The deep rock cycle explained by plate tectonics: deformation and metamorphism

A model showing how plate tectonics can explain metamorphism and rock-deformation

When rock cycle processes were first understood more than 200 years ago, the people studying them knew how the processes worked, but did not know the cause of the deep-Earth processes.

It wasn't until about fifty years ago, when plate tectonic theory was accepted, that the causes of these processes were first properly explained.

This Earthlearningidea models how the deformation and metamorphism of rocks can be caused by mountain-building linked to the movement of tectonic plates.

When continents on two different plates are apart, thick sequences of sediments can be laid down on top of the oceanic plate in between them. If a subduction zone develops in this oceanic area, one of the plates is carried down (subducted) into the mantle and the continents are moved towards each other. As the continents meet one another they form a collision zone where:

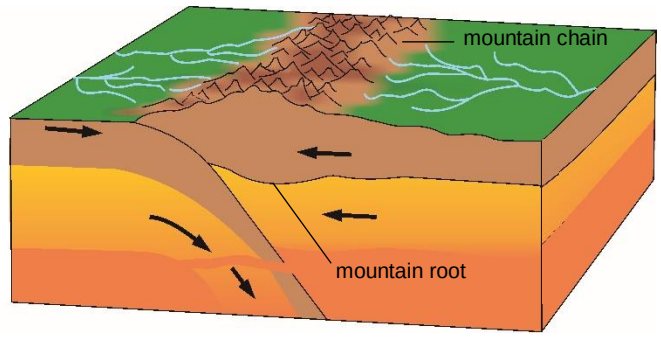
- the enormous sideways (lateral) pressures cause the rocks to be deformed into folds and faults (see the model at: https://www.earthlearningidea.com/PDF/Himalayas_in_30_seconds_final_071029.pdf);
- the deformed rocks rise into mountain chains with deep mountain roots beneath them;
- as rocks become deeply buried, their temperature rises (the rise of temperature with depth is called the geothermal gradient); the collision also increases the temperature;
- under the intense lateral pressures and the high temperatures, the original rocks become metamorphosed into regional metamorphic rocks (see: https://www.earthlearningidea.com/PDF/43_Metamorphism.pdf);
- other changes also occur – as shown in the table in the 'context' section below.

Model how the moving together (convergence) of plates carrying continents can cause deformation, mountain-building and metamorphism as follows.

- Put a piece of paper on one side of a gap between two tables, with a wooden block on top.
- Put part of another sheet of paper down into the gap and lay the rest of it flat on the table; put a wooden block on top, away from the gap.
- Put a piece of cloth such as a folded handkerchief over the wooden blocks.
- *The sheets of paper represent the plates (the* green paper in these photographs).
- The wooden blocks represent two continents which will be moved together by plate movements.
- The folded cloth represents the many layers of sediment laid down by deposition in the ocean and on the continents.

- Pull the paper in the gap downwards to represent the subducting plate
- As you pull, the wooden 'continents' will be moved together, deforming the cloth into folds, pushing up a 'mountain chain' and pushing 'mountain roots' downwards between the blocks.

- The collision zone caused by the converging continents has produced a 'mountain chain' with 'roots' as shown in the diagram below:



The lateral pressures cause deformation into faults and folds in the mountain chain; in the root zone, the intense lateral pressures and the increased temperature cause the rocks there to become metamorphosed into regional metamorphic rocks (see: https://www.earthlearningidea.com/PDF/316_Rock_detective_rock_cycle.pdf

The back up

Title: The deep rock cycle explained by plate tectonics: deformation and metamorphism.

Subtitle: A model showing how plate tectonics can explain metamorphism and rock-deformation.

Topic: A simple model to show how, as the subduction of plates causes continents to move towards one another (converge), the sediments in between are deformed into mountain chains with roots; the rocks in the root zones become regionally metamorphosed.

Age range of pupils: 14 years upwards

Time needed to complete activity: 10 minutes

Pupil learning outcomes: Pupils can:

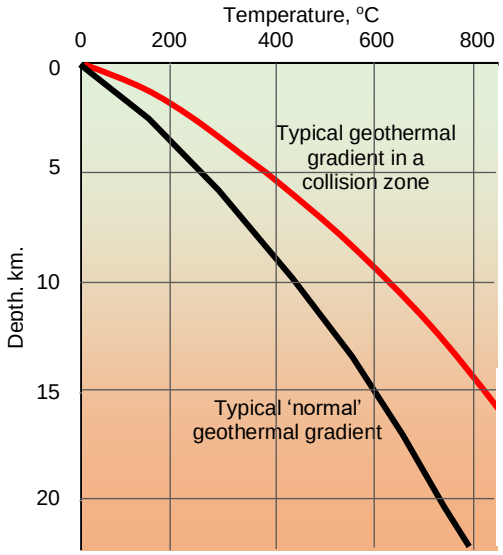
- explain how plates carrying continents are moved together (converge) through plate tectonic subduction;
- explain how this results in sedimentary layers being deformed into mountain chains with roots;
- explain how the rocks become deformed by folding faulting in mountain chains and in the mountain root zones the rocks become metamorphosed by regional metamorphic processes.

