Metamorphism and Metamorphic Rocks

Metamorphic rocks (from the Greek ***meta***, **"change"** and ***morpho***, **"shape"**) constitute the third major group of rocks. **They result from the transformation of other rocks by metamorphic processes that usually occur beneath Earth's surface**. During metamorphism, rocks are subjected to **sufficient heat, pressure and fluid activity** to change their **mineral composition, texture or both**, thus forming new rock.

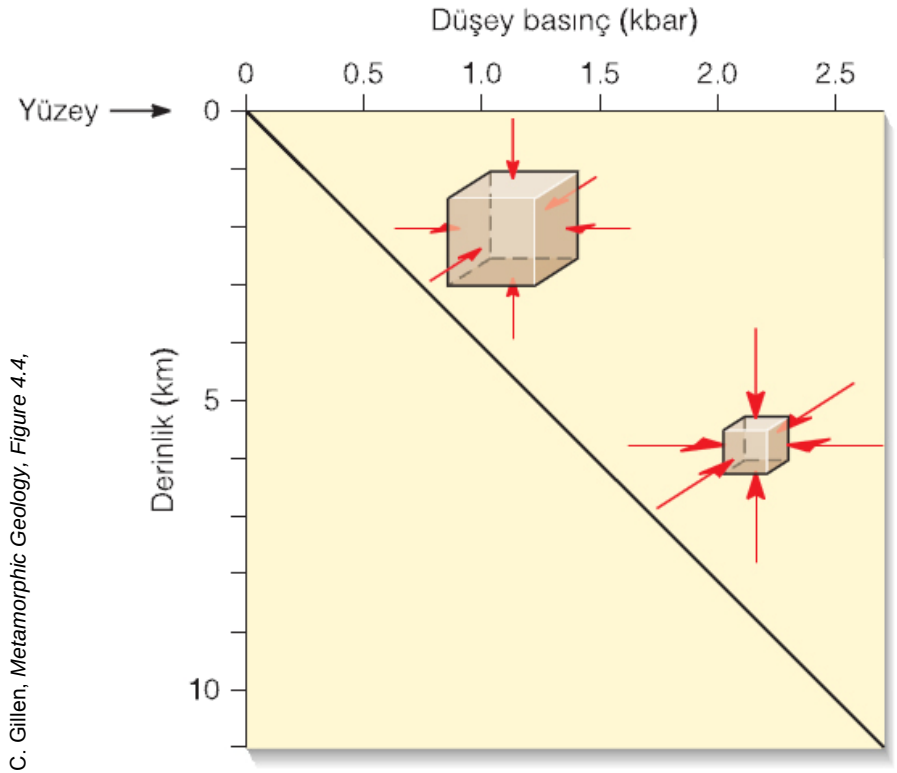
Agents of Metamorphism

Heat, Pressure, Fluid activity

Heat is an important agent of metamorphism because **it increases the rate of chemical reactions** that may produce minerals different from those in the original rock.

The heat may come from **intrusive magmas** or result from **deep burial** in the crust. The temperature increases with depth and that Earth's **geothermal gradient** averages about 25^{o}C/km. The rocks are also subjected to increasing temperature and pressure along subduction zones.

Pressure When rocks are burried, they are subjected to increasingly greater **lithostatic pressure**. This results from the weight of overlying rocks and is ***applied equally in all directions.***

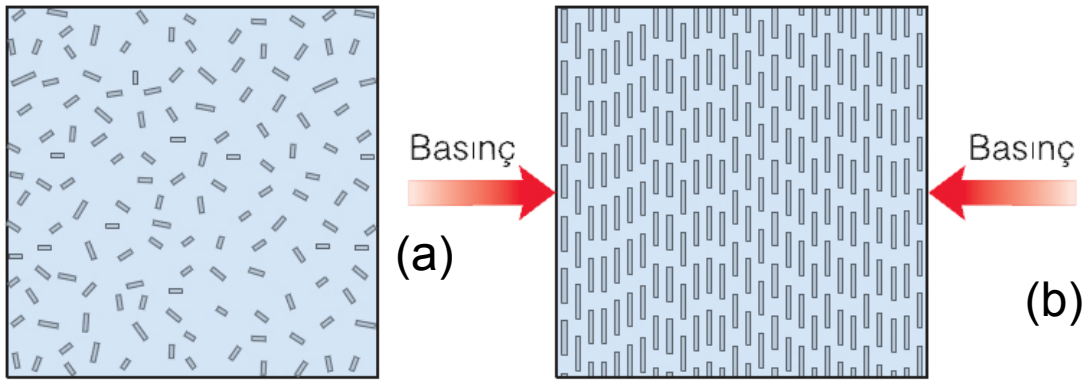


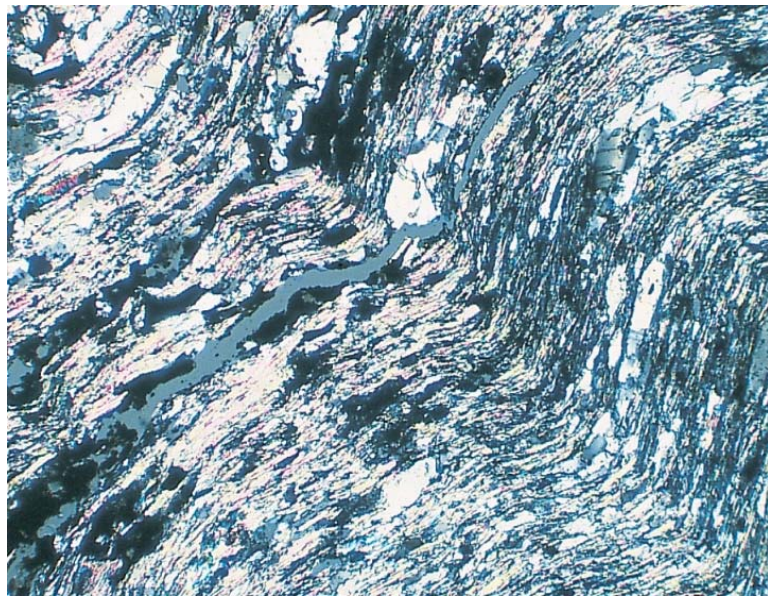
C. Gillen, *Metamorphic Geology, Figure 4.4,*

1 kilobar (kbar) = 1000 bar
Deniz seviyesindeki atmosferik basınç = 1 bar

The pressure increases with depth, as indicated by sloping black line. A similar situation occurs when 200-ml styrofoam cups lowered to ocean depths of approximately 750 m and 1500 m. Increased water pressure is exerted equally in all directions on the cups, and they consequently decrease in volume while still maintaining their general shape.

