

**Grades of Metamorphism**

- Metamorphism is the change in a rock in response to changes in temperature and pressure imposed on that rock
- **How Big do the changes have to be to cause metamorphism?**
- Answer is dependent on:
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_

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**Grades of Metamorphism**

- At low \_\_\_\_\_ and \_\_\_\_\_, found at or very near the Earth's surface, and away from a volcanic region, only \_\_\_\_\_ effects the rocks
- At very \_\_\_\_ temperatures near the \_\_\_\_\_, in areas of \_\_\_\_\_ activity, and at great \_\_\_\_\_ in the crust \_\_\_\_\_ takes place
- Metamorphic conditions lie in between

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**Grades of Metamorphism**

- Not all metamorphism takes place under the same conditions of pressure and temperature
  - Rocks metamorphosed at \_\_\_\_ temperatures (< 300°C) are called \_\_\_\_\_
  - Rocks metamorphosed at relatively \_\_\_\_\_ temperature (> 500°C) are called \_\_\_\_\_
  - Rocks metamorphosed to temperatures between 300 and 500°C are called \_\_\_\_\_ or \_\_\_\_\_

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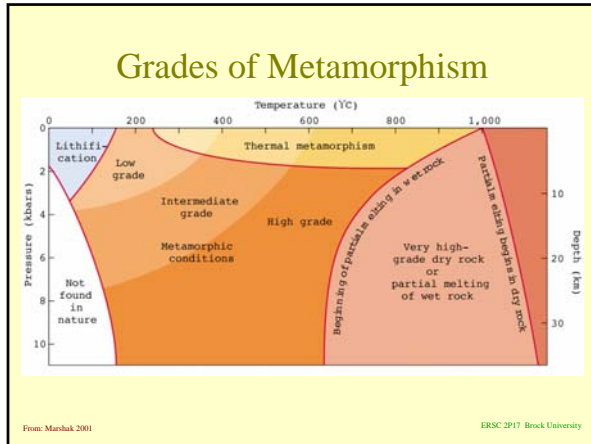
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### Grades of Metamorphism

- Each grade of metamorphism yields different groups of \_\_\_\_\_ and \_\_\_\_\_;
  - low grade rocks are generally \_\_\_\_\_ grained and do contain '\_\_\_\_\_' minerals, i.e. minerals contain OH - biotite, amphibole
  - high grade rocks are generally \_\_\_\_\_ grained and contain '\_\_\_\_\_' minerals, i.e. minerals do not contain OH - pyroxene
- Boundaries between grades are \_\_\_\_\_

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### Metamorphism of Shale

- Shale consists of clay minerals and fine grained quartz, along with \_\_\_\_\_ trapped in the \_\_\_\_\_ between grains and as \_\_\_\_\_ trapped between the layers of clay minerals
- Under low grade conditions the shale transforms to \_\_\_\_\_ which involves:
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_

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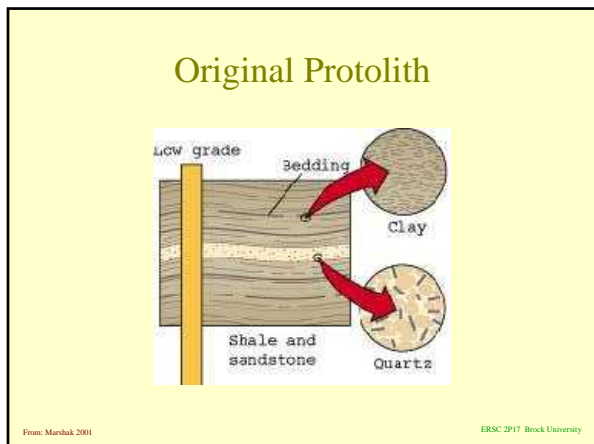
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### Metamorphism of Shale

- All of the above produce \_\_\_\_\_, \_\_\_\_\_ and better \_\_\_\_\_ with a \_\_\_\_\_
- The changes in the rock \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_, explains the physical characteristics of slate
  - \_\_\_\_\_ of slate compared to shale reflects the tighter \_\_\_\_\_ between the clay flakes and the \_\_\_\_\_
  - the ability of slate to be \_\_\_\_\_ into thin sheets reflects the \_\_\_\_\_ orientation of the clay flakes

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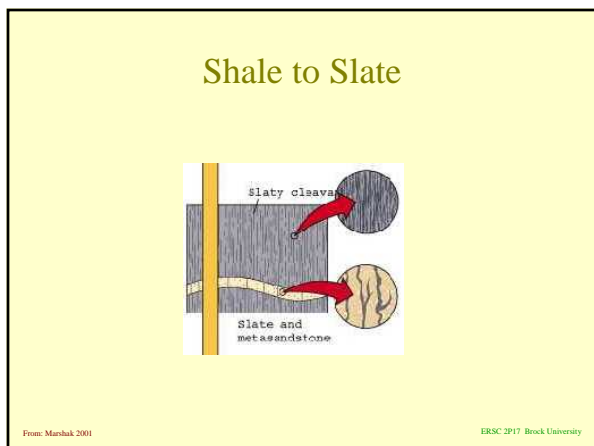
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### Metamorphism of Shale

