

# **Crustal Earthquakes in the Pacific Northwest**

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University of California, Santa Barbara**

# Acknowledgments

Tom Pratt, U.S. Geological Survey

Pacific Northwest Seismograph Network, University of Washington

Pacific Geoscience Center, Victoria, Canada

SUBDUCTION ZONE AND CRUSTAL DYNAMICS OF WESTERN WASHINGTON: A TECTONIC MODEL FOR EARTHQUAKE HAZARDS EVALUATION *By* Dal Stanley, Antonio Villasenor, and Harley Benz USGS Open-File Report 99-311 On-line Edition

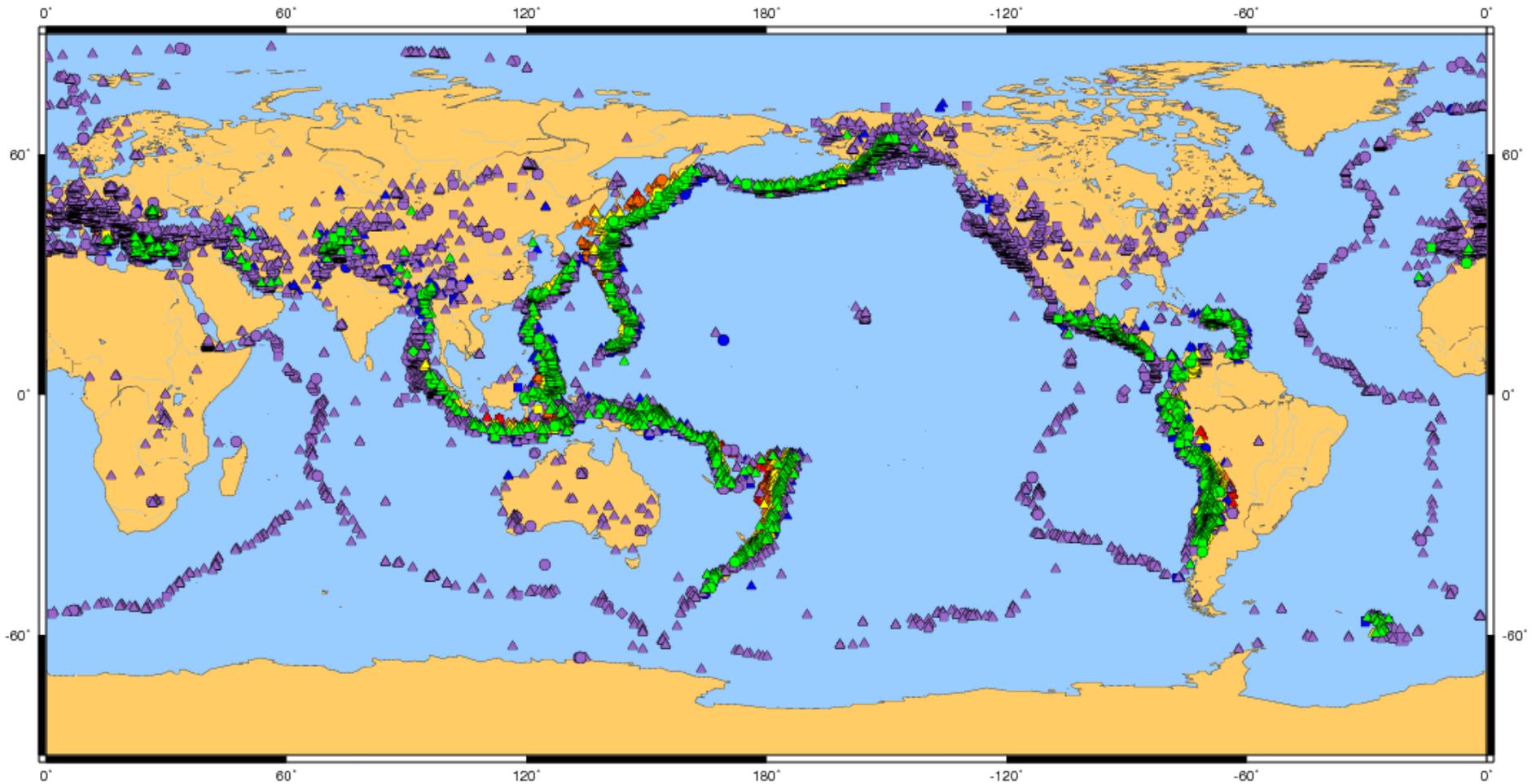
NOAA Tsunami Project

Cascadia Earthquake Region Workgroup (CREW)

Washington Emergency Management Division

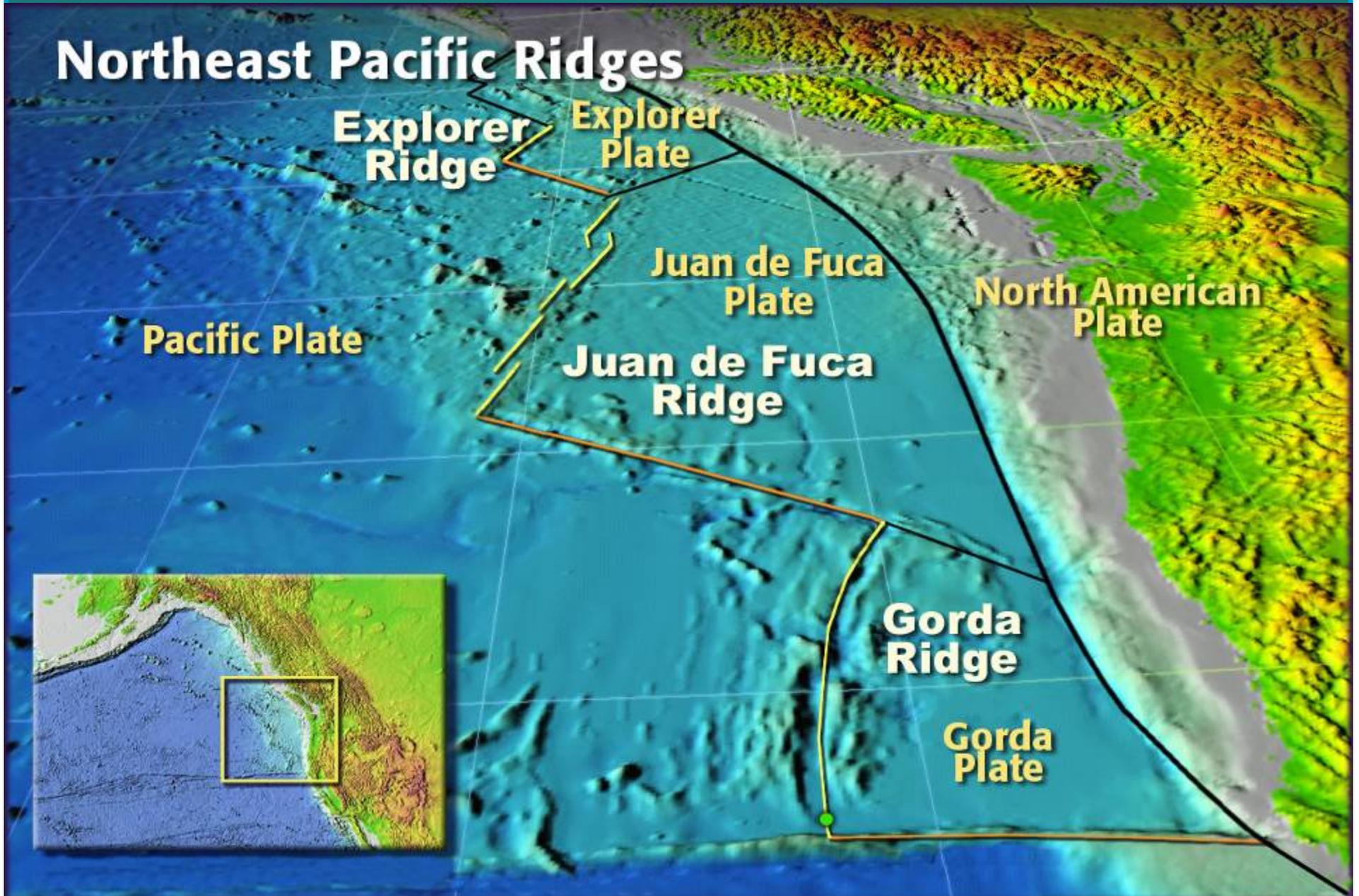
# One Year of Seismicity

2005/02/11 to 2006/02/11

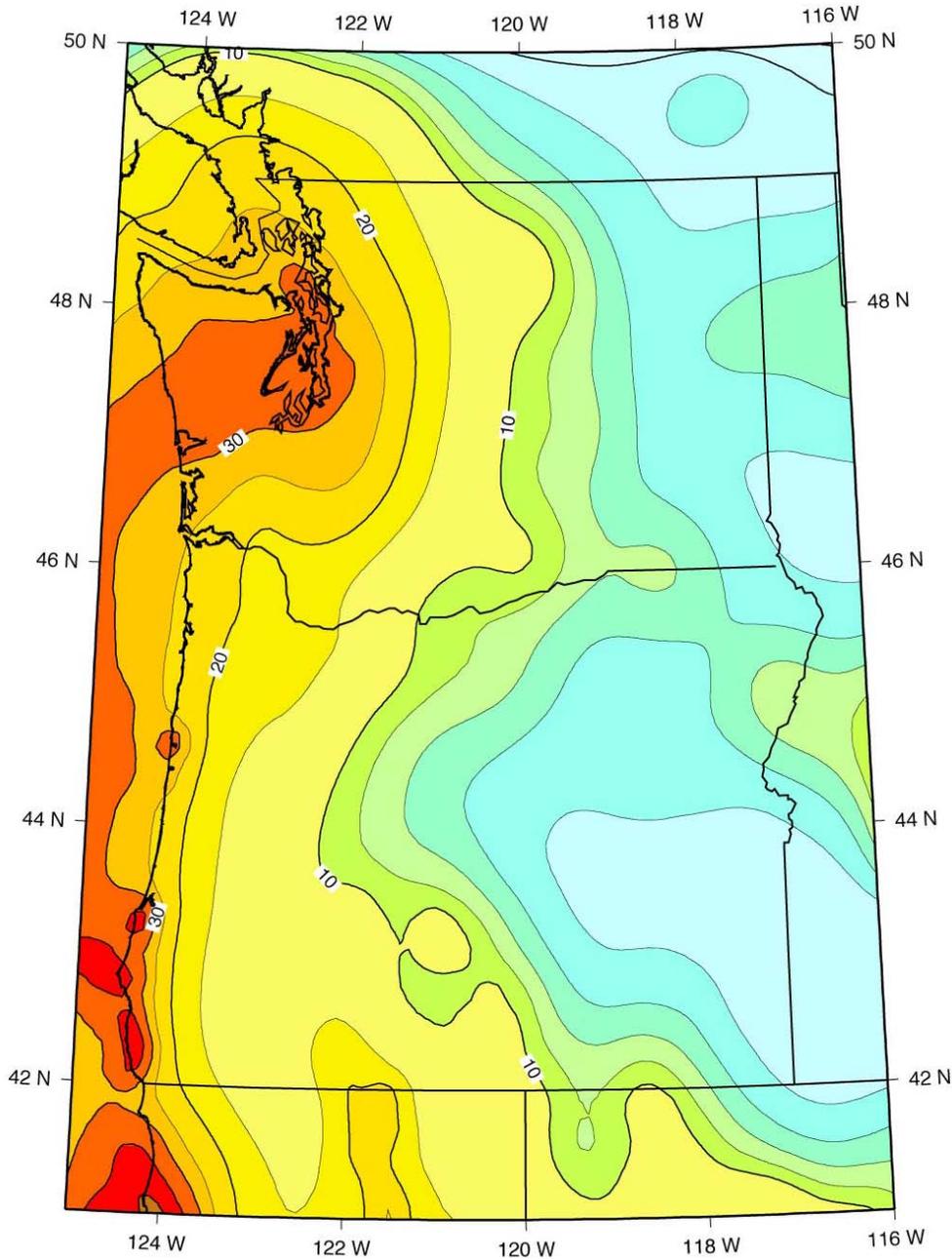


# Tectonic Setting and Earthquakes in the Pacific Northwest

## Northeast Pacific Ridges

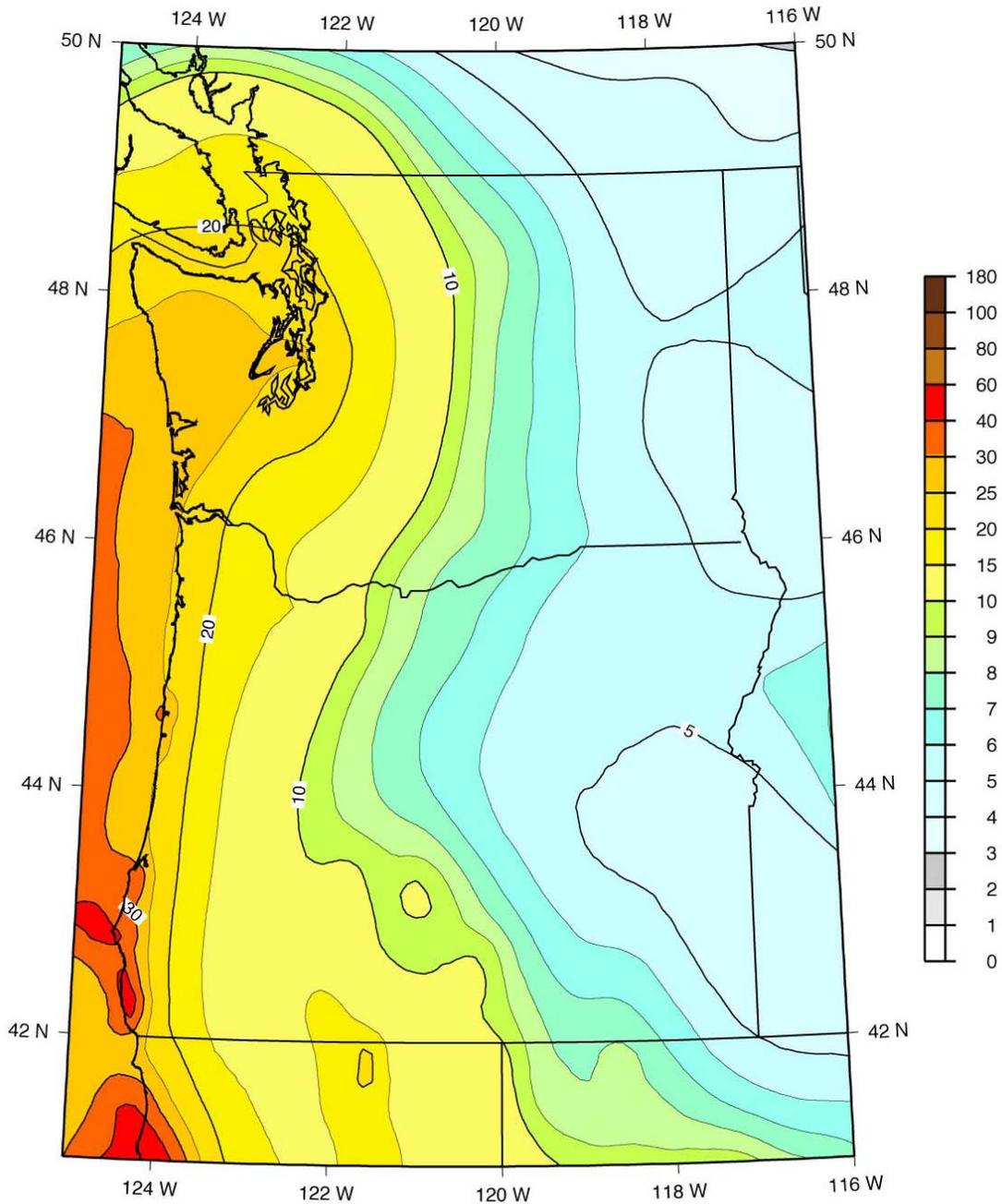


Peak Accel. (%g) with 10% Probability of Exceedance in 50 Years  
USGS Map, Oct. 2002



**USGS**  
**Probability of**  
**Exceedance**  
**PGA**  
**10% in 50 Yrs**

1.0 sec SA (%g) with 10% Probability of Exceedance in 50 Years  
USGS Map, Oct. 2002

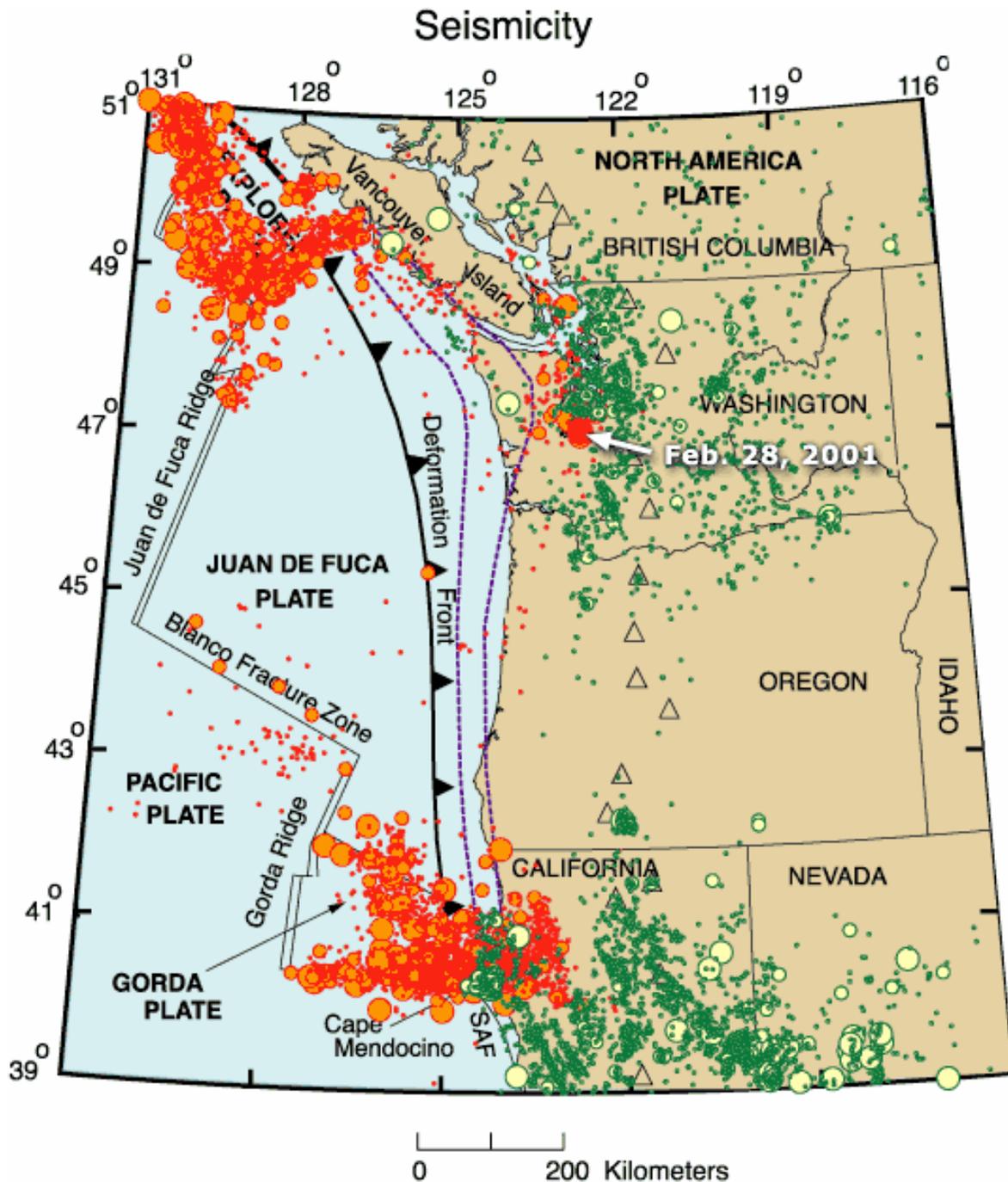


**USGS**  
**Probability of**  
**Exceedance**  
**1.0 SA**  
**10% in 50 Yrs**

# Earthquakes $M > 3$ : 2000-2005

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

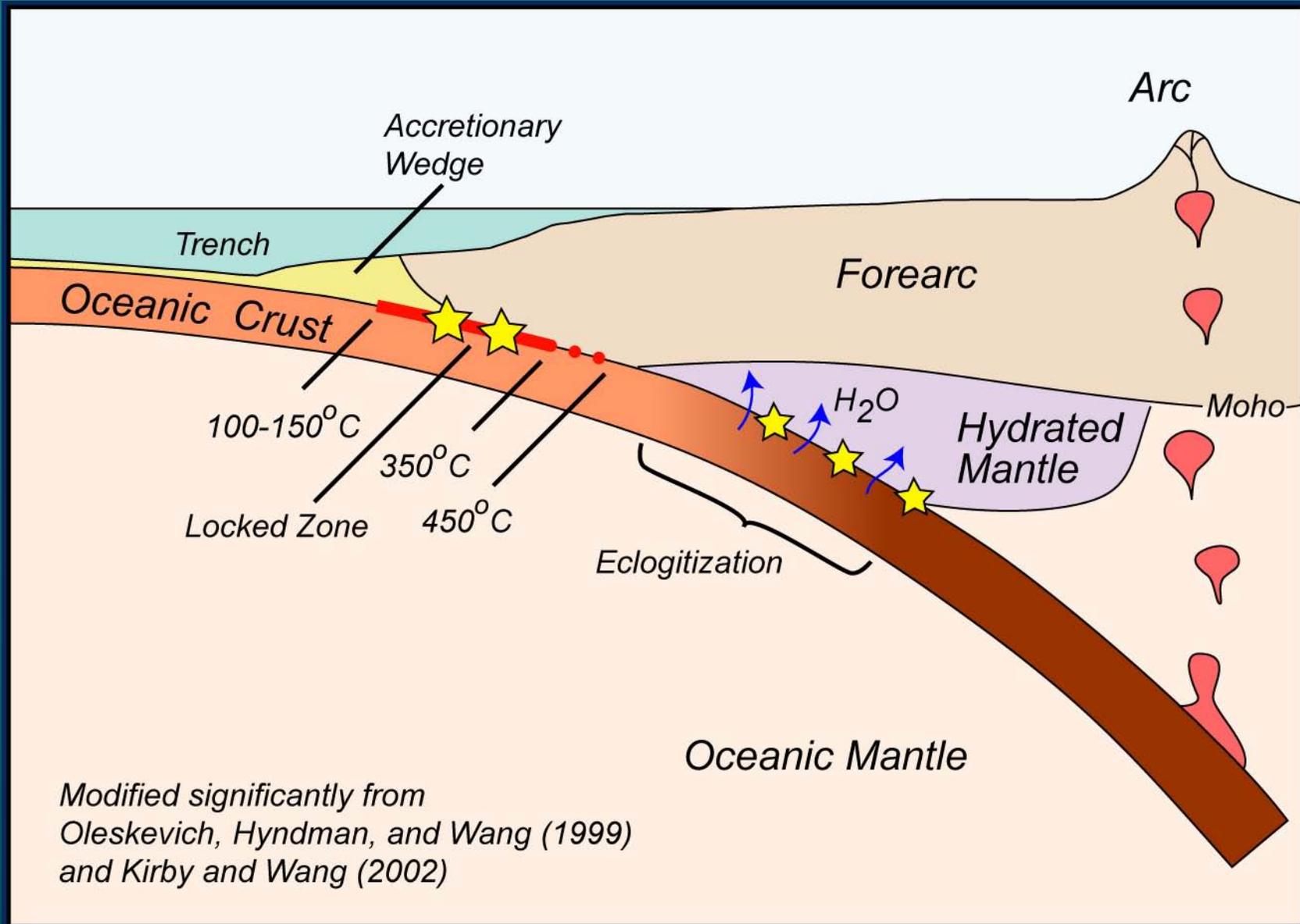
QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.



