Plate Tectonics Sim Design

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Table of Contents:

- Learning Goals (and notes for tips)
- Design Overview
- Resources (Web search on other tectonic sims)
- Physical Model of Plate Tectonics (what math model drives Sim, all background math. Both qual and quant, what rules have to be followed).
    - Model Summary
- Sim Layout (pictures and images from Illustrator).
- Tab 2 Subduction Images
- Inteview Notes
- Discussion Archive

Learning Goals

- Students will understand the differences between oceanic and continental crust, including their respective properties of density, composition, temperature and thickness.
- Students will be able to understand the relationships between: density and composition; density and temperature.

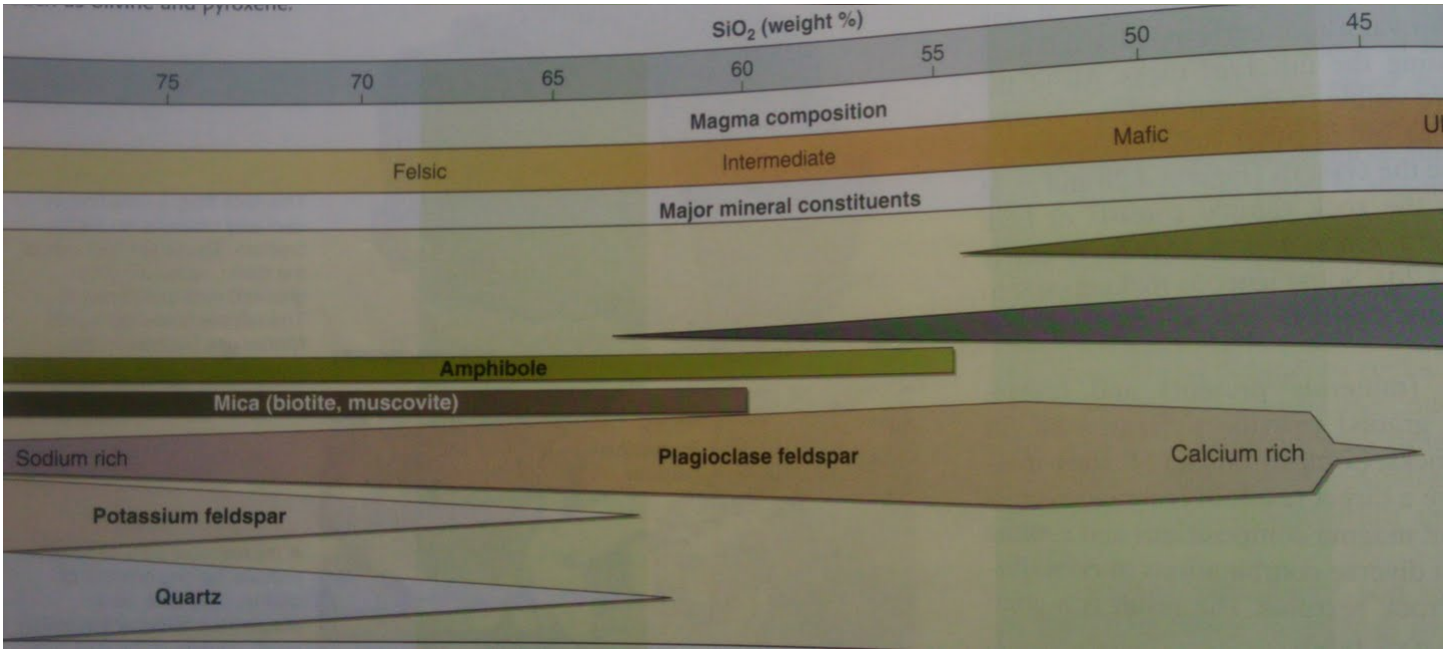
- Students will be able to describe the differences between the mantle and crust. (Terminology of aesthenosphere and lithosphere is not a learning goal? Could be addressed as a check-box).
- Students will be able to describe the different types of plate boundaries and their motions.
- Students will understand how plate tectonics work to create/destroy crust.
- Students will be able to describe what surface features arise from the different processes related to plate motions.

Ideas for tips or future
From: Noah S Podolefsky
Sent: Monday, August 20, 2012 6:58 PM
Subject: addition to plates tips?
Hi Trish,
We sent a link to Plates to David Budd in geology, and he thought that the sim didn't work because the "rewind and new crust buttons were not activated and there is no 'motion box' ". He read in the tips that he might need to update his graphics drivers, but he updated Java instead and didn't know why it wasn't working.
Kathy realized that he just hadn't dragged crust out of the box, which turned out to be the case. He said this might be something to add to the tips.
This is the first person that hasn't figured out to drag crust out, so probably not in issue right now. I just wanted to bring it up, in case we hear similar reports from other users.
-Noah
(We decided not to put anything about how to put crust in for now because there was a concern that teachers might think the sim needs more direction than the interviews indicate are necessary)
On 8/21/2012 4:26 PM, Patricia J Loeblein wrote:
I just thought of another idea other than explaining how to drag crusts– we could rephrase the error information to be more clear about what "run" means.
Presently: "This simulation uses a 3D library that may not run on all computers. If it does not run, updating your graphics drivers may solve the problem."
Possibly?: "This simulation uses a 3D library that may not run on all computers. If it does not <u>open</u>, updating your graphics drivers may solve the problem."
Sounds good to me. Noah and Kathy
8/22 Trish wrote - done and committed.

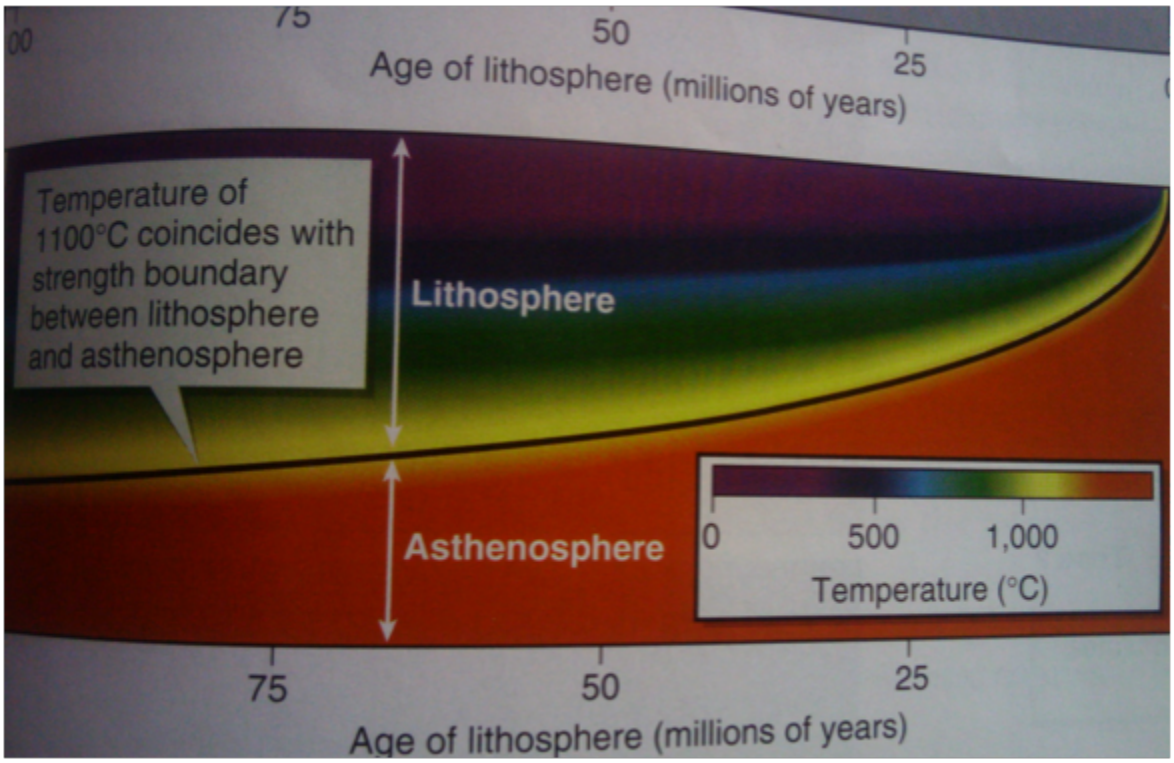
Design Overview

- **Tab 1:** Students will only have a choice of manipulating one crustal type at this time. No mixed plates will occur at this stage.
    - Goals for Tab 1:

        - Students will discover distinguishing features between oceanic and continental crust.
        - Students will discover the relationships between composition and density; temperature and density; and examine crust thickness.
    - Controls for Tab 1:
        - Crust Properties:
            - Thickness in km (have a slider with km readout) Continental crust (35 km), oceanic crust (7 km). From page 350 in Smith and Pun.
            - Composition (have two sliders, one with % Fe read out, the other with % silica + others readout). The sliders will change relative to each other. There's a figure on page 70 (Smith and Pun) that shows % silica vs. % iron. Silica-rich (felsic) = 80%-~63%, Intermediate (which is the composition of Magma) is ~63%-53% silica, mafic (high in Fe and Mg) is about 53%-45% silica, and finally, ultramafic is ~45%-38% silica composition. These values were taken from that figure, so we will want to verify them. Magma.

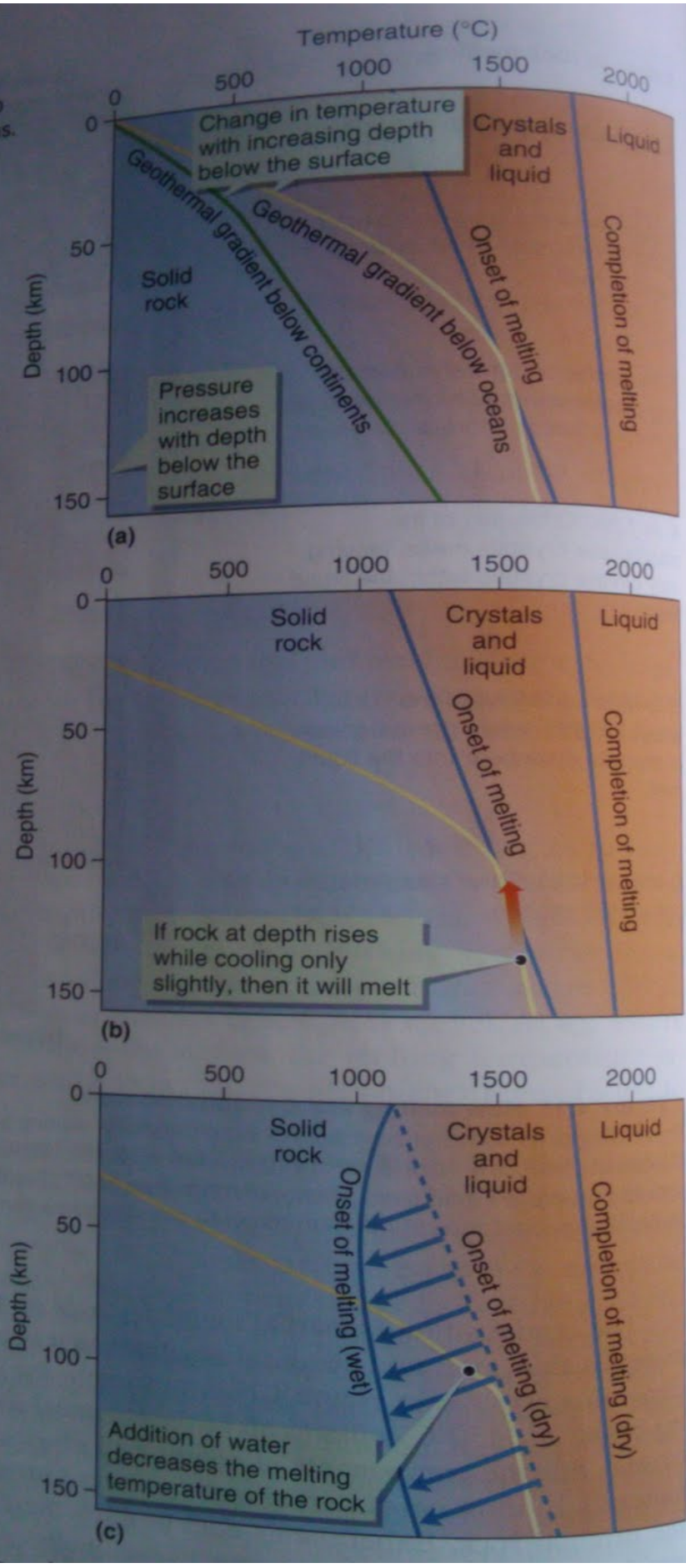


            - Temperature (slider showing cold vs. hot in qualitative sense). Mantle temp/Aesthenosphere (1500-2000 C), transition from strong/rigid lithosphere to weak/fluid aesthenosphere (1100 C), see page 321 in Smith and Pun.

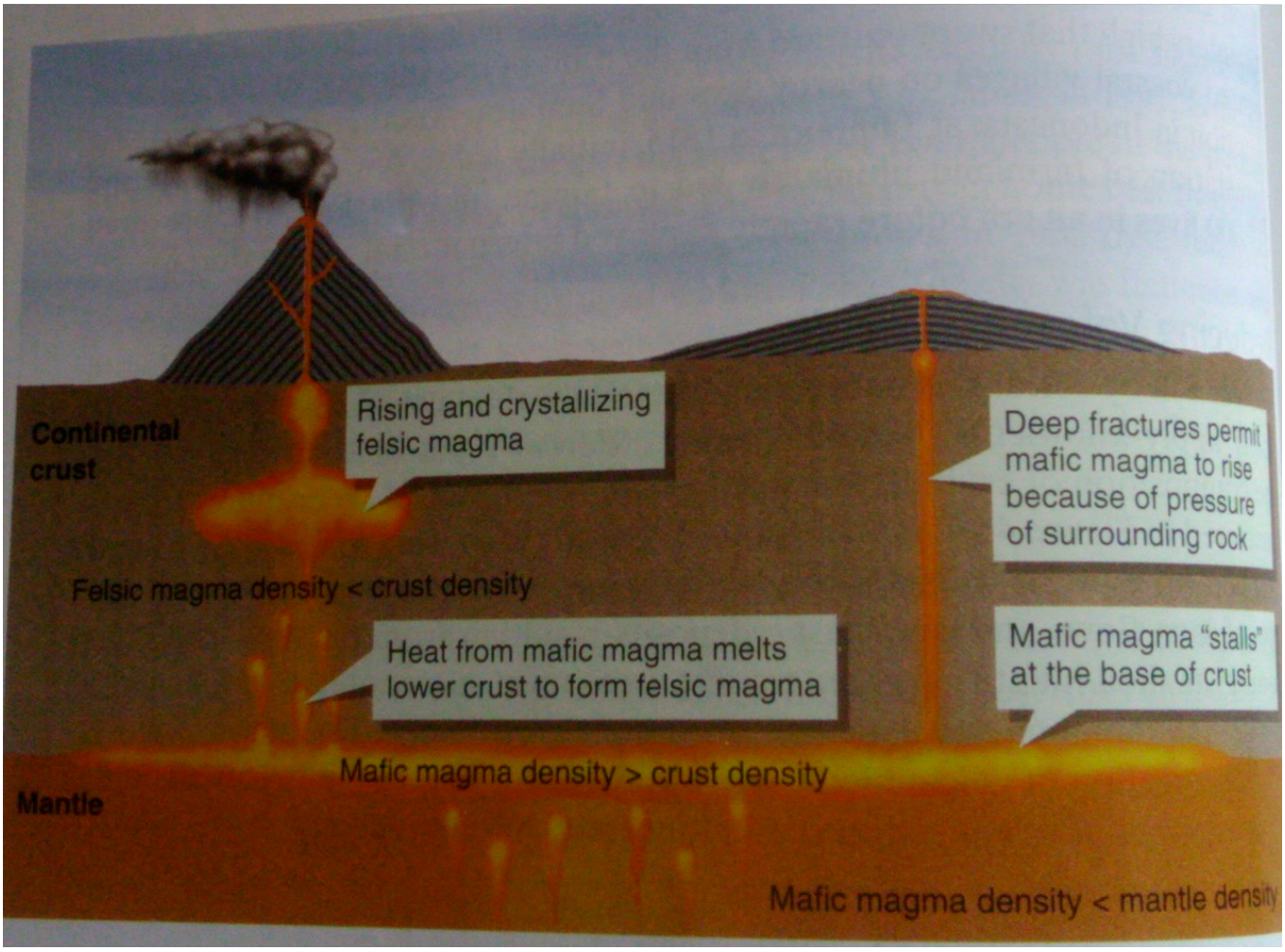


Page 84 Smith and Pun has graphs plotting Temp (C) vs. Depth for melting rock. Look at graphs (a)-(c). There is also an activity on the CD with these graphs. Look at page 86 figure 4.20 for relationship between temp, depth and pressure when melting rock (granite, specifically).

ck to
forms.


Temperature (°C)
0
500
1000
1500
2000
Depth (km)
0
50
100
150
Change in temperature with increasing depth below the surface
Crystals and liquid
Liquid
Geothermal gradient below continents
Geothermal gradient below oceans
Onset of melting
Completion of melting
Solid rock
Pressure increases with depth below the surface
(a)
Solid rock
Crystals and liquid
Liquid
Onset of melting
Completion of melting
If rock at depth rises while cooling only slightly, then it will melt
(b)
Solid rock
Crystals and liquid
Liquid
Onset of melting (wet)
Onset of melting (dry)
Completion of melting (dry)
Addition of water decreases the melting temperature of the rock
(c)

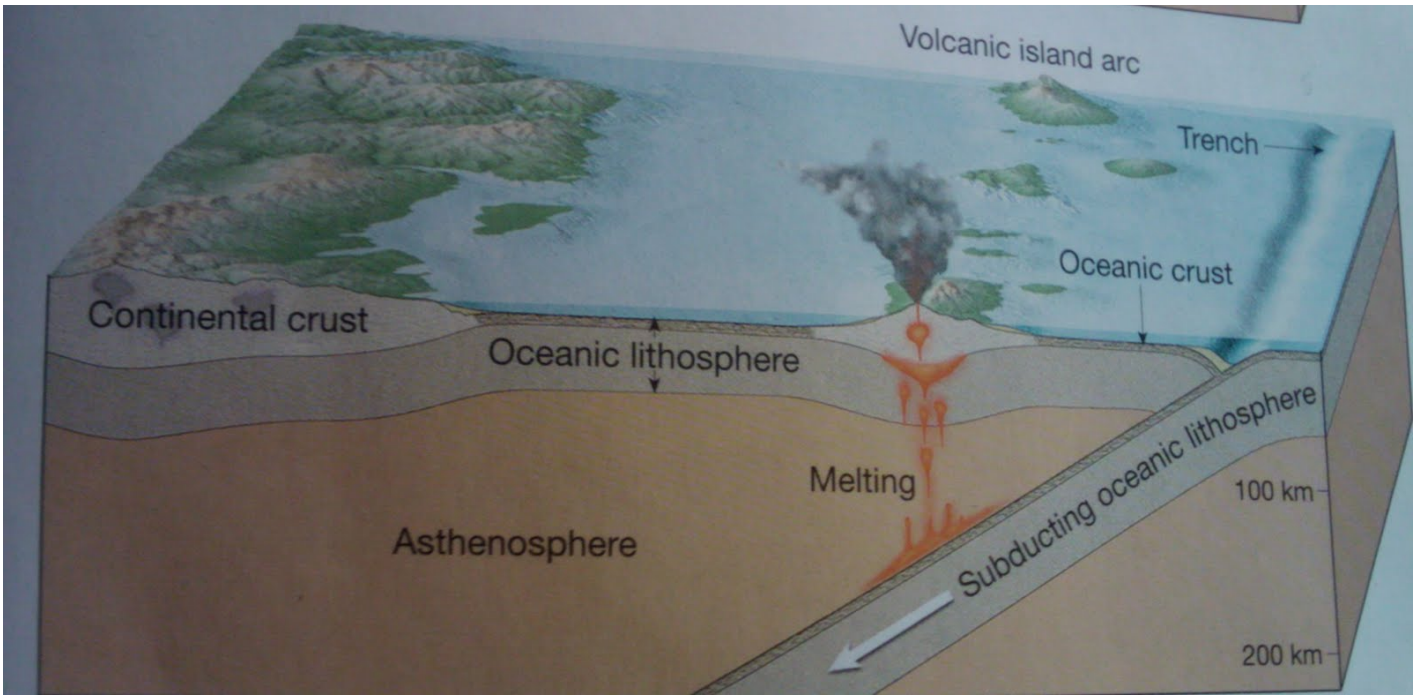
- Density: Continental crust (2750 kg/m^3), Oceanic crust (2900 kg/m^3), Mantle (3300 kg/m^3). For density changes in plates, use color gradients. Very dark gray=most dense, very light gray=least dense. Page 96 in Smith and Pun has a qualitative figure showing mantle/crust densities.



            - We should include an average rate of 6 cm/year for our plate movement. This should help with d=r*t. (Distance = Rate * Time)

        - Feedback:
            - color (Gray Scale) will change with change in density.
            - crust will “sink” or “float” in relation to density changes with respect to surrounding mantle/crust.

