

# Episodic Tremor and Slip: The Case of the Mystery Earthquakes

*Created in collaboration with Roger Groom (Mt. Tabor Middle School), Shelley Olds (UNAVCO), Herb Dragert (Geological Survey of Canada), Bob Butler (U. Portland), and Jenda Johnson (IRIS). Funded in part by the National Science Foundation through EarthScope.*



## The Cascadia Subduction Zone



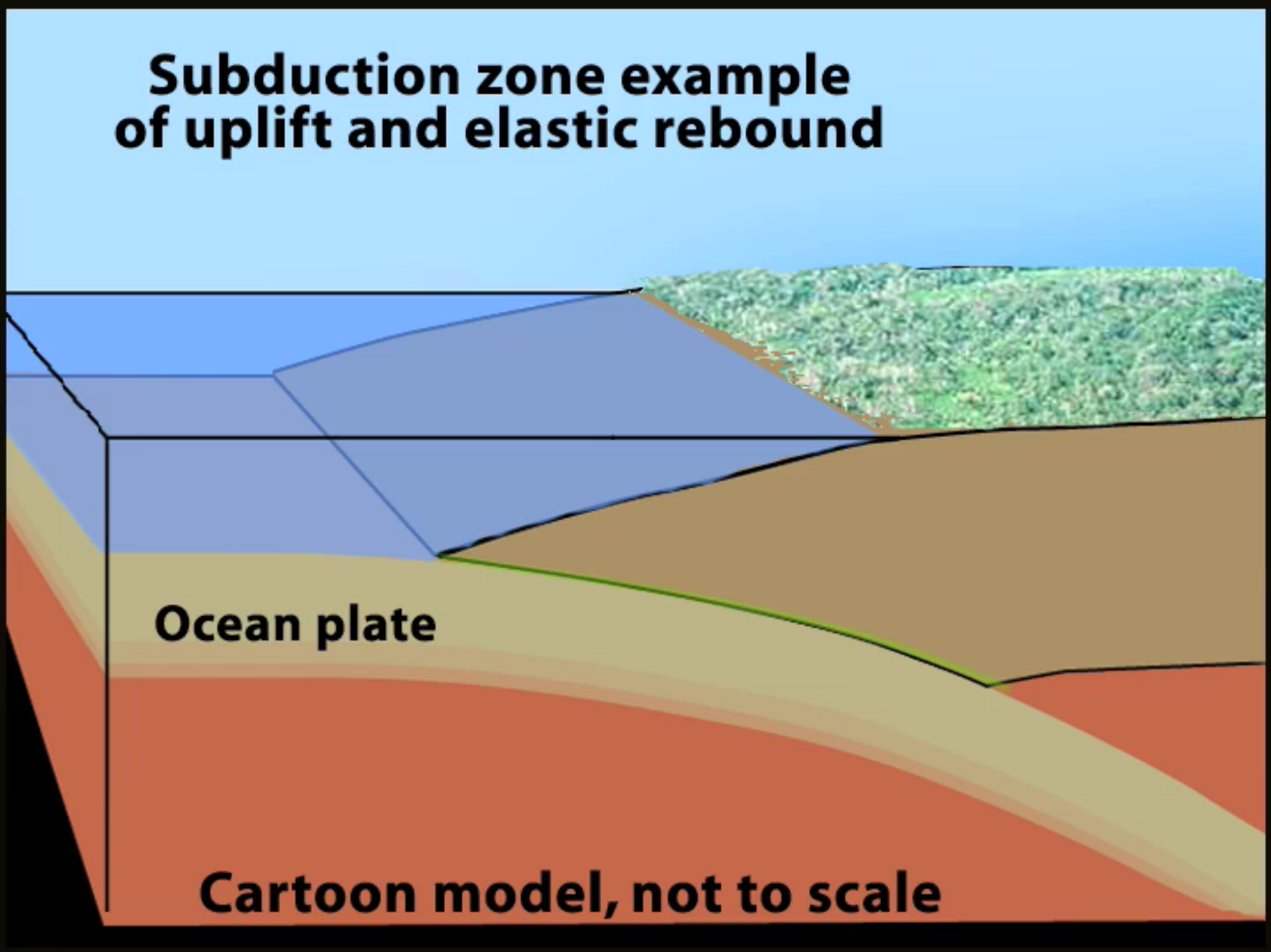
## The Cascadia Subduction Zone





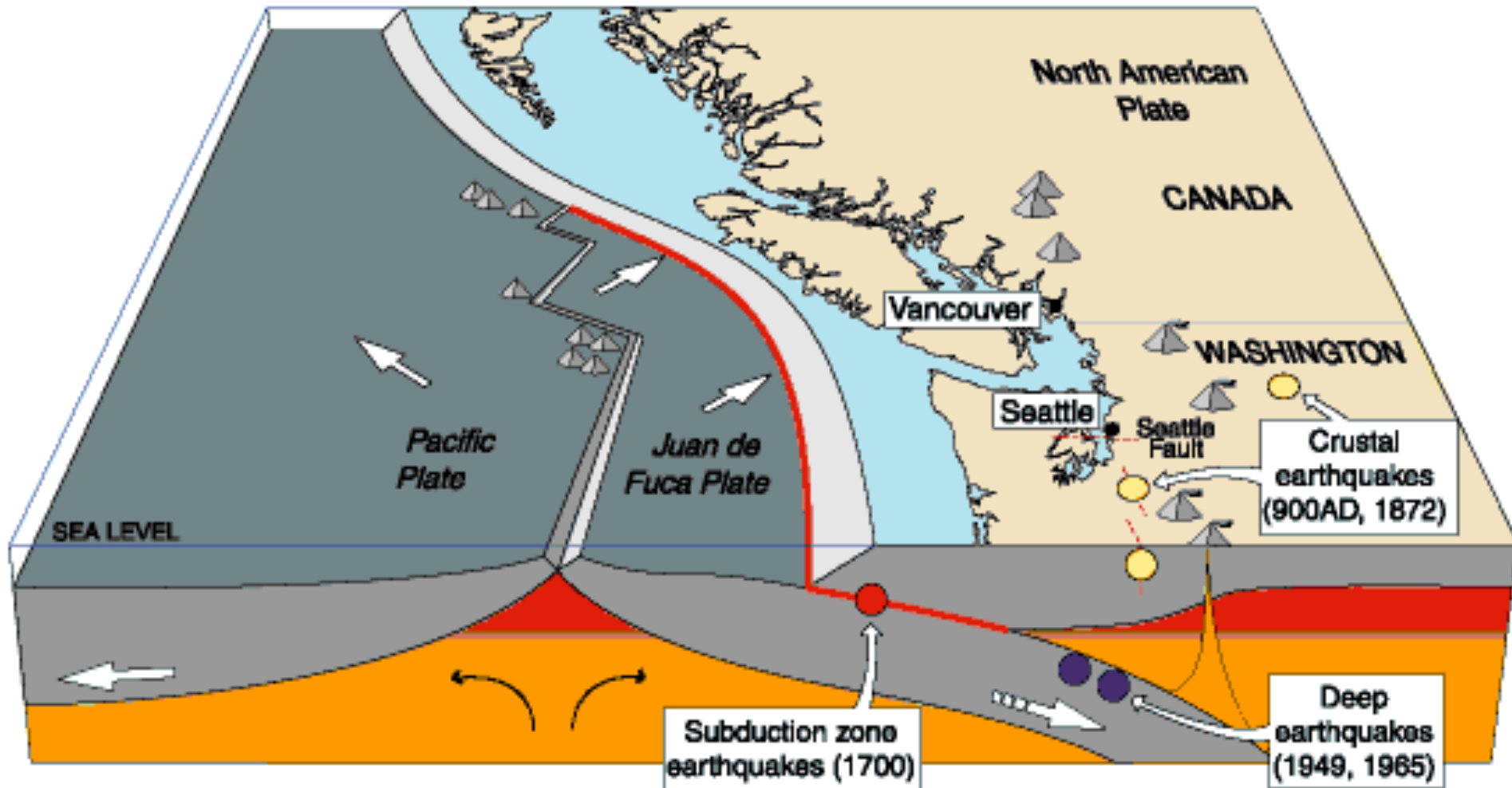
**Subduction zone example  
of uplift and elastic rebound**

