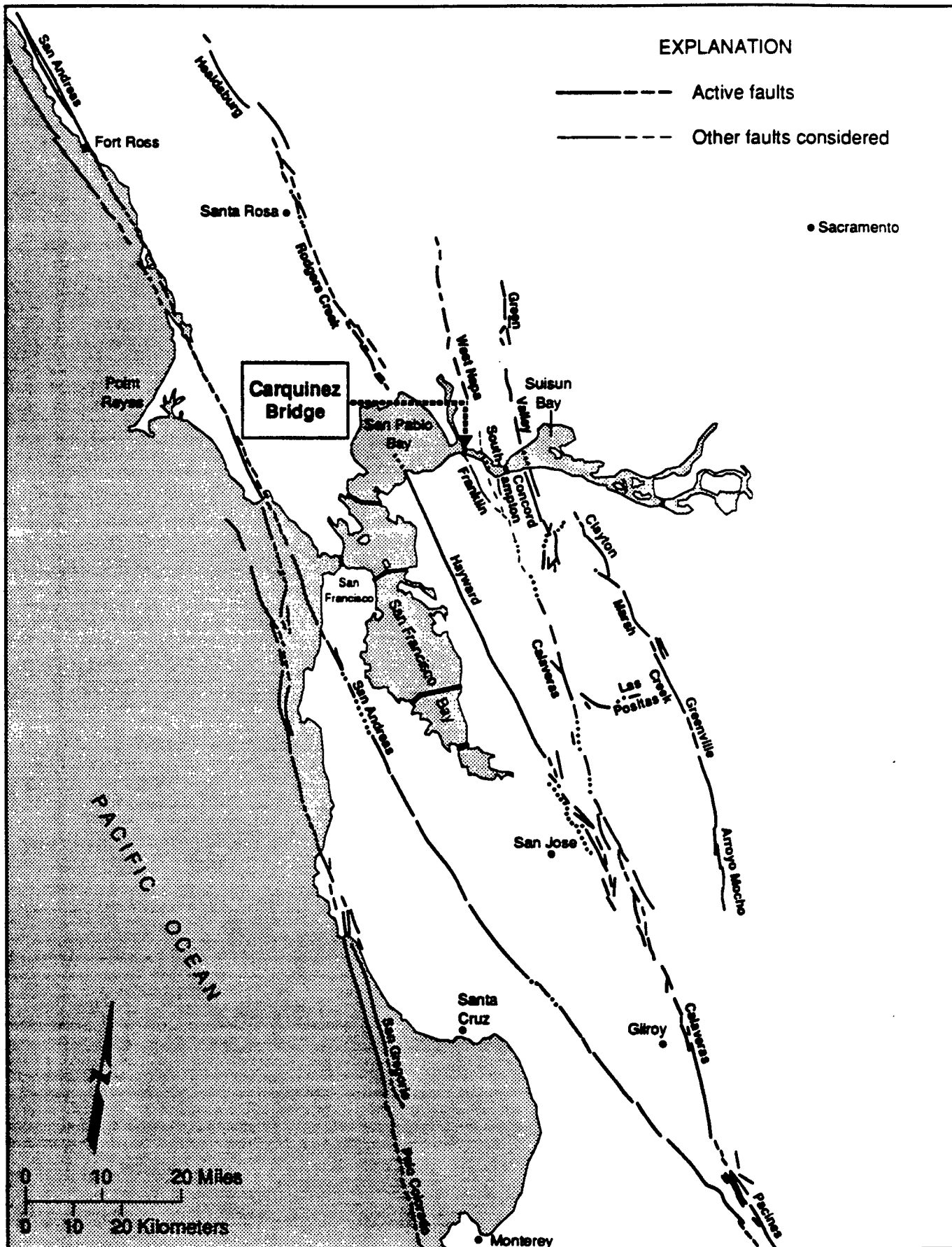
REGIONAL SOURCE FAULT MAP
Seismic Ground Motion Studies for the Carquinez Bridge
Contra Costa and Solano Counties, California

