What is metamorphism?

-Metamorphism represents processes by which rocks undergo **solid-state changes** in mineralogy, texture, or both to reach equilibrium with its changing environment

- Changes in any/all of the following:

  ~ Mineralogy
  ~ Texture
  ~ Chemical composition

-As a convention the domain of metamorphism is confined to the crust, but below the zone of diagenesis and up to the Moho

Metamorphism in open system (change in chemical composition) is named Metasomatism

Agents of metamorphism?

-Three main agents are responsible for almost all of the metamorphic event.

1. Heat
2. Pressure
3. Chemically active fluids

-Most of the metamorphic changes involve all three agents.

-The proportion of influence of the agent varies between types of metamorphism.

Agents of metamorphism: Heat

-Heat provides the energy to drive the re-crystallization process

-Two major change caused by heat
-Crystallization of new minerals & Re-crystallization of earlier minerals to larger size

Source of heat

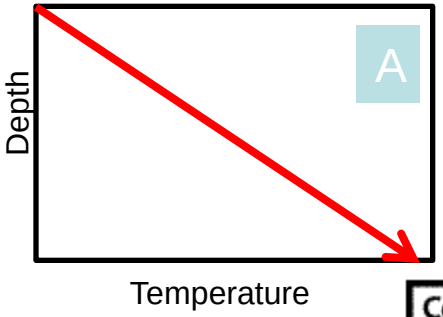
Earth's internal heat comes from

- Continuous radioactive decay

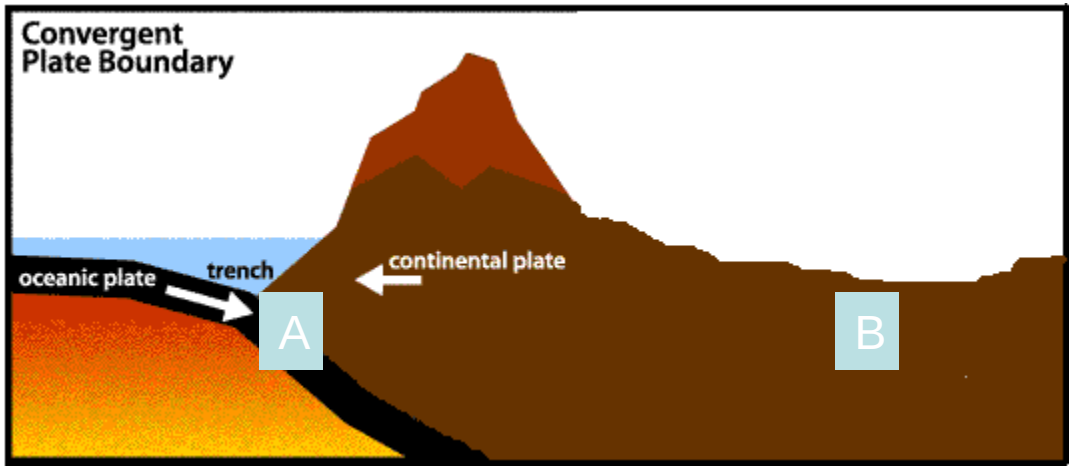
- Thermal energy generated during the formation

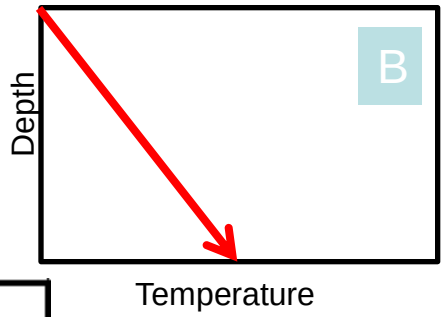
- Geothermal gradient varies in different parts of the world

- Tectonics plays an important role in determining the nature of the gradient.



Temperature changes at a much faster rate with depth.



