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Metamorphic Rocks
and Processes
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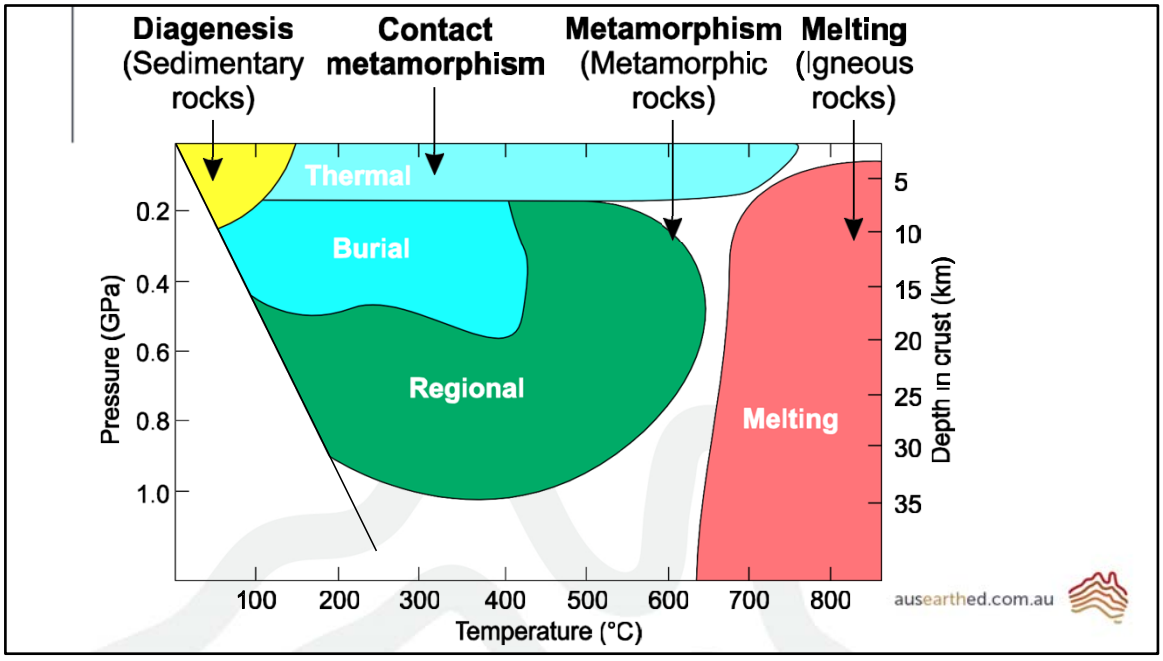
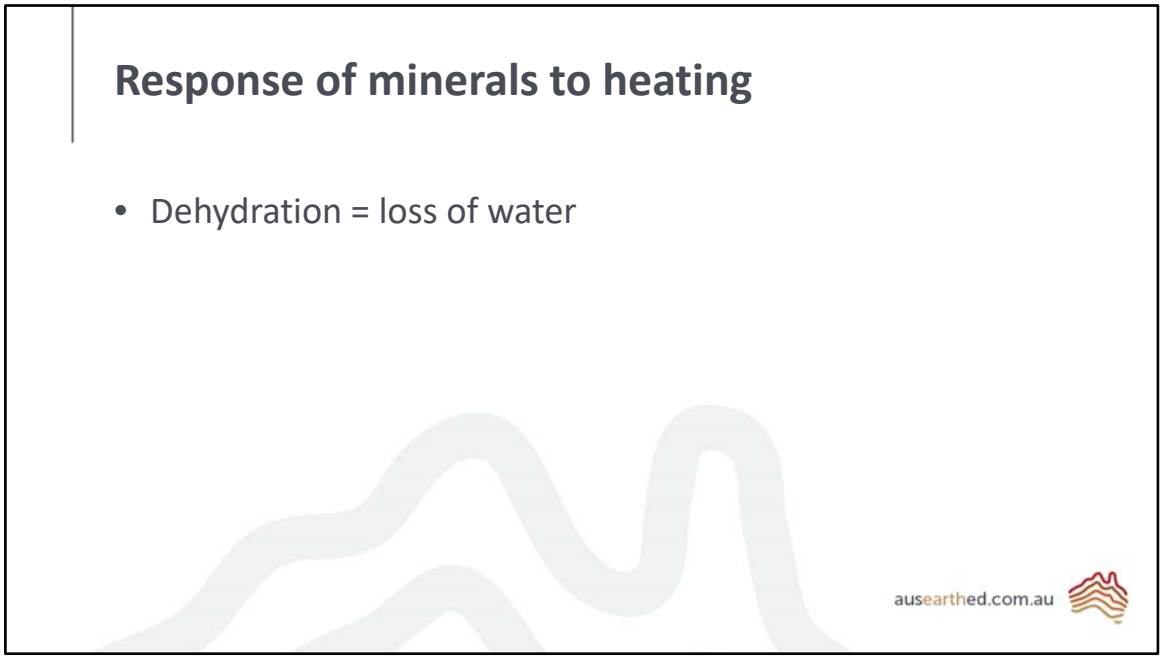


Any rock type subjected to prolonged temperatures and pressures that are different to those of its formation will be metamorphosed. Both the minerals and textures of the rock can change.
The region of diagenesis on this diagram recognises that sedimentary rocks will be subjected to a small amount of heat and pressure in their formation. Temperatures and pressures above this are considered to be when rocks begin to metamorphose.
The upper limit of metamorphism is when rocks melt – moving into igneous

Response of minerals to heating

- Dehydration = loss of water



The most common response of minerals is to dehydrate or lose water.
Minerals like micas often have water in their chemical make-up and when they are heated they become unstable, losing the water.

Response of minerals to heating

- Dehydration = loss of water
- Decarbonation = loss of carbon dioxide

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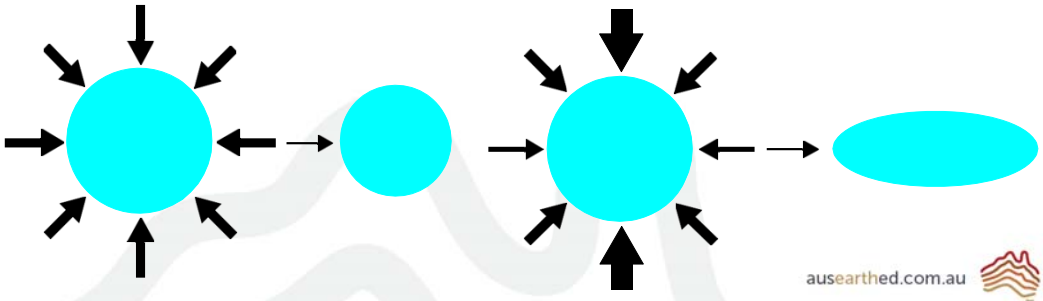
The decarbonation reaction is another response of minerals to heating.
In this case they lose carbon dioxide from their structure.
e.g. the decarbonation of calcite