Rocks may also experience **differential pressure** (***directed pressure***).





Fluid Activity. In almost every region of metamorphism, water and carbon dioxide are present in varying amounts along ***mineral grains boundaries*** or in the ***pore spaces*** of rocks.

These fluids, which may contain ions in solution, enhance metamorphism by ***increasing the rate of chemical reactions***.

$2Mg_2SiO_4 + 2H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + MgO$

Olivine **Sea Water** **Serpentine** **Carried away in solution**

TYPES OF METAMORPHISM

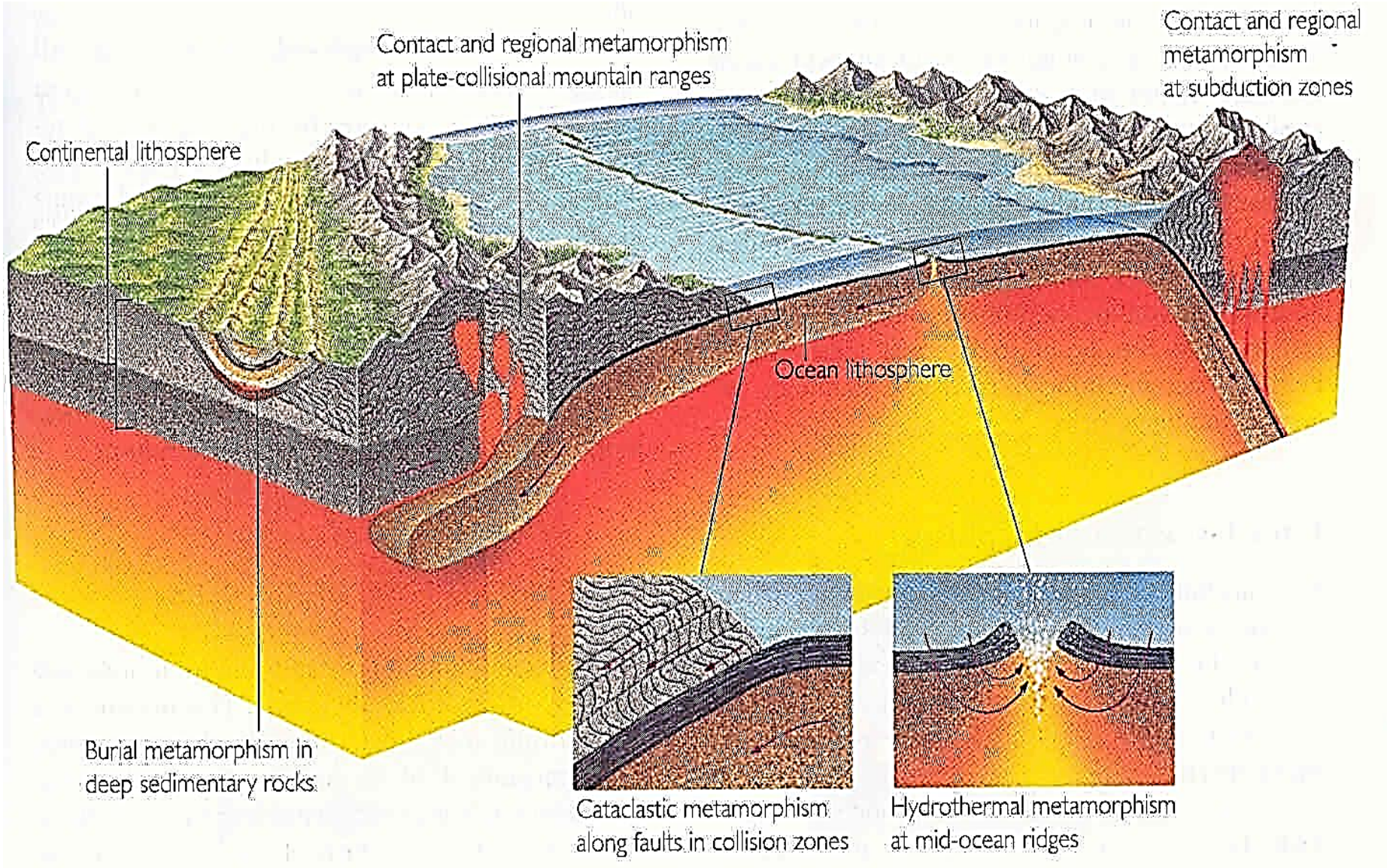
Contact metamorphism (Dokanak-Kontakt Metamorfizması)