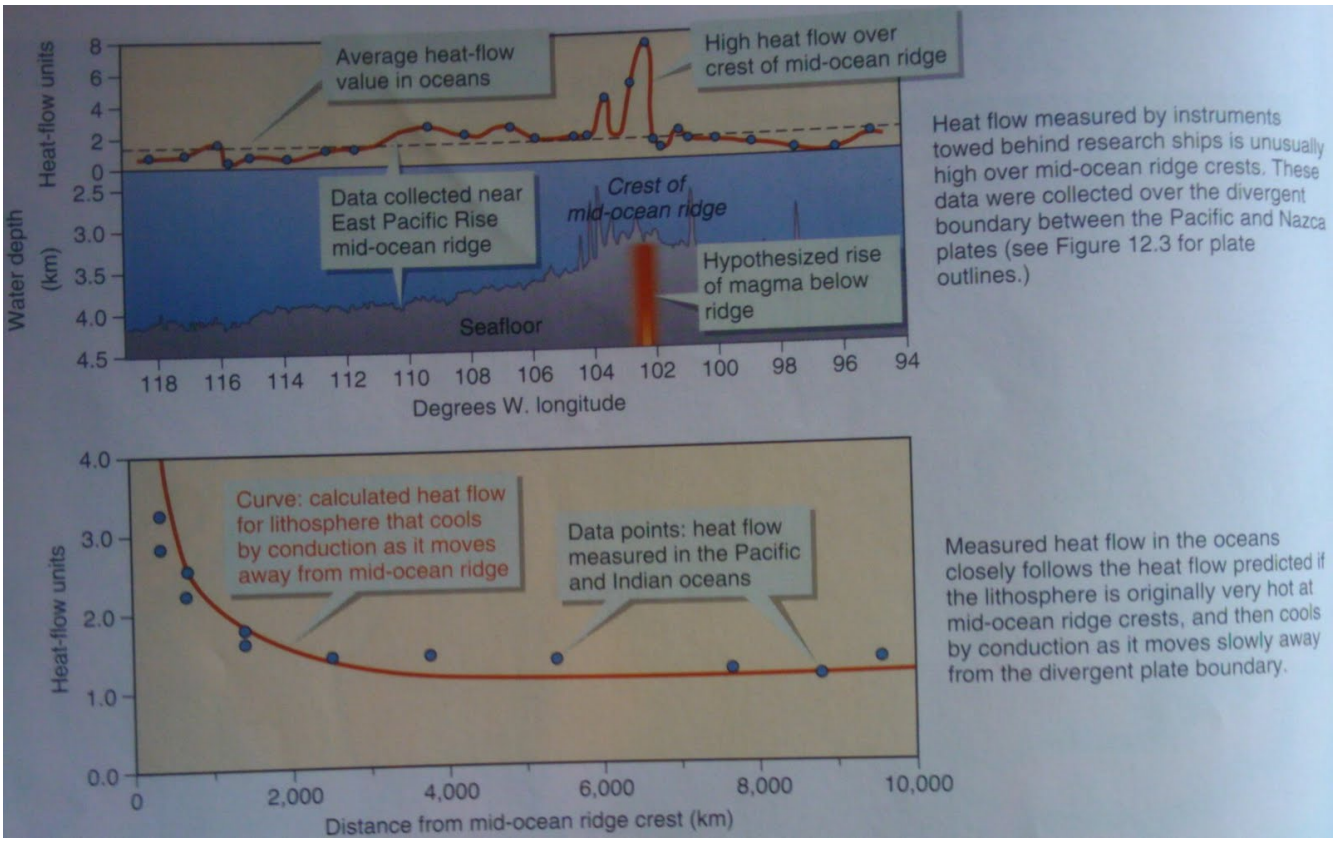
- **Tab 2:** This will have two plates where students can manipulate their motion. They will start with each plate being either oceanic OR continental crust (no mixture single-plate states yet). Depending on the direction they choose to move the plates, this could create a mixed plate through divergence of a continental plate creating oceanic composition at the spreading center.
    - Goals for Tab 2:
        - Students understand motion of plates relative to each other. They will understand what types of motions produce what effects.
        - Students will understand how continental and oceanic crust relate to each other and how new oceanic crust forms.
    - Rules for Tab 2:
        - Once the student starts moving a plate, that direction must remain constant. He/she can not make the plate go “backwards” because that does not happen in the physical world.
        - Students will have the ability to control the velocity and be able to stop the plate.
        - Students will be able to form new oceanic crust from spreading the plates apart/creating divergent boundaries. We need visualize the thickness of continental crust/plate creating new oceanic crust. Page 539 in Tarbuck and Letgens has a good visualization in figure 19.21 (b).



- Tools for Tab 2:
  - For the crust pieces, students will have the option of either:
    - warm, young oceanic crust
    - cold, older oceanic crust
    - continental crust
  - These pieces of crust will have the ability to be dragged and dropped into the play area, so students can determine which combination they want to manipulate.
  - There will be two modes: Manual and Auto
    - Manual mode will give students the ability to physically move the plates, change speeds and determine initial direction of movement (what type of boundary they will form).
    - Auto mode will have the animation play on it's own. A play/ pause button will appear so the student can pause the animation at any given time. We decided that a button will appear for the student to choose what kind of boundary (convergent or divergent), but what about the combo of plates, and velocity?
      KP: Combo of plates is determined by what the student drags and drops into the empty slots.

KP: Velocity is set programmatically to be the 6cm/year. We'll choose a default for the "Sim Speed" that makes time go by reasonably fast, but they'll be able to adjust it.

- Check boxes will include:
  - to show ocean water on top of oceanic plates and where that water level hits continental plate.



  - Density of plates (with probe in toolbox)

Resources

- How Does Earth Work - textbook by Smith and Pun. See page 328: There are computer simulations/activities called "Active Art" and "Annotated Illustrations" with an attached CD. The "Active Art" looks very similar to what we're developing and we could get some good ideas from it.

- From: http://serc.carleton.edu/NAGTWorkshops/visualization/collections.html?&results_start=51
    - There are several "Visualizations" that cover key concepts that might help inform our Sim.
        - http://serc.carleton.edu/NAGTWorkshops/geophysics/visualizations/IsosGrav.html (This covers isostacy and gravity, and how mountains have "roots").
        - http://serc.carleton.edu/NAGTWorkshops/petrology/visualizations/volcano.html (This is volcano visualizations for different topics).
        - http://serc.carleton.edu/NAGTWorkshops/structure/visualizations/folds_faults.html (folds, faults and shear zones. Could be incorporated in our Sim as surface features).
        - http://serc.carleton.edu/NAGTWorkshops/deepearth/visualizations/farallon.html (this is about the Farallon plate being subducted under the North American plate).
        - http://serc.carleton.edu/NAGTWorkshops/deepearth/visualizations/mantle_conv.html (Mantle plums and convection visualizations).
        - http://serc.carleton.edu/NAGTWorkshops/geophysics/visualizations/earthquakes.html (earthquake visualizations)
        - http://serc.carleton.edu/NAGTWorkshops/geophysics/visualizations/PTMovements.html (finally, a whole section devoted to plate tectonic movements).
- http://pubs.usgs.gov/gip/dynamic/understanding.html#anchor15039288 (USGS website on plate tectonics and different boundaries).
- http://earthquake.usgs.gov/learn/animations/ (USGS animations).
- http://www.ucmp.berkeley.edu/geology/tectonics.html (has animations on plate movements).
- http://www.pbs.org/wgbh/aso/tryit/tectonics/index-nojs.html (has an activity for kids on plate tectonics and plate movements).

Physical Model of Plate Tectonics

1. Relative compositions of oceanic, continental crust, mantle.
From The Theory of the Earth (page 48):
Average Bulk Continental Crust Composition
Silica (SiO_2): 59.5%
Aluminum Oxide (Al_2O_3): 16.3%

Average Oceanic Crust Composition (notice how there's still a significant amount of silica. It's more dense because of the added FeO).
Silica (SiO2): 47.8%
Aluminum Oxide (AlO3): 12.1%
Iron (II) Oxide (FeO): 9.0%
Magnesium Oxide (MgO): 17.8%
Calcium Oxide (CaO): 11.2%

TABLE 3-4
Estimates of the Chemical Composition of the Crust
(Weight Percent)

Oxide	Oceanic	Continental Crust		Density (g/cm^3)
	(1)	(2)	(3)	(4)
SiO_2,	47.8	63.3	58.0	2.648
TiO_2	0.59	0.6	0.8	4.23
Al_2O_3	12.1	16.0	18.0	3.95 to 4.1
Fe_2O_3	---	1.5	---	5.242, solid
FeO	9.0	3.5	7.5	5.745
MgO	17.8	2.2	3.5	3.58
CaO	11.2	4.1	7.5	3.35
Na_2O	1.31	3.7	3.5	2.27
K_2O	0.03	2.9	1.5	2.35
H_2O	1 .0	0.9	---	1.0, liquid

References:
(1) Elthon (1979).
(2) Condie (1982).
(3) Tayor and McLennan (1985).
(4) Wikipedea

Also wikipedia has info on continetal crust:
http://en.wikipedia.org/wiki/Crust_%28geology%29

2. Earth's Structure from The Theory of the Earth (page 46). Average continental=35km, average oceanic=7 (from other sources). Include ranges of what we'll use.

Region	Depth/Thickness (km)	Fraction of Earth's Mass	Fraction of Mantle plus Crust
Continental Crust	0-50	3.74E-3	5.54E-3
Oceanic Crust	0-10	9.9E-4	1.47E-3
Upper Mantle	10-400	0.103	0.153
Transition Region	400-650	0.075	0.111
Lower Mantle	650-2890	0.492	0.729

3. Relationships

- Geothermal gradient (Temp vs. Depth)

Simplified Version: Near linear relationship -- temperature increases by 30 degrees C for every 1km you descend toward the center.

Temp=30x, where x=how far in km you descend.

The boundary between the lithosphere and aesthenosphere is 1,100 Celsius, making it about 36-37 km down.

- More precise models:

$$T = T_0 + \frac{q_0}{k} y - \frac{\rho H}{2k} y^2$$

$$q_0 = k(T_1 - T_0)\left(\frac{u}{\pi \kappa x}\right)^{1/2}$$

$$\bar{q}_0 = \frac{2k(T_1 - T_0)}{\sqrt{\pi \kappa \tau}}$$

1. The first equation is the conduction temperature profile for mantle (the geothermal gradient). See page 140 from Geodynamics

ρ is the density=3300 kg/m^3, k is the coefficient of thermal conductivity=4 W/mK, H is the rate of internal heat production=7.38E-12 W/kg, q_0=70 mW/m^2, and T_0=0 Celsius.

2. The second equation is describing the surface heat flux q_0 as a function of age and distance from a mid-ocean ridge crest. This will help our model for coding the temperature differences in "young, warm, less dense ocean crust" versus the "old, cool, dense ocean crust" and during spreading.

(T_1-T_0)=1300K=isotherms beneath the ocean surface as a function of the age of the seafloor. See Figure 4-24 on page 158 in Geodynamics. κ= thermal diffusivity (we can assume 1mm^2/s). We replace t with x/u because the thermal diffusion distance is equal to $\sqrt{\kappa t}$ (page 155). The variable k represents the heat flux into the rock k number of times the temp difference of (T_1-T_0) (page 156).

3. The third equation describes the mean oceanic heat flow at a constant rate of seafloor production with subduction at age τ. We can assume τ to be 120.8 Myr. If we include the parameters from page 159 in Geodynamics, we get find that the mean oceanic heat flow is $qmean_0$=78.5 mW/m^2.

- Distance = rate*time: This can help us calculate the mean age of the oceanic crust if we know the size of the crust (in area = km2) and the rate at which new crust is being created (we can assume something like 2.8 km2/yr). With an area of oceanic crust = 3.2E8 km2, we get a mean age of the oceanic crust to be 57 Myrs.
- Isostasy= (h-b)=h(1-$\rho c / \rho m$) where h=height/thickness of continental crust (assume 35 km), b=level of ocean to bottom on top of mantle, $\rho c = mean\ density\ of\ continent = 2750$ kg/m^3, and $\rho m = mean\ density\ of\ mantle$= 3300 kg/m^3. We find that (h-b)=5.8km. This is only valid using the depth of oceans relative to the continents. See page 74.
- Density = mass/volume
- Buoyancy = for mid-ocean spreading centers: The magma from partial melting beneath the ocean ridge is lighter than the residual mantle rock, making it more buoyant driving it upwards to the surface at the ocean crest. This magma cools forming new oceanic crust.

- Geotherm: Geothermal gradient shows temperature versus depth. I might be able to find studies that have it for subducting plates. http://comp.uark.edu/~sboss/study3f99.htm
- Theory of the Earth http://caltechbook.library.caltech.edu/14/4/TOE03.pdf (broken?)
- Heat transfer through a slab: see page 133 in geodynamics book.
- Lithospheric plate boundary and body forces (as opposed to mantle convection): http://www.umich.edu/~gs265/tecpaper.htm

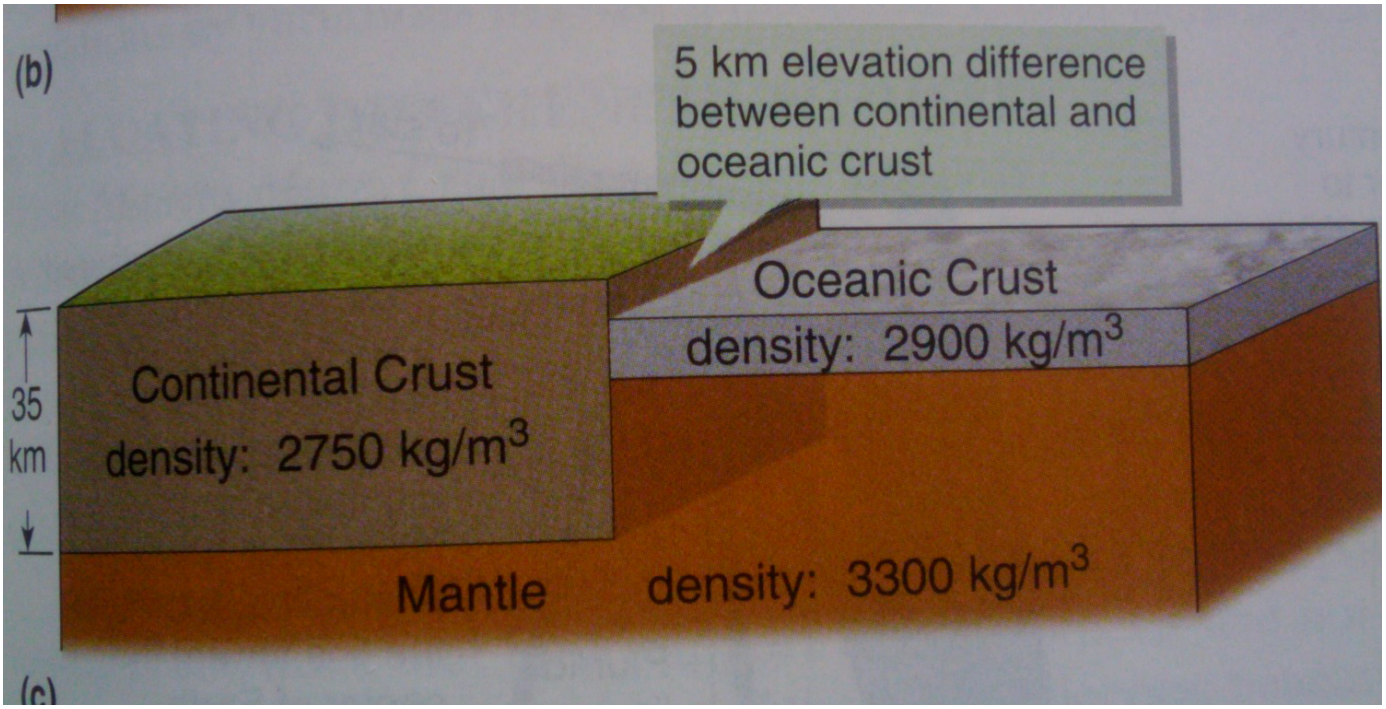
Sim Layout

Start State: Tab 1

- In the play area, there will be the mantle and an outlined box indicating a blank crust piece may be dragged and dropped into that area. There will only be room for one piece of crust - then you get to manipulate it to make either continental or oceanic. ⁻
- The control area will also include the following sliders for student manipulation. They will all start at zero prior to student placing the crustal piece:
    - Thickness of crust in km.
    - Composition of crust in ratio of %Fe + Mg and %Silica + others.
    - Density in kg/m^3 as a probe
    - Temperature in Celsius

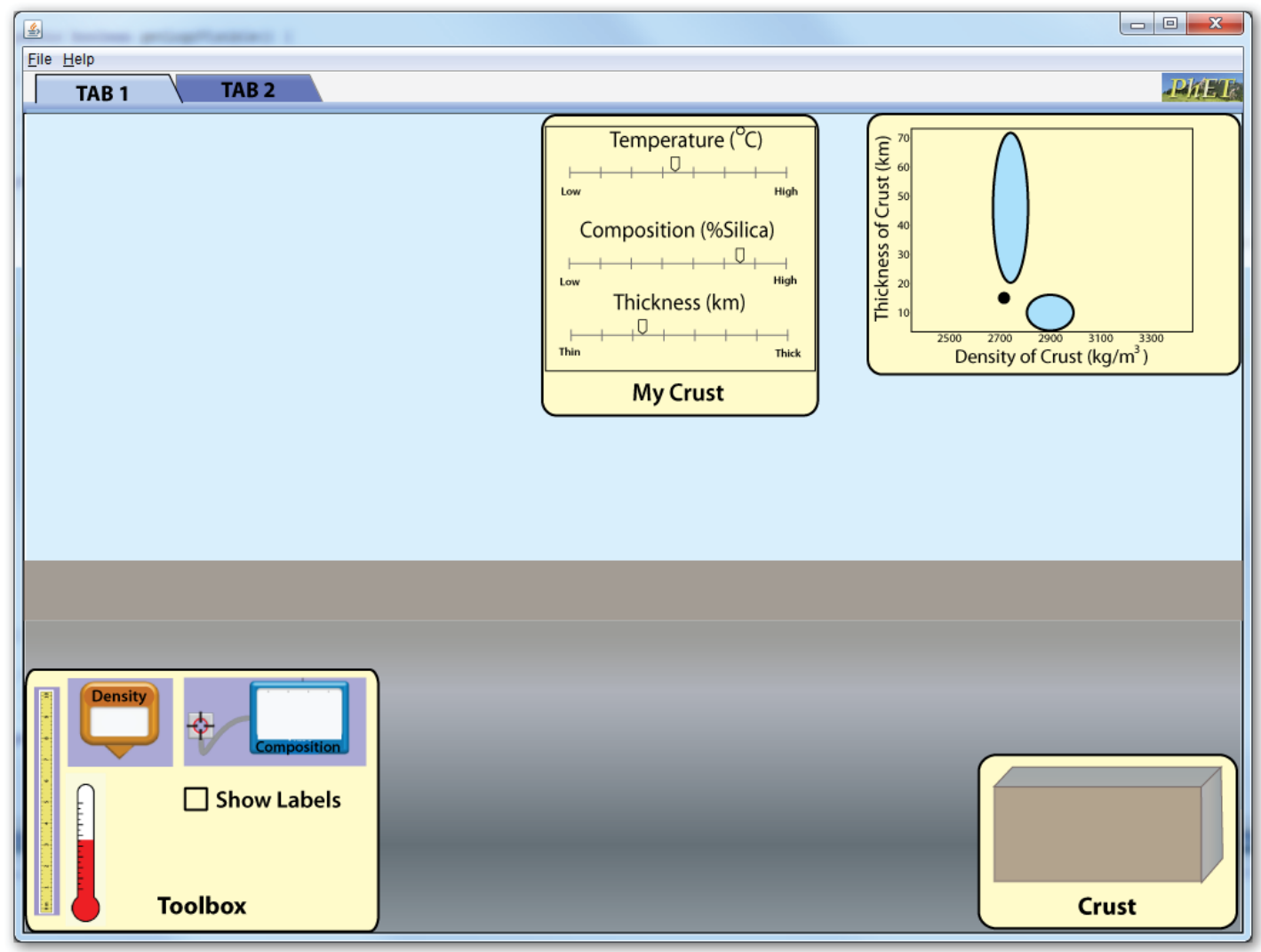
Play State: Tab 1

- Once the student drags and drops the piece of crust onto the mantle:
    - the Mantle will respond to the density of the crust that the student chose. For continental, it will slightly “sink” into the mantle; the oceanic will “sink” a little more. Be careful with how students interpret this.



- Crustal Thickness: Thickness of the crust in the play area will respond to what the student chooses on the slider after the initial, automatic value.
    - There are thicknesses that do not occur in nature: if a student chooses oceanic, the slider will only have the range of 5 km to 10km (see reference) to slide between. That limits students making oceanic crust too thick. If student chooses continental, the slider will only range from 30 km to 70km*. (*There is less than 10% of the worlds crust that exceeds 50 km in thickness. These include the Andes and the Himalayas, USGS). This limits making the continental crust too thin.
    - Lithosphere = crust and rigid upper mantle = 0-100 km depth/ thick. Asthenosphere = from 100 km to 660 km down. http://ser.sese.asu.edu/GEO110/GEO110_S03/Dis2b.pdf
    - We're assuming that our initial thicknesses are:
        - Oceanic Crust = 7 km
        - Continental Crust = 35 km (5 x oceanic thickness)
        - Mantle thickness = 105 km (around 100 km down is where melting starts, and where we will show that melting on our scale. This is 3 x the continental thickness). http://ser.sese.asu.edu/GEO110/GEO110_S03/Dis2b.pdf (reference, from ASU SESE).
- Composition: This has to be aligned with the density. If a student chooses to manipulate composition.
- Temperature: Still need to find definite values for temperature of each type of crust? Is this necessary or will it be qualitative?

This is VERSION 1:

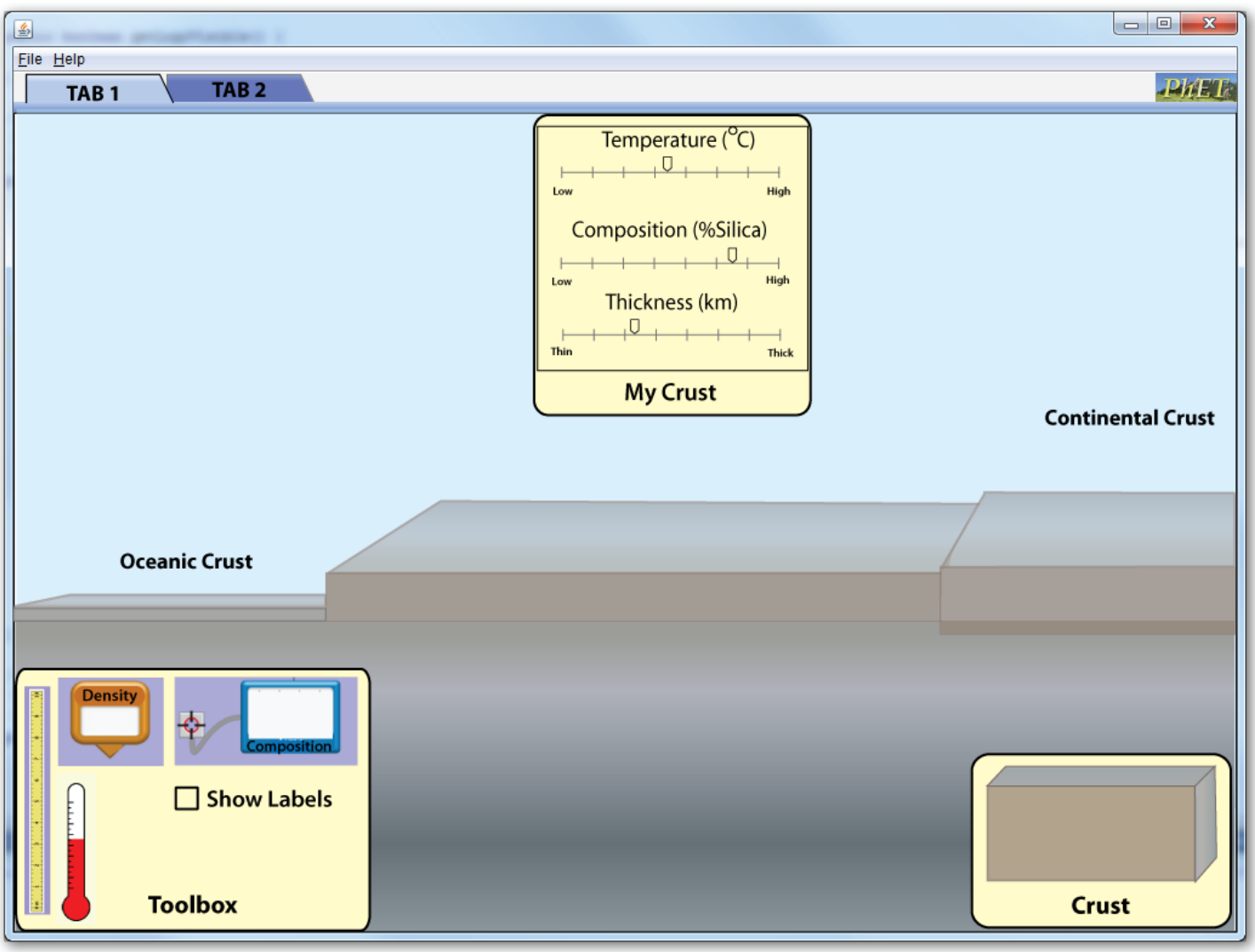


Toolbox Description and Information:

- **Density meter:** The density meter will allow students to measure the densities of the different types of materials in the play area. Students do this by “picking up” the tool and sliding it across what they want to measure, and the readout box will tell them the density of the material that they are hovering over. This will include any plates they want to measure, the mantle, seawater and landforms.
- **Composition meter:** similar to the density meter, only reading out the different compositions of the various materials in the play screen. Students will be able to measure the composition of the different plates, the mantle, and landforms.
- **Ruler:** vertical when the student picks it up. It will display the correct units and range necessary to accurately measure the thicknesses of the plates and landforms. There will not be a separate numerical readout as the density/ composition tools.

