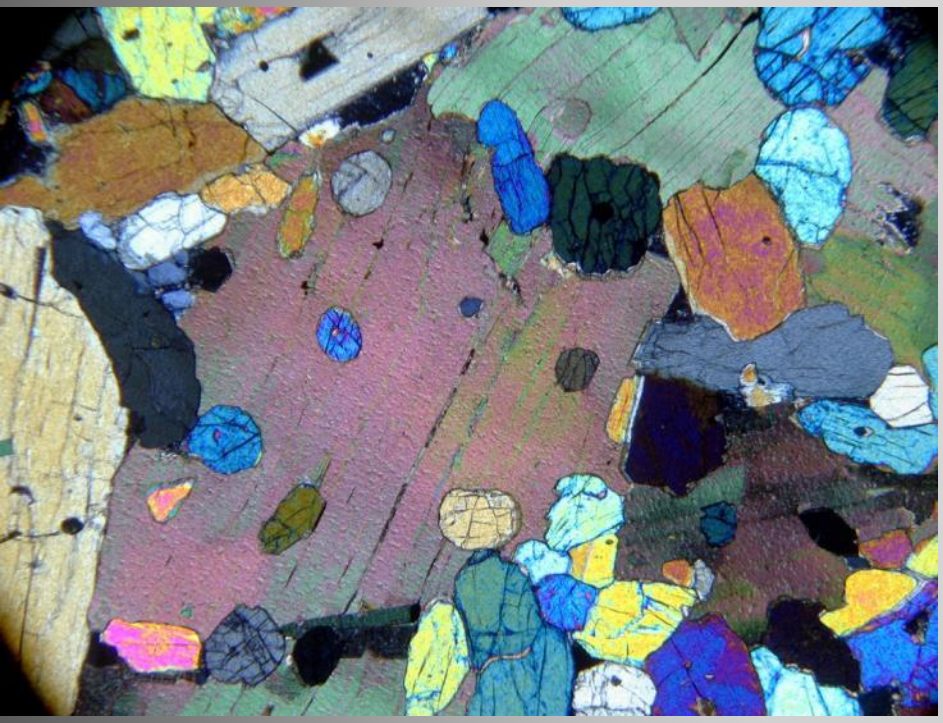
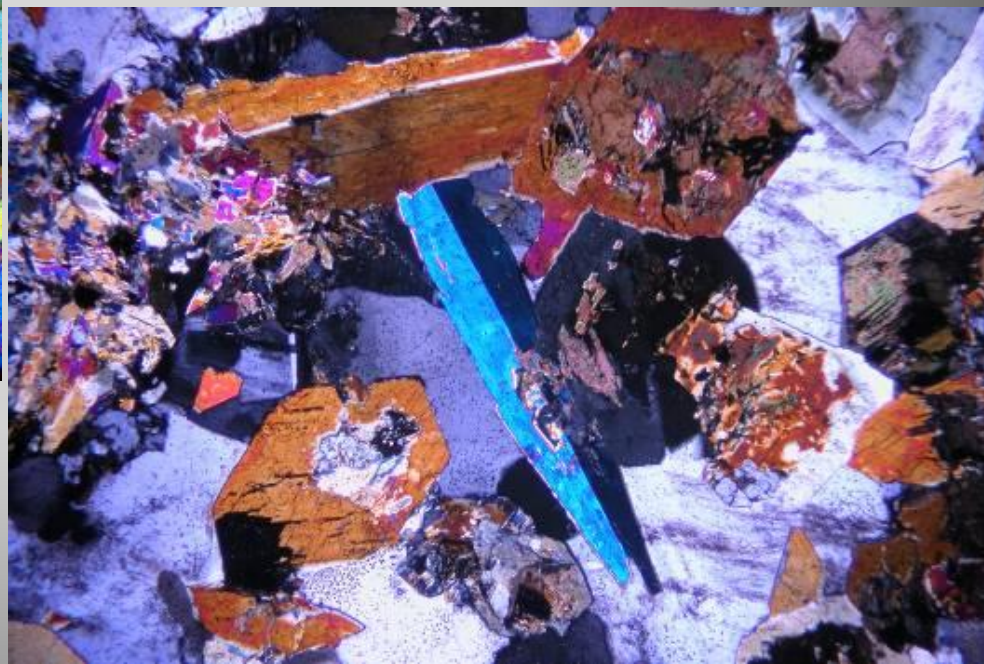
Géodynamique et matériaux