Response of minerals to pressure

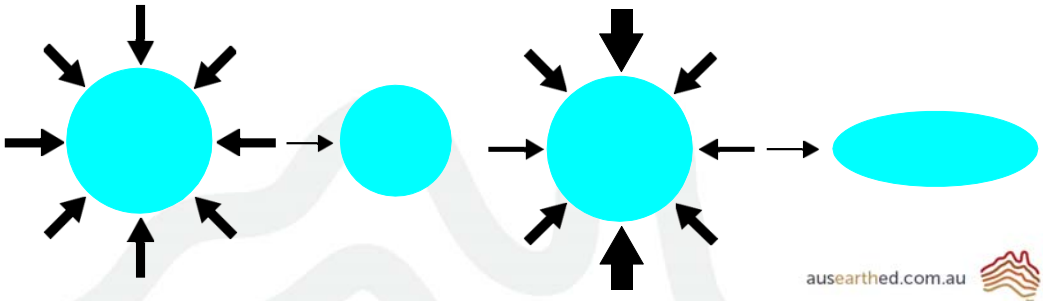
- Changed shape



Depending on the direction of pressure grains and minerals in a rock can be altered

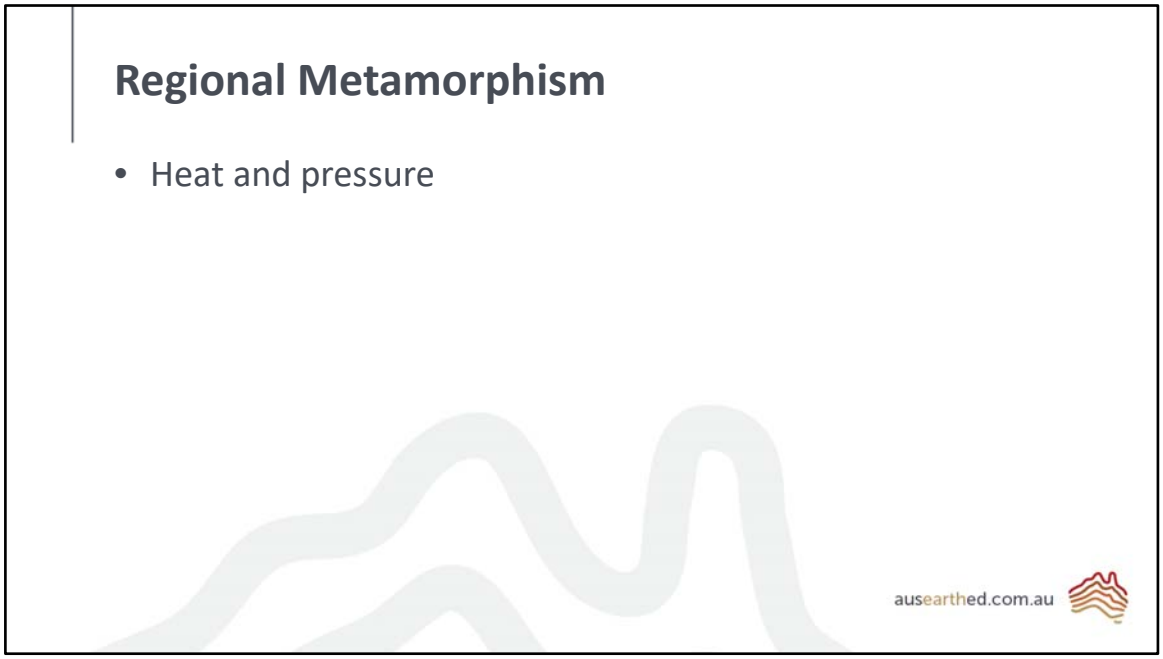
Response of minerals to pressure

- Changed shape
- Changed size



Regional Metamorphism

- Heat and pressure



Exposure of rock to heat and pressure over an extended period of time

Regional Metamorphism

- Heat and pressure
- Common at convergent margins

As the whole region is impacted by heat and pressure – like the cores of mountain ranges (e.g. the Andes)

Regional Metamorphism

- Heat and pressure
- Common at convergent margins
- Very large areas

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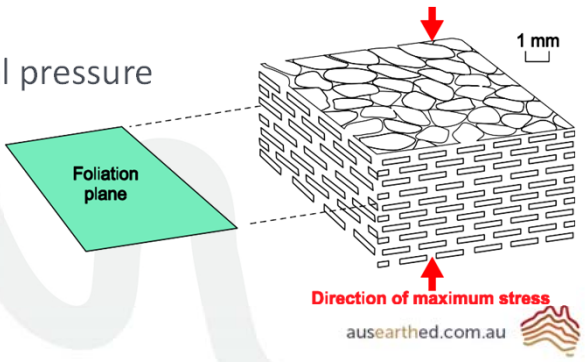
Due to the nature of the margins this occurs at – commonly convergent

Regional Metamorphism

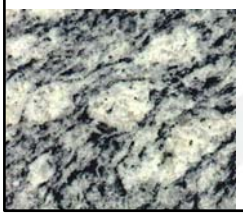
- Heat and pressure
- Common at convergent margins
- Very large areas
- Foliated due to directional pressure

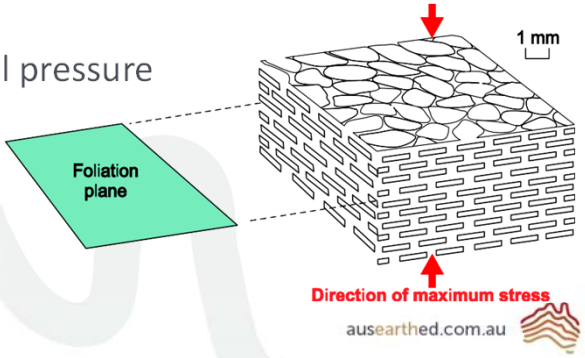


Many regionally metamorphosed rocks will show foliation.
This is due to directional pressure forcing flaky or needle-like minerals to realign (e.g. schist shows schistosity)

Regional Metamorphism

- Heat and pressure
- Common at convergent margins
- Very large areas
- Foliated due to directional pressure
- Often coarser grained





Often coarser grained due to the extended exposure to heat (as minerals will recrystallise slowly)

Rocks from regional metamorphism

slate

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The common parent rocks for a slate is a shale or mudstone.
The parent rock will begin to lose water (dehydrate) and will become composed of clays and micas – parallel orientation of micas gives it foliation – slatey cleavage

