Earthquake Research and Monitoring in the Pacific Northwest

Pacific Northwest Seismograph Network & EarthScope

by Steve Malone
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Dept. Earth & Space Sciences
University of Washington

Presentation using material from many seismologists and volcanologists
EarthScope Workshop - Mount Rainier Learning Center - Apr. 2008

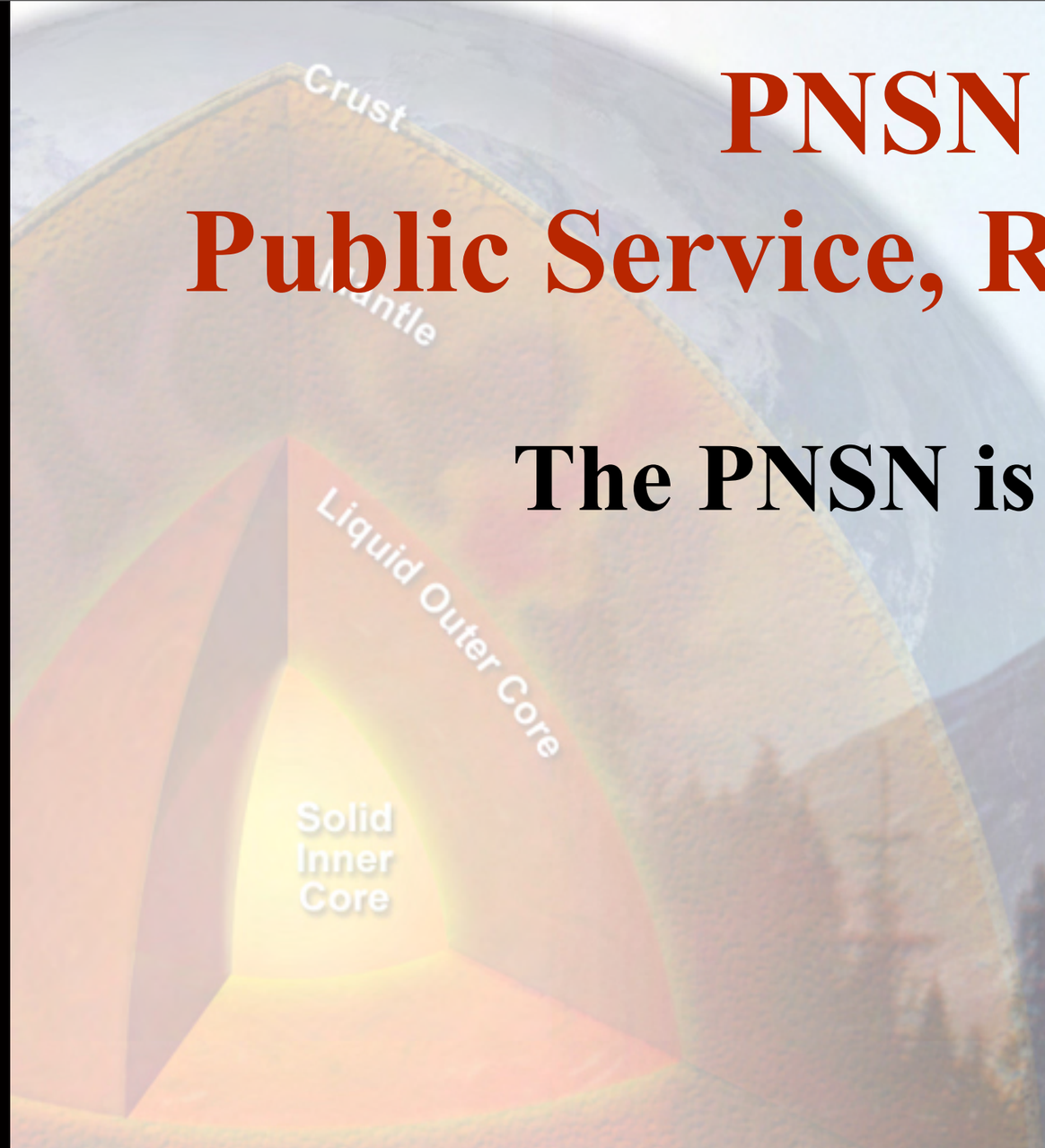
Fade through earthquake seismogram and volcano eruption picture in background

Earthscope - Comparison to a regional seismic network (the PNSN)

Earthscope	PNSN
New effort - last 5 years	> 40 years old
New modern equipment	Much is old analog equipment
Well funded from one source	Only recently well funded, many sources
USArray - temporary	Permanent
Primarily for science	Many, sometimes conflicting, goals
Professional, full-time management and staff	Professorial, part-time management staff includes students

PNSN Mission:
Public Service, Research, Education

The PNSN is responsible for



PNSN Mission:
Public Service, Research, Education

The PNSN is responsible for

- **Seismic monitoring of Washington & Oregon as part of the USGS "Advanced National Seismic System" (ANSS)**
- **Supporting and engaging in research into earthquake and volcanic hazards**
- **Educating the geo-scientists of tomorrow**

PNSN Clients / Stakeholders

- Scientists - UW and others
- Engineers - structural, civil
- Emergency response officials - local & state
- Students - university and secondary Schools
- Press - local and national
- Public - phone, web, e-mail and in person

PNSN Organization

- UW - Recording Processing Center
- USGS CVO - share volcano monitoring
- Batelle Northwest Labs - service eastern Washington
- University of Oregon - service southern Oregon

PNSN funding / support

Operational funding

- U.S. Geological Survey
- State of Washington
- University of Washington
- U.S. Department of Energy

Capital Expansion

- U.S. Geological Survey
- Murdock Charitable Trust
- National Science Foundation - USArray
- Oregon DOGAMI
- State of Washington - WDOT, EMD

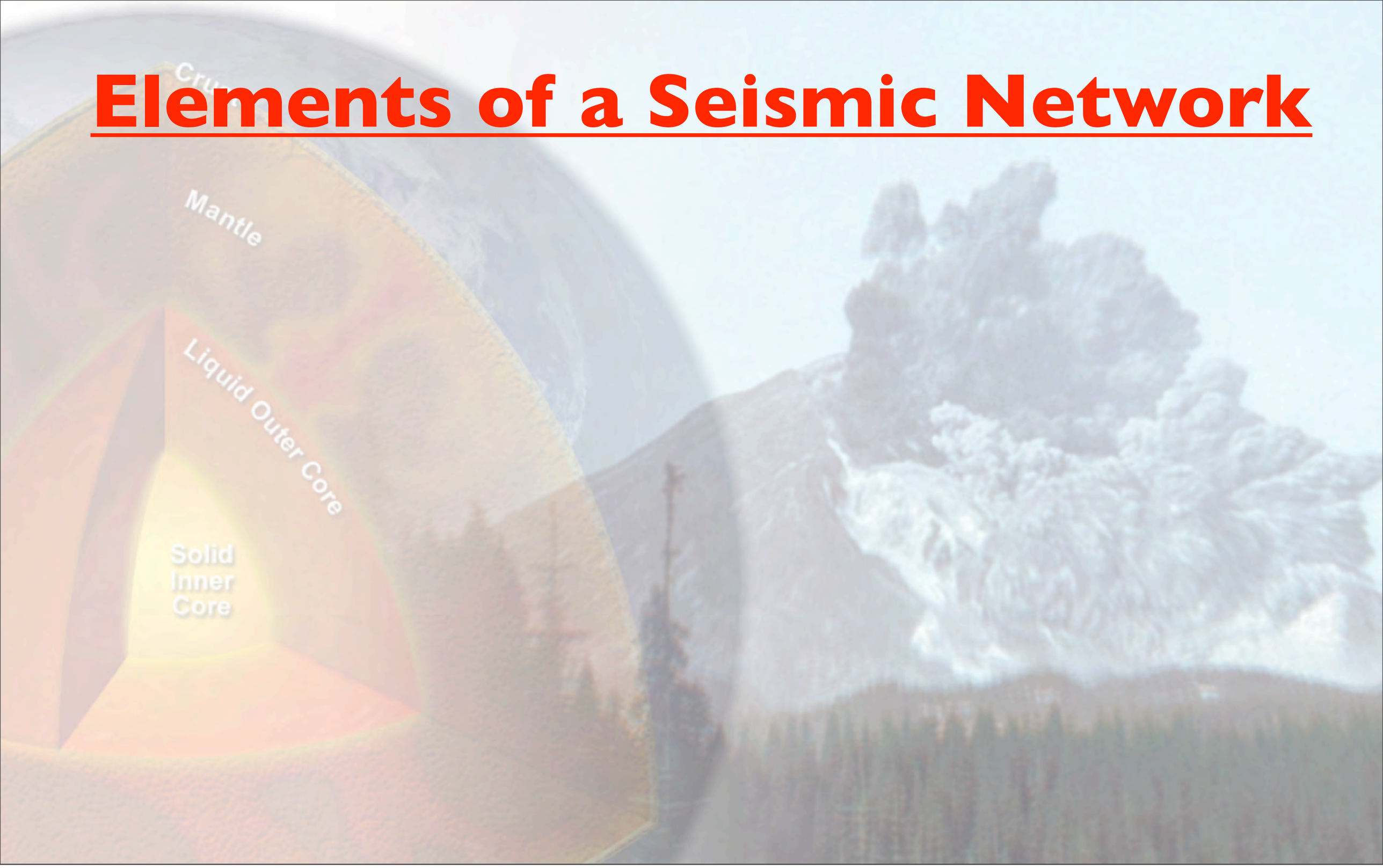
In-kind support

- Bonneville Power Administration
- IRIS DMC
- Puget Sound Energy
- Oregon DOT
- 34 School Districts
- 9 Municipalities
- 8 Private or public institutions

Science research

- U.S. Geological Survey
- National Science Foundation
- State of Washington

Elements of a Seismic Network

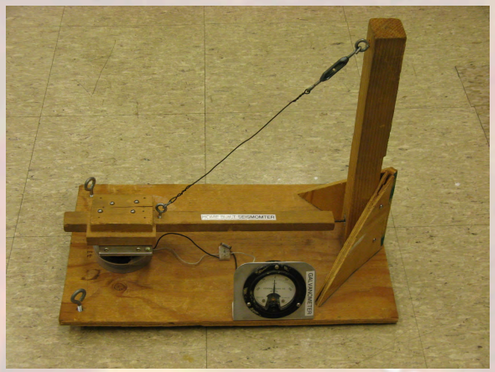


Elements of a Seismic Network

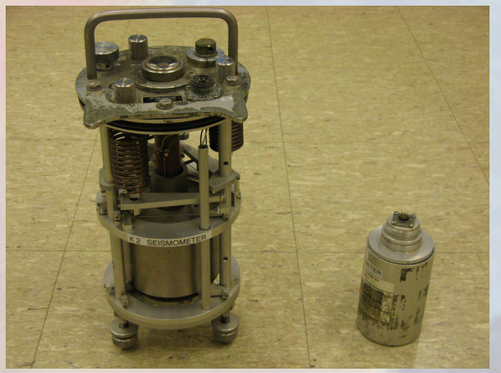
- Seismometer - (sensor)
- Electronics (amplifier, digitizer/VCO)
- Telemetry (radio, telephone, internet)
- Receiver (discriminator, digitizer)
- Recording computer
- Detection software
- Display and analysis software

Seismograph System

Toy Seismometer



Short-period seismometer



Broad-band seismometer

seismometer installation

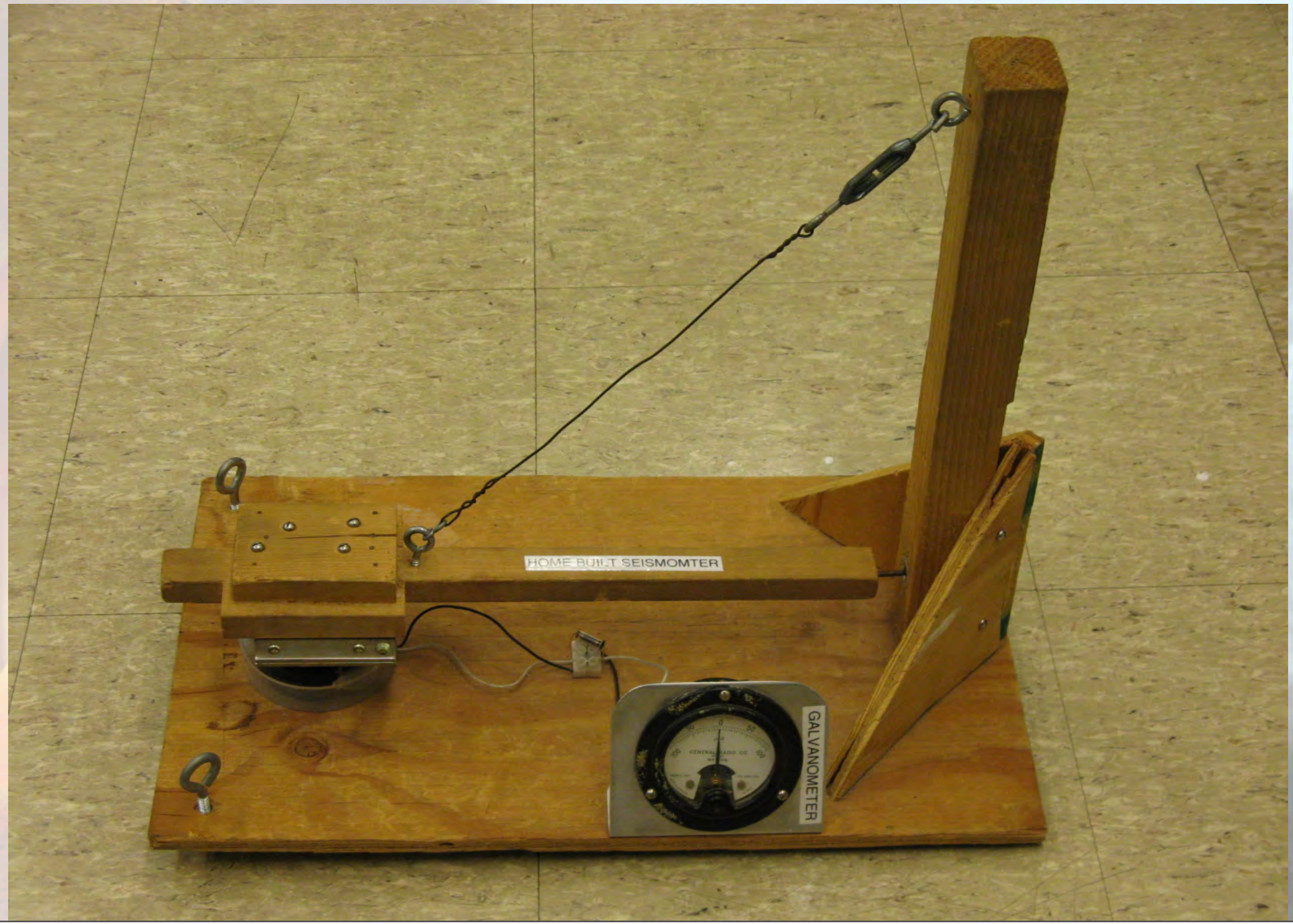
seismometer & electonics

telemetry installation

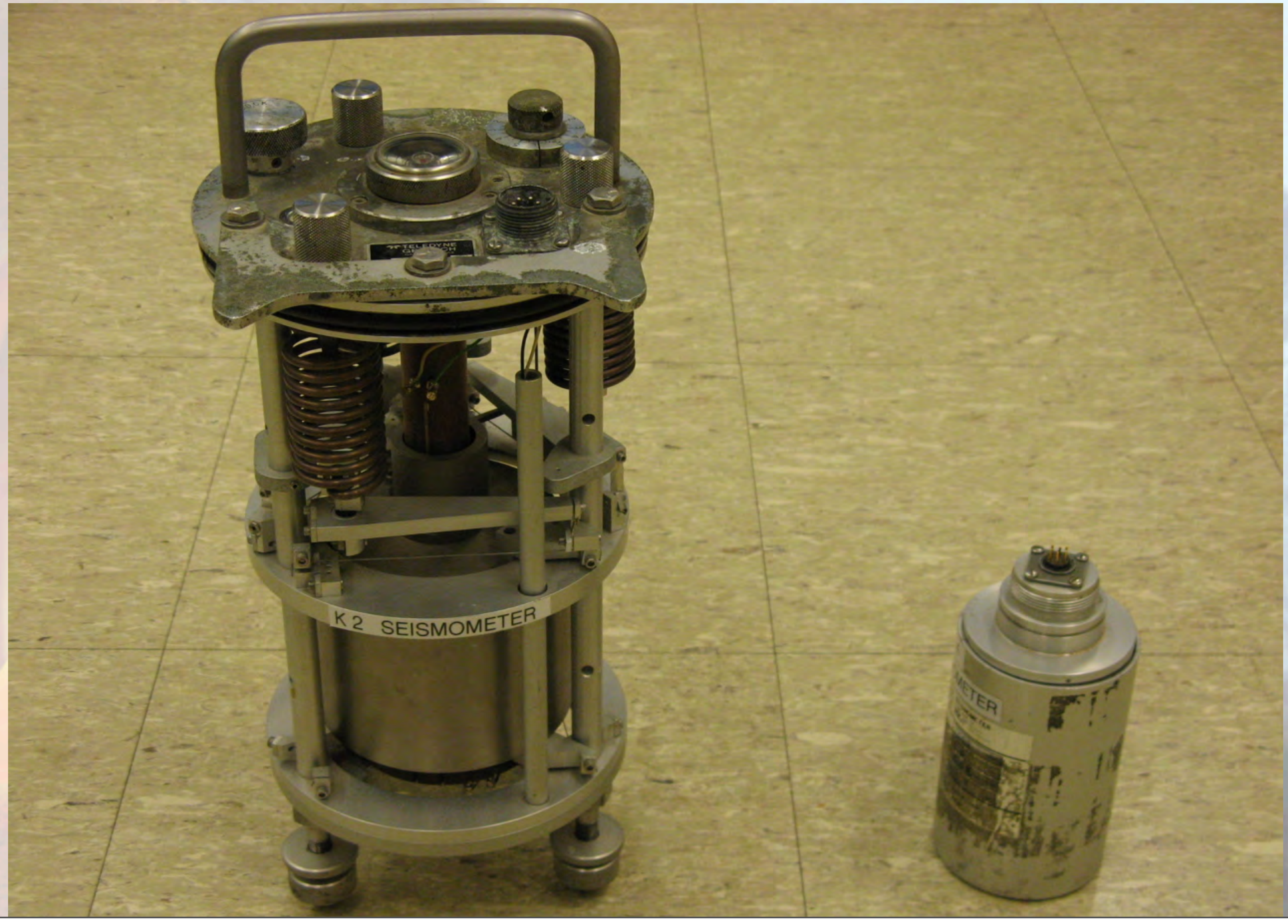
Receiving electronics and computers

Display

Seismograph System



Seismograph System



Seismograph System

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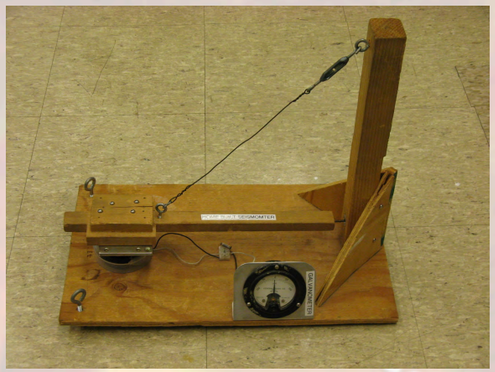

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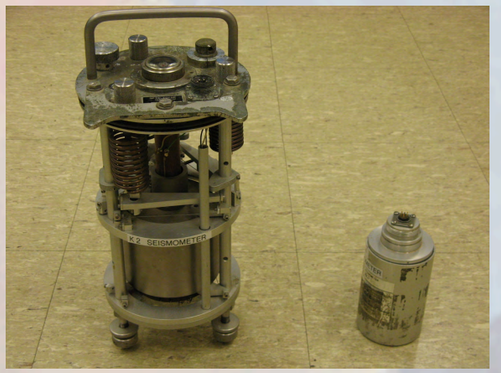

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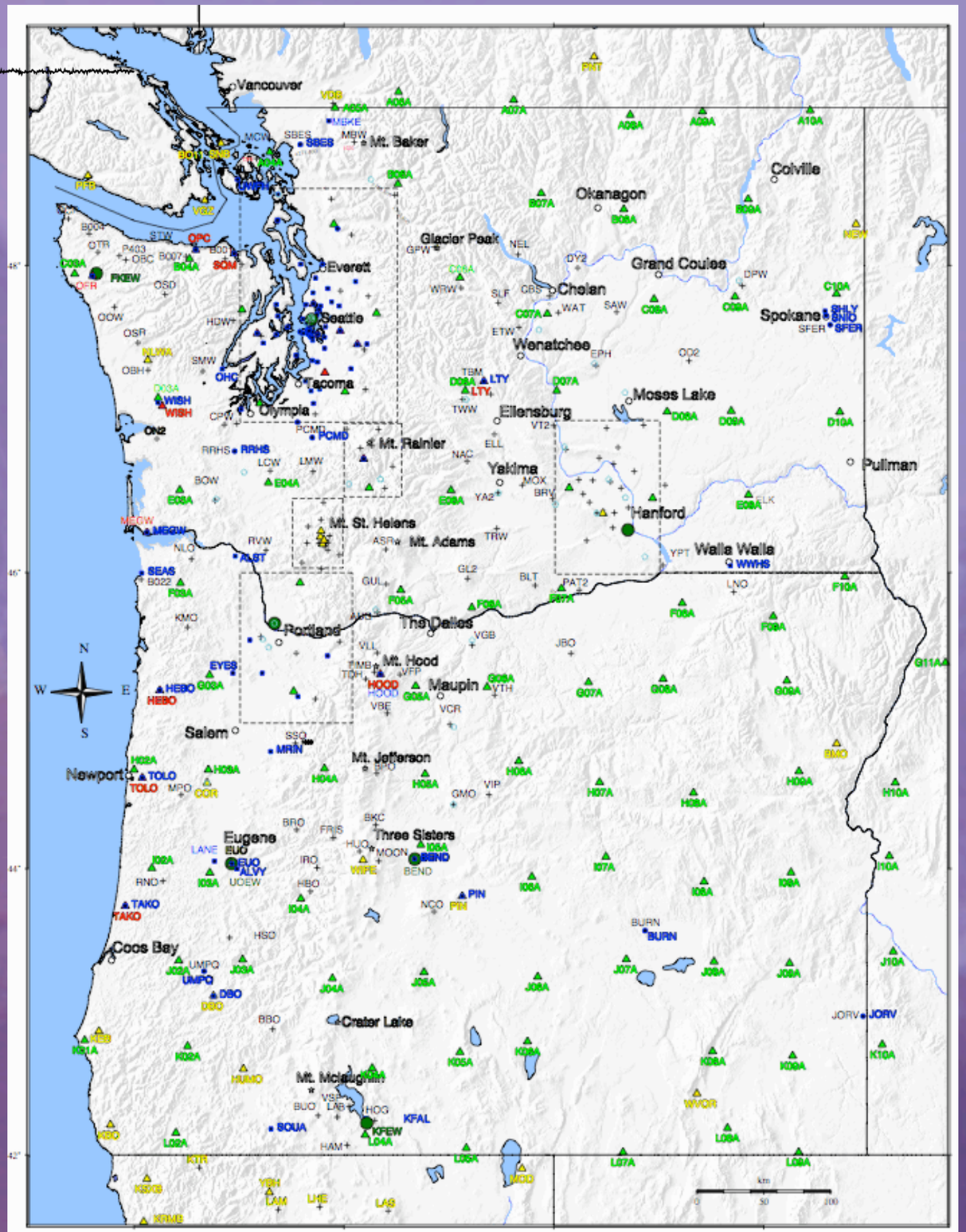
PNSN

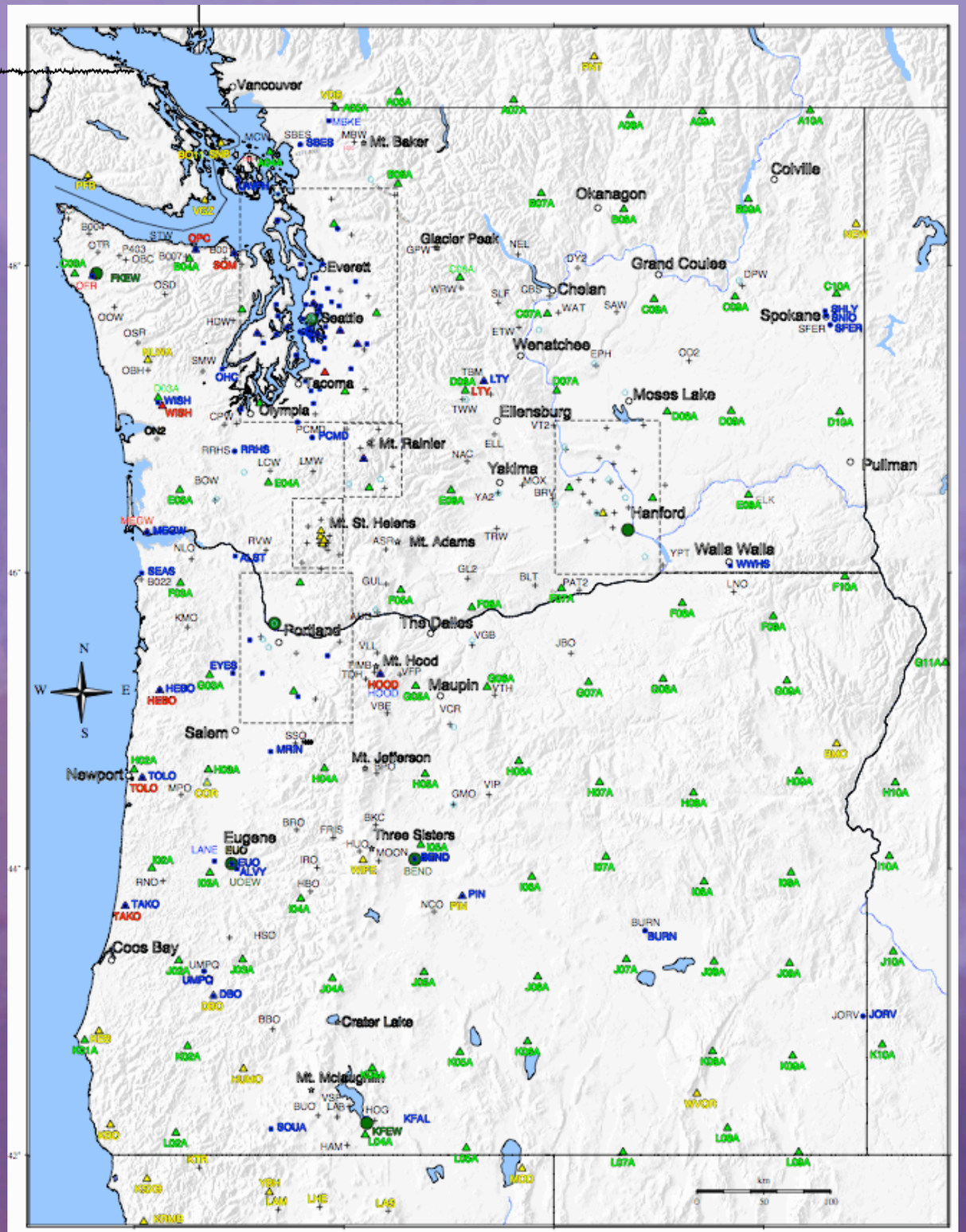
Pacific Northwest Seismic Network



PNSN

Pacific Northwest Seismic Network

- 146 Short-period
- 22 Broad-band
- ~80 TA Broad-band
- 97 Strong-motion
- ~900 channels of data
- 6 data collection nodes
- 16 real-time computers



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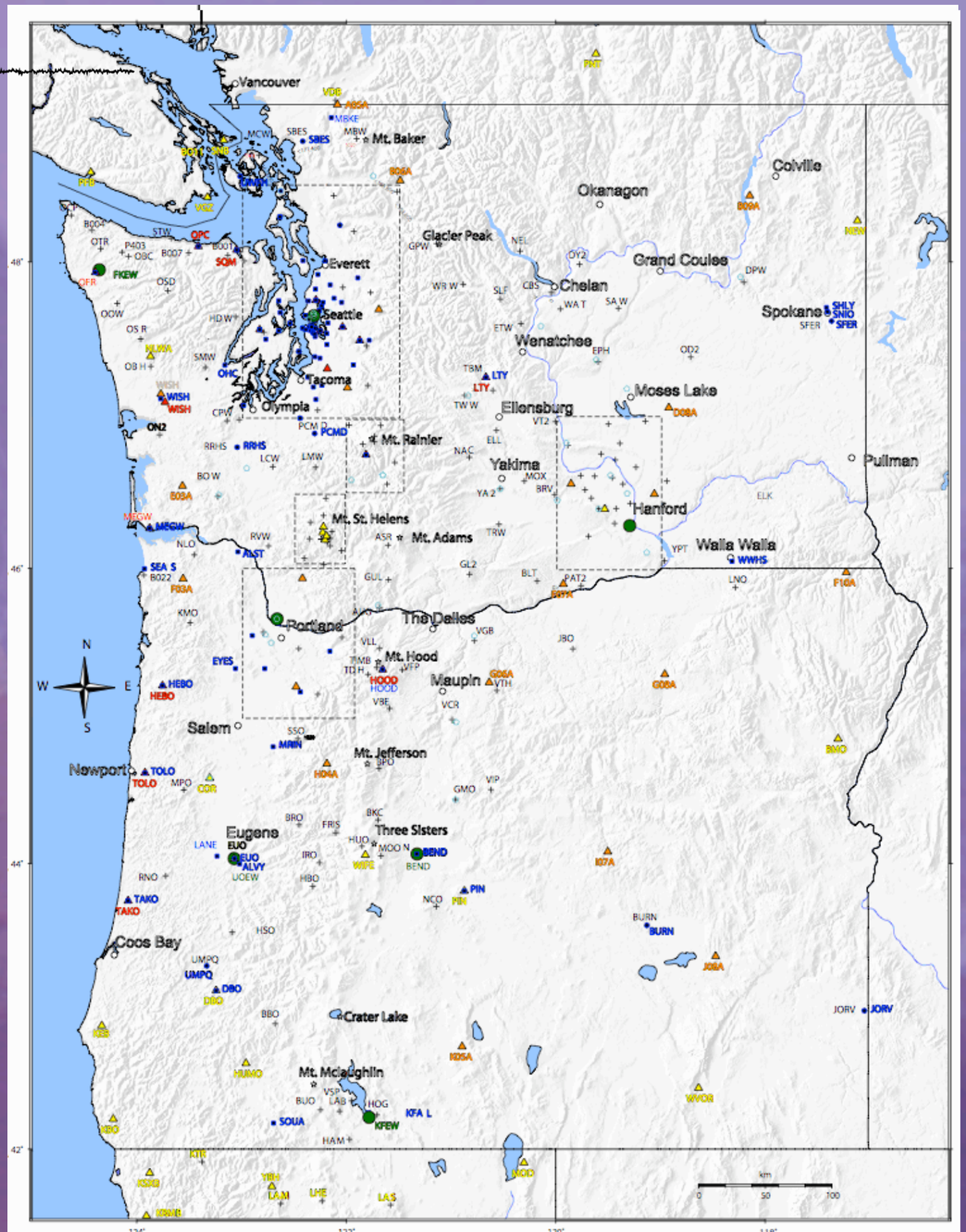