**Ocean plate**



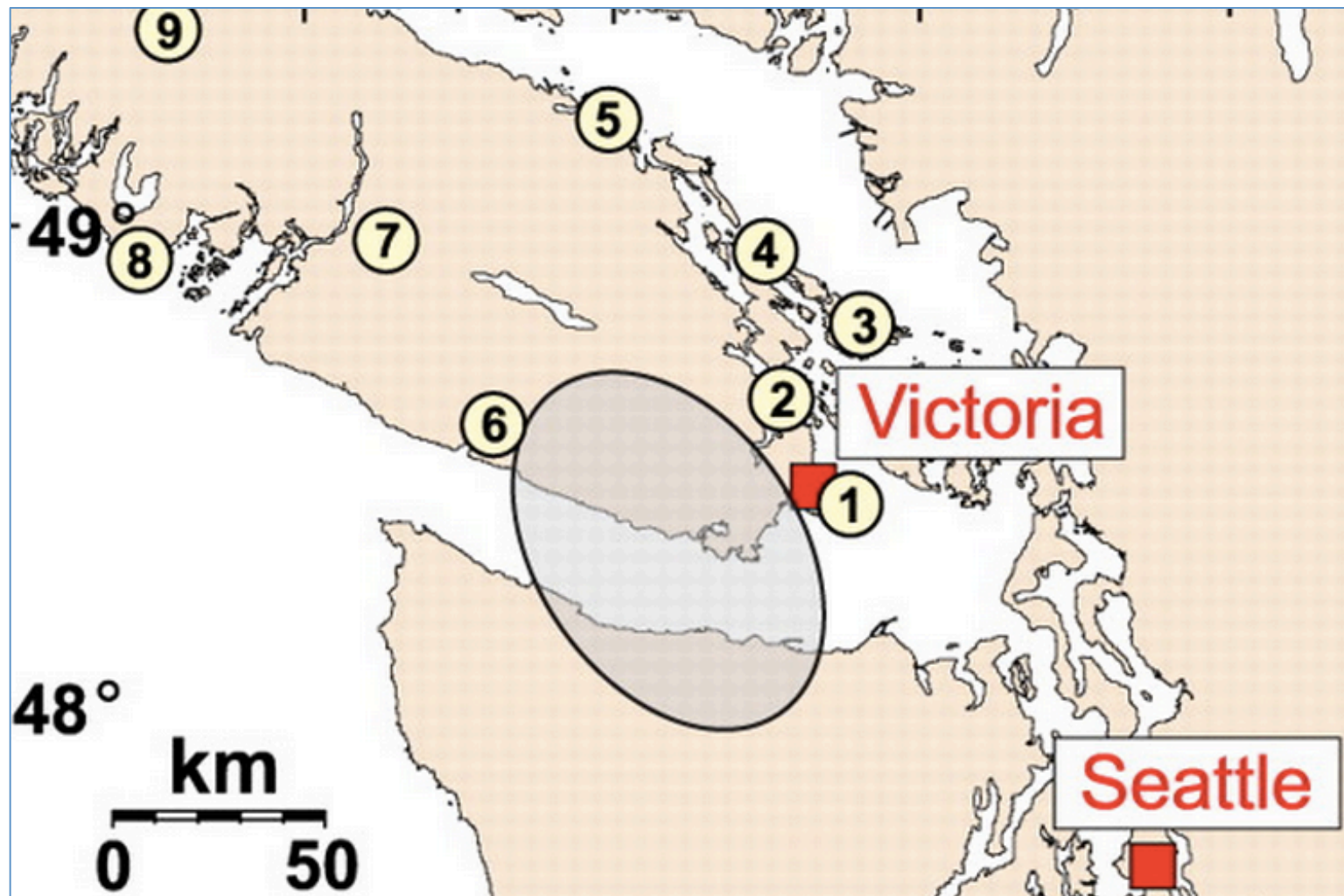
**Cartoon model, not to scale**





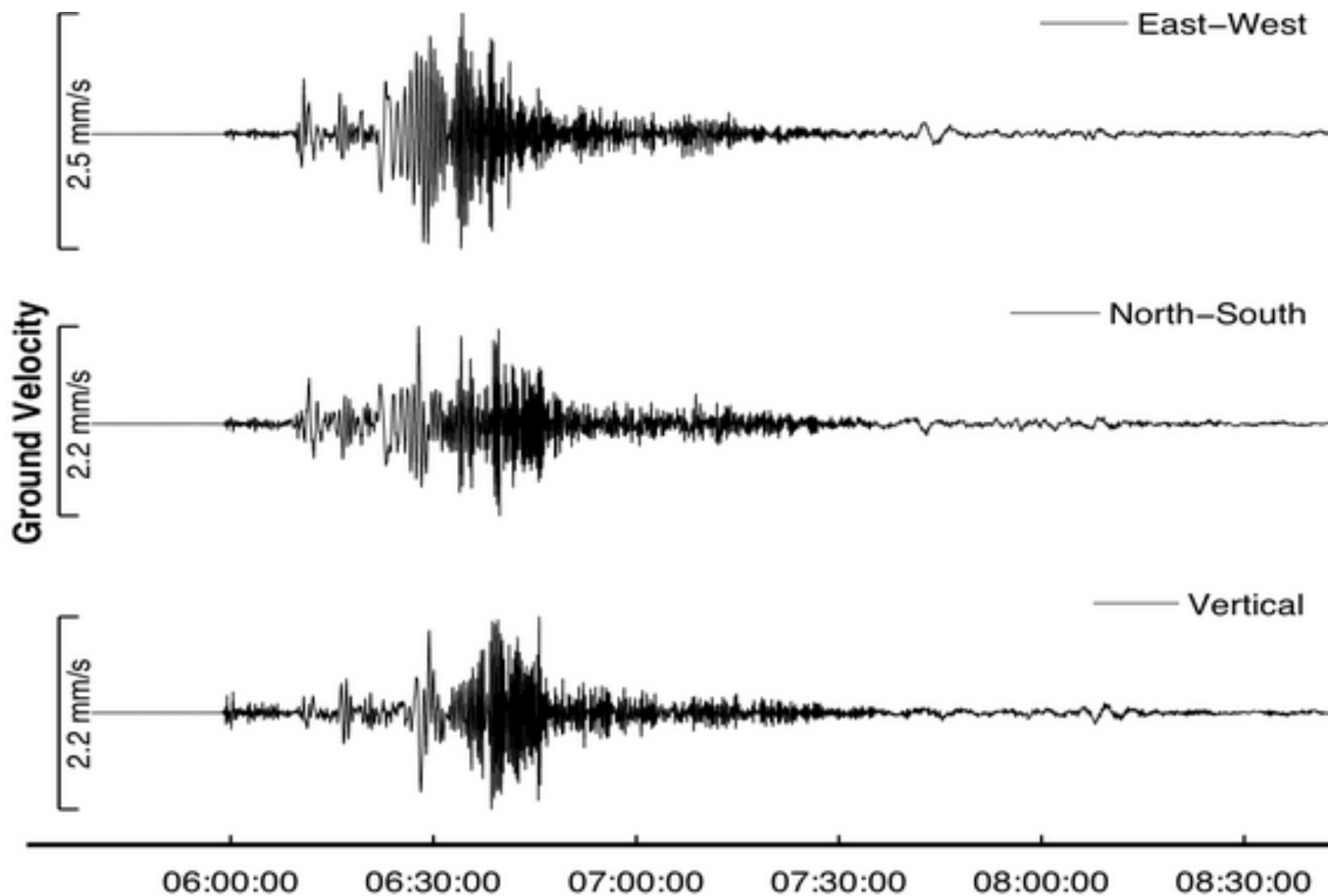
# Hmm . . . What's happening here?

Seismic data from northern Cascadia



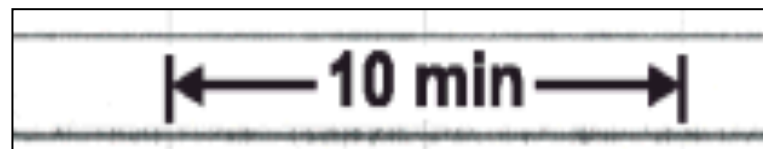
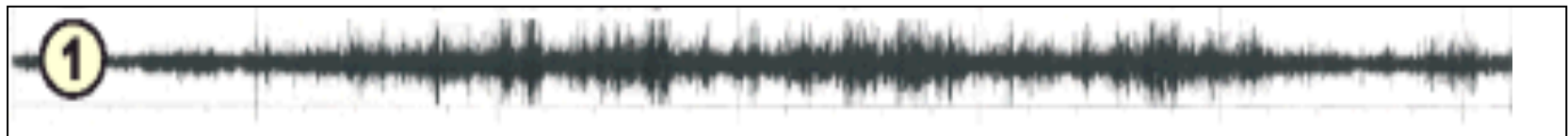


# Hmm . . . What's happening here?



# Hmm . . . What's happening here?

The mystery begins---strange tremors...  
no ground shaking...

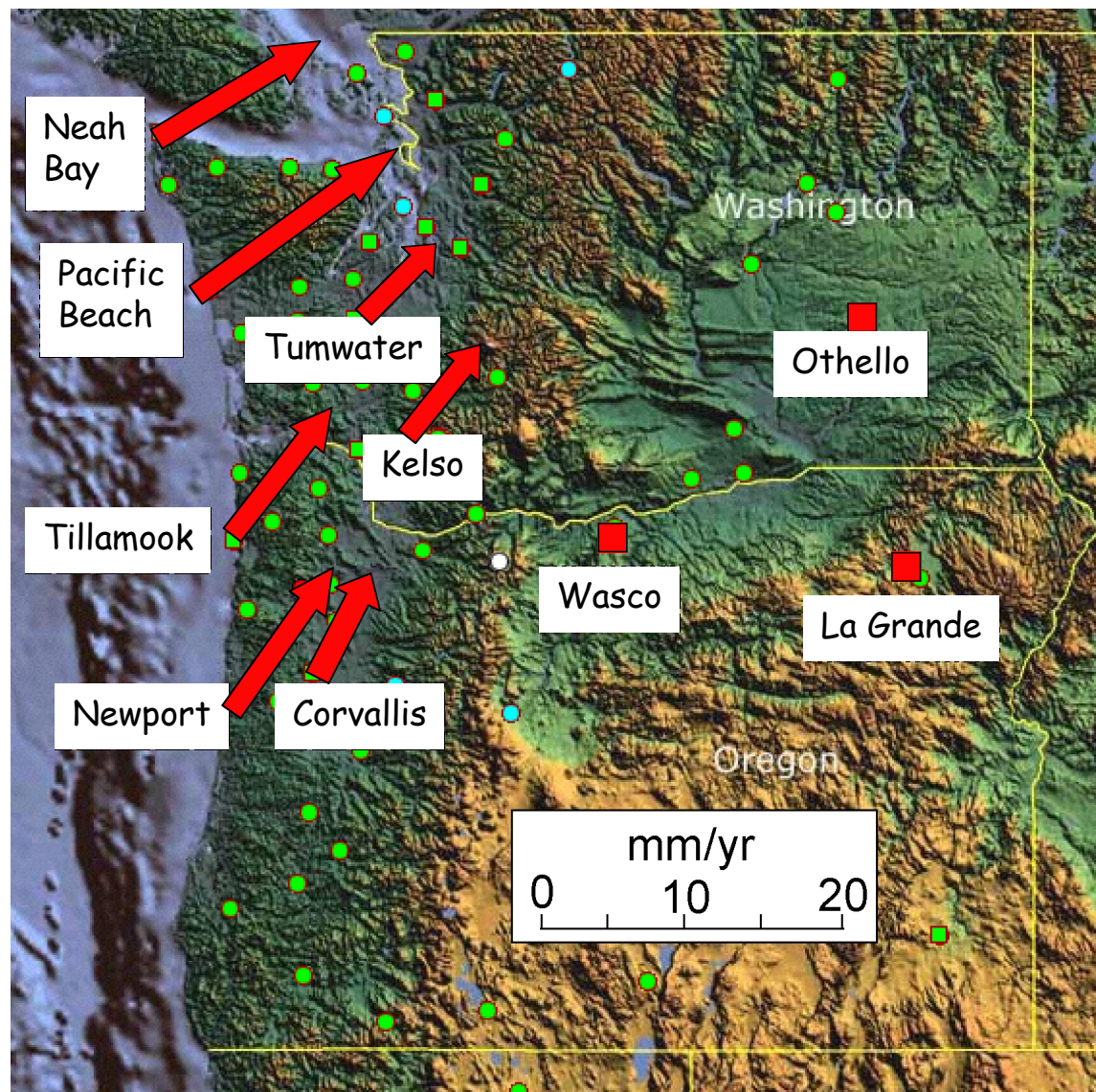




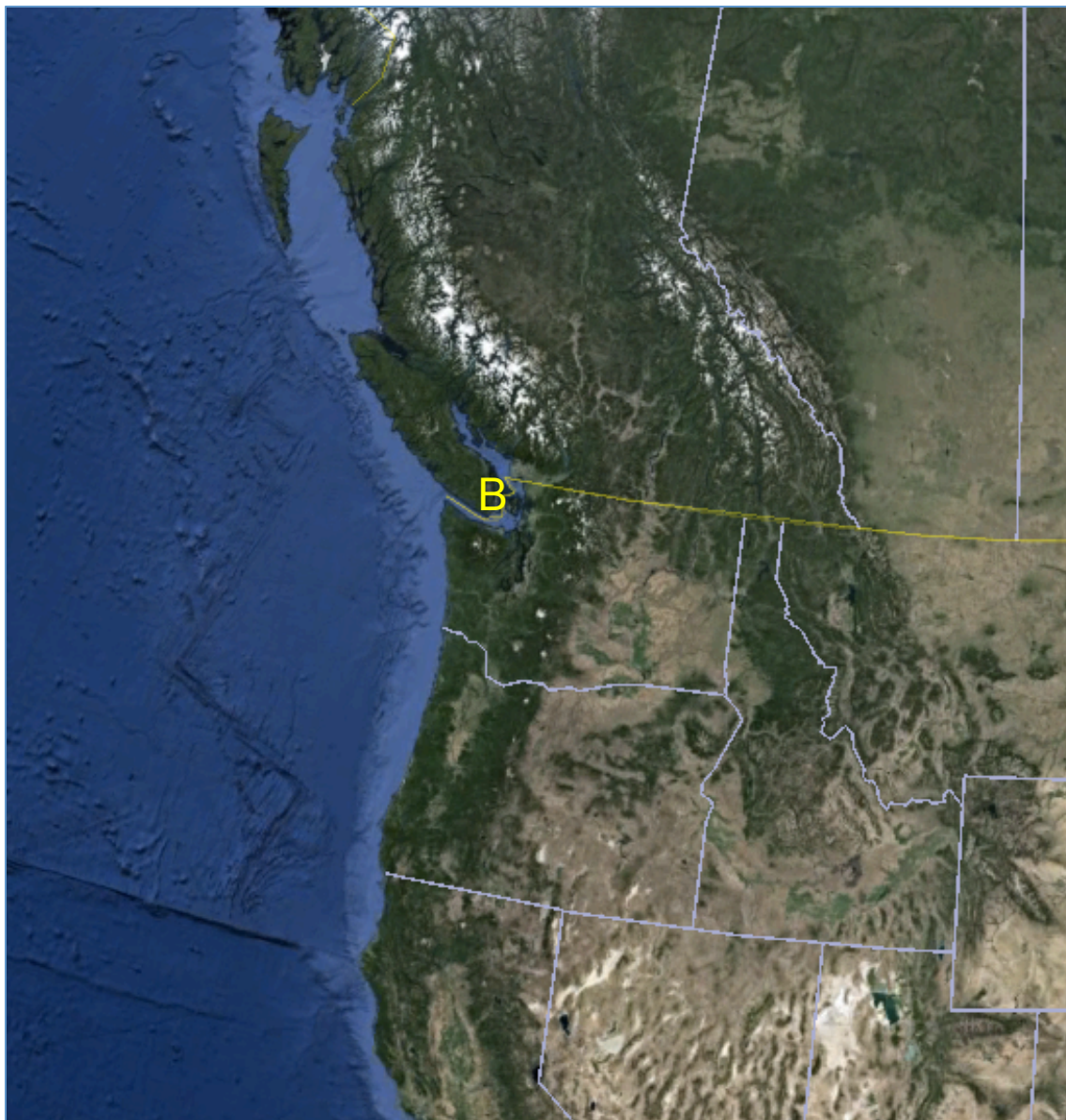
# Hmm . . . What's happening here?

- Seismologists couldn't explain the data.
- Instrument problems?
- Background noise:
  - Herd of cattle walking near the instruments?
  - Wind?
  - Human-made vibrations like cars or trains?
  - Aliens?







