Hashemite University
Faculty of Natural Resources and Environment
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Economic Geology (111201491)

Part4: Metamorphic Ore-Forming Processes

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The word "**Metamorphism**" means:

meta = change,

morph = form,

Metamorphism means to change form.

In geology this refers to the changes in **mineral** assemblage and **texture** that result from subjecting a rock to conditions such pressures, temperatures, and chemical environments different from those under which the rock originally formed.

Diagenesis is a change in form that occurs in sedimentary rocks at temperatures below 200ºC and pressures below about 300 MPa.

Metamorphism occurs at temperatures higher than 200ºC and pressures higher than 300 MPa.

Rocks can be subjected to these higher temperatures and pressures as they are buried deeper in the Earth.

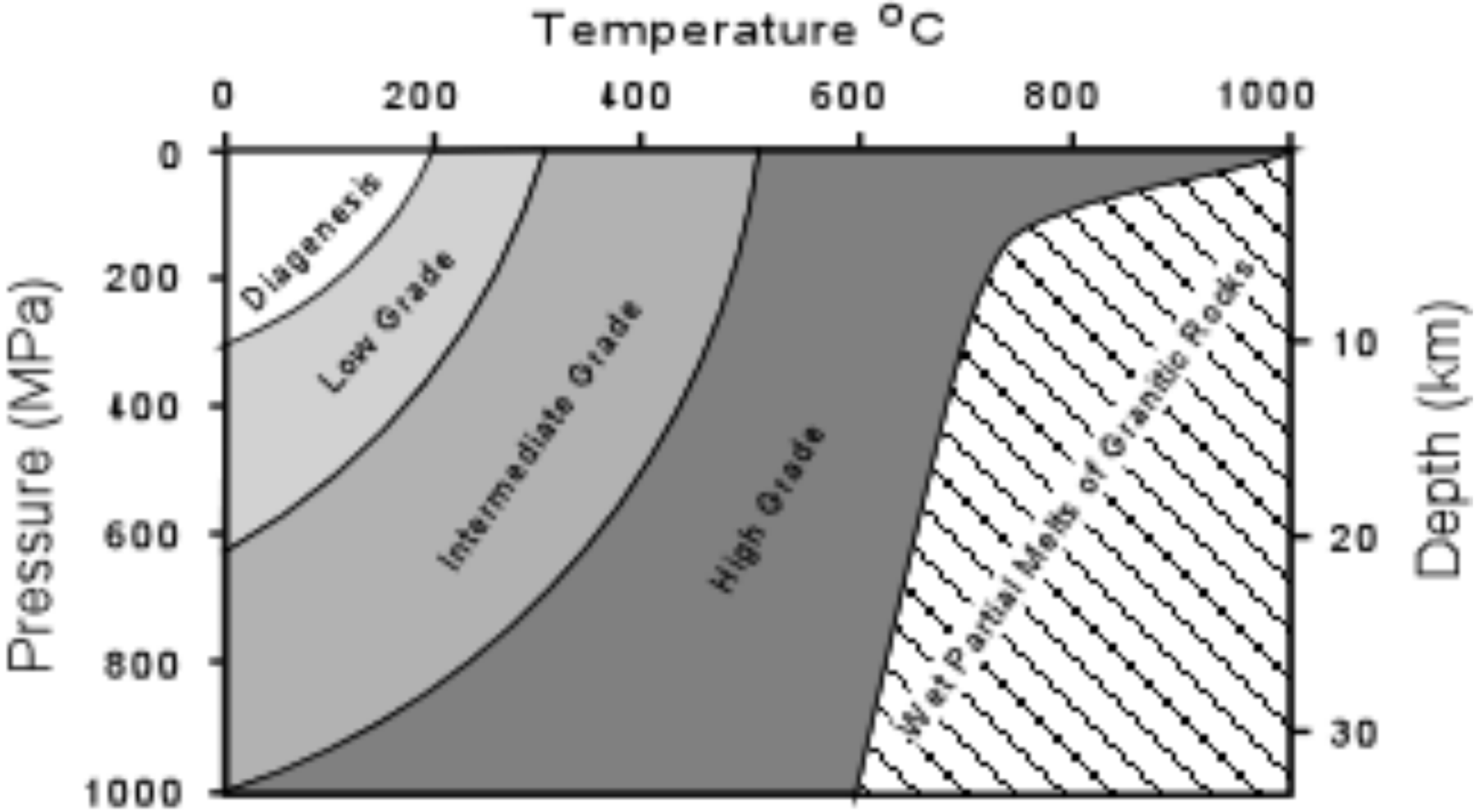
Such burial usually takes place as a result of **tectonic processes** such as continental collisions or subduction.