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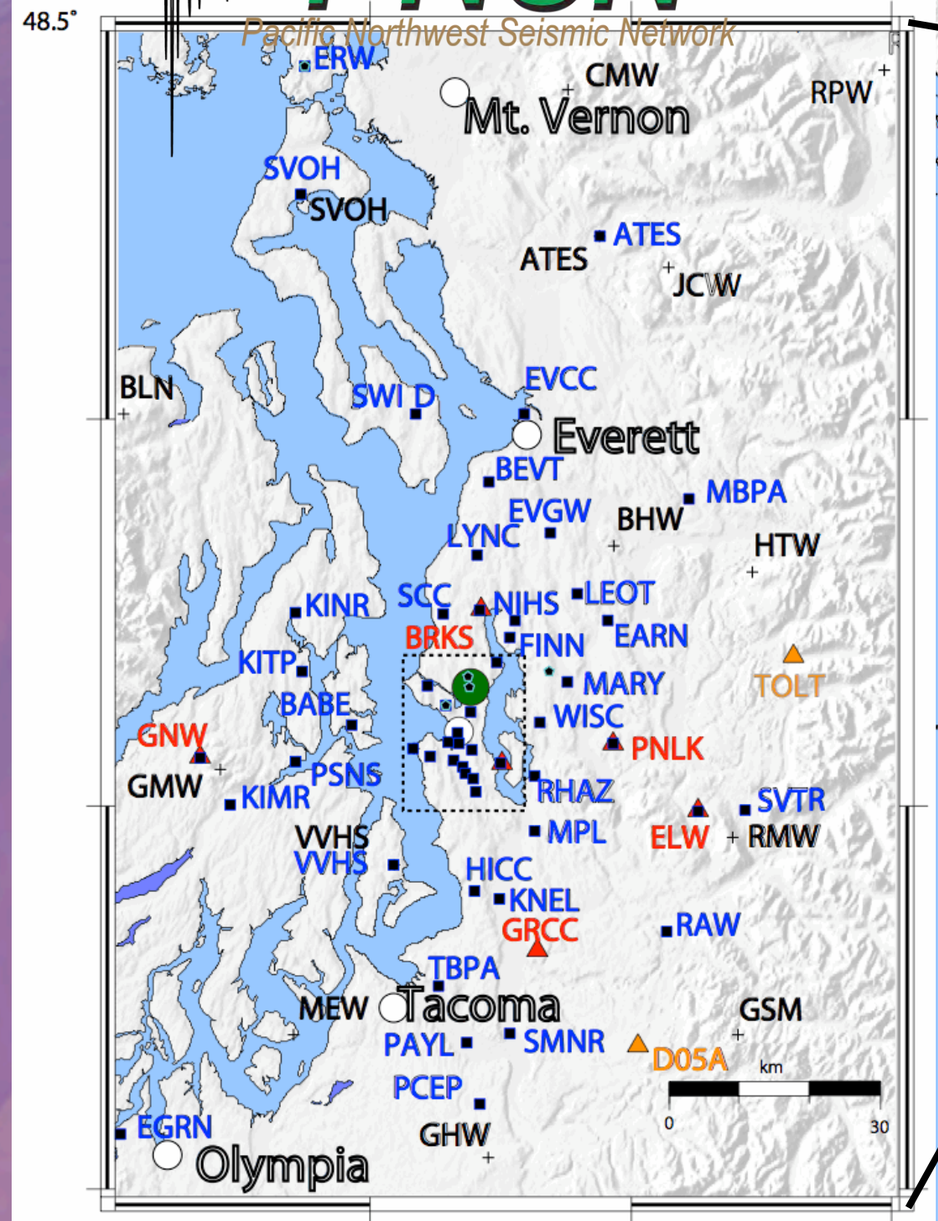
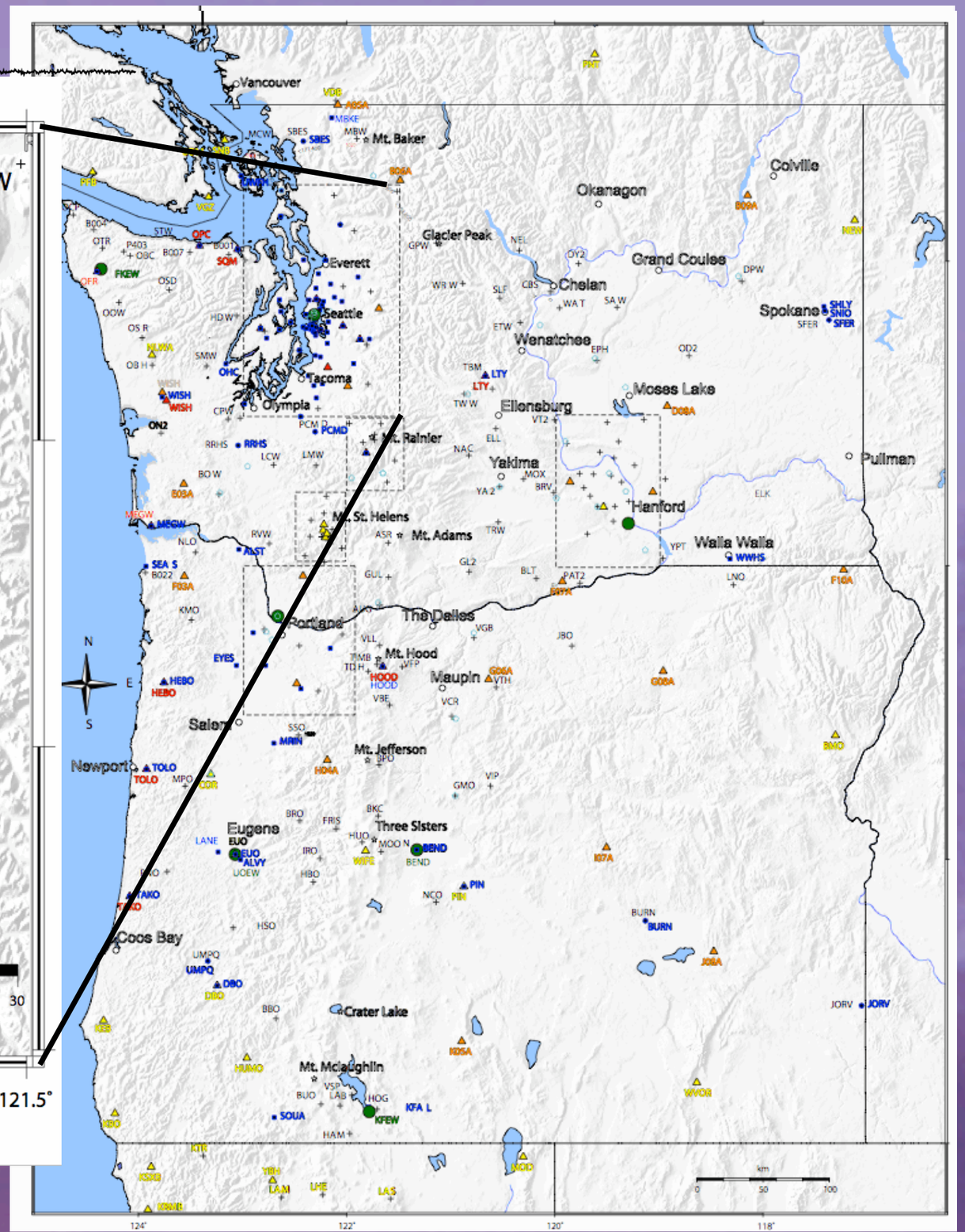


Puget Sound



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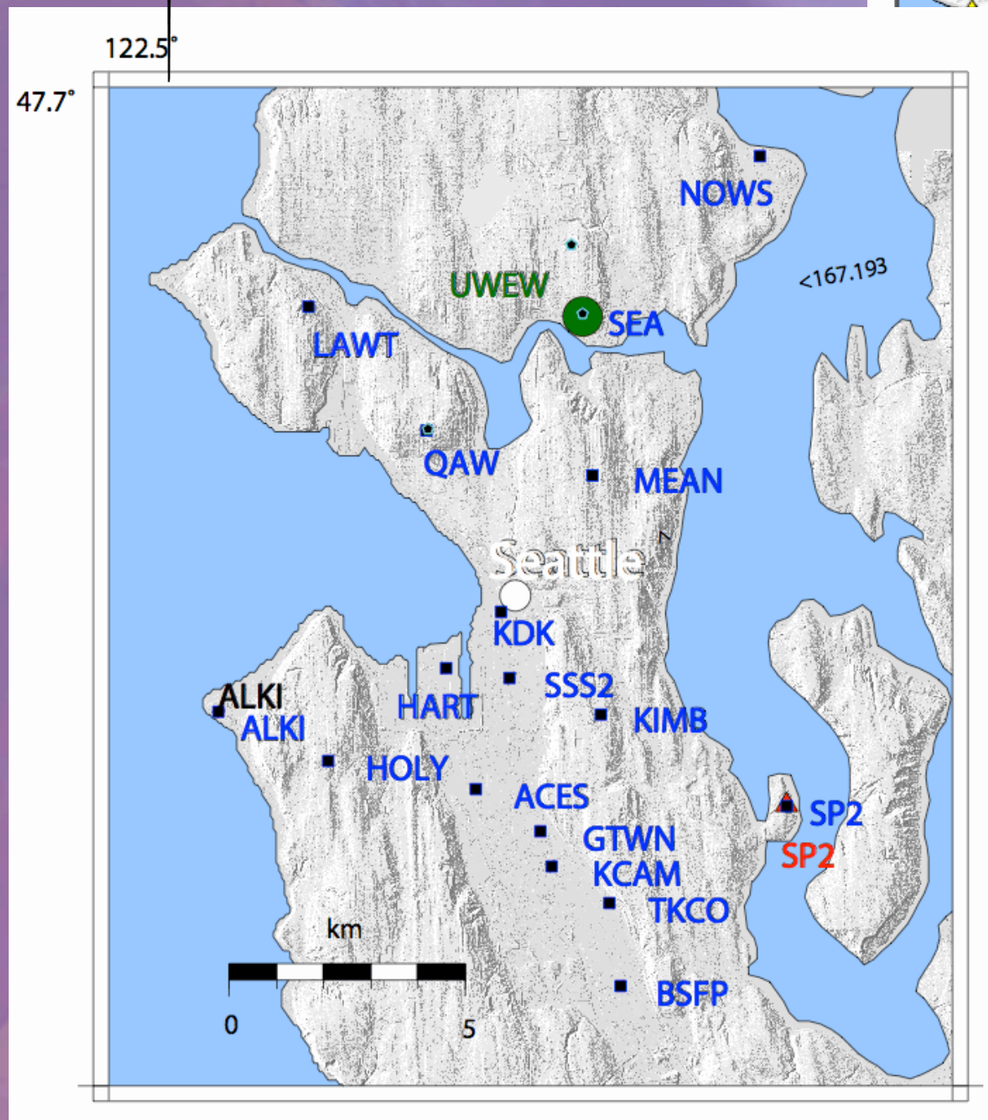
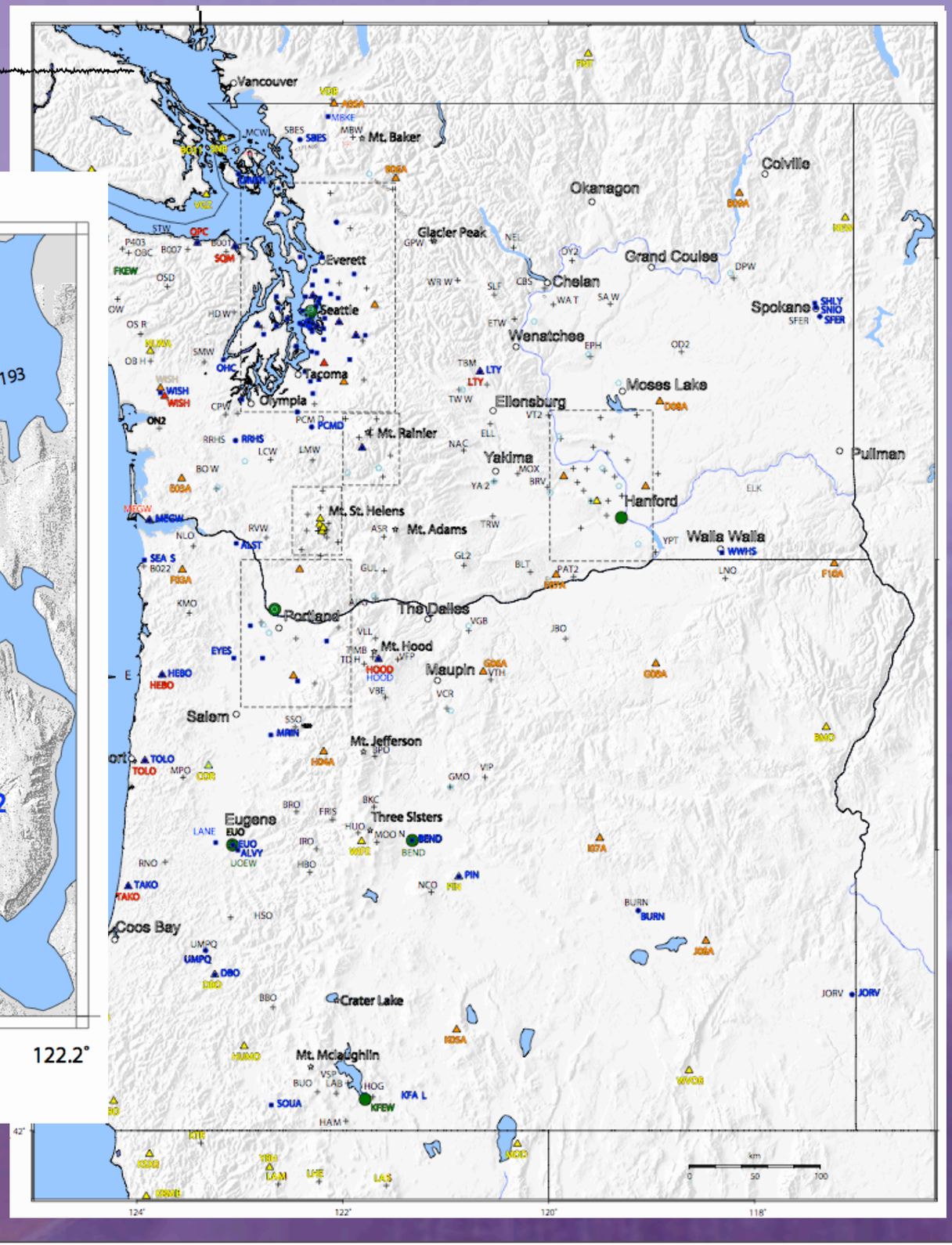


Seattle



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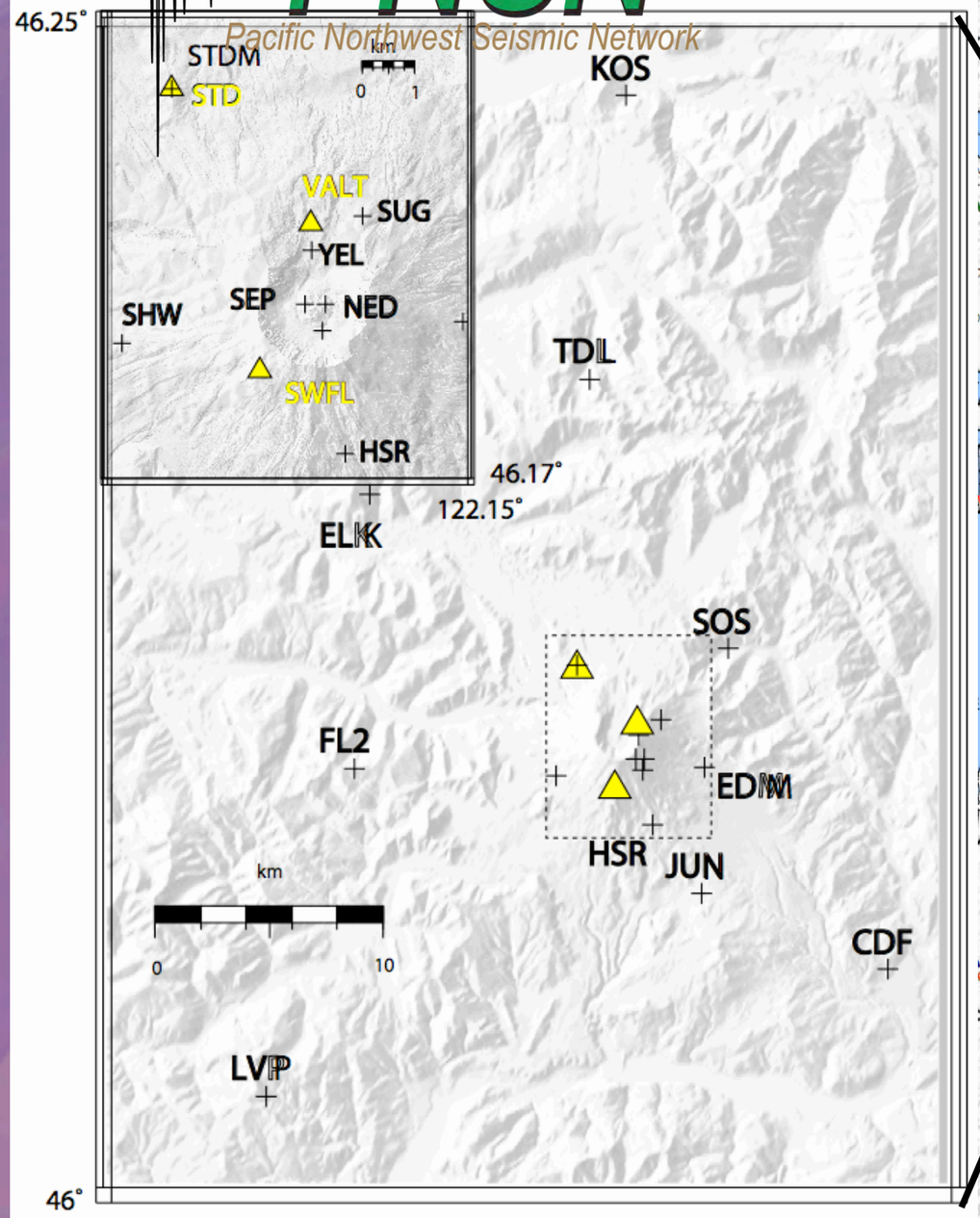
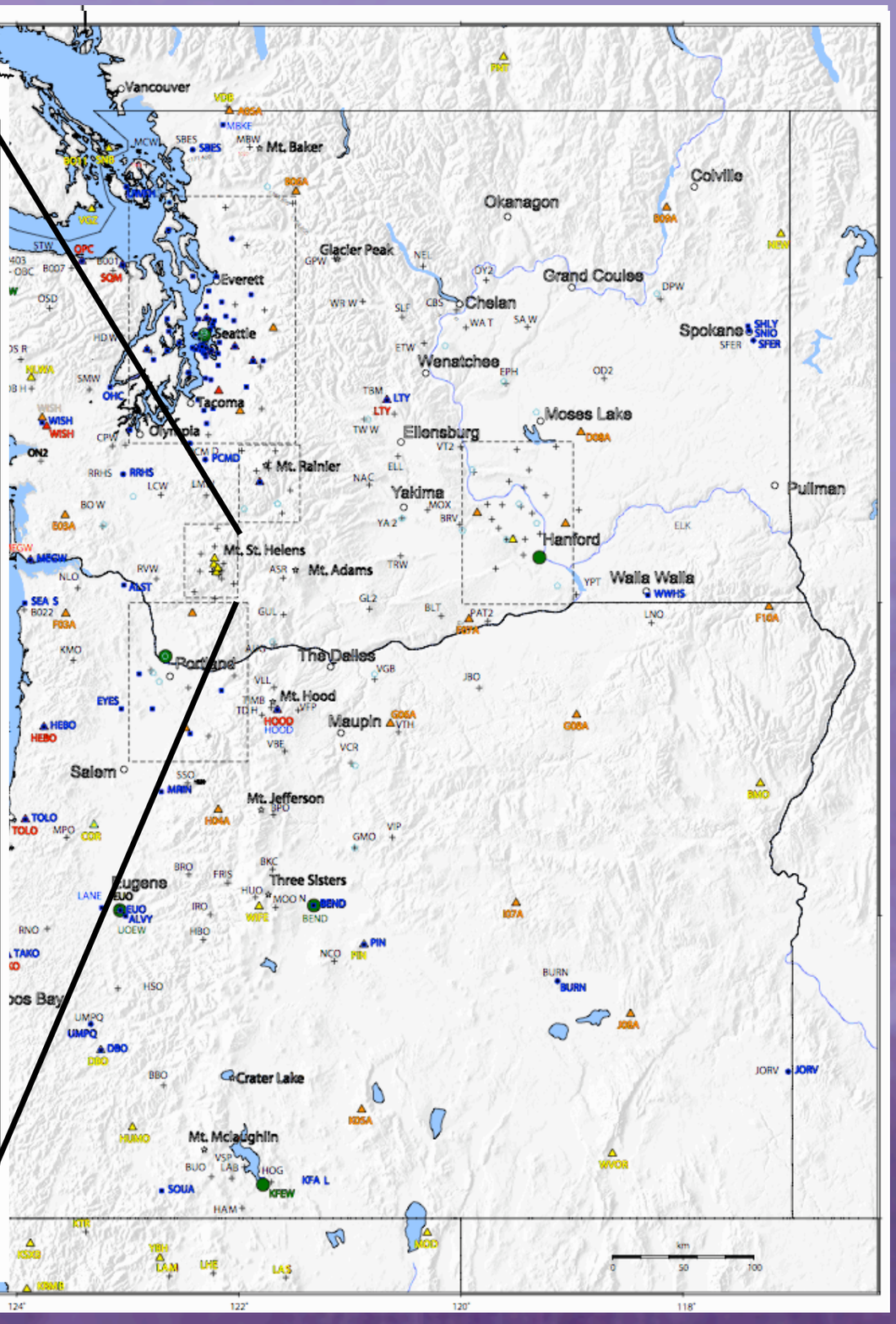
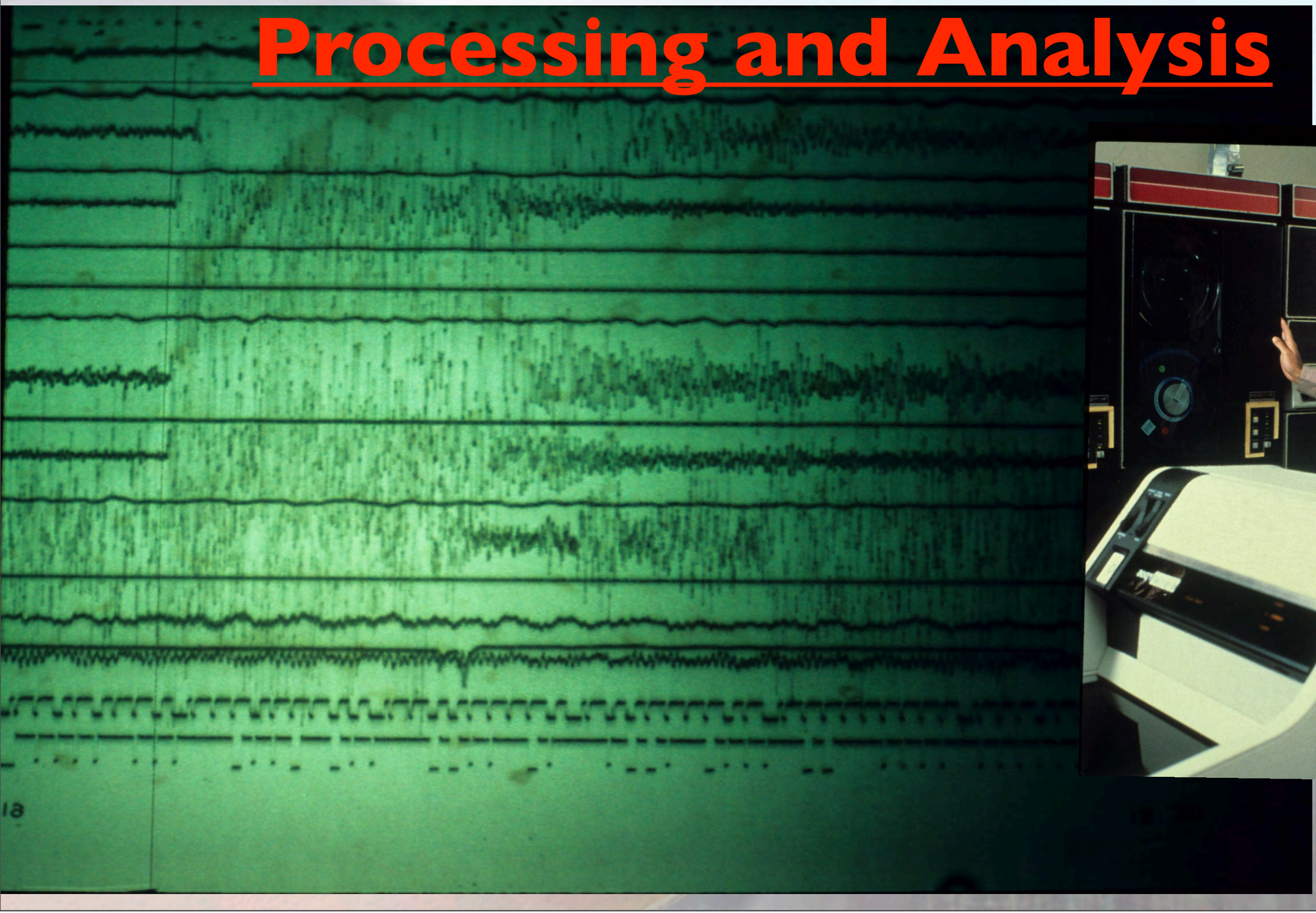


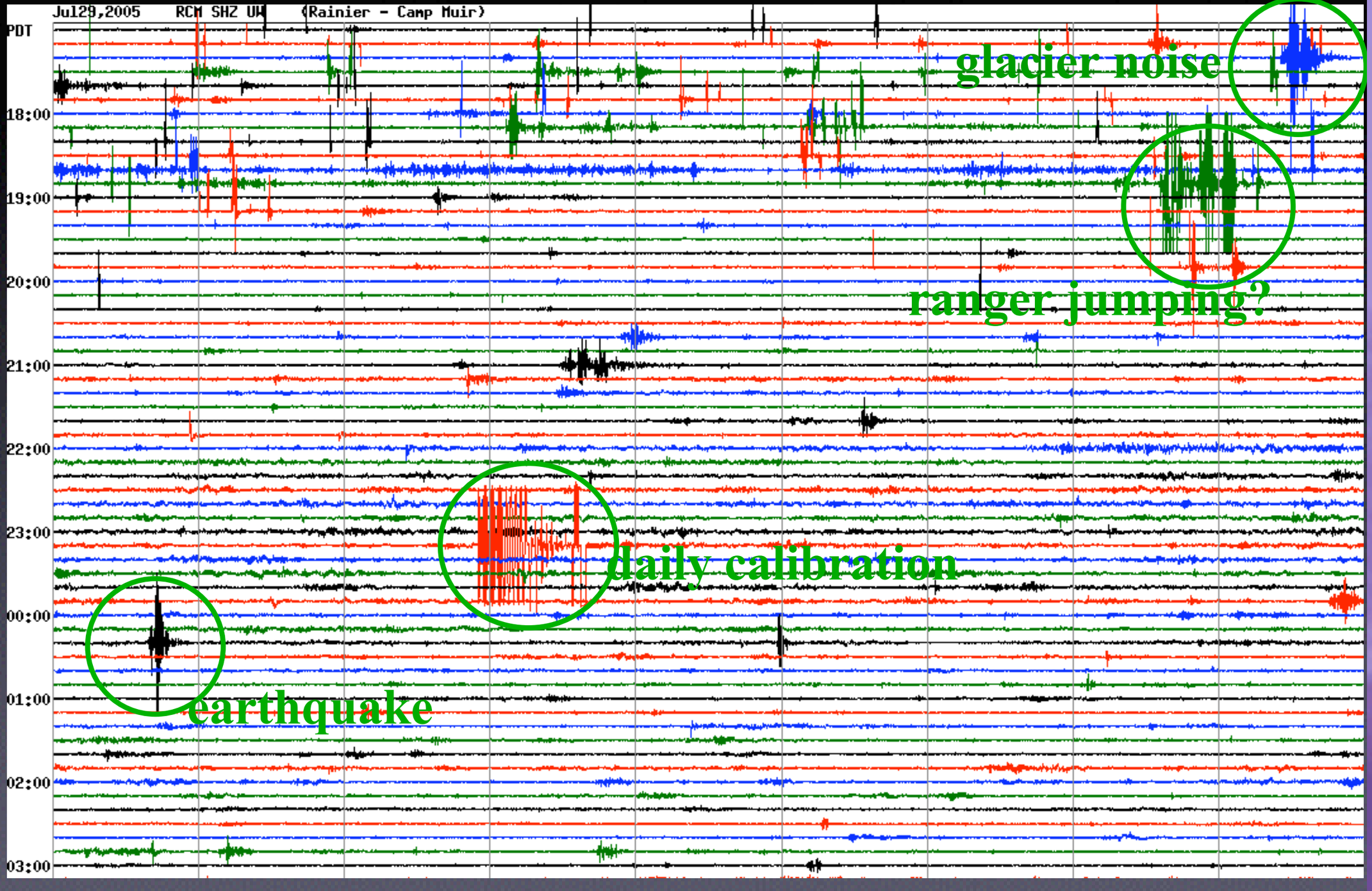


Mt. St. Helens

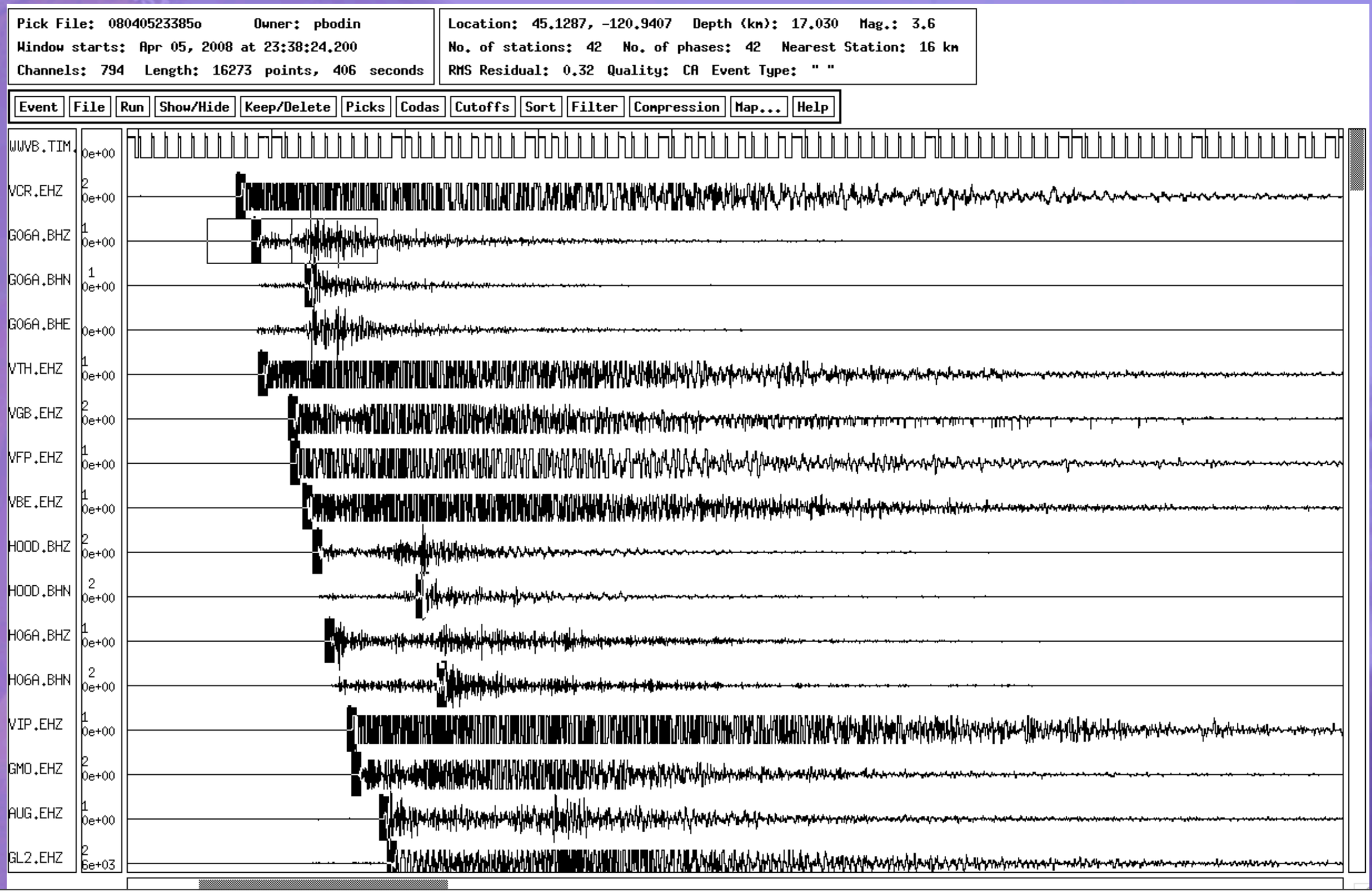
Processing and Analysis



Camp Muir


Jul29,2005 RCM SHZ UW (Rainier - Camp Muir)
PDT
18:00
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
glacier noise
ranger jumping?
daily calibration
earthquake

Manual analysis



Manual analysis

Pick File: 08040523385o Owner: pbodin
Window starts: Apr 05, 2008 at 23:38:24.200
Channels: 794 Length: 16273 points, 406 seconds

Location: 45.1287, -120.9407 Depth (km): 17.030 Mag.: 3.6
No. of stations: 42 No. of phases: 42 Nearest Station: 16 km
RMS Residual: 0.32 Quality: CA Event Type: " "

Event | File | Run | Show/Hide | Keep/Delete | Picks | Codas | Cutoffs | Sort | Filter | Compression | Map... | Help

WWVB.TIM
VCR.EHZ
G06A.BHZ
G06A.BHN
G06A.BHE
VTH.EHZ
VGB.EHZ
VFP.EHZ
VBE.EHZ
HOOD.BHZ
HOOD.BHN
H06A.BHZ
H06A.BHN
VIP.EHZ
GMO.EHZ
AUG.EHZ
GL2.EHZ