Figure
2-1

Project No.
1606E

GEOMATRIX
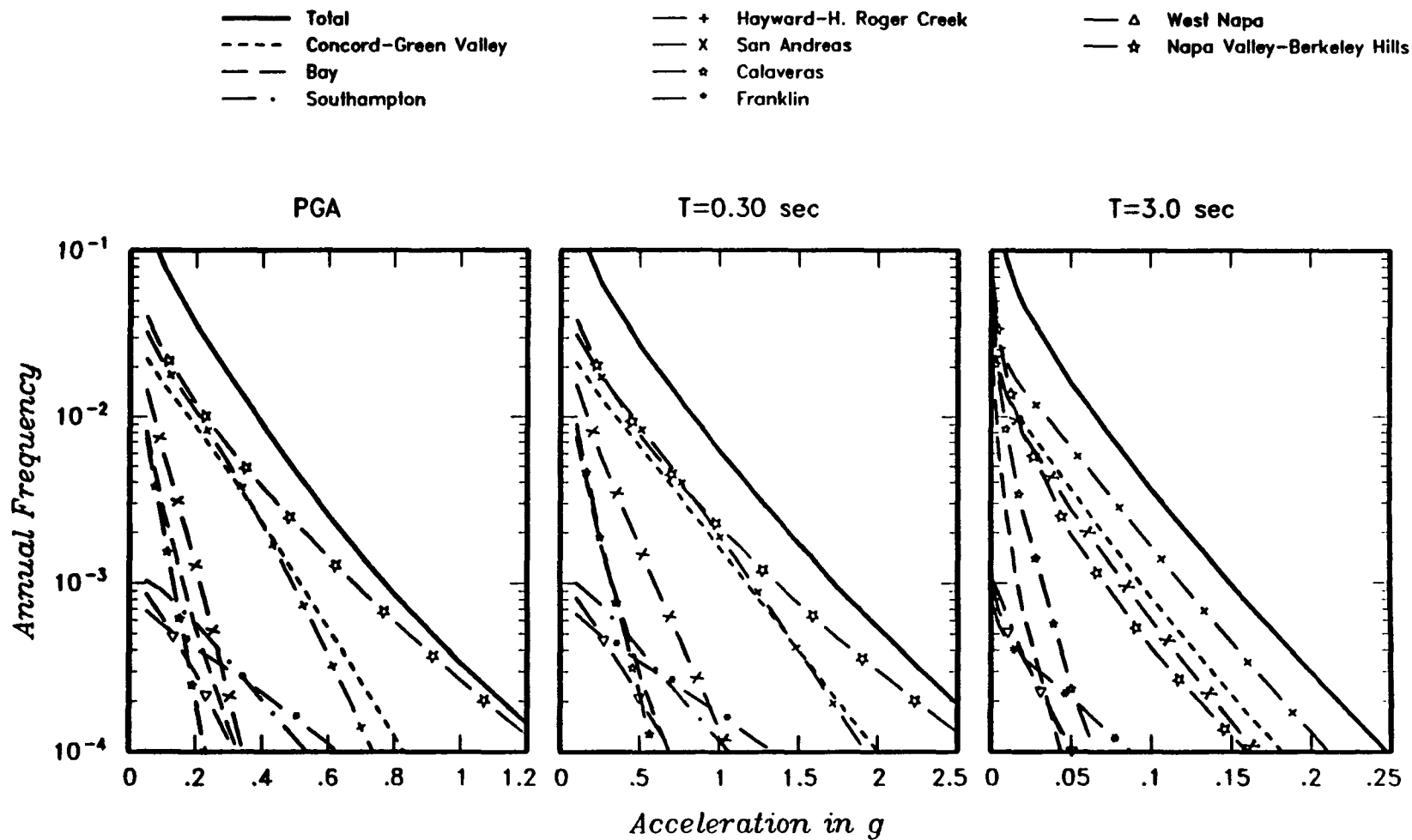
Figure 4-2 Contributions of various fault-specific sources to mean hazard at the Carquinez site. Shown are results for peak acceleration and 5 percent-damped spectral accelerations at periods of 0.3 and 3.0 seconds.
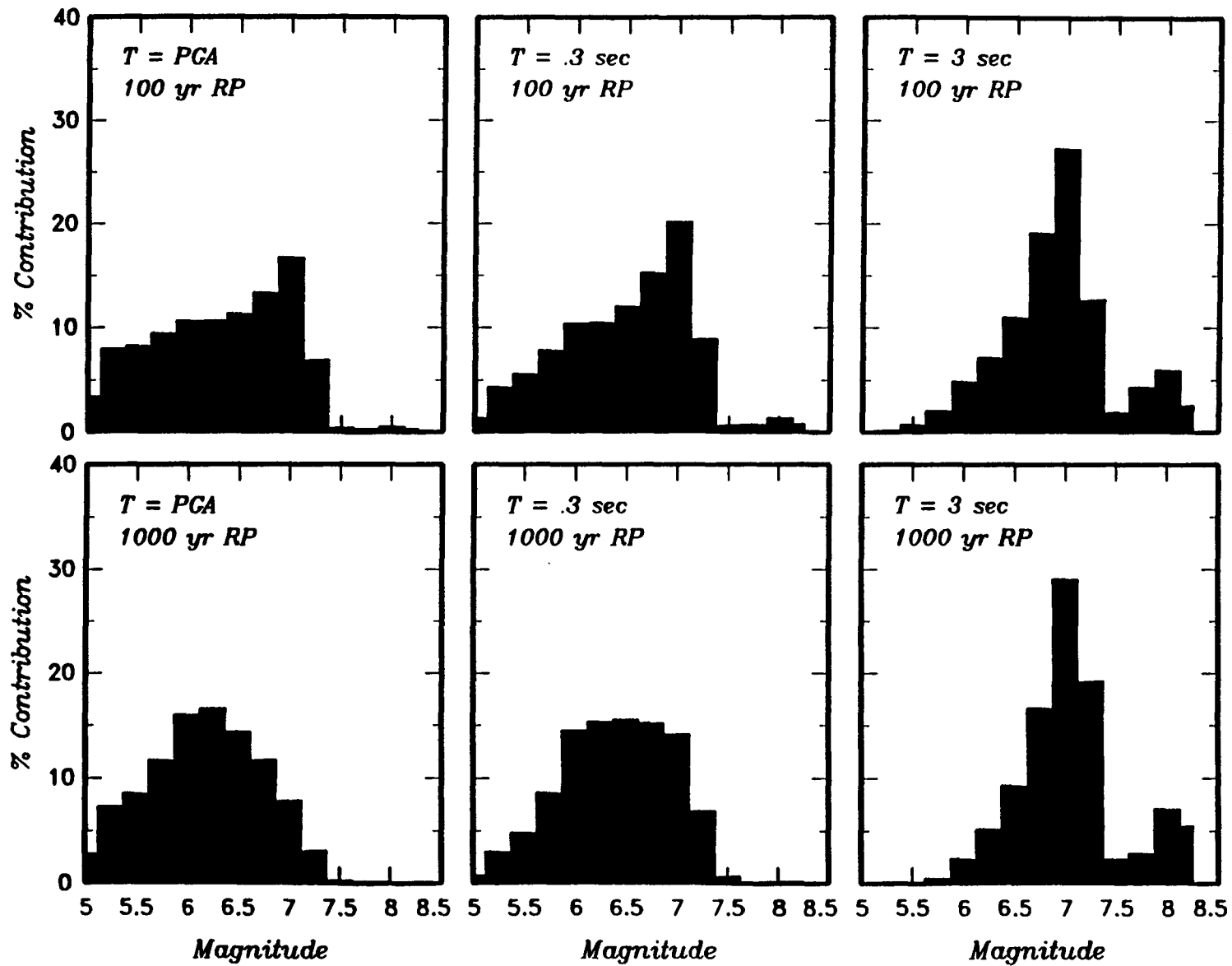
