Plate Tectonics – Laboratory 1

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(name)

Exercise 1

The radius of the Earth along the equator is 6378 km (3963 statute miles). Its polar radius is 6357 km (3950 statute miles).

Question 1

*Which of the three geometrical forms shown in Figure 1 best describes the shape of the Earth?*________________________________

Exercise 2

Planet Earth consists of a number of concentrically arranged shells, each shell having a unique composition (Figure 2). These shells are from outer to inner the ***crust***, ***mantle***, and ***core***. The core is further subdivided into outer and inner parts.

Question 2

On Figure 2 please locate and label the crust, mantle, outer core, and inner core.

Where the crust underlies the oceans of the world it is on average about 7 km thick and basaltic in composition. In contrast, where the crust underlies continental areas it is on average about 45 km thick, but sometimes reaches thicknesses as great as 75 km, and is granitic in composition. Basalts are silicate liquids or there solidified equivalents. They typically have between 45 and 52% silicon dioxide (SiO_2). In contrast, granites are silicate liquids or there solidified equivalents that have greater than about 65% SiO_2 and typically around 72% SiO_2. In addition, basalts tend to be enriched in iron (FeO) and magnesium (MgO) while granites tend to contain relatively high amounts of potassium (K_2O).

Separating the crust from the underlying mantle is the Moho or Mohorovicic Discontinuity.

Question 3

On Figure 2 please locate and label the Moho.

The mantle extends to ~2890 km (1806 miles) depth (Figure 2). It is composed of peridotite, a rock composed of less than 45% SiO_2. The mantle makes up ~82% of the volume of our planet.

Below the mantle is the outer core. It extends to ~5140 km (3219 miles) and is an iron-nickel liquid (Figure 2). Movement of the liquid outer core creates the Earth's magnetic field. In contrast, the inner core is a solid alloy of iron and nickel. The temperature in the inner core reaches about 3000-5000^{o}C.

Students commonly view the compositional shells of the Earth as being analogous to a hard-boiled egg.

Question 4

Describe briefly below how you think that this analogy works.

Superimposed on the outer two compositional shells of planet Earth (i.e., crust and mantle) are three layers that are distinguished by their mechanical properties. These layers are from outer to inner Earth the ***lithosphere***, ***asthenosphere***, and ***mesosphere***. The lithosphere is composed of the crust and outer part of the mantle (Figure 3). It is ~100 km thick, and forms a rigid and relatively cold and strong outer mechanical layer. In contrast, the asthenosphere lies entirely within the mantle and below the lithosphere (Figure 3). Temperatures in the asthenosphere reach and exceed 1000^{o}C. Though mostly solid, the asthenosphere contains about 1% liquid, i.e., partially melted mantle rock. The asthenosphere extends to ~200 km depth and is weak and flows like a plastic. Underlying the asthenosphere is the mesosphere. The mesosphere is not shown in Figure 3, but it makes up the remaining portion of the lower mantle extending to its base at ~2890 km.

Lithosphere is commonly subdivided into oceanic and continental end members (Figure 3). These two types of lithosphere are based solely on the dominant characteristics of the crust. ***Oceanic lithosphere*** underlies the world's oceans and contains oceanic crust, while ***continental lithosphere*** underlies the world's continents and contains granitic crust. Crust that is transitional to these two end members is typical of volcanic ocean islands like that in the Japanese archipelago.

Question 5

The rigid lithosphere encircling planet Earth is broken into a number of plates. In fact there are seven major (large) and seven microplates that have so far been indentified. The seven large plates are (1) ***North American****, (2)* ***South American****, (3)* ***Pacific****, (4)* ***Eurasian****, (5)* ***Indian-Australian****, (6)* ***African****, and (7)* ***Antarctic*** *plates. The seven smaller plates are the (1)* ***Caribbean****, (2)* ***Cocos****, (3)* ***Nazca****, (4)* ***Scotia****, (5)* ***Juan de Fuca****, (6)* ***Arabian****, and (7)* ***Phillippine*** *microplates. On Figure 4 please label and color each of these key Earth features.*

Exercise 3

As you look at your results from exercise 3, note that most plates are composite in the sense that they are made up of both oceanic and continental lithosphere. However, one major plate is composed mostly of oceanic lithosphere.