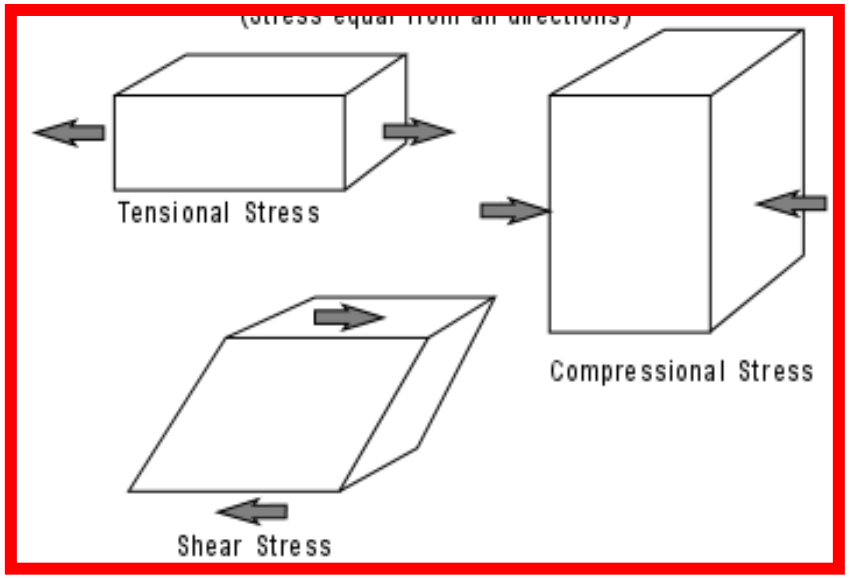


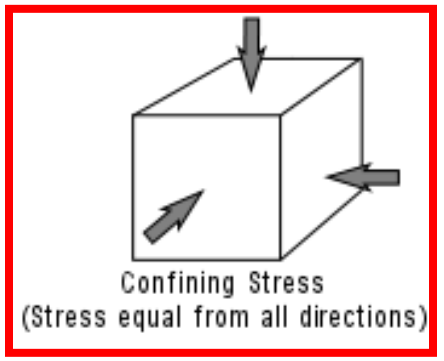
Temperature changes at a much slower rate with depth.

Agents of metamorphism: Pressure

-Pressure increases with depth : Approx 1 kbar per 3 km depth
- There are two main types of pressure that operate on the rocks

1. Confining pressure: Non-directional
2. Differential stress: Directional





Near the surface at low temp. rocks are brittle – tend to fracture
-- minerals tend to get crushed into smaller grain in differential stress

At depths at high temp. rocks are ductile
-- tend to flow
--mineral grains tend to flatten in differential stress

Agents of metamorphism: Fluids

Fluids that play important role in metamorphism is mainly composed of

- Water
- CO_2, SO_2

-These fluids help in recrystallizing minerals

Where do we get the water from??

- Minerals often carry water in their structure (mica, clay etc)
-Temperature causes dehydration of the minerals
-Those expelled water molecules could play important role in ion transport.

-The water could also come from rocks when subjected to extreme heat.

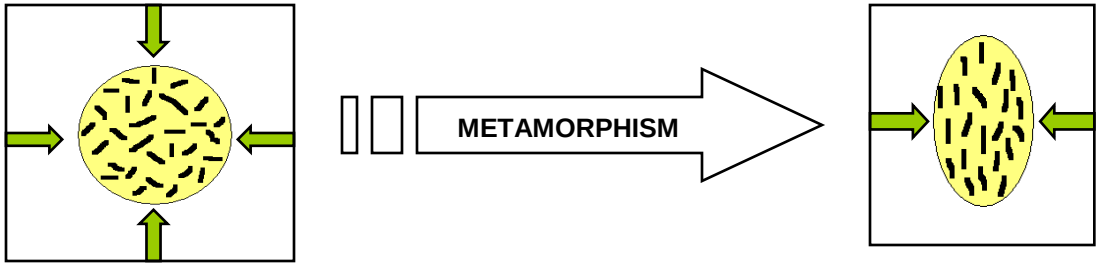
Causes of metamorphic texture

- **Two main types of texture: Foliated and non-foliated**

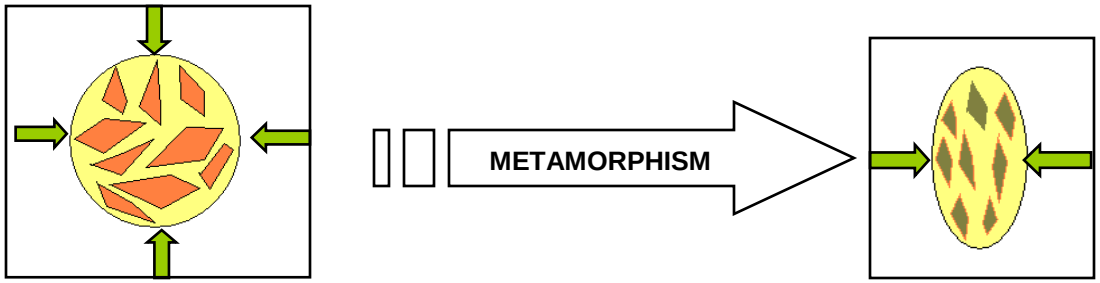
-**Mineral grains are often oriented in a preferred direction. This is called foliation (leaflike)**

- **Foliation could form in any of the following ways:**

1. Rotation of platy and/or elongated minerals



2. Neocrystallization of minerals to form crystals in new preferred direction.



3. Changing the shape of existing mineral in a preferred manner.

Metamorphic texture

1. Foliated: Shows preferred arrangement

a. **Rock / Slaty cleavage:** Closely spaced surfaces which split easily.