Figure 4-3 Contributions of events in various magnitude intervals to the mean hazard at the Carquinez site. Shown are results for peak acceleration and 5 percent-damped spectral accelerations at periods of 0.3 and 3.0 seconds.
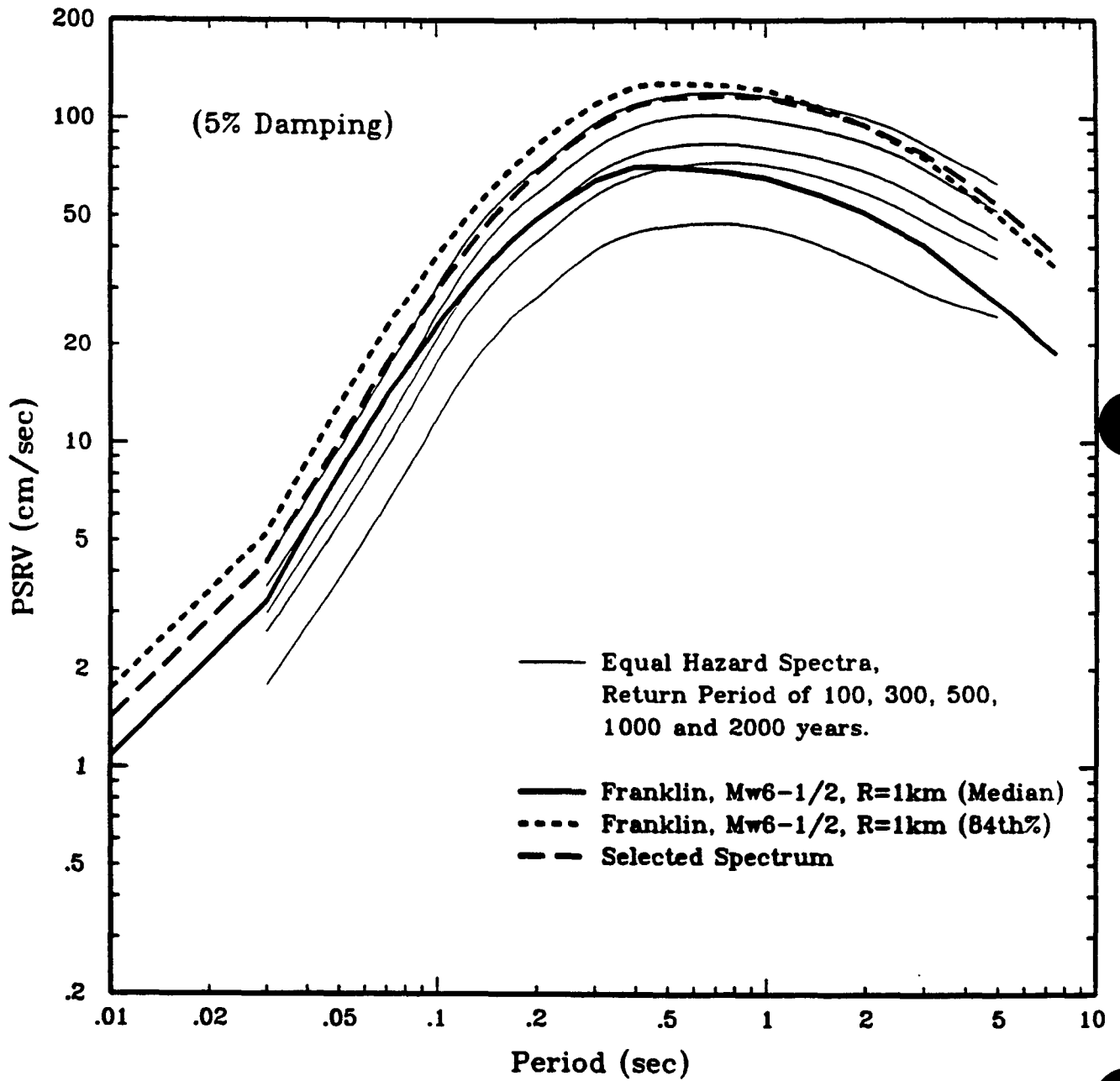
Figure 5-14 Carquinez Bridge, comparison of the deterministic median, 84th percentile, and selected spectra for the Franklin Event with equal-hazard spectra