Gilles CHAZOT

IUEM

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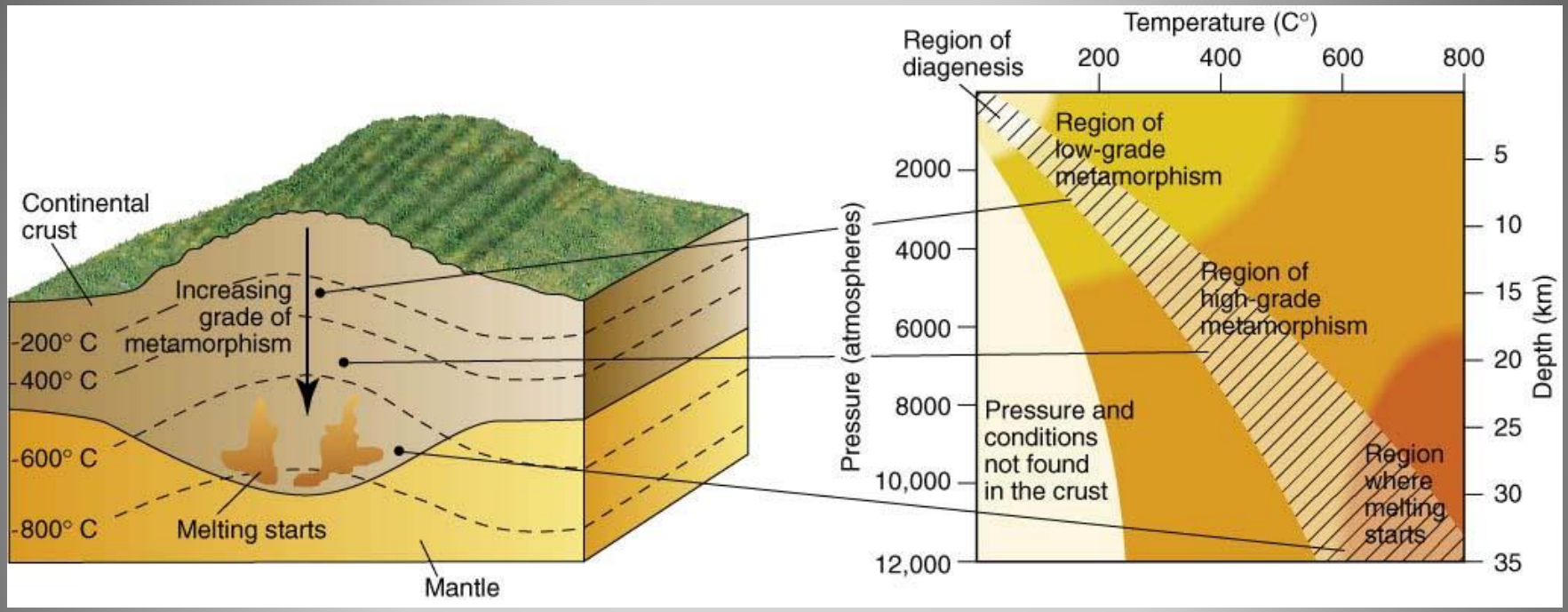
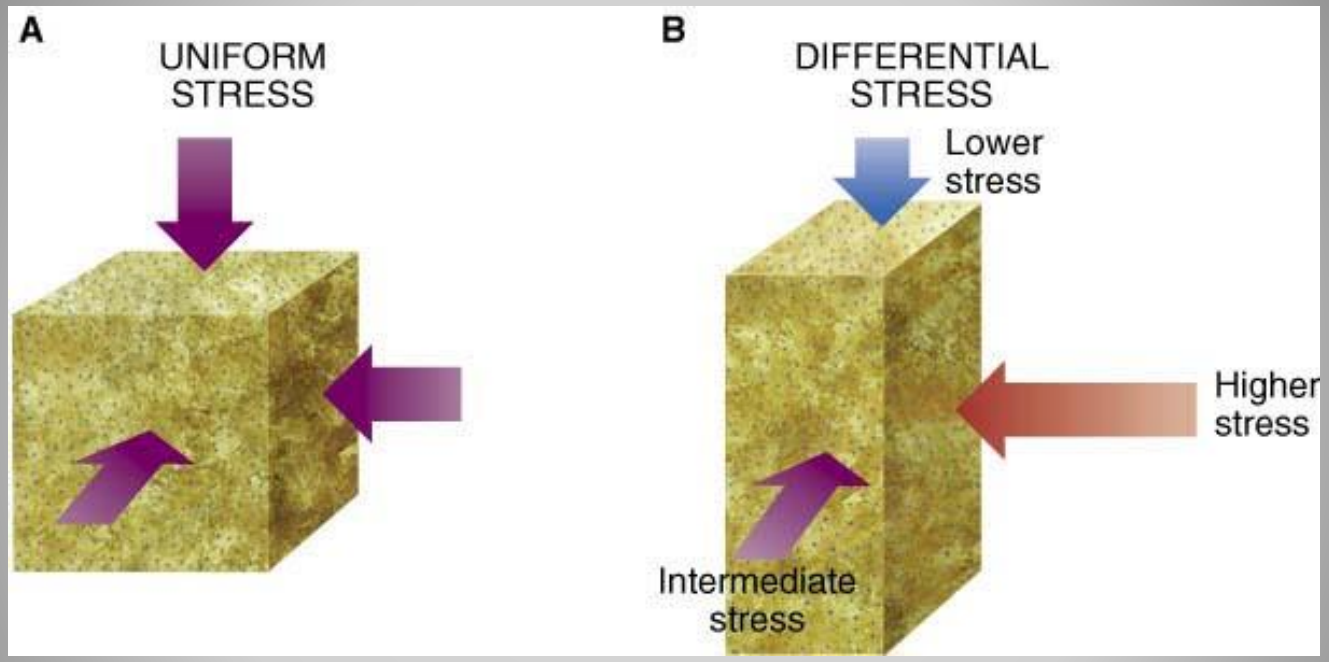
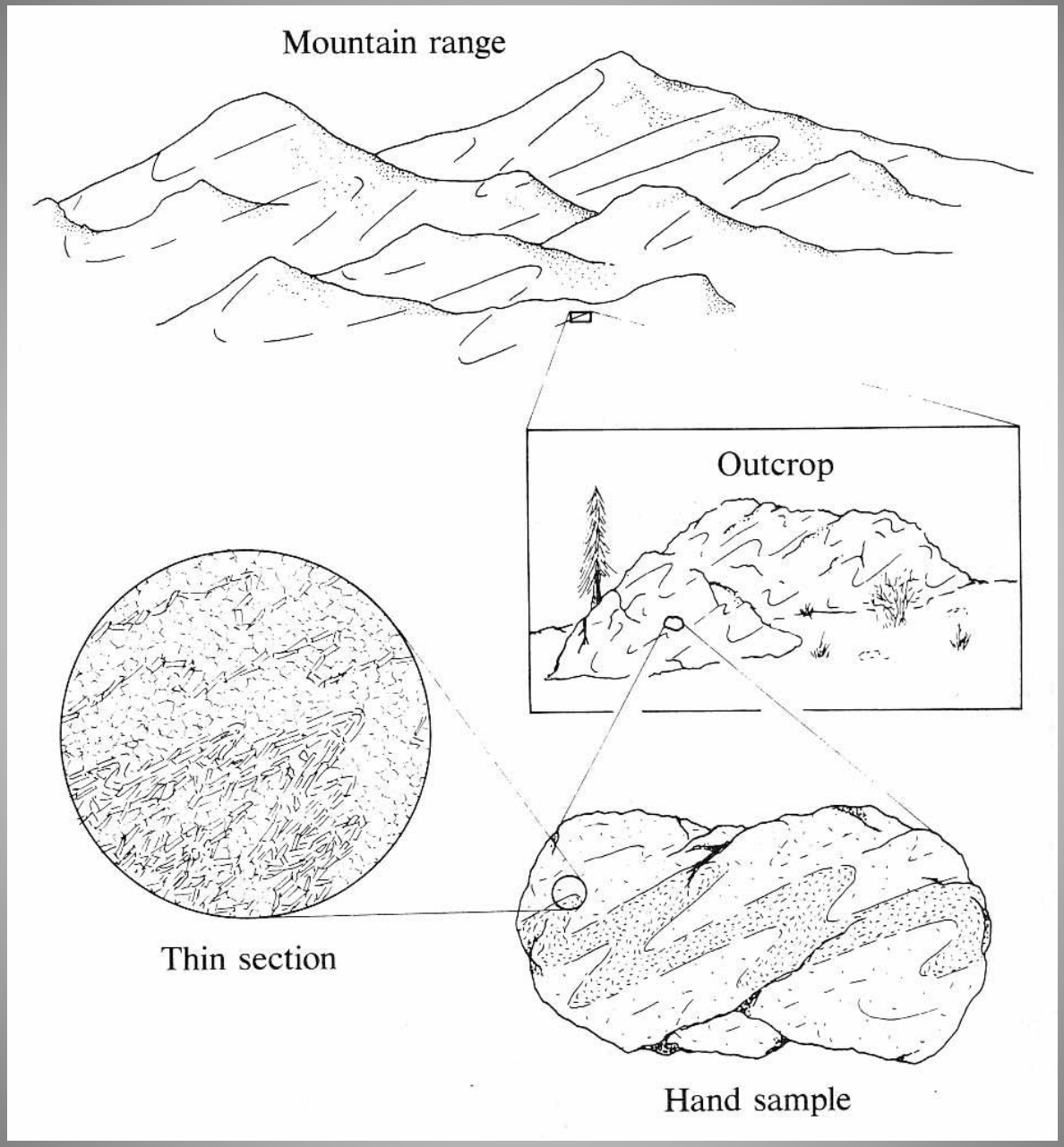
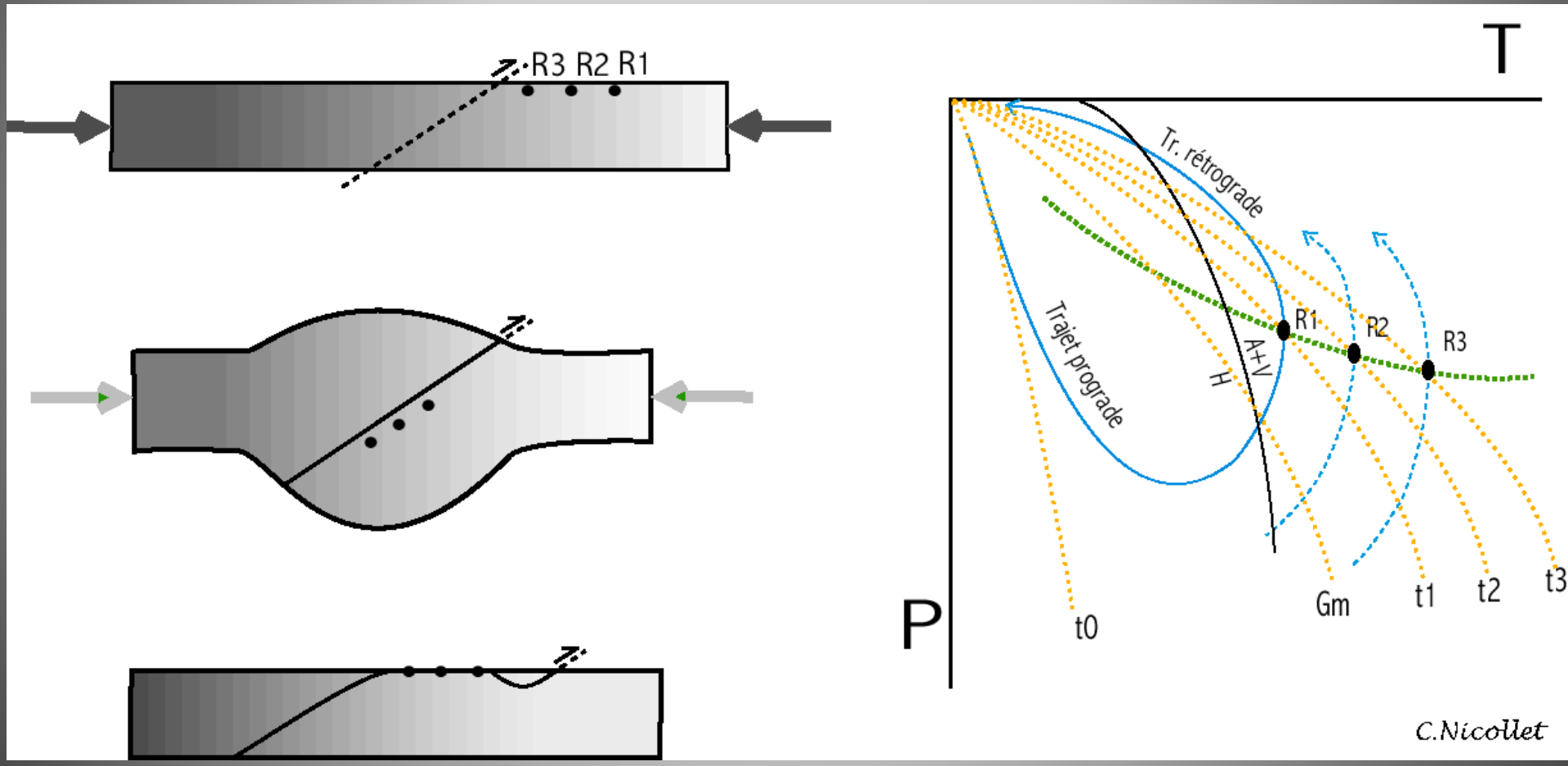
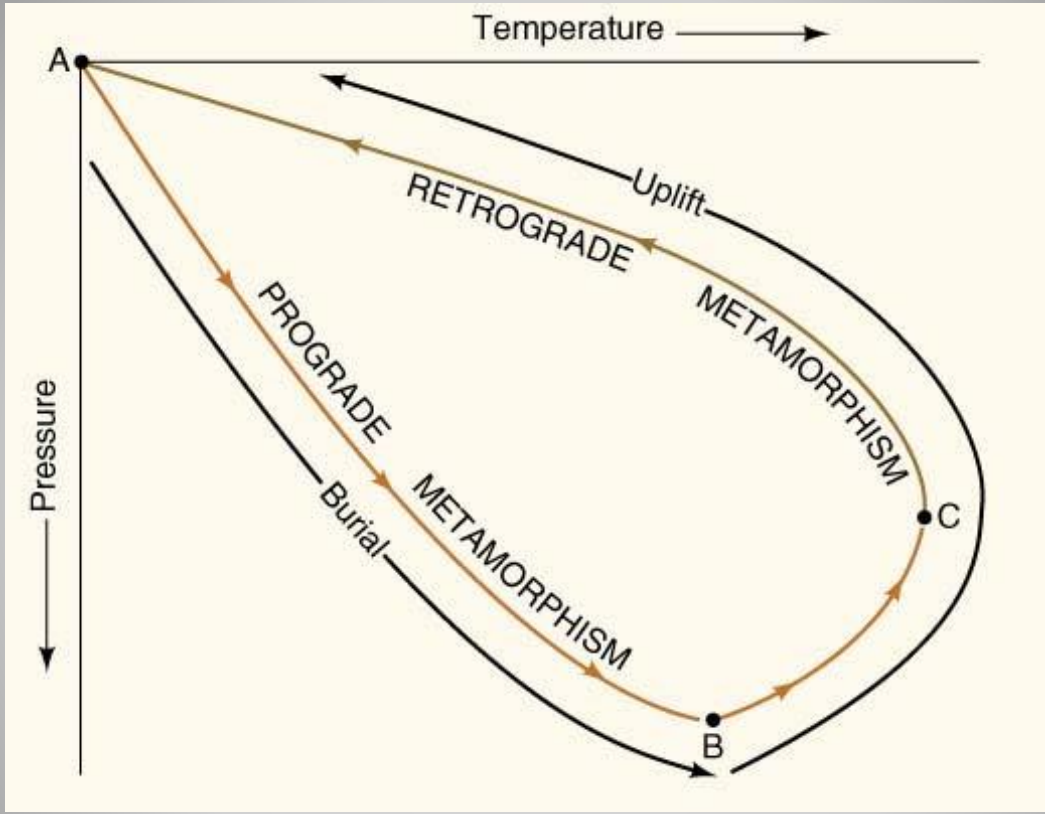

Continental crust
Increasing grade of metamorphism
200° C
400° C
600° C
800° C
Melting starts
Mantle
Region of diagenesis
Temperature (C°)
200
400
600
800
Region of low-grade metamorphism
Region of high-grade metamorphism
Pressure and conditions not found in the crust
Region where melting starts
Pressure (atmospheres)
2000
4000
6000
8000
10,000
12,000
Depth (km)
5
10
15
20
25
30
35


A
UNIFORM
STRESS
B
DIFFERENTIAL
STRESS
Lower
stress
Higher
stress
Intermediate
stress


Mountain range
Outcrop
Thin section
Hand sample

Le métamorphisme



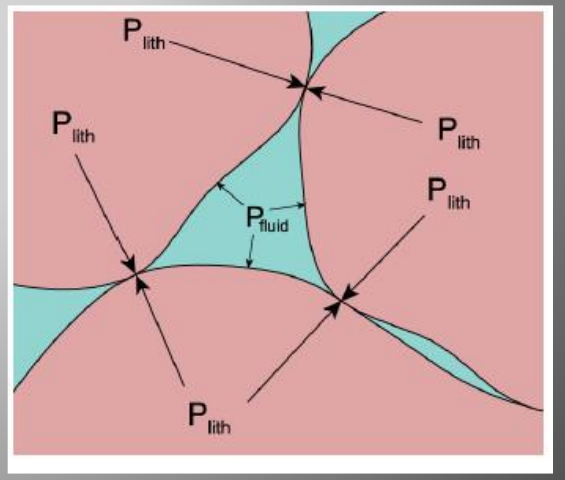

Temperature
A
Uplift
RETROGRADE
METAMORPHISM
PROGRADE
METAMORPHISM
Burial
Pressure
C
B

3 types de pression:

- Pression lithostatique – Dépend de la profondeur et de la densité des roches – Isotrope
  → Pas de déformation

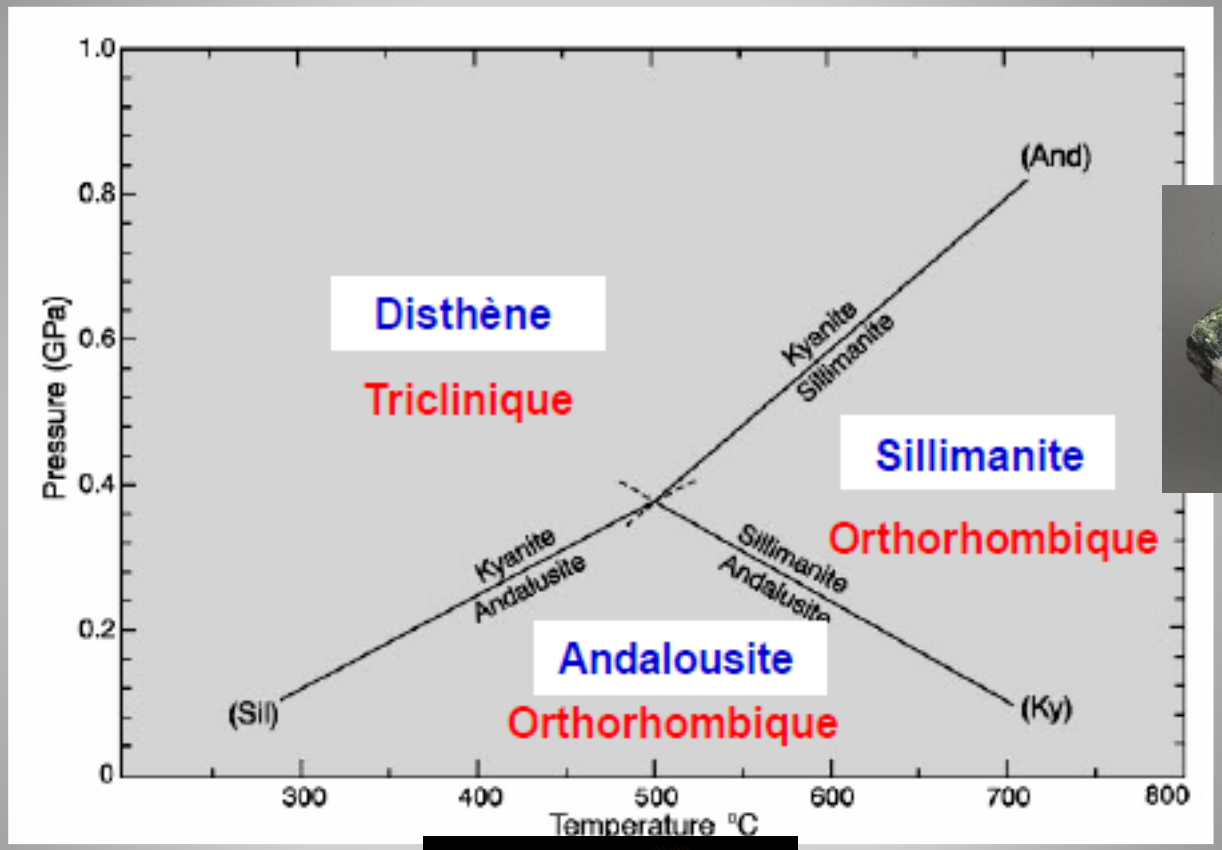
- Contraintes tectoniques – Liées aux mouvements tectoniques (chevauchements, processus orogéniques)
  → Déformation des roches