modified from Weaver and Shedlock, 1996

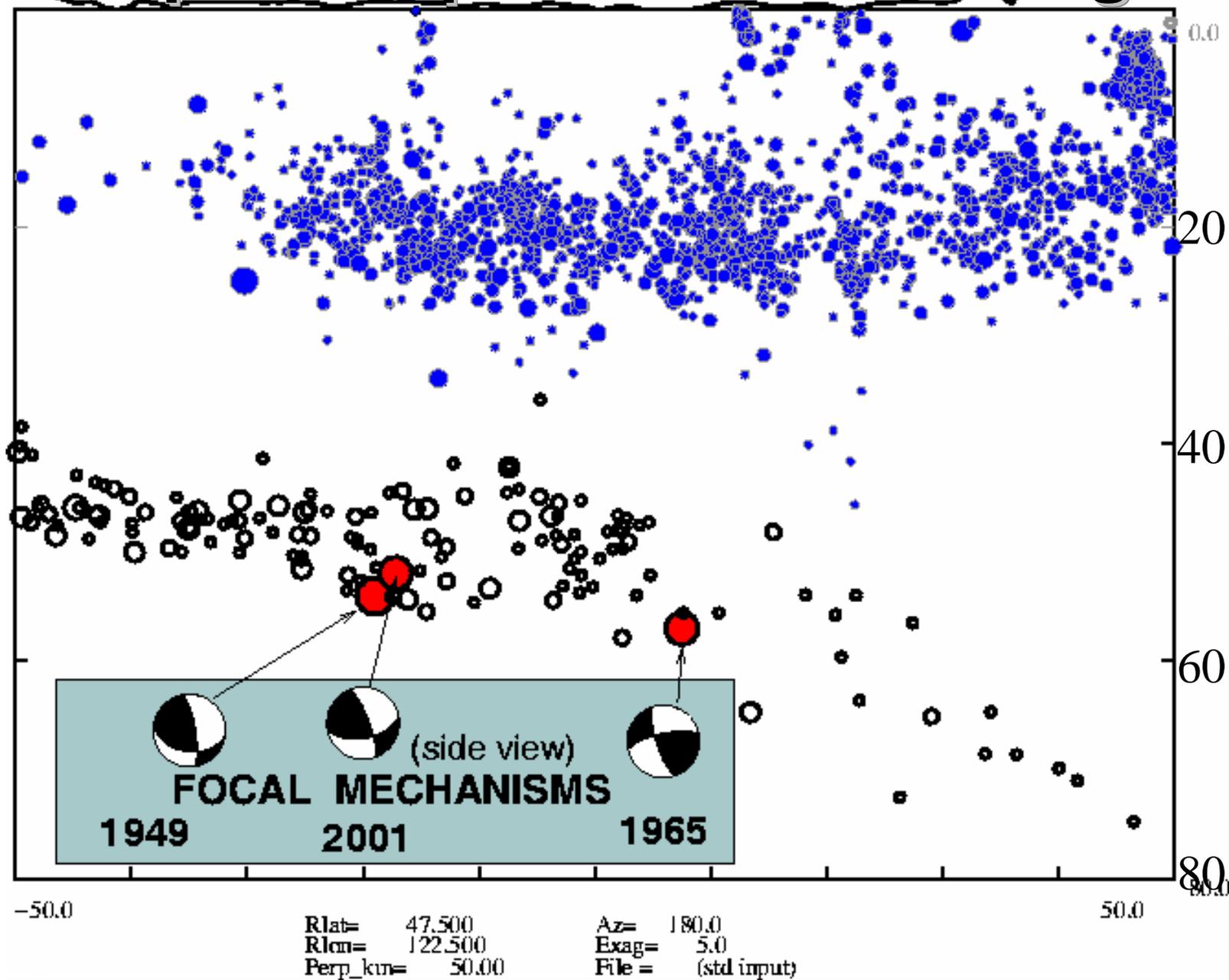
# Seismicity in Pacific Northwest

# Subduction Tectonics



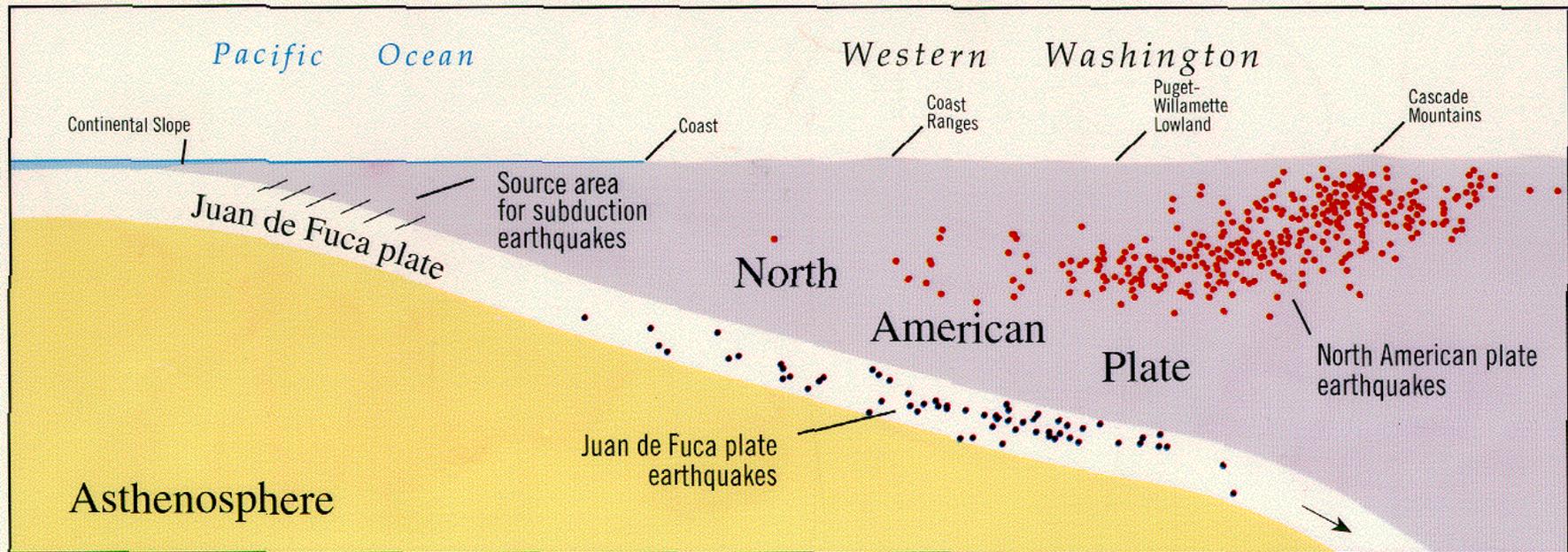
# DEEP EARTHQUAKES BENEATH PUGET SOUND

## Deep Earthquakes Beneath Puget Sound



# Cross Section of Seismicity

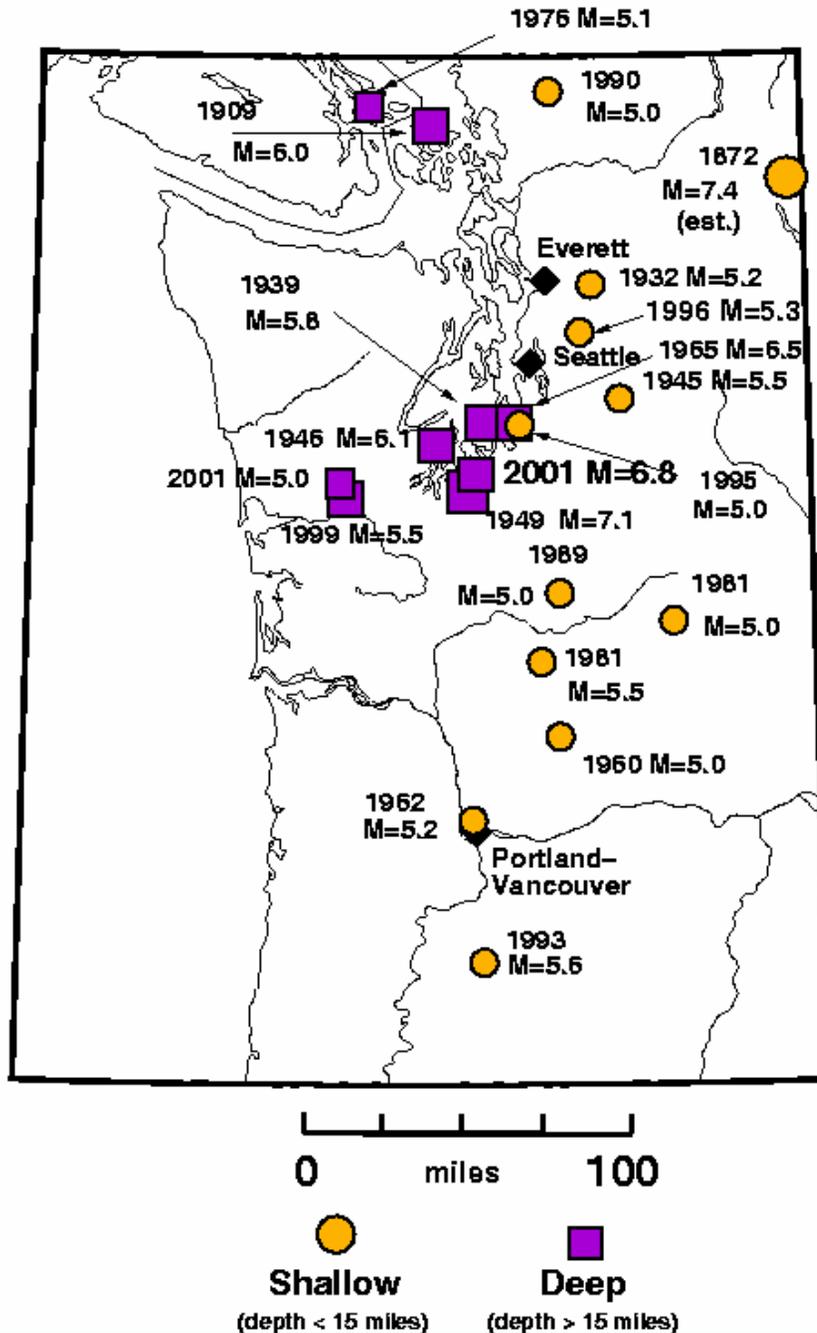
CROSS SECTION: JUAN DE FUCA SUBDUCTION ZONE



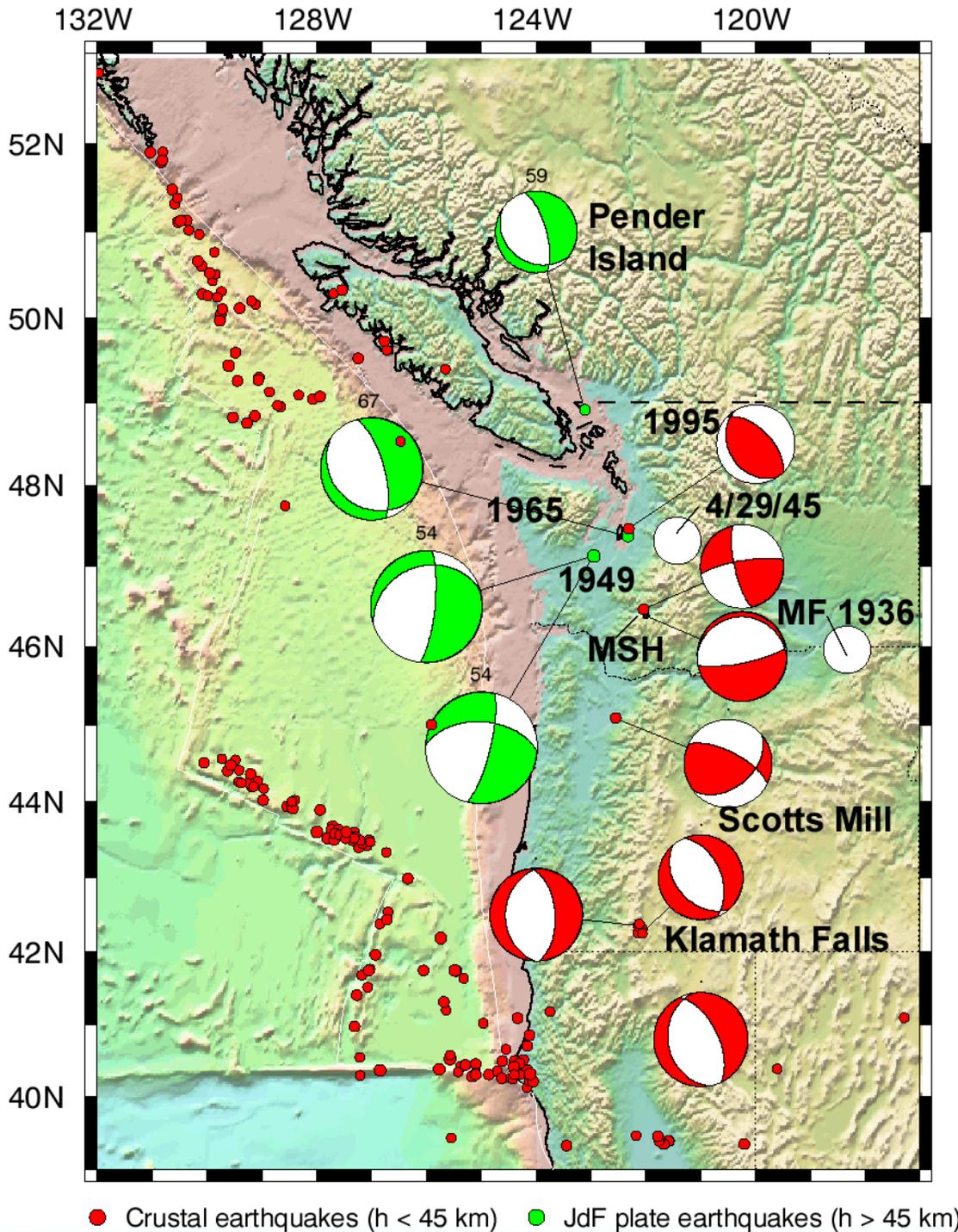
# Earthquakes 1872-1987 MM $\geq$ VIII

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

## Selected Earthquakes since 1872



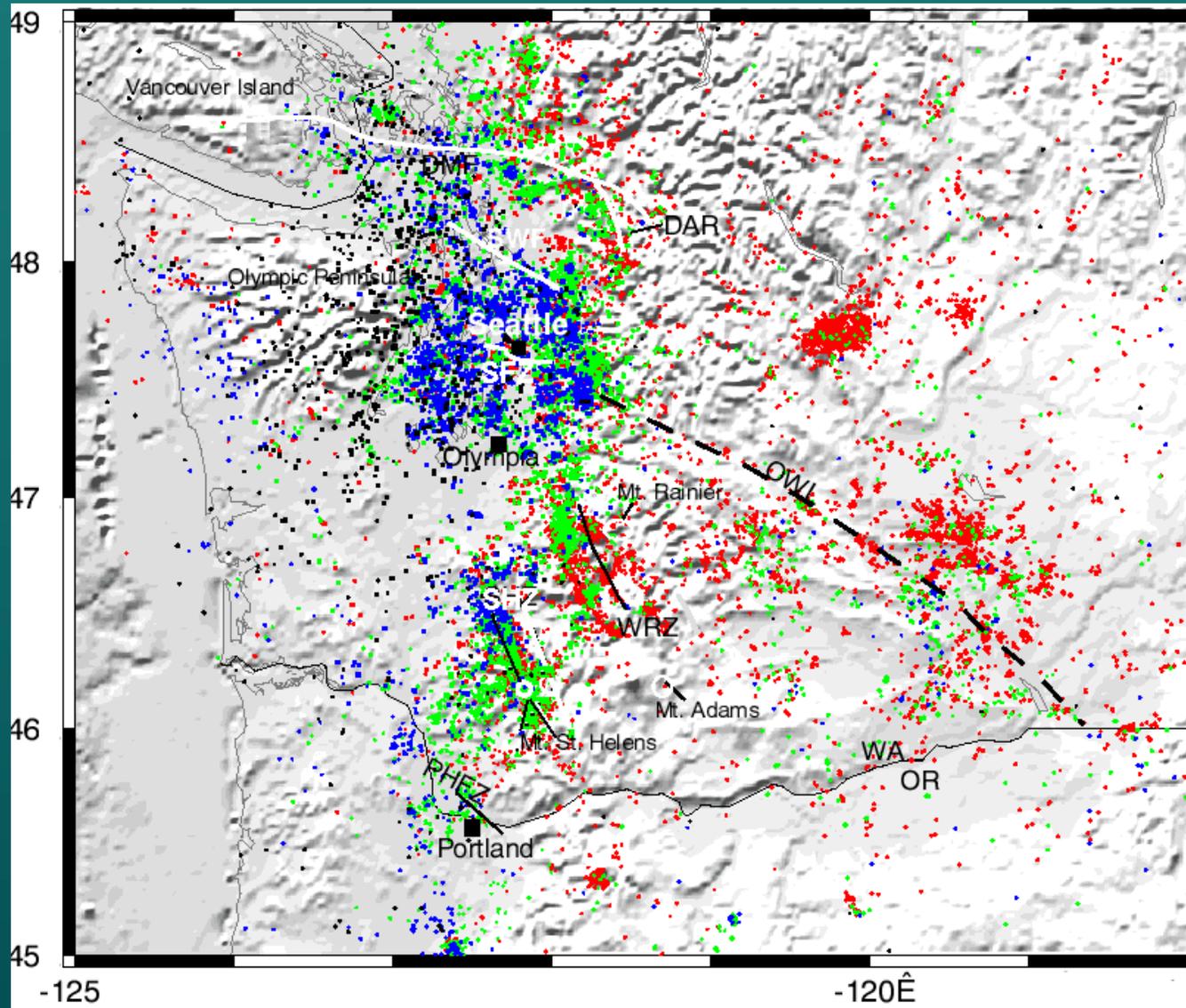
# Pacific Northwest Earthquakes since 1872



● Crustal earthquakes (h < 45 km) ● JdF plate earthquakes (h > 45 km)