(5% Damping)

PSRV (cm/sec)

Period (sec)

Equal Hazard Spectra,
Return Period of 100, 300,
500, 1000 and 2000 years.

—— Mw=8, R=18 km (Median)
— — Mw=8, R=18 km (84th)
—— Mw=7.25, R=12 km (Median)
— — Mw=7.25, R=12 km (84th)
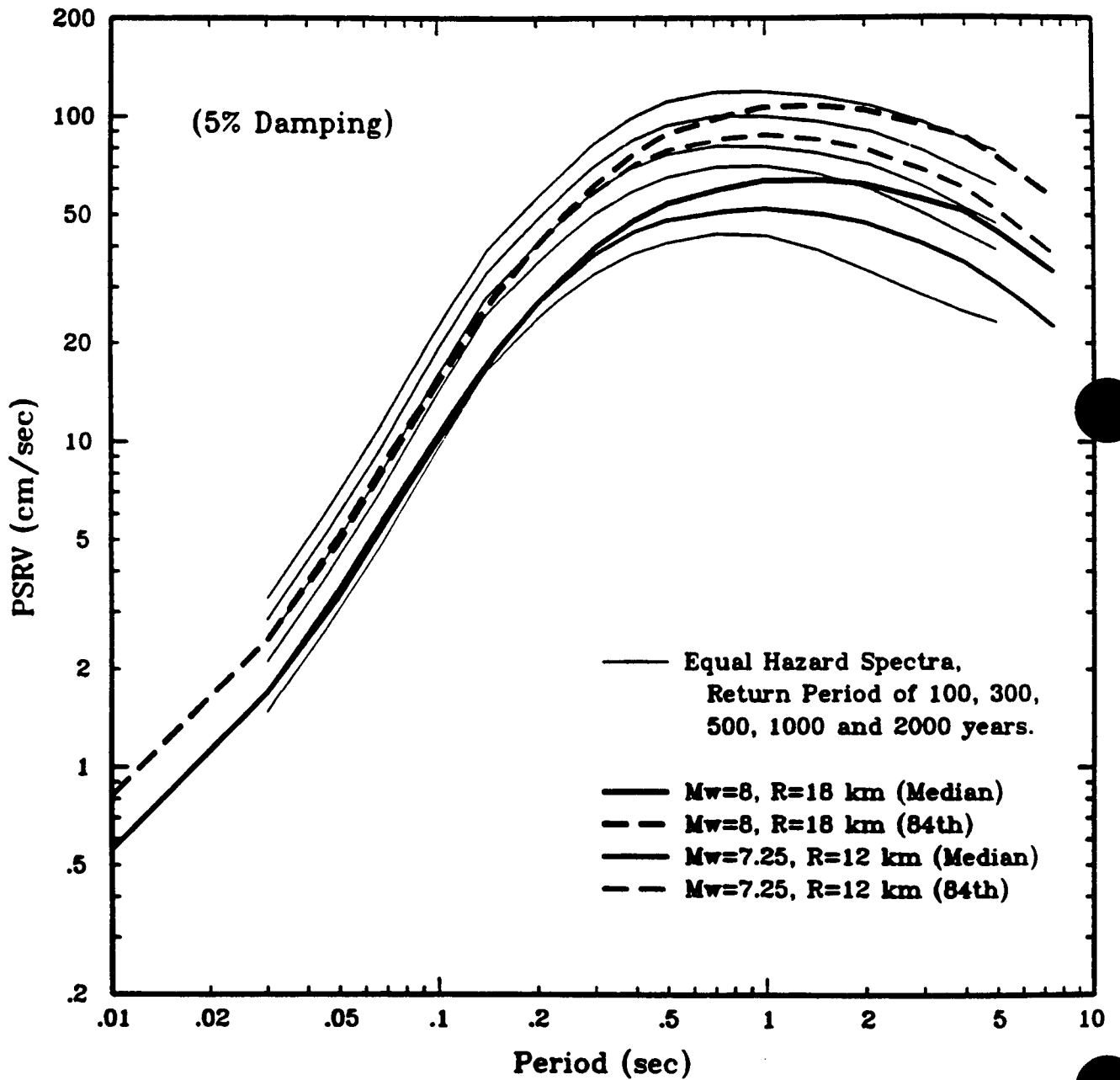
Figure 5-14   Comparison of the deterministic response spectra with equal-hazard
spectra: West San Francisco Bay Bridge, east end.

DOE FACILITIES AT HANFORD, WASHINGTON

- Purpose: define ground motion levels for design review and for new design criteria

- Interpretations from project team including site technical personnel with extensive experience

- Alternative tectonic models considered in the PSHA

- Results to be used according to performance-based criteria of DOE Standard 1021-92
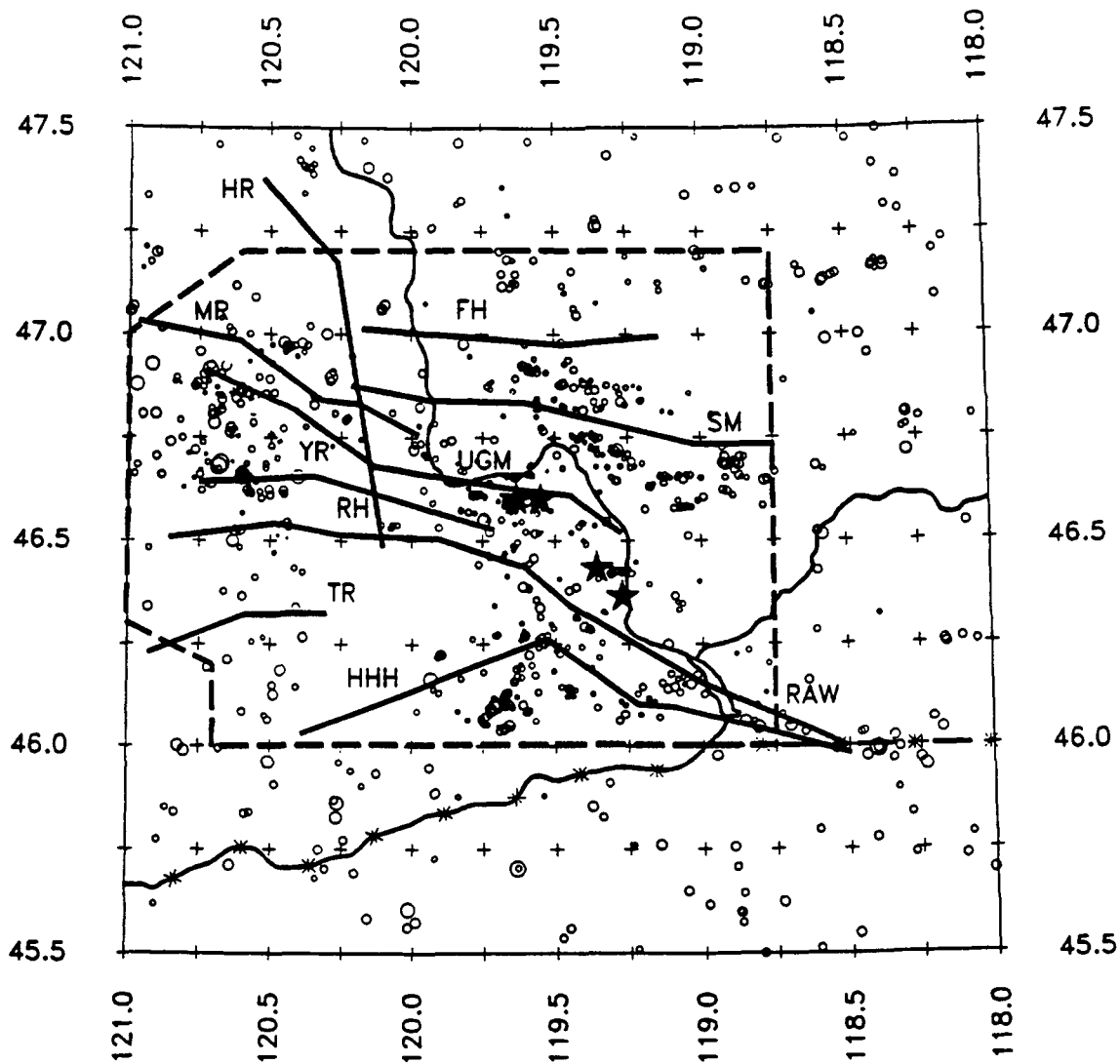
Depth > 5 km