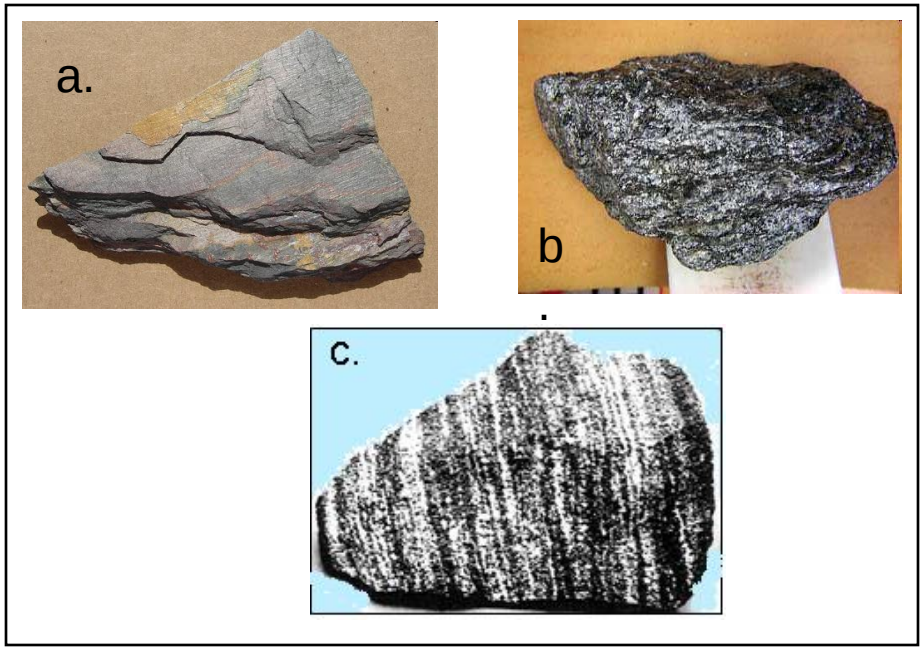
Product of low grade metamorphism. Example: Slate

b. **Schistosity**: Layered structure with high mica content with a sparkly appearance

Medium-high grade metamorphism. Example: Mica schist

c. **Gneissic texture**: Layers of alternating dark and light bands.

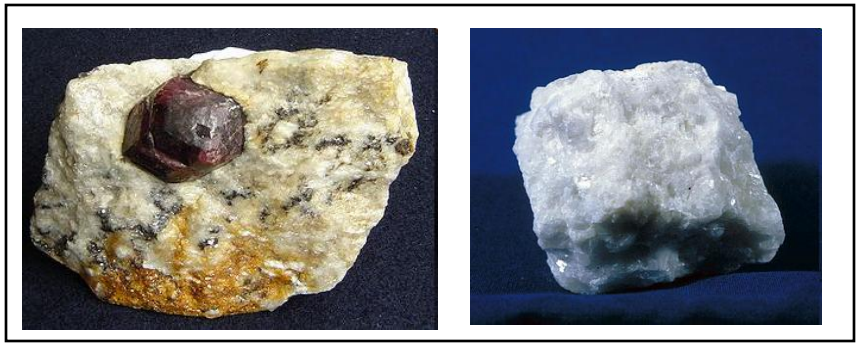
High grade metamorphism. Example: Granite gneiss



2. Non-foliated texture

When there is no preferred orientation.