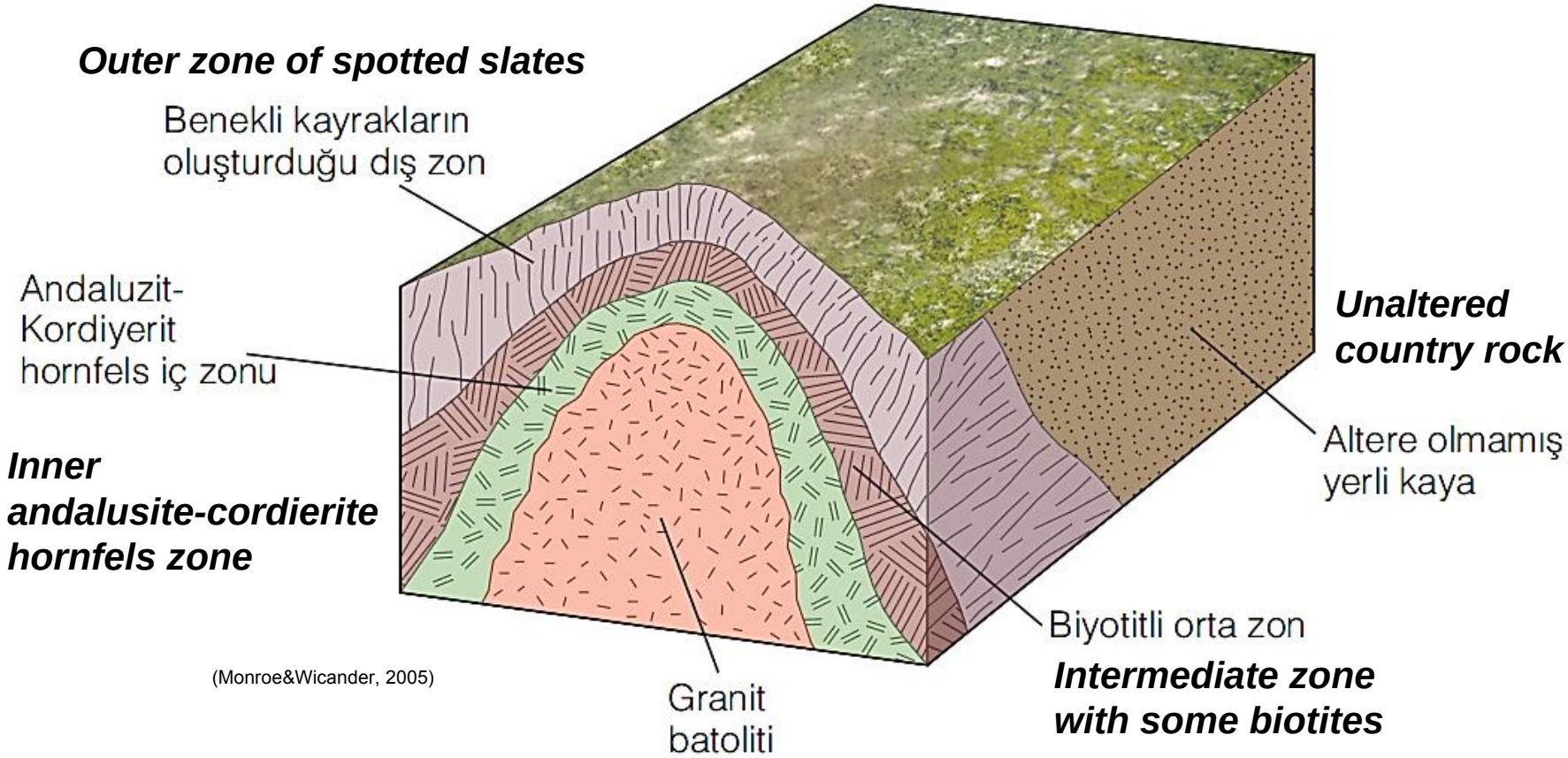
Hydrothermal metamorphism (Hidrotermal Metamorfizma)

Dynamic metamorphism (Dinamik Metamorfizma)

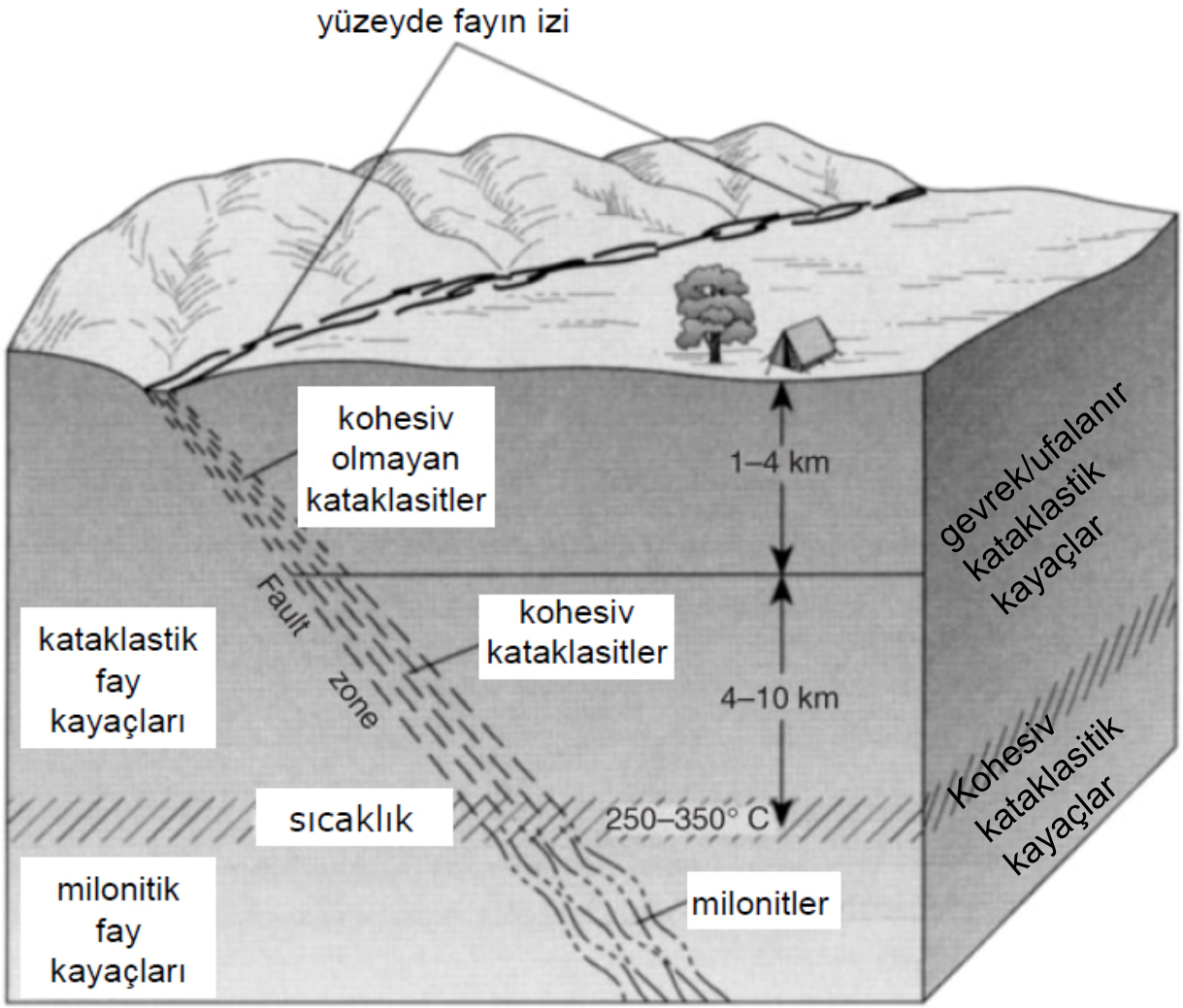
Regional metamorphism (Bölgesel Metamorfizma)

Burial metamorphism (Gömülme)


Contact and regional metamorphism at plate-collisional mountain ranges
Contact and regional metamorphism at subduction zones
Continental lithosphere
Ocean lithosphere
Burial metamorphism in deep sedimentary rocks
Cataclastic metamorphism along faults in collision zones
Hydrothermal metamorphism at mid-ocean ridges