# Significant Events with Focal Mechanisms

# Crustal Earthquakes: 0-60 km



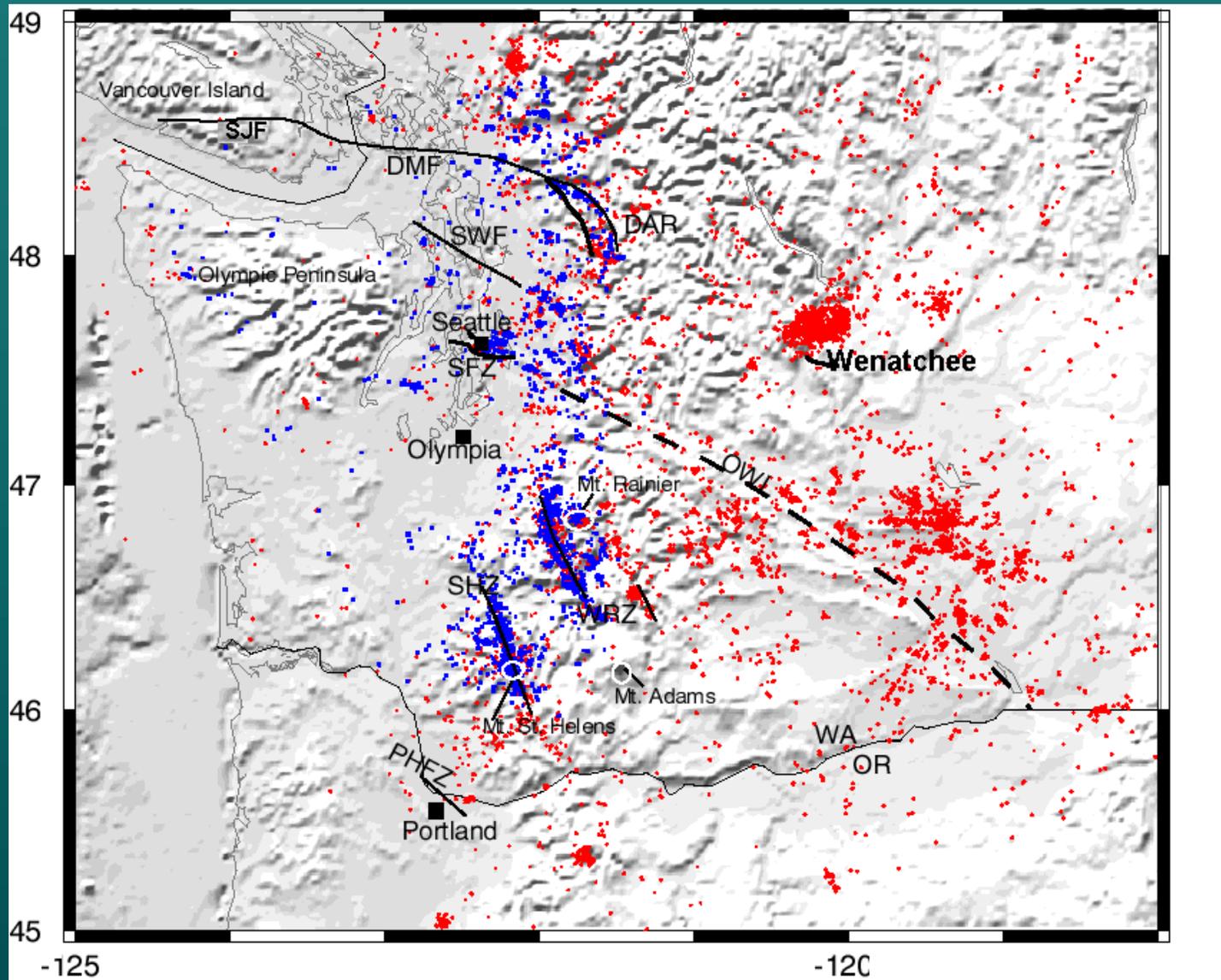
Red: 0-10 km

Green: 10-20 km

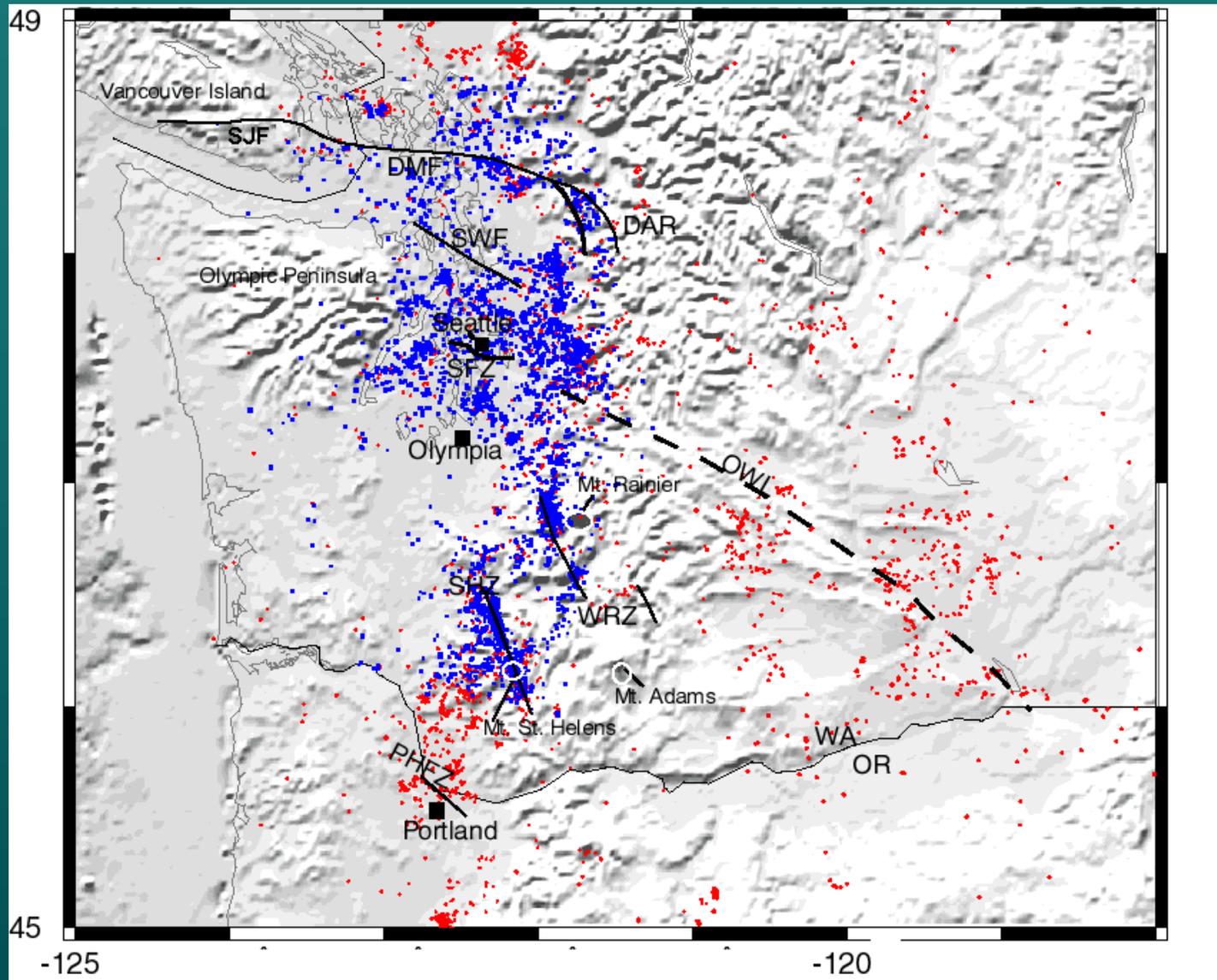
Blue: 20-30 km

Black: 30-60 km

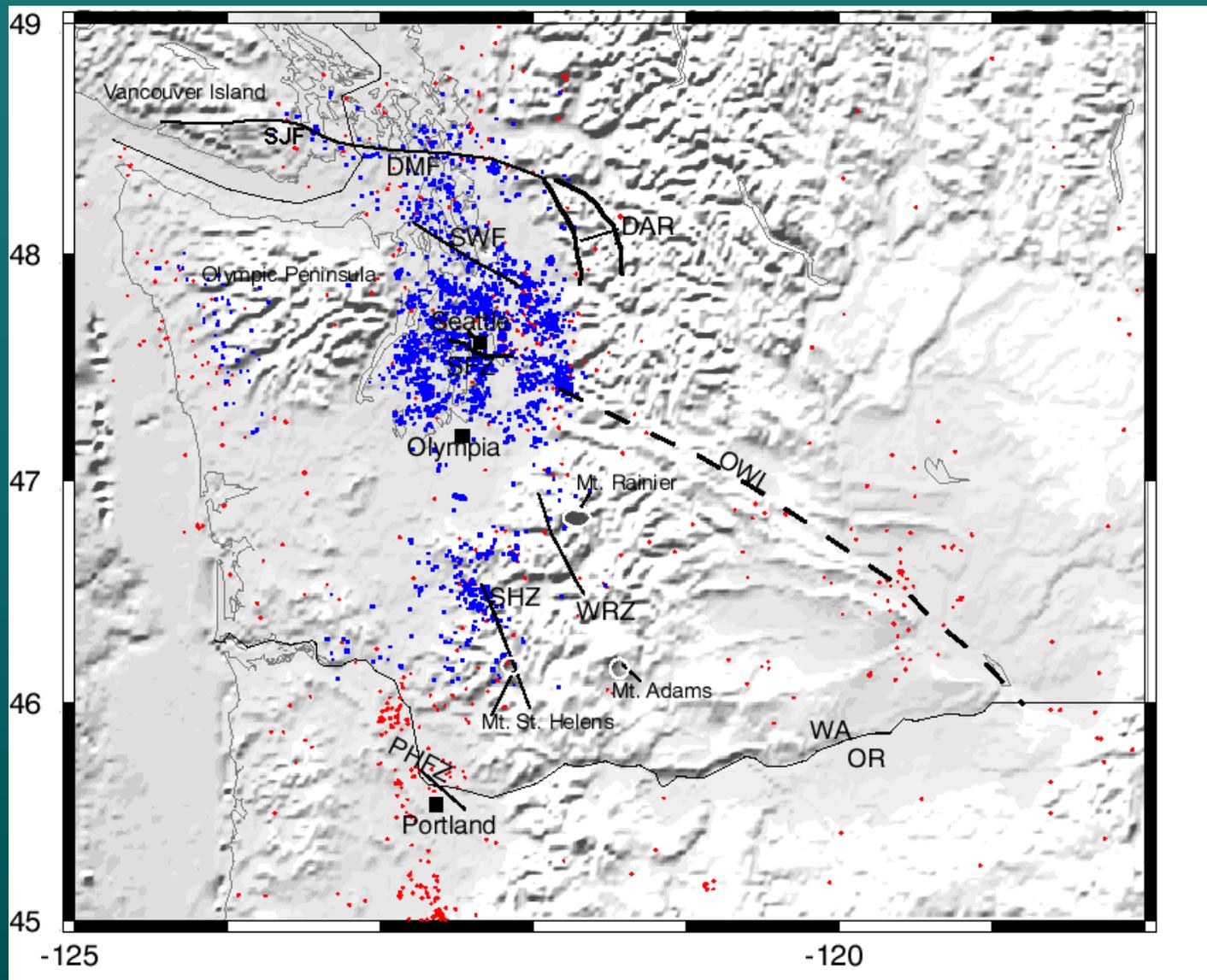
# Crustal Earthquakes: 0-10 km



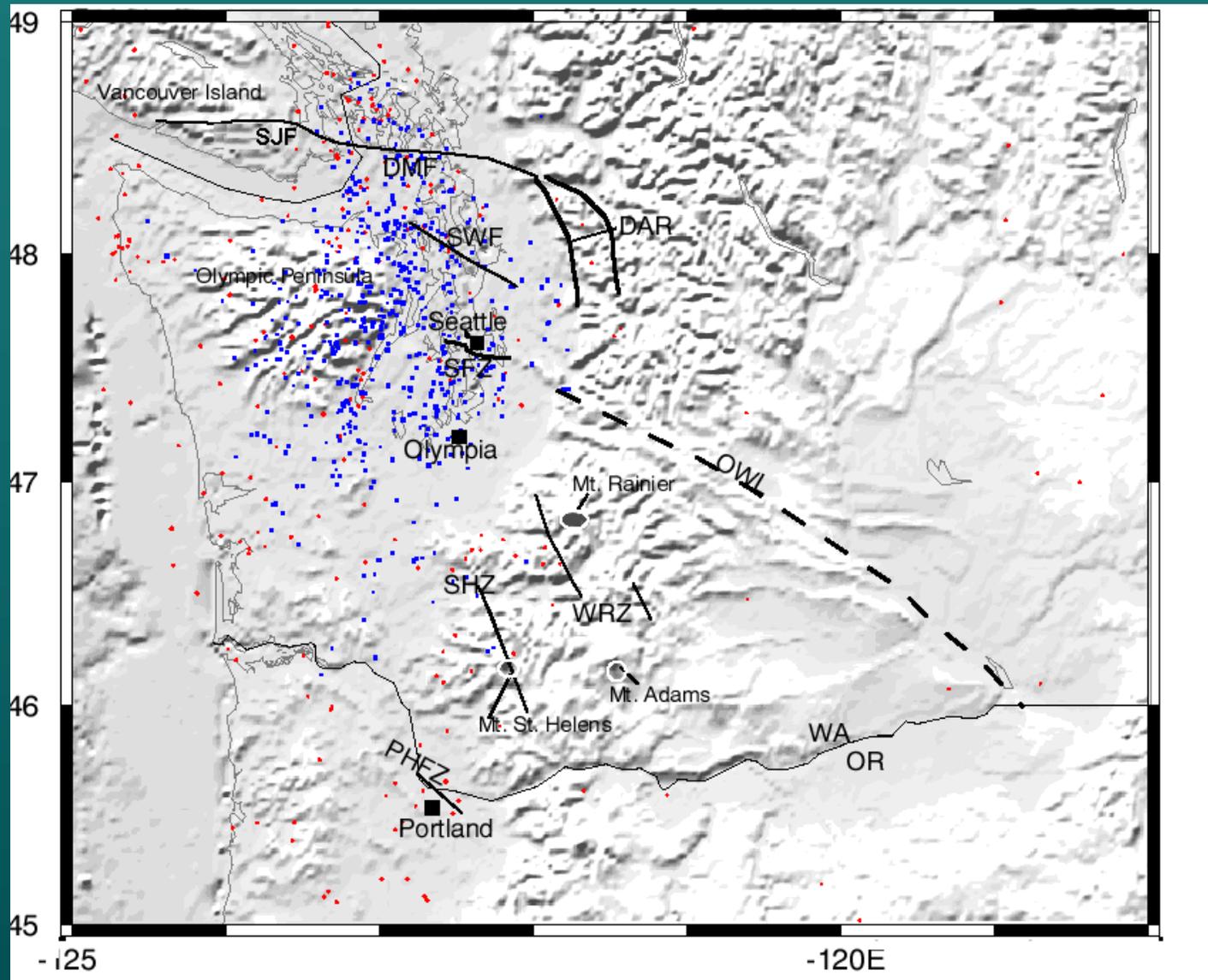
# Crustal Earthquakes: 10-20 km



# Crustal Earthquakes: 20-30 km



# Crustal Earthquakes: 30-60 km



-128°                      -124°                      -120°

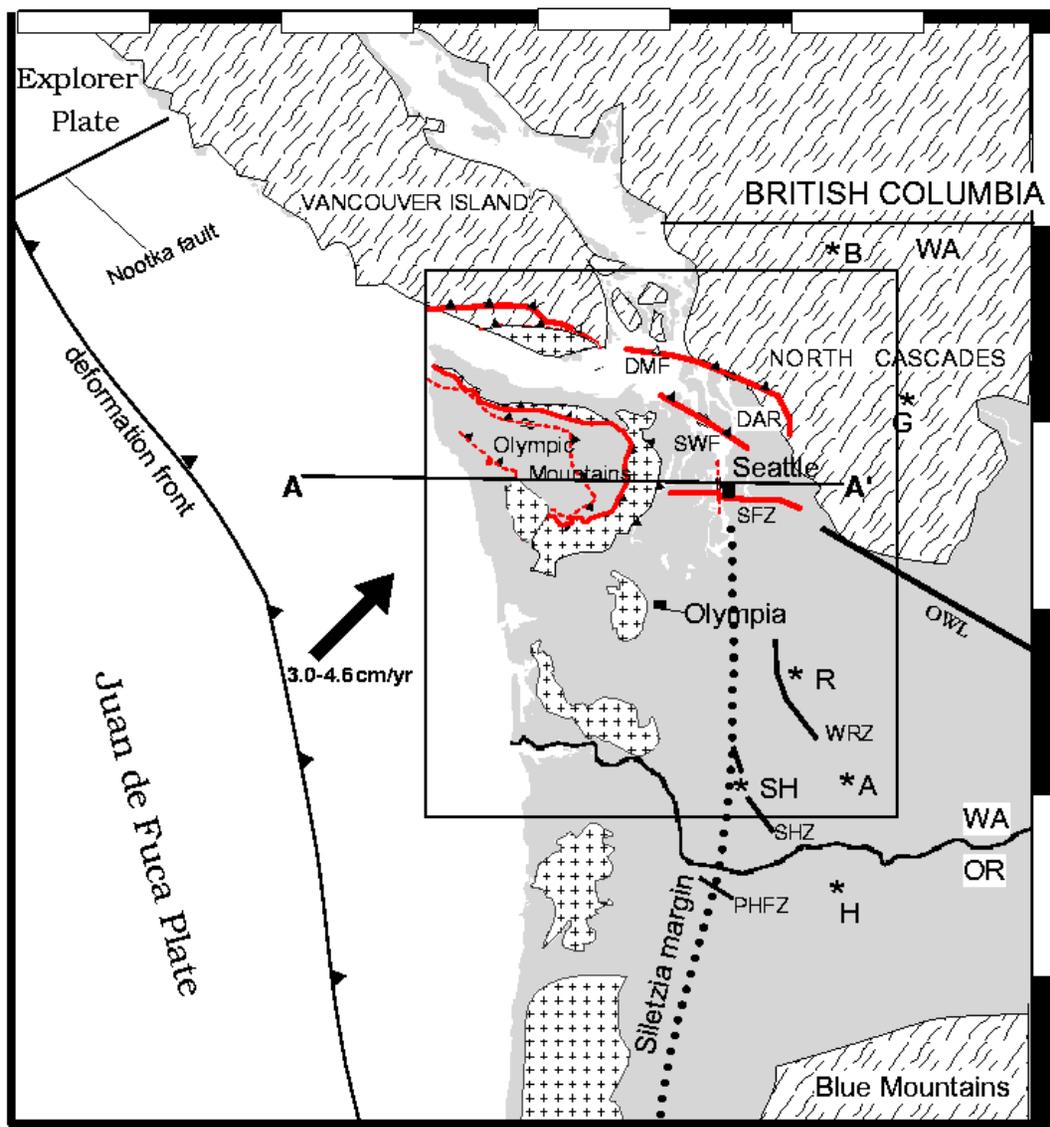
50°

48°

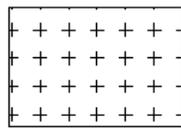
46°

44°

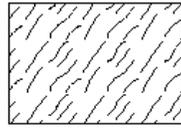
# Major Fault Zones



Quat-Tert. rocks undivided

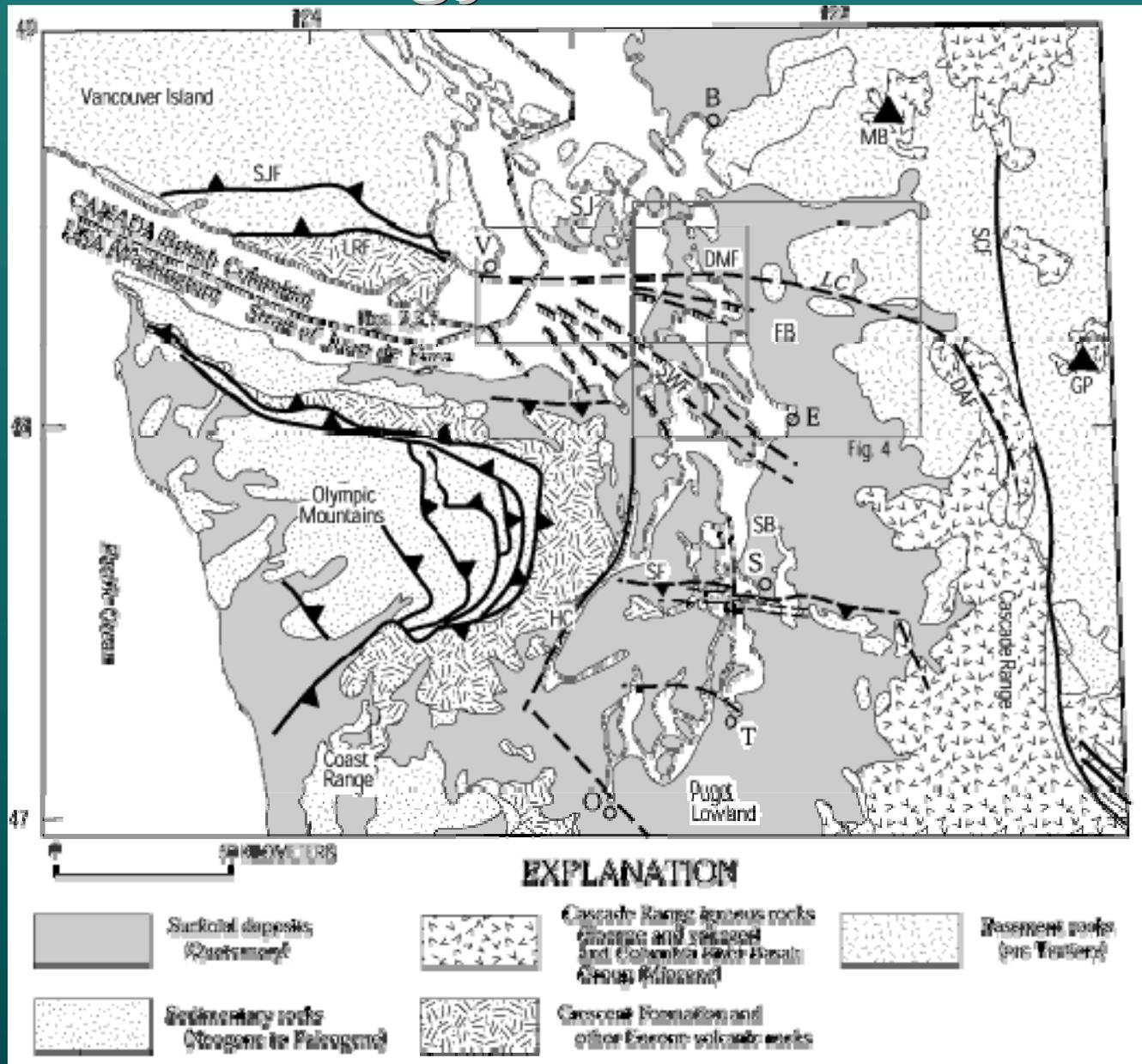


Eocene basalt terrane (Siletzia)

