

G4021 Magmatická a metamorfní petrologie

1. Metamorfóza pelitů

- *1. Celkové chemické složení horniny (zjednodušené)*
- *2. Pelitické sedimenty*
- *3. Diageneze*
- *4. Prográdní metamorfóza pelitů za středních tlaků*
- *5. Vysokotlaká metamorfóza pelitů*
- *6. Kontaktní metamorfóza pelitů*

1. Celkové chemické složení horniny (zjednodušené)

- kvarcity	SiO_2
- křemen-živcové horniny	$\text{SiO}_2\text{-Al}_2\text{O}_3\text{-K}_2\text{O-Na}_2\text{O-CaO-H}_2\text{O}$
- metapelity	$\text{SiO}_2\text{-Al}_2\text{O}_3\text{-K}_2\text{O-MgO-FeO-H}_2\text{O}$
- metabazity	$\text{SiO}_2\text{-Al}_2\text{O}_3\text{-Na}_2\text{O-MgO-FeO-H}_2\text{O}$
- vápenatosilikátové horniny	$\text{SiO}_2\text{-Al}_2\text{O}_3\text{-K}_2\text{O-CaO-MgO-H}_2\text{O}$
- metakarbonáty	$\text{MgO-CaO-CO}_2\text{-H}_2\text{O}$
- křemité dolomity	$\text{MgO-CaO-SiO}_2\text{-CO}_2\text{-H}_2\text{O}$
- ultrabazity	$\text{SiO}_2\text{-MgO-CaO-CO}_2\text{-H}_2\text{O}$

jiné chemické systémy (méně časté)

- cordierit-antofylitové horniny	$\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MgO-FeO-H}_2\text{O}$
- železná formace	$\text{SiO}_2\text{-FeO-Fe}_2\text{O}_3\text{-H}_2\text{O}$
- manganolity, smirky	

jiná označení chemických systémů:

- křemen-živcové horniny	NASH, CASH a CKNASH
- metapelity	KMASH, KFASH a KFMASH
- ultramafity	MS-H ₂ O-CO ₂ , CMS-H ₂ O-CO ₂

2. Pelitické sedimenty

Původní hornina pelit (jílovec a jílové břidlice):

- kaolín, smektity, illit, chlorit, příměs muskovitu, křemene, organických látek, hematitu, limonitu, pyritu, karbonátů, živce
- $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-K}_2\text{O-MgO-FeO-H}_2\text{O}$
- Chemický systém **KMASH, KFASH a KFMASH**

Table 28-1. Chemical Compositions* of Shales and Metapelites

	1	2	3	4	5
SiO ₂	64.7	64.0	61.5	65.9	56.3
TiO ₂	0.80	0.81	0.87	0.92	1.05
Al ₂ O ₃	17.0	18.1	18.6	19.1	20.2
MgO	2.82	2.85	3.81	2.30	3.23
FeO	5.69	7.03	10.0	6.86	8.38
MnO	0.25	0.10			0.18
CaO	3.50	1.54	0.81	0.17	1.59
Na ₂ O	1.13	1.64	1.46	0.85	1.86
K ₂ O	3.96	3.86	3.02	3.88	4.15
P ₂ O ₅	0.15	0.15			
Total	100.00	100.08	100.07	99.98	96.94

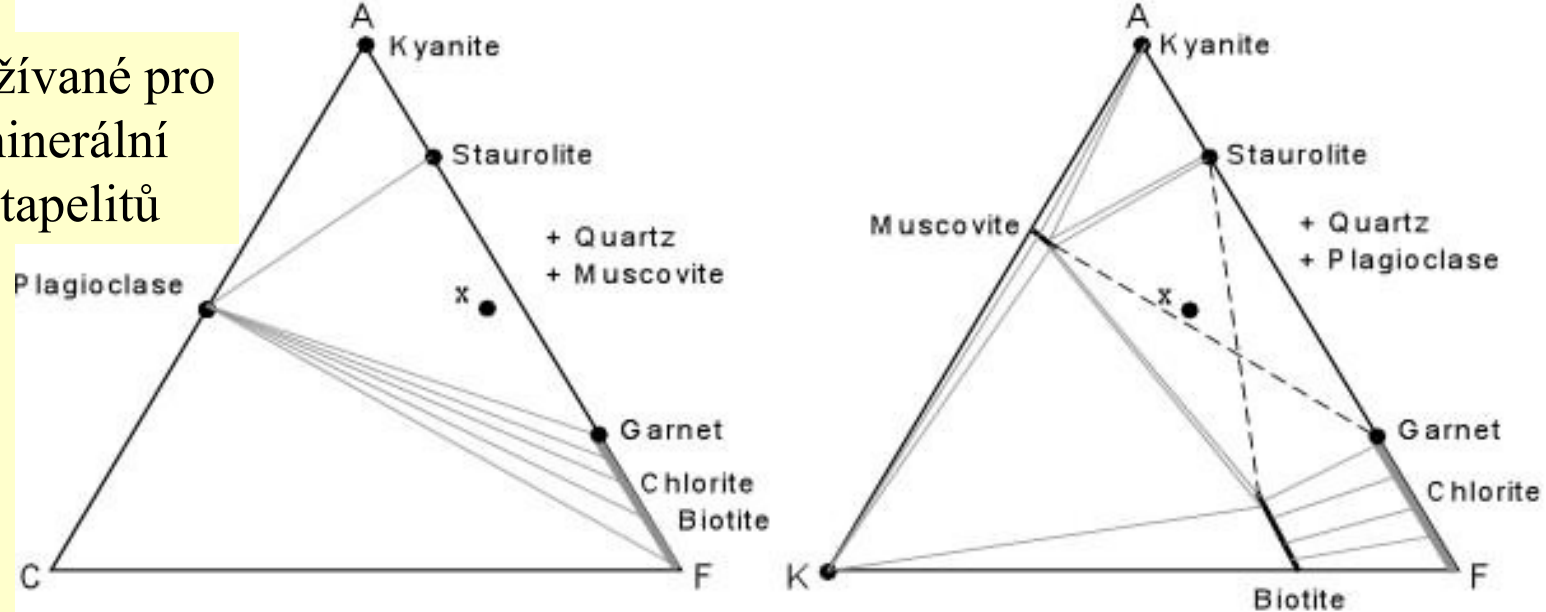
* Reported on a volatile-free basis (normalized to 100%) to aid comparison.

1. "North American Shale Composite". Gromet *et al.* (1984). 2. Average of ~100 published shale and slate analyses (Ague, 1991). 3. Ave. pelite-pelagic clay (Carmichael, 1989). 4. Ave. of low-grade pelitic rocks, Littleton Fm, N.H. (Shaw, 1956). 5. Ave. of



jílová břidlice

Diagramy používané pro prezentaci minerální asociace metapelitů



Typický pelit:

SiO₂ 55-60 wt %

Al₂O₃ 15-20 wt %

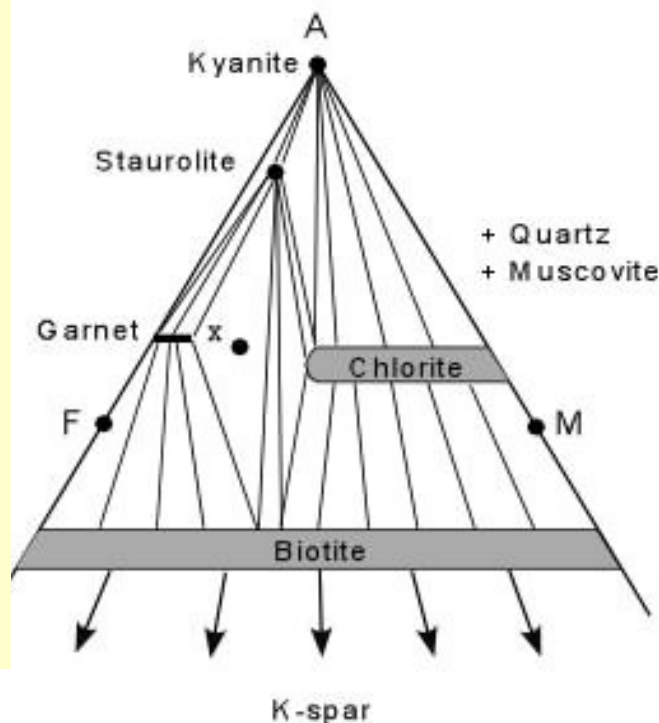
K₂O 2-5 wt %

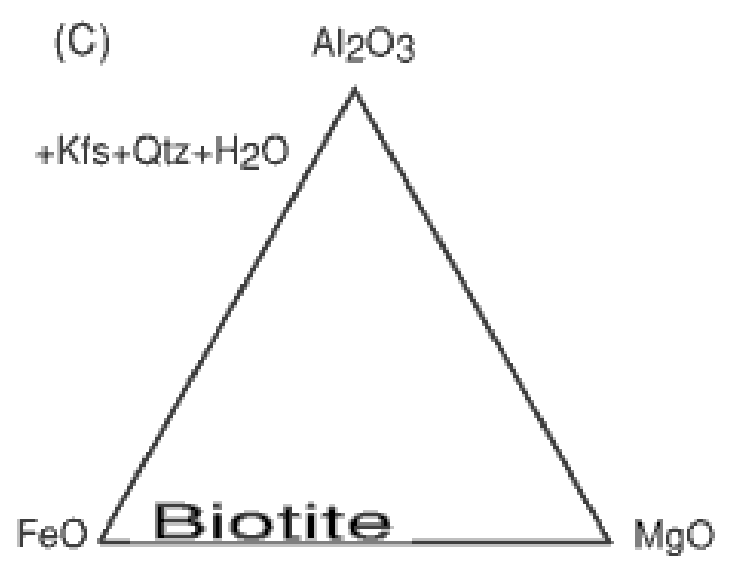
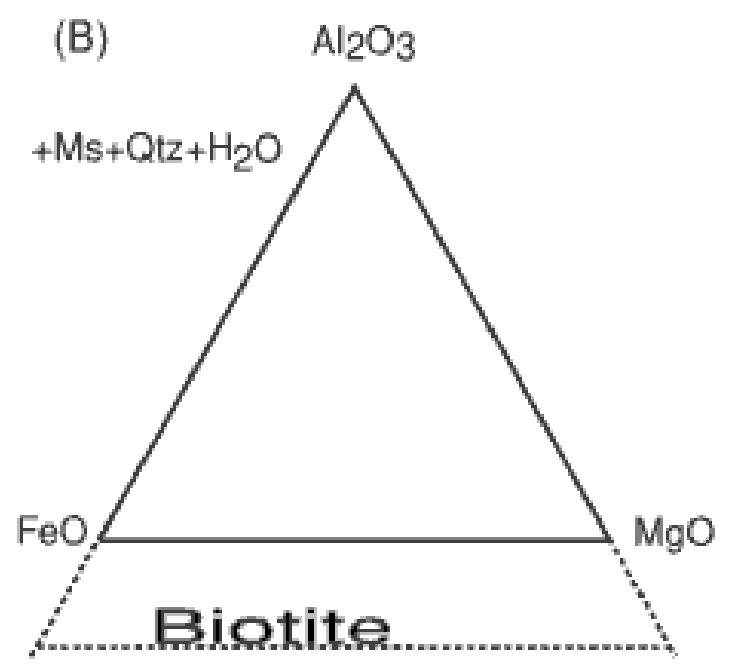
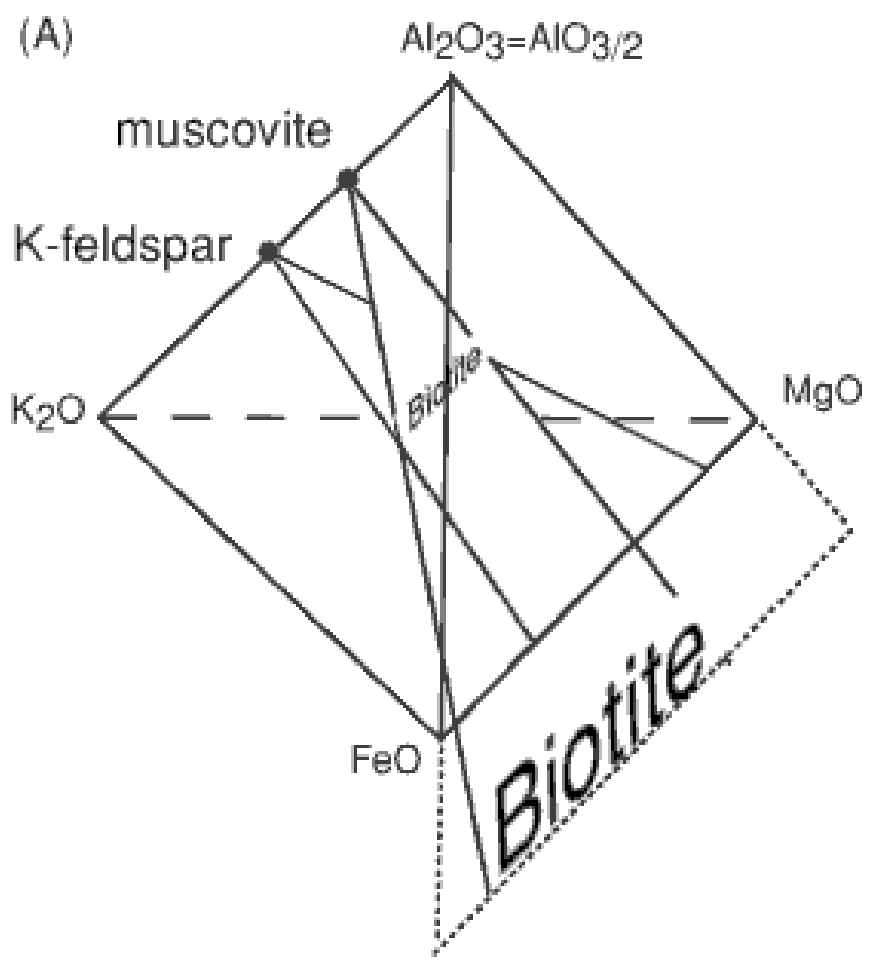
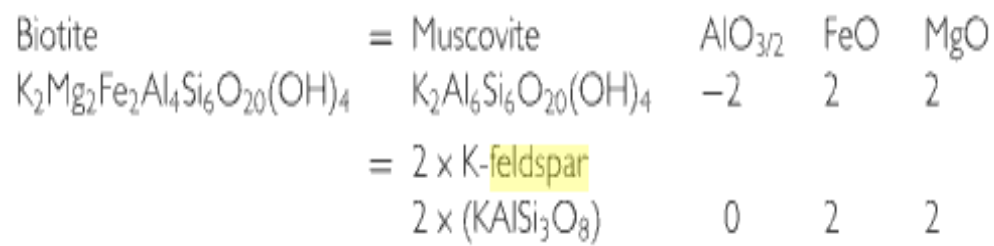
FeO 2-5 wt %

MgO 2-5 wt %

krystalochemicky vázaná voda

H₂O 4-6 wt %





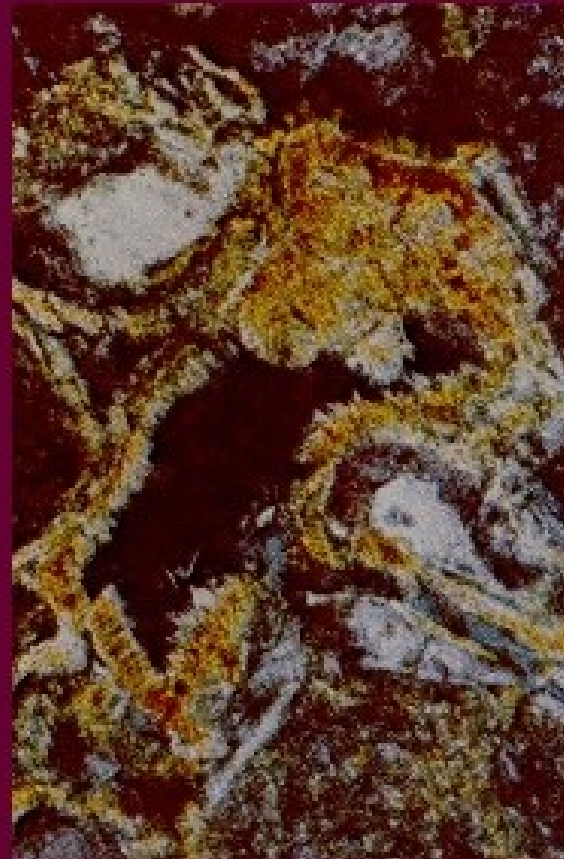
3. Diagenese

- během diagenese se snižuje porozita (z počátku až 50%)
- z horniny je vytlačována voda
- jílové minerály se mění na illit a chlorit
- s rostoucí teplotou roste krystalinita illitu
- organické látky prochází celou řadou přeměn a na konci tohoto procesu zůstává pouze grafit
- za počátek metamorfózy se obvykle považuje 200 C
- hloubka kolem 6 km → jílové břidlice (illit, muskovit, chlorit, křemen, draselné živce, albit, sulfidy, hematit, organická hmota)
- Illit se rozpadá na sericit (muskovit s výraznou *fengitovou* substitucí $\text{Si}^{\text{vi}}(\text{Fe},\text{Mg})^{\text{iv}}\text{Al}^{\text{vi}}_{-1}\text{Al}^{\text{iv}}_{-1}$).

Authigenic clay is perpendicular
to grain boundaries



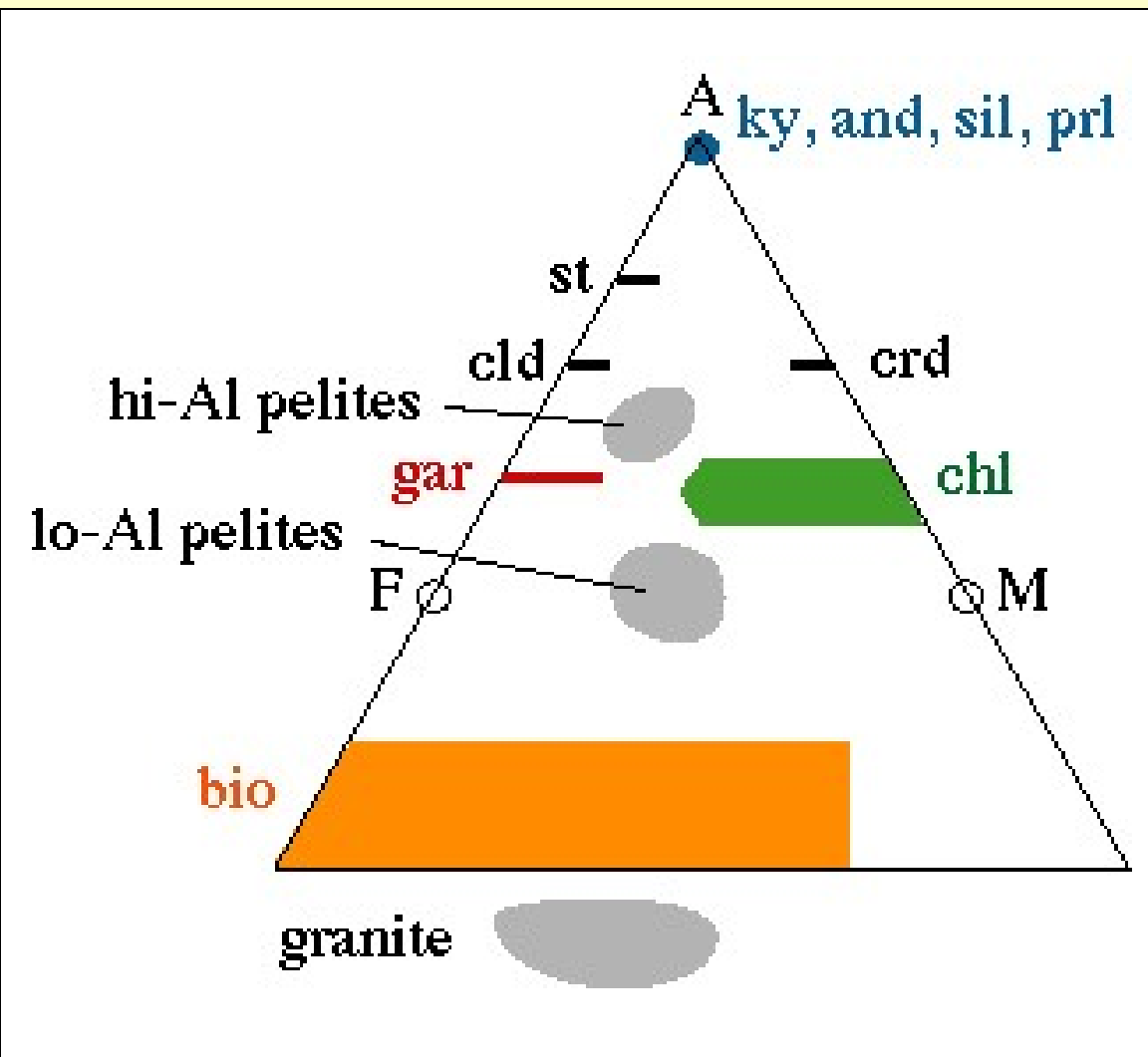
Fe-montmorillonite



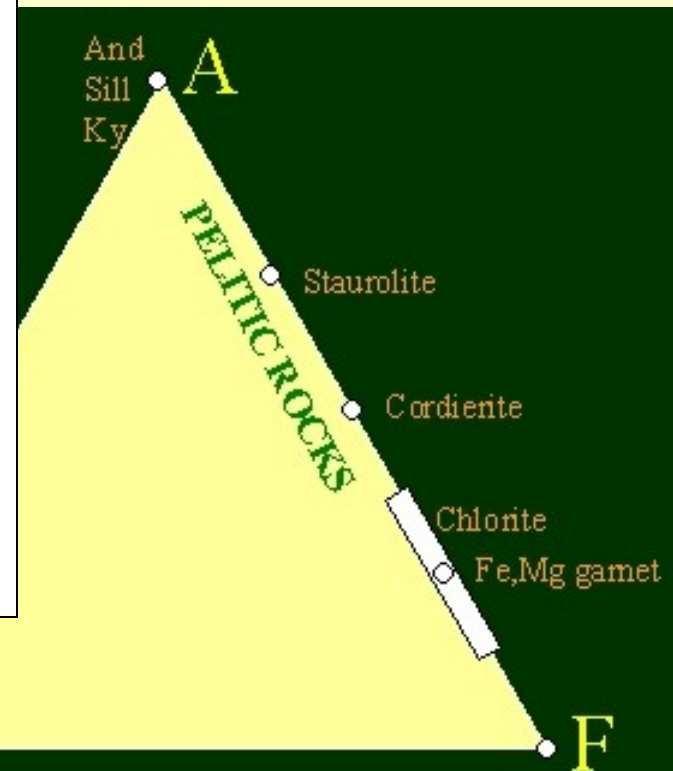


metapelit na kontaktu s metaslínovcem (Qtz+Ms+Chl+Cal+Limonit, Grafit)