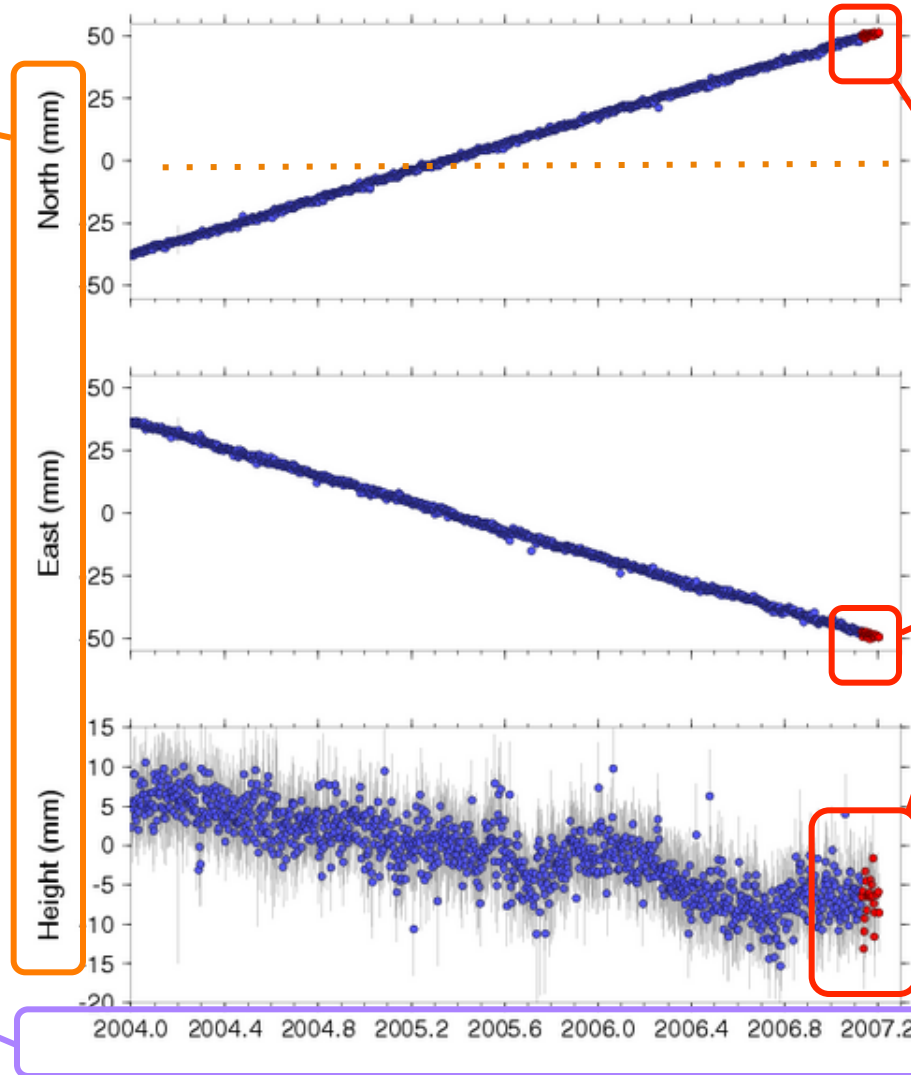


... the change in the GPS position over time

Y-axis:

- North
- East
- Height (Vertical)

X-axis: date of measurement



Red points:  
rapid estimates



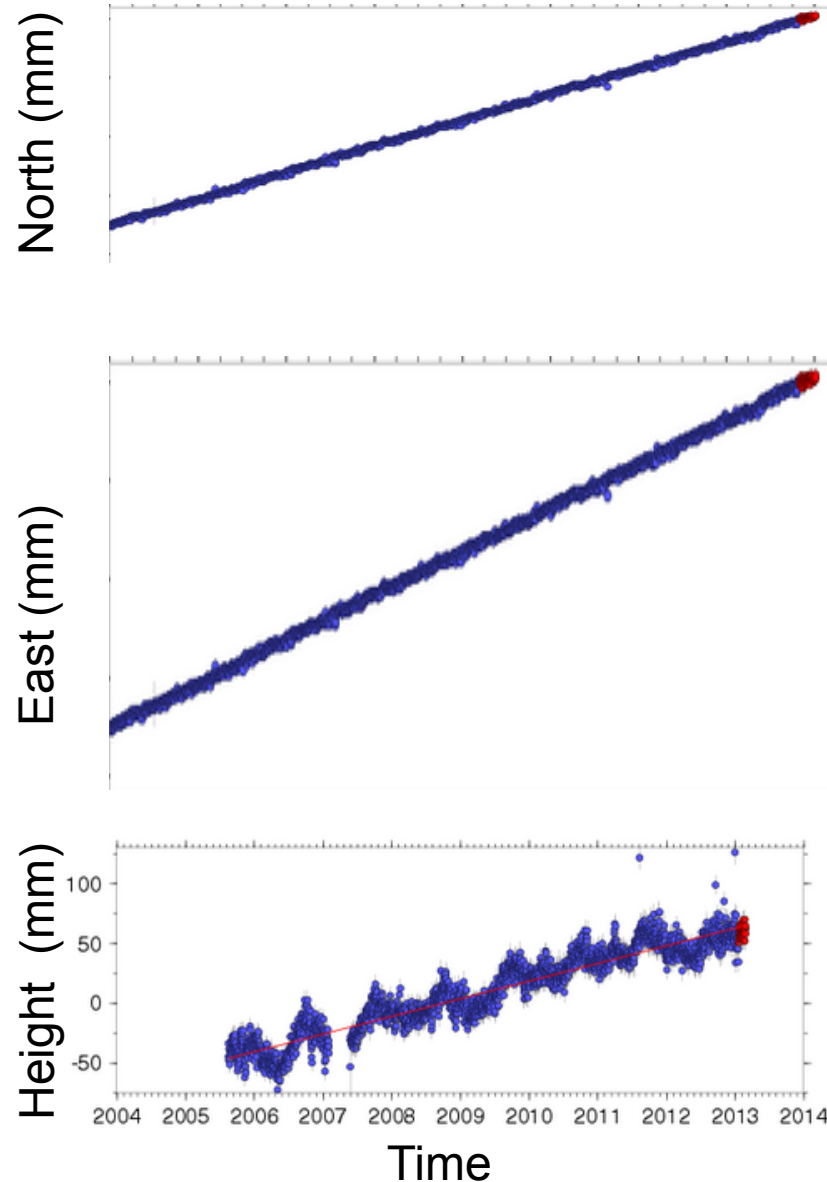
# Which way are we going?

Is the GPS station  
moving

➤ north or south?

➤ east or west?

➤ up or down?



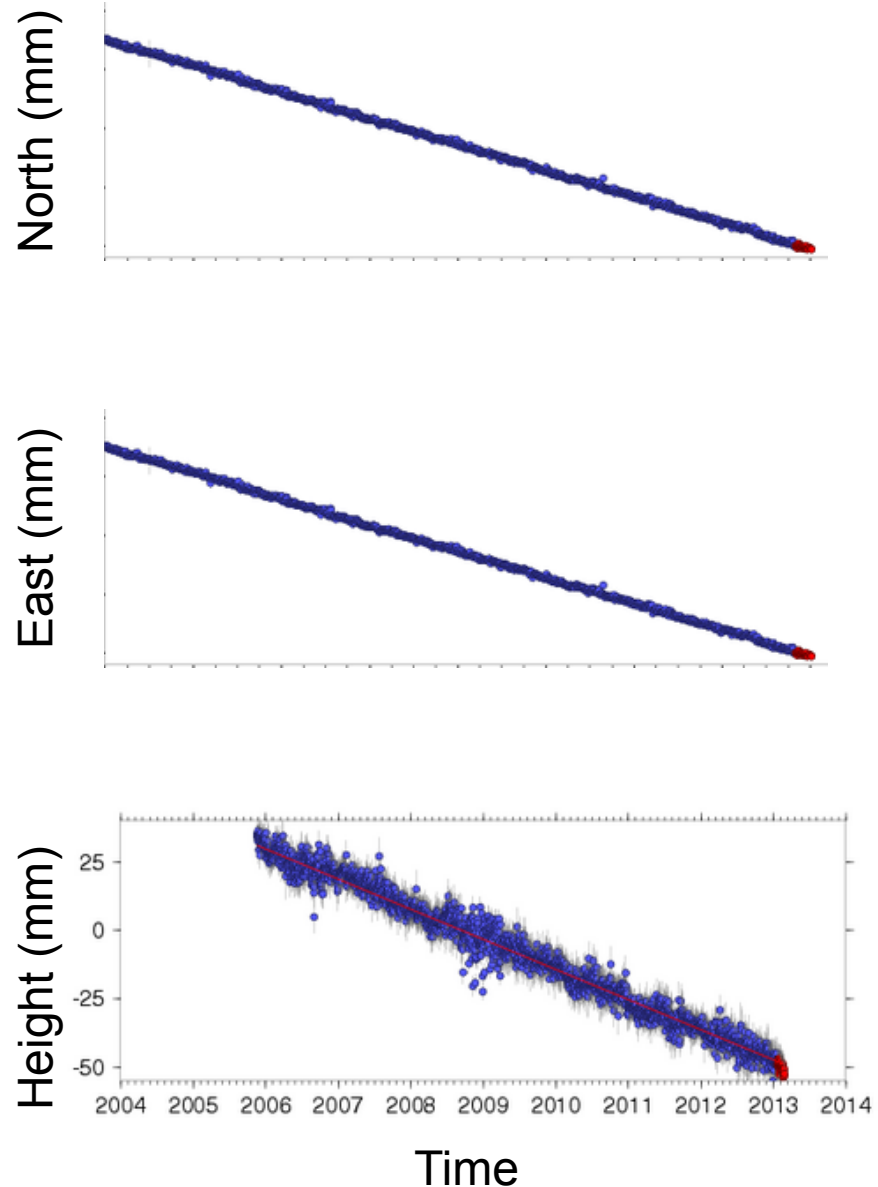
# Which way are we going?

Is the GPS station moving

➤ north or south?

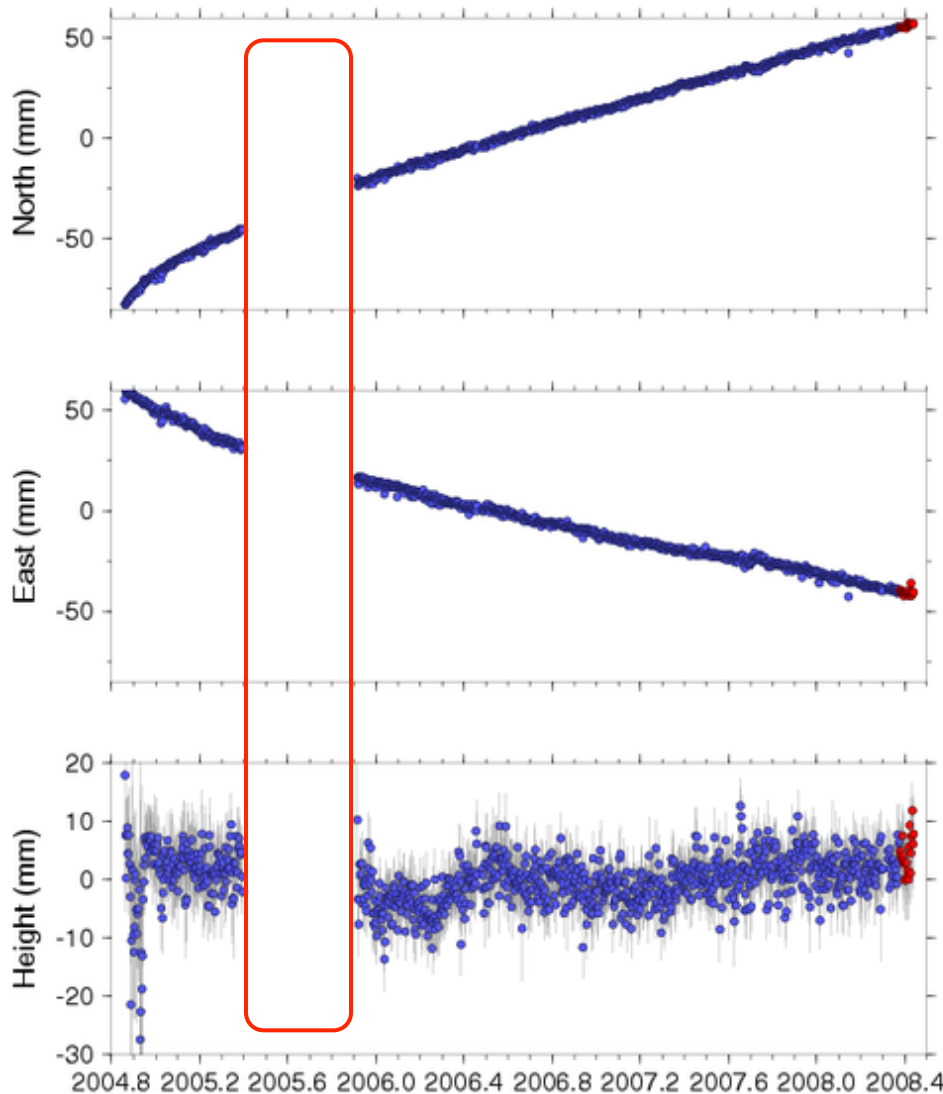
➤ east or west?

➤ up or down?