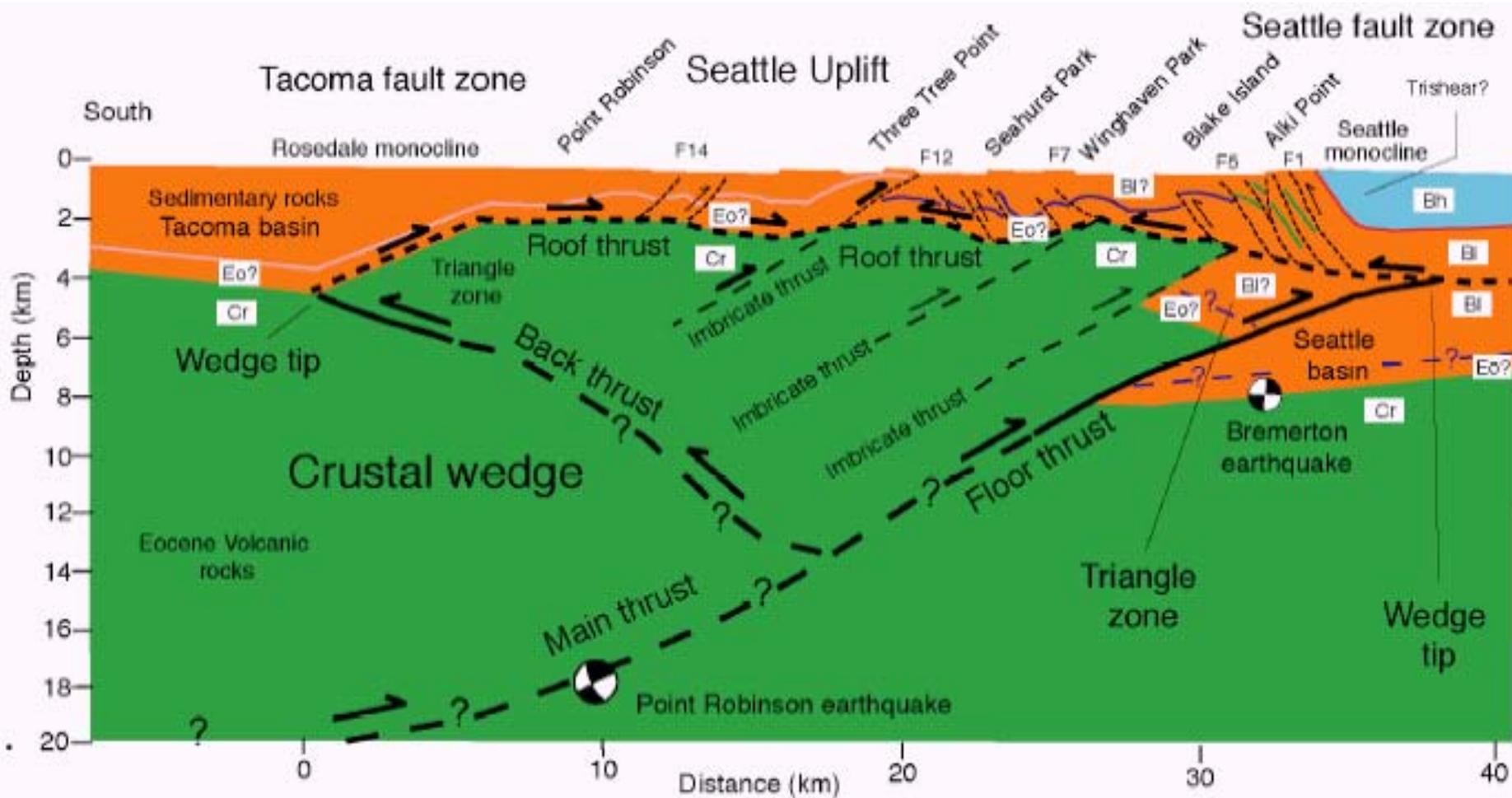


pre-Tertiary rocks undivided

# Geology Near Seattle



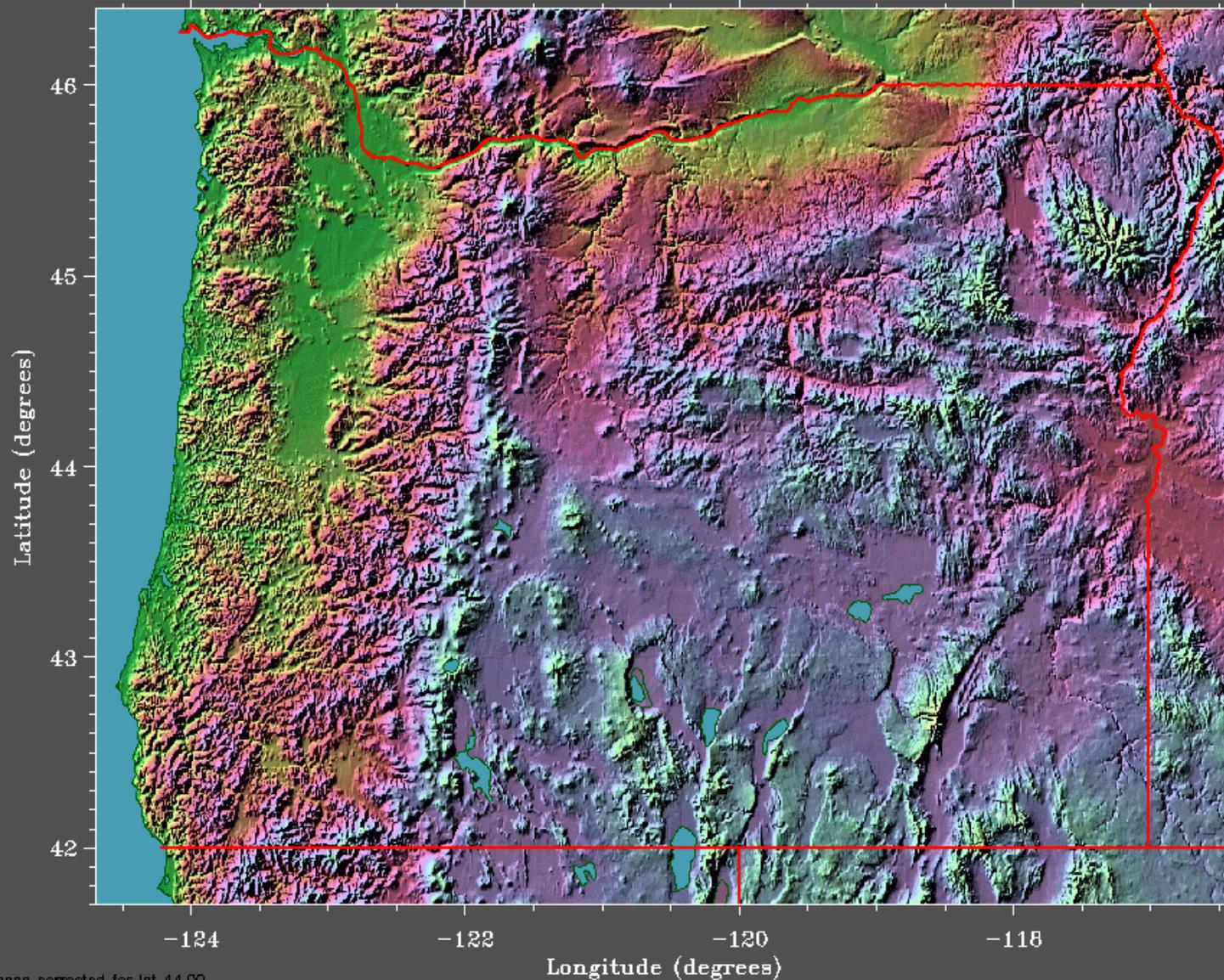
# Seattle Fault Models



# Scenario M 6.7 on Seattle Fault

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

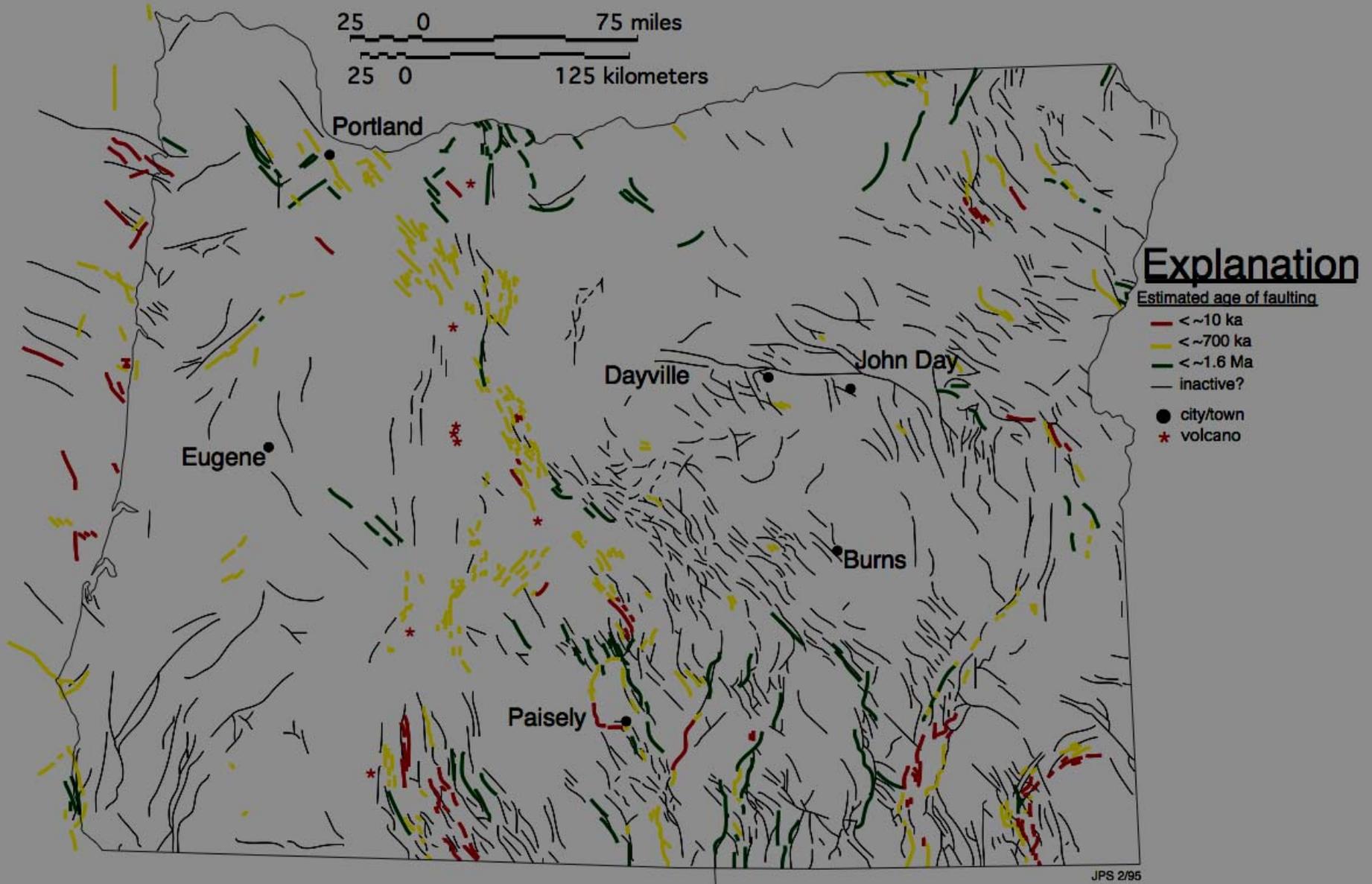
# Oregon Topography



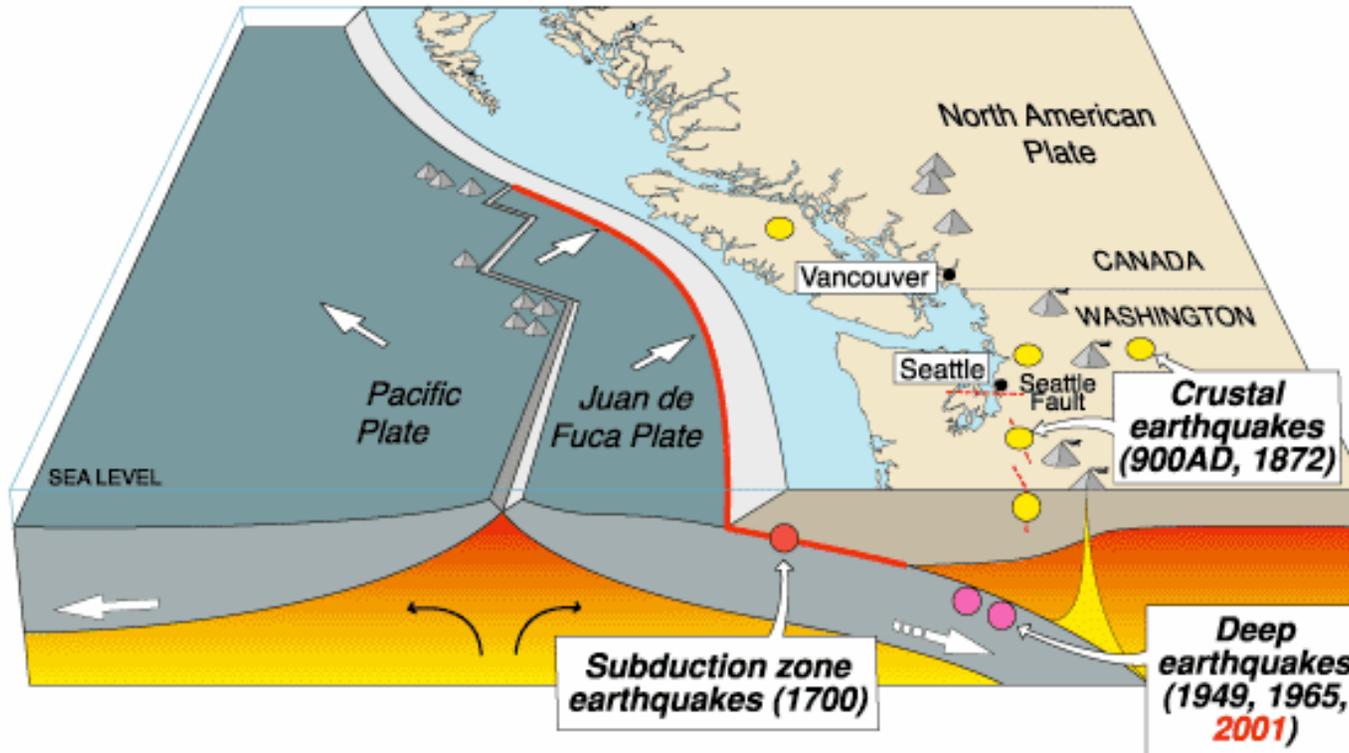
Shape corrected for lat 44.00

V.2.2. COPYRIGHT © 1995 by RAY STERNER, JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY

# Faults in Oregon



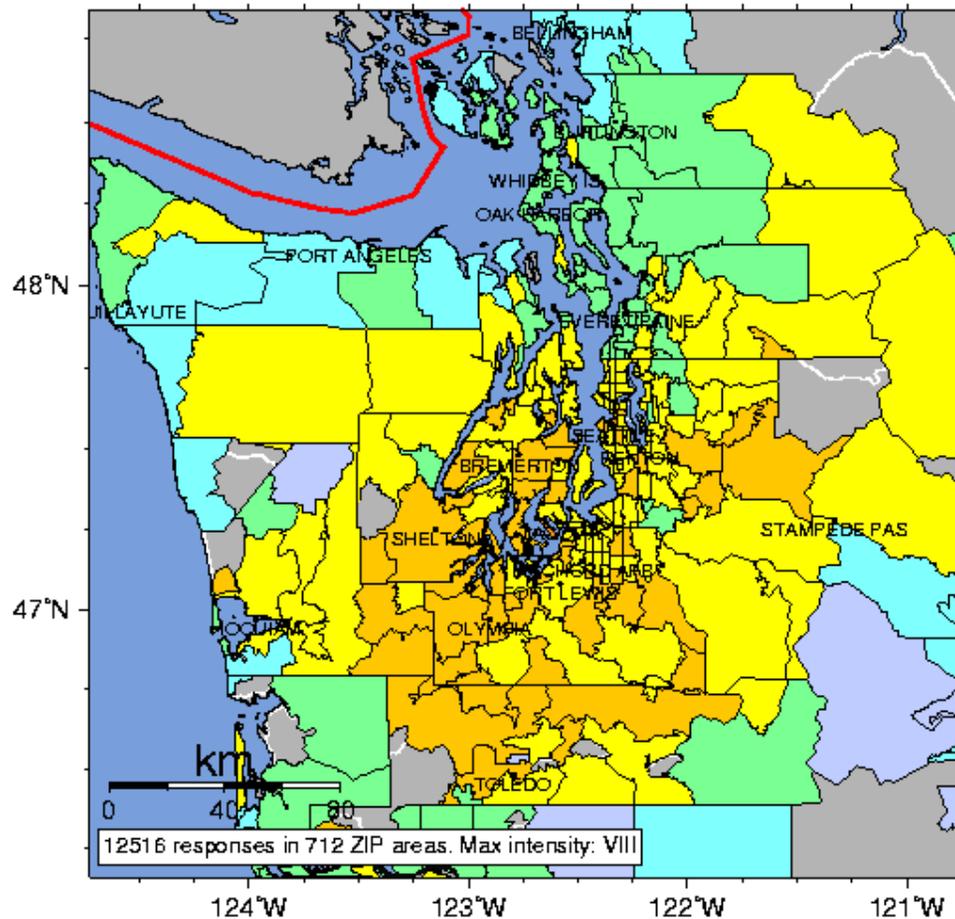
## Cascadia earthquake sources



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?