Question 6

What plate fits this description?

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Exercise 4

Each plate that has been identified on planet Earth has a boundary. However, these boundaries are not everywhere the same. In fact, there are three fundamentally different types of boundaries, each boundary being dependent upon whether or not the plates across the boundary are moving toward each other (***converging***), away from each other (***diverging***), or are sliding pass each other (***transform*** or ***conservative***).

Along converging boundaries one plate descends or **subducts** beneath another. The plate that descends is the ***subducting plate*** while the overlying is the ***over riding plate***. A deep bathymetric furrow commonly marks the position where the over riding and subducting plates first contact each other. This furrow is referred to as a ***trench***. Commonly lying between the trench and the ***volcanic arc*** is a ***forearc basin***. The area in back of the volcanic arc is referred to as the ***backarc*** region.

Question 7

On Figure 5, a cross section across a convergent margin, please identify and label the subducting plate, over riding plate, trench, forearc basin, volcanic arc, and backarc region. Also identify and label the crust, mantle, lithosphere, and asthenosphere.

On Figure 4, which cross section (vertical slice of Earth's interior) A-A' or B-B' would look like Figure 5?

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As the subducted plate descends beneath the over riding plate its upper part undergoes a series of **dehydration** reactions. The result of these reactions is that fluids such as water are given off and rise into the mantle of the over riding plate. On the descending plate, this general process becomes dominant at about 100 km of depth. Dry mantle does not readily melt at depths less than ~100 km, however wet mantle does. Hence, water derived from dehydration reactions in the descending plate infiltrates the lower part of the mantle of the over riding plate changing it from dry to wet, and, as a result, the mantle begins to melt. Silicate liquids that occur beneath the surface of the Earth or the seabed are called **magma**. If they reach the surface of the Earth or flow out along the seabed, then they are called **lava**.

At the base of the over riding plate at first only a thin liquid film forms around mantle grains, but as more liquid is produced thin streams of magma start to migrate up the overlying column of lithosphere. These streams eventually coalesce to form larger streams and continue to rise. At the Moho the upward movement of magma is arrested, and pools of magma begin to accumulate. However, some magma makes it past the Moho and continues to rise into the overlying crust. Eventually, some magma reaches a point in the crust that it can no longer continue to rise. At this point the magma begins to spread outward in all directions forming a pool of silicate liquid called a **magma chamber**. Such chambers underlie volcanoes and through a series of dikes (transitory cracks) fed magma to lava flowing along the surface of the Earth or seabed.

Question 8

Describe the evolutionary stages of magma development from the base of the over riding plate to the Moho and then to a magma chamber lying beneath an active volcano as shown on Figure 5.

Exercise 5

Along diverging boundaries one plate moves directly away from another. Such boundaries commonly are marked by mid-ocean ridges and a rift valley, and are sites where new ocean crust and lithosphere are forming. Beneath rift valleys along divergent boundaries hot asthenosphere has risen **adiabatically** (i.e., without loss of heat) to shallow levels. At such shallow levels it melts to form a **magma chamber** of *crystal mush*, i.e., a chamber composed of crystal and silicate liquid (magma). Magma is fed from the chamber through a series of dikes (transitory vertical cracks) to submarine pillow lava erupting on the sea floor. Some of the magma in the dikes never makes it to the sea floor and freezes in place, while some of the crystal mush and silicate liquid in the magma chamber crystallizes to form the rock gabbro. Hence, oceanic crust characteristically is made up of from seabed down to the Moho of **marine sediments**, **pillow lava**, **sheeted dikes**, and then **gabbro**. When such a section is preserved in the ancient rock record (i.e., in older rocks) it is called an **ophiolite**. In the immediate area of the rift valley, oceanic crust directly overlies the asthenosphere, but further away from the axis of the mid-ocean ridge a section of lithospheric mantle progressively enlarges until the lithosphere reaches its normal ~100 km thickness.

Question 9

On Figure 6, a cross section of a mid-ocean ridge, identify and label the layers corresponding to marine sediments, pillow lava, sheeted dikes, and gabbro. Also label the Moho, rift valley, and magma chamber containing crystal mush.

