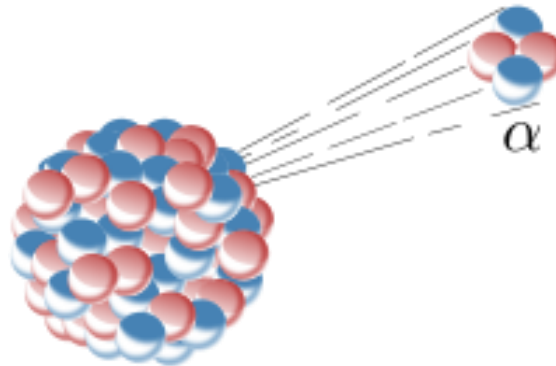


Heat Flow

Heat from Earth's Interior

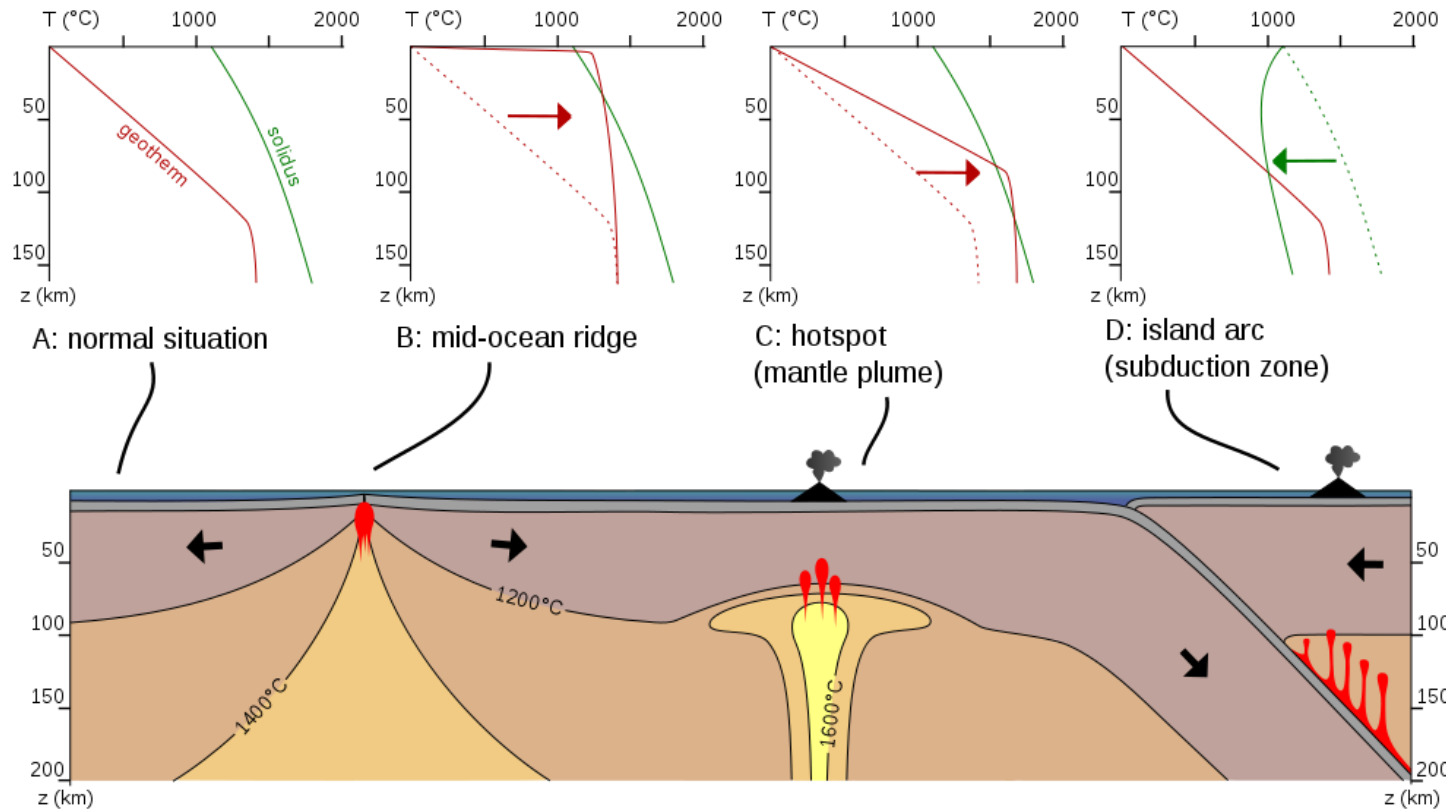
Earth's interior heat comes from a combination of the following factors:



- Original heat from the formation and gravitational compression of the Earth from the solar nebula.
- The decay of short-lived radioactive elements (such as aluminum-26) generated heat energy in the early stages of the Earth's formation.
- The ongoing decay of long lived radioactive elements such as uranium that continue to generate heat.