- **Thermometer:** will have the ability to adjust the liquid mercury as the pic displays. There will be the appropriate units/ranges for the materials on the play area.

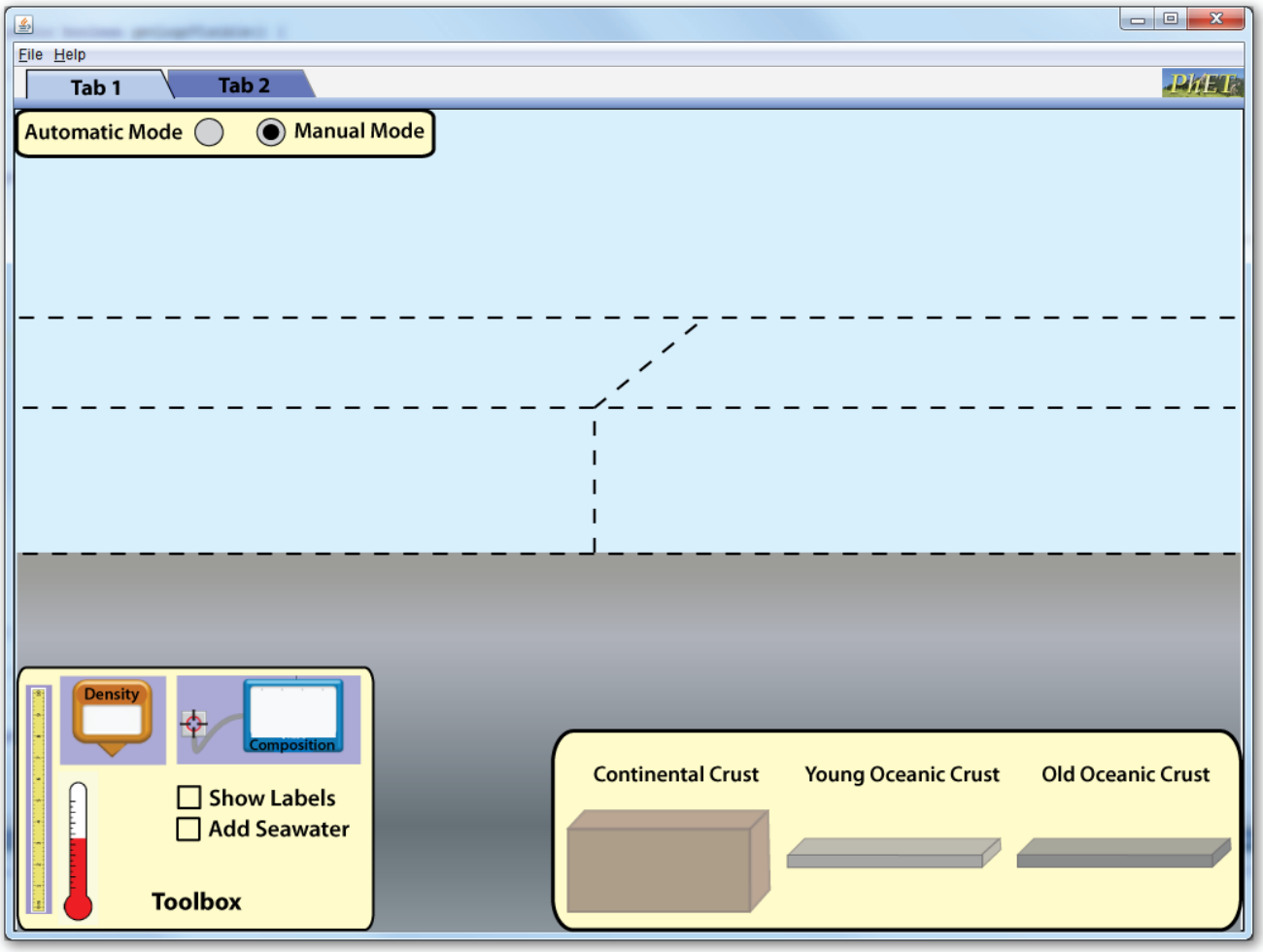
VERSION 2: This version would include a new perspective of the one plate that students can manipulate. It would be in the middle of a continental and oceanic plate, respectively. This will allow students to visually compare their plate to established ones. Because of this feature, having the graph with the moving dot would not be necessary.



Start State: Tab 2 will begin in manual mode.

- There will be two outlined, empty boxes for students to drag and drop crustal pieces.
- On the left control area, there will be three options of crustal pieces to choose from: Continental crust; warm, young, less dense oceanic crust and cool, old, more dense oceanic crust. They will already have their predetermined color of gray associated with density/composition.

- Tab 2 start state with outlined boxes indicating drag and drop. The boxes should have a glowing appearance to indicate to students that something belongs in those areas.

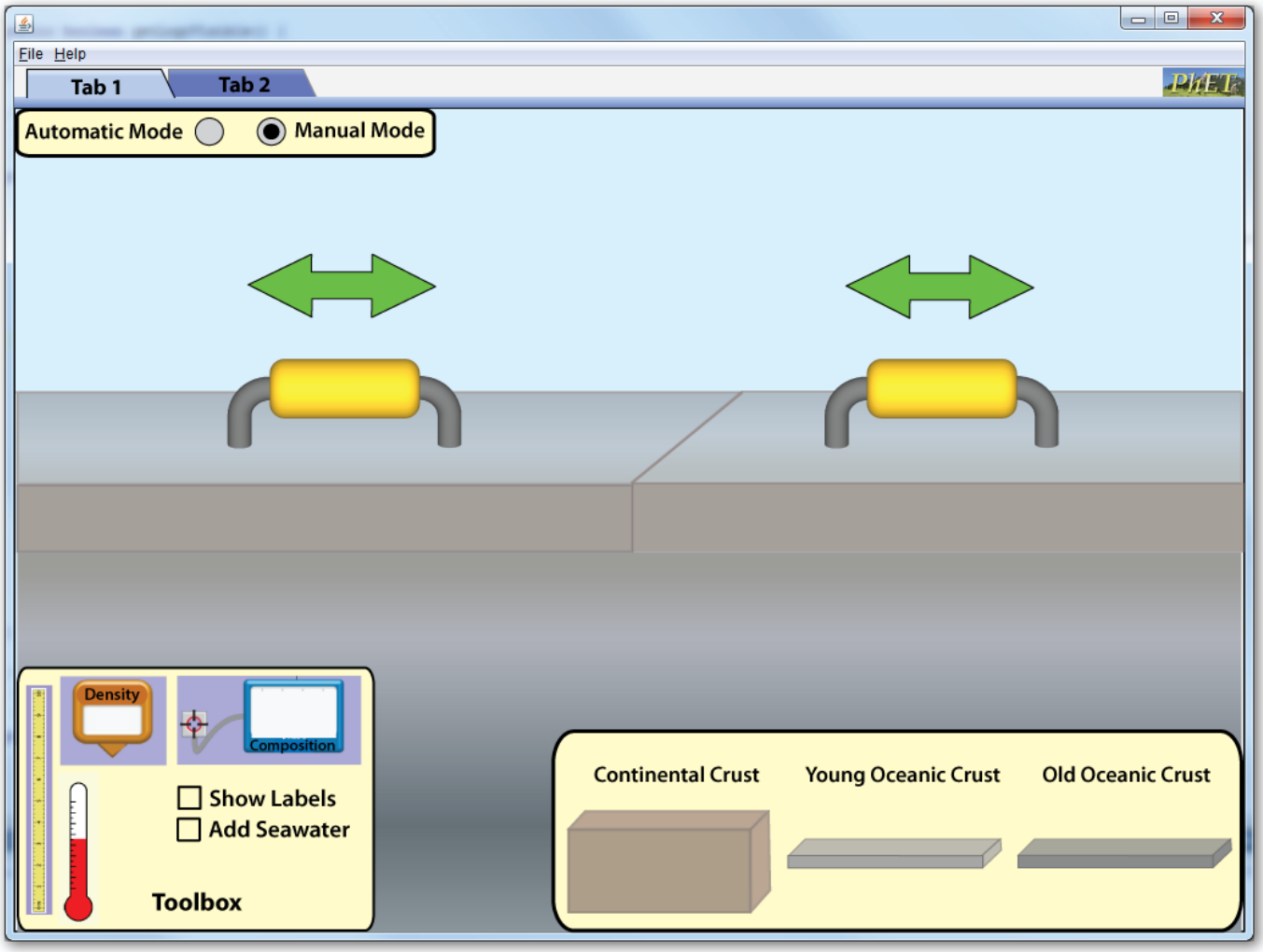


Play State: Tab 2

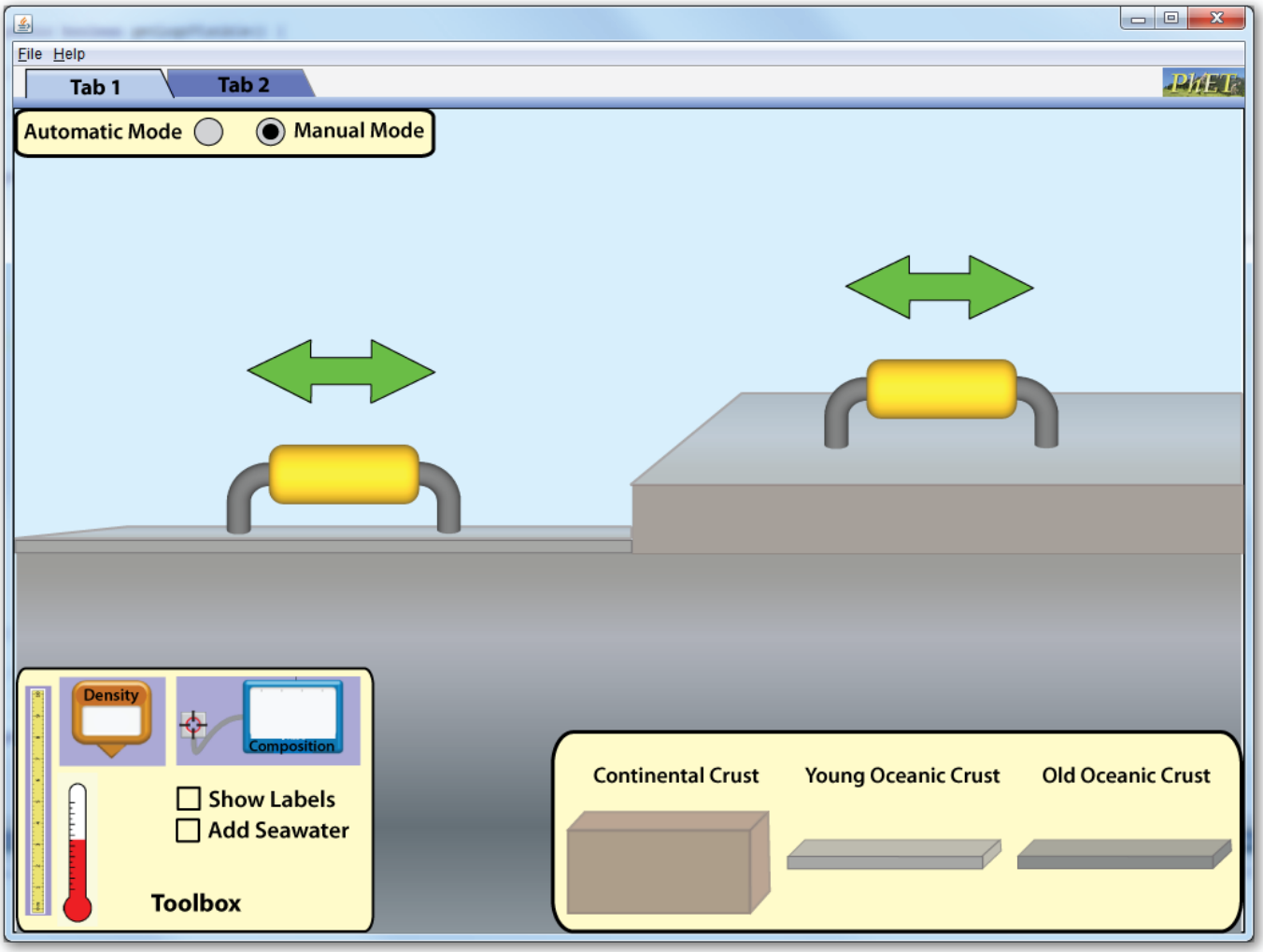
- Manual Mode
    - The student will drag and drop 2 crustal pieces from the left control area into the play area. Once this task is completed, a “handle” on each of

the crustal pieces will appear, indicating the student to slide the crust indicated by the set of arrows. (There will be arrow left to right for divergent/convergent boundaries, and arrows side to side/up to down to indicate a transform boundary). KP: We're still figuring out how to do transform if possible.

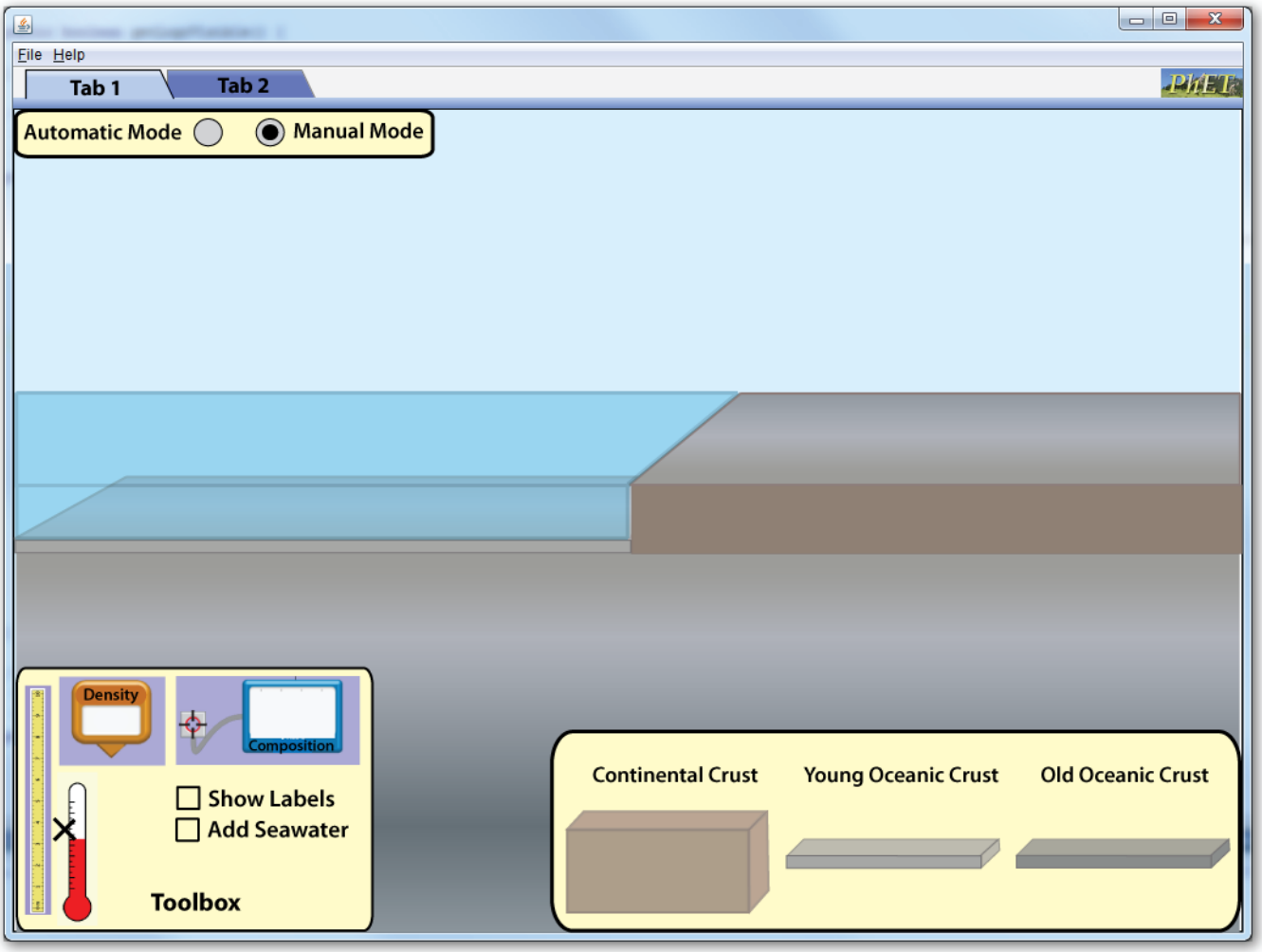
- Continental + Continental Crust. Arrows indicate which directions are permitted.

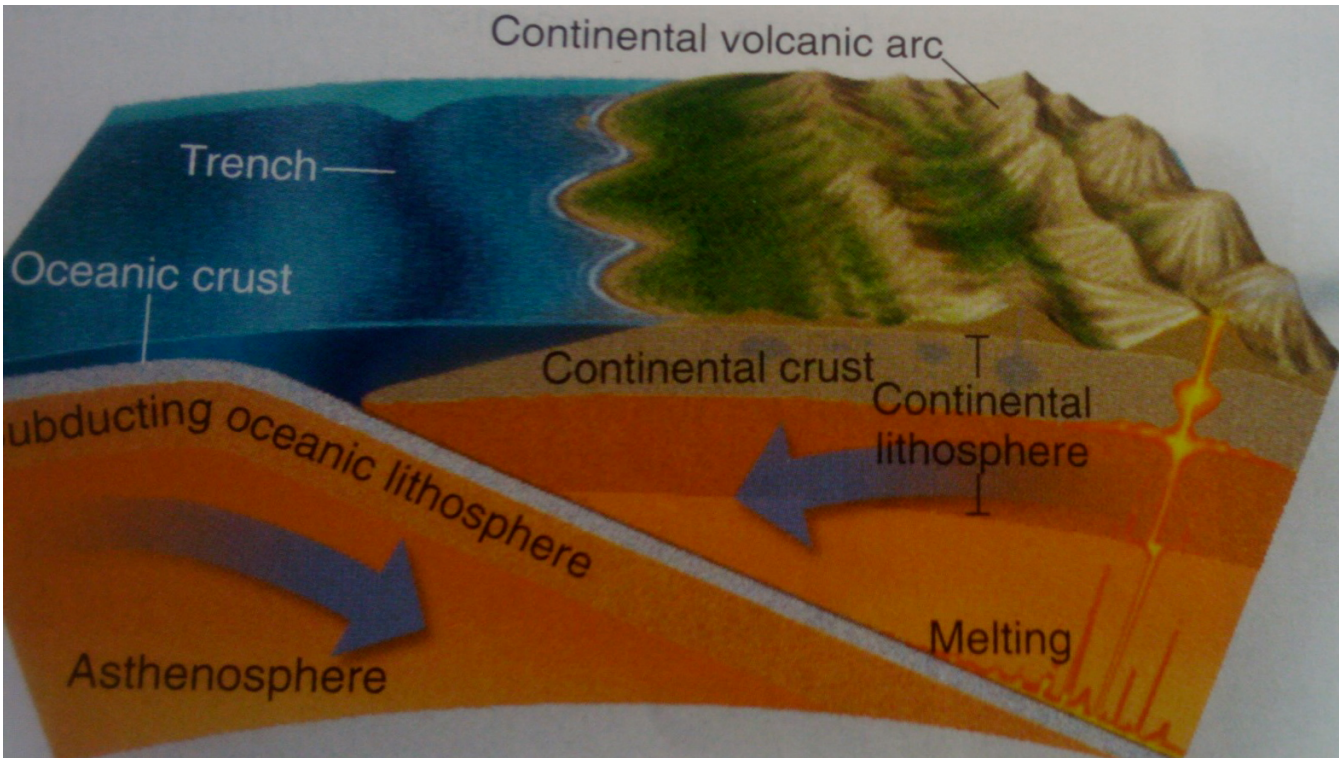


- Young Oceanic Crust + Continental Crust.



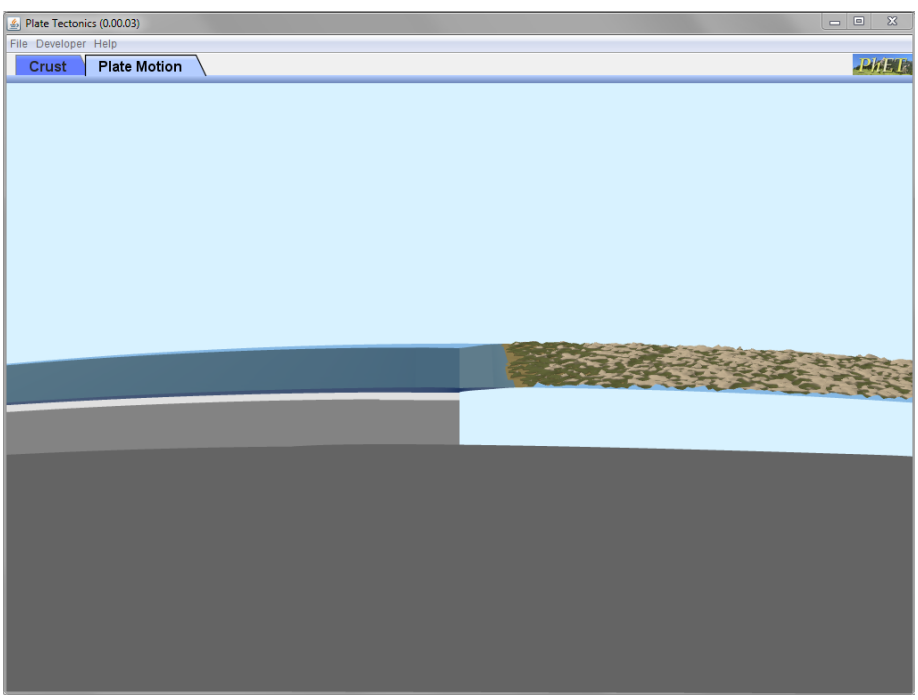
Below is just a snapshot of what this image would look like with the seawater checkbox on. I left out the handles so they didn't look weird in the water. Whenever the situation does not allow to show the seawater, the checkbox for the seawater option will be grayed out.