Example: Marble

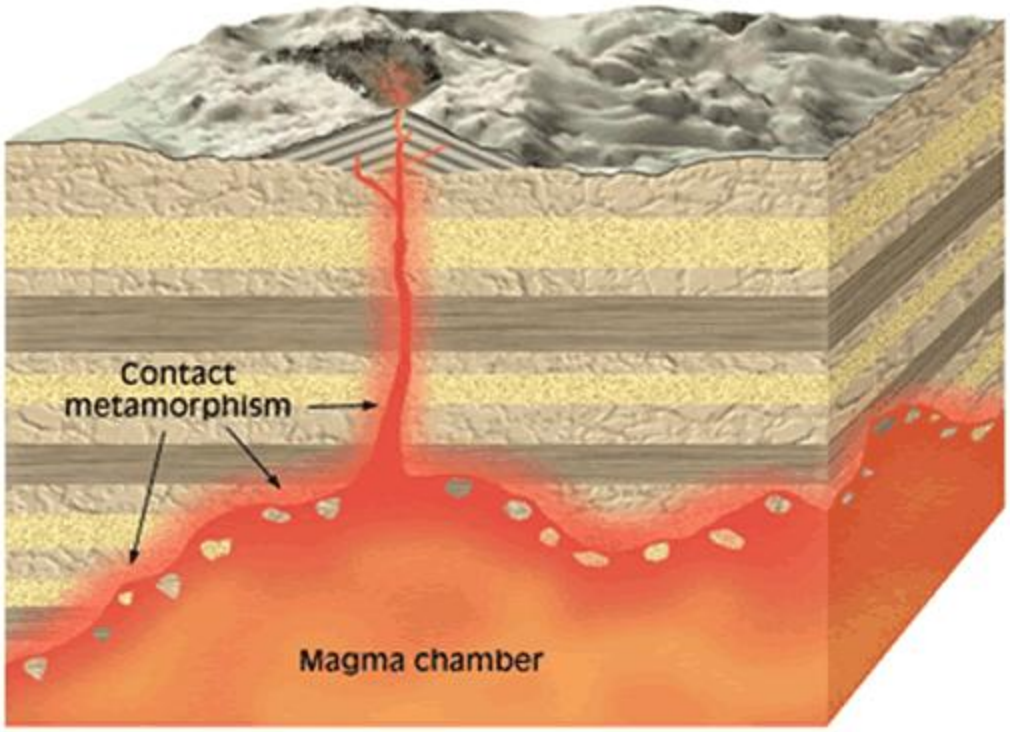


Contact / thermal metamorphism

- Rocks immediately surrounding a molten igneous body are “baked”.

- Main agent is heat.

- Generally no preferred orientation of mineral grains – non-foliated texture.



The affected area of the rock is called Contact Aureole.
Size of the aureole depends on Temperature of the intruding magma, Size of the intrusion, depth of intrusion and nature of the intruded rock

Example:

Marble (from limestone)

