

Metamorphic Rocks

Greek:

meta == change

morph == form



- Rocks of the same chemical composition that are subjected to identical metamorphic environments react to form the same mineral assemblages. For given conditions of metamorphism, the equilibrium assemblages of minerals that form during the metamorphism of rocks of different composition belong to the same metamorphic facies.
- Metasomatism involves the changes in rock composition that occur when material in solution is added to the rock, or material is taken away, as the result of fluids flowing through a rock.
- Hydrothermal solutions are naturally formed hot water solutions that are capable of dissolving and transporting substances and precipitating them to form new minerals.
- Metamorphism can be explained by plate tectonics. Burial metamorphism occurs within the thick piles of sediment at the base of the continental slope; regional metamorphism occurs in regions of subduction and continental collision. High pressure and low temperature metamorphism happens within a subducted plate of oceanic lithosphere, and in any sediment carried down by a subducting plate.
- Metasomatism due to hydrothermal solutions is linked to plate tectonics because the solutions tend to form in, or be associated with, stratovolcanoes. Stratovolcanoes are formed above subduction zones.

Summary

- Metamorphism involves changes in mineral assemblage and rock texture and occurs in the solid state as a result of changes in temperature and pressure.
- Mechanical deformation and chemical recrystallization are the two processes that affect rock during metamorphism.
- The presence of intergranular fluid greatly speeds up metamorphic reactions.
- Foliation, as expressed by directional textures such as slaty cleavage and schistosity, arises from parallel growth of minerals formed during metamorphism and from the mechanical deformation of materials under differential stress.
- Cataclastic metamorphism involves mechanical deformation together with chemical recrystallization, but mechanical deformation is the predominant effect.
- Heat given off by bodies of intrusive igneous rock causes contact metamorphism and creates contact metamorphic aureoles. Contact metamorphism involves chemical recrystallization but little mechanical deformation.
- Regional metamorphism, which involves both mechanical deformation and chemical recrystallization, is a result of plate tectonics. Regionally metamorphosed rocks are produced along subduction and collision edges of plates.

Start with igneous, sedimentary or metamorphic rocks

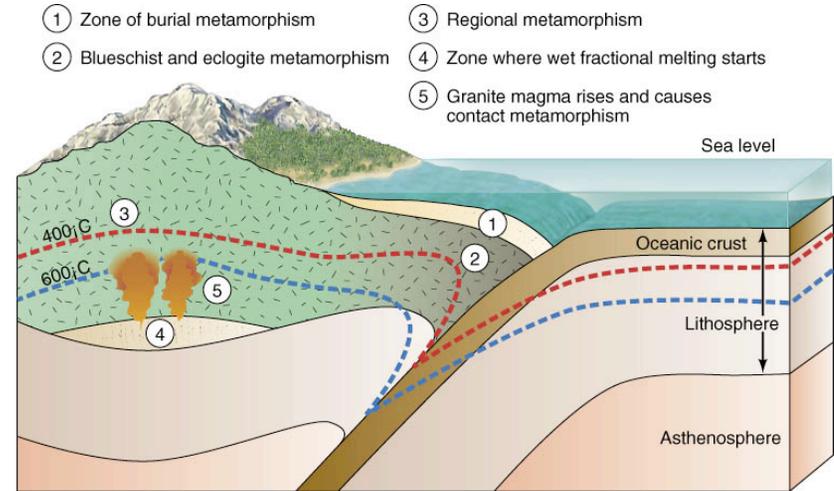
Change the environment:

- Temperature
- Pressure
- Fluids
- Deformation

==> Result: Metamorphic Rocks

Importance

- Geologic Memory
 - reconstruct past events from rock recording
 - Minerals are metastable
- Connection to Plate Tectonics
 - Specific metamorphic characteristics for specific environments

