Partial melting - simple process, huge global impact

How partial melting, coupled with plate tectonics, has changed the chemistry of our planet

Demonstrating partial melting
Prepare two small beakers as described in the resources section below.

Pre-prepared beakers

Photo: C. King.

Show the pupils the beaker containing the mixture of gravel and chopped candlewax before heating; ask what will happen if the beaker is heated until the wax melts. Most will realise that the gravel will sink to the bottom to form a mixed gravel/wax layer, whilst pure wax will flow to the top to form another layer. Then use the second beaker to show that this is what happens.

Explain that this shows the results of partial melting. When solids made of mixed materials start to melt, the substances with the lowest melting point melt first – giving a partial melt. The substances with the highest melting points often don't melt, but sink through the partially molten material to the bottom. The material that flows to the top cools and solidifies; it is composed only of the lower melting point material.

From gravel/wax to rocks
Rocks are made of minerals, which all have different melting points. Minerals containing oxygen (O) and silicon (Si) have the lowest melting points, whilst minerals that contain iron (Fe) and magnesium (Mg) have the highest melting points. When rocks are heated, they often don't melt completely – they partially melt to produce magma richer in oxygen/silicon than the original rock. This has enormous implications for igneous processes and the chemistry of the whole planet.

Explaining the planetary effects of partial melting
Each time that partial melting takes place during different stages of the plate tectonic cycle, materials with different chemical and physical makeup are formed.

The starting point for these processes is the mantle, where the most abundant elements are oxygen, silicon, magnesium and iron in that order. However the Earth's crust contains much more silicon and oxygen and much less magnesium and iron than the mantle, and is formed through these stages:

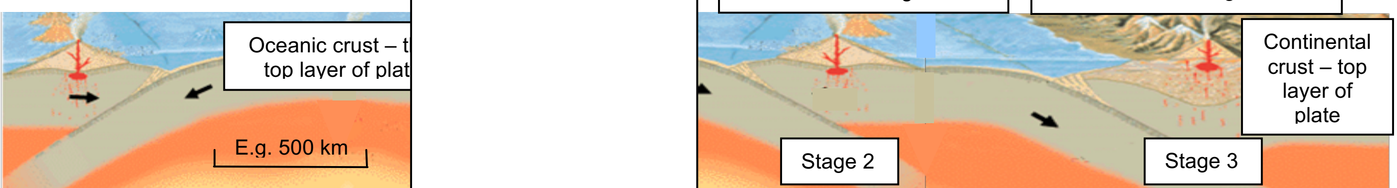
Stage 1: the mantle partially melts beneath oceanic ridges; the melt formed is richer in oxygen/silicon (and poorer in iron/magnesium) than the original mantle rock. This rises and then cools to form new **oceanic crust** and ocean ridge volcanoes, as plates move apart.

Stage 2: the oceanic crust subducted beneath oceanic plates partially melts; the melt is still richer in oxygen/silicon (and poorer in iron/ magnesium) than the original oceanic crust rock. It rises to the surface to form **island arc volcanoes**, often in violent eruptions [Note that island arc volcanic magma is produced by a series of complex processes, and partial melting is only part of this story].

Stage 3: the oceanic crust subducted beneath continental plates partially melts, but the base of the continental plate also partially melts. The melt is even richer in oxygen/silicon (and poorer in iron/magnesium) than the original oceanic crust rock. This rises to form oxygen/silicon-rich rocks that either cool slowly underground to form granites, or rise to the surface in violent volcanic eruptions to form new **continental crust**. This is therefore much more oxygen/silicon-rich (and iron/ magnesium-poor) than the previous rocks.

From mantle to continental crust
So, mantle rock becomes richer and richer in silica, through three stages of partial melting, to form oxygen/silicon-rich continents. Since these have relatively low density, they can never be subducted and will remain 'floating' at the Earth's surface for ever.

Most of the world's people therefore live in a silica-rich environment because of the partial melting process, coupled with plate tectonics – they live on the floating 'scum' of plate tectonic processes.



