

Origin of Magma

From our discussions of the structure of the interior of the Earth, it is clear that the upper parts of the Earth (crust and mantle) are mostly solid because s-waves penetrate those regions. So, do magmas come from the outer core? It is a liquid, but it is the wrong composition. If this is a surprise, you may want to return to the discussion of the composition of the core in the text.

Most mafic magmas come from the upper mantle and lower crust. This handout will address five questions:

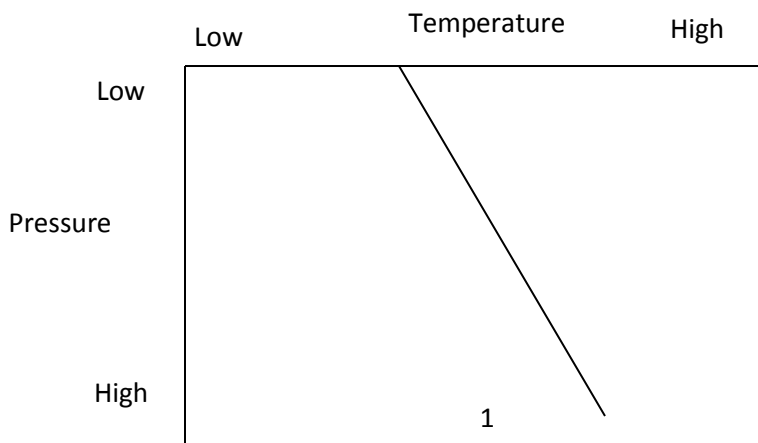
- 1) How do the rocks of the upper mantle and lower crust melt to produce magmas?
- 2) How do we get basalt, andesite, dacite, and rhyolite from rocks that are very low in silica content such as peridotite?
- 3) How do magmas form at divergent plate margins?
- 4) How do magmas form at convergent plate margins?
- 5) How do magmas form in the middle of plates?

How do the rocks of the upper mantle and lower crust melt to produce magmas?

A common answer that people give is that increased temperature will cause a rock to melt. Although this is true, there are two other factors that have an important affect in melting: the pressure on the rock and the amount of water present. In general, thermal energy causes the atoms to move more rapidly even if the atoms are tightly bonded together. At the melting point there is sufficient energy to break most of those bonds and a liquid is formed. In some cases we see evidence that crustal rocks have melted when hot igneous rocks have intruded them. This melting is not widespread and is normally found very close to the boundaries of a batholith or other intrusion.

Lithostatic pressure (pressure due to the weight of the overlying rocks) constrains the motion of the atoms, making it **more** difficult for melting to happen. If we could push a rock deeper and deeper into the Earth, would it melt? The interior of the Earth is hot and gets hotter the deeper we go; however, pressure is also increasing. S-waves from earthquakes tell us that the upper mantle and lower crust are solid. Thermal energy inside the Earth is not sufficient to overcome the tremendous pressure due to the weight of the overlying rocks. This means the melting **does not happen due to the rock being pushed deeper and deeper into the Earth.**

The graphs below represent pressure along the y-axis (notice that we turn the graph so that increasing pressure is in the negative y-axis direction—this is to give the representation of depth inside the Earth) and temperature along the x-axis. Label the solid and liquid regions of this graph.

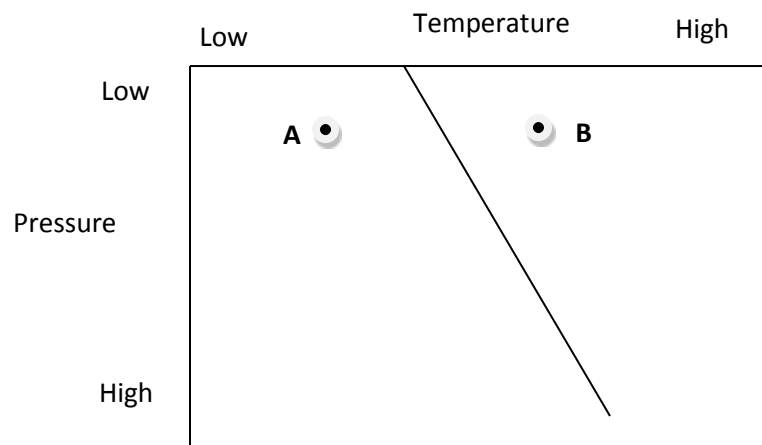


Why does the line separating the liquid and solid regions slope to the right with increasing temperatures and depth?

