

# Metamorphism and metamorphic rocks



# METAMORPHISM AND METAMORPHIC ROCKS

**METAMORPHISM** (*from the Greek words Meta means Change morph means Form*) is the process by which rising temperature and changes in other environmental conditions transforms rocks and minerals. Metamorphism occurs in solid rock, like the transformations in the vase as the potter fires it in her kiln. Metamorphism can change any type of parent rock: sedimentary, igneous, or even another metamorphic rock.



# METAMORPHISM AND METAMORPHIC ROCKS



# METAMORPHISM AND METAMORPHIC ROCKS

## MINERAL STABILITY AND METAMORPHISM

➤ A stable mineral can become unstable when environmental conditions change. Three types of environmental change cause metamorphism;

1. rising temperature
2. Rising pressure, and
3. Changing chemical composition.

For example, when the potter put the clay in her kiln and raised the temperature, the clay minerals decomposed because they became unstable at the higher temperature. The atoms from the clay then recombined to form new minerals that were stable at the higher temperature. Like the clay, every mineral is stable only within a certain temperature range. In a similar manner, each mineral is stable only within a certain pressure range.

# METAMORPHISM AND METAMORPHIC ROCKS

## MINERAL STABILITY AND METAMORPHISM

- A mineral is stable only in a certain chemical environment.
- If fluids transport new chemicals to a rock, those chemicals may react with the original minerals to form new ones that are stable in the altered chemical environment.
- If fluids remove chemical components from a rock, new minerals may form for the same reason.

# METAMORPHISM AND METAMORPHIC ROCKS

## MINERAL STABILITY AND METAMORPHISM

- Each mineral is stable only within a certain range of temperature, pressure, and chemical environment.
- If temperature or pressure rises above that range, or if chemicals are added to or removed from the rock, the rock's original minerals may decompose and their components recombine to form new minerals that are stable under the new conditions.
- Then the process of metamorphism occur.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

Metamorphism commonly alters

- Texture
- mineral content of a rock.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### **Textural changes**

- As a rock undergoes metamorphism, some mineral grains grow larger and others shrink.
- The shapes of the grains may also change.
- For example, fossils give fossiliferous limestone its texture.
- For example, fossils give fossiliferous limestone its texture.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### Textural changes

- Both the fossils and the cement between them are made of small calcite crystals.
- If the limestone is buried and heated, some of the calcite grains grow larger at the expense of others.
- In the process, the fossiliferous texture is destroyed. Metamorphism transforms limestone into a metamorphic rock called marble. Like the fossiliferous limestone, the marble is composed of calcite, but the texture is now one of large interlocking grains, and the fossils have vanished.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES



Large interlocking grained Marble



Fossiliferous Limestone

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### Mineralogical changes:

- When a parent rock (the original rock) contains only one mineral, metamorphism transforms the rock into one composed of the same mineral but with a coarser texture.
- The mineral content does not change because no other chemical components are available during metamorphism.
- Limestone converting to marble is one example of this generalization.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### **Mineralogical changes:**

- Another is the metamorphism of quartz sandstone to quartzite, a rock composed of recrystallized quartz grains.
- In contrast, metamorphism of a parent rock containing several minerals usually forms a rock with new and different minerals and a new texture.
- For example, a typical shale contains large amounts of clay, as well as quartz and feldspar.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### **Mineralogical changes:**

- When heated, some of those minerals decompose, and their atoms recombine to form new minerals such as mica, garnet, and a different kind of feldspar.
- A rock called hornfels that formed when metamorphism altered both the texture and minerals of shale.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES



# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### **Deformation And Foliation:**

- Metamorphic rocks commonly form in large regions of the Earth's crust near a subduction zone, where two tectonic plates converge.
- The tectonic forces crush, break, and bend rocks in this environment as the rocks are undergoing metamorphism.
- This combination of metamorphism and deformation creates layering in the rocks.