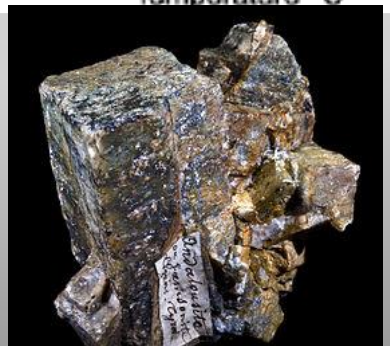
- Pression des fluides – Dépend de la présence d'eau ou de CO_2 – Echanges de matière

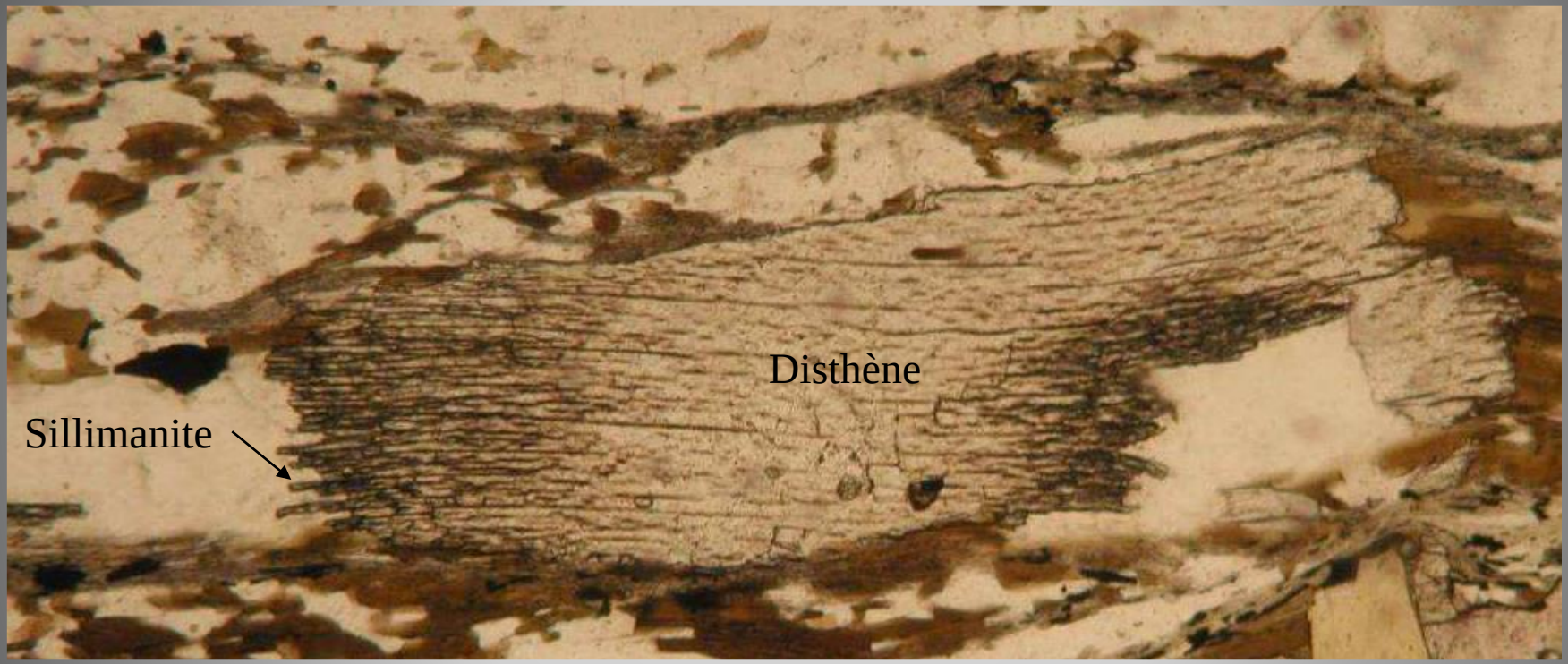


Transformations polymorphiques

Al_2SiO_5





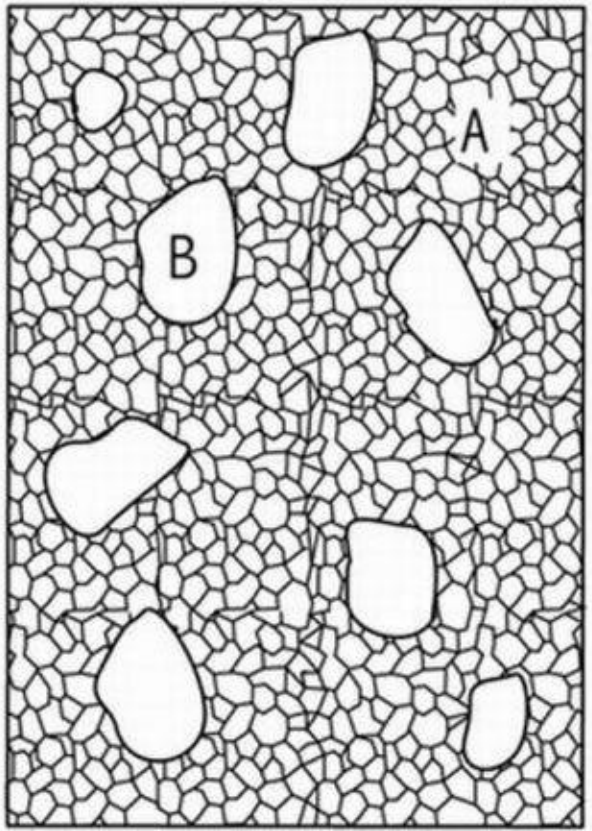

Disthène
Sillimanite

Réactions minéralogiques

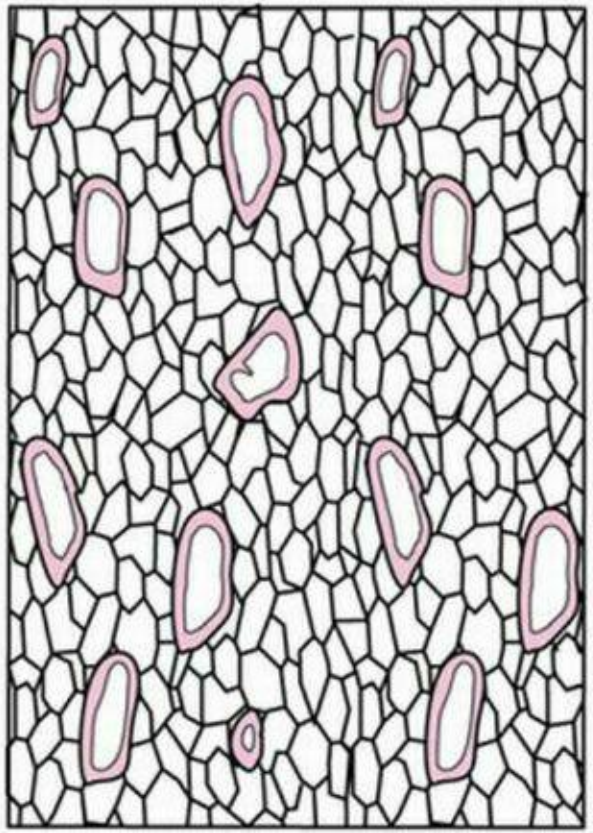
Phase A + Phase B = Phase C

Phase A + Phase B = Phase C + Phase D

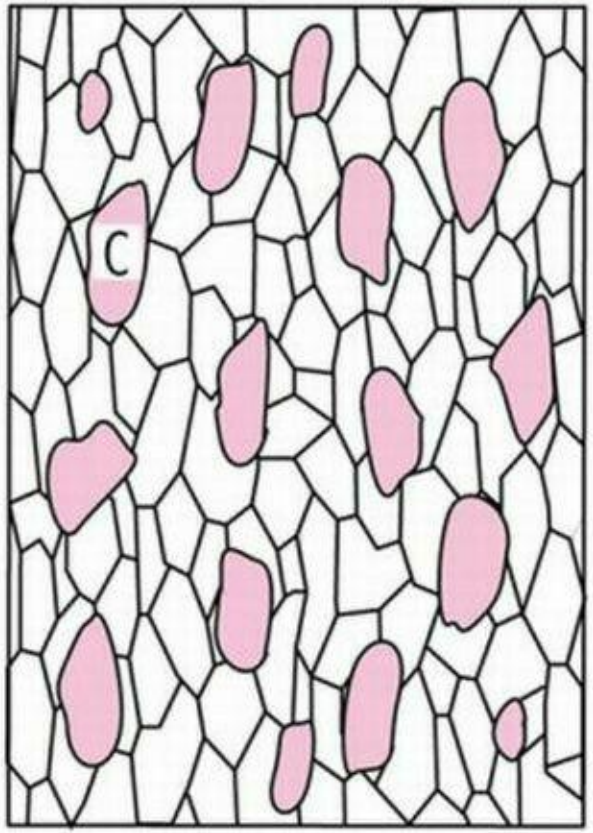
A P0-T0 la roche contient les minéraux A+B



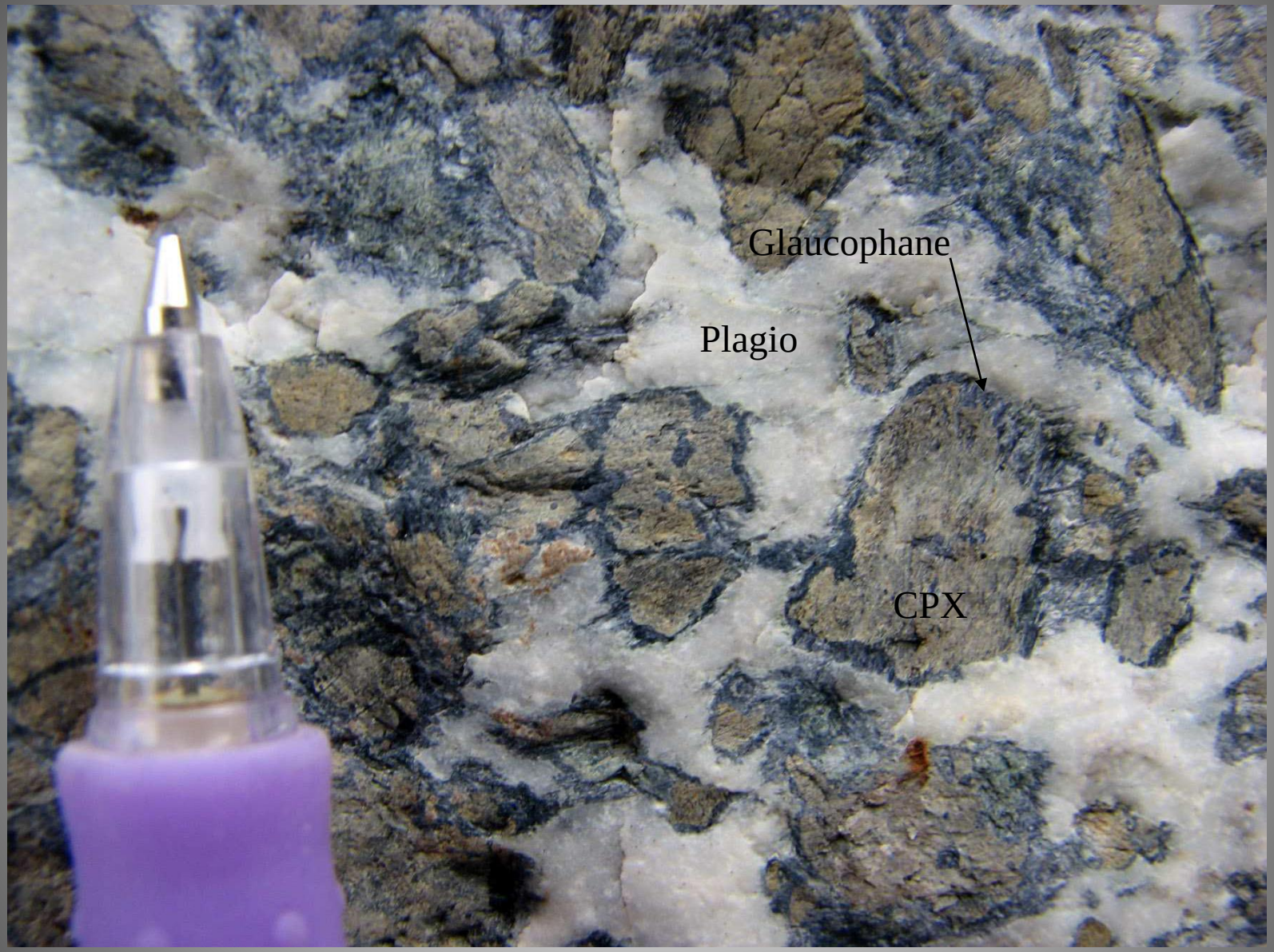
A P1-T1, la réaction A+B=C intervient ...