Two prominent mid-ocean ridge systems that you should be aware of are the Mid-Atlantic Ridge, and the East Pacific Rise. The Mid-Atlantic Ridge separates North America and South America from Africa and Europe while the East Pacific Rise extends through the Gulf of California and forms the western boundary of the Nazca and Cocos microplates.

Question 10

On Figure 4, which cross section (vertical slice of Earth's interior) C-C', A-A', or B-B' would look like Figure 6?

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On Figure 4, locate and label the Mid-Atlantic Ridge and the East Pacific Rise.

Exercise 6

A **fault** is a surface across which Earth material has lost cohesion and across which there has been perceptible displacement. Transform faults or conservative plate boundaries are areas where lithospheric plates are sliding laterally past each other. Ideally, in such a setting there can not be a component of convergence or divergence.

Transform faults are prominent in ocean basins where they appear to offset ridge axes. Geologists used to think that transform faults like the one depicted in Figure 7 offset ridge axes. However, as we will see shortly, this is not the case.

In Figure 7 hot asthenosphere rises beneath the ridge axis. Some of it melts and is fed through dikes to pillow lava flows at the seabed. However some of the upwelling asthenosphere cools and begins to flow laterally away from the axis of the ridge. As it does so it carries or drags the overlying lithosphere along with it. Hence, in Figure 7 plates I and II move away from plates III and IV, as new crust forms along the ridge axis in a process called **sea floor spreading**.

Question 11

Note that line segment X-Y lies across the transform fault. As sea floor spreading continues will it be offset? ____________________________

How about line segment R-S? ___________________________

Now note the position of line segment T-U. As sea floor spreading continues will it be offset? ________________________

What is the significance of points A and B in Figure 7 and in general?

The San Andreas is a transform fault that connects the East Pacific Rise in the Gulf of California to a ridge segment lying offshore of northern California. On Figure 4, please locate and label this feature.

Exercise 7

The connection between diverging, transform, and converging plate margins is depicted in Figure 8. Note that along converging plate margins, the over riding plate may be either oceanic or continental.

The *dominant* but not only process that drives the motions of plates is **convection** within the underlying mantle. This process begins with hot mantle upwelling along mid-ocean ridges. The welled up mantle cools and spreads laterally. At convergent margins it has cooled enough to begin sinking. As it sinks, it heats back up and eventually flows laterally above the outer core and lower mantle boundary back to the zone of upwelling mantle. The overall convective process is then repeated again and again.

Question 12

If the above scenario is carried to completion, then what will happen to the ocean basin, and the intraoceanic and continental arcs?

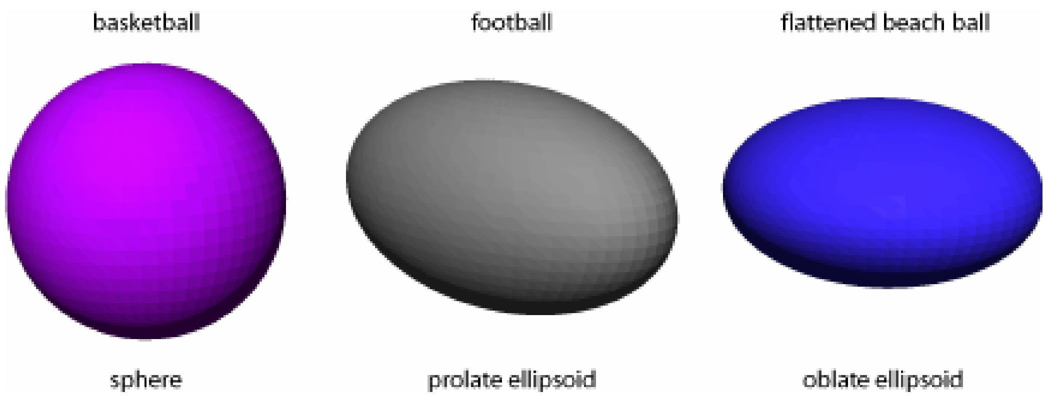

Figure 1. Three common 3-D shapes and their geometrical names. One is shaped like the Earth, while two are not.

