Metamorphic processes: controlled by depth, temperature and pressure

What factors control metamorphism?

Metamorphic rocks may be formed from sedimentary rocks, igneous rocks or existing metamorphic rocks. Loose sediments such as mud, silt or sand first become changed to a sedimentary rock by compaction and by cementation of the grains by a natural “cement”. This cement is mostly composed of chemicals dissolved in the water trapped in the pore spaces between the grains of sediment.

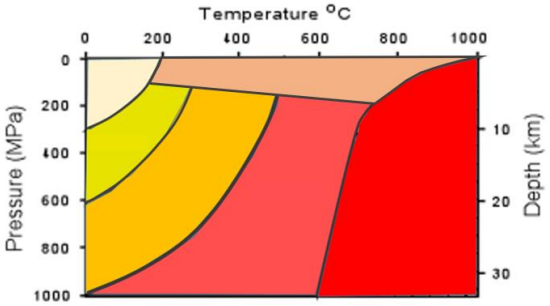
If the sedimentary rock is affected by the heat of a magma rising nearby. e.g. near to a granite intrusion, it may become recrystallised and becomes a metamorphic rock. The main factor causing the metamorphism is the increased heat from the magma, and the process is called thermal metamorphism.

The sedimentary rock may also be metamorphosed by being intensely squeezed from the sides as two plates collide, and become more deeply buried and heated by higher temperatures several kilometres down in the Earth’s crust. This process is called regional metamorphism. It varies from low to high grade, depending on the temperatures and increased pressures. In extreme conditions the rock may begin to melt to form a magma. This is made easier by the presence of water in the rock (which is then referred to as a ‘wet rock’), which lowers the melting point.

Now, label the diagram below, either by using the following terms, which have deliberately been jumbled up, or by cutting out the labels on page 3 and putting them in the right places:

- compaction and cementation into sedimentary rock;
- partial melting of ‘wet rocks’;
- low grade regional metamorphism;
- thermal metamorphism;
- high grade regional metamorphism;
- medium grade regional metamorphism.

(Note that approximate depths in the crust are shown on the right hand side of the graph).



Temperature/pressure graph of the Earth’s crust

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The back up

Title: Metamorphic processes: controlled by depth, temperature and pressure

Subtitle: What factors control metamorphism?

Topic: Identifying the appropriate zones on a pressure/temperature graph for a range of metamorphic processes.

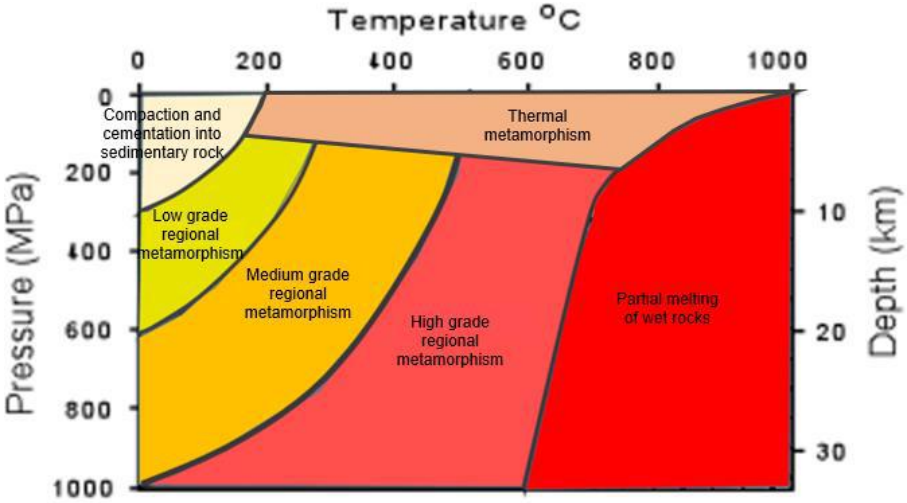
Age range of pupils: 16 -18 years

Time needed to complete activity: 10 minutes, plus 10 minutes for the follow-up.

Pupil learning outcomes: Pupils can:

- describe how changes of temperature are related to distance from a hot body;
- describe the relationship between increased pressure and temperature and the nature of the resulting metamorphic rock.

Context: The activity could form a useful revision lesson on metamorphism. The diagram shows suggested answers to the activity.



Temperature/pressure graph of the Earth’s crust, showing zones of metamorphism

Following up the activity:

- If you have specimens, or good photographs of a mudstone (or shale) and a range of metamorphic and igneous rocks, provide an enlarged version of the diagram above and ask pupils to place the specimens in their correct location on the diagram. *The mudstone should be put in the top left hand corner; coarse-grained igneous rocks should be put at depth in the partial melting zone; medium- and fine-grained igneous rocks should be put at or near the surface of the partial melting zone; slate is in the low grade regional zone; schist at medium grade and gneiss in the high grade zone.*
- Provide a specimen of a limestone and a sandstone, and ask what rocks would be formed if these were to be metamorphosed. *The limestone would become marble and the sandstone, quartzite – or metaquartzite to give it its full title*. *When placed on the graph, marble and metaquartzite can be put anywhere in the thermal or regional metamorphic zones*.
- Ask pupils to name the three main minerals in the gneiss (*quartz, feldspar and mica*). What similarities are there with the minerals of a granite? (*They are the same. Granite can become metamorphosed to gneiss in extreme conditions, the main difference being between the random arrangements of the crystals in the granite compared with aligned minerals in the gneiss*).