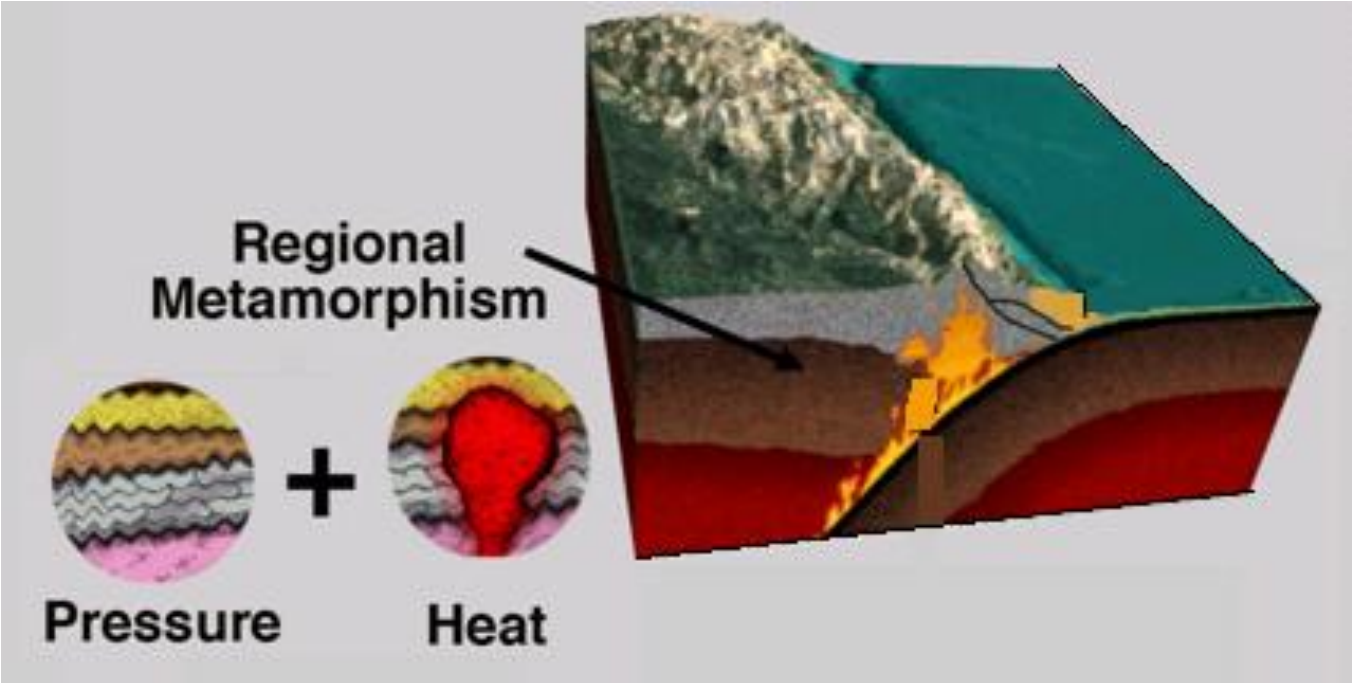
Regional metamorphism

-**Where metamorphism occurs over a very broad area of crust.**

Example: subduction zones, volcanic arcs, and regions of continental crust collisions.

-**Agents high temperature and confining pressure with directional pressure**

- Destroys original textures of both igneous and sedimentary rocks through growth of new minerals.



Shock / impact metamorphism

-It occurs when meteorites strike Earth's surface.

- Agent of metamorphism intense heat and pressure.

- Could cause pulverization and sometimes even melting of some mineral grains.

The products of these impacts are called Impactites.

Some common foliated metamorphic rocks

Slate

Phyllite

Schist

Gneiss

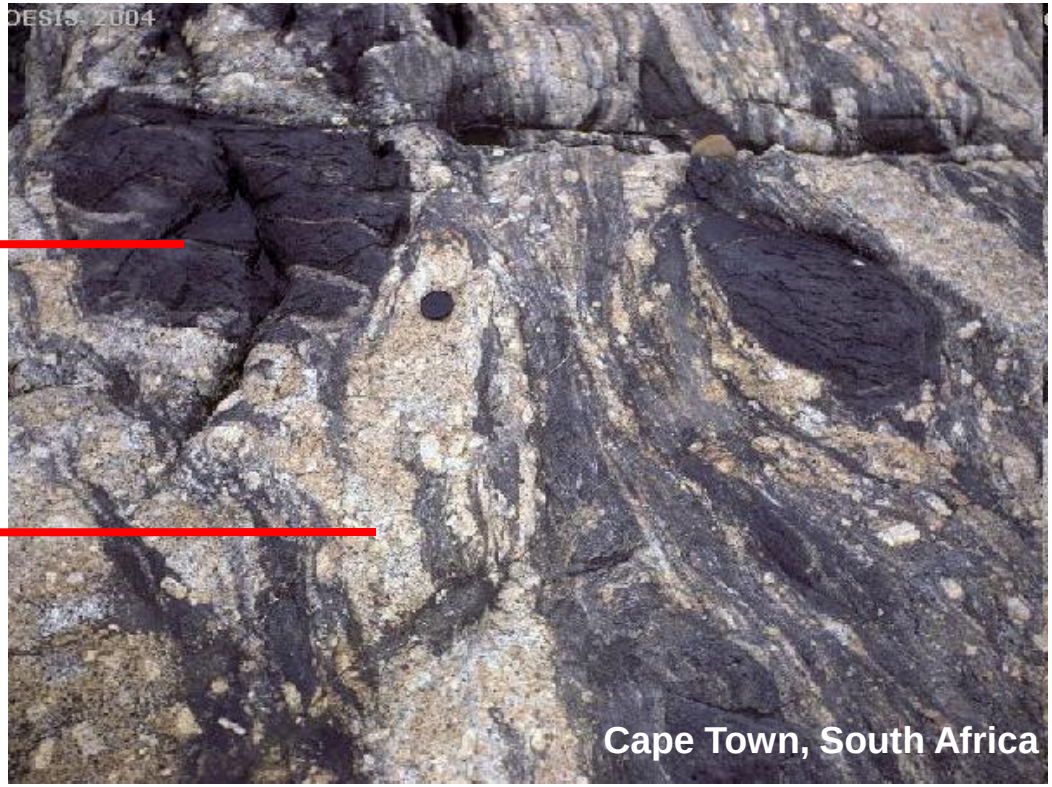
Non-foliated metamorphic rock

Quartzite:
-Made up of mineral quartz (SiO_2)
-Very hard
- Scratches glass
- Parent rock: generally a sedimentary rock (sandstone)

Marble:
-Made up of mineral calcite ($CaCO_2$)
- Soft
- Fizzes in reaction with acid
- Parent rock: generally a sedimentary rock (limestone)

