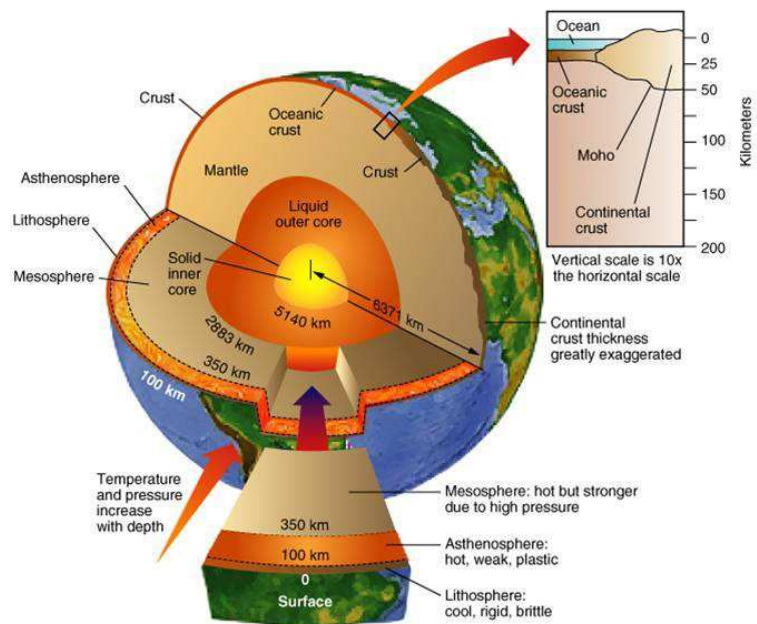


STAAR Science Tutorial 39 TEK 8.9B: Formation of Crustal Features

TEK 8.9B: Relate plate tectonics to the formation of crustal features.

Earth's Layers

- To understand how the Earth's crust has been shaped into the mountains and valleys that exist today, we must first look at the layered structure of the Earth, and how leftover heat in the Earth's core, part of Earth's creation 4.6 billion years ago, still provides most of the energy building mountains today. The decay of radioactive elements such as uranium provides the remaining energy.
- Scientists classify the interior layers of the Earth in two different ways: chemically (that is, what the layers are made of) and structurally (how dense and solid the layers are). Both classification systems for the layers are shown below.
- Chemically, the Earth has three layers: the **core**, made largely of the metals iron and nickel; the **mantle**, made of dense rocks rich in iron; and the **crust**, a very thin surface layer made of less dense rocks rich in aluminum and magnesium. The denser ocean crust is mostly **basalt**, a dense black igneous rock, while the continental crust is less dense rocks like **granite**.
- Structurally, the Earth has five layers. These layers are affected by both pressure and heat, which both increase with depth. In other words, the center of the Earth has both the highest pressure and highest temperature. Pressure and temperature interact on the different layers, creating an alternating solid-liquid-solid-liquid-solid sequence of layers.