Rocks from regional metamorphism

slate

phyllite

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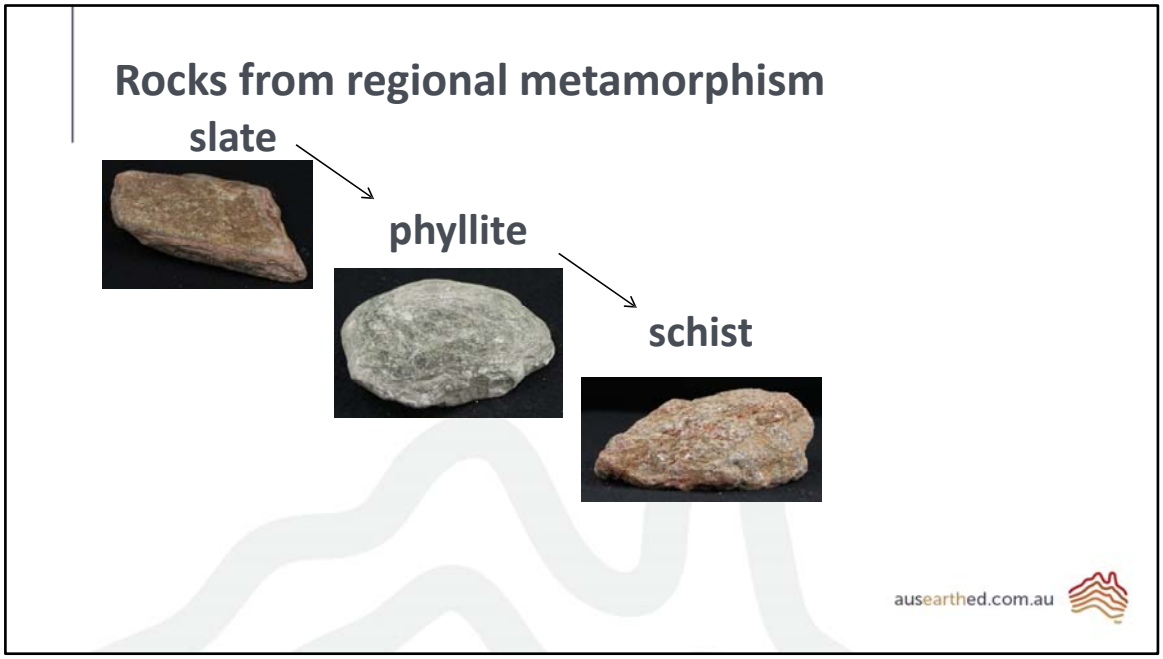
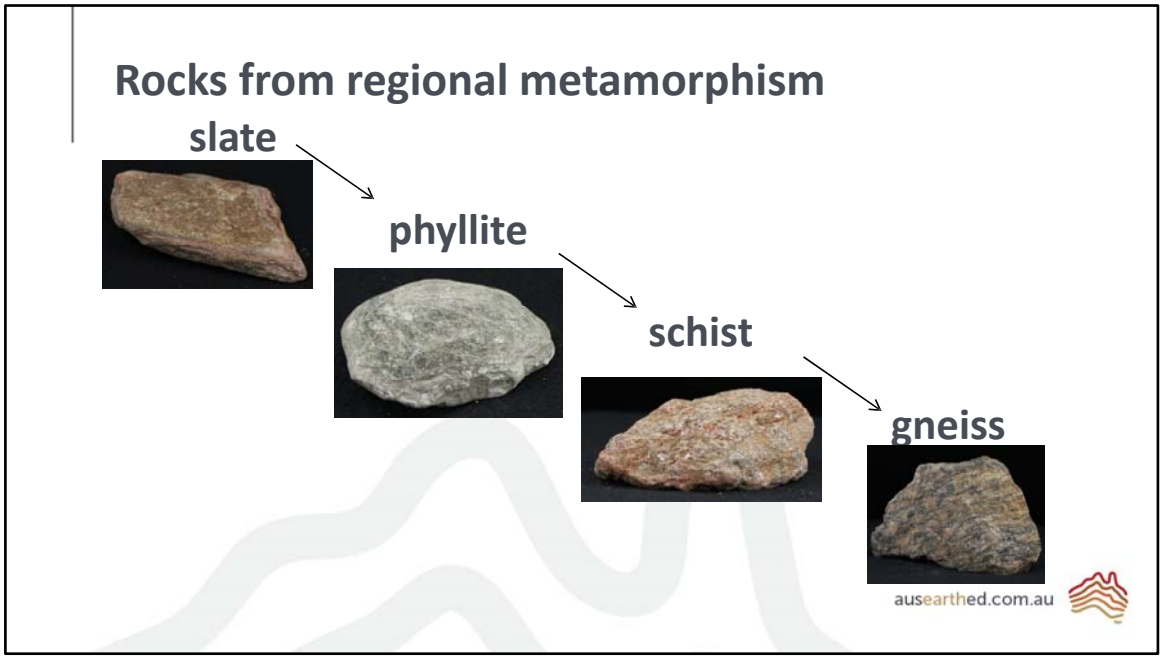
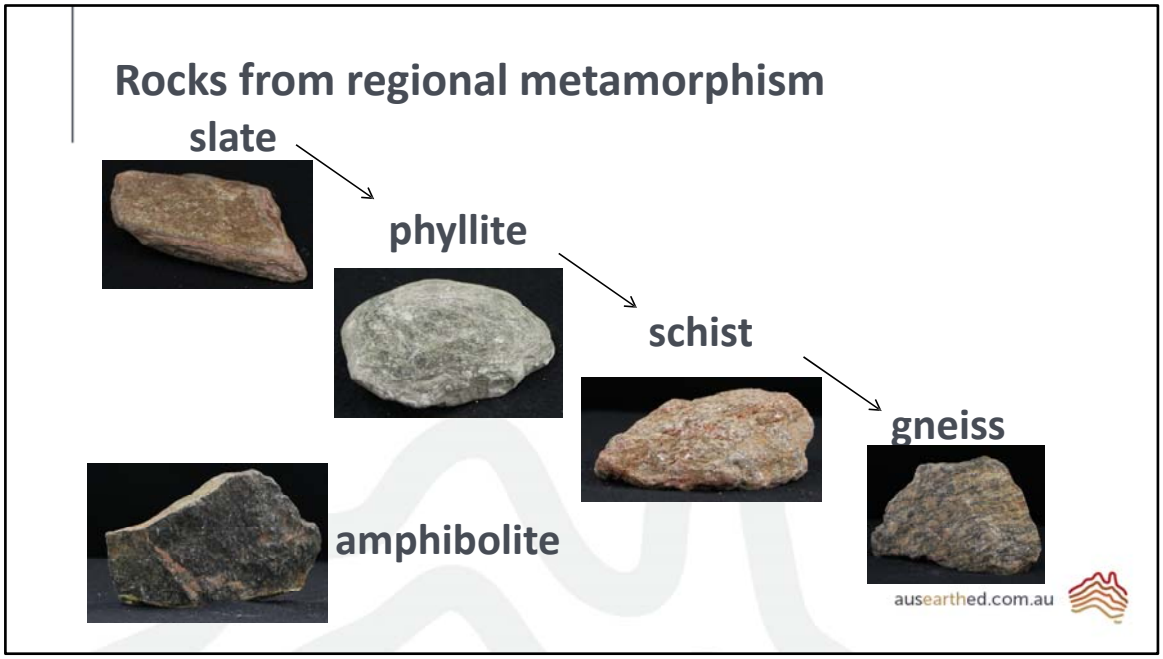
Further dehydration and mobilisation of minerals – micas prominent – crystals slightly larger than those in slate (heating) but foliation less pronounced. Often crenulated or wrinkled.