Magnitude

○	5
○	4
○	3
○	2
.	1
	0

Scale 1 : 2,000,000

– – – – Yakima fold belt
★ · Hanford DOE sites
——— Yakama Folds

FH — Frenchman Hills   RH — Rattlesnake Hills
MR — Manastash Ridge   RAW — Rattlesnake–Wallula
SM — Saddle Mountains   TR — Toppenish Ridge
UGM — Umtanum–Gable Mtn   HHH — Horse Heaven Hills
YR — Yakima Ridge   HR — Hog Ranch

Figure 3-9   Location of major Yakima folds considered as seismic sources in the coupled model. Superimposed is the spatial distribution of seismicity occurring primarily within the crystalline basement (focal depth > 5 km).

Tectonic Model	Sources	Rift Zone Geometry	Crustal Thickness (km)	Maximum Magnitude	Slip Rate/ N(m>3.75) (mm or events/year)	b-Value	Magnitude Distribution

Failed Rift (0.15)

Rift zone
- Narrow (0.6)
- Wide (0.4)

Crustal Thickness: 8 (0.5), 10 (0.5)

Maximum Magnitude: 6 (0.2), 6.5 (0.6), 7 (0.2)

Slip Rate: 0.23 (0.5), 0.29 (0.5)

b-Value: 0.80 (0.2), 0.95 (0.6), 1.10 (0.2)

Magnitude Distribution: Exponential (0.2), Characteristic (0.8)

Adj Basement — N/A

Crustal Thickness: 8 (0.5), 10 (0.5)

Maximum Magnitude: 6 (0.4), 6.5 (0.5), 7 (0.1)

Slip Rate: 0.161 (0.028), 0.103 (0.258), 0.065 (0.489), 0.041 (0.205), 0.026 (0.02)

b-Value: 0.67 (0.038), 0.80 (0.229), 0.92 (0.388), 1.04 (0.259), 1.17 (0.086)

Magnitude Distribution: Exponential (1.0)

Block (0.15)

Basement

Fault A

Fault B

Random (0.7)

Basement — N/A

Crustal Thickness: 8 (0.5), 10 (0.5)

Maximum Magnitude: 6 (0.4), 6.5 (0.5), 7 (0.1)

Slip Rate: 0.152 (0.027), 0.093 (0.255), 0.057 (0.489), 0.035 (0.208), 0.021 (0.021)