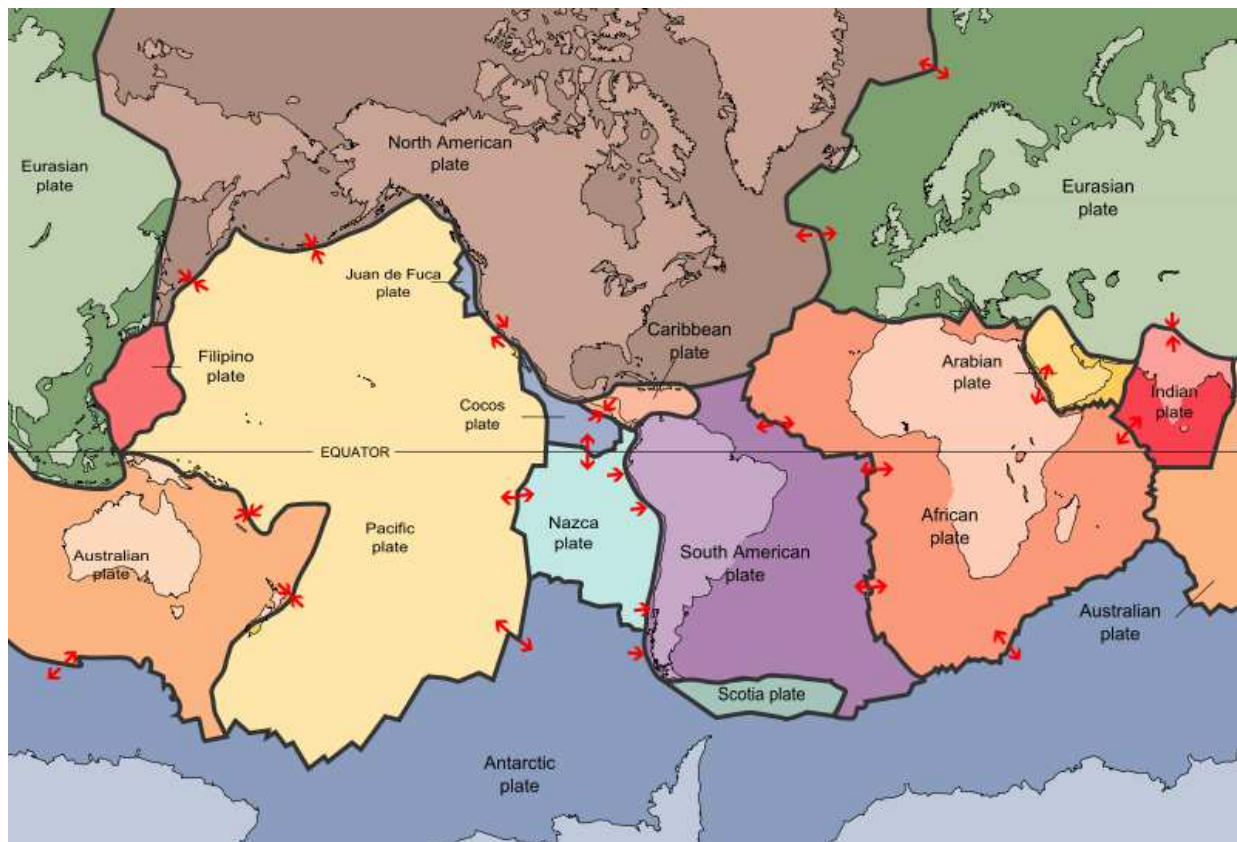


- The innermost layer is the **inner core**, which is mostly solid iron and nickel, possibly forming north-south oriented magnetic crystals. It has temperatures over 5000°C.
- The **outer core** is made of the same metals as the inner core, but the lower pressures allow the metals to melt. It is the movement of the metal in the outer core which creates the Earth's magnetic field.

- The **mesosphere** is the lower, mostly solid part of the mantle. Temperatures and pressures are lower than in the outer core, but the different chemical composition means that the rock is mostly solid, except for some rising plumes of molten rock.
- The **asthenosphere** is the upper, semi-liquid part of the mantle. It has very slow-moving convection currents of molten rock which in turn move the tectonic plates of the lithosphere. Some of the bigger rising plumes of molten rock create “hot-spots” or divergent plate boundaries on the surface. The Hawaiian Islands and Yellowstone National Park are both examples of “hot-spots.”
- The **lithosphere** is the outermost layer of solid rock. It has the lowest temperature and pressure, and the lowest density. The lithosphere floats on the asthenosphere layer below it, in a jigsaw puzzle like mosaic of tectonic plates. The lithosphere is made of the crust and the top, solid part of the mantle.