With additional depth in the Earth, melting requires higher temperature to overcome the effects of additional pressures constraining the atoms.

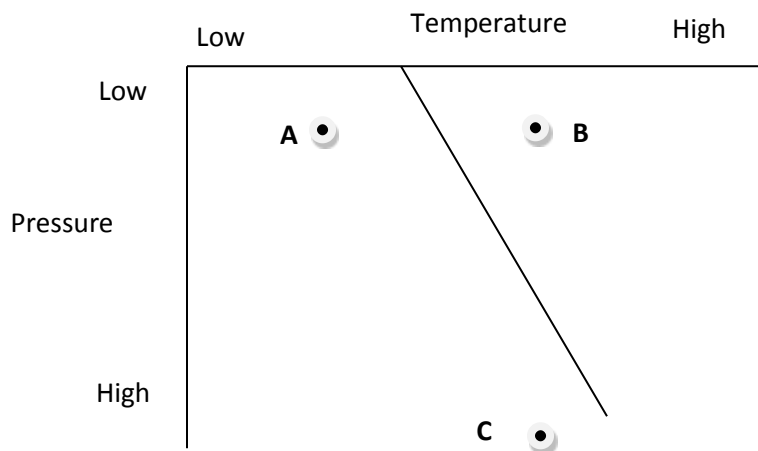
Describe what would happen if a rock changed from A to B in the graph below and your reasoning for this change:

From A to B is only an increase in temperature. This would be like what happens when a host rock is intruded by magma and there is local, small scale melting.



Describe what would happen if a rock changed from A to C in the graph below and your reasoning for this change:

If the rock changed from A to C, the rock would be deeper in the Earth and still solid. The pressures at this depth are too great for melting.



The path from C to B would represent a decrease in pressure while the temperature is constant. This creates melting.

If rock in the mantle melts one possible explanation for the melting is that the rock moved closer to the surface of the Earth, causing a decrease in pressure.

How do we get basalt, andesite, dacite, and rhyolite from rocks that are very low in silica content such as peridotite?

The upper mantle of the Earth appears to consist primarily of peridotite (an ultramafic rock that is primarily pyroxene (augite-like minerals) and olivine). Peridotite is a silicate rock, but it has a lower silica content than basalt/gabbro. That is, if we completely melt peridotite, we do not get basaltic magma. If it is the mantle that generates basaltic magma, how does this transformation happen? To answer question imagine that we have a mixture of 12% alcohol and 88% water that is frozen in a very cold freezer. Below are the melting temperatures of alcohol and water.

Water melts at 0° C (32° F)

Alcohol melts at -117° C (-179° F)

If we put the frozen block of this mixture on the countertop, will the water or the alcohol melt first? ***The alcohol—it has the lowest melting temperature***

So, as the block melts, the _____ will be the first melted product. This same type of **partial melting** happens with peridotite. The first liquid that melts from peridotite is basalt. This is due to: ***the basaltic fraction of the peridotite has the lowest melting temperature.***

How do magmas form at divergent plate margins?

At plate margins that are diverging, the asthenosphere rises into the region where the plates separate. If the rock in the asthenosphere moves toward the Earth's surface, the lithostatic pressure will decrease. This change in pressure causes the rock to melt because:

The decompression permits the rock to expand and it is over the melting temperature for basalt.

Based on the model of partial melting and the knowledge that lower silica materials melt at a lower temperature than high temperature rocks, describe how basaltic magmas form at divergent plate boundaries.

