Geothermal gradient and magma generation teachers' guidance

This topic covers content from the Geology A level however it may be useful content for GCSE/A level standard science clubs or for students interested in pursuing Earth science further at university

Learning outcomes

- Understand what the geothermal gradient is
- Understand that the lithosphere and asthenosphere are made from solid rock – the lithosphere is rigid and brittle but the asthenosphere can flow plastically
- Be able to use the geotherm to describe why in a normal crust-mantle situation magma is not generated
- Be able to use the geotherm to describe the three situations where magma can be generated

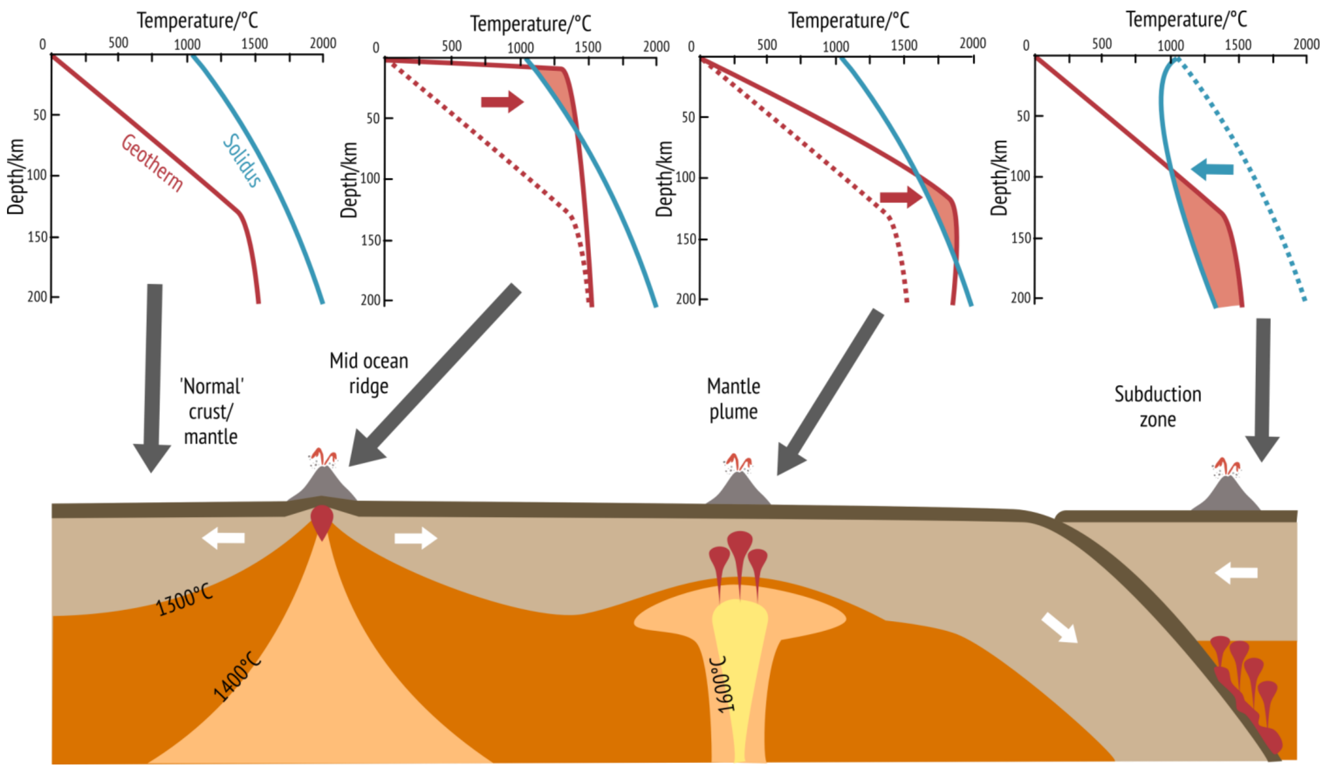
Useful definitions

Lithosphere – the rigid outer part of the Earth made from the crust and upper parts of the mantle which mechanically acts as a single unit. The lithosphere is brittle and cannot flow.
Asthenosphere – the upper mantle below the lithosphere which is ductile and can flow plastically – but is still a solid.
Magma – molten or semi-molten rock below or within the Earth's crust from which lava or other igneous rocks are formed upon cooling

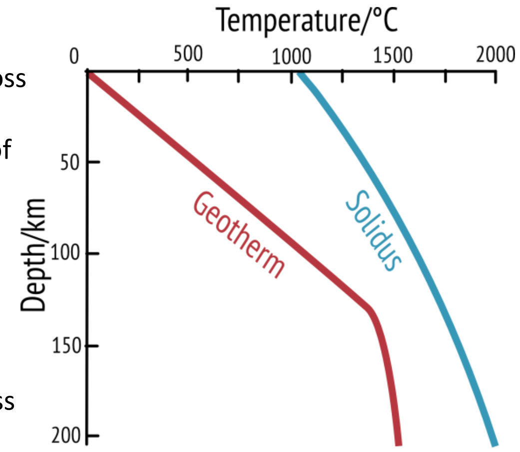
Where does magma come from?