Grade Of Metamorphism

As the temperature and/or pressure increases on a body of rock, the grade of metamorphism increases.

Metamorphic grade is a general term for describing the relative temperature and pressure conditions under which metamorphic rocks form.

a. **Low-grade** metamorphism takes place at temperatures between about 200 to 320°C, and relatively low pressure.


Temperature °C
0
200
400
600
800
1000
Pressure (MPa)
0
200
400
600
800
1000
Depth (km)
10
20
30
Diagenesis
Low Grade
Intermediate Grade
High Grade
Wet Partial Melts of Granitic Rocks

Low grade metamorphic rocks are generally characterized by an abundance of hydrous minerals.

With increasing grade of metamorphism, the hydrous minerals begin to react with other minerals and/or break down to less hydrous minerals.

b. **High-grade** metamorphism takes place at temperatures greater than 500ºC and relatively high pressure.

As grade of metamorphism increases, hydrous minerals become less hydrous, by losing H_2O, and non-hydrous minerals become more common.

Types of Metamorphism

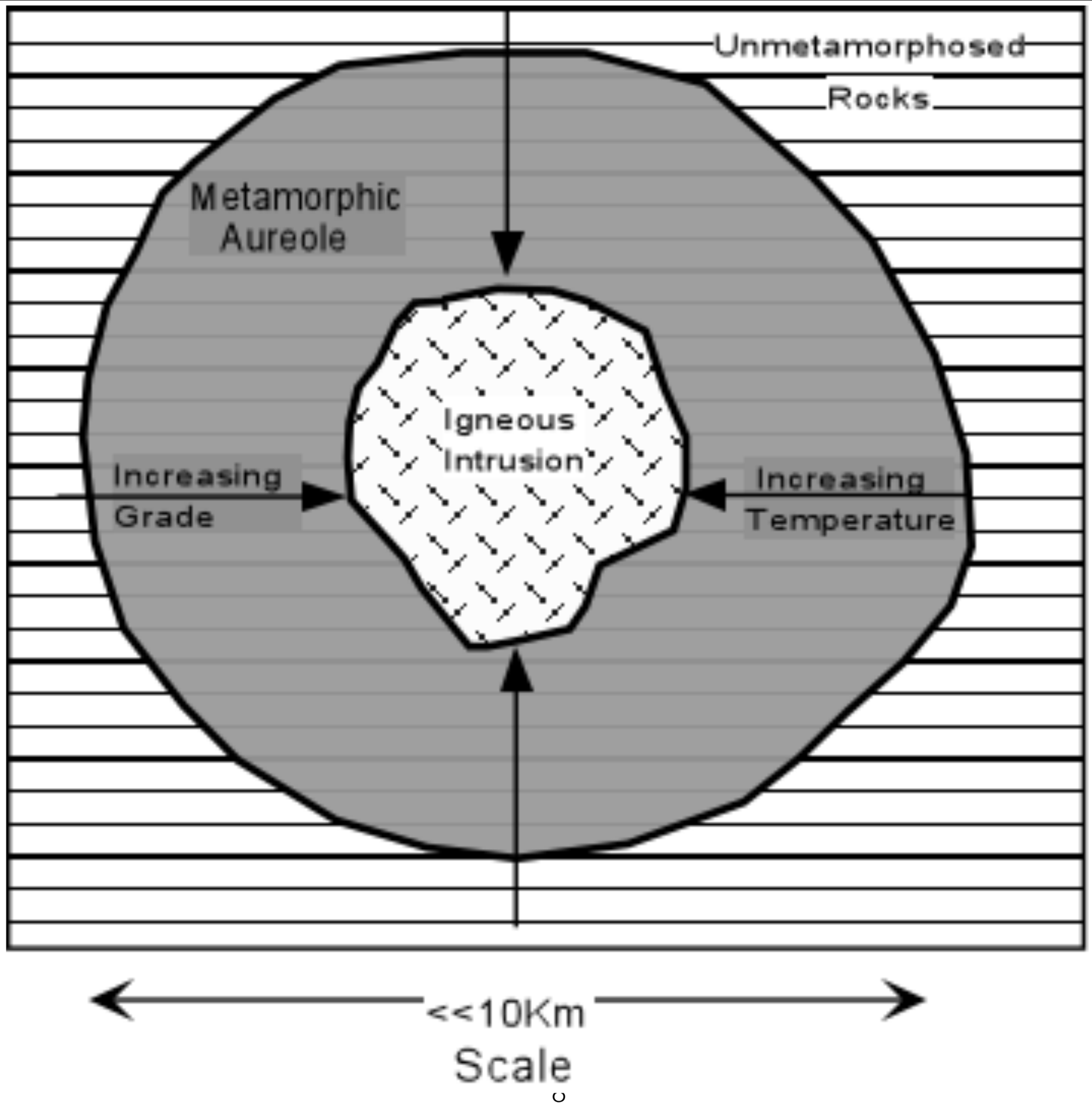
1. Contact Metamorphism

occurs adjacent to igneous intrusions and results from high temperatures associated with the igneous intrusion.

Since only a small area surrounding the intrusion is heated by the magma, metamorphism is restricted to the zone surrounding the intrusion, called a **metamorphic** or **contact aureole**.

Outside of the contact aureole, the rocks are not affected by the intrusive event.

The grade of metamorphism increases in all directions toward the intrusion.


Unmetamorphosed
Rocks
Metamorphic
Aureole
Igneous
Intrusion
Increasing
Grade