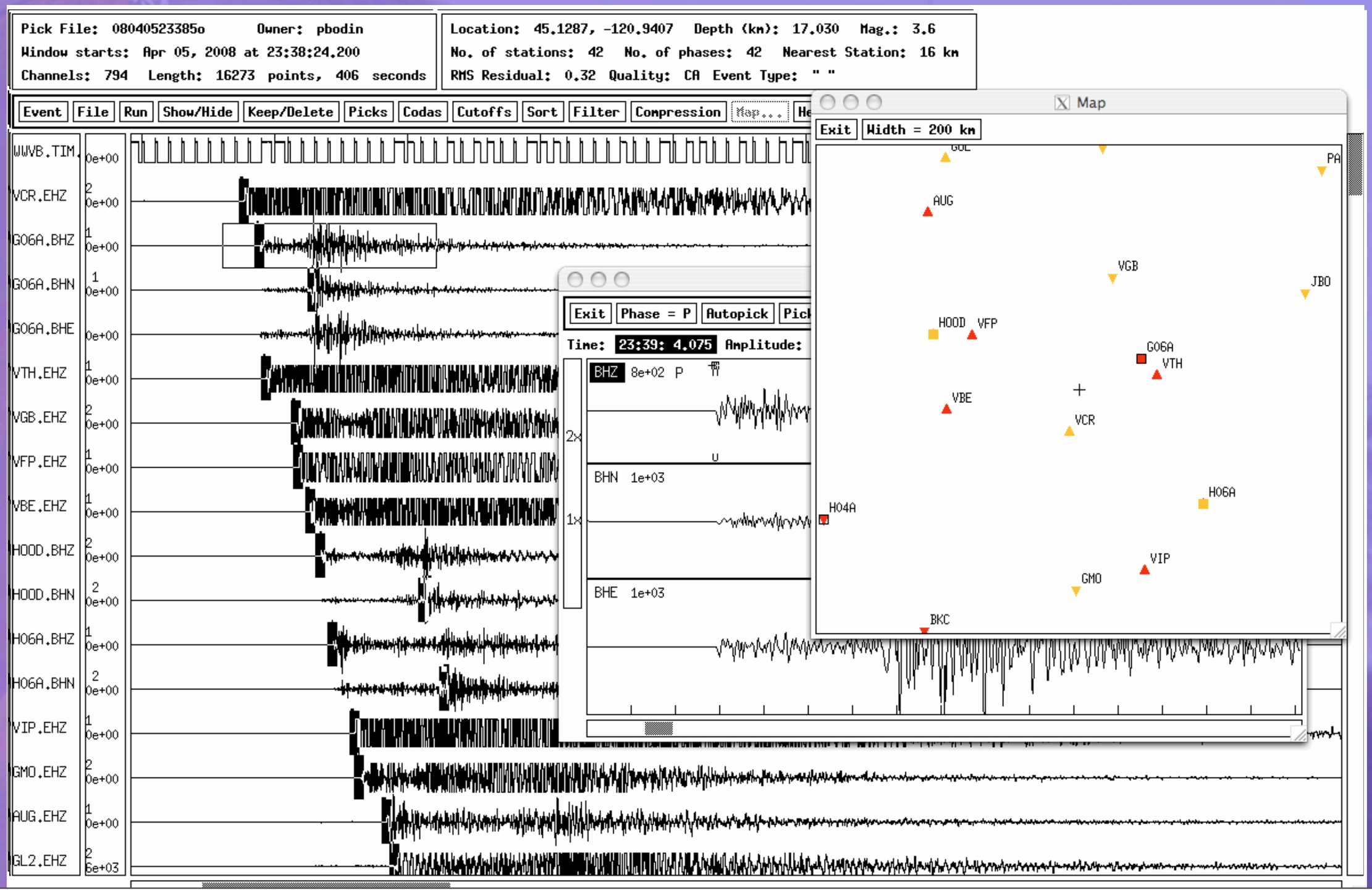
G06A

Exit | Phase = P | Autopick | Pick | Error | Polarity | Amp | Remove | Scale

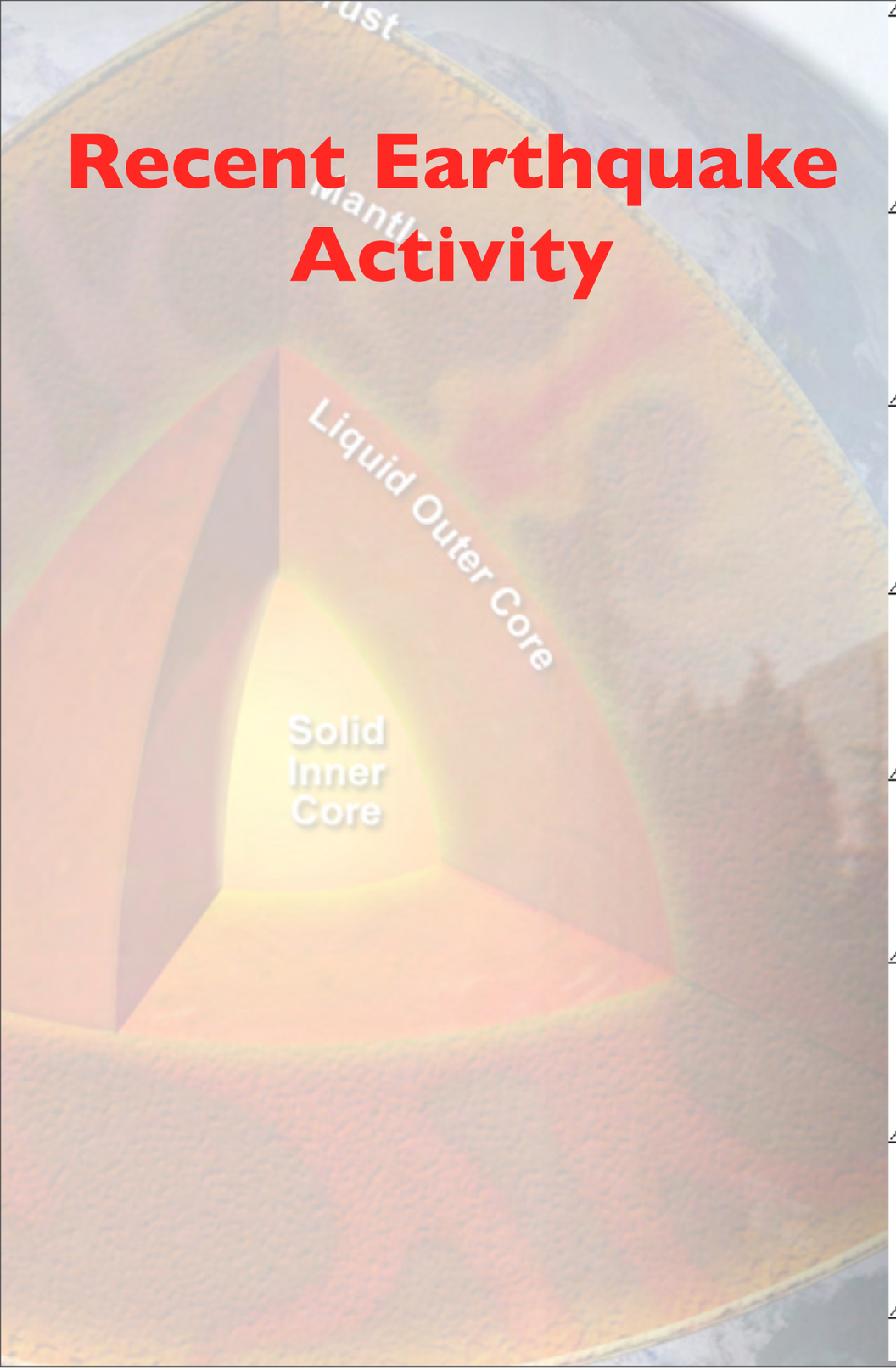
Time: 23:39: 4.075 Amplitude: -28802

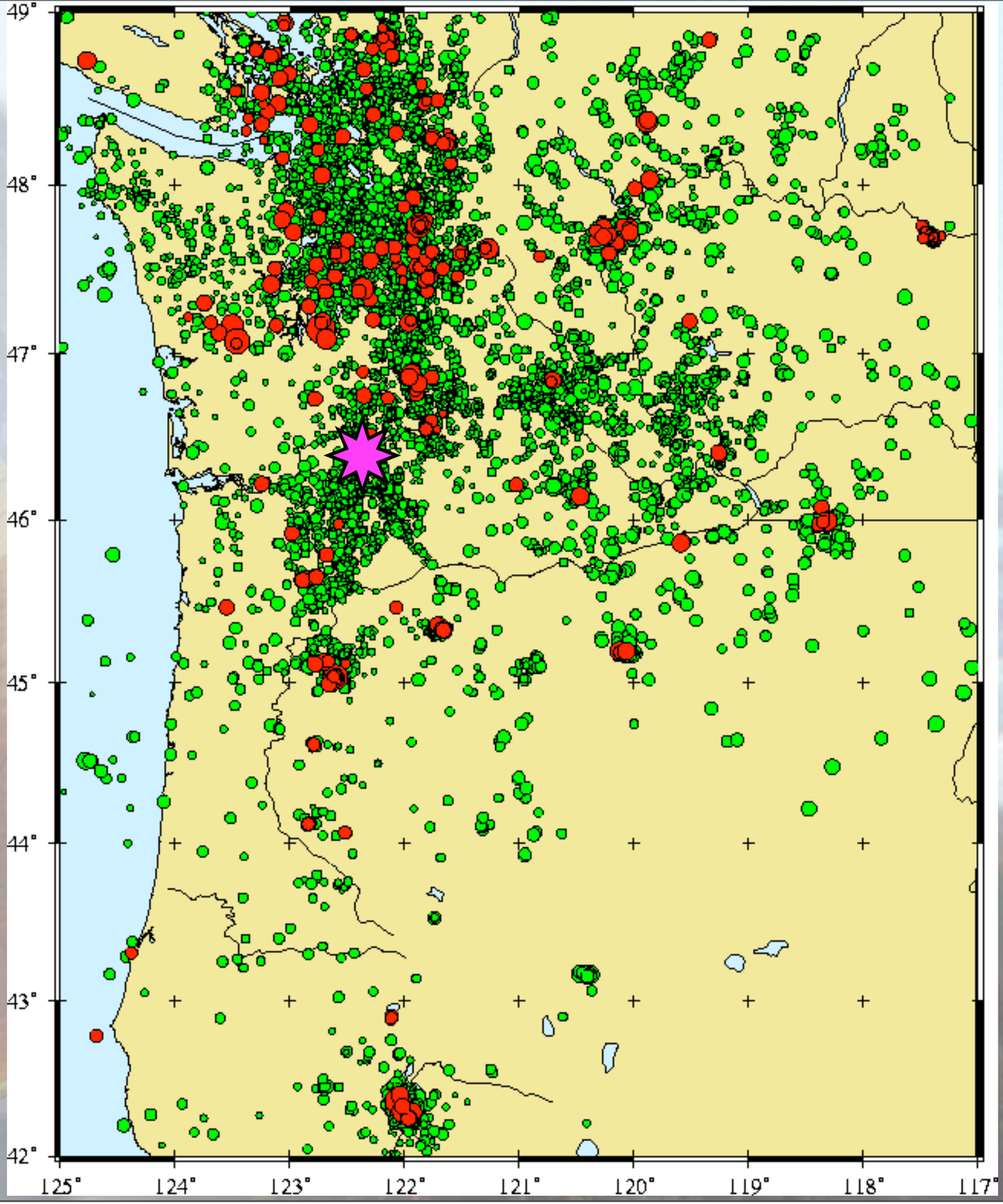
BHZ 8e+02 P
BHN 1e+03 S
BHE 1e+03

Manual analysis



Recent Earthquake Activity



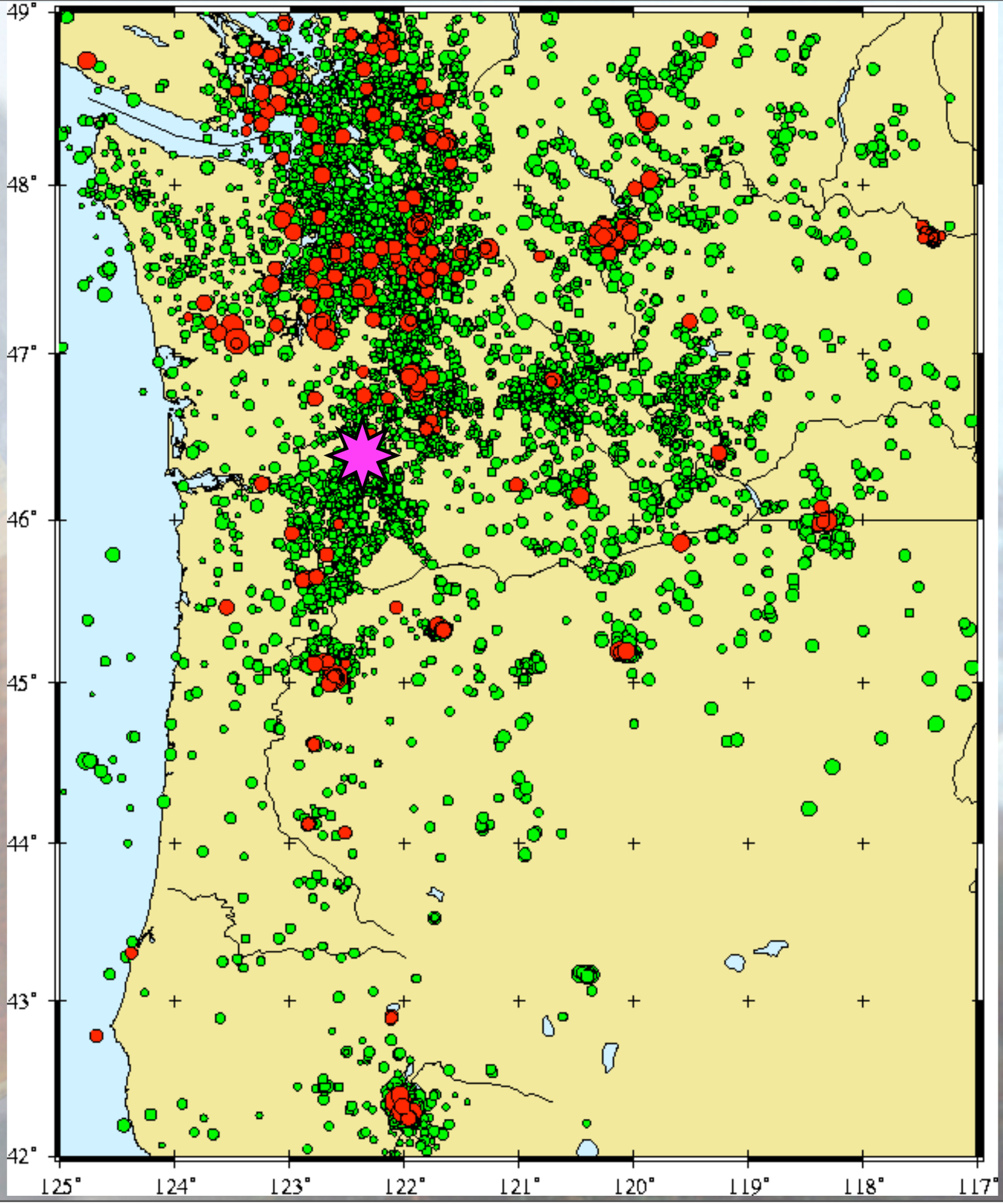


Recent Earthquake Activity

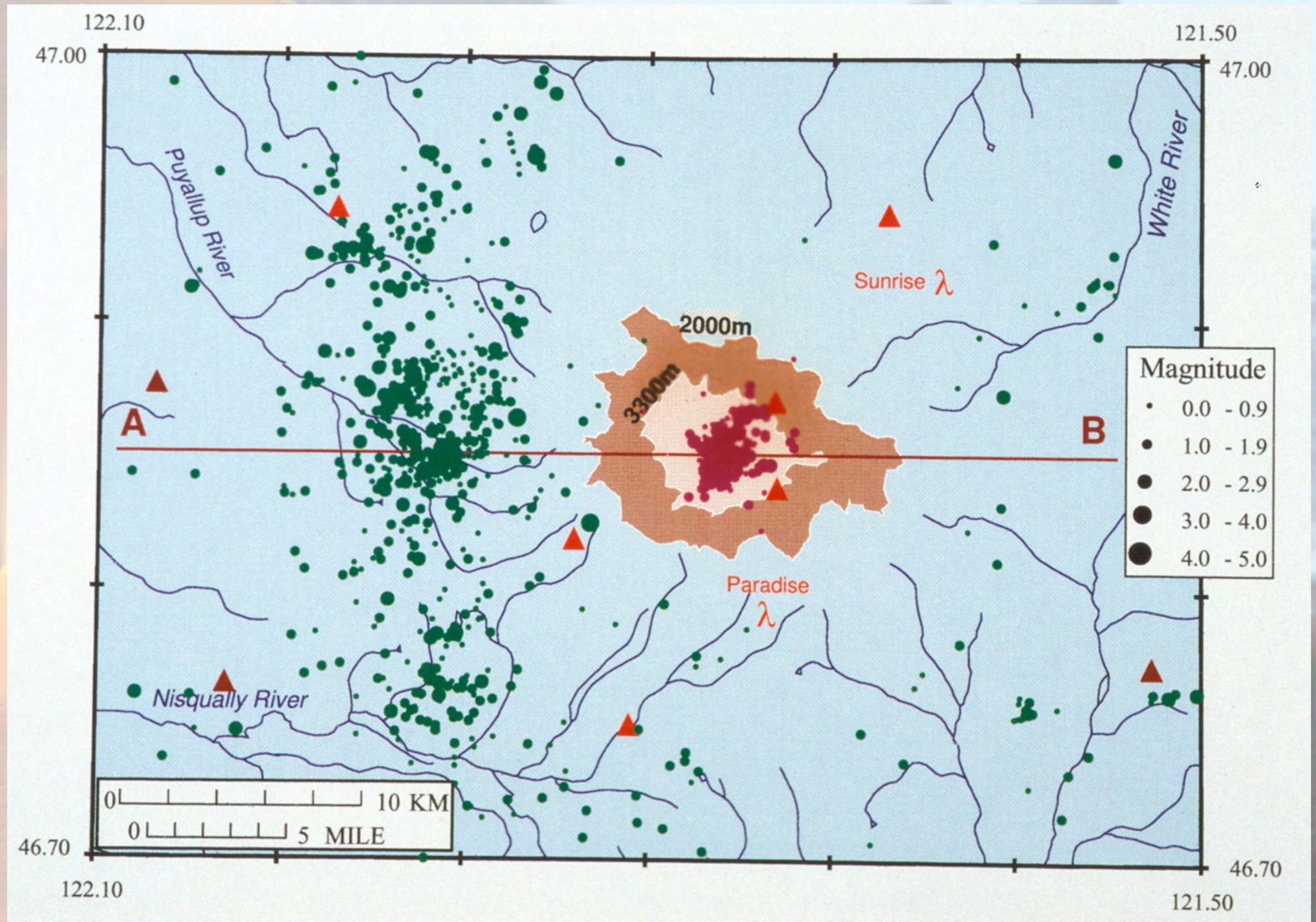
1990 - 2004

Mag > 0.5

- 27,900 events located
- 437 reported felt
- >2,000,000 at Mount St. Helens in 4 years



Mount Rainier Seismicity



The PNSN using EarthScope facilities is involved in many different scientific Studies

Just a few are highlighted here:

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Just a few are highlighted here:

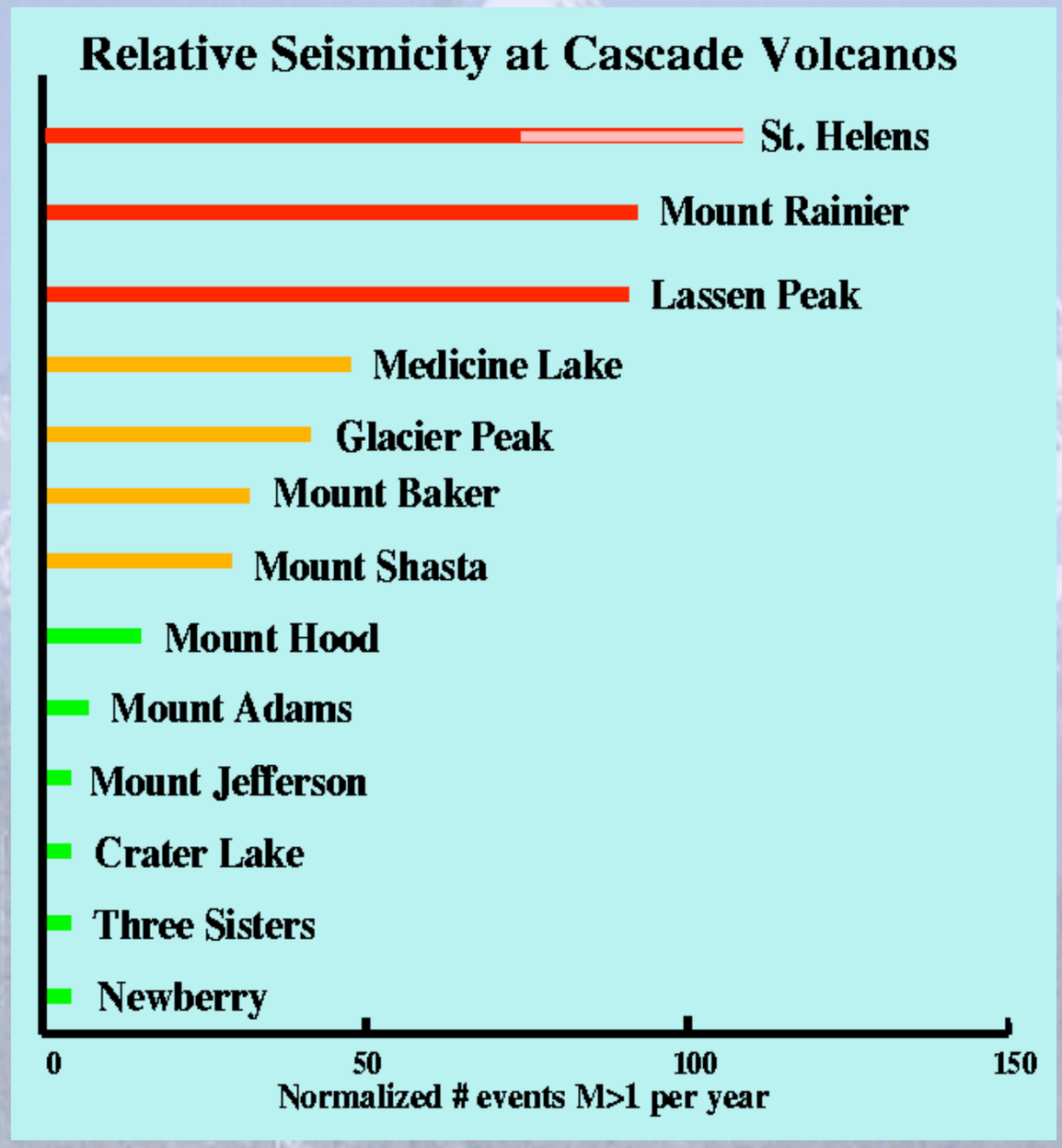
- Volcanic eruptions & Hazards
- Tectonics and earthquake hazards
- Episodic Tremor and Slip (ETS)
- Early Warning

Volcano Research

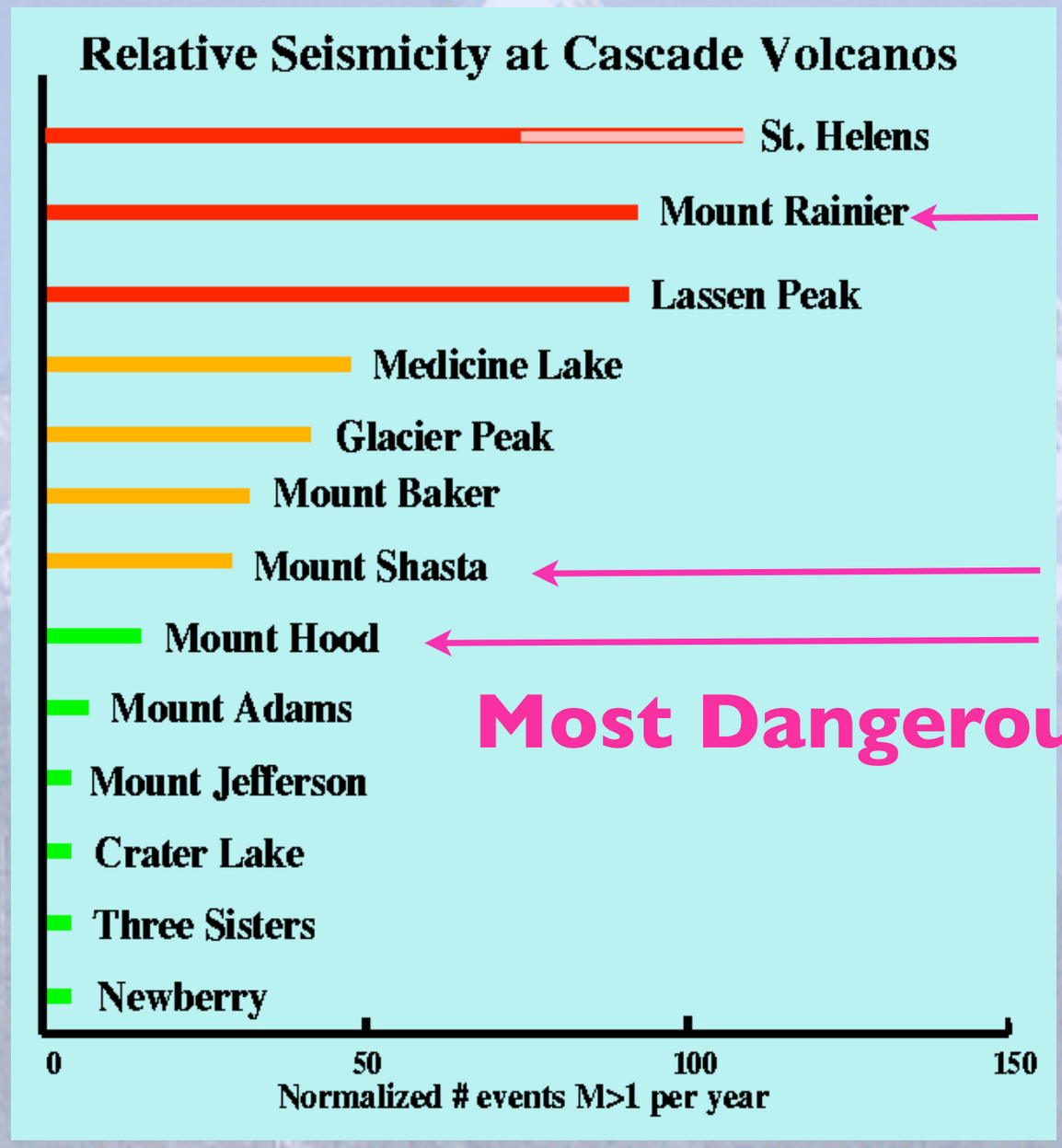
Volcano Research

- All Cascade Volcanoes are monitored
- Primary research efforts have been at Mount St. Helens
- Addition of PBO borehole seismometers is exciting new data source

Comparing Cascade Volcanoes



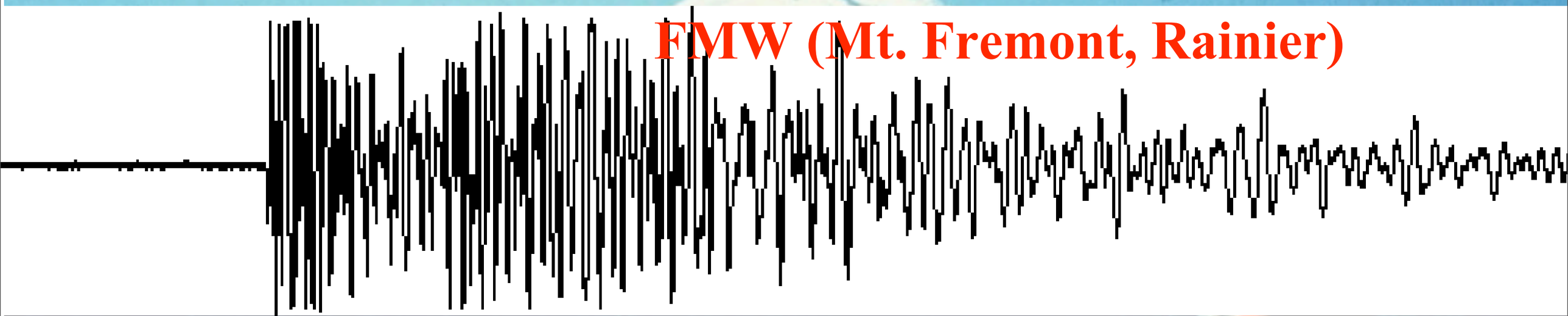
Comparing Cascade Volcanoes



Mount St. Helens - 1979

Mount St. Helens - 1979

It all started with a Magnitude 4.1 earthquake on March 20, 1980



SHW -24 082:0701Z

Helicorder records of the next several days from St. Helens West seismograph

March 22

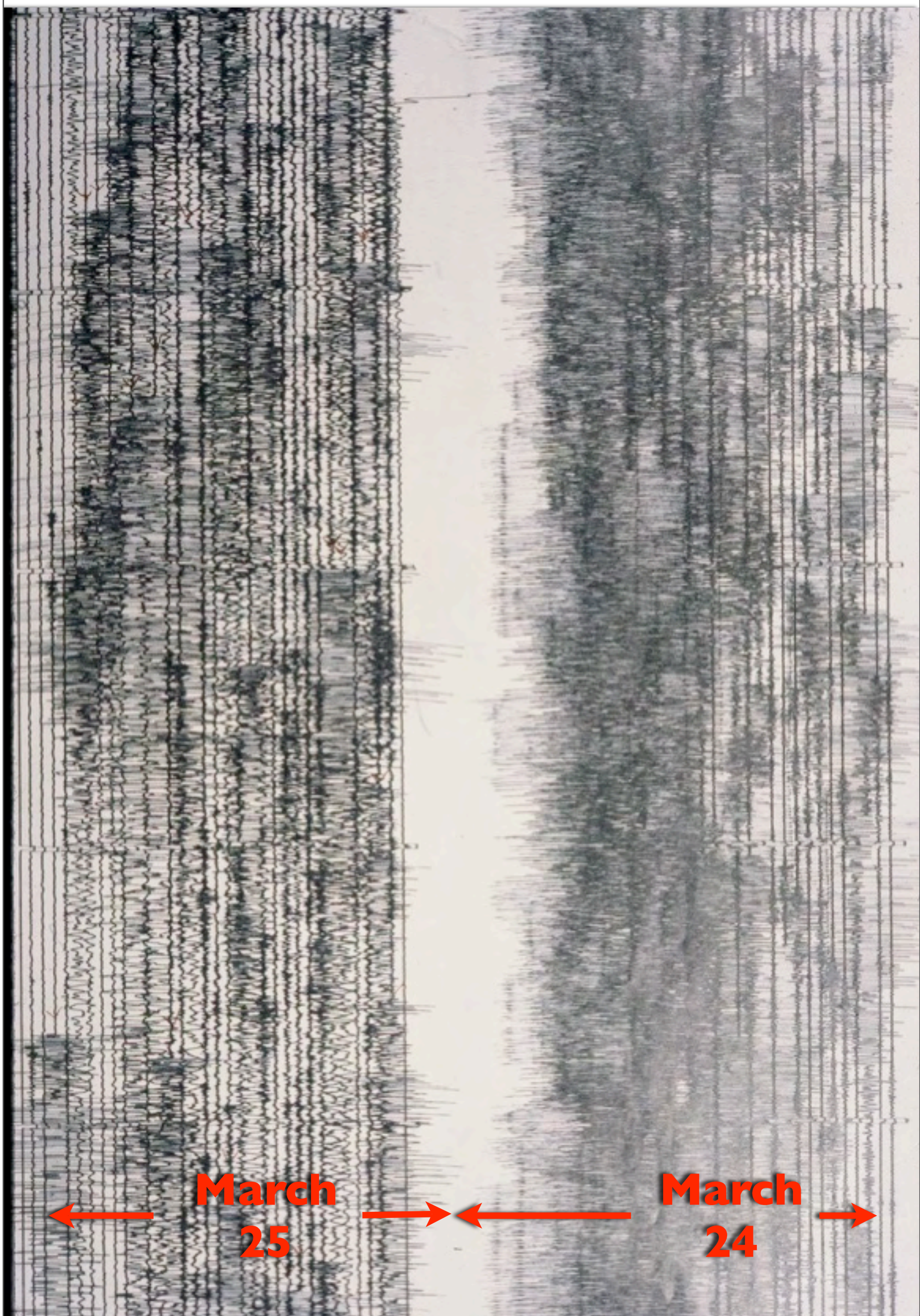
March 23

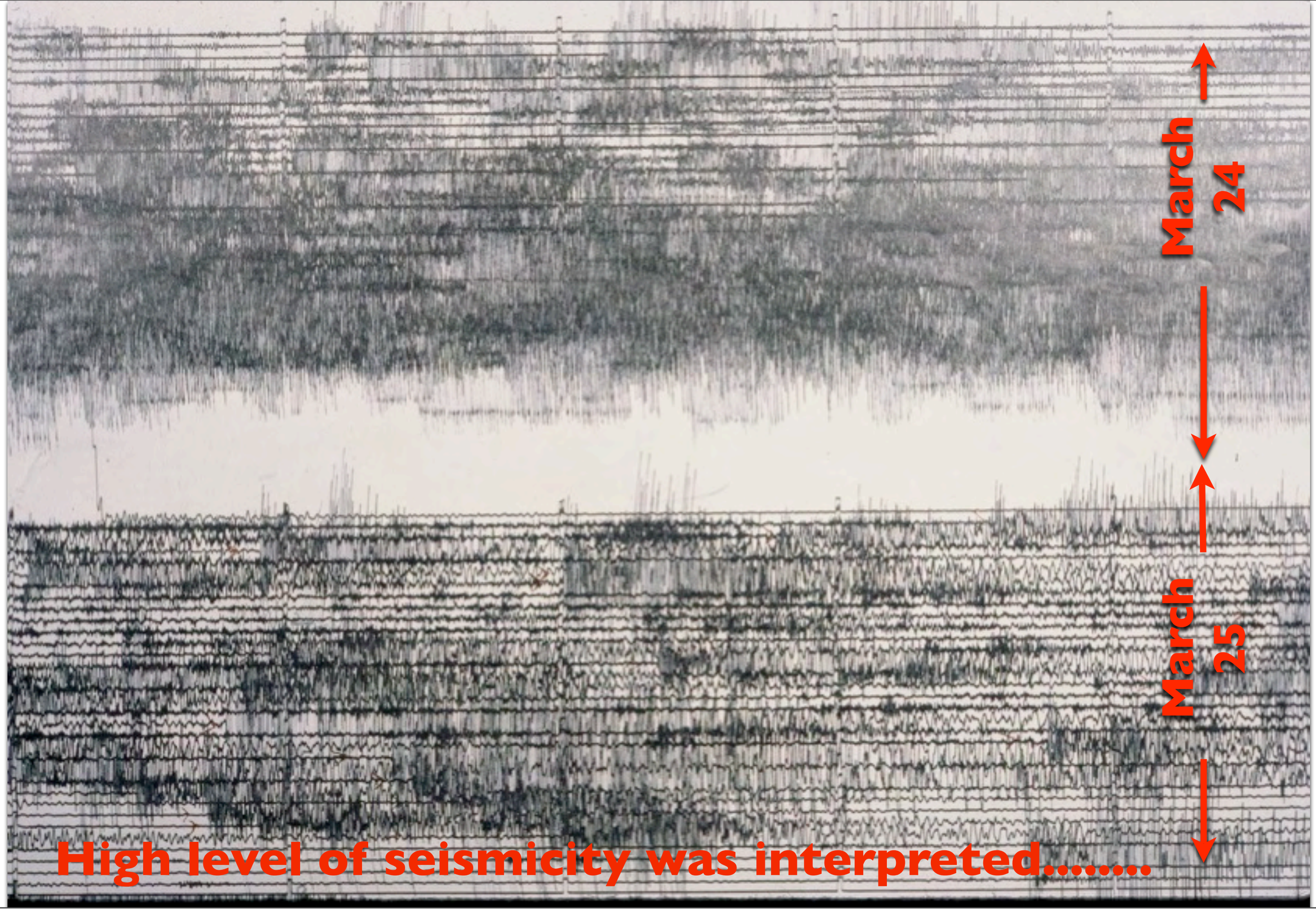
SHW -24 082:0701Z

3

March 22

March 23


March
25
March
24


March 24
March 25
High level of seismicity was interpreted.....