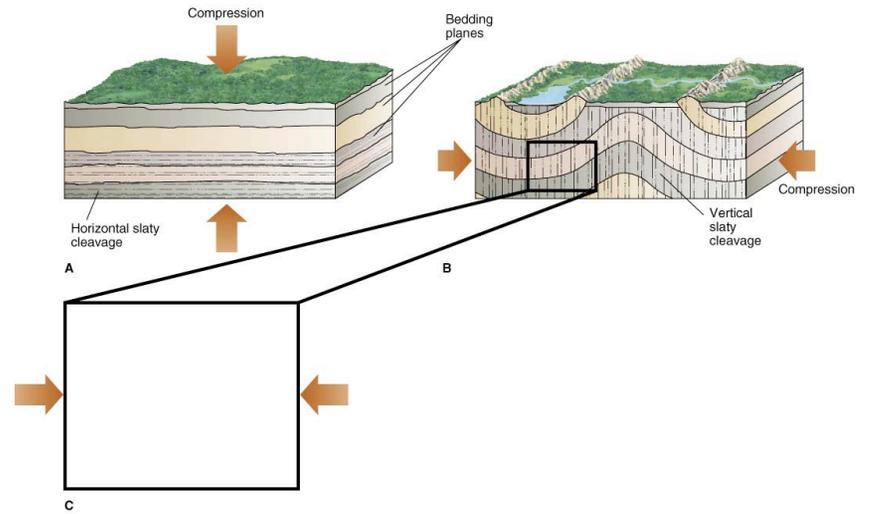
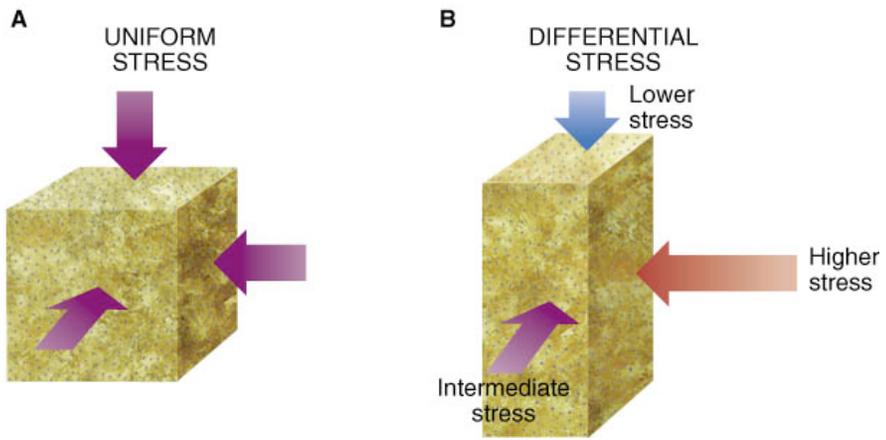


Key Changes

- Mechanical deformation
- Recrystallization
- Chemical reactions

Note important role of fluids in metamorphism (principally water)







A

	Intensity of metamorphism →			
	Not metamorphosed	Low grade	Intermediate grade	High grade
Rock name	Shale →	Slate →	Phyllite →	Schist Gneiss
Foliation	None	Subtle: slaty cleavage	Distinct: schistosity apparent	Conspicuous; schistosity and compositional layering
Size of mica grains	Microscopic	Microscopic	Just visible with hand-held magnifier	Large and obvious
Typical mineral assemblage	Quartz, clays, calcite	Quartz, chlorite, muscovite, plagioclase	Quartz, muscovite, biotite, garnet, kyanite, plagioclase	Quartz, biotite, garnet, sillimanite, plagioclase

B

	Intensity of metamorphism →			
	Not metamorphosed	Low grade	Intermediate grade	High grade
Rock name	Basalt → +H ₂ O	Greenschist →	Amphibolite →	Granulite
Foliation	None	Distinct schistosity	Indistinct; when present due to parallel grains of amphibole	Indistinct because of absence of micas
Size of grains	Visible with hand-held magnifier	Visible with hand-held magnifier	Obvious by eye	Large and obvious
Typical mineral assemblage	Olivine, pyroxene, plagioclase	Chlorite, epidote, plagioclase, calcite	Amphibole, plagioclase, epidote, quartz	Pyroxene, plagioclase, garnet

Former pillow basalt: now amphibolite



Former shale: now gneiss (migmatite)



How to establish common conditions of metamorphism?

