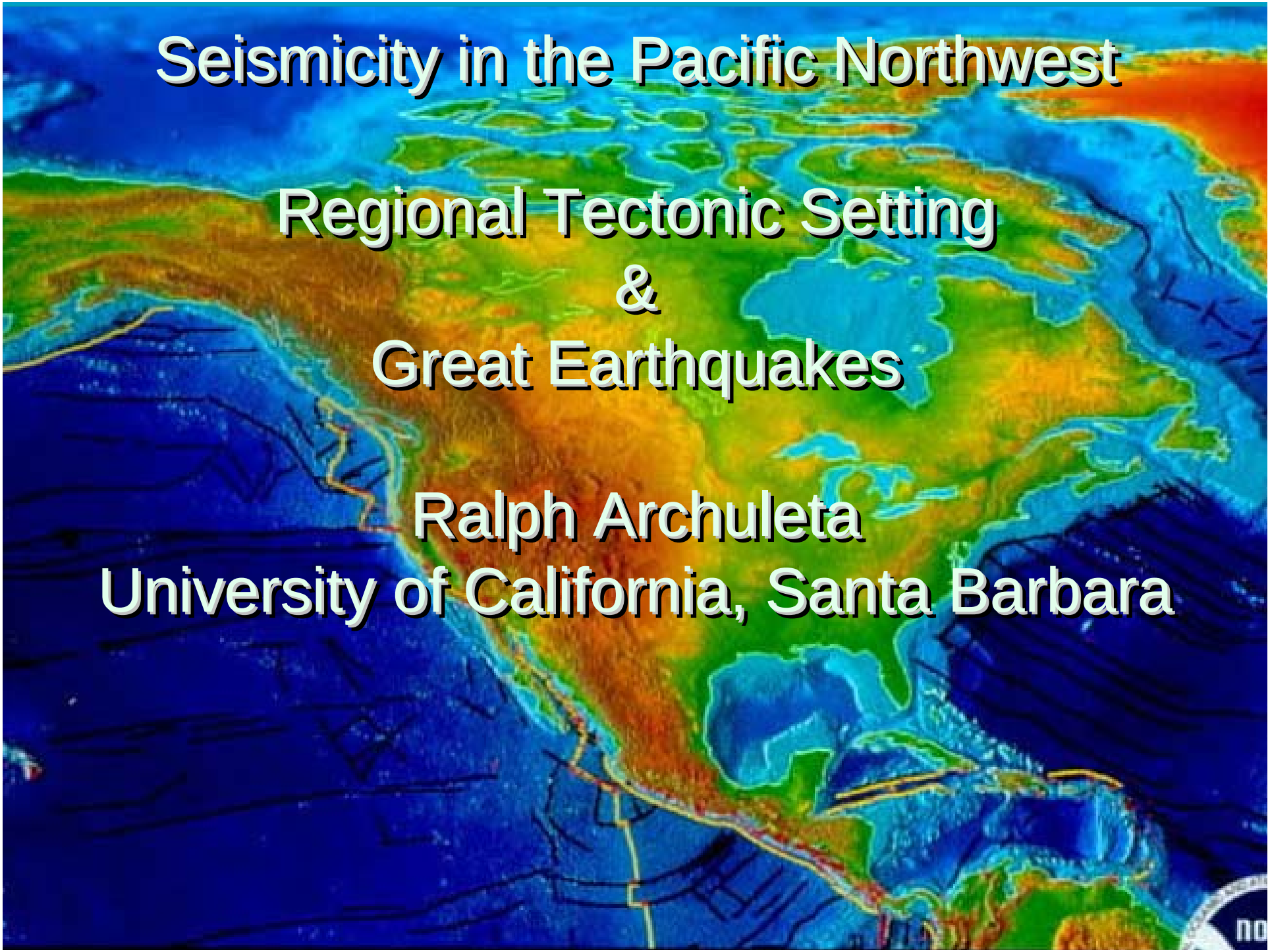


Seismicity in the Pacific Northwest

Regional Tectonic Setting
&
Great Earthquakes

Ralph Archuleta
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

Present Day Plate Boundaries

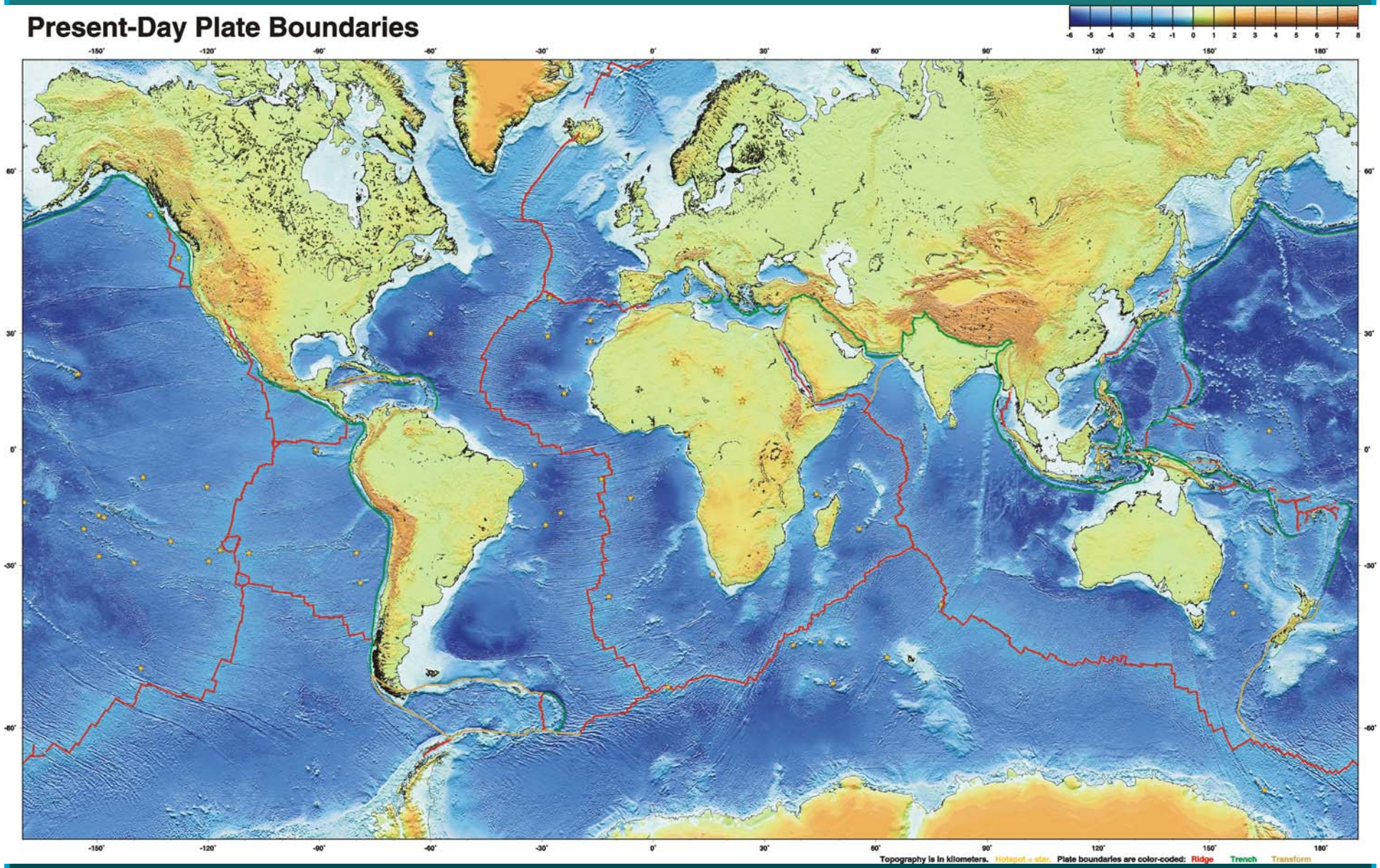
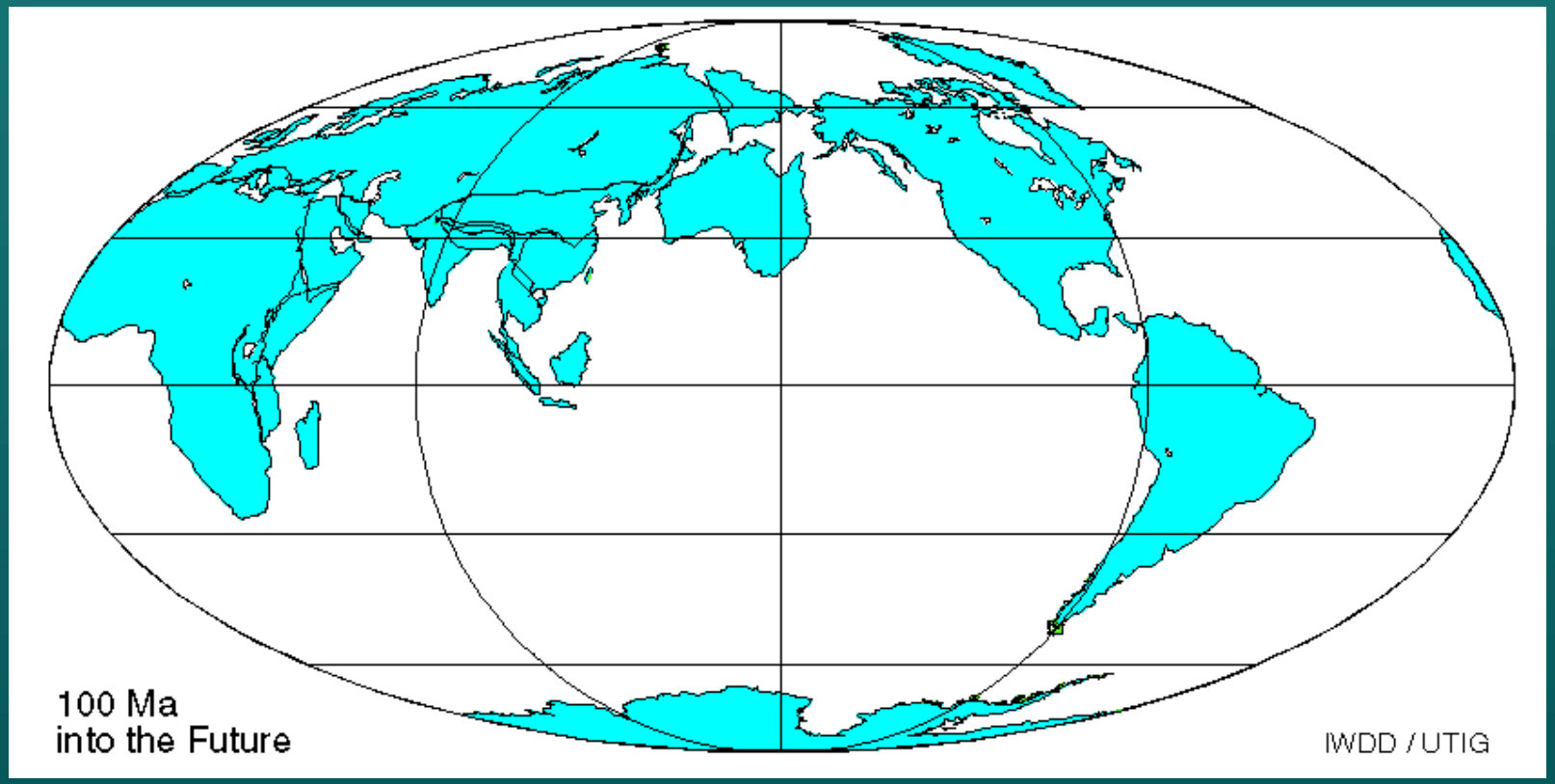
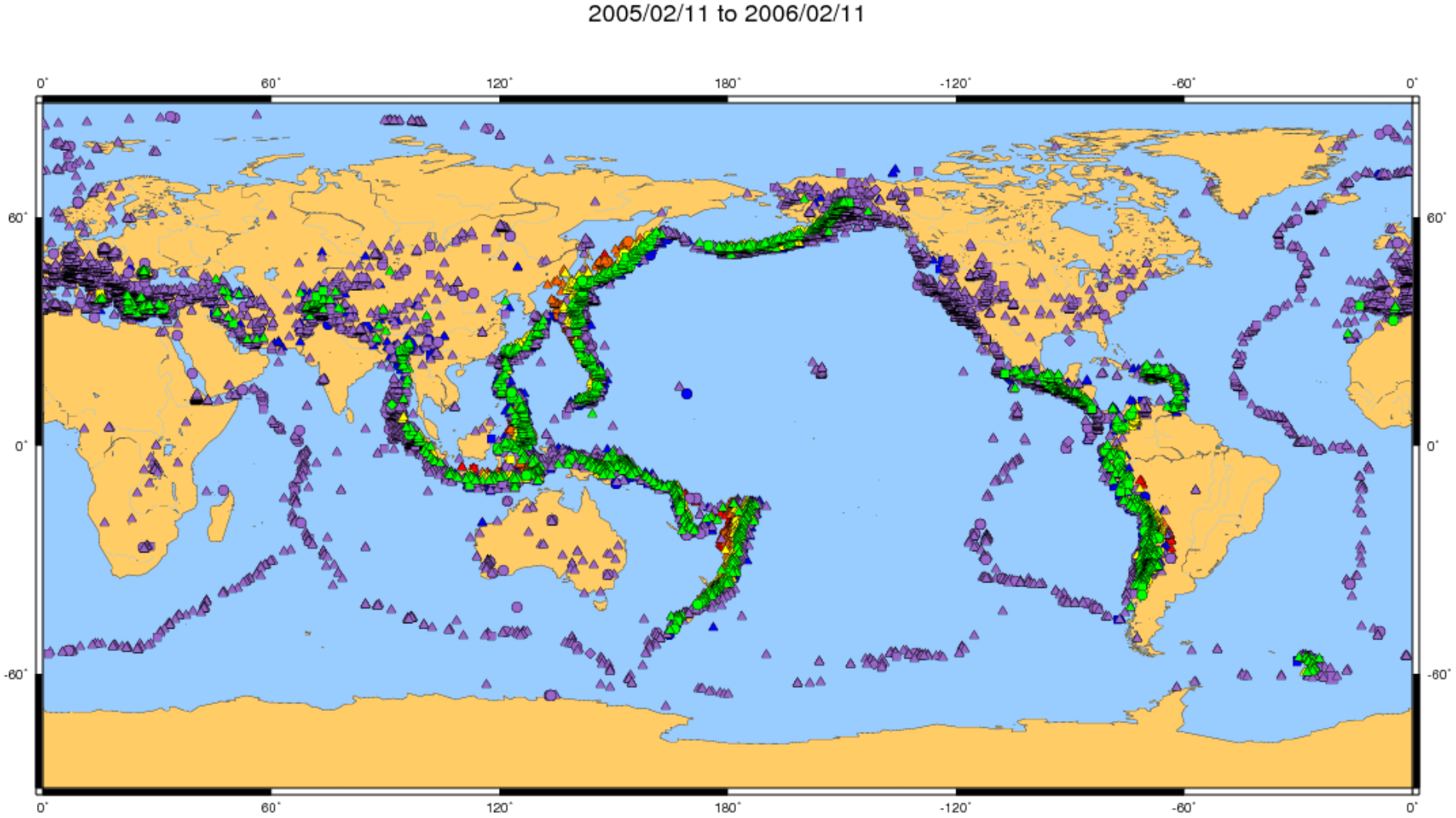
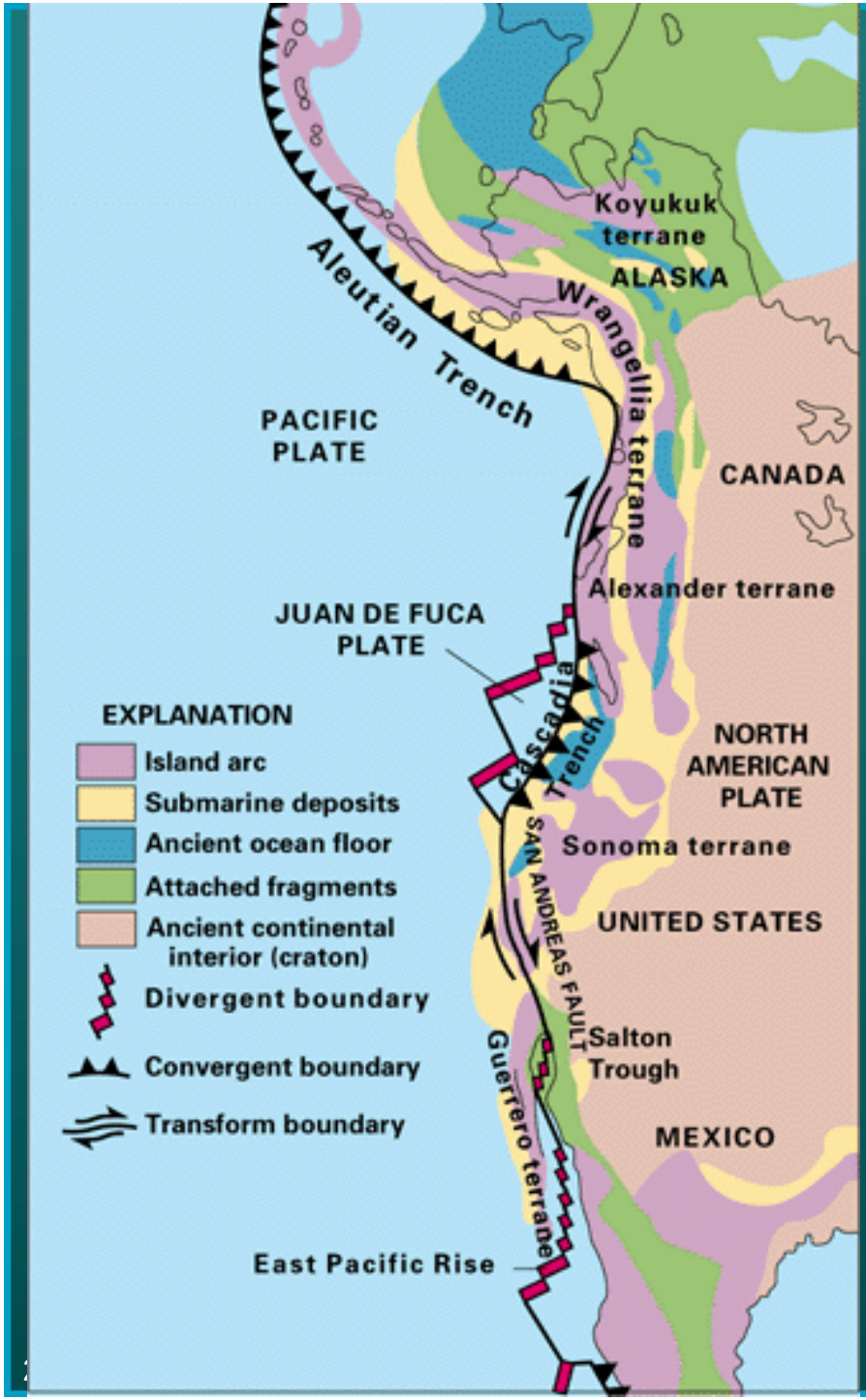