... jusqu'à disparition de B.

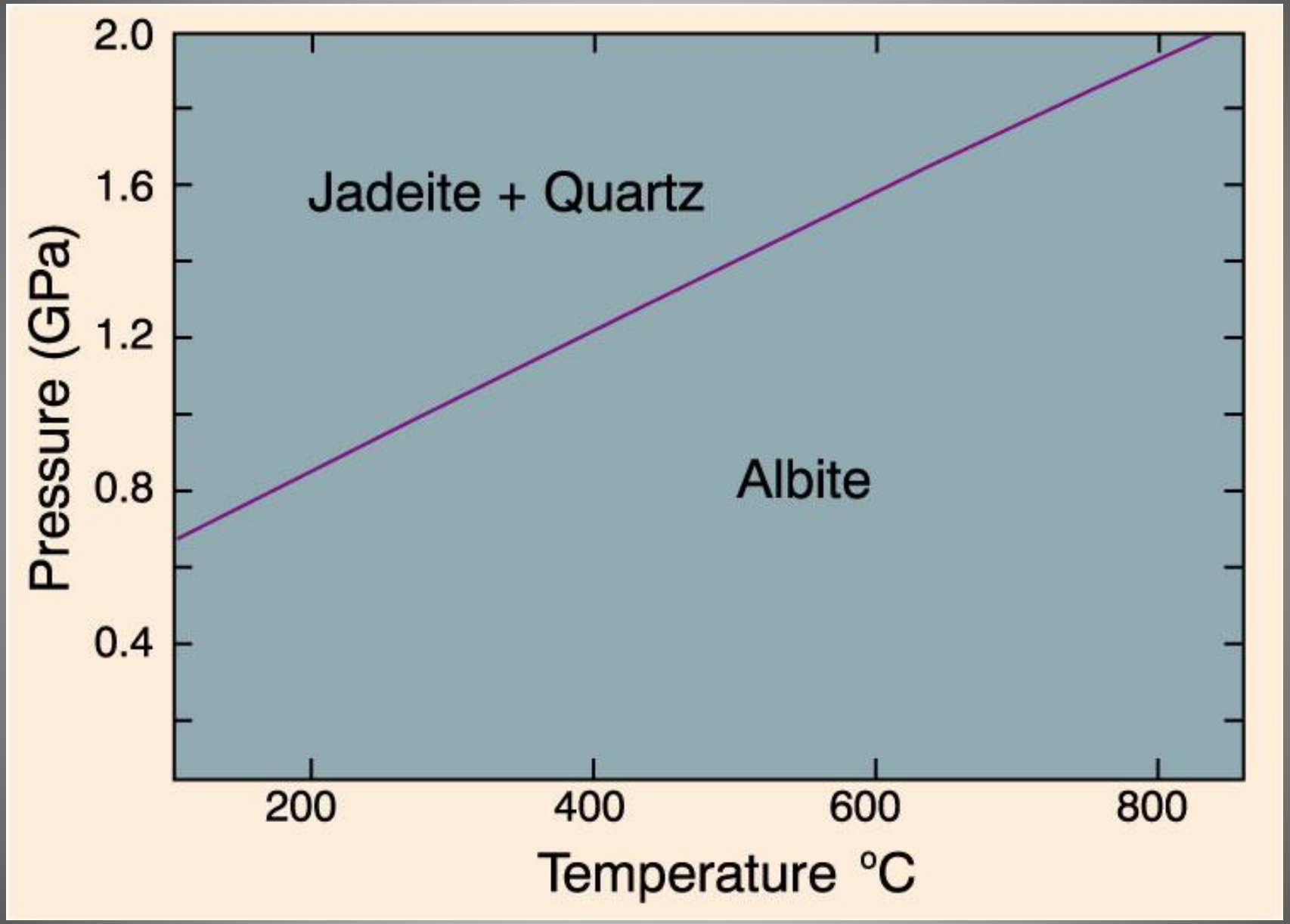


c. Nicollet


Glaucophane
Plagio
CPX


C.Nicollet


Cpx2
Opx1
Opx3
+Pl3
Gt2+
Q
Pl1
C.Nicollet


2.0
1.6
1.2
0.8
0.4
Pressure (GPa)
Jadeite + Quartz
Albite
200
400
600
800
Temperature °C

$$NaAlSi_2O_6 + SiO_2 = NaAlSi_3O_8$$

Jd Qtz Ab

$$MgSiO_3 + CaAl_2Si_2O_8 = CaMgSi_2O_6 + Al_2SiO_5$$

En An Di And

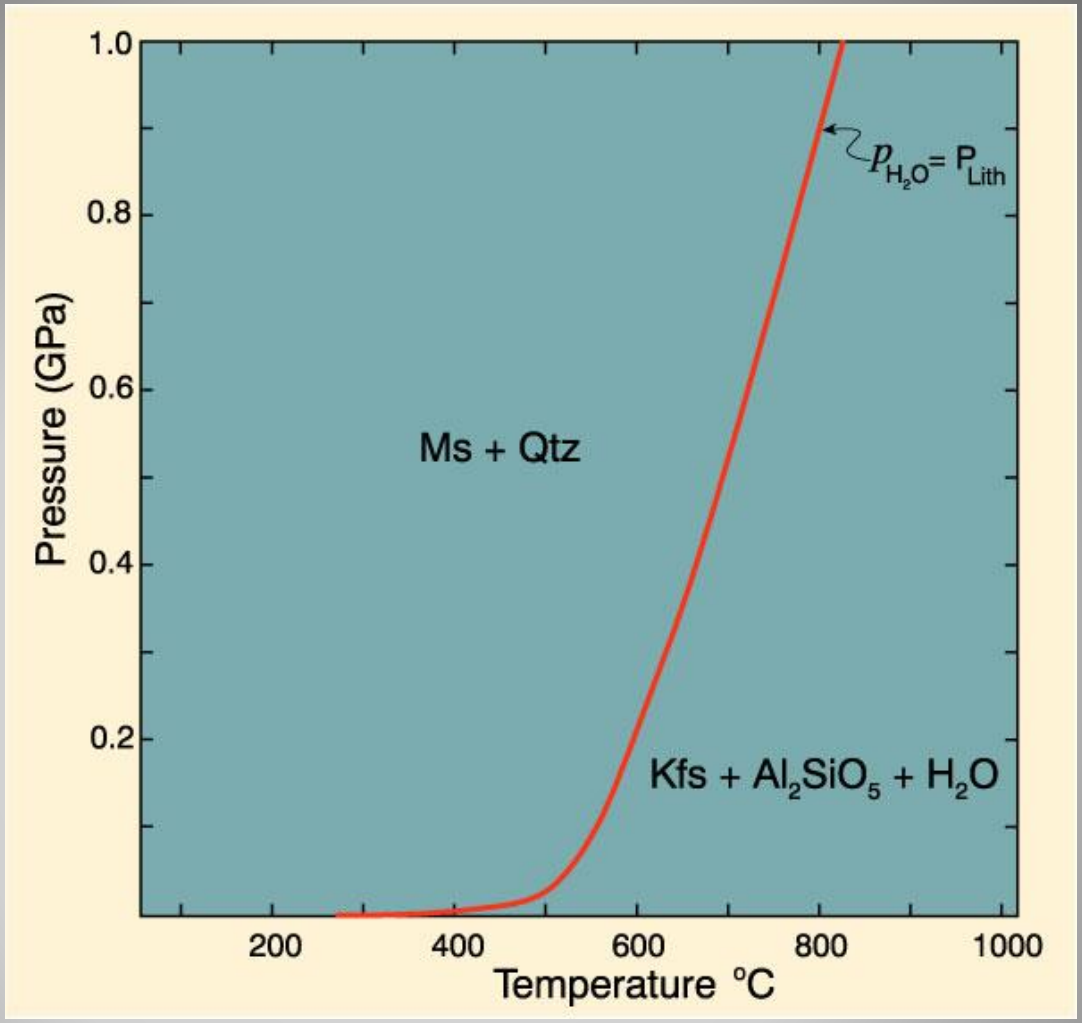
$$4\,(Mg,Fe)SiO_3 + CaAl_2Si_2O_8 =$$

Opx Plag

$$(Mg,Fe)_3Al_2Si_3O_{12} + Ca(Mg,Fe)Si_2O_6 + SiO_2$$

Gnt Cpx Qtz

Déshydratation



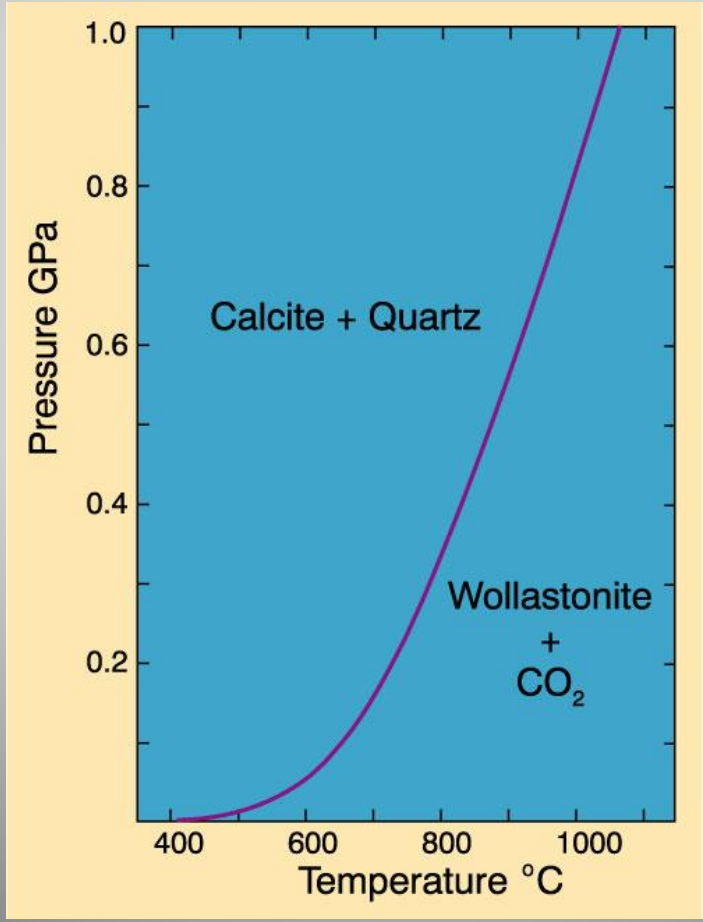
$$KAl_2Si_3AlO_{10}(OH)_2 + SiO_2 = KAlSi_3O_8 + Al_2SiO_5 + H_2O$$