==> metamorphic *FACIES*

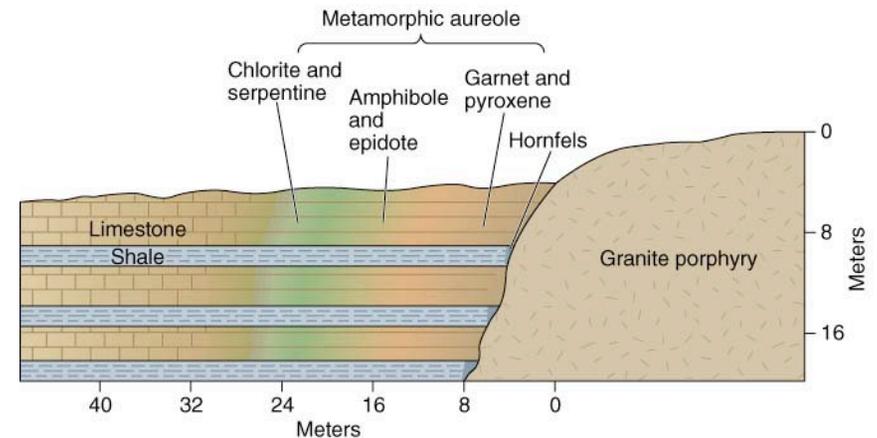
- Facies type refers to a limited range of T and P
- Index to tectonic settings
 - different geotherms in different plate tectonic settings

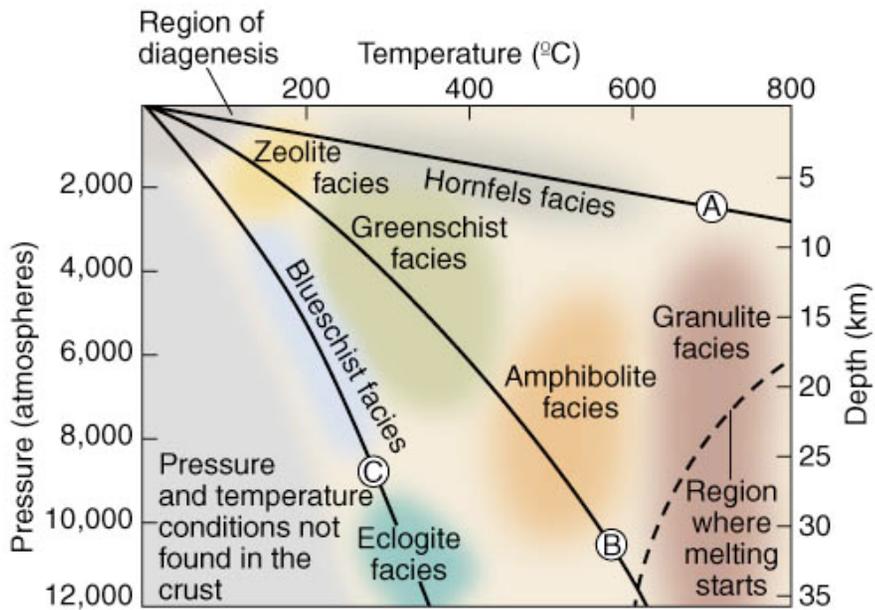
Types of metamorphism (*Specific geologic environments*)

- **contact metamorphism**
 - scale from meters to a few kilometers
- **burial metamorphism**
- **regional metamorphism**

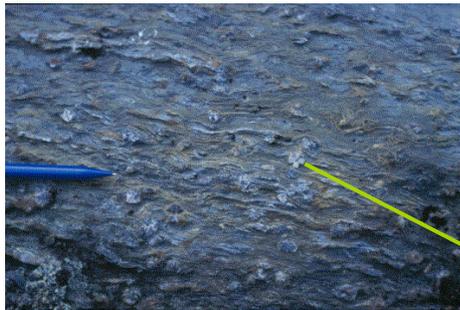
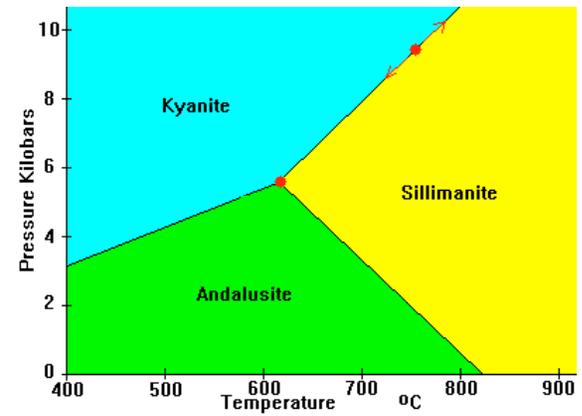
Metamorphic Facies