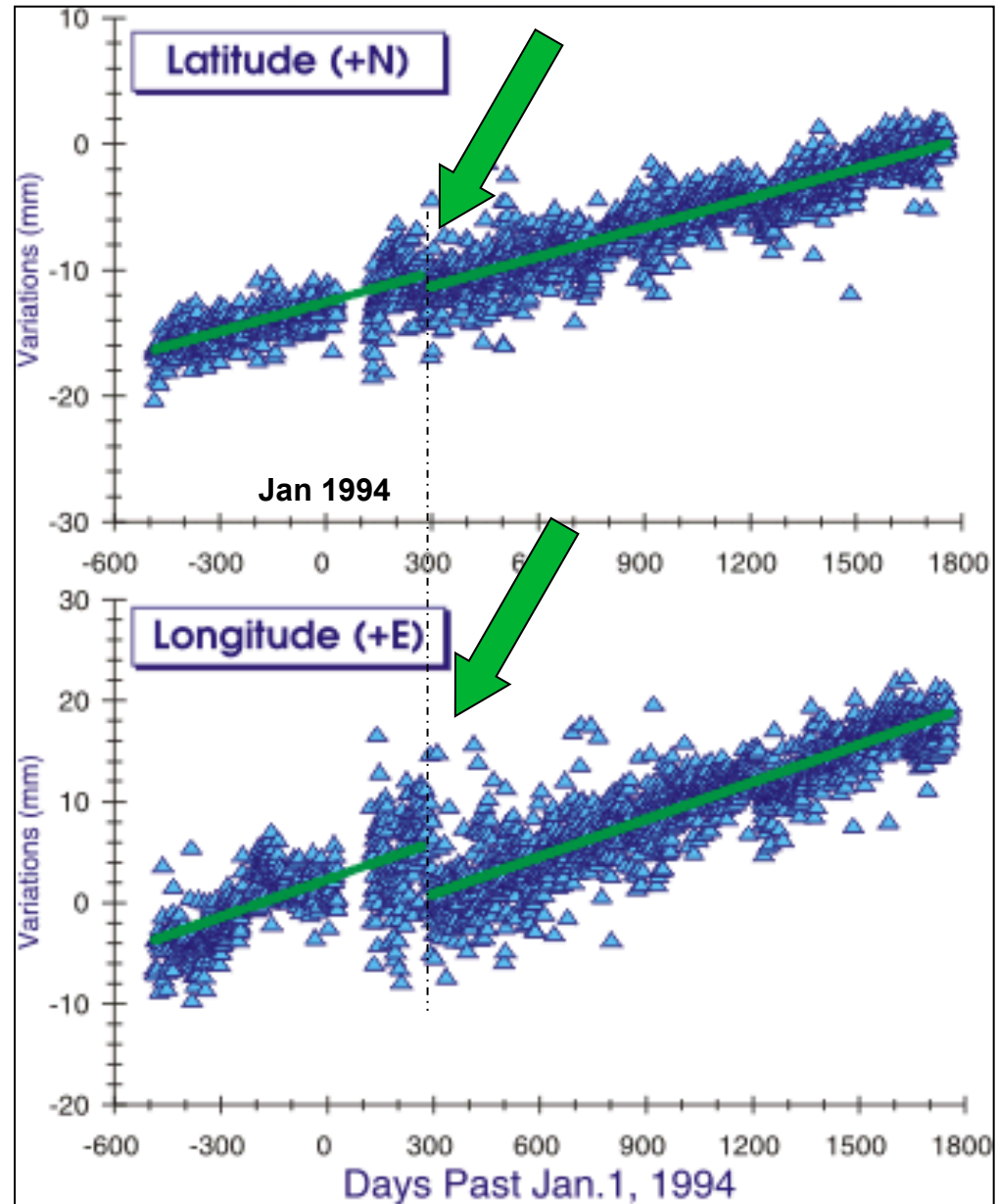
P281 (CholameCrkCN2004)



## Causes:

- power outages;
- snow coverage;
- equipment failure;
- vandalism;
- wildlife; or
- aliens again?

What happens where  
the green line breaks?

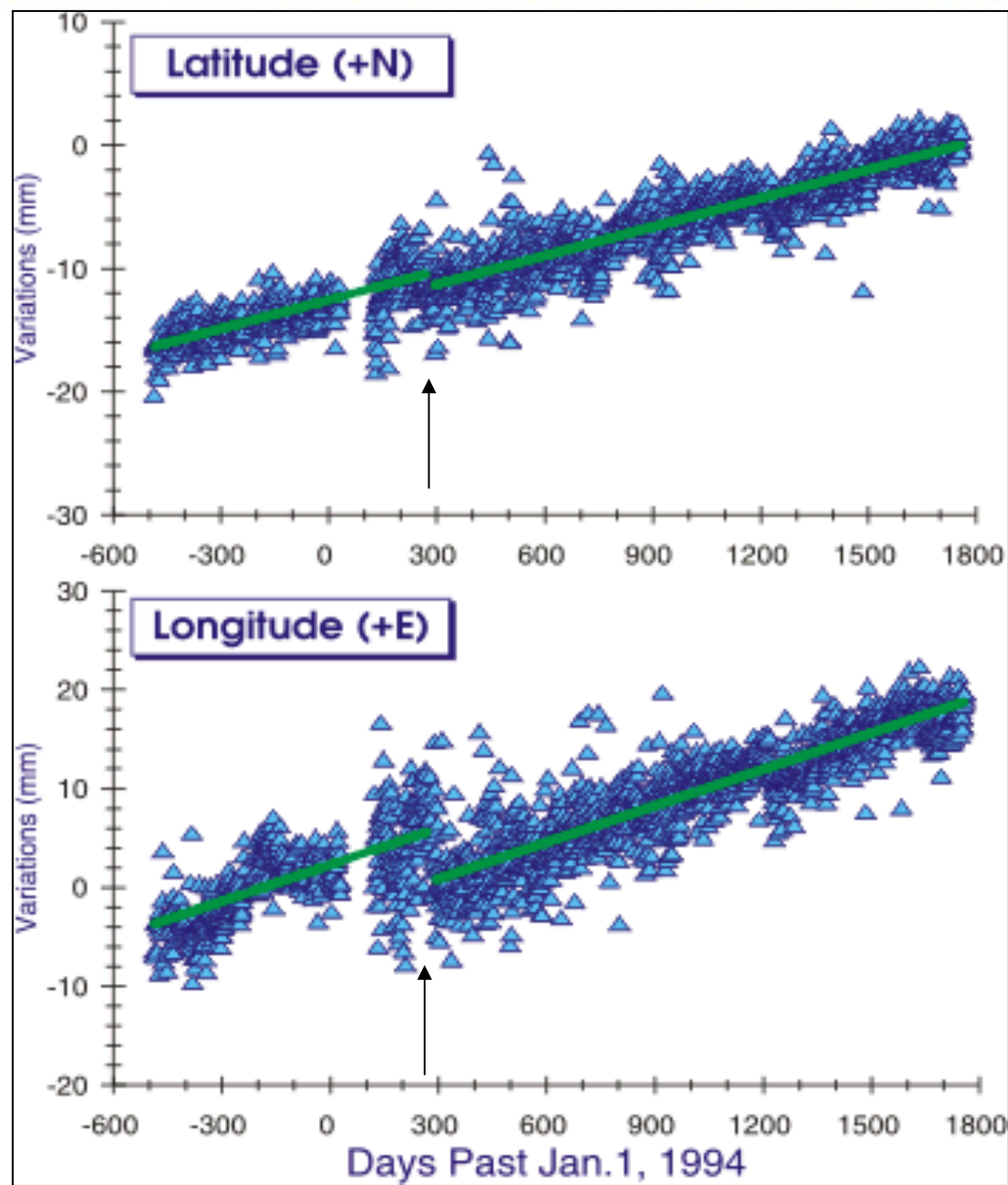


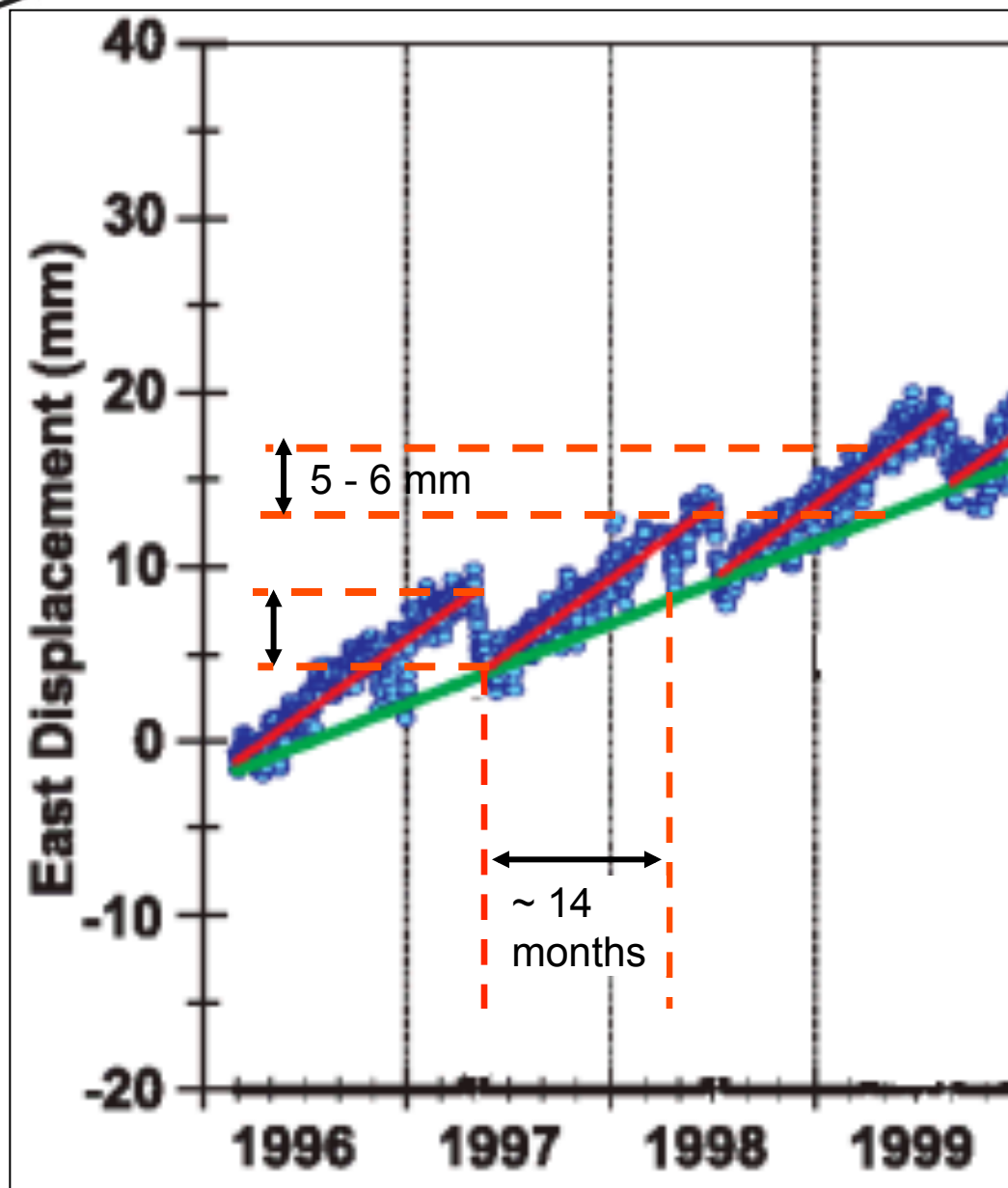


Oct 1 – Oct 15,  
1994 motion  
measures

~2 mm south  
~6 mm west

Why?



