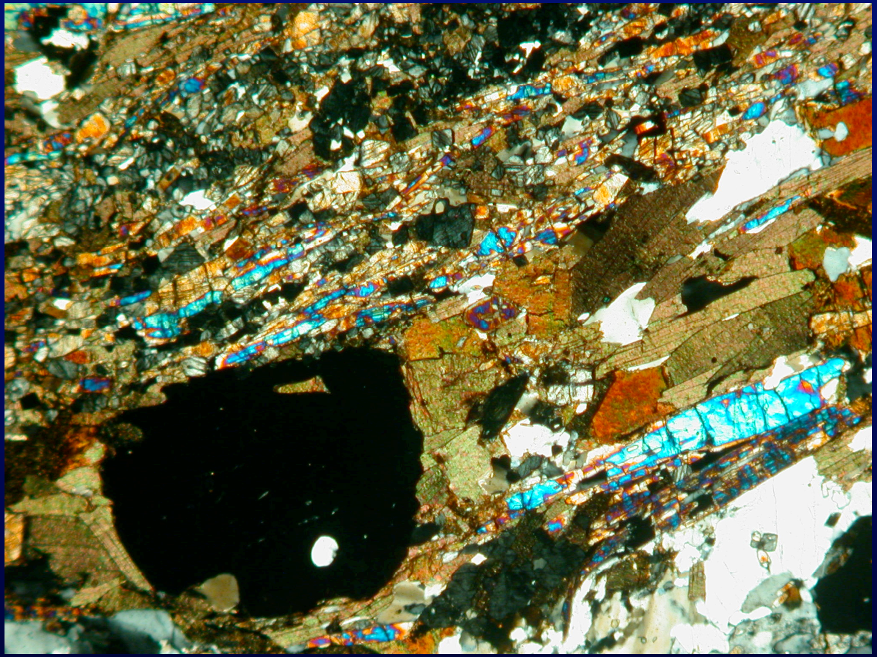
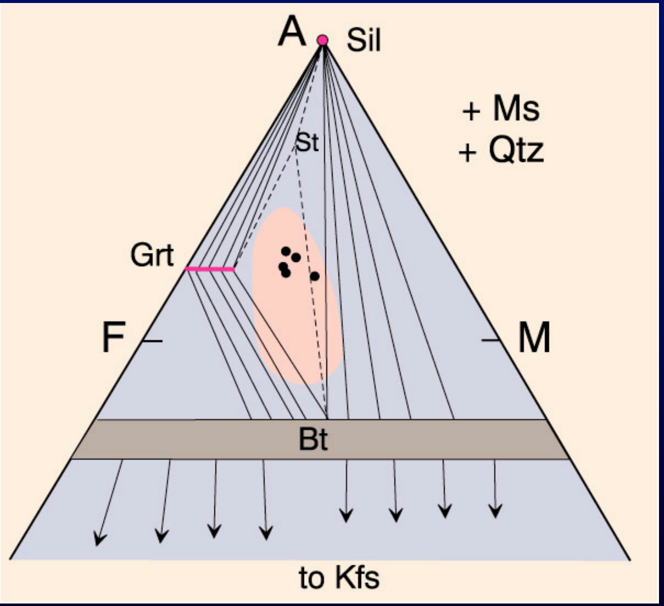
7b. Metamorphism of Pelitic Sediments





A. Rottura: Lezioni di Petrografia Metamorfica a.a.2008-2009 “La Scienza com arte dell’approssimazione” (Luca Cavalli-Sforza)

Metapelites

- Pelitic sediments (mudstones and shales): very fine grained clastic sediments derived from continental crust

- Metapelites represent a distinguished family of metamorphic rocks, because the *clays are very sensitive to variations in temperature and pressure*, undergoing extensive changes in mineralogy during progressive metamorphism

Metapelites

- The mineralogy of pelitic sediments is dominated by fine Al-K-rich phyllosilicates, such as clays (kaolinite, illite, montmorillonite/smectite), fine white micas (muscovite, phengite, paragonite) and chlorite, all of which may occur as detrital or authigenic grains
- The phyllosilicates may compose more than 50% of the original sediment
- Fine quartz constitutes another 20-30%
- Other common constituents include feldspars (albite and K-feldspar), iron oxides and hydroxides, zeolites, carbonates, sulfides, and organic matter