Schist is a very common metamorphic rock. Crystals can be seen with the ‘naked’ eye. Often consisting of micas and new minerals such as garnet or kyanite (index minerals). Noticeably foliated – schistosity.



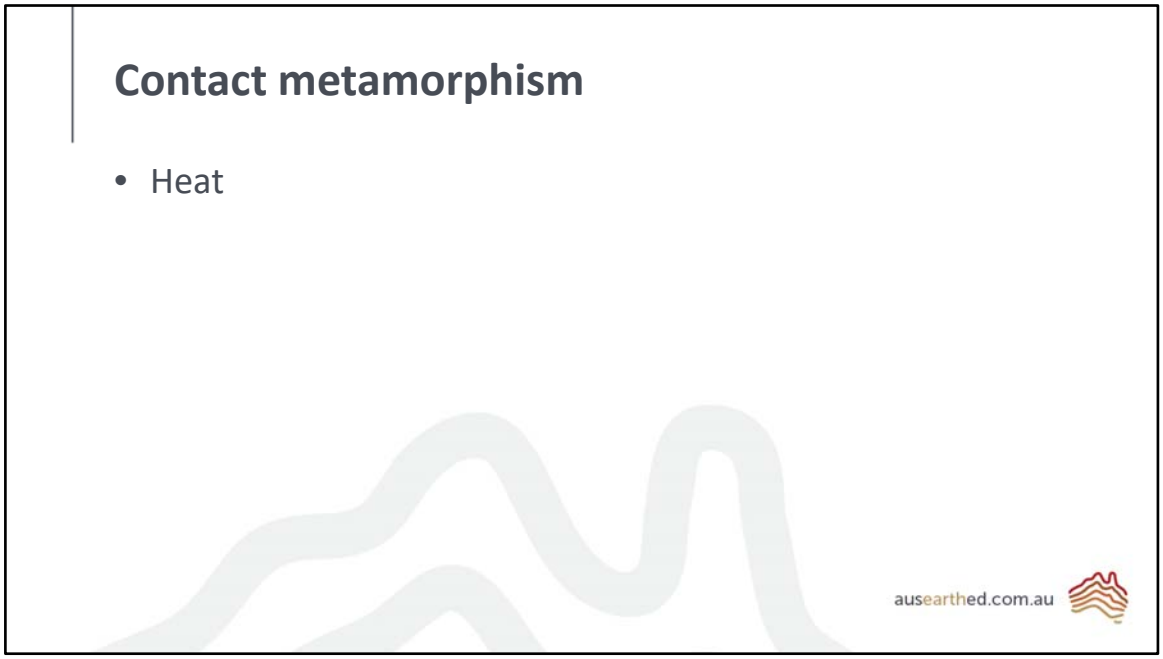
Gneiss is a high grade metamorphic rock with banding of lighter minerals (feldspar & quartz) and darker minerals (amphibolite and biotite). This is due to mineral mobilisation and formation of new minerals. Further heat and pressure will push through to melting and therefore igneous processes.



Amphibolite can be formed from the regional metamorphism of mafic igneous rocks (basalt, dolerite, gabbro). Composed primarily of amphibole and plagioclase and can often contain index minerals like garnet. Often weakly foliated to not foliated and medium to coarse grained.

Contact metamorphism

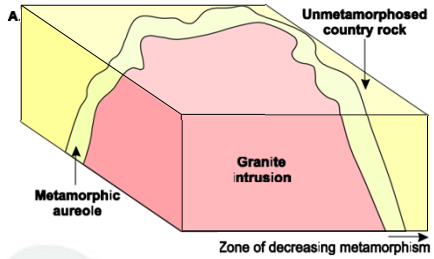
- Heat



Injection of heat into the country rock

Contact metamorphism

- Heat
- Common around igneous intrusions



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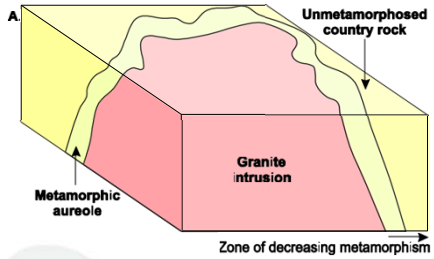
Commonly an igneous intrusion provides the heat source usually in the upper levels of the Earth's crust (deeper brings pressure in to play as well)

Contact metamorphism

- Heat
- Common around igneous intrusions
- Size depends on the extent & heat of the intrusion



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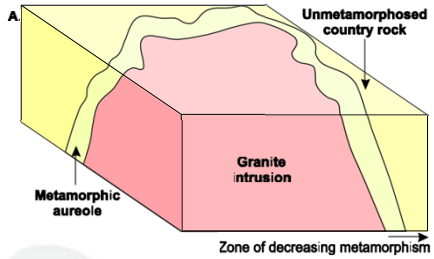
The zone of contact metamorphism, known as the aureole, can range in size greatly (from a few centimetres to a few hundred metres). The rocks closest to the intrusion are altered the most with alteration decreasing as you move away from the intrusion (until you can see no change at all)

Contact metamorphism

- Heat
- Common around igneous intrusions
- Size depends on the extent & heat of the intrusion
- Often fine-grained



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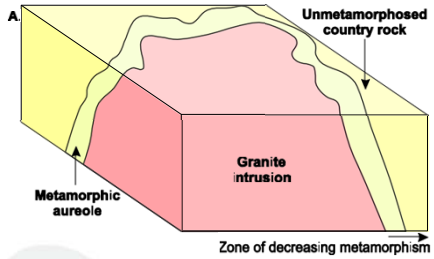
The country rocks partially melt and recrystallise often becoming finer grained than originally

Contact metamorphism

- Heat
- Common around igneous intrusions
- Size depends on the extent & heat of the intrusion
- Often fine-grained
- Weak or no foliation



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The lack of pressure, particularly directional, leads to weak or no foliation. The rocks usually appear granular – a bit like the sugar bowl after you put a wet spoon in it

Rocks from contact metamorphism

Limestone 

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Rocks from contact metamorphism

Limestone   Marble

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Limestone contact metamorphoses to marble.
Primary made up of calcite, which is stable at very high temperatures, the calcite crystals grow larger under sustained metamorphism

