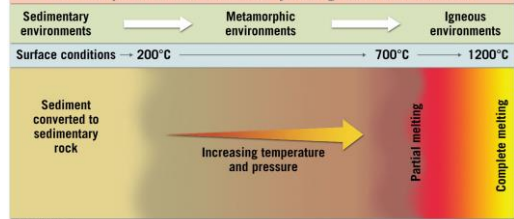


Metamorphism and Metamorphic Rocks



1

Metamorphic Versus Sedimentary and Igneous Environments



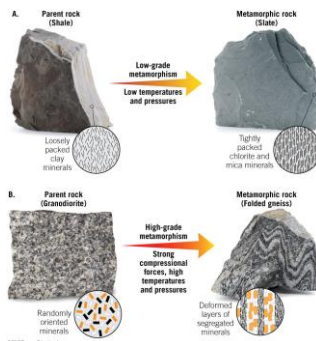
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Metamorphic rocks have undergone changes in mineralogy, texture and/or chemical composition as a result of changes in temperature ($>200^{\circ}\text{C}$) and pressure

2

Metamorphic Reactions

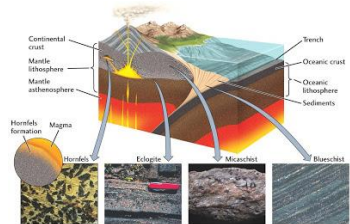
- Many metamorphic reactions occur in the presence of fluids
- Original rock may have been:
 - Igneous
 - Sedimentary
 - Another metamorphic rock



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3

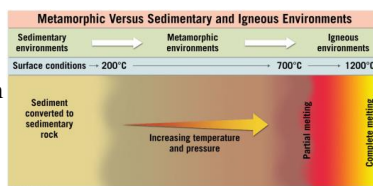
Agents of Metamorphism



- Agents of Metamorphism:
 - Heat
 - Pressure (stress)
 - Chemically active fluids
- During metamorphism, rocks are usually subjected to all three agents simultaneously

4

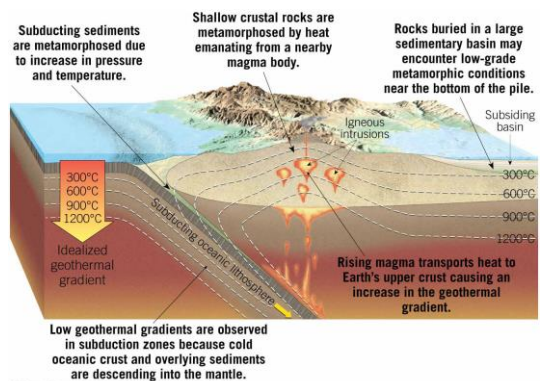
Agents of Metamorphism



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- Heat is the most important agent
- Two sources of heat:
 - Magma
 - Geothermal gradient: increasing temperature with depth
- Recrystallization results in new minerals that are stable under the higher temperature and pressure conditions

5

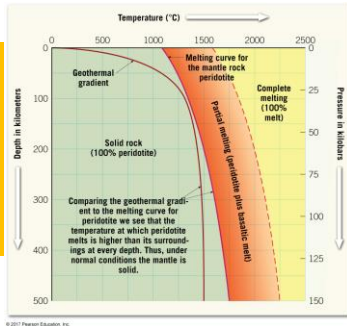


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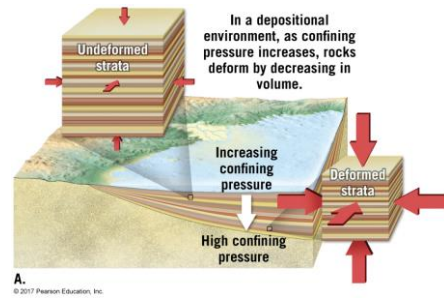
Agents of Metamorphism

- Pressure also important
- Pressure increases with depth
- Two types:
 - Confining pressure
 - Differential stress