4. Metamorfóza pelitů za středních tlaků

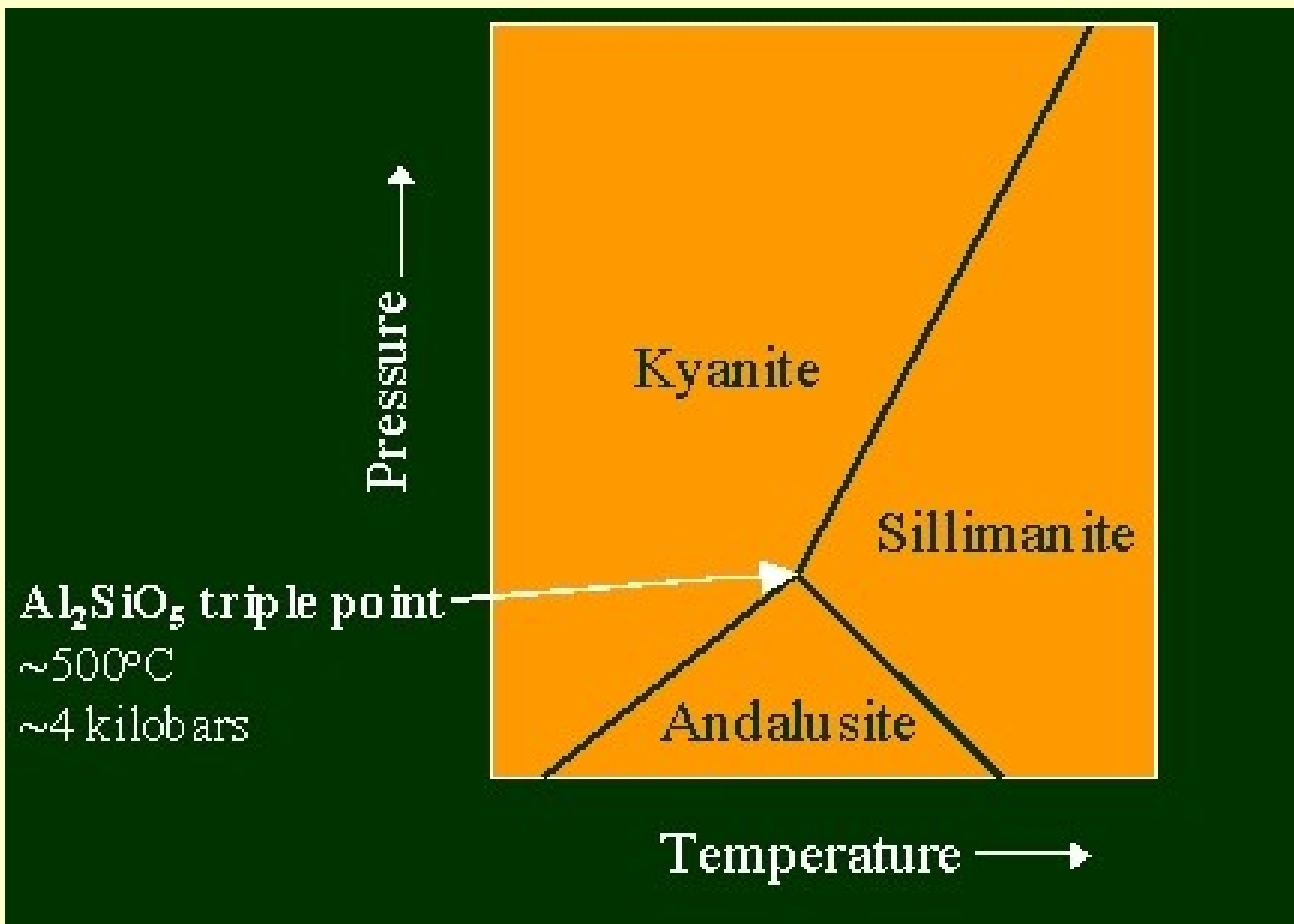


- Jíly 15-20 % Al_2O_3
- Granity 14 % Al_2O_3

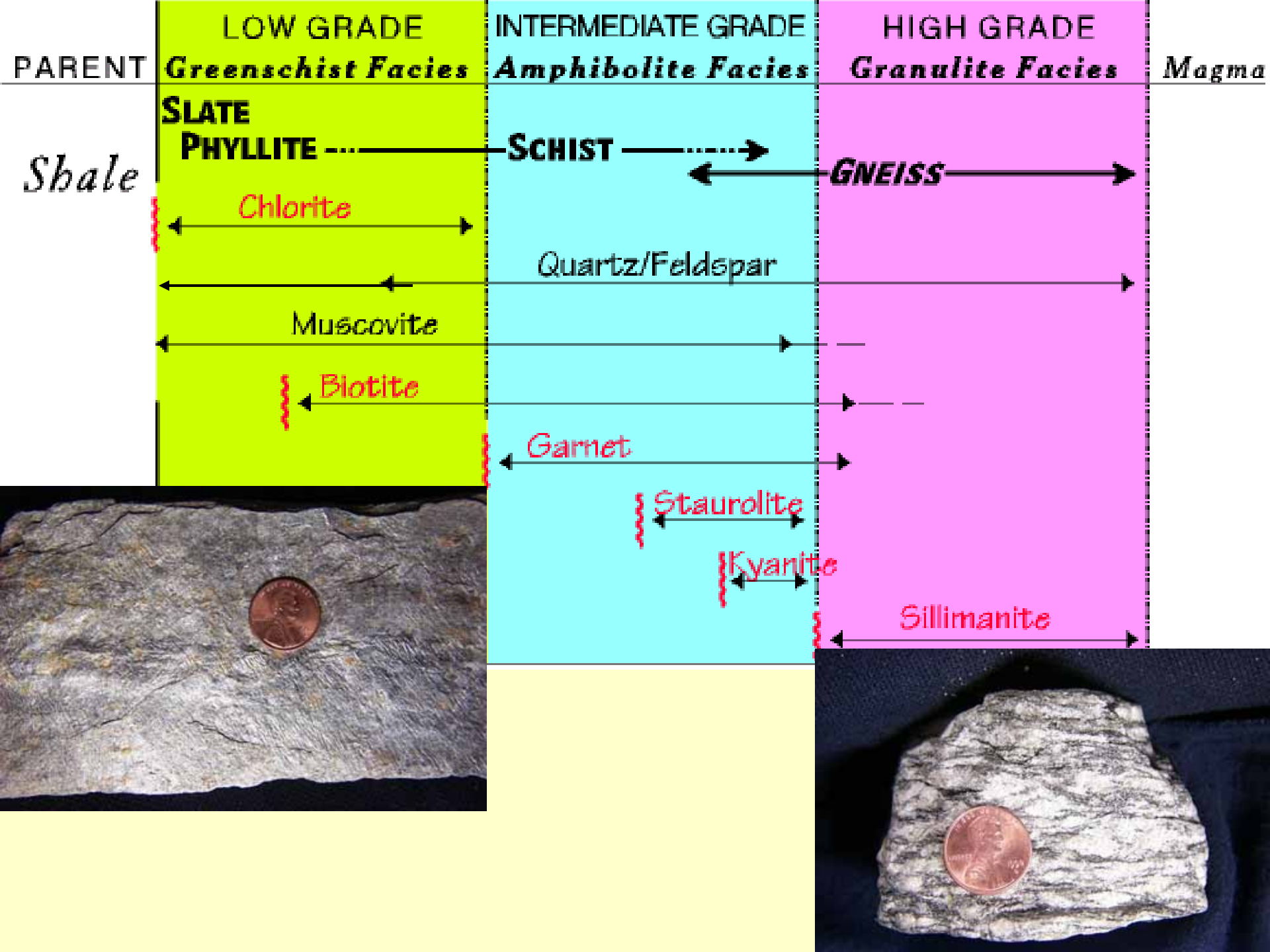


C

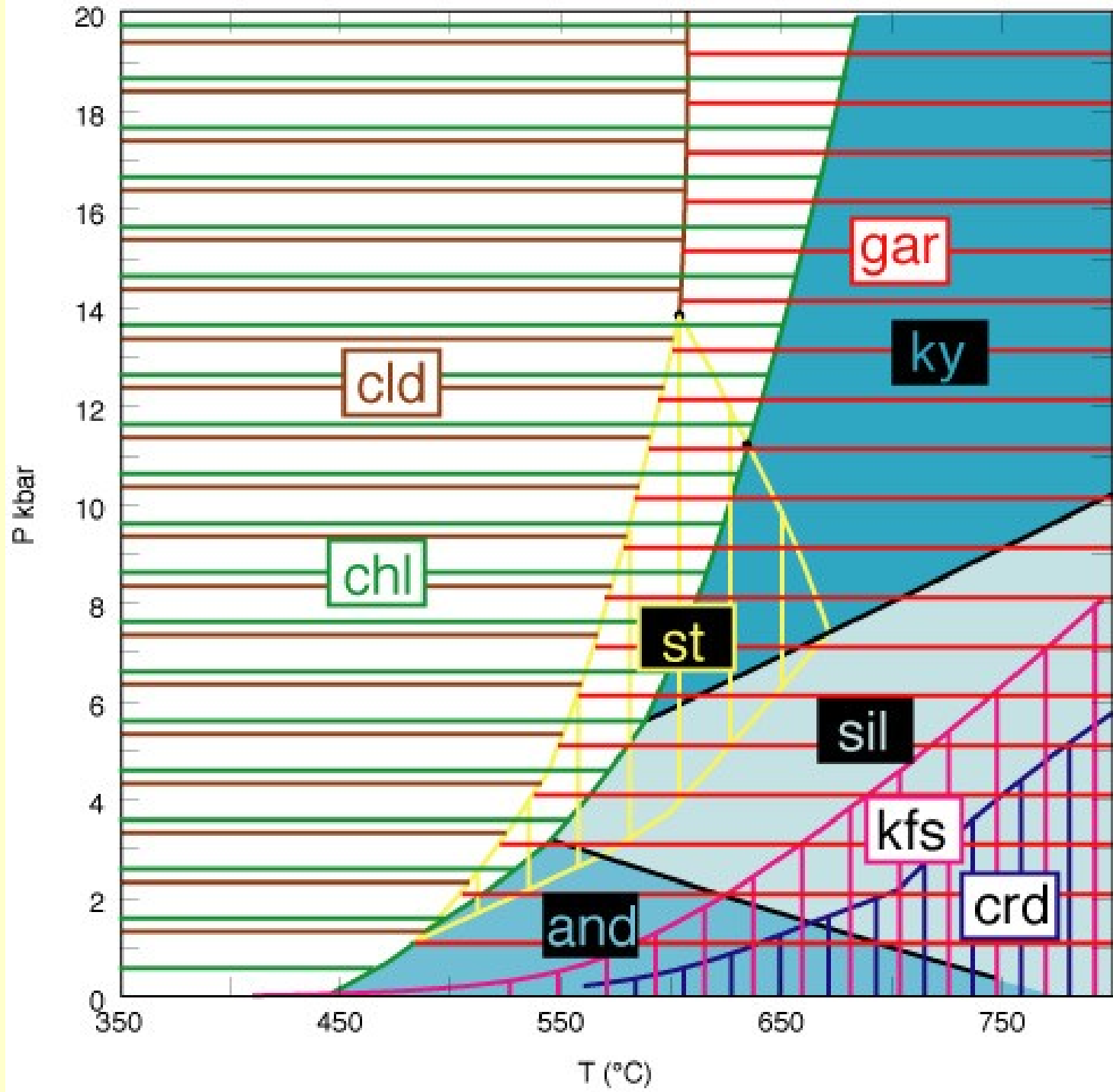
F

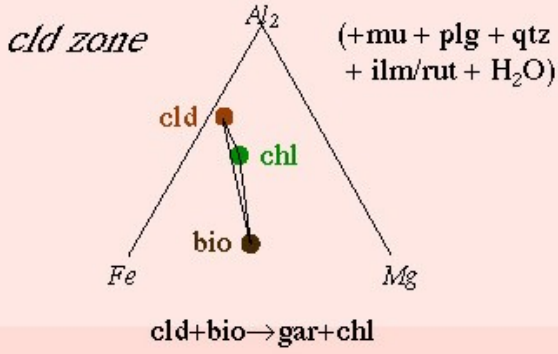


- andalusit ⇒ nízké P
- kyanit ⇒ vysoké P
- sillimanit ⇒ vysoké T

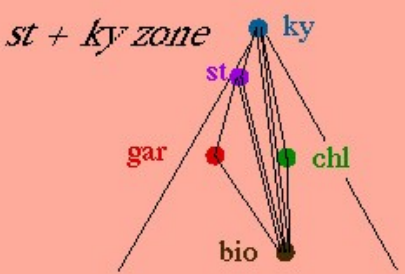
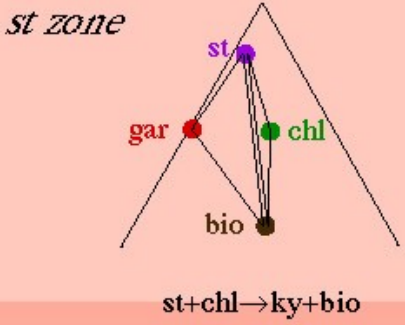
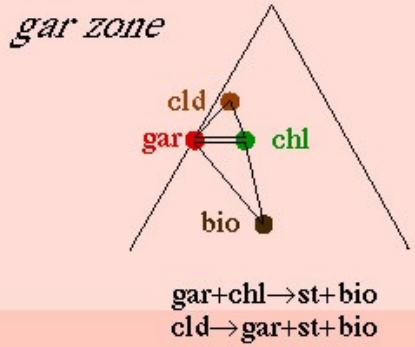


- **muskovit** (Mu) : $K_2Al^{vi}_4(Al_2Si_6)^{iv}O_{20}(OH)_4$
substituce : $(Mg,Fe)SiAl^{iv}_{-1}Al^{vi}_{-1} > \text{fengit}$
- **chlorit** (Chl): $(Mg_5Al)^{vi}(AlSi_3)^{iv}O_{10}(OH)_8 > \text{klinochlor}$,
substituce : $FeMg_{-1} > \text{chamosit}$, $Al^{vi}Al^{iv}(Fe,Mg)_{-1}Si_{-1} >$
- **biotit** (Bt): $K_2Mg^{vi}_6(Al_2Si_6)^{iv}O_{20}(OH)_4 > \text{flogopit}$
substituce : $FeMg_{-1} > \text{annit}$, $Al^{vi}Al^{iv}Mg_{-1}Si_{-1} > \text{eastonit}$
- **granát** (Grt): $Mg_3Al_2Si_3O_{12} > \text{pyrop}$
substituce : $FeMg_{-1} > \text{almandin}$, $MnMg_{-1} > \text{spessartin}$
- **staurolit** (St): $Mg_2Al_9Si_4O_{22}(OH)_2$,
substituce : $FeMg_{-1}$
- **cordierit** (Cdr): $Mg_2Al_4Si_5O_{18}$
substituce: $FeMg_{-1}$
- **draselný živec** (Kfs); $KAlSi_3O_8$
- **plagioklas** (Pl): $NaAlSi_3O_8 > \text{albit}$
substituce : $CaAlNa_{-1}Si_{-1} > \text{anortit}$
- **andalusit** (And), **sillimanit** (Sill), **kyanit** (Ky); Al_2SiO_5 ,
- **křemen** (Qtz): SiO_2
- **Ilmenit** (Ilm): $FeTiO_3$
- **Rutile** (Rt): TiO_2





chlorit $(Mg_5Al)^{vi} (AlSi_3)^{iv}O_{10}(OH)_8 \Rightarrow$ nízké T
biotit $K_2 (Mg,Fe)^{vi}_6 (Al_2Si_6)^{iv}O_{20}(OH)_4 \Rightarrow$ střední T
granát $(FeMgMnCa)_3Al_2Si_3O_{12} \Rightarrow$ střední až vysoké T
staurolit $Mg_2Al_9Si_4O_{22}(OH)_2 \Rightarrow$ střední až vysoké P
chloritoid $(Fe,Mg)_2Al_4Si_2O_{10}(OH)_4 \Rightarrow$ střední až vysoké P
cordierit $(MgFe)_2Al_4Si_5O_{18} \Rightarrow$ nízké P
paragonit $NaAl_2[AlSi_3]O_{10}(OH)_2 \Rightarrow$ vysoké P



Barrovienské zony	minerály
chloritová zóna	chl + ms + qtz + H ₂ O + reliktní min.
biotitová zóna	chl + bt + ms + qtz + H ₂ O
granátová zóna	chl + bt + grt + ms + qtz + H ₂ O
staurolitová zóna	st + bt + grt + ms + qtz + H ₂ O
kyanitová zóna	ky + bt + st + grt + ms + qtz + H ₂ O
sillimanitová zóna	grt + bt + sil + ms + qtz + H ₂ O
druhá sillimanitová zóna	sil + or + qtz + H ₂ O + melt

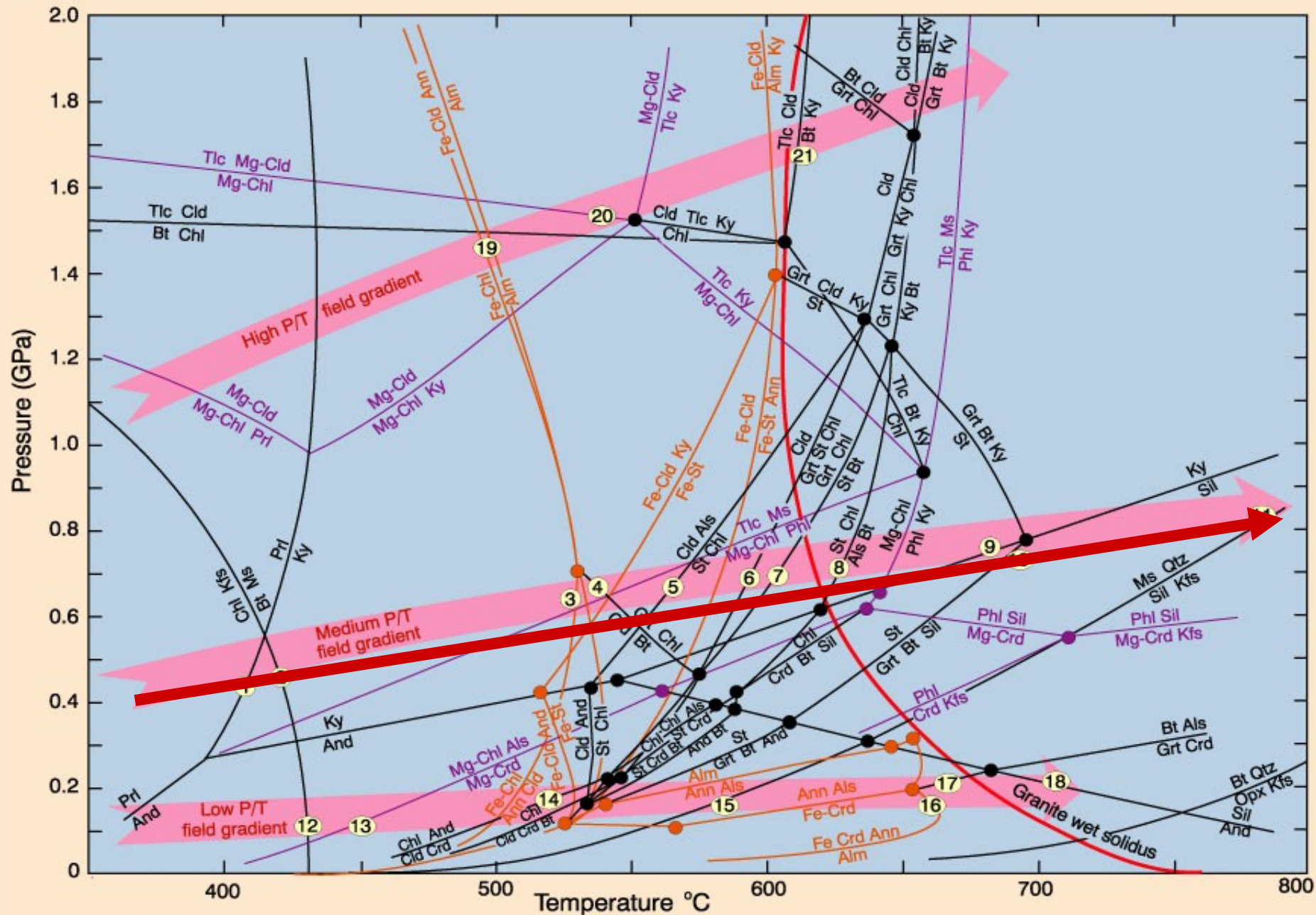
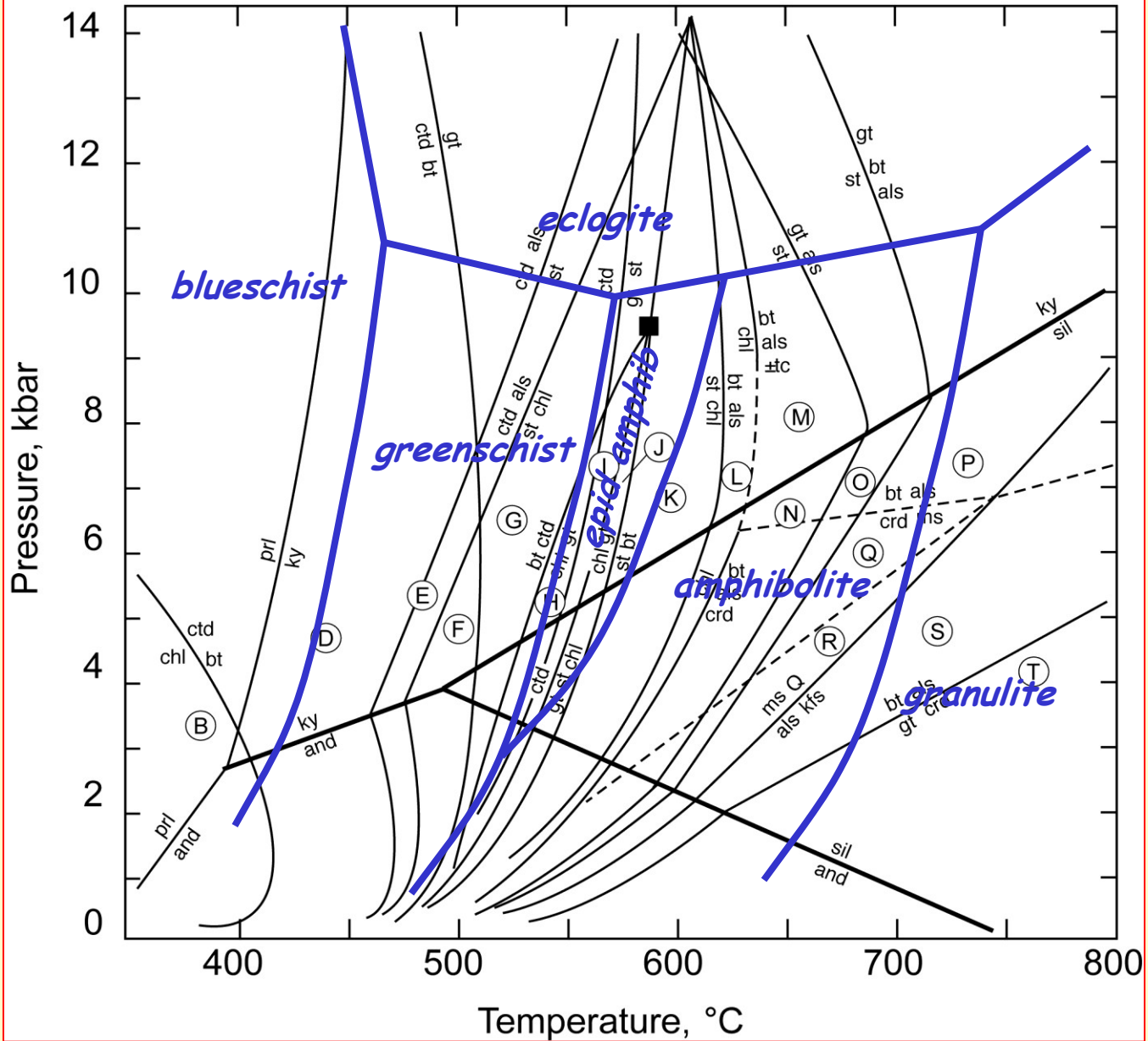


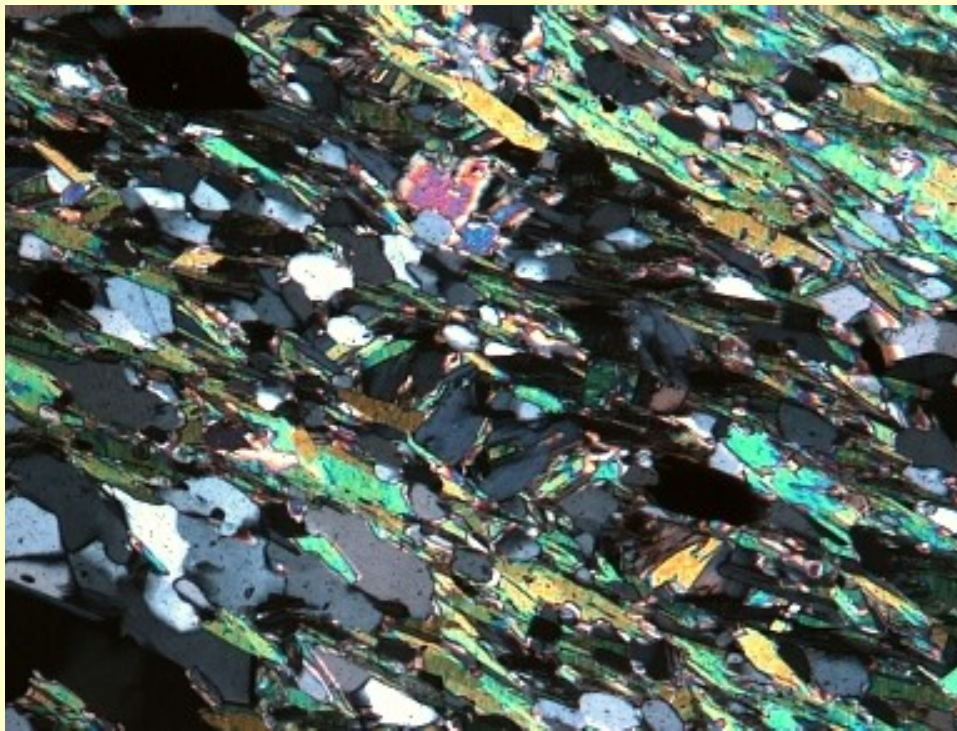
Figure 28-2. Petrogenetic grid for the system KFMASH at $P_{\text{H}_2\text{O}} = P_{\text{total}}$. Orange curves represent the system KFLASH and purple curves represent the system KMASH. Reactions are not balanced, and commonly leave out quartz, muscovite, and water, which are considered to be present 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).



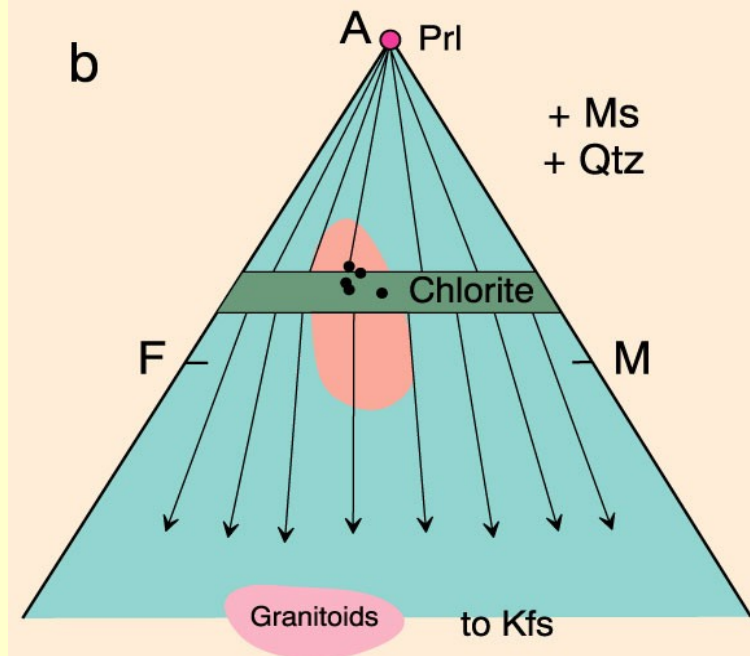
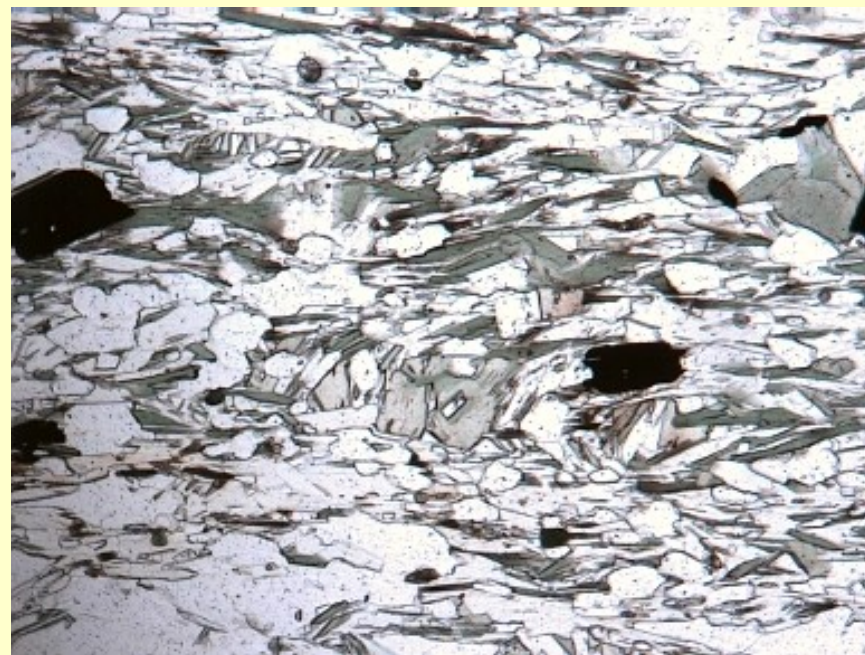
Průběh metamorfózy pelitů za středních tlaků

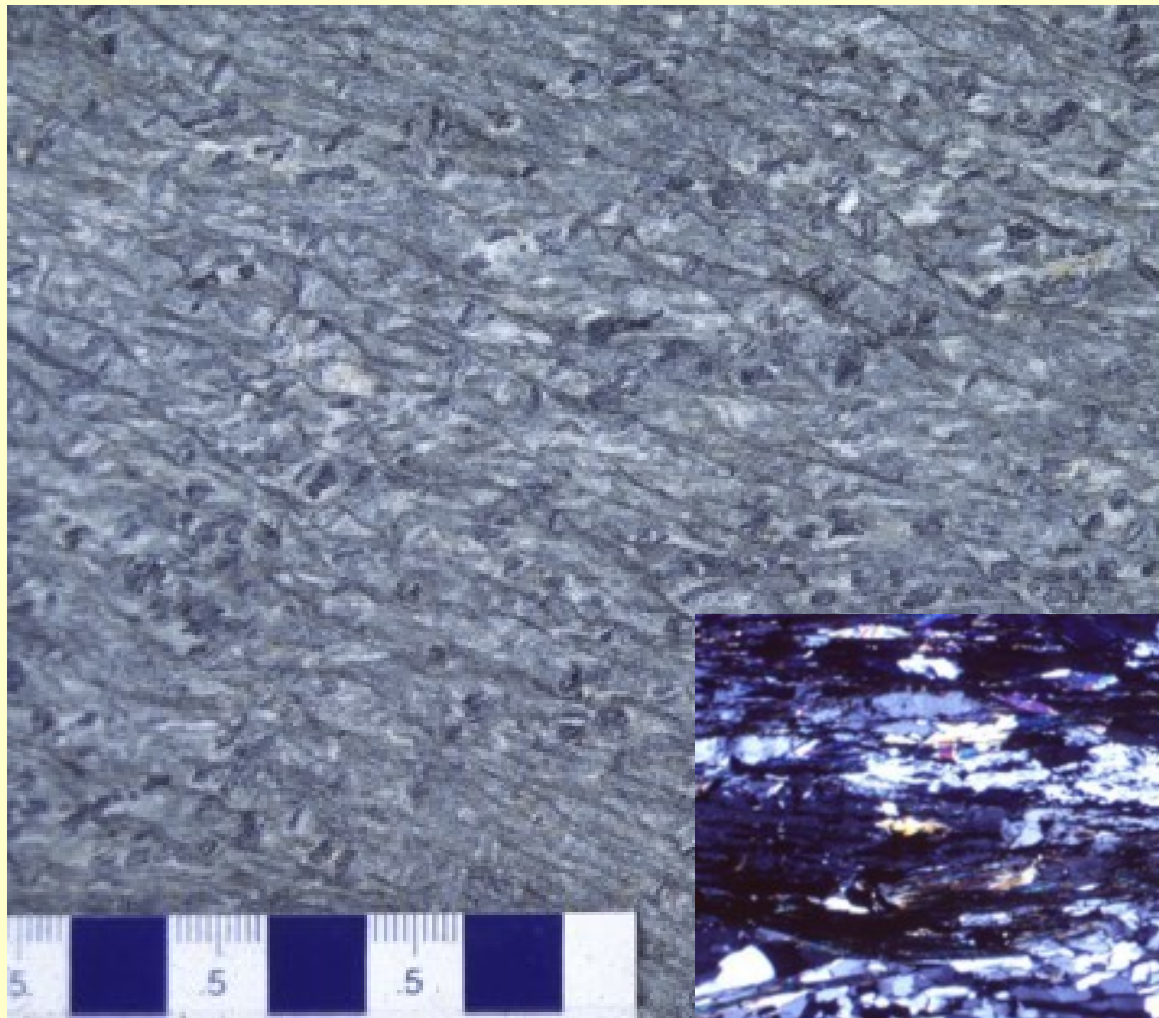
1) Chloritová zóna

- anchimetamorfózou vznikají v Al-bohatých pelitech: pyrofylit / $\text{Al}_2((\text{OH})_2\text{Si}_4\text{O}_{10})$ / a chlority



Fylit: $\text{Qtz} + \text{Ab} + \text{Chl} + \text{Ms}$





Fylit

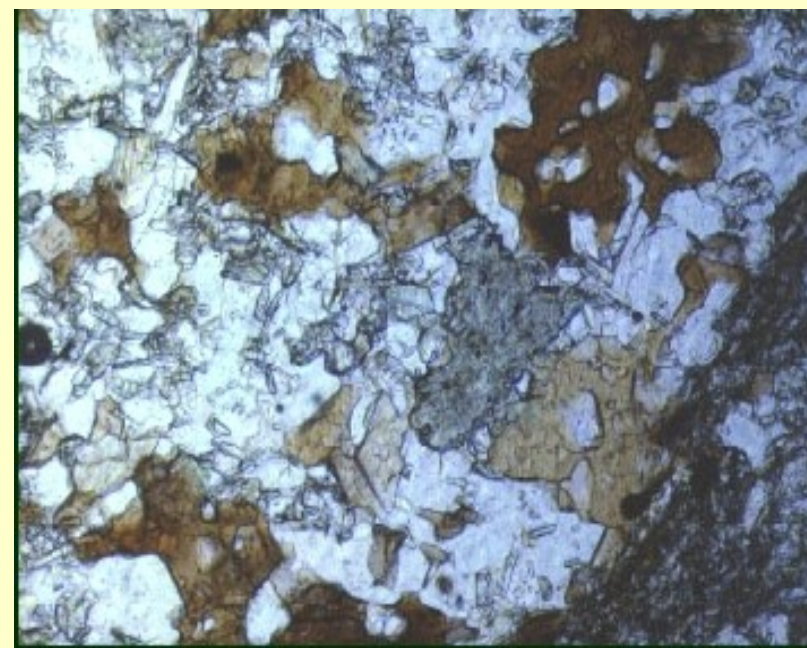
Ms+Chl+Qtz+Ab \pm Prf \pm Kfs

2) Biotitová zóna (300-400 C)