File Help
Tab 1
Tab 2
PhET
Automatic Mode
Manual Mode
Density
Composition
Show Labels
Add Seawater
Toolbox
Continental Crust
Young Oceanic Crust
Old Oceanic Crust

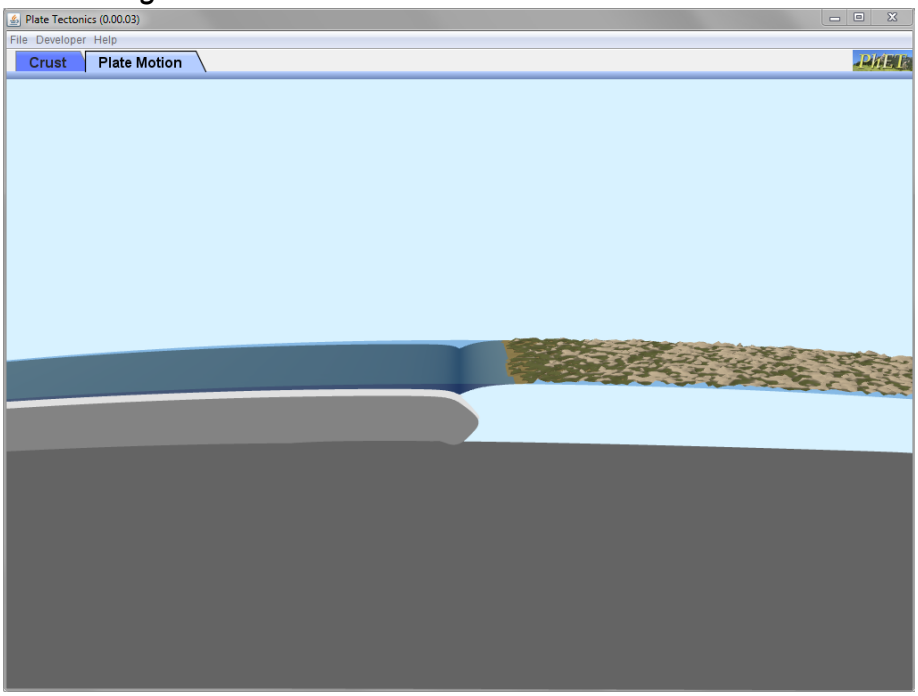


Below is a sequence of oceanic subducting under continental. Note that this does not show melt and formation of volcanoes. We should decide if this is always shown and how.

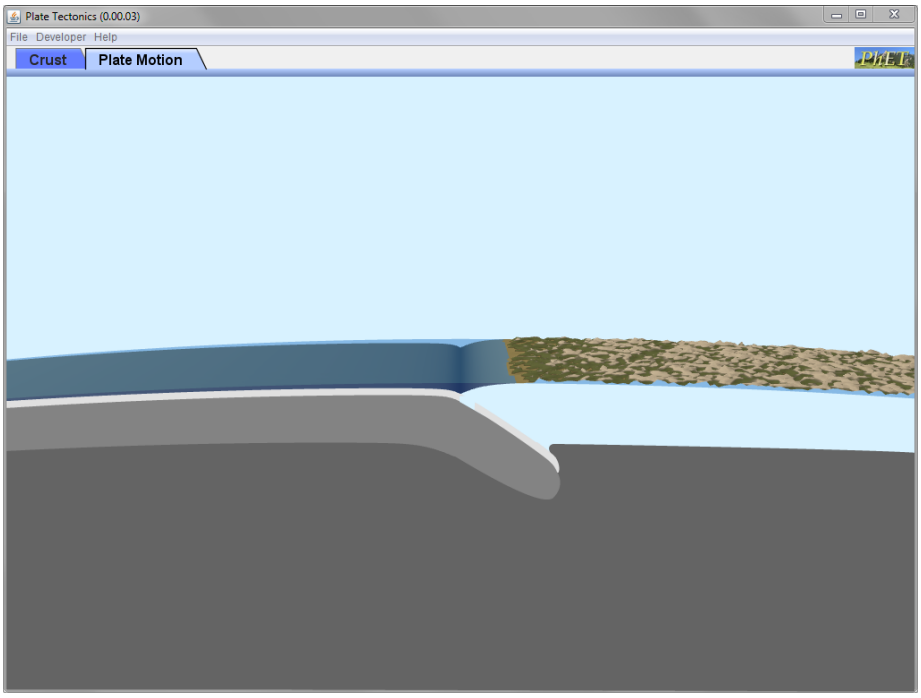
Start



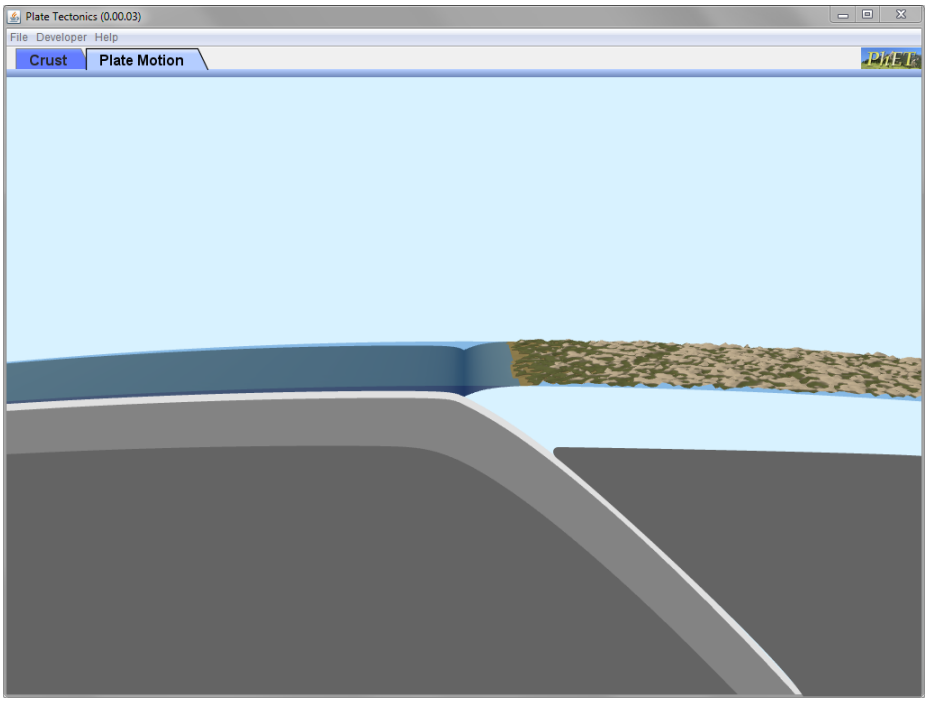
Crusts begin to deform at collision



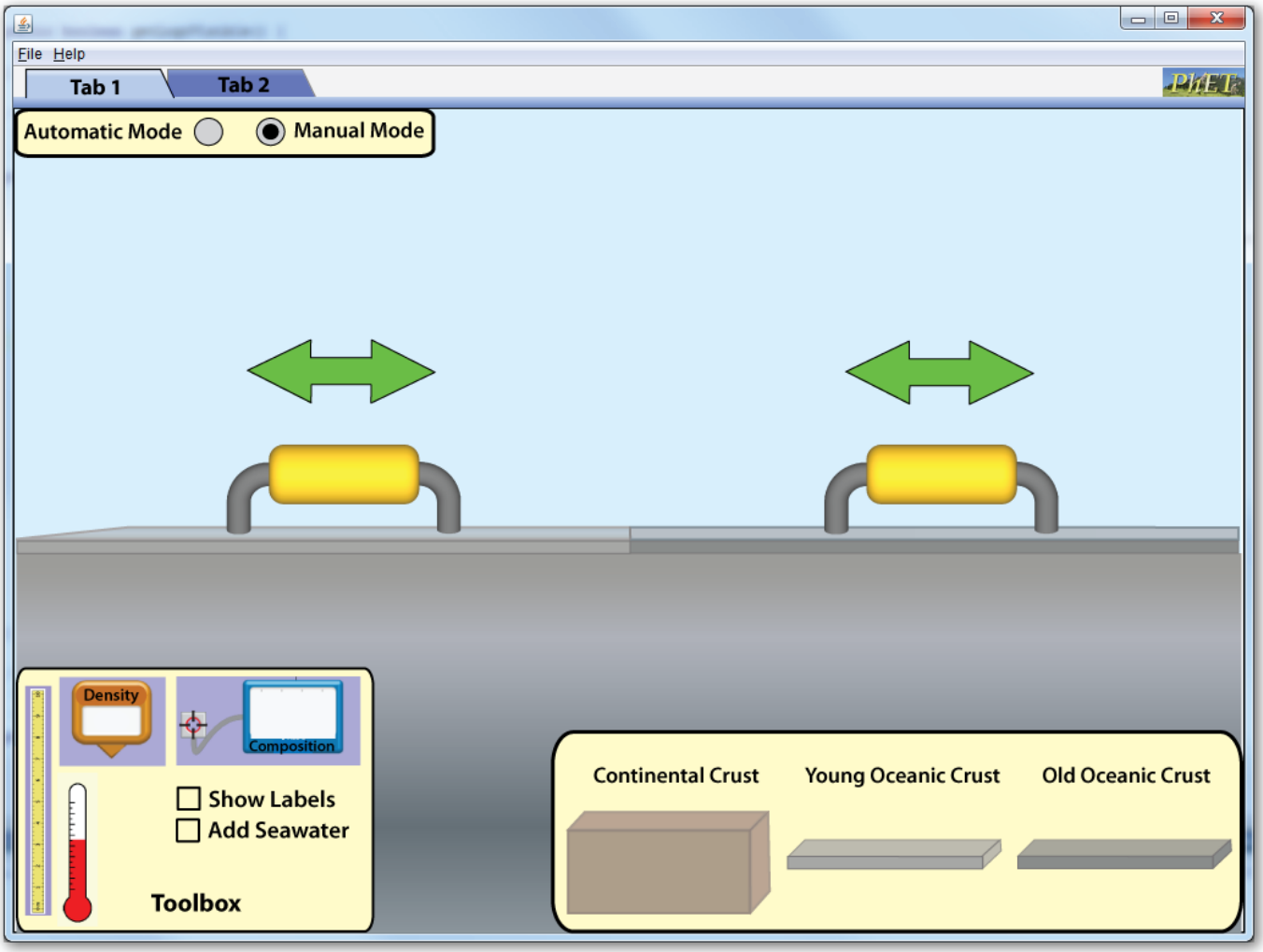
Oceanic subducts under continental



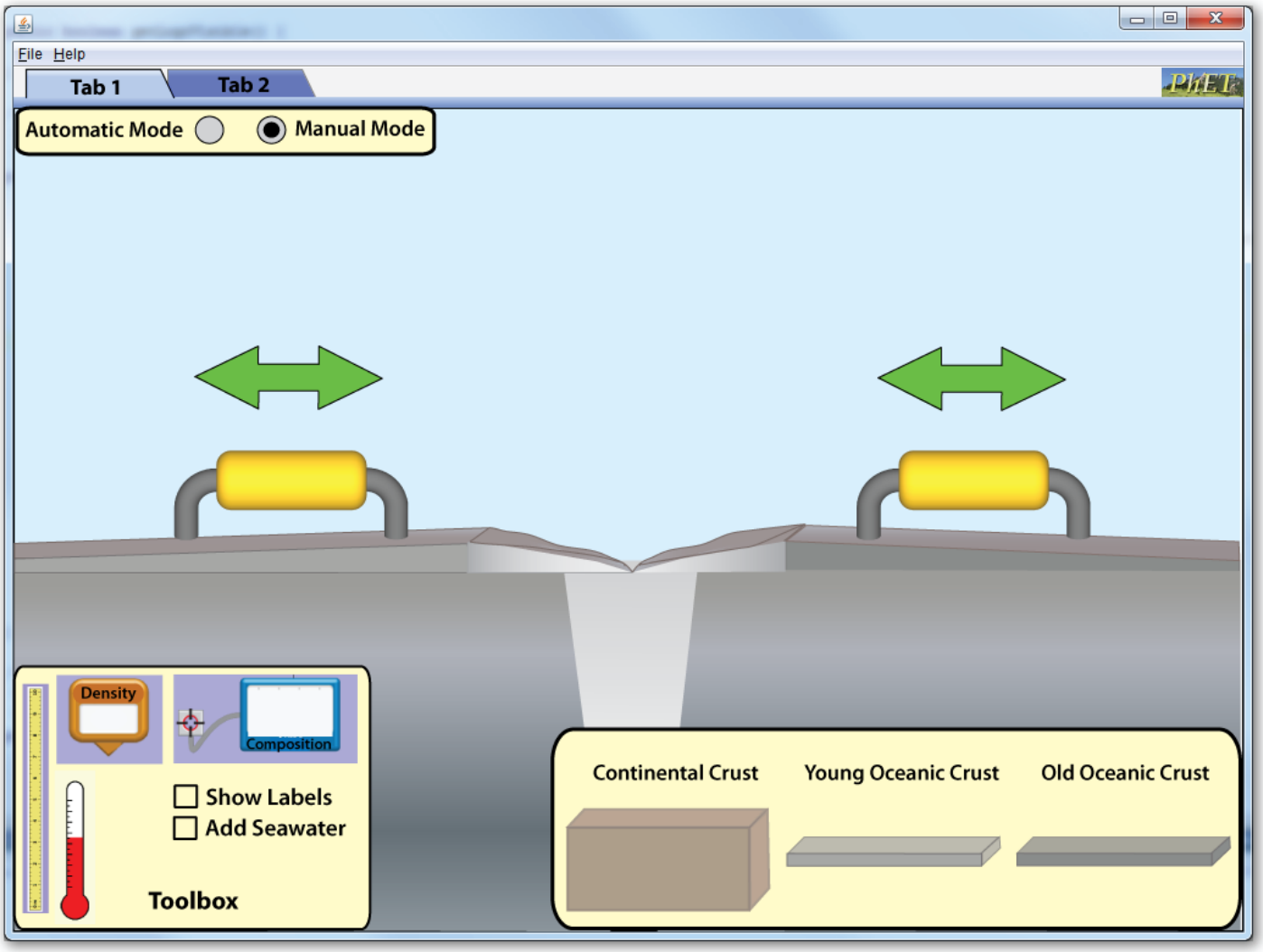
Eventually oceanic has descended far below continental



- Young oceanic crust + old oceanic crust.

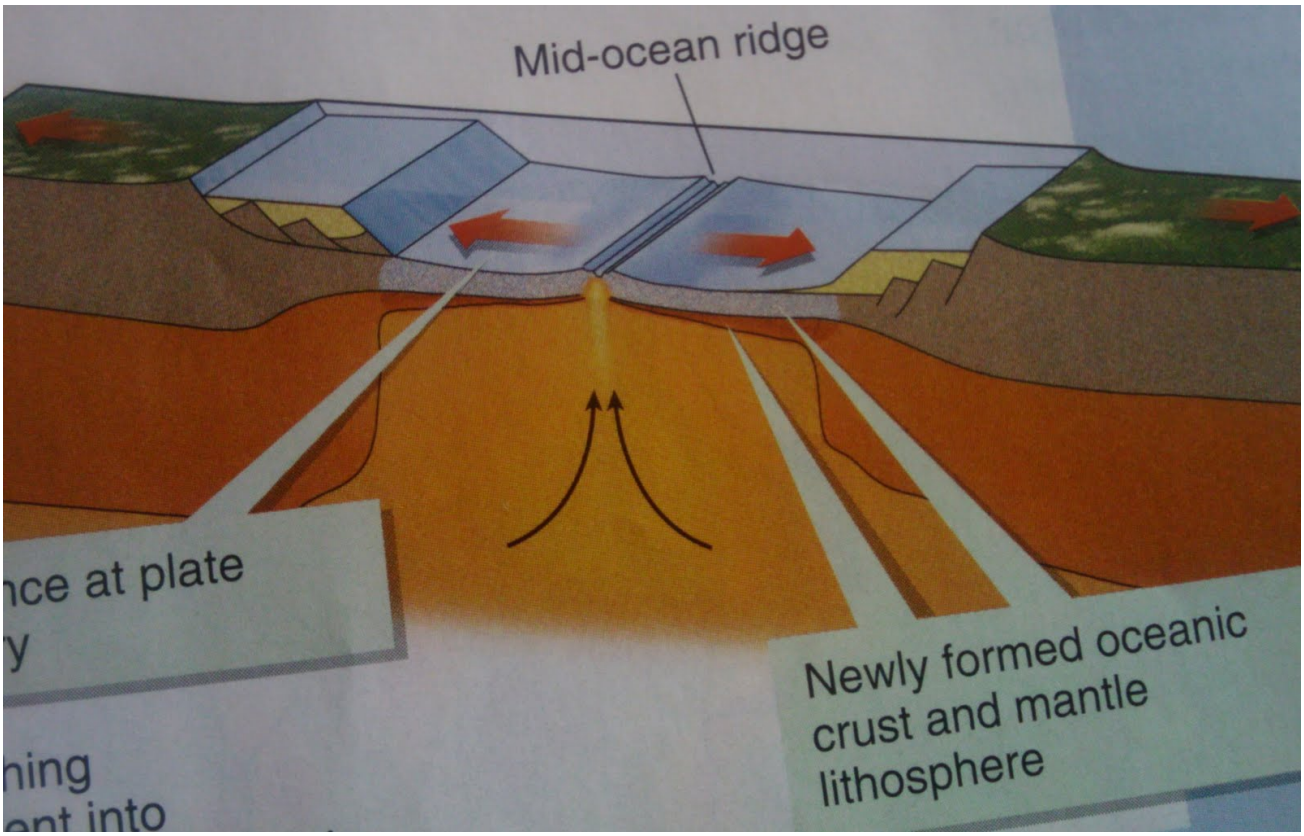


- If the student chooses to create a divergent boundary:
  - The plates will spread apart at the rate chosen by the student. This will initiate the creation of new, young oceanic crust at the plate boundary. Beginning at the time of separation, the mantle will have a light-gray “plume” that will rise to the surface, indicating that hot, fluid mantle below the lithosphere is what creates new oceanic plate compositions.
  - Please note that the plume will not look exactly like that. It needs to be more flowing, bulbous and form seamlessly into the new crust. I was struggling in Ai to make these changes.

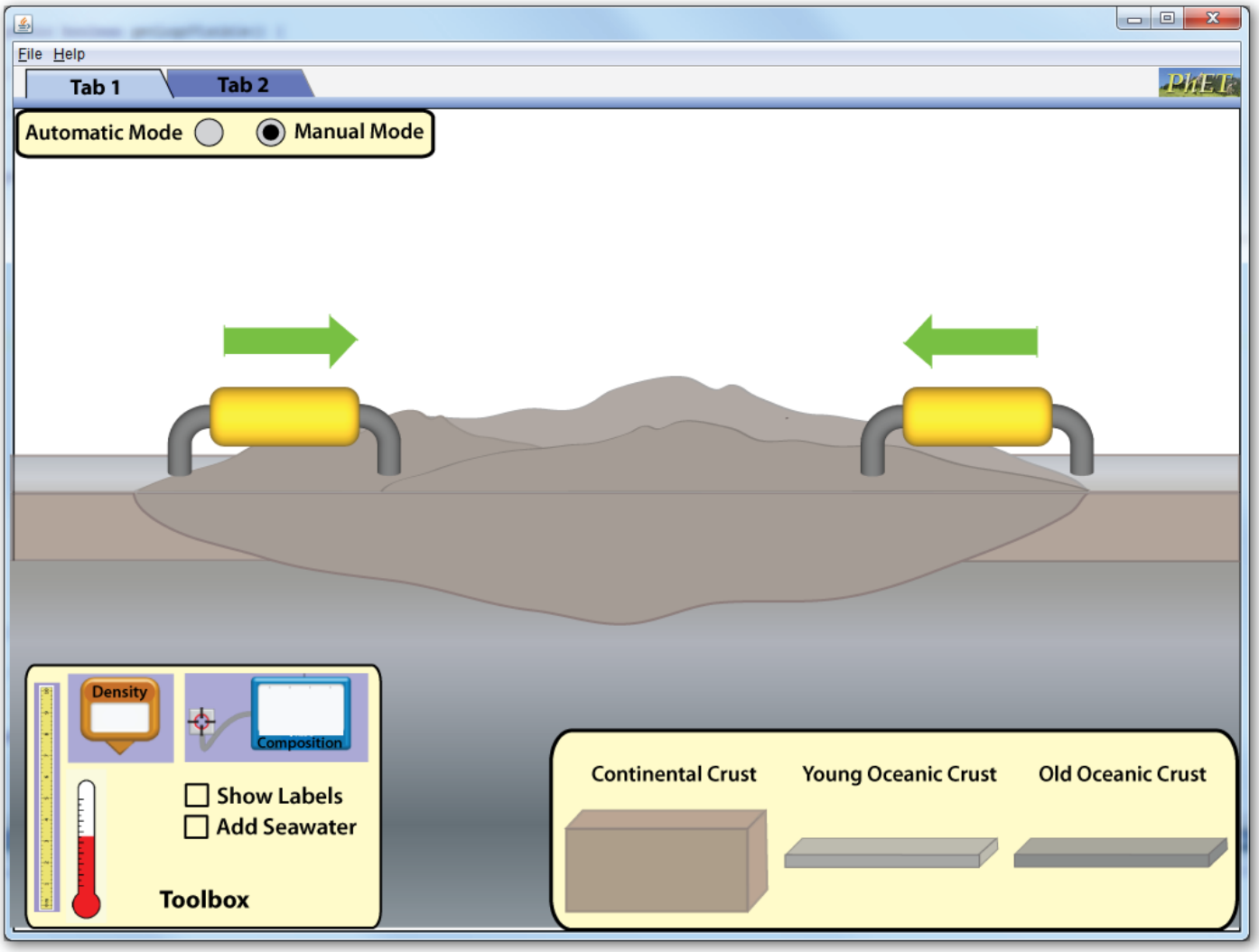


If you look at the picture from the textbook below, I am trying to show the zoomed up perspective of the mid-ocean ridge crest that forms right at the spreading center. After material wells up, cools in that “v” shape, there is a crest that forms as it spreads apart and accumulates. That is the highest point on my image, with the slight sloping downward crust moving away from the mid-ocean ridge.

TEXTBOOK IMAGES OF DIVERGENT BOUNDARY.