# METAMORPHISM AND METAMORPHIC ROCKS

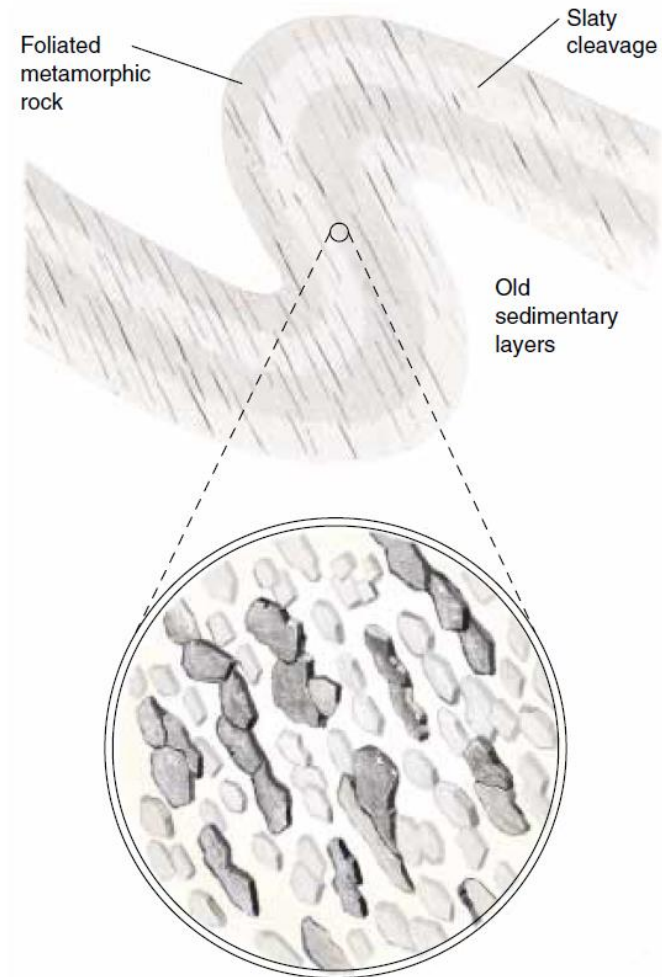
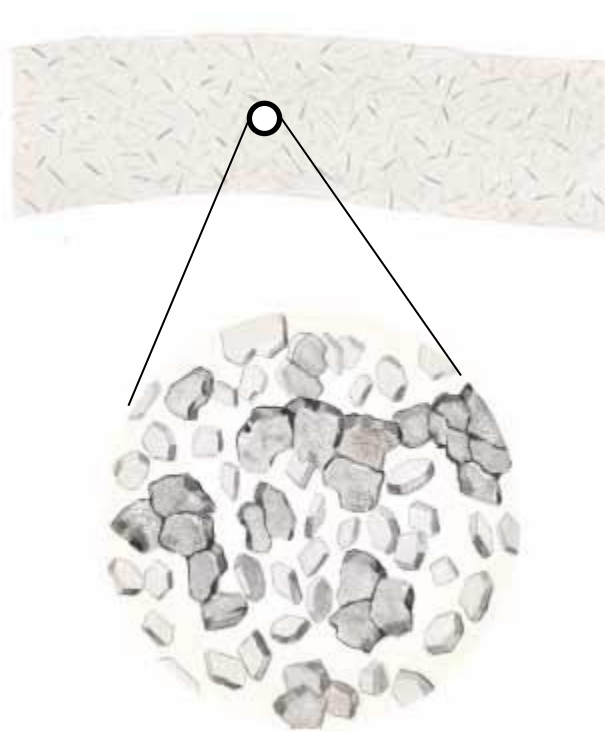
## METAMORPHIC CHANGES

### **Deformation And Foliation:**

- Micas are common metamorphic minerals; they form as many different parent rocks undergo metamorphism.
- When metamorphism occurs without deformation, the micas grow with random orientations, like pie plates flying through the air.
- When metamorphism and deformation occur together, the micas develop a parallel orientation.
- This parallel alignment of micas (and other minerals) produces the metamorphic layering called foliation.
- The layers range from a fraction of a millimeter to a meter or more in thickness.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES



# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### **Metamorphic grade:**

- Metamorphic grade expresses the intensity of metamorphism that affected a rock.
- Because temperature is the most important factor in metamorphism, metamorphic grade closely reflects the highest temperature attained during metamorphism.
- Geologists can interpret the metamorphic grade of most rocks because many metamorphic minerals form only within certain temperature ranges.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