Plate Boundaries: 100 MY



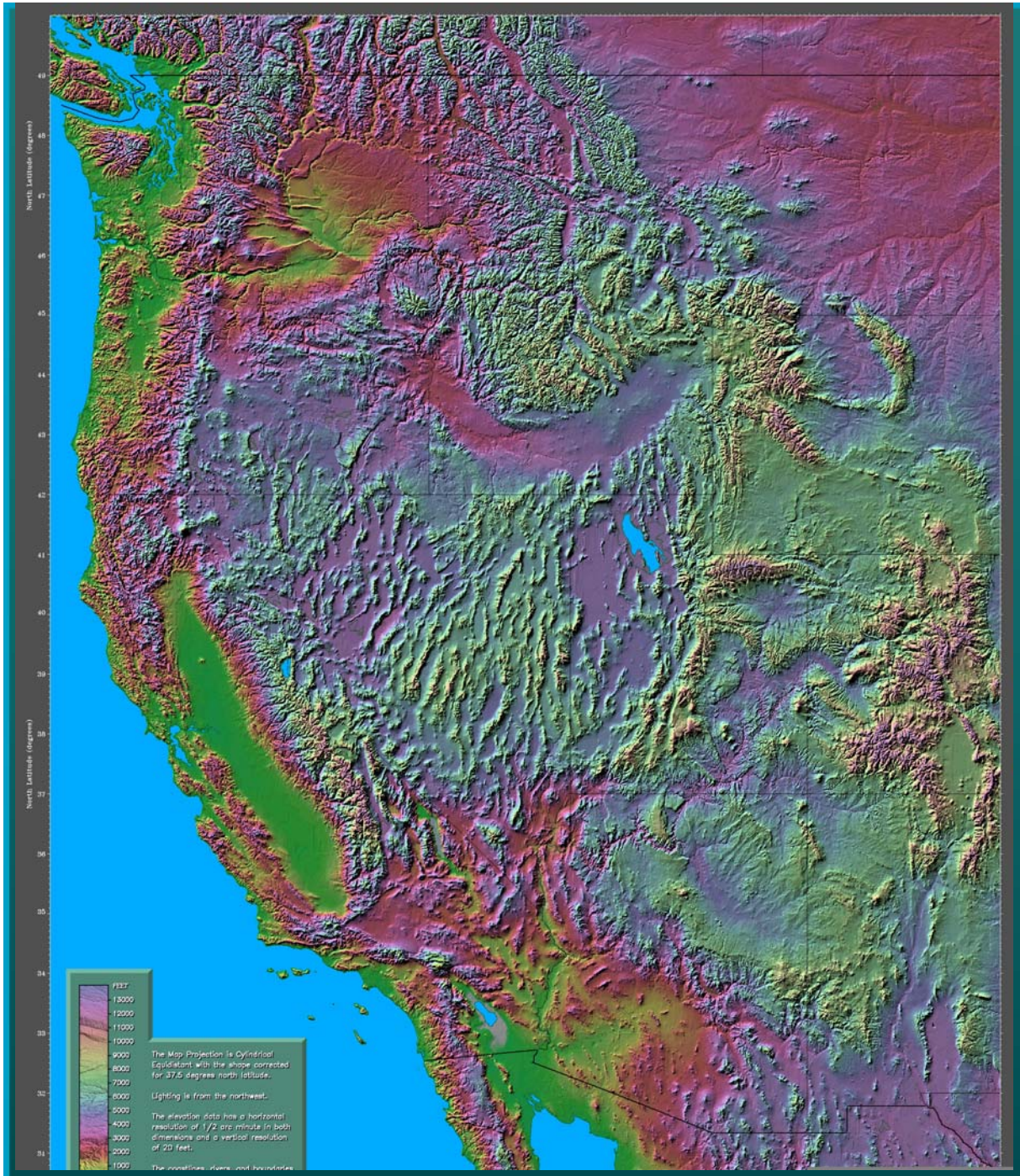
One Year of Seismicity





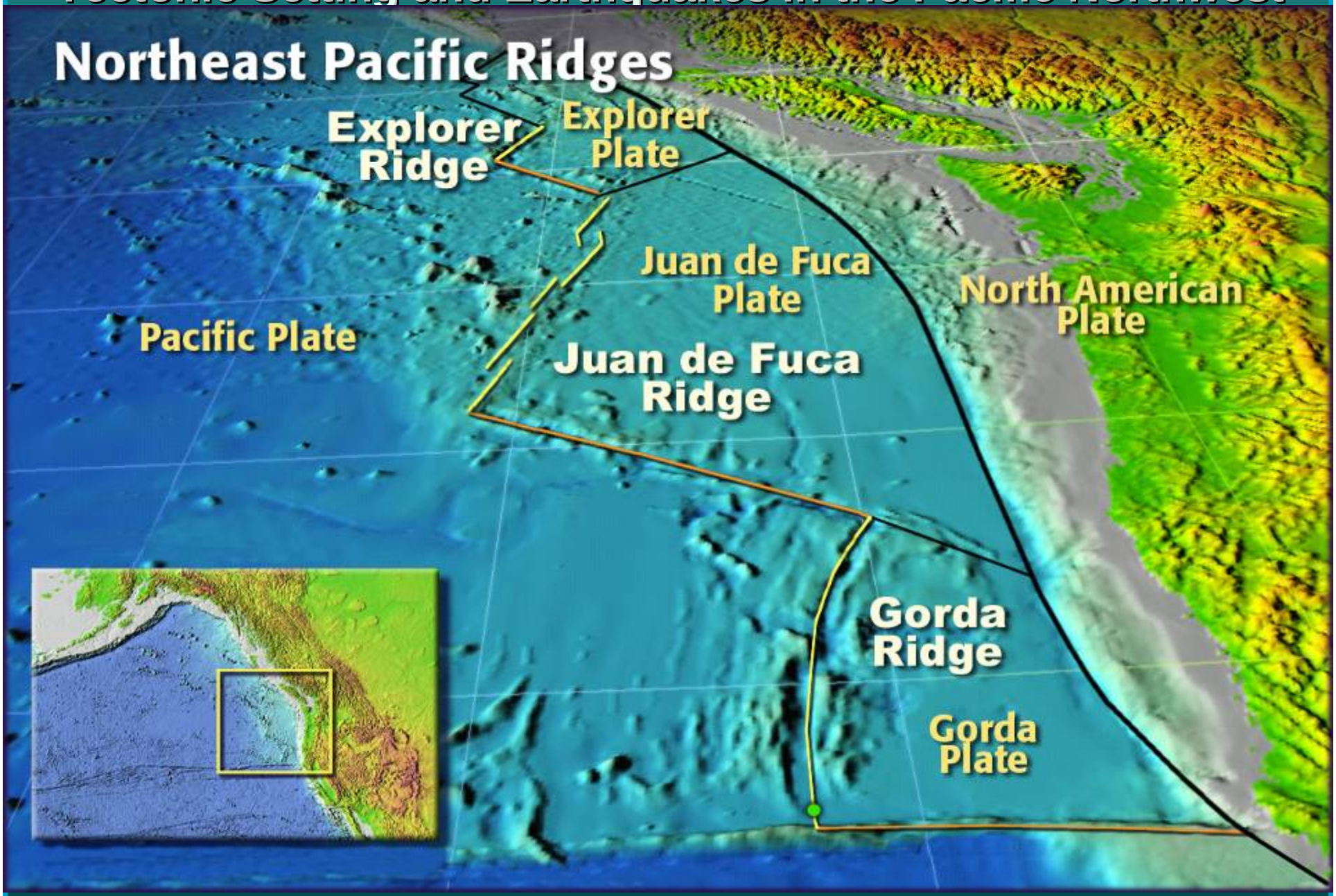
Pacific-North American Plate Boundary

USGS



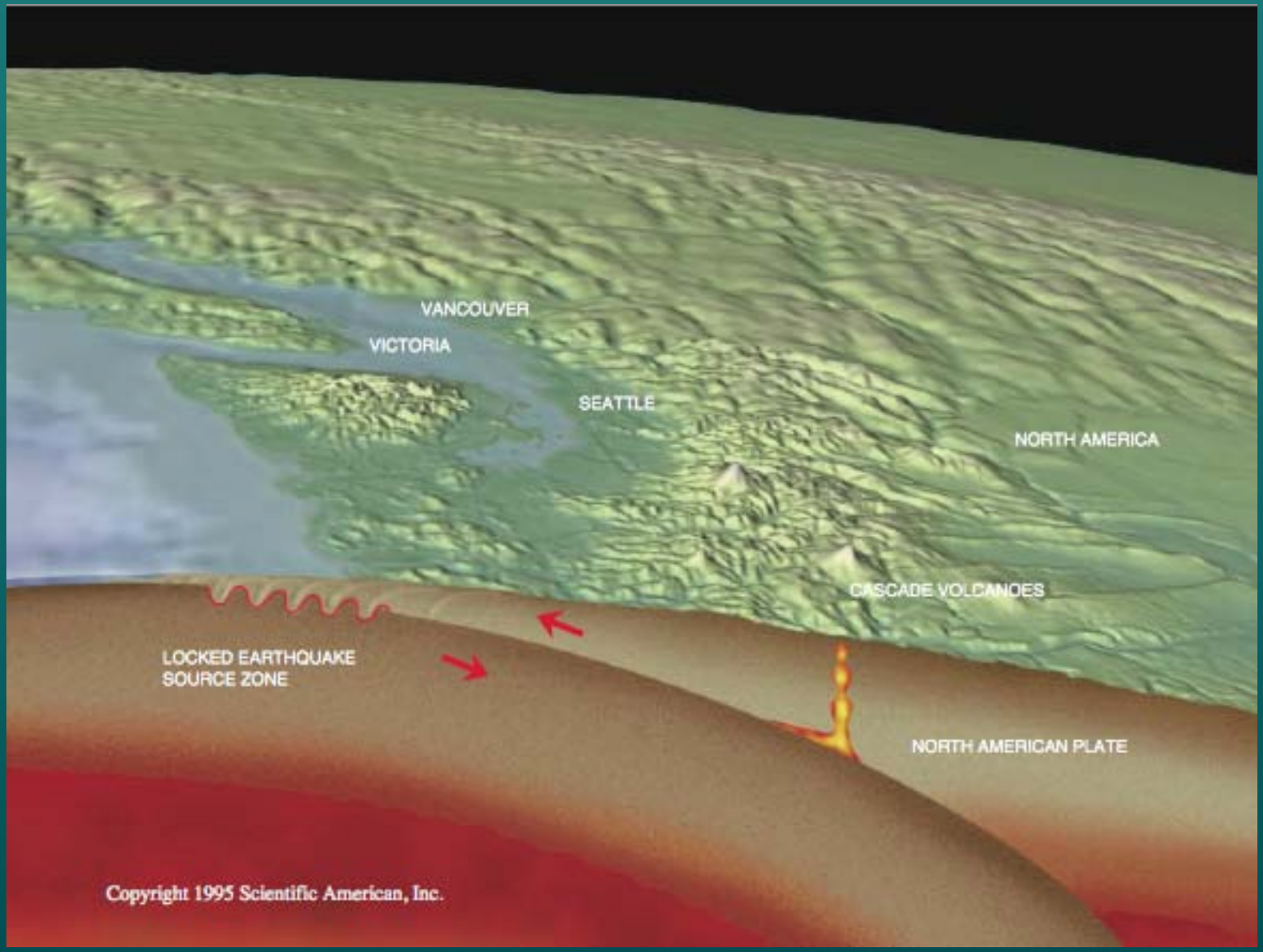
Topography Western US

Tectonic Setting and Earthquakes in the Pacific Northwest

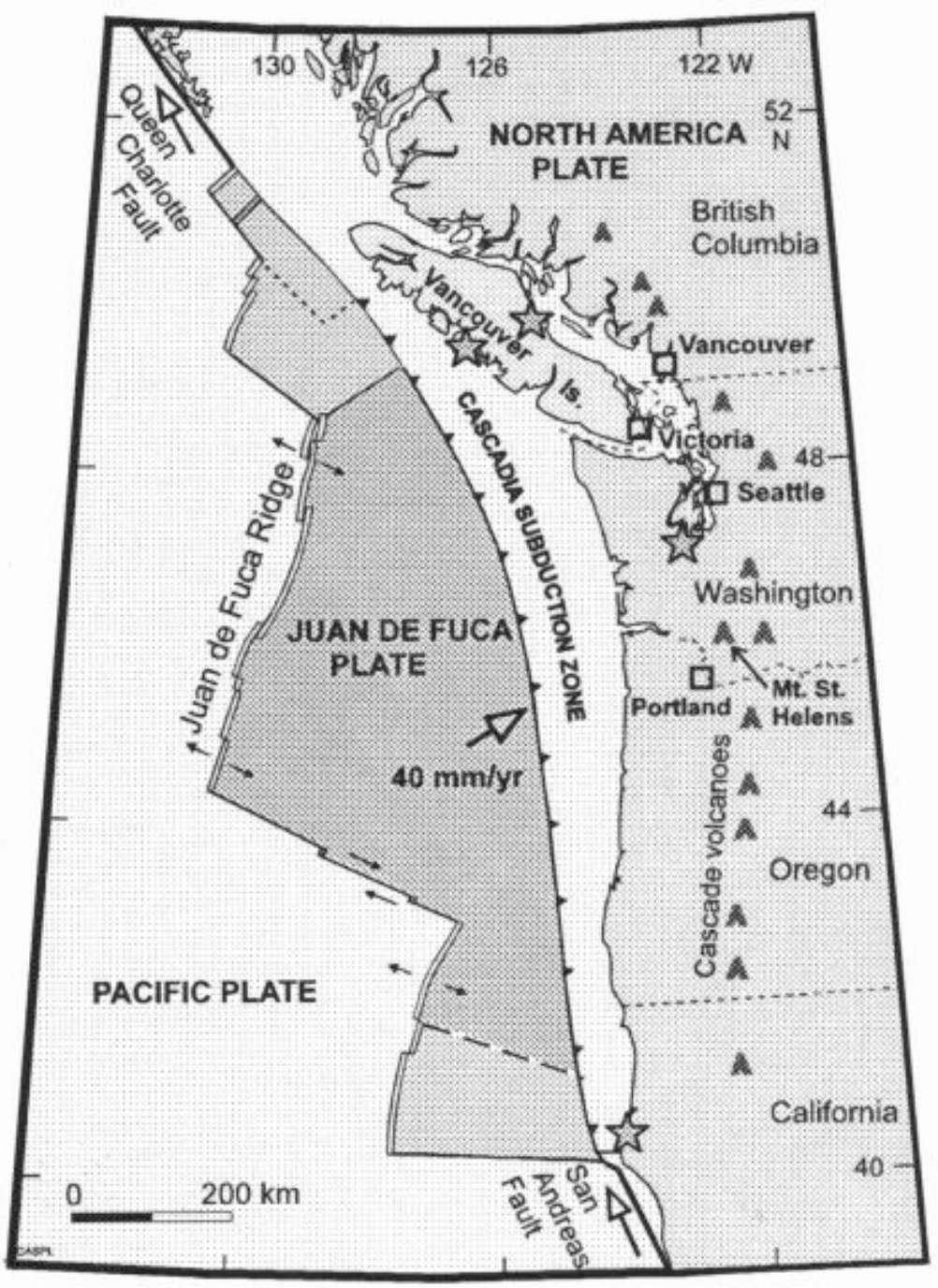


Pratt, USGS

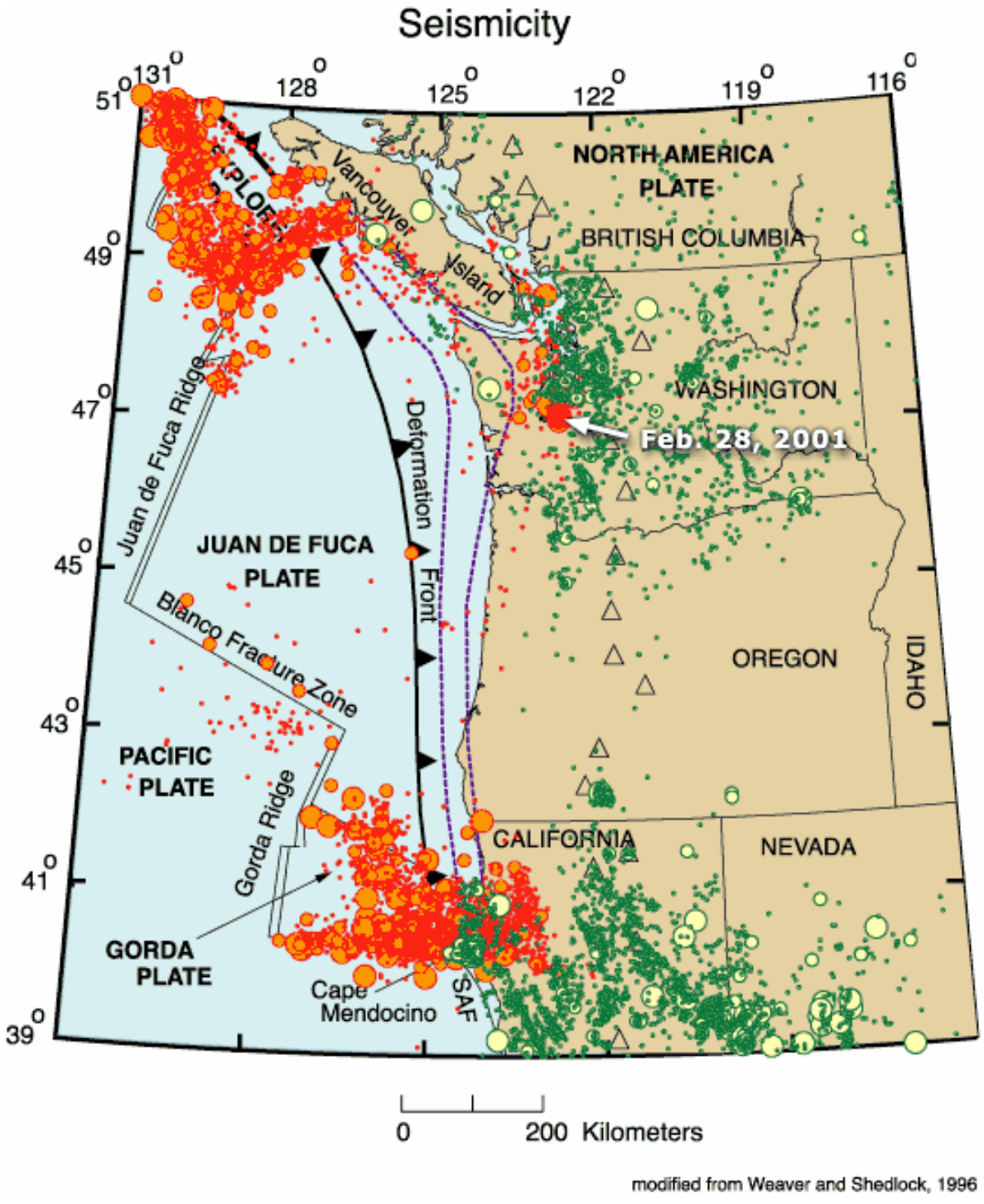
Panoramic View of the Subduction



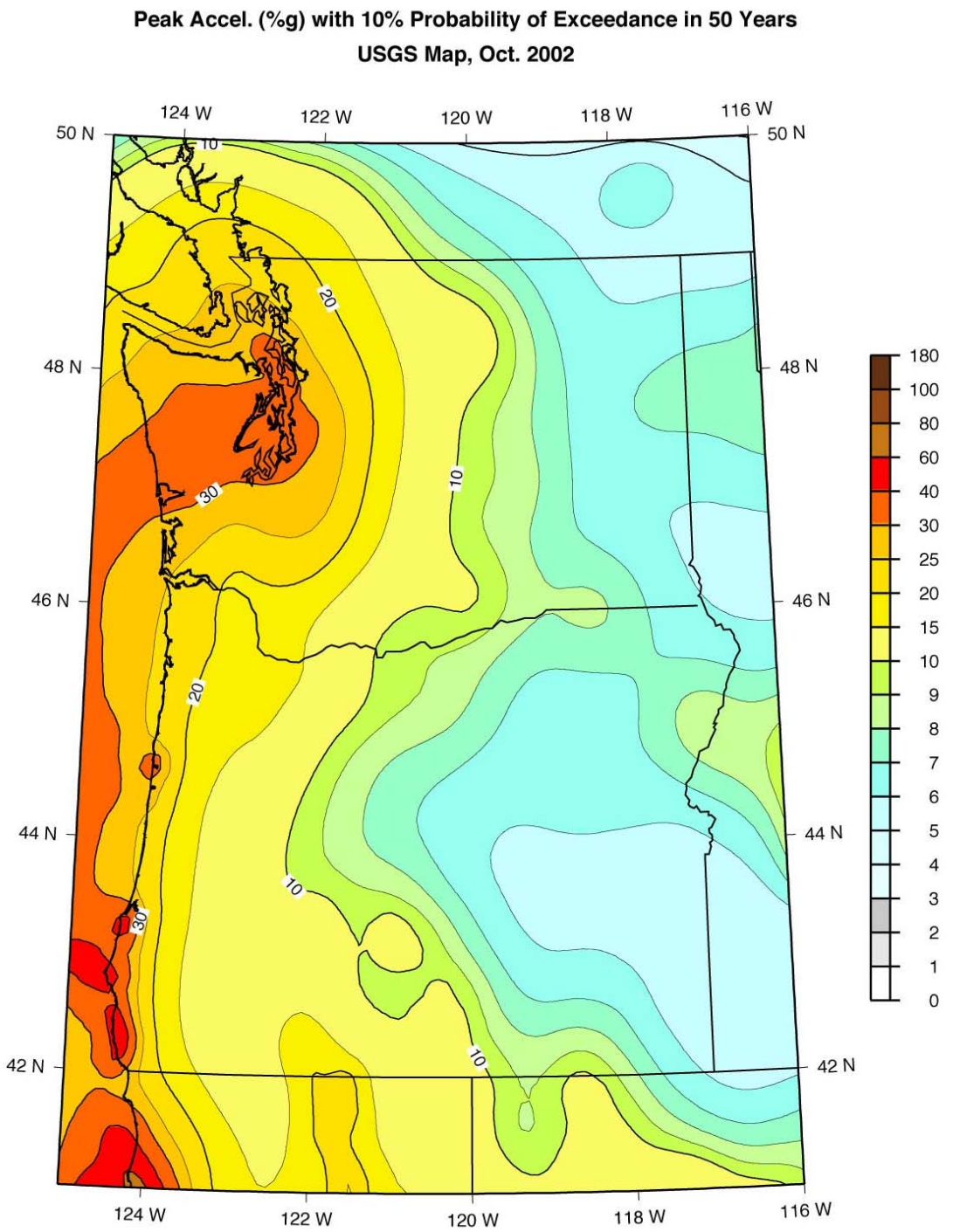
Scientific American: Hyndman



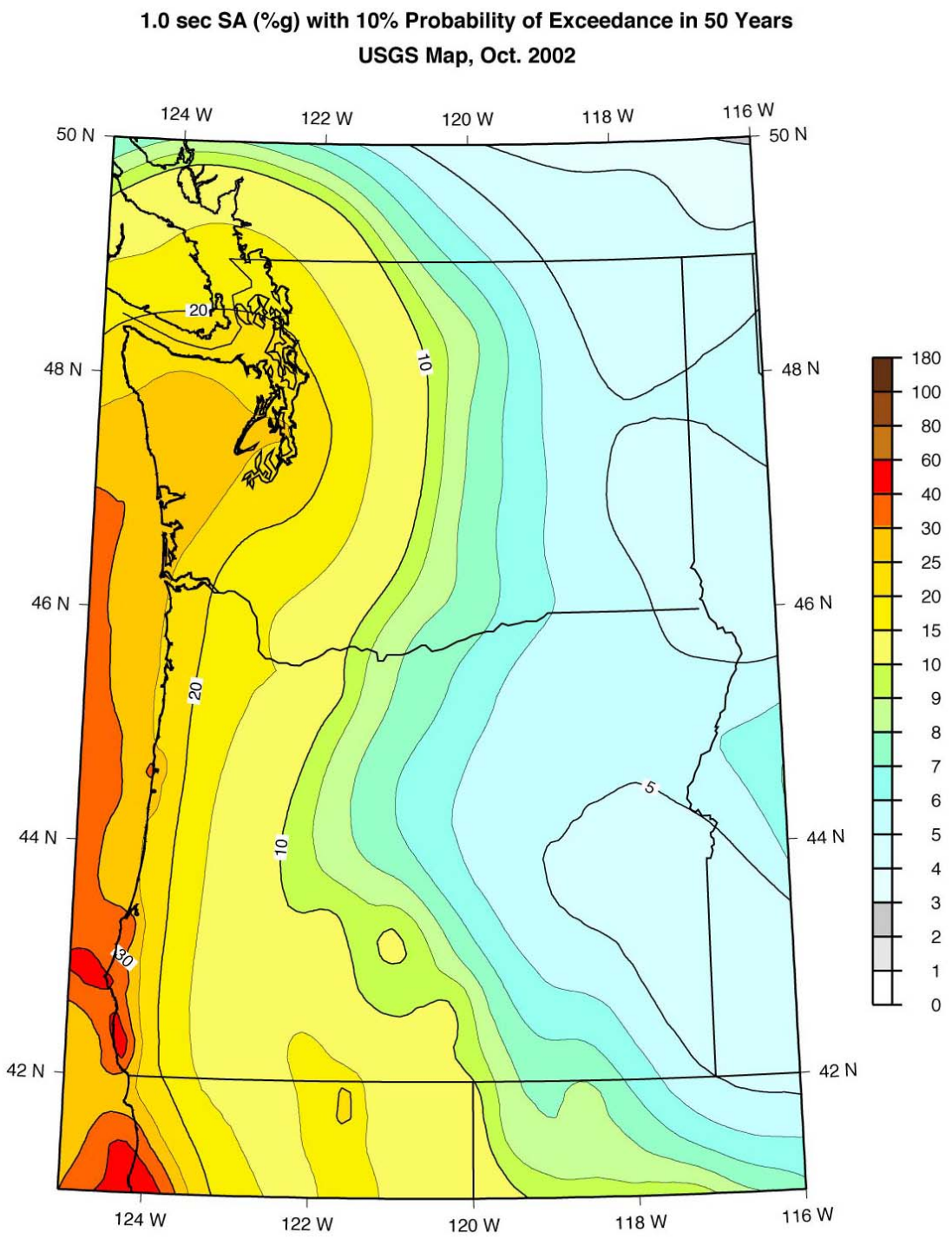
Juan de Fuca Plate Subducting Beneath North America



Seismicity in Pacific Northwest



USGS Probability of Exceedance PGA 10% in 50 Yrs

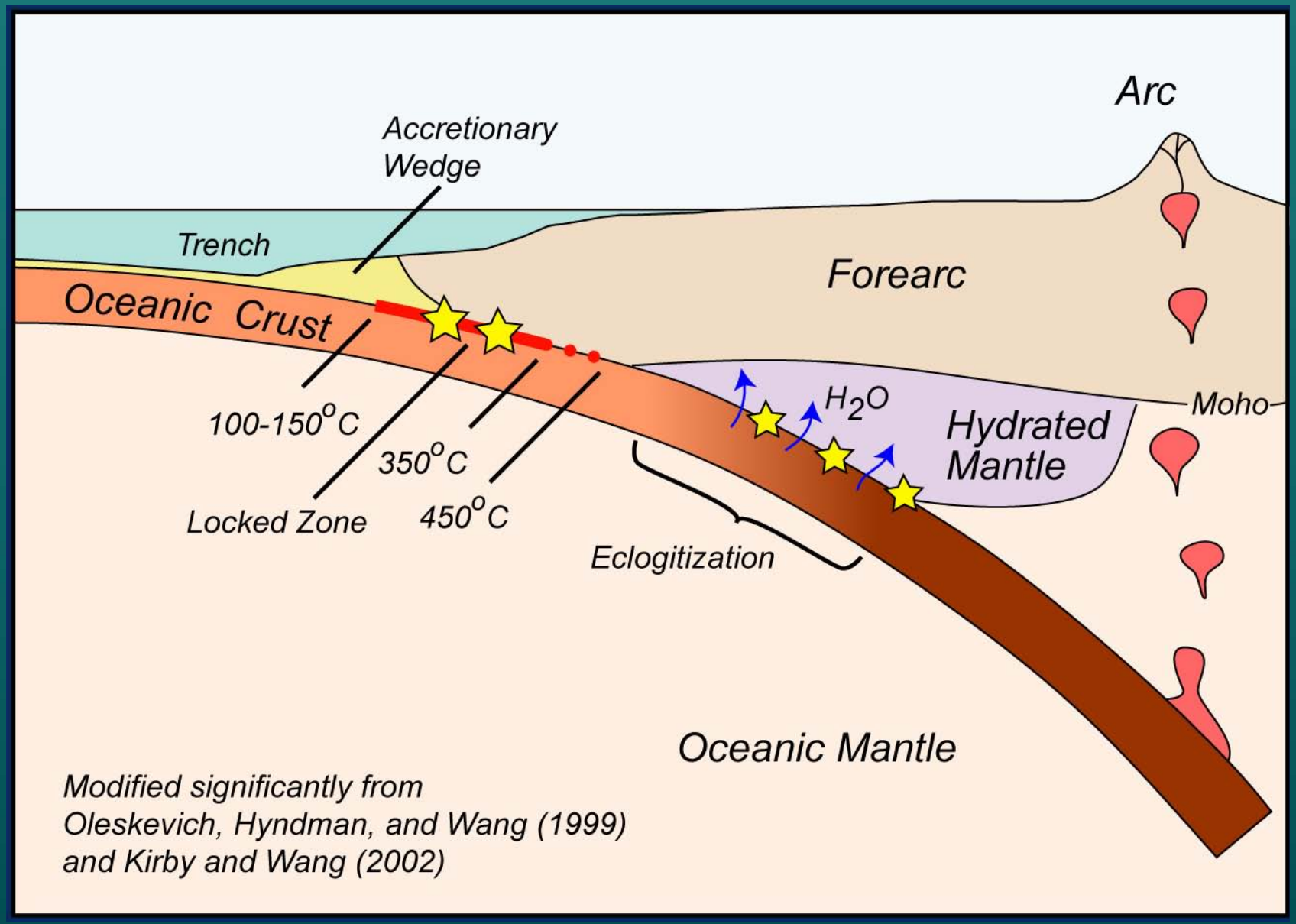


USGS Probability of Exceedance 1.0 SA 10% in 50 Yrs

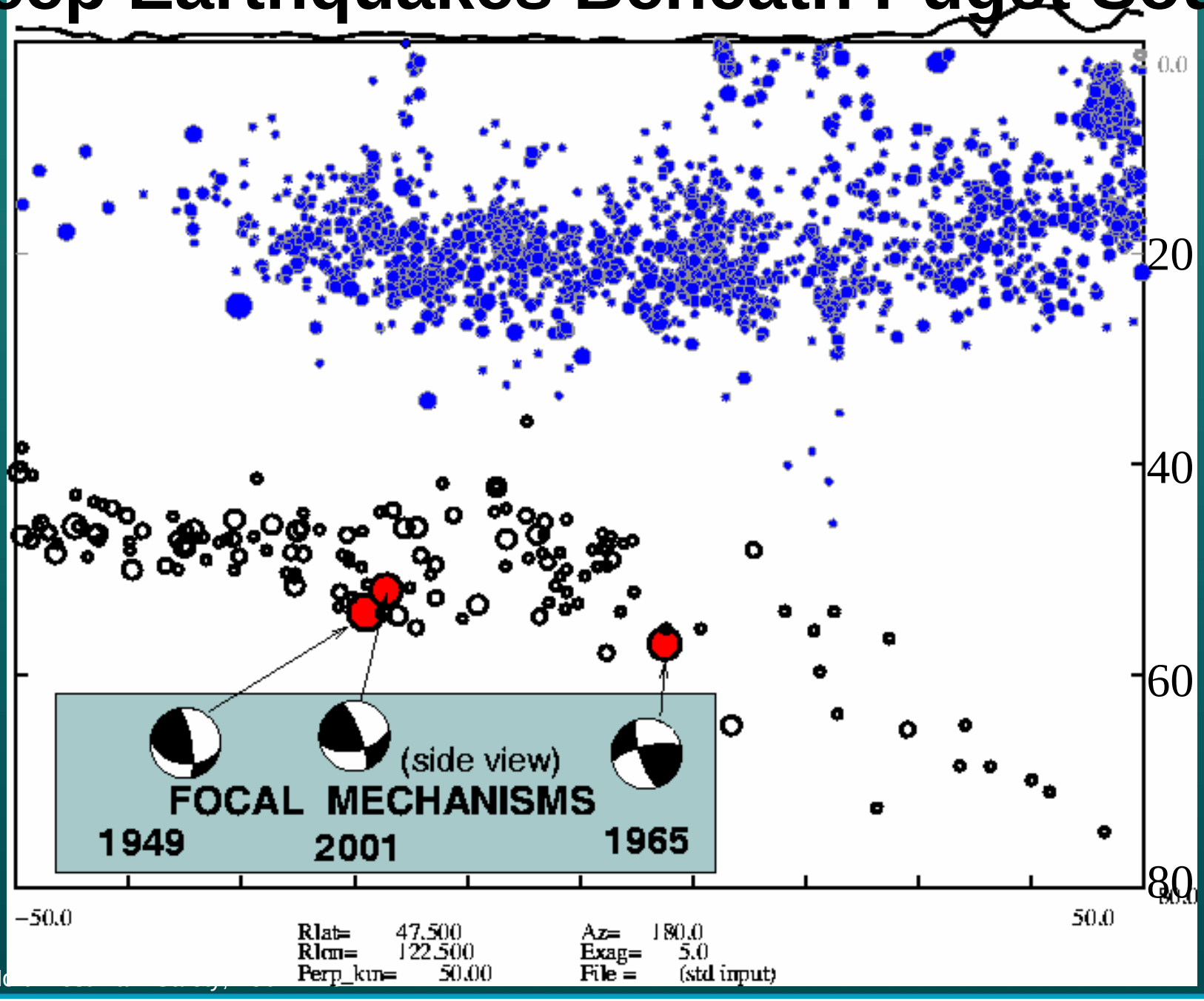
Subduction

QuickTime™ and a
Video decompressor
are needed to see this picture.