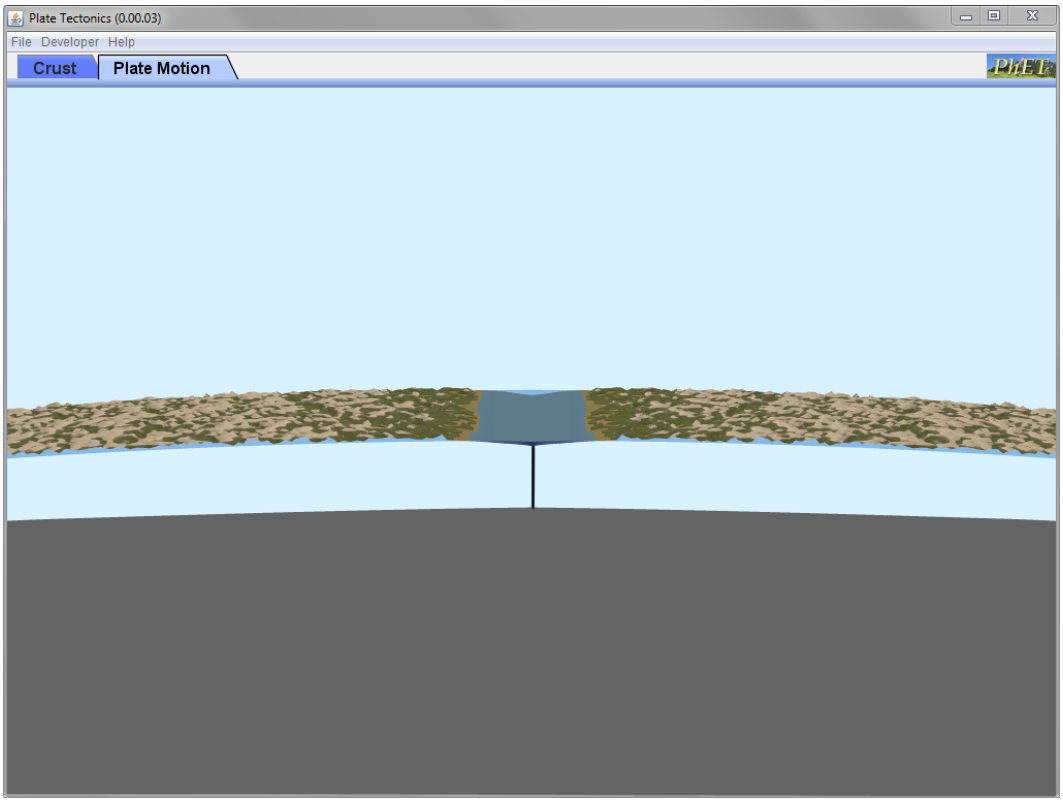


- If the student chooses to create a convergent boundary: See page 539 in T & L.
    - Two continental plates will create mountains. The mountains will also “bulge” downward creating “roots” that will slightly deform/ penetrate into the lithosphere. See pages 539, and 560 in Tarbuck and Lutgens.

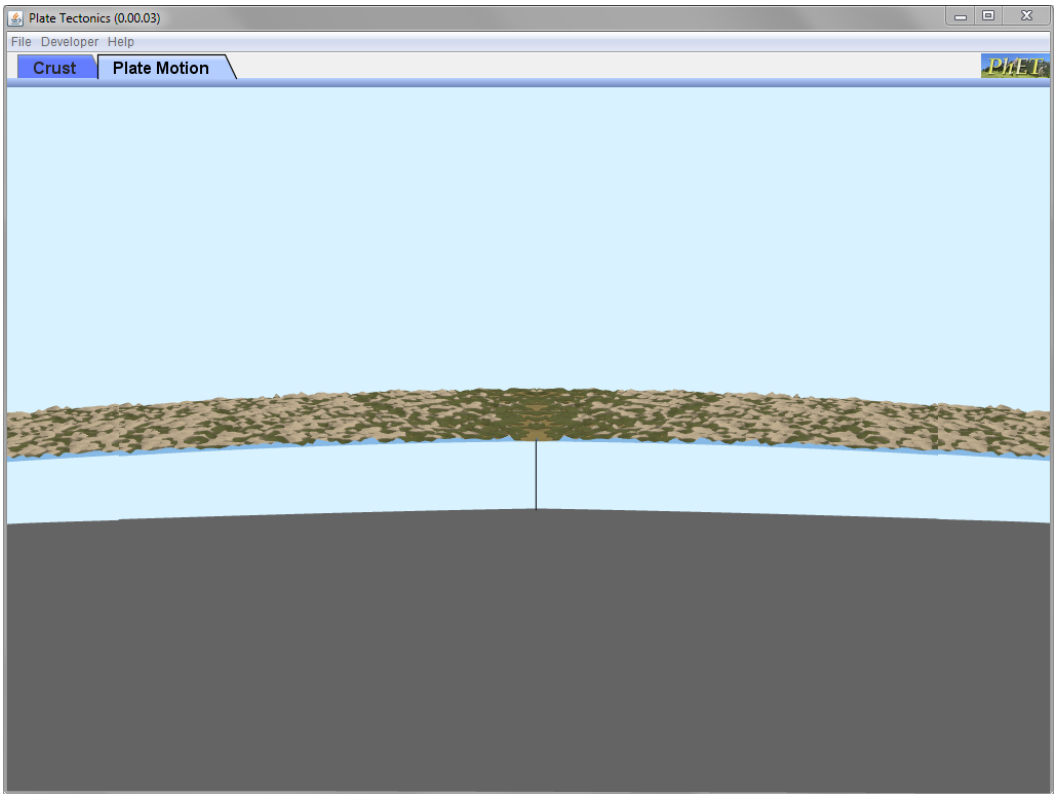


Images of continental-continental collision.
Modeled on animation here:
http://www.youtube.com/watch?v=ngV66m00UvU&feature=related

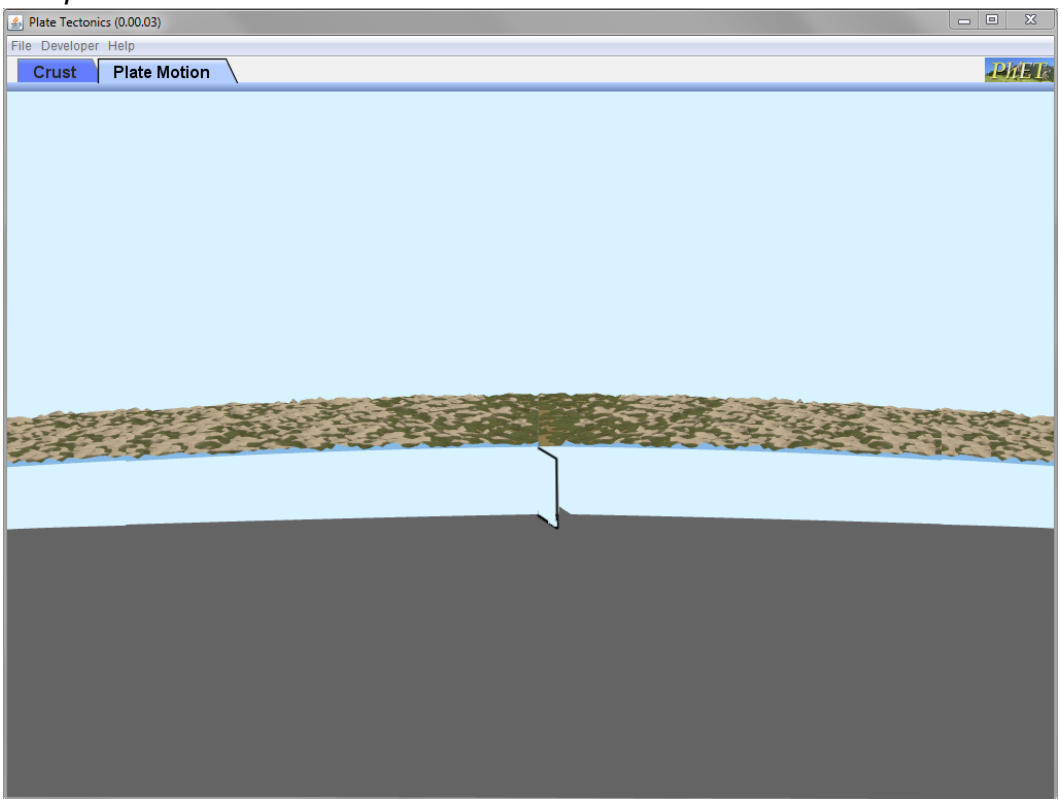
Start



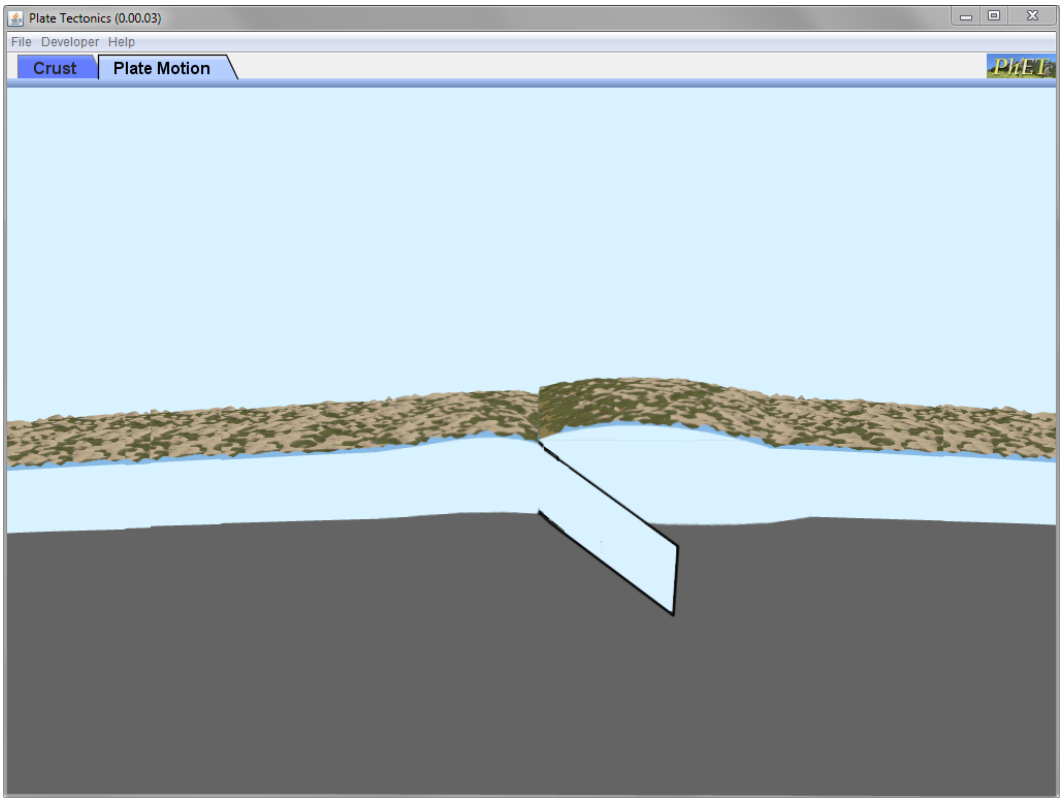
Plates collide.



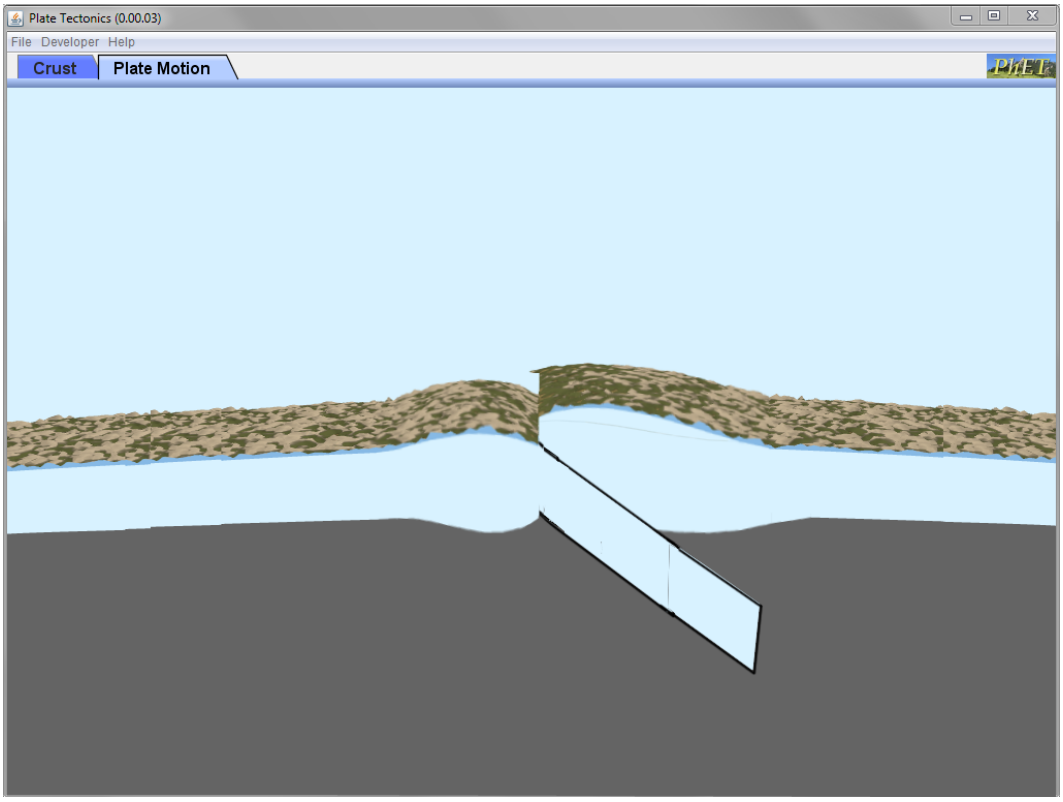
Left plate starts to subduct.



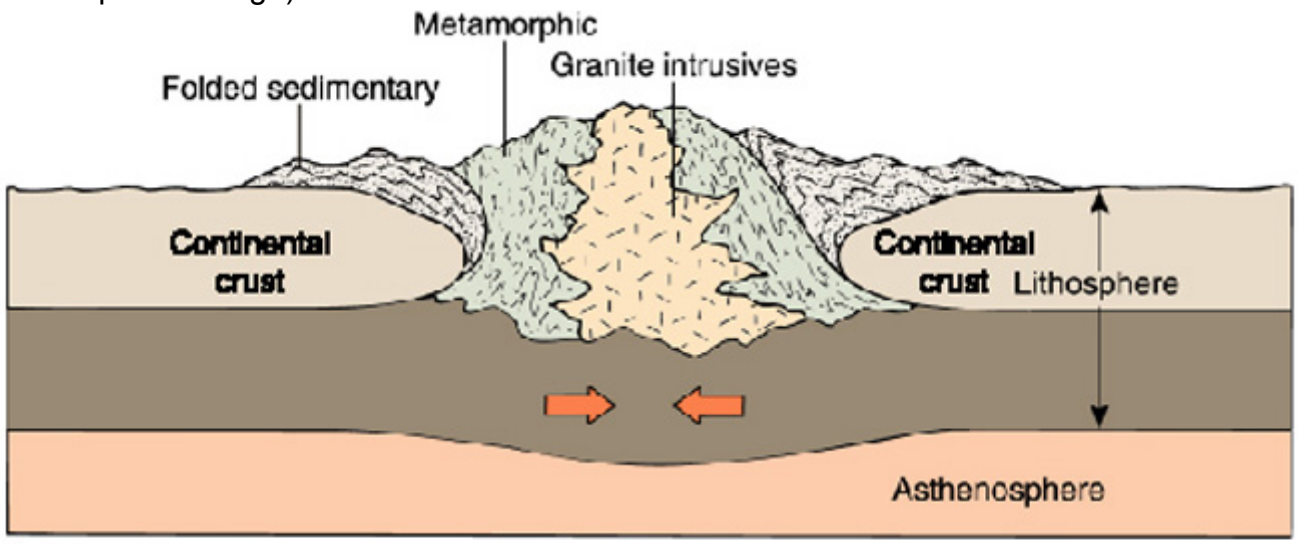
Plates bulge as plate subducts and push against each other.



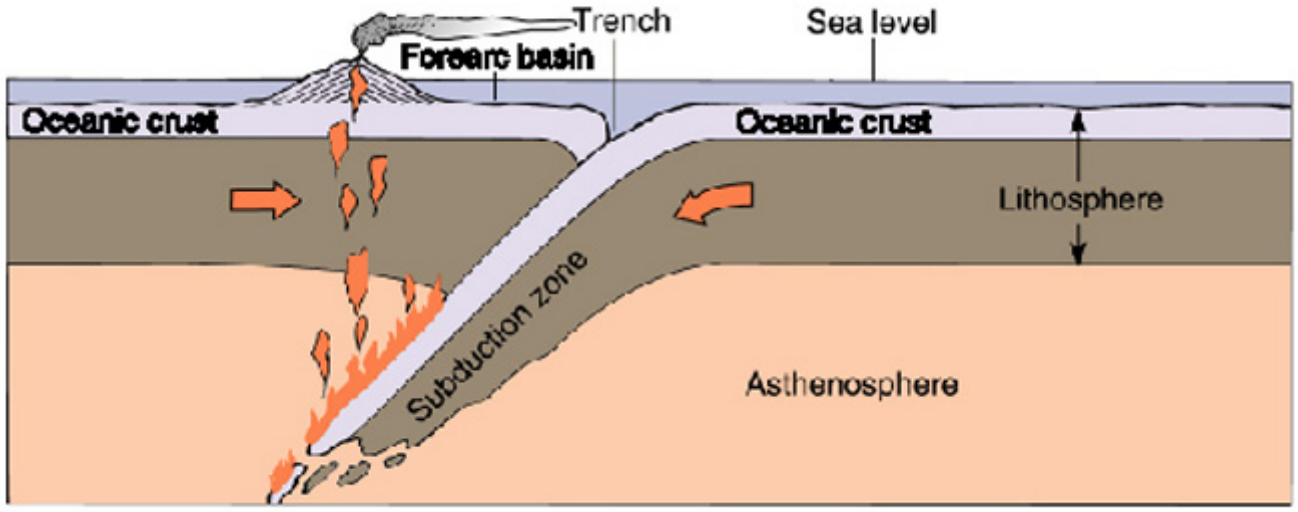
Plates bulge more as plate subducts more.



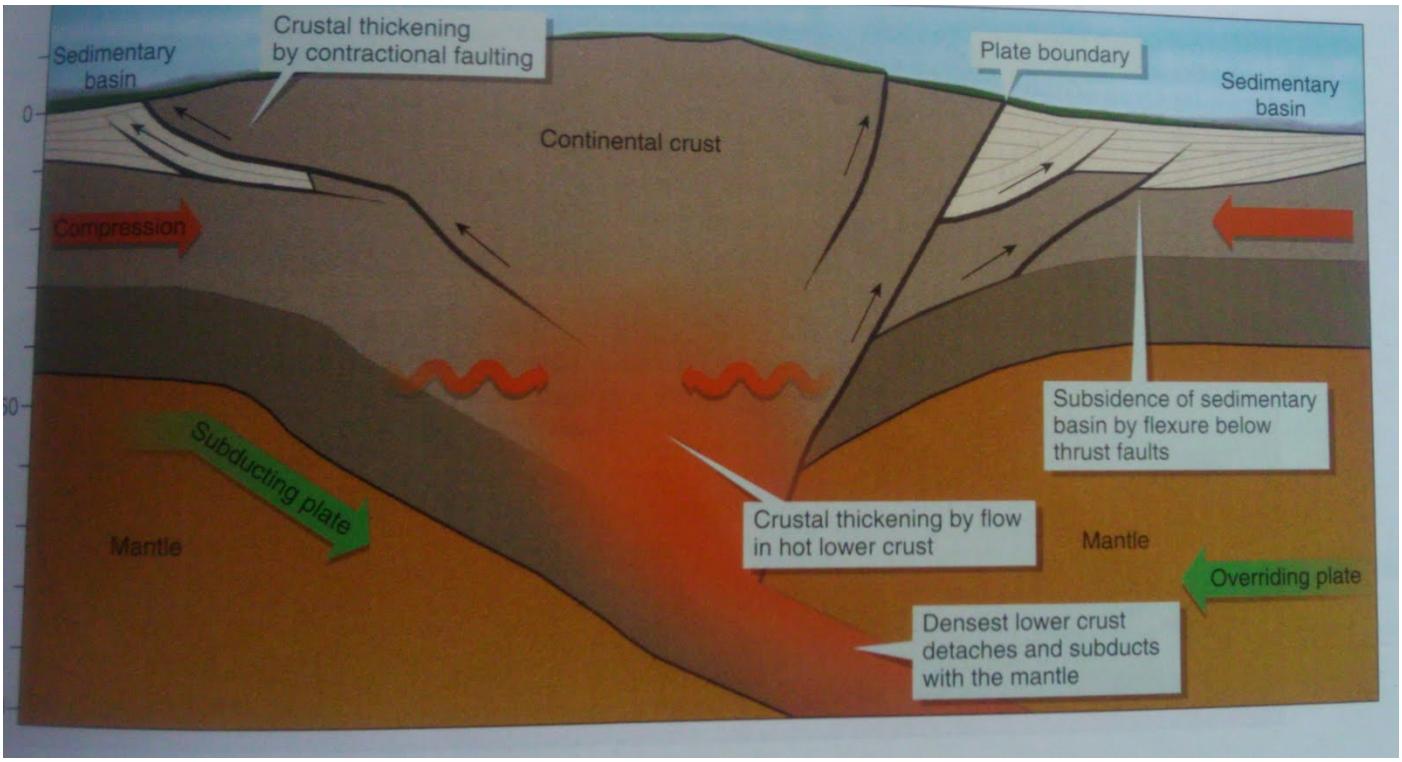
But we should try to make this image of the mountains look more like this (ignore bottom part of image):