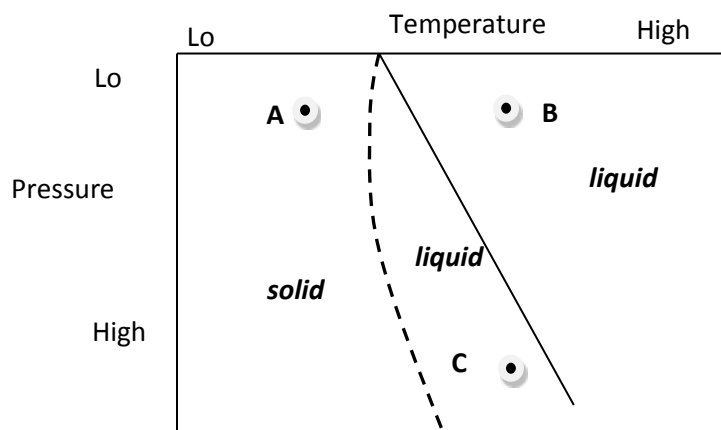
Peridotite moves toward the surface in divergent zones. This movement toward the surface decreases the pressure on the peridotite causing the partial melting forming basalt from the peridotite. The basaltic magma then moves toward the Earth's surface because it is less dense.

How do magmas form at convergent plate margins?

Although it may initially seem simple that a subducted plate melts as it sinks deeper in the Earth, we previously found that this does not work because:

At depth there is too much pressure to permit rocks to melt.

Another way that melting happens in the Earth is due the presence of water. Water causes rock to melt at lower temperatures than if the rock is dry. Label the solid and liquid regions in the graph below if the dashed line is the line for wet rock:



Notice that point C is now in the liquid zone. So, rock can melt at depth if the rock has water present.

In a convergent plate boundary, how does water get incorporated into in the boundary?

Clays contain water and clays are formed at the divergent zone due to the circulation of hot water through the crust.

The water in the plate is found in small fractures in the basalts and as water in clays. The water in fractures is expelled early as the oceanic crust is subducted. The water in the clays must reach a certain temperature to be expelled, which requires that the plate descend to a certain depth. (This is analogous to water being driven off from clay in a kiln in a pottery studio.) At this depth the rock above the plate is mantle rock, peridotite. The water moves into the mantle causing it to melt. What is the partial melting product of peridotite discussed previously in this handout?

This basalt will rise toward the surface because it is less dense than the surrounding rock. Sometimes this basalt migrates to the Earth's surface forming a basaltic lava flow. (Ape Cave at Mt. St. Helens formed as a lava tube in a basaltic lava flow from St. Helens.)

The basalt generated in the subduction zone may also melt continental crust. Recall that the melting temperature of the higher silica igneous rocks is lower than basalt. This means that thermal energy from the basalt will melt the continental crust which is primarily dioritic in composition. This melting generates magmas of a higher silica content such as andesite or dacite.

How do magmas form in the middle of plates?

Chemical analyses of basalts from mid-ocean ridges and volcanoes within the plates show that the magma sources are different. As described before, the sources of basalts in divergent zones are relatively shallow. However, basalts forming volcanoes within plates are most likely from the deep mantle. The volcanism within plates is termed “hot spot” volcanism. The processes that cause melting in the deep mantle that create hot spots are not well understood. There is a possibility that upwelling of the outer core into the mantle may cause some of the overlying mantle rocks to convect toward the Earth’s surface.

Summary:

Basaltic magma forms from melting of: *the mantle (peridotite)*

The intermediate and high silica volcanic rocks are normally formed by the melting of:

The continental crust

Magma at divergent plate boundaries is formed by:

Basaltic magma forms from peridotite in the mantle. As the peridotite is moved closer to the surface, the pressure is decreased and the rock begins to melt. The first melting product of a peridotite is basalt.

What is the role of water in forming magmas formed at convergent plate margins (like the Pacific Northwest)?

Water expelled from a subducting plate lowers the melting temperature of the overlying mantle rock (peridotite). As discussed before, the first melting product of peridotite is basalt. This basalt moves toward the Earth’s surface and begins to melt the continental crust. The melted continental crust forms the intermediate and high silica magmas of andesitic, dacitic, or rhyolitic composition.