# Intensity Map for Nisqually Earthquake

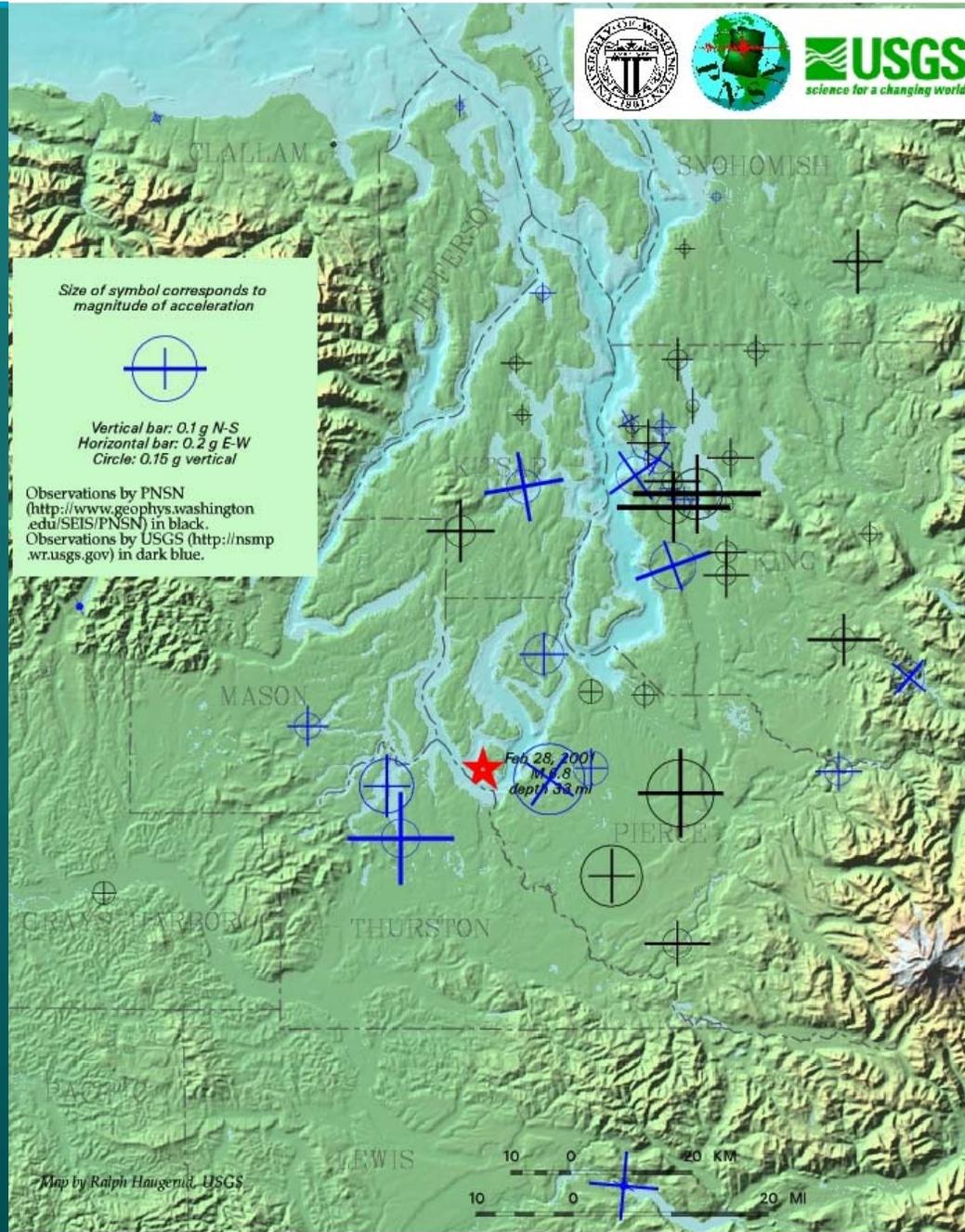
Community Internet Intensity Map for Nisqually (FEB 28 2001)  
 10:54:33 PST Mag=6.8 Latitude=N47.15 Longitude=W122.73



Map last updated on Fri Sep 21 15:30:54 2001

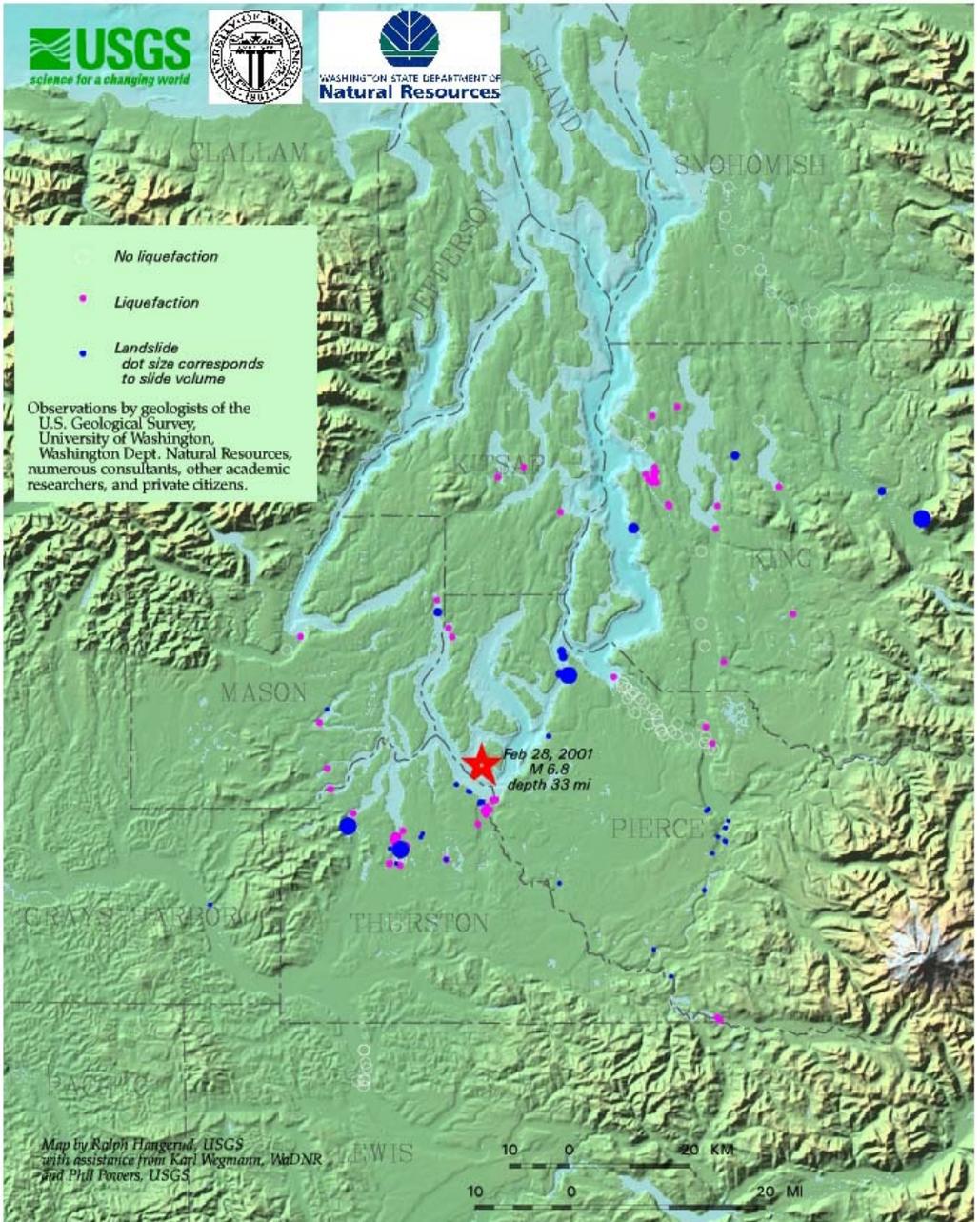
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

# Peak Accelerations



Accelerations were not large but broadly distributed because of the depth.  
Amplification on the soft soil around Puget Sound

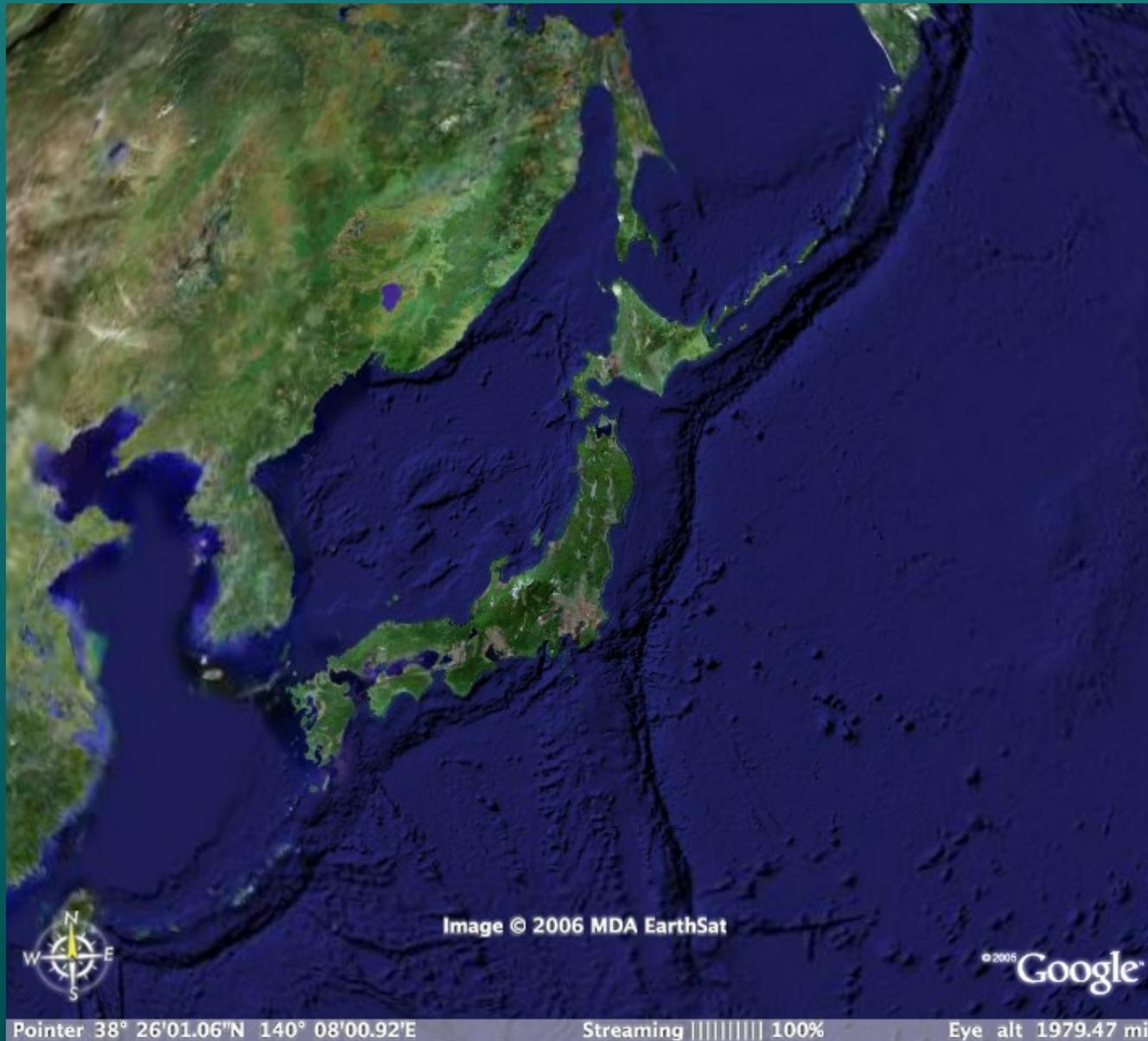
Preliminary peak ground accelerations, Nisqually earthquake



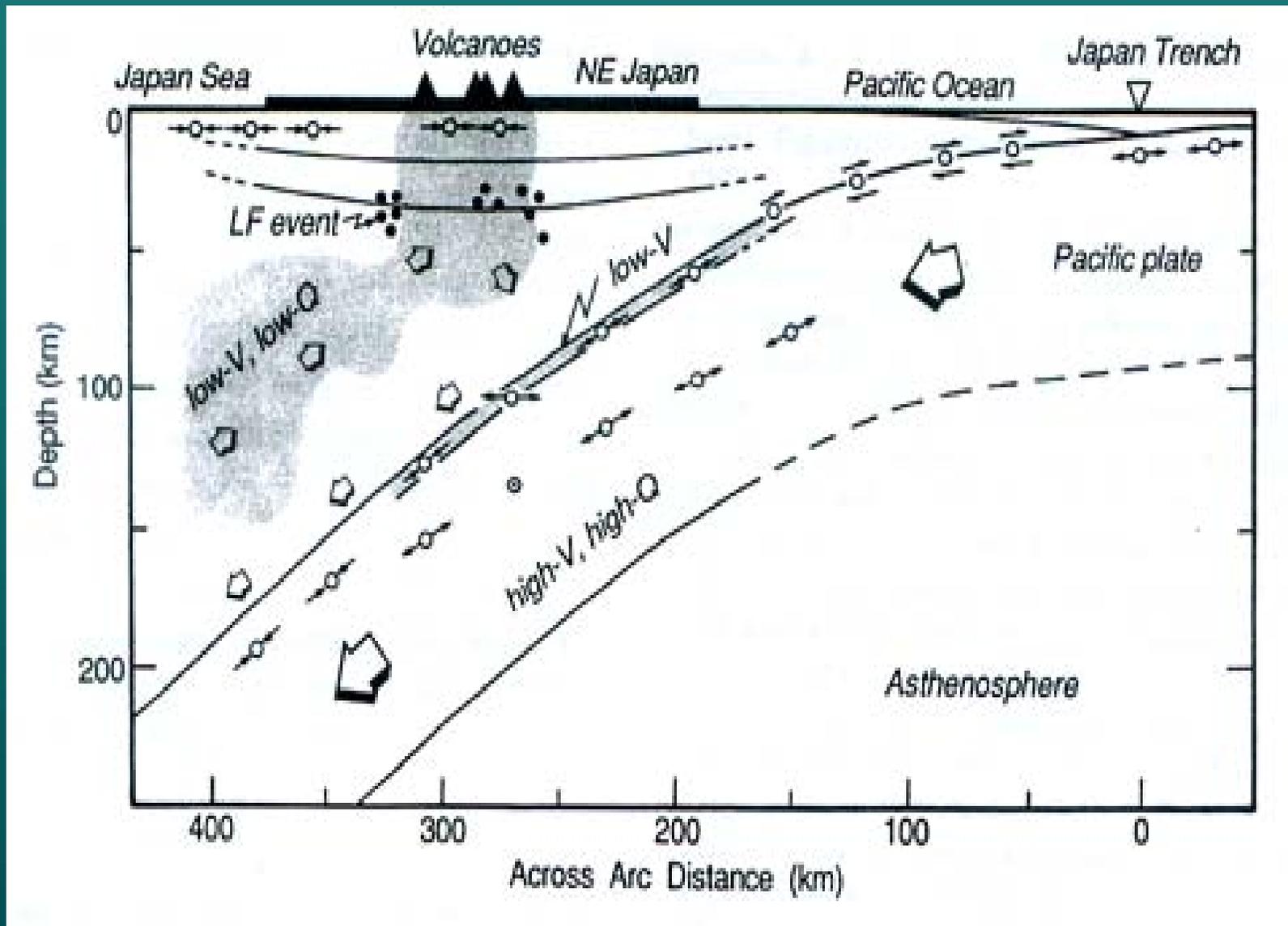
# Liquefaction and Landslides Nisqually Earthquake M 6.8

Preliminary observations of ground deformation, Nisqually earthquake

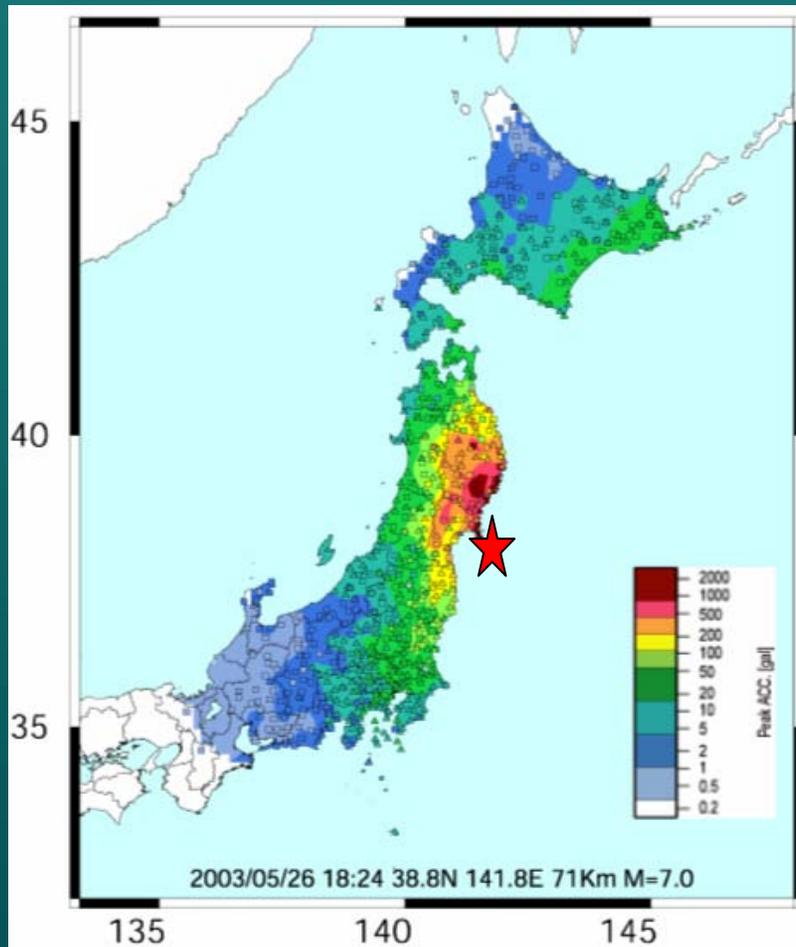
# Tectonics for Japan Subduction



# Tectonics for Japan Subduction



# PGA 2003 Event



## Source Information

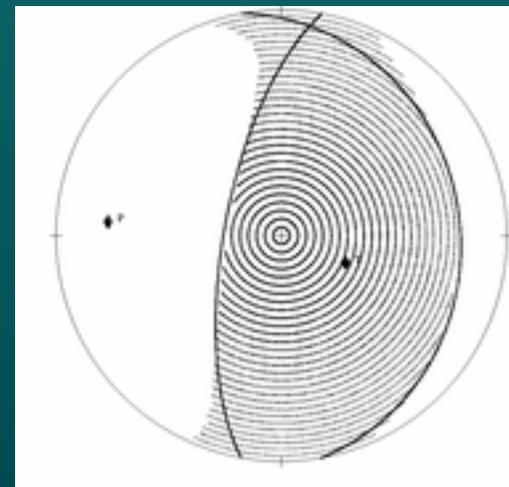
Epicenter: (38.3N, 141.7E)

Mw=7.0

Depth: 71 Km

(strike, dip, rake) =(190,72,101)

Yamanaka and Kikuchi (2003)



**K-NET, KiK-net**

# 2005 Miyagi Event

## Source Information

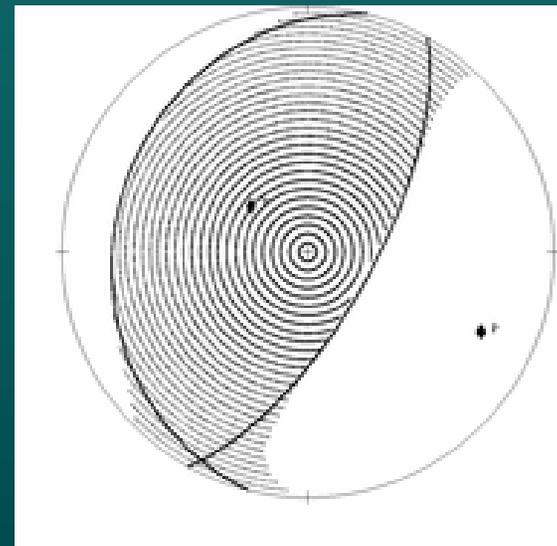
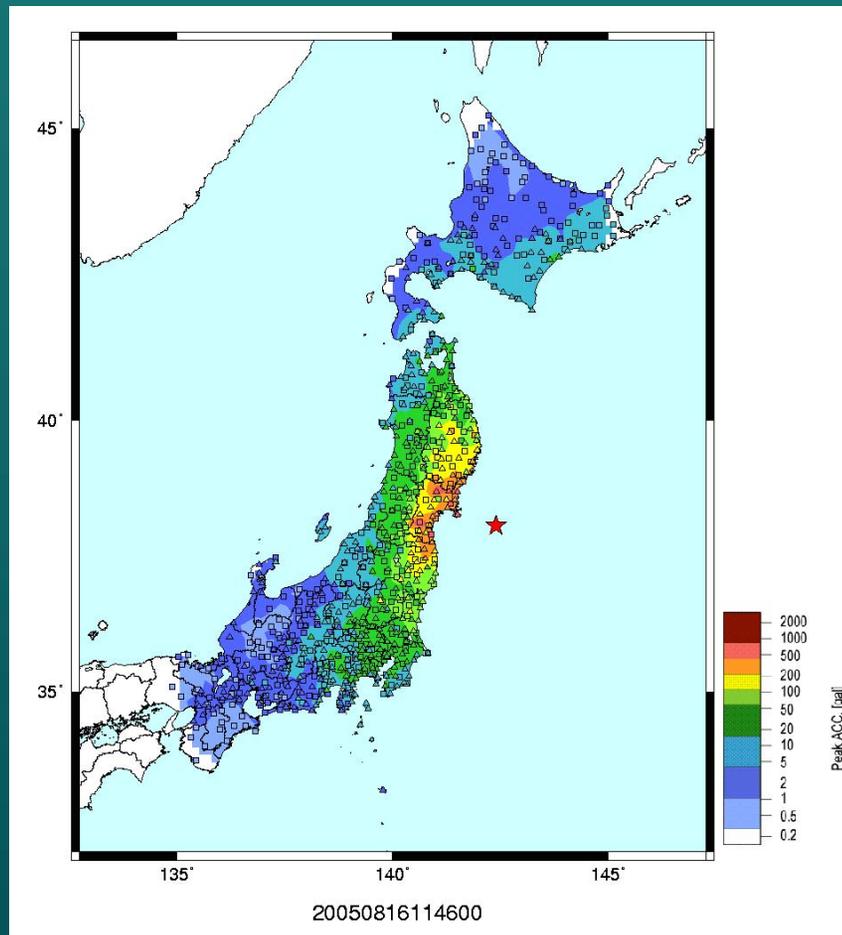
Epicenter: (38.1N, 142.4E)