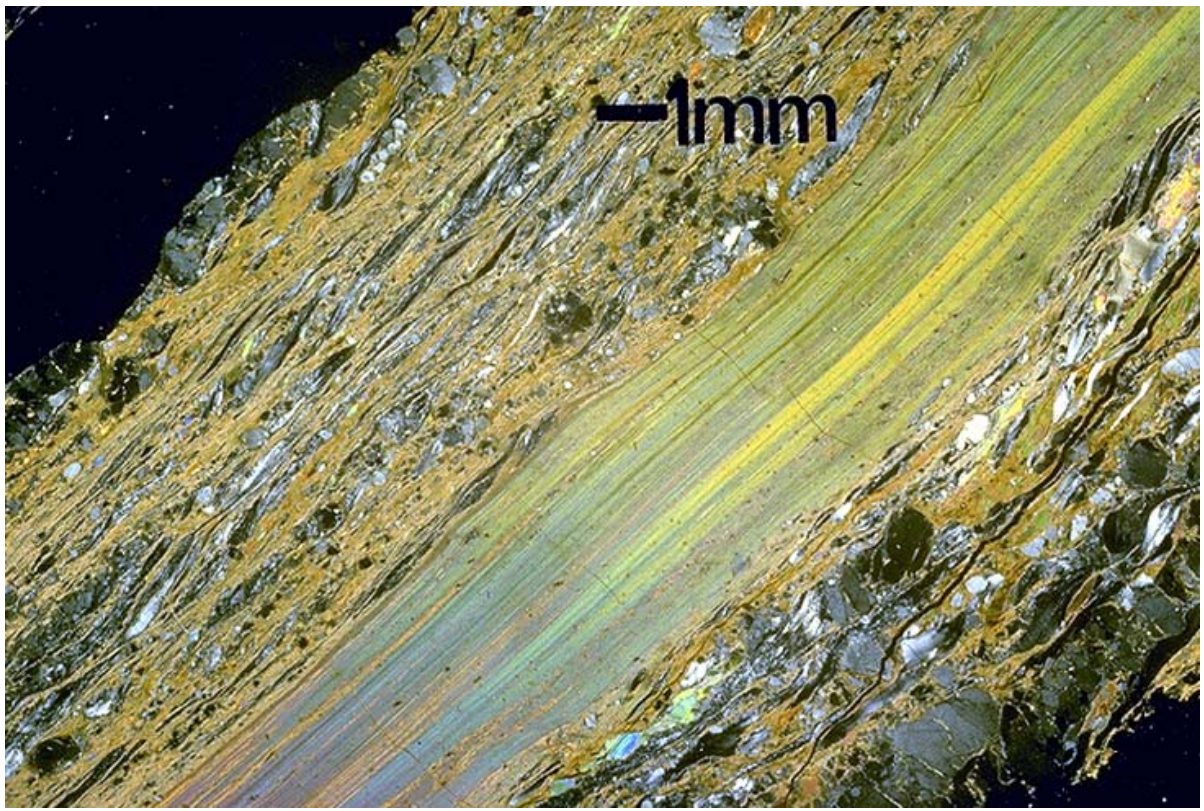


A metamorphic aurole typically surrounds many igneous intrusions. The above idealized granite intrusion contains three zones of mineral assemblages reflecting the decreases in temperature with distance from the intrusion.

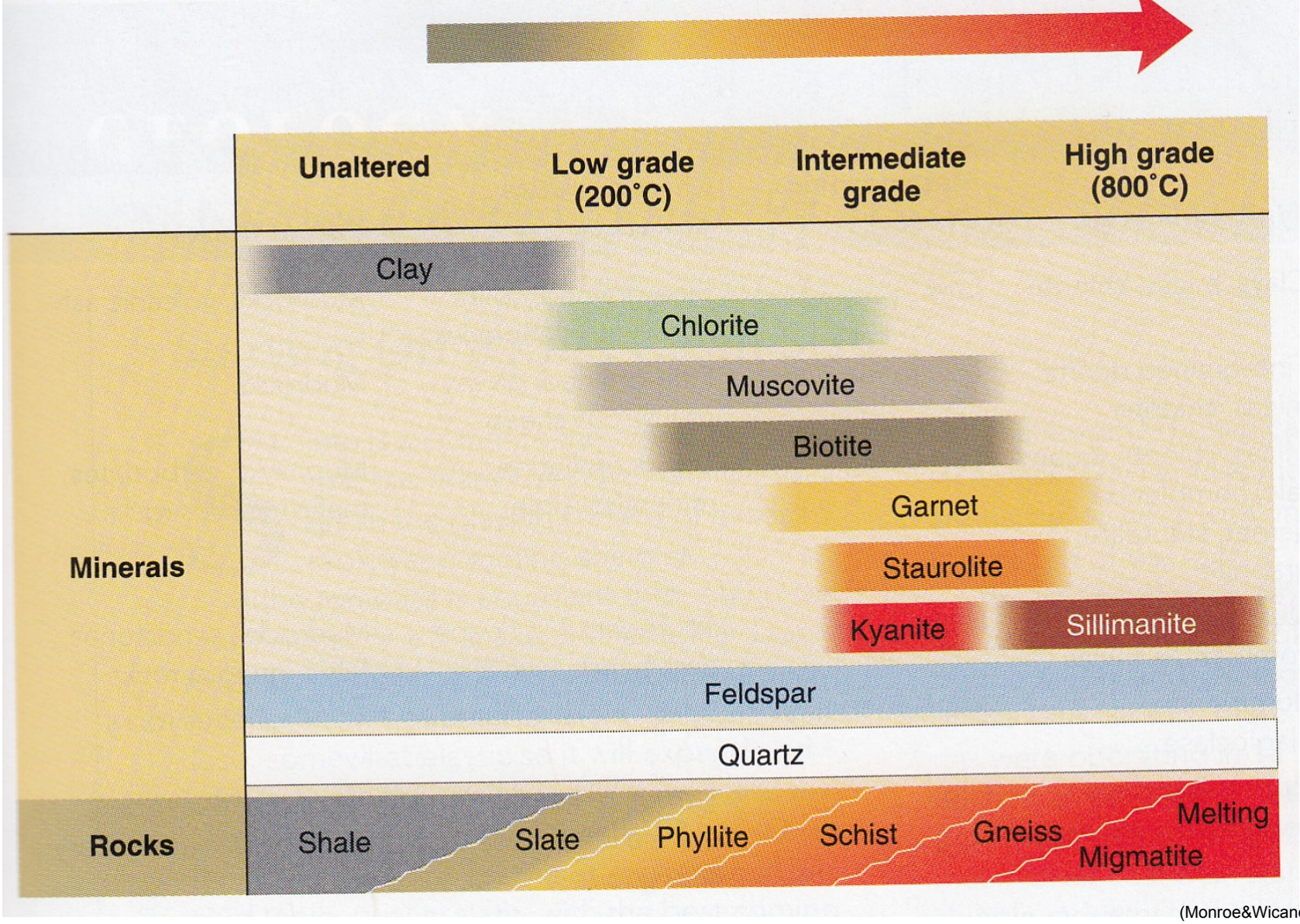


Dynamic metamorphism is associated with fault zone where rocks are subjected to high differential pressure.