7

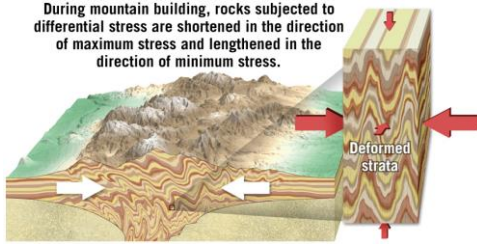
Confining Pressure: Stress Is Applied Equally In All Directions



8

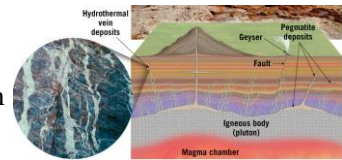
Differential Stress: Stress Applied Unequally And Predominates In One Direction

During mountain building, rocks subjected to differential stress are shortened in the direction of maximum stress and lengthened in the direction of minimum stress.



9

Agents of Metamorphism



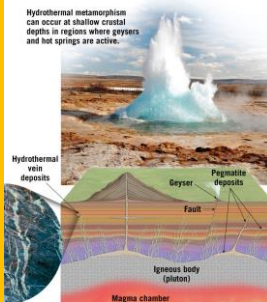
Chemically active fluids:

- Mainly water with other volatile components
- Enhances migration of ions from one site in the crystal structure to another
- Aids in recrystallization of existing minerals
- Can also transport mineral matter considerable distances
- Metasomatism involves substantial chemical changes in the rock due to reactions with active fluids

10

Sources of Chemically Active Fluids

- Localized sources:
 - Pore spaces of sedimentary rocks
 - Fractures in igneous rocks
 - Hydrated minerals such as clays and micas release water at higher temperatures and pressures
- Regional (hydrothermal) sources:
 - Geysers and hot springs
 - Percolating seawater along mid-ocean ridges

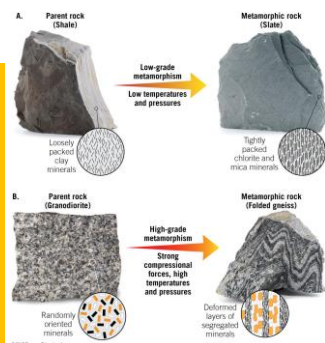


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Agents of Metamorphism

The importance of parent rock:

- Most metamorphic rocks have the same overall chemical composition as the parent rock from which they formed
- Mineral makeup determines, to a large extent, the degree to which each metamorphic agent will cause change



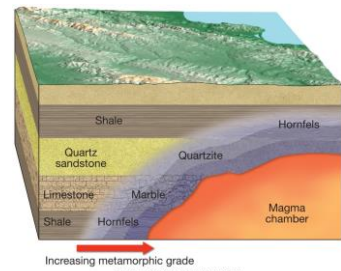
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Types of Metamorphism

There are several different types of metamorphism

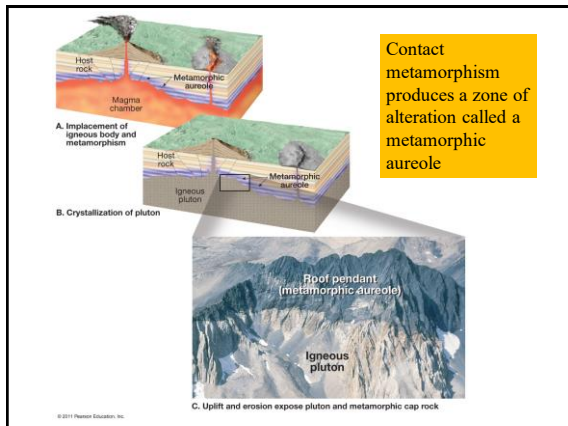
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Contact Metamorphism