Rocks from contact metamorphism

Limestone 

Sandstone 

Marble

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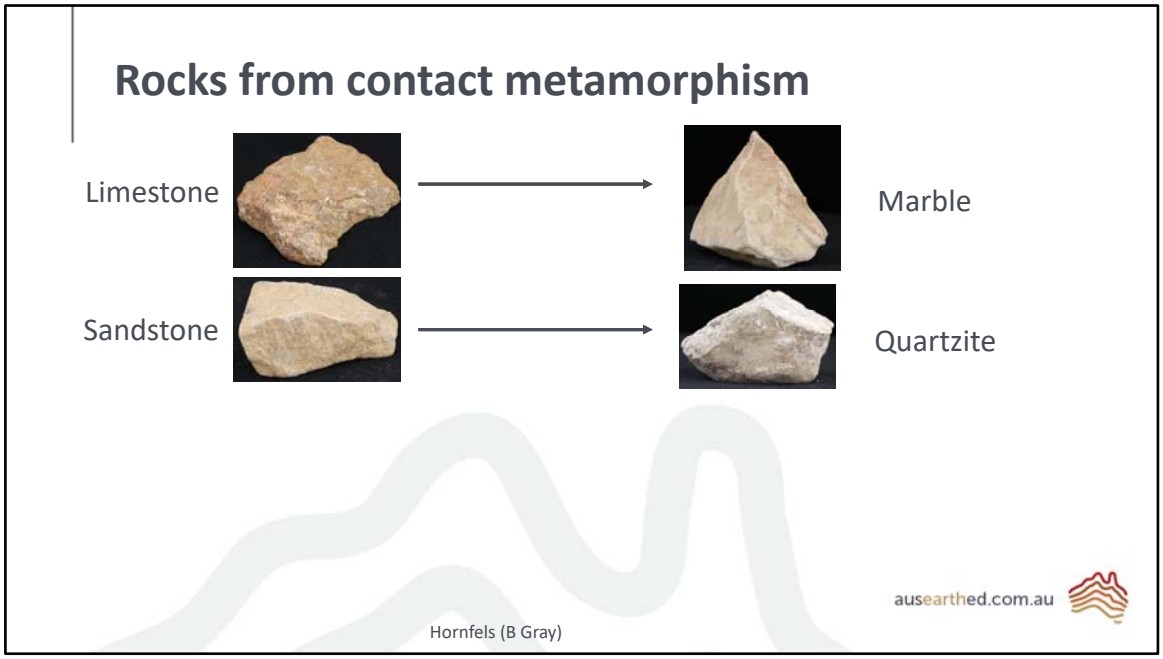

Sandstone (particularly high in quartz) contact metamorphoses to quartzite – again growth of quartz crystals

Rocks from contact metamorphism

Limestone 

Marble

Sandstone 

Quartzite

Mudstone or other parent 

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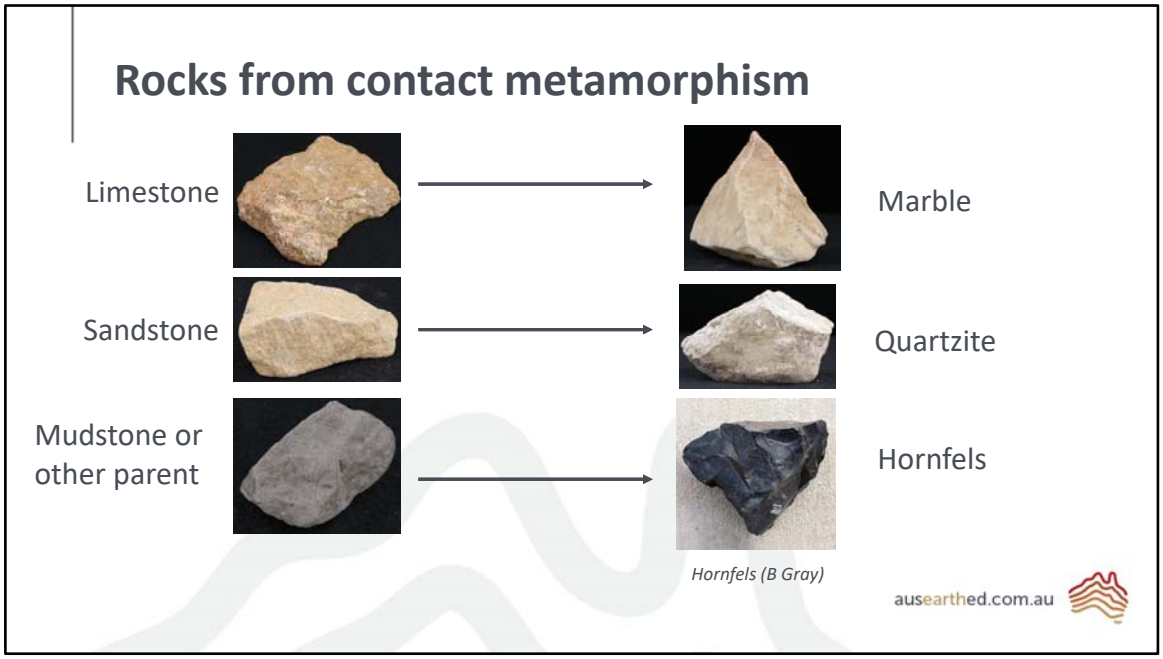
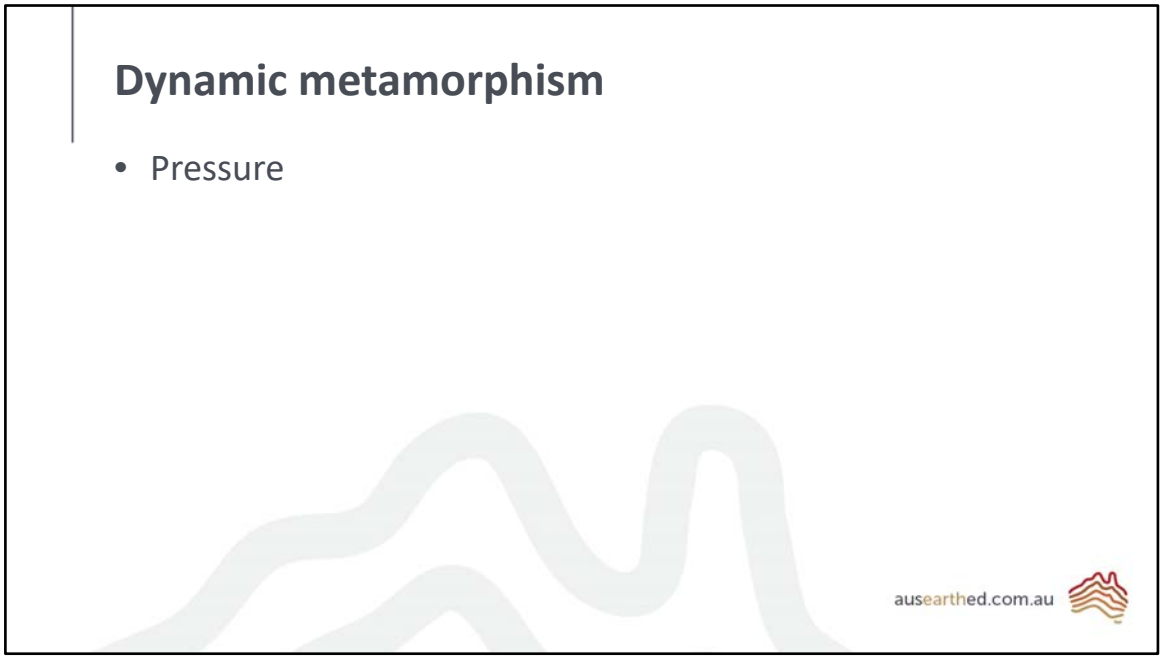
Rocks from contact metamorphism