Geothermal Gradient

The **geothermal gradient** is the rate at which the temperature of the Earth's interior increases with increasing depth.



Average geothermal gradient: Continental areas away from tectonically active zones have average geothermal gradients. The geotherm never reaches the solidus (melting point) of the rock.

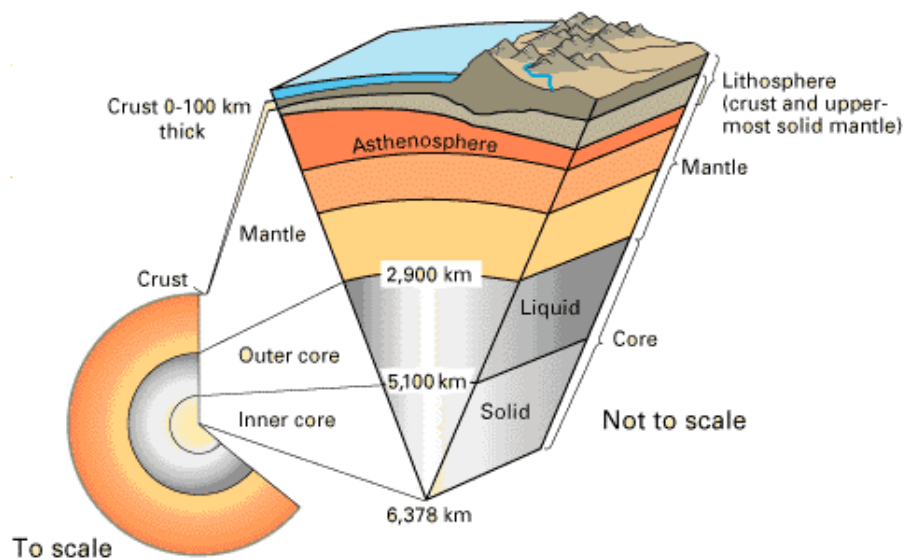
High geothermal gradient: Temperature increases quickly with depth at mid-ocean ridges. This is due to rising hot magma beneath a thinner lithosphere. Note that there is a zone in which the geotherm exceeds the solidus, leading to melting and magma formation.

Low geothermal gradient: Temperature increases slowly with depth at subduction zones. This is due to the relatively cool sediments and fluids (i.e.: seawater) being subducted along with old, cold ocean lithosphere that penetrates to great depths. Even though the rock is relatively cool, the solidus is depressed by water-bearing rock and sediment, leading to melting and convergent plate boundary volcanism.

Overview of Heat Flow

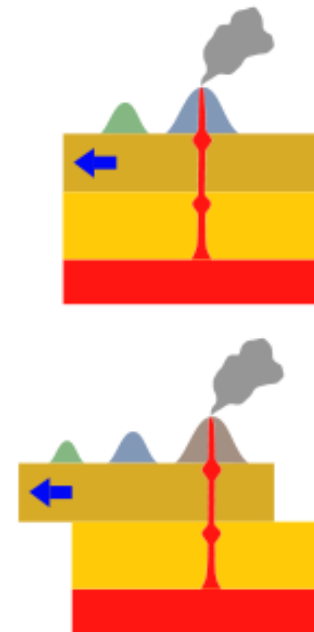
In order for melting from a mantle plume in the Earth's interior to reach the surface, there are two obstacles to overcome. Surface heat flow is determined by how thick the tectonic plates are and how fast they are moving.

Thickness



Thicker lithosphere is more difficult to "melt" through. The thickness requires more heat to reach the surface, to erupt molten lava, and to make a volcano. In the above diagram, notice that oceanic lithosphere is thinner than continental lithosphere.

Motion



Faster moving lithosphere is more difficult to "melt" through. Upwelling hot material melts the base of the lithosphere. Then, the lithosphere moves out of place. The process of melting has to start over again.