- **Granulite facies**
- **Amphibolite facies**
- **Epidote-amphibolite facies**
- **Greenschist facies**
- **Blueschist facies**
- **Eclogite facies**
- **hornfels facies**
- **zeolite facies**

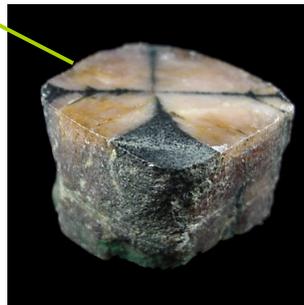




Polymorphs of Al_2SiO_5



Andalusite in a schist: variety-
Chialstolite



Reactions of clay and quartz:

- Kaolinite + Quartz \rightleftharpoons Pyrophyllite + water
- Pyrophyllite \rightleftharpoons Kyanite + Quartz + water



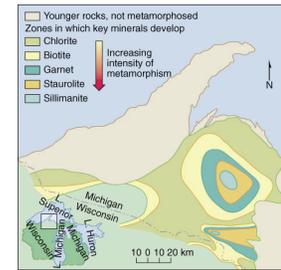
Pyrophyllite + quartz



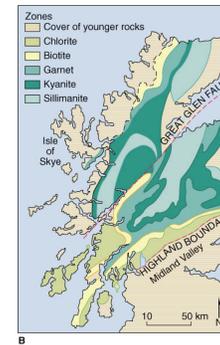
Kyanite

Metamorphism at Active Margins (Convergent Zones)

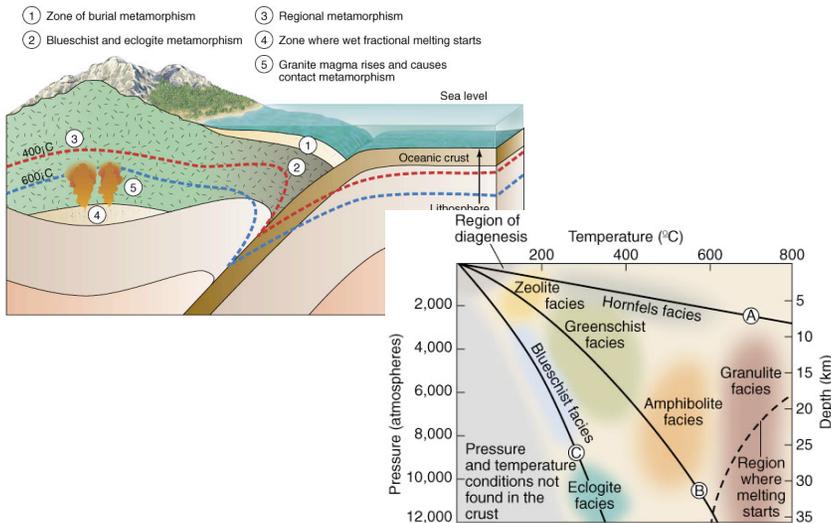
- Down going plate carries rocks into zones of greater pressure and temperature
- Collision between plates can thicken crust
- Partial melting in mantle provides fluids



Regional metamorphism: a record of former plate tectonic event



Metamorphic zones: reconstruct the history of the region



Vocabulary

- **Prograde:** changes while pressure and temperature are rising
- **Retrograde:** changes while P and T are declining
- **Foliation:** plane defined by planar sets of minerals or banding of minerals
- **Lamination:** parallel arrangement of elongated minerals
- **Rock/Slaty Cleavage:** rocks break into plate-like fragments along planes

- **Schistosity:** parallel arrangement of coarse grains of mica or chlorite
- **Contact/thermal metamorphism:** change due to adjacent bodies of magma intruded into cooler crustal rocks
- **Isograd:** Line on a map connecting first occurrence of a given metamorphic marker mineral
- **Metamorphic zones:** regions on map between isograds
- **Metamorphic Facies:** collection of minerals in equilibrium over a restricted range of P & T
- **Migmatite:** A composite rock containing an igneous and metamorphic component