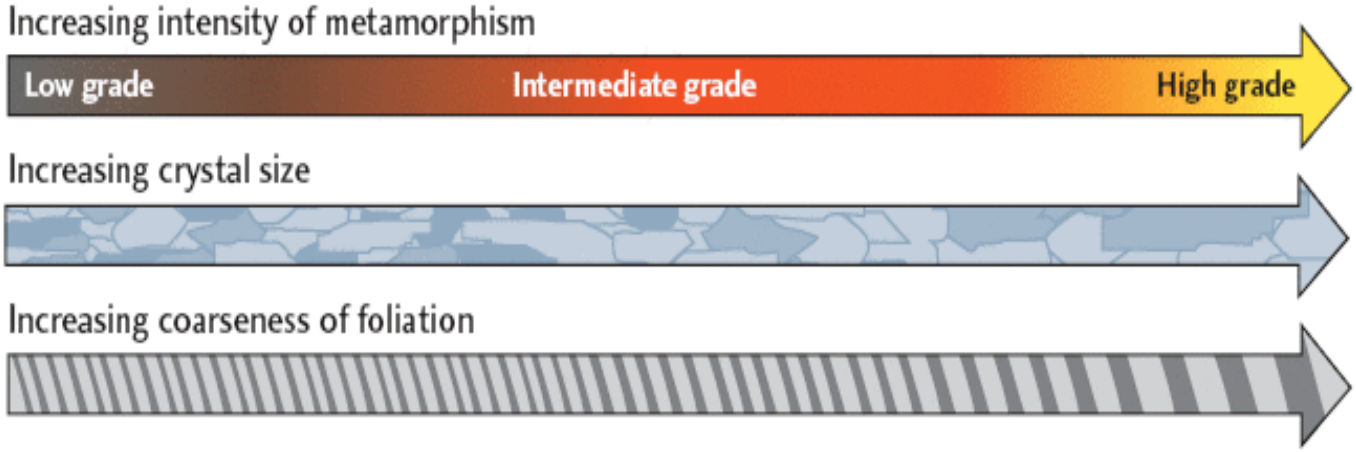
Migmatites: most extreme environment

- **Migmatites are mixed rocks -- part igneous, part metamorphic.**
- **They form when rocks are heated to the point where they begin to melt.**
- **The molten material partly separates out, but crystallises before it can move right away.**
- **Light silicates melt first, they will flow.**
- **Dark silicates remain solid.**

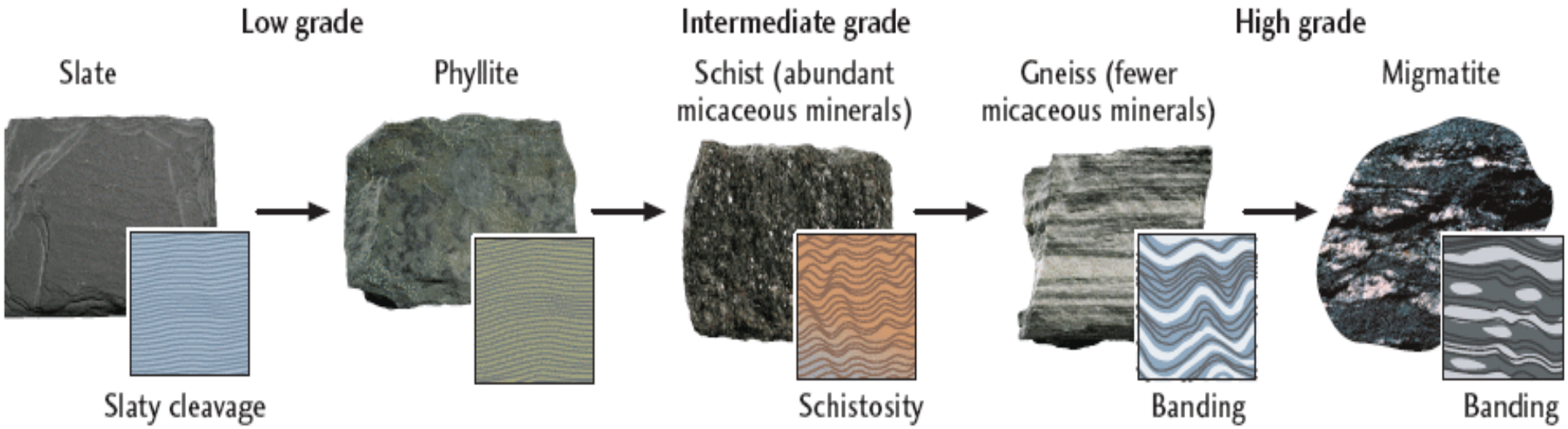


Metamorphic grade: textural variation

As intensity of metamorphism increases, so does crystal size and coarseness of foliation.