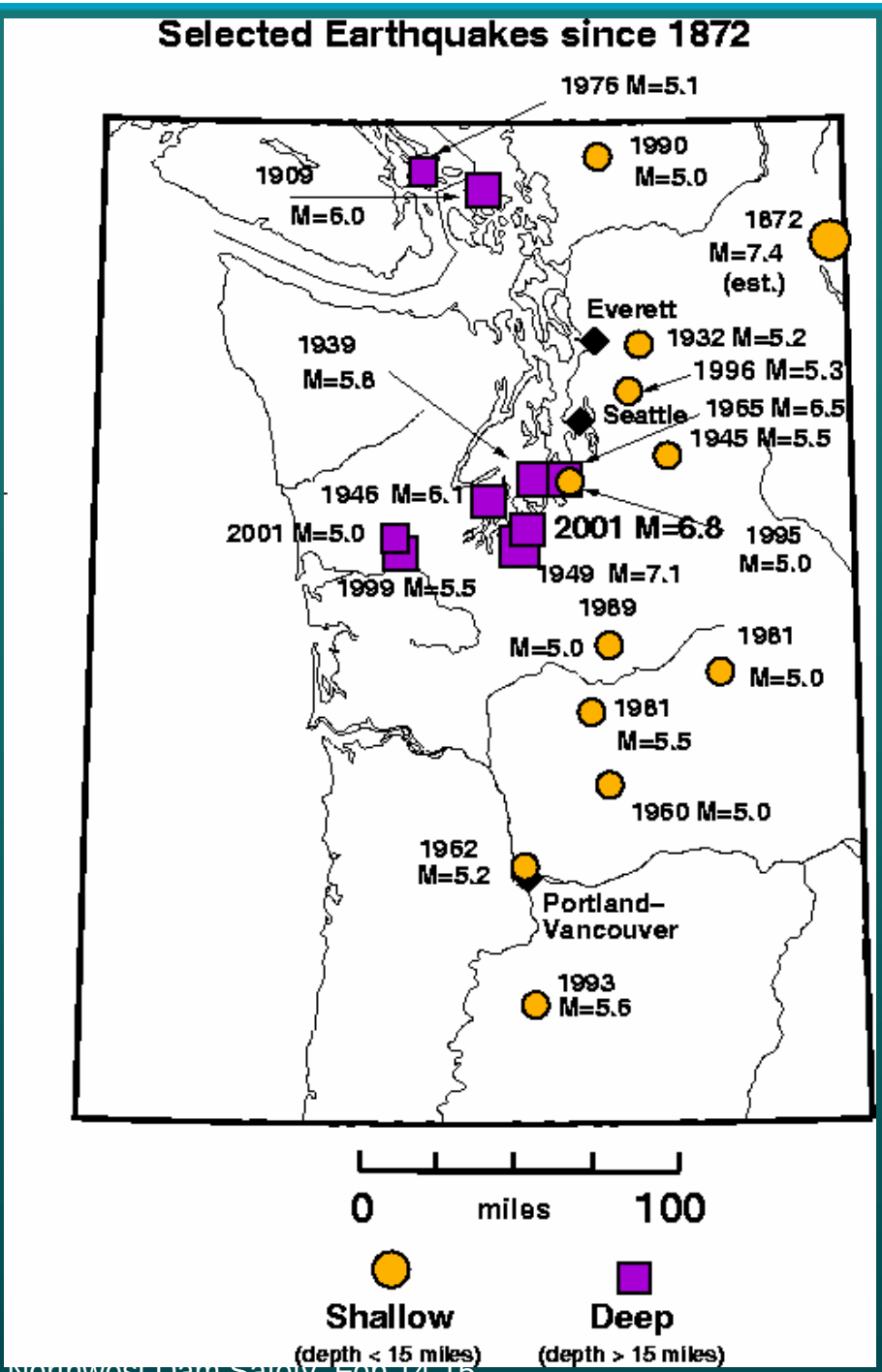
Subduction Tectonics



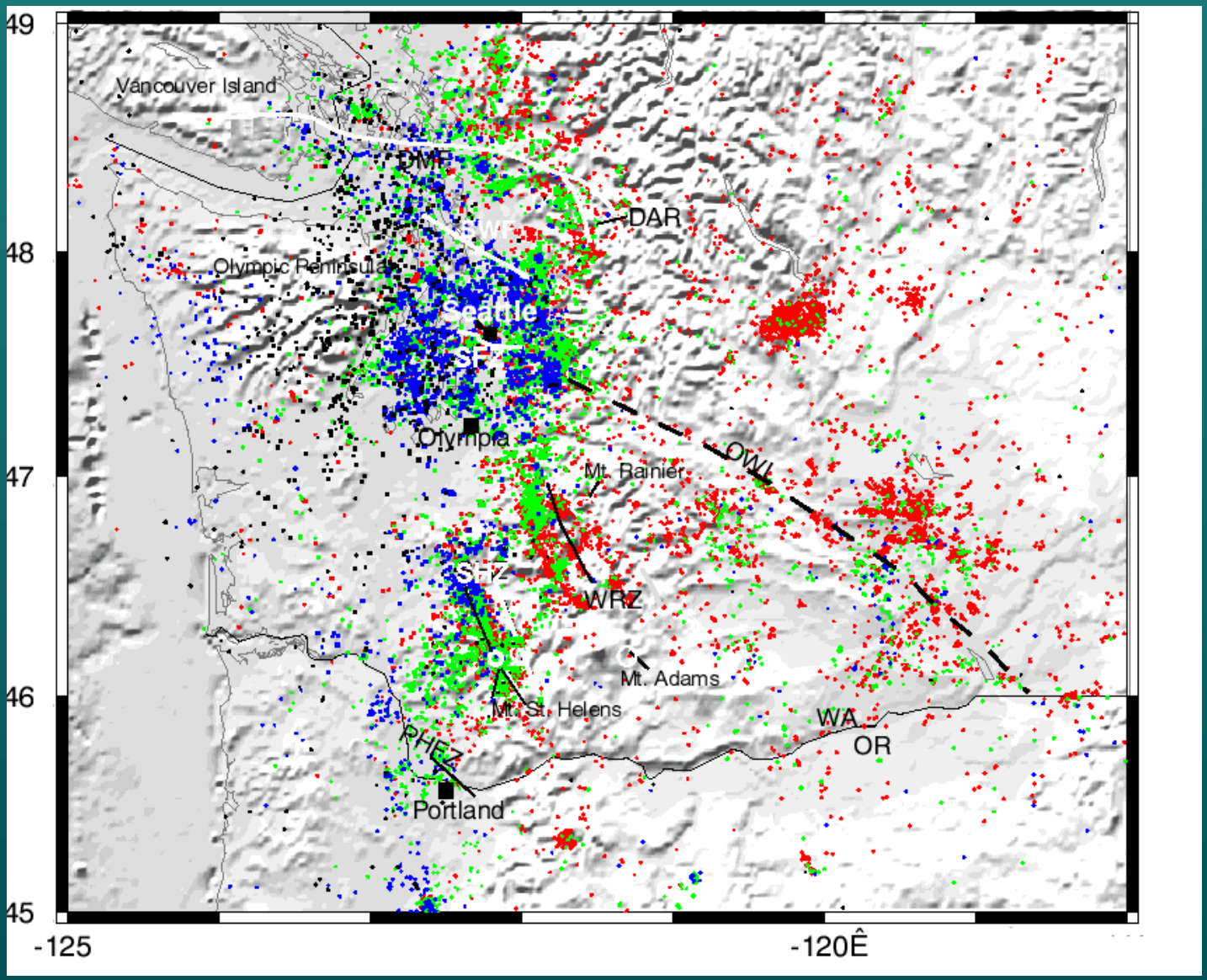
Deep Earthquakes Beneath Puget Sound



Earthquakes in the Pacific Northwest



Crustal Earthquakes: 0-60 km

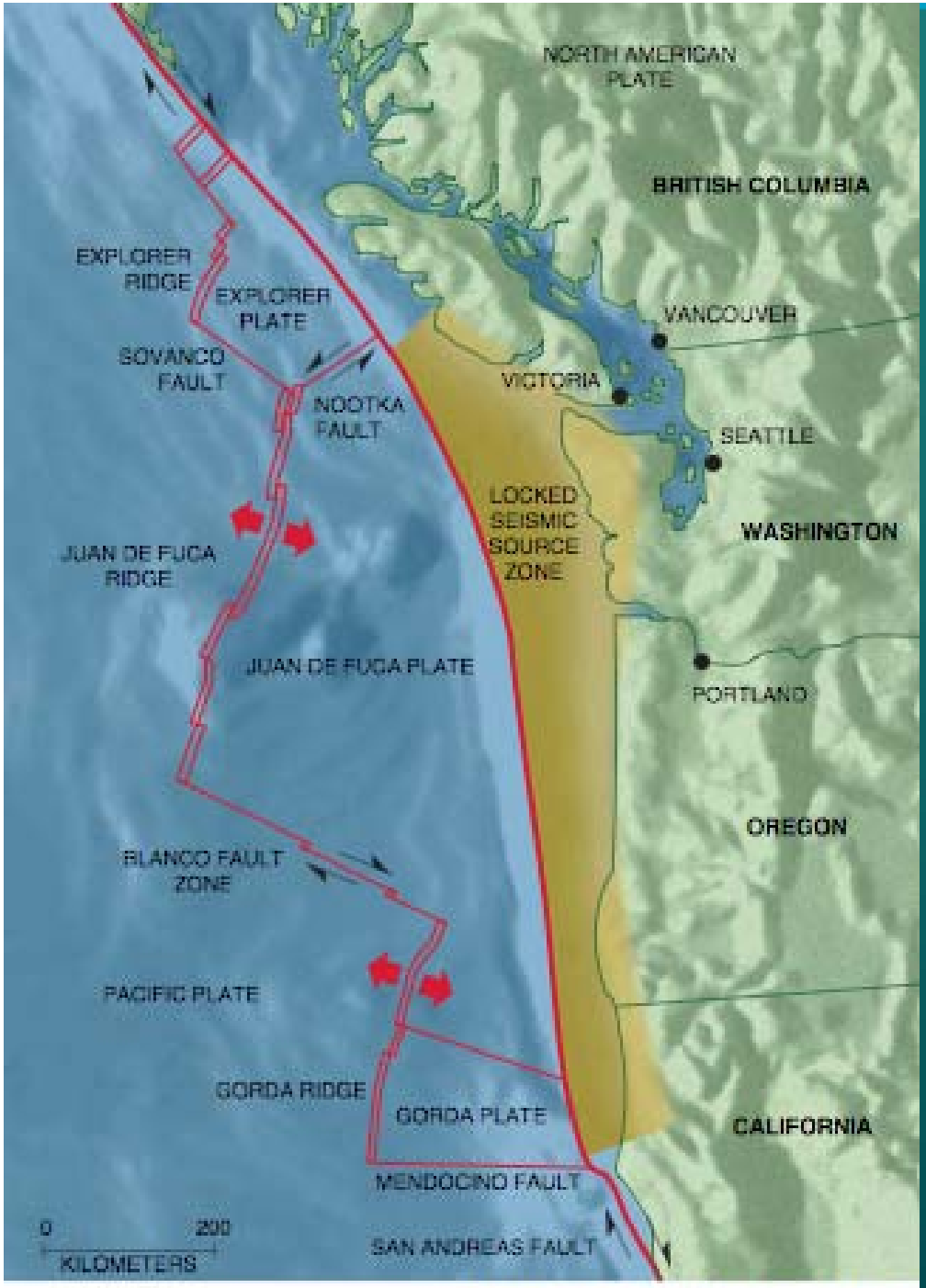


Red: 0-10 km

Green: 10-20 km

Blue: 20-30 km

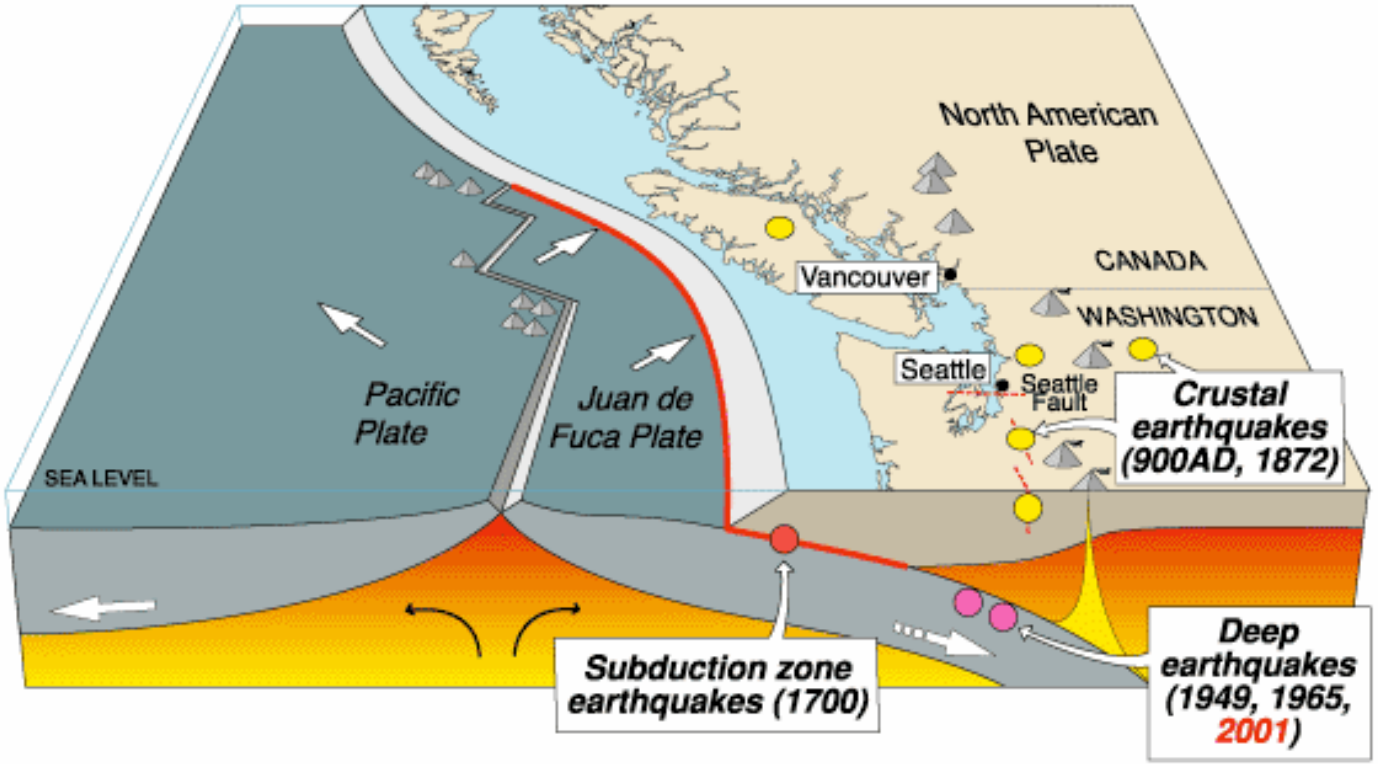
Black: 30-60 km



Tectonic Plates with Locked Zone Source Region M 9

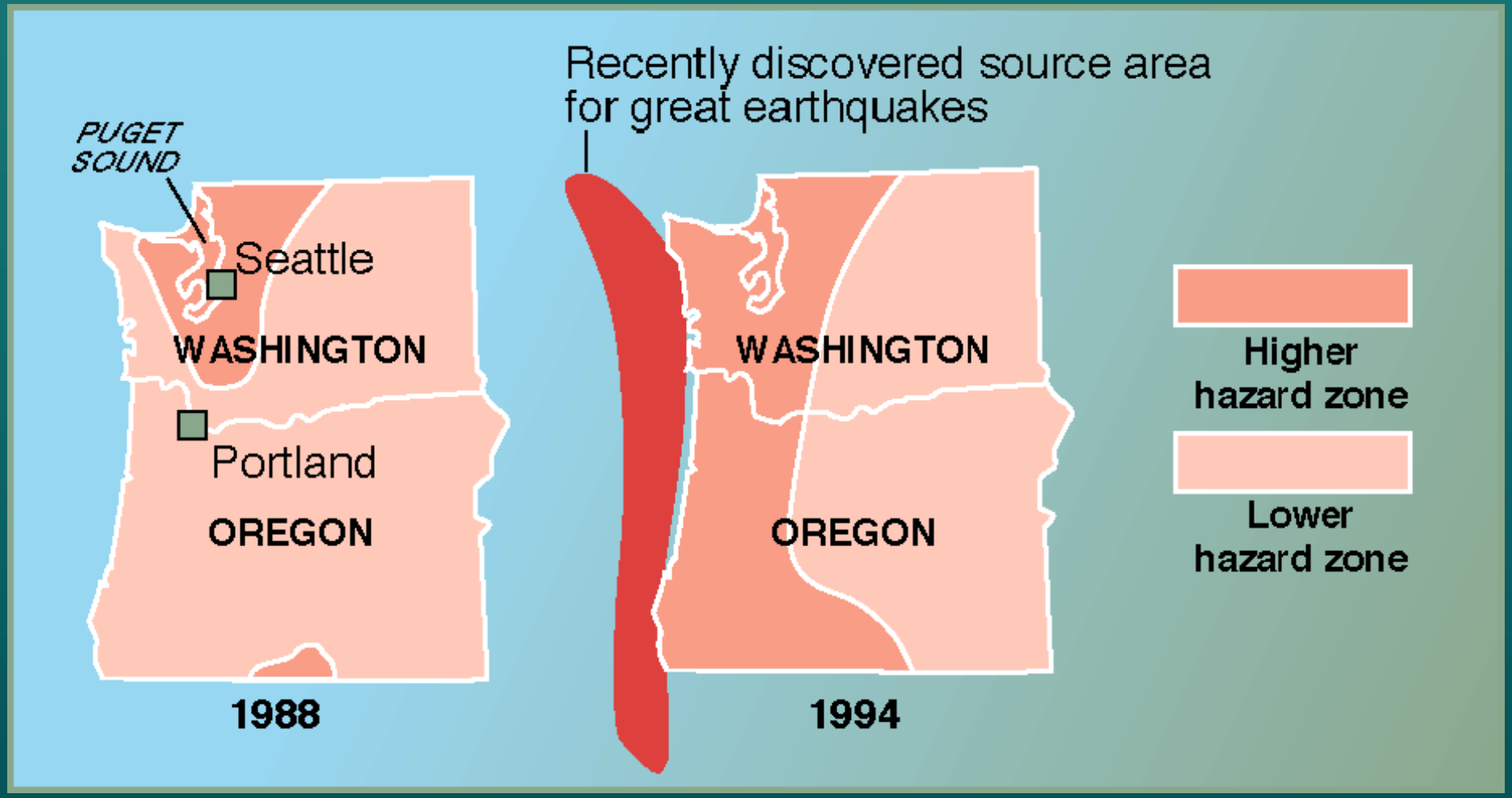
Cascadia Tectonics

Cascadia earthquake sources



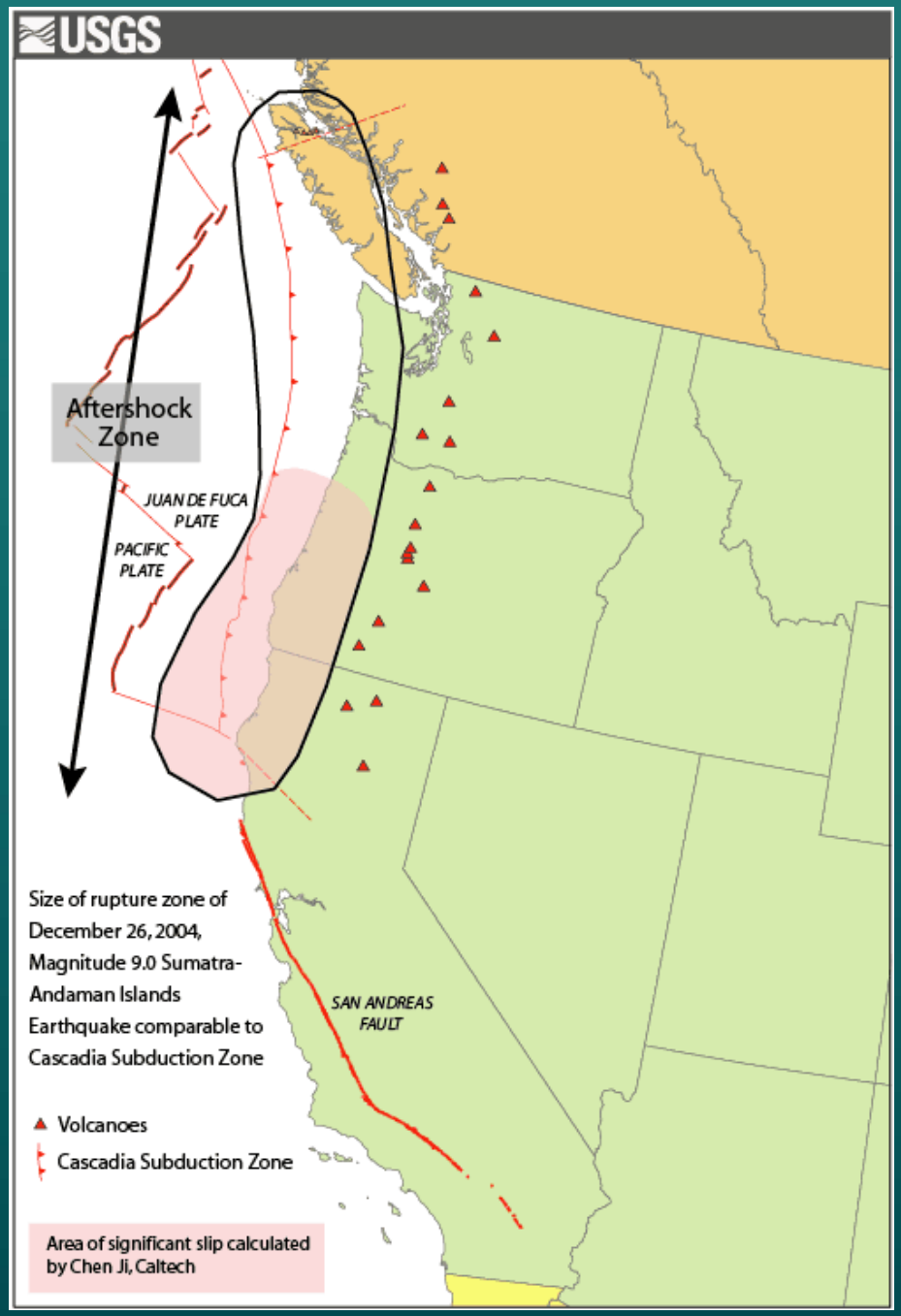
Source	Affected area	Max. Size	Recurrence
Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