Mudstone or any other parent rock can be metamorphosed into hornfels. Hornfels can be a specific term for a mudstone contact metamorphosed or a fine-grained metamorphic rock produced by contact metamorphism (any parent)

Dynamic metamorphism

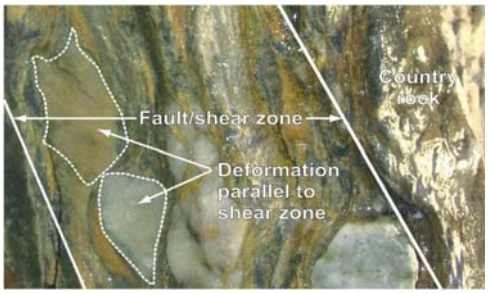
- Pressure



Primary force is pressure with a little frictional heat

Dynamic metamorphism

- Pressure
- Common at fault and thrust zones



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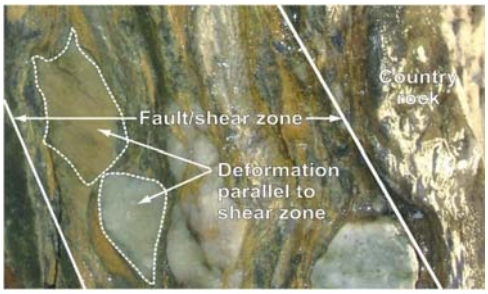
Highly directional pressure

Dynamic metamorphism

- Pressure
- Common at fault and thrust zones
- Often localised



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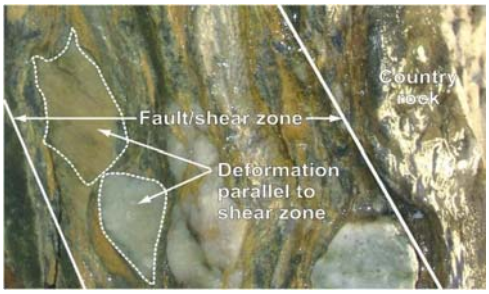
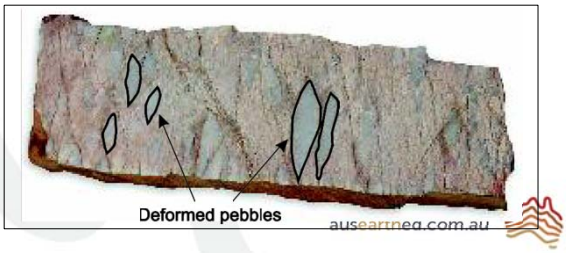
Usually quite small regions, along fault zones

Dynamic metamorphism

- Pressure
- Common at fault and thrust zones
- Often localised
- Deformed or angular fragments
- Rock ‘flour’

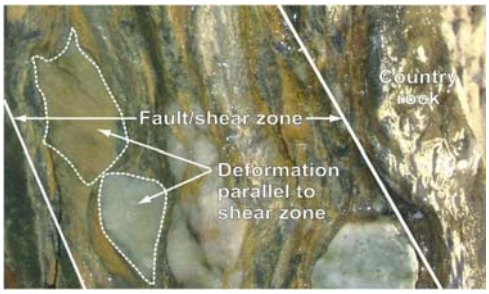


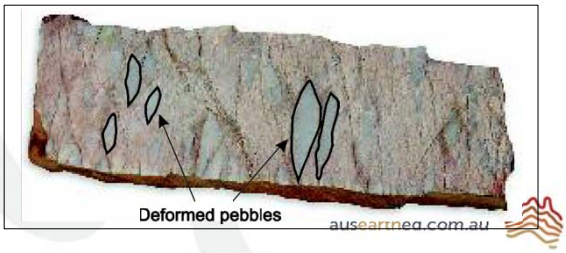


Can form angular fragments (usually closer to surface where load pressure is smaller)

Dynamic metamorphism

- Pressure
- Common at fault and thrust zones
- Often localised
- Deformed or angular fragments
- Rock ‘flour’
- Partial recrystallisation

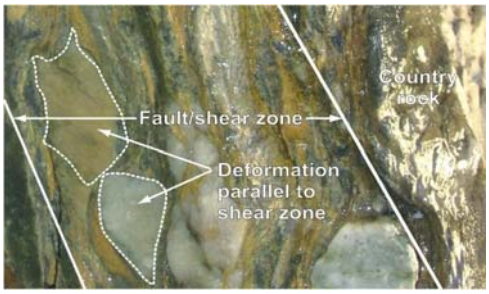


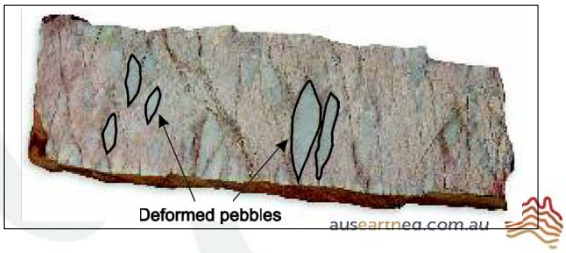


At depth the load (burial) pressures will add to the forces (as well as increased heat) causing partial recrystallisation

