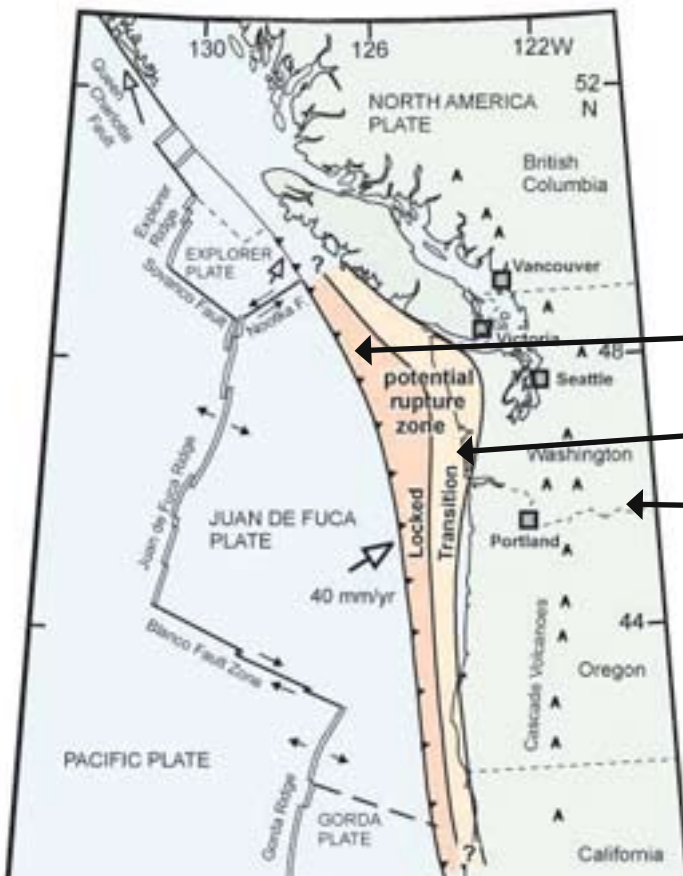
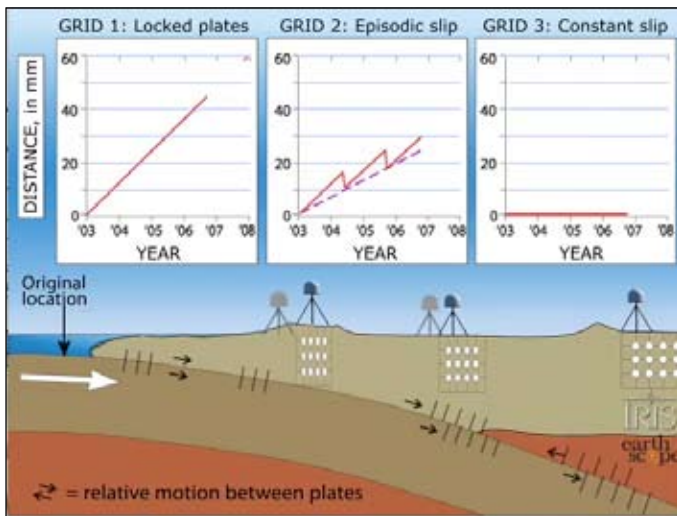


Activity— ETS (Episodic Tremor & Slip)

Tectonic processes in a subduction zone

Episodic Tremor and Slip (ETS) is a process by which a portion of the accumulated elastic energy is released along a subduction zone plate boundary at intermediate depth. During ETS events on the Cascadia subduction zone, the Juan de Fuca Plate slips a few centimeters farther beneath the North American Plate over an interval from a few days to two weeks. This “slow slip” is accompanied by release of seismic waves in a “tremor”-like fashion that is much longer in duration and lower in frequency than seismic waves released by standard earthquakes.*

Here’s the problem – if the slow earthquakes are relieving stress in the ‘slip’ zone, what’s happening in the locked zone? What some geologists are thinking is that any stress that is relieved in the slip zone is transferred to the locked zone! The locked zone is getting stress added to it from both sides!