b-Value: 0.72 (0.04), 0.83 (0.231), 0.95 (0.388), 1.06 (0.258), 1.18 (0.083)
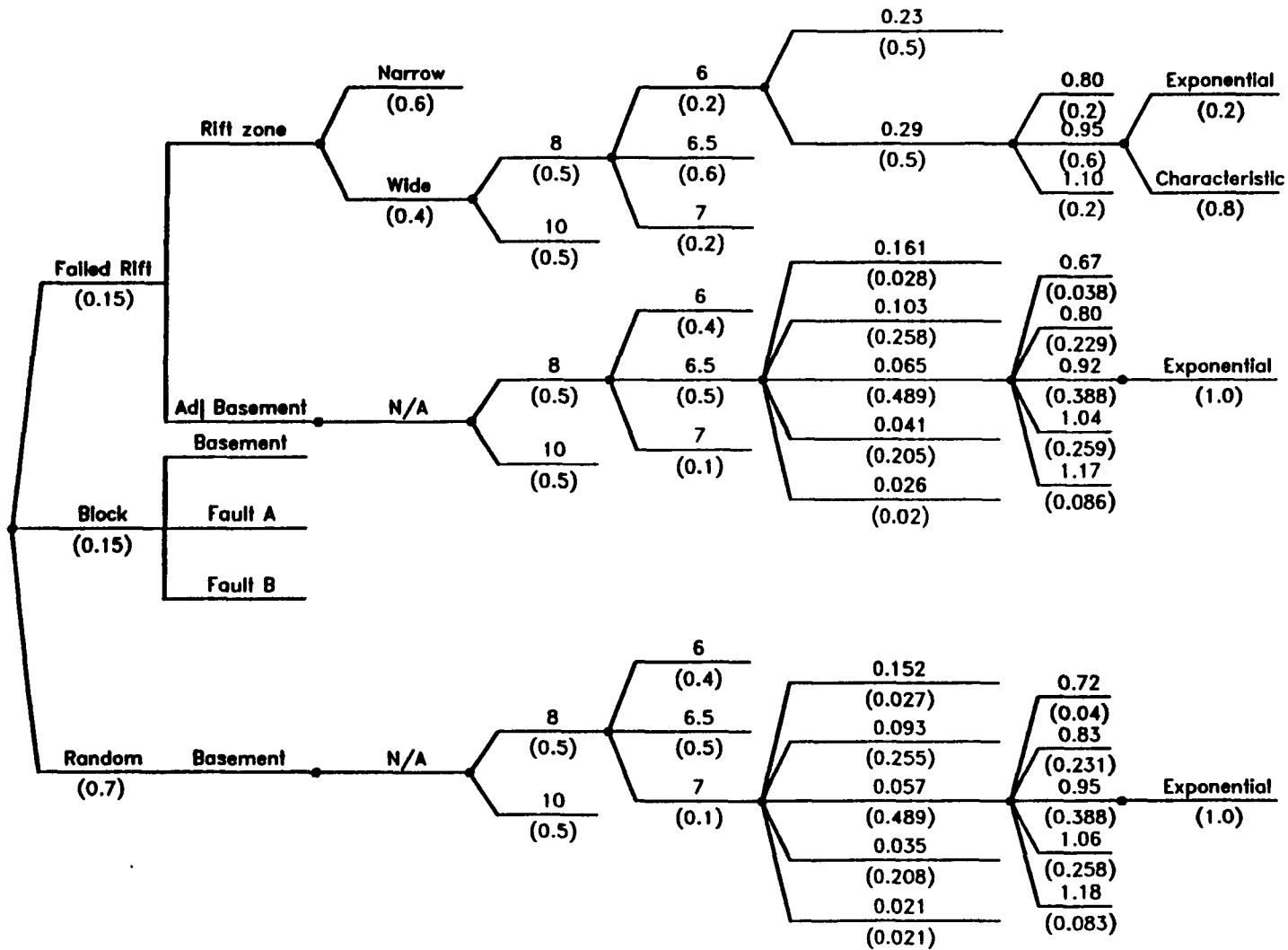
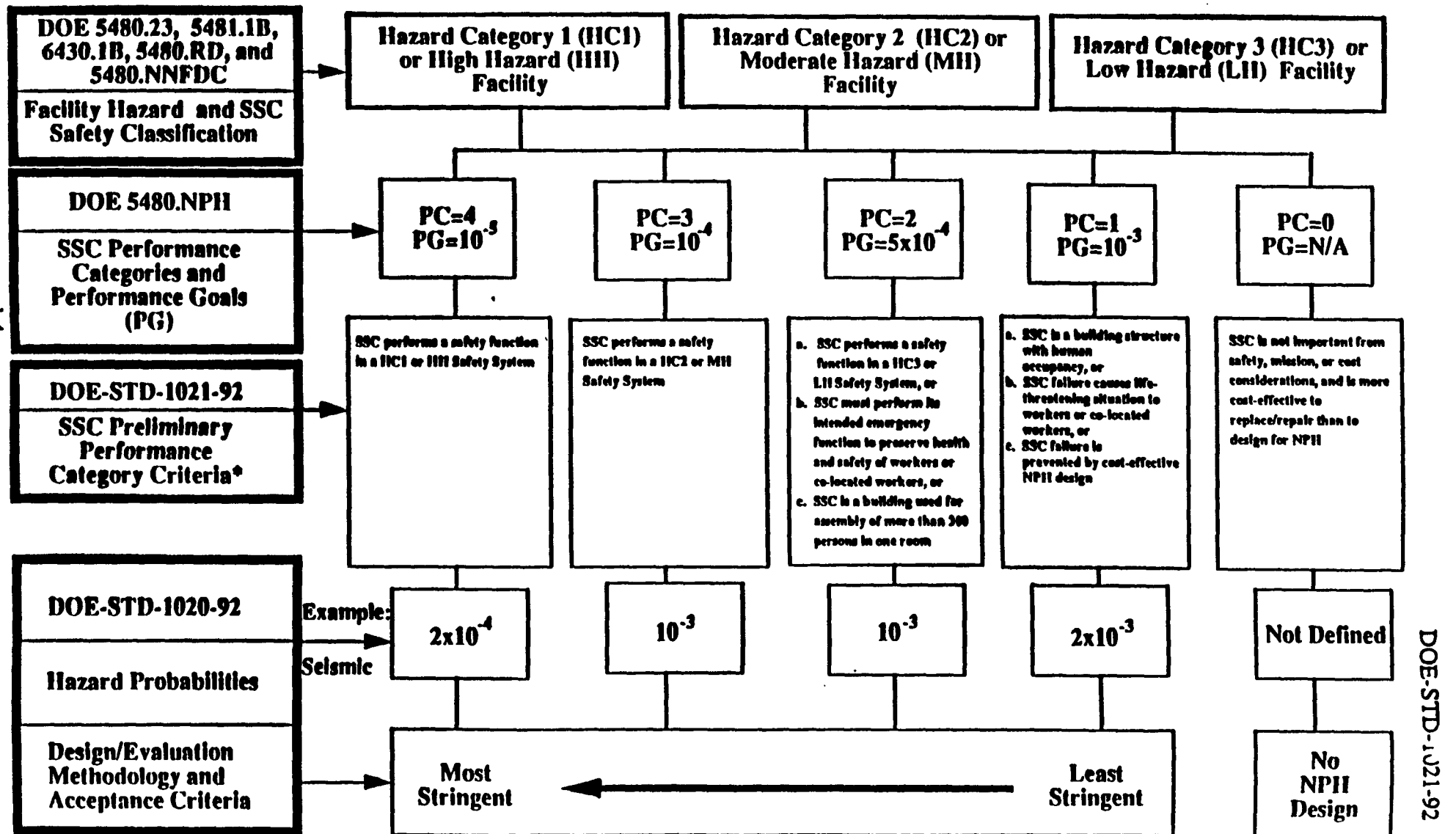Magnitude Distribution: Exponential (1.0)

Figure 3-18   Logic tree for crystalline basement sources.