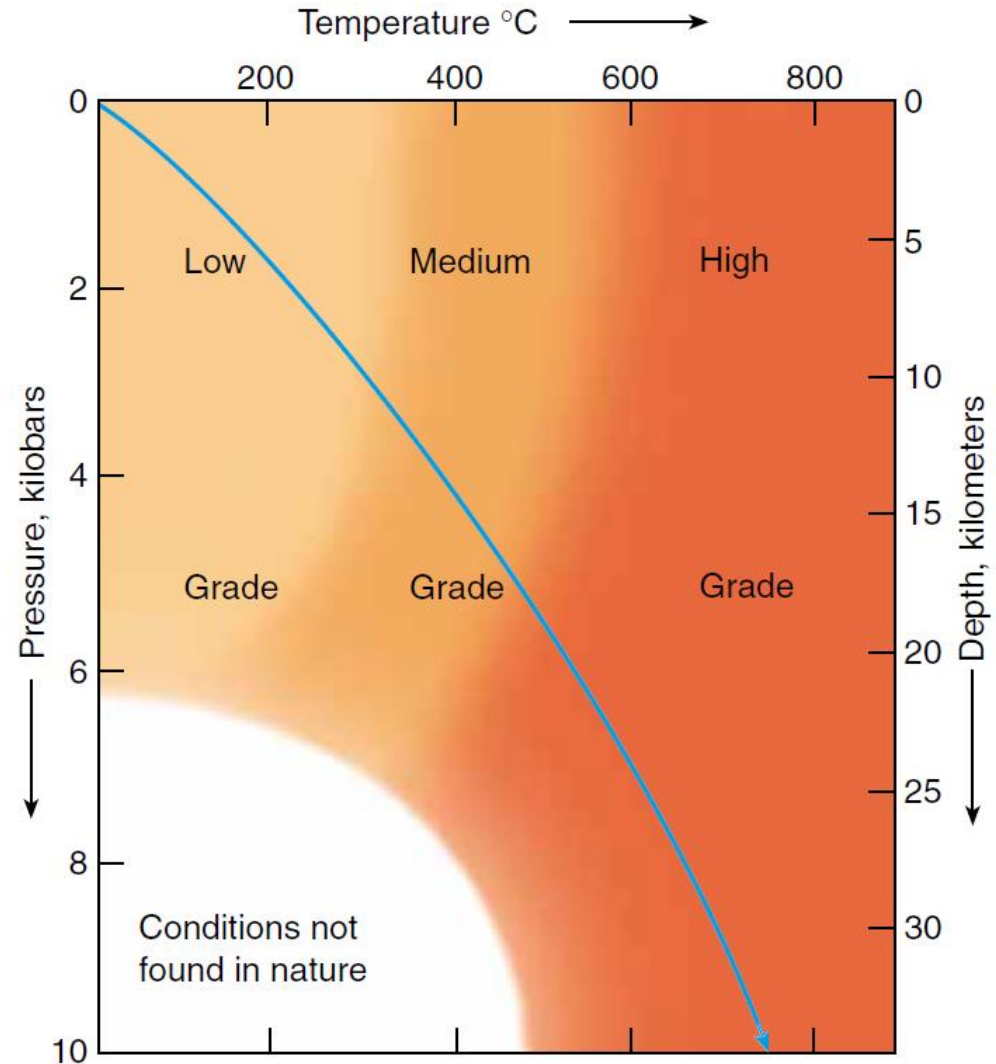
### **Metamorphic grade:**

- Low-grade metamorphism occurs at shallow depths, less than 10 to 12 kilometers beneath the surface, where temperature is below 350°C.
- High-grade conditions are found deep within continental crust and in the upper mantle, 40 or more kilometers below the Earth's surface. The temperature in these regions is 600°C or hotter and is near the melting point of rock.
- High-grade metamorphism can occur at shallower depths, where magma rises to a shallow level of the Earth's crust.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

Metamorphic grade commonly increases with depth because the Earth becomes hotter with increasing depth. The blue line traces an average geothermal gradient: the path of temperature and pressure in an average part of continental crust.



# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### **The rate of metamorphism:**

- A rule of thumb among laboratory chemists is that the speed of a chemical reaction doubles with every 10°C rise in temperature.
- Thus, reactions occur slowly in a cold environment, but rapidly in a hot one.
- For the same reason, metamorphic changes occur slowly at low temperature, but much faster at high temperature.

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC CHANGES

### **The rate of metamorphism:**

- The upper limit of metamorphism is the point at which rocks melt to form magma.
- That temperature varies depending on rock composition, pressure, and amount of water present, but it is between  $600^{\circ}$  and  $1200^{\circ}$  C for most rocks.
- A rock heated to its melting point creates magma, which forms igneous rocks when it solidifies.

*Metamorphism refers only to changes that occur without melting.*

# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

Three conditions cause metamorphism

- I. rising temperature
- II. rising pressure,
- III. Changing chemical environment.

➤ Tectonic deformation develops foliation and thus strongly affects the texture of a metamorphic rock. These conditions occur in four geologic environments.