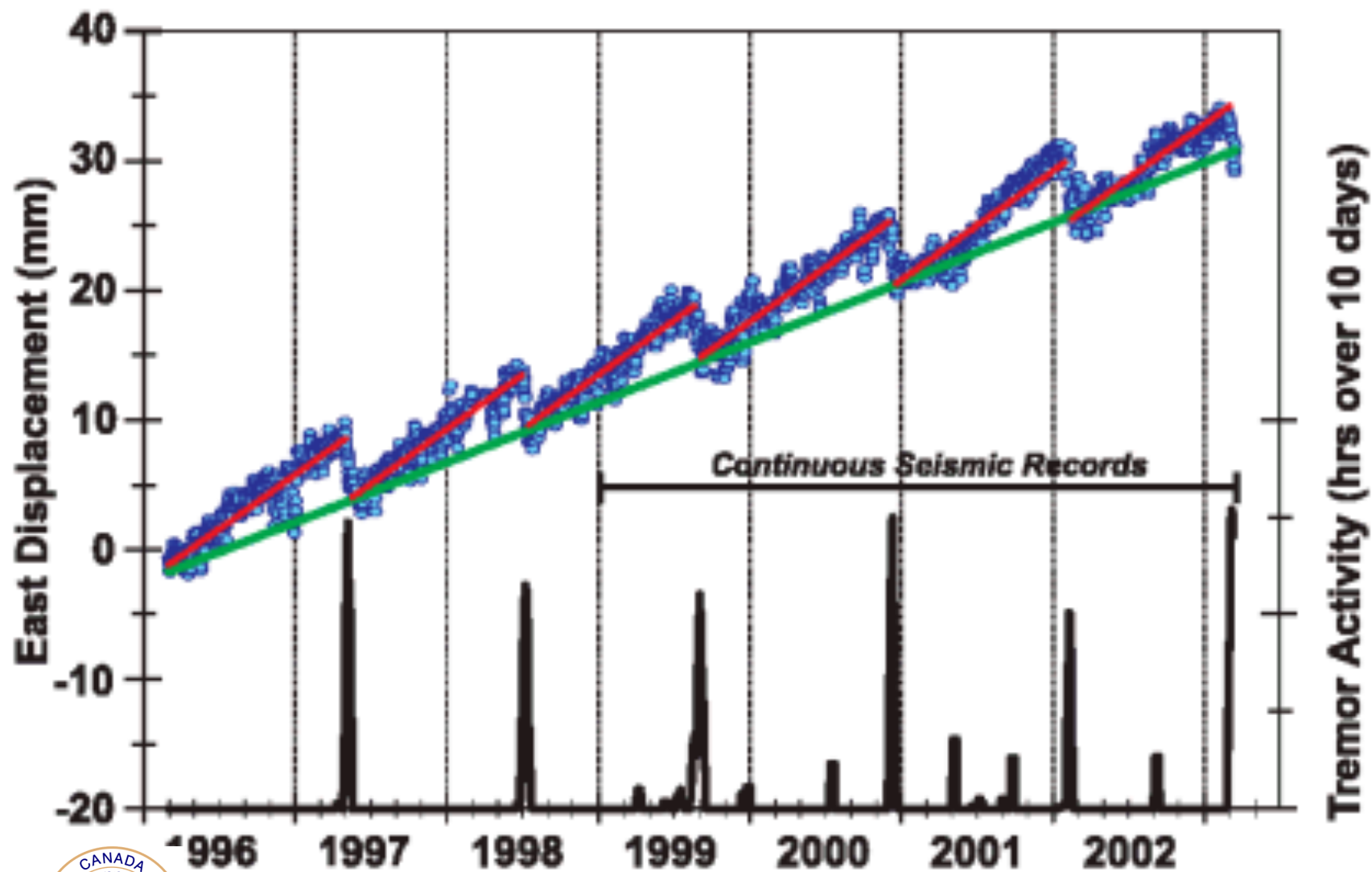


Answer questions 5 - 7 on your worksheet.



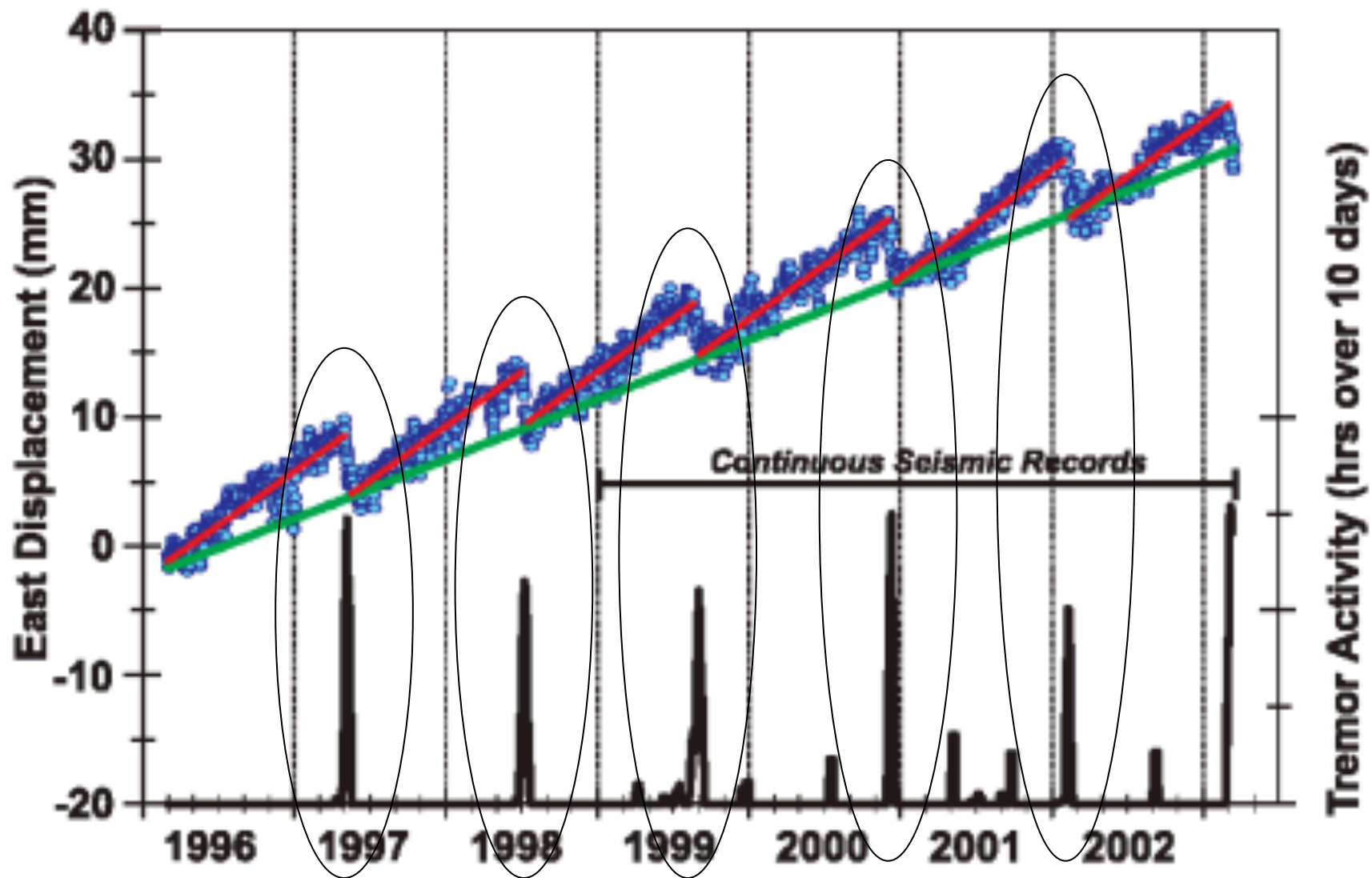
- The technology of GPS measurement advanced dramatically.
- Continuous GPS stations were installed.
- The pattern was seen again... and again....
- Large areas experienced tremors at about the same time, and tremors repeated every so often.
- In 1999, Herb Dragert from the Geological Survey of Canada confirmed this strange reversing pattern in the continuous data from more GPS stations.

# Putting the pieces together

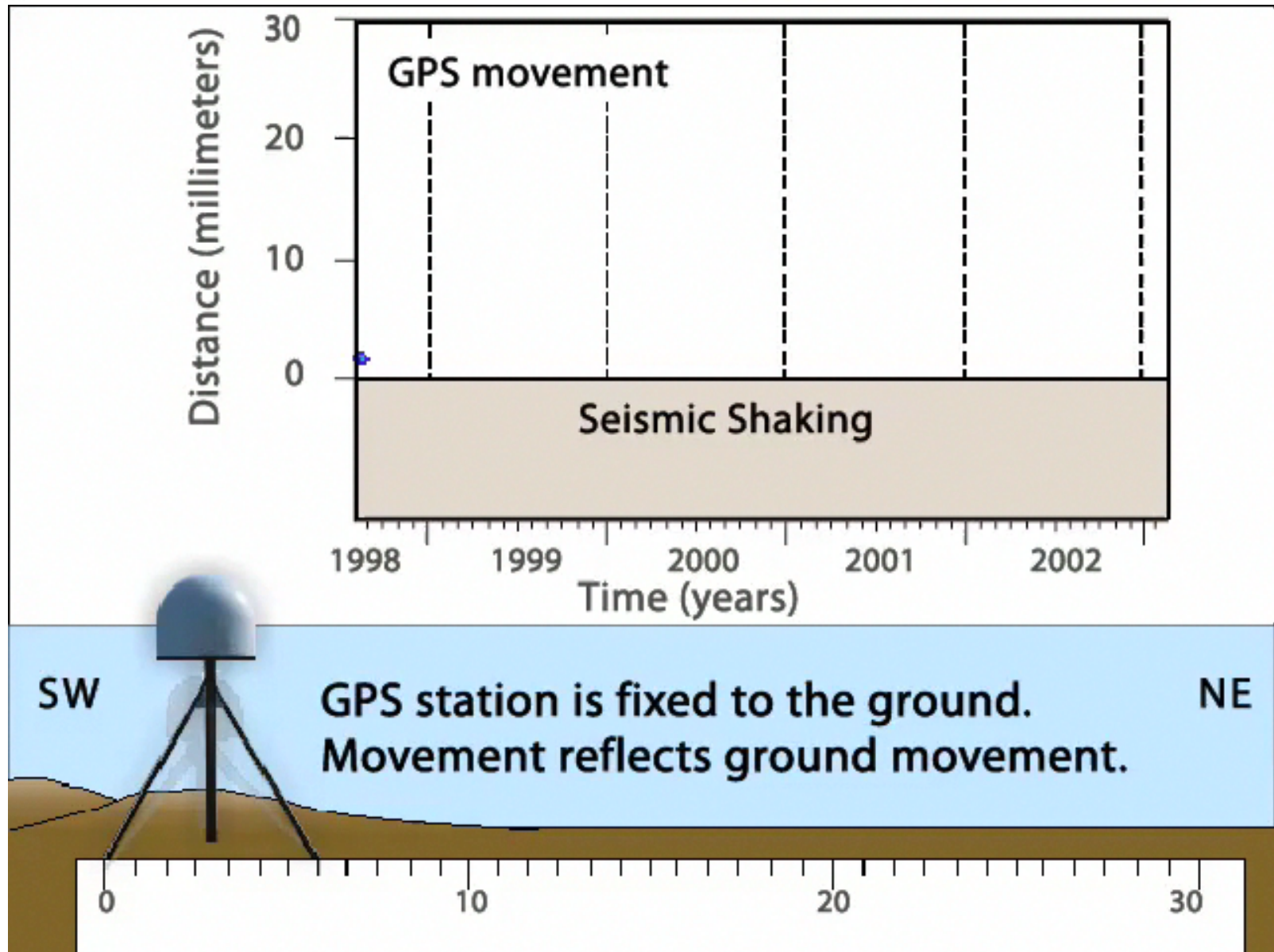




# Putting the pieces together



# Putting the pieces together



## What have we learned?

Slow slip tremors (slow earthquakes) last 6 -14 days every ~14 months;

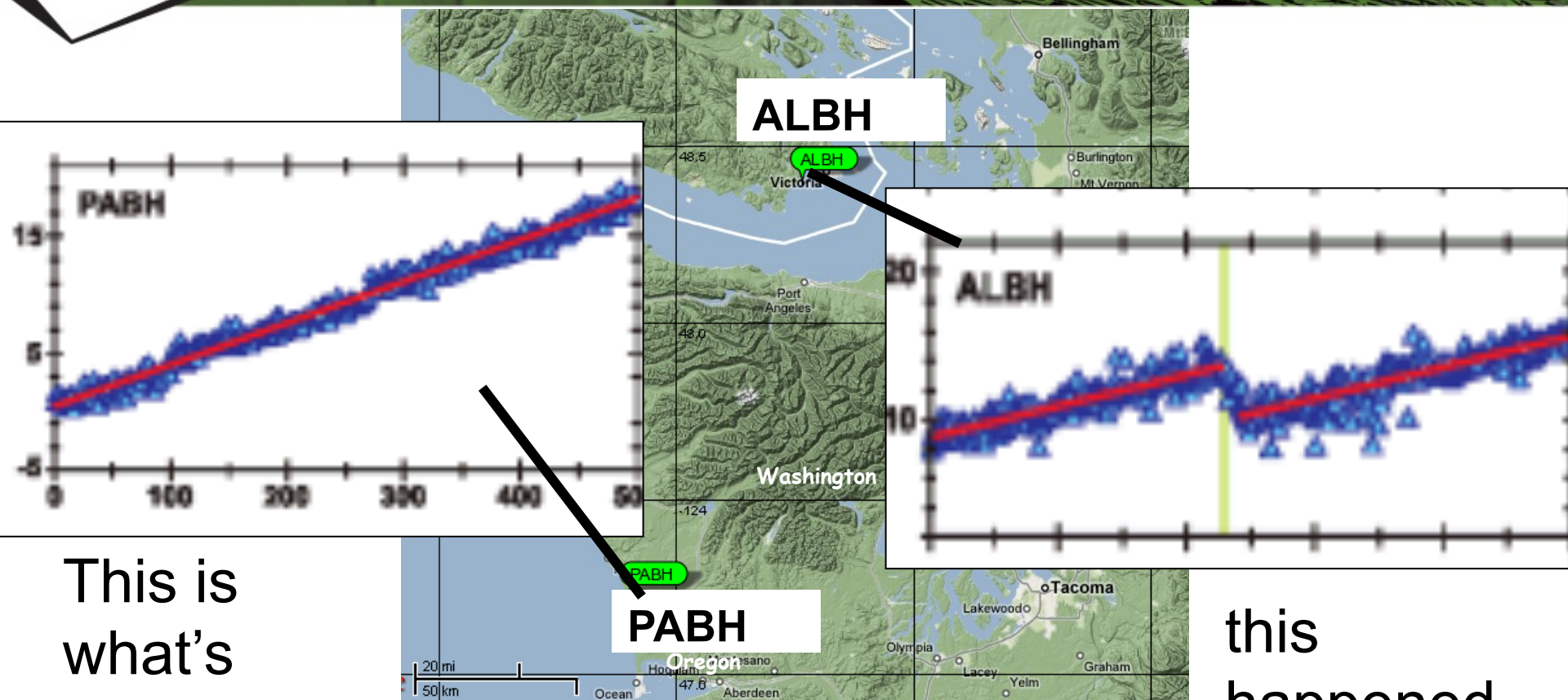
Equivalent of  $M_w = 6.7$  earthquake; and

“Episodic Tremor and Slip” or “ETS.”