Figure 1-1: Relationship among Facility Hazard Class/Category, SSC Performance Category and Pertinent DOE Orders and Standards.

| DOE 5480.23, 5481.1B, 6430.1B, 5480.RD, and 5480.NNFDC | Hazard Category 1 (HC1) or High Hazard (HH) Facility | Hazard Category 2 (HC2) or Moderate Hazard (MH) Facility | Hazard Category 3 (HC3) or Low Hazard (LH) Facility |

Facility Hazard and SSC Safety Classification

DOE 5480.NPH

SSC Performance Categories and Performance Goals (PG)

| PC=4 PG=10^{-5} | PC=3 PG=10^{-4} | PC=2 PG=5×10^{-4} | PC=1 PG=10^{-3} | PC=0 PG=N/A |

DOE-STD-1021-92

SSC Preliminary Performance Category Criteria*

| SSC performs a safety function in a HC1 or HH Safety System | SSC performs a safety function in a HC2 or MH Safety System | a. SSC performs a safety function in a HC3 or LH Safety System, or b. SSC must perform its intended emergency function to preserve health and safety of workers or co-located workers, or c. SSC is a building used for assembly of more than 300 persons in one room | a. SSC is a building structure with human occupancy, or b. SSC failure causes life-threatening situation to workers or co-located workers, or c. SSC failure is prevented by cost-effective NPH design | SSC is not important from safety, mission, or cost considerations, and is more cost-effective to replace/repair than to design for NPH |

DOE-STD-1020-92

Hazard Probabilities

Example: Seismic

| 2×10^{-4} | 10^{-3} | 10^{-3} | 2×10^{-3} | Not Defined |

Design/Evaluation Methodology and Acceptance Criteria

Most Stringent ← Least Stringent

No NPH Design

*...e these criteria only in the context of Sections 2 and ... is document; also, see Section 2.5 for System Interacti... ffects

BULL RUN DAM SITES, OREGON

- Purpose: define ground motions for FERC safety review using both probabilistic and deterministic approaches