The Weather
DECREASING SHOWERS with periods of clearing. Increasing clouds tonight. Highs 45-55; lows 35-40. Winds south to southwest 10 to 20 mph. Chance of rain 30 percent. Table, Page F-8.

P-I Phone Listings, Page A-5

5★

Seattle
Post-Intelligencer

THE VOICE OF THE NORTHWEST ... SINCE 1863

Copyright 1980, Seattle Post-Intelligencer

Thursday, March 27, 1980

20c in Western Washington; Canada 30c; Elsewhere as Posted

THURS. A.M.

Evacuation Plans Made

Mt. St. Helens Eruption 'Soon'

Tremors Still Go On

By Michael Sweeney

Emergency service agencies around Mount St. Helens mapped evacuation plans last night as a Portland geologist predicted that the earthquake-rocked dormant volcano would erupt soon.

Leonard Palmer, a geologist at Portland State University, said flatly yesterday that a volcanic eruption on the Southwest Washington mountain "is imminent."

"It could appear within days," Palmer told The Associated Press. "There is very definitely a pattern of earthquakes before they (volcanoes) erupt."

The man most familiar with the geology of Mount St. Helens, U.S. Geological Survey geologist Donal Mullineaux, conceded that a similar pattern of earthquakes had preceded volcanic eruptions in Japan.

But Palmer's prediction of an imminent eruption "is not a statement that I would care to make," Mullineaux said.

"We can't even say yet whether

AM
FRIDAY
March 28 1980

Mine elevator falls a mile, 23 die A 2

Washington's largest newspaper

The Seattle Times

84 pages

20c

Good morning

Rain likely

The weather forecast calls for clouds with an increasing chance of rain today and rain likely tonight. Showers and periods of clearing tomorrow. Highs, 50 to 55. Lows, 35 to 40. Southerly winds, 5 to 15 miles an hour. Chance of rain: 30 per cent today, 50 per cent tonight. D 2.

Northwest

Mystery illness. A mysterious illness that has beached 30 seals may be linked to a spill of toxic chemicals off a container ship that ran into rough seas. D 1.

Colacurcio involved. James E. Eyre, Sr., facing charges of stealing more than $350,000 from a Wenatchee church, testified that Frank Colacurcio, Seattle nightclub figure, got Eyre a $40,000 personal loan. D 1.

Adoption invalidated. A King County judge overturned the adoption of an Indian girl, ruling she should live with relatives in California. D 1.

Rising prices. Natural-gas companies were granted rate increases totaling $108 million to offset the higher cost of Canadian gas. D 2.

Nation

Bank ripoff. An Italian financier was convicted of looting New York's Franklin National Bank of $45 million, causing it to collapse in the biggest bank failure in the nation's history. A 4.

House probe. The House of Representatives approved a probe of seven House members implicated in a Federal Bureau of Investigation bribery investigation. A 4.

Mount St. Helens erupts; new crater heaves, cracks widen

A steaming, churning crater and widening cracks near the summit of Mount St. Helens were watched closely last night, following the mountain's first volcanic activity in more than a century.

"The crater is heaving and falling in," said Sylvia Brucchi of the United States Forest Service. "It's constantly increasing in size."

The mountain, dormant since 1857, erupted with a thunderous boom and a spray of ash about 1 p.m. yesterday. The blast was heard up to 45 miles away and the dark ashes covered the snow in several directions from the summit.

The continual widening of the cracks and crater caused uncertainty over how far the eruption would progress.

The oblong crater, created when sections of the mountain's snowy cone collapsed, was originally reported as about 200 feet across, but was estimated to be more than 300 feet wide by last night.

Ms. Brucchi said infrared photography of the summit showed "heat emissions" from the cracks, a hint of violent seismic activity inside the mountain.

The state Department of Emergency Services said all areas near the mountain were evacuated "on an advisory basis." Residents were told of the danger, but were

Volcano Research continues

- Stay tuned ..... for the next presentation

Rapid Notification research

The Earthquake has just taken place.
accurate information can help.

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- Mobilize rescue efforts to the right place

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- Direct inspection crews efficiently

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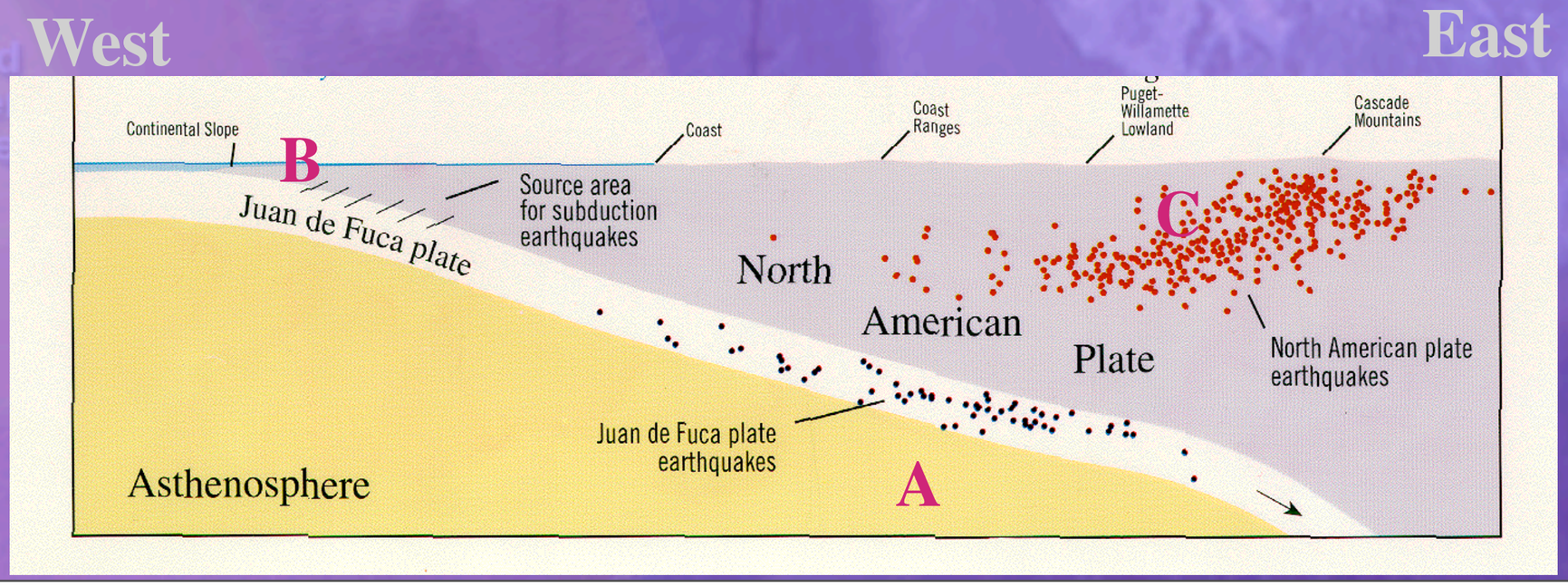
- Mobilize rescue efforts to the right place
- Direct inspection crews efficiently
- Estimate losses (costs) quickly

Our Vulnerability

The Pacific Northwest is vulnerable to a number of different geologic hazards.

Our Vulnerability

- **Seismic hazards**
  - **A. Benioff zone (earthquakes deeper than 40km)**
  - **B. Cascadia mega-thrust (along 1000 km of coast)**
  - **C. Crustal faults (most of region)**
  - **Shaking amplification from deep basins with shallow, soft soils**
  - **Many vulnerable structures (bridges, buildings dams)**



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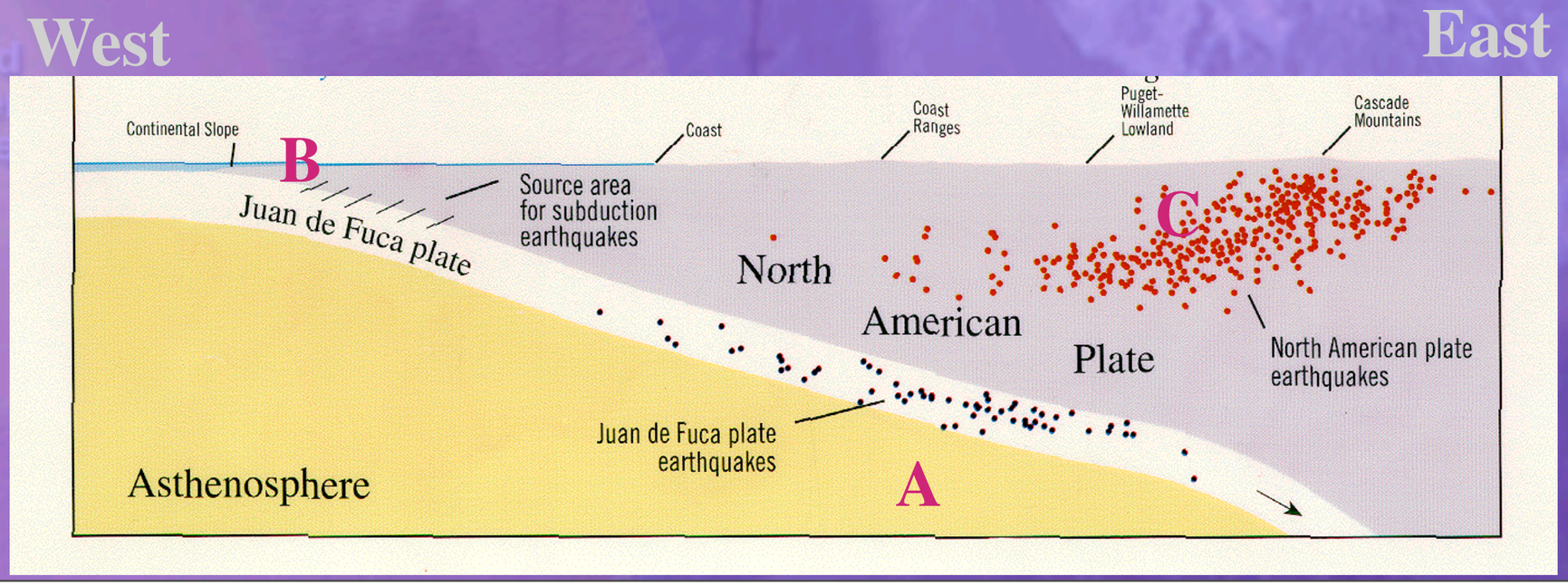
- **Volcanic hazards**



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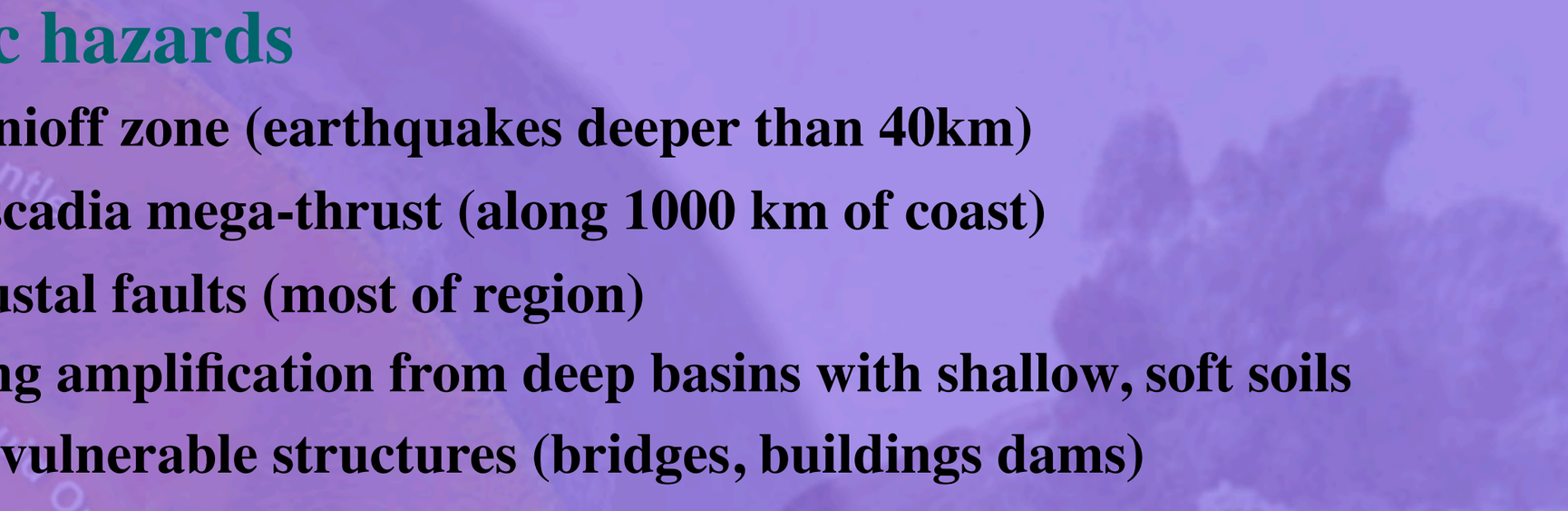
- **Volcanic hazards**
- **Tsunami Hazards**



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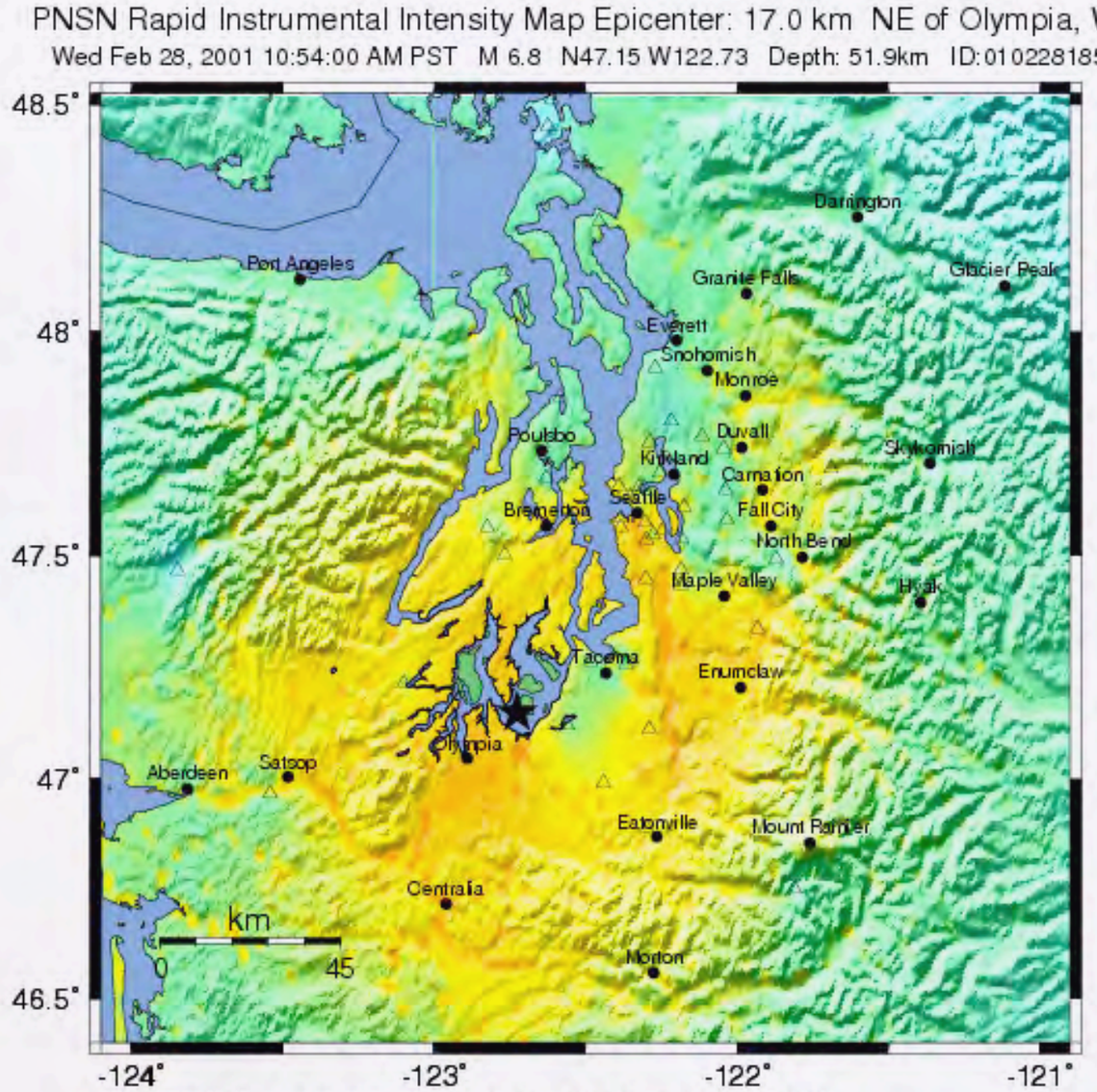
ShakeMap for 2001 Nisqually Earthquake

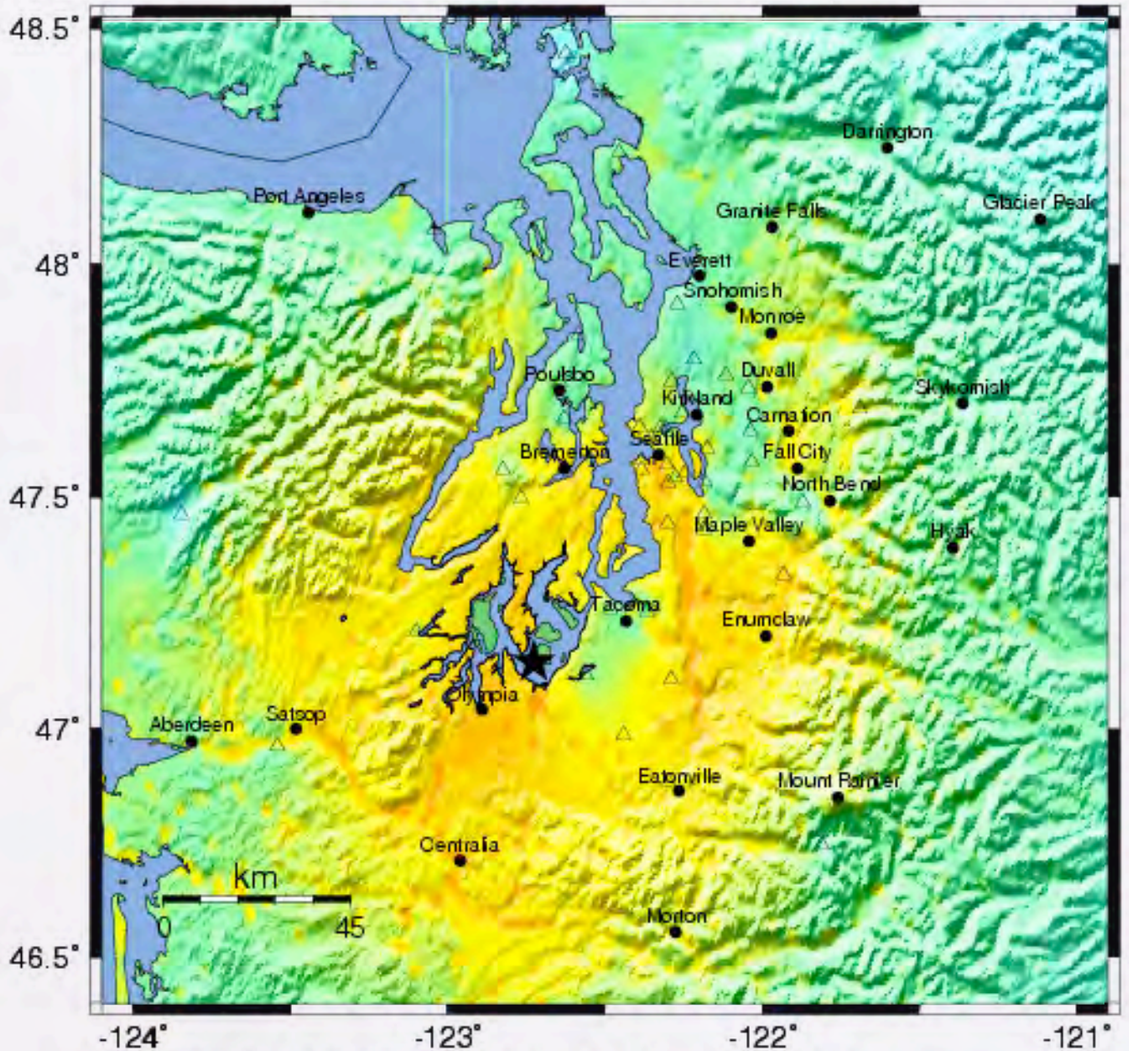


PROCESSED: Mon Oct 13, 2003 06:47:37 AM PDT, -- NOT REVIEWED BY HUMAN

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+

ShakeMap for 2001 Nisqually Earthquake

Shows distribution of shaking based on earthquake source, geology and measured values at specific sites

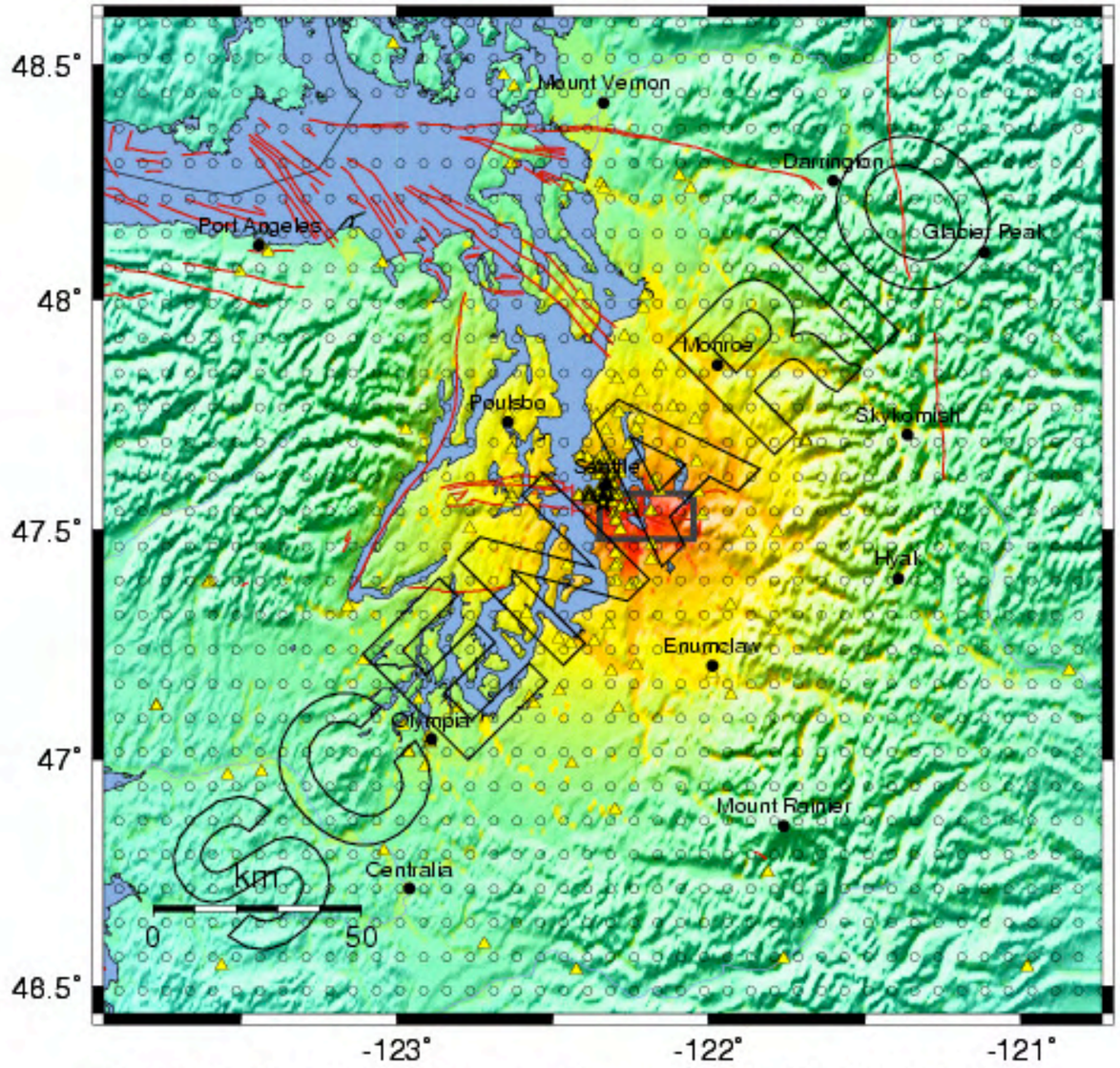


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	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 SoundShake08-3 Scenario

Scenario Date: Wed Mar 5, 2008 07:54:01 AM PST M 6.7 N47.56 W122.34 Depth: 10.0km

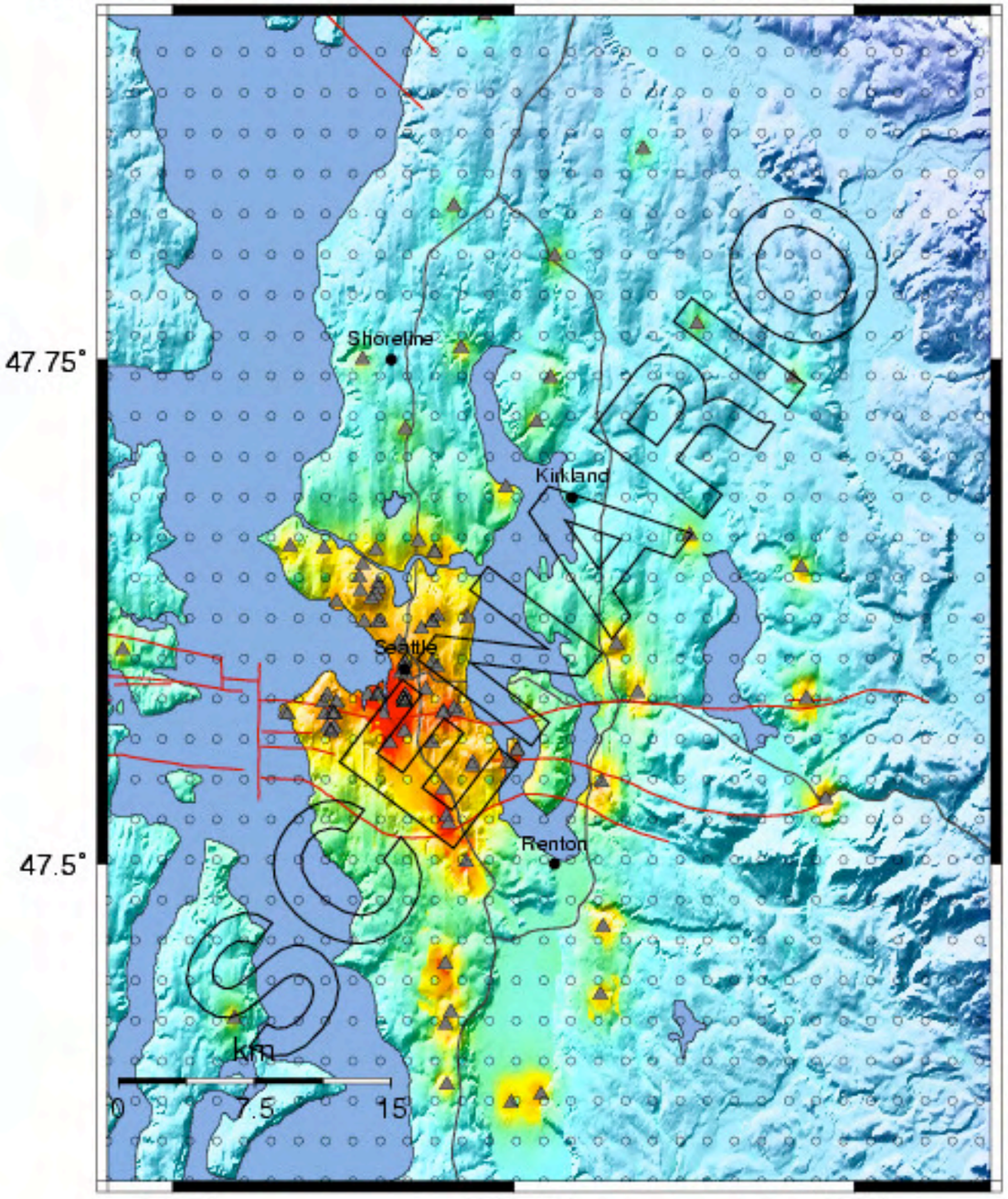


PLANNING SCENARIO ONLY -- Map Version 3 Processed Fri Feb 22, 2008 03:43:08 PM PST

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+

ShakeMap for SoundShake08-1 Scenario

Scenario Date: Wed Mar 5, 2008 07:54:01 AM PST M 4.7 N47.57 W122.35 Depth: 10.0km