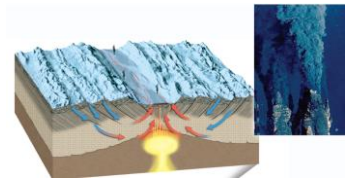
- Contact metamorphism occurs at high temperatures
- Restricted to a small area around the margins of a magmatic intrusion
- Type of metamorphic rock produced depends on the composition of the parent rock

14



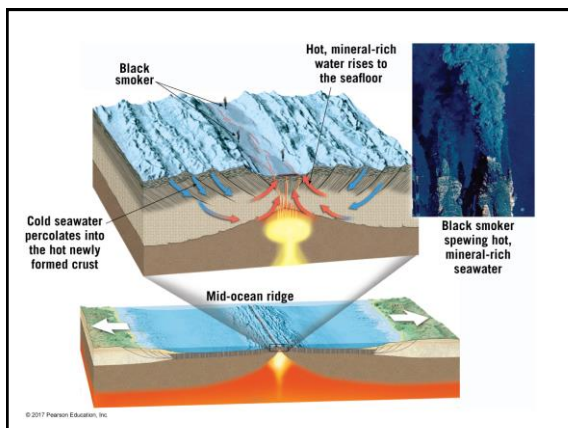
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Hydrothermal Metamorphism



- Takes place along mid-ocean ridges where heated seawater percolates through hot, fractured basalt
 - Chemical reactions occur between heated seawater and basaltic crust
- Crustal rocks on continents can react with invading, hot fluids associated with igneous intrusions

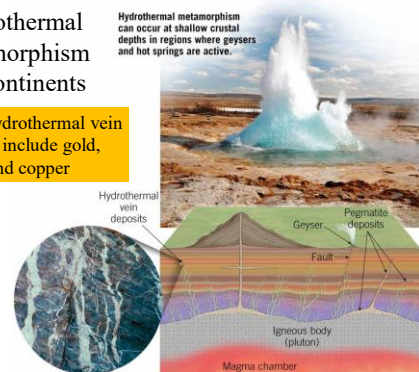
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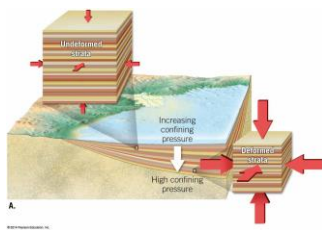
Hydrothermal Metamorphism On Continents

Some hydrothermal vein deposits include gold, silver, and copper



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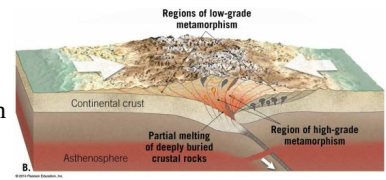
Burial Metamorphism



- A relatively mild type of metamorphism
- Sedimentary rocks are buried to greater depths:
 - Diagenesis grades into burial metamorphism
- Results in partial alteration of mineralogy and texture:
 - Original bedding and sedimentary structures usually preserved

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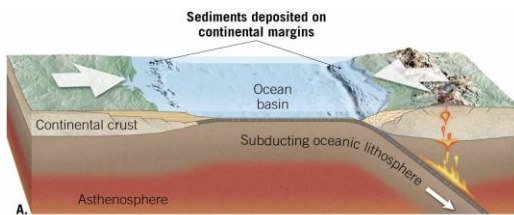
Regional Metamorphism



- Regional metamorphism occurs when temperatures & pressures increase beyond range of burial metamorphism
- Takes place under high temperatures & pressures over large areas
- Results in intense alteration of rock mineralogy and texture:
 - Original sedimentary structures destroyed
- Caused by major tectonic forces

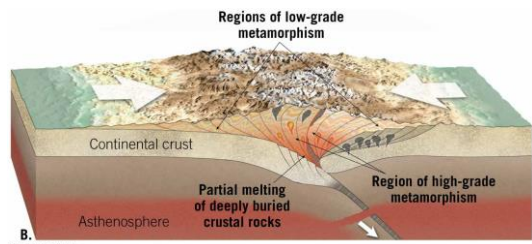
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Closing Ocean Basin