Increasing
Temperature
<<10Km
Scale

Because the temperature contrast between the surrounding rock and the intruded magma is larger at shallow levels in the crust where pressure is low, contact metamorphism is often referred to as high temperature, low pressure metamorphism.

The rock produced is often a fine-grained rock that shows no foliation, called a **hornfels**.

2. **Regional Metamorphism**

Most regional metamorphism is accompanied by **deformation** under differential stress conditions.

The differential stress results from **tectonic forces** that produce compressional stresses in the rocks, such as when two continental masses collide.

Compressive stresses result in folding of rock and thickening of the crust, which tends to push rocks to deeper levels where they are subjected to higher temperatures and pressures.

Generally regional metamorphism occurs over large areas

The formed metamorphic rocks that are strongly foliated, such as slates, schists, and gniesses.

3. **Cataclastic metamorphism**

occurs as a result of mechanical deformation, like when two bodies of rock slide past one another along a fault zone.

Heat is generated by the **friction** of sliding along such a shear zone, and the rocks tend to be mechanically deformed.

Cataclastic metamorphism is not very common and is restricted to a narrow zone along which the shearing occurred.

4. **Hydrothermal Metamorphism**

Rocks that are altered at high temperatures and moderate pressures by hydrothermal fluids.

The hydrothermal metamorphism results in alteration to such Mg–Fe rich hydrous minerals as talc, chlorite, serpentine, actinolite, tremolite, zeolites, and clay minerals.