Heat Flow: Lithosphere Thickness

The crust of continents and ocean are made of different kinds of rock. They vary in thickness and conduct heat flow differently.



Oceans are basaltic. Ocean crust is only 0-10 km thick. This is much thinner than continental crust. The thinner crust, along with relatively rapid hydrothermal circulation, allows more of the Earth's interior heat to conduct through.

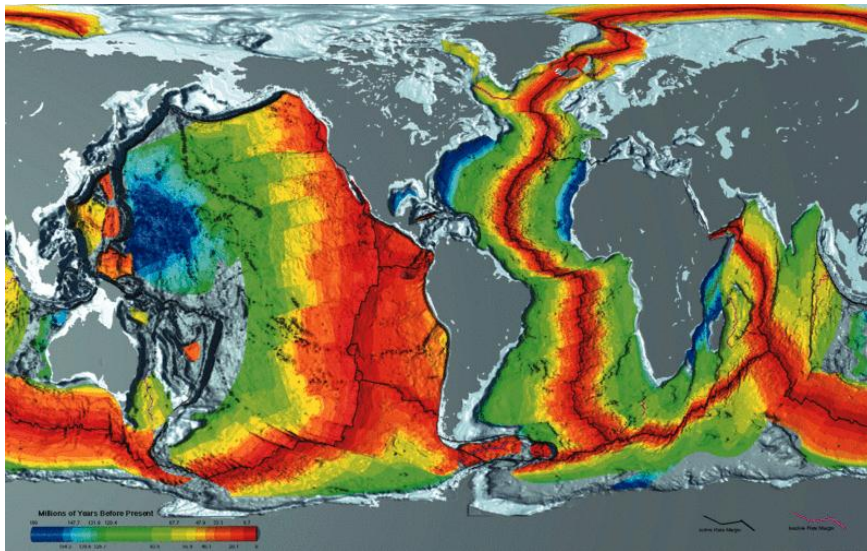


Continents are granitic. Continental crust is 35-70 km thick. This is much thicker than oceanic crust. The thick crust acts like an insulating blanket, reducing heat flow from the interior to the surface.

Heat Flow: Ocean Floor

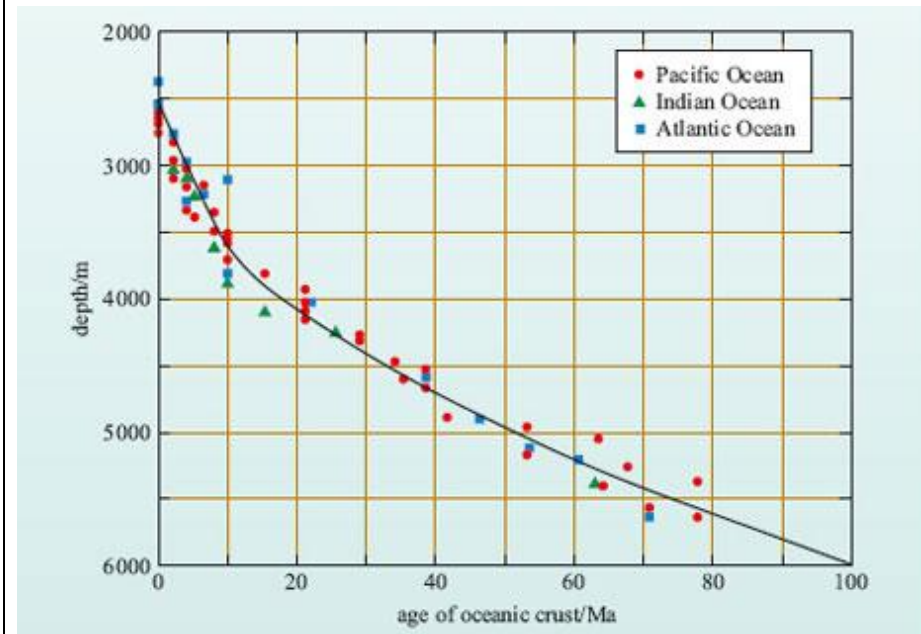
The youngest parts of the ocean floor are hot and shallow compared to older parts that are cold and deep.

Young is Hot, Old is Cold



Heat flow is greatest at very young ocean floor, because it starts out as molten lava, then cools with age. In the map above, red areas are hotter, greener areas are cooler.