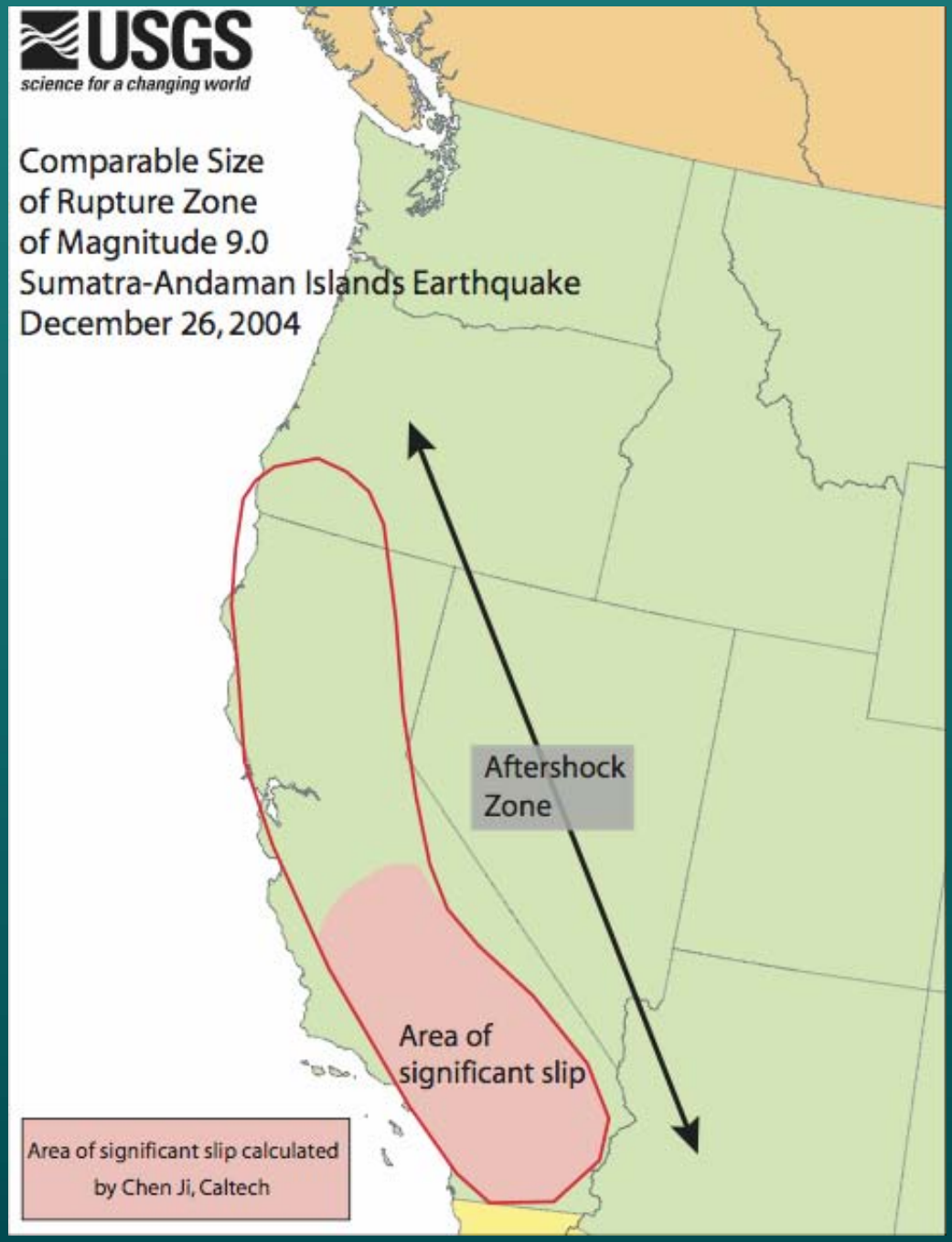
Cascadia: Potential for M 9 Earthquake



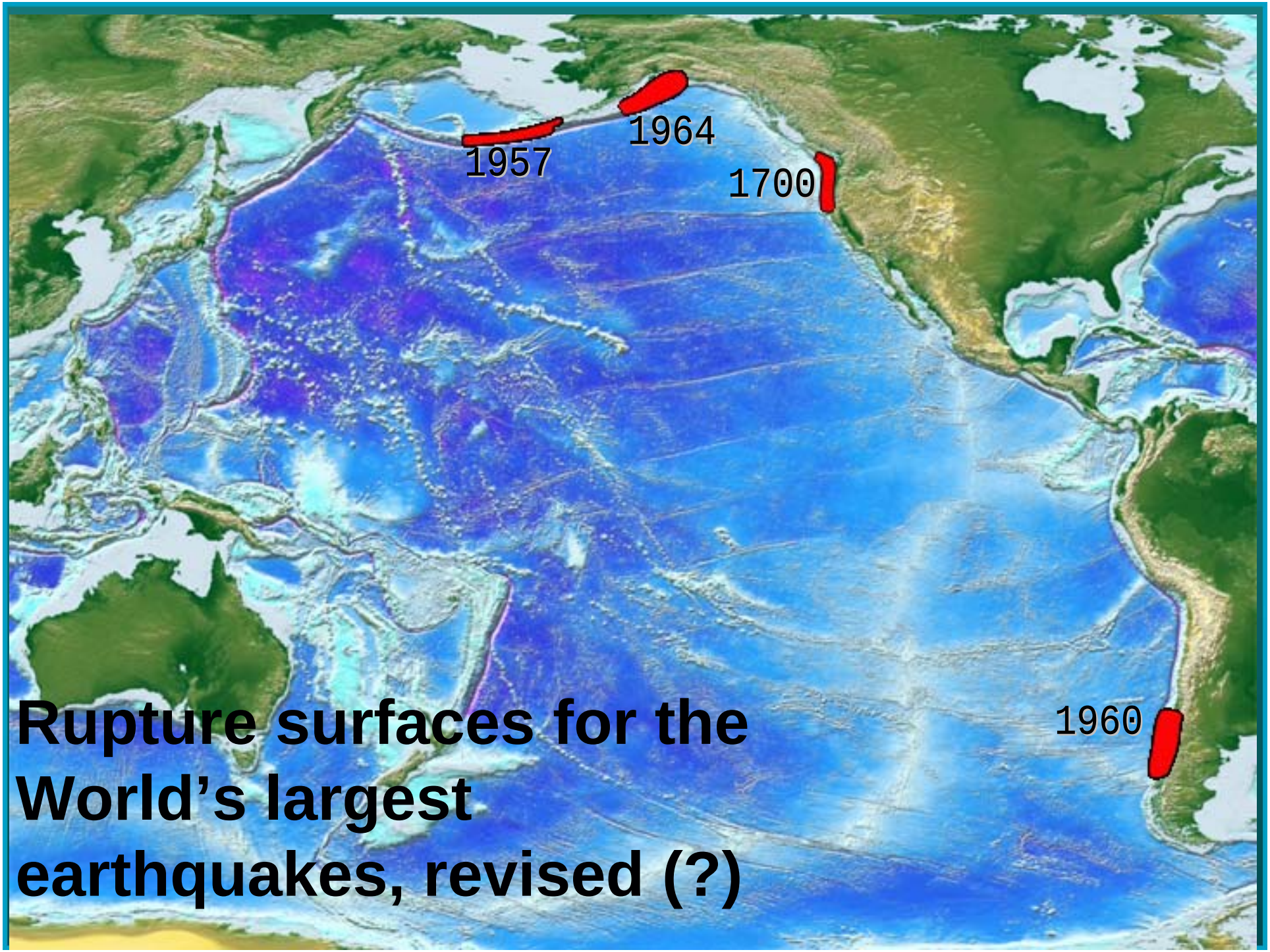
9PM on January 26, 1700

Sumatra Source Superposed on Source Zone for M 9 in Cascadia

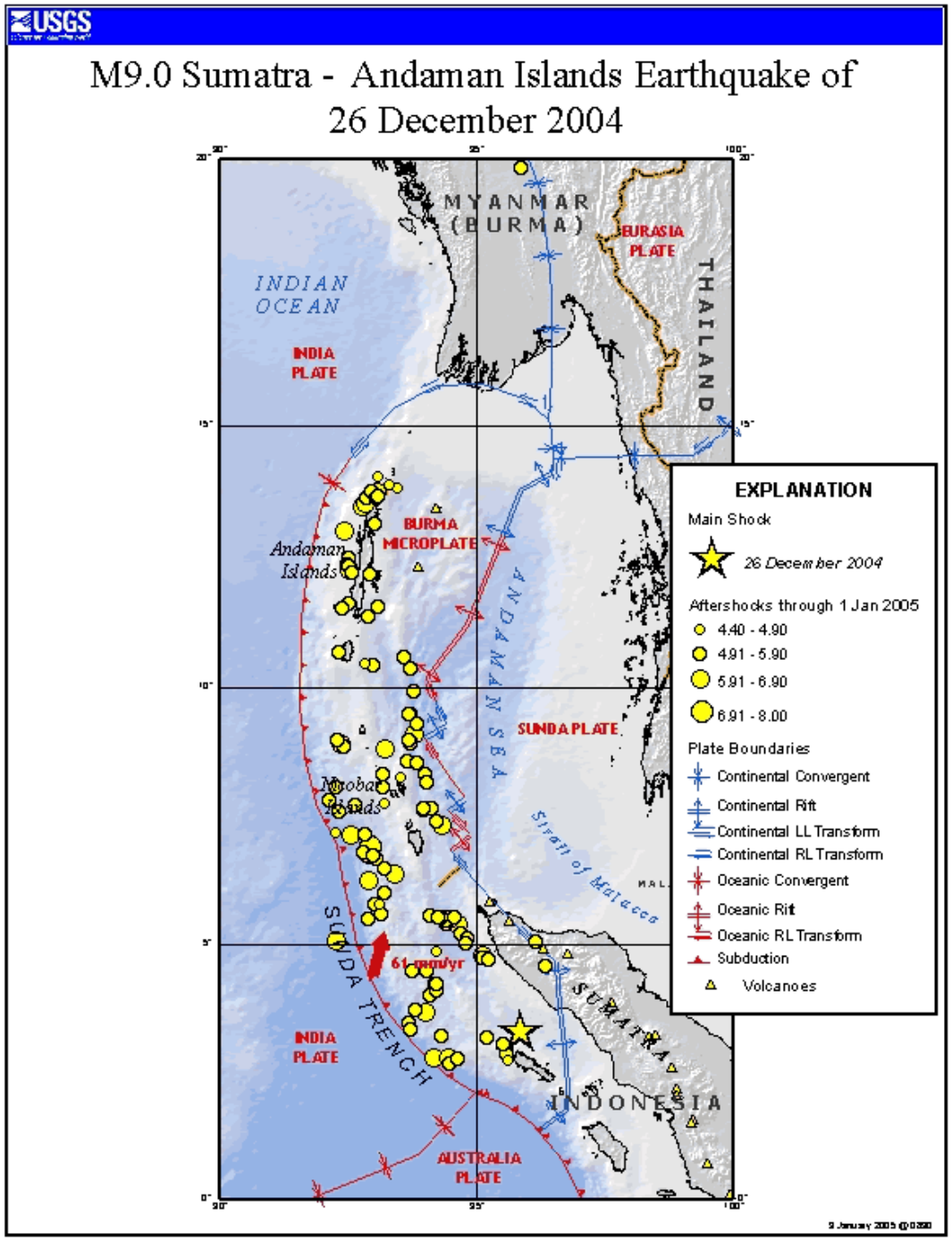




Sumatra Aftershock Zone Superposed on California


1964
1957
1700
1960
Rupture surfaces for the World's largest earthquakes, revised (?)

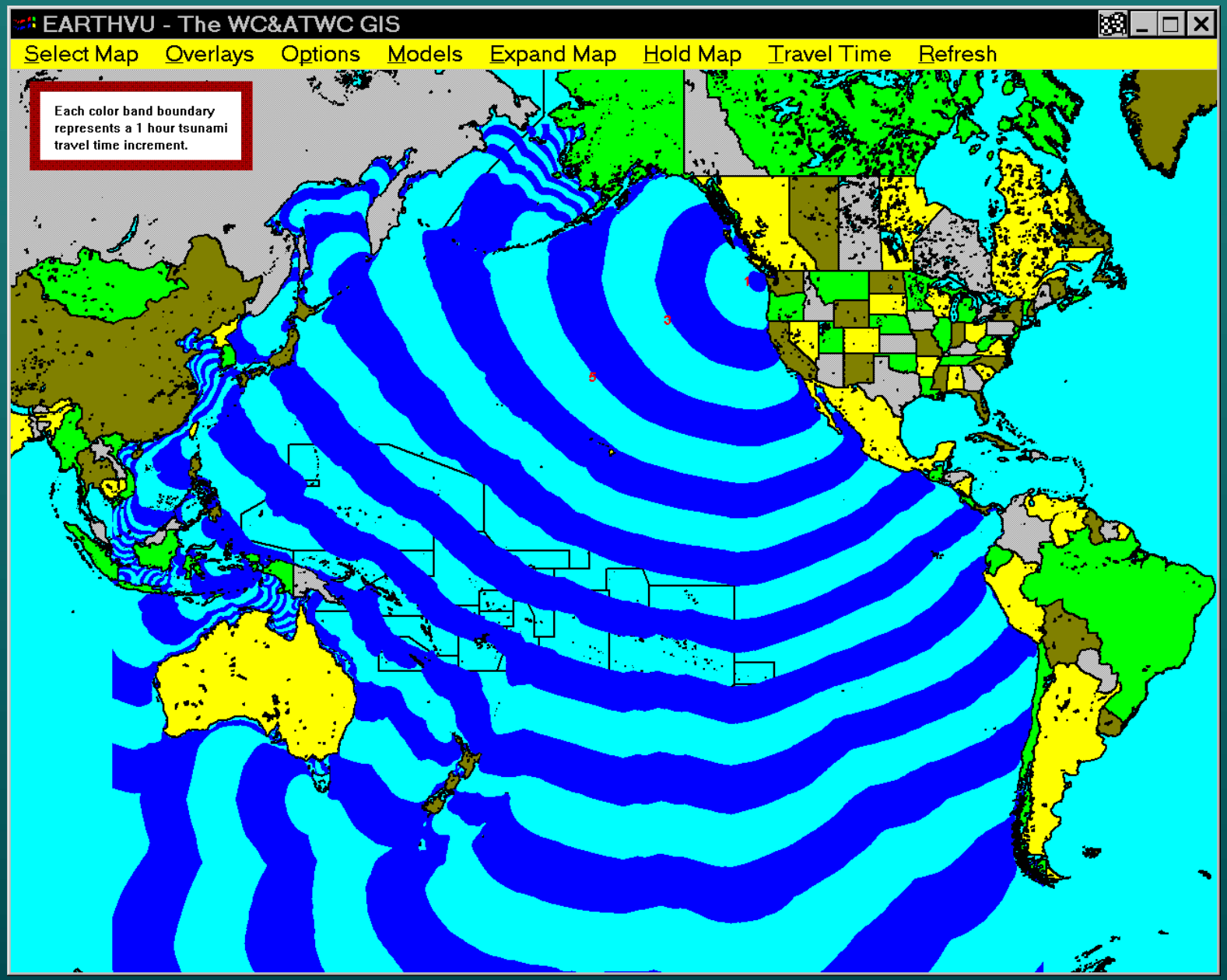
Aftershocks Sumatra Eqk



Cascadia Tsunami

QuickTime™ and a
Video decompressor
are needed to see this picture.

Travel Time of Cascadia Tsunami



Seiche

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

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

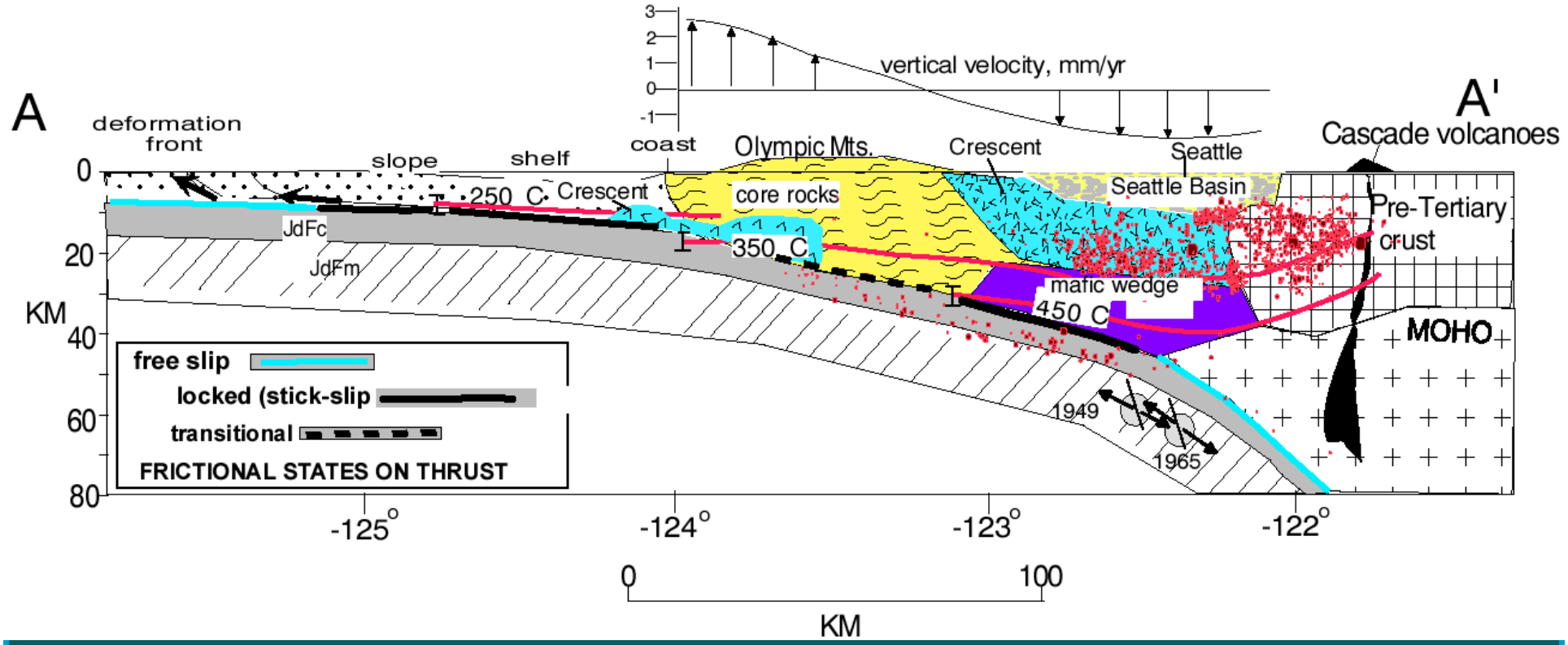
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Makings of a M ~9 in 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.