Mw=7.2

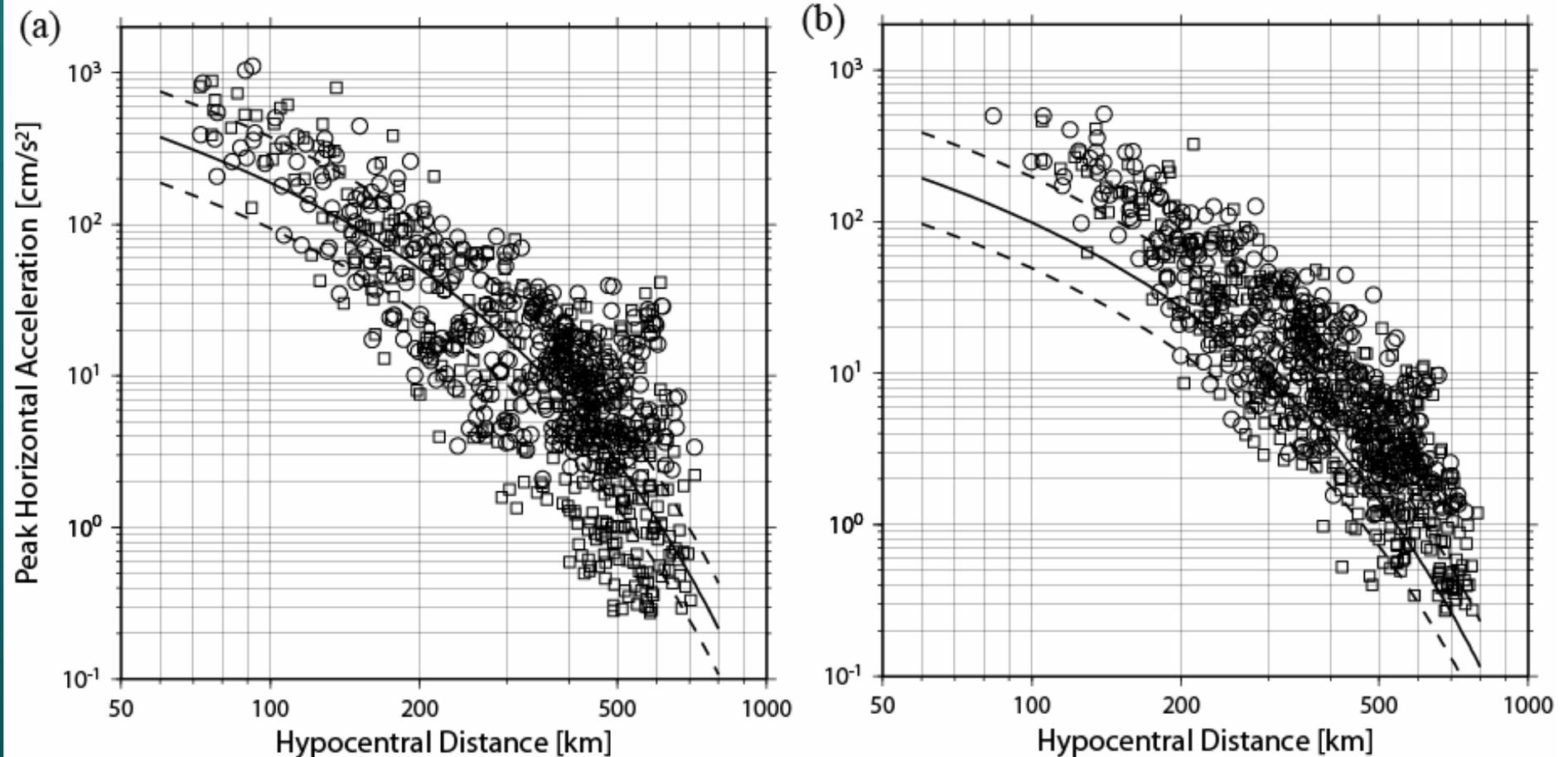
Depth: 42 Km

(strike, dip, rake) =(198, 25, 82)

Yamanaka (2005)

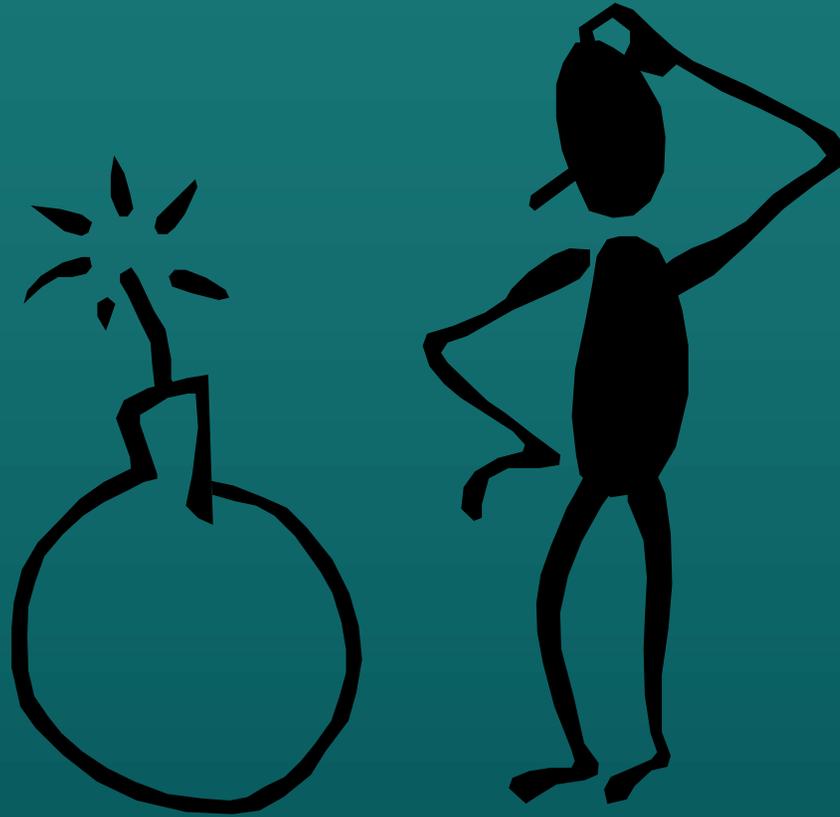


# Attenuation Relations

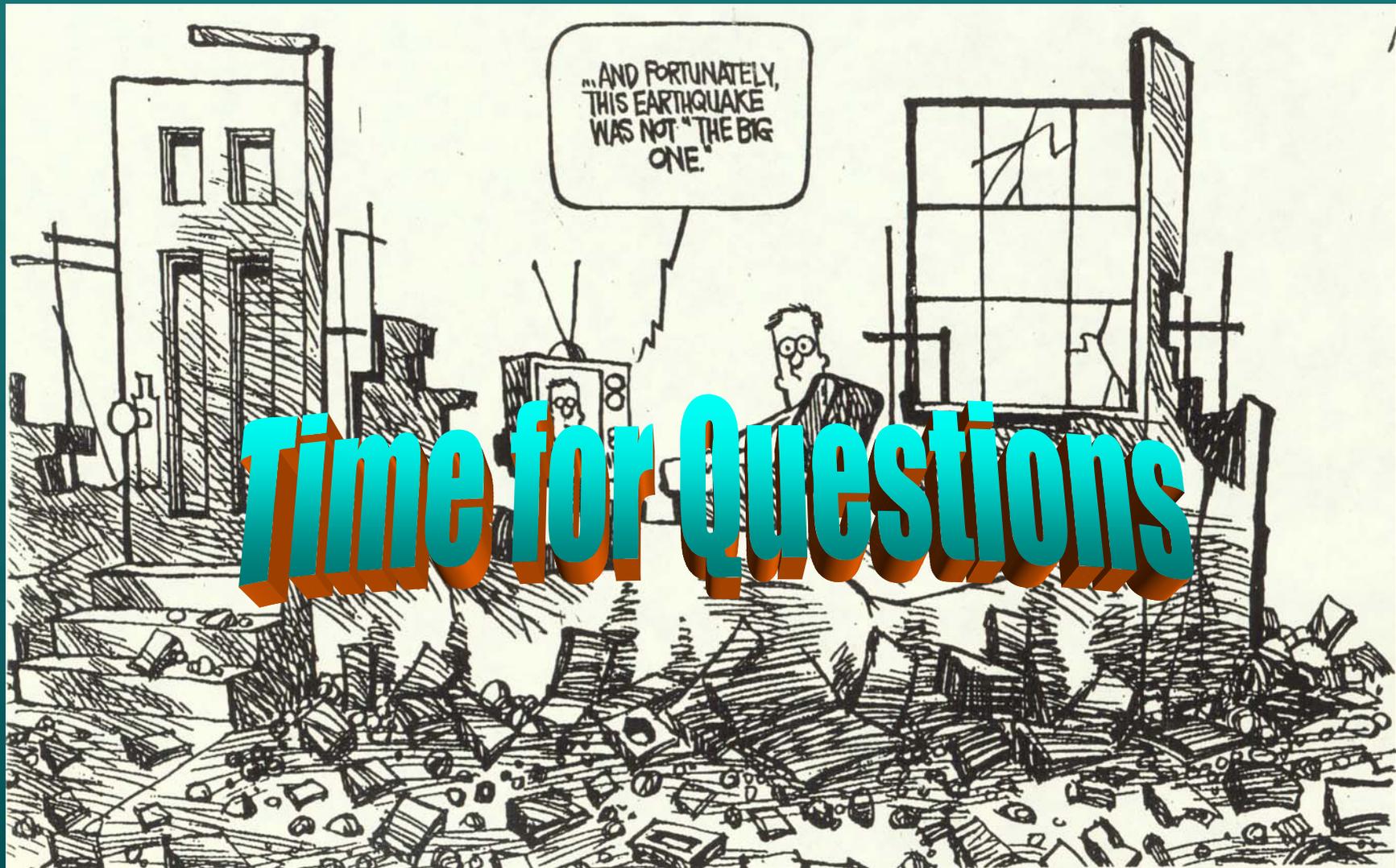


(a) 2003 event (M<sub>w</sub>=7.0) (b) 2005 event (M<sub>w</sub>=7.2)  
Shi and Midorikawa (1999)

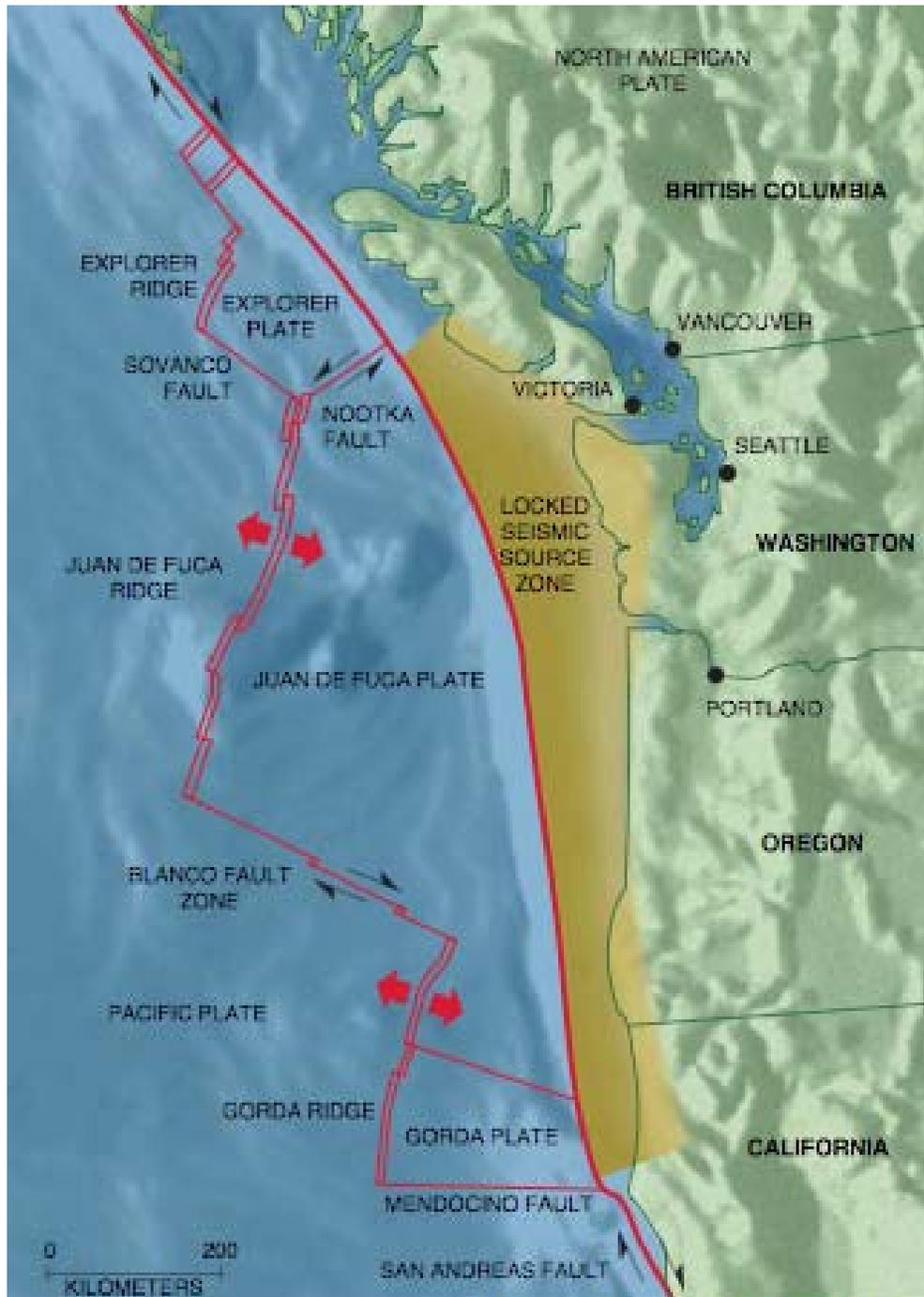
# Waiting, Watching, Wondering



# Waiting, Watching, Wondering

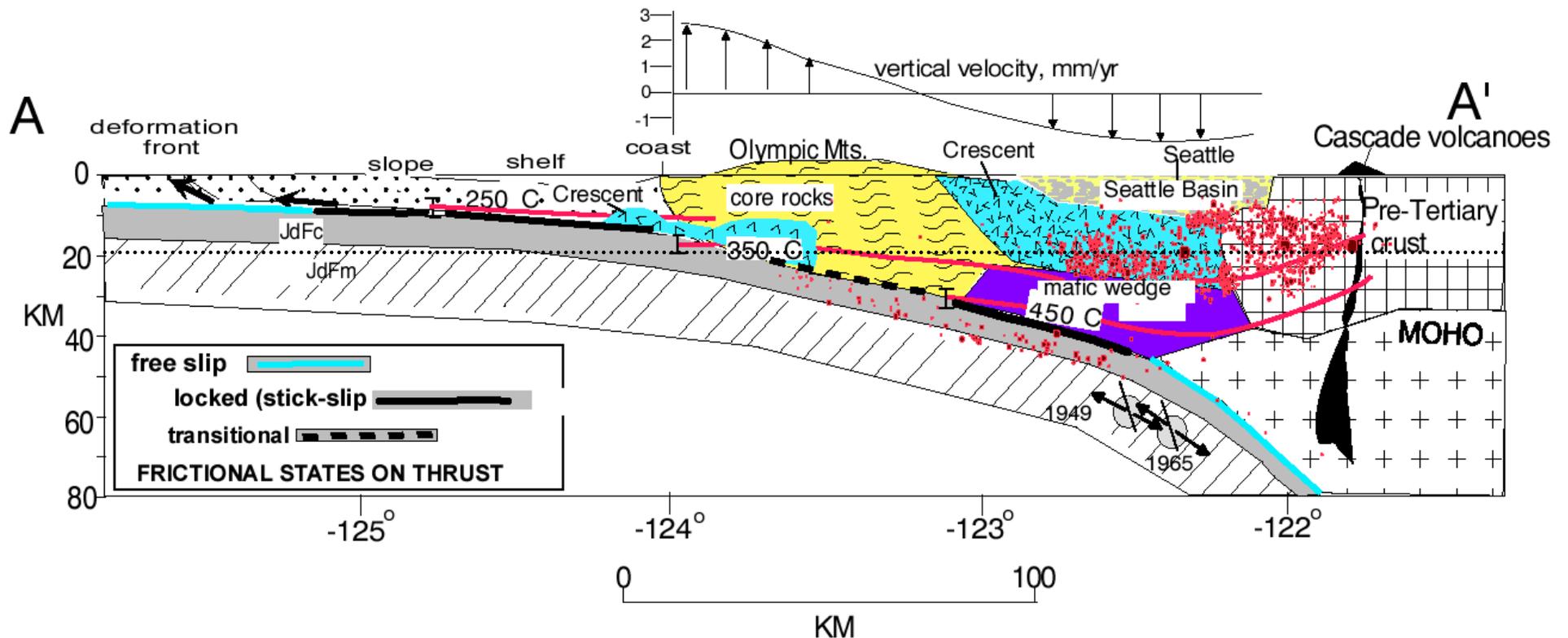


# Tectonic Plates with Locked Zone Source Region M 9



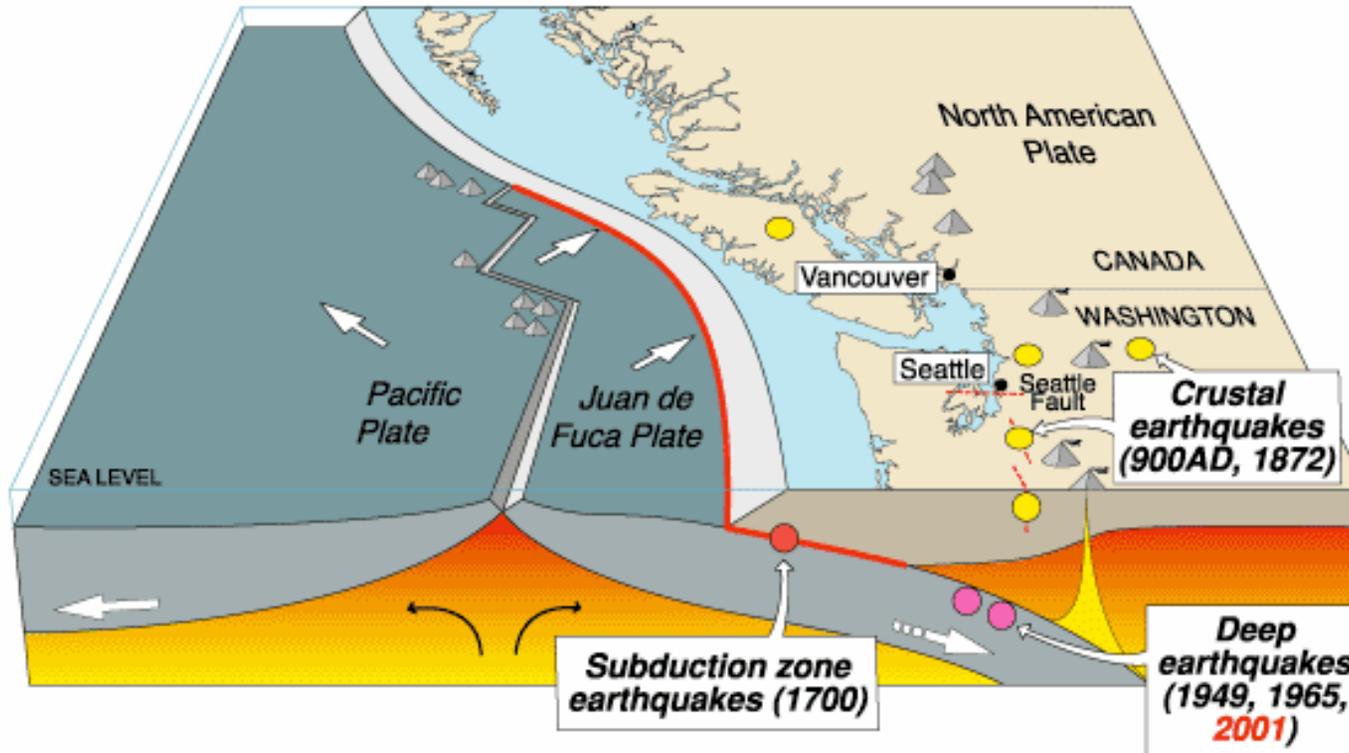
Copyright 1995 Scientific American, Inc.