Foliated rocks are classified by the intensity of metamorphism.



Characterization of metamorphism

Any mineral association in a metamorphic rocks is a function of a. Pressure, b. Temperature, c. Composition of the original rock and d. Nature of the chemically active fluids

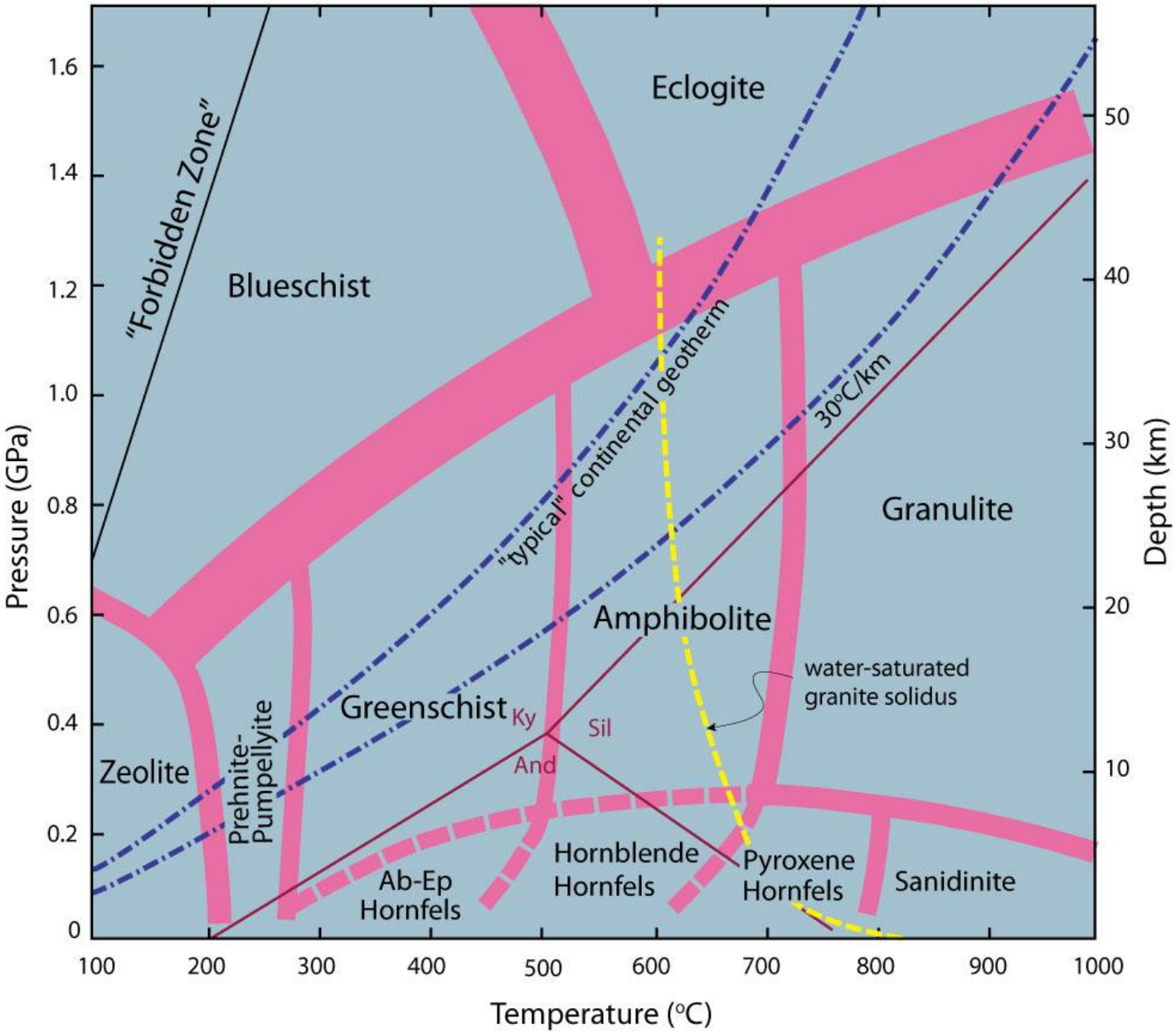
The Pressure term refers to Confining Pressure

Directional Pressure influences the texture of the rock

How to describe metamorphic P-T conditions?