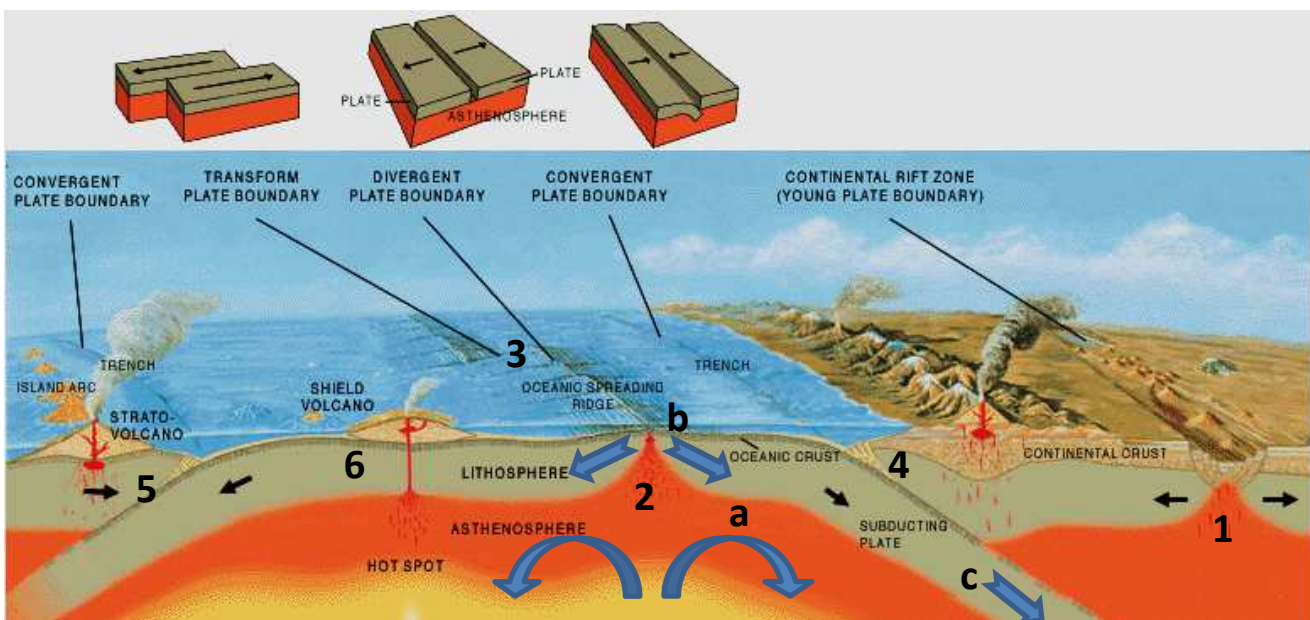
Plate Tectonic Theory

- Science’s best understanding of how crustal features such as mountains and rift valleys form is described in the **Plate Tectonic Theory**. According to this theory, the lithosphere (which includes the crust) is broken into nine major and many smaller tectonic plates, which float on the denser semi-liquid asthenosphere. Convection currents of thick molten rock in the asthenosphere move the plates slowly over millions of years, opening up gaps that fill with lava, colliding plates together to build mountains, and subducting ocean crust to form volcanic mountains. (Tutorial 38 describes the historic development of the plate tectonic theory.) The USGS diagram below shows the major plate boundaries.