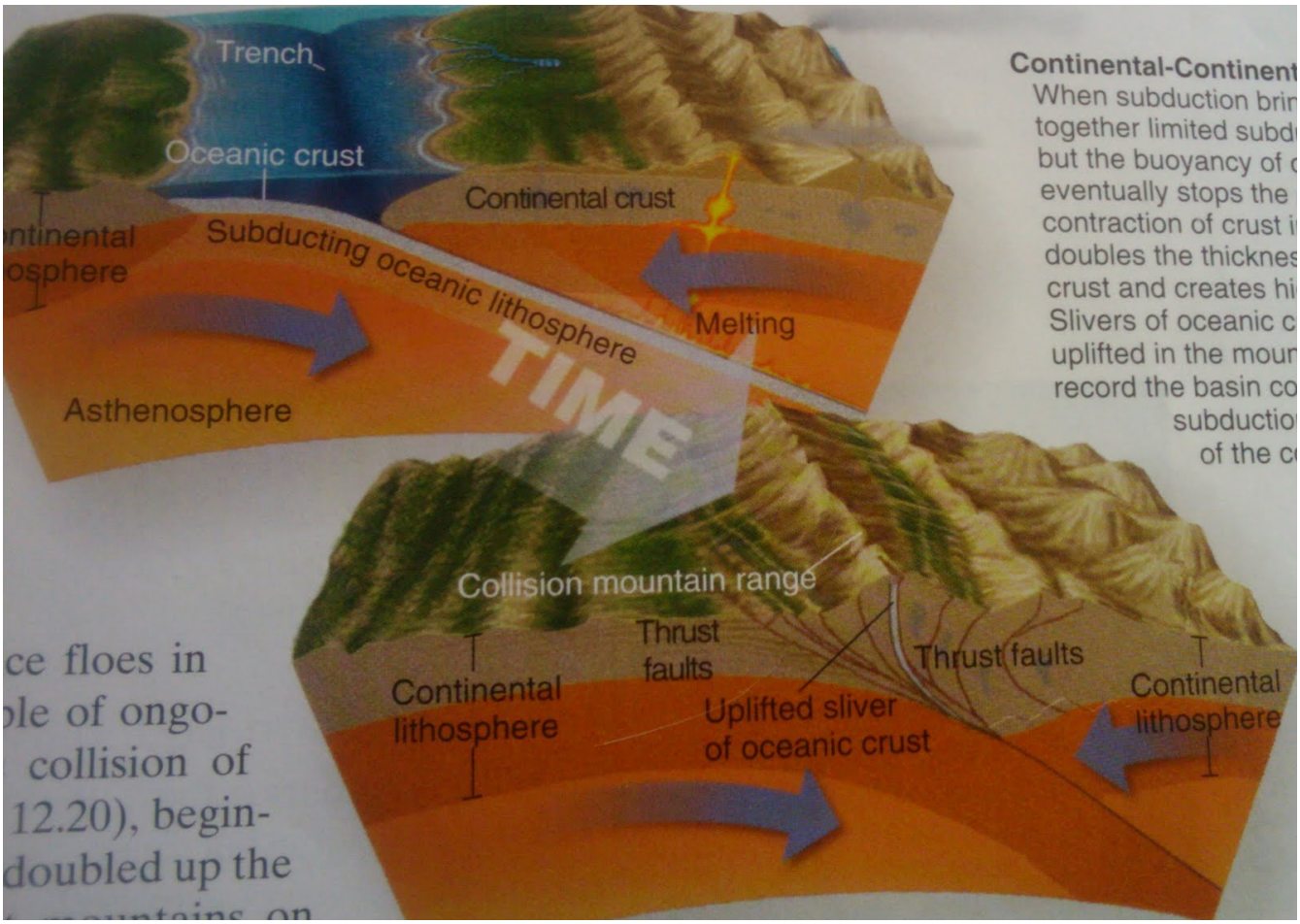


A

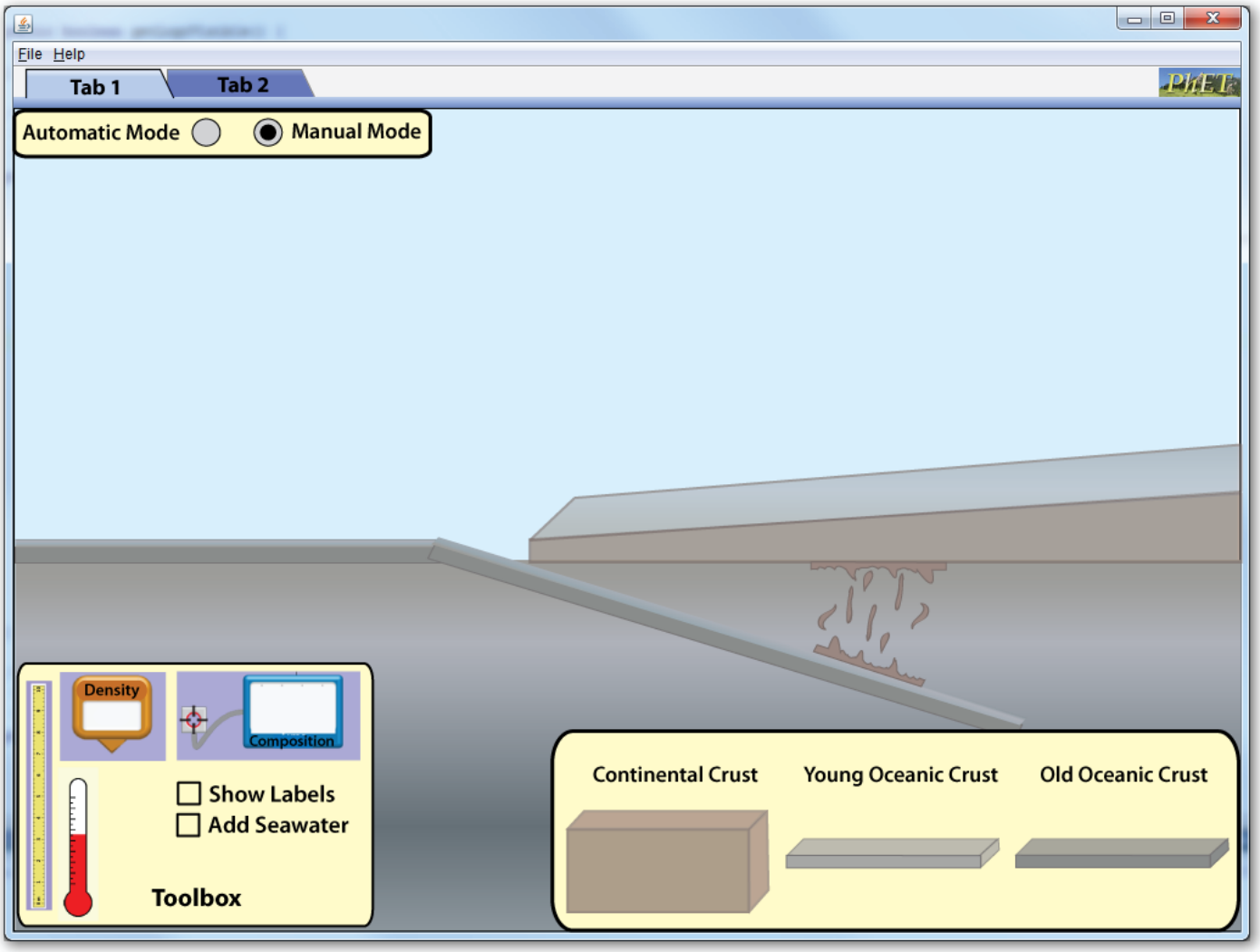


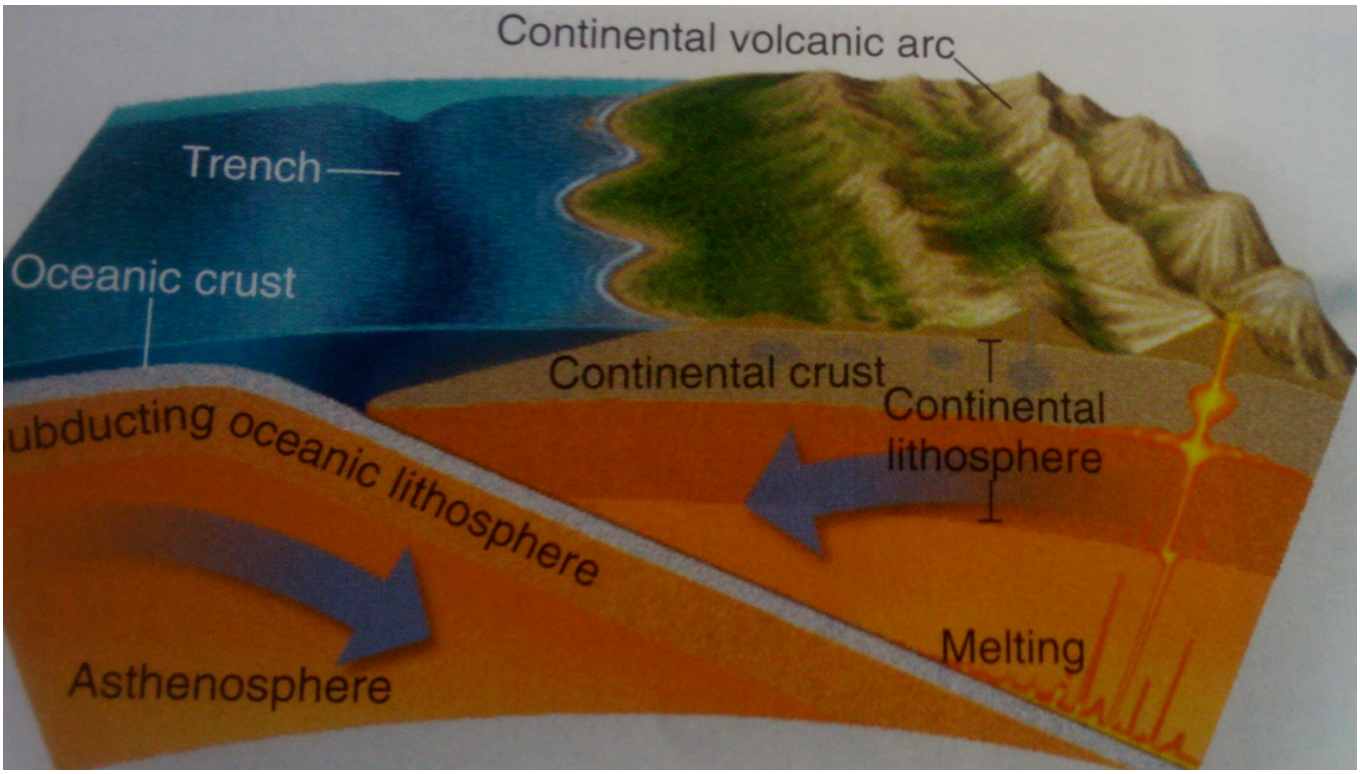
B

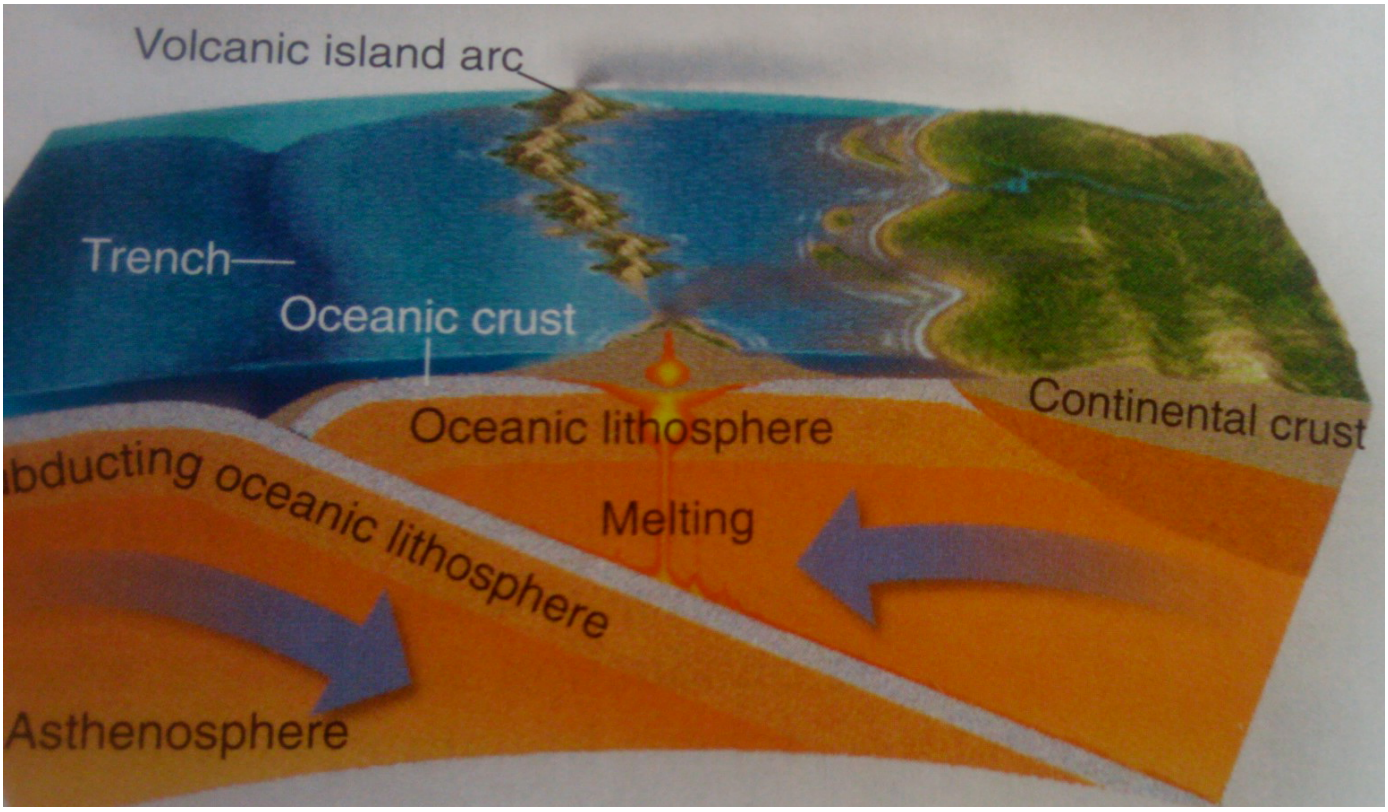

Sedimentary basin
Crustal thickening by contractional faulting
Plate boundary
Sedimentary basin
0
Continental crust
Compression
50
Subducting plate
Mantle
Subsidence of sedimentary basin by flexure below thrust faults
Crustal thickening by flow in hot lower crust
Mantle
Overriding plate
Densest lower crust detaches and subducts with the mantle



- Two oceanic plates will converge, and the more dense plate will subduct. This will create an oceanic trench at the zone of subduction, and a volcanic island arc above the melting point of subduction.
- An oceanic plate and continental plate will have the dense, oceanic plate subduct under the buoyant continental plate. This will create an oceanic trench, and a continental volcanic arc above the melting point of the subducting oceanic plate.


File Help
Tab 1
Tab 2
PhET
Automatic Mode
Manual Mode
Density
Composition
Show Labels
Add Seawater
Toolbox
Continental Crust
Young Oceanic Crust
Old Oceanic Crust



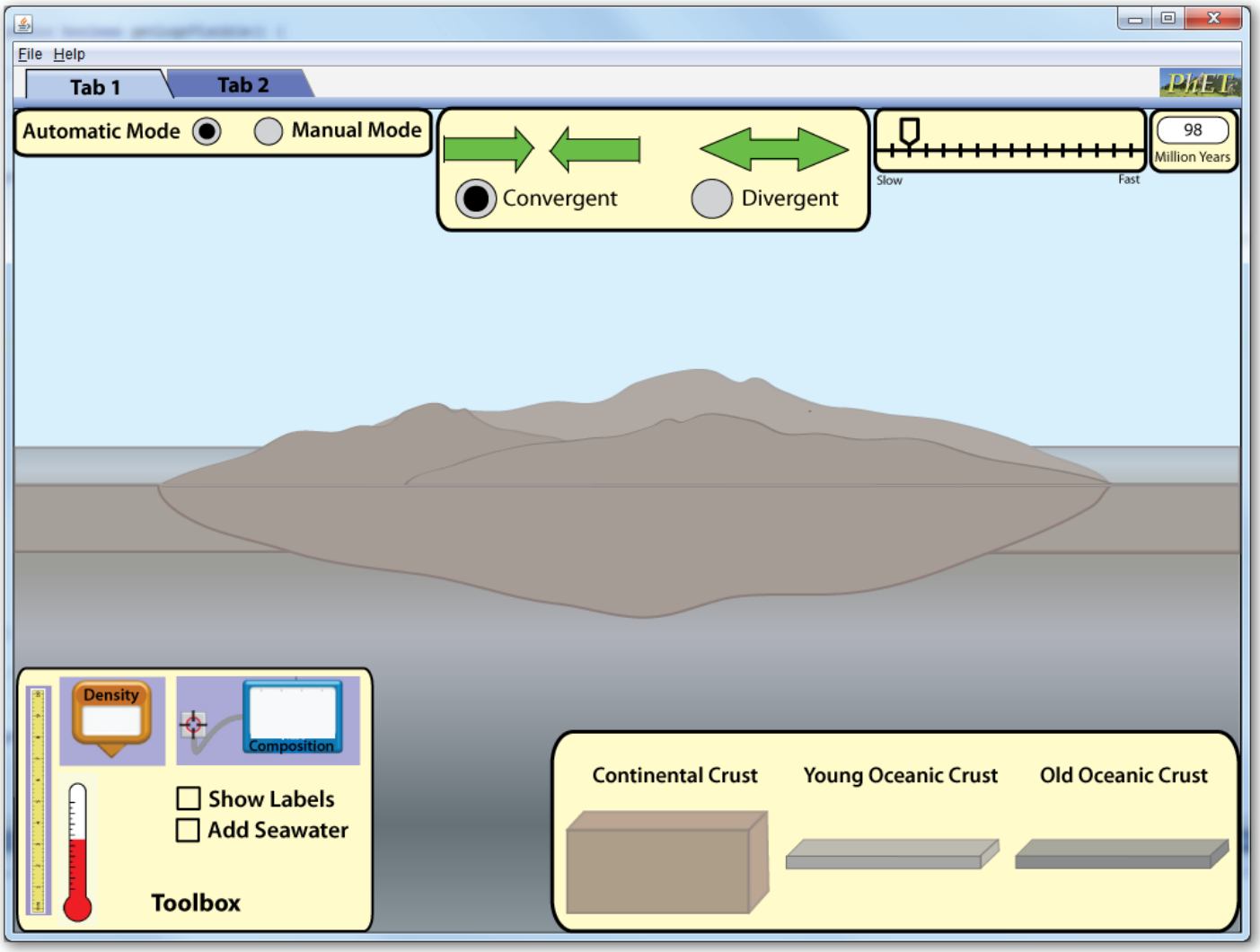


Still need to figure this part out - about transform boundaries.

    - If the student chooses to create a transform boundary:
        - Plates move past each other without destroying or creating plates. They are conservative plate margins.
    - Check boxes will appear once the student has created a boundary/placed crustal pieces in the play area.

- Auto Mode
    - In Auto mode, a play/pause button will appear on the bottom of the play area.
    - A set of buttons will also appear in the control area allowing students to choose either a convergent boundary or divergent boundary (should we include transform as well?)
    - Check boxes will appear again in the control panel.

Here is the preliminary design for the Auto mode. It is showing an example of a convergent boundary creating mountains. It is my first attempt at making a “gooey” appearance. Stay tuned for the previous images to share similar qualities.



Interviews Summary

Plate Tectonics 00.00.47
Age:11 M
Grade: 6th (going into)

Cool
Show labels
Temperature
Density
Both
Changes temperature, no color output
Changes composition and thickness

‘how do I make a volcano?

2nd tab
makes crust
goes to first tab
second tab
tries to click on time box
gets it to play
how do I start a new one
clicks on joystick, but wrong direction
gets it going
‘I made the ring of fiery destruction stuff’
clicks around on joystick, doesn’t get it working
moves on to upper options
‘hey I’m forming a mountain range’
seems more into the playing animation part
goes back to manual
adds continental crust (deliberately)
gets joystick going
“Hey check it out”

“How do I make the biggest mountains?”

am I forming mountains or a rift valley?
‘see, stuff just keeps bubbling up”

“mountains are forming “, where are the mountains? “there” [clicks on volcanoes]

pulls out meter at 3:30

about?
Plate tectonics, crust, plate movement, plates sliding down
Two different combinations
- combination of two rock layers (young something crust and continental crust) every combination formed mountains except two youngs
- stuff kept bubbling

Learn anything?
Computer programs more/less accurate
Simpler form what’s going on with tectonics and stuff

It’s possible to invent software that shows stuff

Overall:
Seemed more engaged with Plate Tectonics than Chemical Reactions.
Some possible activity questions:
“How can you make a volcano?”
“How can you make mountains?”
“How can you make the biggest mountains?” (maybe getting at time element)

Grade: 6th F
Age: 11
v. 0.00.47

- moves sliders slowly
- uses meters, doesn’t talk, though.

2nd tab
uses joystick fine.
**tries to drag out density meter, but it won’t go

**Sim freezes

Student into playing with manual mode. Doesn’t want to stop

General:
She liked this one better. I asked her about the tools. She thought the density meter gave you a measure of depth, but she interpreted a high and low reading just fine. Same with thermometer, she interpreted high and low temperature just fine.

She didn’t seem sure about what the land/water representations were about. She said that the darker blue was water, but didn’t know what the other things were.

*Sim seemed to slow down, and eventually froze up. Had to restart.
* Density meter didn’t drag out of toolbox as expected.

Plate Tectonics
Grade: Going into 6th grade
Age 12 M

PhET use: maybe something about atoms in 5th grade

v. 0.00.47

Ooh! I like this!
Moves sliders
Oh, that's ocean, never mind (I think he was slightly confused about something briefly)

Zooms in and out
'what do you think that's showing?"

ohh, that's interesting, the more iron the ocean comes out a lot more.
Iron is a lot heavier than silica.
Maybe the silica floats?
Changes thickness, whoa
If it's thicker…
Makes continental crust
Shows labels
Moves density meter, doesn't move at all
Moves thermometer
Pulls out ruler
Measures from bottom
About meters 'I don't know what these are for'

10:30 I mention a second tab
clicks on arrows, doesn't get joystick to move
gets automatic to go.
Whoa, this ones cool.
Speeds it up, sees volcanoes…oh
Starts it over

Volcanoes, looks like smoke to me
"little volcanoes, after 50 million years"
10:33 gest joystick moving
tries to get them to move in, but doesn't
pays attention to the number of years

still clicks arrows, but gets joystick going
"that's cool, makes mountains then"
"what if it goes out, I'm sure it just makes a valley""

shows water, pulls apart

What's sim about?
Plate motion and crusts
Like kind of what earthquakes do, I guess
'I want to see the valley, with water, after 1 millin years, like how oceans form'
My question is what's that? (light color bubbling up)

Pulls out meters, "they don't do anything"

Learn anything?
That if you, I don't know, if two continental crusts pull apart, I guess either a valley or water shows up" but with young oceanic crusts, it doesn't really do anything.

Did you like:
It was really cool? I don't think I had any dislikes, pretty much useless. Pulls out desnity meter, does change, I figured it out.
Figures out arrow on thermometer, changes temperature
Water and land are the same temperature, notices lower is hotter,
Gets extra thermometer
It gets higher and hiterh, and then it gets more, inner core almost three full bars of temperature…so it's warm

Plate Tectonics Interview Summary (4 students)
Four middle school students were interviewed on a preliminary version of plate tectonics. Students used all of the controls and had little trouble interacting with the sim overall. All students changed the temperature, density, and composition and observed the changes to the middle plate in tab 1. They used the temperature and density meters, and zoomed out to see the larger view of the earth. This presented some issues since the density meters scale with the zoom, making them hard to use. Students also used the ruler to measure the thickness of the crust.

In tab 2, students dragged various combinations of plates and used the joystick to move the plates. Students also used the "automatic" mode. Students observed how different combinations of plates led to different behavior at the plate boundaries. They noticed that the arrows near the joysticks indicted which movements were possible.

Students used the temperature, density, and “both” views. Students tended to prefer the temperature and density views over “both”. They could associate the color gradients with the temperature and density changes within the crust and mantle.

The major issue to be addressed in the sim is the use of temperature and density meters when zoomed out. Temperature and density change over a large range, so we need a solution to show this which also had good resolution when zoomed in (the default view).

This has been addressed in the latest version. Interviews demonstrate that the new design works well for students.