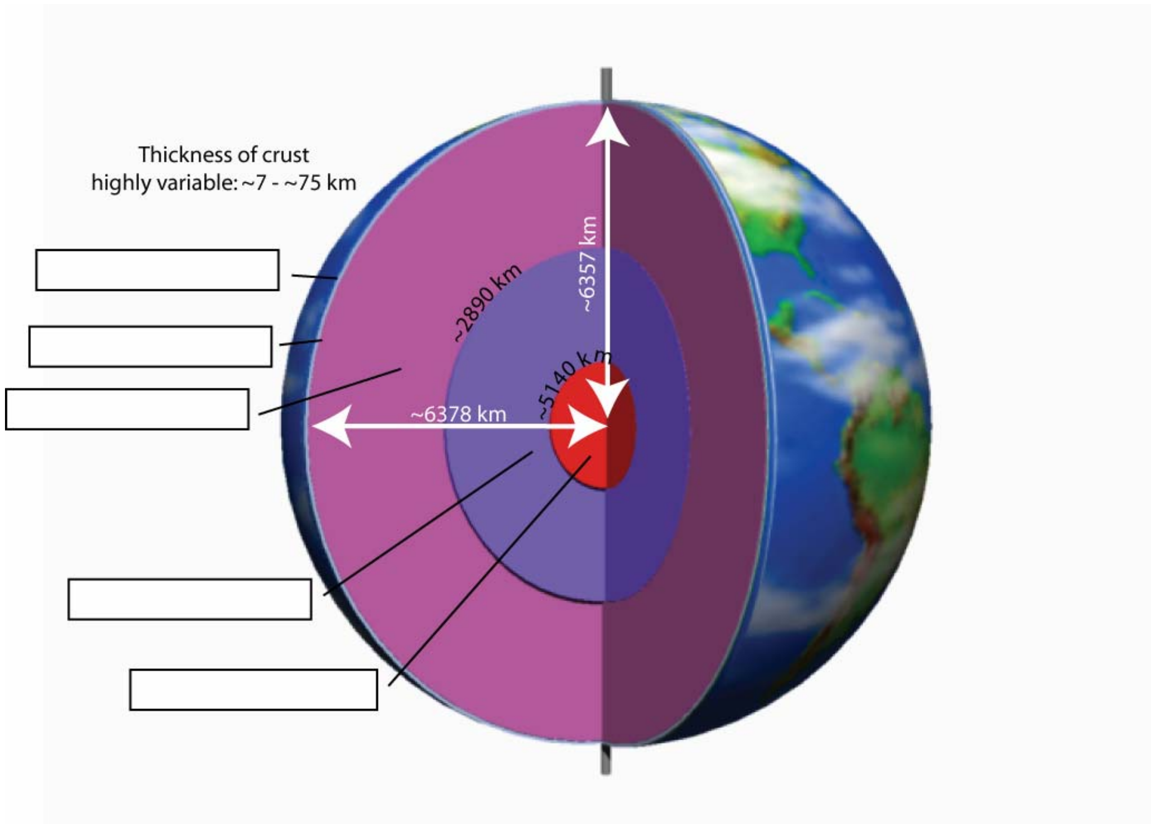

Figure 2. A cut away view of the Earth's interior.