Grid 1: Locked Plates (contact between subducting oceanic and overlying continental plates)

Grid 2: Episodic slip with accompanying tremor (coastal GPS stations are being pushed NE)

No GPS movement; this area is above the “unlocked” contact between the plates.

Science Standards (NGSS; pg. 287)

- From Molecules to Organisms—Structures and Processes: MS-LS1-8
- Motion and Stability: Forces and Interactions HS-PS2-1, MS-PS2-2
- Energy: MS-PS3-1, MS-PS3-2, HS-PS3-2, MS-PS3-5
- Waves and Their Applications in Technologies for Information Transfer: HS-PS4-2, MS-PS4-3, HS-PS4-5
- Earth’s Systems: HS-ESS2-1, MS-ESS2-2, HS-ESS2-2, MS-ESS2-3, HS-ESS2-3
- Earth and Human Activity: HS-ESS3-1, MS-ESS3-2

Animation depicted above is on the CEETEP DVD in the folder:

- 3. Cascadia Earthquakes & Tsunamis
 - > 2. ANIMATIONS Cascadia Earthquakes & Tsunamis
 - > Monitoring Subduction_GPS & ETS
 - > GPS_3grid_subduction_Groom.mov

* http://gsc.nrcan.gc.ca/geodyn/ets_e.php

EPISODIC TREMOR AND SLIP Slide show and Demonstration

Learning objectives:

Understand how EarthScope's Plate Boundary Observatory GPS data can be used to determine motions within the Pacific Northwest active continental margin. The shallow portion of the boundary between the North American Plate and the Juan de Fuca Plate is currently "Locked and Loading" as both plates deform near the plate boundary. This accumulating elastic energy will be released in the next Cascadia megathrust earthquake. In the intermediate depth region of the subduction zone, some of the accumulating elastic energy is periodically released in episodic tremor and slip (ETS) events. Above the ETS zone, GPS stations move in a "sawtooth" pattern. Most of the time, they move toward the northeast in response to a northeasterly push from the Juan de Fuca Plate. However, during ETS events, GPS stations above the ETS zone move back to the southwest for intervals of a few days to two weeks. During ETS events, some compressional stress is transferred from the intermediate depth portion of the subduction zone to the shallower locked portion of the plate boundary. Some seismologists believe that the likelihood of a Cascadia megathrust earthquake is therefore increased during episodic tremor and slip.

Background activities

The previous activities on GPS:

Cascadia GPS_Gumdrop and
Cascadia GPS_Locked and Loading_PBO data

provide the perfect introduction to this presentation that emphasizes why three parallel regions above a subduction zone behave differently from each other.

Understanding elastic rebound enhances understanding of the locked zone. The GPS activity shows how we learned about the ETS zone that periodically relieves some of its accumulated elastic energy during slow-slip events that generate seismic tremor. The one-block Earthquake Machine activity provides a good model for the shallow locked zone while the two-block Earthquake Machine nicely models some properties of the shallow locked zone AND the intermediate-depth ETS zone. The blue block in the animation **Earthquake Machine_TimeStrain.mov** has rough grit sand paper on the bottom to model the high-friction and shallow locked zone. The blue block moves in infrequent but often large jumps that represent earthquakes in the shallow high-friction

Materials & set up

- PowerPoint presentation in the folder:

 **4. ACTIVITIES_Cascadia Earthquakes & Tsunamis**

>  **ETS_Episodic Tremor & Slip**

> **ACTIVITY_ETS Student Presentation.ppt**

- Dry lasagna noodles (described in ppt file)
- Beaker of water per group
- Student Worksheets (following pages)
- For referenced .mov files, go to folder:

 **ANIMATIONS & VIDEO for ETS**

portion of the subduction zone. The red block has smooth grit sand paper and represents the intermediate-depth zone that moves in more frequent but generally smaller ETS events. The hand pulling the elastic band connected to the red block moves steadily and represents the freely sliding deep part of the subduction zone. Every time the red block moves, the elastic band between the red and blue blocks is stretched a little more adding to the elastic force on the blue block. If the red block has lower friction than the blue block, it will move in many small steps while the blue block moves in less frequent larger jumps. An important observation is that a small motion of the red block will sometimes be followed by a large motion of the blue block. In a sense, a small motion of the red block can "trigger" a large displacement of the blue block. This models how some seismologists believe an ETS event in the intermediate-depth portion of a subduction zone may trigger a megathrust earthquake in the shallow portion of the subduction zone. The two-block earthquake machine is demonstrated in the video:

DEMO_EarthquakeMachine_2block.mov.