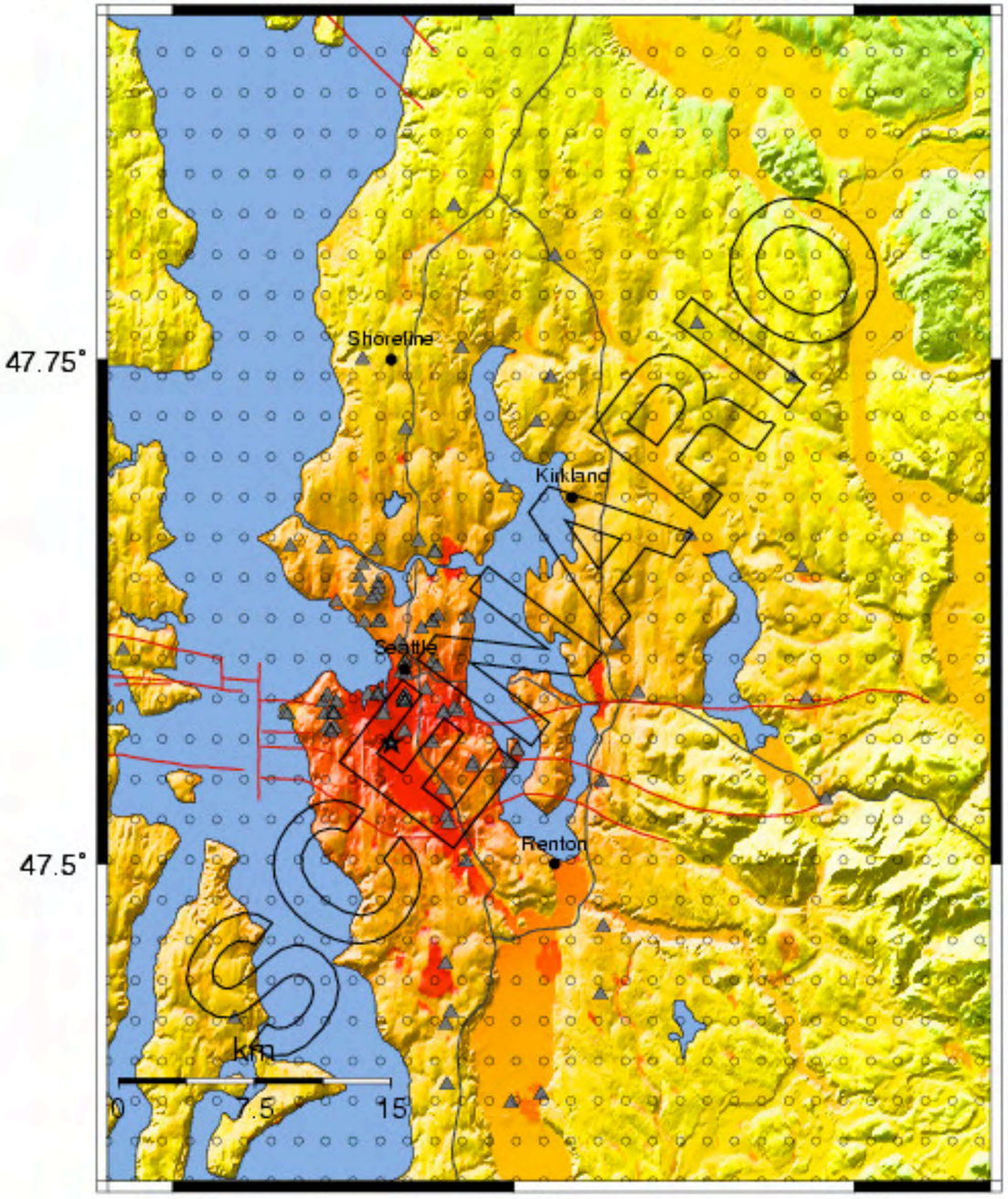


PLANNING SCENARIO ONLY -- Map Version 9 Processed Fri Feb 22, 2008 02:44:55 PM PST

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

ShakeMap for SoundShake08-2 Scenario

Scenario Date: Wed Mar 5, 2008 07:54:01 AM PST M 6.7 N47.56 W122.34 Depth: 10.0km

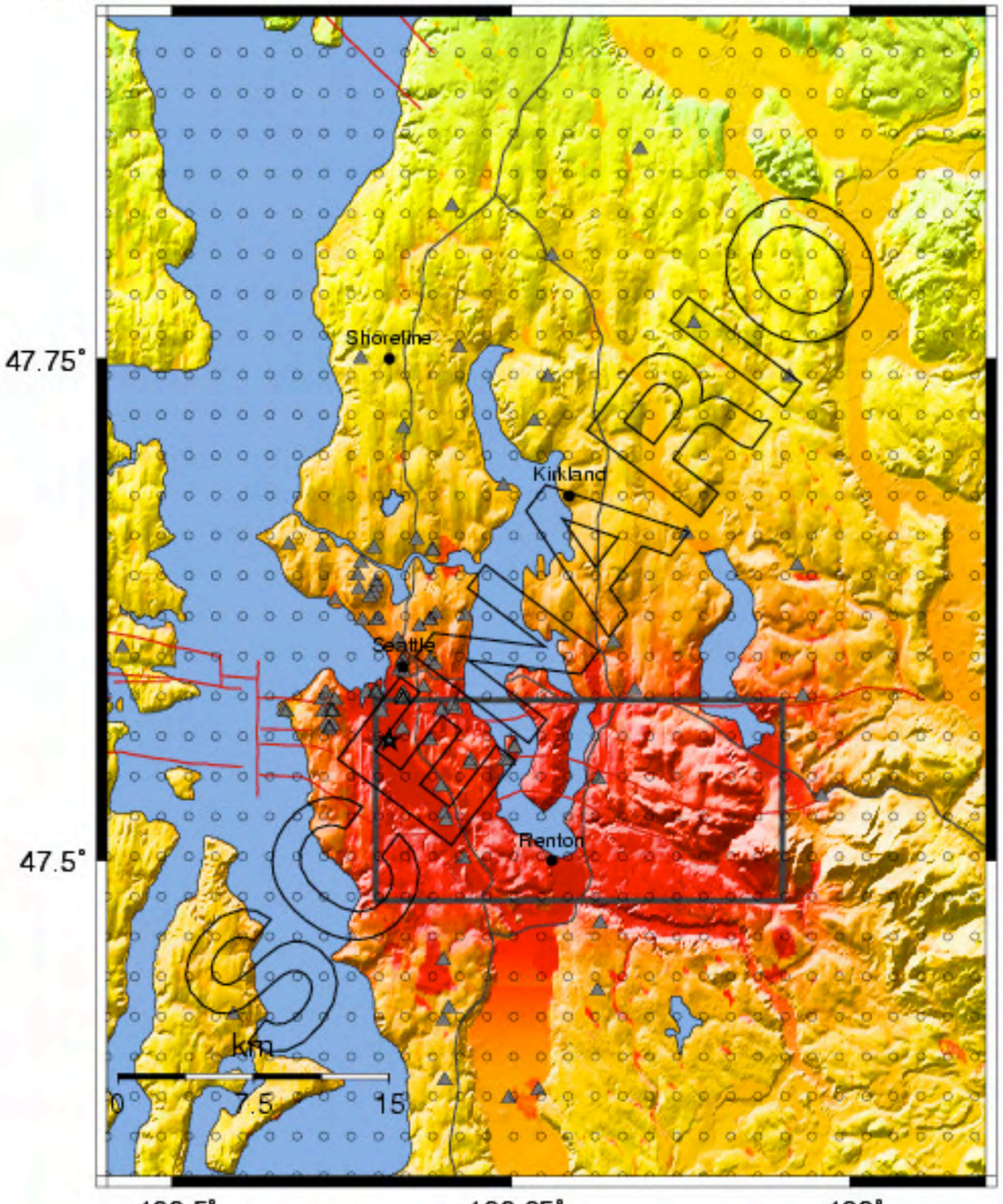


PLANNING SCENARIO ONLY -- Map Version 5 Processed Fri Feb 22, 2008 03:12:48 PM PST

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

ShakeMap for SoundShake08-3 Scenario

Scenario Date: Wed Mar 5, 2008 07:54:01 AM PST M 6.7 N47.56 W122.34 Depth: 10.0km



PLANNING SCENARIO ONLY -- Map Version 2 Processed Fri Feb 22, 2008 02:54:07 PM PST

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

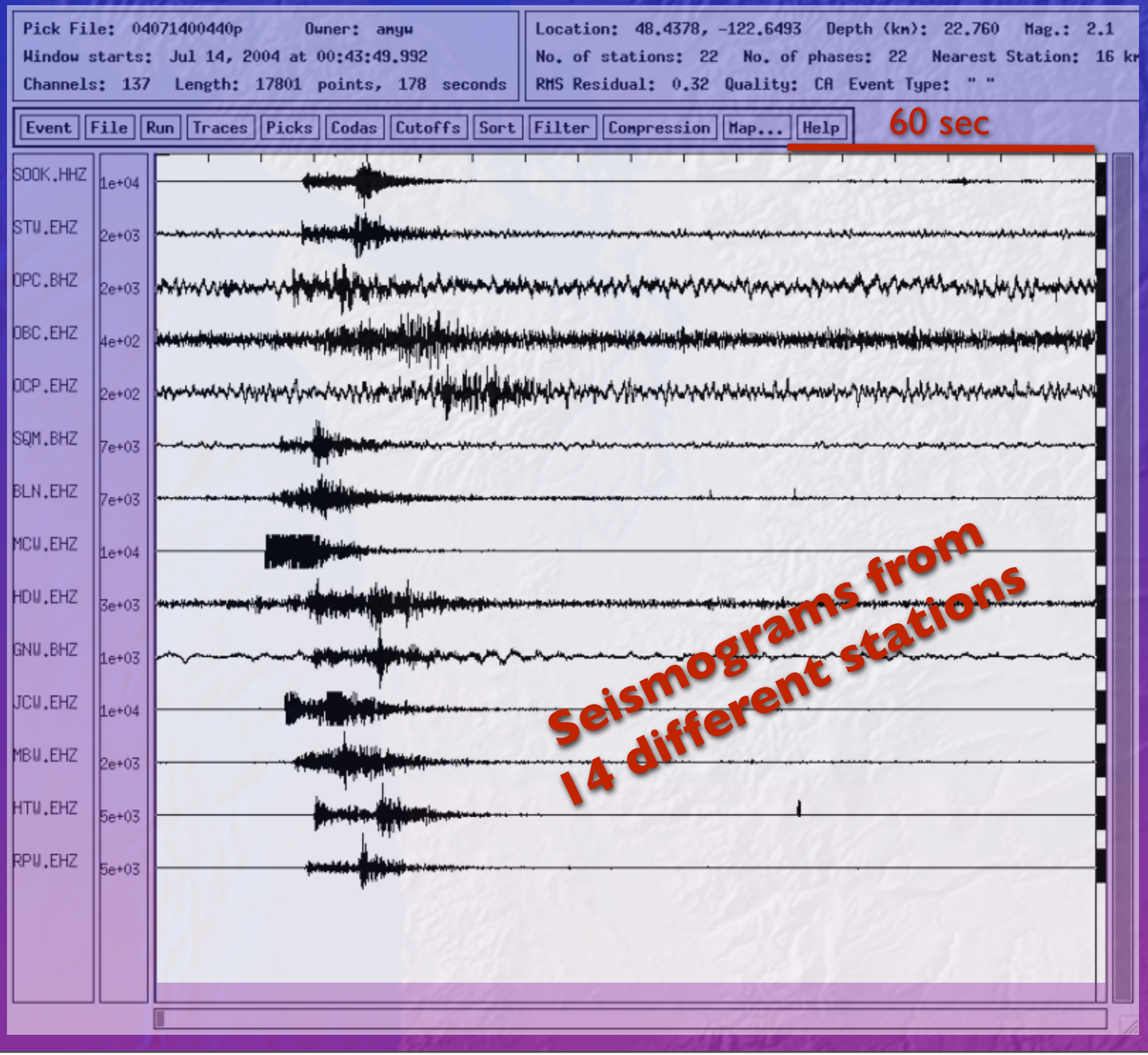
Episodic Tremor & Slip

Recently discovered

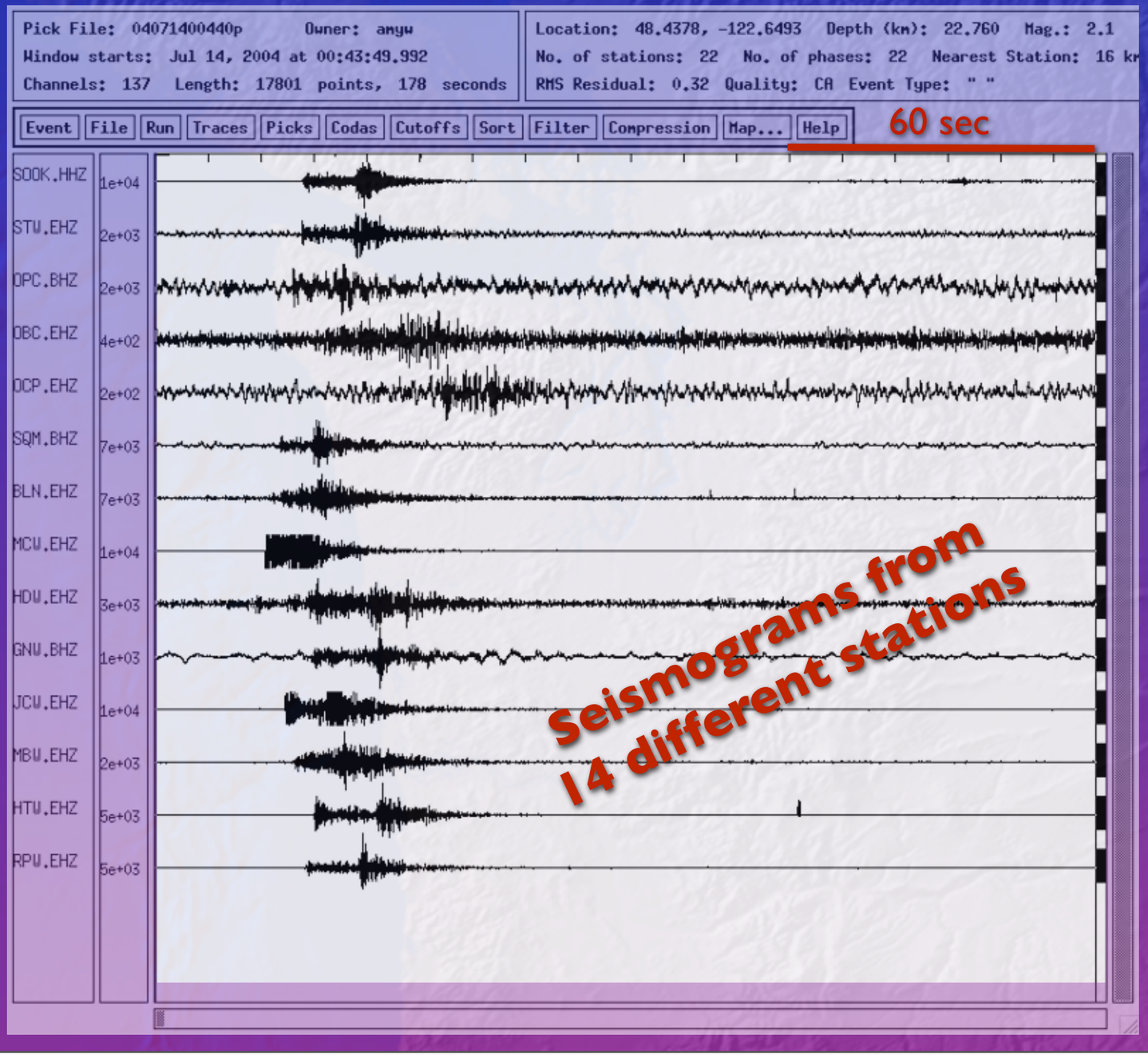
Both geodetic and seismic evidence

Significance still not understood

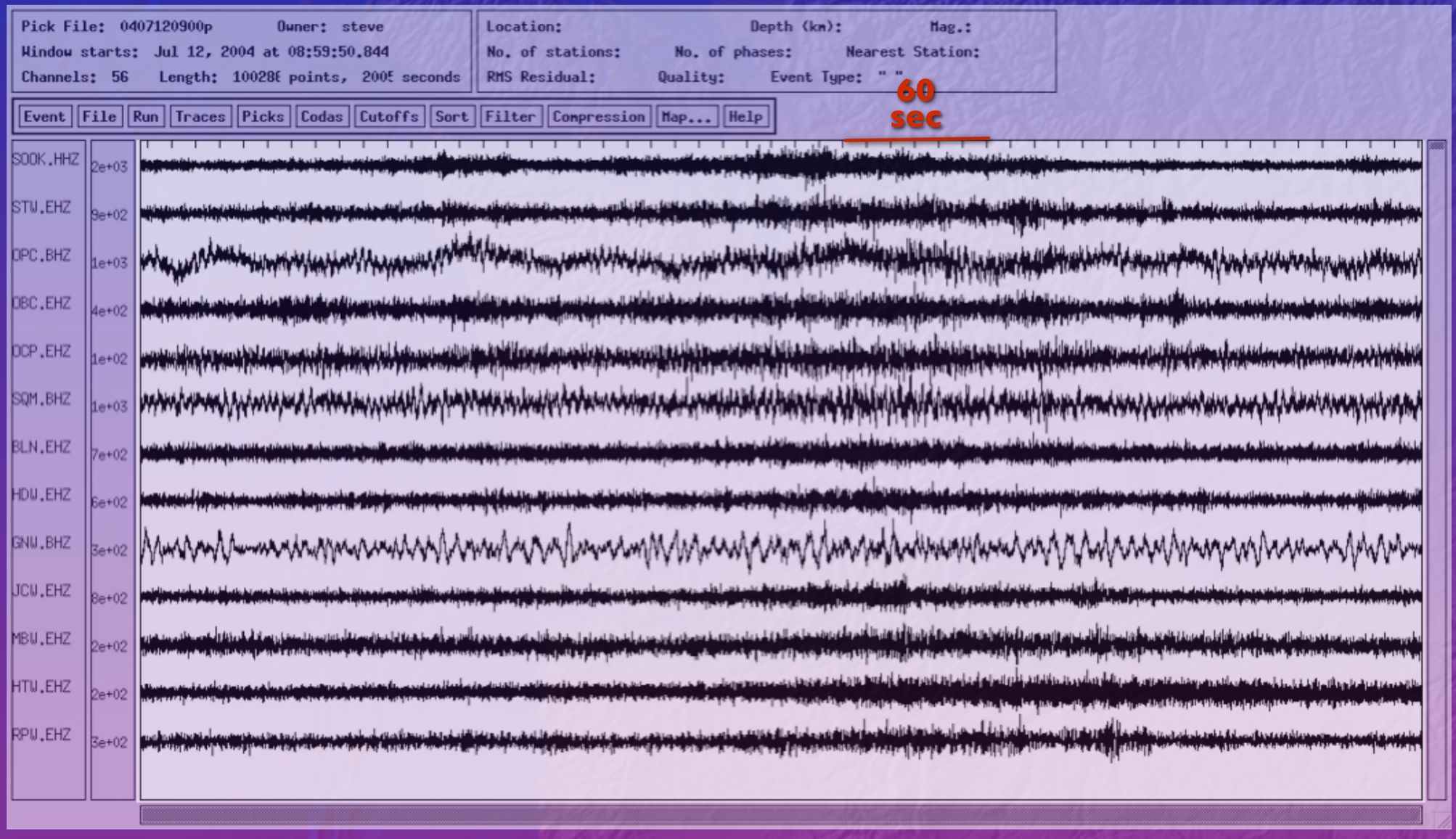
Compare typical tectonic earthquake



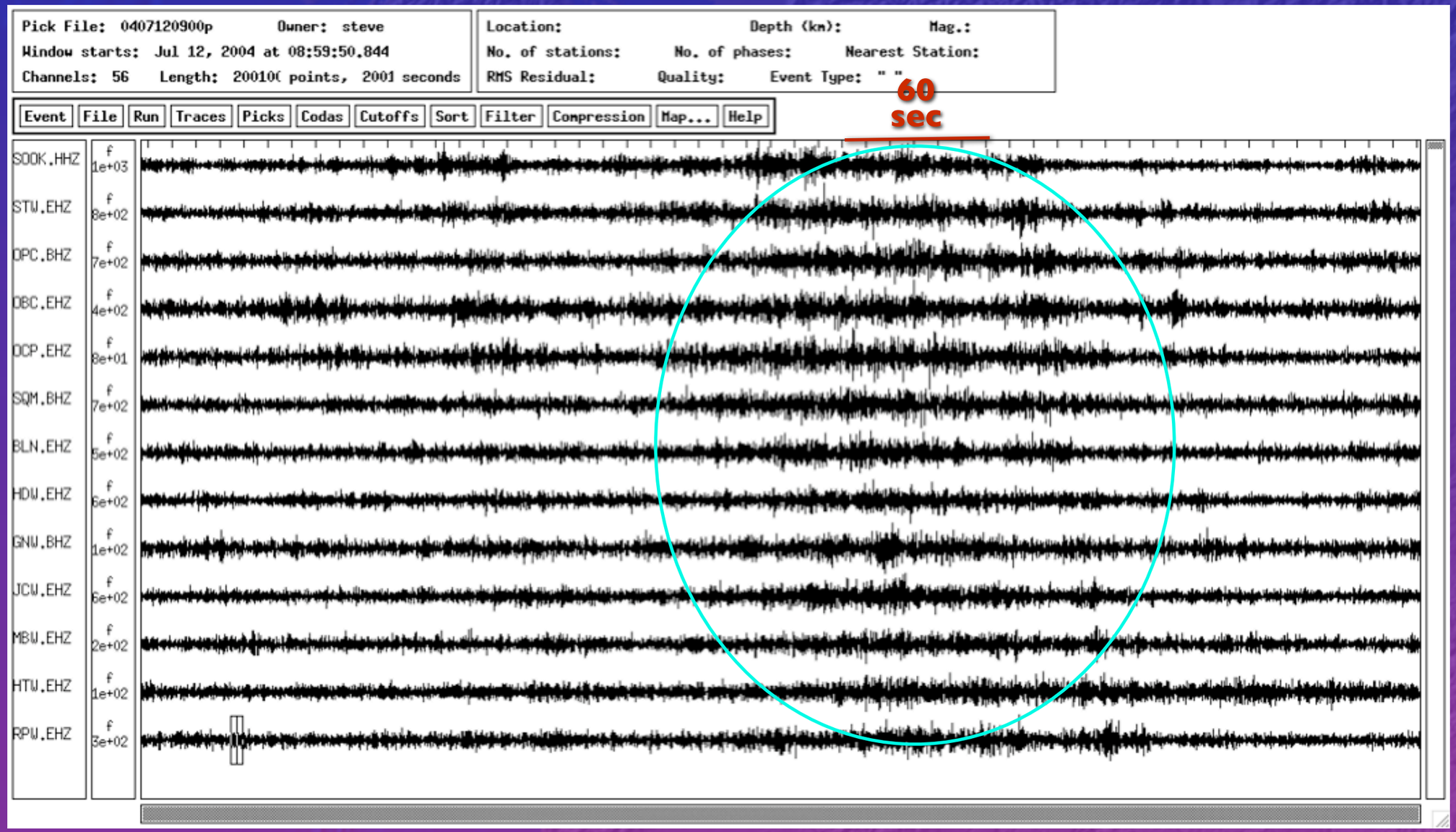
Compare typical tectonic earthquake with....



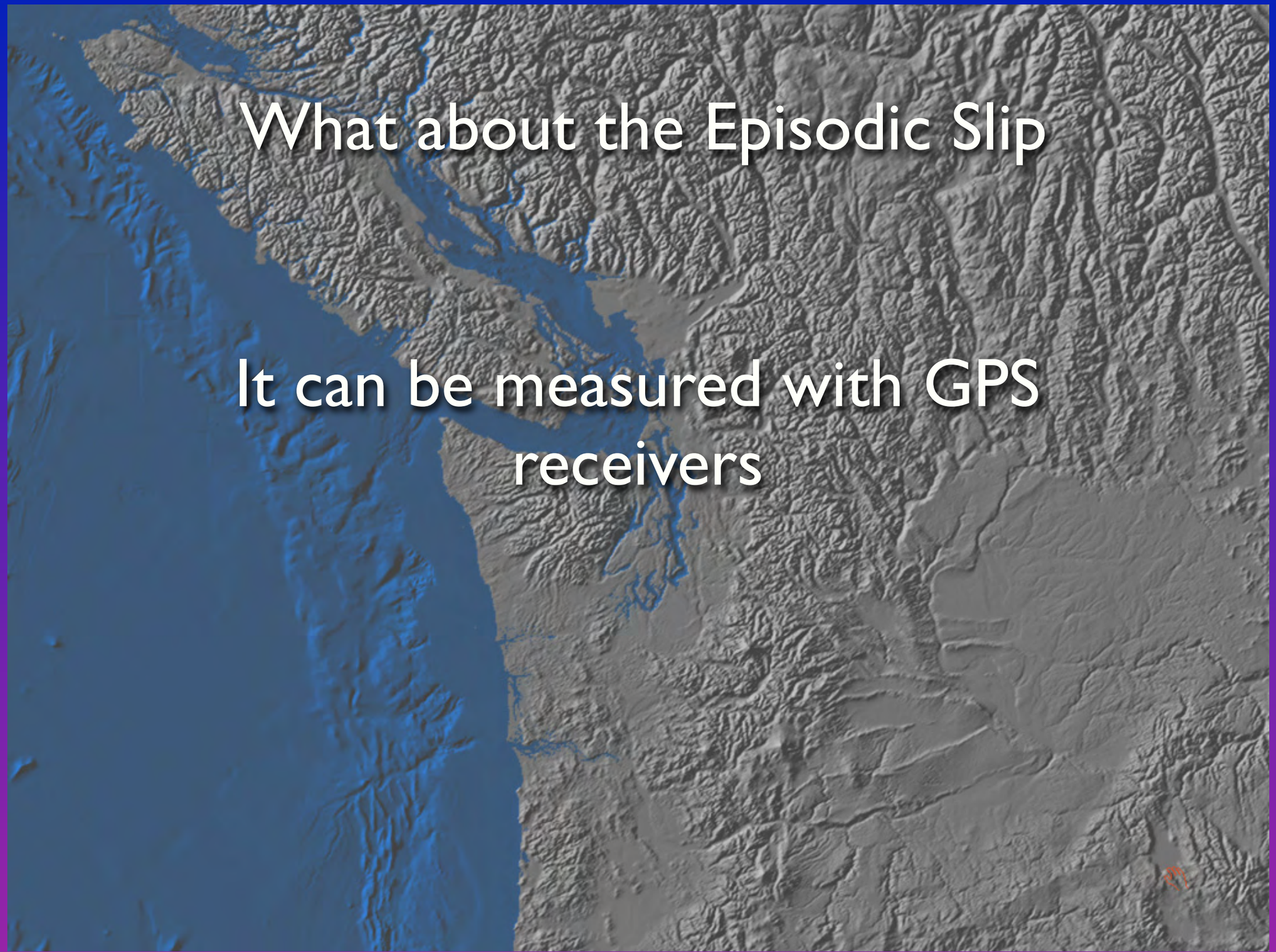
Seismic background signals....

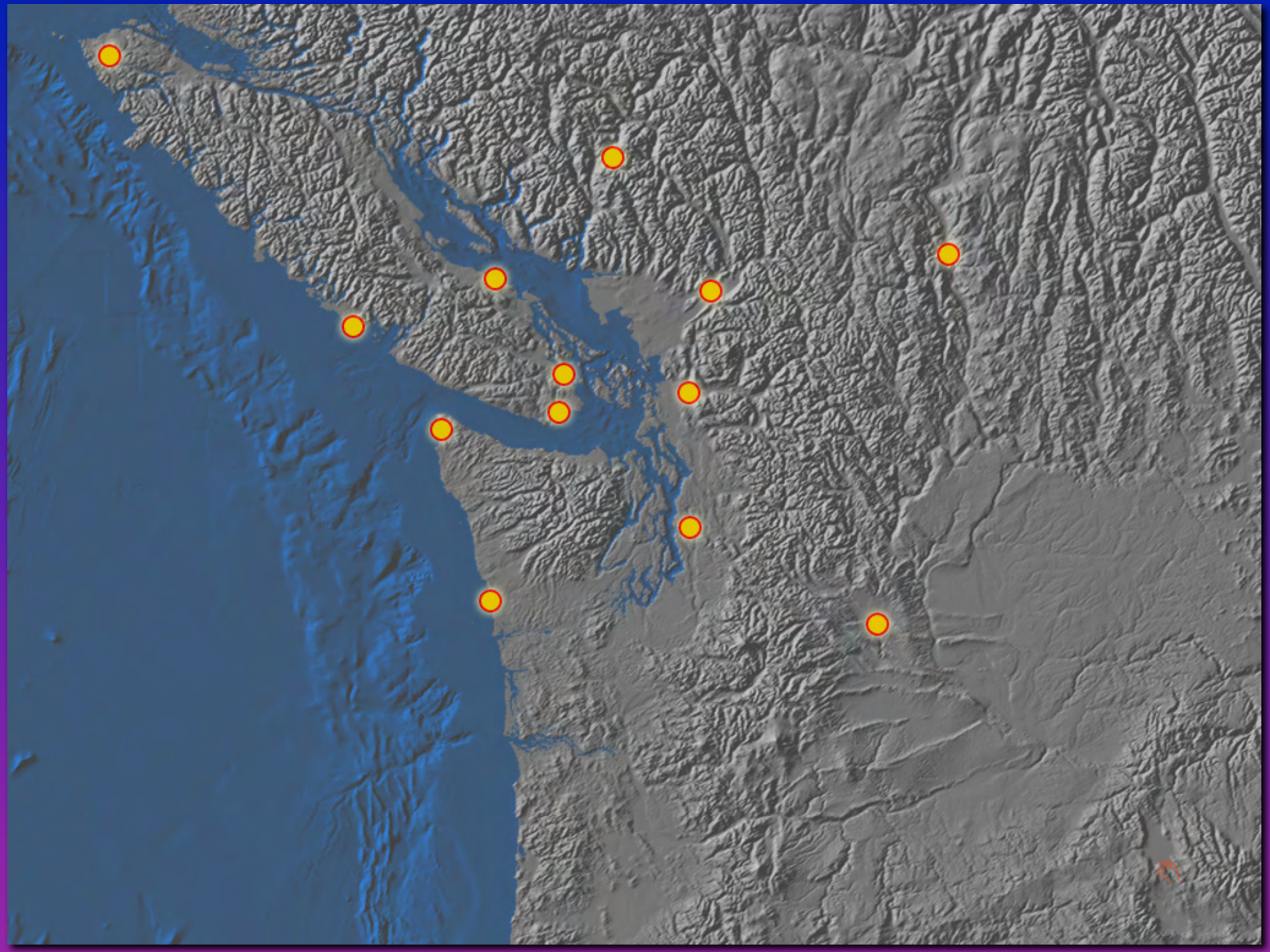


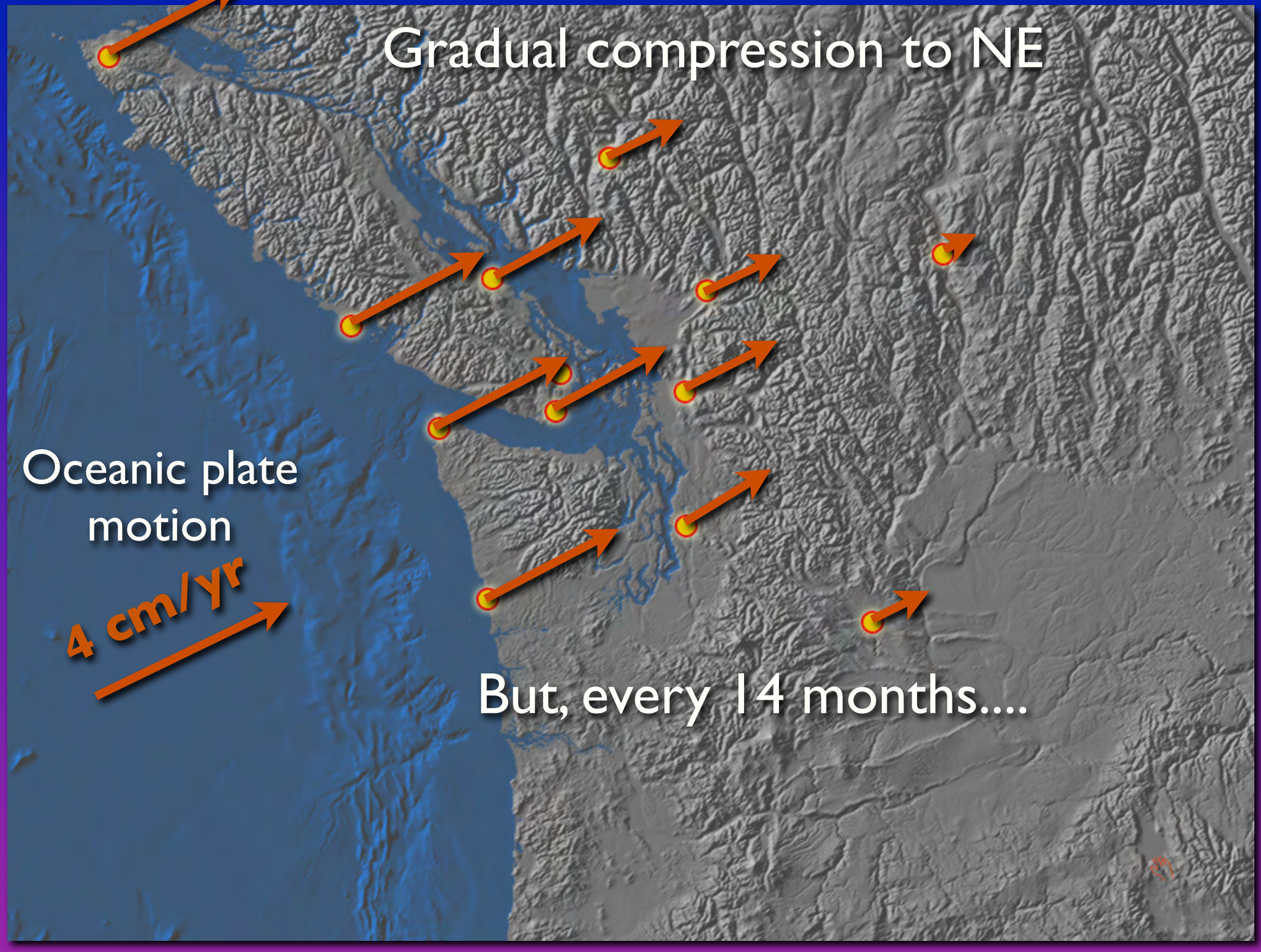
Deep non-volcanic tremor



What about the Episodic Slip

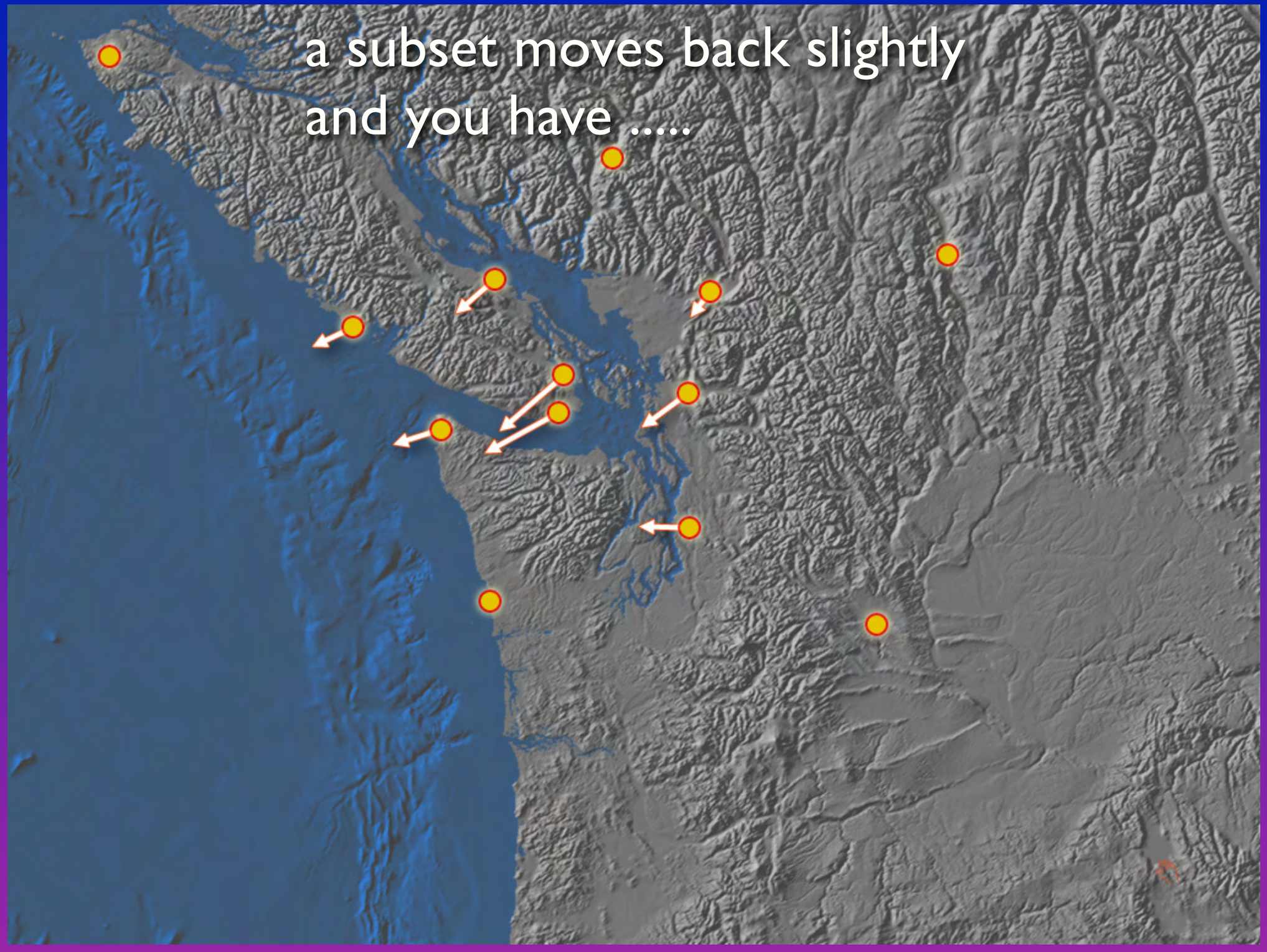

What about the Episodic Slip
It can be measured with GPS receivers




Gradual compression to NE
Oceanic plate motion
4 cm/yr
But, every 14 months....