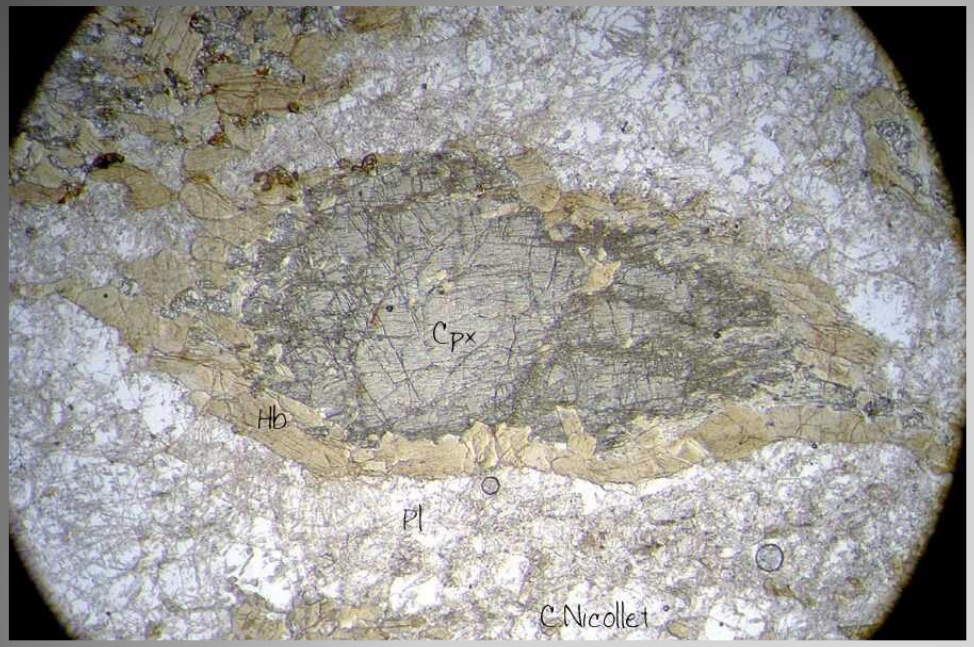
Ms Qtz Kfs Sill W

Décarbonatation

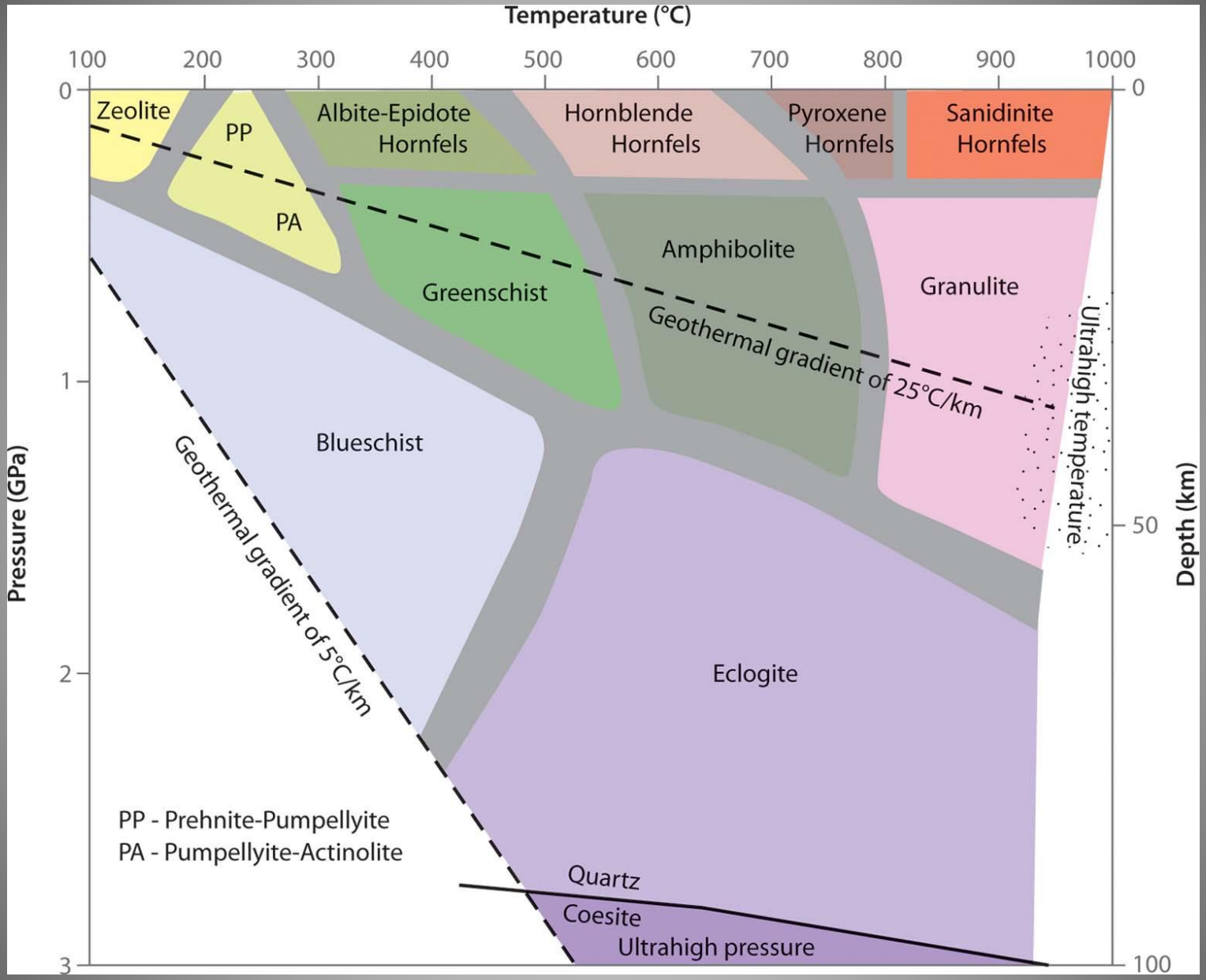
$$CaCO_3 + SiO_2 = CaSiO_3 + CO_2$$

Cal Qtz Wo

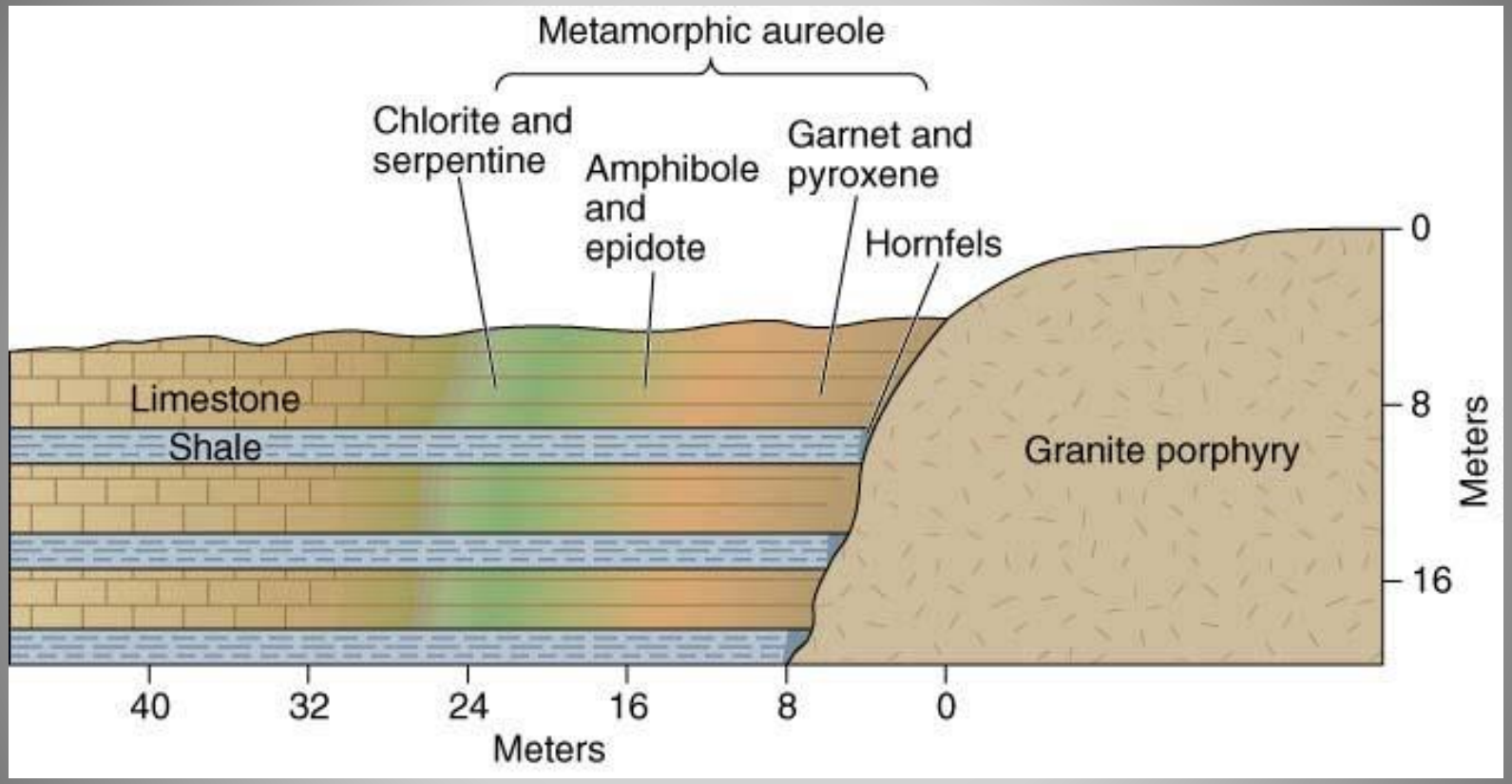



Cpx
Hb
Pl
C.Nicollet

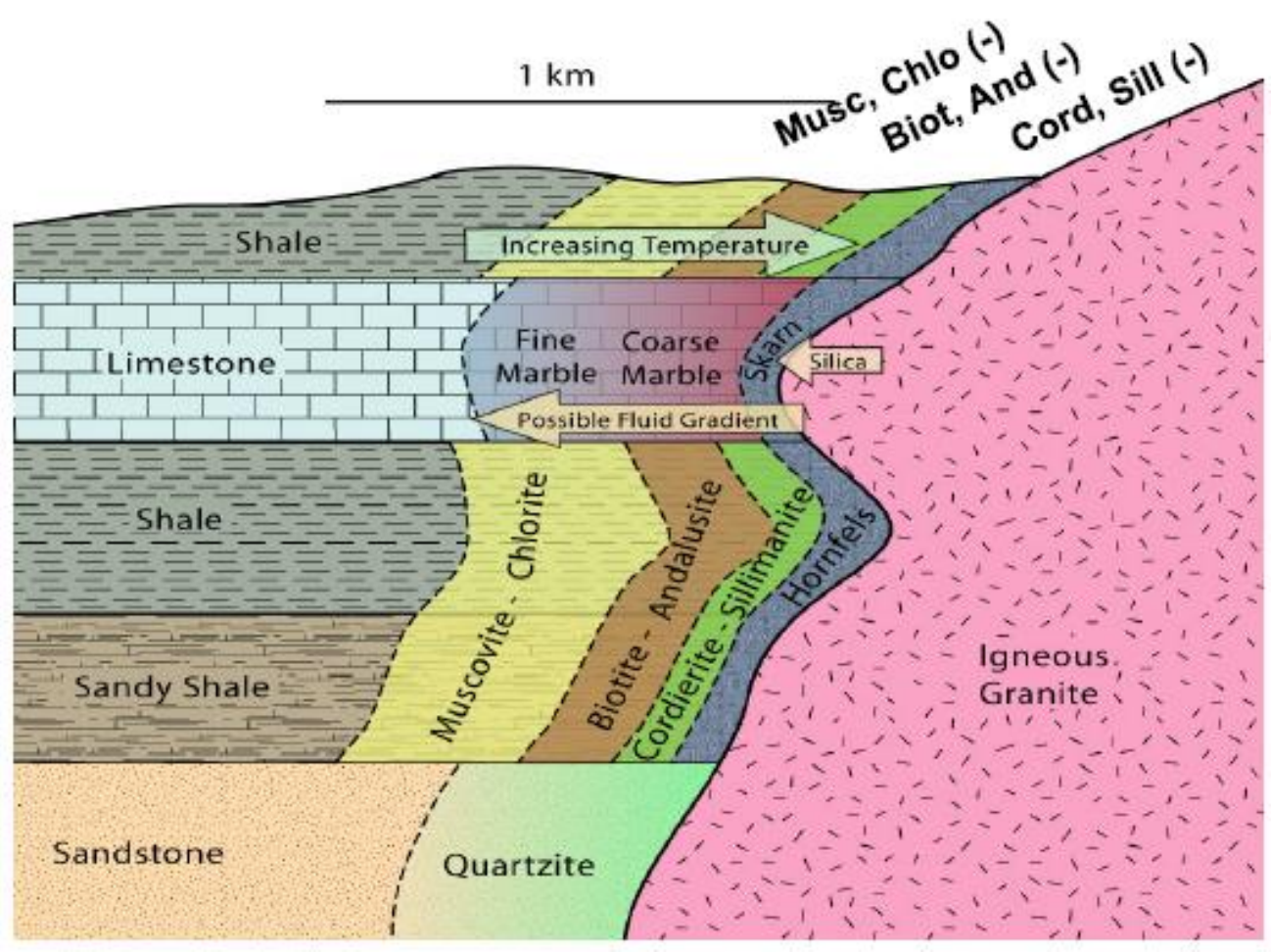

Amphibole
CPX
Plagio

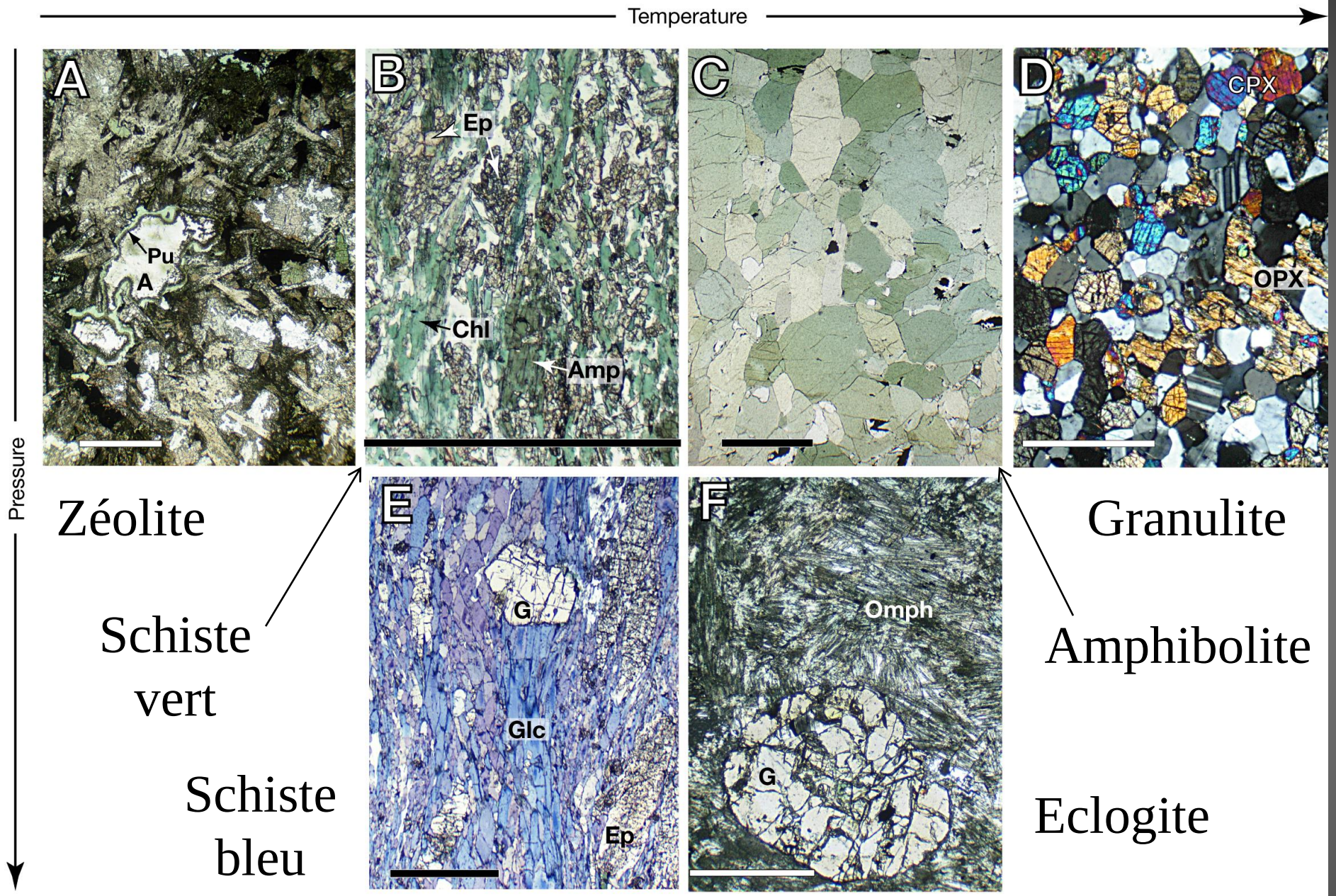

Temperature (°C)
100
200
300
400
500
600
700
800
900
1000
0
Zeolite
PP
PA
Albite-Epidote Hornfels
Hornblende Hornfels
Pyroxene Hornfels
Sanidinite Hornfels
Greenschist
Amphibolite
Granulite
Geothermal gradient of 25°C/km
Ultrahigh temperature
1
Blueschist
Geothermal gradient of 5°C/km
Eclogite
2
PP - Prehnite-Pumpellyite
PA - Pumpellyite-Actinolite
Quartz
Coesite
Ultrahigh pressure
3
Pressure (GPa)
0
50
100
Depth (km)