Preparation:

Students, in groups or pairs, will get a beaker of hot water and a lasagna noodle to observe the effect of temperature on the noodle's brittleness. Timing is important, as it takes at least 5 minutes of sitting in the hot water for the noodle to get the right texture. Sitting too long in the hot water should be avoided as well - otherwise, the lower half of the noodle will fall right off when you try to pick it up!

Presentation:

Open the PowerPoint presentation. Text in the notes box will give ideas of what to say and demonstrations that work for this. Again, you will need to have some very warm water on a burner for an activity you'll be doing with the lasagna noodles on SLIDES 27, 33, 34, 35.

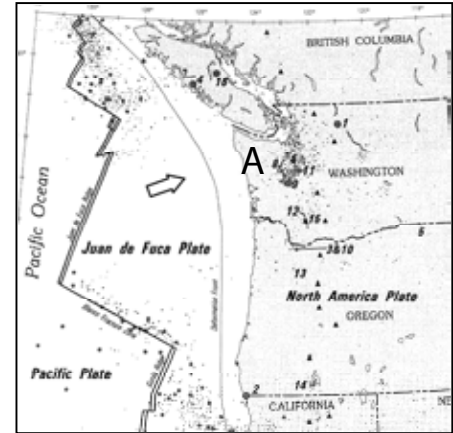
EPISODIC TREMOR AND SLIP

The Basics: Review of the Cascadia Region

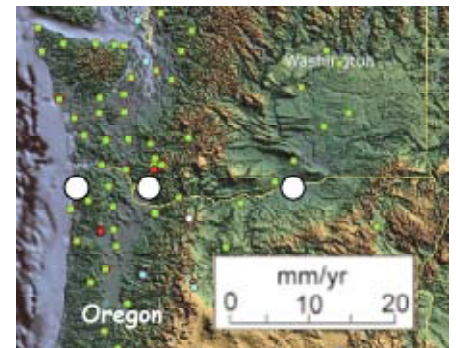
This is an image of the Cascadia region:

Let's review a few things:

1. What type of boundary exists between the Juan de Fuca plate and the North American plate?
2. What types of tectonic plates are they?
Juan de Fuca: _____
North American: _____
3. The Juan de Fuca Plate is more dense than the North American Plate, so it's slipping below the North American Plate. What is the name of this process?
4. a. Compare the animation to the Cascadia region. What overall direction would you expect point A (on the map above) to be moving due to the deformation?
How do you know that?



b Think about the activity we did with the GPS data from the coast, the urban corridor, and eastern areas. From the white dots, draw arrows showing approximate direction and distance moved using the scale provided.



Evidence #1: Hmmmm . . . What's Happening Here?

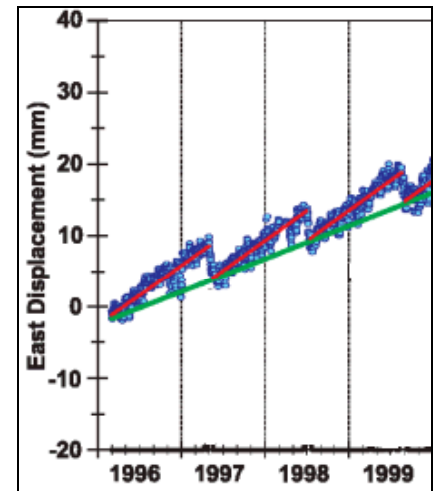
Strange seismic signals that lasted a really long time - weeks - as opposed to seconds or minutes. They released the same amount of energy as a sudden earthquake - it was just spread out over a longer time.

Evidence #2: What was that???

GPS monuments in certain areas were showing reversals of their long term northeast movement. Every so often they'd move southwest.

Evidence #3: A Pattern Seems to Emerge . . .