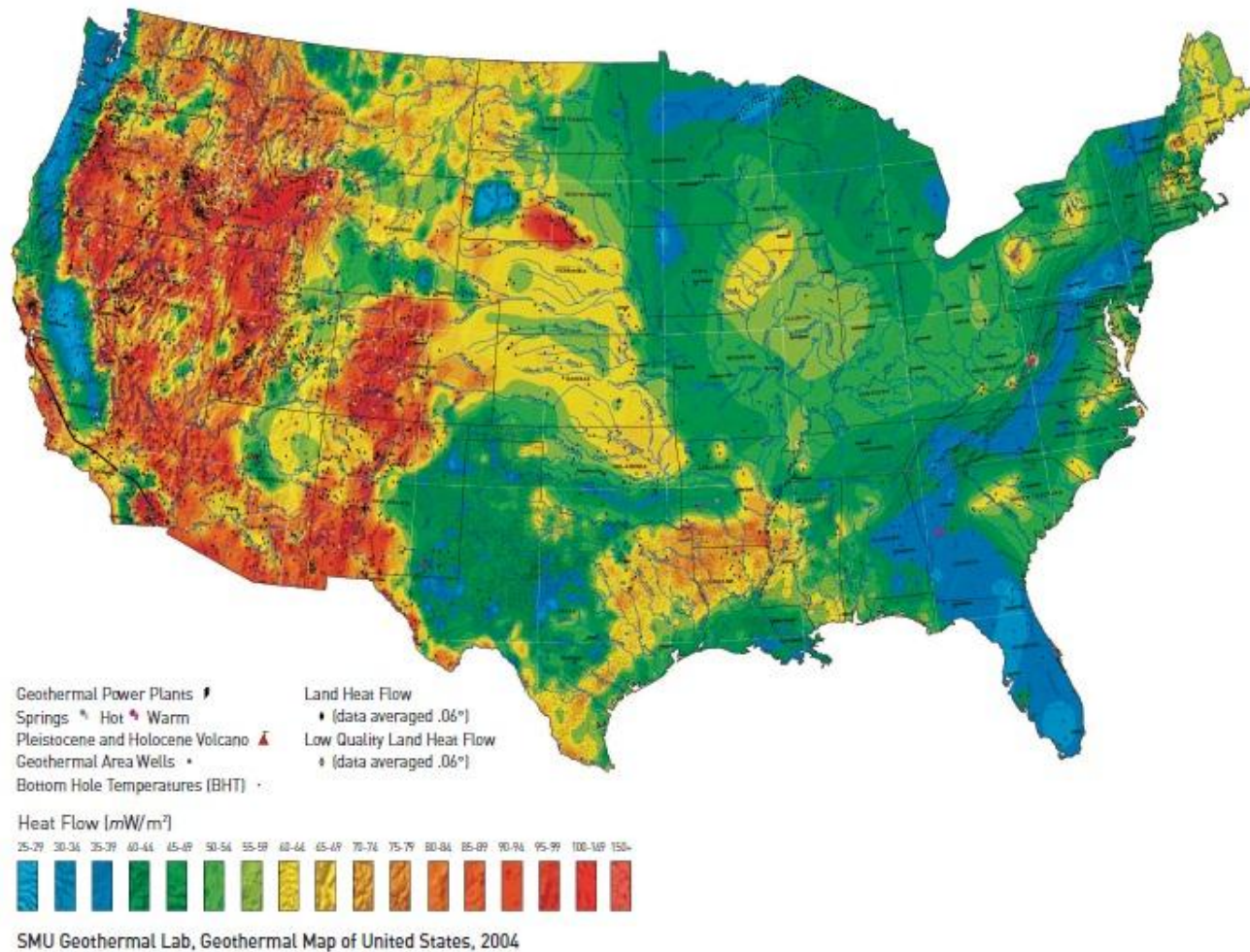
Young is Shallow, Old is Deep



As ocean lithosphere ages and cools over time, the cooling causes it to become denser (like most substances that contract when cooled), and thus subside to greater depths. The mass of rock from the deep mantle to the surface is roughly constant wherever you go, but because the rock density depends on temperature, cooler places are not as high, and are thus covered with deeper water. Younger areas with high heat flow are shallower.