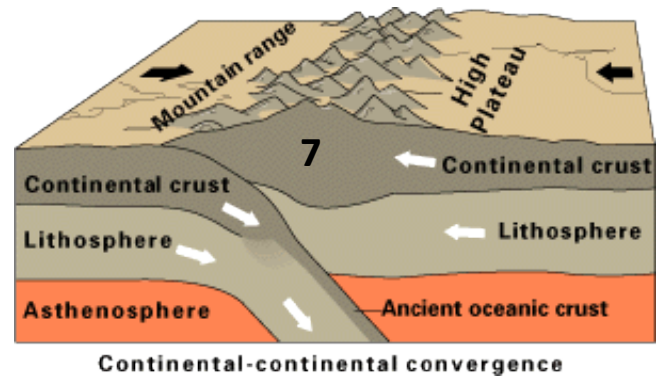


Tectonic Plate Boundary Types

- There are three main types of tectonic plate boundaries: convergent, divergent and transform. (The numbers and letters in parenthesis are keyed to the diagram below.)
- A **divergent boundary** occurs when two plates move away from one another ("diverge"). This can either happen on a continent, creating a new **rift valley** (1) or under the ocean at a **mid-ocean ridge** (2). If a rift valley divergent boundary remains active long enough, the valley eventually fills with water, becoming the start of a new ocean basin. The forces causing plate movement probably include (a) friction with convection currents, (b) gravity pulling the plates down and laterally on either side of the ridge (ridge-push), and (c) gravity pulling down the subducting crust into the asthenosphere (slab-pull).
- A **transform boundary** (3) occurs when the two plates are sliding past one-another in opposite directions. Long divergent or convergent boundaries often alternate with short sections of transform boundary, allowing for changes in the boundary's direction. The **San Andreas Fault** in California is a transform boundary between the Pacific and North American plates.
- A **convergent boundary** occurs when two plates come together ("converge"). When one plate is oceanic and the other continental (4), the oceanic plate always **subducts** (dives below) under the continental plate. When both plates are oceanic (5), the denser one will subduct under the less dense plate. As the water-soaked oceanic plate subducts and melts, steam pressure causes the magma to rise, eventually reaching the seafloor surface as an underwater volcano, perhaps eventually becoming a volcanic island.
- The USGS diagram below shows (1) a continental rift valley type of divergent boundary; a mid-ocean ridge with alternating (2) divergent and (3) transform boundaries; (4) an ocean-continent subduction convergent boundary; and (5) an ocean-ocean subduction convergent boundary. Also shown is (6) a "hot-spot" volcanic island not associated with a tectonic plate boundary.

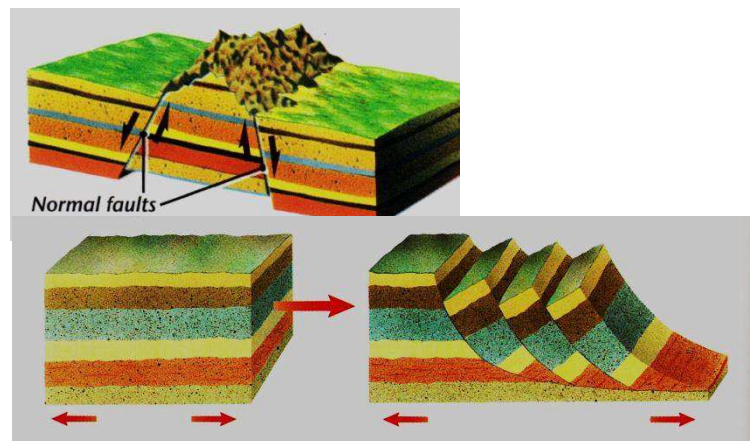


- The other type of convergent boundary is a (7) continent-continent convergent boundary without subduction. The USGS diagram to the right shows the collision of the India and Eurasian plates, forming the Himalayan Mountains. Note that the subduction shown is from an ocean-continent subduction that occurred before the India continental crust reached the Eurasian continental crust.