5. From looking at the data, describe the direction of movement of the western edge of the North American Plate between 1996 and 1999. Remember this is a time series plot - look carefully at what is being measured on the Y-axis!



6. About how often is the reverse motion happening?

7. Approximately how many millimeters of reverse motion occurs during each slip event?

Evidence #4: Putting the Pieces Together

8. Now, what do you notice about the seismograms?

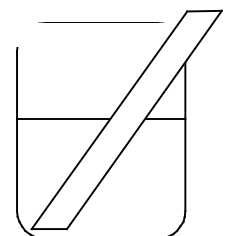
Now What? The Implications of What We've Learned

9. What is the data showing here? Did PABH experience a reverse motion or slow slip event?

10. Explain how the data from PABH are different from observations at ALBH.

Let's try to model what's happening with the Juan de Fuca Plate as it moves under the North American Plate.

11. Take the noodle out of the water. Gently bend the lasagna on the part that was under the warm water. Describe what happens.



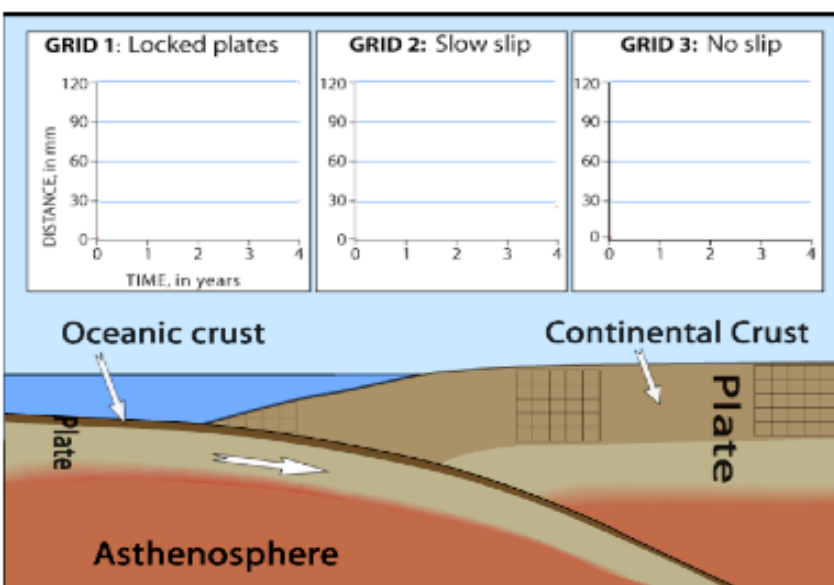
12. Now, using the same amount of pressure as you did in number 11, try to bend the part that was not in the water. What happens?

13. Keep applying pressure to the cool, dry lasagna. What eventually happens?

14. How do you think this models what's happening with the subducting Juan de Fuca plate? Tie in the idea of the 'locked' zone and the 'slip' zone.

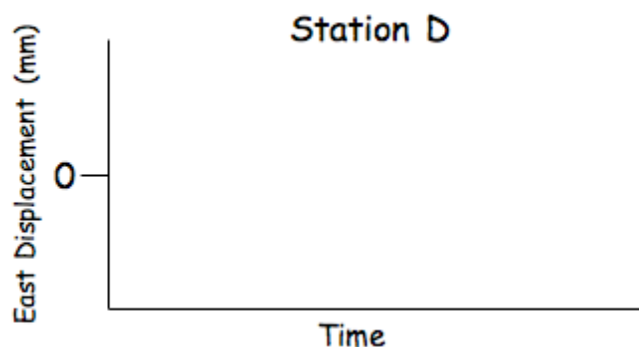
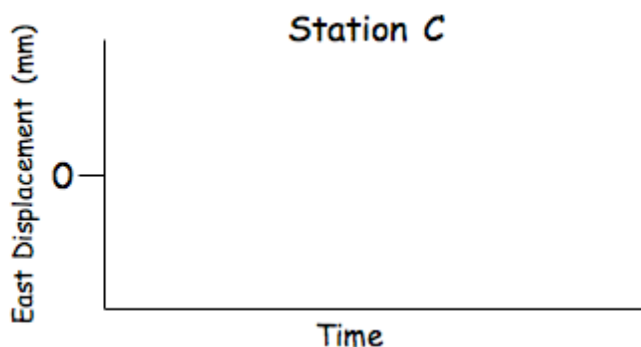
15. After watching the animation, draw in what the time series plots look like for the 3 areas:

Locked
Slow slip
No slip



Predicting the Future! Why Episodic Tremor and Slip Matters

16. Draw a sketch of what the time series plots looked like for Stations located at C and D on the map. This is just one campaign of one slow-slip event. Don't worry about



**The BIG Picture:
Why You NEED to Know This!**

17. Draw a quick sketch of the setup of the blocks demonstration.

18. Describe what happens as you pull on the rubber band attached to the red block.

19. Given a 'slip-deficit' of 3 centimeters per year, how much would accumulate in 500 years? About how many feet is that?

20. Why would predicting when a great earthquake and tsunami would happen be so important?

TEACHER ANSWER KEY

Name:

Class:

EPISODIC TREMOR AND SLIP

The Basics: Review of the Cascadia Region

This is an image of the Cascadia region:

Let's review a few things:

1. What type of boundary exists between the Juan de Fuca plate and the North American plate?

CONVERGING BOUNDARY

2. What types of tectonic plates are they?

Juan de Fuca: OCEANIC

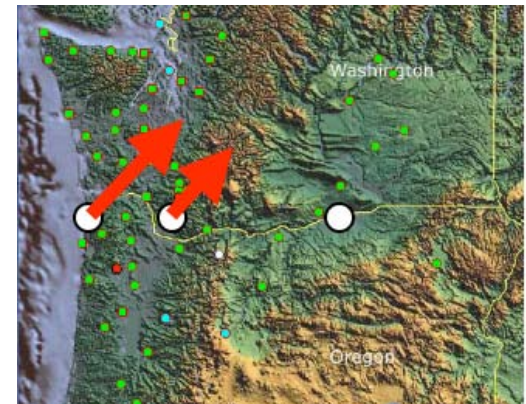
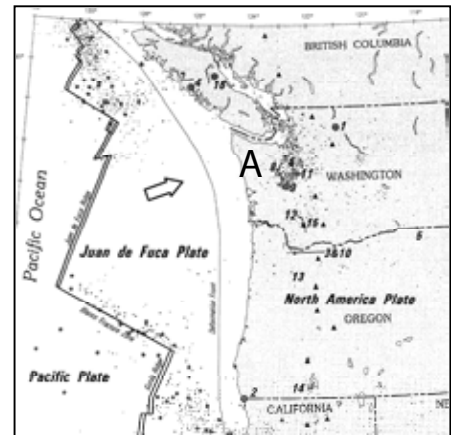
North American: CONTINENTAL

3. The Juan de Fuca Plate is more dense than the North American Plate, so it's slipping below the North American Plate. What is the name of this process?

SUBDUCTION

4. a. Compare the animation to the Cascadia region. What overall direction would you expect point A (on the map above) to be moving due to the deformation? How do you know that?

WOULD EXPECT POINT A TO MOVE NORTHEAST AS JUAN DE FUCA PLATE SUBDUCTS AND PUSHES ON CONTINENTAL MARGIN



b Think about the activity we did with the GPS data from the coast, the urban corridor, and eastern areas. From the white dots, draw arrows showing approximate direction and distance moved using the scale provided.

Evidence #1: Hmmm . . . What's Happening Here?

Strange seismic signals that lasted a really long time - weeks - as opposed to seconds or minutes. They released the same amount of energy as a sudden earthquake - it was just spread out over a longer time.

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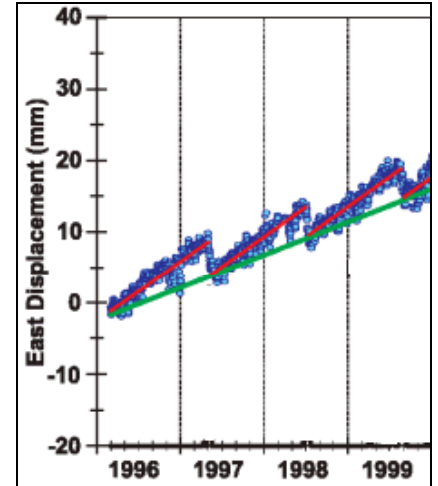
GPS monuments in certain areas were showing reversals of their long term northeast movement. Every so often they'd move southwest.