# Does ETS occur everywhere?



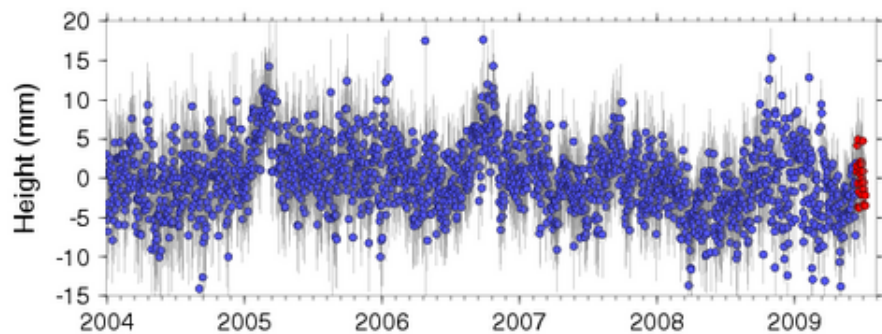
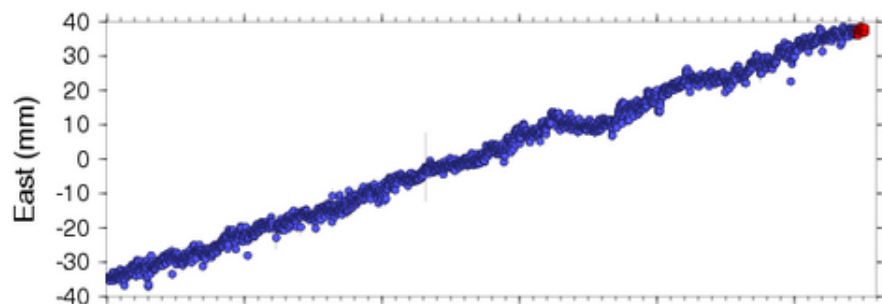
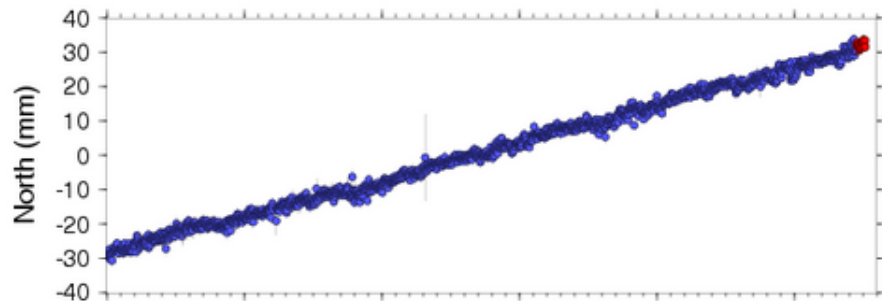
This is  
what's  
expected,  
but...

this  
happened  
during the  
same time.

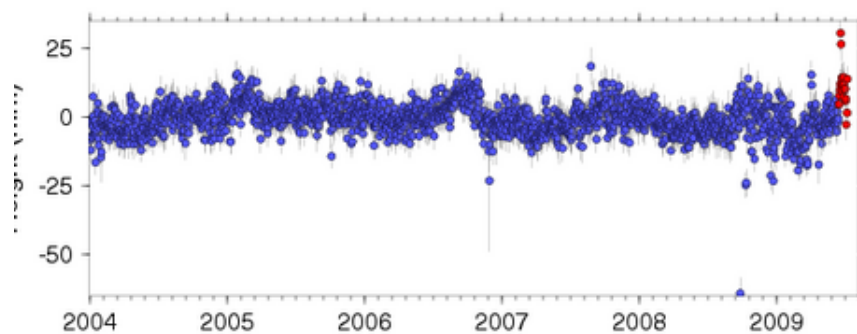
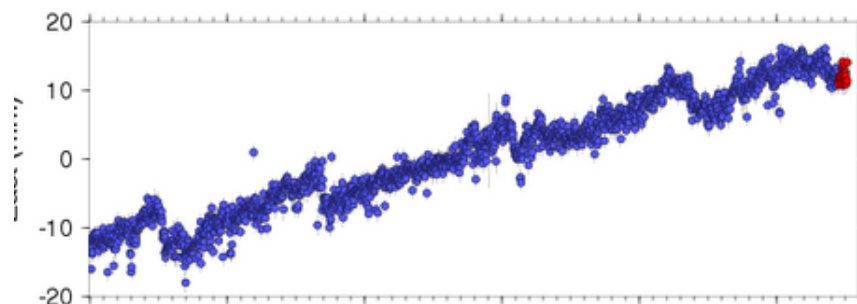
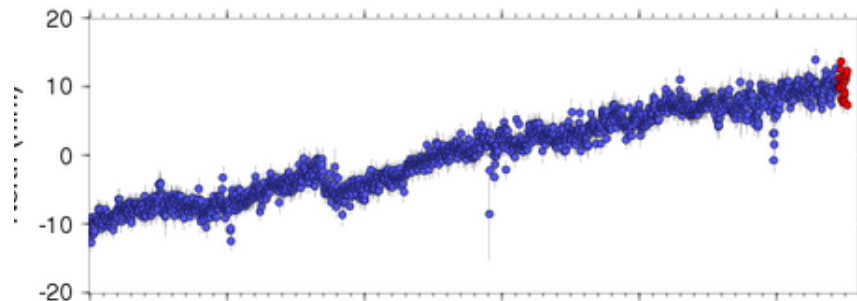
So what's happening????

# Does ETS occur everywhere?

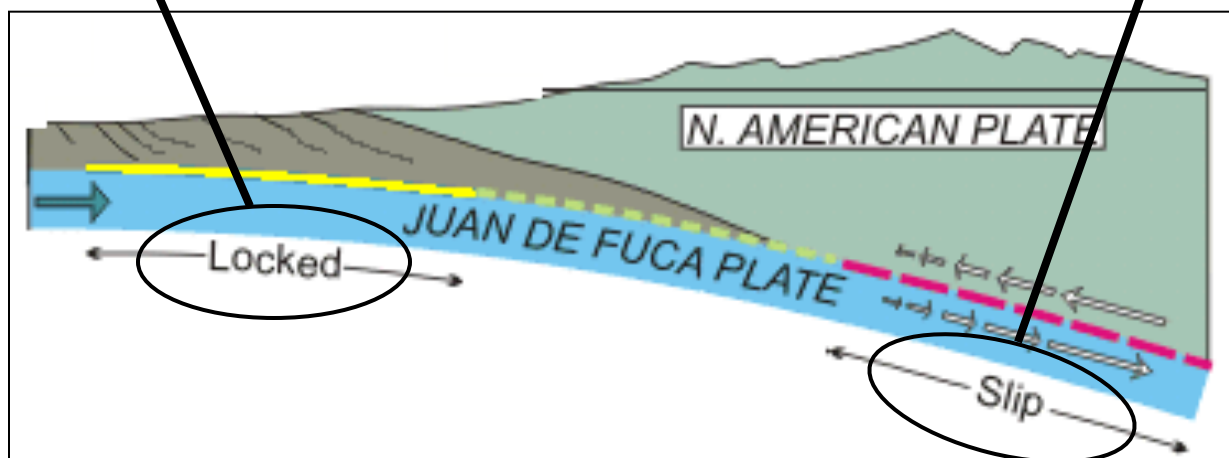
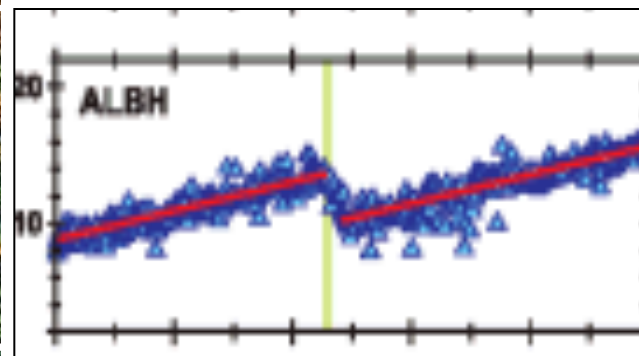
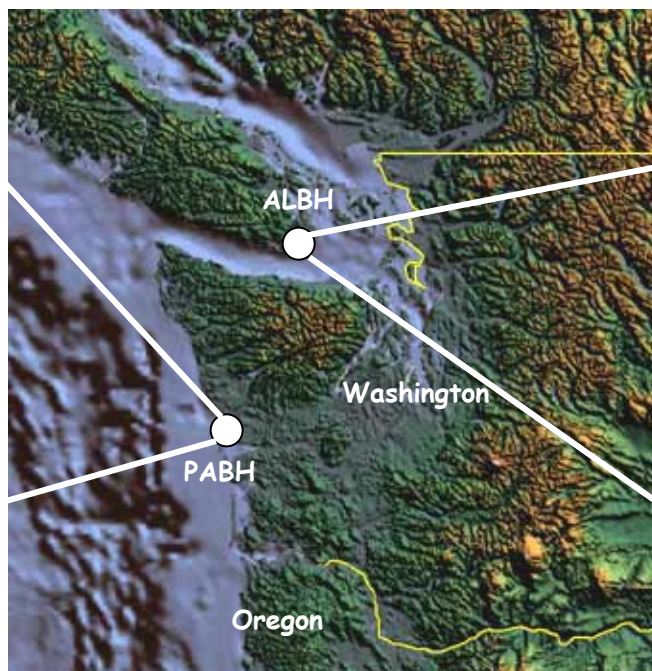
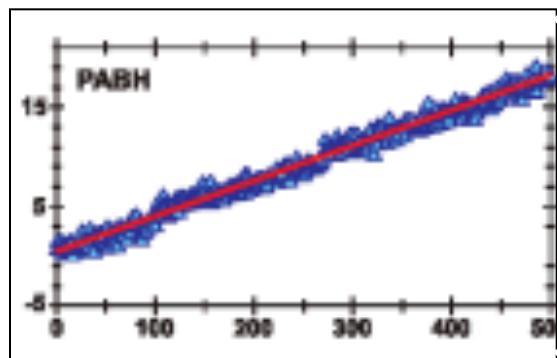
PABH (PABH\_PNGA\_WA1997)



ALBH (Albert\_Head)





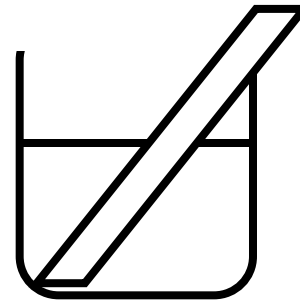




Noodles!