# METAMORPHISM AND METAMORPHIC ROCKS

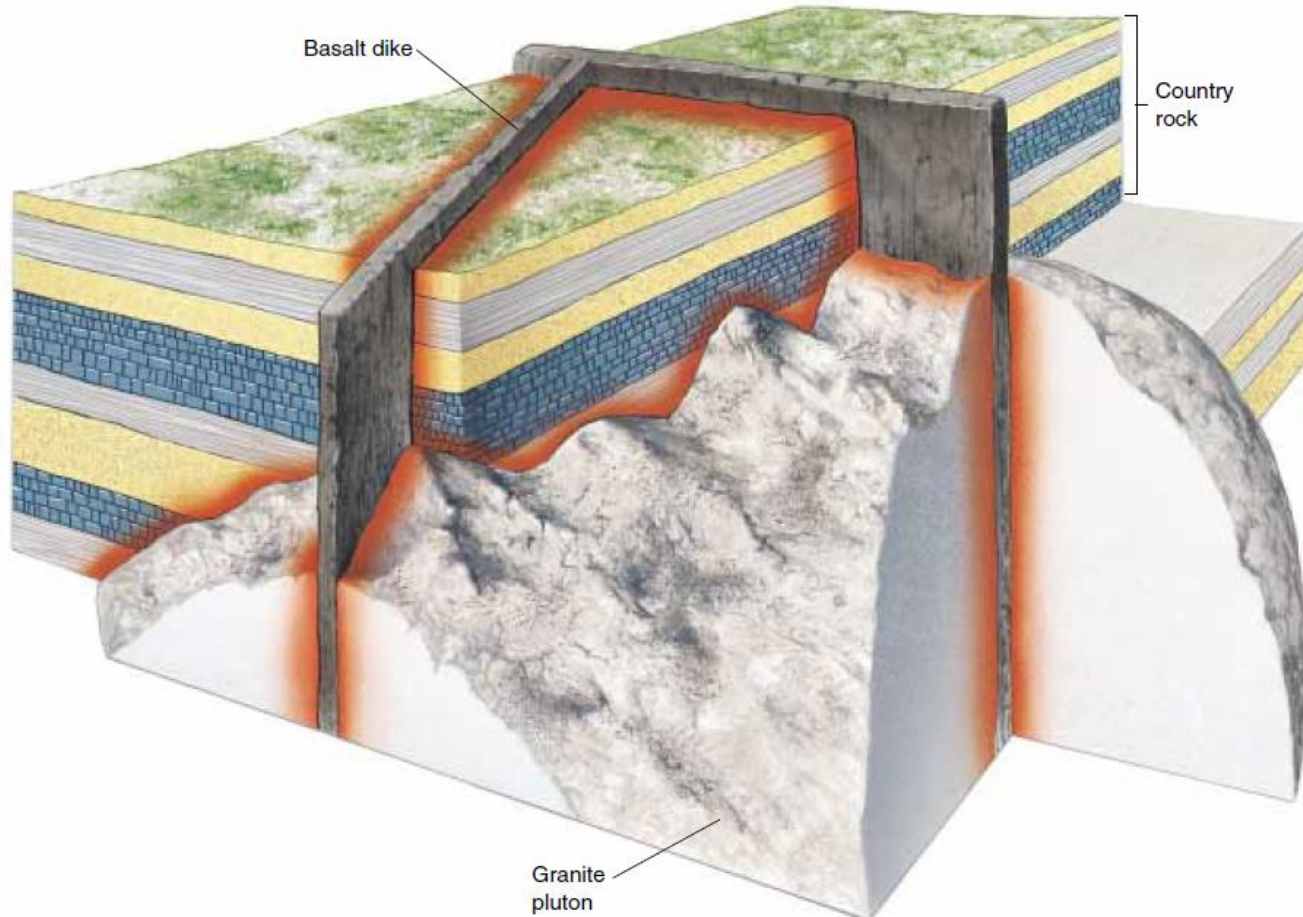
## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### **Contact metamorphism:**

- Contact metamorphism occurs where hot magma intrudes cooler country rock.
- The country rock may be of any type—sedimentary, metamorphic, or igneous.
- The highest-grade metamorphic rocks form at the contact, closest to the magma. Lower-grade rocks develop farther out.

# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS



# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### Contact metamorphism:

- A metamorphic halo around a pluton can range in width from less than a meter to hundreds of meters, depending on the size and temperature of the intrusion and the effects of water or other fluids.
- Contact metamorphism commonly occurs without deformation.
- As a result, the metamorphic minerals grow with random orientations and the rocks develop no metamorphic layering.

# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### **Burial Metamorphism**

- Burial metamorphism results from deep burial of rocks in a sedimentary basin.
- A large river carries massive amounts of sediment to the ocean every year, where it accumulates on a delta.
- Over tens or even hundreds of millions of years, the weight of the sediment becomes so great that the entire region sinks isostatically.
- Younger sediment may bury the oldest layers to a depth of more than 10 kilometers in a large basin.

# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### Burial Metamorphism

- Because rocks are heavy, pressure within the Earth increases rapidly with depth, at a rate of about 0.3 kilobar per kilometer.
- Over time, temperature and pressure increase within the deeper layers until burial metamorphism begins.
- Burial metamorphism occurs without tectonic deformation.
- Consequently, metamorphic minerals grow with random orientations and, like contact metamorphic rocks, burial metamorphic rocks are unfoliated.

# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### Regional Metamorphism

- Regional metamorphism occurs in and near a subduction zone, where tectonic forces build mountains and deform rocks.
- It is the most common and widespread type of metamorphism and affects broad regions of the Earth's crust.
- Figure (in next slide) shows magma forming in a subduction zone, where oceanic lithosphere is sinking beneath a continent.

# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### Regional Metamorphism

- As the magma rises, it heats large regions of the crust.
- The high temperatures cause new metamorphic minerals to form throughout the region.
- At the same time, the tectonic forces squeeze and deform rocks.
- The rising magma further deforms the hot, plastic country rock as it forces its way upward.

# METAMORPHISM AND METAMORPHIC ROCKS

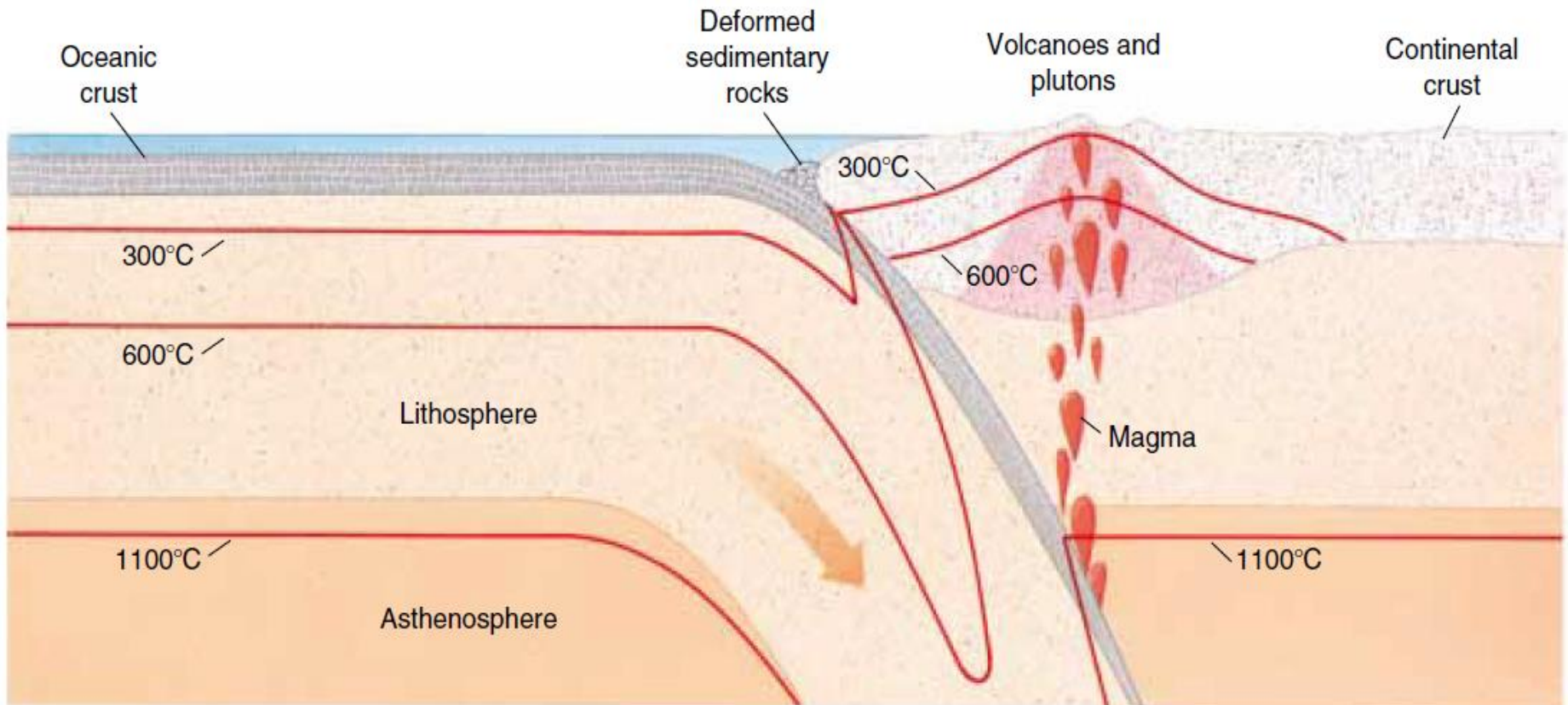
## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### Regional Metamorphism

- As a result of all of these processes acting together, regionally metamorphosed rocks are strongly foliated and are typically associated with mountains and igneous rocks.
- Regional metamorphism produces zones of foliated metamorphic rock tens to hundreds of kilometers across.

# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS



# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### Hydrothermal metamorphism

- Water is a chemically active fluid; it attacks and dissolves many minerals.
- If the water is hot, it attacks minerals even more rapidly.
- Hydrothermal metamorphism (also called hydrothermal alteration and metasomatism) occurs when hot water and ions dissolved in the hot water react with a rock to change its chemical composition and minerals.
- The water responsible for hydrothermal metamorphism can originate from three sources.

# METAMORPHISM AND METAMORPHIC ROCKS

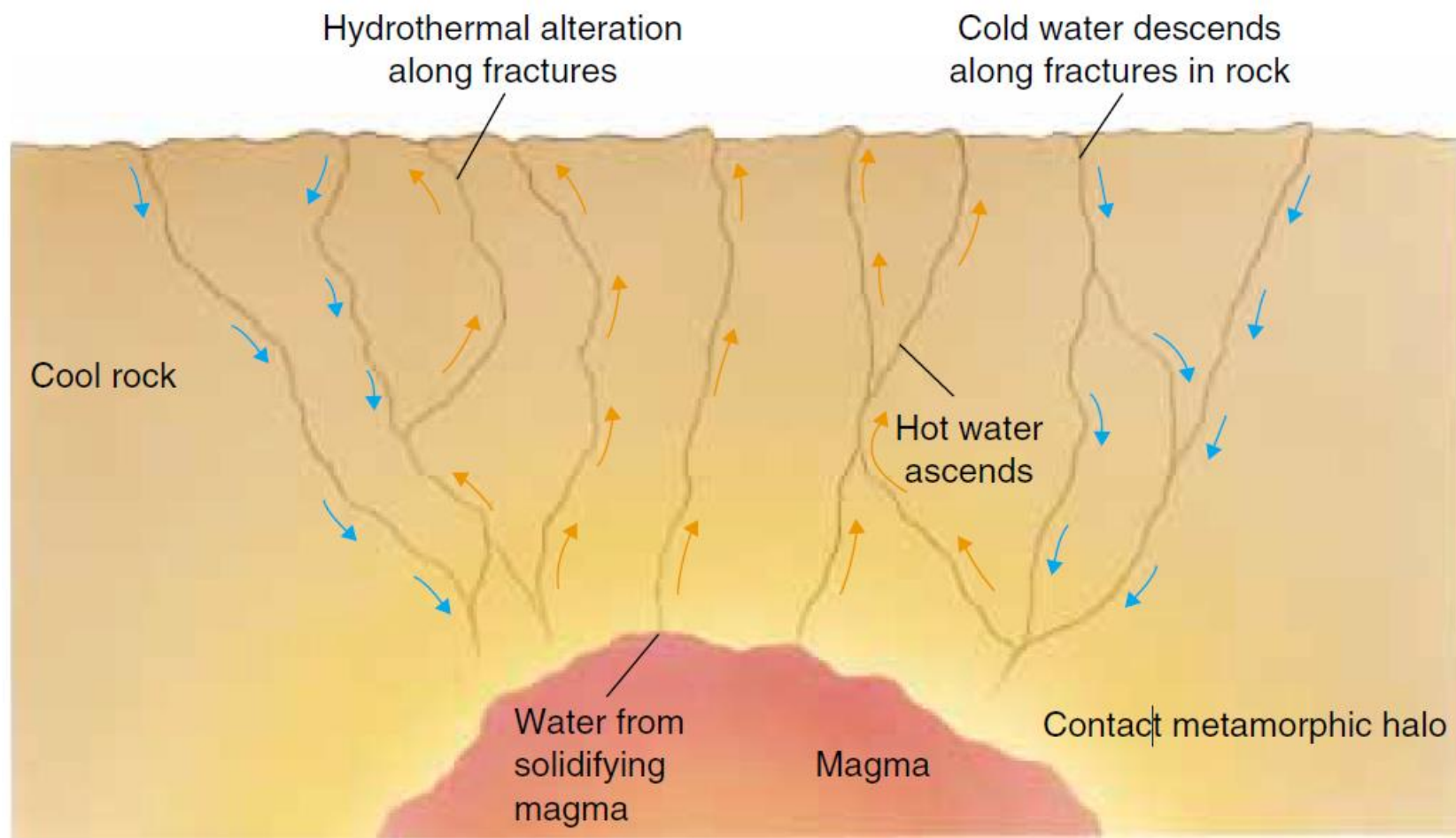
## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS

### Hydrothermal metamorphism

- Magmatic water is given off by a cooling magma.
- Metamorphic water is released from rocks during metamorphism.
- Cold ground water sinks through bedrock fractures to depths of a few kilometers, where it is heated by the hotter rocks at depth or, in some cases, by a hot, shallow pluton.
- Upon heating, the water expands and rises back toward the surface through other fractures. As it rises, it alters the country rock through which it flows.