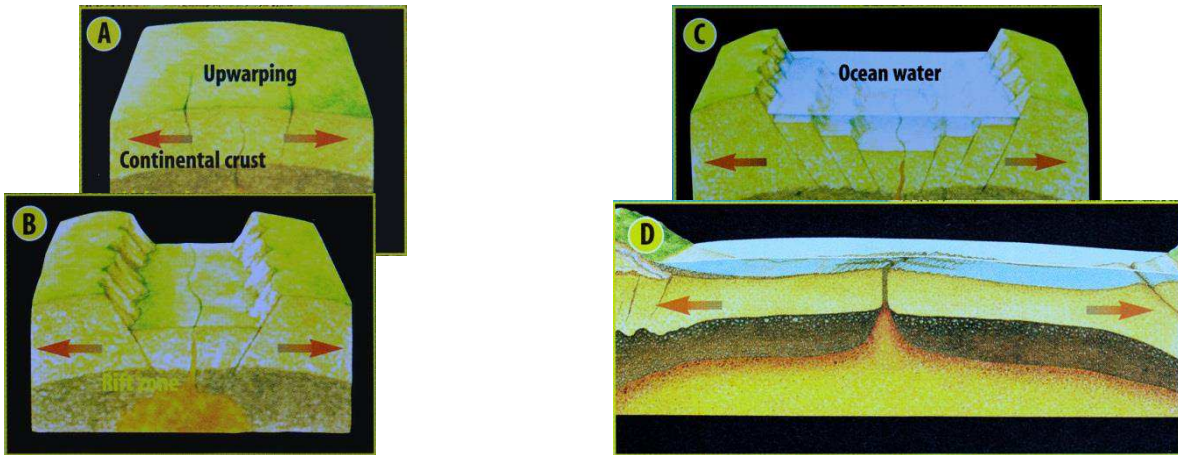
Mountain Building

- As shown in the diagram above at (7), when one continental plate converges with another continental plate, the two plates are squeezed together with "**compressional**" forces. Over time, the rock layers can fold and fracture, creating "**folded**" mountain chains parallel to the boundary. The Appalachian Mountains of the eastern U.S. were created when the continents forming Pangaea came together. At the time, these mountains were as tall as the Rocky Mountains are today. The Himalaya Mountains in southern Asia (presently the tallest mountains on Earth) and the Alps in southern Europe are younger examples of folded mountains.
- When an ocean plate subducts under a continental plate, as shown at (4) in the diagram on the previous page, compressional forces at the edge of the continental plate will also create some folding mountains. But magma from the subducting ocean plate also can build mountains parallel to the subduction zone by **volcanic eruption** and "**upwarping**," a mass of magma that pushes towards the surface without actually breaking through. The dome of magma ends up cooling underground, forming an intrusive igneous rock, such as the granite dome of Stone Mountain outside of Atlanta or Enchanted Rock in the hill country of Texas.
- When one ocean plate subducts under another ocean plate, the magma from the subducting ocean plate pushes back to the surface, forming a chain or **arc of volcanic islands**. The Aleutian Islands of Alaska and the Indonesian Islands of the southwest Pacific Ocean are volcanic island chains formed from subduction. These are part of the "ring of fire", the volcanoes that form a ring around the Pacific Ocean's subduction zones.
- Tension** (stretching or pulling apart) forces within a plate can cause the plate to break into sections, some of which sink, while other sections rise. An example of this **fault block** mountain formation is the Teton Mountains in Wyoming, as shown in the upper diagram to the right. The state of Nevada is broken into a



series of such mountains, shown is the process on the lower right.

- When tension forces act on the crust at divergent boundaries and places where asthenosphere convection currents pull the crust in opposite directions, rift valleys can form. The below series of diagrams show the development of a new divergent boundary (A); to a rift valley (B); to a narrow lake or sea (C); to an ocean basin with mid-ocean ridge (D).



Practice Questions

- Chemically, the three layers of the Earth's interior, stated in order from center to surface, are the (1) _____, made of metal, the (2) _____, made of dense, iron rich rock, and the (3) _____, made of less dense, aluminum and magnesium rich rocks.
- Structurally, the five layers of the Earth's interior, stated in order from center to surface, are the (1) _____, which is solid metal, the (2) _____, which is liquid metal, the (3) _____, which is mostly solid rock, the (4) _____, which is plastic (semi-solid to liquid) rock, and the (5) _____, which is solid rock.
- The ocean crust is mostly made of the rock _____.
- The continental crust is mostly made of less dense rocks such as _____.
- The lithosphere is made of the _____ and the top solid part of the _____.
- The lithosphere is broken into nine major plates (see map), including the (1) _____, (2) _____, (3) _____,

- (4) _____, (5) _____, (6) _____,
(7) _____, (8) _____, and (9) _____.
7. The plate that is surrounded by subduction zones and volcanoes, giving it the name "the ring of fire" is the _____ plate.
8. The three main types of tectonic plate boundaries are the _____, _____ and _____.
9. A _____ boundary occurs where two plates move apart, causing a _____ in an ocean basin and a _____ on land.
10. A _____ boundary occurs where two plates move in opposite directions parallel to the boundary. A famous example of this boundary type is the _____ Fault.
11. A _____ boundary occurs where plates come together.
12. When two ocean plates come together, one ocean plate _____ under the other, causing a chain of _____ to form.
13. When an ocean and a continental plate comes together, the _____ plate subducts under the _____ plate, causing a chain of _____ mountains, as well as some folded mountains.
14. When two continental plates come together, they form _____ mountains. The highest such mountains on Earth are the _____ Mountains, formed when the _____ and _____ plates collided.
15. When plates are put under tension, they may break into sections and form _____ mountains. Examples of this kind of mountains include the _____ Mountains of Wyoming and the many parallel mountain ranges in the state of _____.
16. When a new divergent boundary forms, a _____ forms on land and eventually becomes an _____ basin with a _____ at its center.
17. When magma rises through the lithosphere but cools before it reaches the surface, forming dome-shaped mountains, it is called _____.