Métamorphisme de contact



Métamorphisme de contact: les minéraux formés dépendent de la composition de départ





Différents faciès métamorphiques pour un basalte en fonction des conditions de pression et de température.

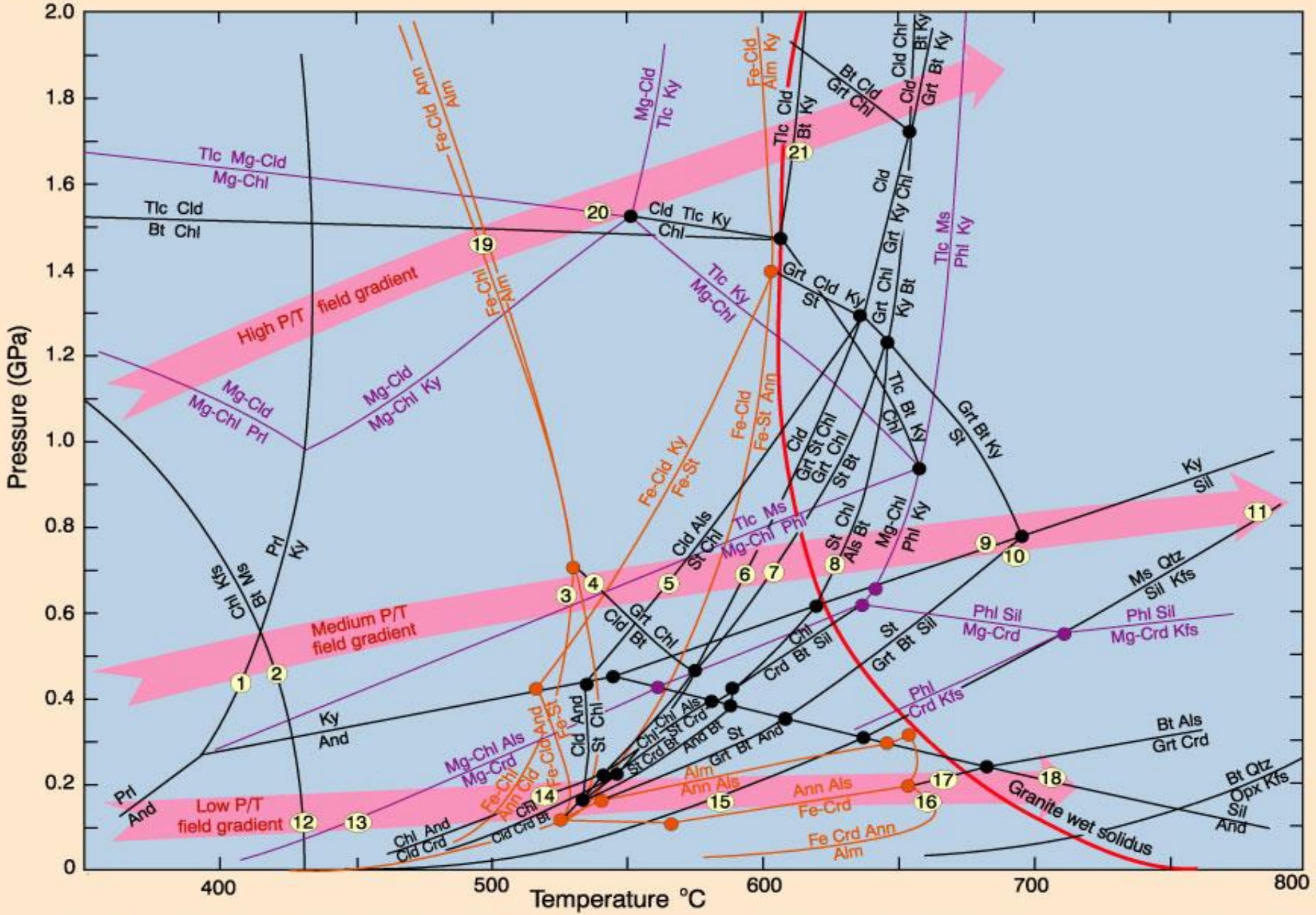
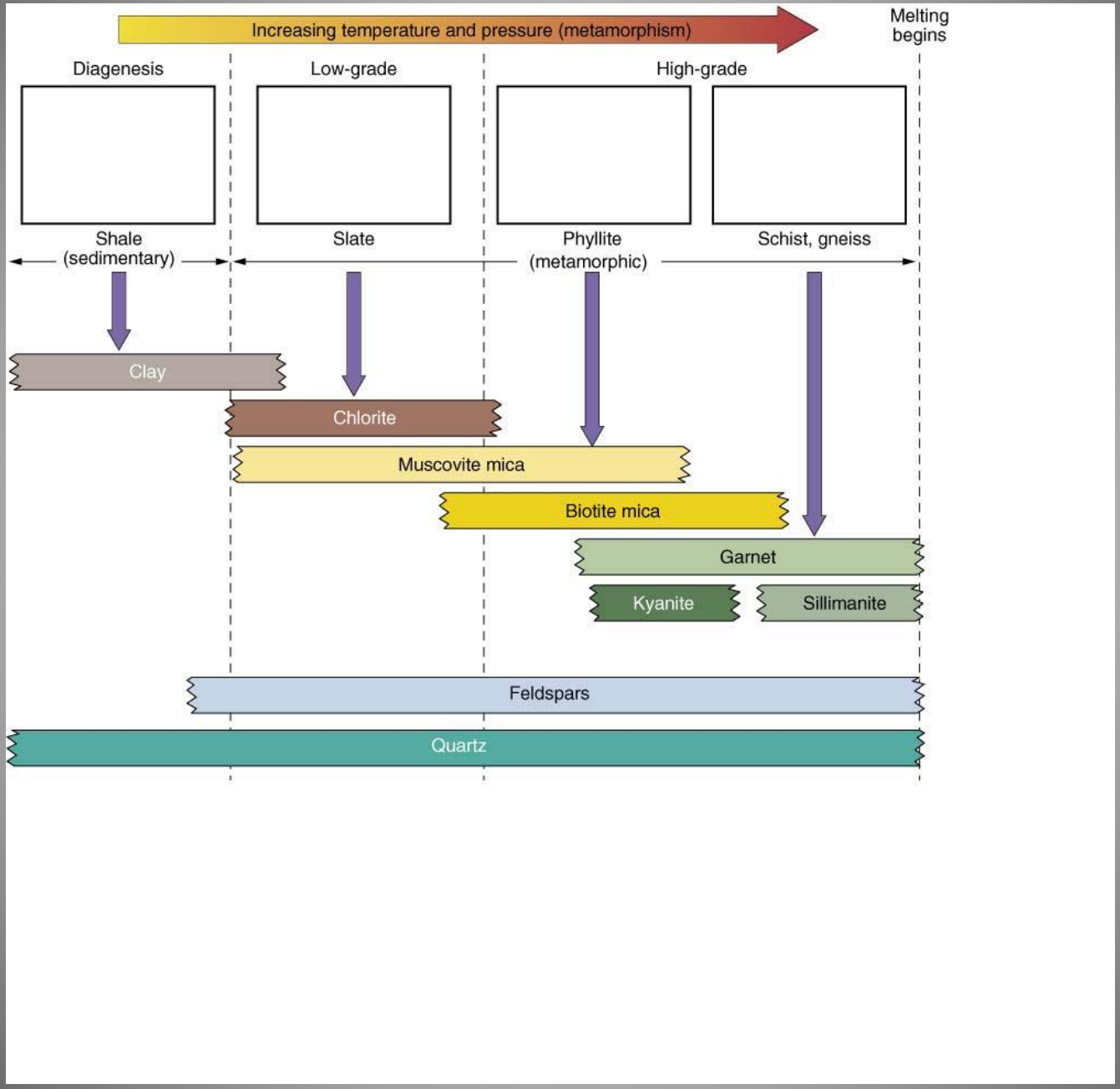


Figure 28-2. Petrogenetic grid for the system KFMASH at $P_{H2O} = P_{total}$. Orange curves represent the system KFASH and purple curves represent the system KMASH. Reactions are not balanced, and commonly leave out quartz, muscovite, and water, which are considered to be present in excess . Typical high, medium, and low P/T metamorphic field gradients are represented by broad pink arrows. After Spear and Cheney (1989), and Spear (1999).