- KFASH: Fe-chlorit + K-živec = muskovit + biotit + křemen + H₂O (A)

3) Vznik chloritoidu (~ 400 C)

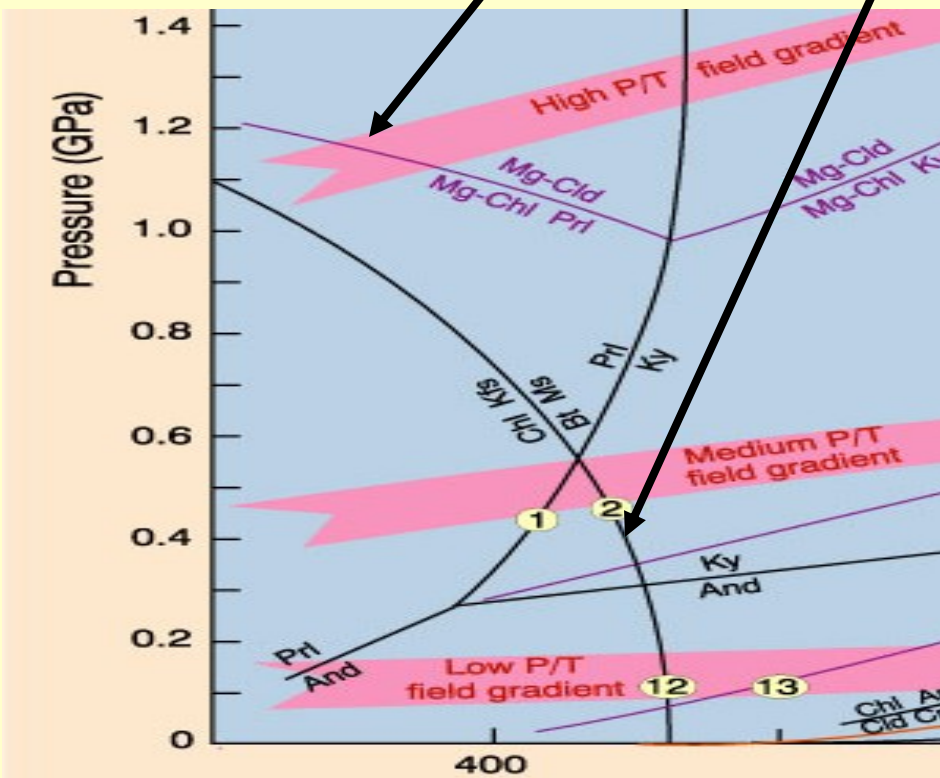
- pro střední tlaky Fe-chlorit (KFASH), v Al bohatých horninách
- KMASH: Mg-chlorit + pyrofylyt = Mg-chloritoid + křemen + H₂O (B)

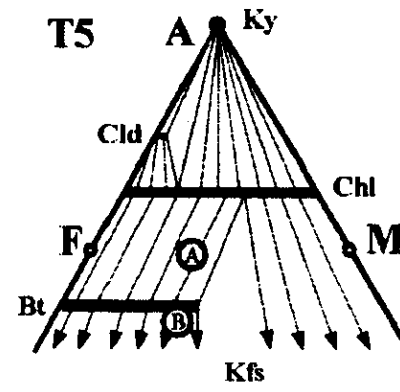
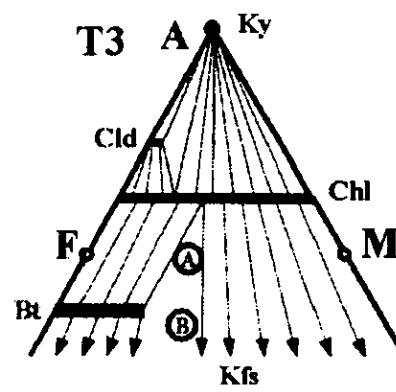
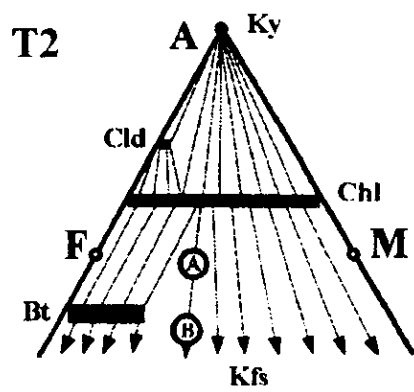
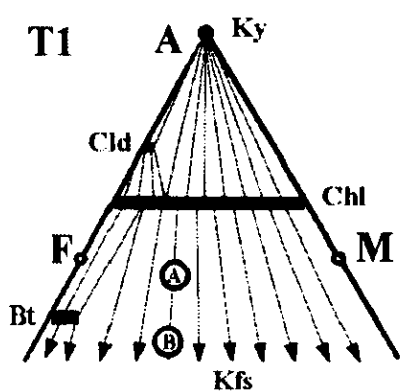
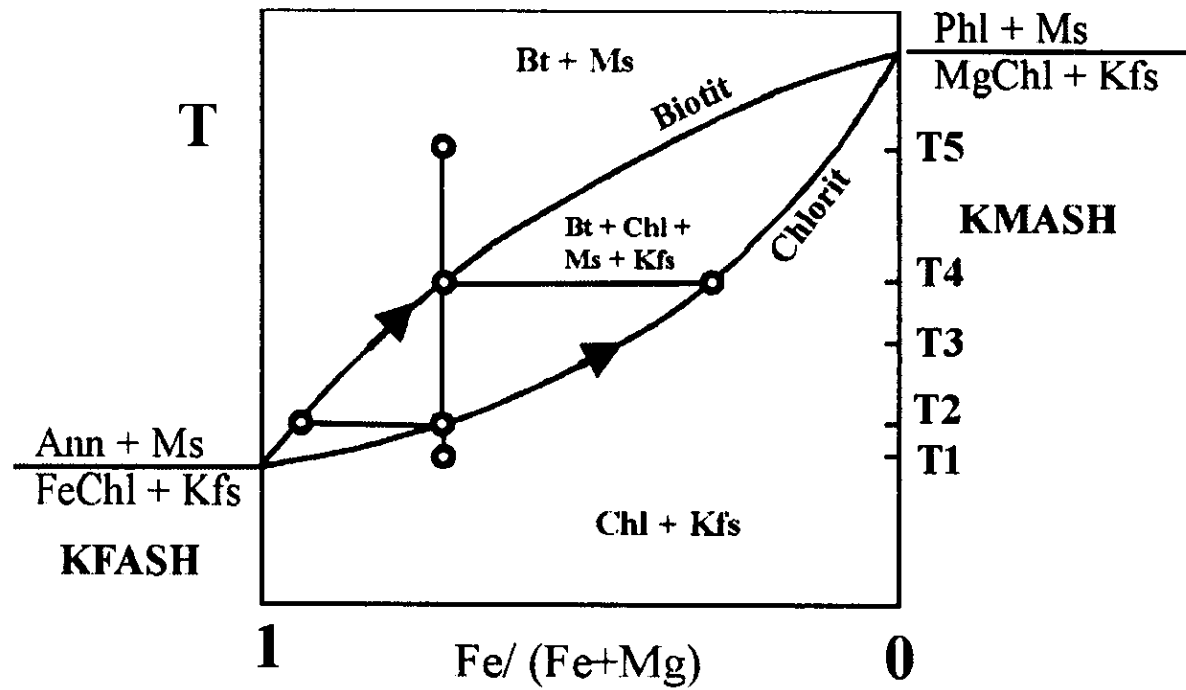


Fylit: Qtz+Ab+Bt+Chl+Ms+Ab



Fylit: Qtz+Ab+Bt+Chl+Ms+Ab+Cld

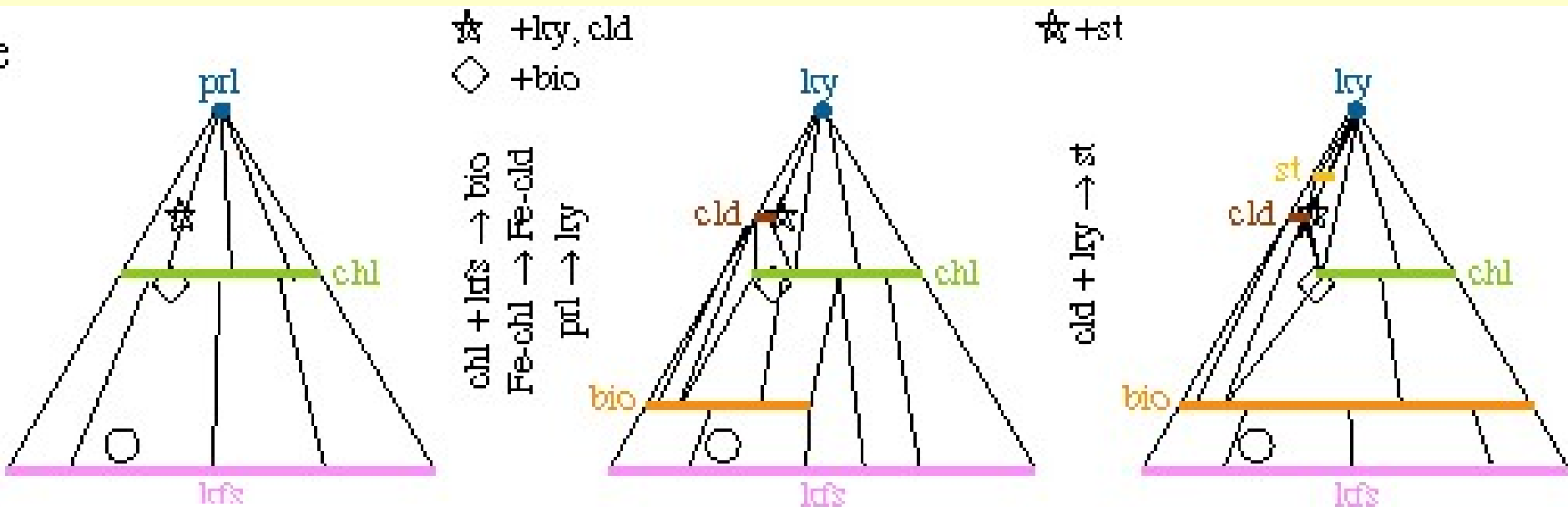




T-X diagram a odpovídající AMF diagramy pro kontinuální reakci:
 chlorit + K-živec = muskovit + biotit + křemen + H₂O v KFMASH systému

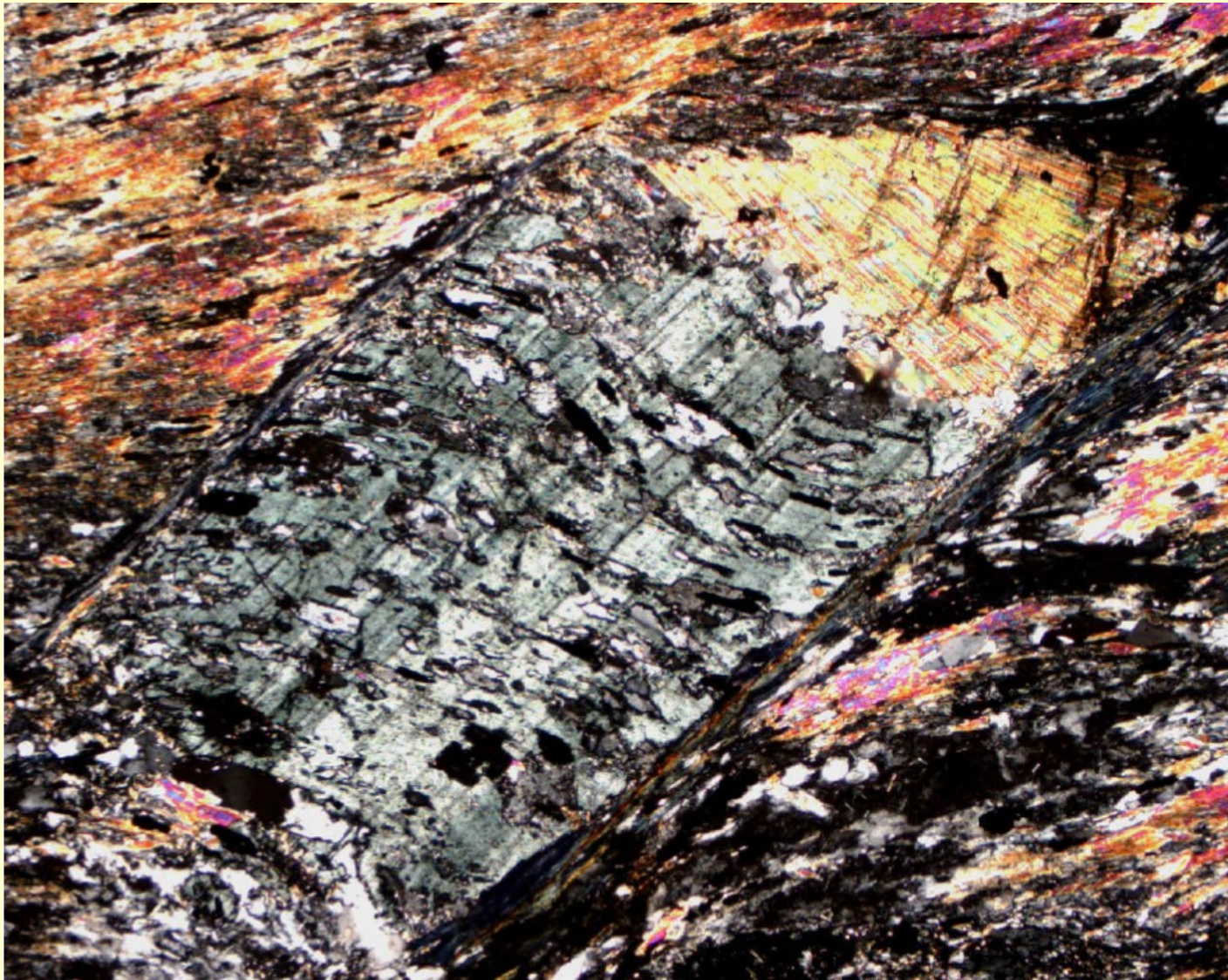
4) *Biotit-chloritoidová zóna*

- $\text{Chl} + \text{Bt} + \text{Ms} + \text{Qtz} + \text{H}_2\text{O} \pm \text{Cld}$
- KFLASH: Fe-chlorit + muskovit = Fe-chloritoid + annit + křemen + H_2O (B2)
- ASH: pyrofyilit = kyanit + křemen + H_2O (C)
- FASH: Fe-chloritoid + kyanit = Fe-staurolit + H_2O (D)

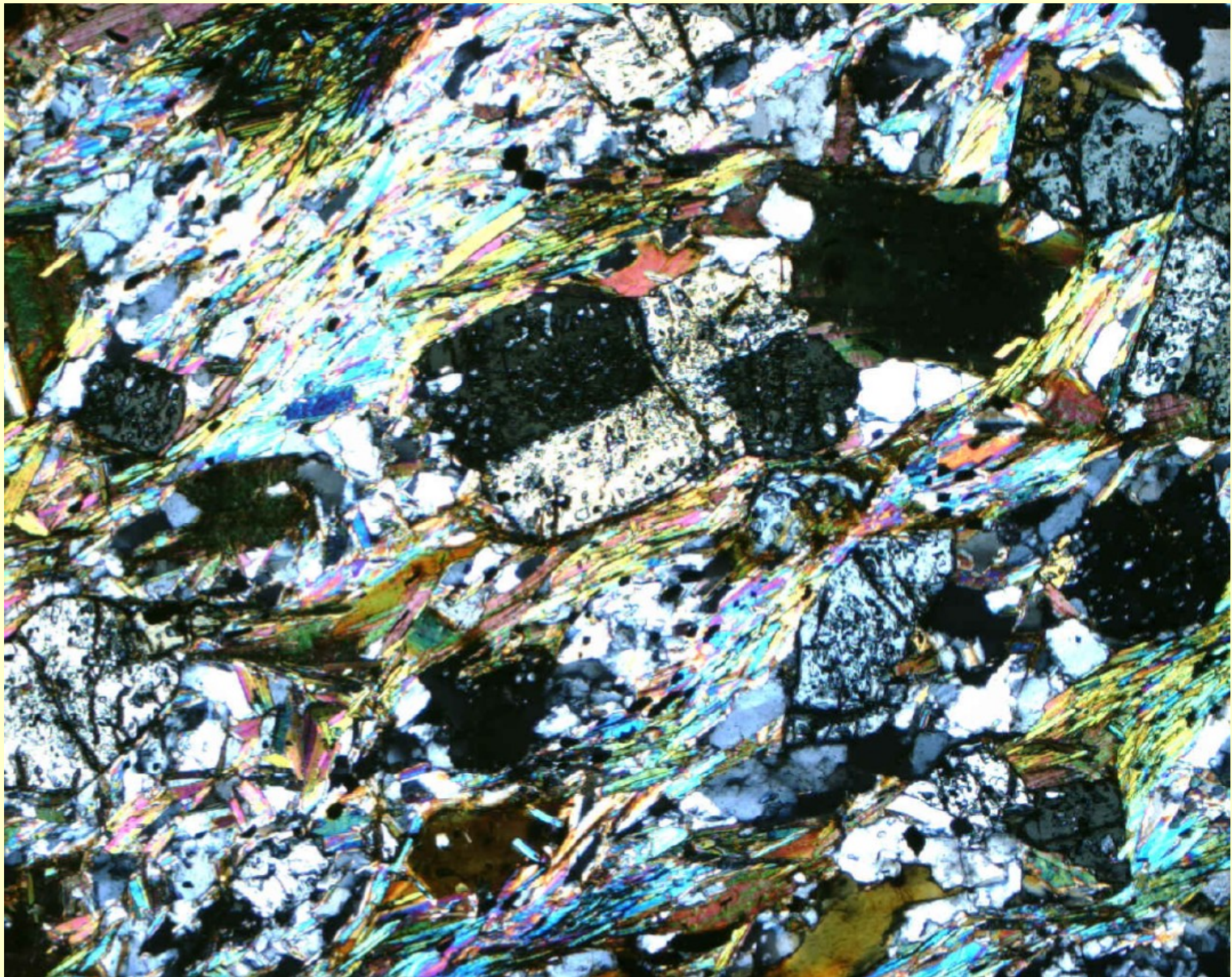


AKFM medium pressure
+ qtz + mu + H_2O

- ☆ hi-Al pelite
- ◇ lo-Al pelite
- granite



Chloritoidová břidlice (Qtz+Bt+Ms+Chl+Ctd)



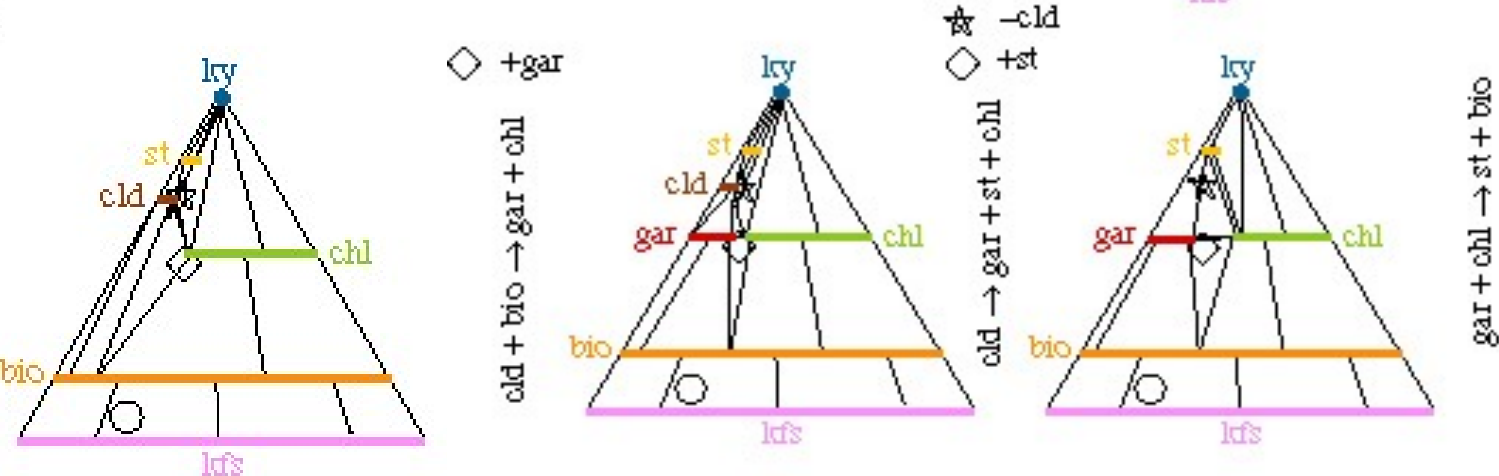
Staurolitický svor (Qtz+Bt+Ms+St)

5) Granátová zóna (~ 500 C)

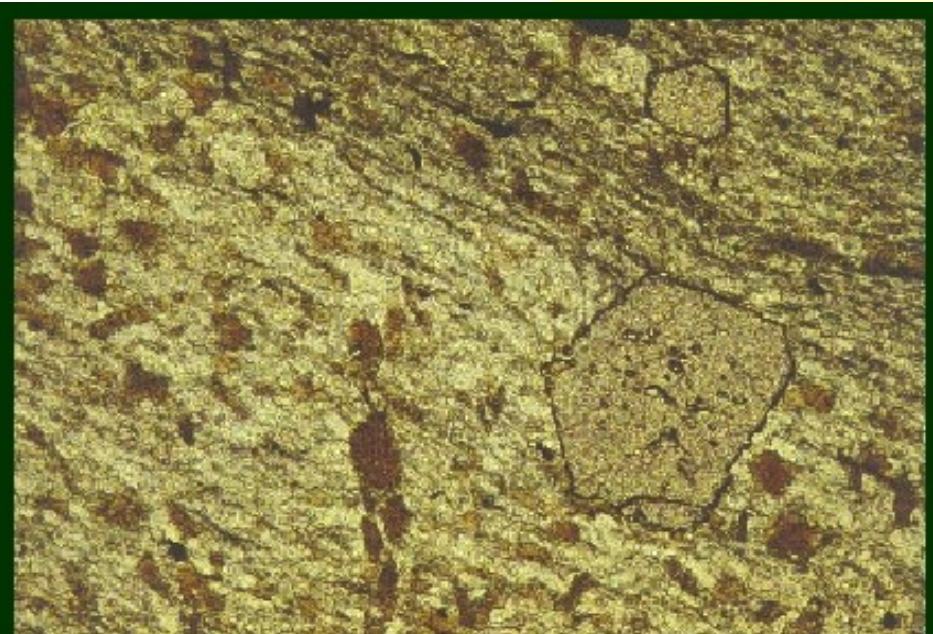
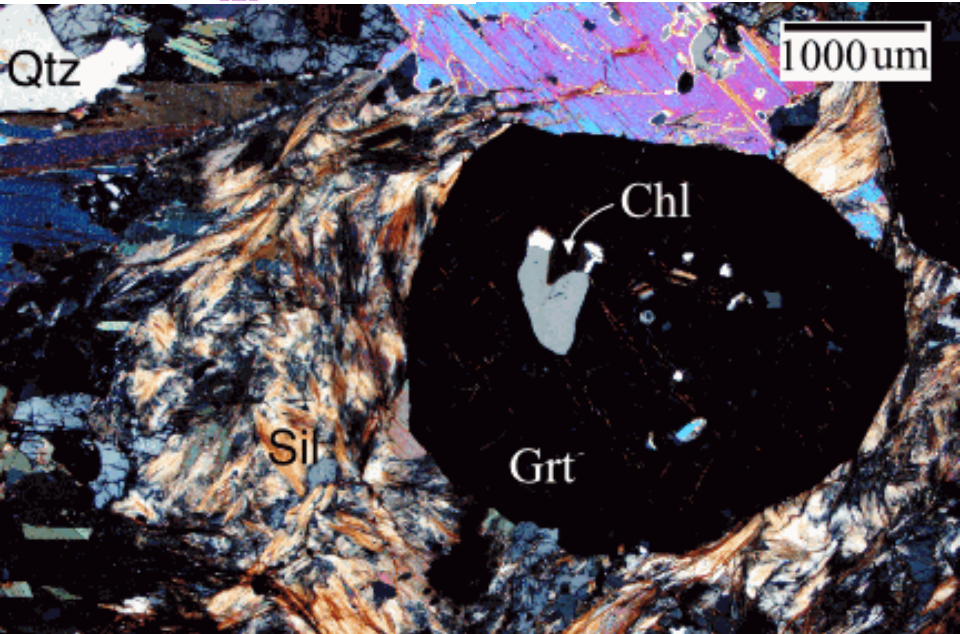
AKFM medium pressure
+ qtz + mu + H₂O

- KFLASH: Fe-chloritoid + annit = almandin + muskovit + H₂O (E)
- KFMASH: chloritoid + biotit = granát + chlorit (F)