To have a volcano erupt we first need to make liquid magma. The interior of the Earth is hot due to the decay of radioactive minerals like potassium, uranium and thorium and from the residual heat from the formation of the Earth and solar system (small moons and asteroids crashing together produces a lot of heat!). Because of this the Earth's core is 5000-6000°C. Even though the core of the Earth is really hot the lithosphere and asthenosphere are not hot enough to be liquid rock and the Earth's tectonic plates <u>do not</u> float upon a sea of molten magma (a common misconception). The asthenosphere is instead solid rock (peridotite in composition) that can flow plastically. Magma generation can all be explained through the Earth's geothermal gradient.

Please note that the following graphs are for demonstration purposes so may be exaggerated in some parts.

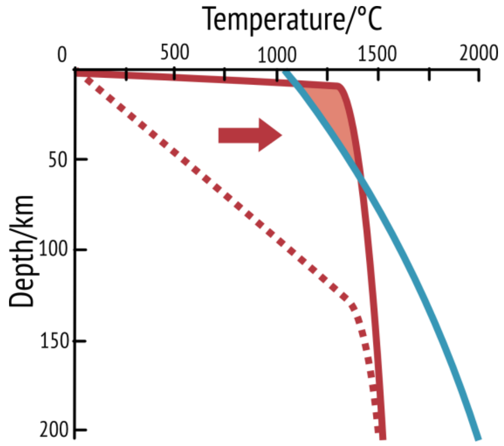


The red line on the graph is the geothermal gradient which shows the rate of increasing temperature with respect to increase with depth into the Earth's interior. On average (i.e. away from plate boundaries and hotspots) temperature increases at a rate of 25-30°C per km in the lithosphere. The kink in the geothermal gradient indicates the lithosphere-asthenosphere boundary which occurs at ~1300°C.

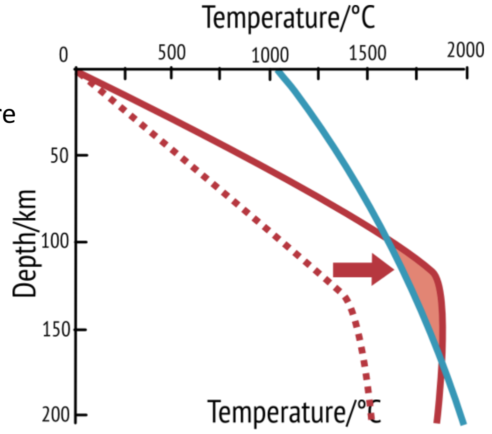


For rocks to melt the geothermal gradient (or geotherm) must cross the solidus (blue line). The solidus marks the transition from solid rock to rock that can melt and form pockets of magma. Because of pressure increases the solidus increases in temperature the further down you go. In an average section of crust and mantle the geotherm <u>does not cross</u> the solidus and therefore no liquid magma can be produced (the solidus is for the rock peridotite which makes up the average composition of the mantle).

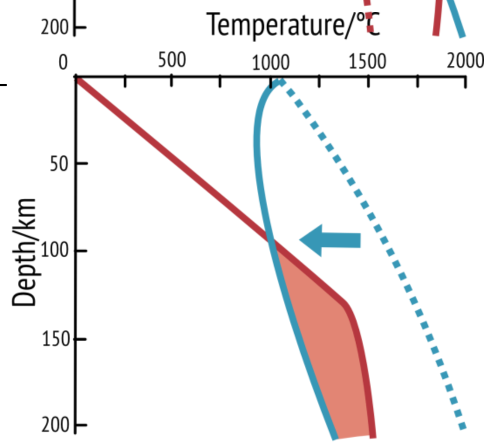
There are three situations where we can get the geotherm to cross the solidus and therefore we can get melting and so we can get magma for our volcanoes.



Mid ocean ridge
This graph shows what happens at a divergent/constructive boundary – a point where two plates are moving away from each other (for example the Mid Atlantic Ridge or the Pacific Rise). Because the lithosphere is thinned here, the asthenosphere (1300°C) rises and therefore geotherm moves upwards and crosses the solidus near the top of the graph. Therefore in this zone magma can be generated and we can get volcanoes and new basalt ocean crust.



Hotspot
This graph shows what happens when we increase the temperature of the mantle. This happens when there is a hotspot in the mantle for example under the Hawaiian Islands. Because the mantle temperature is hotter than usual, the geotherm shifts to the right and crosses the mantle solidus. Therefore we can generate molten magma.



Subduction zone
This graph shows what happens when water gets into the mantle – this is what happens at subduction zones (destructive/convergent boundaries) where one tectonic plate is thrust beneath another. Hydrated minerals in the crust heat up and release water into the mantle. This lowersthe mantles melting point and therefore the shape of the solidus changes – hydrated mantle rocks melt at a lower temperature and whilst the geotherm has stayed the same, it now crosses over the solidus and can generate magma.