Heat Flow: United States

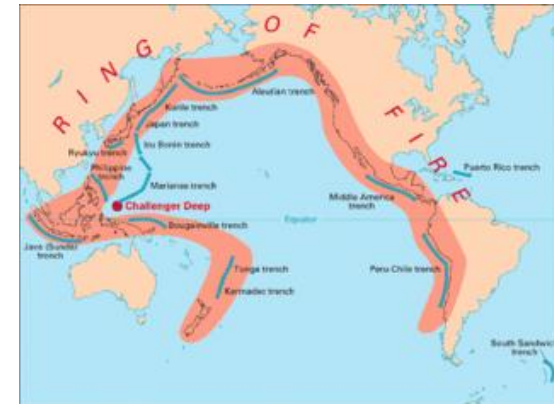
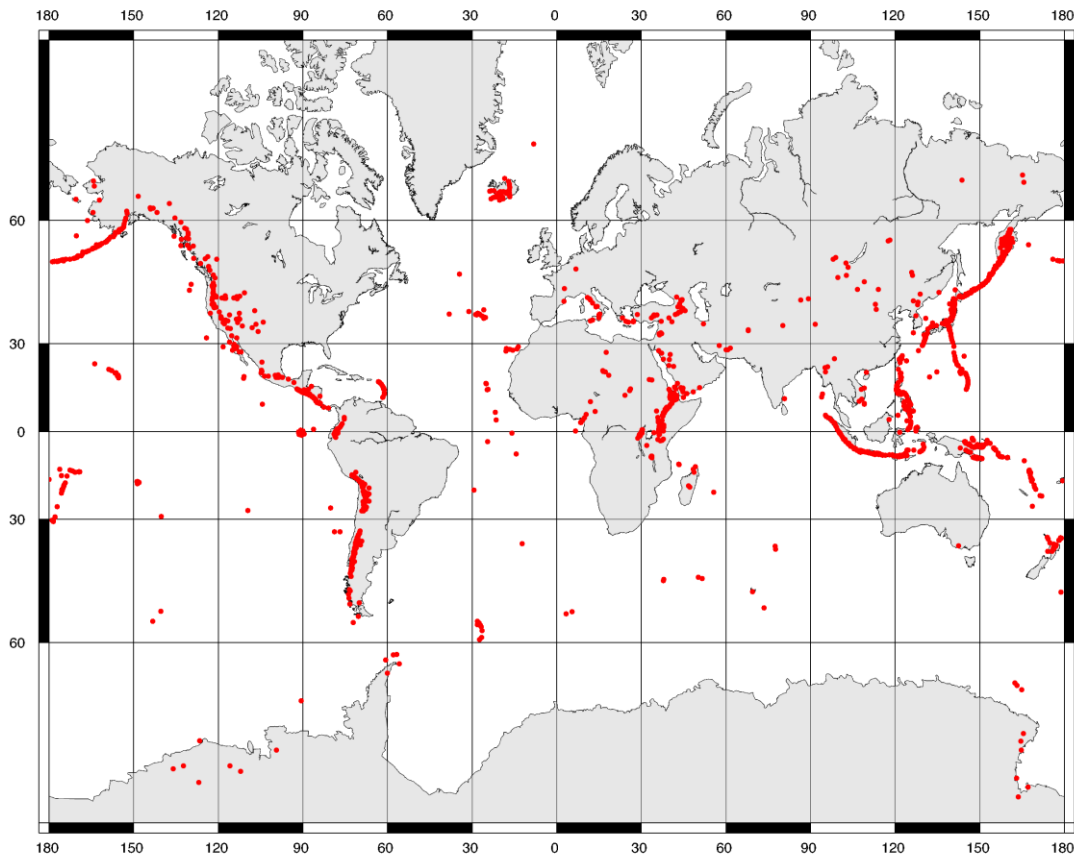
The continental crust of the United States has hotter areas with high heat flow and colder areas with low heat flow.



The Appalachian Mountains and Sierras are thickened continental crust with low heat flow. In essence, tectonic compression that made the mountains and their mountain roots thickened the insulating blanket of continental crust, thus reducing surface heat flow. Florida is underlain by very old, cold lithosphere that was once part of Africa, and thus also has low heat flow.

Evidence of Heat Flow: Volcanoes

The partial melting of rock deep in the Earth creates lava. Magma accumulates in an underground chamber and rises through the crust to the surface to form a volcano. Erupting "pyroclastic" material can include anything from lava (molten fluid rock) to ash (tiny, dust-sized fragments of frozen melt from an exploding magmatic foam).