- ★ hi-Al pelite
- ◇ lo-Al pelite
- granite

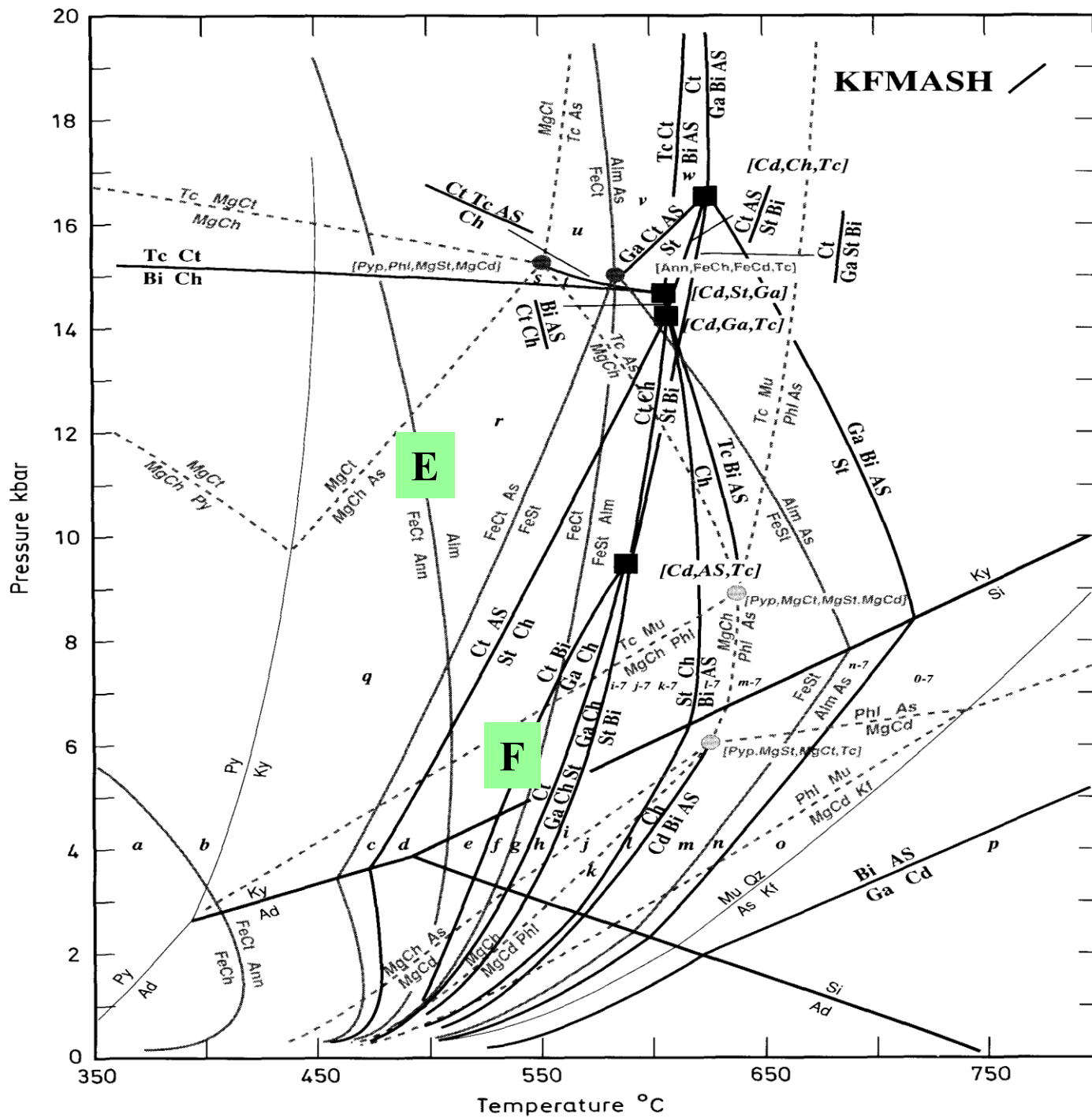


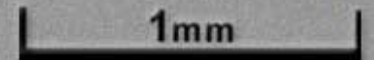
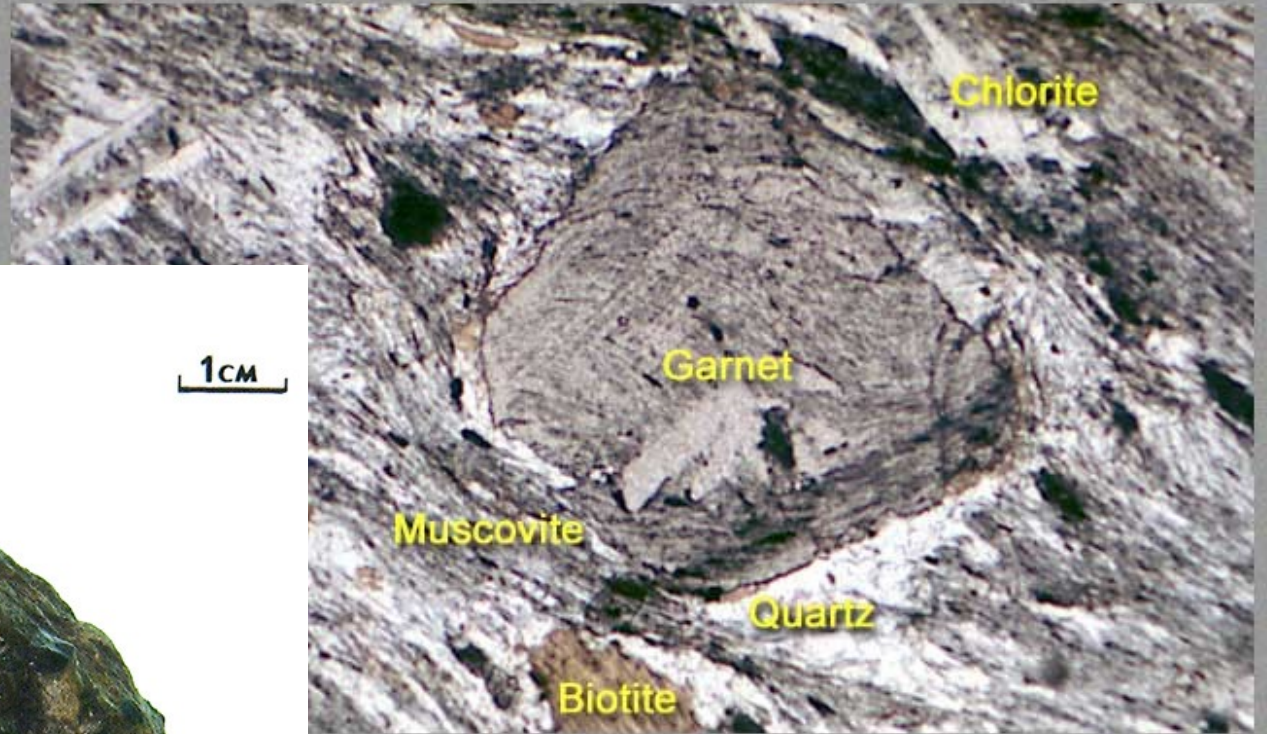
Svory:
Chl + Bt +
Grt + Ms +
Qtz + H₂O



chloritoid + biotit = granát + chlorit + H₂O

svor: Qtz + Ms + Bt + Grt





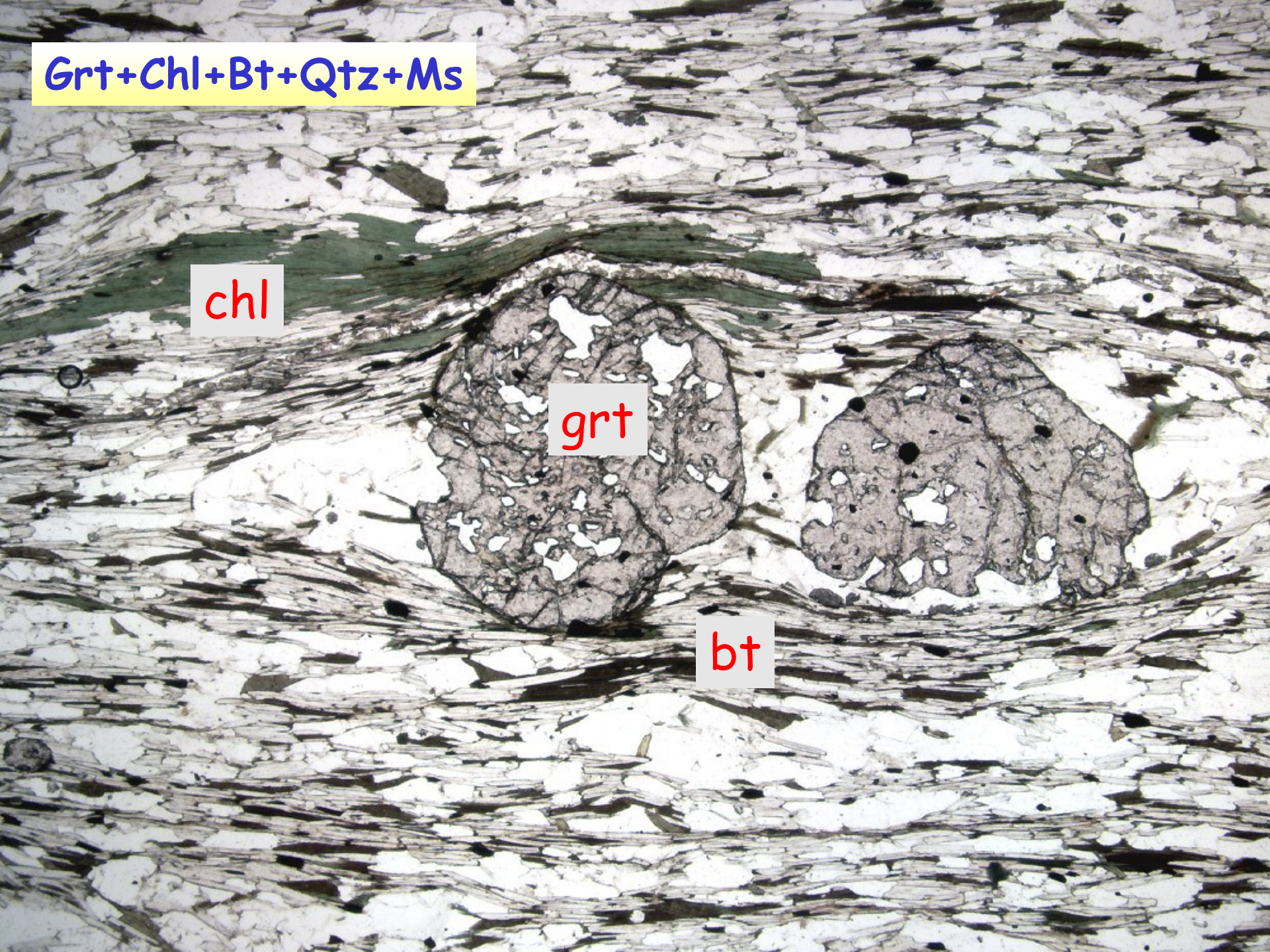
svor: Qtz+Ms+Bt+Grt+Chl+St

Grt+Chl+Bt+Qtz+Ms

chl

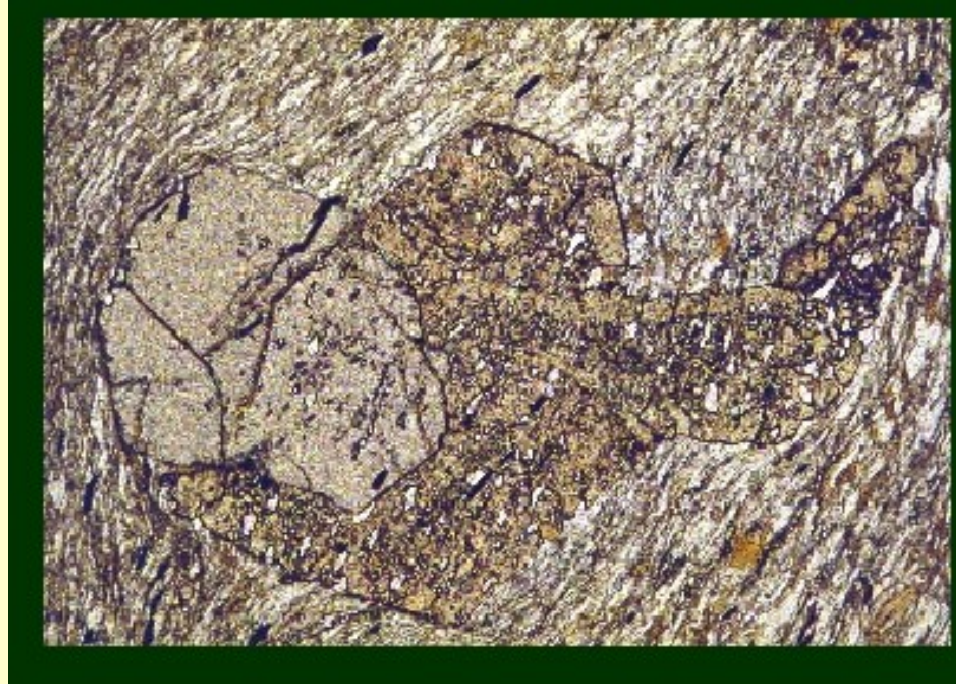
grt

bt

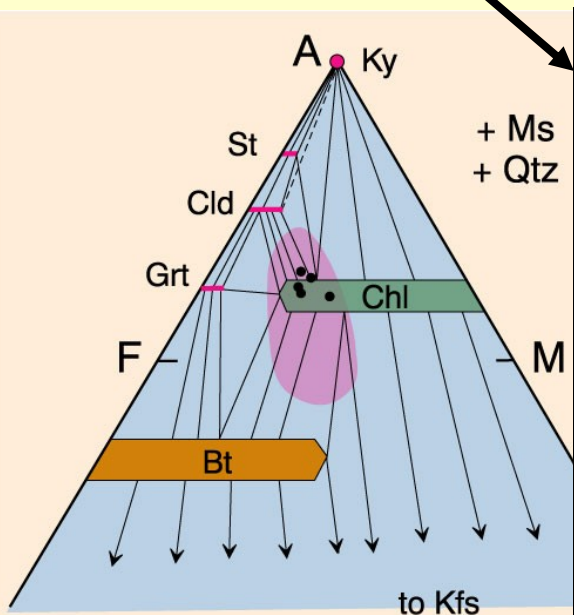


6) Reakce konzumující chloritoid

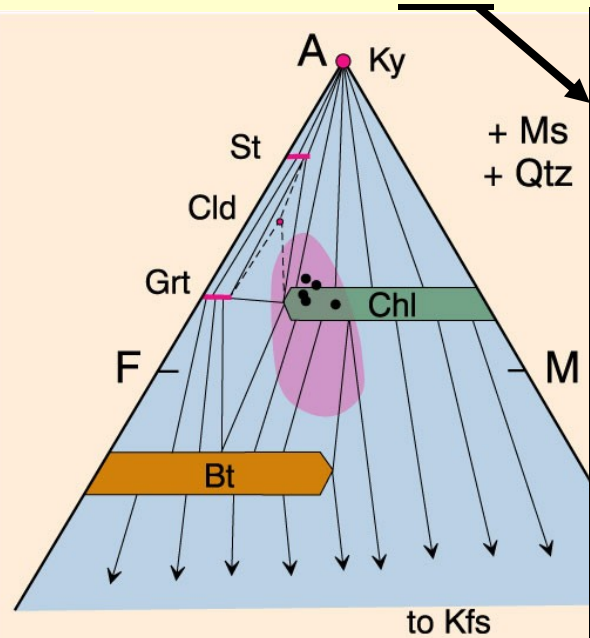
- KFLASH:
- Fe-chloritoid = Fe-staurolit + almandin + H₂O (**G**)
- KFMASH:
- chloritoid = granát + chlorit + staurolit + H₂O (terminální reakce) (**H**)



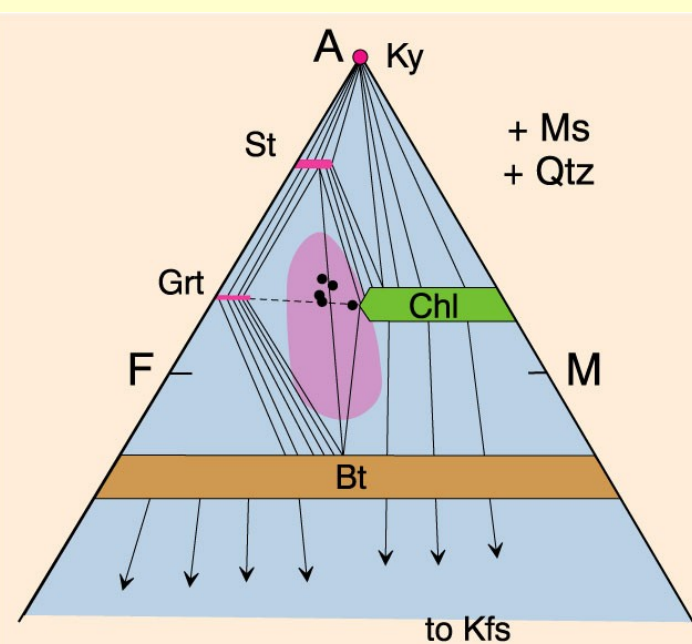
G



H



svor: $Qtz + Ms + Bt + Grt + St$

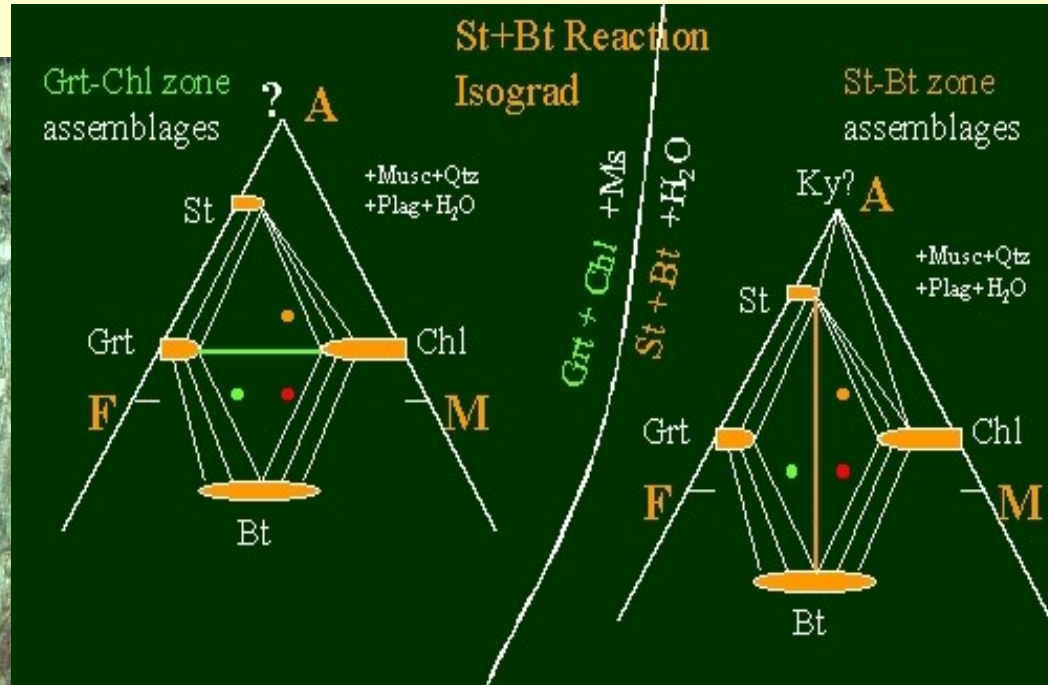
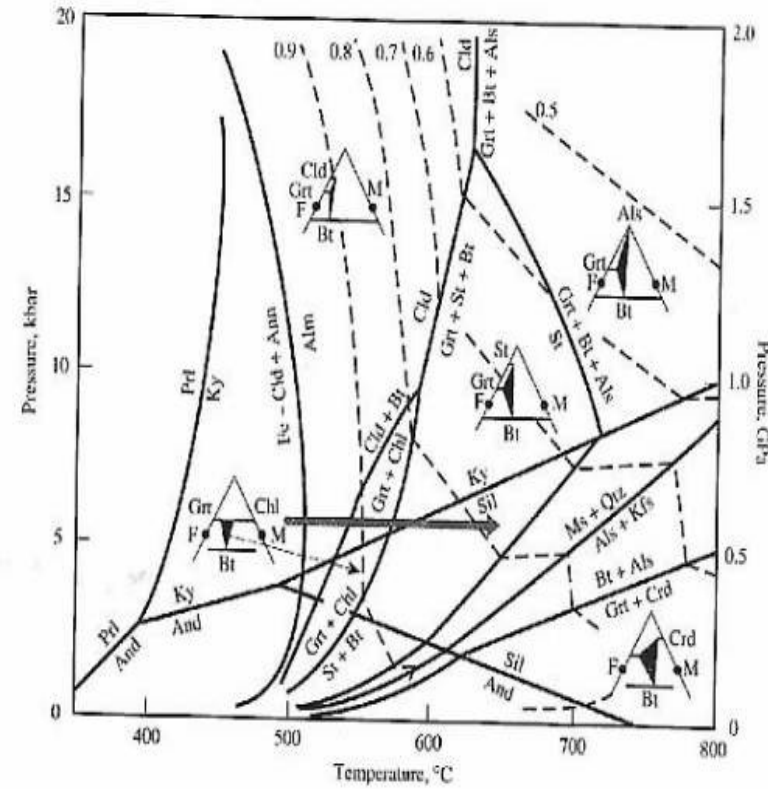




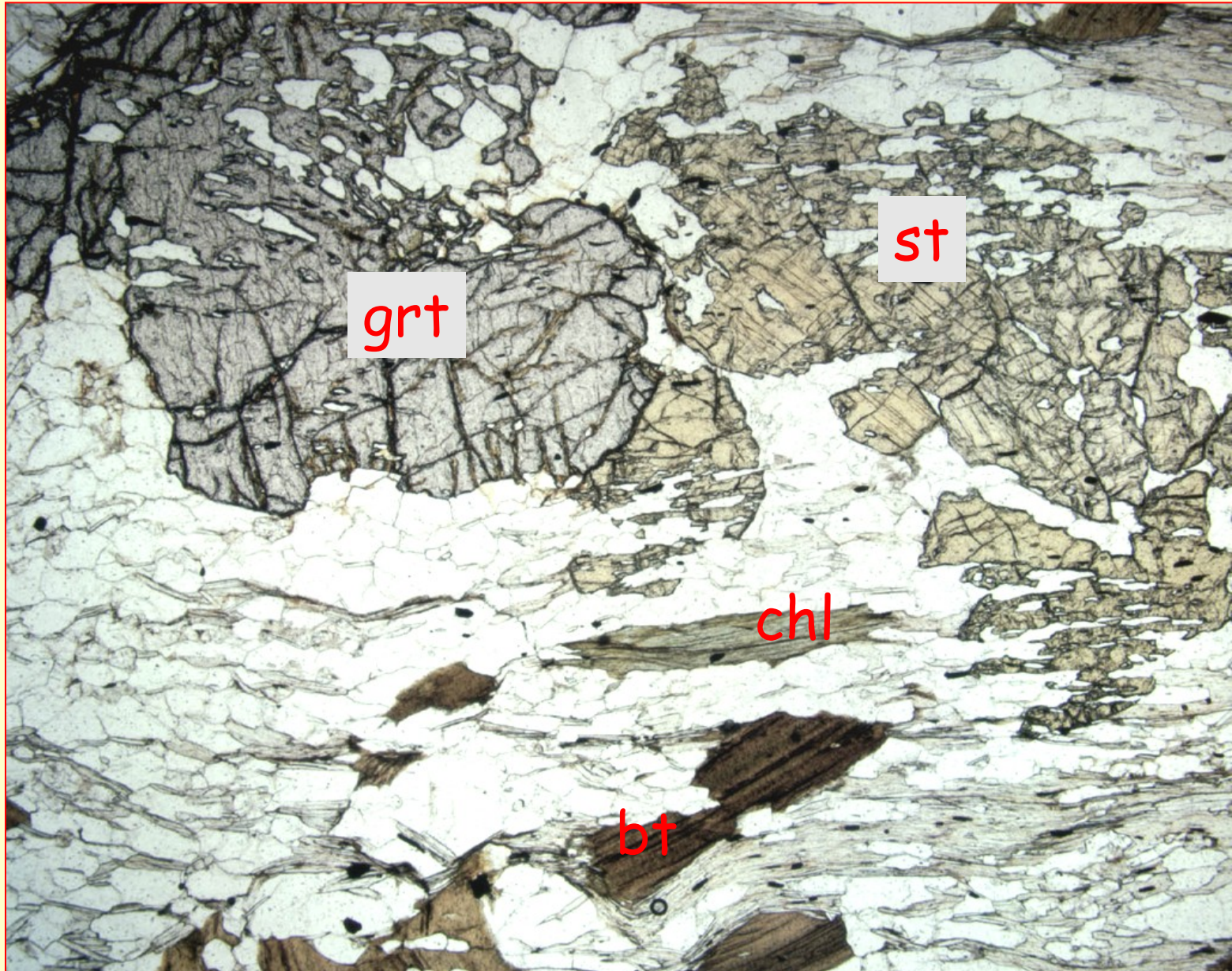
Starolitický svor: Qtz+Ms+Bt+Grt+St+Pl

7) Staurolitová izograda (~ 550 C)

- Objevují se automorfní porfyroblasty staurolitu
- KFMASH:
- granát + chlorit = staurolit + biotit + H₂O (*Ch*)



svor: porfyroblasty staurolitu

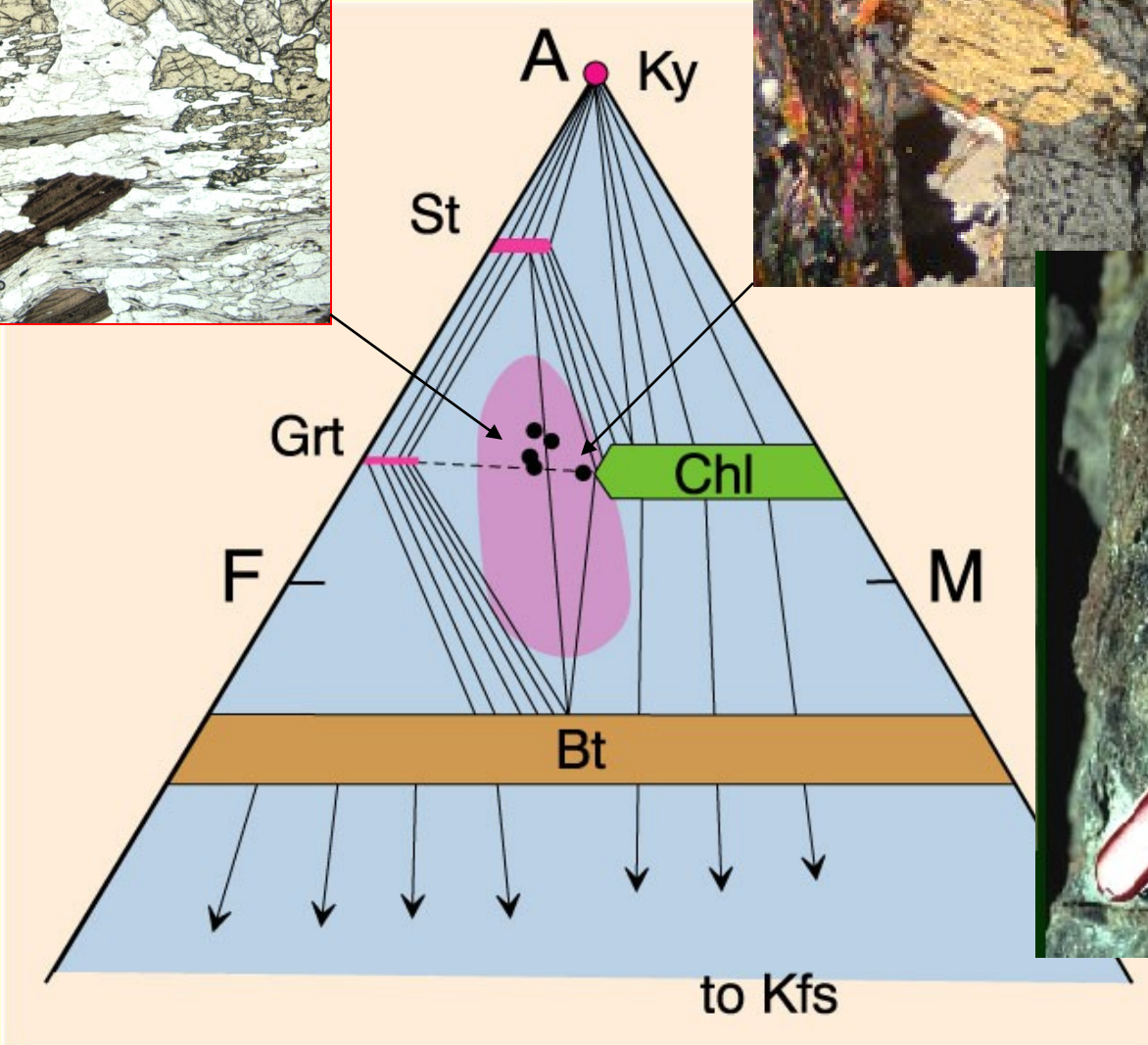
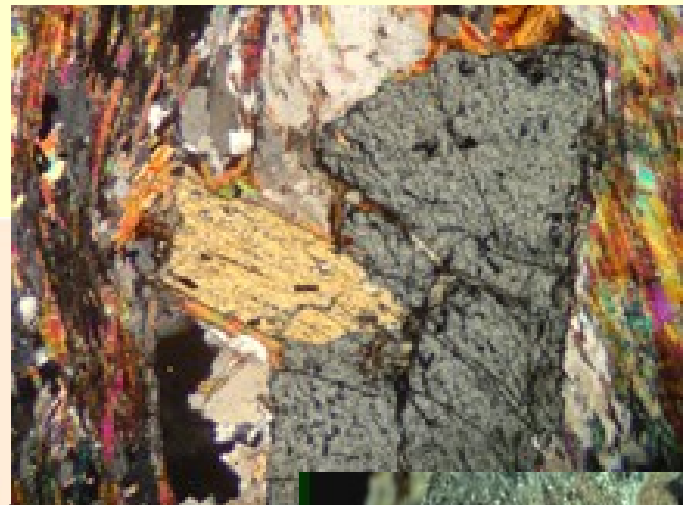