Geological Cross Section

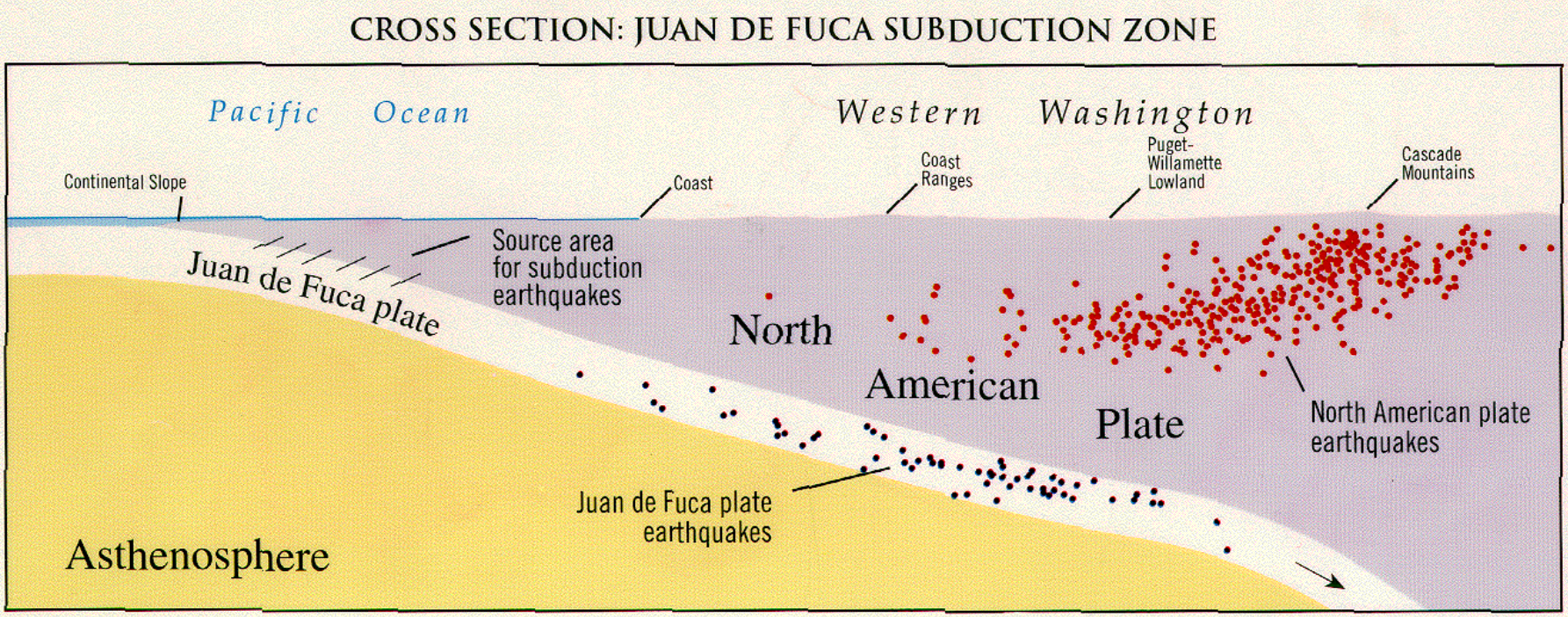


USGS OF 99-311

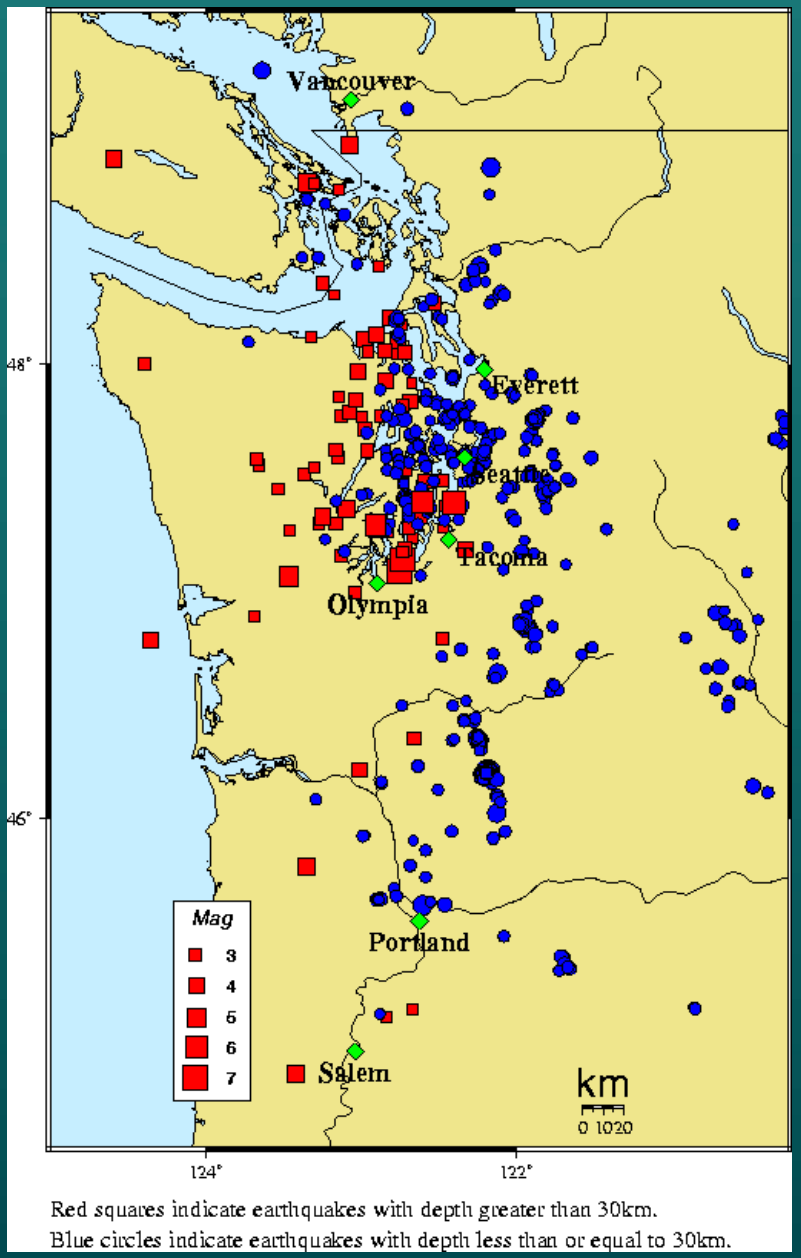
Locked Zone

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

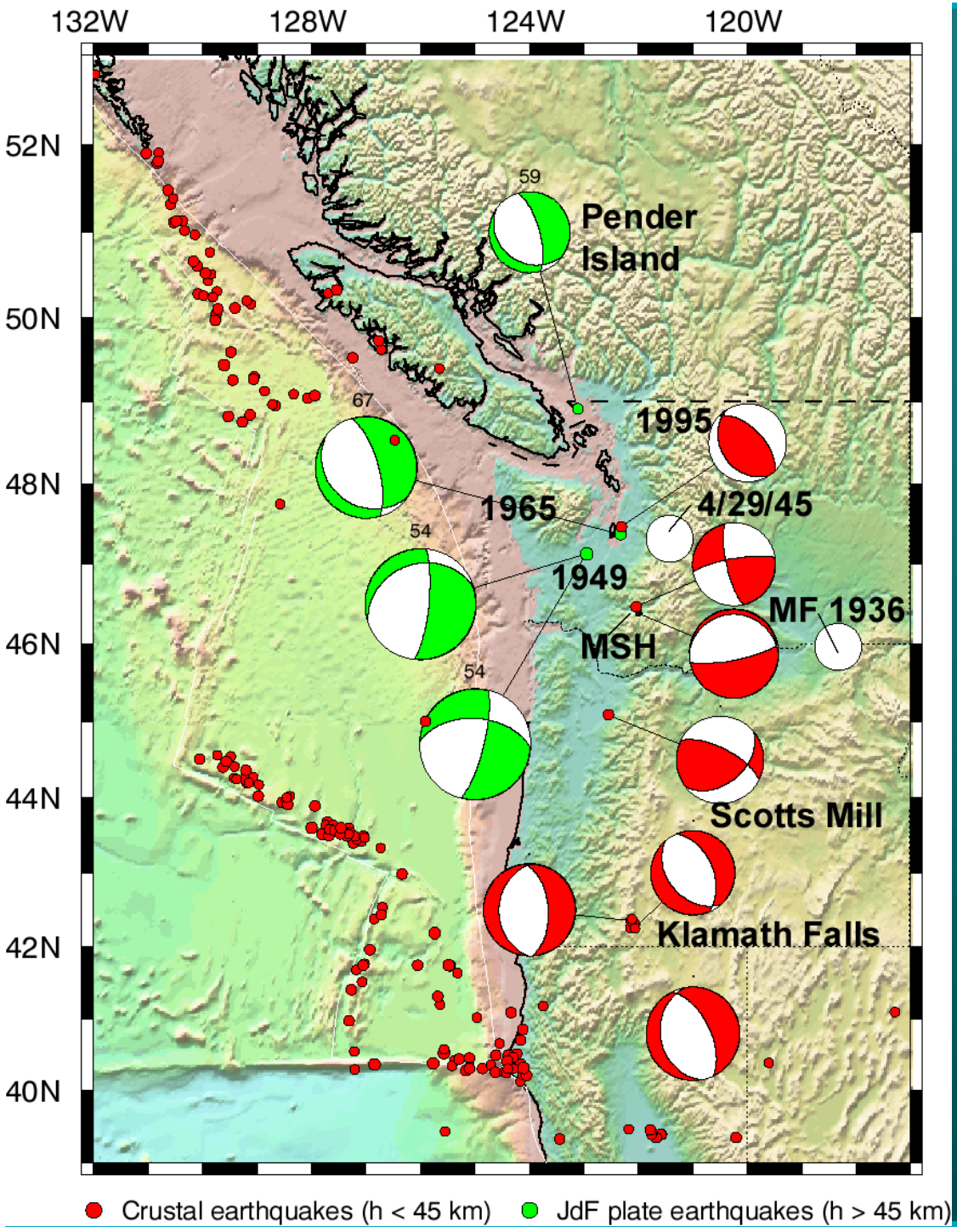
Cross Section of Seismicity



Seismicity Pacific Northwest



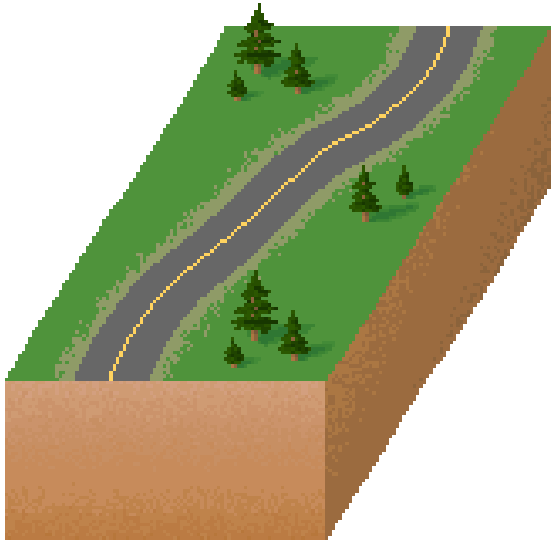
Red squares indicate earthquakes with depth greater than 30km.
Blue circles indicate earthquakes with depth less than or equal to 30km.



Significant Events with Focal Mechanisms

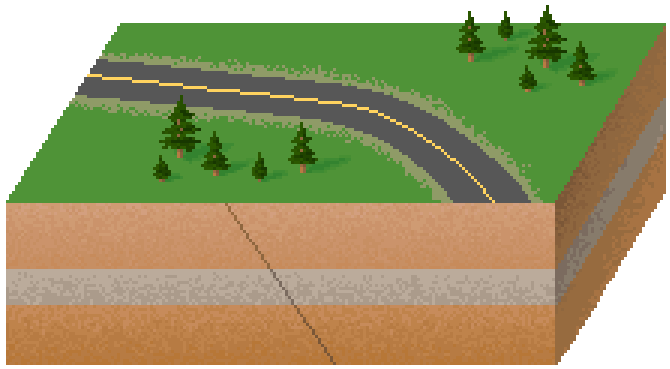
USGS OF 99-311

Style of Faulting

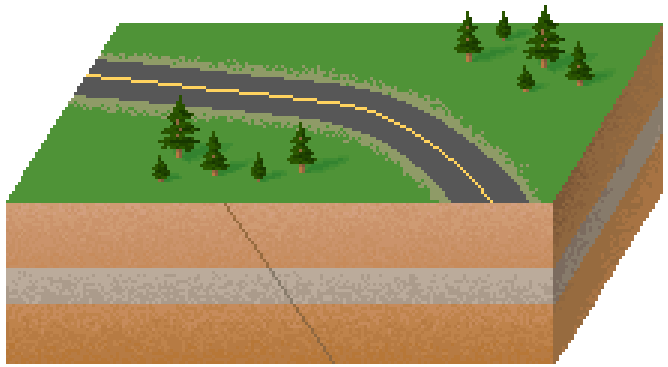


Right-Lateral Strike Slip,
e.g., San Andreas

Dip Slip Normal Faulting,



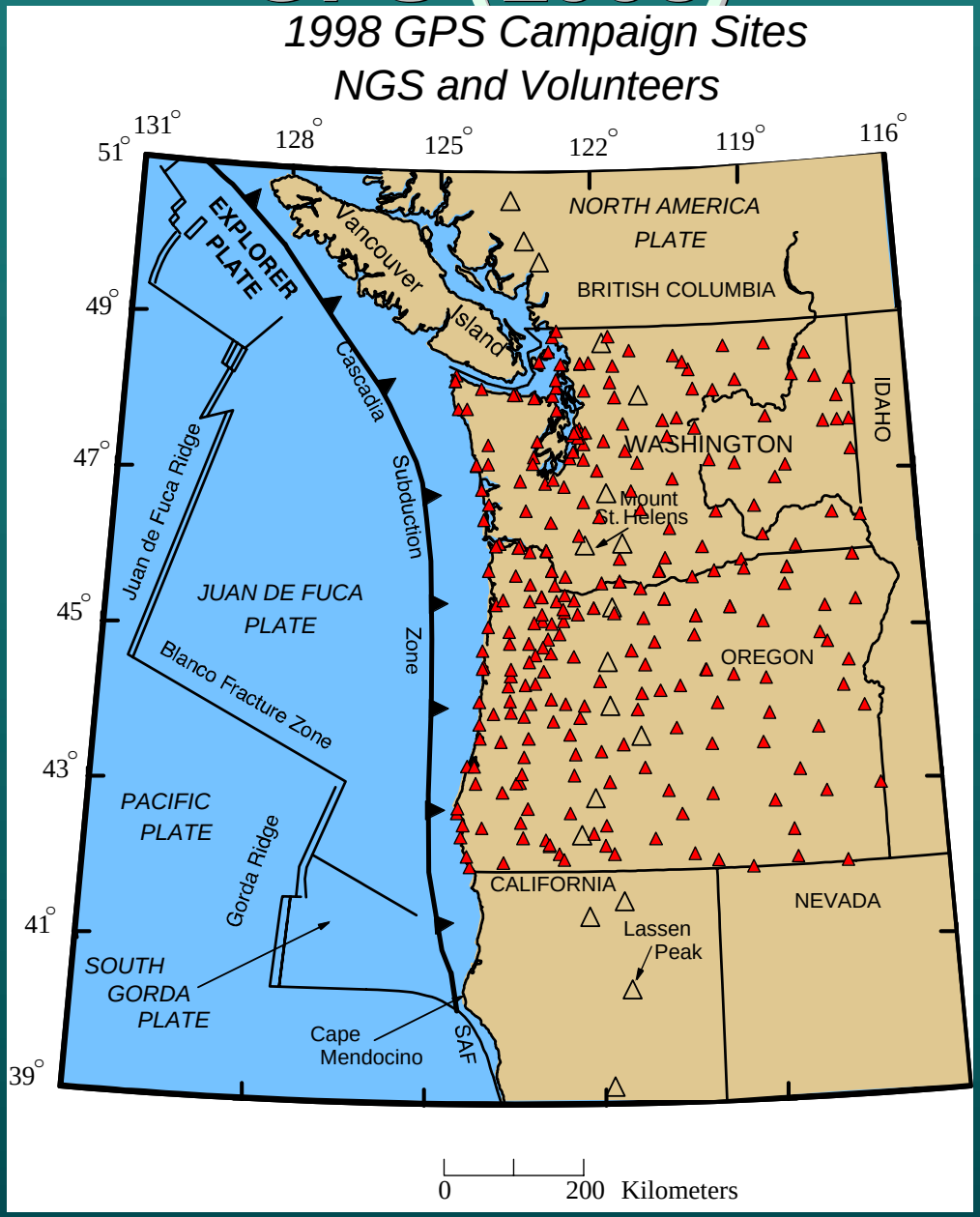
Dip Slip Reverse Faulting,



Earthquakes History

1. 1909, magnitude = 6.0
2. 1918, magnitude = 7.0
3. 1946, magnitude = 7.4
4. 1872, est. magnitude = 7.4
5. 1945, magnitude = 5.5
6. 1965, magnitude = 6.5
7. 1939, magnitude = 5.8
8. 1946, magnitude = 6.1
1882, magnitude = 5.7
9. 1949, magnitude = 7.1
10. 1880, magnitude = 6.0
2001, magnitude = 6.8
11.1981, magnitude = 5.5
12.1936, magnitude = 5.6
13.1877, magnitude = 5.3;
14. 1993, magnitude = 5.6
1962, magnitude = 5.3
15. 1993, magnitude = 5.9;
16. 1873, magnitude = 6.7
1993, magnitude = 6.0
17. 1980, magnitude = 7.4
18. 1932, magnitude = 6.4;
1954, magnitude = 6.6
19. 1853, magnitude = 5.7;
20. 1923, magnitude = 7.3;
1860, magnitude = 5.7;
1941, magnitude = 6.4;
1875, magnitude = 5.8
1947, magnitude = 5.6;
1951, magnitude = 6.0;
1968, magnitude = 5.9;
1987, magnitude = 5.5
21. 1909, magnitude = 6.4
22. 1871, magnitude = 5.9;
1890, magnitude = 6.0;
1992, magnitude = 7.1, 6.6, 6.7
23. 1991, magnitude = 6.2
24. 1878, magnitude = 5.8
25. 1894, magnitude = 5.8
26. 1700, magnitude = 9.0*

GPS (1998)


1998 GPS Campaign Sites
NGS and Volunteers
131°
128°
125°
122°
119°
116°
51°
49°
47°
45°
43°
41°
39°
EXPLORER PLATE
Vancouver Island
NORTH AMERICA PLATE
BRITISH COLUMBIA
Cascadia Subduction Zone
Juan de Fuca Ridge
JUAN DE FUCA PLATE
Blanco Fracture Zone
PACIFIC PLATE
Gorda Ridge
SOUTH GORDA PLATE
Cape Mendocino
SAF
WASHINGTON
IDAHO
Mount St. Helens
OREGON
CALIFORNIA
NEVADA
Lassen Peak
0
200 Kilometers

Deformation Between and During Events

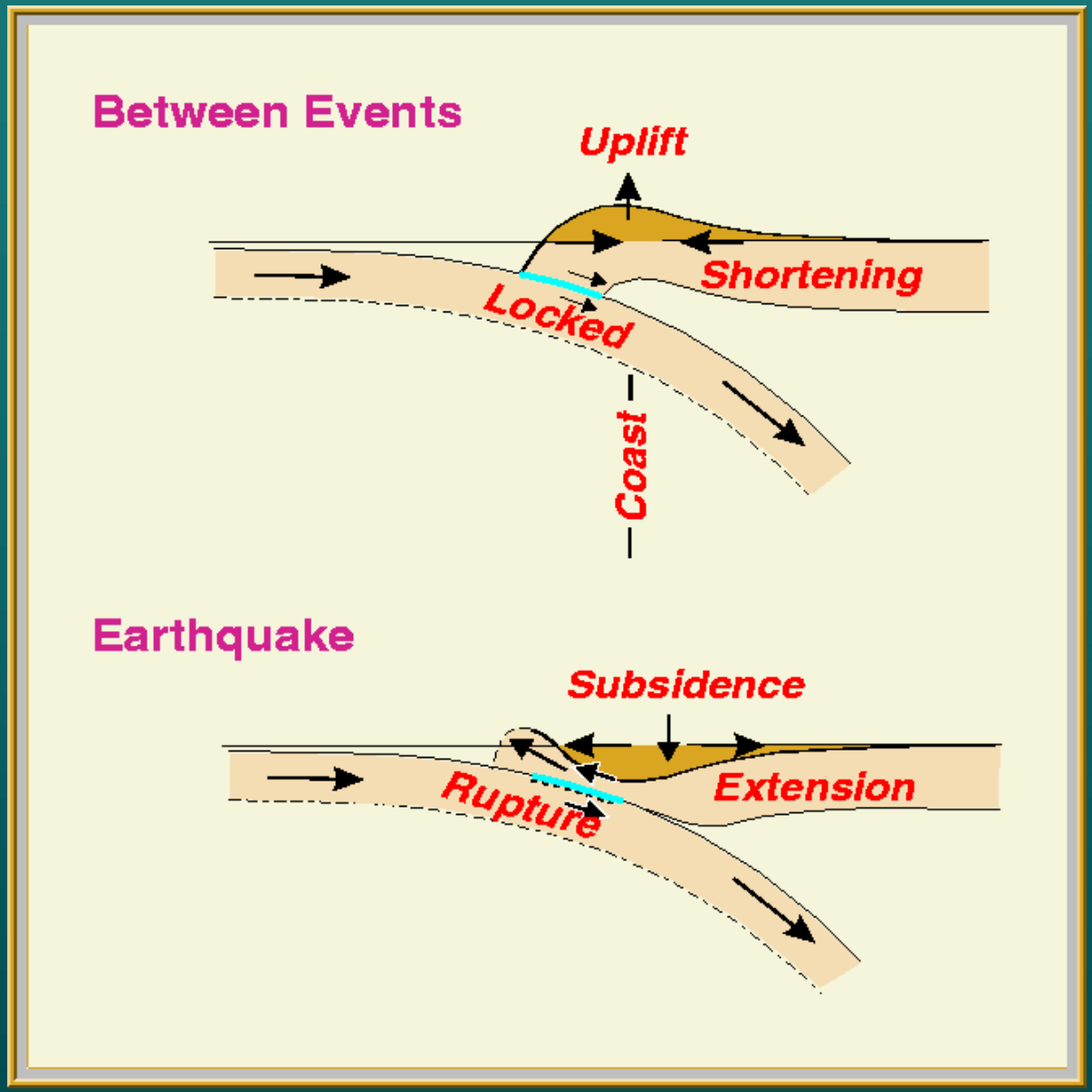
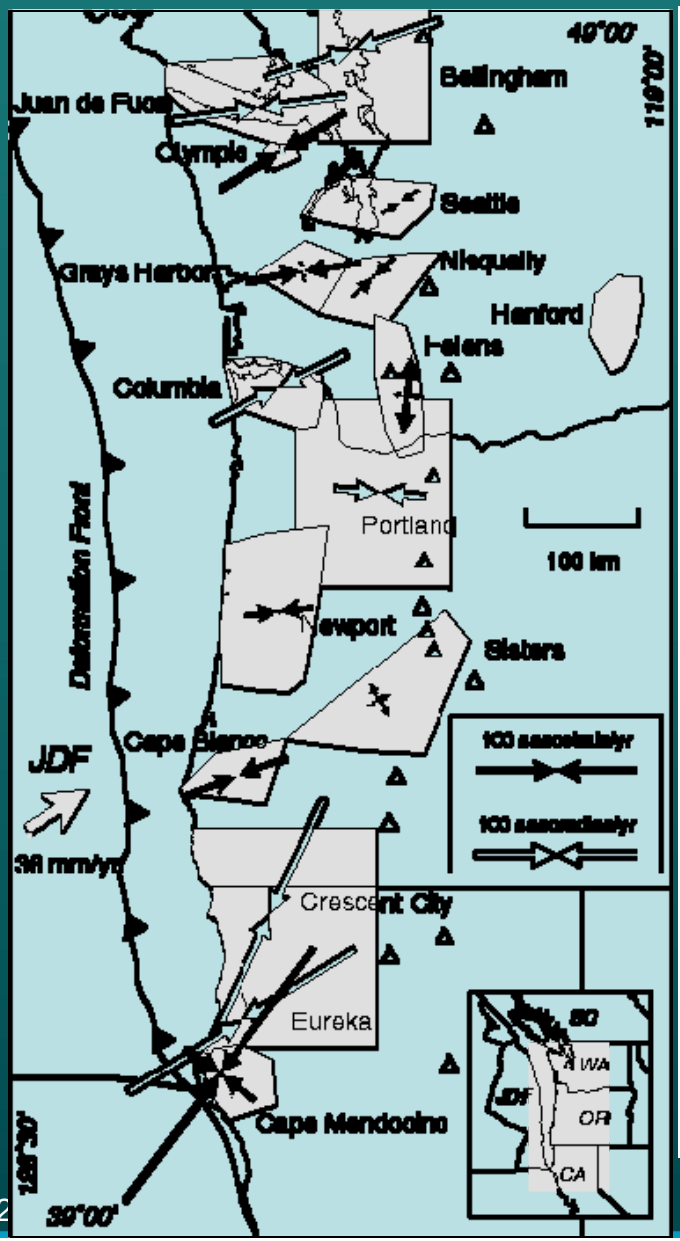
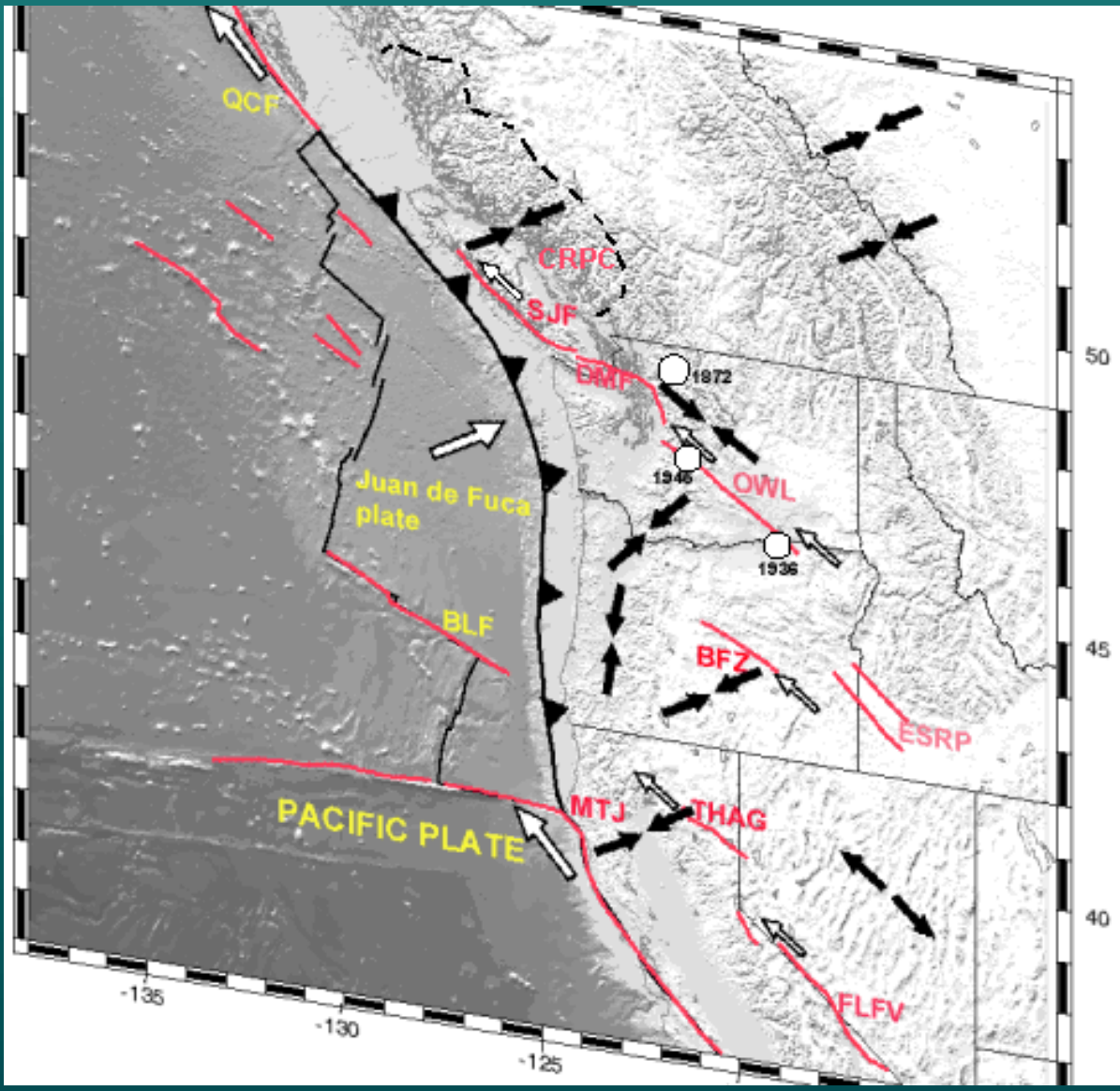