- As metamorphic grade \_\_\_\_\_ (T and P \_\_\_\_\_) the clay minerals \_\_\_\_\_ to fine-grained \_\_\_\_\_
- The rock transforms into a \_\_\_\_\_ (rich in mica) and exhibits the \_\_\_\_\_ lustre
- Continued increase in P and T to medium grade, results in;
  - muscovite grains growing \_\_\_\_\_ and
  - metamorphic \_\_\_\_\_ new minerals
    - eg. quartz, garnet, staurolite, andalusite, etc.
  - and the phyllite becomes a \_\_\_\_\_

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Slate to Phyllite

Phyllite to Schist

Phyllite and quartzite

Schist

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### Metamorphism of Shale

- Muscovite has the chemical formula:
  - $K_2Al_4(Si_6Al_2O_{20})(OH)_4$
- During metamorphic reactions under high grade conditions, the OH separates from the the muscovite and becomes a \_\_\_\_\_ which escapes from the rock

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### Metamorphism of Shale

- Under \_\_\_\_\_ conditions another mineral assemblage forms through \_\_\_\_\_ between earlier formed minerals producing new minerals, feldspar, sillimanite, quartz, pyroxene that are \_\_\_\_\_ - lack water
- This process is accompanied by the formation of a \_\_\_\_\_

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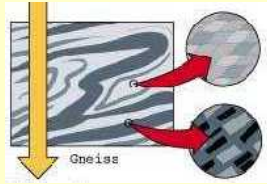
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### Schist to Gneiss



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### Metamorphism of Shale

- Further increases in temperature cause the rock to be subjected to \_\_\_\_\_ or \_\_\_\_\_ melting, depending on the \_\_\_\_\_, forming a magma
- The end result is a \_\_\_\_\_
- All the rocks described - shale, slate, phyllite, schist, gneiss and migmatite, form from the same protolith - the differences reflect \_\_\_\_\_ and the \_\_\_\_\_

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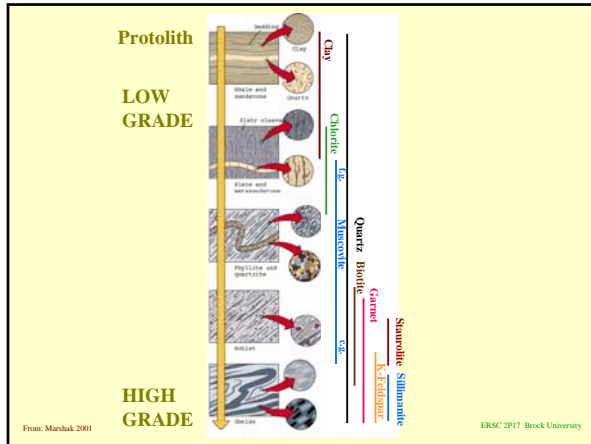
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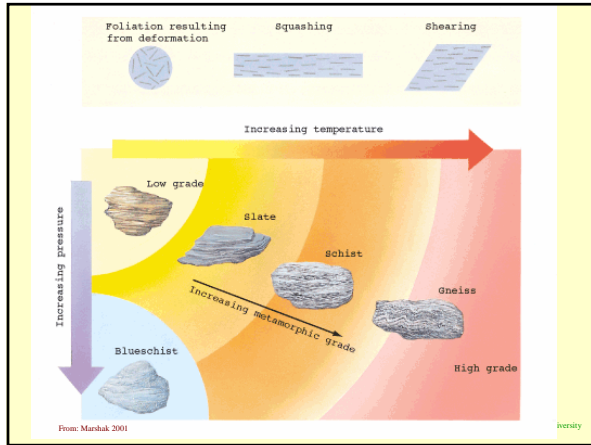
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### Index Minerals

- Some minerals present in metamorphic rocks also occur in igneous and sedimentary rocks, eg:
  - mica, quartz
- Some metamorphic rocks contain minerals that only form under metamorphic conditions, e.g:
  - kyanite, staurolite

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### Index Minerals

- These latter minerals serve as good indicators of the \_\_\_\_\_
- They only form under very specific \_\_\_\_\_ and \_\_\_\_\_ conditions that the rock has been subjected to
- These minerals are called \_\_\_\_\_

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### Index Minerals

- In the field metamorphic rocks of different grades are separated by lines drawn to indicate the \_\_\_\_\_ of an \_\_\_\_\_
- On the higher grade side of the line rocks \_\_\_\_\_ the index mineral, on the lower grade side the index mineral is \_\_\_\_\_
- Lines are called \_\_\_\_\_ - (lines of equal grade)

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### Index Minerals

- The outcrops between successive isograds are termed metamorphic zones named for the index mineral present