a subset moves back slightly

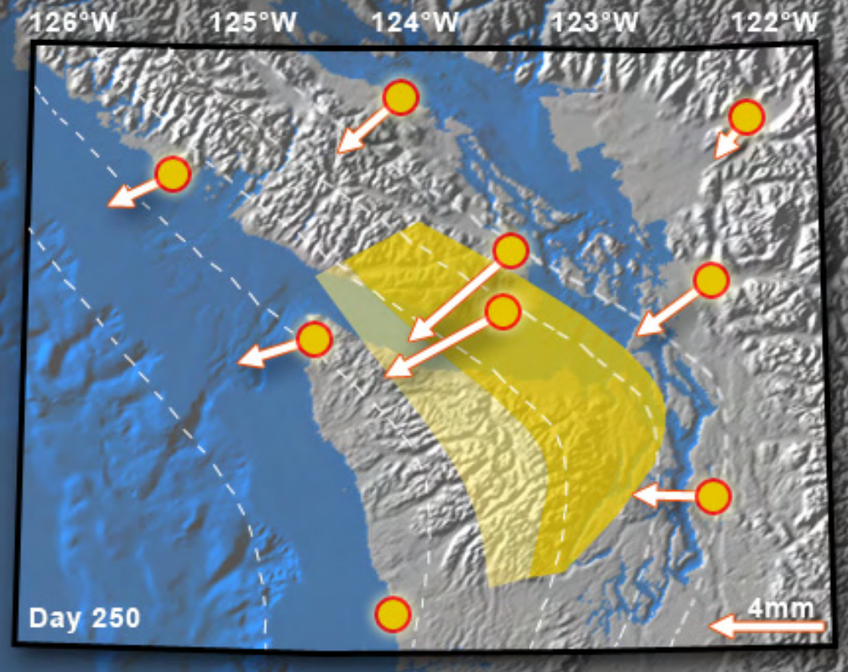
and you have .....



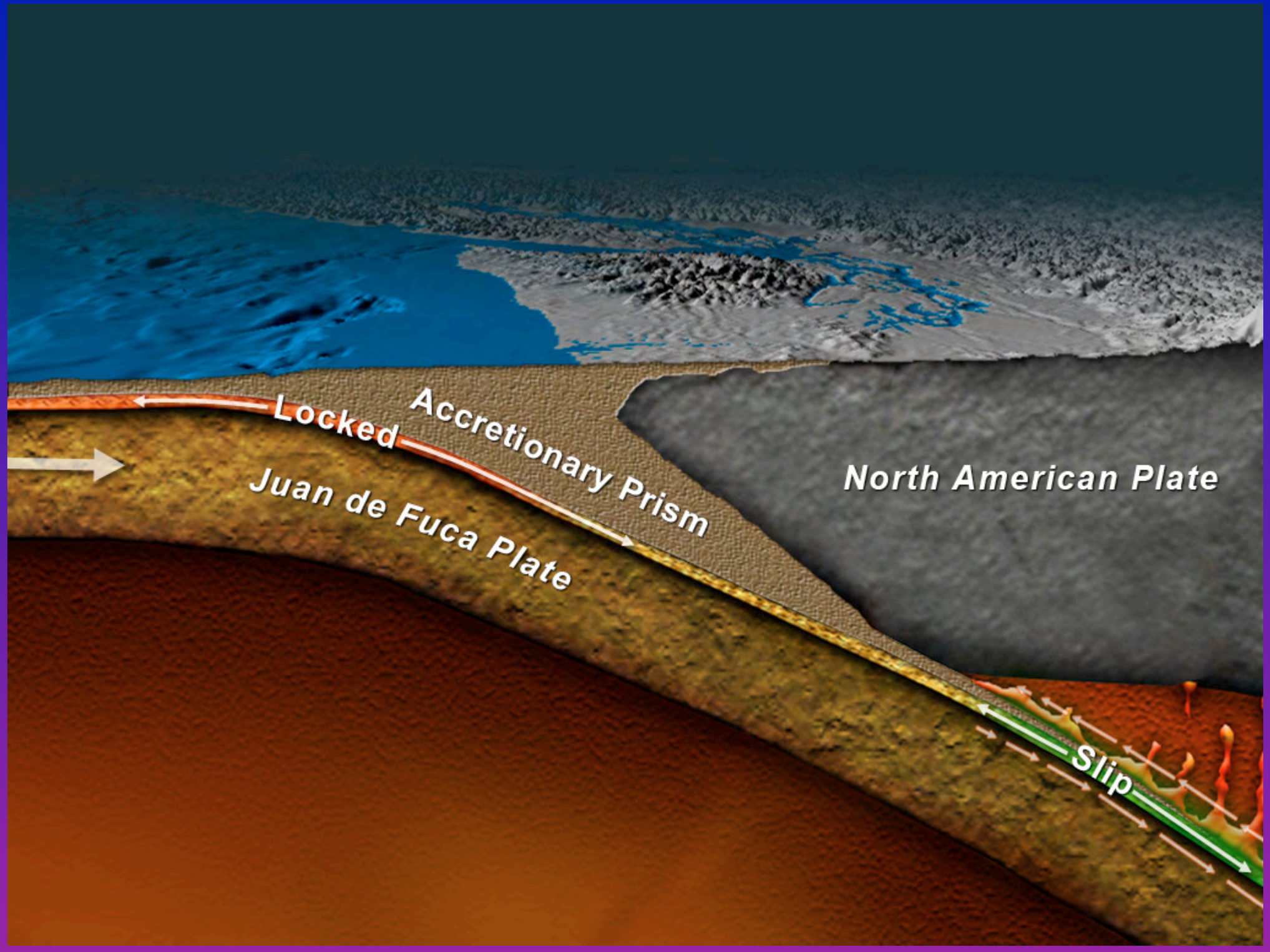
a subset moves back slightly
and you have .....**Episodic Slip**

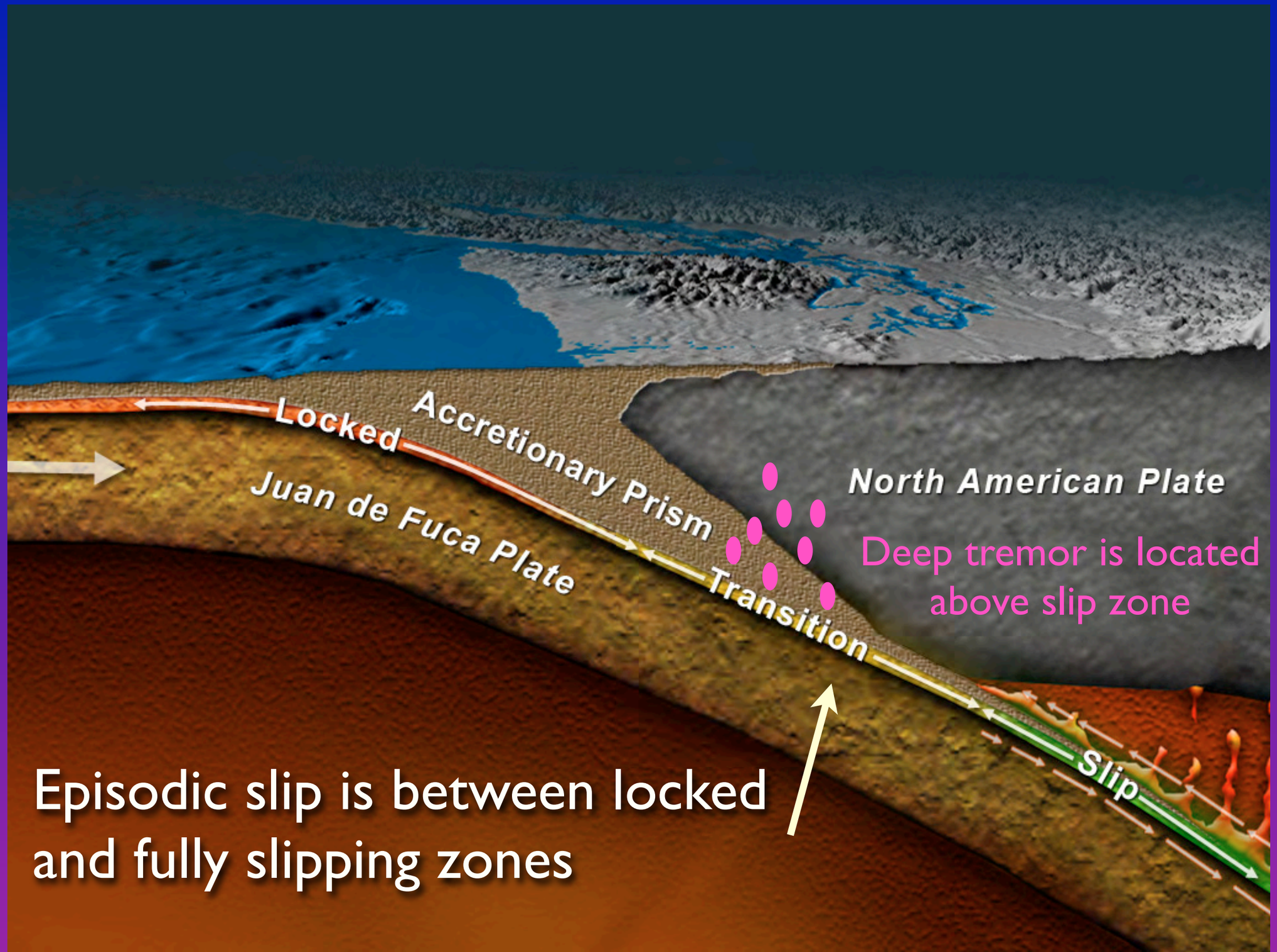
This can be modeled as slip on
a patch

Episodic Slip

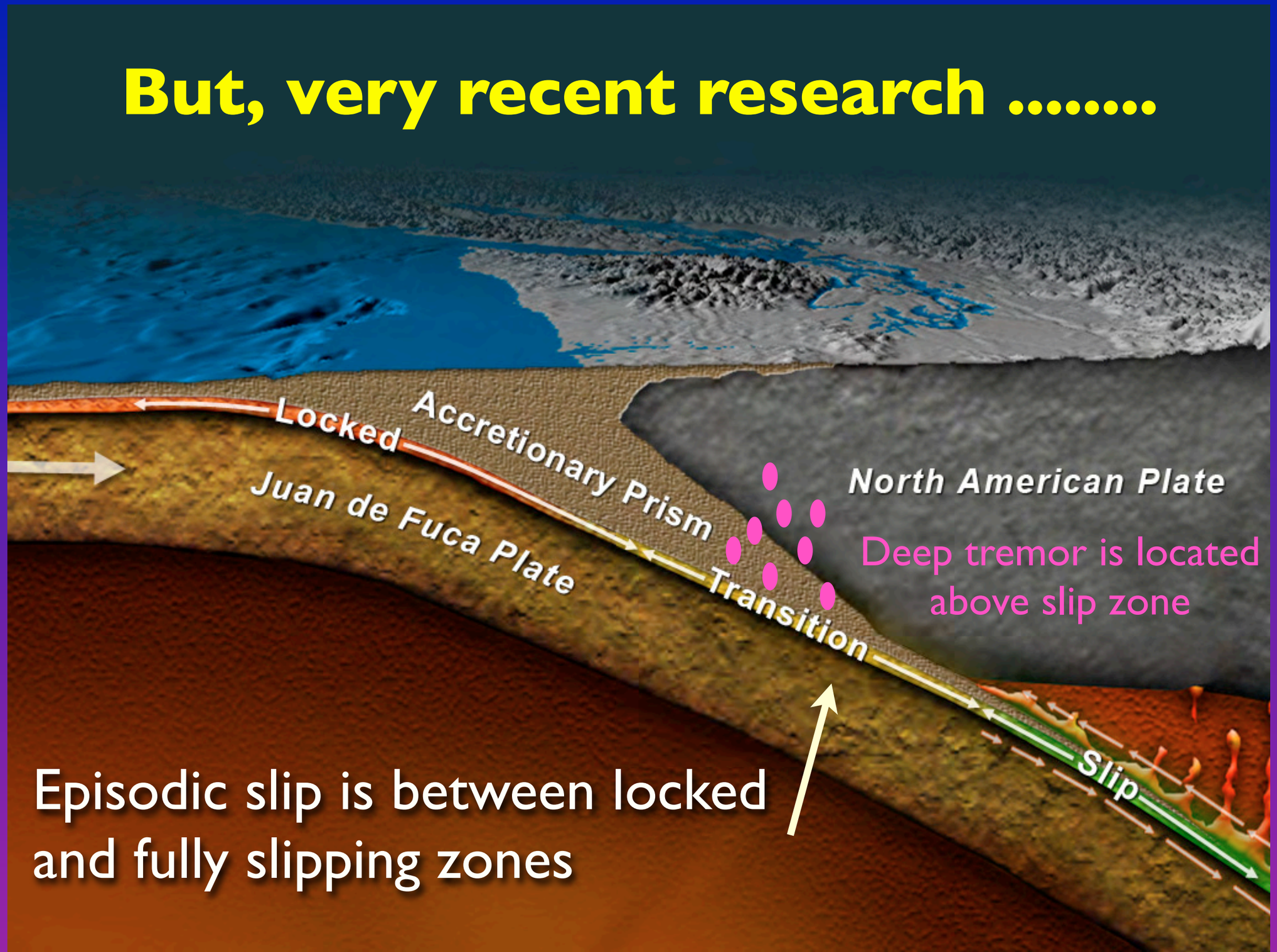


This can be modeled as slip on a patch on the plate interface

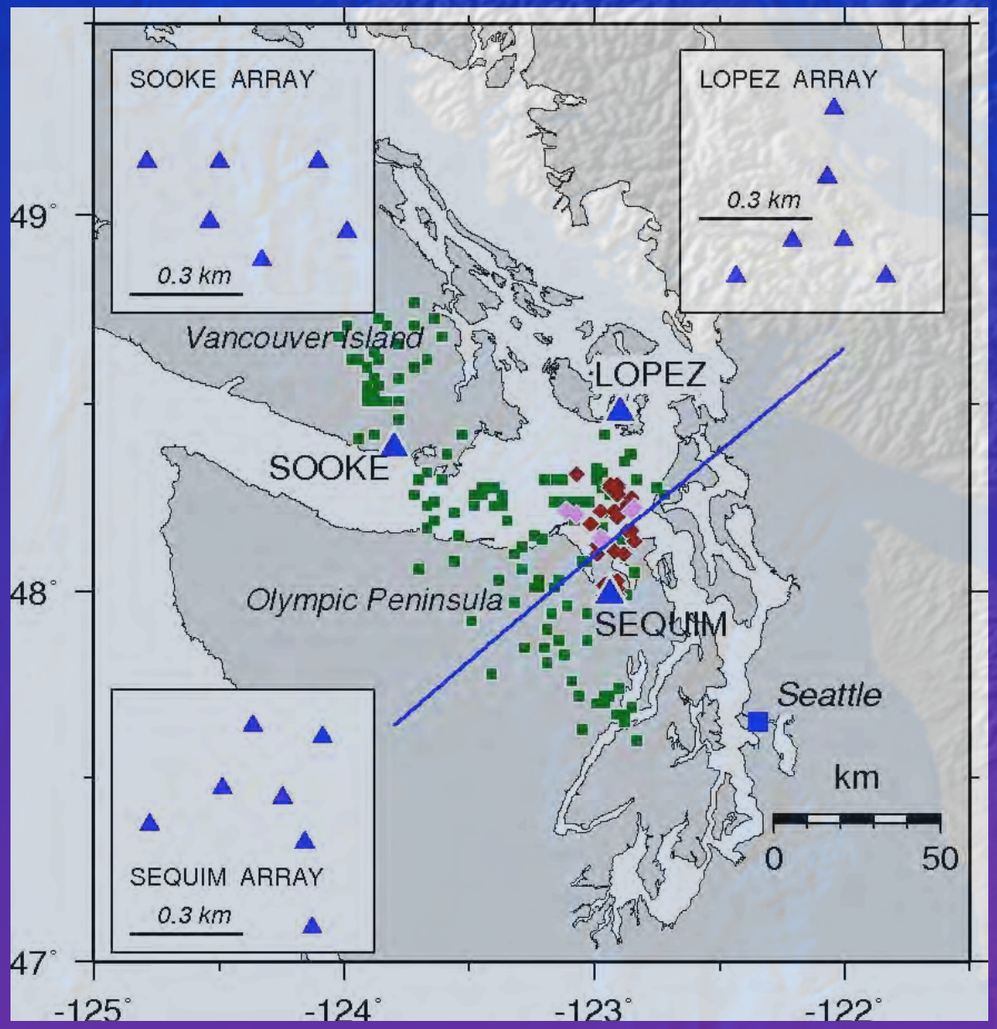

Locked
Accretionary Prism
North American Plate
Juan de Fuca Plate
Slip


Locked
Accretionary Prism
North American Plate
Juan de Fuca Plate
Transition
Deep tremor is located above slip zone
Slip
Episodic slip is between locked and fully slipping zones

But, very recent research .....