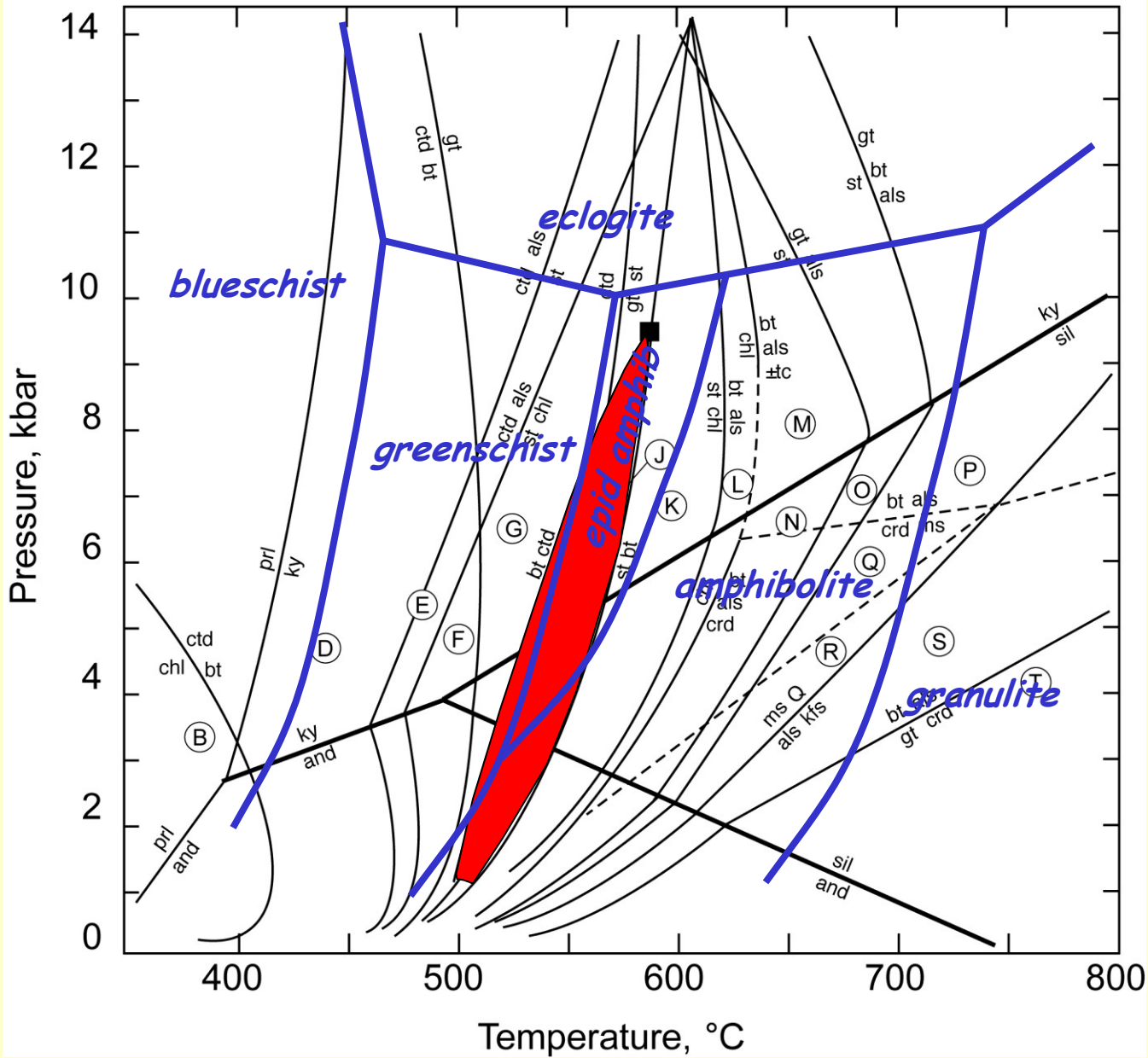
grt

st

chl

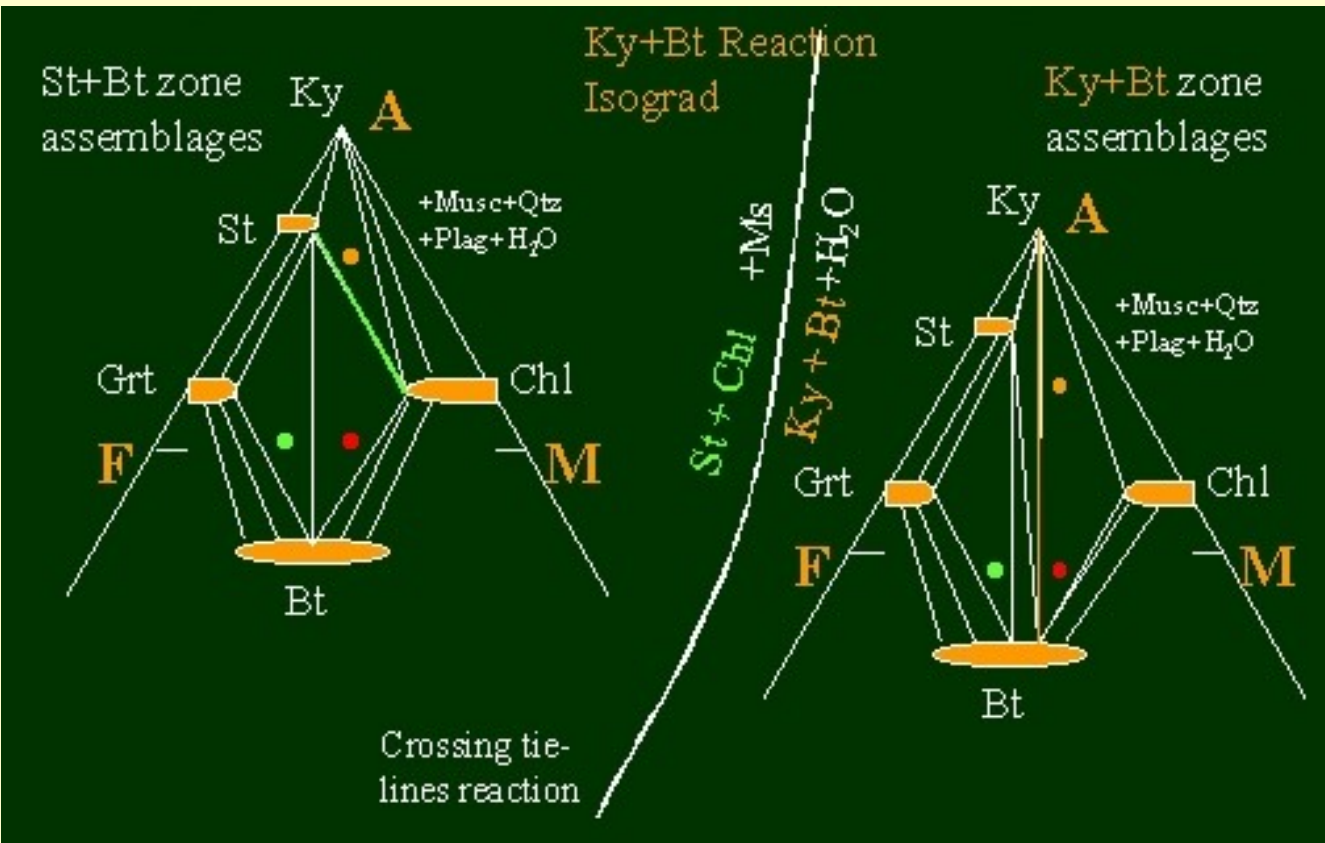
bt



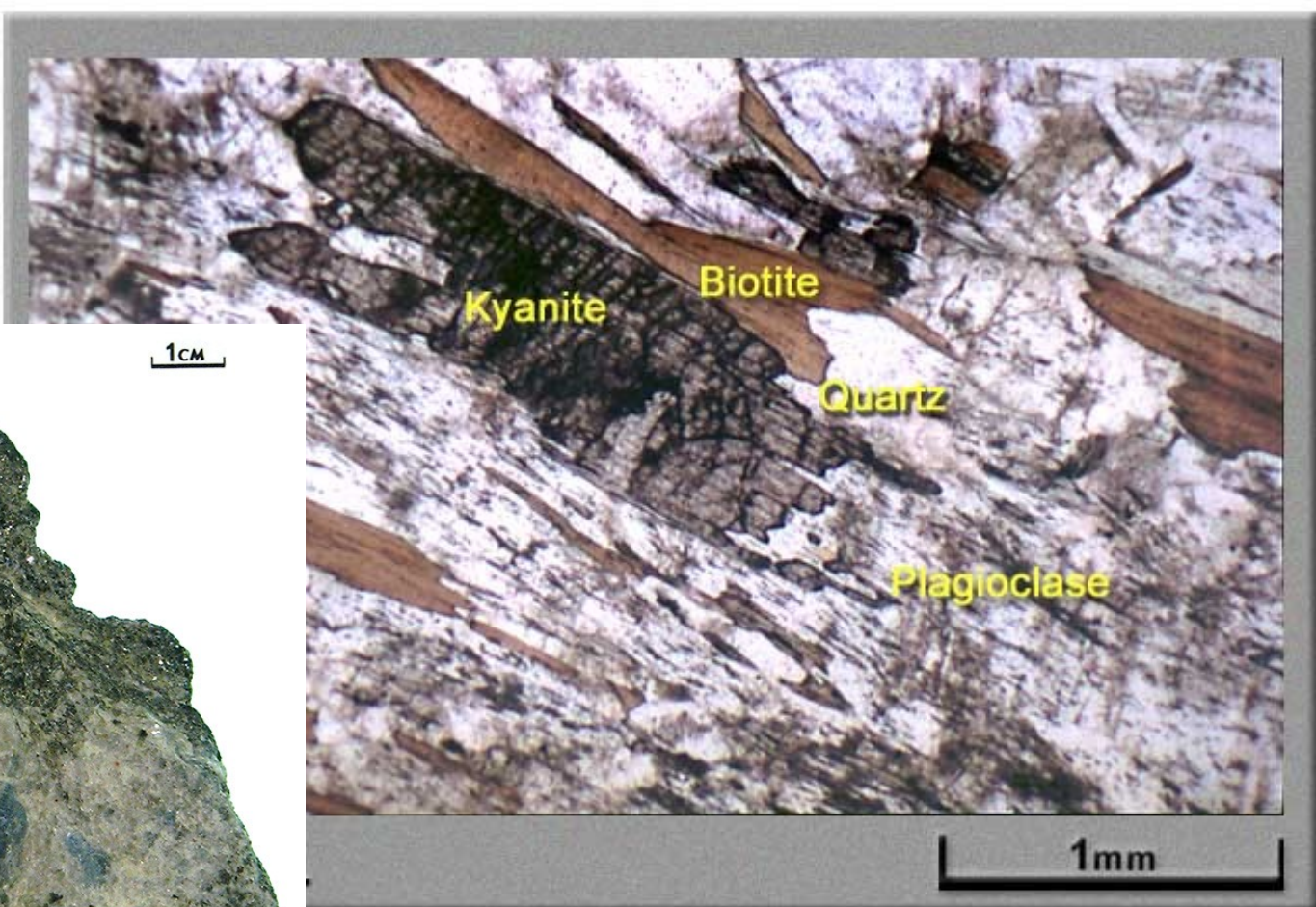


8) *Kyanit-staurolitová zóna*

- Kyanitová izograda v Al-chudých metapelitech (~ 600 °C)



- KFMASH: staurolit + chlorit = biotit + kyanit + H₂O (**I**)
- KMASH: Mg-chlorit + muskovit = flogopit + kyanit + H₂O (**J**)



9) *Sillimanitová zóna*

- AS: kyanit = sillimanit (**K**)
- Sillimanit ale většinou nezatlačuje přímo kyanit, ale roste jako vlákna mezi muskovitem a biotitem, zatímco kyanit je zatlačován muskovitem. Tj. tzv.
- 1. *sillimanitová izográda*.
- kyanit + muskovit I = sillimanit + muskovit II

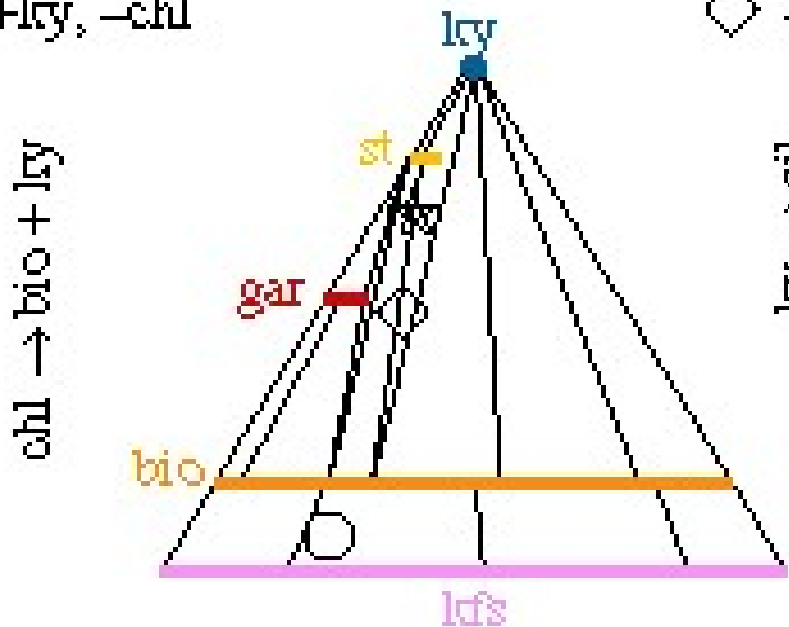
AKFM medium pressure
+ qtz + mu + H₂O

- ☆ hi-Al pelite
- ◇ lo-Al pelite
- granite

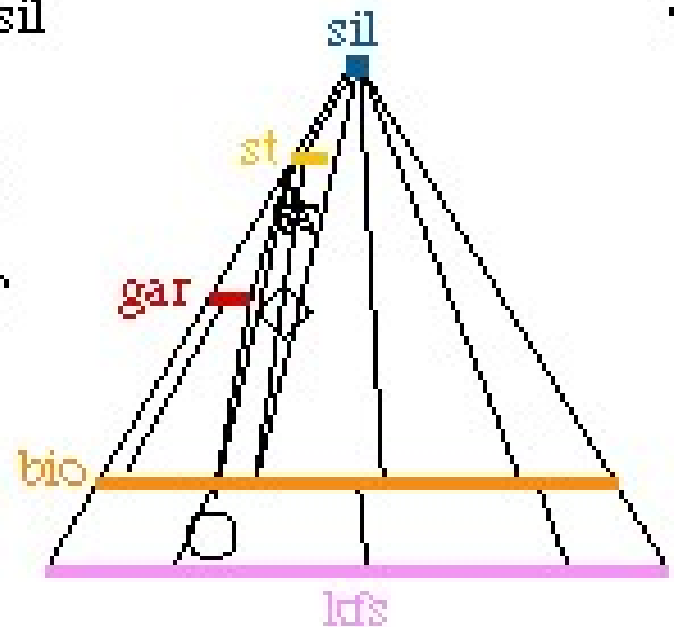
- ☆ -chl
- ◇ +lry, -chl

- ☆ +sil
- ◇ +sil

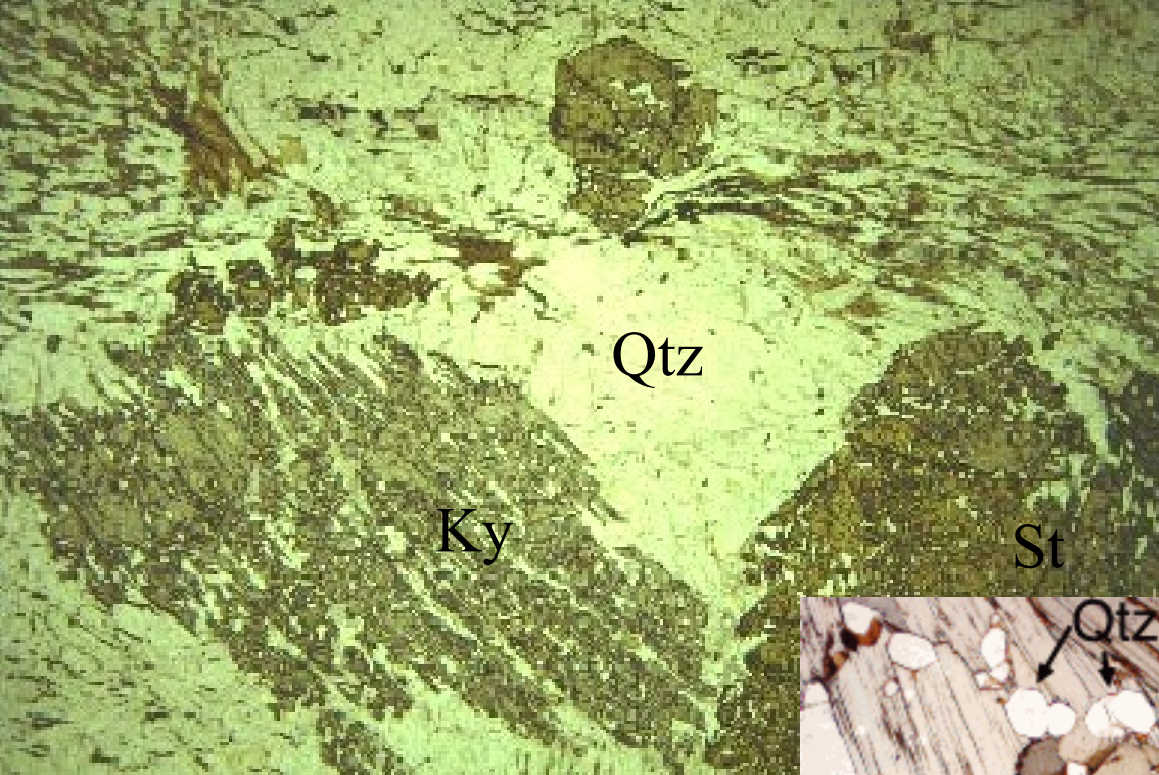
- ☆ -st
- ◇ -st



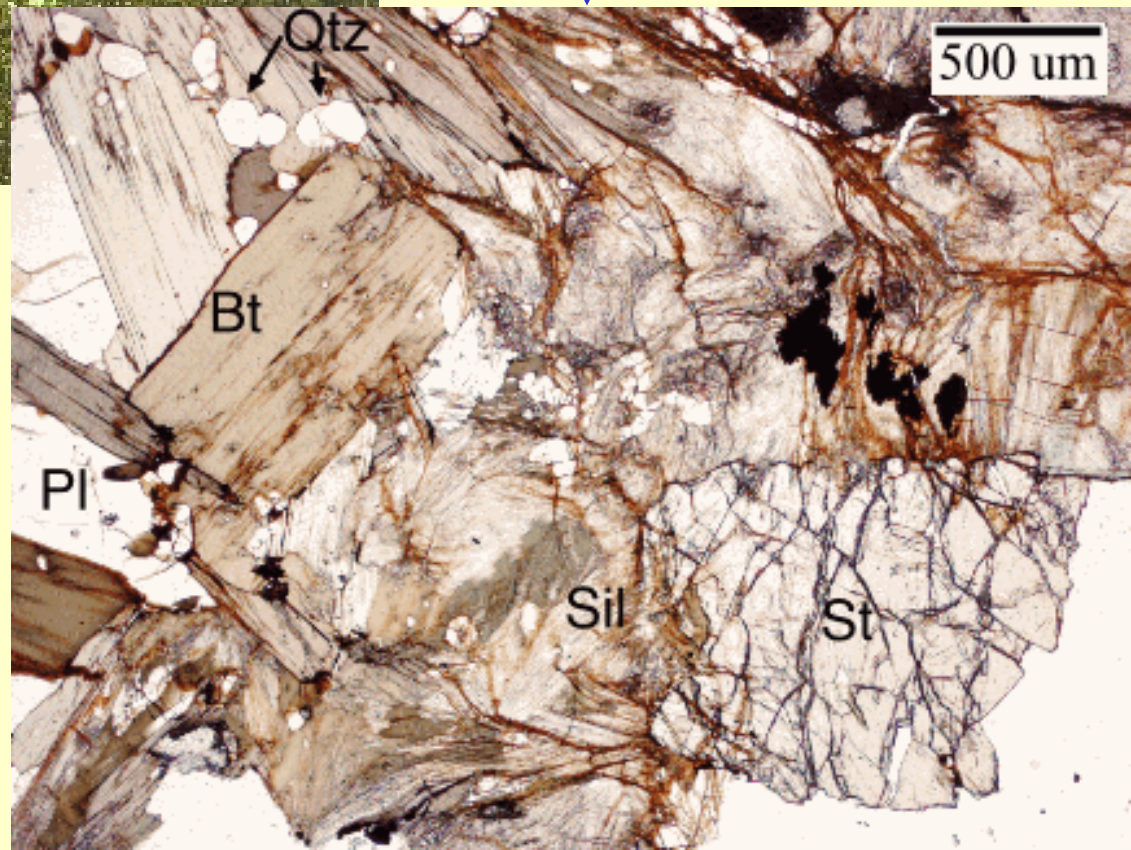
lry → sil

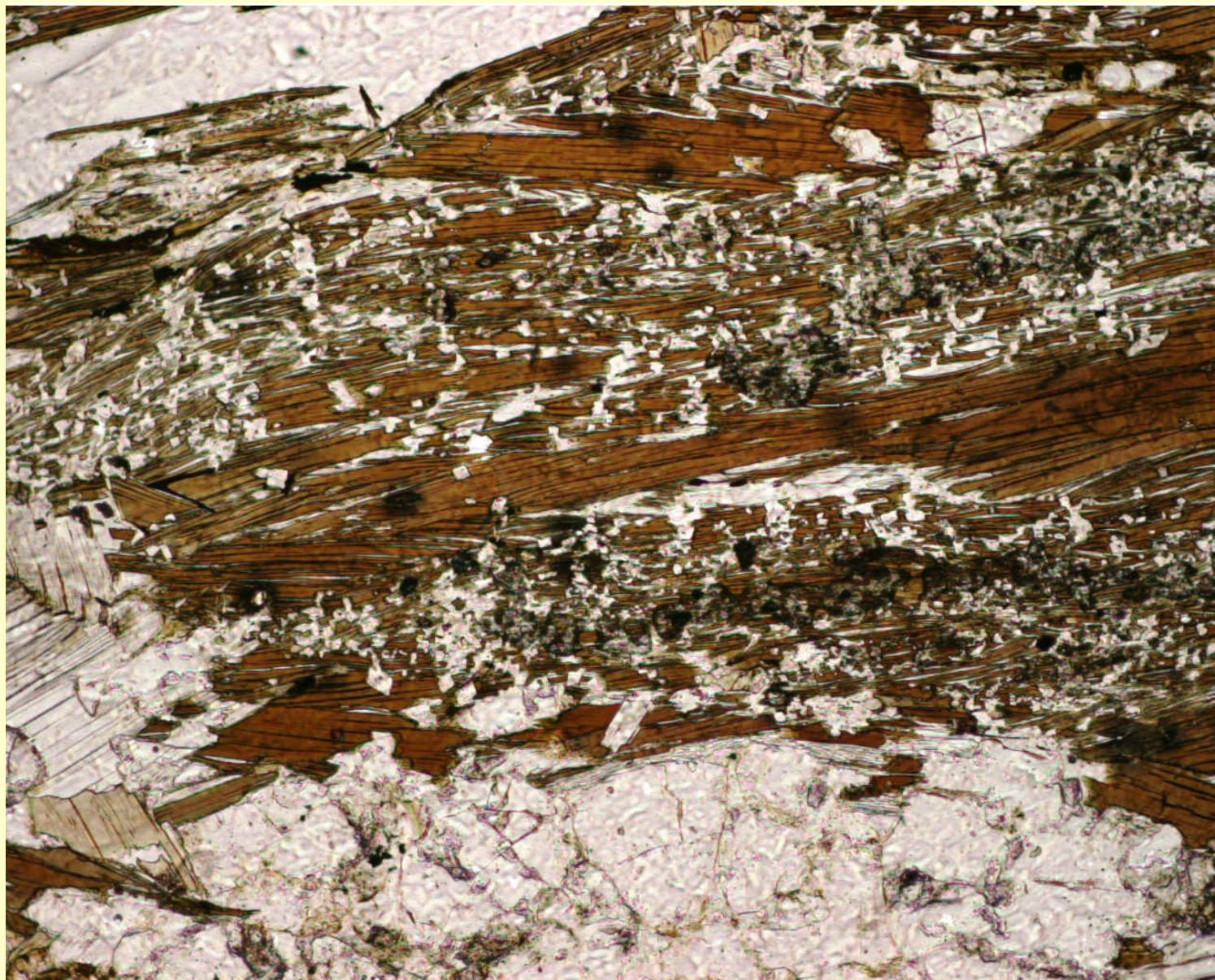


st → gar + bio + sil



kyanit = sillimanit





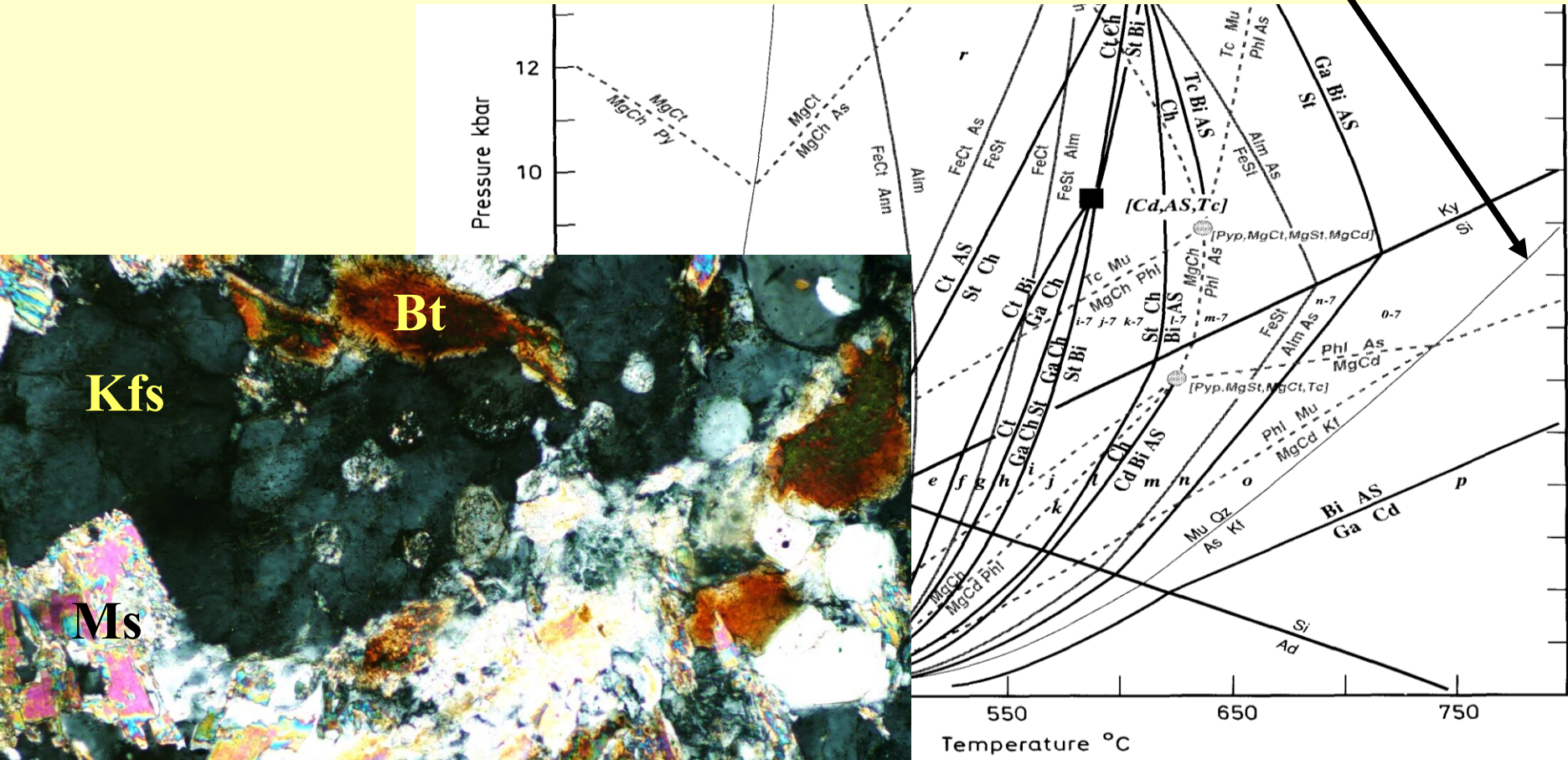
Granátická rula se sillimanitem: Qtz+Ms+Bt+Grt+Sil+Pl



Granátická rula se sillimanitem: $Qtz+Ms+Bt+Grt+Sil+Pl+Tu$

- 11) Rozpad muskovitu
- KASH: muskovit + křemen = K-živec + Al_2SiO_5 + H_2O (N)

Tj. tzv. 2. sillimanitová izograda.