Cataclasite



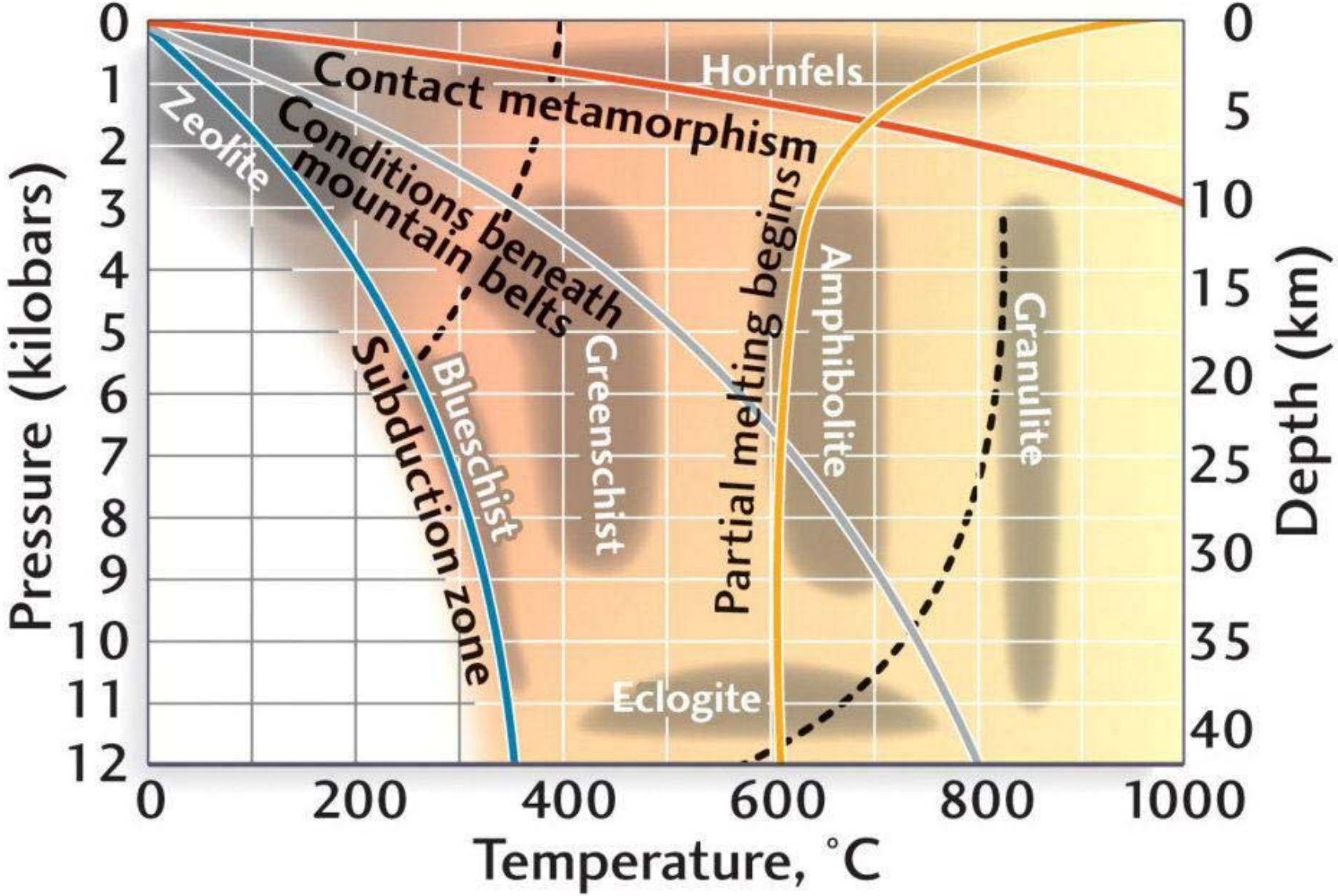
Ultramylonite developed in mylonite



(Monroe&Wicander, 2005)

Certain minerals form only within specific temperature and pressure ranges. Such minerals are named as **index minerals**.

