SECTION II

METAMORPHIC FACIES

II. METAMORPHIC FACIES

II.1 Isograde

The concept of "isograde" was initially used by Tilley (1924) to describe a stage of metamorphism that can be identified by the initial occurrence of an indicator mineral, such as staurotide, almandine, biotite, etc.

An isograde is a curve on a map joining the points of first appearance of indicator minerals, that is, the points where a specific change in the mineral assemblage indicates that a chemical reaction has taken place (e.g., isograde chlorite, isograde biotite, isograde garnet, etc.). For example, the isograde'staurolite' is defined by the reaction:

Garnet + chlorite + muscovite = staurolite + biotite + quartz + H_2O.

II.2 Metamorphism pathway (prograde / retrograde)

Prograde Metamorphism

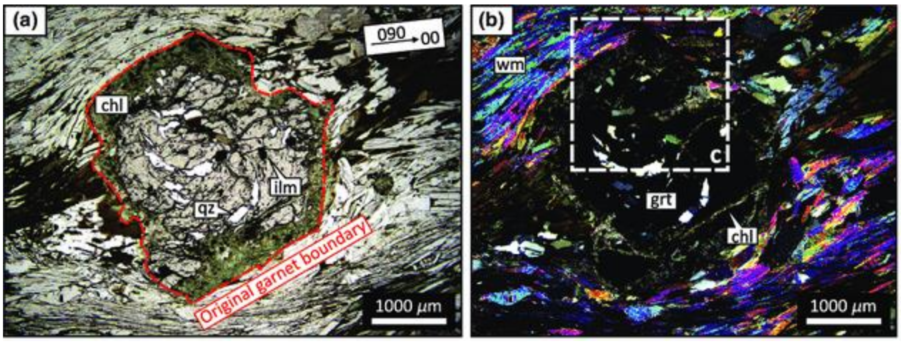
Prograde metamorphism refers to the changes that occur in a rock as it is subjected to increasing temperature and pressure over time. This process typically involves the conversion of low-grade or unmetamorphosed rocks into higher-grade metamorphic rocks through a series of mineralogical and textural adjustments.

Prograde metamorphism is often accompanied by the release of fluids, which can facilitate further reactions by acting as fluxes, promoting the development of new mineral assemblages.

Retrograde Metamorphism

Retrograde metamorphism occurs when high-grade metamorphic rocks are subjected to decreasing temperature and pressure conditions. This process typically results in the alteration of minerals formed during prograde metamorphism into those stable at lower temperatures.

During retrograde metamorphism, high-temperature minerals may be replaced by lower-temperature minerals through hydration or other reactions. For example, garnets may develop chlorite rims as they react with water during cooling. Olivine to serpentine in ultramafic rocks during retrogression, often seen in subduction zones.



Transformation of garnet to chlorite with decreasing temperature (https://www.researchgate.net/profile/Ryan-Thigpen-2/publication/307444229/figure/fig5/AS:614241606332431@1523458019927/Photomicrographs-of-garnet-that-experienced-post-growth-rim-replacement-a-plane-and.png)

II.3 Metamorphic gradient

Metamorphic gradients include three primary types (Fig. III-1):

- The low-pressure, high-temperature metamorphic gradient (Abukuma type) (around 100°C/km) characterizes divergence zones.
- The medium-pressure, high-temperature metamorphic gradient (Barrowian type) (around 30°C/km) characterizes collision zones.
- The high-pressure, low-temperature metamorphic gradient (Franciscan type) (around 10°C/km) characterizes subduction zones.