Metapelites

Chemical compositions of *shales* in comparison with *metapelites*

Distinctive chemical characteristics are:

- high Al_2O_3 and K_2O, and low CaO
- $Al_2O_3 > Na_2O + K_2O + CaO$ (mol)
- $MgO > CaO$; $K_2O > Na_2O$

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_2O_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_2O	1.13	1.64	1.46	0.85	1.86
K_2O	3.96	3.86	3.02	3.88	4.15
P_2O_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

5. Average of amphibolite-facies pelitic rocks (Ague, 1991).

Metapelites

- Chemical characteristics reflect the high clay and mica content of the original sediment and lead to the *dominance of* muscovite and quartz throughout most of the range of metamorphism
- High proportion of micas → common development of foliated rocks, such as slates, phyllites, and mica schists

Metapelites

- Il carattere *peralluminoso* comporta la presenza, in aggiunta alla muscovite, di uno o più minerali alluminiferi

cloriti e granato a *basso grado*

granato, staurolite. andalusite e cianite a *medio grado*

granato, cordierite e sillimanite ad *alto grado*

Metapelites

The chemical composition of pelites can be represented by the system K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O ("**KFMASH**")

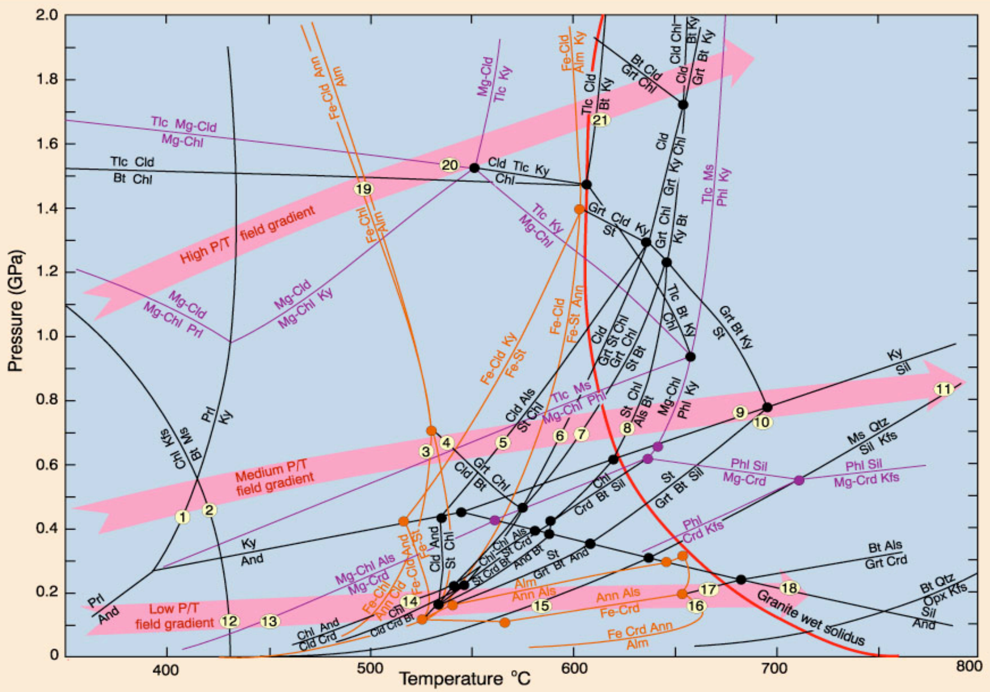
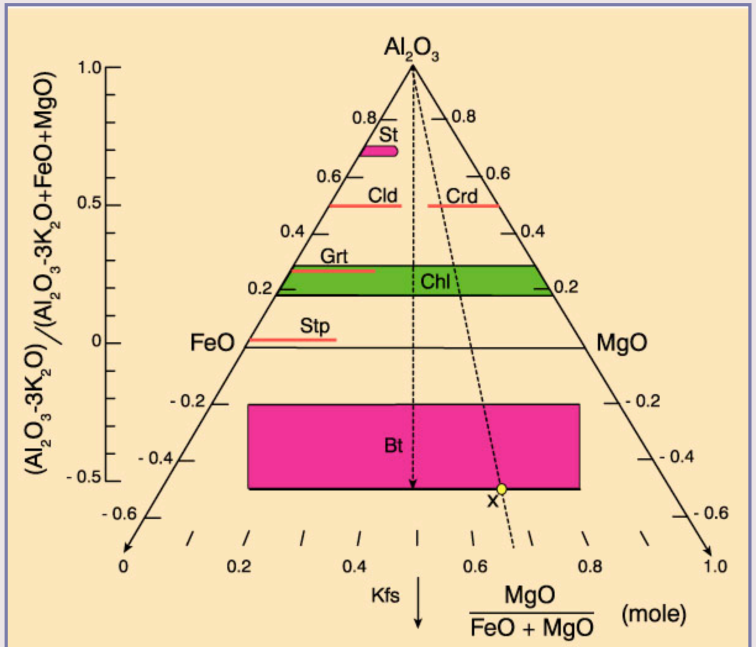
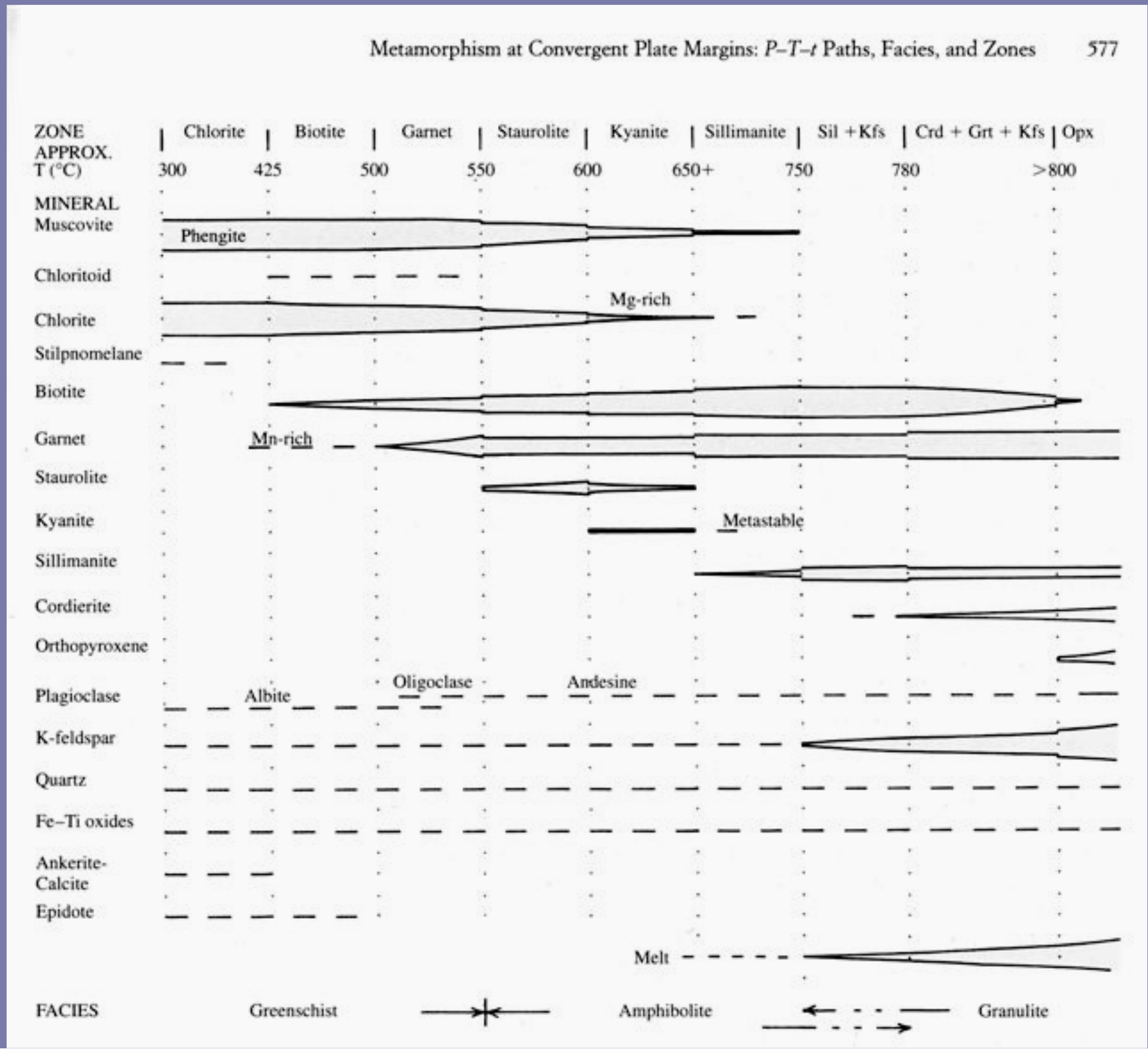