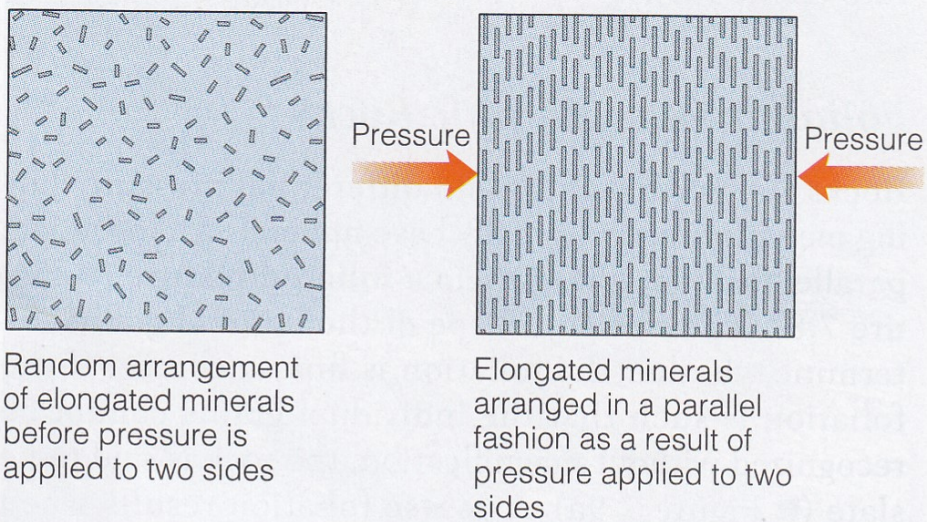
INDEX MINERALS, GRADE, AND FACIES DESCRIBE METAMORPHISM

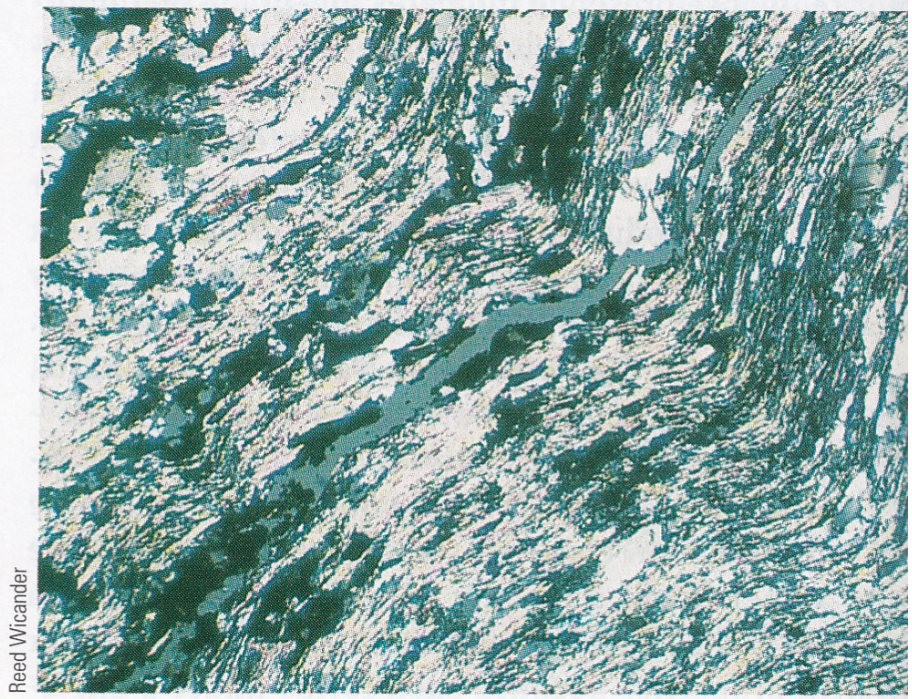


CLASSIFICATION OF METAMORPHIC ROCKS

Foliated Metamorphic Rocks

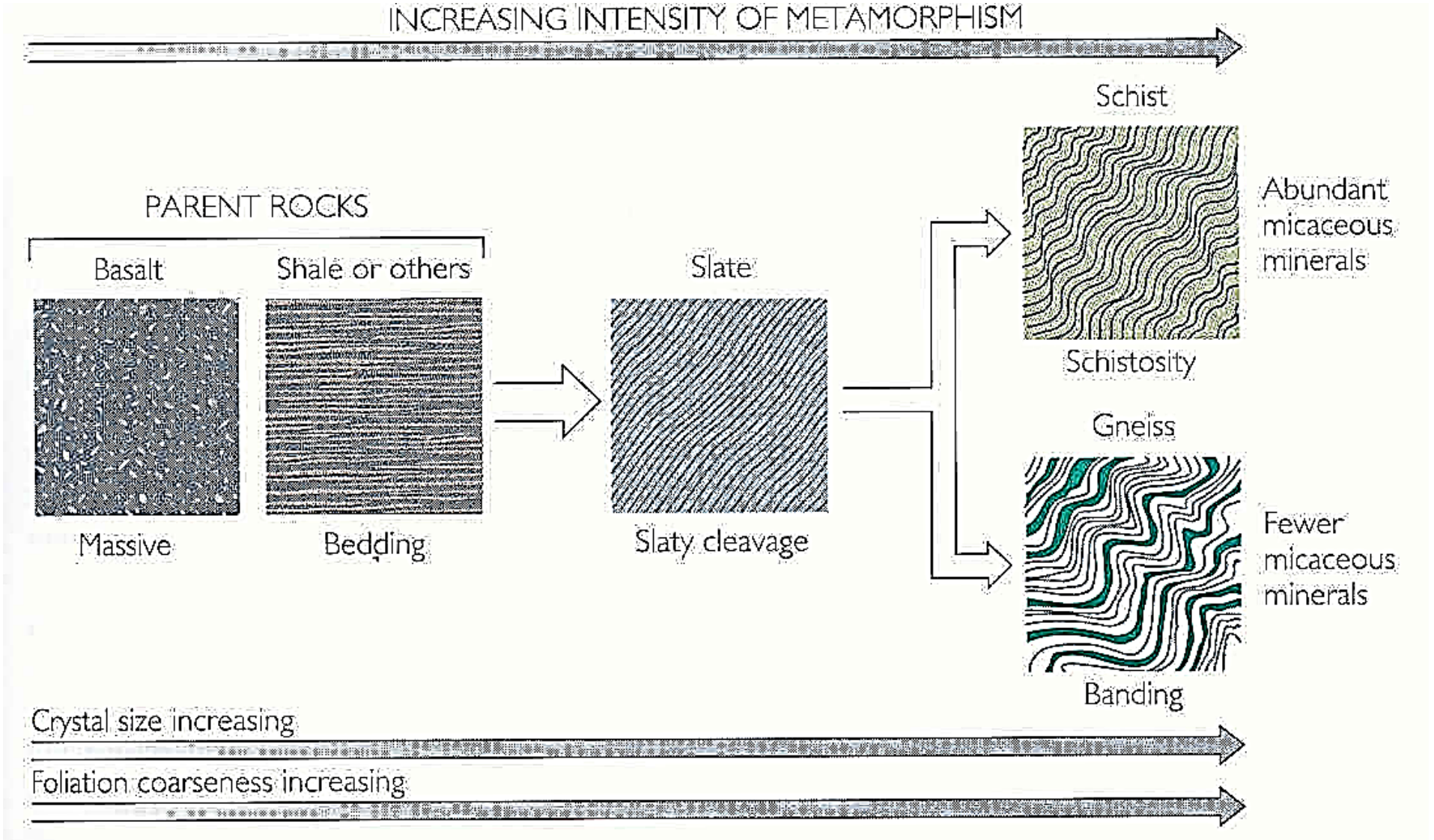
Rocks subjected to heat and differential pressure during metamorphism typically have minerals arranged in a parallel fashion, giving them a **foliated texture**.