Metamorphic Grade: Based on single minerals

Metamorphic facies: Based on association of minerals in rocks as function of composition


Eclogite
"Forbidden Zone"
Blueschist
"typical" continental geotherm
30°C/km
Granulite
Amphibolite
water-saturated
granite solidus
Greenschist
Ky
Sil
And
Zeolite
Prehnite-
Pumpellyite
Ab-Ep
Hornfels
Hornblende
Hornfels
Pyroxene
Hornfels
Sanidinite
Pressure (GPa)
Depth (km)
Temperature (°C)
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0.2
0.4
0.6
0.8
1.0
1.2
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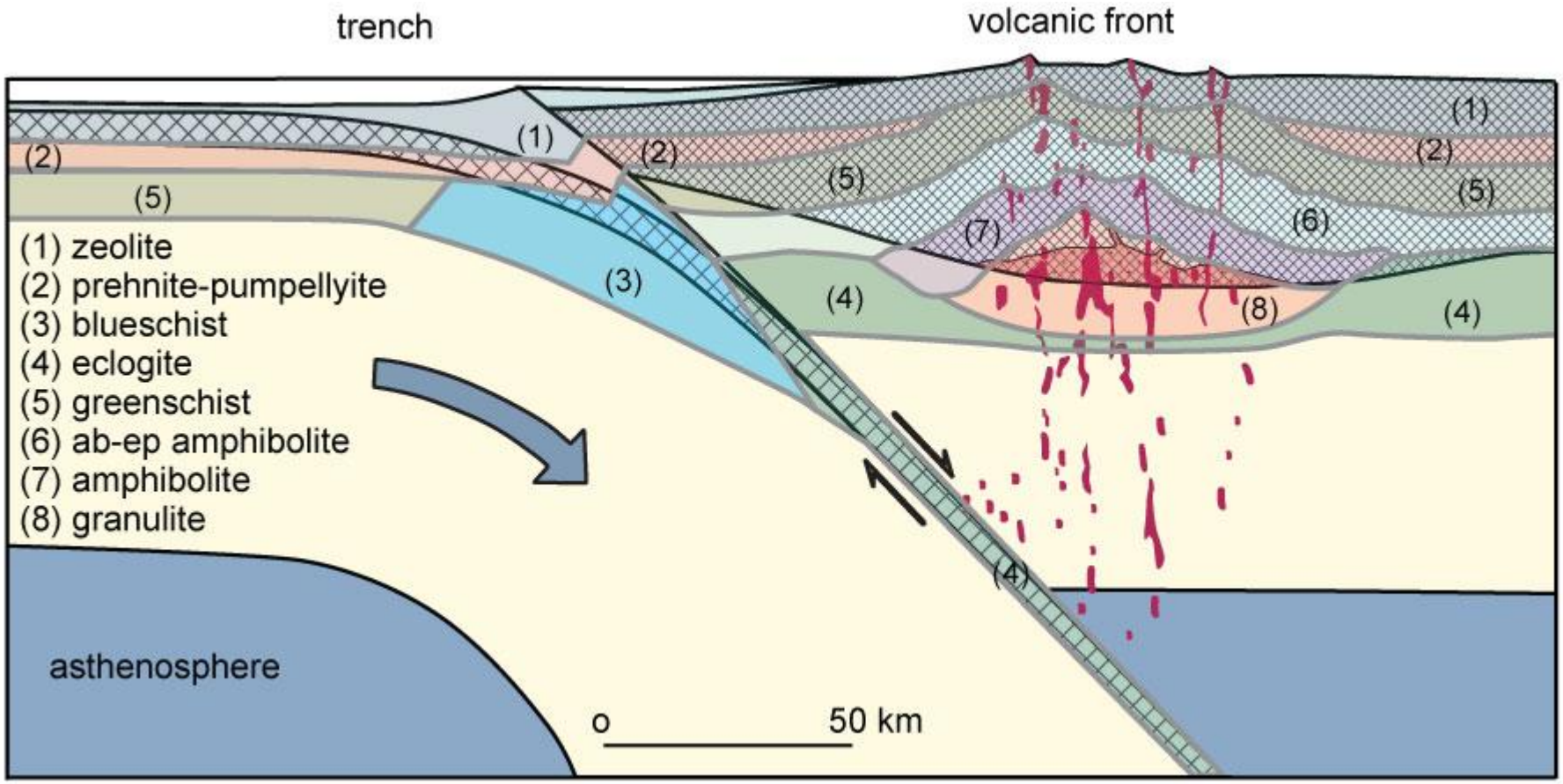
trench
volcanic front
(1) zeolite
(2) prehnite-pumpellyite
(3) blueschist
(4) eclogite
(5) greenschist
(6) ab-ep amphibolite
(7) amphibolite
(8) granulite
asthenosphere
o
50 km