# Geologic Cross Section



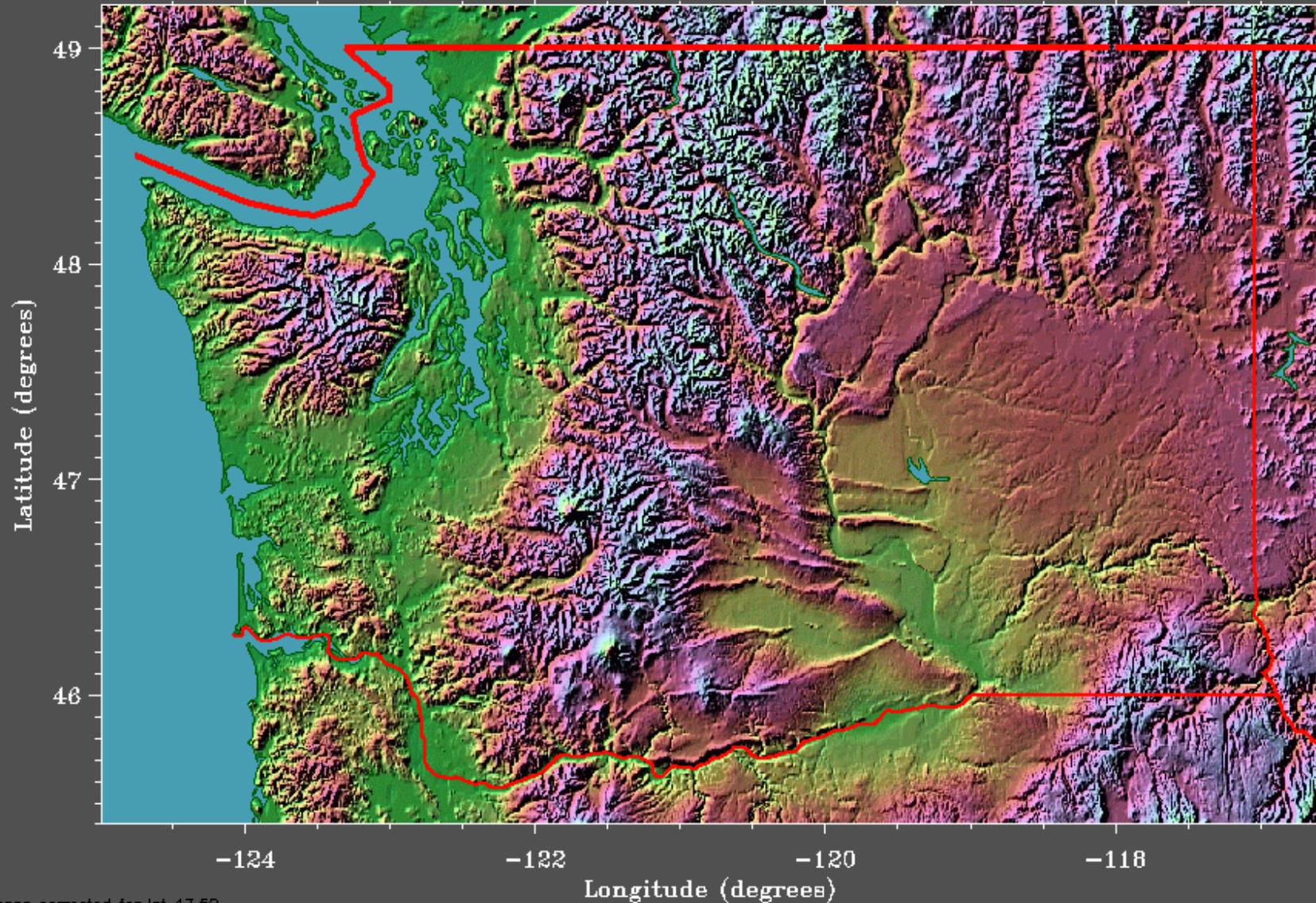
# Cascadia Tectonics

## 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?

# Washington Topography



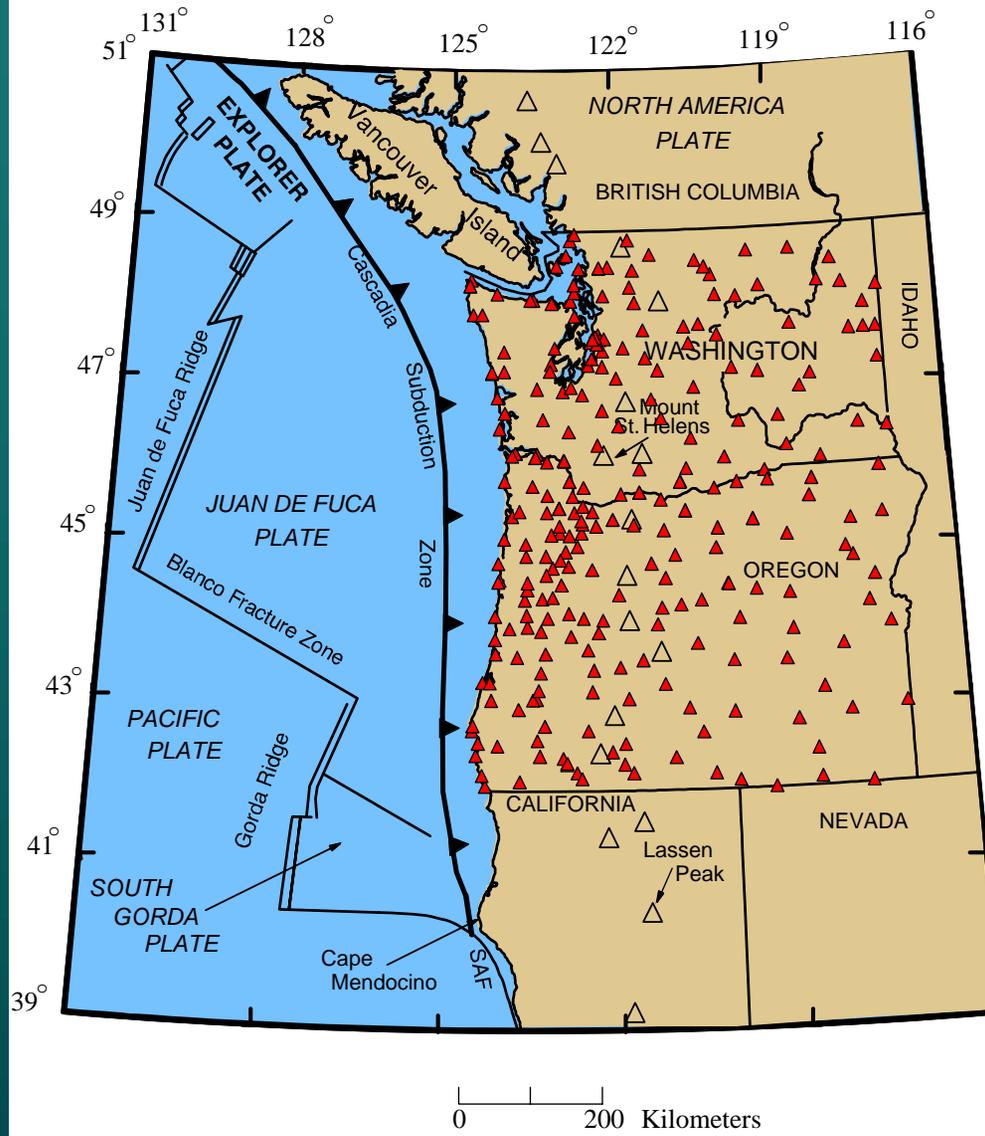
Shape corrected for lat 47.50

V 2.2 COPYRIGHT © 1995 by RAY STERNER, JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY

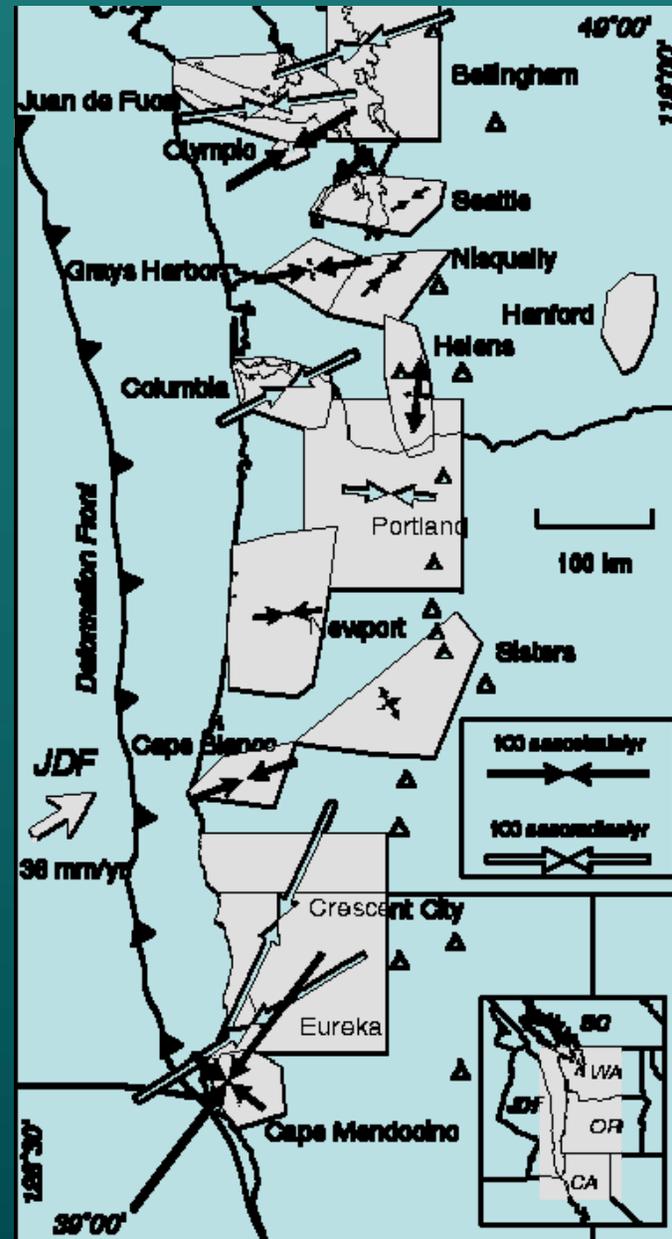
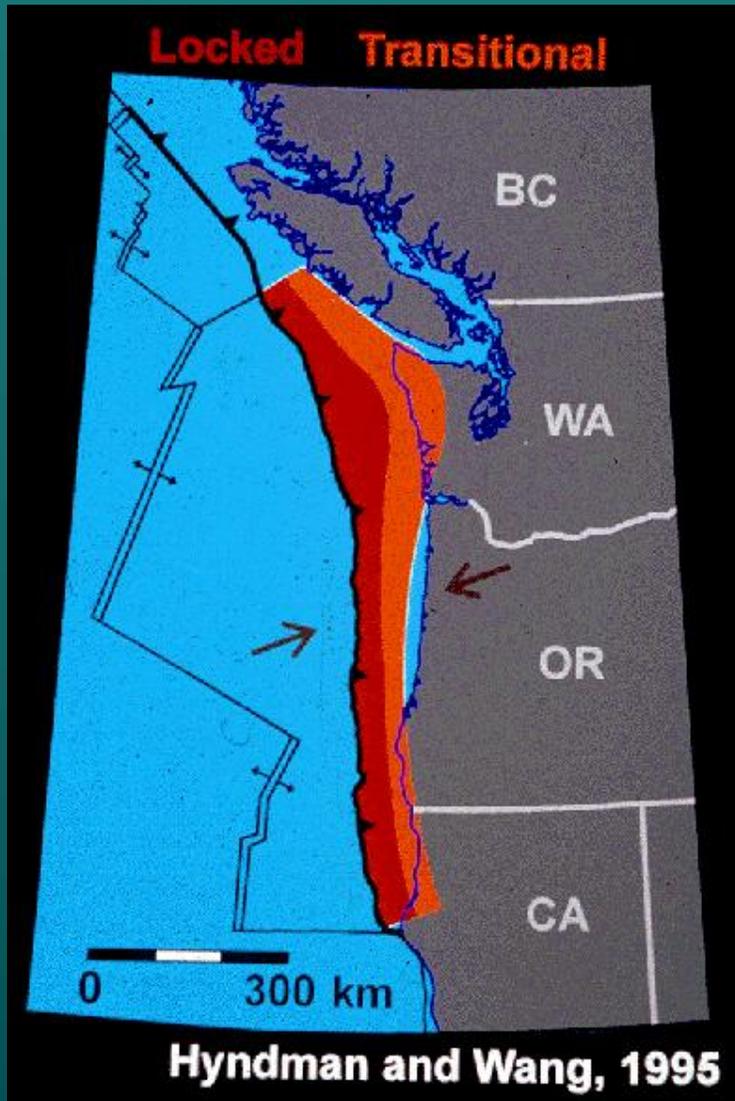
2006 Northwest Dam Safety, Feb 14-15

# GPS (1998)

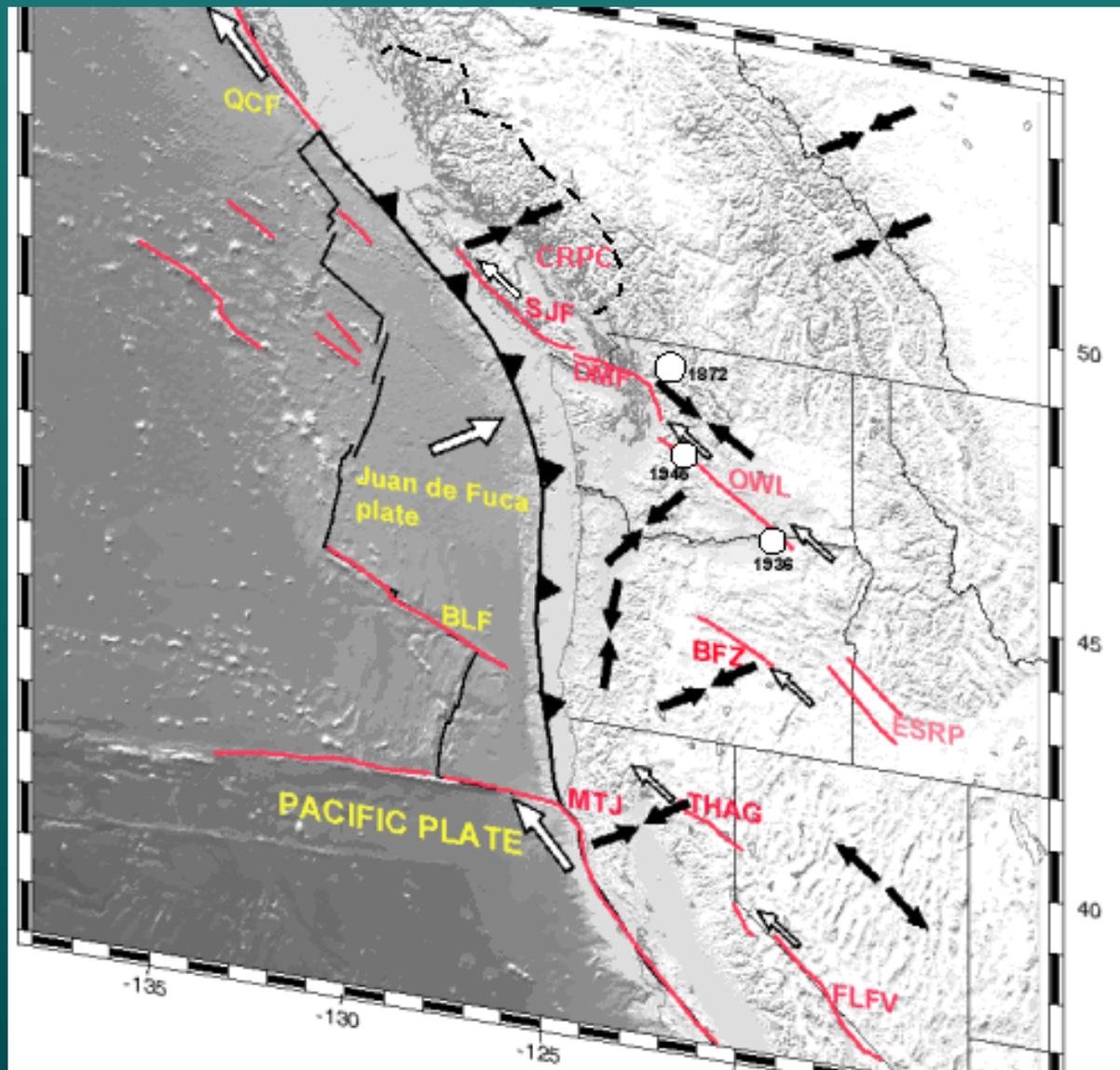
## 1998 GPS Campaign Sites NGS and Volunteers