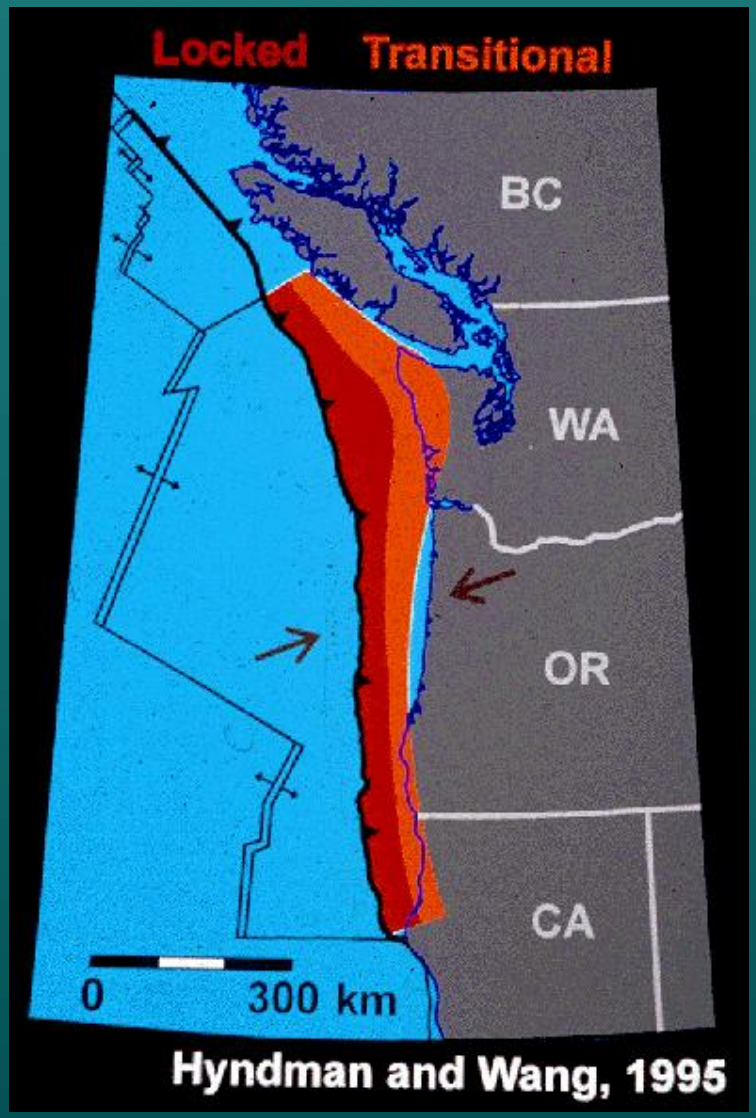
Plate Interactions with Maximum Stress Directions

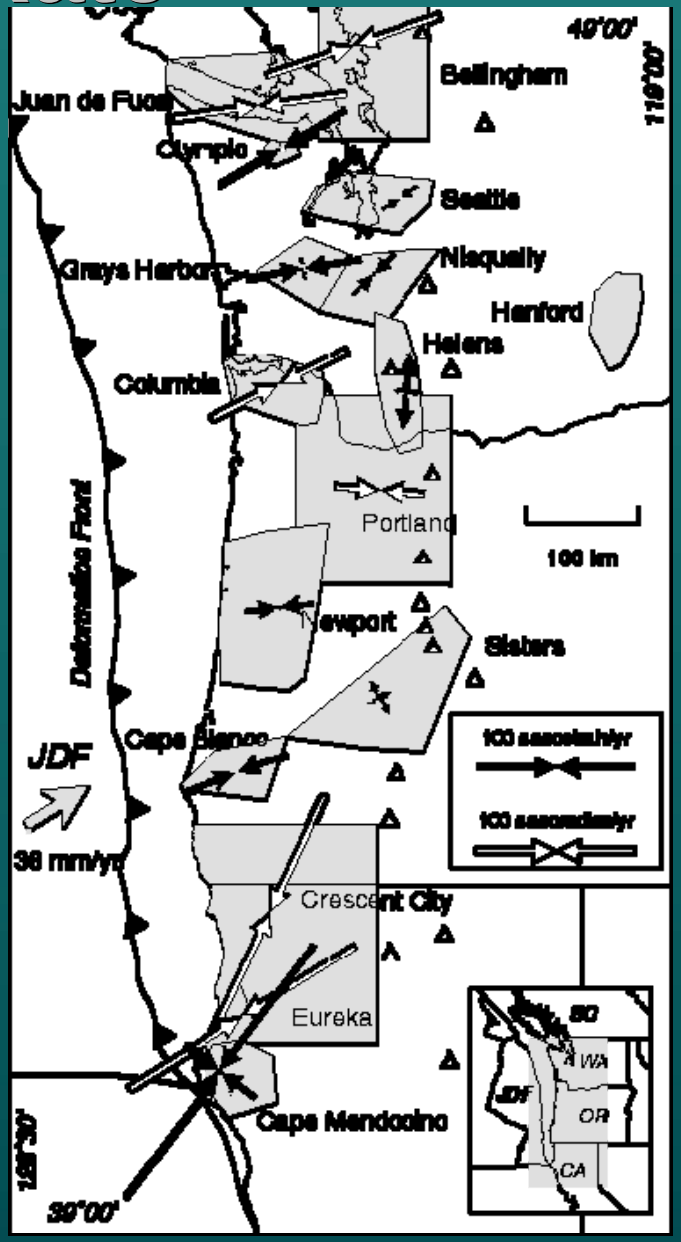




USGS OF 99-311

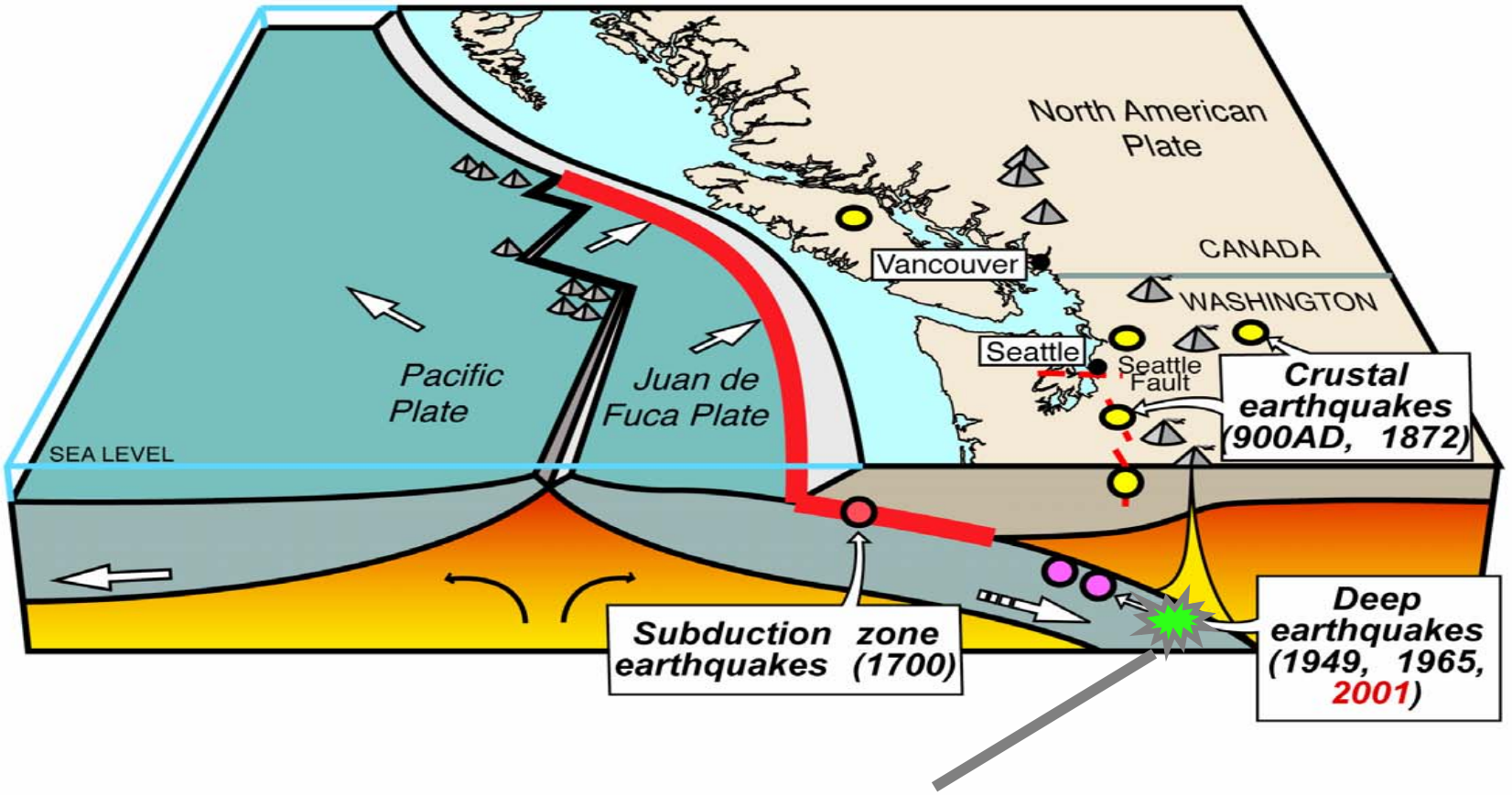
Strain Rate


Locked
Transitional
BC
WA
OR
CA
0
300 km
Hyndman and Wang, 1995


49°00'
119°00'
Bellingham
Juan de Fuca
Olympia
Seattle
Grays Harbor
Niaqually
Hanford
Helens
Columbia
Portland
100 km
Deformation Front
Newport
Sisters
JDF
Cape Blanco
38 mm/yr
Crescent City
Eureka
Cape Mendocino
40°30'
125°30'
39°00'
BC
WA
JDF
OR
CA

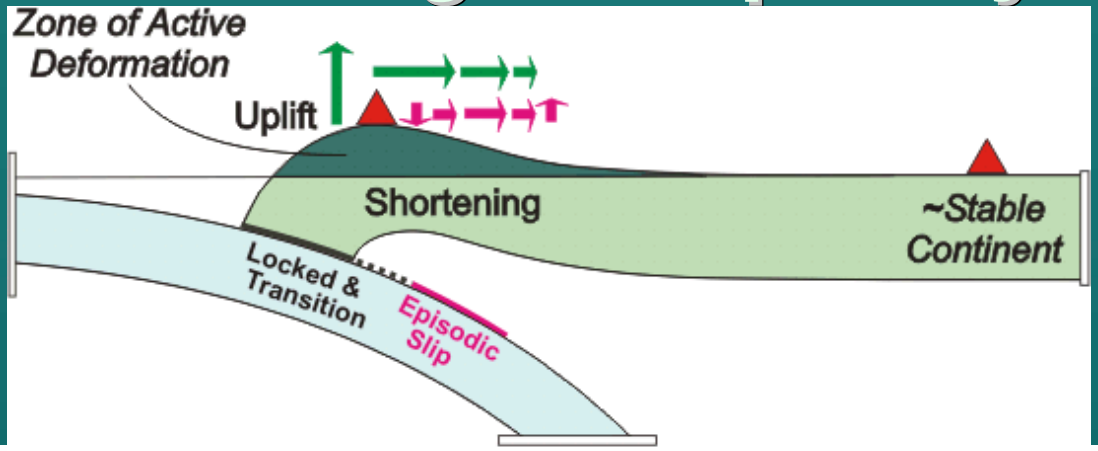
USGS
science for a changing world

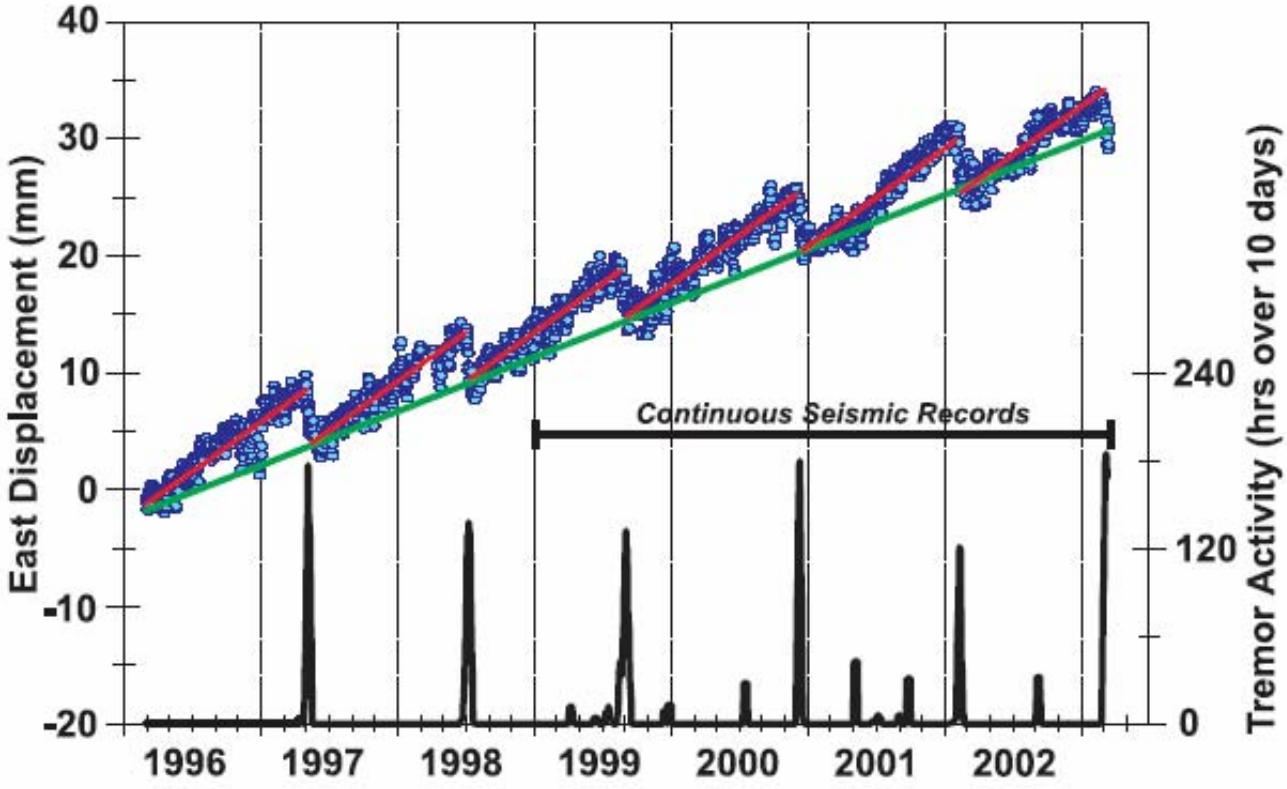
Cascadia earthquake sources



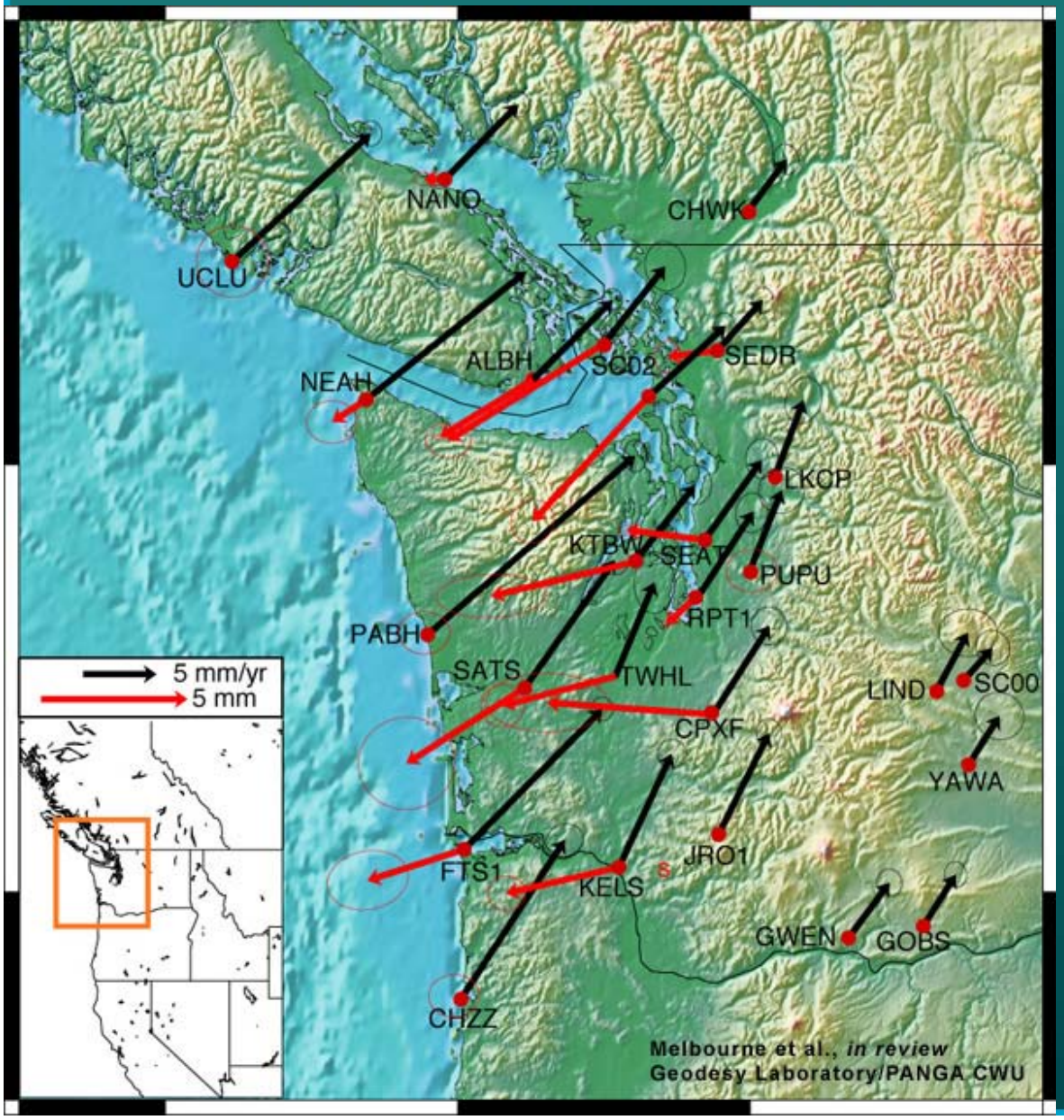
Episodic tremor and slip events (ETS)

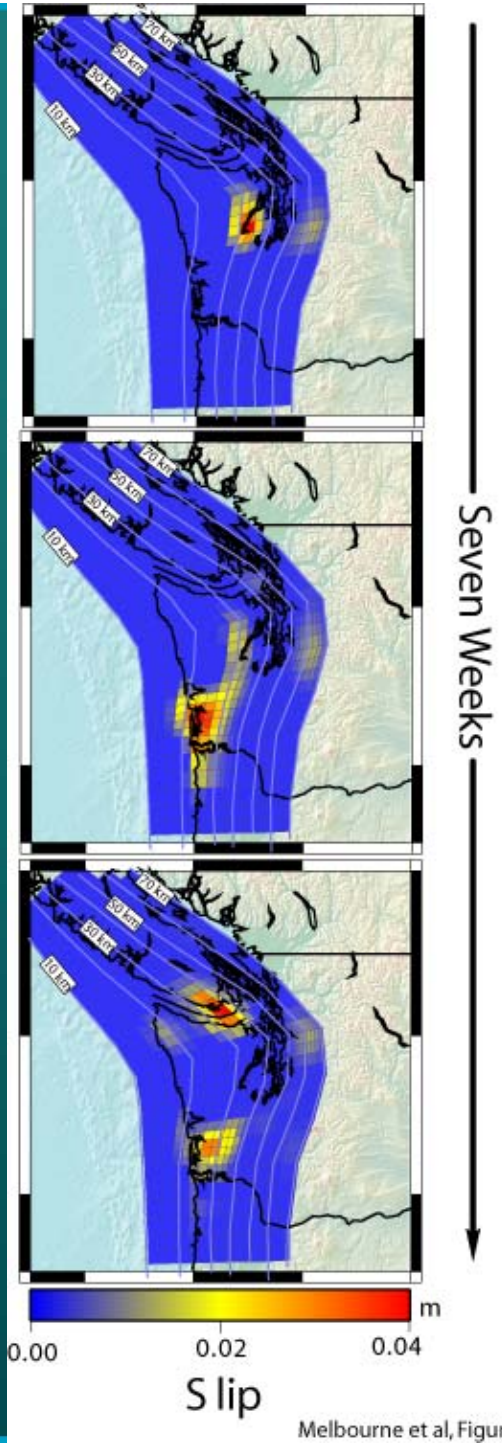
Tremor With High Frequency Bursts



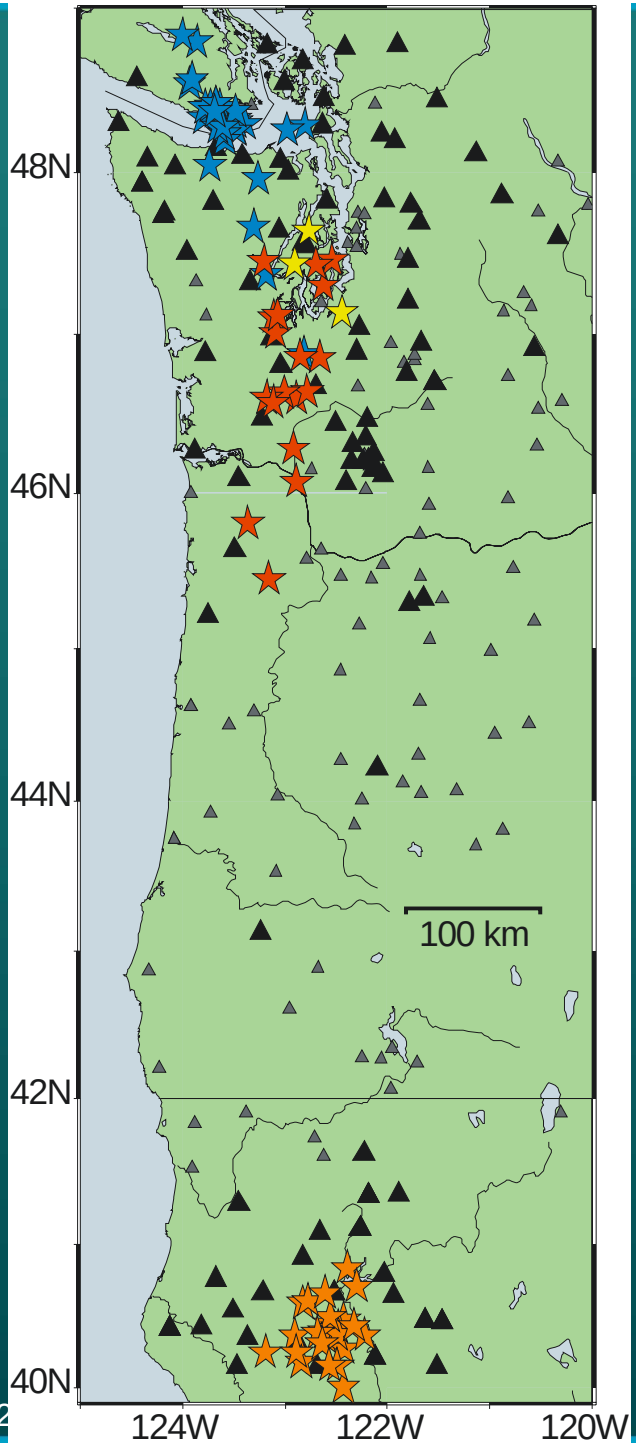


GPS & Source Area for Tremor



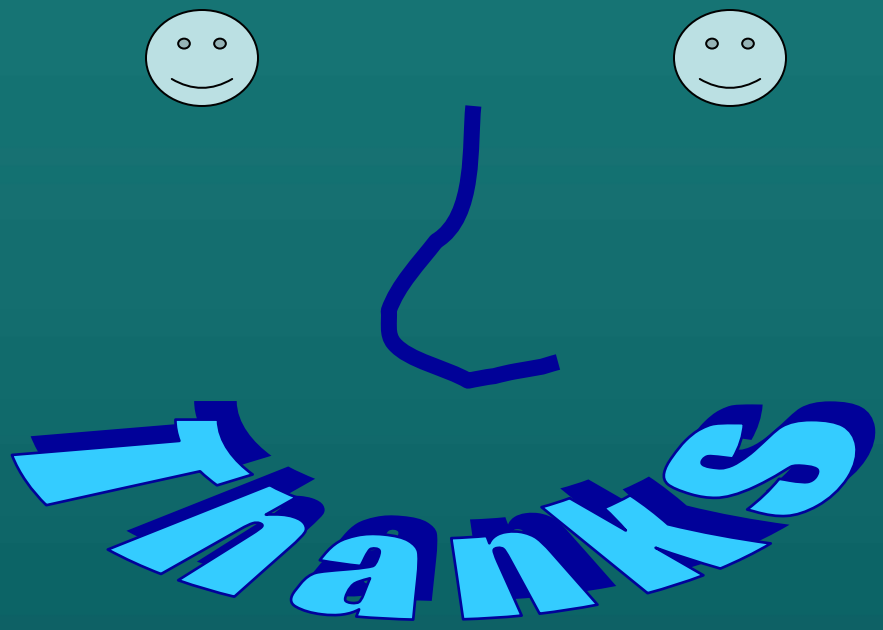


Melbourne et al, Figure 3



Recent Tremor Activity

- Tremor Epicenters
  June 5, 2004
- California Tremor Epicenters
  May 23 – June 2, 2004
- Tremor Epicenters
  Apr 27 – May 25, 2004
- Tremor Epicenters
  Feb – March, 2004
- Network Stations Used
  PNSN, Univ of OR, N. CA
- Other Unused Stations