Bt

Kfs

Ms

Sill

0.1 mm

Temperature °C

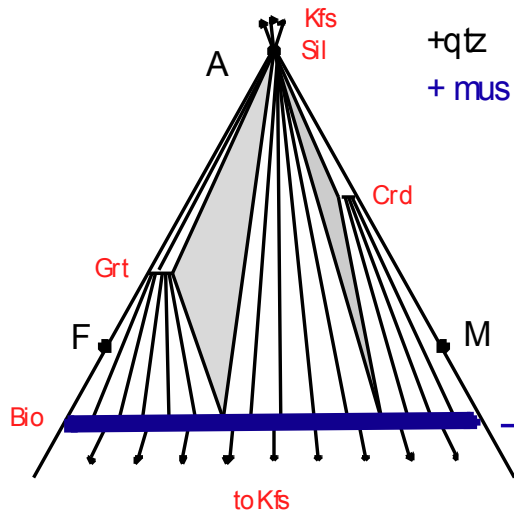
Pressure kbar

550 650 750

Musc projection

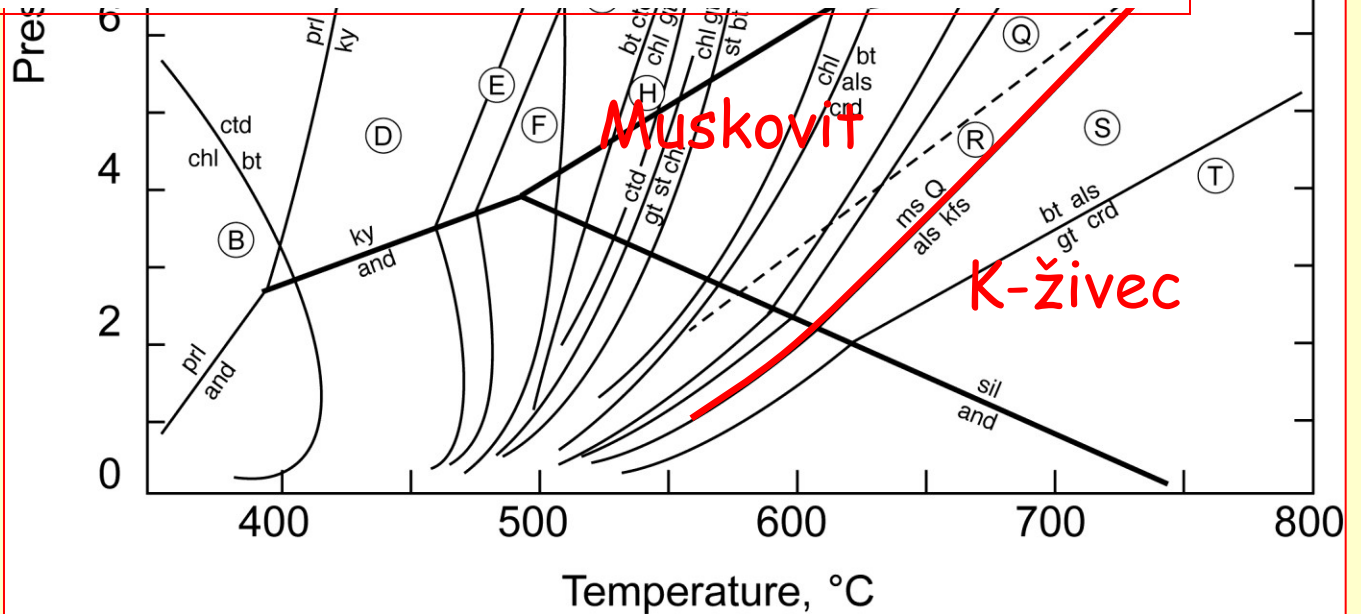
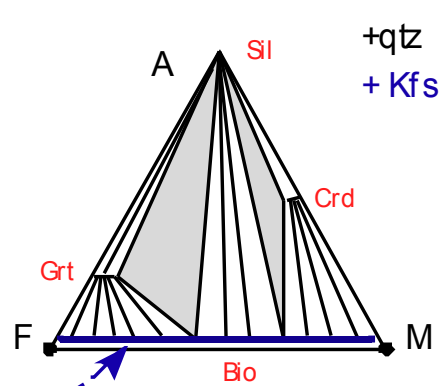
Kspar projection

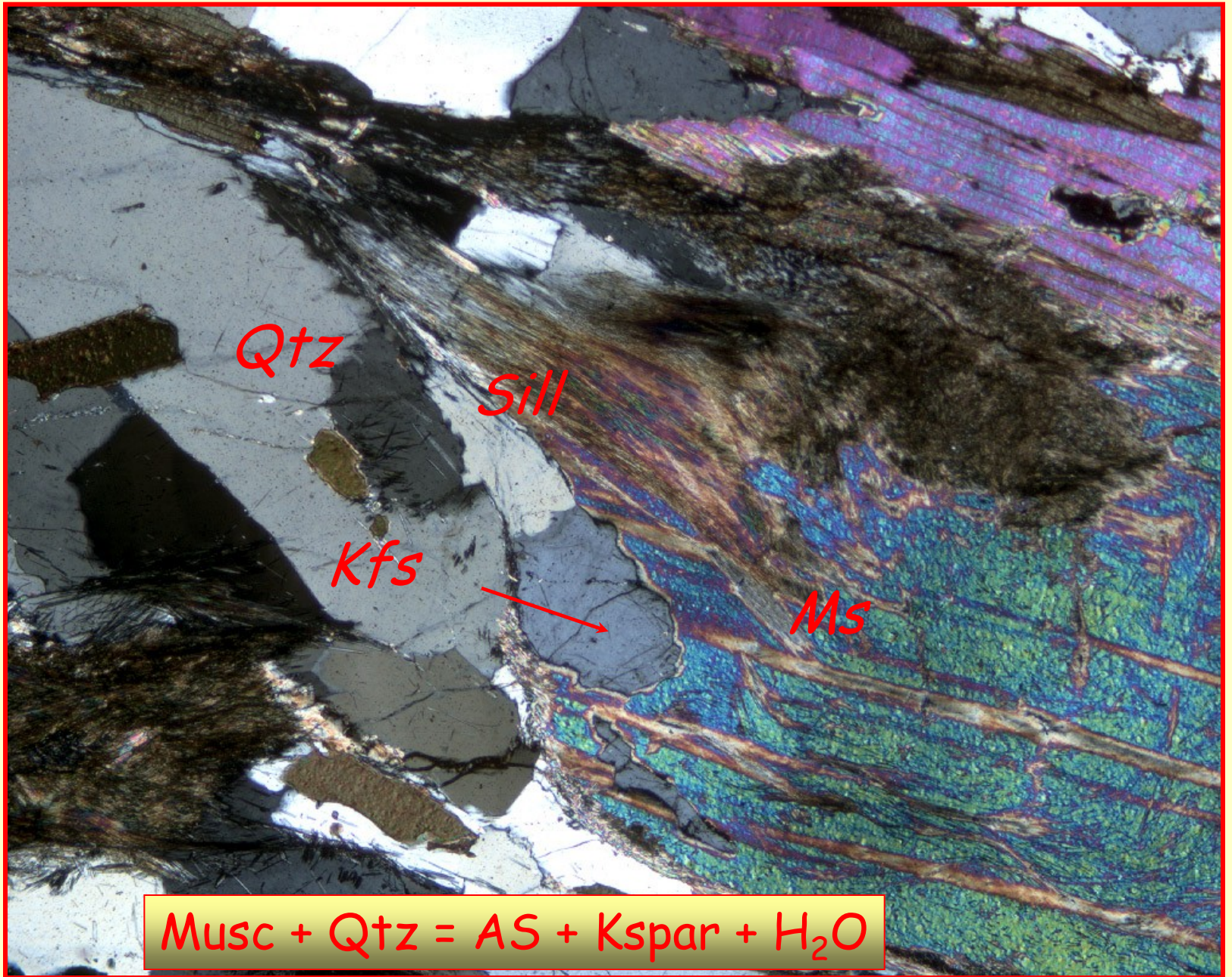
ear, 1993

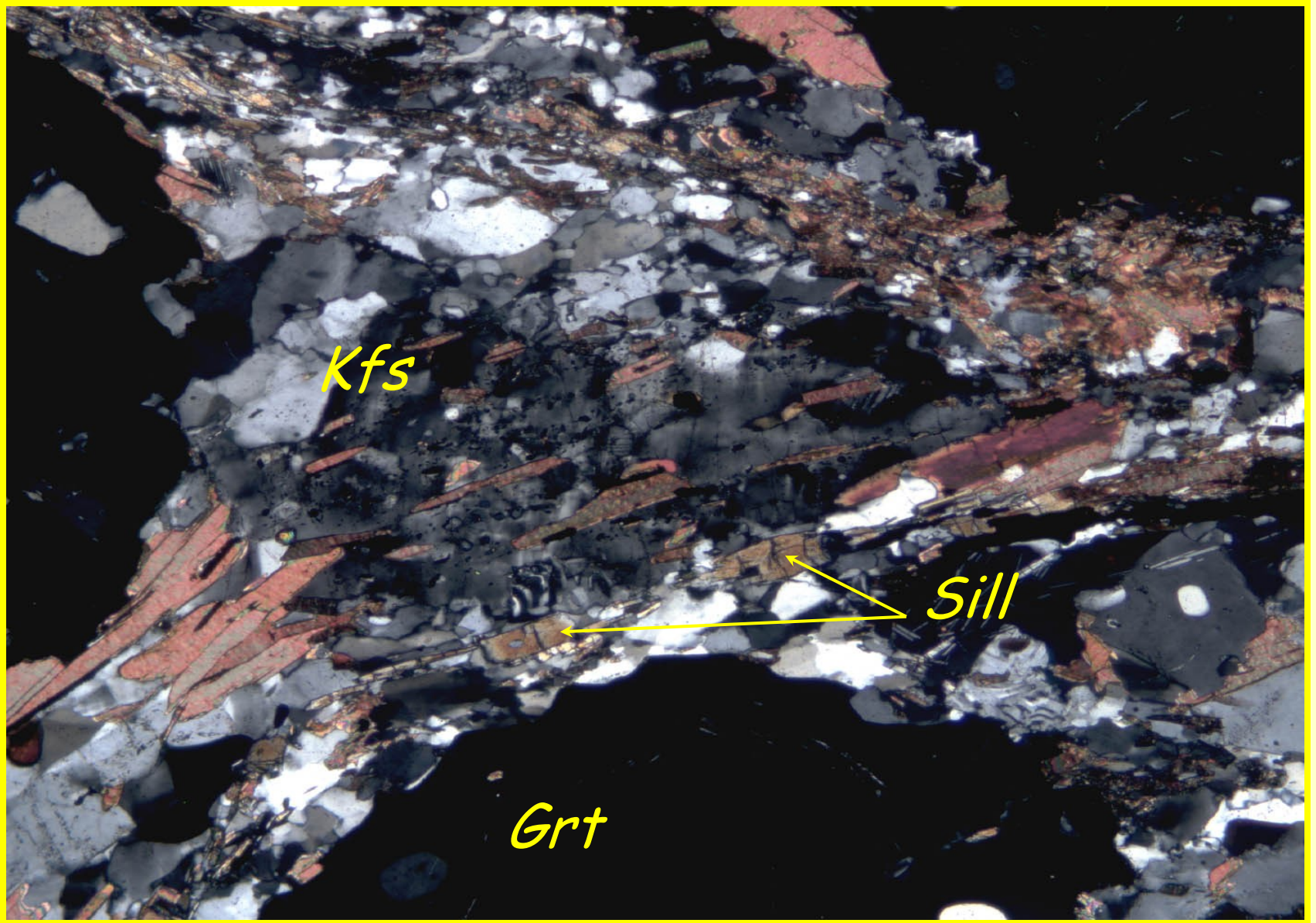


Mus
+
Qtz

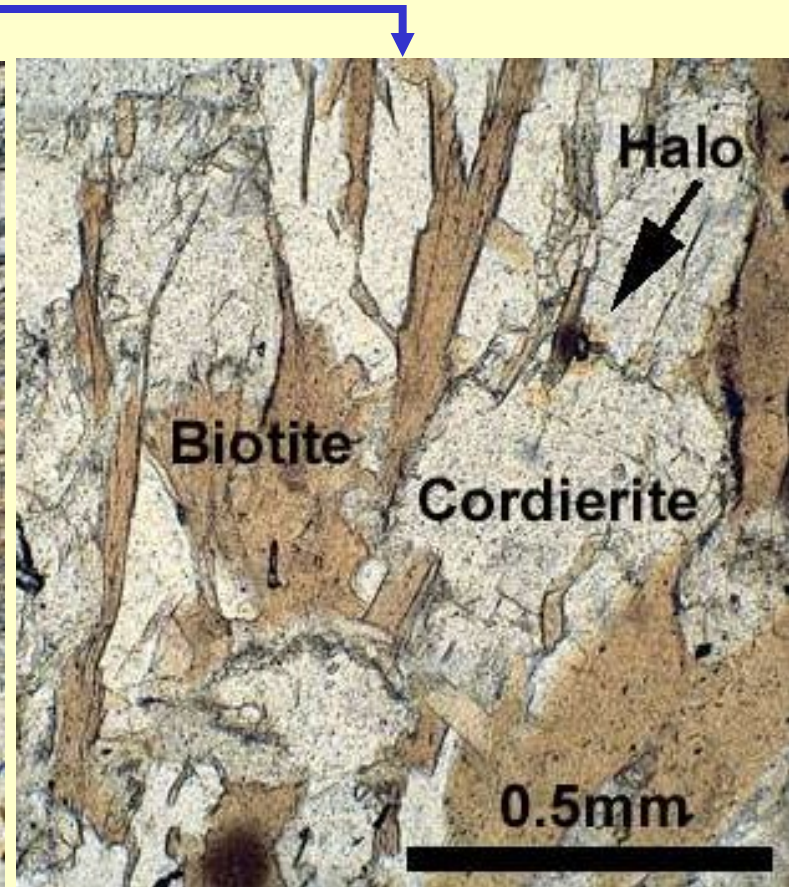
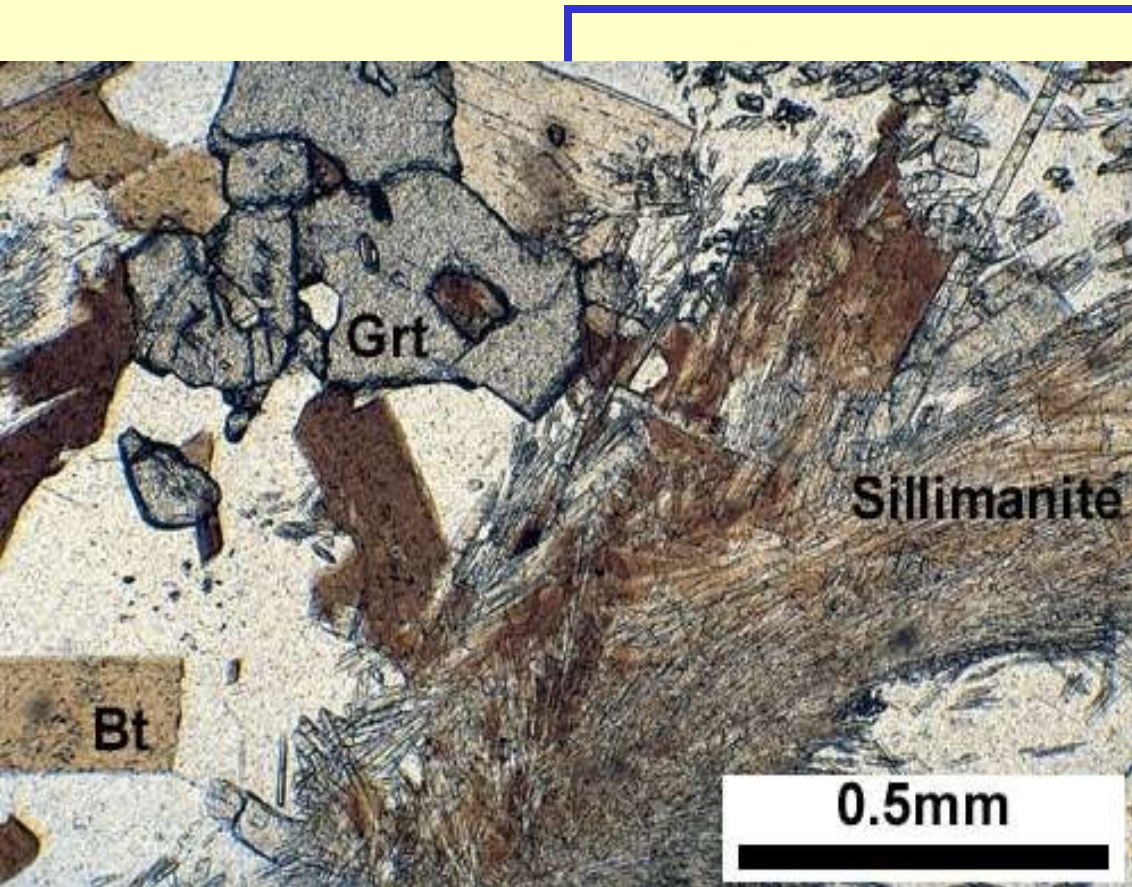
AS
+
Kfs

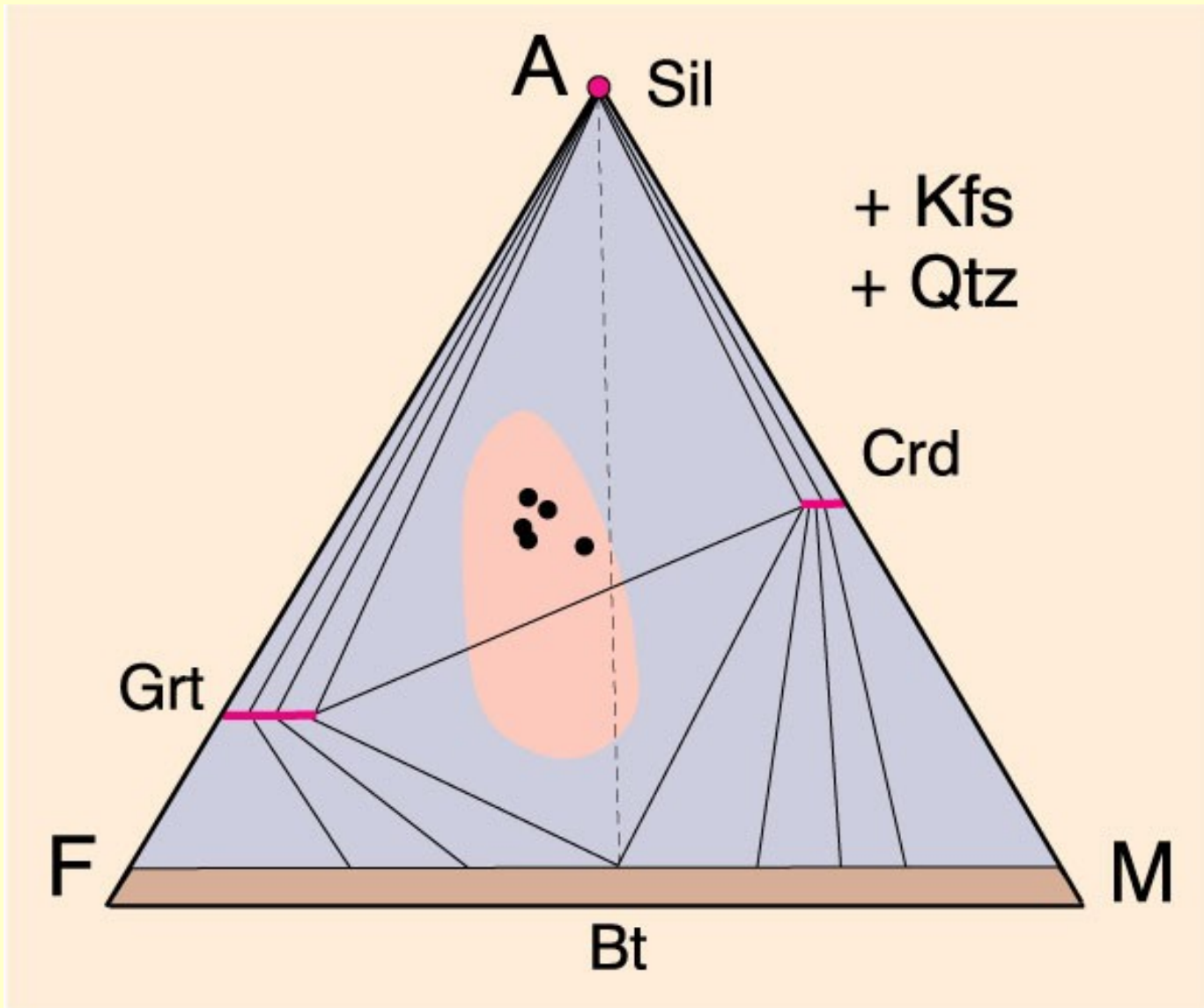




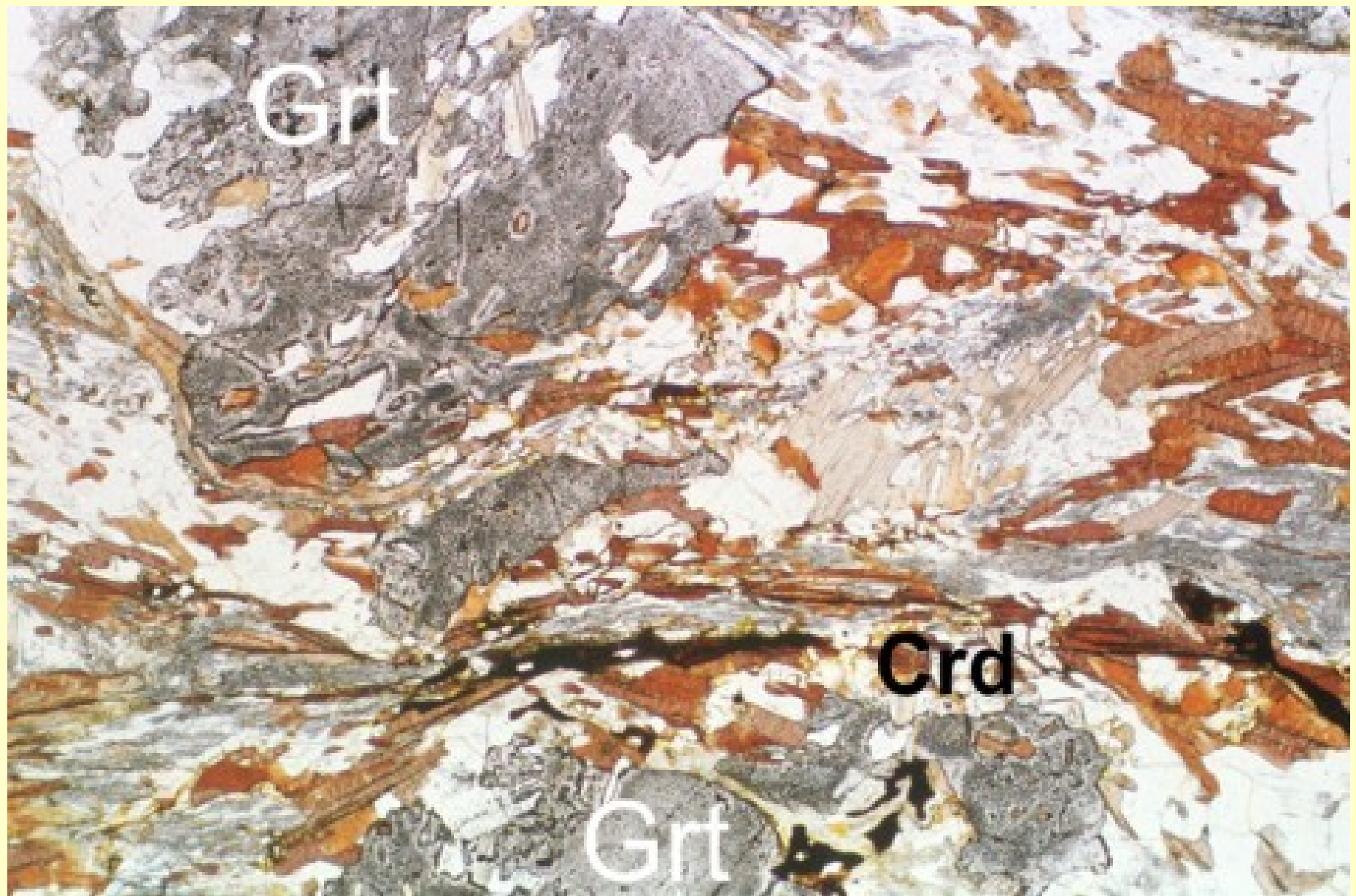


- 12) *Vznik cordieritu* (na hranici granulitové facie)
- KMASH: flogopit + sillimanit = Mg-cordierit + muskovit
- KMASH: flogopit + muskovit = Mg-cordierit + K-živec + H₂O
- KFMASH: biotit + sillimanit = granát + cordierit + H₂O (O)



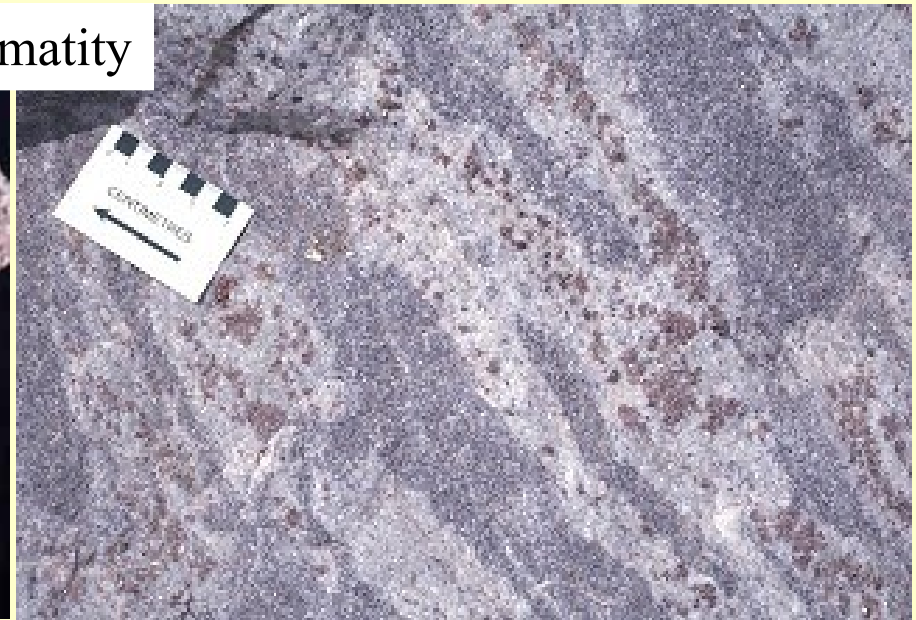


AFM diagram pro cordieritovou izográdů (granulitová facie). Zpočátku je v diagramu linie Sill – Bt za vyšších teplot zmizí a místo ní vznikne linie Grt - Cdr. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.



Cordieritická rula

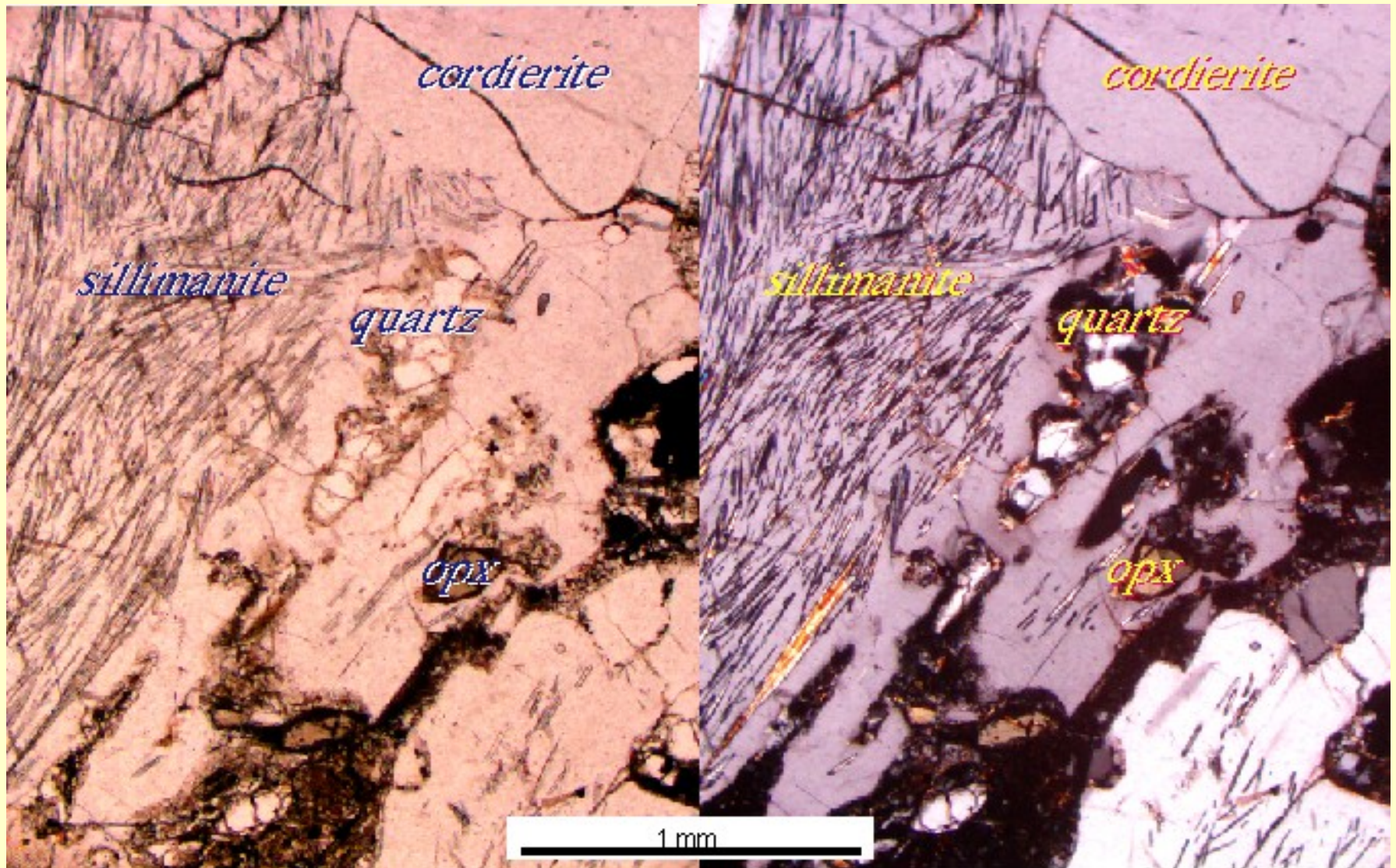
Migmatity



Za podmínek granulitové facie probíhají v metapelitech dehydratační reakce (Ms, Bt), které produkují taveninu a bezvodý restit.