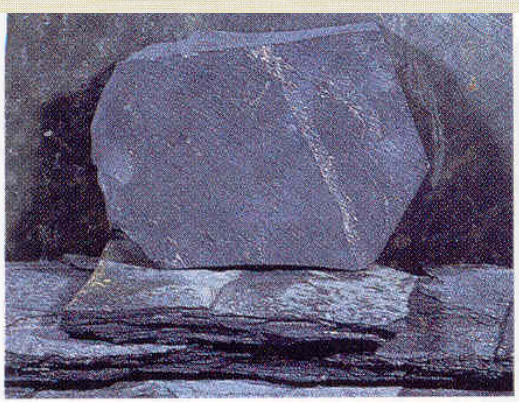
(a) When rocks are subjected to differential pressure, the mineral grains are typically arranged in a parallel fashion, producing a foliated texture. (b) Photomicrograph of a metamorphic rock with a foliated texture showing the parallel arrangement of mineral grains.


Direction
of compressing
forces
Preferred
orientation
Direction
of compressing
forces


INCREASING INTENSITY OF METAMORPHISM
PARENT ROCKS
Basalt
Shale or others
Massive
Bedding
Slate
Slaty cleavage
Schist
Schistosity
Abundant micaceous minerals
Gneiss
Banding
Fewer micaceous minerals
Crystal size increasing
Foliation coarseness increasing

Classification of Common Metamorphic Rocks

Texture	Metamorphic Rock	Typical Minerals	Metamorphic Grade	Characteristics of Rocks	Parent Rock
Foliated	Slate	Clays, micas, chlorite	Low	Fine-grained, splits easily into flat pieces	Mudrocks, volcanic ash
	Phyllite	Fine-grained quartz, micas, chlorite	Low to medium	Fine-grained, glossy or lustrous sheen	Mudrocks
	Schist	Micas, chlorite, quartz, talc, hornblende, garnet, staurolite, graphite	Low to high	Distinct foliation, minerals visible	Mudrocks, carbonates, mafic igneous rocks
	Gneiss	Quartz, feldspars, hornblende, micas	High	Segregated light and dark bands visible	Mudrocks, sandstones, felsic igneous rocks
	Amphibolite	Hornblende, plagioclase	Medium to high	Dark, weakly foliated	Mafic igneous rocks
	Migmatite	Quartz, feldspars, hornblende, micas	High	Streaks or lenses of granite intermixed with gneiss	Felsic igneous rocks mixed with sedimentary rocks
Nonfoliated	Marble	Calcite, dolomite	Low to high	Interlocking grains of calcite or dolomite, reacts with HCl	Limestone or dolostone
	Quartzite	Quartz	Medium to high	Interlocking quartz grains, hard, dense	Quartz sandstone
	Greenstone	Chlorite, epidote, hornblende	Low to high	Fine-grained, green	Mafic igneous rocks
	Hornfels	Micas, garnets, andalusite, cordierite, quartz	Low to medium	Fine-grained, equidimensional grains, hard, dense	Mudrocks
	Anthracite	Carbon	High	Black, lustrous, subconcoidal fracture	Coal



(a)

(b)

(c)

Non foliated Metamorphic Rocks

Kireçtaşı

Metamorfizma

Mermer

Kuvars kumtaşı

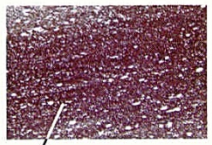
Metamorfizma

Kuvarsit

Figure 98. Slate

Hand specimen

Photomicrograph (X5)



Deformed shale particles

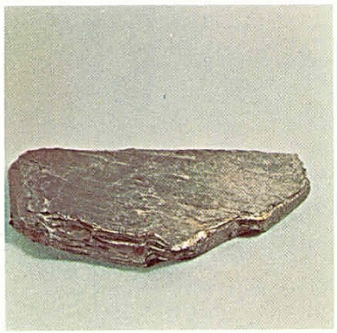
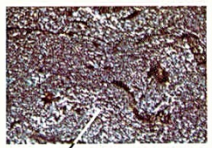


Figure 99. Phyllite

Hand specimen

Photomicrograph (X5)



Mica crystals

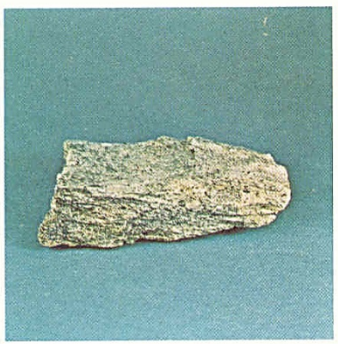
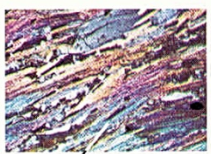


Figure 100. Schist

Hand specimen

Photomicrograph (X5)



Mica crystals

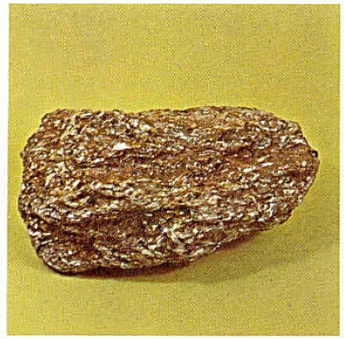
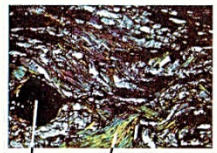


Figure 101. Schist

Hand specimen

Photomicrograph (X5)

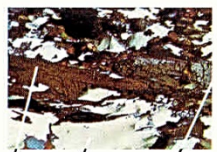


Garnet Mica

Figure 102. Gneiss

Hand specimen

Photomicrograph (X5)



Mica Quartz Feldspar

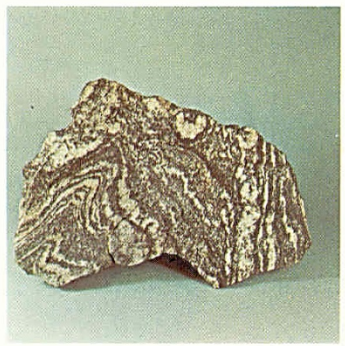


Figure 103. Gneiss

Hand specimen

Photomicrograph (X5)

Quartz Pyroxene Mica

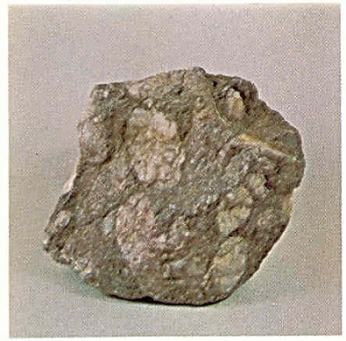
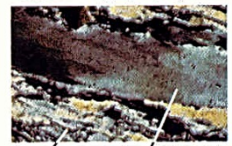