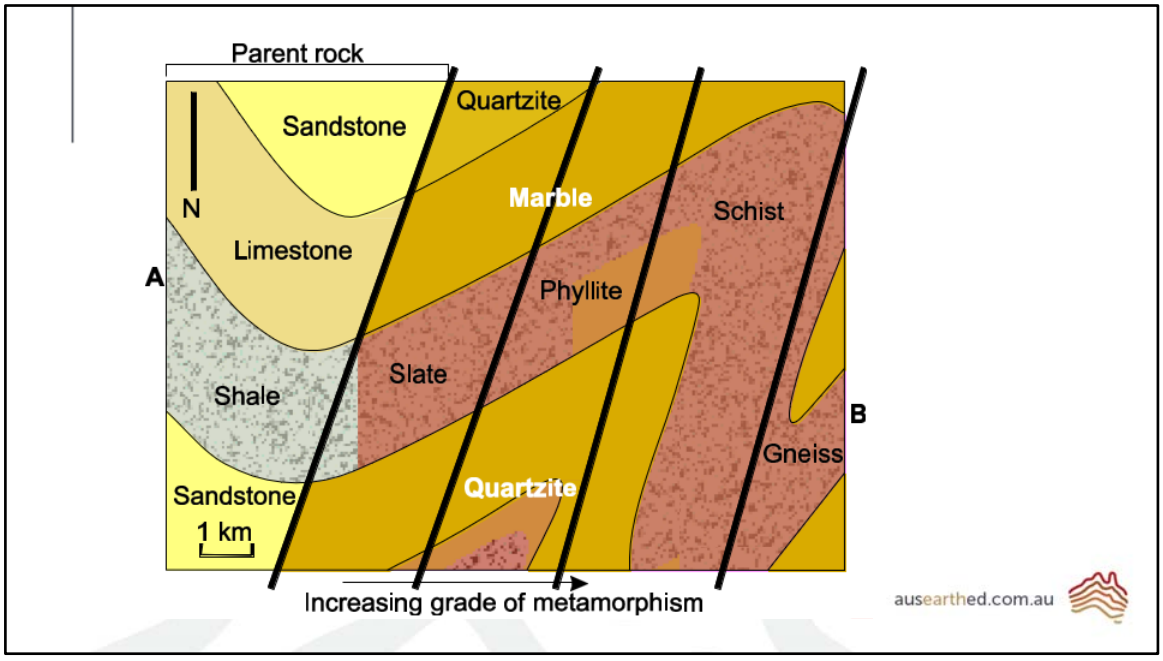
Dynamic metamorphism

- Pressure
- Common at fault and thrust zones
- Often localised
- Deformed or angular fragments
- Rock ‘flour’
- Partial recrystallisation
- Mylonite



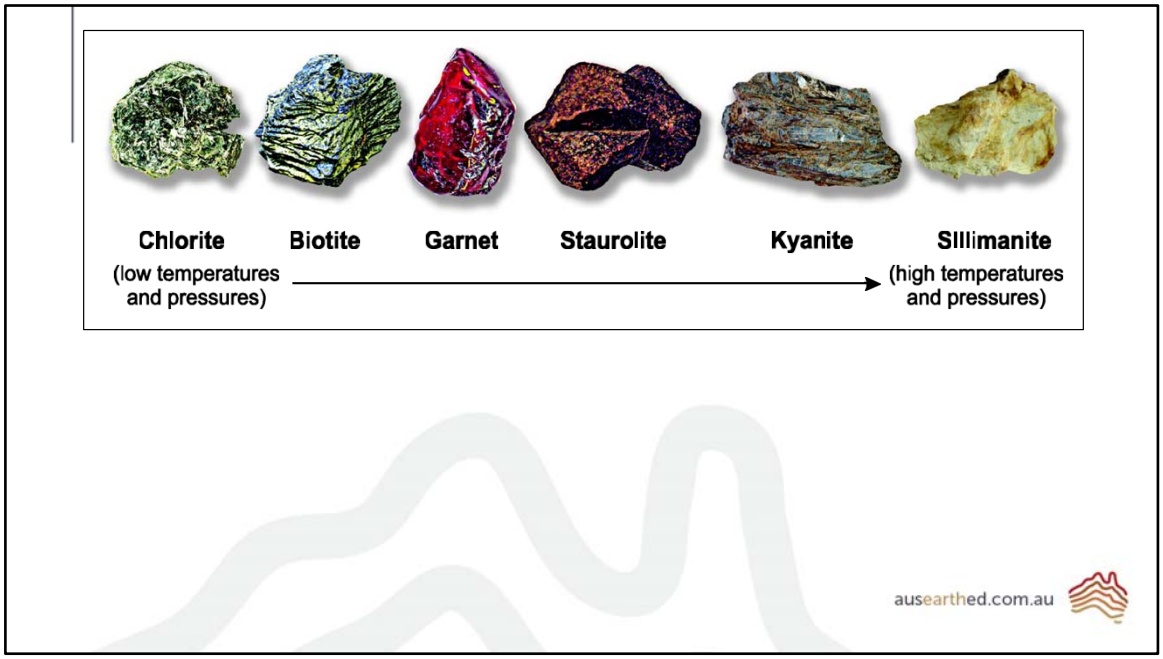


Can form a class of rocks called mylonite – often looks shiny like it has been polished

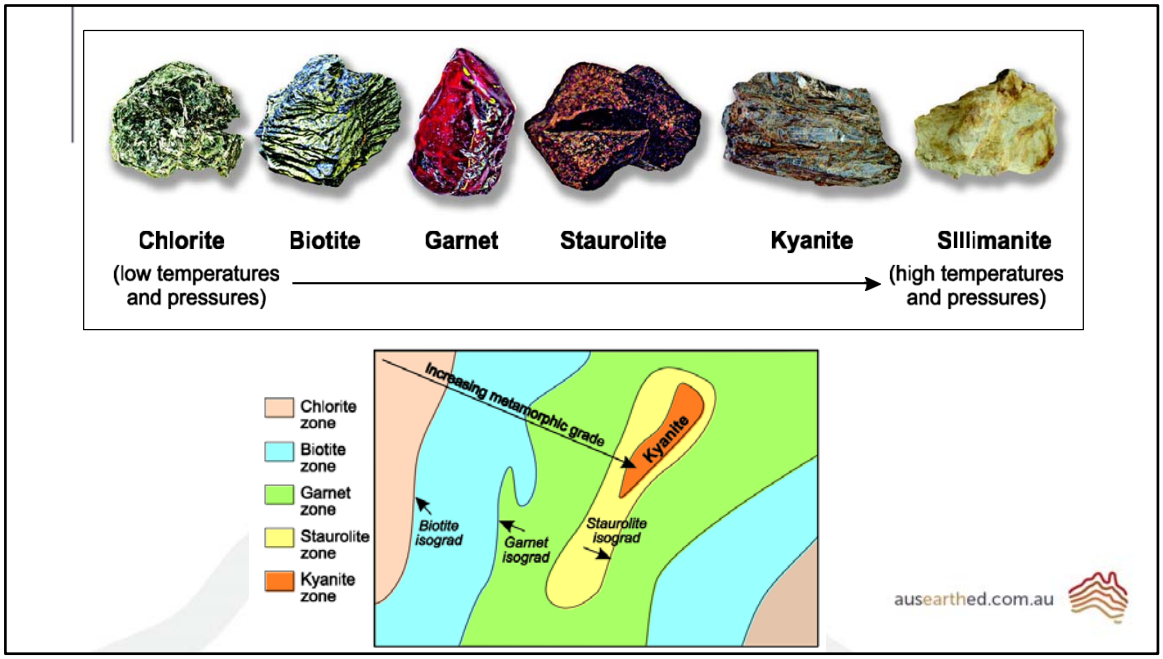


As a rock is subjected to increasing temperatures and pressures it will continue to change (usually via the loss of water and realignment of minerals). This diagram shows progressive metamorphism, highlighting the changes of grade.