# METAMORPHISM AND METAMORPHIC ROCKS

## TYPES OF METAMORPHISM AND METAMORPHIC ROCKS



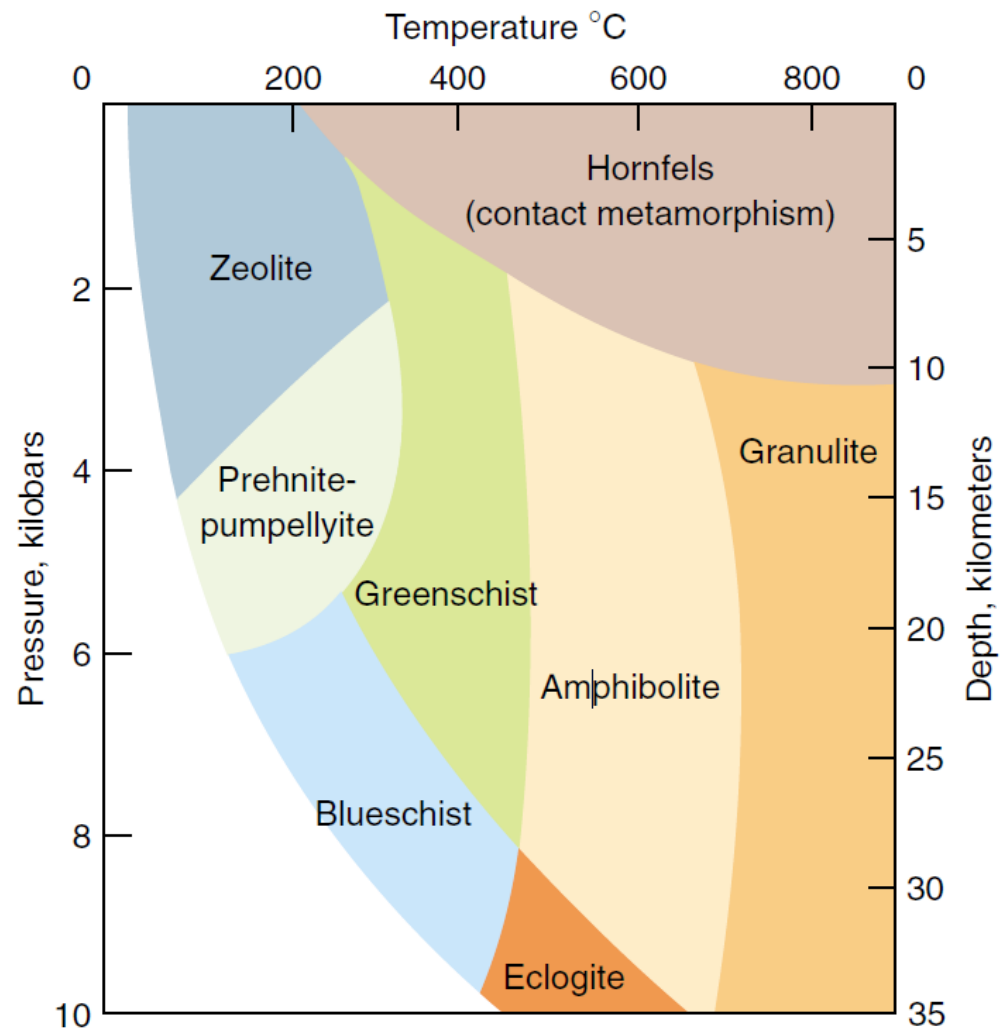
# METAMORPHISM AND METAMORPHIC ROCKS

## **METAMORPHIC FACIES:**

- All metamorphic rocks that formed under identical temperature and pressure conditions are grouped together into a single category called a metamorphic facies.
- Each rock differs from others in the same facies by having a different chemical composition and therefore a different mineral assemblage.
- Metamorphic facies differ from one another in that they form under different conditions of temperature and pressure.
- Each facies is given a name derived from a mineral and/or texture commonly found in rocks of that facies .

# METAMORPHISM AND METAMORPHIC ROCKS

## METAMORPHIC FACIES



# METAMORPHISM AND METAMORPHIC ROCKS

## COMMON METAMORPHIC ROCKS

### Amphibolite

- Amphibolite is a coarse-grained metamorphic rock that is composed mainly of green, brown, or black amphibole minerals and plagioclase feldspar.
- The amphiboles are usually members of the hornblende group.
- It can also contain minor amounts of other metamorphic minerals such as biotite, epidote, garnet, wollastonite, andalusite, staurolite, kyanite, and sillimanite.
- Quartz, magnetite, and calcite can also be present in small amounts.