Thanks

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1860, magnitude = 5.7;
1941, magnitude = 6.4;
1875, magnitude = 5.8
1947, magnitude = 5.6;
1951, magnitude = 6.0;
1968, magnitude = 5.9;
1987, magnitude = 5.5
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22. 1871, magnitude = 5.9;
1890, magnitude = 6.0;
1992, magnitude = 7.1, 6.6, 6.7
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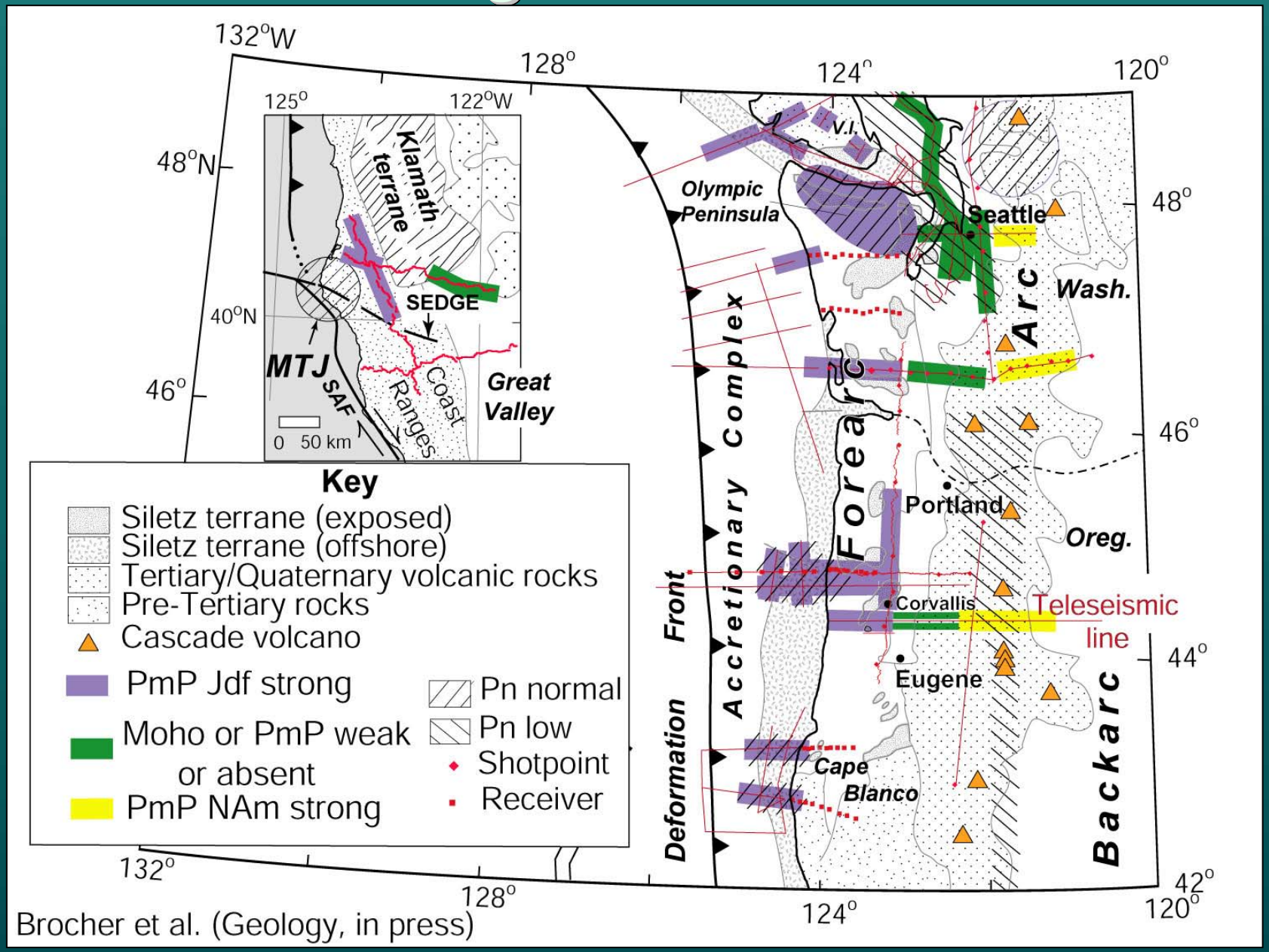
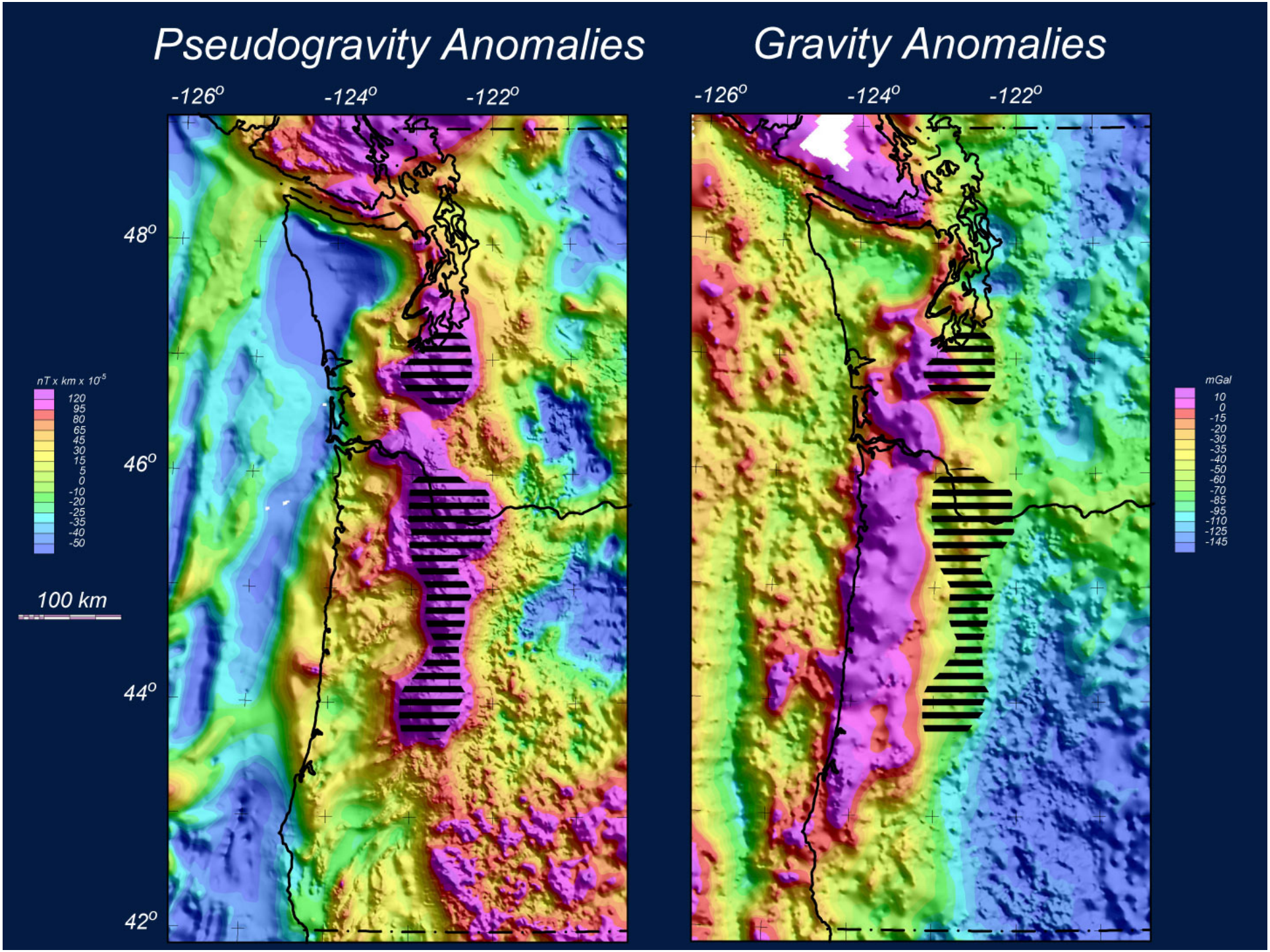
25. 1894, magnitude = 5.8
26. 1700, magnitude = 9.0*

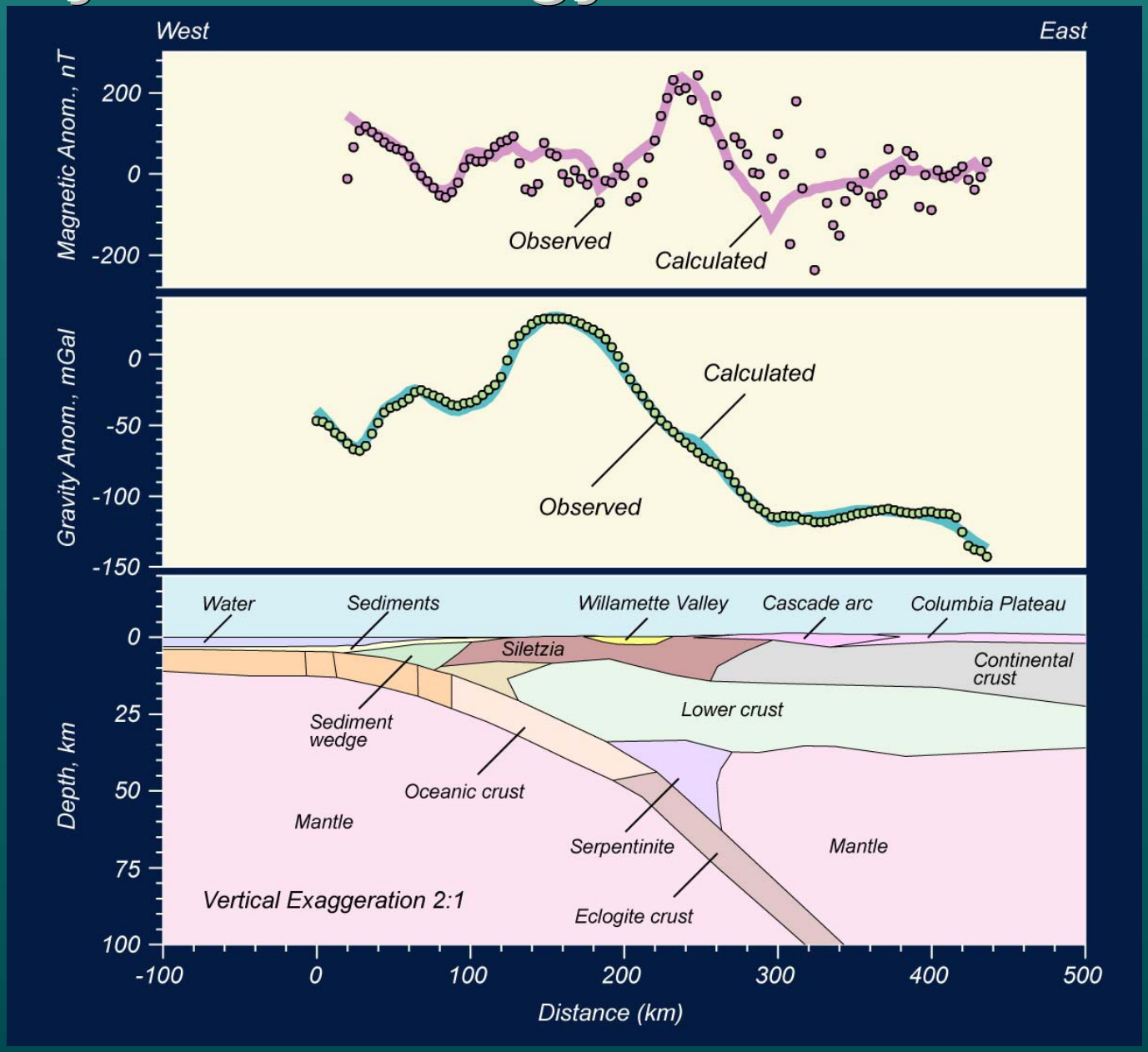
Geological Terranes



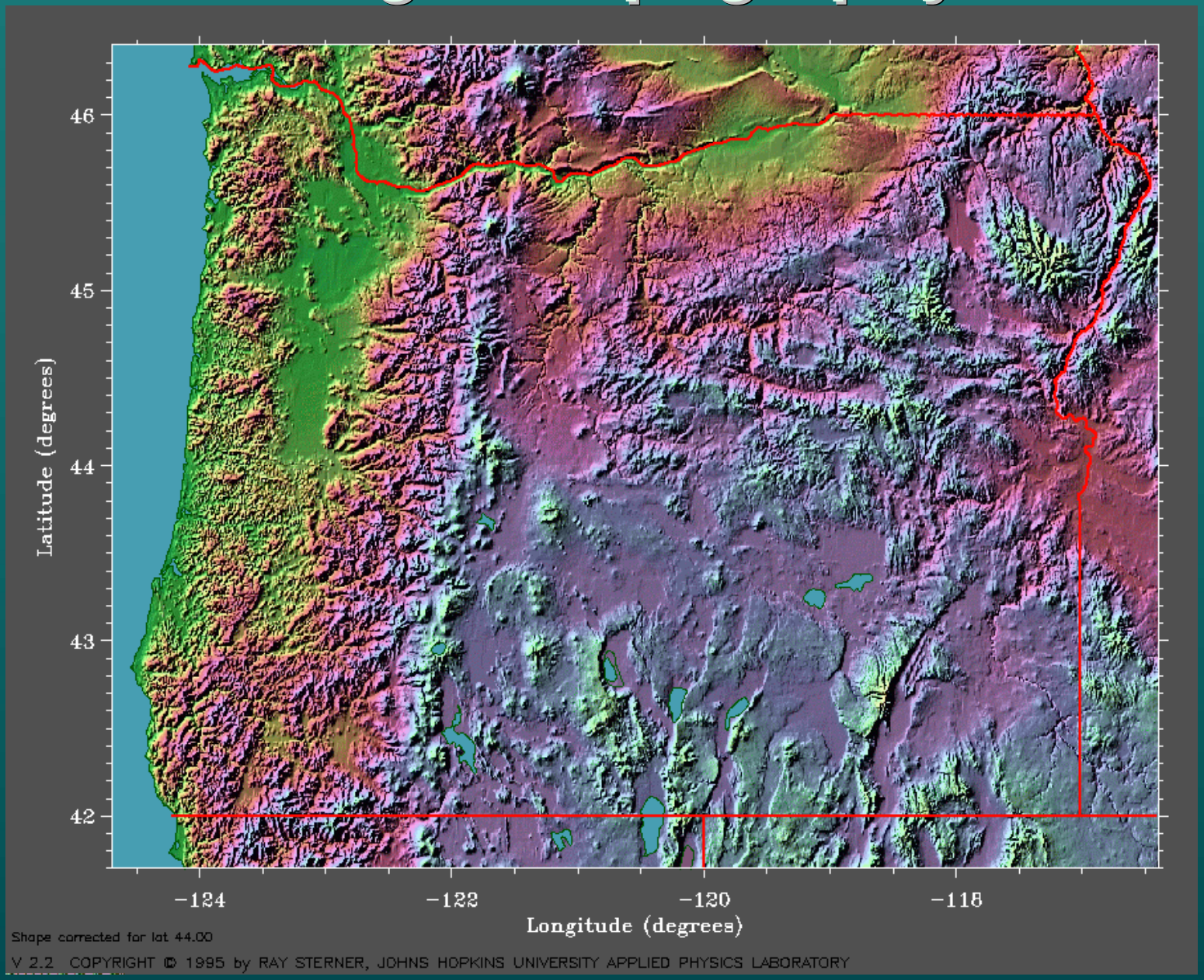
Brocher et al. (Geology, in press)


Pseudogravity Anomalies
Gravity Anomalies
-126°
-124°
-122°
48°
46°
44°
42°
nT x km x 10-5
120
95
80
65
45
30
15
5
0
-10
-20
-25
-35
-40
-50
100 km
mGal
10
0
-15
-20
-30
-35
-40
-50
-60
-70
-85
-95
-110
-125
-145