TEACHER ANSWER KEY

Evidence #3: A Pattern Seems to Emerge . . .

5. From looking at the data, describe the direction of movement of the western edge of the North American Plate between 1996 and 1999. Remember this is a time series plot - look carefully at what is being measured on the Y-axis!

WOULD EXPECT POINT A TO MOVE NORTHEAST AS JUAN DE FUCA PLATE SUBDUCTS AND PUSHES ON CONTINENTAL MARGIN



6. About how often is the reverse motion happening?

IT'S HAPPENING ABOUT EVERY 14-15 MONTHS

7. Approximately how many millimeters of reverse motion occurs during each slip event?

REVERSE MOTION IS ABOUT 6 MM WEST EACH TIME

Evidence #4: Putting the Pieces Together

8. Now, what do you notice about the seismograms?

ALL THE SEISMOGRAPHS SHOW SIMILAR TREMOR PATTERNS ACROSS A WIDE AREA

Now What? The Implications of What We've Learned

9. What is the data showing here? Did PABH experience a reverse motion or slow slip event?

NO, THERE WAS NO SOUTHWEST MOTION

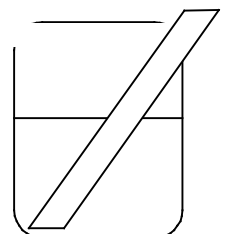
10. Explain how the data from PABH are different from observations at ALBH.

PABH DIDN'T SEEM TO BE AFFECTED - IT WAS LOCKED COMPARED TO A SLIP EVENT FOR ALBH

Let's try to model what's happening with the Juan de Fuca Plate as it moves under the North American Plate.

11. Take the noodle out of the water. Gently bend the lasagna on the part that was under the warm water. Describe what happens.

NOODLE IS EASY TO MOVE WHERE IT'S BEEN HEATED



12. Now, using the same amount of pressure as you did in number 11, try to bend the part that was not in the water. What happens?

NOODL E DOESN'T MOVE EASILY IN COLD PART – IT'S VERY BRITTLE

13. Keep applying pressure to the cool, dry lasagna. What eventually happens?

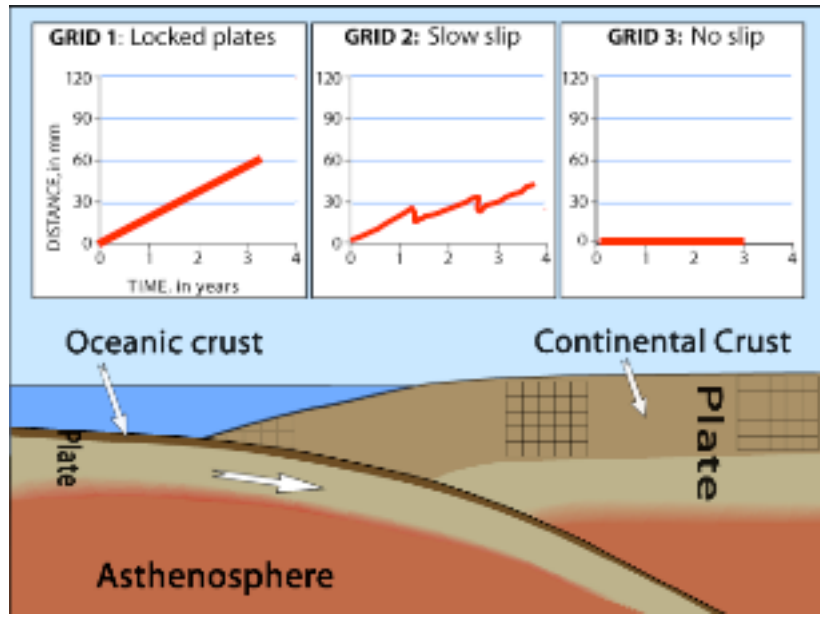
NOODL E EVENTUALLY BREAKS VIOLENTLY

14. How do you think this models what's happening with the subducting Juan de Fuca plate? Tie in the idea of the 'locked' zone and the 'slip' zone.