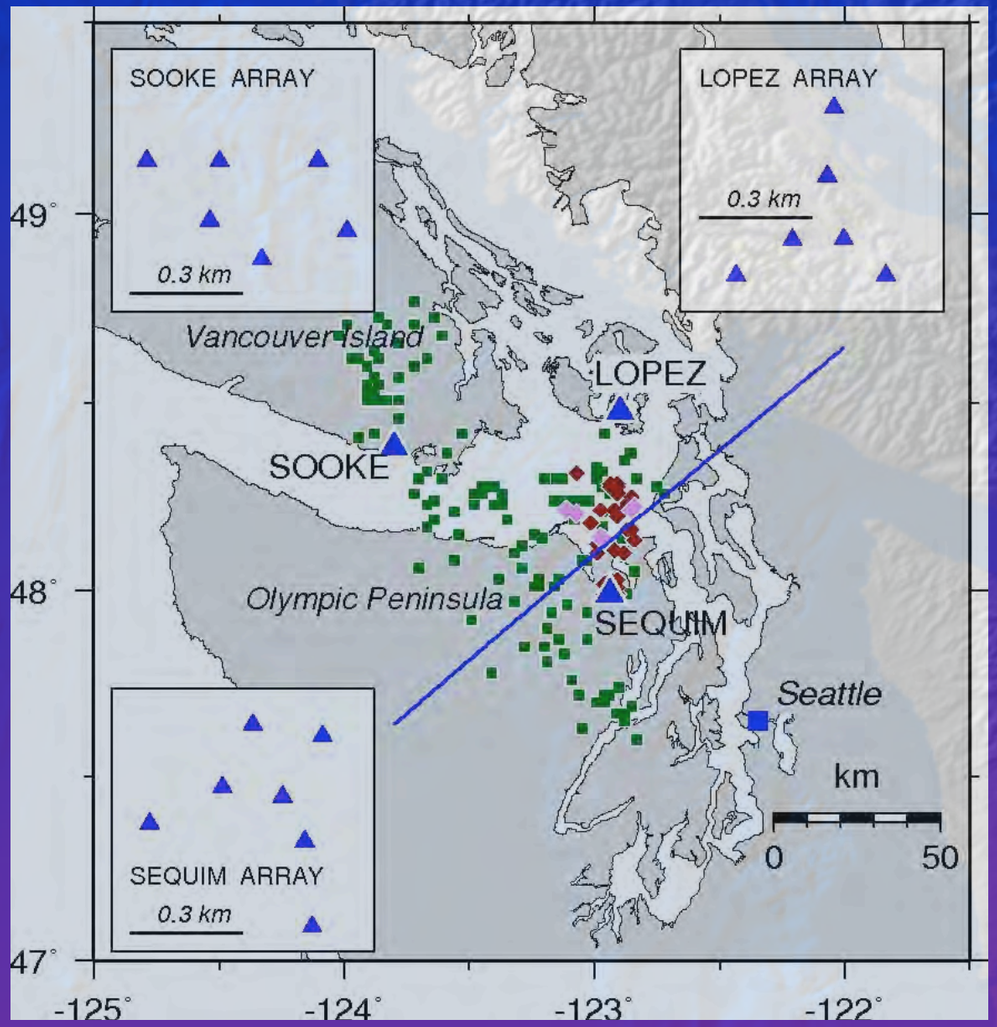
S-P depth control

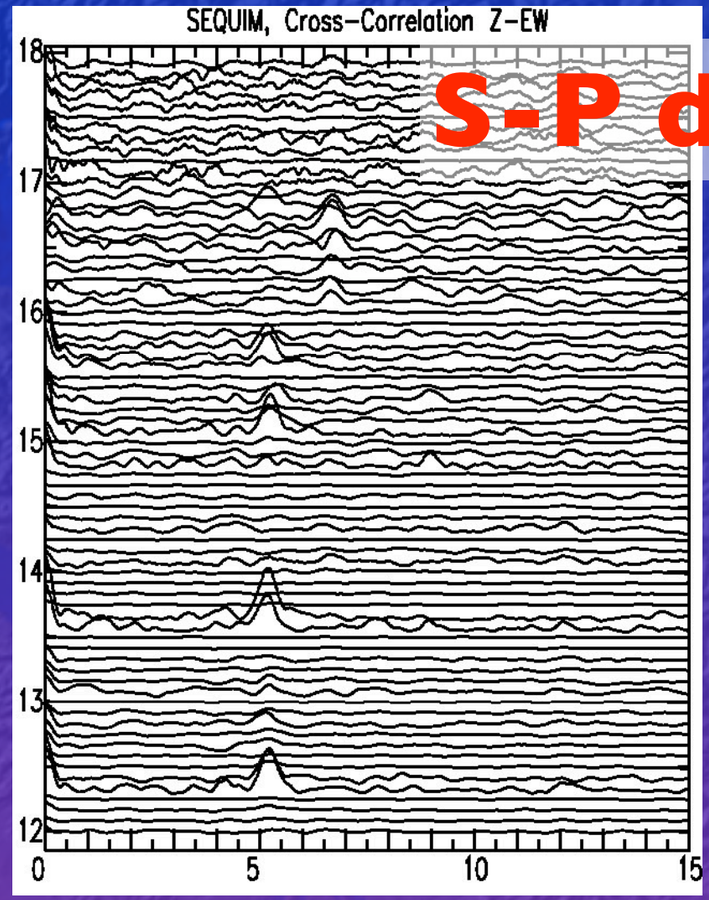


Earthscope transportable array experiment

La Rocca et.al.
submitted to
Nature

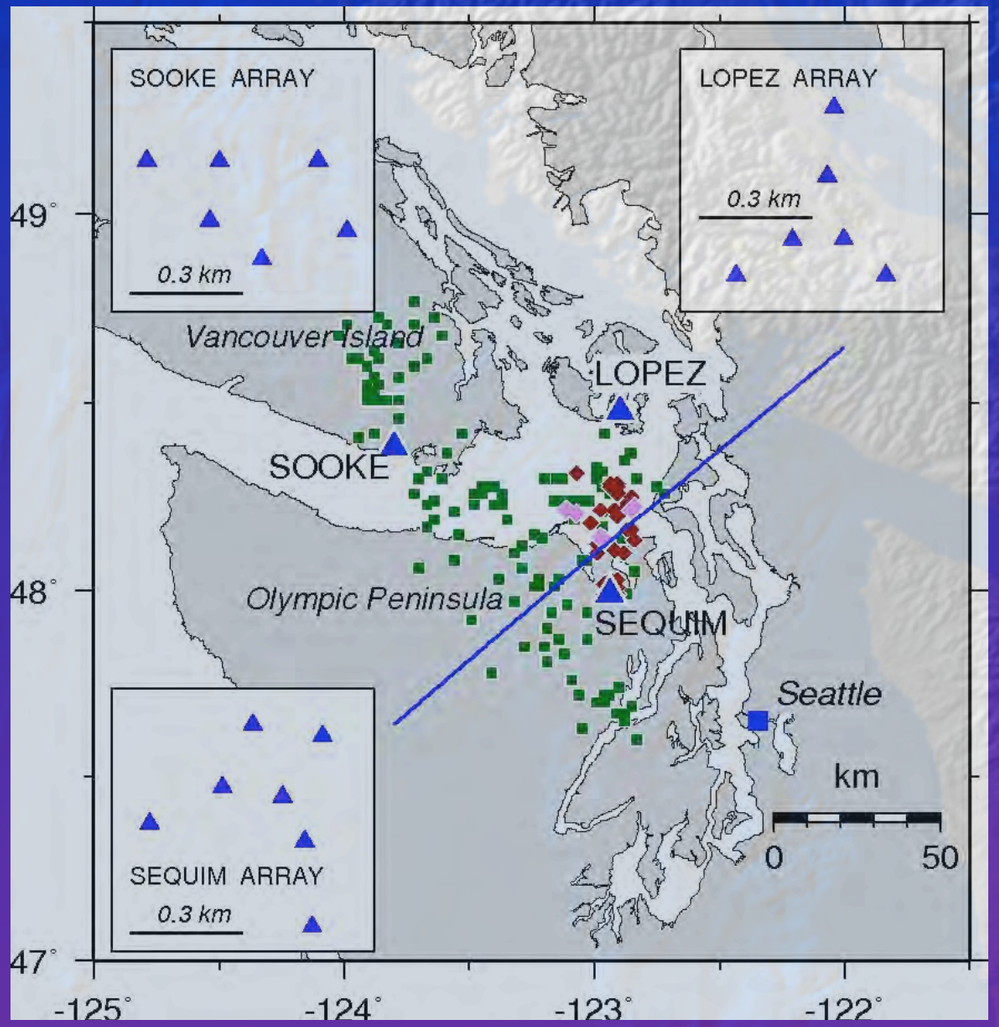
S-P depth control

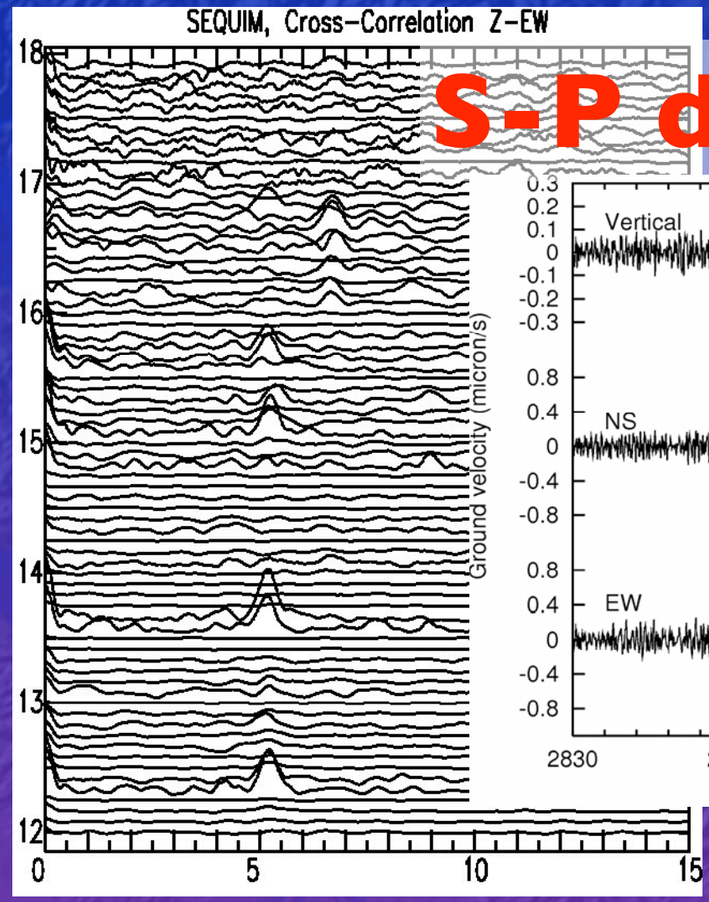


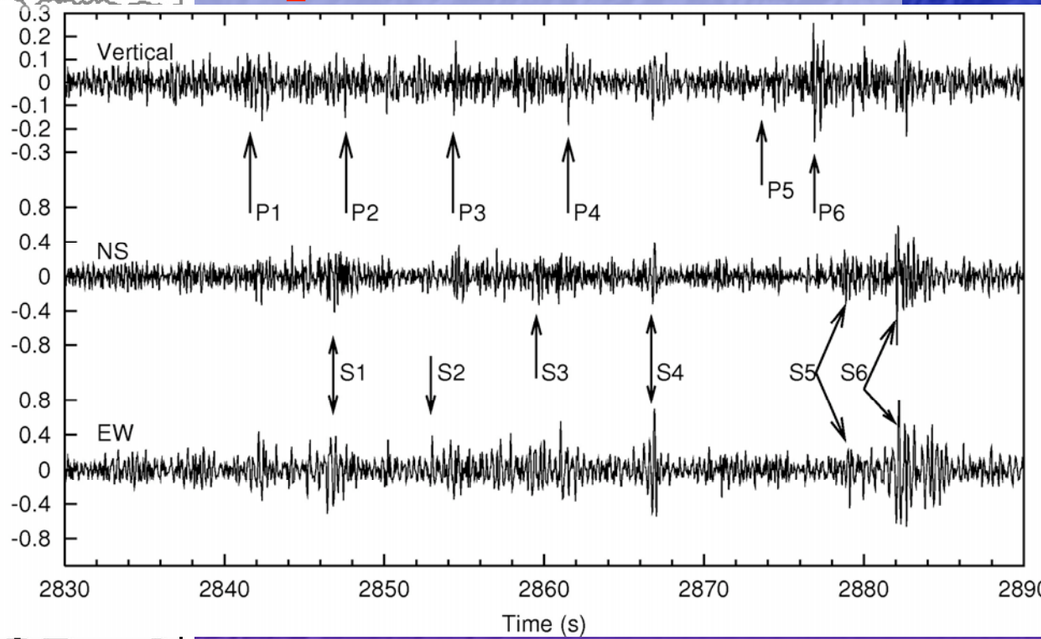


La Rocca et.al.
submitted to
Nature

S-P depth control

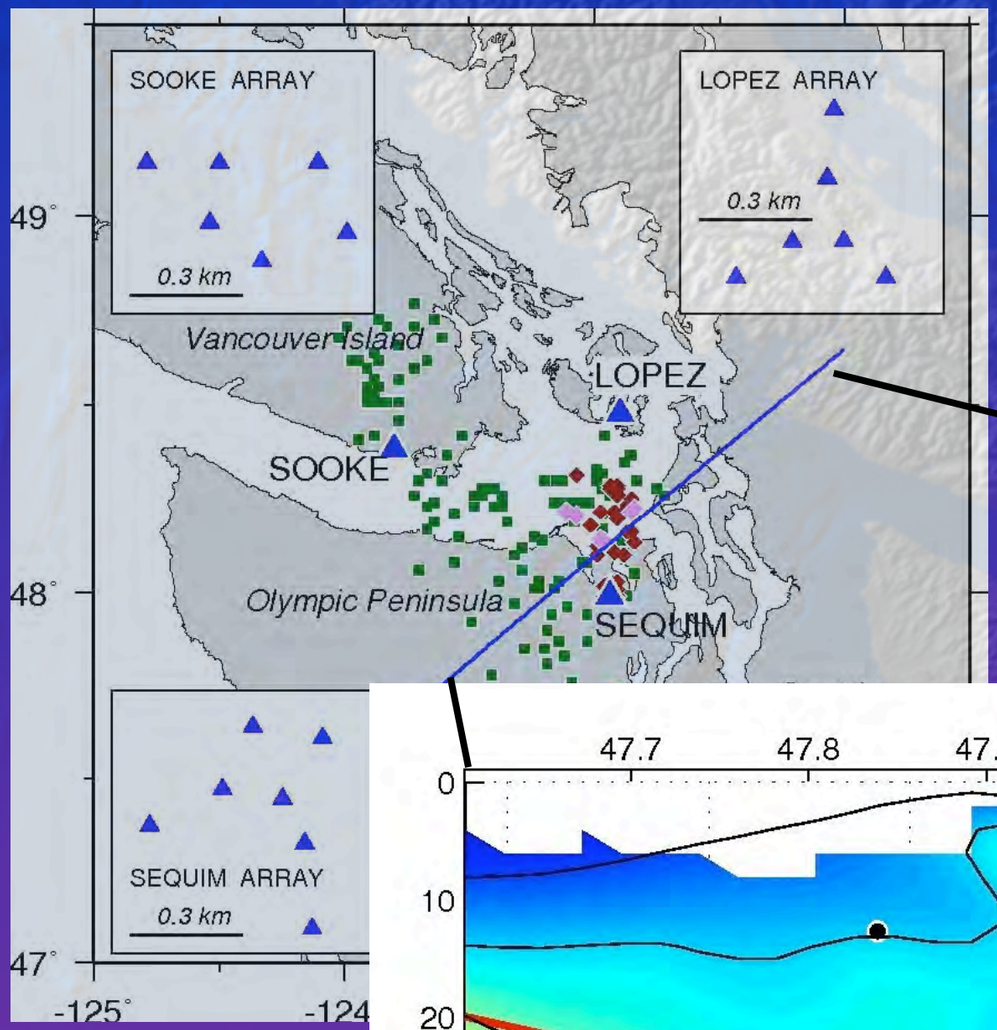


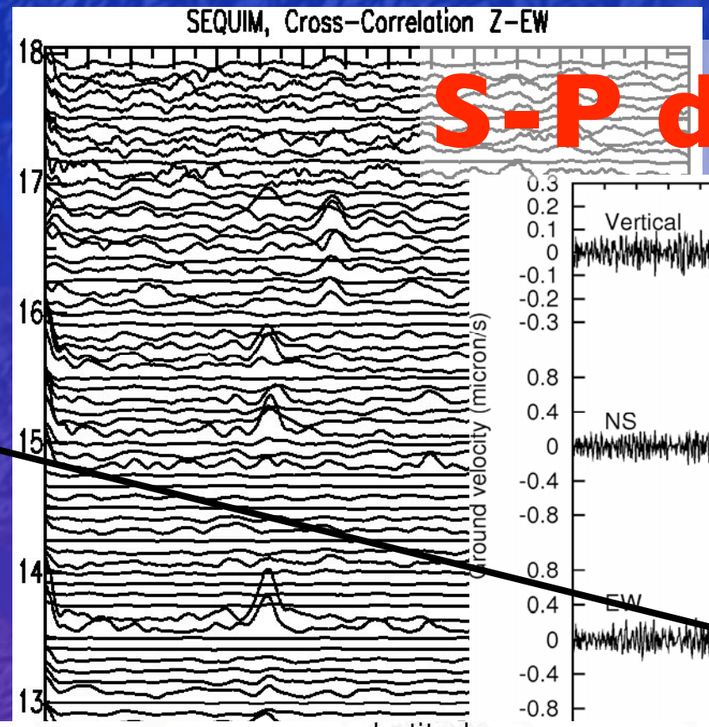


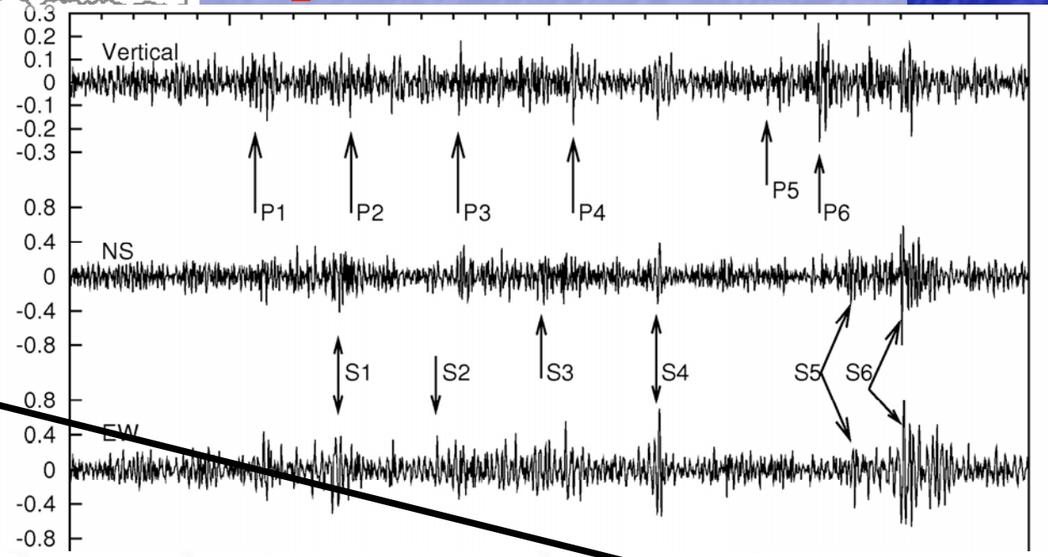


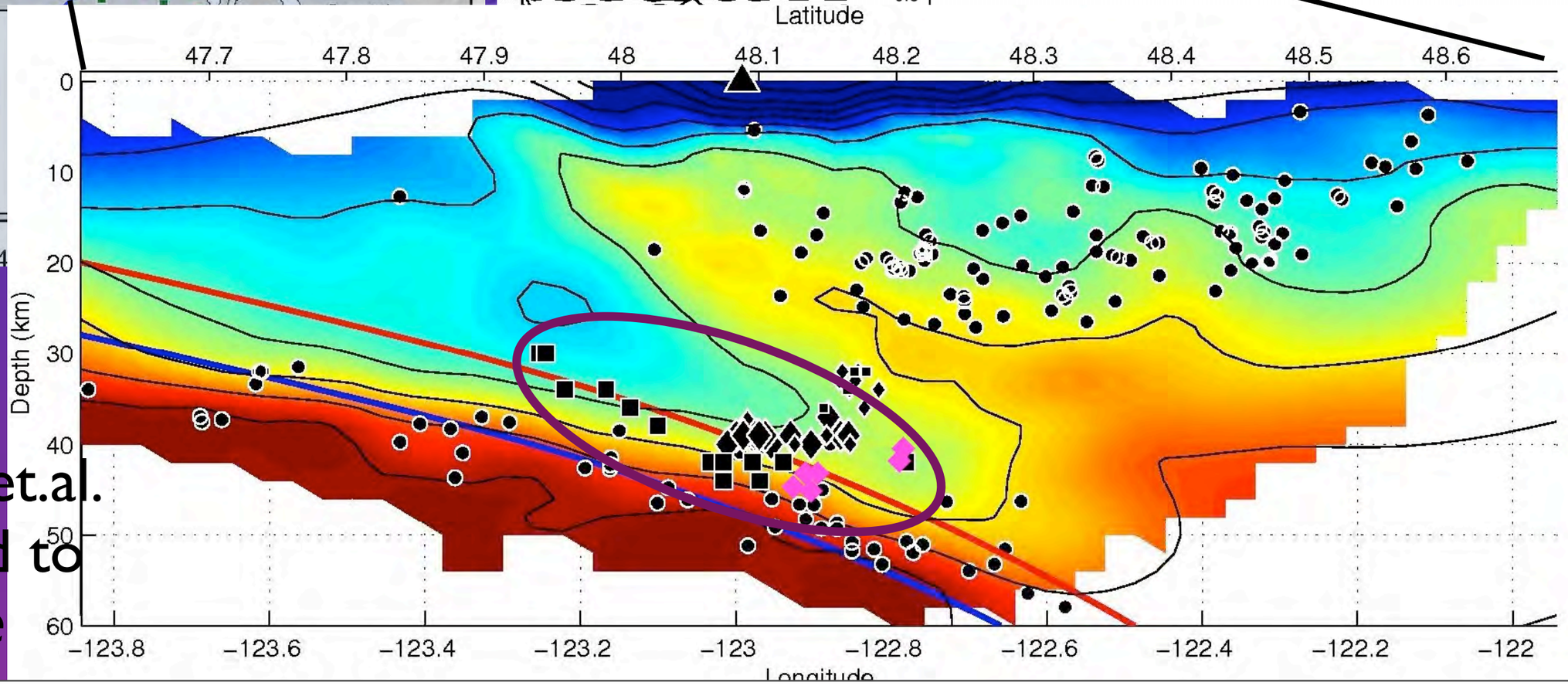
La Rocca et.al.
submitted to
Nature

S-P depth control



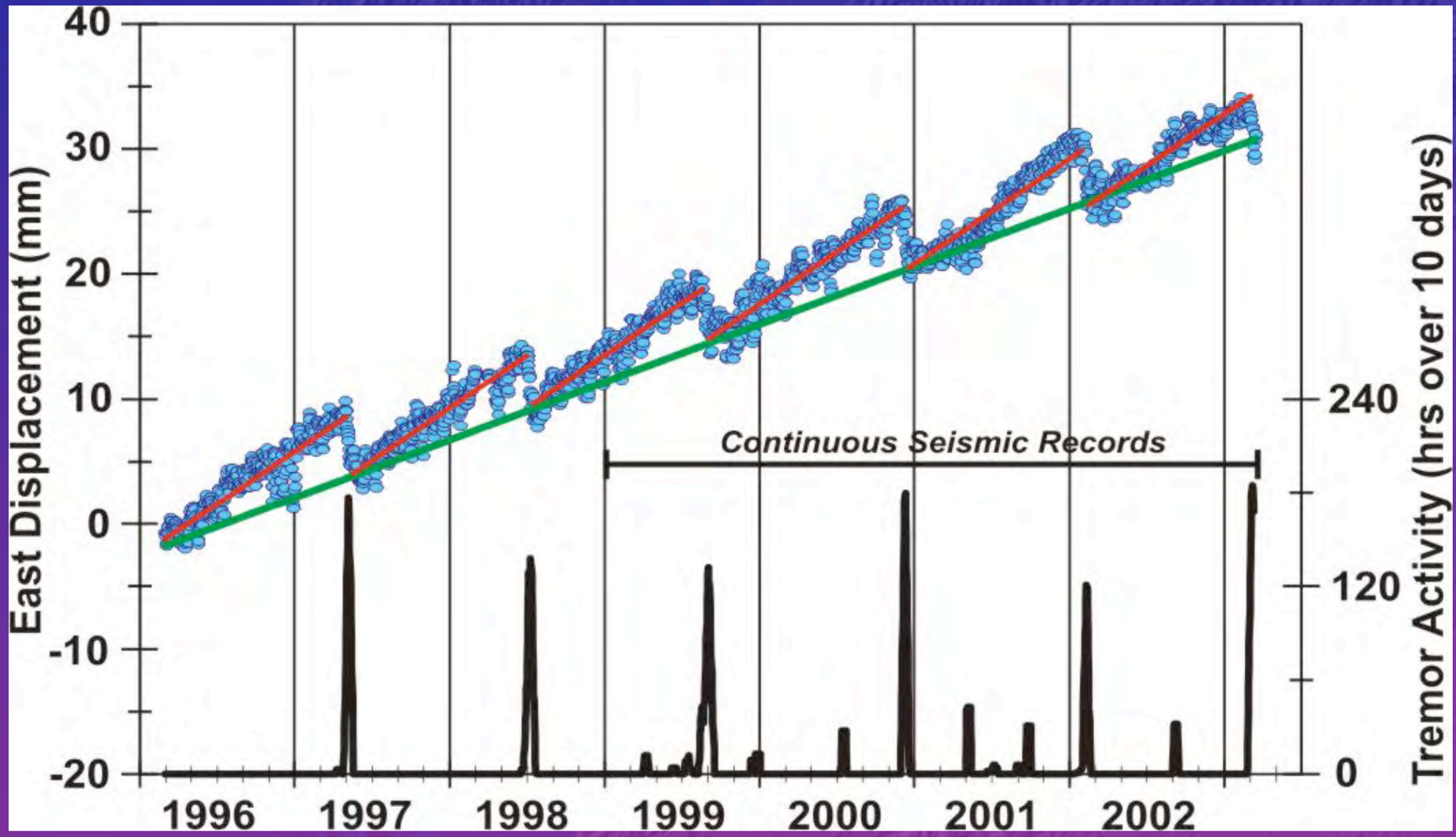






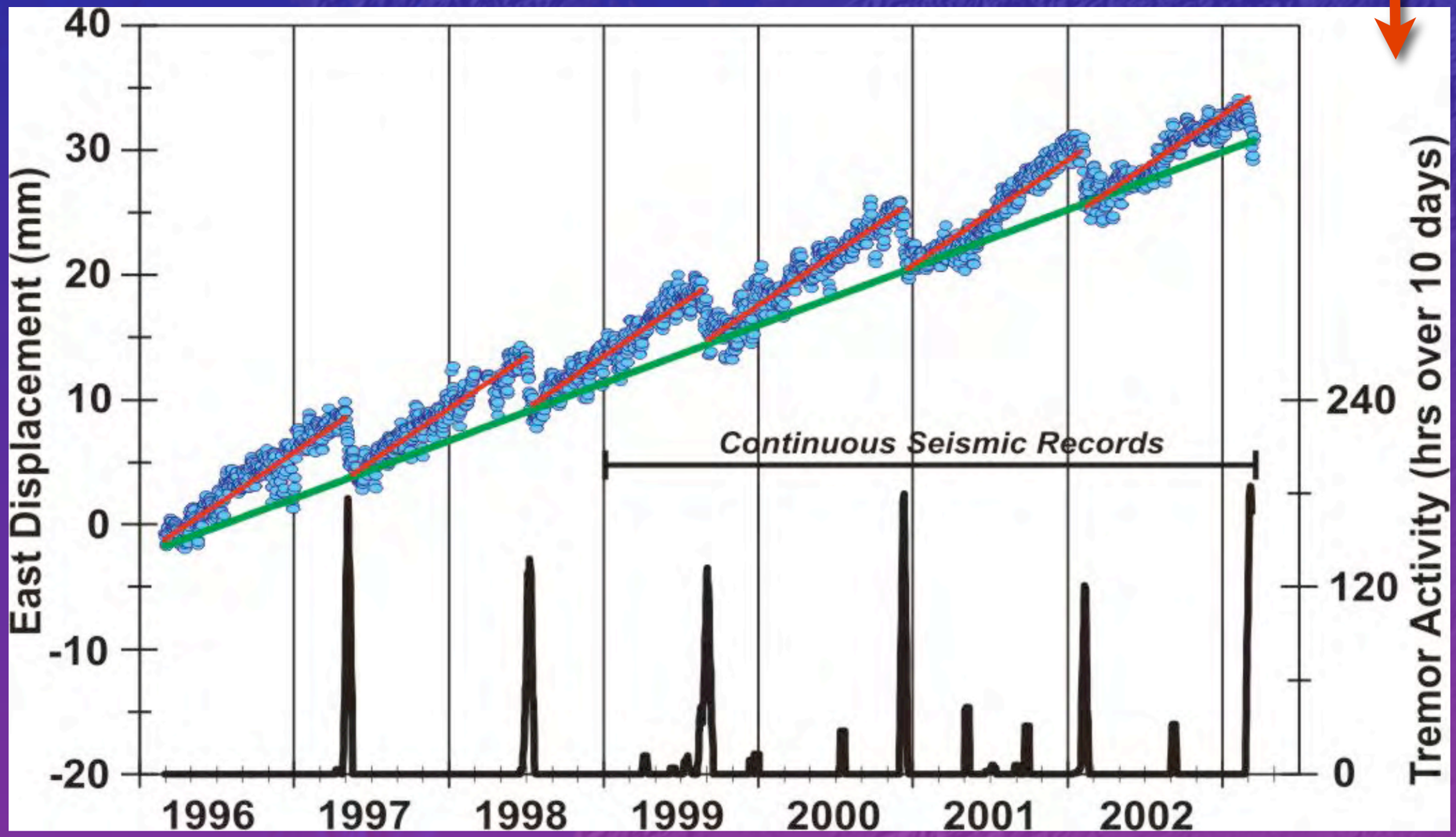
La Rocca et.al. submitted to *Nature*

Slip and tremor occur at the same time in a regular pattern

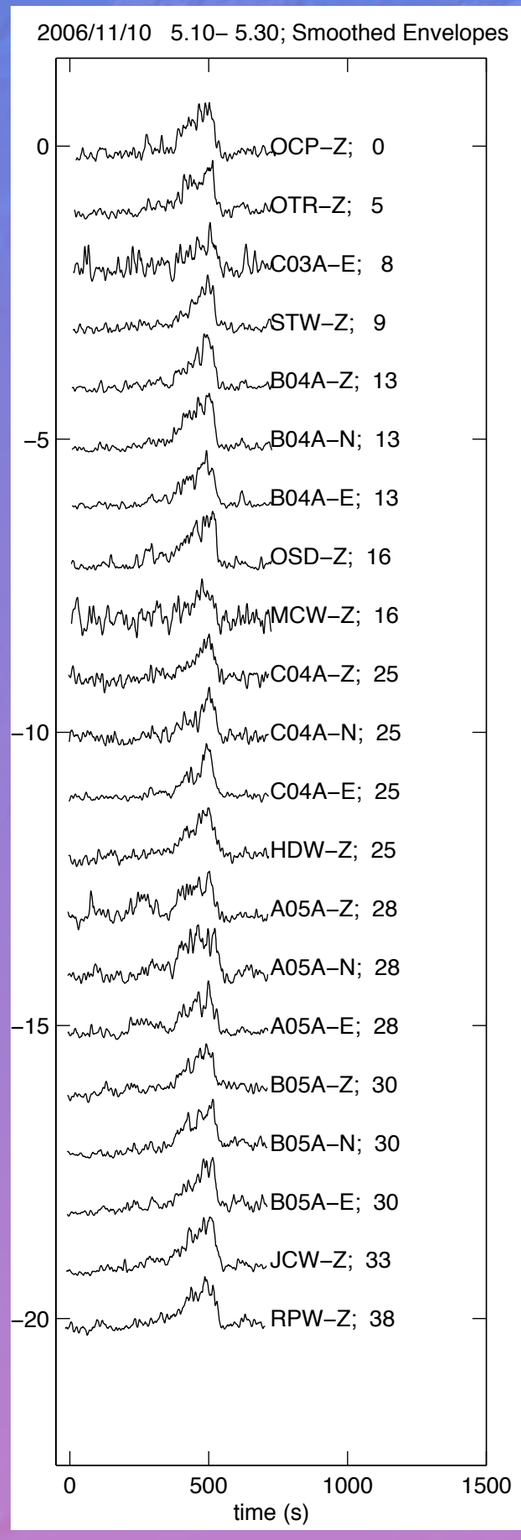


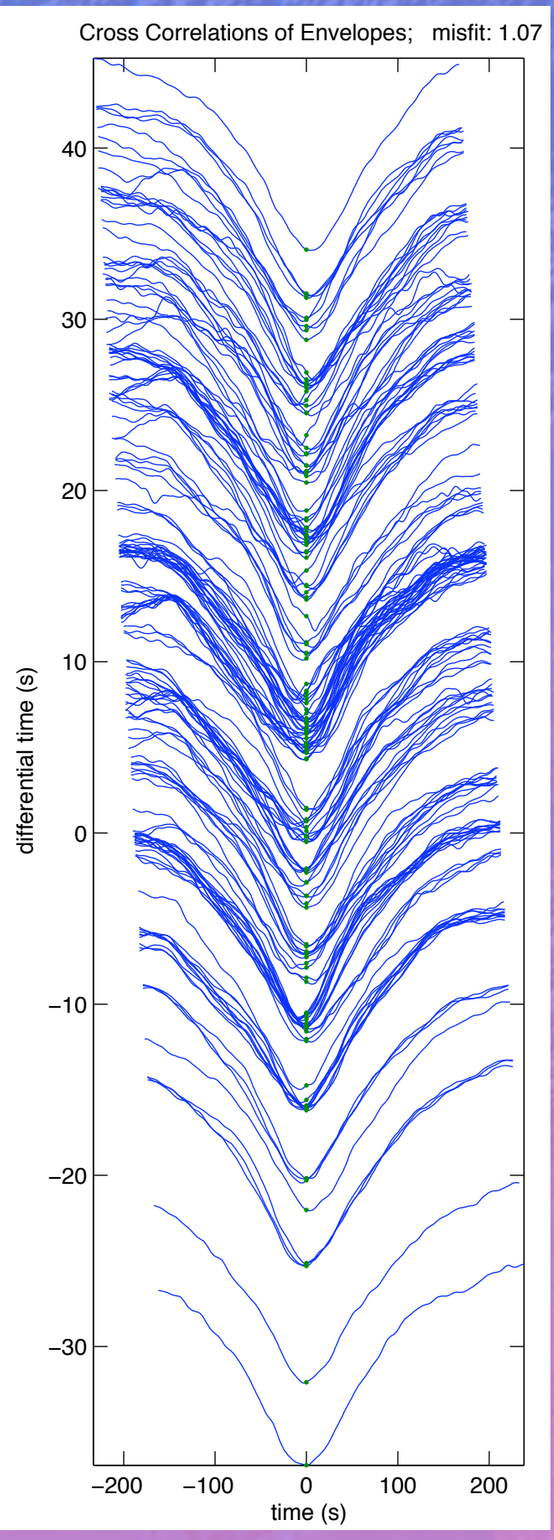
Dragert & Rogers, 2003

July, 2004, Sep, 2005, Jand 2007 predicted and did occur on schedule

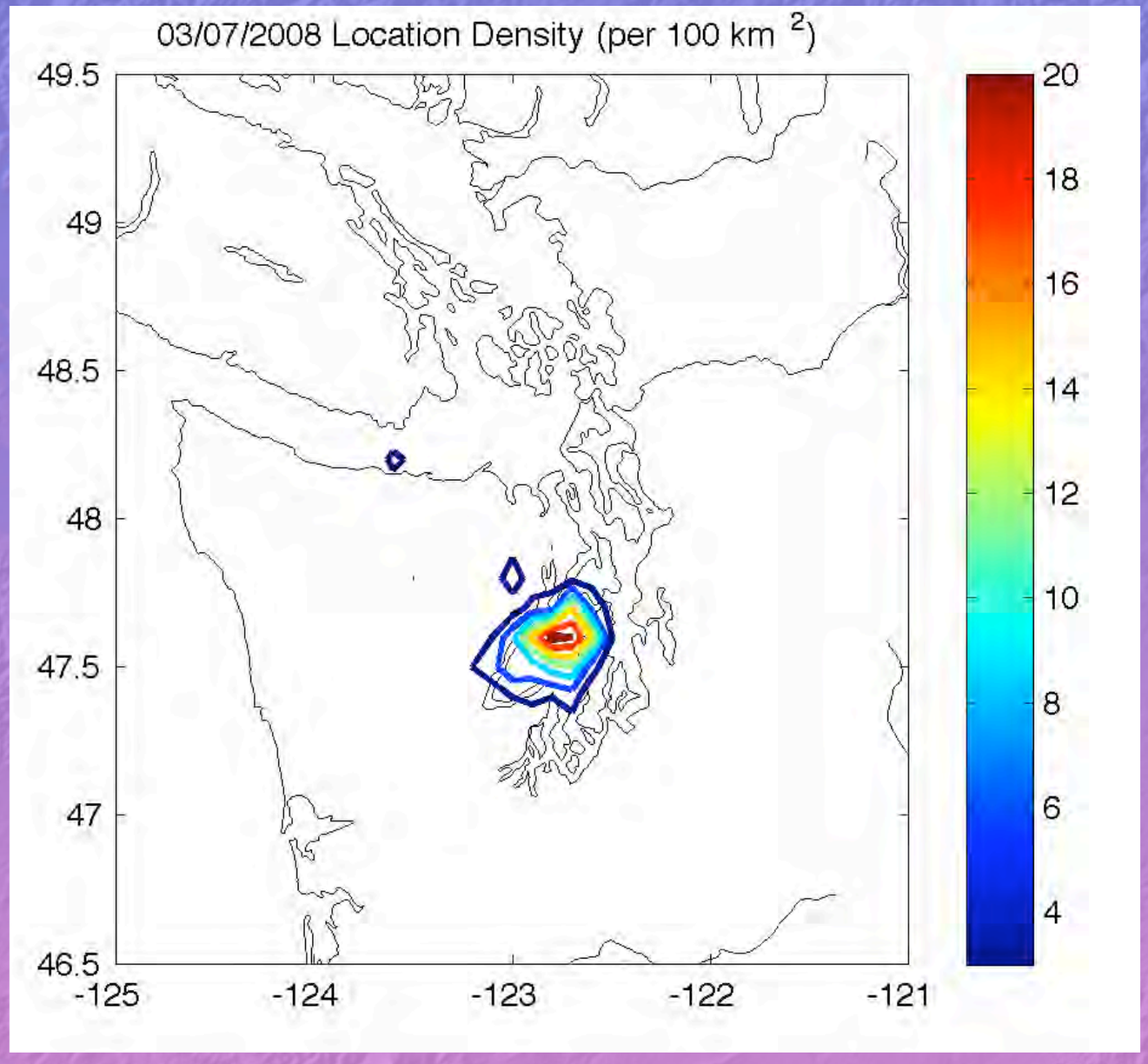


Dragert & Rogers, 2003





AND, last month tremor was detected



http://www.pnsn.org/WEBICORDERS/DEEPTREM/winter2008.html

Shortcuts:

Seismic Envelope Plots | ETS diagnostic Webicorders | Main Webicorder Index | Spectrograms | Tremor hours summary | Auto-Tremor Map | Main Tremor Index |

Cascadia Arrays For EarthScope (CAFE) - Deep Tremor News: Jan, 2008 - .... (Winter, 2008)

This page will have frequent updates from observations and studies of Cascadia deep tremor expected during the winter of 2008 CAFE has several different goals including imaging the structure of the Cascadia subduction zone and a study of deep tremor associated with Episodic Tremor and Slip (ETS).
News will be posted on this page (latest at the top) and references to figures from time to time.

There is a PDF Map of CAFE stations in operation from fall of 2006, planned through summer of 2008.