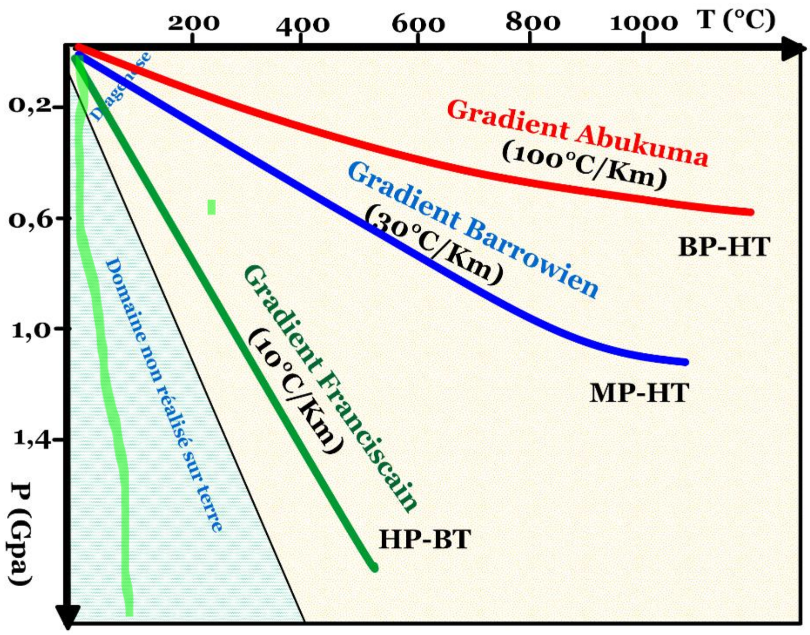


Figure III.1 *Diagramme P-T montrant les trois gradients métamorphiques*

II.4 Metamorphic Facies

Eskola developed the concept of metamorphic facies (1915). Rocks that "may be assumed to have undergone metamorphosed under identical conditions" are classified as metamorphic facies. Page 115. Therefore, a group of rocks that underwent the same metamorphism under the same conditions is called a metamorphic facies.

P. Eskola (1920 and 1939) developed the term "mineral facies" after he believed that some igneous rocks had nearly identical mineral assemblages to some metamorphic rocks.

A metamorphic facies is an assemblage of minerals that characterises identical physico-chemical conditions during the formation of the rocks. This assemblage is independent of the chemical composition of the metamorphosed rocks.

As a result, the minerals found in the rock serve as indicators of the temperature and pressure during metamorphism. Each facies thus represents a range of temperatures and pressures.

☒ Metamorphic facies in regional metamorphism

There are eight recognized mineral facies (Fig. III.2):

- Facies of zeolites
- Facies of prehnite-pumpellyite
- Facies of schiste verts

- Facies of amphibolites
- Facies of schiste bleus
- Facies of hornfels (mostly for contact metamorphism)
- Facies of granulites
- Facies des eclogite

Given that the concept of ''metamorphic facies'' has been used according to mineral assemblages of a metabasite, the name of different facies are derived.

The table III-1 below summarize different metamorphic facies within the broad protoliths. They are also plotted in P-T diagram in Figure III.2.

Table III-1

Facies	Pelitic	Calcareous	Mafic
Zeolite 100-200° C	interlayered smectite/chlorite calcite	calcite	Laumonite, thompsonite, calcite, interlayered smectite/chlorite
Prehnite-Pumpellyite 150-300° C	Prehnite, pumpellyite, calcite, chlorite, albite	calcite	Prehnite, pumpellyite, calcite, chlorite, albite
Greenschist 300-450° C	muscovite, chlorite, quartz, albite, biotite, garnet	calcite, dolomite, quartz, epidote, tremolite	albite, chlorite, quartz, epidote, actinolite, sphene
Epidote Amphibolite 450-550° C	muscovite, biotite, garnet, albite, quartz	calcite, quartz, tremolite, epidote,diopside	albite, epidote, hornblende, quartz
Amphibolite 500-700° C	garnet, biotite, muscovite, quartz, plagioclase, staurolite, kyanite or sillimanite	calcite, diopside quartz, wollastonite	hornblende, plagioclase, garnet, quartz, sphene, biotite
Granulite 700-900° C	garnet, Kspar, sillimanite or kyanite, quartz, plagioclase, hypersthene	calcite, quartz, plagioclase, diopside, hypersthene	plagioclase, augite, hypersthene, hornblende, garnet, olivine
Blueschist 150-350° C P > 5-8 Kb	Jadeite, albite, quartz, lawsonite, aragonite, paragonite	aragonite, white mica	Glaucophane, albite, lawsonite, sphene, ± garnet
Eclogite 350-750° C P > 8-10 Kb	coesite, Kspar, sillimanite, plagioclase	aragonite, quartz, plagioclase, diopside, hypersthene	omphacite (px), pyrope garnet