- Particular interest in incorporating new knowledge of earthquake sources

- Source interpretations made by project team

- Probabilistic results used to establish 'conservatism' of mean and 84th percentile deterministic results
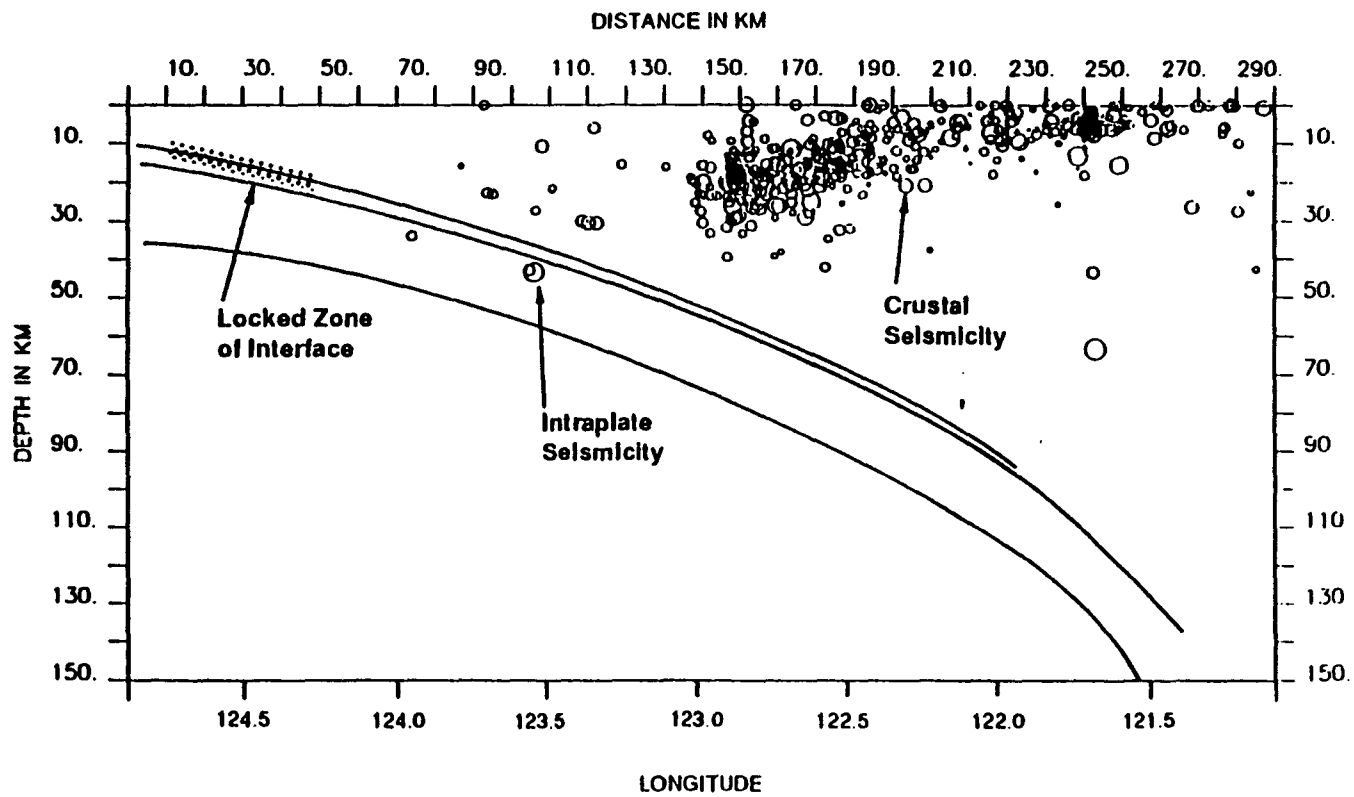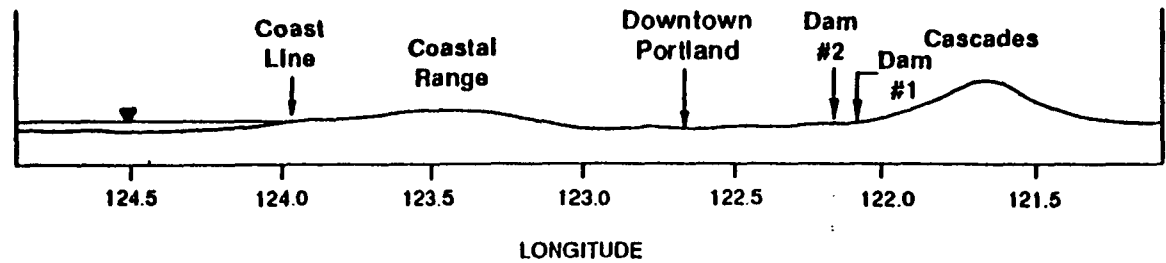
Cross-section of seismicity centered on latitude 45.5 with inferred location of subducted portion of Juan de Fuca Plate.
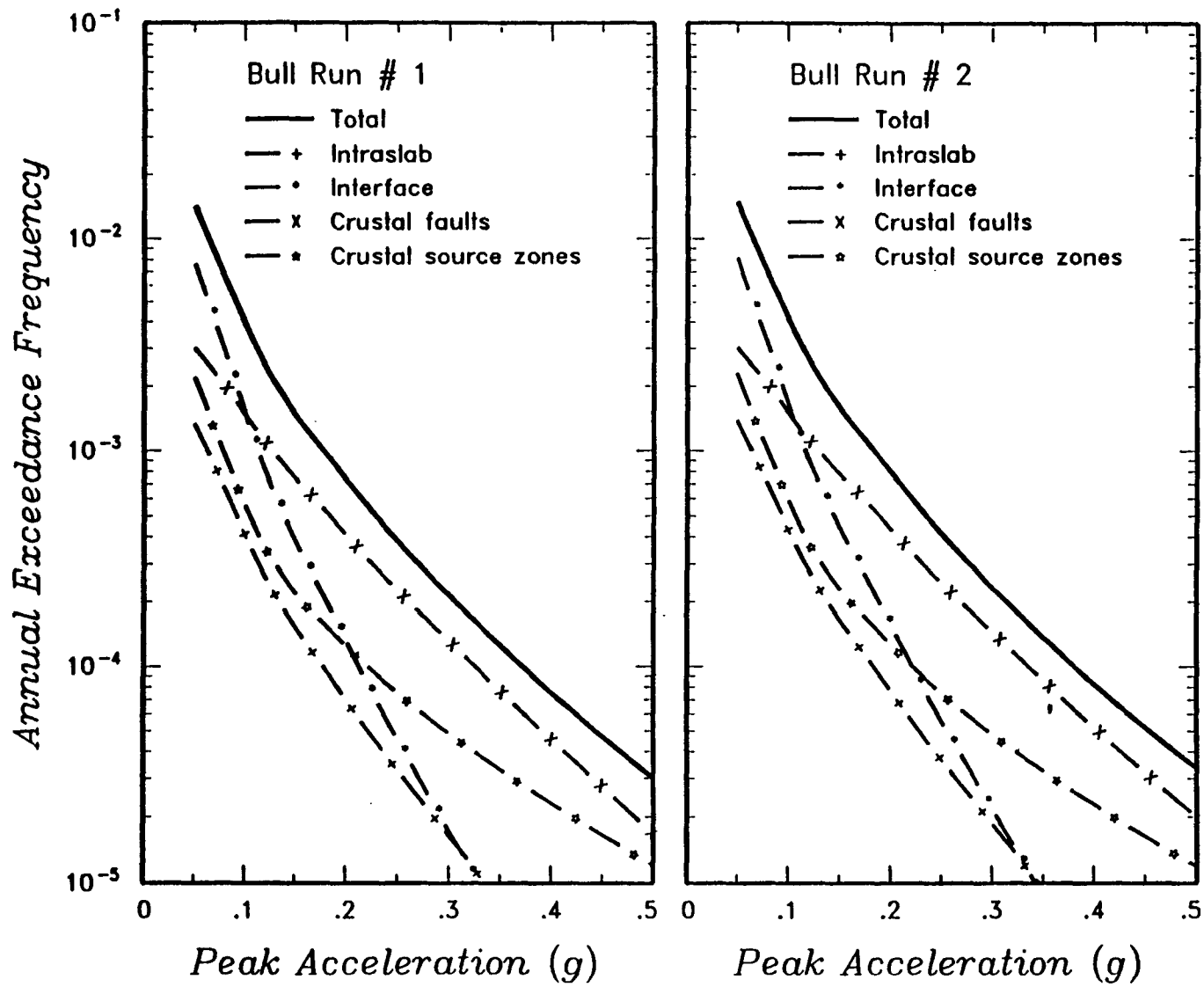
Contributions of various sources to the total hazard for the Bull Run Dams
No. 1 and No. 2.

	Bull Run Dam No. 1			Bull Run Dam No. 2		
Ground Motion Level	Peak Accel. (g)	Probability of Exceedance	Return Period (years)	Peak Accel. (g)	Probability of Exceedance	Return Period (years)
Mean	0.21	6×10^{-4}	1,667	0.25	4×10^{-4}	2,500
84th	0.30	2×10^{-4}	5,000	0.36	1.5×10^{-4}	6,667

LESSONS LEARNED FROM PSHA IN PRACTICE

- Deterministic approaches do not take into account likelihood of occurrence (rate) and uncertainties; design values were often contentious

- Probabilistic approaches have gained increasing use as methods have become better understood; rate-related parameters (slip rates, paleoseismic recurrence intervals, elapsed time, etc.) focus of research

- In some cases both deterministic and probabilistic results are desired to compare the two. The deterministic assessment is not a 'worst-case'; probabilistic analysis quantifies the likelihood of exceeding the deterministic case

- Probabilistic assessments incorporate uncertainties in models and parameter values; we have grown accustomed to acknowledging explicitly these uncertainties

- The burden and advantage of probabilistic approaches is the extensive documentation required to justify various models and parameters; such documentation is now commonplace in PSHA for critical facilities

- A variety of approaches have been used to capture differences in interpretations of data in PSHA; accepted approaches include elicitation of multiple experts individually; expert consensus assessments of uncertainties; and assessments by a single team with review by peer reviewers