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The back up

Title: Partial melting - simple process, huge global impact.

Subtitle: How partial melting, coupled with plate tectonics, has changed the chemistry of our planet.

Topic: A simple demonstration of partial melting leads into an explanation of how this has affected the chemistry of the planet, and the characteristics of igneous rocks and eruptions.

Age range of pupils: 14 – 18 years

Time needed to complete activity: 15 mins

Pupil learning outcomes: Pupils can:

- use the gravel/wax partial melting demonstration to explain how partial melting of a rock will produce a magma with a different chemical composition from the original rock (often richer in oxygen/silicon and poorer in iron/magnesium);
- explain how three stages of partial melting that can take place as part of plate tectonics, produce crustal rocks that are progressively richer in oxygen/silicon (and poorer in iron/magnesium).

Context:
The effects of partial melting on rocks and the planet can be summarised in a table.

Material	Chemical composition	Typical igneous rocks	Typical eruption style	Photo	Photo acknow-ledgement	
Continental crust and continental volcanoes	Even richer in O/Si and poorer in Mg/Fe than oceanic crust	• Rhyolite (fine) (also andesite) • Granite (coarse) (also volcanic ash)	High and very high viscosity, so frequently very violent, eg. Mt Redoubt - opposite		*These images are in the public domain because they contain materials that originally came from the United States Geological Survey.*	↑
Island arc volcanoes	Richer in O/Si and poorer in Mg/Fe than oceanic crust	• Andesite (fine) • Diorite (coarse) (also volcanic ash)	High viscosity, so violent, eg. Montserrat - opposite			Progression
Oceanic crust and oceanic volcanoes	Richer in O/Si and poorer in Mg/Fe than the mantle	• Basalt (fine) • Gabbro (coarse)	Low viscosity, so gentle (unless added water makes them explosive), eg. Iceland - opposite			↑
Mantle	Mainly O, Si, Mg, Fe in that order	• Peridotite (coarse)	No eruption	None – since the mantle is beneath the crust and cannot be seen		

Following up the activity:
Try heating the beaker of gravel and chopped wax on a hotplate or Bunsen burner in front of the pupils, to show the results of partial melting in action.

Underlying principles:

- When solid mixtures partially melt, it is the lower melting point materials that melt first.
- Separation can occur in partial melts, with the high melting point materials sinking to the bottom and the liquid from the lower melting point materials flowing to the top. These two different materials, that have different chemical compositions and different physical properties, may then be further separated, eg, by the liquid rising further through overlying materials, leaving the solid behind.
- Oxygen/silicon- rich rock-forming minerals have lower melting points than iron/magnesium-rich minerals.
- Each stage of partial melting produces rocks enriched in oxygen/silicon (and depleted in iron/magnesium)
- Partial melting explains how the mantle, oceanic crust, and continental crust all have different compositions and properties.

Thinking skill development:
The transfer of the partial melting idea from the demonstration to the 'real world' requires bridging. Further discussion of how this affects global products and processes involves elements of construction, cognitive conflict and metacognition.

Resource list:

- two small beakers (eg. 50 or 100 ml)
- fine gravel
- chopped candlewax

Prepare the beakers shown in the photo, as follows. In each beaker, put about 1 cm depth of fine gravel mixed thoroughly with about 2 cm depth of candlewax that has been cut into fragments about the same size as the pieces of gravel. Warm one of these on a hotplate or over a Bunsen until the candlewax melts. At this stage, the gravel will sink to the bottom, leaving a layer of pure candlewax at the top. Leave the beaker to cool and the wax to solidify.

Useful links:
The US Geological Survey has published a useful downloadable book about the plate tectonics on its website, called '*This dynamic Earth: the story of plate tectonics*' available at: http://pubs.usgs.gov/gip/dynamic/dynamic.html

Source: Devised by Chris King of the Earthlearningidea Team. Many thanks to Professor Steve Sparks for his comments on an early draft. This activity forms part of the workshop "The Earth and plate tectonics", Earth Science Education Unit, Keele University, http://www.earthscienceeducation.com .