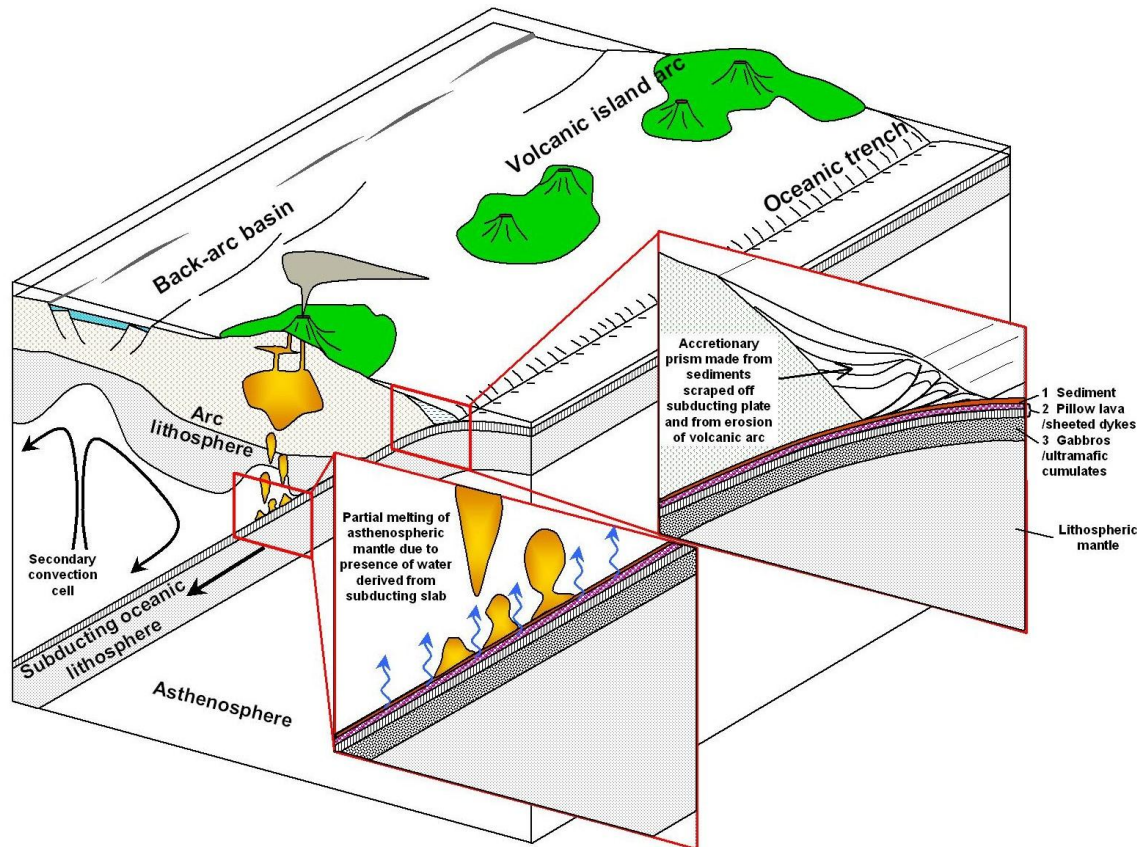
Most volcanoes occur at plate boundaries. The Pacific Ring of Fire is a well-known series of volcanoes occurring around the Pacific plate.



Volcanoes that do not occur at plate boundaries are called hot spots. The Hawaiian Islands are examples of this type of volcano.

Heat Flow: At Convergent Boundaries

Melting beneath the crust occurs for two basic reasons. A close look at a subduction zone explains the first reason. Subduction zones drive ocean crust and its blanket of marine sediments down into the mantle.



The subducting slabs are relatively cold. They have been at the cold ocean bottom and have cooled since formation at a mid-ocean ridge. Further, the sediments they carry contain minerals that have low melting points, having been formed at the Earth's surface at cool temperatures.