Initial Design Meeting Images

Tab 1

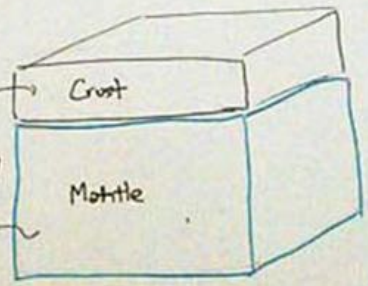
- discover distinguishing features between Oceanic Crust & Continental Crust
- Relationship between
  composition → density
  (?) temperature → density

look up appropriate units?
temp value?
temp vs depth of mantle?

tools: ☐ density meter
☐ % iron meter
☐ temp meter

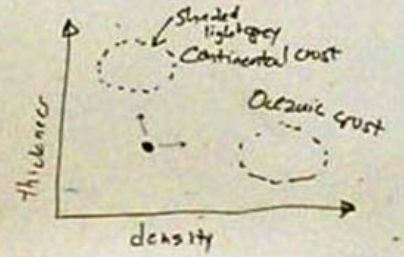
Feedbacks:

1) Δ color w Δ density
dark → lighter grey
brownish



very dark grey

2) Sink/Float w/density



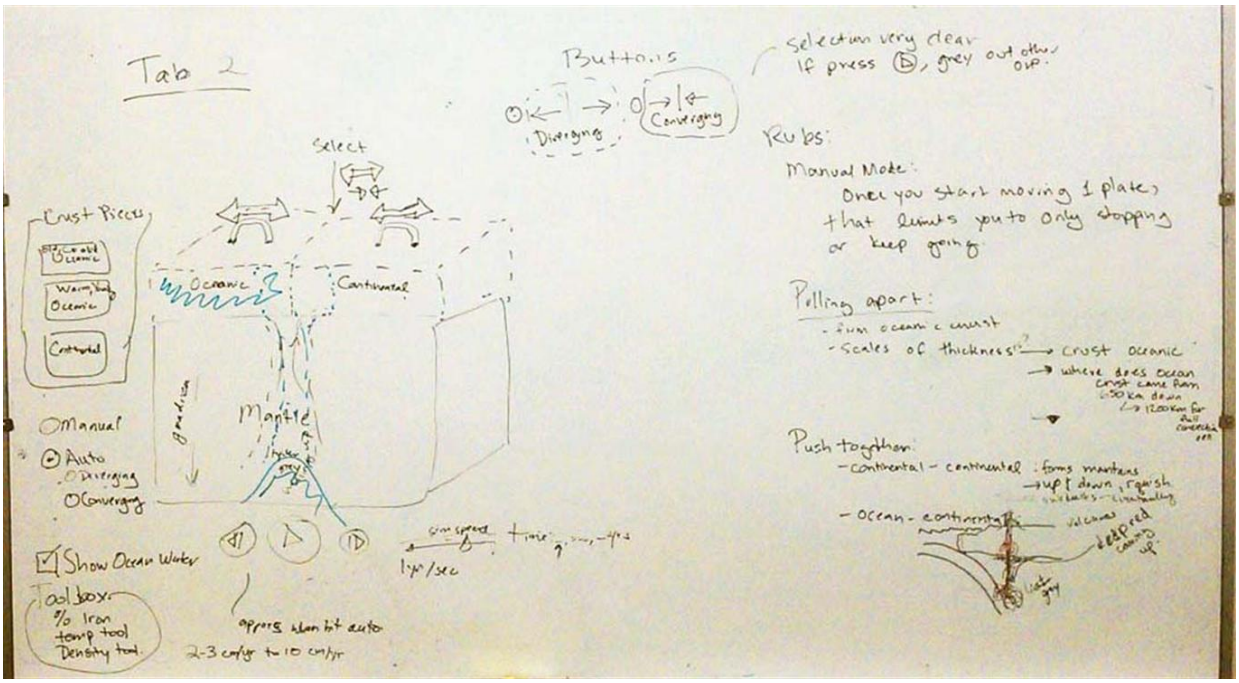
Crust Properties

Thickness
thin Δ thick km

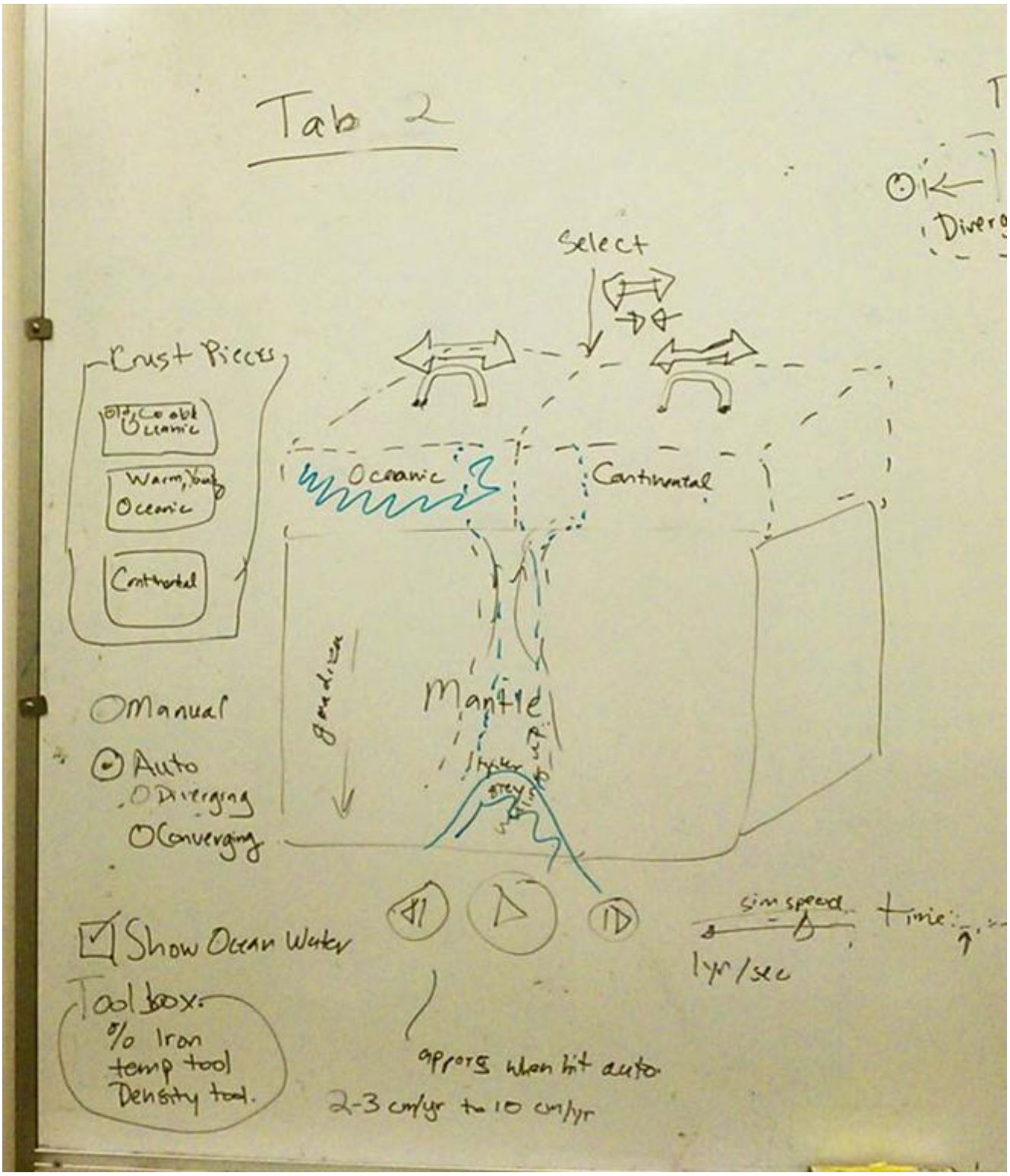
Composition
% iron 0% 100%
% silica + other 0% 100%

Temperature
cold Δ hot

Density
Δ Kg/m³



See larger images of this image below.


Tab 2
Select
Crust Pieces
Cool Oceanic
Warm, Young Oceanic
Continental
Oceanic
Continental
Mantle
Manual
Auto
Diverging
Converging
Show Ocean Water
Tool box:
% Iron
temp tool
Density tool.
sim speed
time:
1yr/sec
approx when hit auto
2-3 cm/yr to 10 cm/yr

selection very clear
If press (D), grey out other OLP.

rging

Rubs:

Manual Mode:

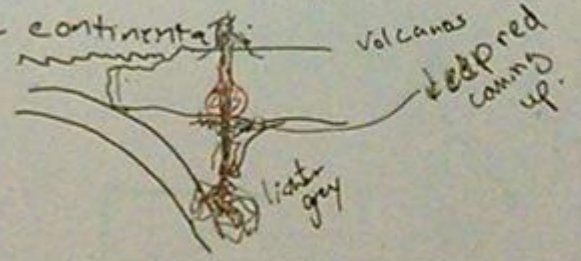
Once you start moving 1 plate, that limits you to only stopping or keep going.

Pulling apart:

- form oceanic crust
- Scales of thickness? → crust oceanic
  → where does ocean crust come from
  650 km down
  ↳ 1200 km for full convection cell

Push together:

- continental - continental : forms mantains
  → up & down, squish.
  ... quakes - eventually
- ocean - continental



Discussion Archive

1. I think we should also include magnesium in the mixture. We could have a read out that says something like, %Silica +others, and % Iron +Magnesium. Would that be too confusing?

2. Andrea's comment: I'm a bit confused by the focus on temperature - but maybe I'm to blame as I emphasized it in controlling subduction between oceanic plates. While it certainly is important in the overall processes, what is the relevance of the vertical temperature contrast here?
composition seems to be the more relevant factor in the vertical stratification of layering.

3. Should we include AGE and DEPTH sliders/readouts? Many of the graphs and cross sections include the relationships of the above with age/depth of plates.
KP: Seems like a ruler would be good for depth readouts.
KP: For AGE: maybe it would be appropriate to have an age probe, but seems like defining the programmatic rules would be very difficult. Ideas?

4. Graphs for Tab 1:
There will be a density vs thickness graph that displays the two regions of oceanic and continental crust in relation to these two variables. There will be a dot that will move according to what is happening in the play area. Andrea's comment: Do you really want to plot density as a function of depth? Highly recommend a single density values for each kind of crust and the upper mantle, rather than the range of values (not sure if this implied here, but I got that idea elsewhere too).

5. We still need to determine how the parameters will be set for the Auto function. Where will the animation start, and with what plate combo, speed, direction, etc.

6. Composition: %Fe+Mg & %Silica
Temperature of plates at different locations (Smith and Pun have a graph of heat flow units vs distance from mid-ocean ridge which may be helpful way of plotting the information, page 320).

7. Surface features at plate boundaries? Volcanoes, Island Arcs, more detailed view of mountains, continental volcanic arc, oceanic trench etc. Have we decided how we're going to show surface features yet?

8. What are other major components in Continental Crust? This only adds to 76%
There are lots of other constituents, most of which only account for a few percent so I didn't initially include them. I'll include a few of the more prevalent ones.

There are lots of other constituents, most of which only account for a few percent so I didn't initially include them. I'll include a few of the more prevalent ones.

9. KP: We'll need to assign densities to each of these materials in order to calculate the average density on the first tab where they can manipulate the components.
I think it's way easier to simply use the average densities of the bulk crustal and mantle compositions - see the references I posted but I think generally good values are 2.7g/cm^3 for continental crust, 3.0 for oceanic crust, and 3.3 for upper mantle. I've looked up values from various sources for in-class activities and this is what I've used (been faculty reviewed)

10. KP: Based on this model seems like we could have a qualitative "thermometer" that has 1 mark at 1000 C, and otherwise just shows a red bar going up and down as you move it around and explore temperature.

11. KP: I am not following why this is an area, and not a linear km/year? Is the "area" the thickness measure of the oceanic crust? Sorry, just not following at all.
HH: Oh sorry! It's the example from the book. The area is the actual size of the plate, the x and y directions of the plate (not depth, z). We have that kind of information from knowing the general sizes, so that's why they used the full size of the plate, an area, not a linear km/year. So that's why I had to take the square root to get it to the linear relationship.
AB: There must be simple linear age model available, or that one could easily calculate with a map and age information.

12. KP: This can also all be calculated using same model in the density sim too. Geologists make special meaning out of h.

13. ~~On the left control area, there will be two crustal pieces to choose from: dense oceanic or less dense continental. These will already have the predetermined shade of gray that we're using to show differences in density (oceanic=darker gray, continental=lighter gray). We will not yet introduce cool, old oceanic or warm, young oceanic. This will come in Tab 2.~~
KP: What should be default values? (for temperature, or we should leave it as qualitative).

- 14. Tab 1 start state: Outlined box indicating drag and drop.
  KP: Any need / use to having this in perspective like the others will be? Not quite sure how that would work, exactly.
- KP: Need some edits to Tab 1 image:
  1) ~~Remove Density slider~~ … density is a result of varying the other sliders, so itself is a readout.
  2) Let's think about whether we could use a more "gooey" toolbox, like the one being used in "Bending Light" for the probes - Density, Temperature, Ruler, Composition, etc.

3) ~~Probably not "show water" on this tab … not sure what it would actually show? Hmm... We might be able to do … "add water on top"~~
4) Maybe we could also have a drop down list of "locations" which would be preset and show them something about the composition there? This could also allow us to get into mixed plates on this panel if we want, and could bring in "real world" as well.
5) ~~Maybe just a "Show Labels" checkbox … that would then show the lines and label the sections?~~
6) ~~Are these now "to scale" in terms of the depth that we need to be showing?~~ Yes.
7) Add a visual of a ruler … ~~maybe a "Show ruler" checkbox.~~

KP (5/20/2011): I removed the old schematics - since they are outdated.
Comment:
JO: Could we potentially simplify this to one composition slider which has "More silica" and "Less silica" on each range?

14. I'm not sure if this idea is going to give students the correct conceptions about the relationship between crust densities and the mantle. Look at page 357 in Smith and Pun, model C. This will be helpful for Tab 2.

- ~~If student chooses oceanic crust, the thickness slider will automatically slide to 7 km.~~
- ~~If student chooses continental crust, the thickness slider will automatically slide to 35 km.~~

15. ~~, the density slider will automatically go and gray out.~~
KP: I'm thinking we just remove that density slider and use the density readout. Otherwise we are in the situation that we have to decide how the composition will change if students change density. The cause-effect goes from composition to density.

- ~~If a student chooses oceanic crust, the composition slider will automatically slide to __ and only have the range of __ to __ for Fe+Mg and __ to __ for Silica + others.~~
- ~~If a student chooses continental crust, the composition slider will automatically slide to __ and only have the range of __ to for Fe+Mg and __ to __ for Silica + others.~~

KP: We are not doing this right? We are just doing exploration of the full range … and then feedback on what they made? Correct. I agree. I'll take out that density slider. :)

- ~~Density: This has to be aligned with the composition. If a student chooses to manipulate density, the composition slider will automatically go and gray out.~~
    - ~~If student chooses oceanic crust, the slider will automatically go to (2900 kg/m^3). The range will be from __ to __.~~
    - ~~If a student chooses oceanic crust, the slider will automatically go to (2750 kg/m^3). The range will be from __ to __.~~

16. *Was Comment:*
JO: Could we possibly show small unchangeable sections of other oceanic and continental crusts on the far edges of our modifiable crust? This seems like it would help with comparison, especially due to the density (you could see how crust that is more dense than usual continental crust would "sink" more, and have a direct visual comparison of what the Density vs. Thickness plot shows)
heather.houlton
3:17 PM Apr 18, 2011
I'm putting up a new image for the basics in Tab 1. It does not yet include the perspective plates on either side. It's refined for a more friendly interface.

17.
QUESTIONS AND ANSWERS FROM EMAIL CORRESPONDENCE:
1. We want to confirm that this will be more representational, plates will be more 'gooey' (straight lines don't seem realistic); important to emphasize ductility in transition
> A picture of what you think an initial starting block of continental or oceanic crust should look like would be helpful.

I think part of this question just comes from not knowing how close the "mock-up" is to what you really envision; we realize it was a mock-up.

I just wanted to get the very basic ideas down for the mock up. We realize that plates are not this structured and square with such straight lines. That's why I included all the textbook pics within this design doc to help Jonathan see what we may want it to look like.

2. In the collision zone we weren't sure what was happening to the plate boundary – how will that be represented (it seemed to disappear in the mountains)
> What should happen to the boundary?

You’re right. I forgot to include the plate boundary in the mock up. I included your image in the design doc so that we can see a better representation of what should go on there.

3. Can tools for density and temperature be used on magma not just plates?
> Why wouldn't you want to measure the density of the plates? Isn't the point that the denser one always subducts underneath? Please correct my conceptual vision hear if I have something off.
>I think our question wasn't clear -- yes we would like to measure density of plates, also just wanted to confirm you could measure density elsewhere or more locally, e.g., in a bubble of magma underground at a subduction zone.

The tools in the toolbox will be able to measure everything in the play area: plates, magma, etc.

4. Will density and temperature change over time as the oceanic crust is being created?
> It does in reality, so we can model this ... at least we are working to make sure we understand it. Do you want the crust that is further away from the origin of the source to be cooler/denser?
I know we had a big discussion about this when Lauren and I were in CO and I can't remember what we decided made sense. I thought there was some logistical or conceptual problem with representing it correctly (as you described above) but I may be remembering wrong

This is just my thoughts on this, but since we do have to use it in the model, why don’t we simplify the concept and make it more qualitative for the students. So if they do measure the temp/density of the plates further away from the spreading zone, they can see the thermometer/density reader qualitatively change as opposed to giving explicit numeric outputs (this may only be possible for temp).

5. We would like to remove the handles above the plates, but keep the arrows—have cursor turn into hand to show you can grab
> We've found handles to be very good user-interface cues ... can you elaborate on your concern here?

>We thought they looked really bizarre, but maybe that's just because it was a mock-up -- they were so huge and artificial looking. We are happy to go with your experience, at least for the initial version!

Sorry about the handles! I know the PhET team has handles they used before in Sims that look more like handles and not so goofy. I'll try to get the Illustrator files for that image and replace my big, awkward ones. They'll look way more like realistic handles once they're in the image.

Link to Overthrust Fault Image:
https://docs.google.com/viewer?a=v&pid=gmail&attid=0.1&thid=1302dce7c774da2d&mt=image/tiff&url=https://mail.google.com/mail/?ui%3D2%26ik%3D81545f0083%26view%3Datt%26th%3D1302dce7c774da2d%26attid%3D0.1%26disp%3Dattd%26zw&sig=AHIEtbROys-4xOx-UkBl4-NWvIMOw8UAeA&pli=1

Clark and Thomas Image:
https://docs.google.com/viewer?a=v&pid=gmail&attid=0.1.3&thid=1300f57086bb81a4&mt=image/tiff&url=https://mail.google.com/mail/?ui%3D2%26ik%3D81545f0083%26view%3Datt%26th%3D1300f57086bb81a4%26attid%3D0.1.3%26disp%3Dattd%26zw&sig=AHIEtbRb6Leql27c8mVI3DgNN-gqFW7ylw

18. *KP Comments to Tab 1:*
Remove "Crust Properties Meters" check boxes, since these are all now gooey.
Gooey ruler should be vertical
Probably don't need words in addition to icons
Remove Show Ruler and Add Seawater (I think)
Move Show Labels checkbox to the Tools gooey box.
Remove right hand panel and just have a floating control box in upper right for Crust Properties.
(Also try alternative design that has no graph, but a small bit of Ocean crust on left and Continental Crust on right, and large center region that has Crust Properties box with sliders below it, and title saying "My Crust")

19. ~~The control area will also include the following sliders for student manipulation. They will all start at zero prior to student placing the crustal piece. There will be a set of these sliders for each type of crust the student chooses:~~
    - ~~Thickness of crust in km.~~
    - ~~Composition of crust in ratio of %Fe + Mg and %Silica + others.~~
    - ~~Density in kg/m³~~
    - ~~Temperature in Celsius~~
- ~~We still need to determine the placement/location of each set of sliders, since the values will be different depending on the type of crust the student chooses.~~

20. KP Comments on this Tab:
- Remove right hand panel
- Add “Tools” title to tool box
- Remove words in tool box
- Add “Show Labels” checkbox in toolbox
- Add “Add Seawater” checkbox in with the crust selection tool
- Make crust pieces in Selection tool look 3D
- Need a manual mode / Auto play radio button control somwhere … upper left maybe

Jonathan's Comments / Questions

Unanswered Questions

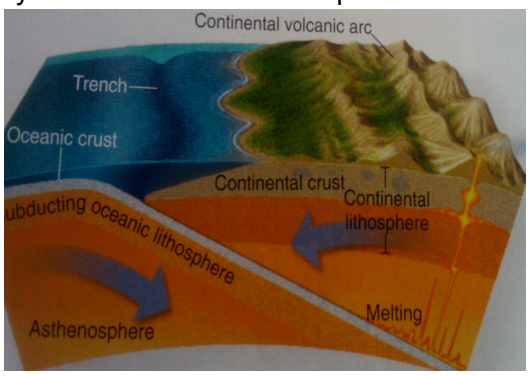
- Other mockups
    - How should the composition meter look? Do we want to show qualitative readouts for specific minerals / elements, or just one slider showing the mafic/ felsic balance?
- Model information. Bold questions are the more important parts. Gray parts are less applicable based on qualitative readouts. Sorry about some of the repetitive parts, this has gone through multiple iterations.
    - Better isostacy (elevation given density) function that handles oceanic crust. The suggested formula (h-b)=h(1-$\rho c / \rho m$)is only a rough approximation for continental crust, according to the original source. It would actually predict that oceanic crust would be ABOVE sea level!
    - **Here is a better model for oceanic crust:**
        - $h_w = \frac{(\rho_m - \rho_{cc})}{(\rho_m - \rho_w)} h_{cc} - \frac{(\rho_m - \rho_{oc})}{(\rho_m - \rho_w)} h_{oc}$
        - hw is height from sea level to top of oceanic crust, m=mantle, cc=continental crust, w=water,oc=oceanic crust
        - (From Turcotte and Schubert, p. 75).