Figure 104. Metaconglomerate

Hand specimen

Photomicrograph (X5)



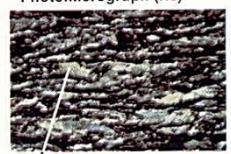
Quartzite matrix

Quartzite pebble

Figure 105. Quartzite

Hand specimen

Photomicrograph (X5)



Deformed sand grains

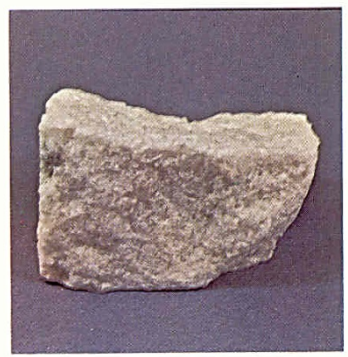
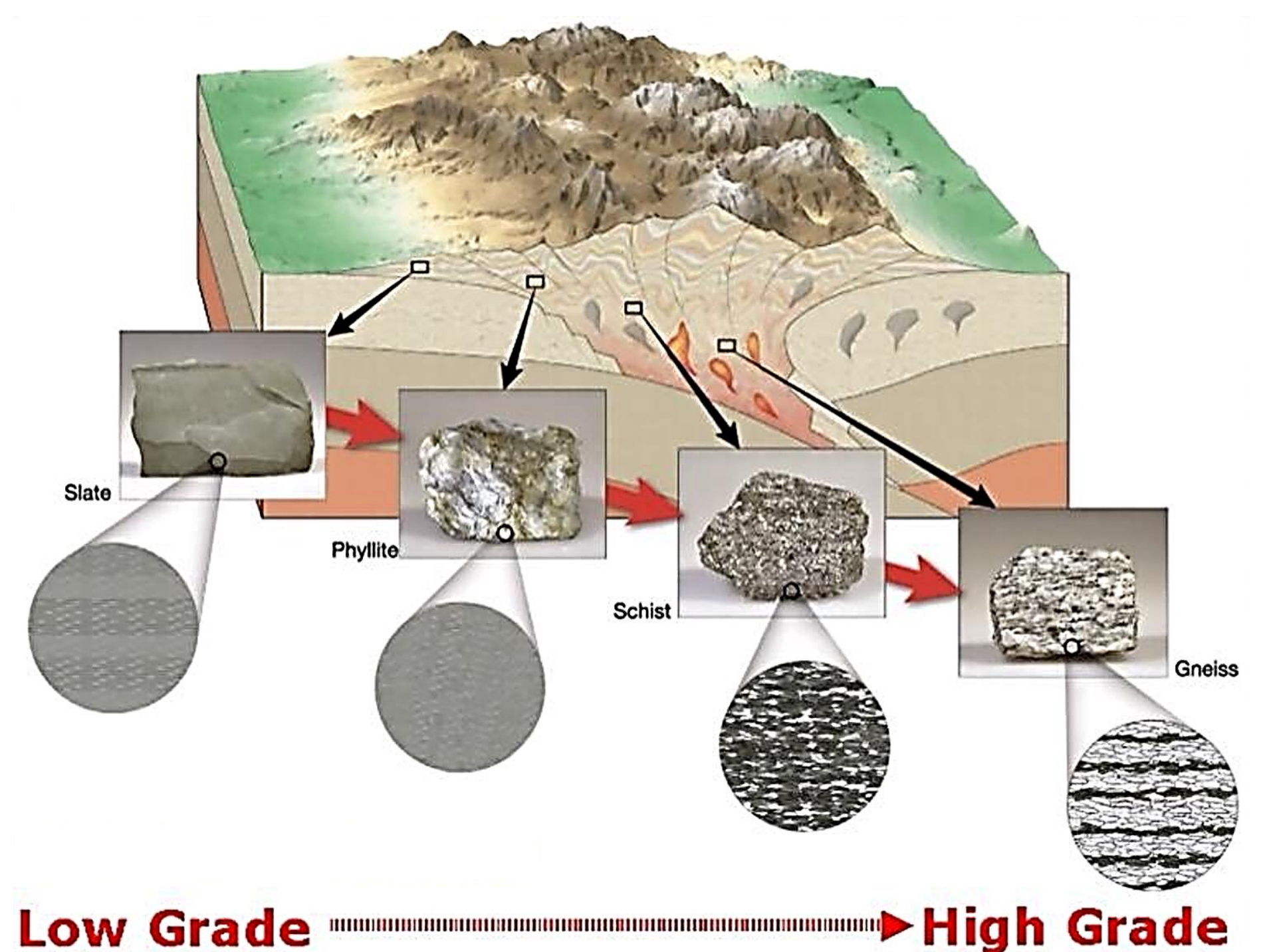


Figure 106. Marble

Hand specimen

Photomicrograph (X5)

Calcite crystals


Slate
Phyllite
Schist
Gneiss
Low Grade
High Grade

METAMORPHISM AND NATURAL RESOURCES

Marble and slate used as construction materials

Talc for talcum powder

Graphite for pencils and dry lubricants

Garnet and corundum used for abrasives or gemstone

Andalusite, kyanite, sillimanite for manufacturing high-temperature porcelains

The Main Ore Deposits Resulting from Contact Metamorphism

Ore Deposit	Major Mineral	Formula	Use
Copper	Bornite Chalcopyrite	Cu_5FeS_4 $CuFeS_2$	Important sources of copper, which is used in various aspects of manufacturing, transportation, communications, and construction
Iron	Hematite Magnetite	Fe_2O_3 Fe_3O_4	Major sources of iron for manufacture of steel, which is used in nearly every form of construction, manufacturing, transportation, and communications
Lead	Galena	PbS	Chief source of lead, which is used in batteries, pipes, solder, and elsewhere where resistance to corrosion is required
Tin	Cassiterite	SnO_2	Principal source of tin, which is used for tin plating, solder, alloys, and chemicals
Tungsten	Scheelite Wolframite	$CaWO_4$ $(Fe,Mn)WO_4$	Chief sources of tungsten, which is used in hardening metals and manufacturing carbides
Zinc	Sphalerite	(Zn, Fe)S	Major source of zinc, which is used in batteries and in galvanizing iron and making brass