Figure 28-2. Petrogenetic grid for the system KFMASH at $P_{H2O} = P_{total}$. Orange curves represent the system KFASH and purple curves represent the system KMASH. Reactions are not balanced, and commonly leave out quartz, muscovite, and water, which are considered to be present in excess . Typical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



The petrogenesis of pelites is represented well in **A(K)FM** diagrams (after Winter, 2001)

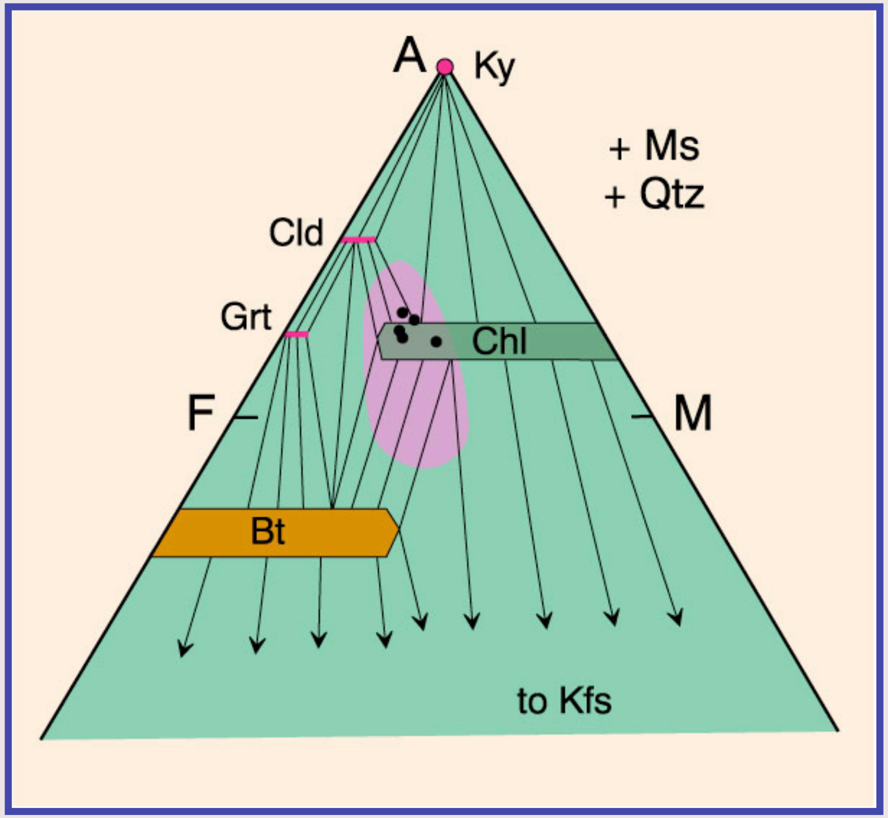
Mineral compatibilities in the typical Barrovian zones in pelitic rocks metamorphosed under IP



(after Best, 2003)

Metapelites

AFM projection for the upper *biotite zone,* greenschist facies. Although garnet is stable, *it is limited to unusually Fe-rich compositions,* and does not occur in natural pelites (after Winter, 2001)