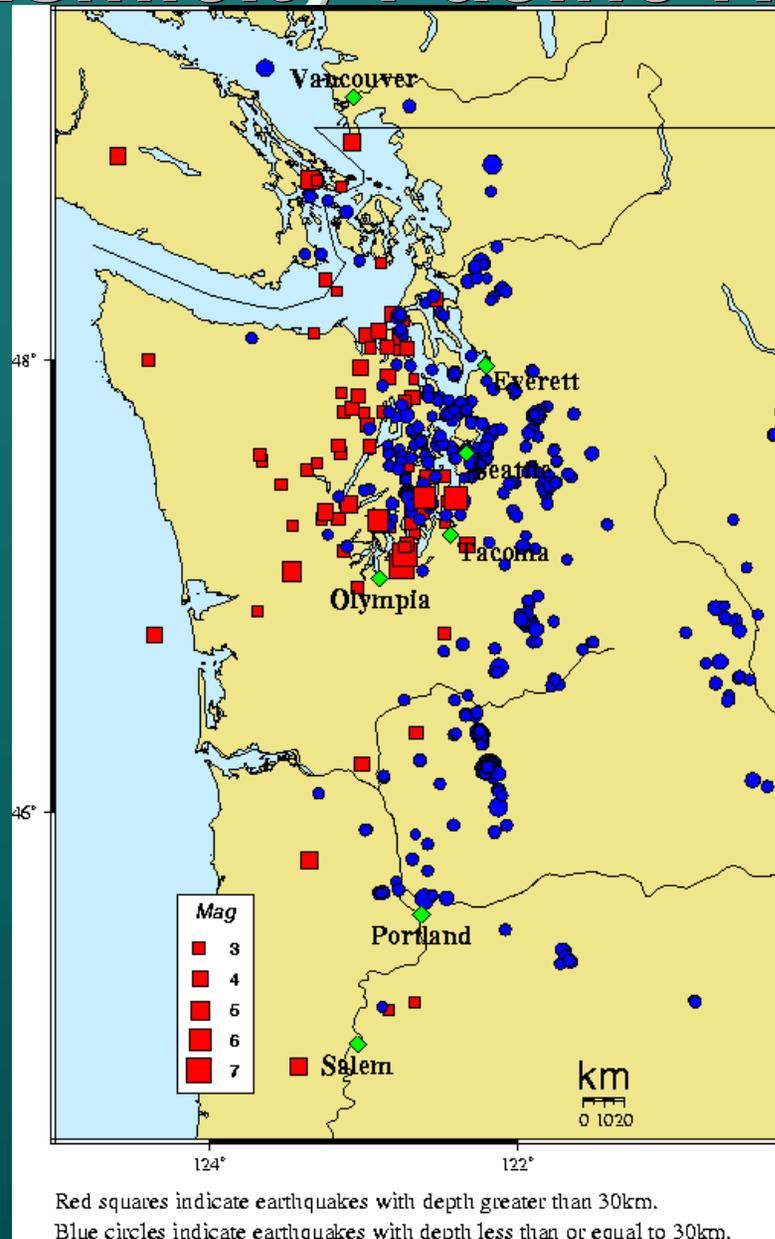
# Strain Rate in Cascadia



# Plate Interactions with Maximum Stress Directions



# Seismicity Pacific Northwest

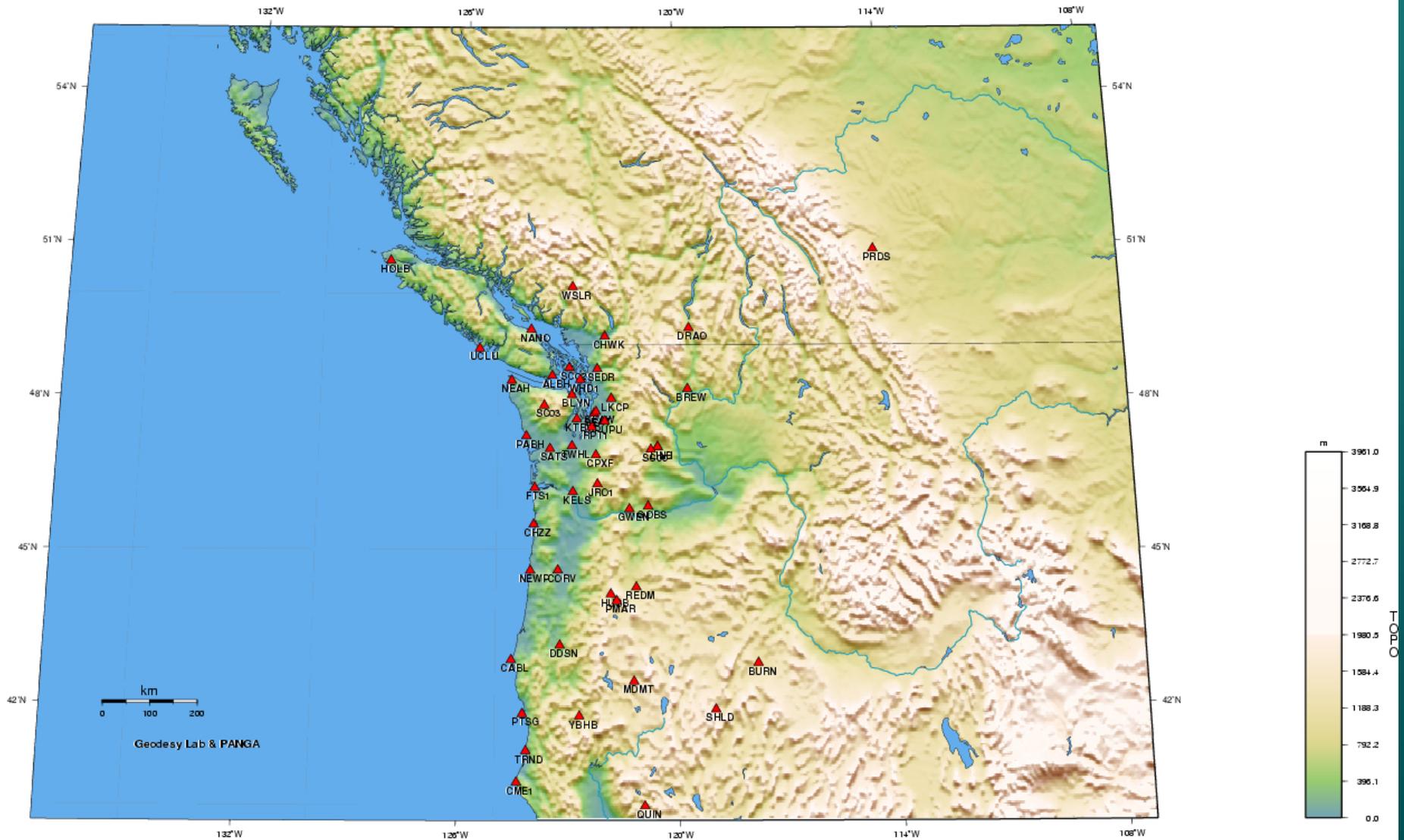


Blue  $Z < 30$  km

Red  $Z > 30$  km

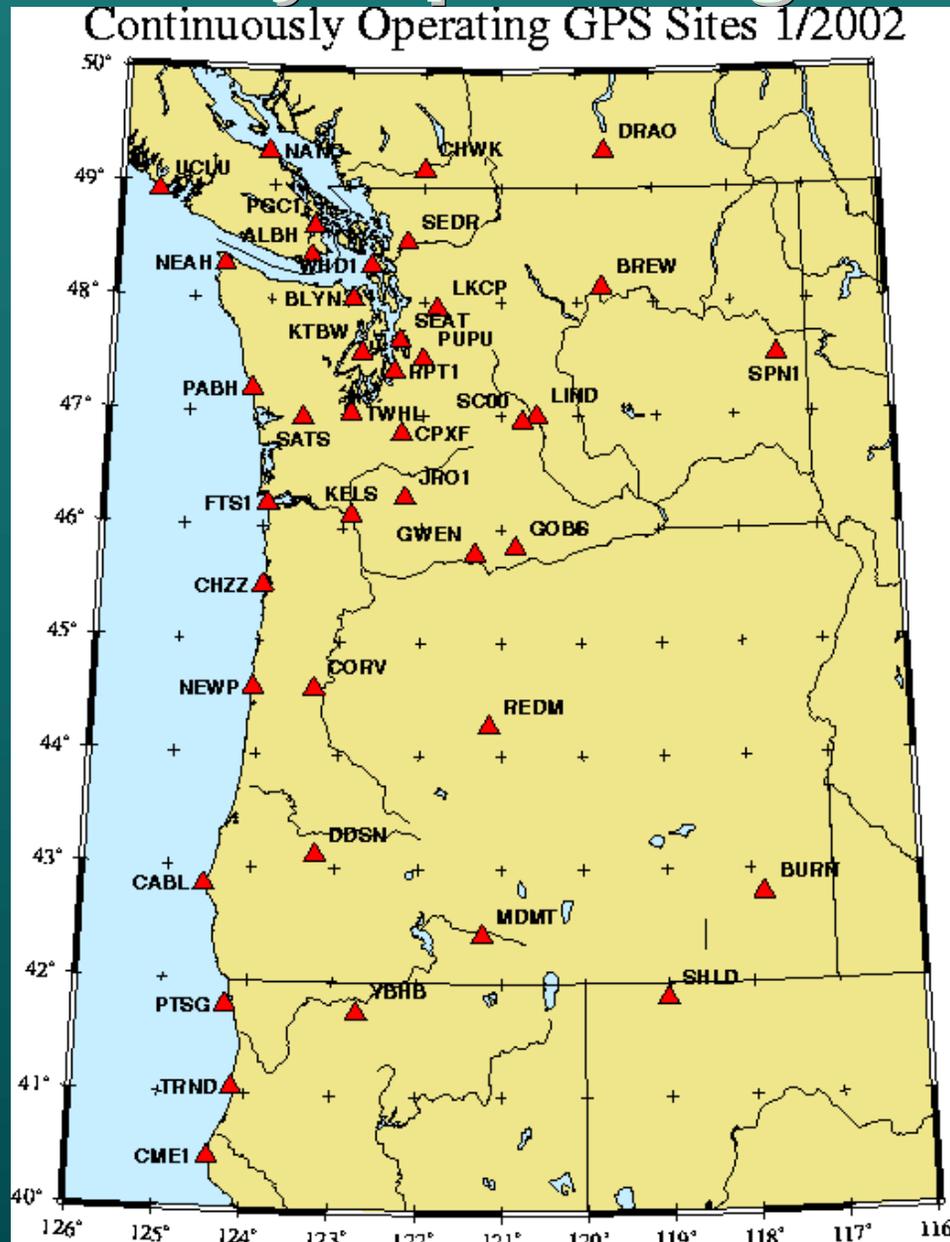
# PANGA (Pacific Northwest GPS Array)

## PANGA

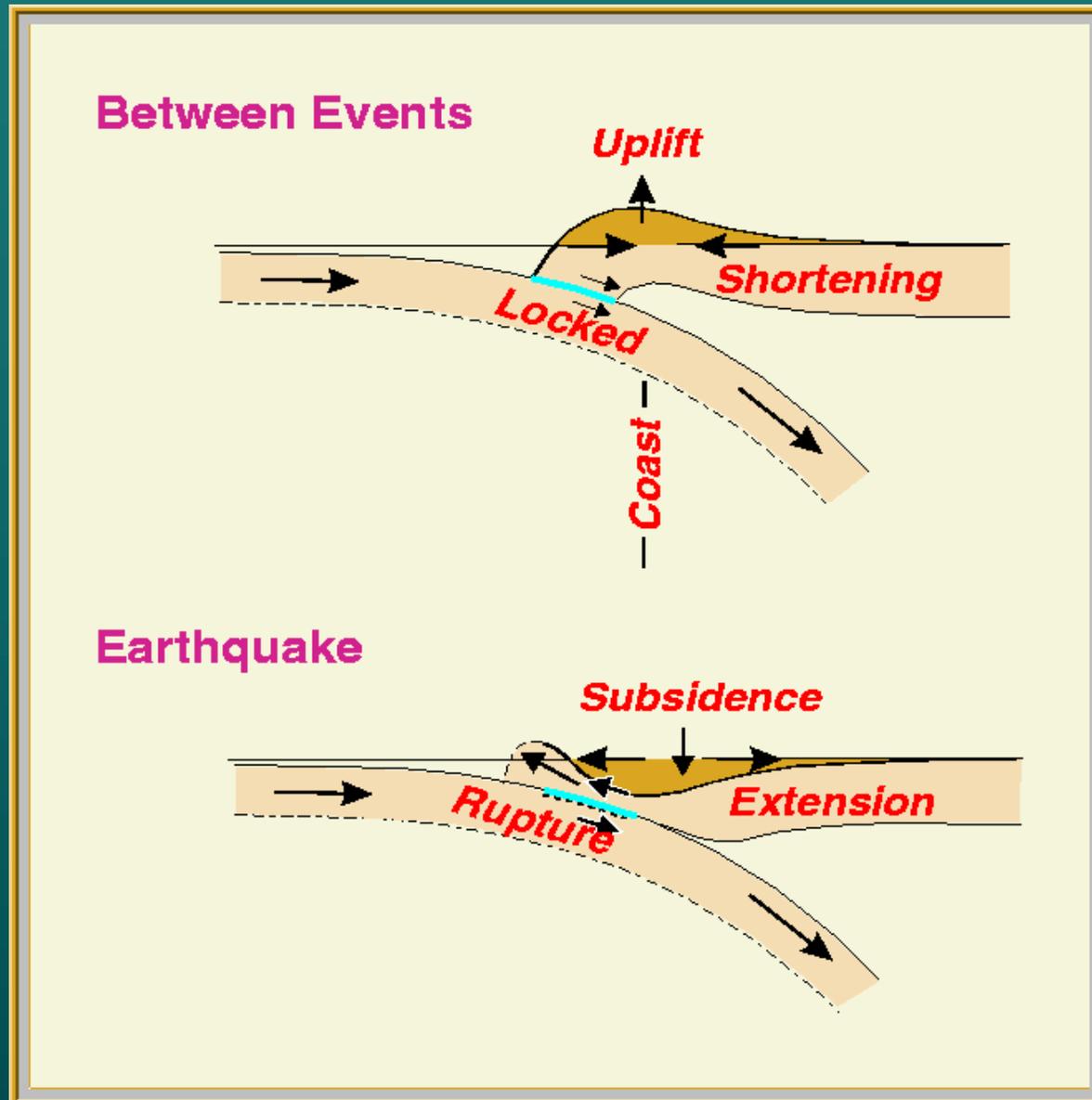


GMT 2004 May 5 02:16:45 Geodesy Lab & PANGA

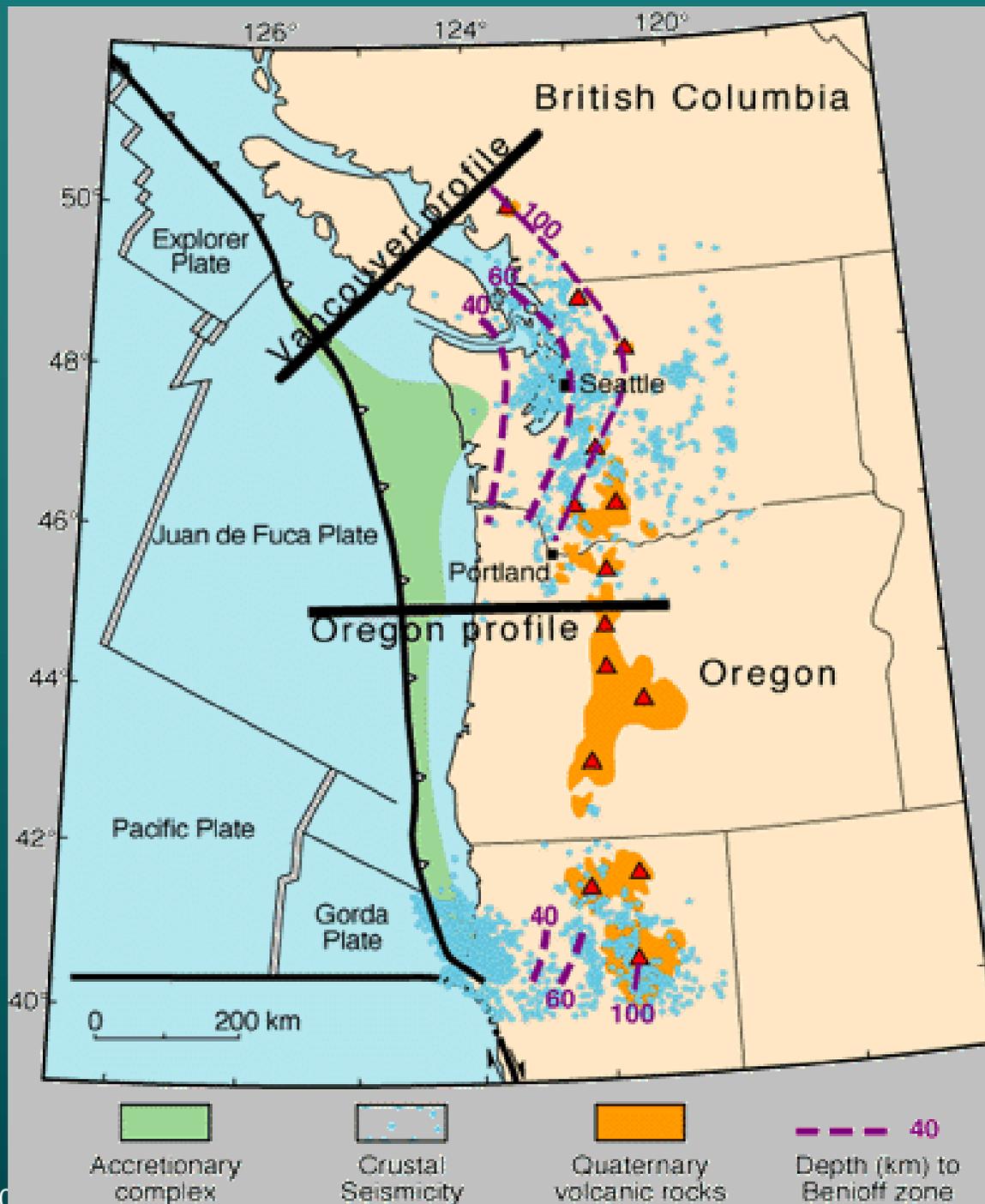
# Continuously Operating GPS 2002



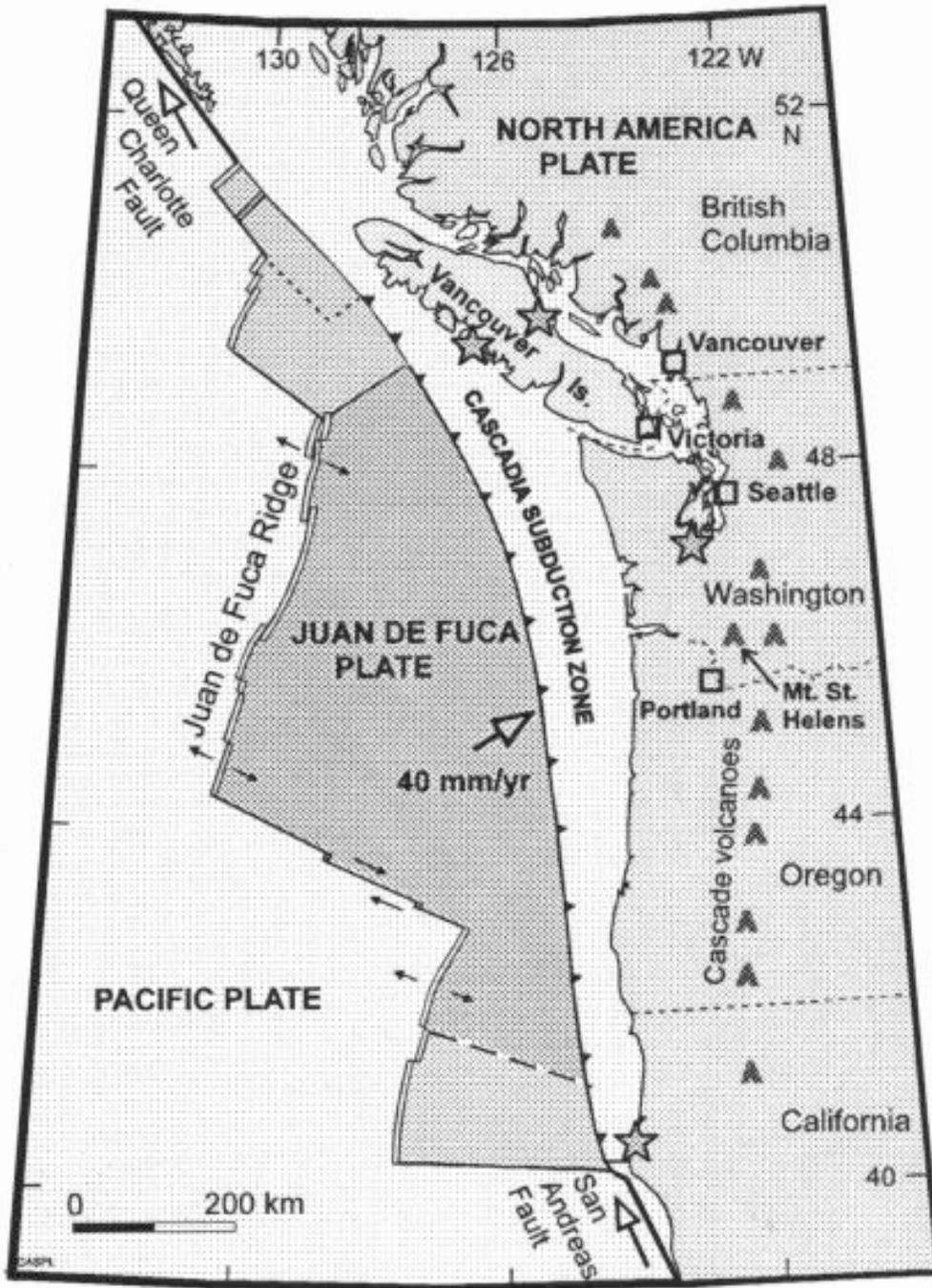
# Deformation Between and During Events



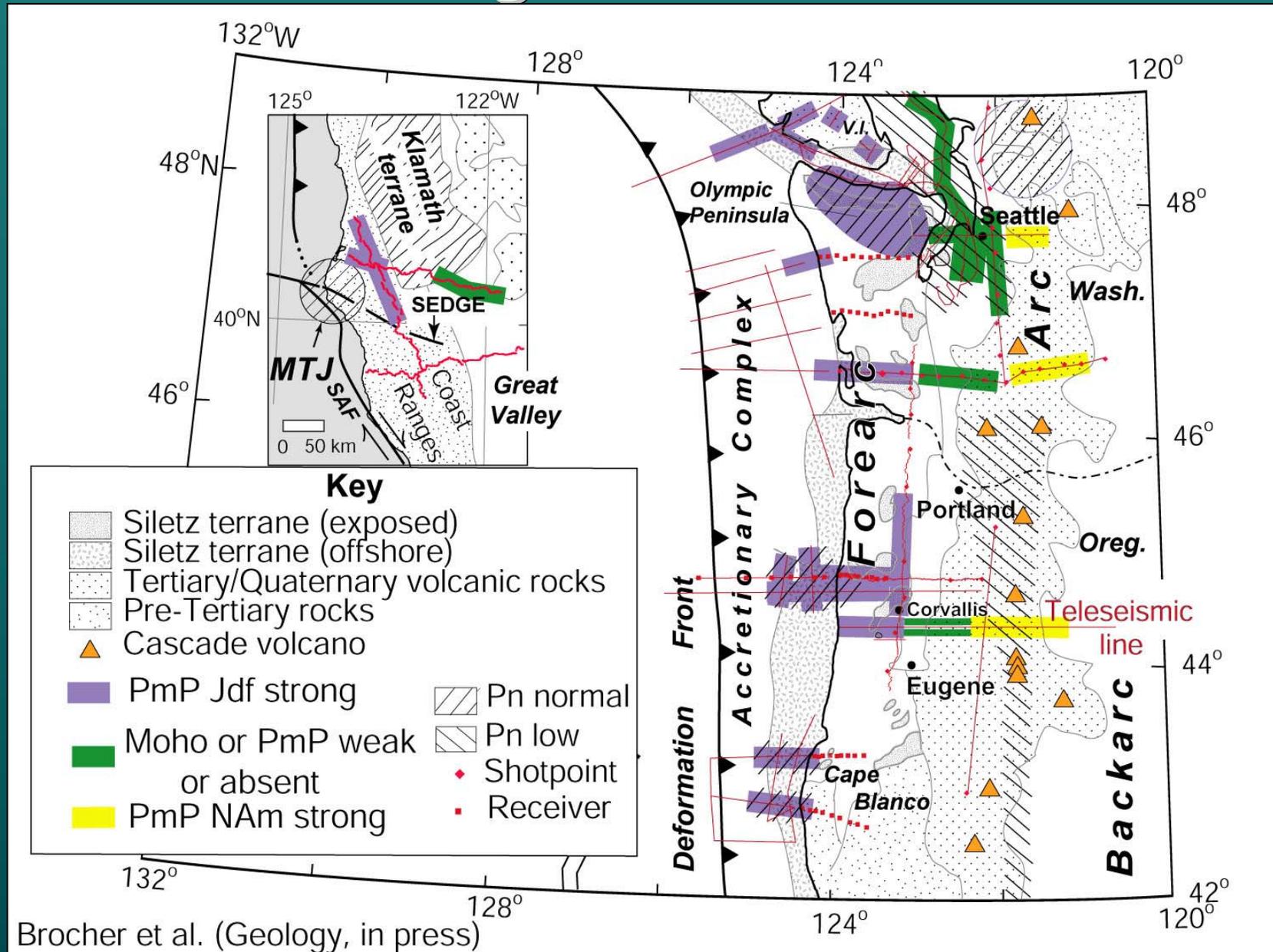
# Cascadia Trench and Earthquakes



# Juan de Fuca Plate Subducting Beneath North America



# Geological Terranes



Brocher et al. (Geology, in press)

# Tectonics of Cascadia

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

# Locked Zone (Hyndman & Wang)

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

# Fault Map: Western Washington

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

# 1982-1987

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

Cassidy, 1991