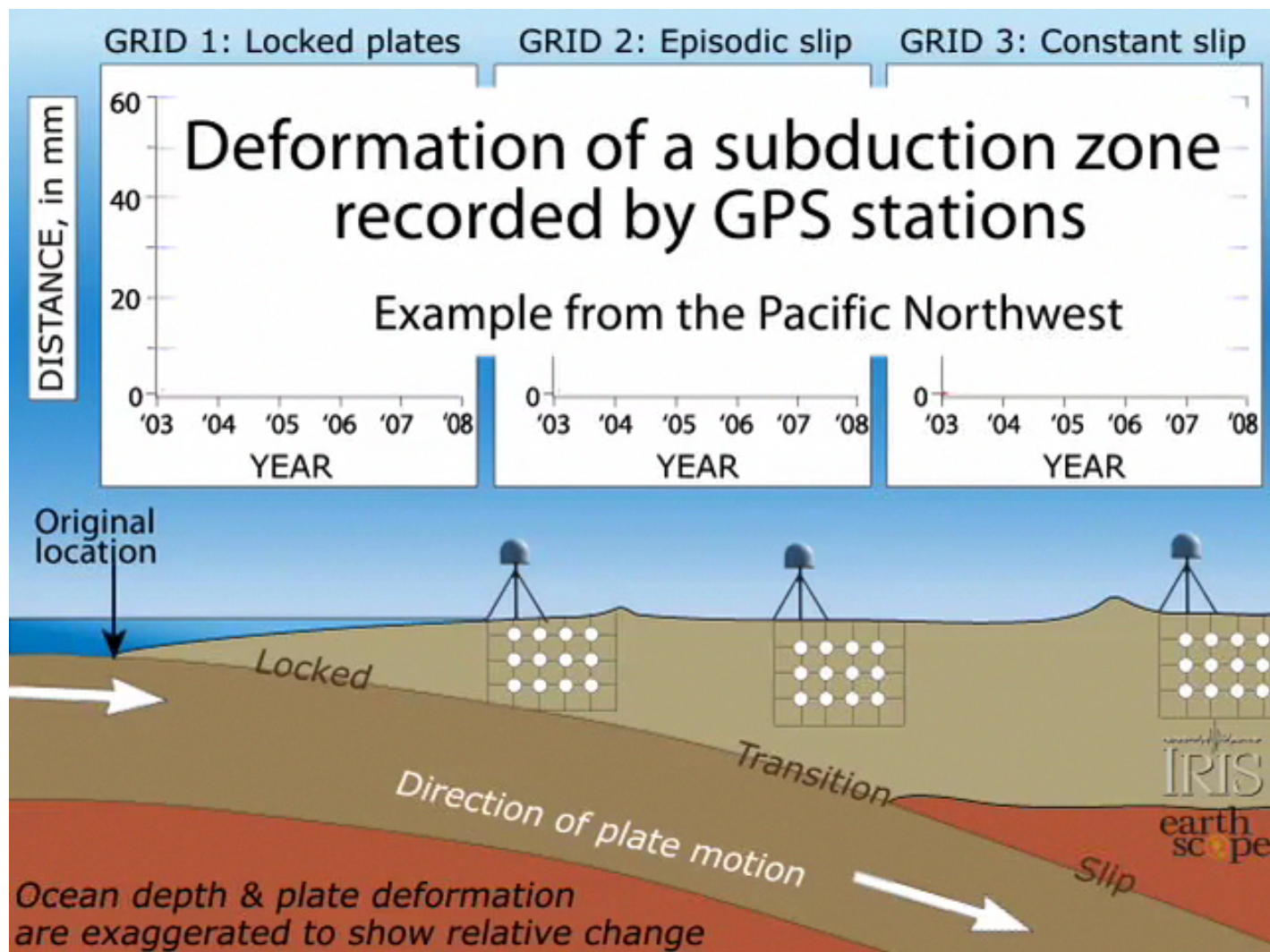
1. Fill a beaker with hot water.
2. Take a piece of lasagna noodle and submerge it partway into the beaker of hot water, like this:

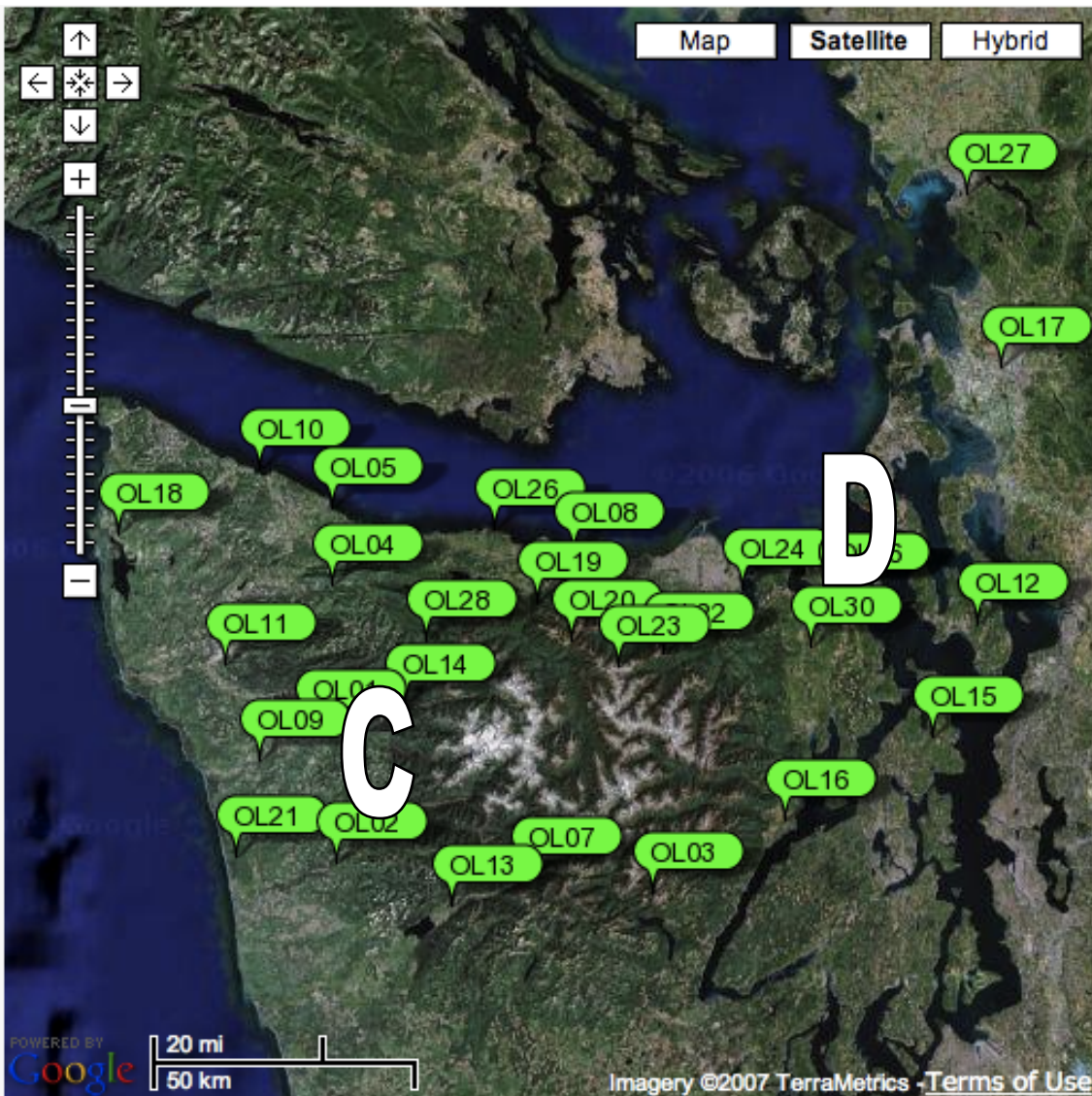


3. Wait about five minutes and then take the noodle out of the water.
4. Answer questions 11 – 14 on your worksheet.

- The Juan de Fuca Plate becomes hotter (around 400 - 500 °C) as it gets deeper.
- The plate becomes more ductile as it subducts.
- Slip occurs along the boundary between the Juan de Fuca Plate and the North American plate.
- Shallower areas are cooler and brittle.
- But, there has not been any recent “breaking” along the coast.





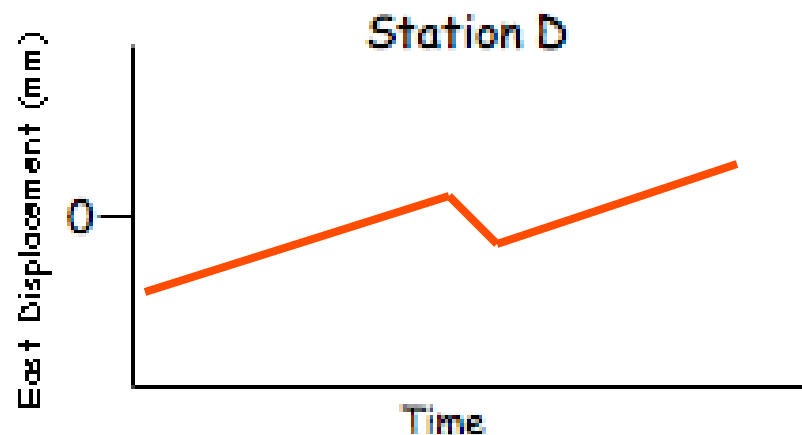
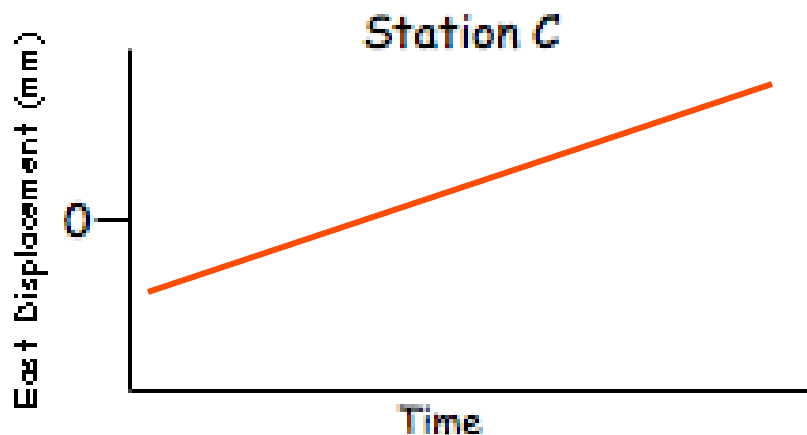


Predict what stations C and D would show on east time series plots.

Hint: think about locked vs. slip zones . . .



Station C would move steadily northeast, while Station D would show a slow slip event.



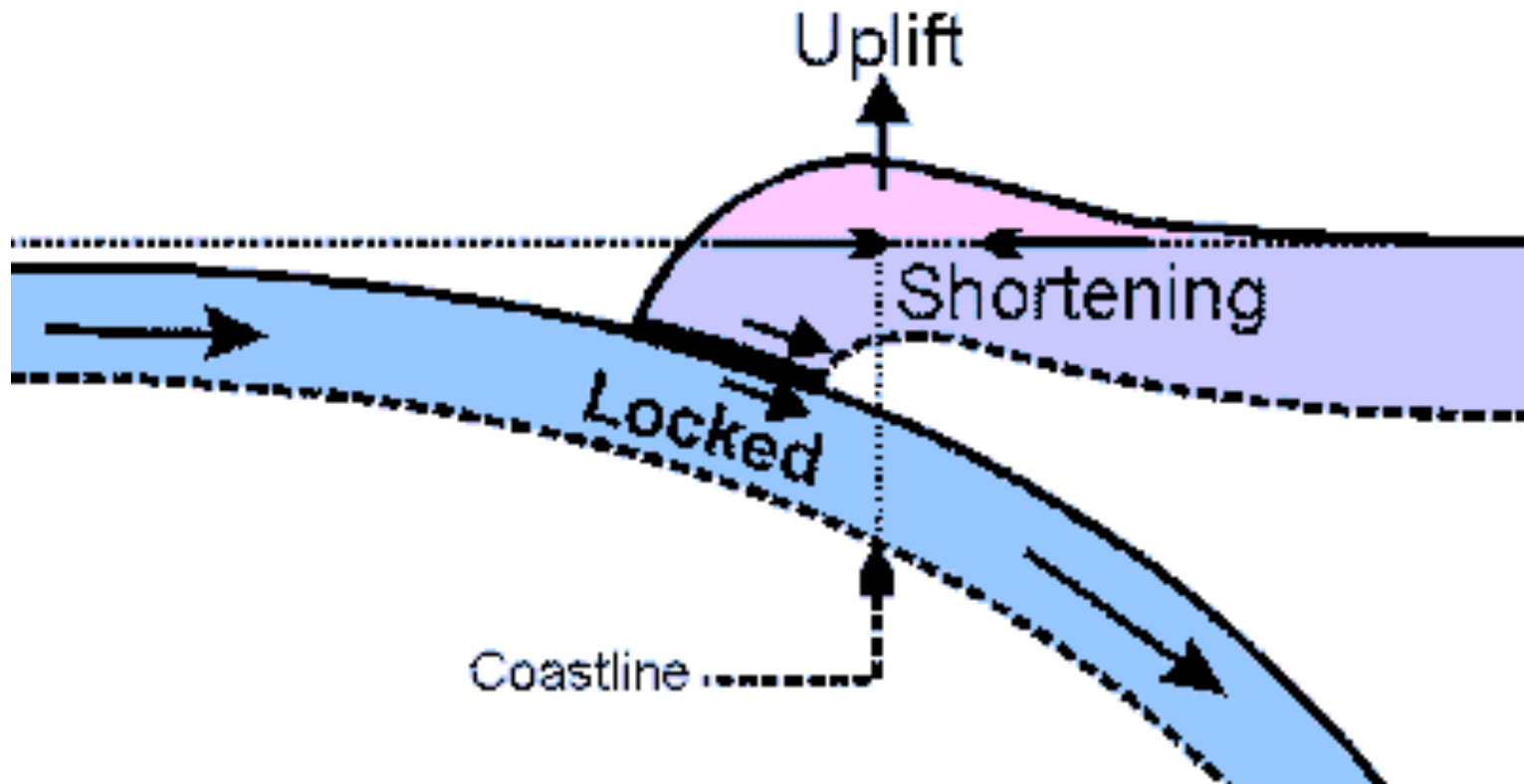
How close were your predictions??