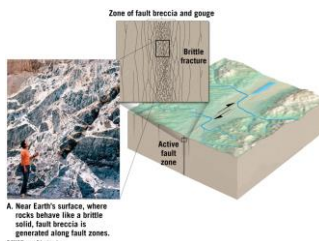
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Regional Metamorphism



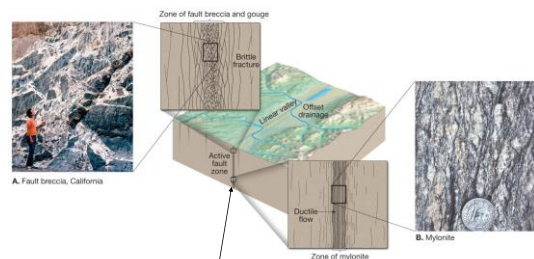
22

Cataclastic Metamorphism



- Results from the crushing and shearing of rock during tectonic movement
- Generally localized along fault planes:
 - Shallow depths: Fault breccia
 - Greater depths: Sheared, highly deformed mylonites

23



Movement along fault fractures and pulverizes rock

24

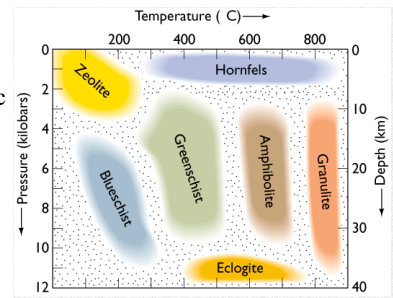
Impact Metamorphism

- Occurs when high speed projectiles called meteorites strike Earth's surface
- The impact pulverizes, shatters, and melts rock
- Leaves behind impact crater
- Products are called impactites



25

Metamorphic Facies



- Metamorphic facies describes the grouping of rocks formed under different temperatures and pressures
- Encompass different regions of P-T space

26

Facies Are Named After Certain Characteristic Minerals Usually Formed Through The Metamorphism Of Basalt

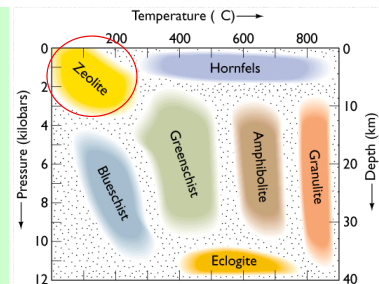
Diagenesis	Low grade	Intermediate grade	High grade
Zeolites	Greenschists	Amphibolites	Pyroxene granulites
<div> <div>Chlorite</div> <div>Zeolites</div> <div>Epidote</div> <div>(No aluminum) Amphibole (Aluminous)</div> <div>Garnet</div> <div>Pyroxene</div> <div>(Sodium-rich) Plagioclase (Calcium-rich)</div> </div>			

27

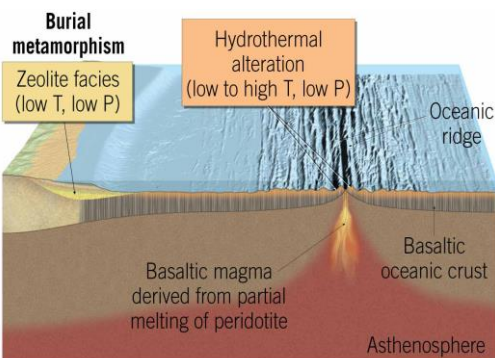
Zeolite Facies

P-T range of < 4kb, < 250° C

- Very low grade metamorphism
- Metamorphism of basalt forms zeolite minerals
- Typically associated with burial and hydrothermal metamorphism