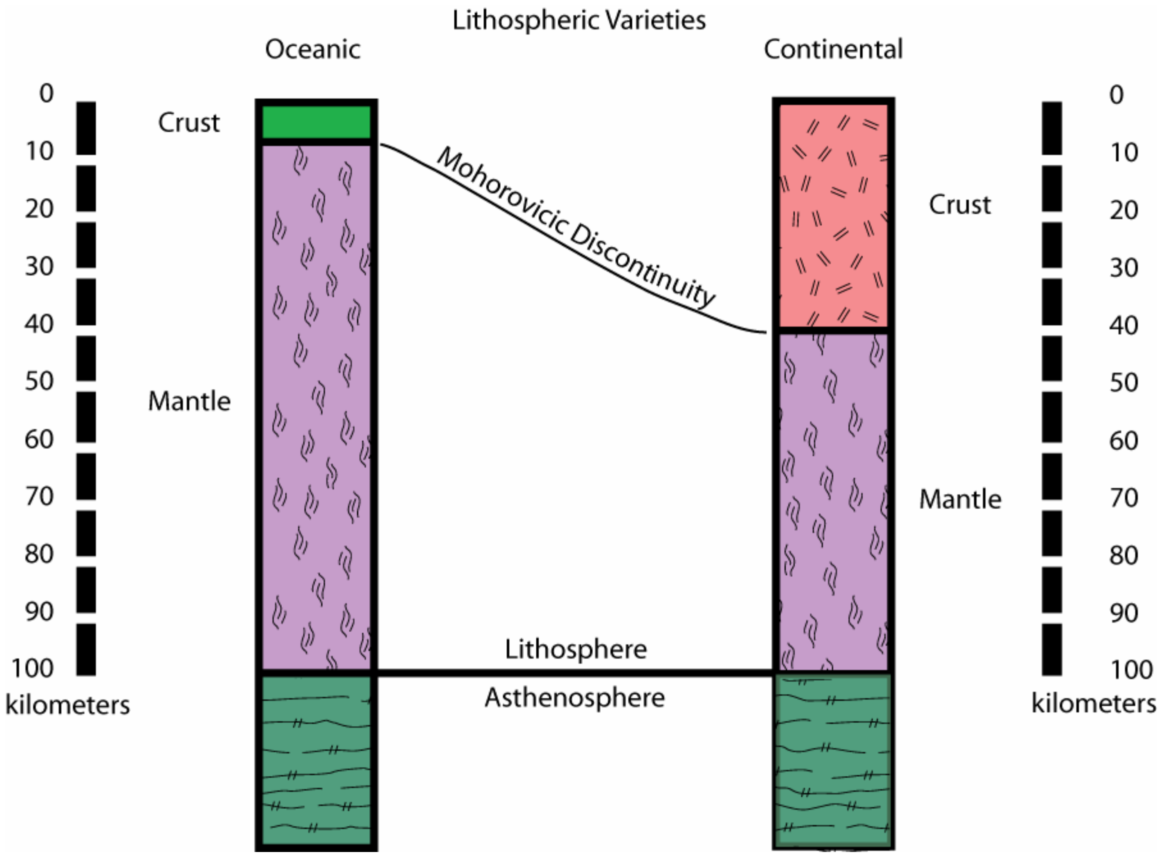

Figure 3. Two end member types of lithosphere. Oceanic lithosphere is characteristic of ocean basins, while continental lithosphere is characteristic of continental areas. Note that the two different end member types are distinguished on the basis of their crustal characteristics.