Granulit





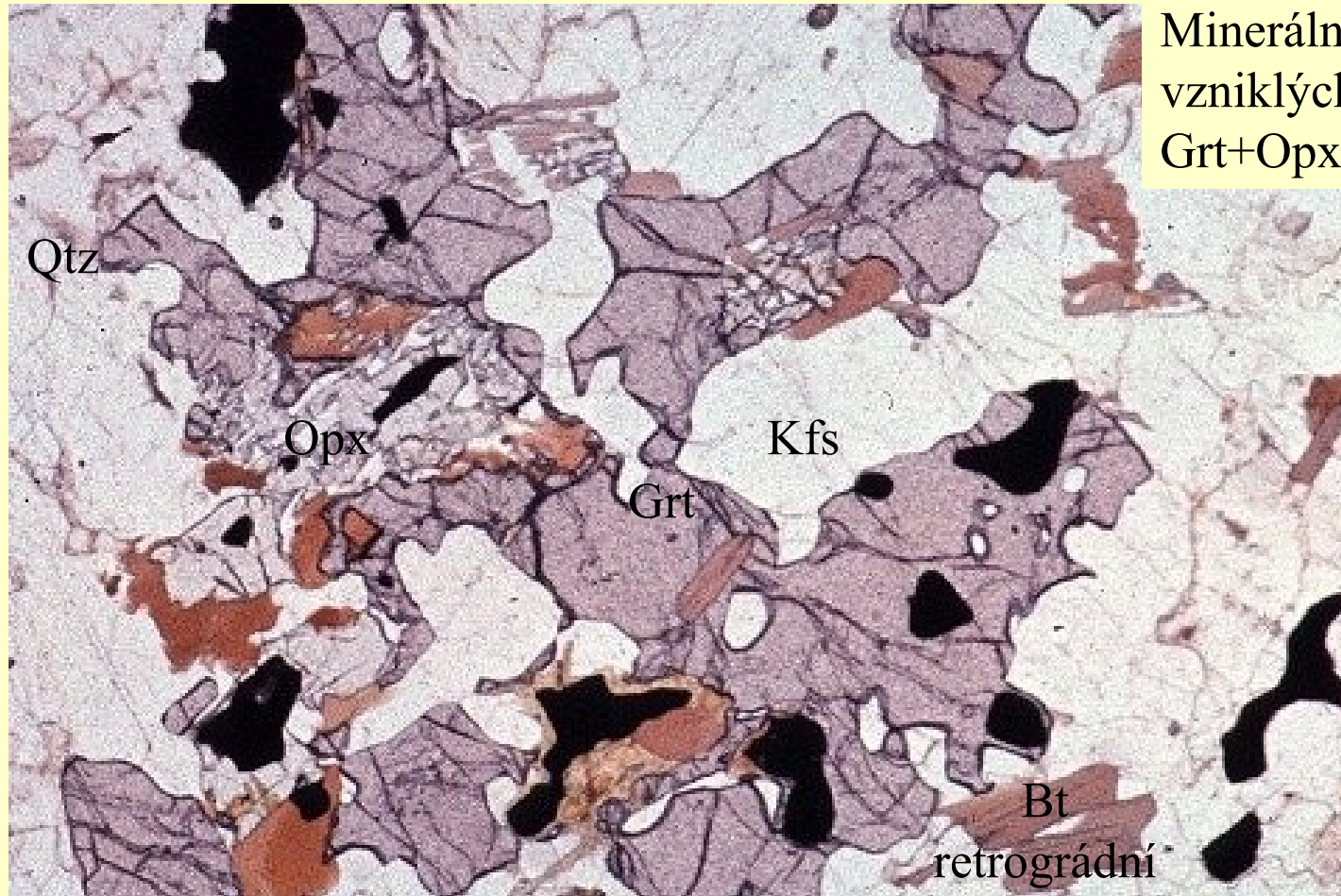
Při HT metamorfóze (teploty nad 850 a $P_{H_2O}=0$)
– dehydratační tavení muskovitu a biotitu



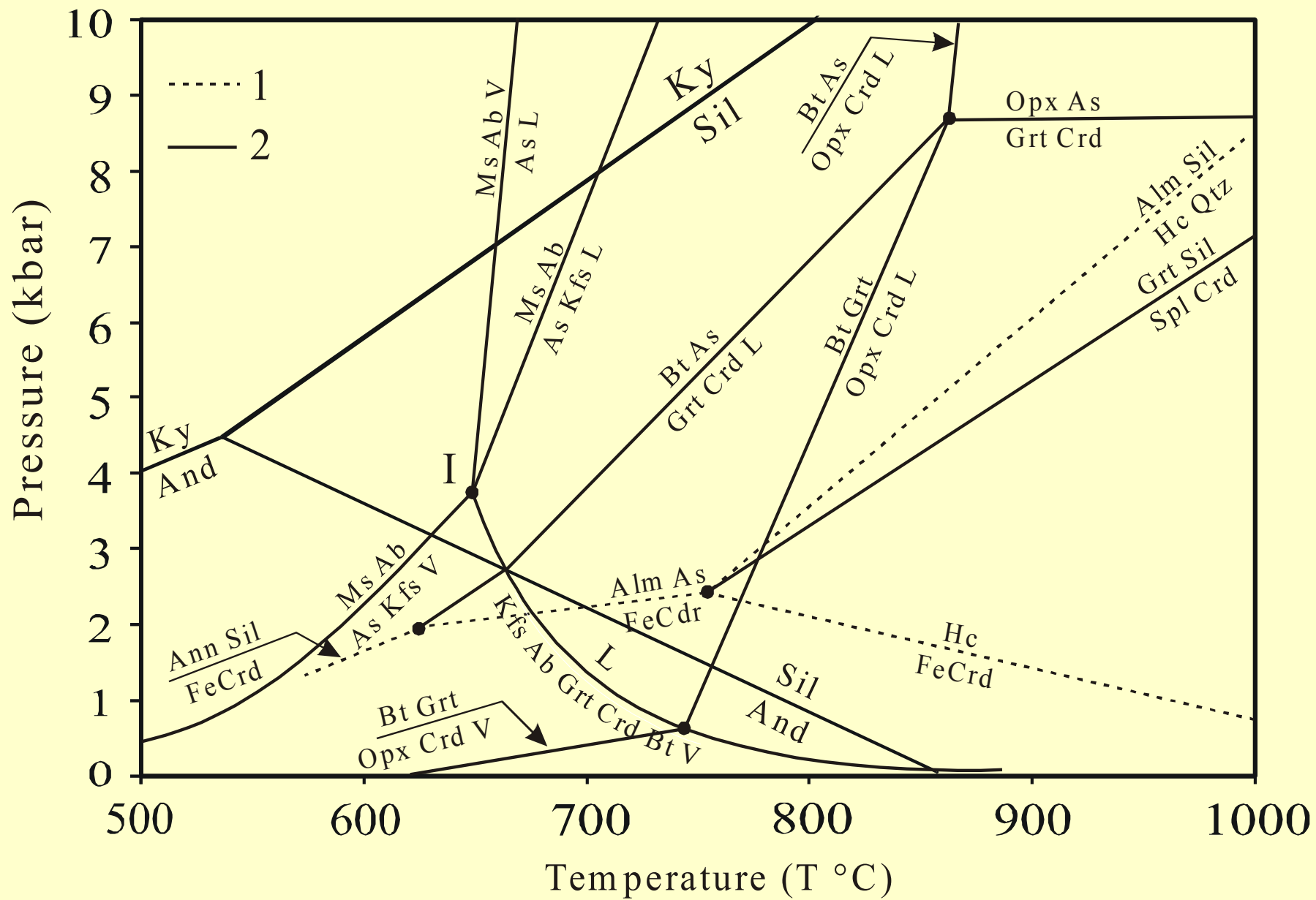
Migmatity jsou částečně natavené horniny. Angmagssalik area, E. Greenland.
Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

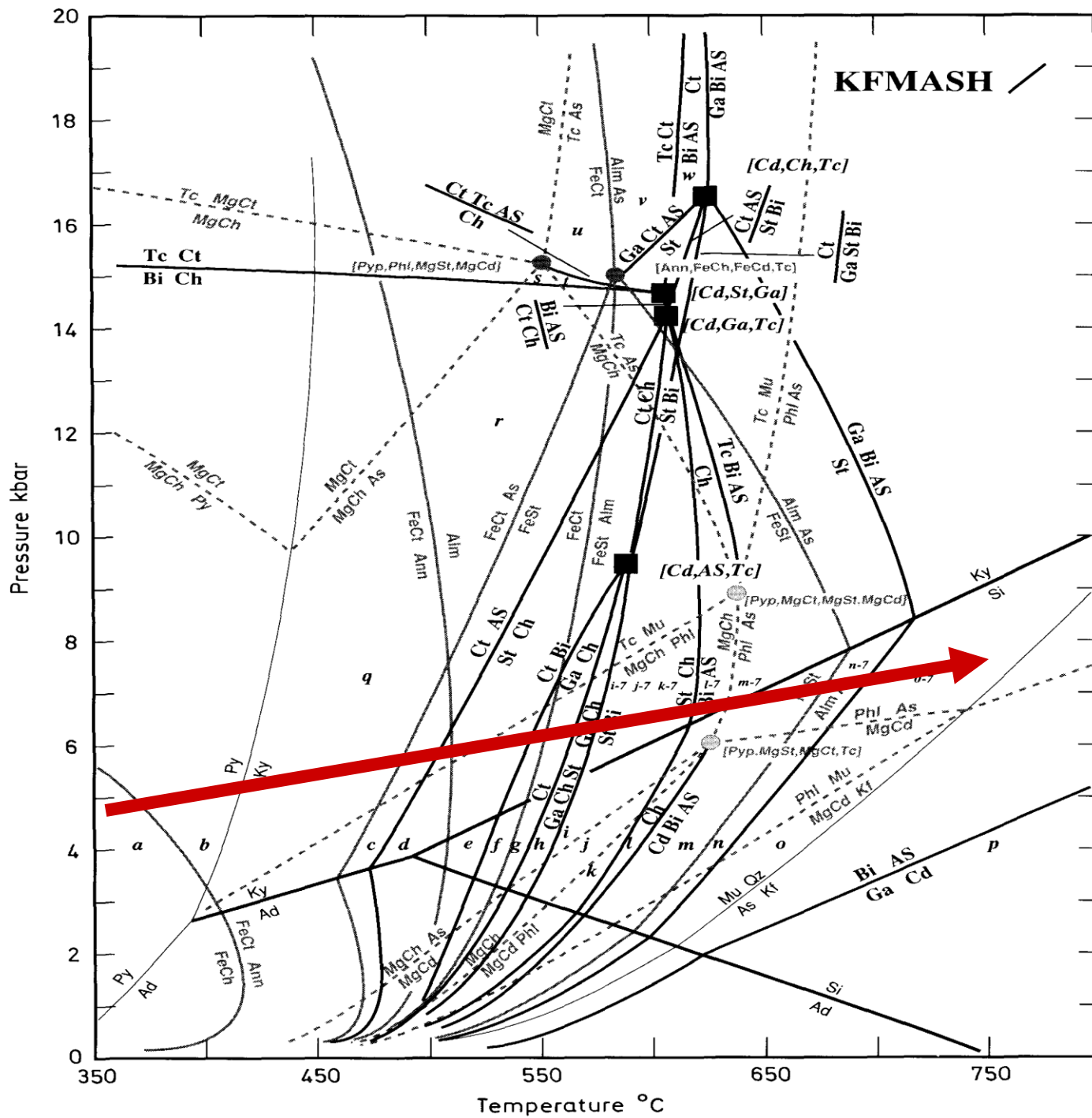
13) Ultra vysokoteplotní metamorfóza pelitů (granulitová facie)

- KFMASH: biotit = ortopyroxen + K-živec + H₂O
- dále minerály jako safírín, hercynit, osumilit



Minerální asociace granulitů
vzniklých z metapelitů:
Grt+Opx+Ky+Kfs+Qtz+Sp

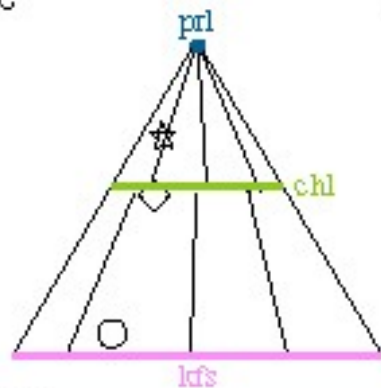




AKFM medium pressure

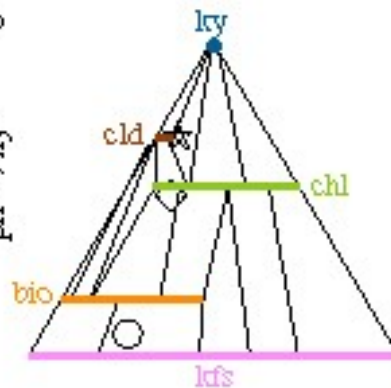
+qtz + mu + H₂O

- ★ hi-Al pelite
- ◇ lo-Al pelite
- granite

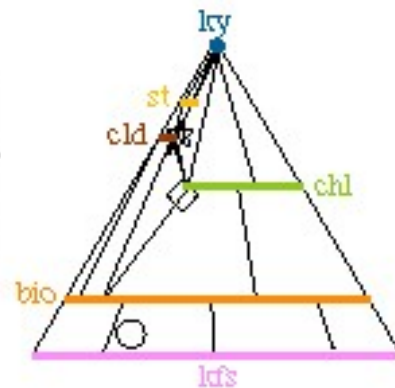


- ★ +lry, cld
- ◇ +bio

chl + lfs → bio
Fe-chl → Fe-cld
prl → lry

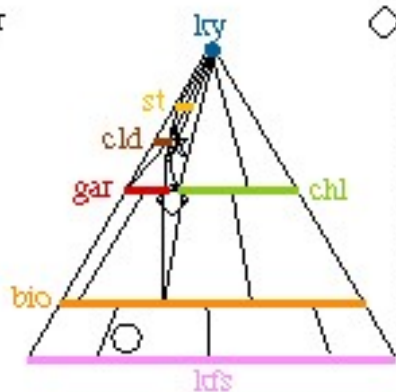


cld + lry → st



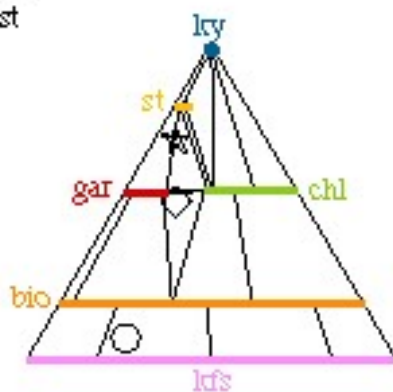
- ◇ +gar

cld + bio → gar + chl

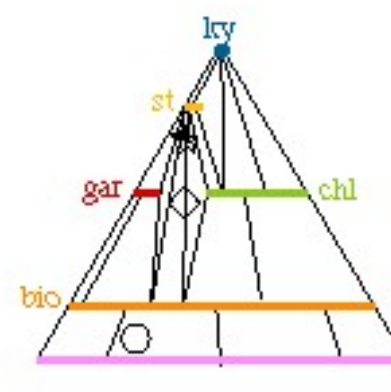


- ★ -cld
- ◇ +st

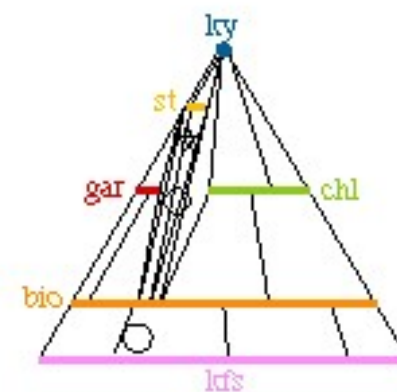
cld → gar + st + chl



gar + chl → st + bio



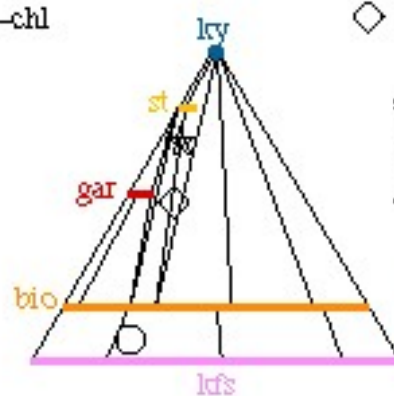
st + chl → lry + bio



- ★ -chl

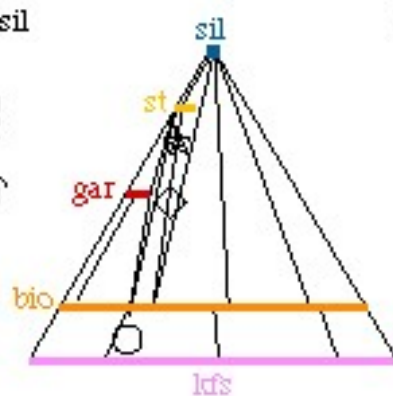
- ◇ +lry, -chl

chl → bio + lry



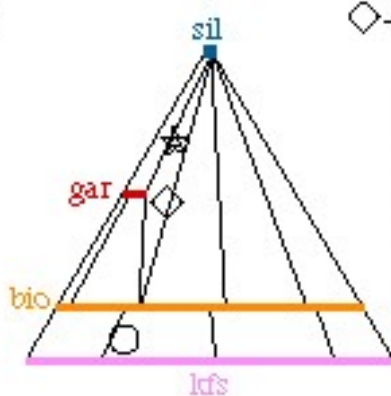
- ★ +sil
- ◇ +sil

lry → sil



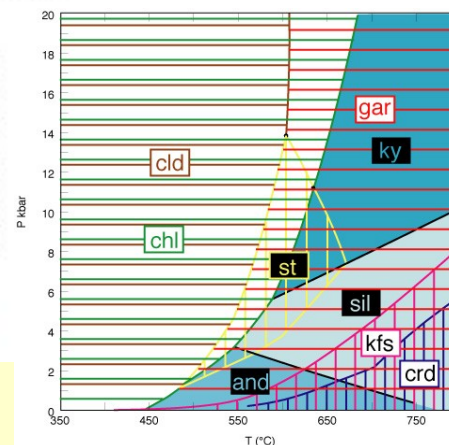
- ★ -st
- ◇ -st

st → gar + bio + sil

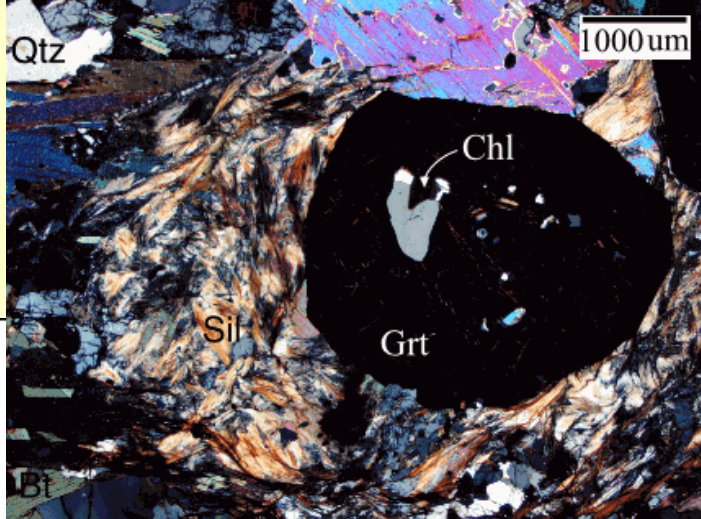


- ★ +sil + or
- ◇ +sil + or

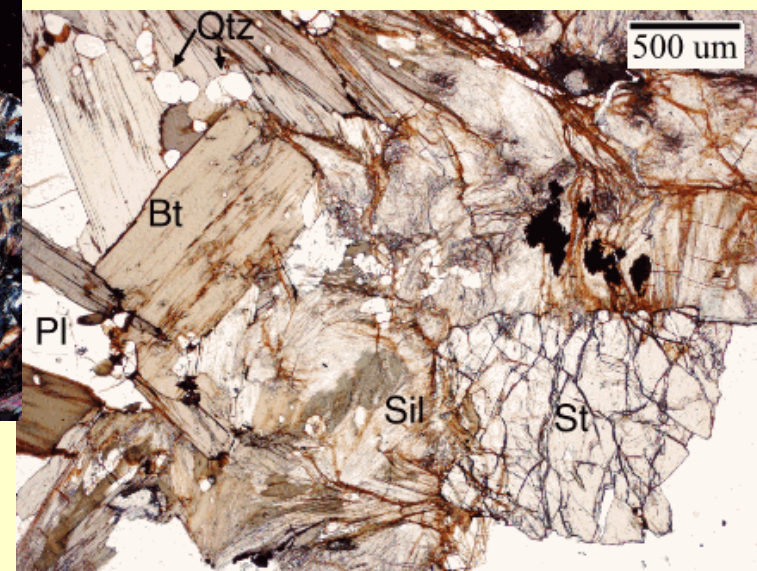
mu → lfs + sil



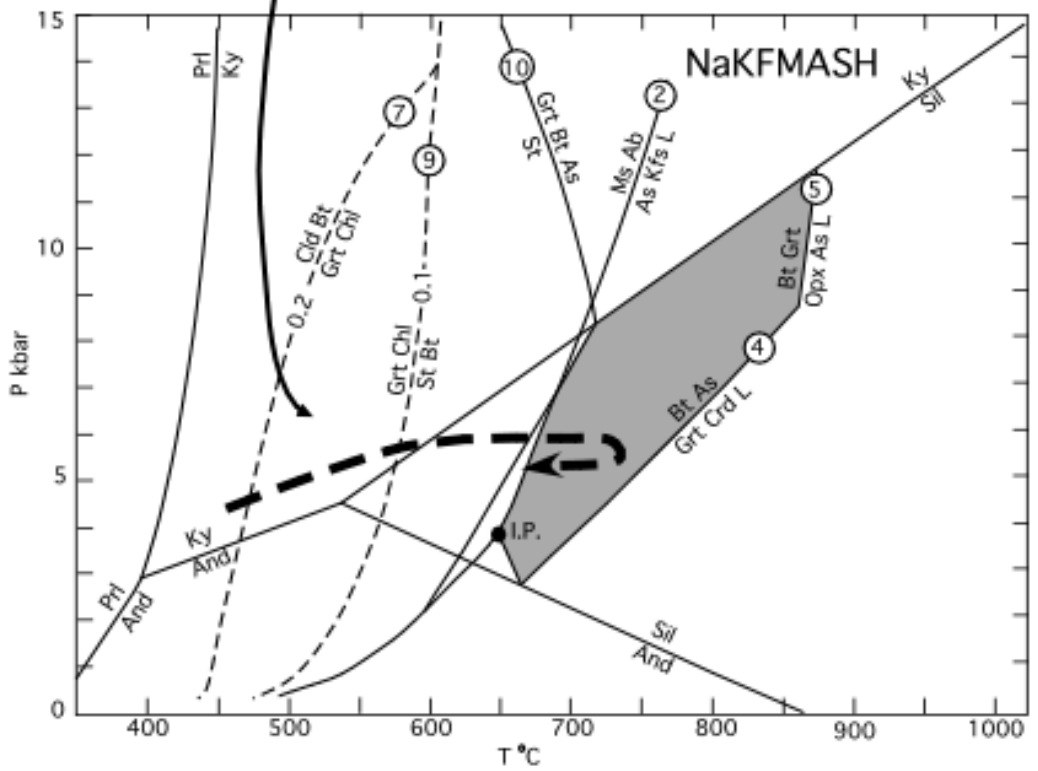
**chloritoid + biotite =
garnet + chlorite + H₂O**



**garnet + chlorite + muscovite = staurolite +
biotite + H₂O**

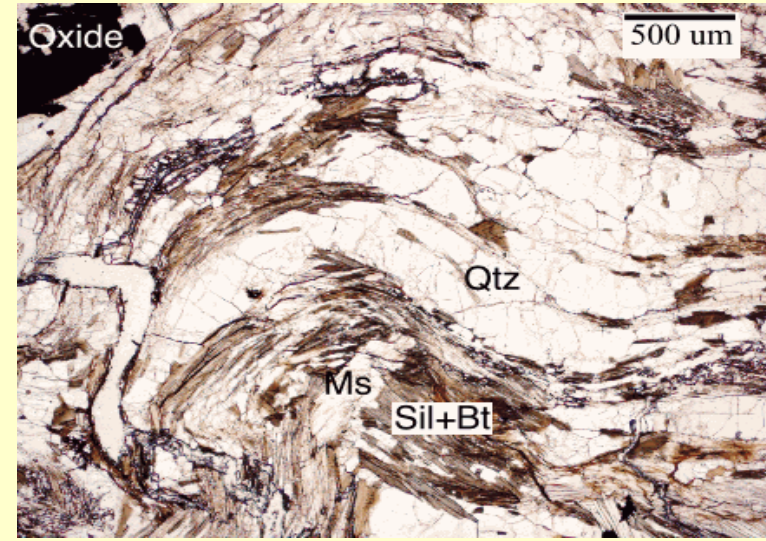


Grt + Chl
stability field
---0.2---
Mn/(Mn+Fe+Mg)
in grt



--- = SPECULATIVE P-T PATH

staurolite = garnet + biotite + Al₂SiO₅ (sillimanite)



**biotite + Al₂SiO₅ (sillimanite) =
garnet + K-feldspar + melt**

5. Vysokotlaková metamorfóza pelitů

- Ve facii modrých břidlic je v pelitech stabilní karfolit (chem. vzorec odpovídá součtu chloritoid + křemen + H₂O)
- Charakteristické jsou asociace s mastkem
- Tc+Ms, Ms+Ky, Ms+Cld → bílé břidlice

- reakce např.: $Bt + Chl = Tc + Cld + H_2O$ (*P*)
- Asociace s chloritoidem jsou stabilní za vyšších teplot.
- S nárůstem tlaku roste X_{Mg} v chloritoidu a staurolitu

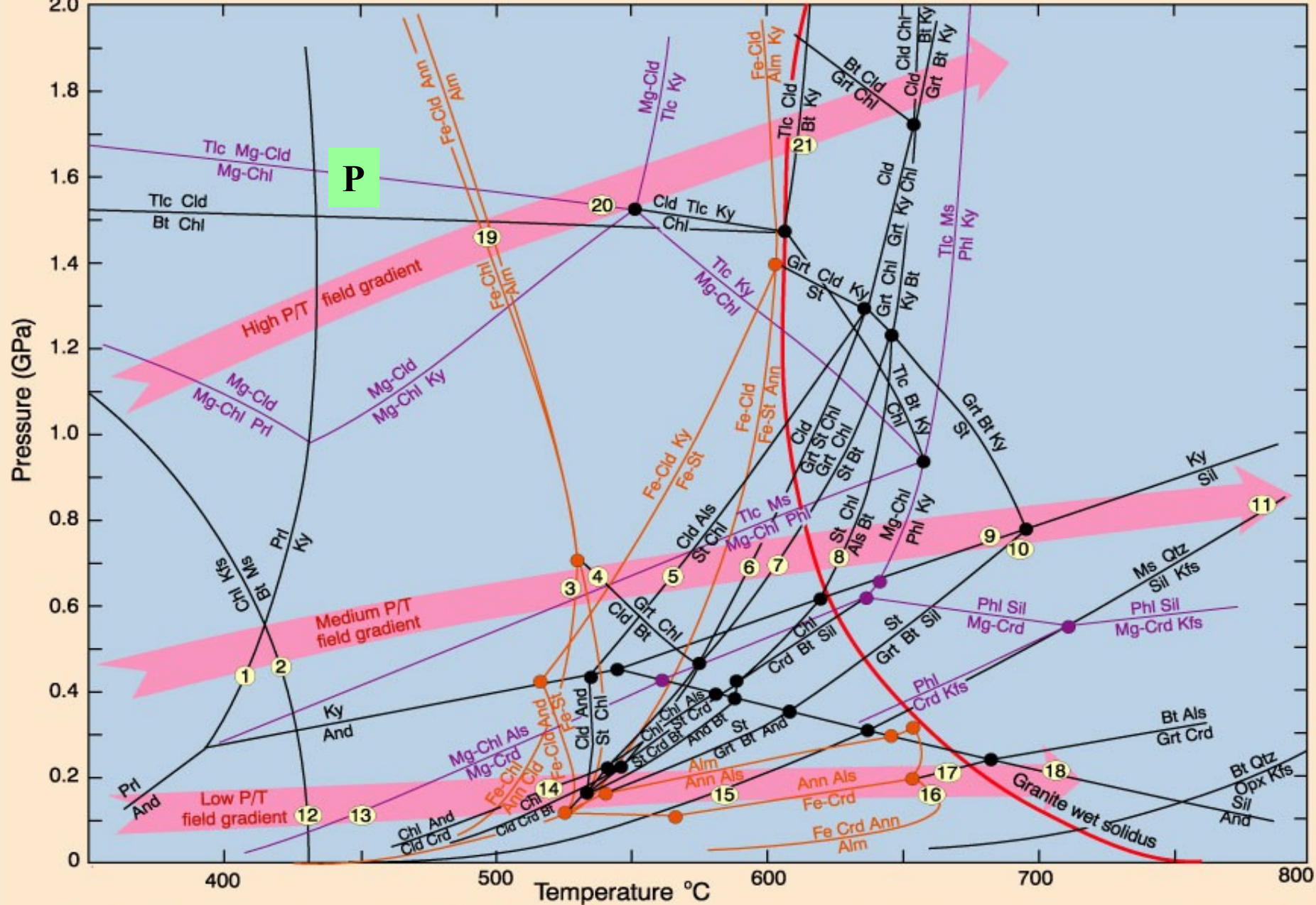
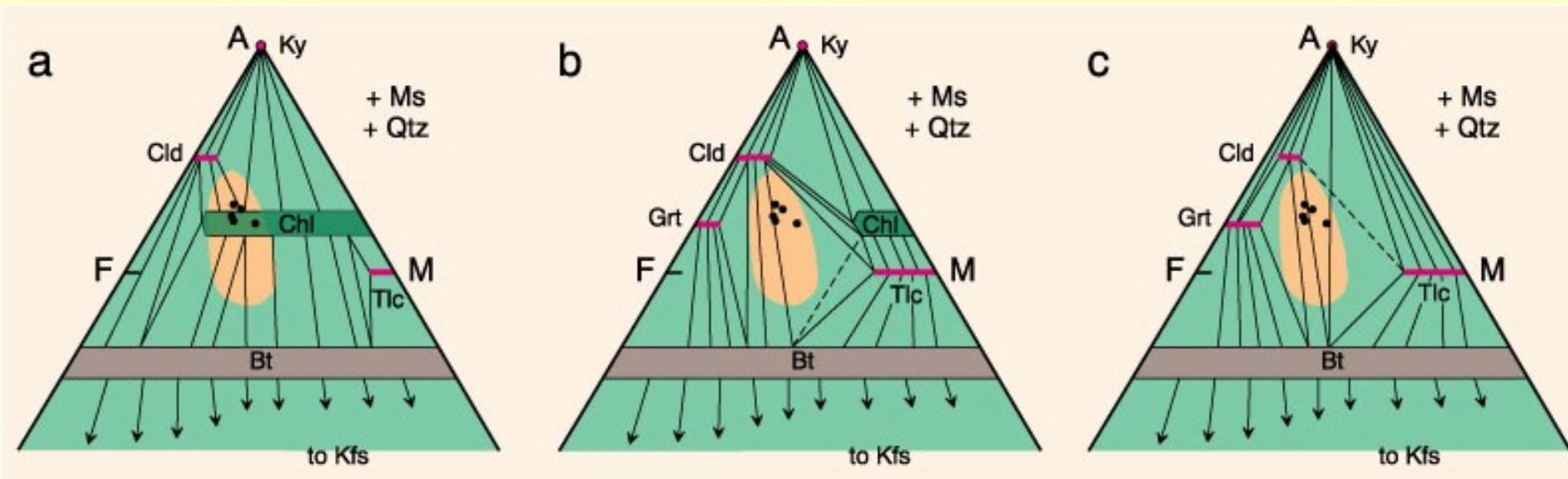


Figure 28-2. Petrogenetic grid for the system KFMASH at $P_{H_2O} = P_{total}$. Orange curves represent the system KFMASH and purple curves represent the system KMASH. Reactions are not balanced, and commonly leave out quartz, muscovite, and water, which are considered to be present in excess. Typical high, medium, and low P/T metamorphic field gradients are represented by broad pink arrows. After Spear and Cheney (1989), and Spear (1999).