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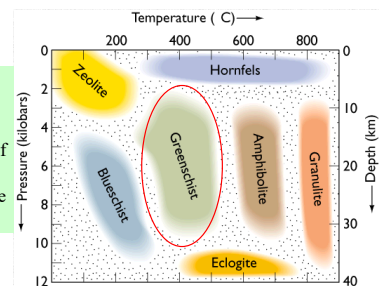
C.
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Greenschist Facies

P-T range 2 - 9 kb, 250° - 450° C

- Low grade metamorphism
- Metamorphism of basalt forms green minerals of chlorite and epidote

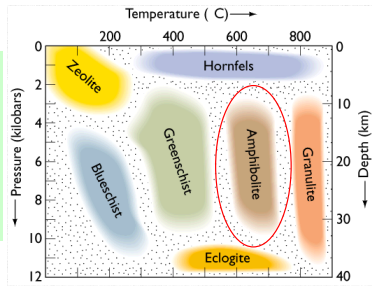


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Amphibolite Facies

P-T range 2 - 9 kb, 450° - 700° C

- Medium grade metamorphism
- Metamorphism of basalt forms amphibole minerals such as hornblende

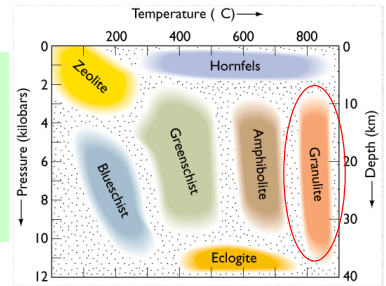


31

Granulite Facies

P-T range 4 - 10 kb, >700° C

- High grade metamorphism
- Metamorphism of basalt forms pyroxene granulites (with Ca-plagioclase)

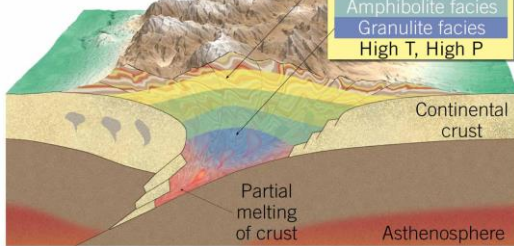


32

Progression towards higher metamorphic grade (increasing temperatures and pressures) at greater depth

Regional metamorphism

Low T, Low P
Zeolite facies
Greenschist facies
Amphibolite facies
Granulite facies
High T, High P



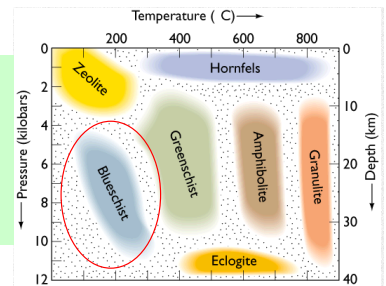
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Blueschist Facies

Very high pressures, relatively low temperatures

- Occurs within subduction zones
- Metamorphosed basalt and shale contain blue amphiboles (glaucofan)

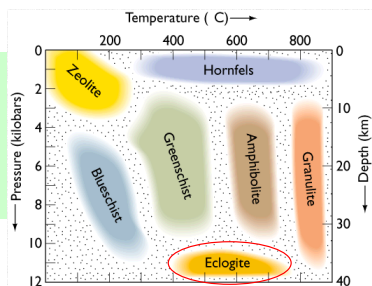


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Eclogite Facies

Extremely high pressures (>10 kb), moderate-high temperatures

- Occurs deep within subduction zones
- Basalt converts to eclogite rich in garnet & pyroxene



35

Subduction zone metamorphism

Blueschist facies (low T, high P)

Trench

A. Blueschist

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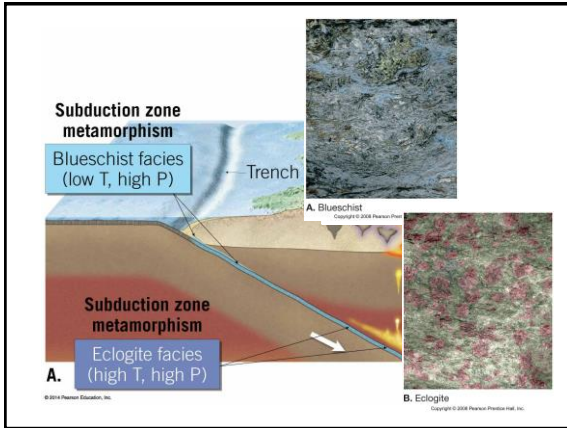
Subduction zone metamorphism

A.