Context:
Rock cycle processes were first described by James Hutton and his colleagues around 230 years ago – see: https://www.earthlearningidea.com/PDF/93_James_Hutton.pdf.

The evidence for plate tectonics was first developed into a global theory by J. Tuzo Wilson around 50 years – see: https://www.earthlearningidea.com/PDF/91_Wegener.pdf.

The rock cycle can be modelled in the classroom by: https://www.earthlearningidea.com/PDF/253_Rock_cycle_product_process.pdf. Rock cycle processes can also be modelled and discussed in the classroom, see: https://www.earthlearningidea.com/home/Teaching_strategies.html#rockcycle. Meanwhile, plate movement and plate tectonic processes can be modelled and discussed in the classroom as well, see: https://www.earthlearningidea.com/home/Teaching_strategies.html#platetectonics.

The result of converging continental plates is a 'collision zone' in which the sedimentary layers and other rocks become deformed into mountain chains. In the mountain root zones the geothermal gradient (caused by radioactive decay in some minerals in the crust and mantle together with some of the remaining heat from the early Earth) is increased by collision effects (see red line on the geothermal gradient graph below).



The intense lateral pressures and the increased temperatures regionally metamorphose the rocks. These regionally metamorphosed rocks often have aligned crystals, with the crystal alignment at right angles to the main pressure directions.

Note that mountain-building, with its deformation and regional metamorphic effects also occurs at collision zones between oceanic plates and plates carrying continents.

This table showing how internal rock cycle processes are explained by plate tectonics was taken from King, C. (2019) *Exploring geoscience across the globe*. Pub IGEO at: http://www.igeoscied.org/teaching-resources/geoscience-text-books/ pp 82.

Internal rock cycle process	Plate tectonic explanation
Metamorphism	Regional metamorphism: when mountain chains are formed at ocean-continent and continent-continent plate margins, rocks are carried down to depths where the temperatures and the pressures of the overlying rocks are very high; the extra compressive stress of the colliding plates causes the rock to recrystallise
	Thermal metamorphism: intruded magmas, formed as described below, bake the surrounding rocks in a metamorphic aureole
Melting (partial melting)	At subduction zones: the subducting plate carries water with it; the water and increased temperatures cause the rocks above the plate to partially melt and the lower density magma formed by this process then rises

	At divergent plate margins: beneath oceanic ridges the mantle becomes hot enough to partially melt, generating the iron/magnesium-rich magmas that form new oceanic plate material
Igneous intrusion	As magma at plate margins rises into the cooler crust above, it cools and crystallises in large magma chambers as plutons or batholiths
Volcanic activity	If magma at plate margins and hot spots reaches the surface, it erupts; the eruptions range from relatively safe to catastrophically dangerous
Uplift	When mountain chains are formed at oceanic-continent or continent-continent plate margins, some rock is uplifted whilst other areas are forced down into the roots of the mountains. Since the mountain chain 'floats' in the solid mantle, as the overlying rock is removed by erosion the rocks beneath rise and become uplifted
Deformation	At divergent margins: as the plates are moved apart, the brittle rocks fracture into normal faults, with one side sliding down past the other
	At conservative margins: in transform fault-formation one plate slides past another and the brittle rocks fracture into strike-slip faults
	At oceanic-continent or continent-continent convergent plate margins, the enormous compressive forces cause the rocks near the surface to fracture into reverse and thrust faults; at greater depths, rocks deform through folding

Following up the activity:
Try some of the other Earthlearningideas focussed on convergent plate margins at: https://www.earthlearningidea.com/home/Teaching_strategies.html.

Underlying principles:
- Plates carrying continents are moved towards each other (converge) by subduction.
- As this happens, the sediments and rocks in between are deformed into mountain ranges with mountain roots.
- The mountain chain rocks are deformed by folding and faulting.
- In the root zones, the intense lateral pressures and high temperatures (resulting from the increased geothermal gradient) cause regional metamorphism.

Thinking skill development:
Understanding the model involves construction; applying the model to plate tectonic processes and the rock cycle processes of deformation and regional metamorphism, involves bridging.

Resource list:
- two pieces of A4 paper (maybe coloured blue or green to represent oceanic plates)
- two wooden blocks of wood as shown in the photos, to represent continents
- some folded cloths such as handkerchiefs to represent sediments
- a narrow gap between tables or benches, that the 'oceanic plate' can be made to subduct down into by pulling

Useful links:
See the animation at: https://www.youtube.com/watch?v=G2VQ6diA_0A
Source: Chris King of the Earthlearningidea Team *(photos by Chris).*