It is important to note that rocks can be subjected to further metamorphism. If the temperatures and pressures reached are higher than in the original event, then this is known as prograde metamorphism and a higher grade metamorphic rock will be produced. If temperatures and pressures reached are lower, then a lower grade metamorphic rock is produced and this is called retrograde metamorphism (it regresses back to a lower grade).



Geologists have noted that specific sets of minerals tend to form under certain temperature and pressure conditions. These are called index minerals. A pneumonic that might help you to remember these is: Carrying Big Guns Sticks Karen Silly
(Thought of after speaking to my friend Karen about her training to become a police officer. Apparently running with a gun is painful!)



A diagrammatic example of increasing metamorphic grade and the index minerals expected in each region

Hydrothermal processes

- Hot fluids percolate through rocks

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Most of these hot fluids are also saline

Hydrothermal processes

- Hot fluids percolate through rocks
- Minerals are chemically altered and may be completely replaced

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Hot fluids react with the country rocks raising their temperature. This causes the minerals to respond allowing for the redistribution, the removal or addition of elements.

Hydrothermal processes

- Hot fluids percolate through rocks
- Minerals are chemically altered and may be completely replaced
- Metamorphic or igneous source of fluids

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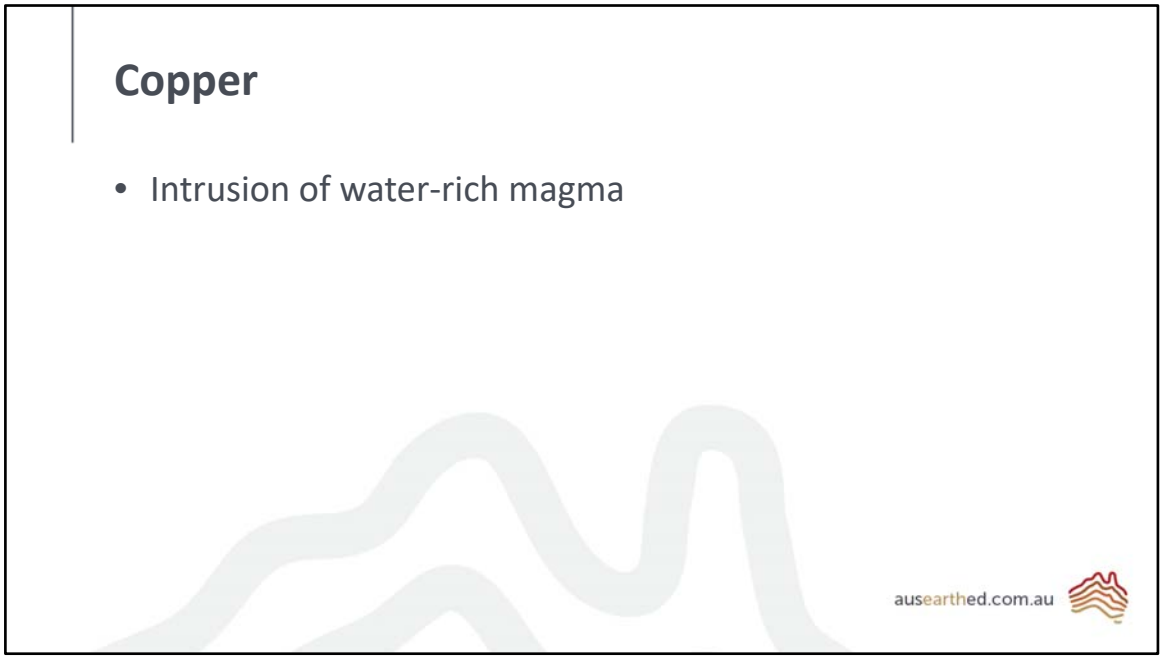
The sources of this hot fluid could be metamorphic (loss of water from minerals) or igneous in source. The water itself may have also come from sources like the sea and been heated by an igneous source.

Copper

- Intrusion of water-rich magma



Low grade porphyry copper deposits may be formed by
the following steps (please be aware that each deposit will have it own
unique history)
Hydrous magma is forcefully emplaced into rocks at relatively shallow depths

Copper

- Intrusion of water-rich magma
- Residual liquid crystallises on edges

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As it begins to crystallise it forms a shell around the edges of the intrusion. Any residual fluid tends to concentrate just below this shell

Copper

- Intrusion of water-rich magma
- Residual liquid crystallises on edges
- Metals such as copper are concentrated here

Also molybdenum, iron, zinc, silver, gold, arsenic, lead and sulfur

Copper

- Intrusion of water-rich magma
- Residual liquid crystallises on edges
- Metals such as copper are concentrated here
- Pressure increase forces super-heated fluids into country rocks

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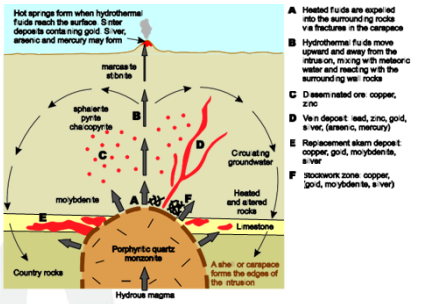
Pressure builds up within this ‘shell’ until finally it fractures and the super-heated residual fluids (containing metals) are injected into the country rocks.

Copper

- Intrusion of water-rich magma
- Residual liquid crystallises on edges
- Metals such as copper are concentrated here
- Pressure increase forces super-heated fluids into country rocks
- Cools and precipitates out metal rich minerals



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This very hot fluid reacts with the surrounding rocks, mixes with meteoric (ground) water and moves upwards and away from the intrusion. As the fluids cool they precipitate minerals like chalcopyrite (contains copper).
The magma inside the chamber then cools at a much faster rate (due to the loss of fluids) and so displays a porphyritic texture.

Gold

- Hydrothermal gold vein deposits – Eastern Goldfields
- Hot saline fluids (metamorphic origin) leached out gold and other metals moving up through country rock
- Move through faults, fractures and brittle rocks
- Cools and precipitates out (often in and around quartz veins)

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Many of you will be using the Eastern Goldfields (Kalgoorlie) as your main mining case study and should understand the formation of these deposits in some detail. A quick overview is here.

References

- Hornfels photograph, Bobby Gray, accessed at http://www.texasbeyondhistory.net/trans-p/nature/images/hornfels.html, on May 15, 2012.

Unless otherwise stated all information and graphics are from:

- Tompkins, D.E. (Ed.), 2011, Exploring Earth and Environmental Science Stages 1, 2 and 3, Earth Science Western Australia
- ESWA photo/graphic library

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