5. **Burial Metamorphism**

When sedimentary rocks are buried to depths of several hundred meters, temperatures greater than 300ºC may develop in the absence of differential stress.

New minerals grow, but the rock does not appear to be metamorphosed.

The main minerals produced are often the Zeolites.

6. **Shock Metamorphism (Impact Metamorphism)**

When an extraterrestrial body, such as a **meteorite** or **comet** impacts with the Earth or,

if there is a very large volcanic explosion, ultrahigh pressures can be generated in the impacted rock.

These ultrahigh pressures can produce minerals that are only stable at very high pressure, such as the SiO_2 polymorphs coesite and stishovite.

Classification of Metamorphic Rocks

A. Chemical Composition (Mineralogy)

The most distinguishing minerals are used as a prefix to a textural term. Thus, a schist containing biotite, garnet, quartz, and feldspar, would be called a biotite-garnet schist. A gneiss containing hornblende, pyroxene, quartz, and feldspar would be called a hornblende-pyroxene gneiss. A schist containing porphyroblasts of K-feldspar would be called a K-spar porphyroblastic schist.

B. Texture

Metamorphic Ore deposits

Several kinds of nonmetallic mineral deposits are formed as a result of regional metamorphism.

The source materials are rock constitutions that have undergone recrystallization or re-combination, or both.

The enclosing rocks are wholly or in part metamorphosed; it is the rock metamorphism that has given rise to the deposits.

- **Ornamental stone**: **marble, slate, migmatite**
- **The mineral deposits thus formed are asbestos**, graphite, talc, soapstone, andalusite-kyanite- sillimanite, garnet, and possibly some emery.

The **Asbestos** forms by the metamorphism (hydration) of ultrabasic igneous rocks – peridotites and dunites.

Graphite forms by regional metamorphism of organic matter or contact metamorphism

Talc and **pyrophyllite** form by a mild hydrothermal metamorphism of magnesian minerals eg tremolite, actinolite, olivine, epidote and mica.

Talc also occurs in regionally metamorphosed limestones.

The Andalusite–kyanite–sillimanite – wollastonite these minerals are high grade refractories.

Kyanite is formed by the hydrothermal metamorphism of aluminous silicate minerals.

Andalusite is formed by the contact metamorphism of aluminous silicates.