Underlying principles:

- Metamorphism involves the recrystallisation of an original rock, without melting taking place.
- The original rock may be of sedimentary, igneous, or metamorphic origin.
- Metamorphism may be caused by increased temperature (e.g. >300^{o}C), and/or by increased pressure.
- The increased pressure mostly comes from plate tectonic forces, which act on the rocks.
- Flaky minerals in a mud-rock (such as clay minerals) recrystallise into other flaky minerals (such as micas) to lie perpendicular to the forces which affected the rock.
- Larger, more equi-dimensional grains, as in sandstone or limestone, tend to recrystallise together in roughly hexagonal shapes when metamorphosed.
- Quartzite and marble can be formed by metamorphism by increased heat OR pressure (or both), however, directed pressure is essential to form a slate, schist or gneiss, with the characteristic cleavage of slate, the schistosity of schist and the banding of gneiss.

Thinking skill development:

Understanding the progressive nature of metamorphism under increasing pressures and temperatures is a constructive activity. Placing the marble and quartzite on the graph may involve cognitive conflict, as does appreciation that igneous and metamorphic rocks may themselves become metamorphosed. Applying the graph to metamorphic rocks on the ground involves bridging skills.

Resource list:

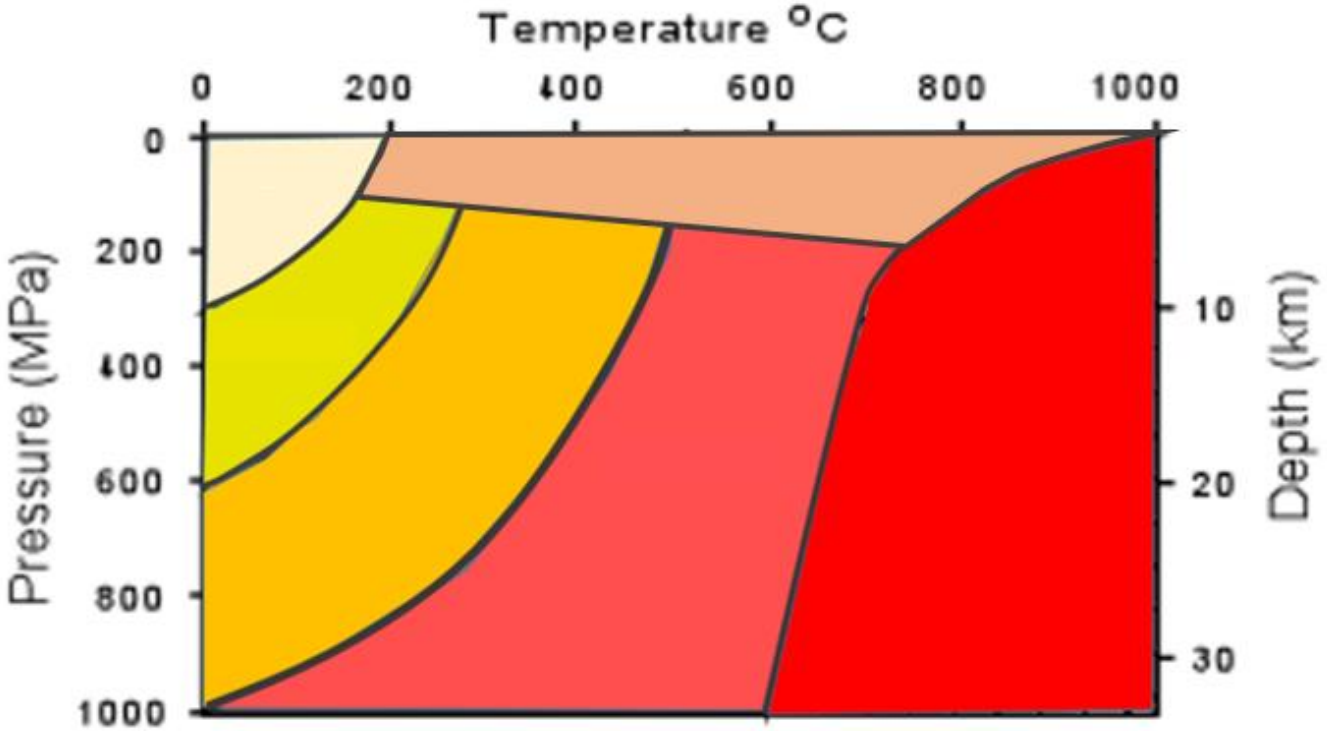
- paper copies of the graphs or the cut outs from page 3;
- optional: specimens or good photographs of sandstone, mudstone, slate, schist, gneiss, marble, metaquartzite and a range of igneous rocks of different grain size.

Useful links:

https://www.earthlearningidea.com/PDF/43_Metamorphism.pdf
https://www.earthlearningidea.com/PDF/252_Metamorphic_aureole.pdf
Also Virtual Rock Kit for photographs of rocks:
https://www.earthlearningidea.com/virtual_rock_kit/START.htm

Source:

The diagram is based on:
http://www.tulane.edu/~sanelson/eens212/metaclassification&facies.htm



medium grade regional metamorphism	partial melting of 'wet rocks'	thermal metamorphism
low grade regional metamorphism	high grade regional metamorphism	compaction and cementation into sedimentary rock