# METAMORPHISM AND METAMORPHIC ROCKS

## COMMON METAMORPHIC ROCKS

### Gneiss

- Gneiss is a foliated metamorphic rock identified by its bands and lenses of varying composition, while other bands contain granular minerals with an interlocking texture.
  - Other bands contain platy or elongate minerals with evidence of preferred orientation.
- It is this banded appearance and texture - rather than composition - that define a gneiss.



# METAMORPHISM AND METAMORPHIC ROCKS

## COMMON METAMORPHIC ROCKS

### Hornfels

- Hornfels is a fine-grained nonfoliated metamorphic rock with no specific composition. It is produced by contact metamorphism.
- Hornfels is a rock that was "baked" while near a heat source such as a magma chamber, sill, or dike.

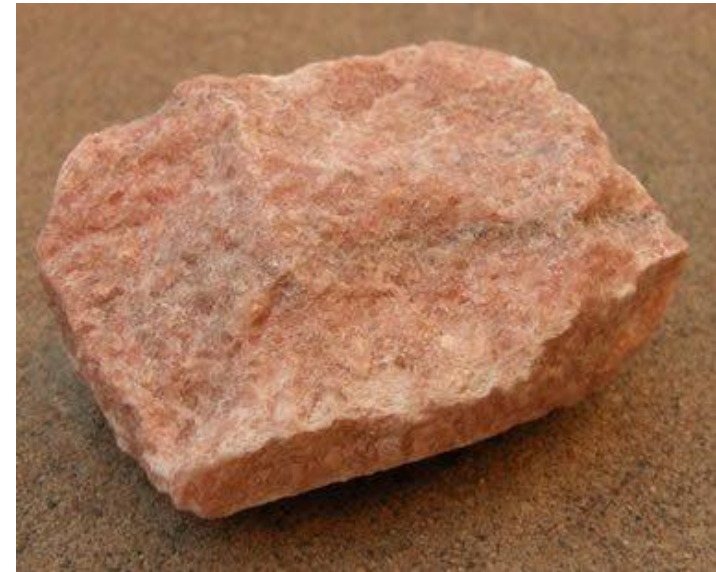


# METAMORPHISM AND METAMORPHIC ROCKS

## COMMON METAMORPHIC ROCKS

### Marble

- Marble is a metamorphic rock that forms when limestone is subjected to the heat and pressure of metamorphism.
- It is composed primarily of the mineral calcite ( $\text{CaCO}_3$ ) and usually contains other minerals, such as clay minerals, micas, quartz, pyrite, iron oxides, and graphite.
- Under the conditions of metamorphism, the calcite in the limestone recrystallizes to form a rock that is a mass of interlocking calcite crystals.
- A related rock, dolomitic marble, is produced when dolostone is subjected to heat and pressure.



# METAMORPHISM AND METAMORPHIC ROCKS

## COMMON METAMORPHIC ROCKS

### Phyllite

- Phyllite is a foliate metamorphic rock that is made up mainly of very fine-grained mica.
- The surface of phyllite is typically lustrous and sometimes wrinkled.
- It is intermediate in grade between slate and schist.



# METAMORPHISM AND METAMORPHIC ROCKS

## COMMON METAMORPHIC ROCKS

### Quartzite

- Quartzite is a non-foliated metamorphic rock composed almost entirely of quartz.
- It forms when a quartz-rich sandstone is altered by the heat, pressure, and chemical activity of metamorphism.
- These conditions recrystallize the sand grains and the silica cement that binds them together.
- The result is a network of interlocking quartz grains of incredible strength.



# METAMORPHISM AND METAMORPHIC ROCKS

## COMMON METAMORPHIC ROCKS

### Schist

- Schist is a foliated metamorphic rock made up of plate-shaped mineral grains that are large enough to see with an unaided eye.
- It usually forms on a continental side of a convergent plate boundary where sedimentary rocks, such as shales and mudstones, have been subjected to compressive forces, heat, and chemical activity.



# METAMORPHISM AND METAMORPHIC ROCKS

## COMMON METAMORPHIC ROCKS

### Slate

- Slate is a fine-grained, foliated metamorphic rock that is created by the alteration of shale or mudstone by low-grade regional metamorphism.
- It is popular for a wide variety of uses such as roofing, flooring, and flagging because of its durability and attractive appearance.



# METAMORPHISM AND METAMORPHIC ROCKS

Any Question???

You may ask freely..!!



# METAMORPHISM AND METAMORPHIC ROCKS

## Questions

1. Describe the two general kinds of changes that a rock undergoes during metamorphism.
2. How does contact metamorphism differ from regional metamorphism?
3. What is a metamorphic facies?
4. Name and briefly describe each of the different types of metamorphism.
5. What is the difference between metamorphism and magmatism?
6. What are the metamorphic changes? Describe with one example.

# METAMORPHISM AND METAMORPHIC ROCKS

*Thank You*