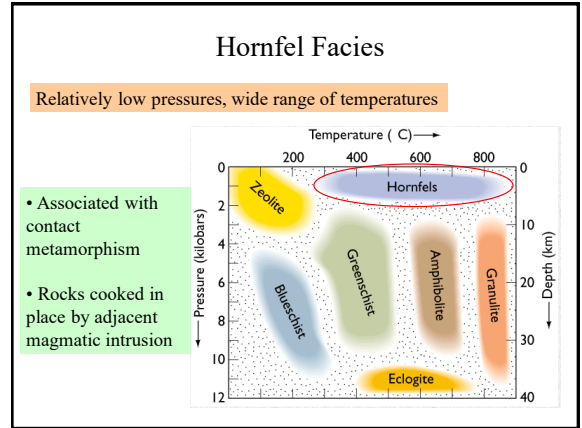
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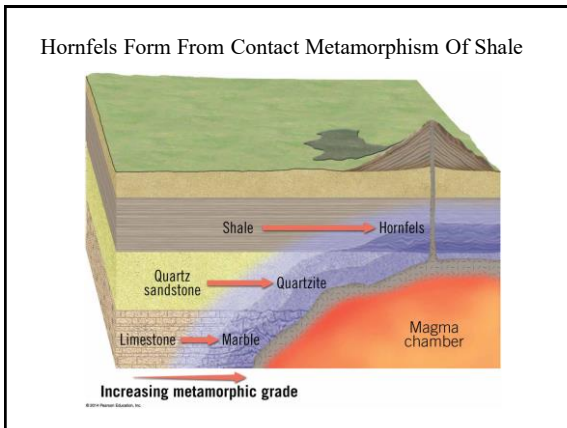
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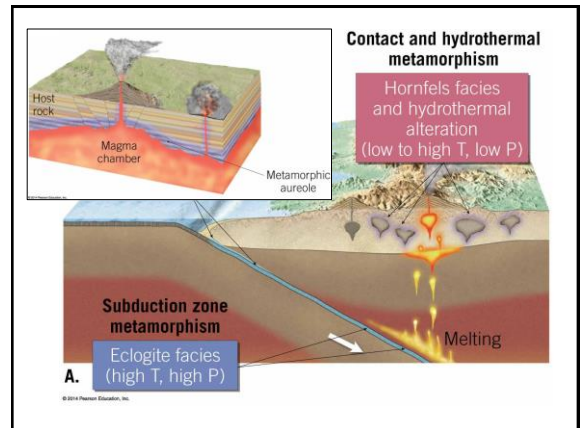
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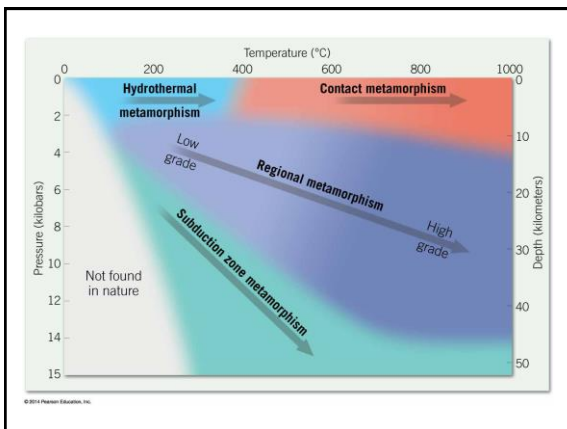
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