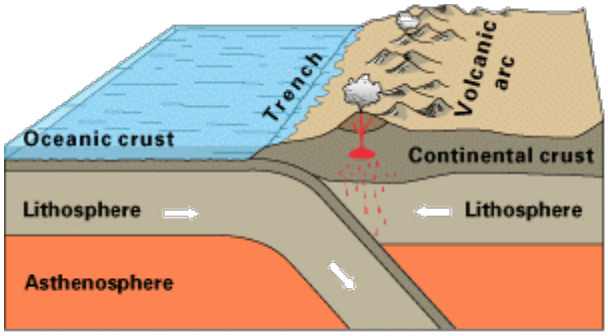
        - Current "hack" code (in meters) for Tab 1: elevation = thickness * (1 - density / MANTLE_DENSITY) - 3500
        - **Are the current heights on the 1st tab acceptable?**
- Temperature as a function of depth that is not near a plate boundary. We should have this for oceanic crust (extra parameter is age) and for continental crust (extra parameter is thickness). I can calculate the lithosphere boundary from this, etc.
    - The design doc formulas stated below are only for the mantle and assume simplified convection. As the text states in the original source below the parameters (http://books.google.com/books?id=-nCHlVuJ4FoC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false), "The conclusion is that this conduction analysis does not predict the temperature in the Earth's mantle.". Furthermore it predicts temp at 150km as approximately 2500C, while figures below show that it is less than 1700C there, and has a surface geothermal gradient of just 17 C/km
    - Not sure how to calculate temperature from heat flow, so either please specify temperature(depth), or a way to calculate it!
    - If information can be provided for near a plate boundary, that would be great! For instance I think I know:
        - Temperature at crust/mantle boundary between 200-400C?
            - **Does this vary based on crust thickness? (Should the bottom of a 70km continental crust be hotter than the bottom of a 7km oceanic crust?)**
        - Temperature at lithosphere/aesthenosphere boundary 1100C
        - Subducting plate usually has melting between 80-120km in depth (from sea level? from the top of the crust?), and that is at what temperature?
        - Subducting plate not detectable after 600km in depth
- **Approximate temperature and density gradient functions for normal young oceanic/old oceanic/continental crusts and the mantle below. I can blend and do other handling based on these.**
    - **Here is a model of temperature vs depth/time for oceanic lithosphere:**
        - $$\frac{(T-T_1)}{(T_0-T_1)} = erfc\frac{y}{2\sqrt{\kappa t}}$$
        - *T* is the temperature at depth *y* and time *t* (measured from *t=0* at the spreading center). T_1 is the temperature at *t=0* (temperature of upwelling melt), T_0 is the temperature at *y=0* (surface). erfc is the *complememtary error function*. κ is the diffusivity (use value 1 mm^2/s).
    - **Here is a model of temperature vs depth for continental crust:**

- $T = T_0 + (T_1 - T_0)\frac{y}{y_{L0}}$
- Temperature (T's) are same as above. y_{L0} is the thickness of the plate.

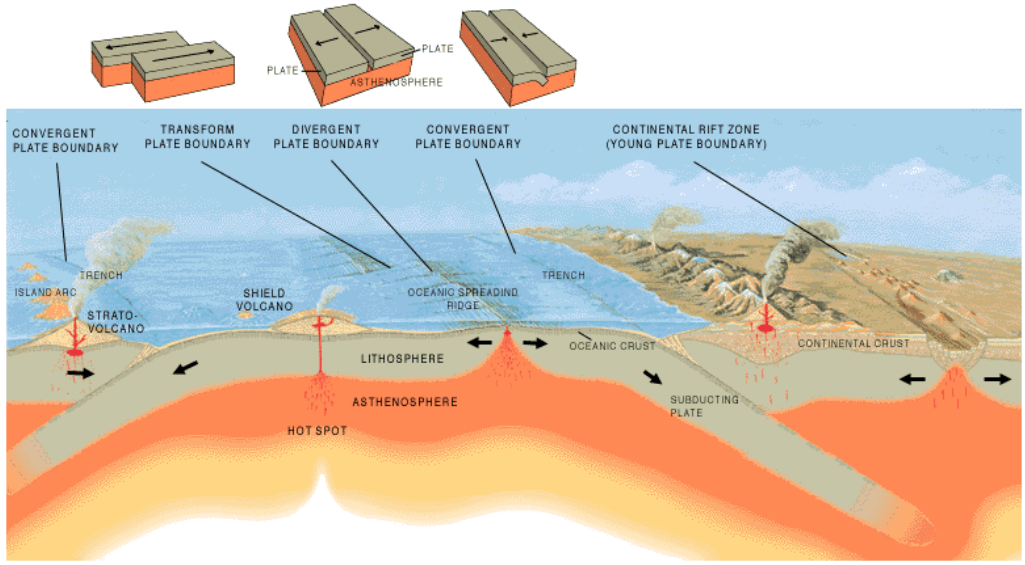
- **Density data**
  - Density can't be modeled well with simple equations. The real density vs. depth data is found experimentally. I've scanned data from Turcotte & Schubert and put it here.
  - Note that this is very general, and the crust density will vary for oceanic and continental crust. I believe you can use the OC and CC values, and then pick up from the chart below that.
  - The transition from crust to mantle will be very abrupt. I think a step function is OK **(but we should check with collaborators).**
- Composition data.
  - Does it vary with depth? (upper/lower crust?) I assume so but have no data
  - Variation between old and new oceanic crust?
  - Mantle composition! (less important the more qualitative we show things)
- **Thickness of oceanic crust, as a function of age**
  - **This is going to be the depth along an isotherm (constant temperature line) as given by the equation above**
  - Need to look up the temperature for this isotherm
- Tab 1
  - These are not relevant for the qualitative readouts.
  - Temperature ranges for crust pieces, based on the slider.
  - Function for approximate crust density, given a {0,1} function from mafic to felsic composition, and approximate crust temperature
  - Temperature function of depth, under oceanic, continental, and our modifiable crust. (The modifiable crust temperature is different, since it can have unrealistic parameters)
  - Approximate temperature and density functions
  - (example oceanic crust 3000kg/m3 density, 7km thickness. example continental crust 2750kg/m3 density, 45km thickness)
- Tab 2
  - **In general, moving at 2-10 cm / year?**
    - **How fast is crust added onto an overriding plate during subduction?**
    - **If we have fake erosion, strip off 0.1-0.5 mm/yr?**
  - Melting at the subduction plate is around 80-120km deep? What temperature range should be there? The magma is formed from the overriding aesthenosphere, with a bit of water from the melted hydrous minerals (so composition is same mafic but has lower density?)
  - Any data on differences between oceanic (young/new), continental (normal), continental (upraised), continental (rifting) crust numbers would

be good (thickness of all layers, geothermal gradients, density gradients, etc.) would be great

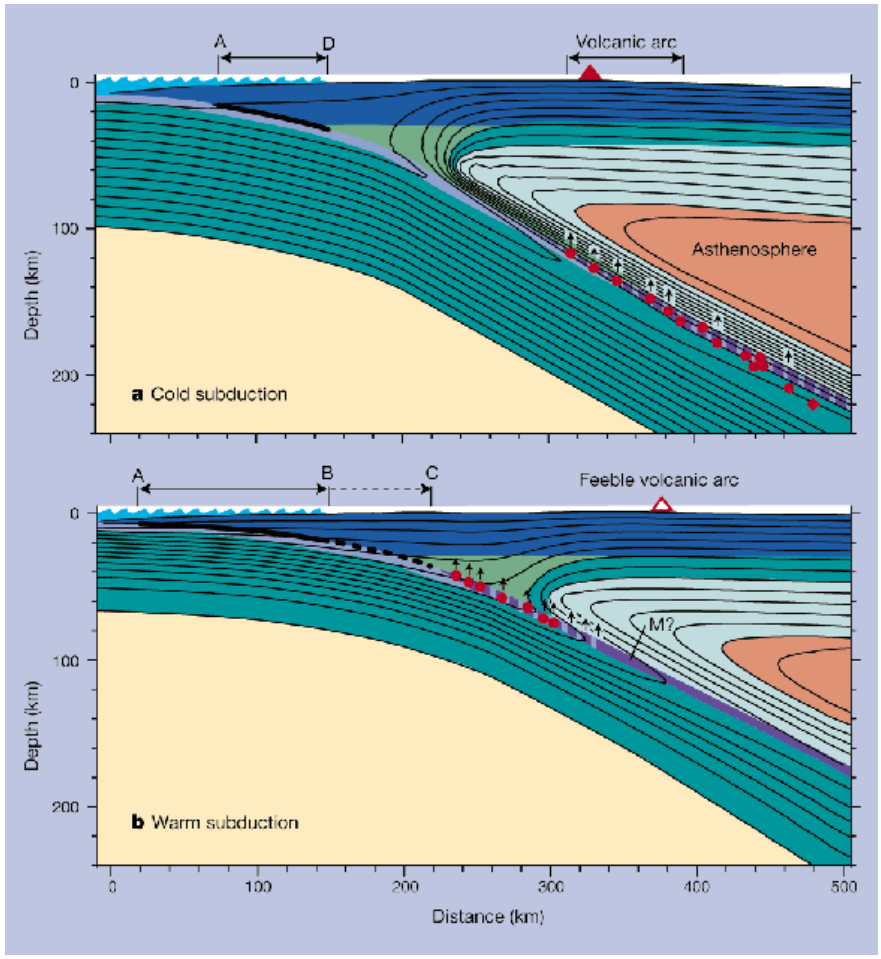
- Subducting plate usually not differentiated from surrounding rock at 600-650km depth?
- Any references on models would be extremely appreciated
- Visual notes about what is the most correct way to show a subduction boundary with one continental. Options:
  - 

    - Here, the trench is emphasized, however the continental crust is much farther to the right. It shows the thicker lithosphere (which seems correct).
  - 

Oceanic-continental convergence
    - Here, lithospheres are the same (incorrect?), the continental crust and oceanic crust boundary is very different, etc.

- 

- Similar to the 2nd example, but more differences in the lithosphere / lower crust thickness, with an accretionary wedge, and showing the subducting plate fading away at a certain depth. This is possibly the most accurate? (Although the lithosphere thickness difference between oceanic and continental crust isn't that large?)

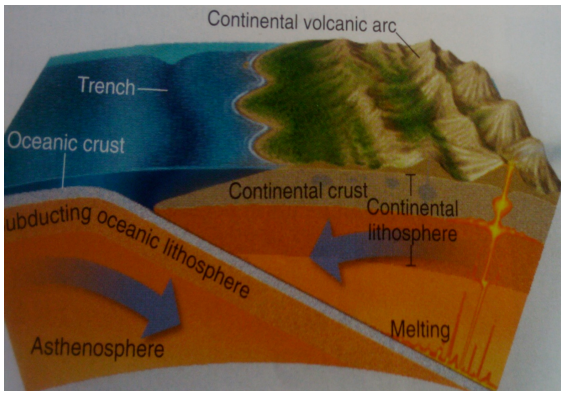
- 

    - Above is similar, but showing the isotherms. Does this look right for what the thermometer should read (and for the temperature display?)
  - Are there any established models that would work well for mountain building and erosion?
  - **Are there any resources that show a better picture of magma rising in volcanic arcs?**

Answered Questions

- For Tab 1, should the temperatures behave like density (i.e. completely discontinuous in both directions), or should we have it be a continuous function vertically? If so, what should that function be?
  - **See what realistic gradient values look like?**
- Many example images show the correct curvature of the earth. Should we show it? (It may be noticeably incorrect if we don't, so I'm leaning towards adding this)
  - **Keep curvature (for now). Looks good, but potentially future issues?**
- What should the tab names be? ("Crust" and "Plate Motion" recommended, and used for now)
  - **These are OK for now**

- Continental collision (continental x2 with convergence) usually starts out with a small tract of oceanic crust subducting inbetween according to Wikipedia (http://en.wikipedia.org/wiki/Continental_collision). One option to support this view would be to create an "add continental crusts" option during oceanic subduction, which would add continental crusts on both sides (if not already there) that would eventually collide and display this behavior
    - **Ignore this, continental collisions can happen without ocean**
- Preferences for a more continuous model without sharp boundaries, or a sharper model with discontinuous boundaries? or both?
    - **Try continuous for now, evaluate once we have a better idea**
- It would be possible to zoom out to view our cross-section all the way to the core
    - **Zoom slider control on the edge, to show out the whole core (then see if the geologists like it)**
- Will the view always be centered always on the plate boundary?
    - **Center it, transform cross-section remains stationary**
- Should the cross-sections have a "grain" that moves with the sections? Without arrows or anything else, it is almost impossible to see the movement
    - **Yes, there should be a texture that moves with the rock**
- Would a tool like the drill in glaciers be good, so that we could mark a position and watch it move?
    - **Potentially add markers in?**
- Should the meters (ruler, thermometer, density and composition meters) instead read out qualitative amounts instead of quantitative results? Since this is not specified enough in the design doc (and much of it has a large uncertainty anyways), this would make things a ton easier.
    - **Composition, temperature, density qualitative readouts (redesign tools?)**
- Consider adding radio buttons to select between different "colorings" of the earth cross-section, that would change the color of the earth cross-section based on the selected property. It would be simpler than having an array of tools to inspect properties, and may be easier to visualize.
    - Different "colorings" or "layers":
        - Density (dark = heavier, like current design). default
        - Temperature
        - Mineral composition (mafic and felsic rocks would look different)
        - Possibly a "textbook-style" coloring, like:

- 

    - A key for "dark = more dense, light = less dense" to the side would be helpful for this, but also in general if these colorings are not added.
    - This would be faster and easier to evaluate the differences in the 1st tab. To see the composition / temperature differences in the oceanic / continental crusts, you would just need to switch modes and see the difference instead of having to position probes on the oceanic and continental plates one at a time.
    - (Possibly) show a numeric / qualitative readout of the "coloring" value when mouse is over the earth. E.g. when in density mode, mouse is like the "Density Meter", and in temperature mode, mouse is like the Thermometer.
    - **Decision: Complement with toolbox (don't replace it). Have at least density and temperature colorings.**
        - **Avoid that "liquid" looking red**
- Good 3D handling would be greatly helped by using JMonkeyEngine (like in Molecule Shapes, but better texture, etc.) This would require the user accepting permissions (as in Molecule Shapes).
    - Should be able to show fairly helpful surface features with this similar to the textbook images, like
        - Transparent water, shows trenches and accretionary prisms during subduction, ridges and rifts during divergence, etc.
        - Mountain and island creation
    - Wouldn't be much extra difficulty, would look good, and would help with understanding. I highly recommend this, instead of using a 2D version.
    - **Decision: Yes!**
- May be useful to have a labeling option, that would label the crust, mantle, lithosphere and aesthenosphere.
    - **Decision: Yes. Examine typical labeling techniques for ideas, or wait for mock-up**
- Are we having density be constant values for each crust and for the mantle? Density variation in the divergence case may be important. (Oceanic crust farther from the boundary is more dense, and the magma is less dense than the surrounding mantle rock at the same depth)
    - **Issue: Dropping "constant" oceanic crust will be replaced by a variable-density version, and the constant density would not be realistic. How to handle density on a dropped oceanic crust?**

- **Update: June 9th, 2011**
- These are the ideas and changes discussed in meeting with Andrea's input.

- We mostly discussed Tab 1, version 2 see here. The main points were:
  - The idea of our divergent boundary is incorrect: Two plates do not just move apart from one another. You always start with one continental plate and as a rift zone forms, it starts to separate and gradually creates oceanic plates symmetrically on either side. So, we need to fix our conceptual model for divergence.
    - 1. do we start the concept so that students begin with one continental plate, and if they choose divergence, they'll see it has to start there....
    - 2. Or, do we not start the actual concept of divergence until the process is further along where two oceanic plates have already been established? See textbook images: here.
- Another topic we discussed was the use of Fe vs. Silica: Perhaps we shouldn't be concentrating on the elements independently, but rather the minerals. We still need to make it intuitive to the students, so perhaps label the sliders: "Iron Mineral" vs. "Silica Mineral".
- We're still working on the colors. Overall, the color gradients represent changes in density.
- The Temperature tool is really only applicable when we're measuring the T of oceanic plates when they're young vs. cold. Do we want to include the thermometer in the toolbox all the time? The problem with including thermometer all the time, is that temperature is also dependent on volume. So, allowing the students to adjust the temp will also have to adjust the volume of the plate and the density. So it might be way too complicated to have that option.

    - However, a learning goal for the students is for them to understand the relationship between temp and density, so how do we get around this problem?
- The term “thickness” we used for the plate is not quite accurate. What would be a better word? How else can we describe the “height” of what students are viewing?

    - Here is a quick synopsis of Andrea’s notes and comments, and what items have been discussed and already addressed from Kathy and Heather’s conversations:
    - **Andrea’s Comments:**
    - 1. How do we address the qualitative and quantitative aspects of plate tectonics together in the Sim? We need to be more explicit about the details between what’s happening at plate boundaries (qualitative) versus the physical modeling of the movements (quantitative).
    - 2. Plates ride on mantle, not magma (which is termed correctly in our Ai pictures, but the here textbook made it confusing. The composition of the upper-mantle is equivalent to ultra-mafic rock. That was the important point.
    - 3. We’re still struggling with the importance/complications of introducing such a heavy focus on temperature and the geothermal gradient.
    - 4. She highly recommends using single density values for each kind of crust/mantle rather than a range of values. What is the purpose of including density ranges?
    - 5. It doesn’t make sense to have a divergent boundary with two different crusts because divergent boundaries always start with a continental plate rifting apart. See above discussion here.
    - 6. Andrea thinks it's way easier to simply use the average densities of the bulk crustal and mantle compositions - see the references posted but generally good values are 2.7g/cm^3 for continental crust, 3.0 for oceanic crust, and 3.3 for upper mantle. She’s looked up values from various sources

for in-class activities and this is what she's used (been faculty reviewed).
    - 7. These ranges for the thickness of crusts/mantle are good but could simply start at .5 or 1 for oceanic crust; most continental crust is 20km or greater. no numbers but nice contour map is at http://earthquake.usgs.gov/research/structure/crust/index.php
    - 8. I think there are some standard models and parameter values used for subduction (convergence) and spreading (divergence) models that are likely very useful here. I'll have to find those....
    - 9. An email correspondence with posed questions and answers about current topics is here. Reading through this should clarify what questions have been answered.
    -
    - **Andrea's links, papers etc. can be found in the dropbox that Noah sent out. The Ai files and png images are also found there.**
    -
    -
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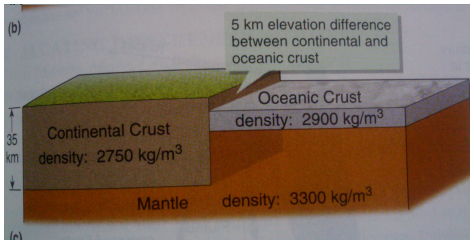
    -
    - # To-Do Design
- How will we distinguish between the types of plates visually?
    - Colors, textures, scale, perspective?
    - The learning goals initially describe the three types of boundaries (convergent, divergent and transform). However, in discussion about the Sim, it only addressed the first two. Are we purposefully excluding transform boundaries? If so, what are the benefits of this decision?
- How will we conceptualize and visualize differences in density and composition of plates?
    - How will we conceptualize the lithosphere so it's intuitive for students, in aspects of composition, density and behavior?

- How will we handle ideas of scale and deep time?
    - We could include a pop-out window from the play space of the Sim to demonstrate changes and structures on larger/longer scales.
    - What perspective of cross-sections will be most efficient and intuitive for students to learn and understand?
    - Create a time slider for the student to manipulate how fast time progresses
    - in the Sim.

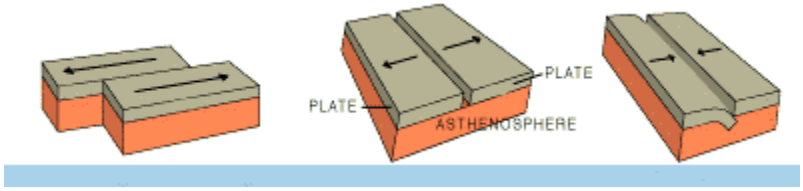
Tab 1

- For this tab, should the plates be "blocky" (rectangular cross section), like in the below image?
    - 

    - "Blocky" advantages:
        - Seems to show the isostacy (buoyancy-like) effect nicely that exists with changing density and crustal thickness
    - "Blocky" disadvantages:
        - Unrealistic (and wouldn't match the Tab 2 appearance), especially at plate boundaries.
        - Discontinuities in temperature and density (for meters or "coloring") along the plate boundaries.
    - Is there a way we could mark the equivalent of a "..." between the main crust and the example oceanic / continental crusts so that we could effectively tell the students "these aren't connected, they are just examples for comparison"
    - Otherwise, should we try to show more realistic boundaries (has problems like switching subduction / etc.) or just scrapping the example oceanic / continental crusts?
    - **Decision: Blocky is just fine. Discontinuities not a major issue**
- Slider issues: they aren't really changing parameters that are independent in nature
    - If the sliders don't modify each other (as currently designed), you can create a mutant plate that wouldn't occur in nature (e.g. oceanic thickness and composition, but continental density)
    - Temperature seems to be dependent on depth (not applicable for crust-wide changes) and oceanic crust age (also not applicable, since we have a generic crust). Not sure why we have this control.
    - Density is heavily dependent on the composition, due to the Iron in mafic rocks.

    - Potential solutions:
        - Allow creation of crust that would not occur in nature
        - Constrain sliders, like in Buoyancy (e.g. composition changing to more iron would increase the density)
        - Don't include both density and composition sliders. Have just one, and rely on either the tools or the "colorings" to display the correct density and composition.
    - **Decision: Do not include density slider. Sliders are unconstrained. Density is a function of composition AND temperature, so keep temperature.**
    - **Pending: Get function of density**
- Are we showing a temperature difference between the oceanic and continental crust temperatures here? Crustal temperatures in the model part of this document relate mainly to either a more complicated model (looks useful for Tab 2 and underlying model simulation), or just to depth. Temperature may be better left to Tab 2?
    - **Pending: Get temperature differences between oceanic / continental that would be typical, and integrate with the depth model**
- When changing the thickness or the density, should the change in vertical position of the crust be instantaneous, or should it act more like a block in the Buoyancy sim?
    - **Decision: act more like Buoyancy version, with a high damping**

Tab 2

- It should be possible to show transform boundaries effectively, as surface variation and landmarks on one side could move towards the user, and on the other side away from the user. A few design complications are mentioned below.
    - **Decision: Yes. Have 4 arrows when possible that are in the 3d plane parallel to earth, and base our "how are we dragging" to the closest direction. (add "wiggle room" at start of drag)**
- Divergence issue (divergence starts in the middle of one continental crust piece) options:
    - (1) We could only allow divergence if the user selects continental crust for both sides.
    - or (2) We could have the user first select the type of boundary (convergent / divergent / transform), and then allow the user to pick the crust options that would be valid. Would look something like below (pulled from USGS image):
        - 

    - Useful reference animation for divergence. See http://whs.moodledo.co.uk/mod/resource/view.php?id=972, then click on the 1st "Click Here" link
    - **Decision: Basically (1), where we will only allow divergence if both crusts are continental**
- How should the crusts look once placed?

    - See http://www.youtube.com/watch?v=ngV66m00UvU for how we could have crusts start next to each other without a normal plate boundary, but then once moving forms the correct boundary
    - We could also try starting with a "subduction-in-progress" state for certain configurations (anything with an oceanic plate) if we don't allow transform boundaries. Two continental crusts could start flush. Would act like the YouTube video for convergence, or the WHS video above for divergence.
    - Alternatively, crusts would start flush and never in a "subduction-in-progress" state.
    - **Decision: Start in a blocky state, and animate over time into the standard shapes. Video shows continental example, but will need to handle oceanic as well.**
- Manual mode issues:
    - Student can drag at any rate, effectively changing how fast time elapses as they drag.
        - Recommendation: instead of the "drag" moving the plate by how much the mouse moved, it should move at a velocity proportional to how far the mouse is from where the drag started on the plate.
        - **Decision: Yes. Velocity proportional to the mouse dragspot/position distance**
    - Can only drag a handle in one direction, which may not be intuitive?
        - Recommendation: Instead of handles and arrows, could we make the actual plate draggable, or add a different control?
        - **Decision: Arrows will disappear for the "wrong" directions on a drag, so it isn't much of an issue**
        - **Decision: Crust should be draggable itself?**
        - **Issue: Handle design. On the top, on the cross-section? How to deal with handles once they move off screen, or on mountainous parts (as terrain can change)? Maybe a handle tool?**