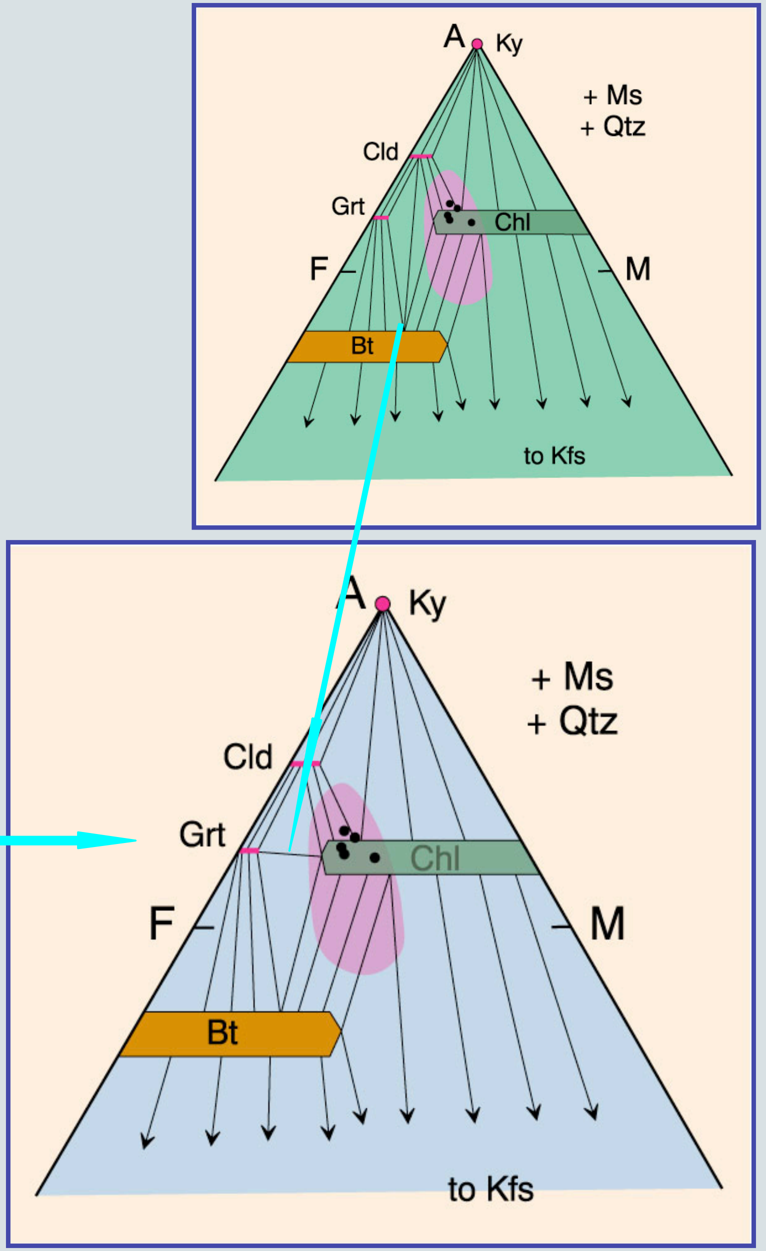


Metapelites

AFM projection for the *garnet zone,* transitional to the amphibolite facies, showing the tie-line flip associated with reaction

$Cld+Bt(+Qtz+H_2O)=Grt+Chl$

which introduces garnet into the more Fe-rich types of common (shaded) pelites (After Spear, 1993 in Winter, 2001)