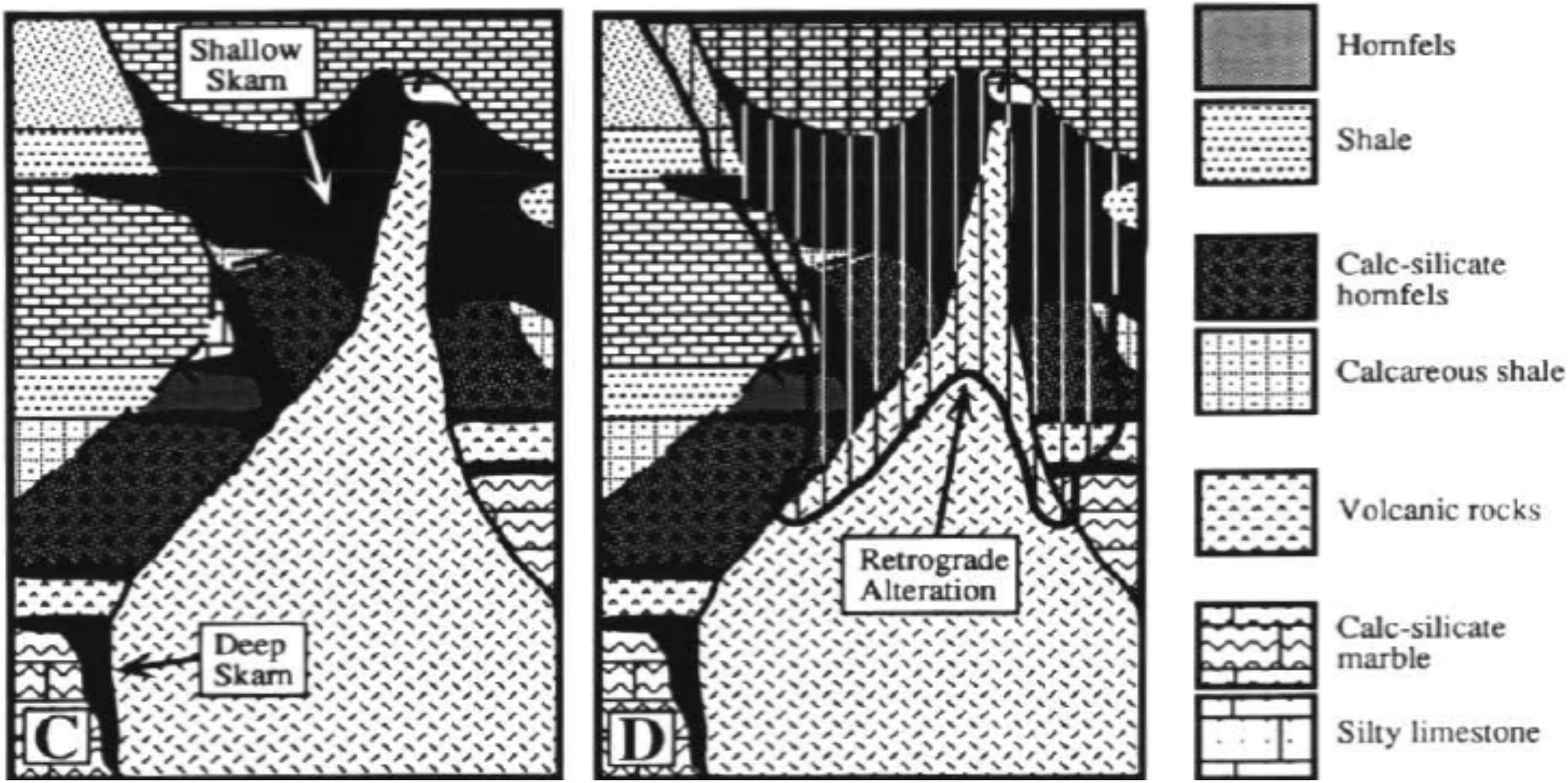
Sillimanite results from high temperature metamorphism of aluminous crystalline rocks.

Garnet for abrasives forms during the regional and contact metamorphism and is consequently found in schists and gneisses.

Emery is a mixture of corundum and magnetite with hematite or spinel and is a product of contact metamorphism.

Skarn deposits are mineral occurrences of economically valuable commodities that occur in the skarn environment or as a result of the process of skarnitisation i.e.

the process at which the hot waters (fluids) carrying a plethora of metals mix in the contact zone, dissolve calcium–rich carbonate rocks, and convert the host carbonate rock to skarn deposits in a metamorphic known as “metasomatism”.


Shallow Skarn
Deep Skarn
C
Retrograde Alteration
D
Hornfels
Shale
Calc-silicate hornfels
Calcareous shale
Volcanic rocks
Calc-silicate marble
Silty limestone

Skarn deposits

can form during regional or contact metamorphism and from a variety of metasomatic processes involving fluids of magmatic, metamorphic, meteoric.

Mineralogy includes a wide variety of calc–silicate and associated minerals but usually is dominated by garnet and pyroxene. Some minerals, such as quartz and calcite, are present in almost all skarns.

Skarn deposits

- **Iron Skarn**: They are mined for their magnetite content and although minor amounts of Cu, Co, Ni and Au may be present, iron is typically the only commodity recovered.

- **Gold skarns**
- **Zinc skarns**
- **Other types of skarn deposits includes**: tungsten, copper, molybdenum and tin which can be found in association with the other types discussed above e.g. copper skarns are highly associated with iron or sometimes gold and zinc.