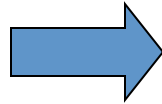
If slow earthquakes are relieving strain in the “slip” zone, what’s happening in the locked zone?

Strain relieved in the slip zone is transferred to the locked zone!

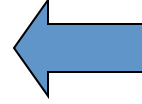
The locked zone is getting strained from both sides!



The Juan de Fuca plate is moving eastward from the mid-ocean ridge.



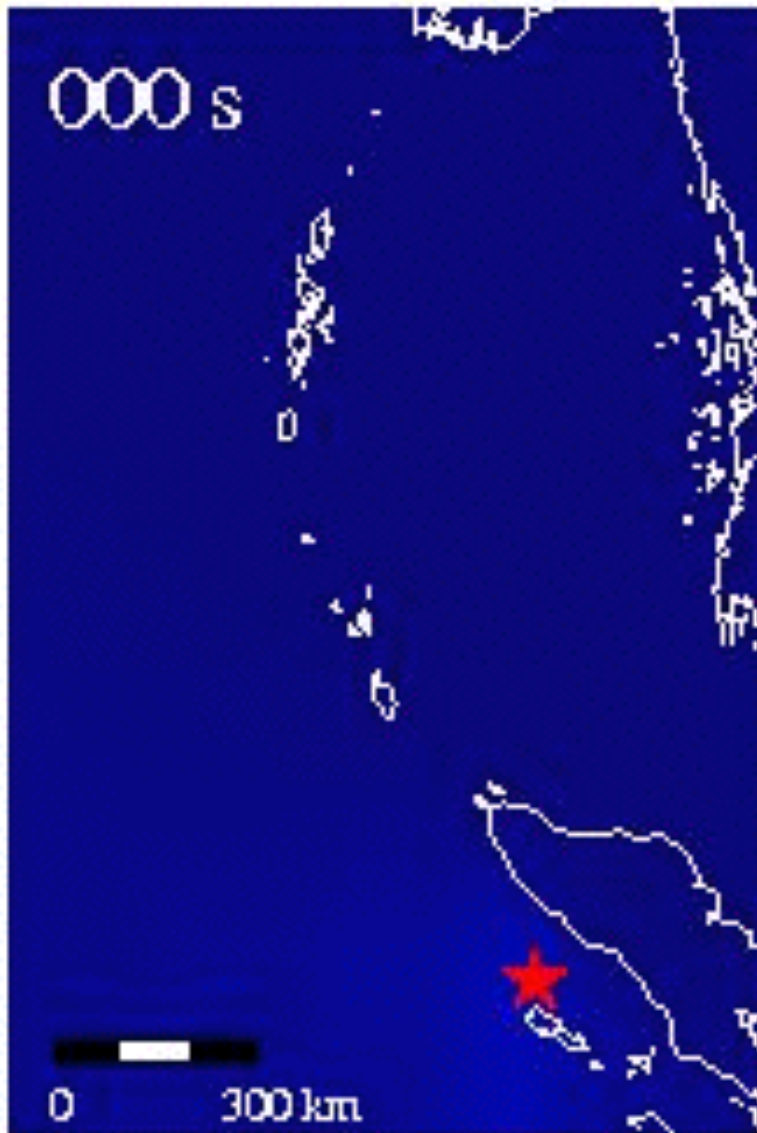
Locked Zone



Strain relieved by the slow earthquakes is transferred westward.

Think again of the lasagna experiment....





Sumatra-Andaman  
earthquake, 2004

## Interactive Tremor Map

Last activity: 05/20/2011

Updated: Fri May 20, 2011 18:24:48 PDT

Webpage Info

Monitoring Resources

Contributing Networks

Tremor &amp; Slip Info

FAQ

## Region Options (?)

- ☐ All
- ☒ Vancouver Island ([more](#))
- ☒ Northern Washington
- ☒ Southern Washington
- ☐ Northern Oregon
- ☐ Central Oregon
- ☐ Southern Oregon
- ☐ Northern California

## Time Options

Start: 8/12/2010 End: 9/6/2010

Plot Chart

☐ Single ☒ Range

## Overlay Options

Type: Color vs. Time

- ☐ Seismometers
- ☒ Plate Depth (20,30,40 km)

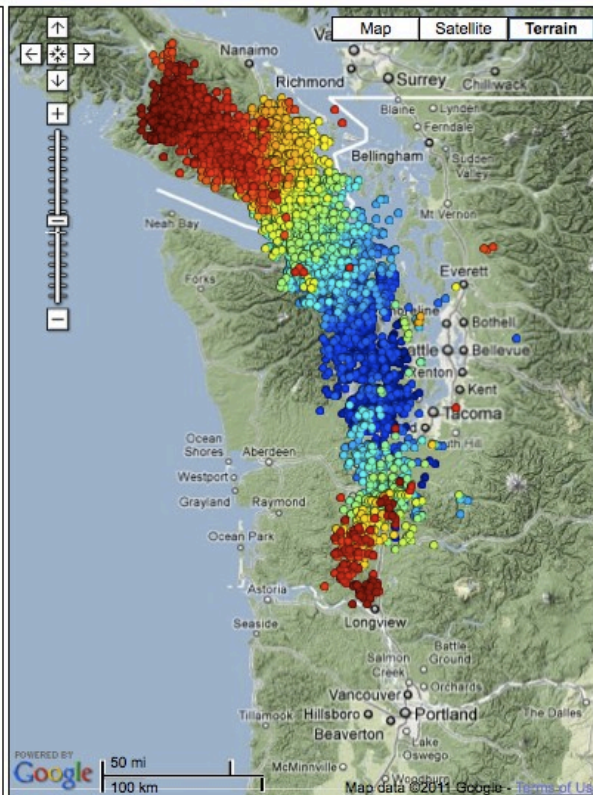
## Download

Data:

Timeline GET

Envelope PDF:

08/12/2010



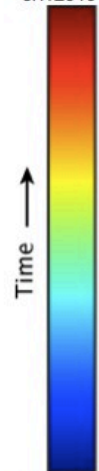
08/12/2010 - 09/06/2010

592.5 Hours

10397 Epicenters (UTC)

Request too large...only showing 5000.

9/7/2010

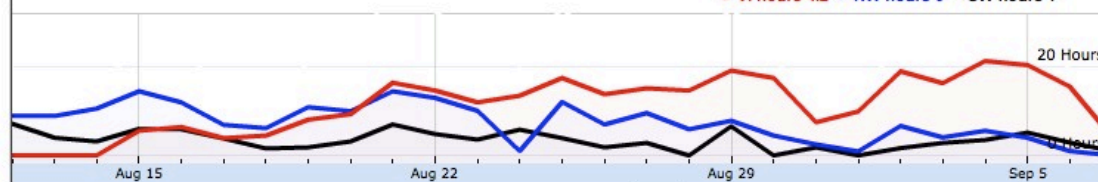


8/12/2010

Zoom: 1d 5d 1m 3m 6m 1y Max

September 07, 2010

• VI hours 4.2 • NW hours 0 • SW hours 1



- During ETS events, the transition zone of the deep plate slides 2 - 4 cm/yr to the southwest.
- Strain accumulates across the locked zone.
- The locked zone prevents relative plate motion; a “slip-deficit” builds up for the locked zone.
- In 500 years, how much “slip deficit” would build up on the locked portion of the plate interface? (Use 3 cm/yr.)

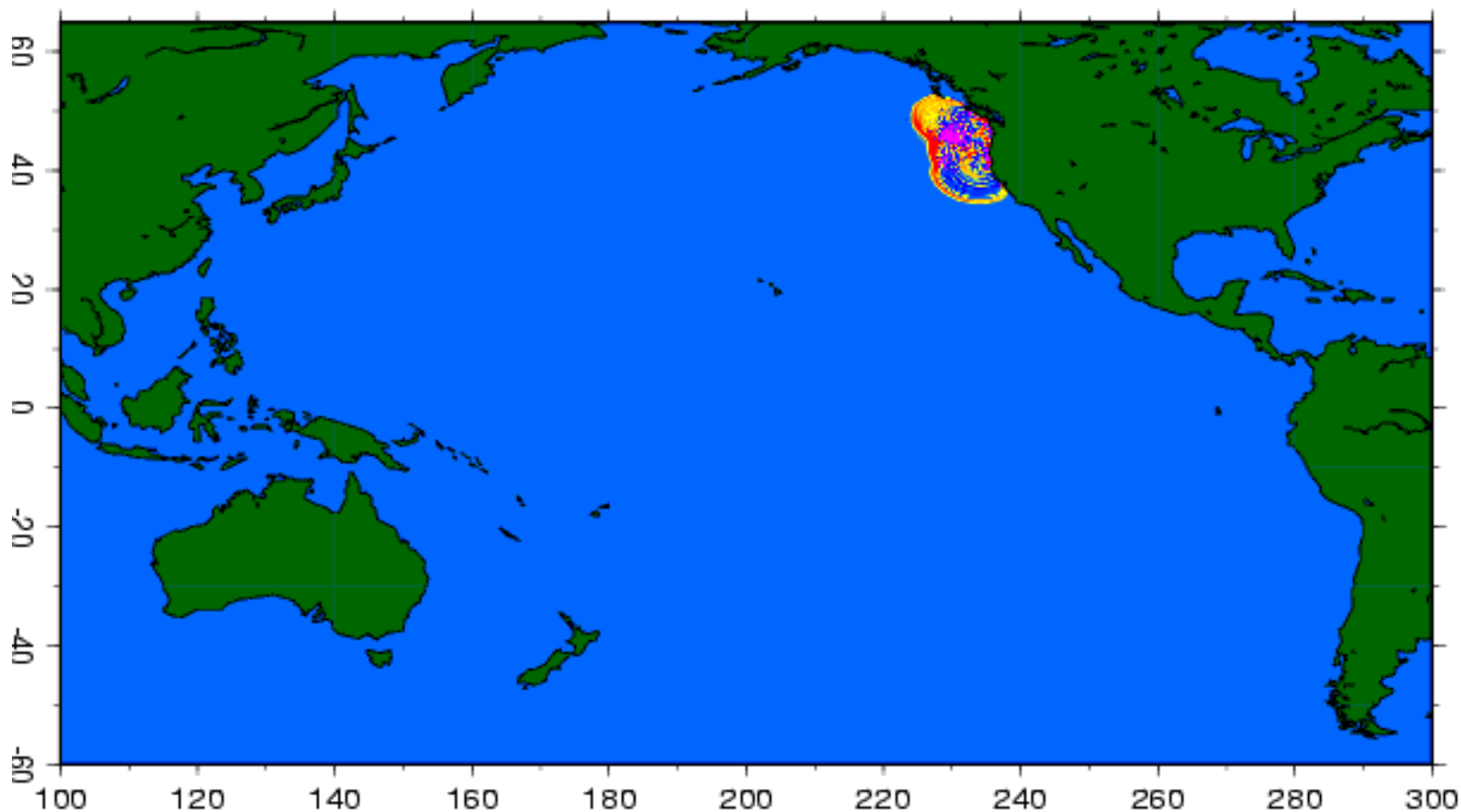


- What did you get?
  - 1500 centimeters slip deficit
- If the locked zone breaks, the ground will snap to the southwest 1500 centimeters, or 15 meters!

More than 6.7 million  
people live in western  
Washington and  
Oregon...

Who among your friends  
or family is there?

01 hour





If another great earthquake were to occur near the coast of Cascadia...



Land along the coast would subside, and a tsunami would inundate coastal regions hundreds of meters inland--impacting many, many lives.



Contact: Shelley Olds  
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<http://www.unavco.org/>

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- UNAVCO animations of ETS
  - <http://www.unavco.org/cws/pbonucleus/draftresources/ETSmystery/ETSanimations/>
- Animations on slides 4, 22, and 30 by Jenda Johnson, IRIS

- UNAVCO GPS, Earthquake, Volcano Viewer
  - <http://geon.unavco.org/unavco/GEV.php>
- IRIS Earthquake Browser
  - <http://www.iris.washington.edu/servlet/eventserver/map.do>