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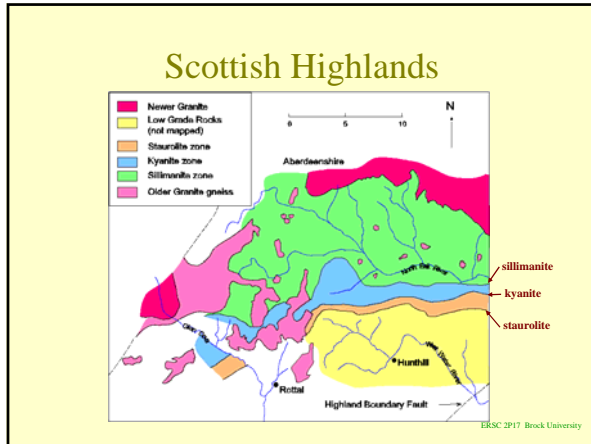
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### Prograde Metamorphism

- Metamorphism that occurs as a result of \_\_\_\_\_ temperature and pressure is termed **Prograde Metamorphism**
- The progressive change from shale to slate to phyllite to schist to gneiss is an example of prograde metamorphism
- During this process \_\_\_\_\_ is essentially driven out of minerals and \_\_\_\_\_ the rock

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### Retrograde Metamorphism

- Metamorphism can also take place as a result of \_\_\_\_\_ temperature and pressure conditions
- This type is referred to as \_\_\_\_\_ **Metamorphism**
- For retrograde metamorphism to occur water must be \_\_\_\_\_ to the rock, and thus it takes much longer to occur than prograde metamorphism

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### Retrograde Metamorphism

- Retrograde metamorphism is usually associated with a \_\_\_\_\_ solution (hot water)
- Retrograde metamorphism does not happen automatically when a high-grade rock is uplifted to the Earth's surface
- Recrystallization under \_\_\_\_\_ conditions is a very, very slow process, taking billions of years to complete

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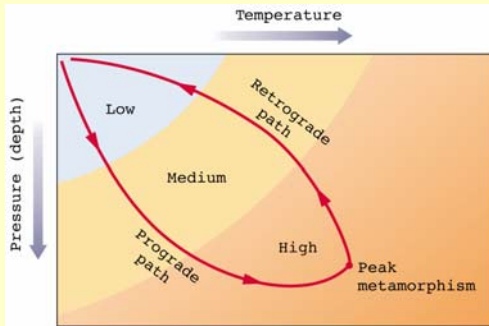
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### Prograde vs Retrograde



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### Metamorphic Environments

- Wherever rocks are being subjected to conditions (P, T etc.) that are different from the conditions where the rock originally formed the rocks undergo metamorphism

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

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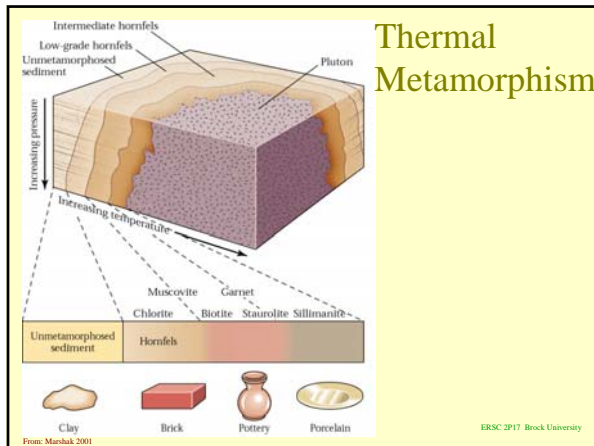
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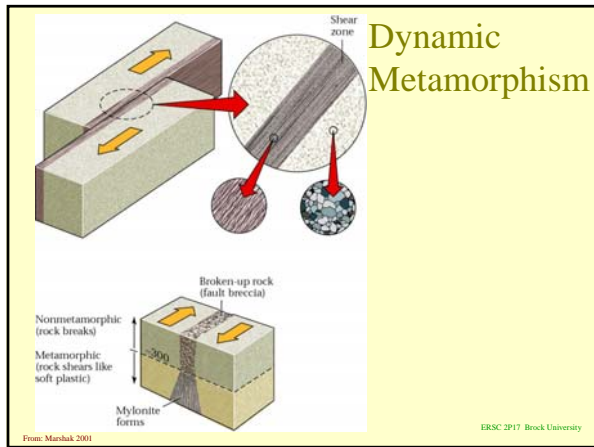
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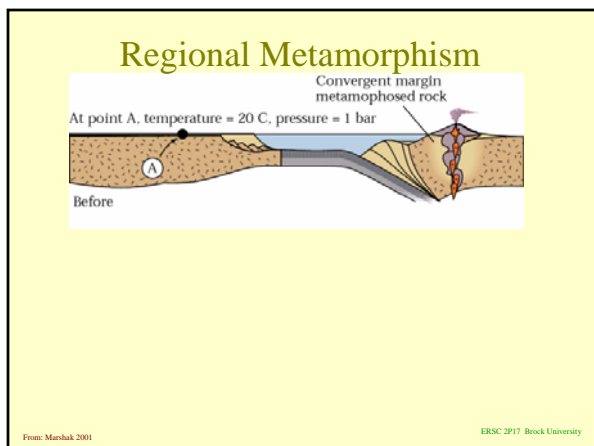
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