Increasing temperature and pressure (metamorphism)
Melting begins
Diagenesis
Low-grade
High-grade
Shale (sedimentary)
Slate
Phyllite (metamorphic)
Schist, gneiss
Clay
Chlorite
Muscovite mica
Biotite mica
Garnet
Kyanite
Sillimanite
Feldspars
Quartz

A

Intensity of metamorphism →

	Not metamorphosed	Low grade	Intermediate grade	High grade
Rock name	Shale →	Slate →	Phyllite →	Schist / Gneiss
Foliation	None	Subtle: slaty cleavage	Distinct; schistosity apparent	Conspicuous; schistosity and compositional layering
Size of mica grains	Microscopic	Microscopic	Just visible with hand-held magnifier	Large and obvious
Typical mineral assemblage	Quartz, clays, calcite	Quartz, chlorite, muscovite, plagioclase	Quartz, muscovite, biotite, garnet, kyanite, plagioclase	Quartz, biotite, garnet, sillimanite, plagioclase

B

Intensity of metamorphism →

	Not metamorphosed	Low grade	Intermediate grade	High grade
Rock name	Basalt $\xrightarrow{+H_2O}$	Greenschist →	Amphibolite →	Granulite
Foliation	None	Distinct schistosity	Indistinct; when present due to parallel grains of amphibole	Indistinct because of absence of micas
Size of grains	Visible with hand-held magnifier	Visible with hand-held magnifier	Obvious by eye	Large and obvious
Typical mineral assemblage	Olivine, pyroxene, plagioclase	Chlorite, epidote, plagioclase, calcite	Amphibole, palgioclase, epidote, quartz	Pyroxene, plagioclase, garnet

Table 14.1 Common minerals in metamorphic facies.

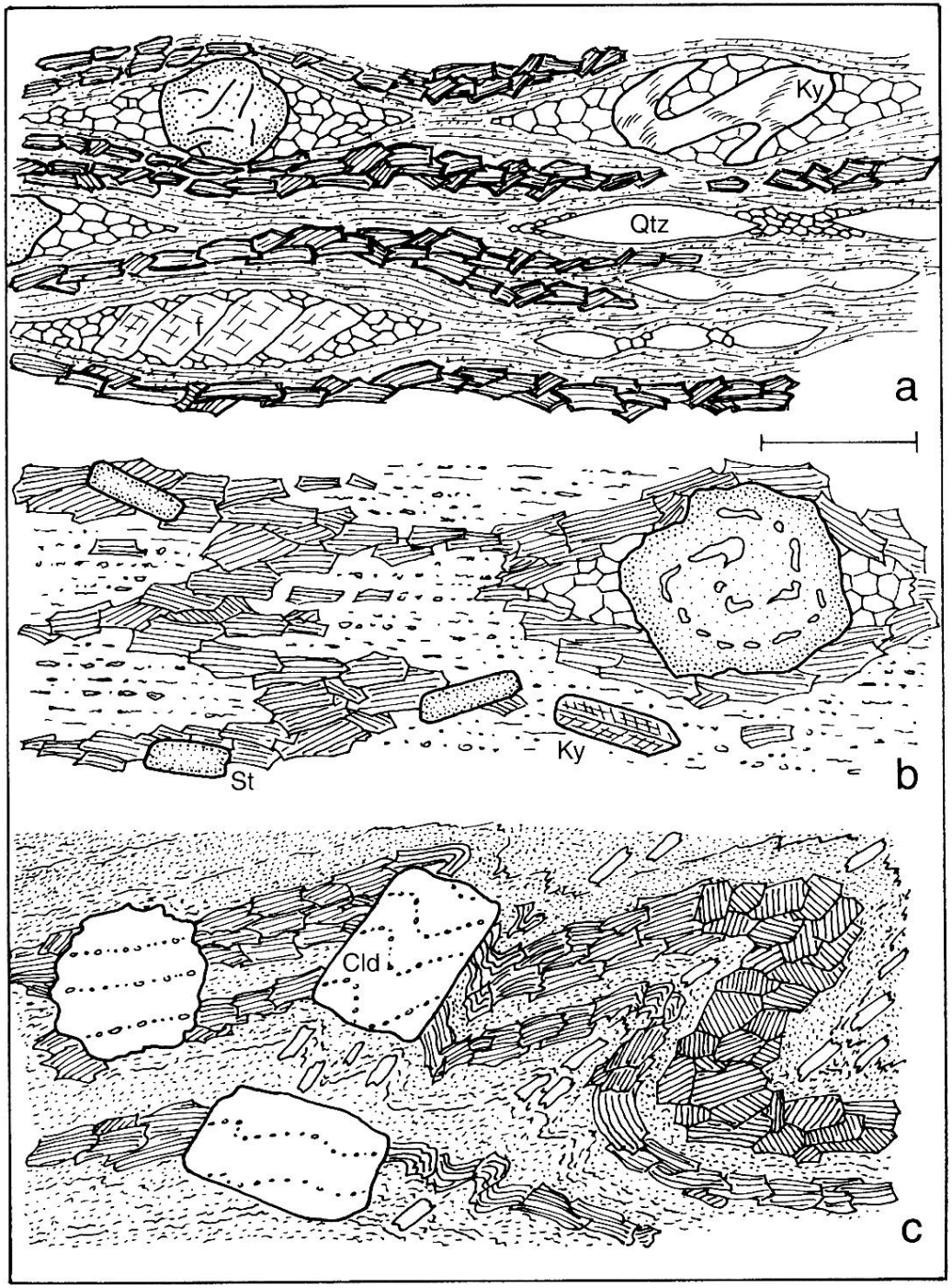
Facies	Mafic protolith	Pelitic protolith	Carbonate protolith
Zeolite	Chlorite, serpentine, clay minerals, zeolites, analcite, albite, quartz, prehnite, pumpellyite, calcite, dolomite	Chlorite, illite, clay minerals, quartz, albite, calcite, dolomite	Calcite, dolomite, quartz, chlorite, illite, clay minerals, albite
Prehnite-pumpellyite	Chlorite, serpentine, prehnite, pumpellyite, quartz, albite, calcite, dolomite	Chlorite, muscovite, clay minerals, quartz, albite, calcite dolomite	Calcite, dolomite, quartz, clay minerals, albite
Blueschist	Glaucophane, lawsonite (or epidote), quartz, garnet	Glaucophane, Si-rich muscovite, lawsonite (or epidote), quartz, garnet	Aragonite, dolomite, glaucophane, epidote, albite
Greenschist	Chlorite, actinolite, epidote, albite, quartz	**Chlorite zone:** chlorite, muscovite, quartz, albite **Biotite zone:** chlorite, muscovite, biotite, quartz, albite **Garnet zone:** muscovite, biotite, garnet, quartz, albite	Calcite, dolomite, muscovite, quartz, albite
Albite-Epidote hornfels	Albite, pyrophyllite, epidote, actinolite, chlorite, quartz	Muscovite, chlorite, biotite, albite, quartz, pyrophyllite	Calcite, epidote, actinolite, quartz
Amphibolite	Hornblende, plagioclase, quartz, garnet	**Staurolite zone:** muscovite, biotite, quartz, garnet, staurolite, plagioclase **Kyanite zone:** muscovite, biotite, quartz, garnet, kyanite, staurolite, plagioclase **Sillimanite zone:** muscovite, biotite, quartz, garnet, sillimanite, plagioclase	Calcite, dolomite, quartz, biotite, amphibole, diopside, K-feldspar, wollastonite
Hornblende hornfels	Cordierite, plagioclase, anthophyllite, hornblende, diopside, garnet, quartz	Andalusite, muscovite, cordierite, quartz, biotite	Calcite, diopside, grossular, biotite, quartz
Pyroxene hornfels	Diopside, orthopyroxene, plagioclase, biotite, quartz	Andalusite, cordierite, orthoclase, biotite, quartz	Wollastonite, grossularite, diopside, biotite, quartz
Granulite	Clinopyroxene, orthopyroxene, plagioclase, garnet, quartz	Quartz, K-feldspar, plagioclase, sillimanite, garnet, biotite, orthopyroxene, cordierite	Calcite, dolomite, quartz, diopside, wollastonite, K-feldspar, forsterite
Sanidinite	Sanidine, clinopyroxene, orthopyroxene, plagioclase, quartz	Sillimanite or mullite, spinel, sanidine, quartz	Monticellite, melilite, diopside, calcite
Eclogite	Pyrope-rich garnet, jadeite-rich pyroxene, quartz, kyanite, rutile	Si-rich muscovite, quartz, jadeite-rich pyroxene, pyrope-rich garnet, kyanite, rutile	Aragonite, dolomite, jadeite-rich pyroxene, epidote, quartz, Si-rich muscovite, pyrope-rich garnet

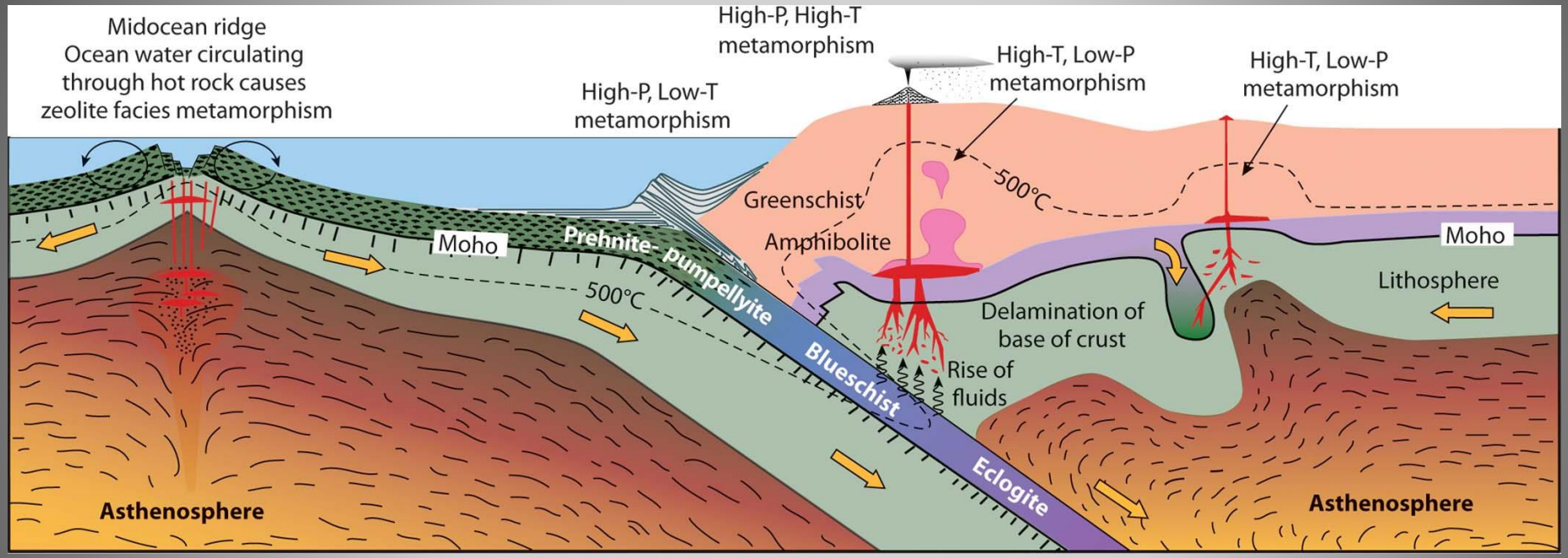
Paragenèse:

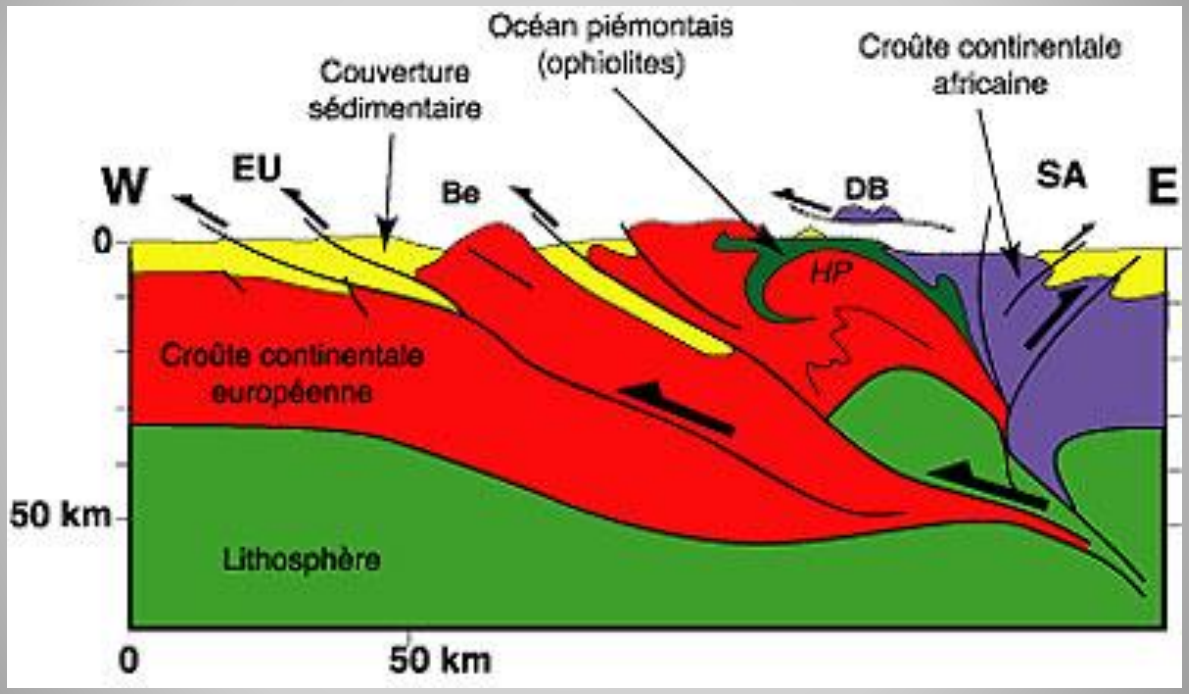
- antécinématique

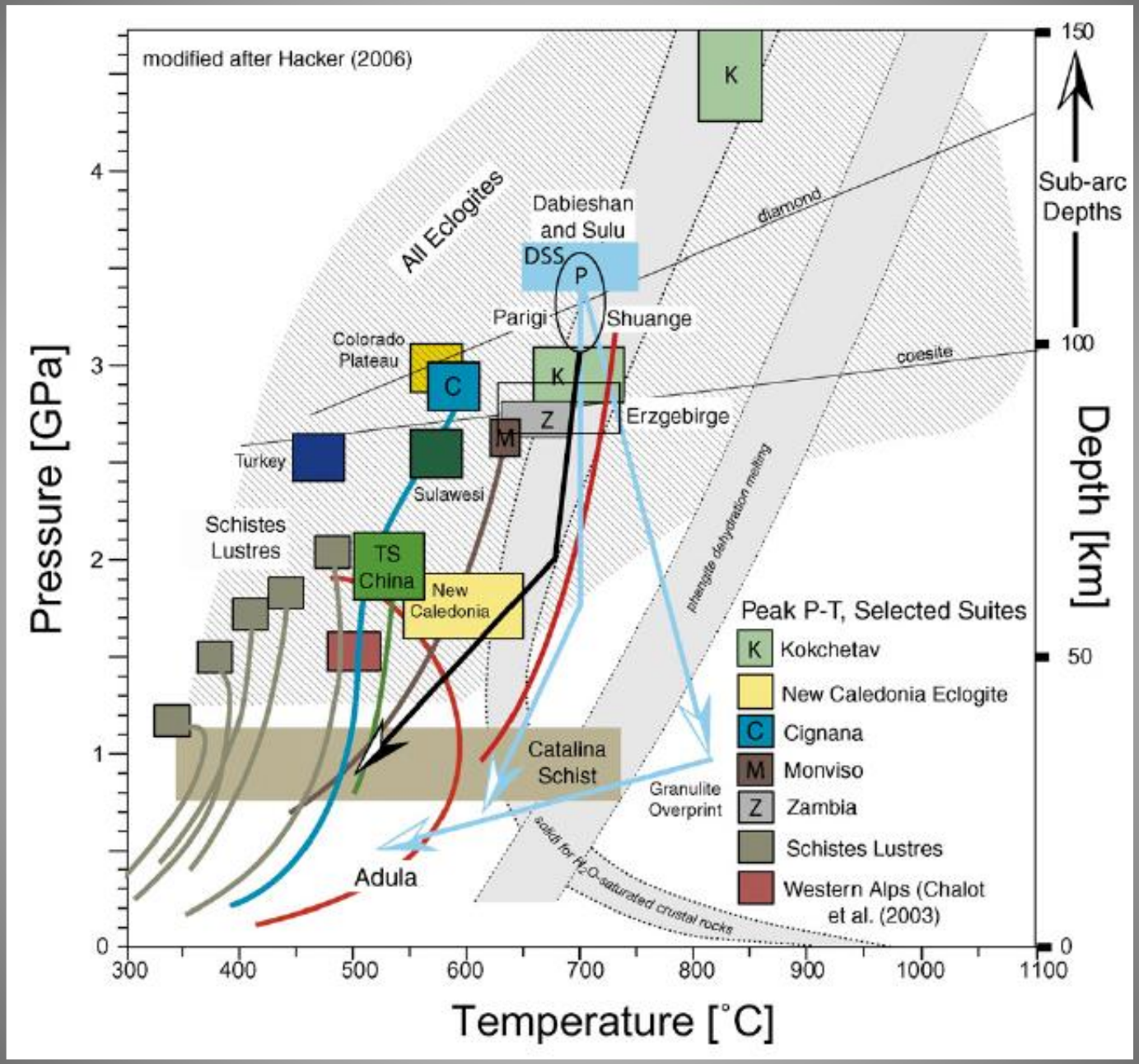
- syncinématique

- postcinématique

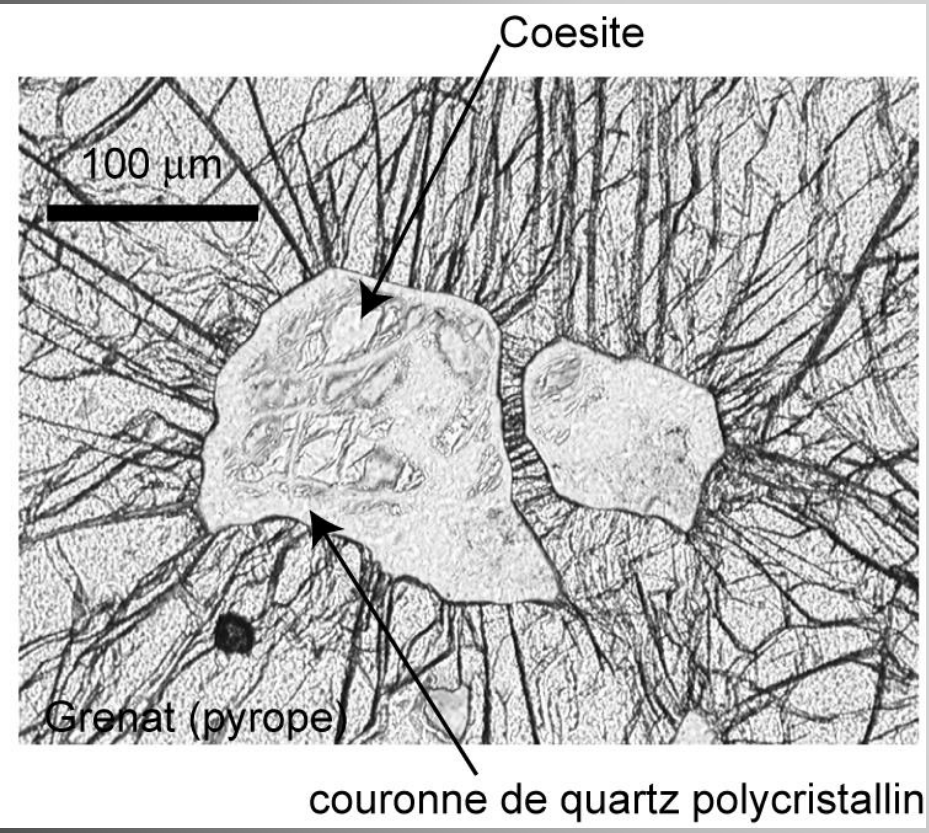


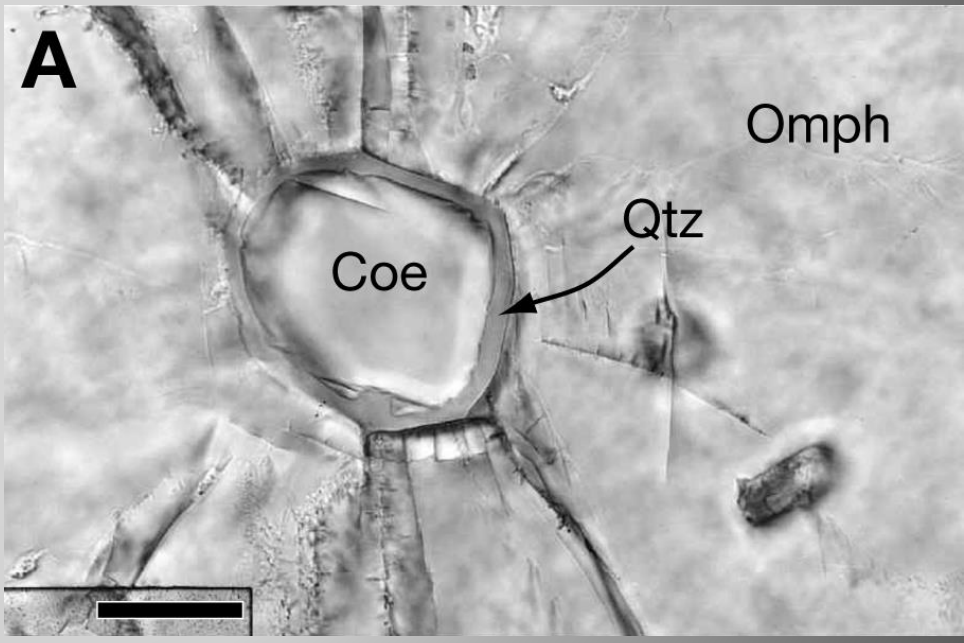

Midocean ridge
Ocean water circulating
through hot rock causes
zeolite facies metamorphism
High-P, Low-T
metamorphism
High-P, High-T
metamorphism
High-T, Low-P
metamorphism
High-T, Low-P
metamorphism
Greenschist
Amphibolite
500°C
Moho
Prehnite- pumpellyite
500°C
Blueschist
Eclogite
Delamination of
base of crust
Rise of
fluids
Moho
Lithosphere
Asthenosphere
Asthenosphere


Océan piémontais
(ophiolites)
Croûte continentale
africaine
Couverture
sédimentaire
W
EU
Be
DB
SA
E
0
HP
Croûte continentale
européenne
50 km
Lithosphère
0
50 km


modified after Hacker (2006)
All Eclogites
Dabieshan
and Sulu
DSS
P
Parigi
Shuange
Colorado
Plateau
C
K
Z
M
Erzgebirge
Turkey
Sulawesi
Schistes
Lustres
TS
China
New
Caledonia
Catalina
Schist
Adula
Granulite
Overprint
diamond
coesite
phengite dehydration melting
solidi for H2O-saturated crustal rocks
Peak P-T, Selected Suites
K Kokchetav
New Caledonia Eclogite
C Cignana
M Monviso
Z Zambia
Schistes Lustres
Western Alps (Chalot
et al. (2003)
Pressure [GPa]
Temperature [˚C]
Depth [km]
Sub-arc
Depths
0
1
2
3
4
300
400
500
600
700
800
900
1000
1100
0
50
100
150

Deux polymorphes de SiO_2:
Quartz → basse pression
Coesite → haute pression





Collision dans les Alpes:
Des roches enfouies à plus de 100 km de profondeur et aujourd'hui à l'affleurement

Apparition de la coésite