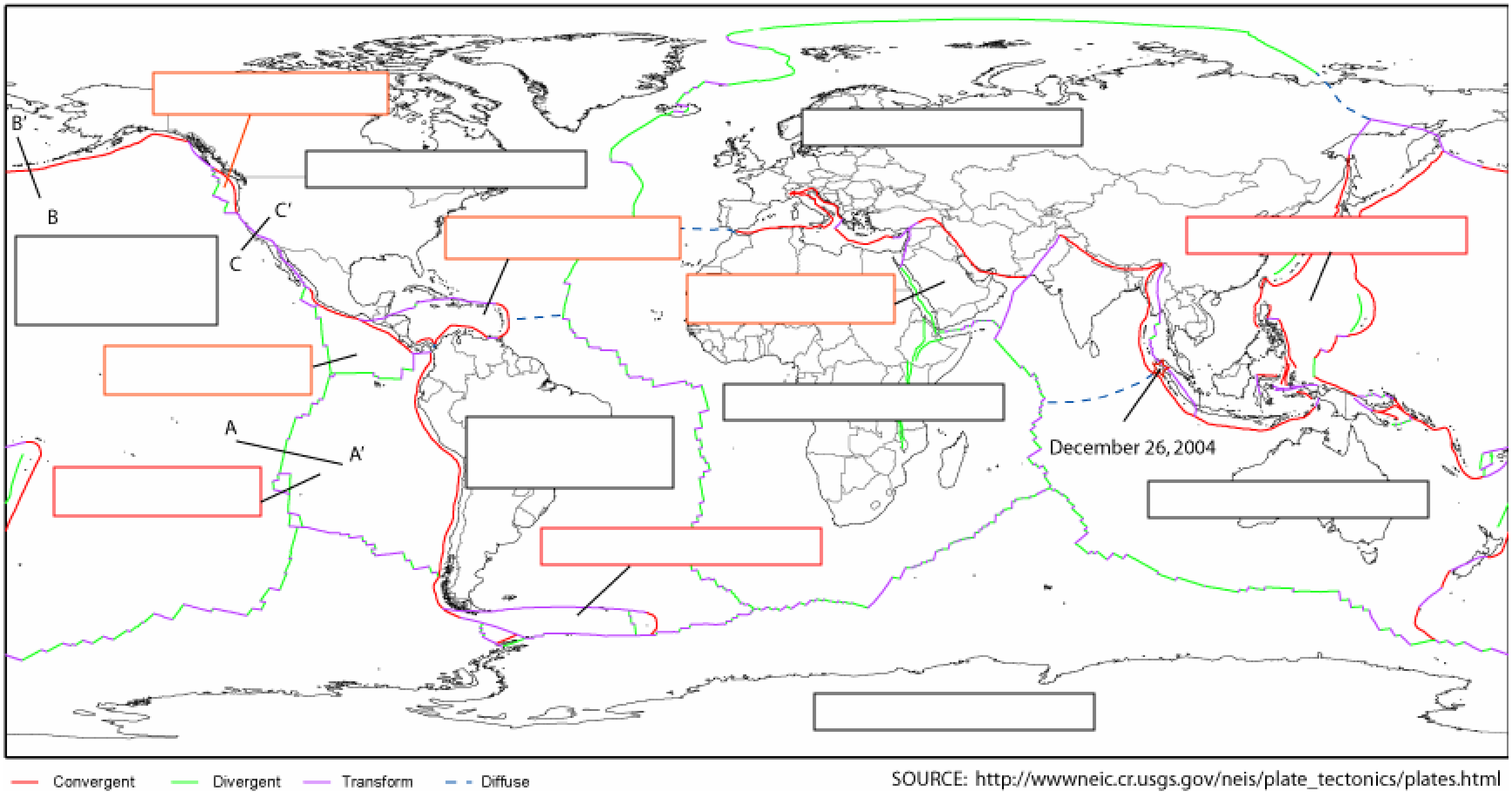

Figure 4. Map showing the locations of different types of plate boundaries.

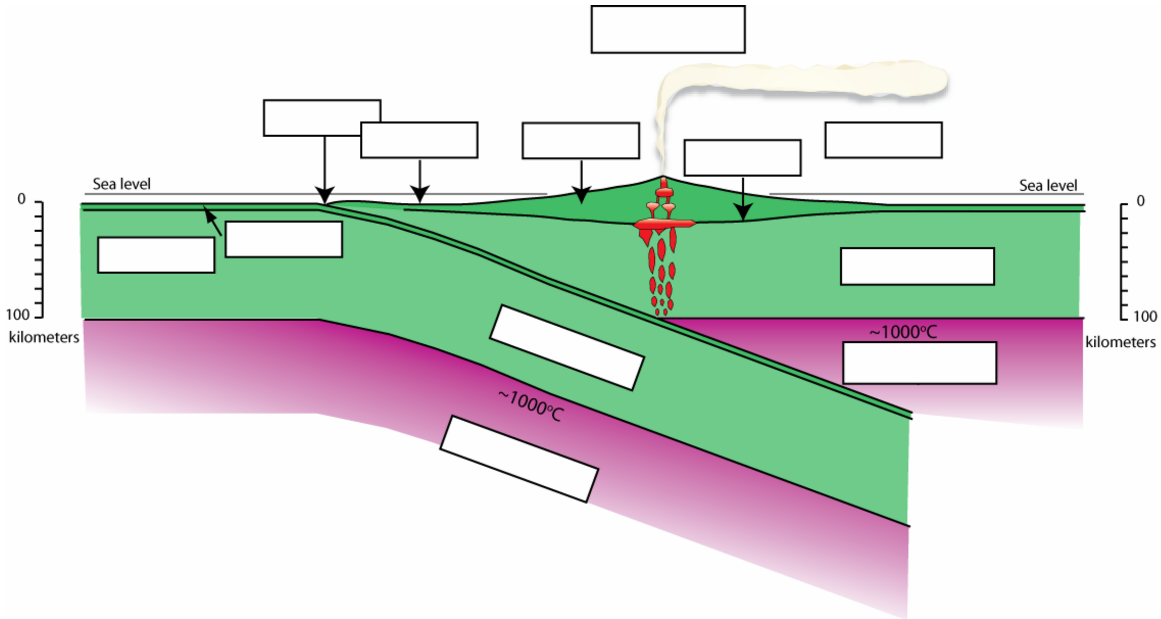

Figure 5. Cross sectional view of a typical intraoceanic island arc.