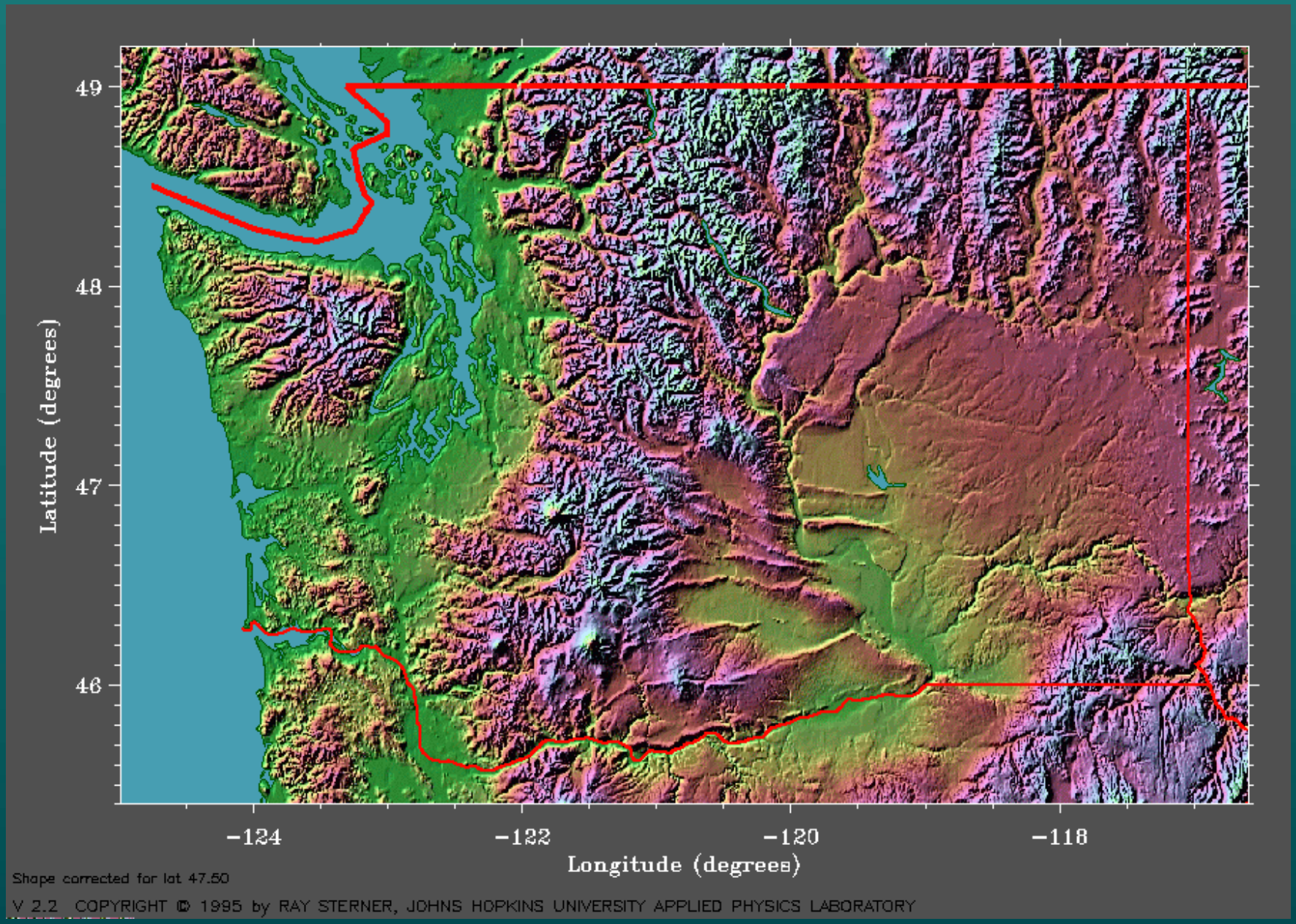
Gravity and Geology: Subduction Zone



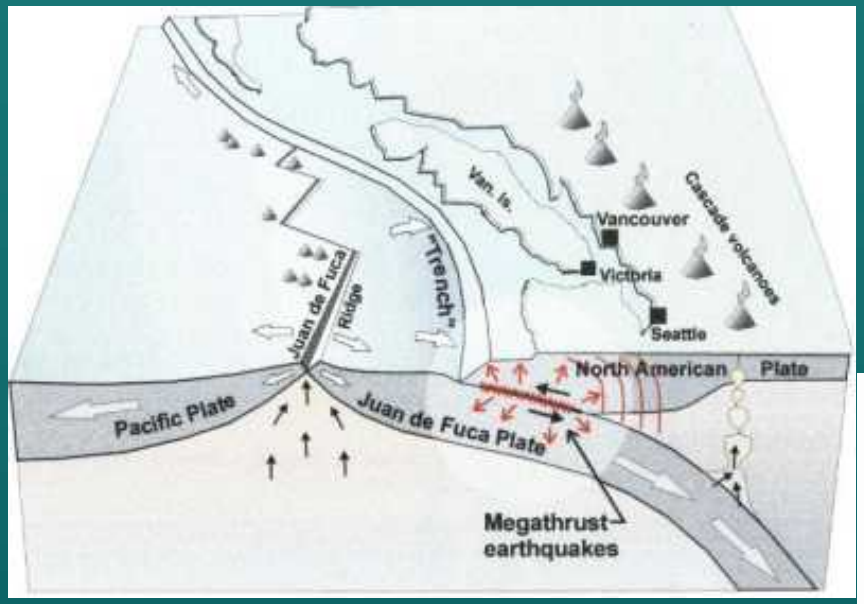
Oregon Topography

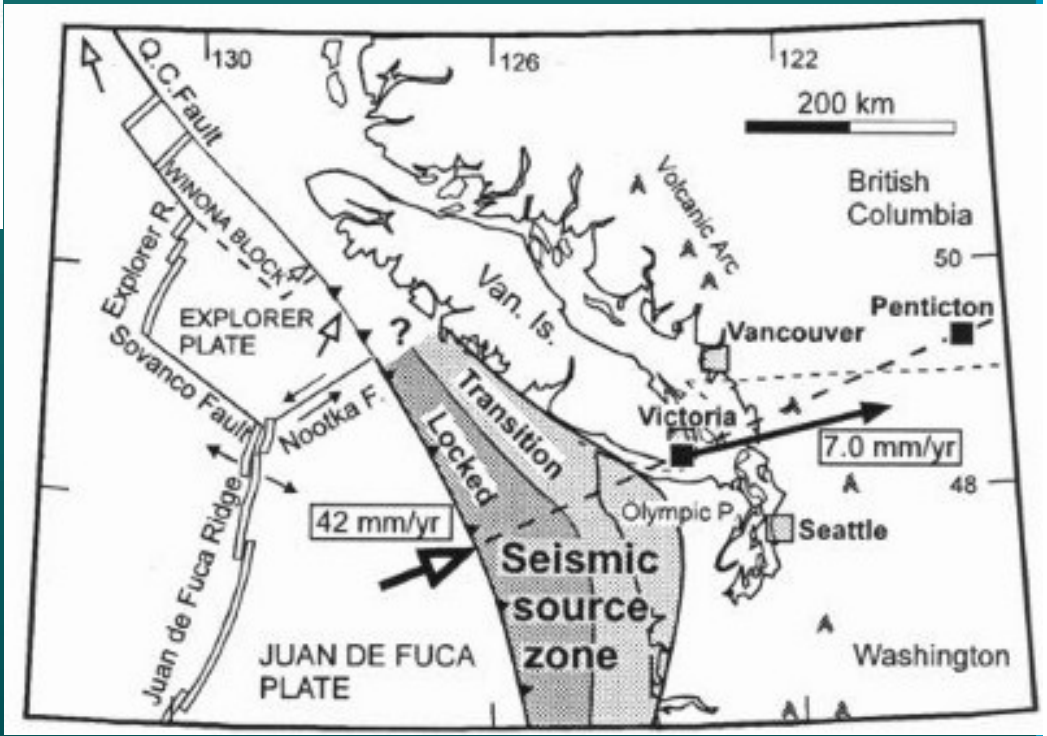


Washington Topography

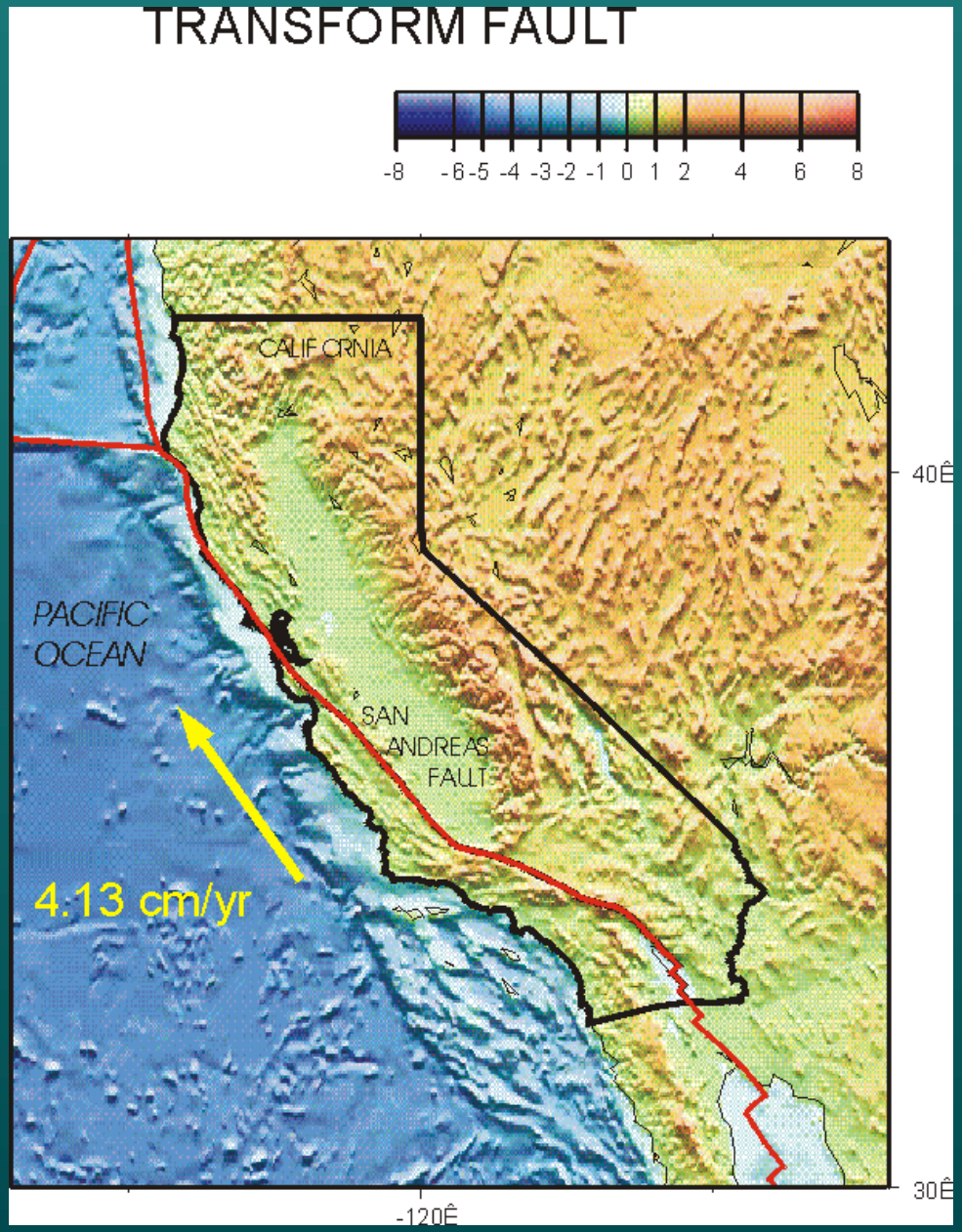


Locked Zone--Seattle and Vancouver

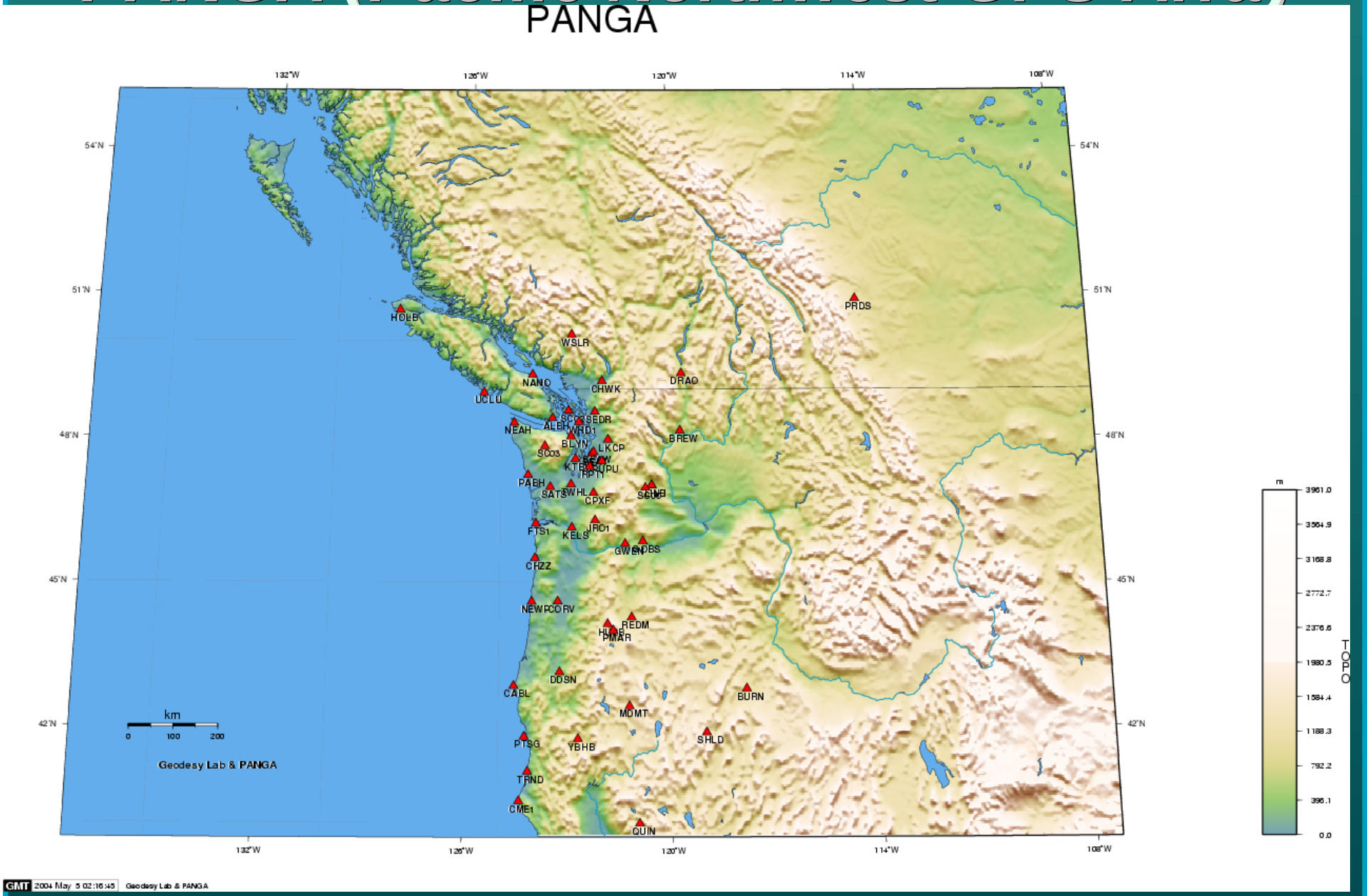




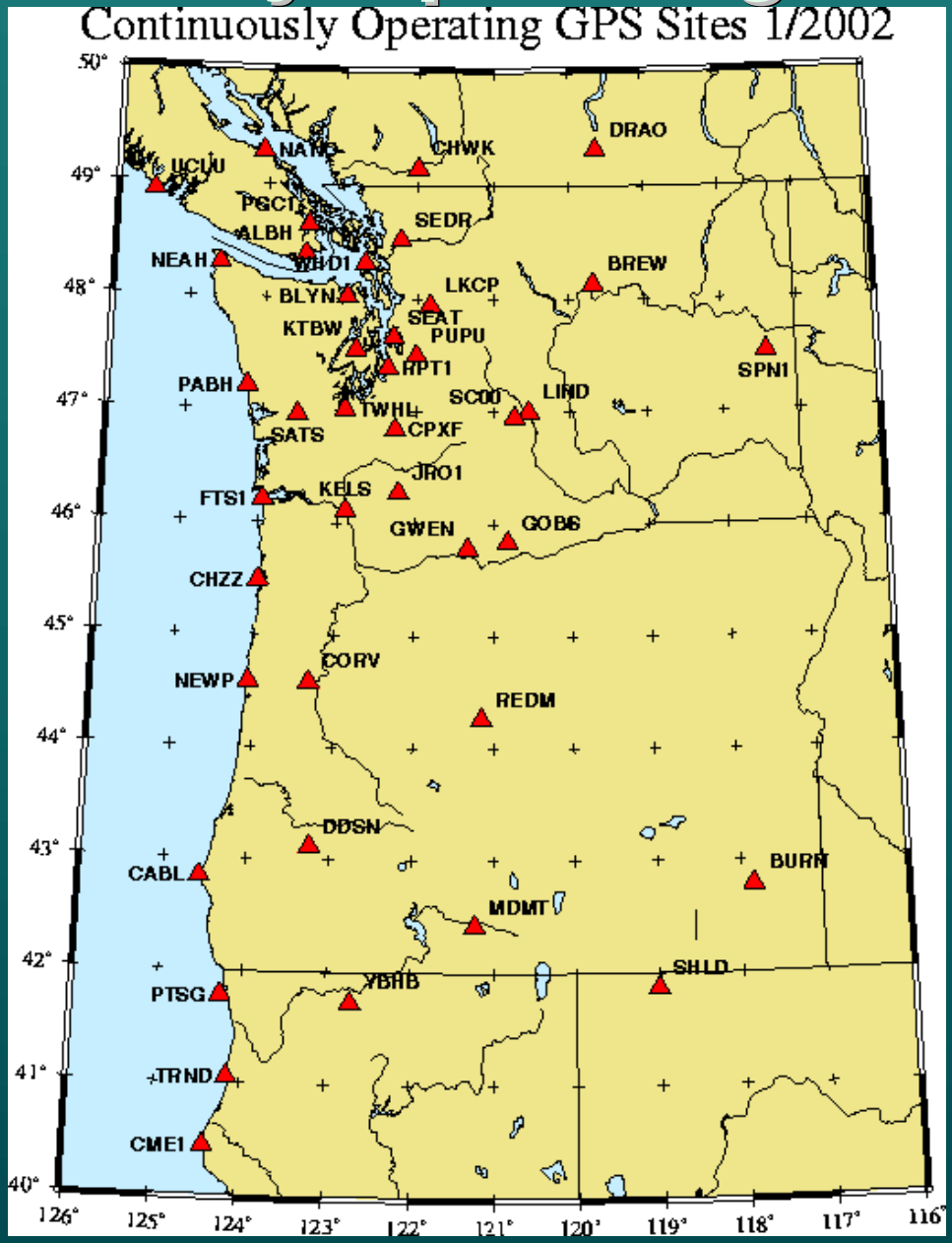
California Transform Fault



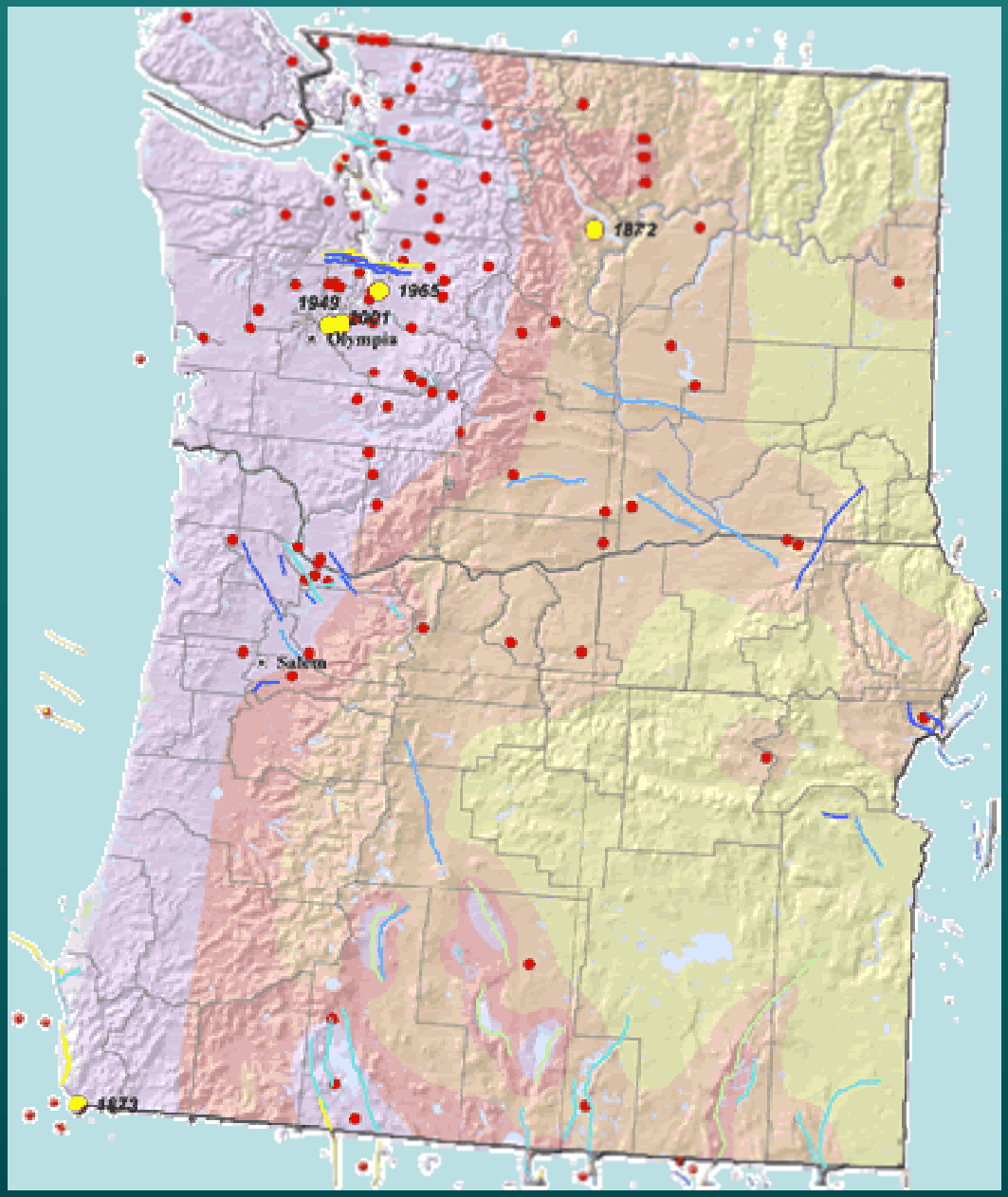
PANGA (Pacific Northwest GPS Array



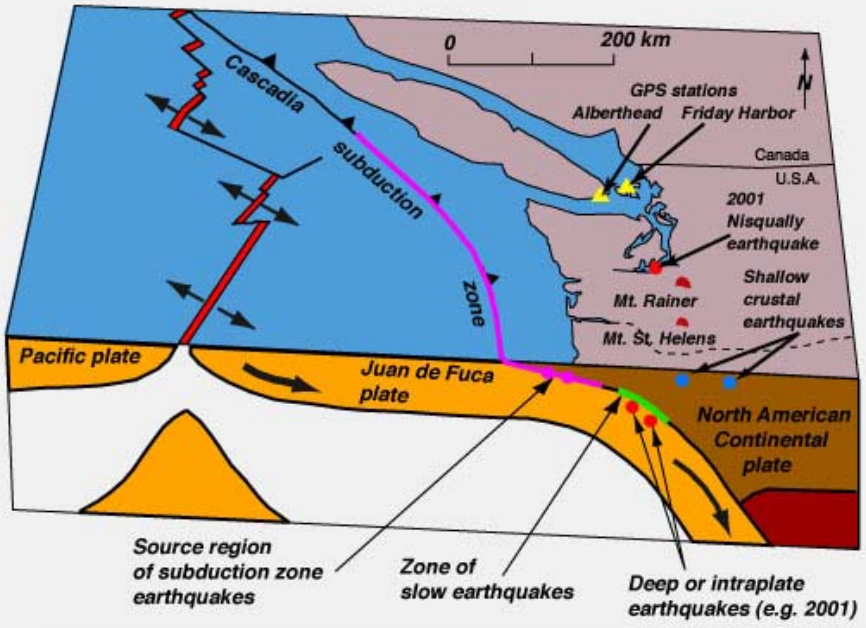
Continuously Operating GPS 2002



Earthquakes in Pacific Northwest



Subduction with explanation



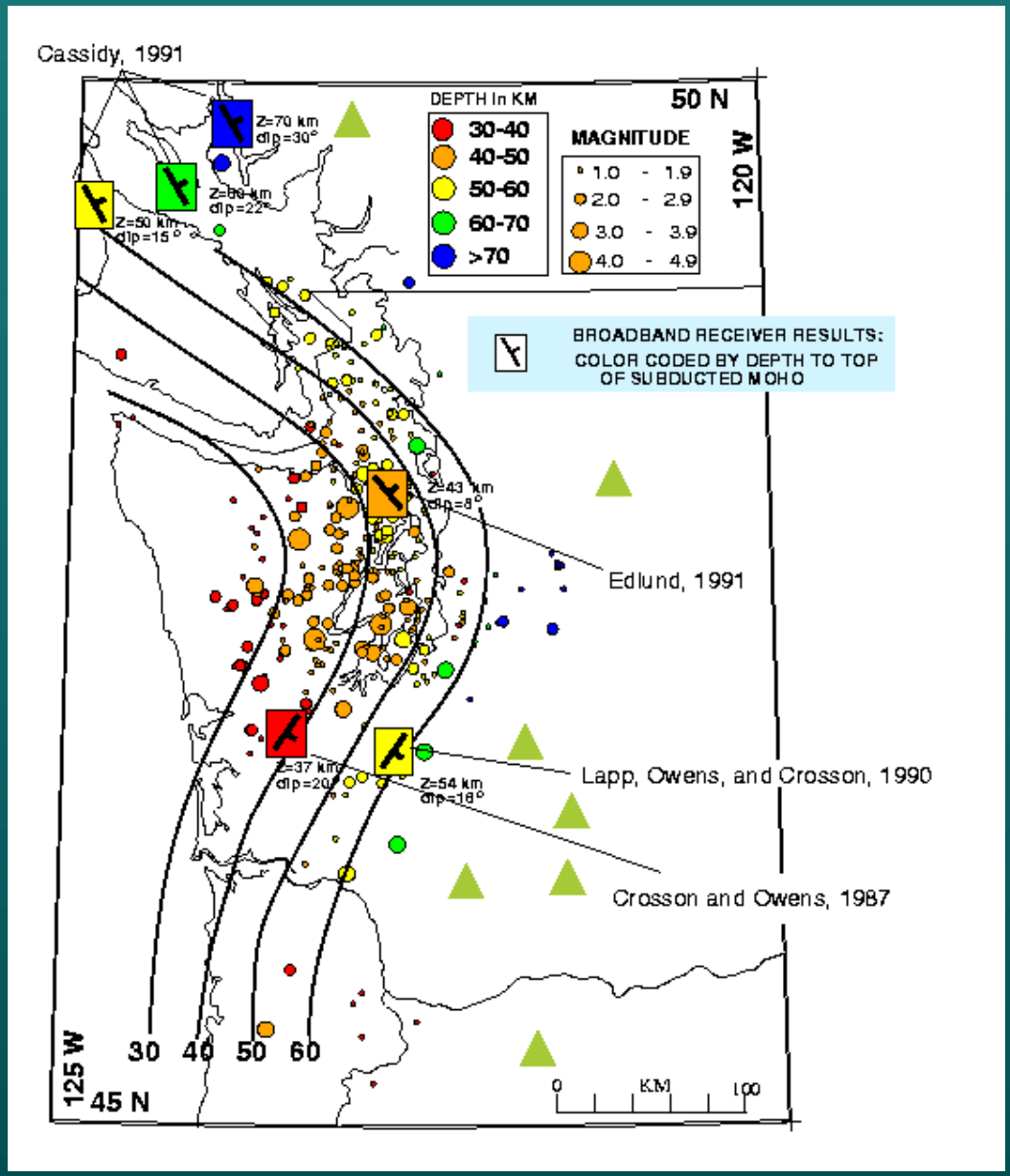
- Deep intraplate earthquakes occur within the subducting Juan de Fuca oceanic plate as it bends beneath the Nortth American plate. These are called bending moment earthquakes. The largest deep earthquakes in the Pacific Northwest in the 20th century occurred in 1949 (M~7.1), 1965 (M~6.5) and 2001 (M=6.8).
- Shallow crustal earthquakes, located usually within 15 kilometers of the surface, occur along faults within the North American plate. For example, about 1,100 year ago, a M ≥ 7.0 earthquake occurred along the Seattle fault.
- Subduction zone earthquakes occur along the interface between the Juan de Fuca and North American plates. The relative plate motion between the two plates is about 40 mm/yr. The most recent earthquake along the Cascadia subduction zone occured in 1700 AD. The earthquake's estimated magnitude was about 8.9. The 1700 AD earthquake produced a tsunami that was recorded in Japan.
- Slow earthquakes occur along the interface between the Juan de Fuca and North American plates, approximately 30 to 50 kilometers deep. There is an observed regularity over the past 10 years of observations. Every 14.5 months on average there is a few centimeters of slip at the interface resulting in a displacement of about 5 millimeters at the surface without detectable seismic shaking.

Eqks 1872-1987 MM≥VIII

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
DEPTH In KM
30-40
40-50
50-60
60-70
>70
MAGNITUDE
1.0 - 1.9
2.0 - 2.9
3.0 - 3.9
4.0 - 4.9
50 N
120 W
125 W
45 N
30 40 50 60
BROADBAND RECEIVER RESULTS:
COLOR CODED BY DEPTH TO TOP
OF SUBDUCTED MOHO
Z=70 km
dip=30°
Z=50 km
dip=15°
Z=43 km
dip=8°
Z=37 km
dip=20°
Z=54 km
dip=18°
Edlund, 1991
Lapp, Owens, and Crosson, 1990
Crosson and Owens, 1987
0
KM
100

Stress Orientations in Pacific Northwest

Model Calculation of Stresses in PN

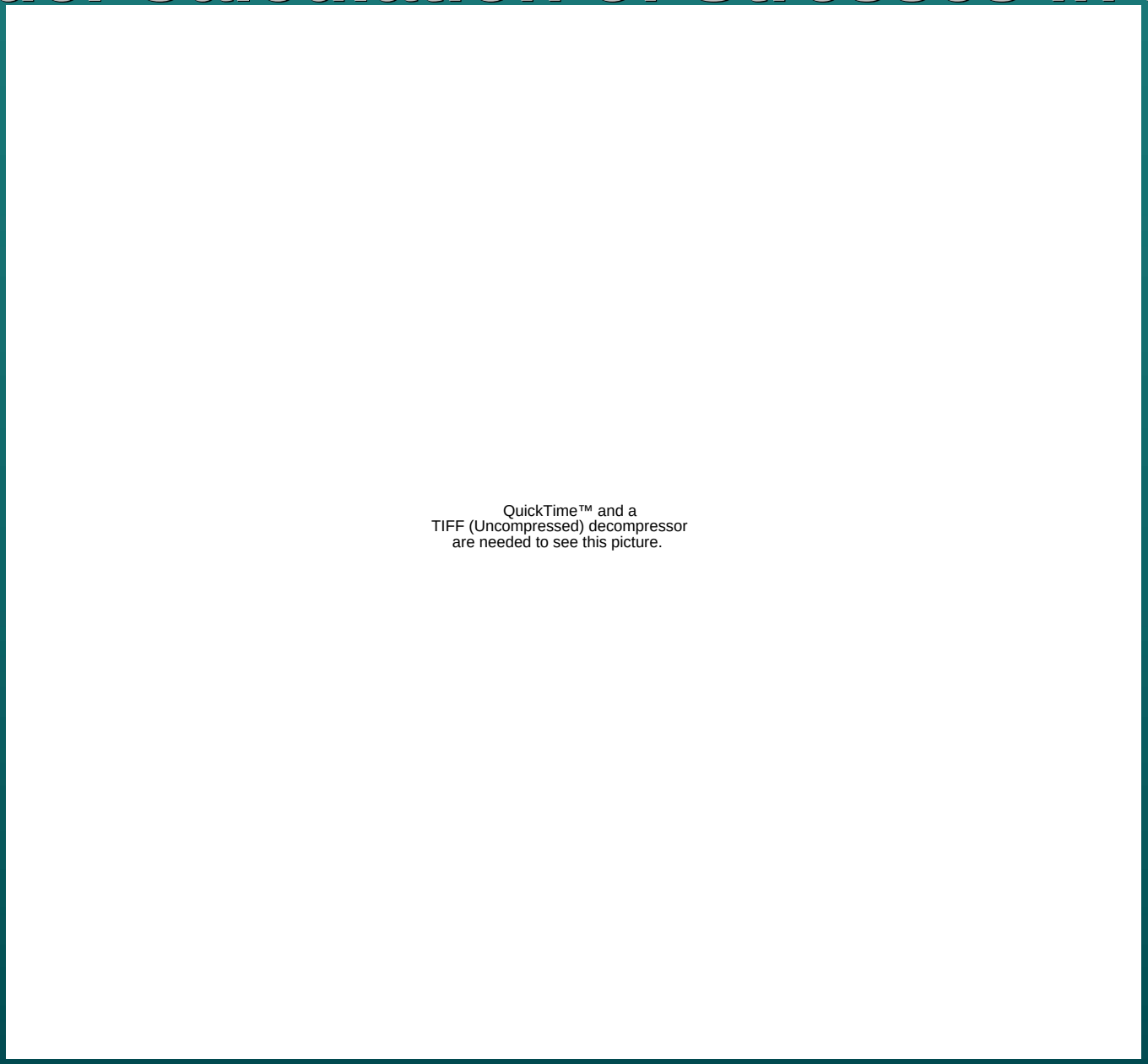


Plate Subducting

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