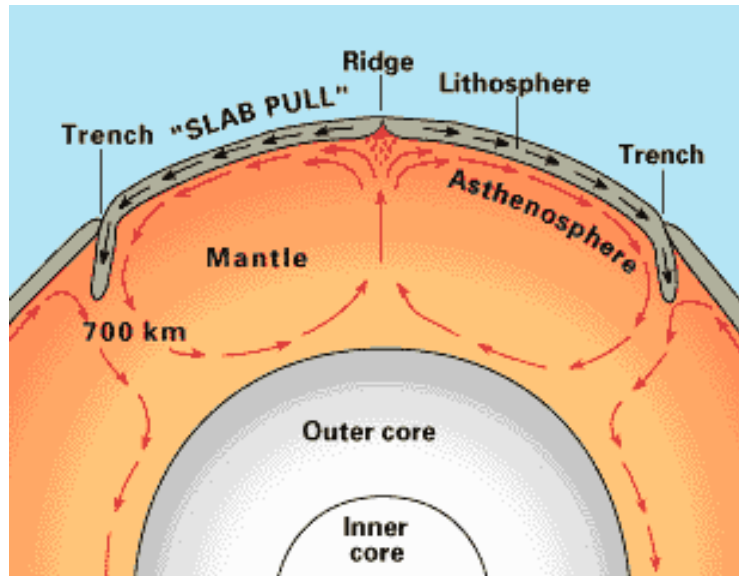
Subducting slabs are also accompanied by water, which further depresses melting points for the minerals. Consequently, as the slabs are carried into the deeper, hotter mantle, they heat up and partially or completely melt.

This molten rock, or magma, is less dense than the surrounding rock, and rises buoyantly through the lithosphere to the surface where it makes volcanoes.

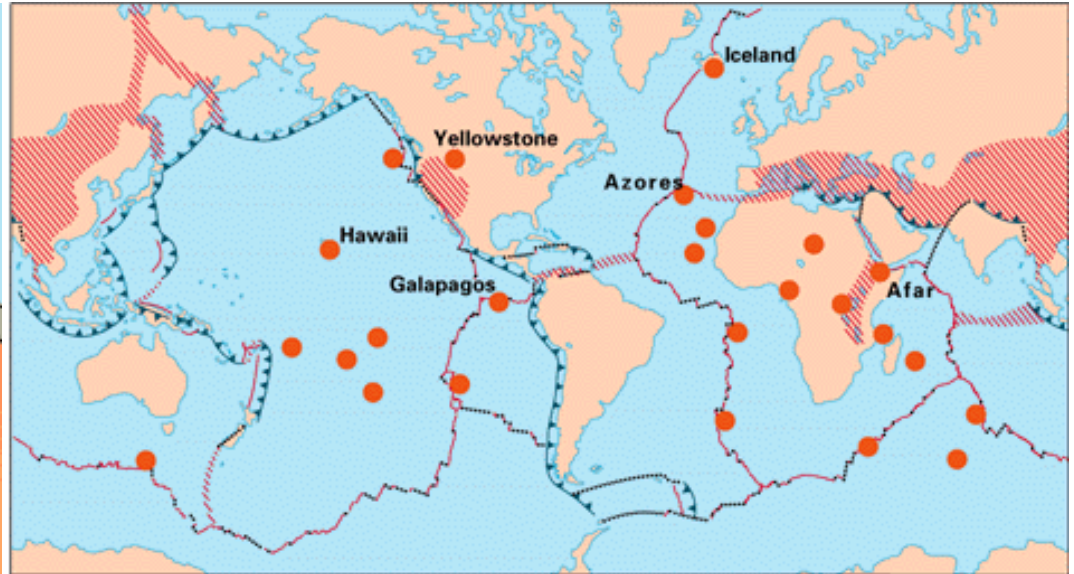
Volcanoes occur wherever subduction occurs and are found at all convergent plate margins. They are the most common type of volcano aside from mid-ocean ridges.

Heat Flow: Hot Spots

The other reason melting occurs beneath the crust is mantle convection. Mantle convection brings heat to the surface causing hot spots to occur.



Heat is delivered to the base of the lithosphere by mantle convection that brings hot material to shallower depths, thus releasing pressure, enabling melting of both the rising material, and the lithospheric rocks that it contacts. The sites where volcanoes form from this sort of deep-seated heat delivery are called **hot spots**.



Modern seismic imaging has made it possible to construct the distribution of mantle convection cells globally. They are roughly, but not completely uniformly distributed around the Earth.

Hot spots can and do occur anywhere on the Earth's surface. However, because the lithosphere is thicker in some places than others, and because lithospheric plates move laterally relative to the mantle convection system at various rates, some plates and parts of plates have more hot spots than others. As a result, the slow moving plates that include continents such as Africa and Antarctica have numerous hot spots, as do thin plates, such as the Pacific plate, which is entirely composed of thin ocean lithosphere.