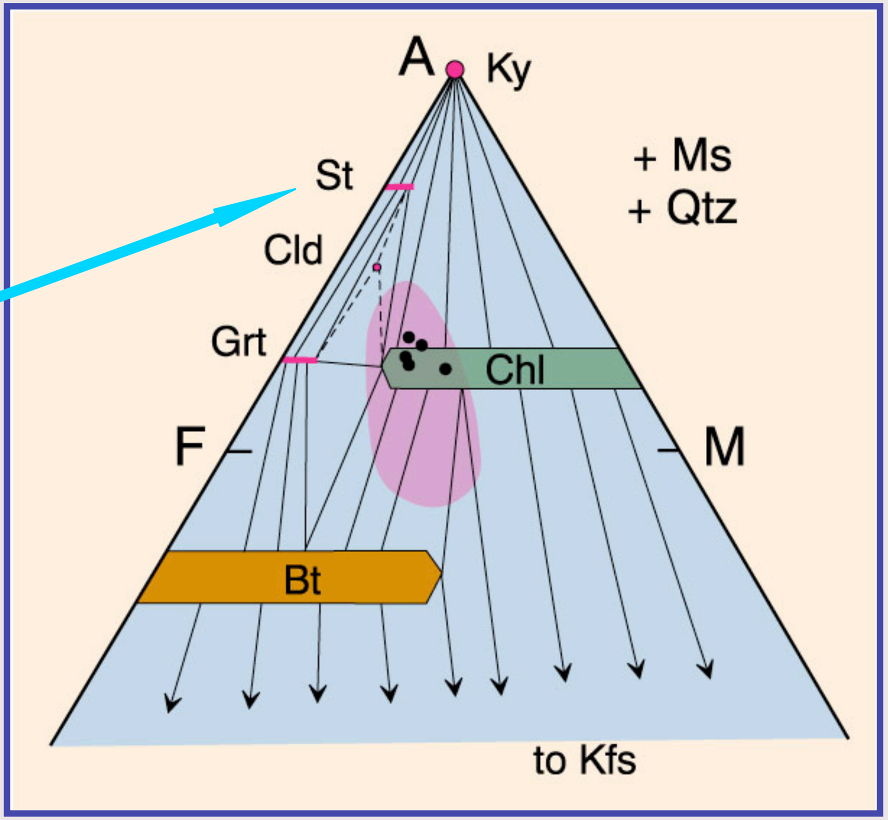


Metapelites

AFM projection in the staurolite zone of the amphibolite facies, showing the change in topology associated with the terminal reaction

$$Cld+Qtz=Grt+Chl+St+H_2O$$

in which chloritoid is lost (lost tie-lines are dashed), yielding to the Grt-St-Chl sub-triangle that surrounds it (Winter, 2001)

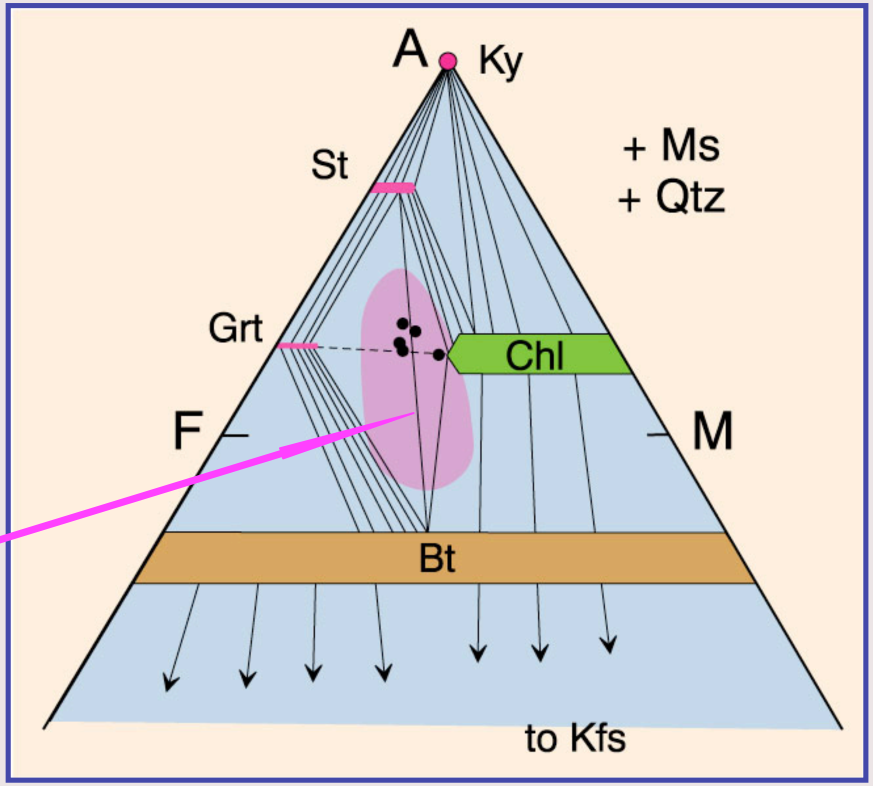


Metapelites

AFM diagram for the *staurolite zone,* amphibolite facies, showing the tie-line flip associated with reaction