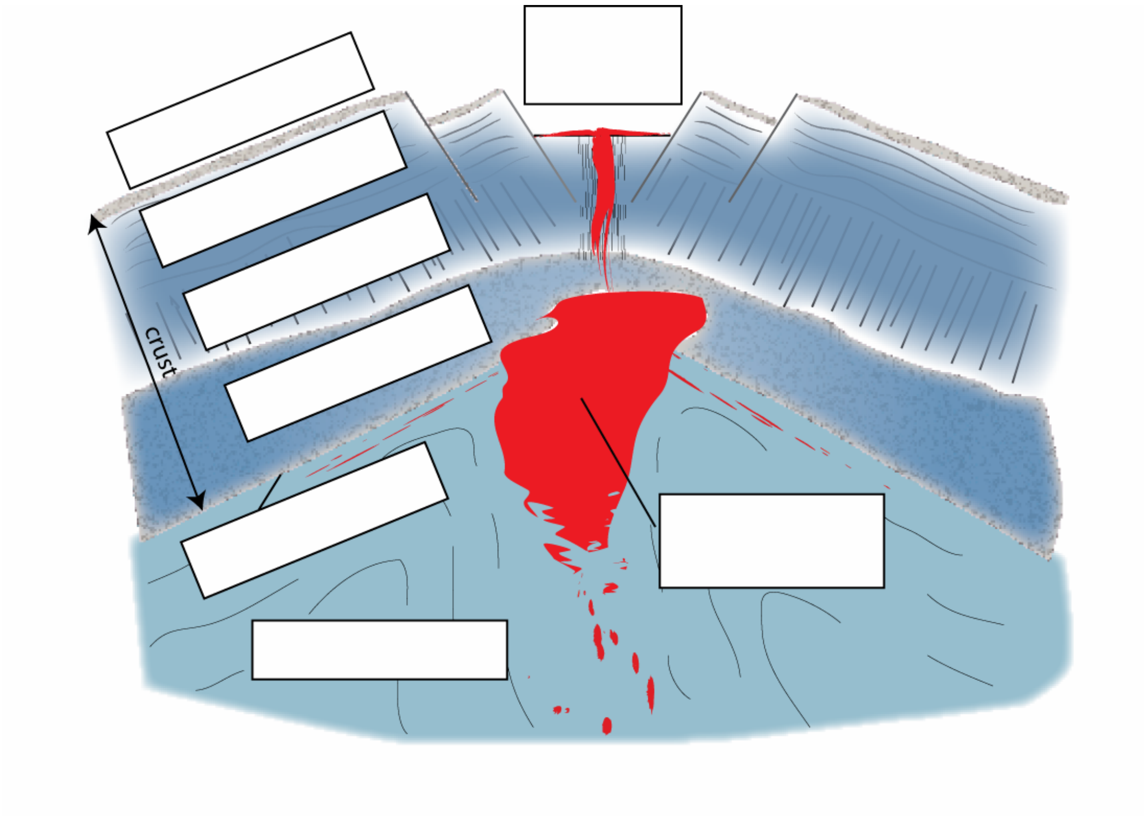

Figure 6. Idealized cross section of a mid-oceanic ridge.