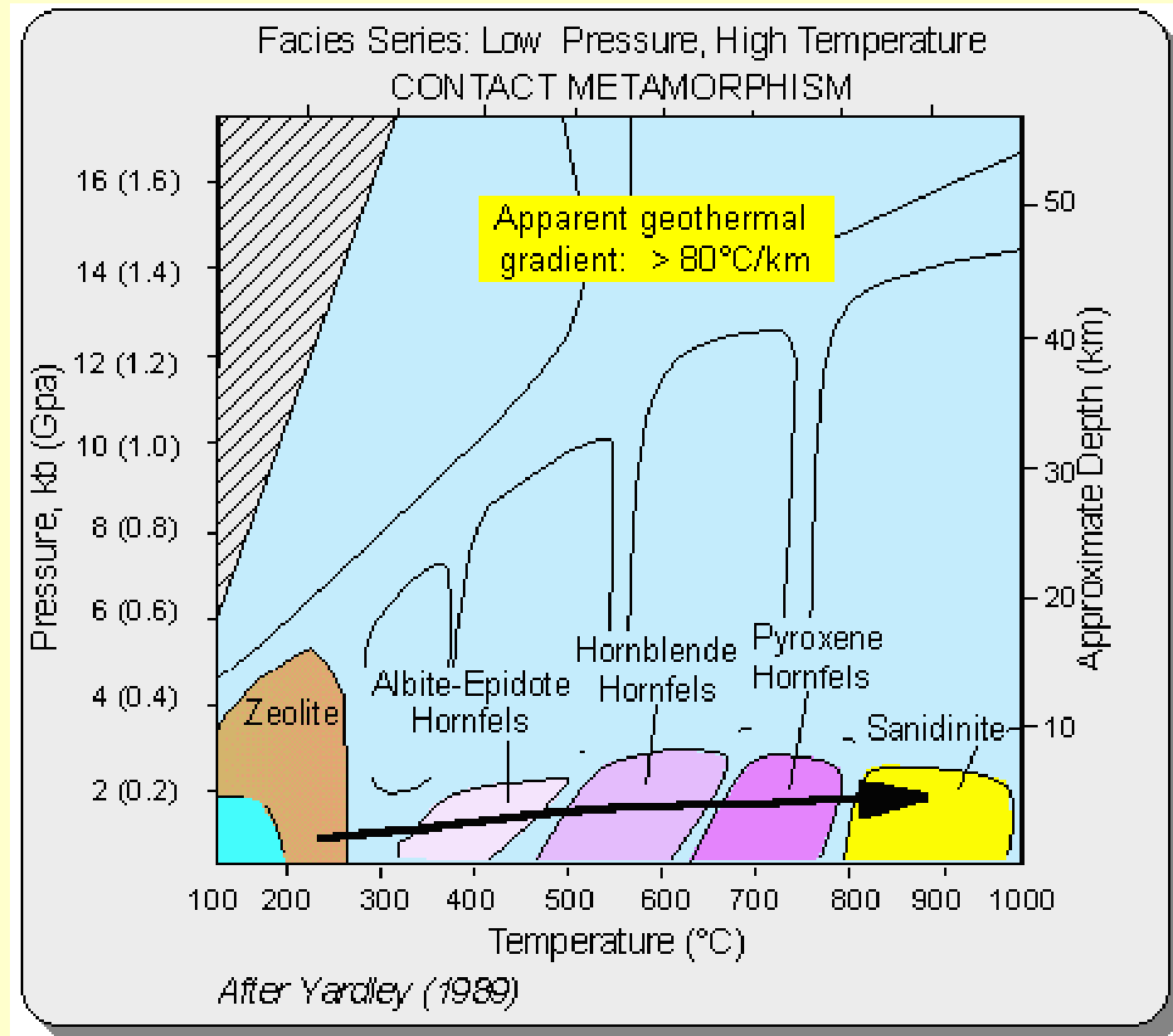
Eklogitová Facie

- Typická asociace pro tlaky nad 20 kbar: Prp + Ky + Tc + Qtz + fengit
- Vysokotlaké modifikace křemene (coesit – nad 25 kbar)
- Ve světlých slídách stoupá s tlakem obsah fengitové komponenty (MgSi = AlAl)



AFM diagram pro pelity metamorfované za vysokého poměru P/T (eklogitová facie): a. v horninách s vysokým obsahem Mg může vznikat mastek, b. vzniká spojnice mezi Cld - Tc a část metapelitů může tyto minerály obsahovat, c. zaniká chlorit a většina metapelitů obsahuje kyanit Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

6. Kontaktní metamorfóza pelitů



Facie	Mafické horniny	Ultramafické horniny	Pelitické horniny	Vápence
Albit-epidotické rohovce	albit, epidot nebo zoisit, aktinolit, chlorit	serpentin, mastek, tremolit, chlorit, brucit	křemen, albit, muskovit, chlorit, biotit	kalcit, dolomit, křemen, tremolit, mastek,
Amfibolické rohovce	hornblend, plagioklas, diopsid	forsterit, diopsid, tremolit, mastek, chlorit, antofylit, (Al-spinel, magnetit)	křemen, plagioklas, muskovit, biotit, cordierit, andalusit	kalcit, dolomit, křemen, tremolit, diopsid, forsterit
Pyroxenické rohovce	orthopyroxen, augit, plagioklas, (granát)	forsterit, orthopyroxen, klinopyroxen, plagioklas, Al-spinel	křemen, plagioklas, orthoklas, andalusit, sillimanit, cordierit, orthopyroxen	kalcit, diopsid, forsterit, wollastonit
Sanidinové rohovce	ortopyroxen, augit, plagioklas, (granát)	forsterit, orthopyroxen, klinopyroxen, plagioklas	křemen, sanidin, plagioklas, sillimanit, cordierit, orthopyroxen, korund, safirin, Al-spinel	kalcit, diopsid, forsterit, periklas, wollastonit, monticellit, akermanit

- Plodová břidlice



2 CM

Kontaktní břidlice s chloritoidem:

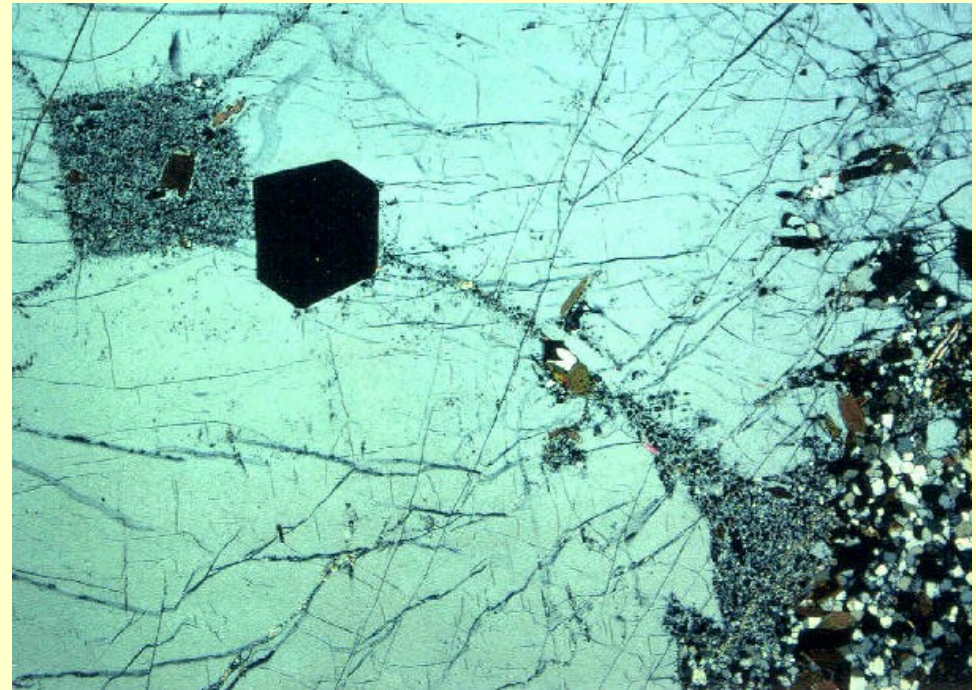
- KFLASH: Fe-chlorit + pyrofylit = Fe-chloritoid + křemen + H₂O



Met. asociace:
Prl + Cld + Chl

Al-bohaté pelity

Facie albit-epidotických rohovců



Pod hranicí 400 °C při 2 kbar rozpad pyrofylitu a vznik andalusitu

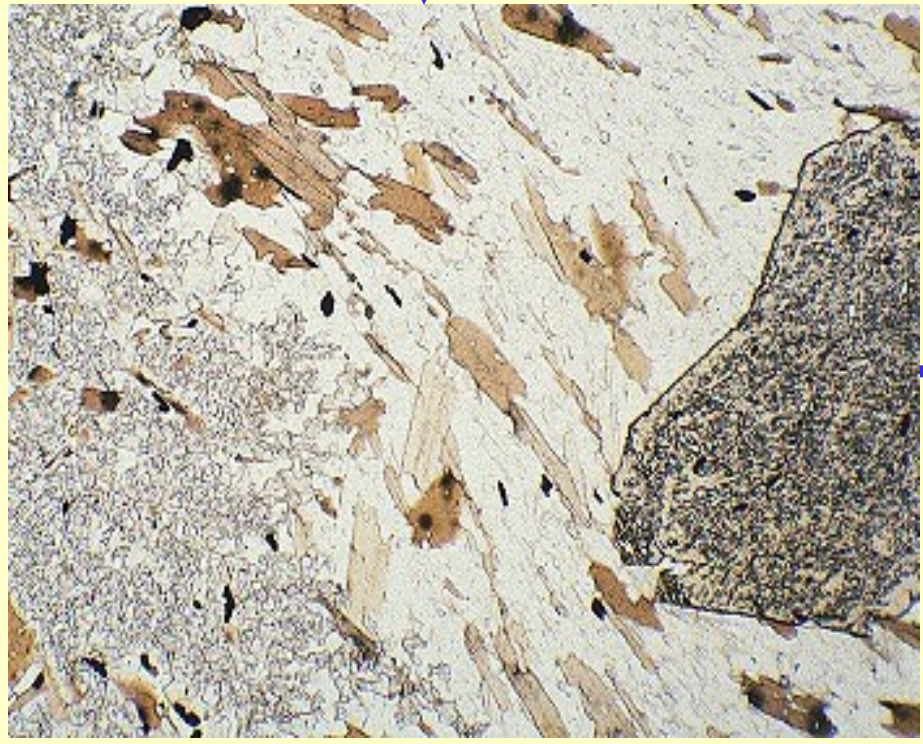
Kontaktní břidlice s andalusitem:

- Porfyroblast andalusitu je obklopen: Cld + Chl + Qtz + Ms

chloritoid + andalusit = staurolit + chlorit



staurolit + chlorit = biotit + andalusit.



Kontaktní břidlice se staurolitem a andalusitem:

- Staurolit tvoří porfyroblast v základní tkáni tvořené Bt+Qtz+Chl+Ms velikost obr. 2,5 mm.

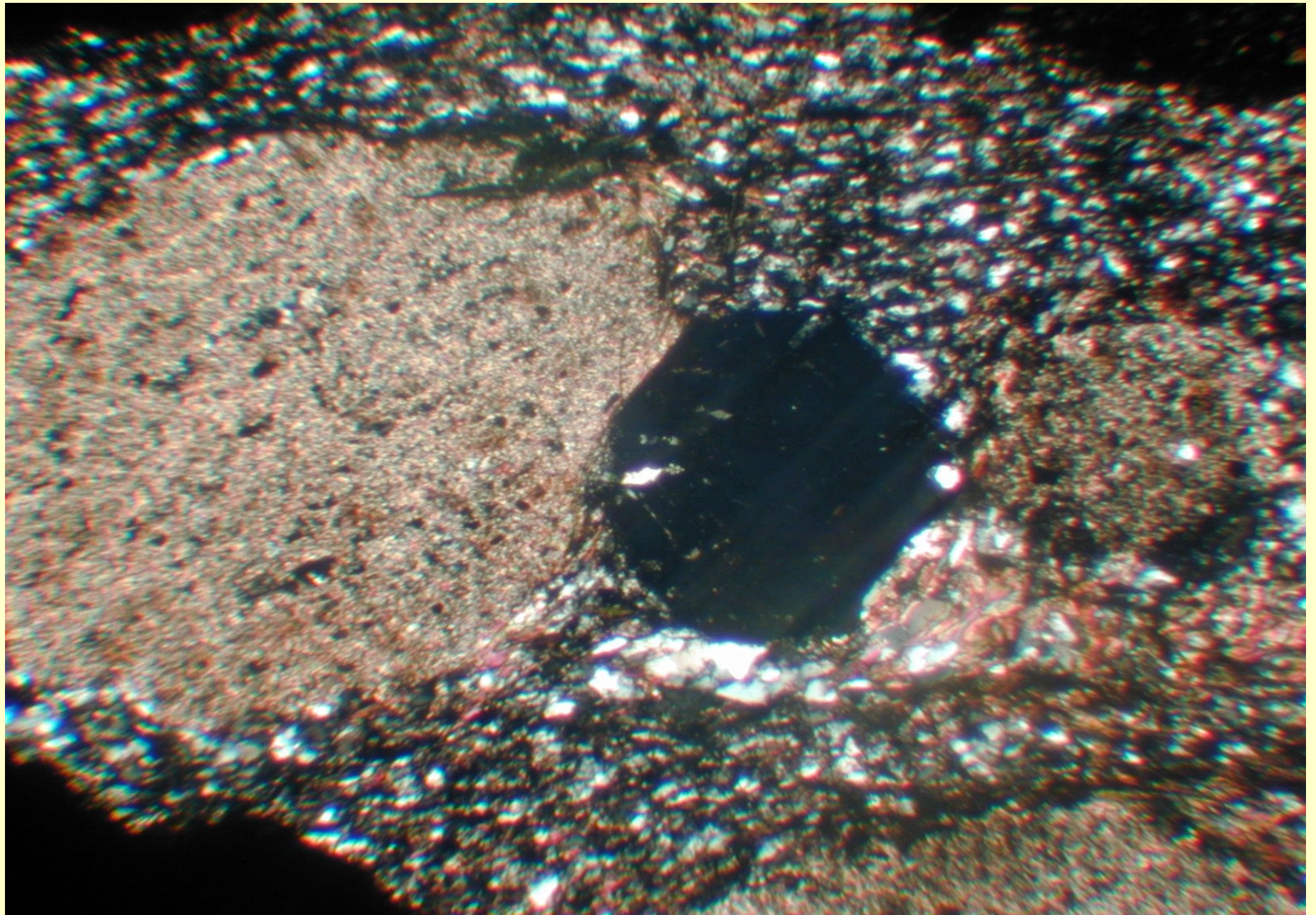
Facie amfibolických rohovců

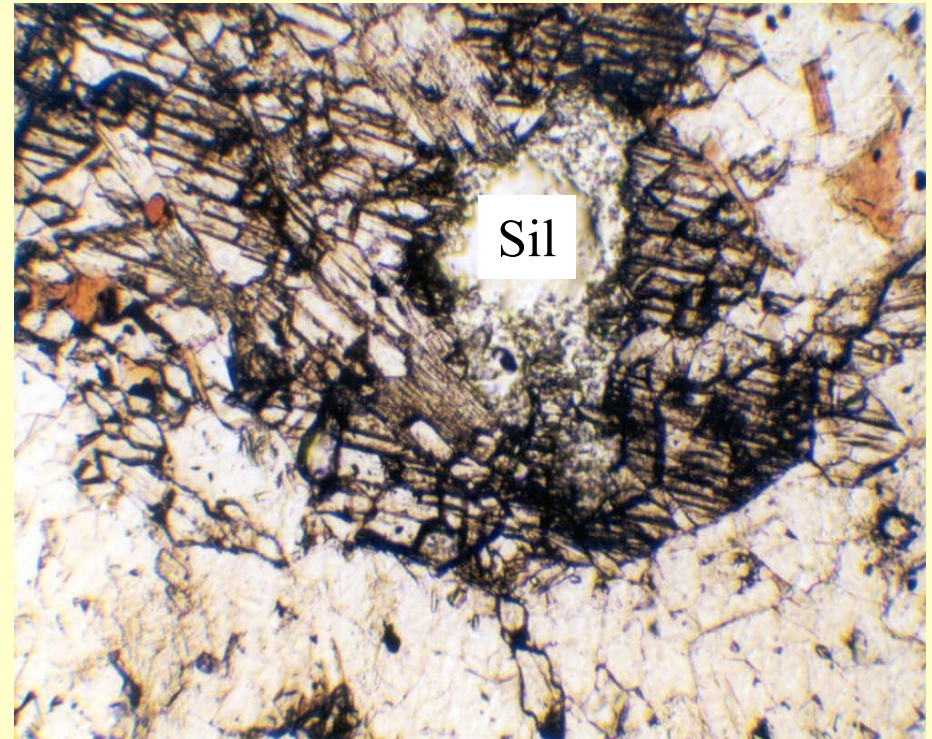
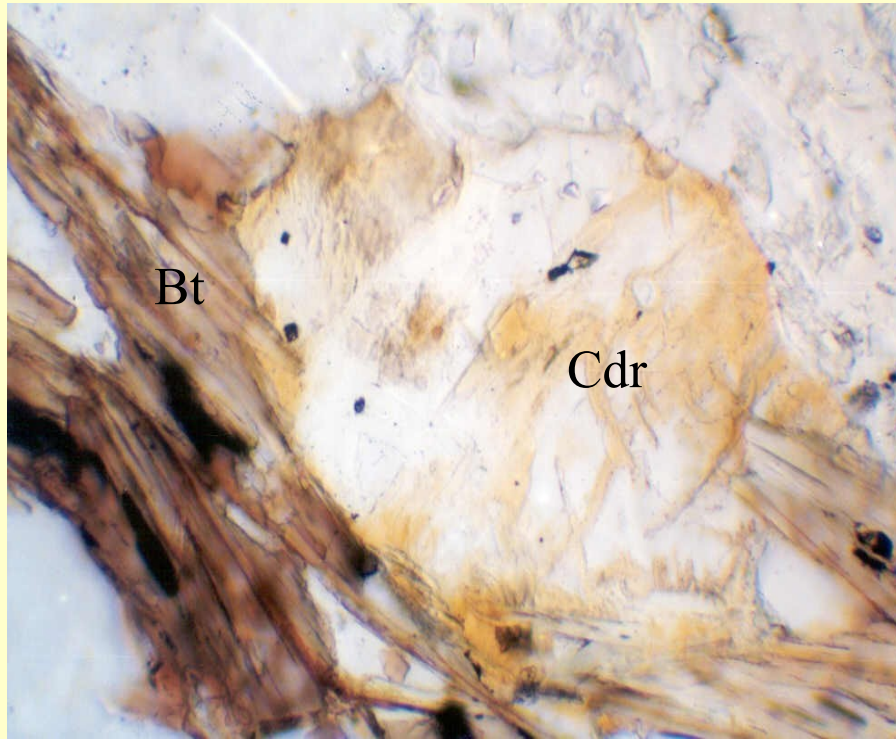


chlorit = cordierit + biotit + andalusit



Oválný porfyroblast cordieritu obklopený jemnozrnnou matrix z Ms+Bt+Qtz a porfyroblasy And+St (facie amfibolitových rohovců).

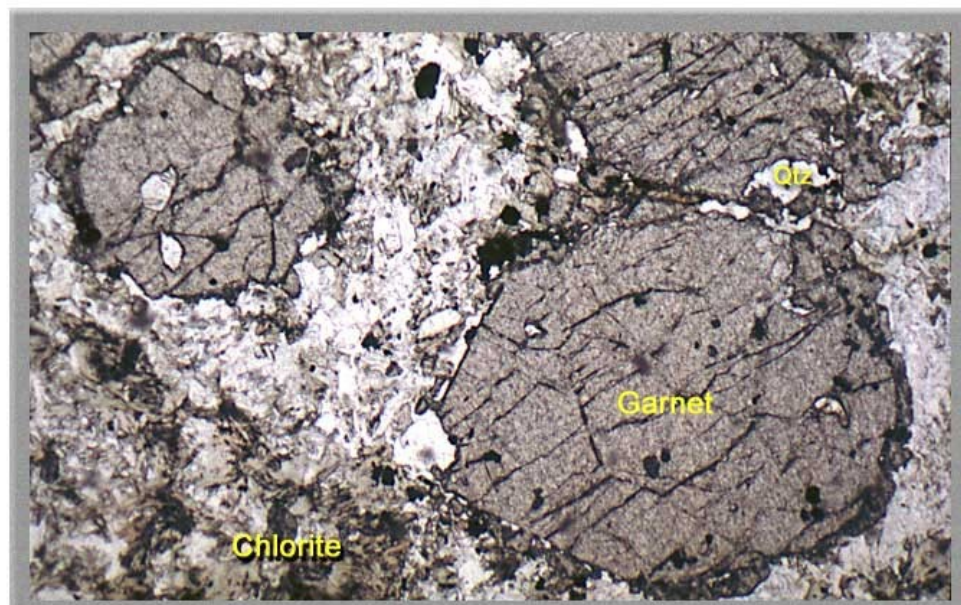




další cordierit poroste během kontinuální reakce biotit + andalusit = cordierit
andalusit je nahrazen sillimanitem, reakcí andalusit = sillimanit
výsledná asociace je sillimanit + biotit + cordierit (+ křemen + muskovit)
granát může být přítomný díky komponentám MnO a CaO

Al-chudé pelity

- Al-chudé pelity ve 350 °C a 2 kbar mají asociaci
-
- chlorit + biotit (+ muskovit + křemen).
- chlorit = andalusit + biotit (kontinuální reakce)
- chlorit = cordierit + andalusit + biotit
- andalusit + biotit = cordierit (kontinuální reakce)
- nahrazení andalusitu sillimanitem a konečná asociace je: Sill + Cdr + Bt + Ms + Qtz ± Grt



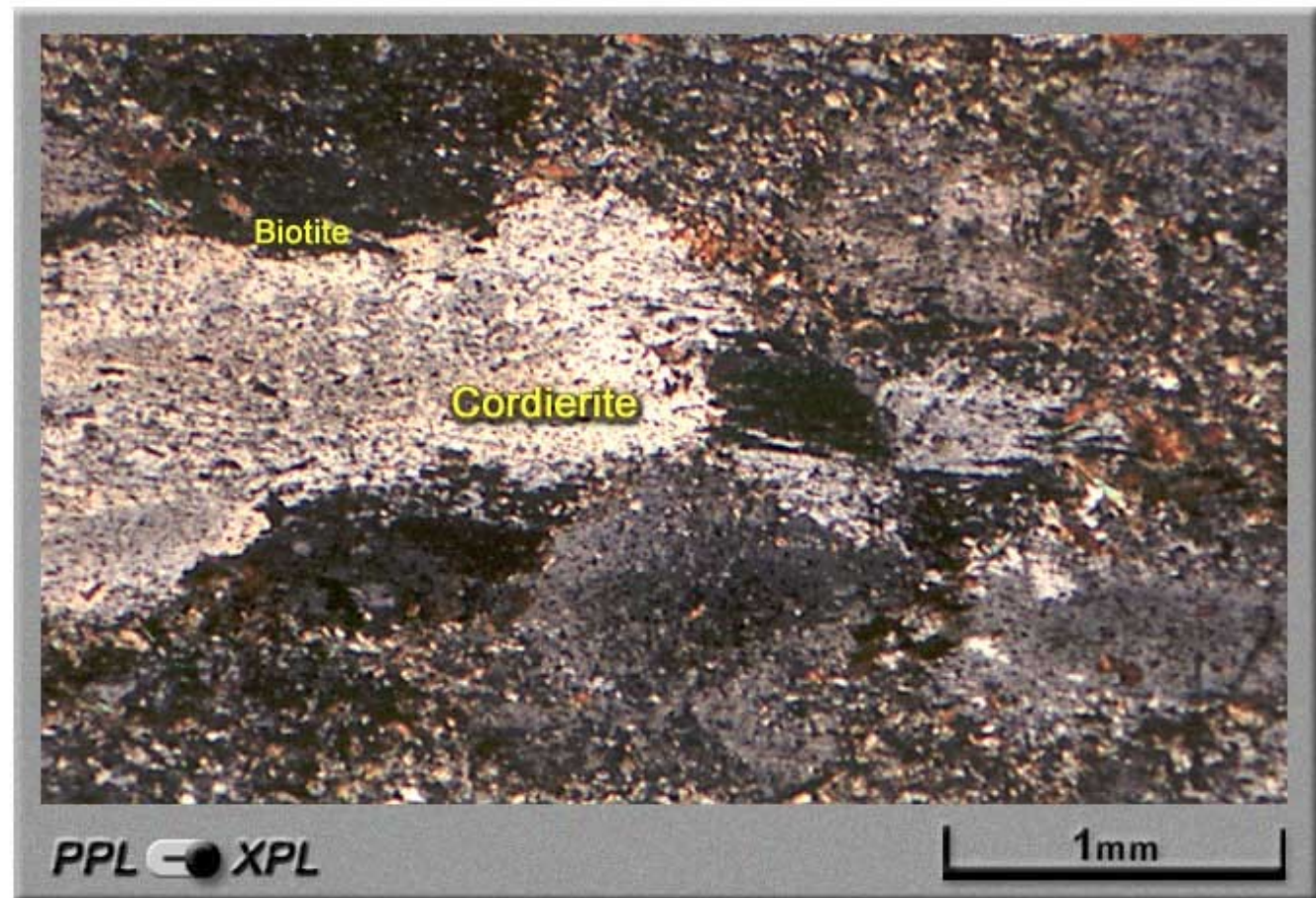
Granátický kontaktní rohovec



Andalusitický kontaktní rohovec

Cordieritický kontaktní rohovec

- And + Cdr + Bt + Ms + Qtz



Literatura

- Dudek, A. - Fediuk F. - Palivcová M. (1962): Petrografické tabulky
- Hejtman, B. (1962): Petrografie metamorfovaných hornin
- Konopásek, J. – Štípská P. – Klápková H. – Schulmann K. (1998): Metamorfnní petrologie
- Naprostá většina obrazového materiálu pochází z celé řady internetových stránek věnujících se metamorfnní petrologii