LOCKED ZONE EQUATES TO COLD LASAGNA – AREA IS MORE BRITTLE AND PRODUCES LOTS OF ENERGY WHEN BROKEN. SLIP AREA IS DEEPER AND WARMER AND SO MOVES EASIER. IT'S ABLE TO SLIP RATHER THAN RUPTURE

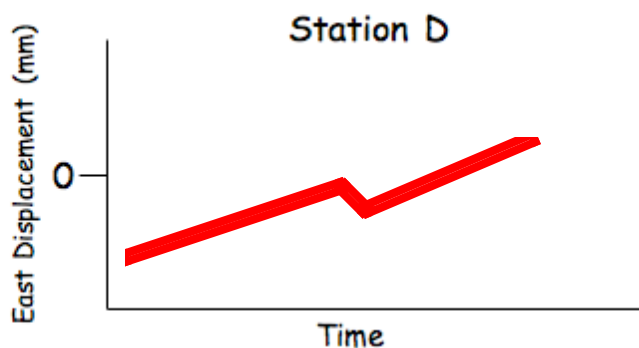
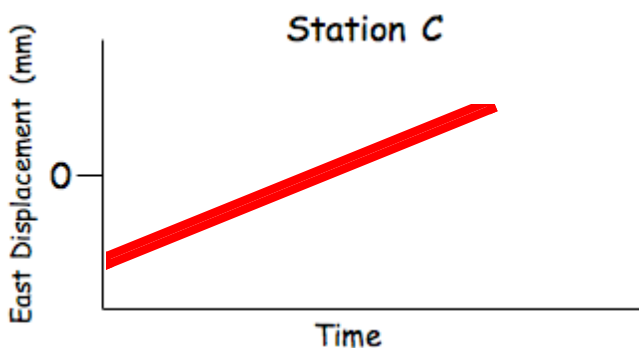
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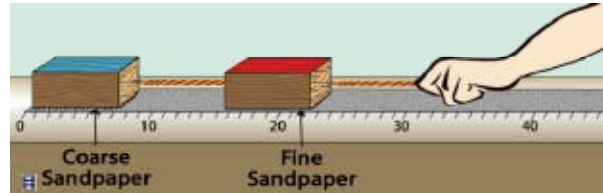
Predicting the Future! Why Episodic Tremor and Slip Matters

16. Draw a sketch of what the time series plots looked like for Stations located at C and D on the map. This is just one campaign of one slow-slip event. Don't worry about where to start the line - you can start it either below the 0 line or right on it.



**The BIG Picture:
Why You NEED to Know This!**

17. Draw a quick sketch of the setup of the blocks demonstration.



18. Describe what happens as you pull on the rubber band attached to the red block.

RED BLOCK MOVES IN SMALL JERKY MOTIONS TO RELIEVE STRAIN, WHILE BLUE BLOCK DOES N'T MOVE. FINALLY, WHEN ENOUGH STRAIN HAS BUILT UP IN RUBBER BAND BETWEEN RED AND BLUE BLOCKS, THE BLUE BLOCK WILL MOVE SUDDENLY, AND VERY FAR, COMPARED TO RED BLOCK.

19. Given a 'slip-deficit' of 3 centimeters per year, how much would accumulate in 500 years? About how many feet is that?

AT 3 CENTIMETERS PER YEAR, 1500 CENTIMETERS WOULD BUILD UP OVER 500 YEARS. THAT'S 15 METERS, OR ABOUT 45 FEET.

20. Why would predicting when a great earthquake and tsunami would happen be so important?

PREDICTING A GREAT EARTHQUAKE AND SUBSEQUENT TSUNAMI COULD SAVE THOUSANDS AND LIVES. PROPERTY COULD BE SAVED, AND BUILDINGS RETROFITTED TO SURVIVE THE GREATER SHAKING.