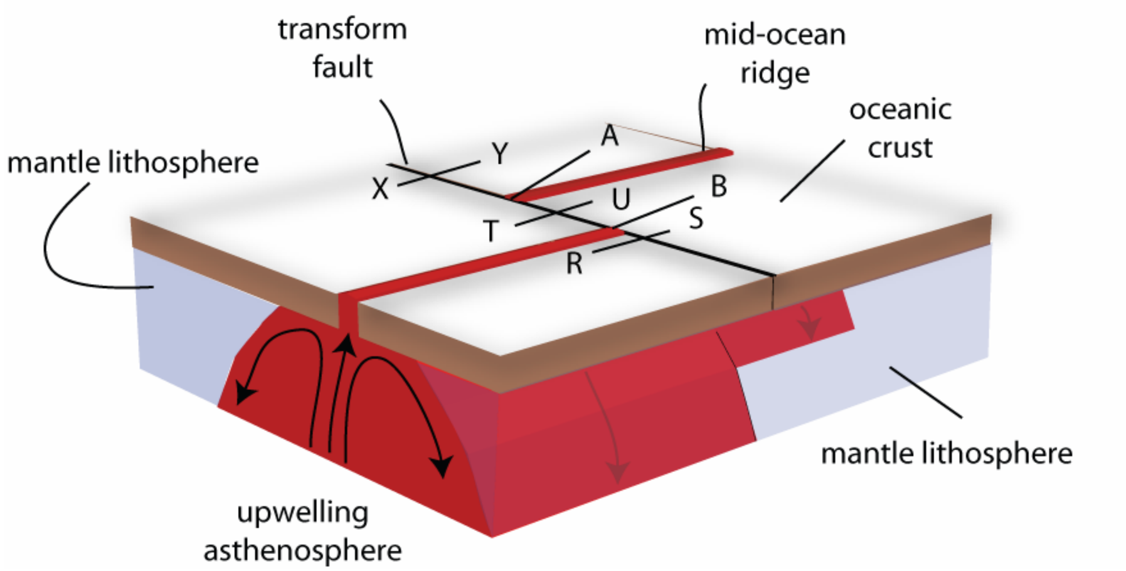

Figure 7. Block diagram of a transform fault offsetting a mid-ocean ridge.

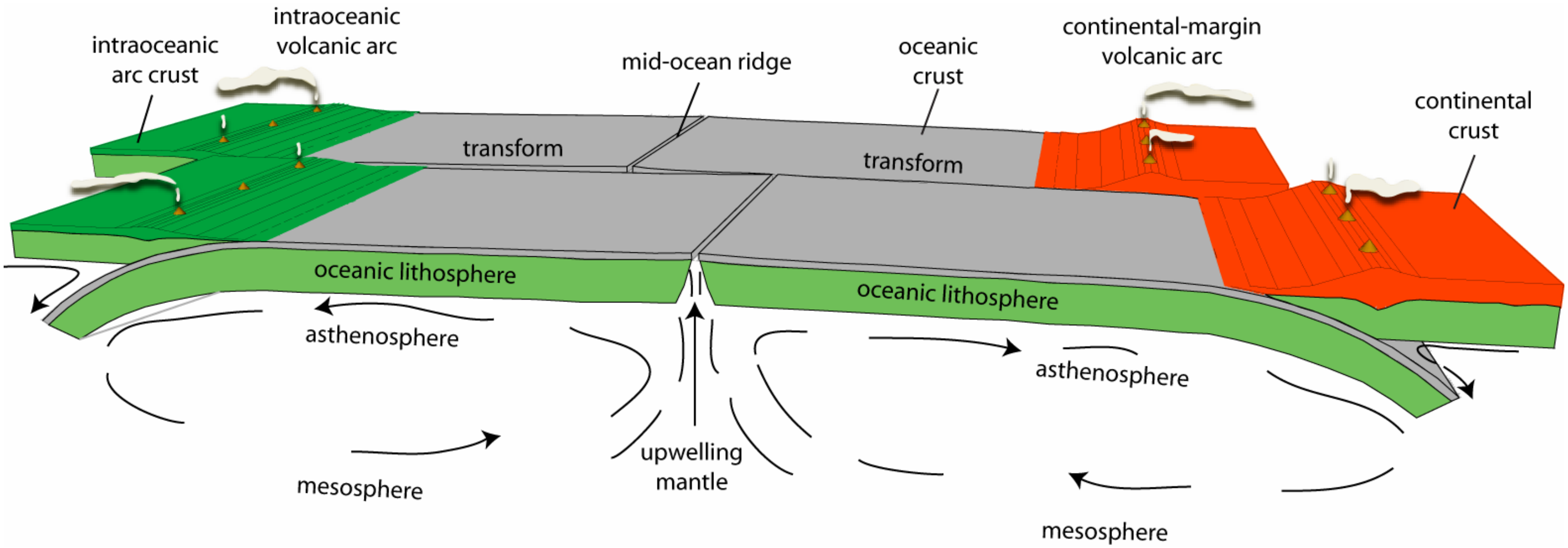

Figure 8. Block diagram depicting convection within the mantle and how it is the predominate mechanism that drives the motions of plates.