☒ Metamorphic facies in contact metamorphism

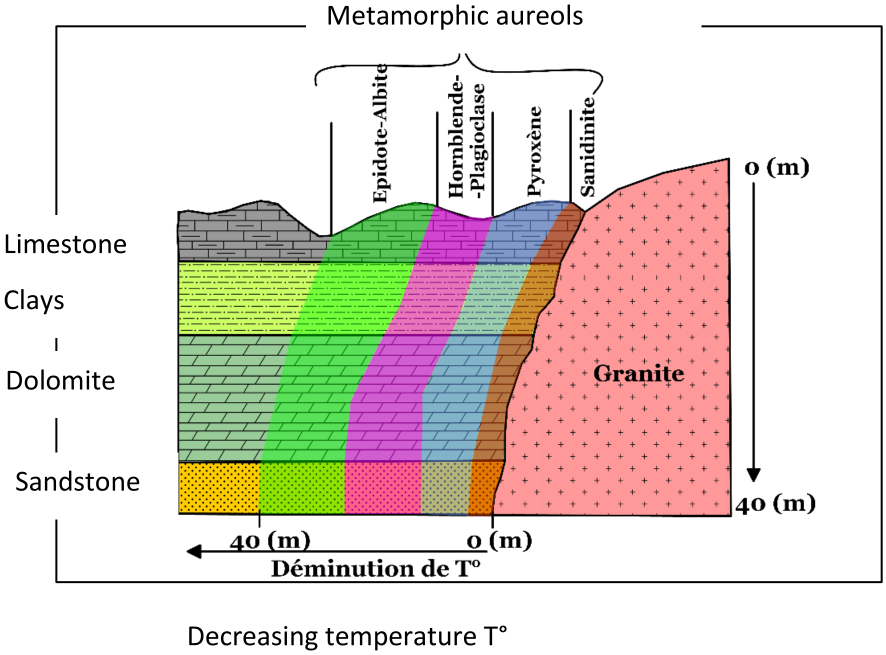


Figure III.2. Metamorphic facies and their temperature-pressure relationships (after Eskola, 1939)

NB. ** Although albite-epidote and hornblende facies can occur in regional metamorphism and are thus referred to as albite-epidote and hornblende amphibolite facies, respectively, it should be noted that hornfels facies are strongly represented in contact metamorphism (very low pressure).

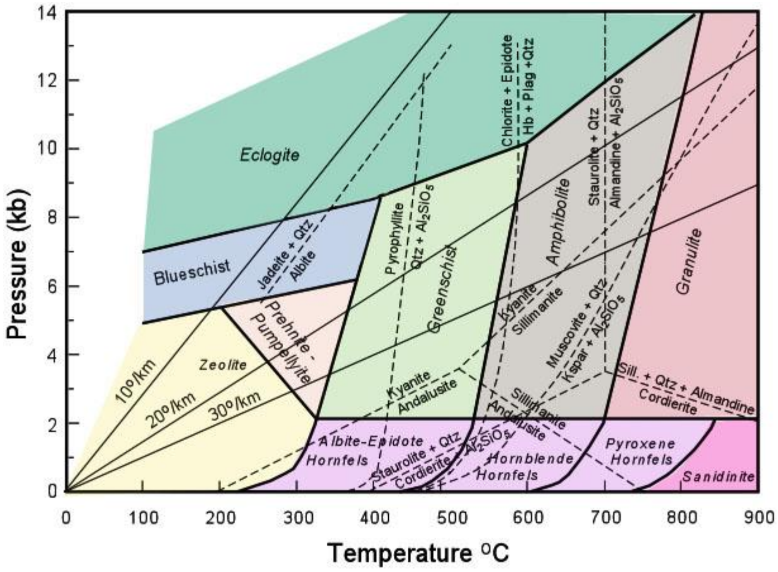


Figure *Schematic representation and distribution of hornfels facies around a pluton (contact metamorphism)*

☒ Metamorphic grade (degree)

A rough guide to the types of metamorphic rocks that form from different parent rocks at different grades of regional metamorphism				
Protolith	**Very Low Grade (200-300°C)**	**Low Grade (300-450°C)**	**Medium Grade (450-550°C)**	**High Grade (Above 550°C)**
Mudrock	**slate**	phyllite	**schist**	**gneiss**
Granite	no change	no change	almost no change	granite gneiss
Basalt	**greenschist**	**greenschist**	amphibolite	amphibolite
Sandstone	no change	little change	**quartzite**	**quartzite**
Limestone	little change	**marble**	**marble**	