NEWS (latest at the top)

- Apr 4, 2009 - It has been very quite around here. No tremor in Washington for several weeks. However the PGC dudes (Honn Kao, Garry Rogers, Herb Dragert) report fairly strong tremor in the north Vancouver Island area lasting for four days and then quiting yesterday and without any detectable GPS motions. Maybe that section is mimicing the southern Puget Sound section and "faking" and ETS event starting.
- Mar 12, 2009 - No tremor for the past three days. A 21 day seismic envelope plot of the period Feb 28 to Mar 12, 2008 shows the 7+ days of tremor that looked to be the beginning of an ETS. Note that it is quite strong on HDW but not nearly as obvious on the nearby stations, CPW, SMW and GNW though it can be seen above the noise there too. Other noises showing up on many stations are obviously diurnal cultural noises that even are lower levels on weekends. The Auto-Tremor Map for the past few days shows almost no tremor locations.
- Mar 9, 2009 - After some very strong tremor on Mar 7 tremor seems to have decreased during Mar 8. Over the past 24 hours (Mar 9 GMT) there has only been very weak tremor now and then. It seems that the ETS has either stalled or this is not the main event. As previously scheduled the almost 90 Texan seismographs in the Olympics were serviced, swapping existing ones for new ones.

http://www.pnsn.org/WEBICORDERS/DEEPTREM/winter2008.html

Shor

Seismic Envelope Plots | ETS diagnostic Webicorders |
Tremor hours summary | Auto-Tremor Map | Main Tr

Cascadia Arrays For

Deep Tremor News: Jan, 2

This page will have frequent updates from observations an
winter of 2008 CAFE has several different goals including i
a study of deep tremor associated with Episodic Tremor ar
News will be posted on this page (latest at the top) and ref

There is a PDF Map of CAFE stations in operation from fall

NEWS (latest at the top)

- Apr 4, 2009 - It has been very quite around here. No trem
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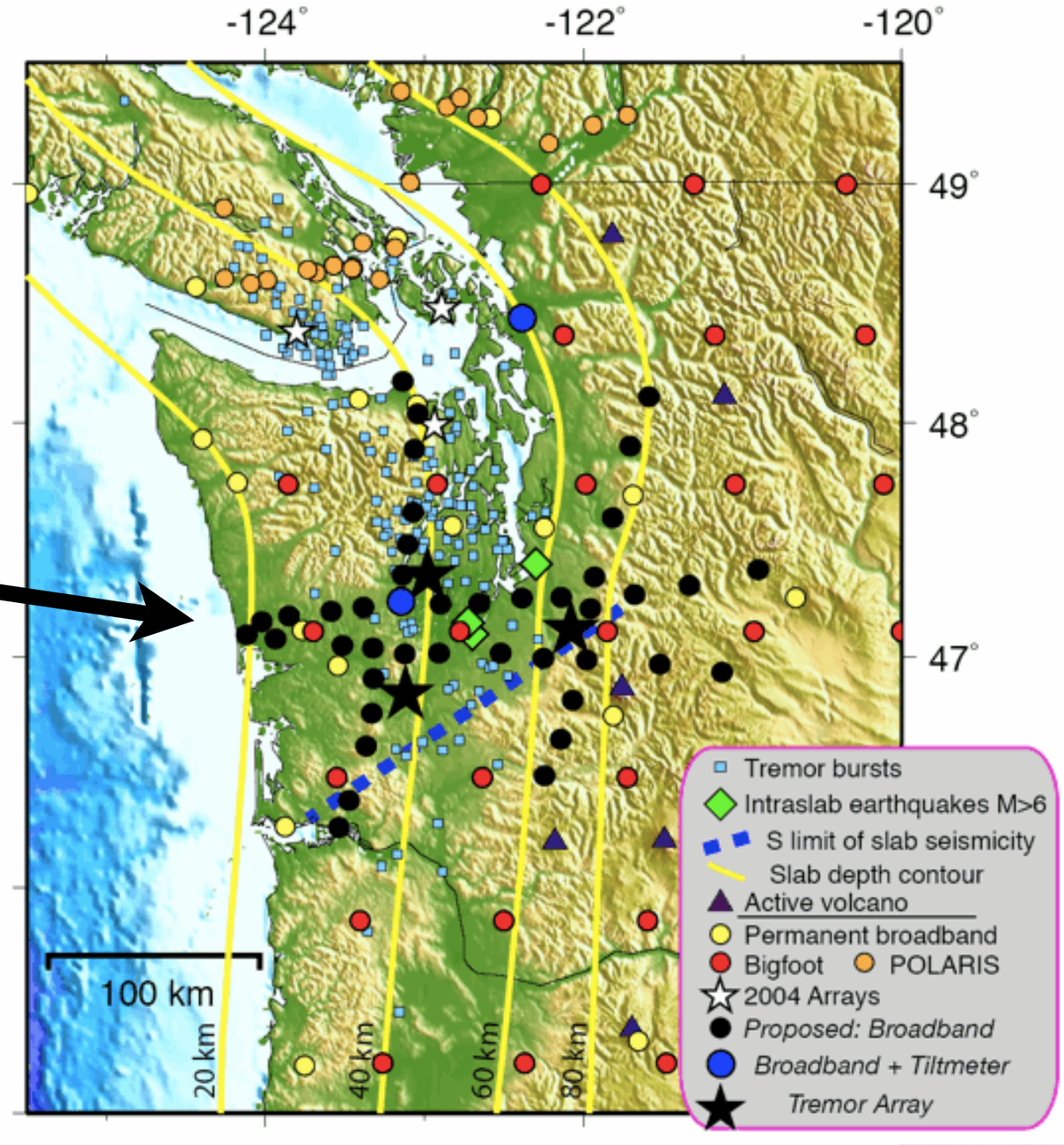


PNSN > 2006 Tremor Episode > Special seismic studies of deep tremor

http://www.pnsn.org/WEBICORDERS/DEEPTREM/winter2008.html

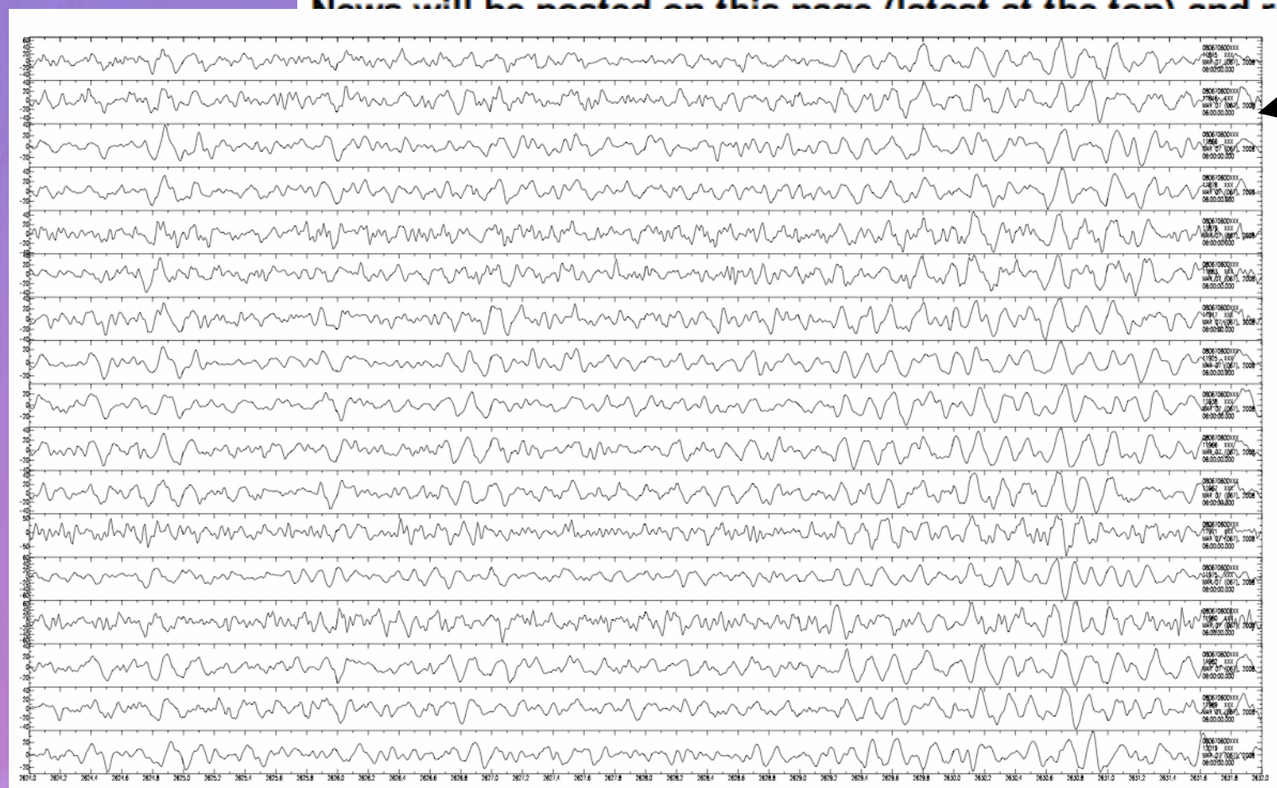
Shor

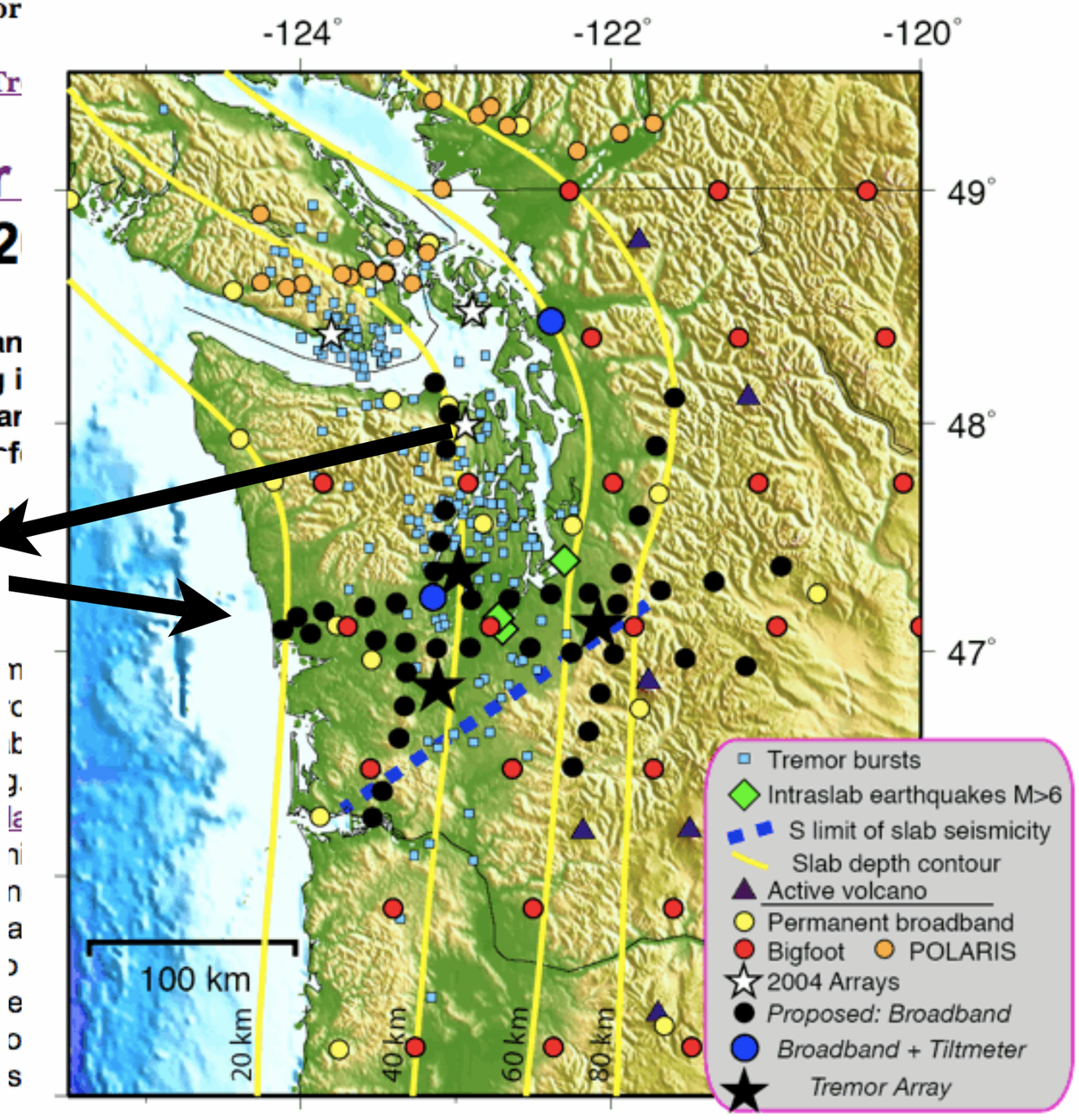
Seismic Envelope Plots | ETS diagnostic Webicorders |
Tremor hours summary | Auto-Tremor Map | Main Tr

Cascadia Arrays For

Deep Tremor News: Jan, 2

This page will have frequent updates from observations an
winter of 2008 CAFE has several different goals including i
a study of deep tremor associated with Episodic Tremor ar





Early Warning research

Early Warning research

- Explosive eruption has started - Warn aircraft away from expanding ash cloud

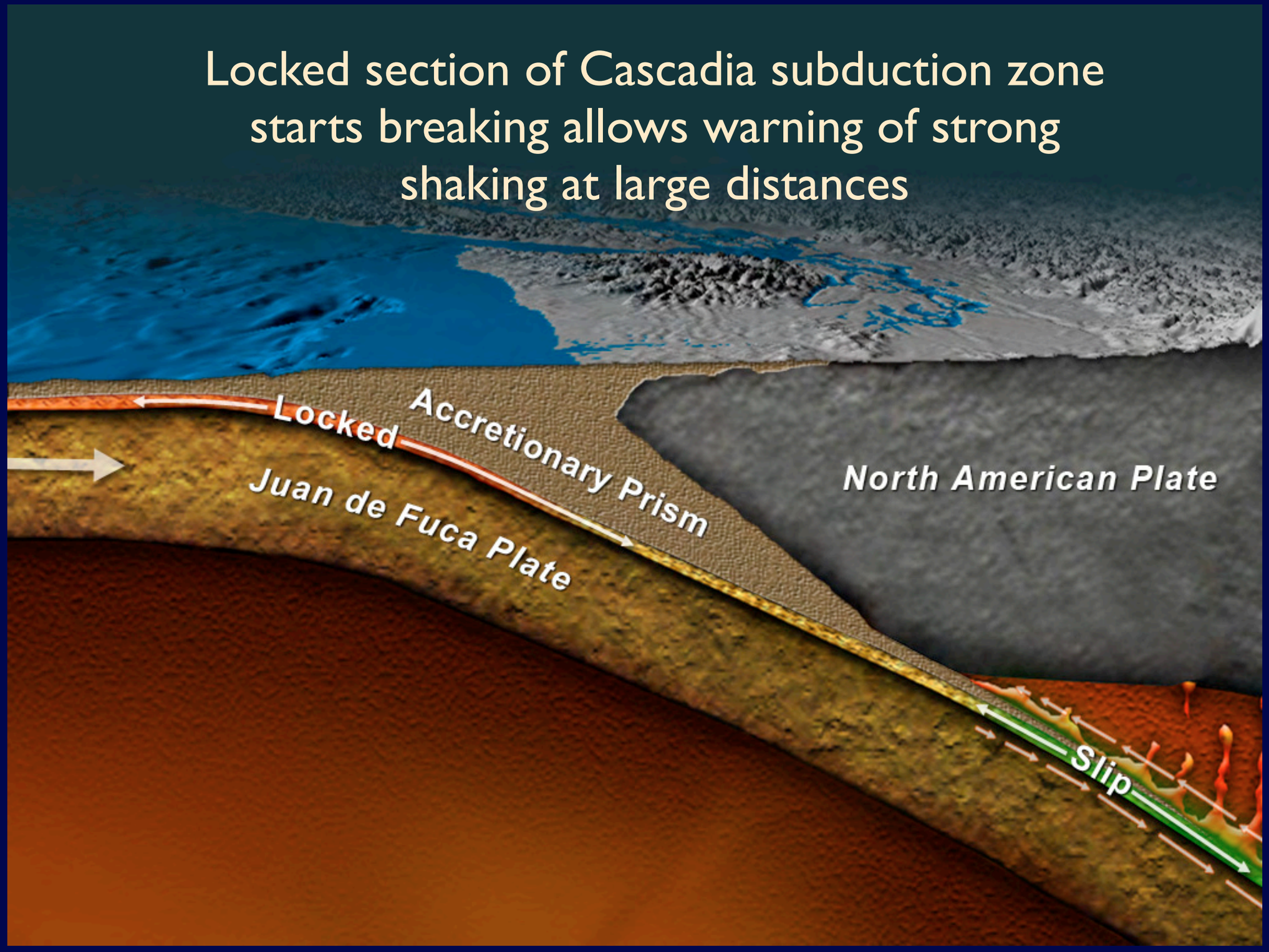
Early Warning research

- Explosive eruption has started - Warn aircraft away from expanding ash cloud
- Large subduction earthquake has occurred - warn coastal populations of tsunami

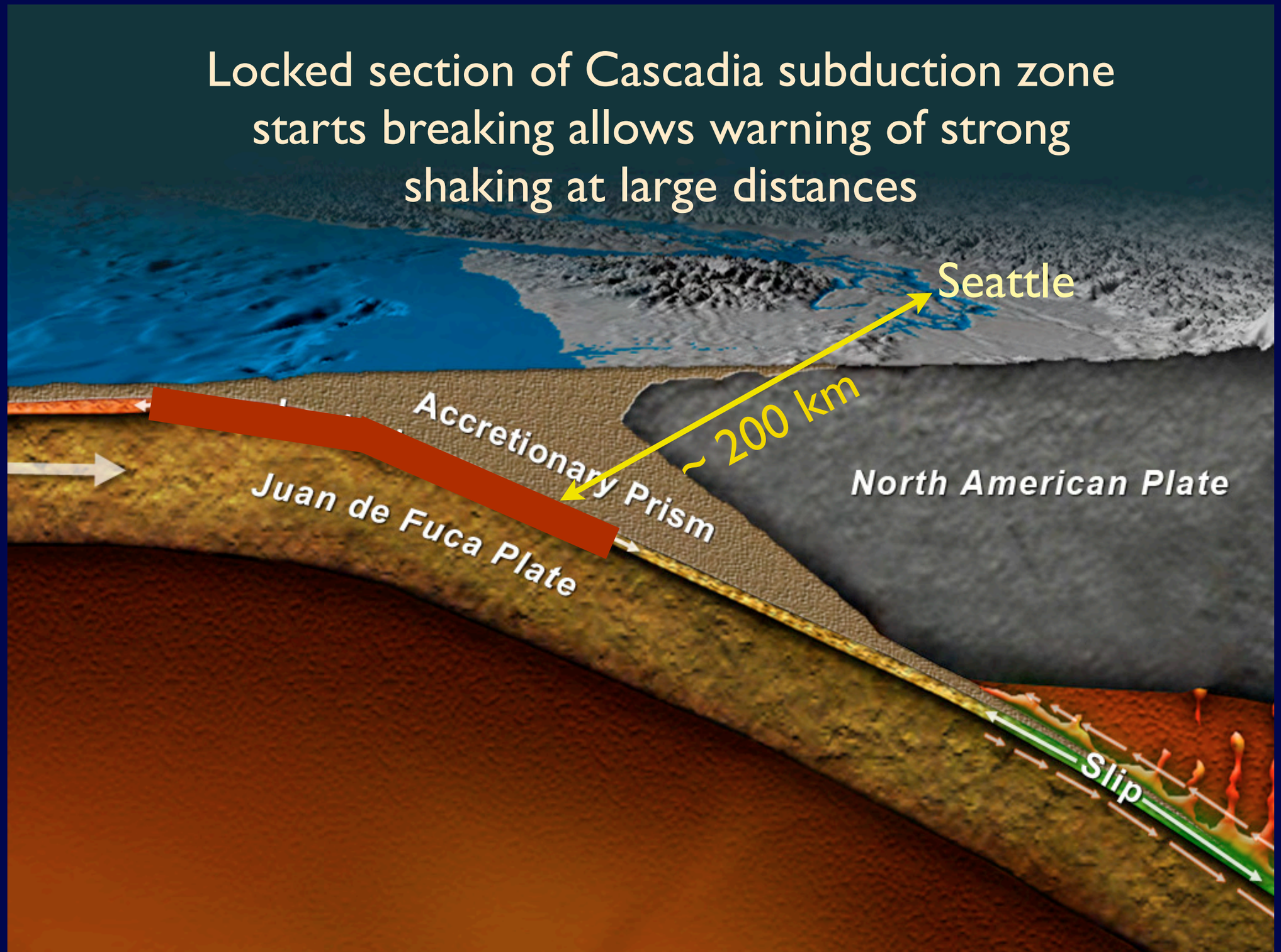
Early Warning research

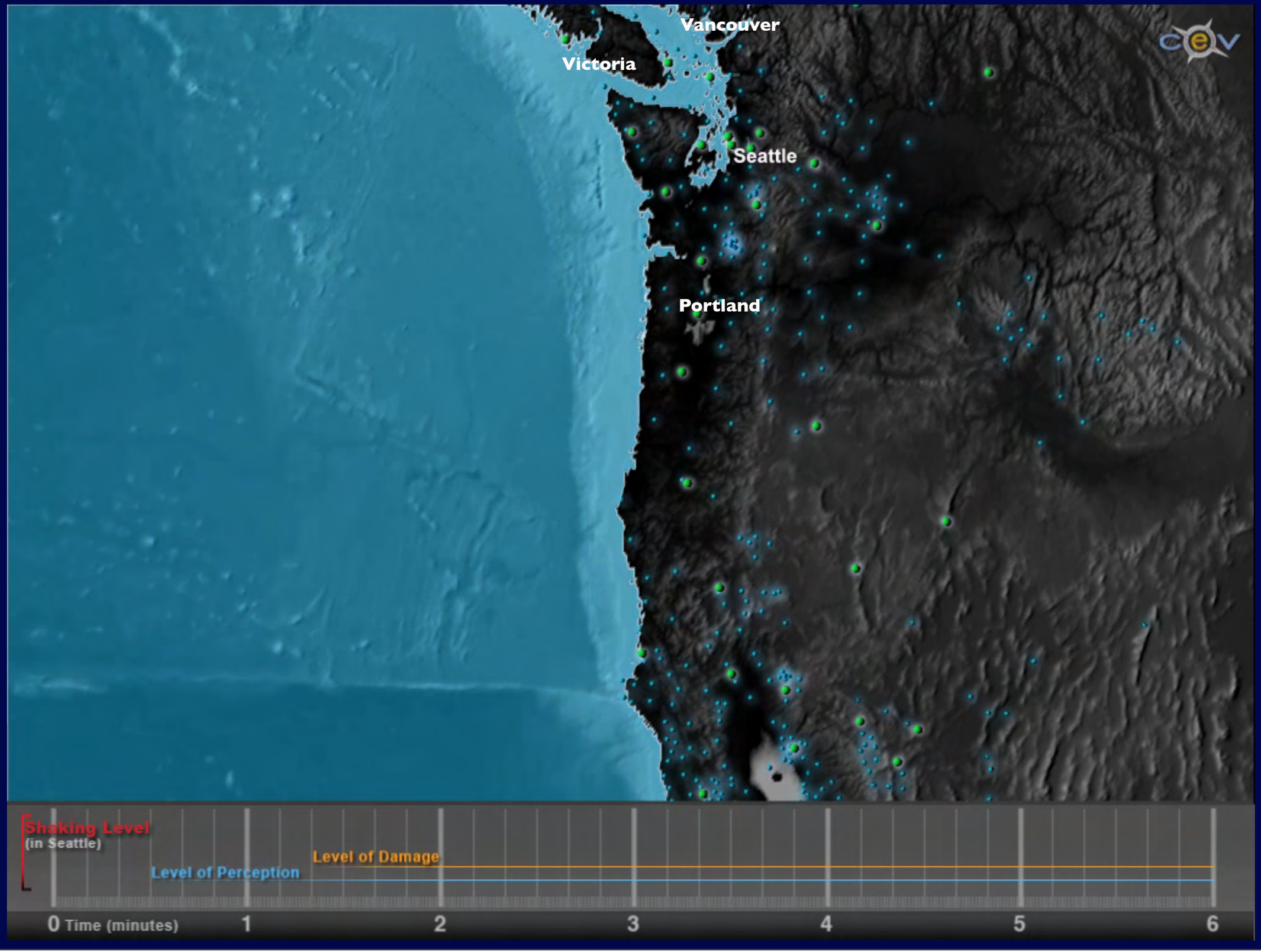
- Explosive eruption has started - Warn aircraft away from expanding ash cloud
- Large subduction earthquake has occurred - warn coastal populations of tsunami
- Large earthquake has started - warn population at distance of strong ground motion coming

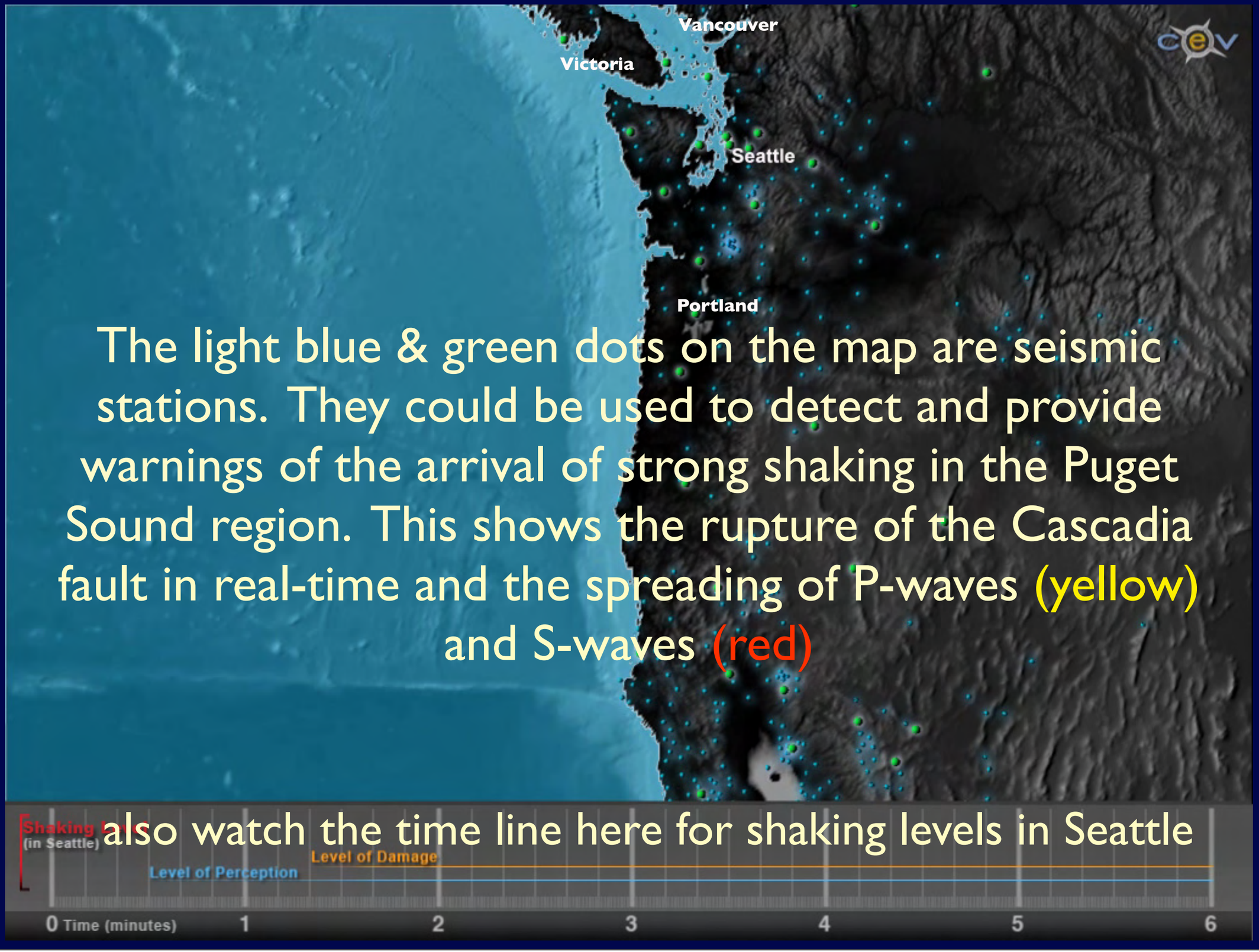
Locked section of Cascadia subduction zone starts breaking allows warning of strong shaking at large distances

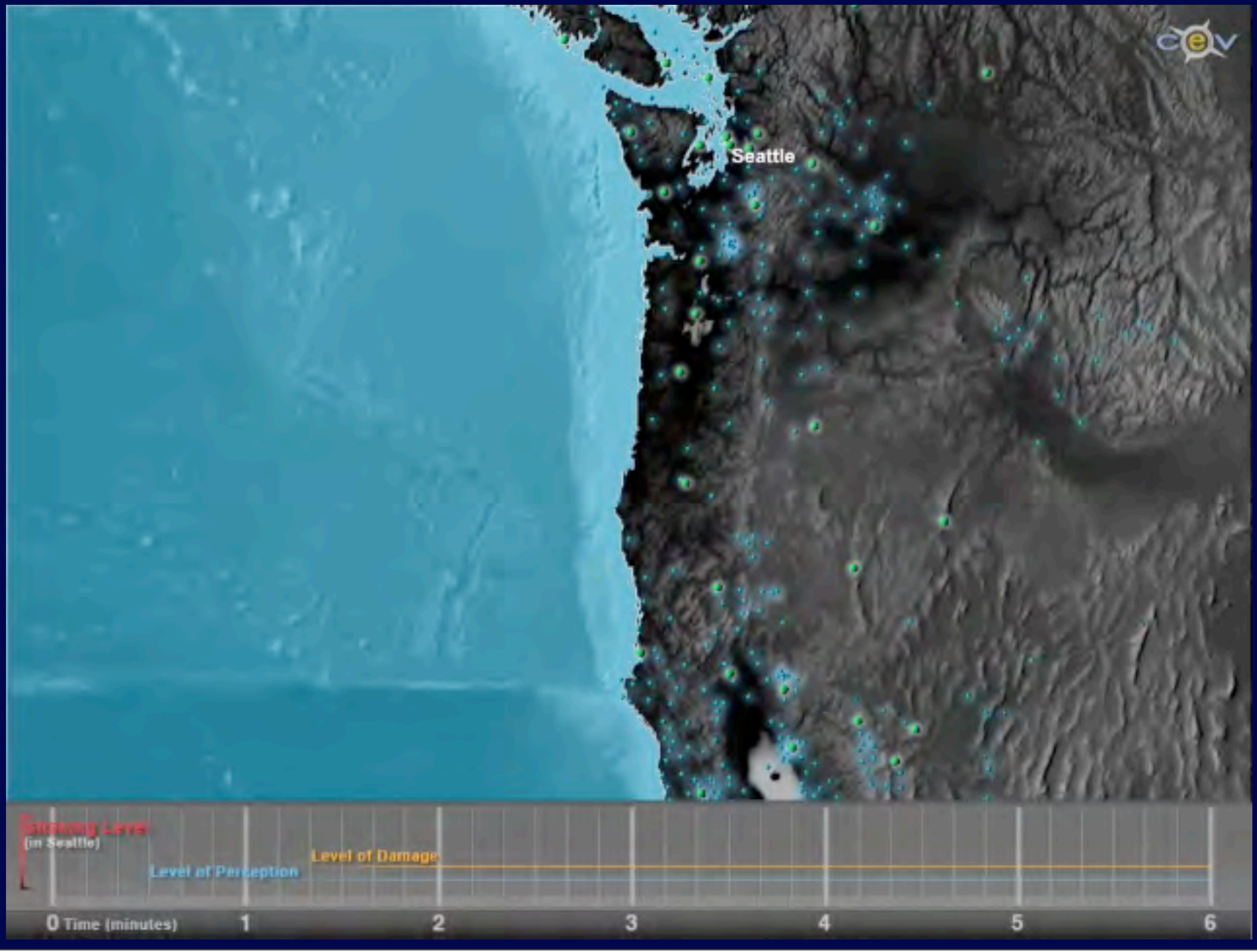


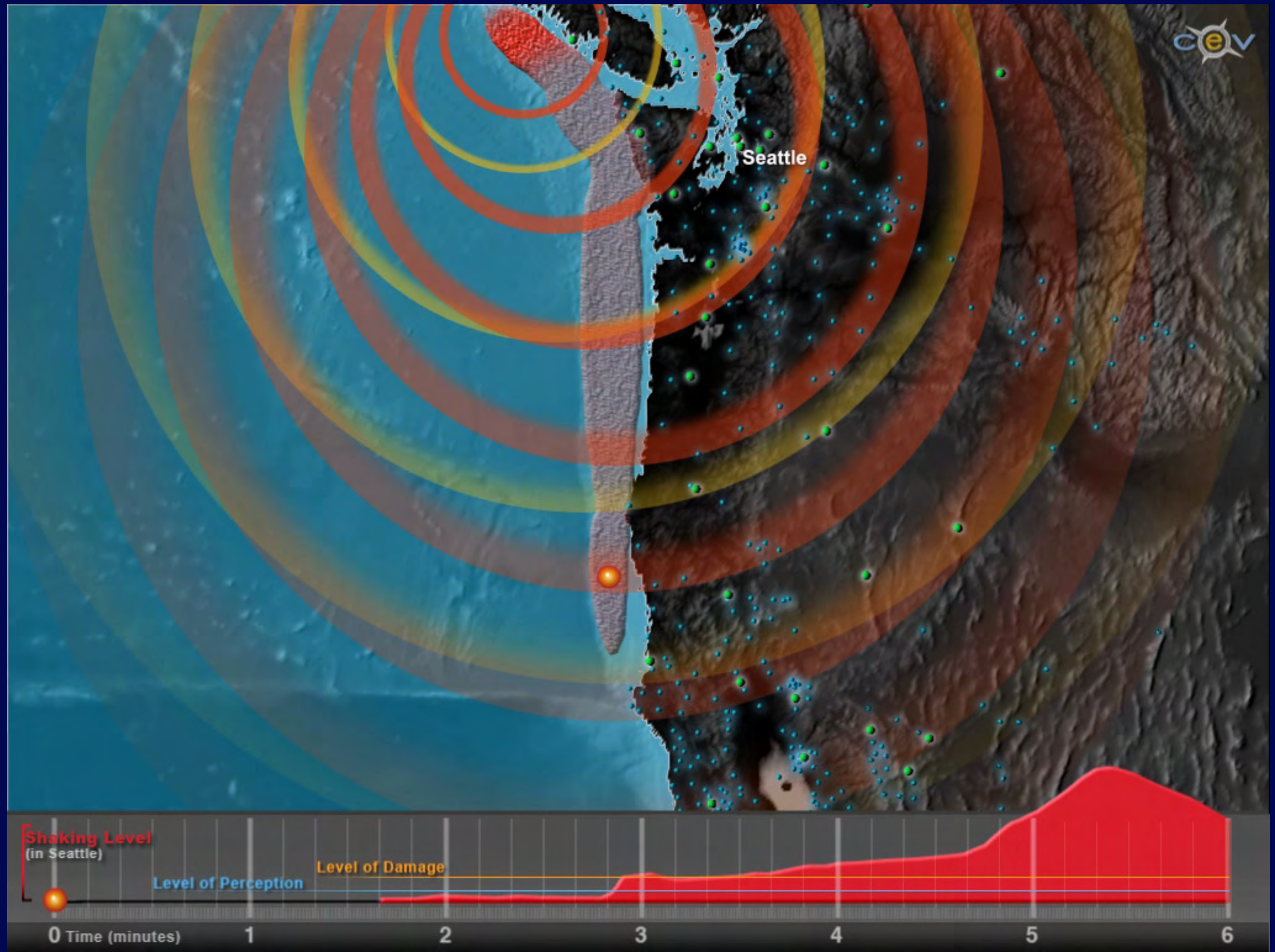
Locked section of Cascadia subduction zone starts breaking allows warning of strong shaking at large distances




Vancouver
Victoria
Seattle
Portland
Shaking Level
(in Seattle)
Level of Damage
Level of Perception
0 Time (minutes)
1
2
3
4
5
6


Vancouver
Victoria
Seattle
Portland
The light blue & green dots on the map are seismic stations. They could be used to detect and provide warnings of the arrival of strong shaking in the Puget Sound region. This shows the rupture of the Cascadia fault in real-time and the spreading of P-waves (yellow) and S-waves (red)
also watch the time line here for shaking levels in Seattle
Shaking Level (in Seattle)
Level of Damage
Level of Perception
0 Time (minutes)
1
2
3
4
5
6


Seattle
Shaking Level
(in Seattle)
Level of Perception
Level of Damage
0 Time (minutes)
1
2
3
4
5
6


Seattle
Shaking Level
(in Seattle)
Level of Perception
Level of Damage
0 Time (minutes)
1
2
3
4
5
6

END

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