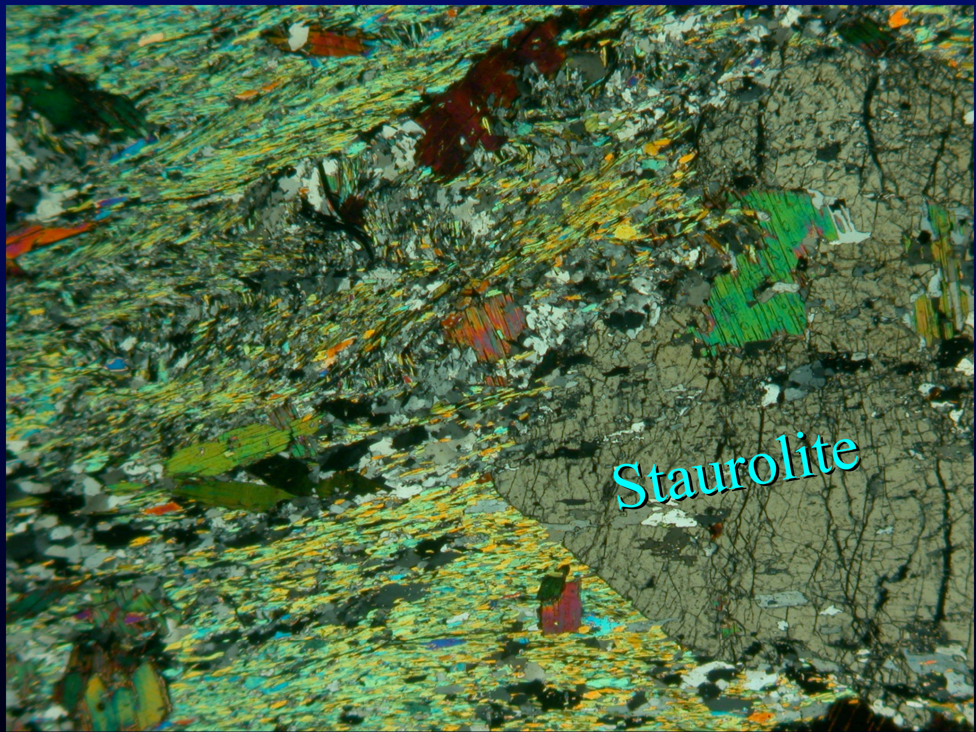
Grt+Chl= St+Bt

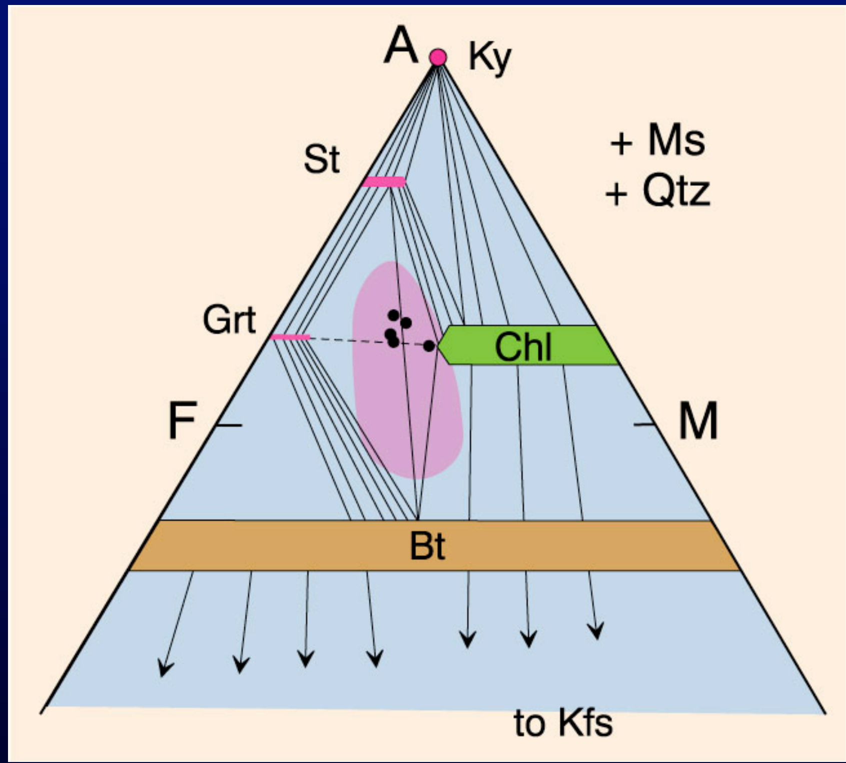
which introduces *staurolite into many low-Al common pelites* (shaded) (Winter, 2001)



Metapelites

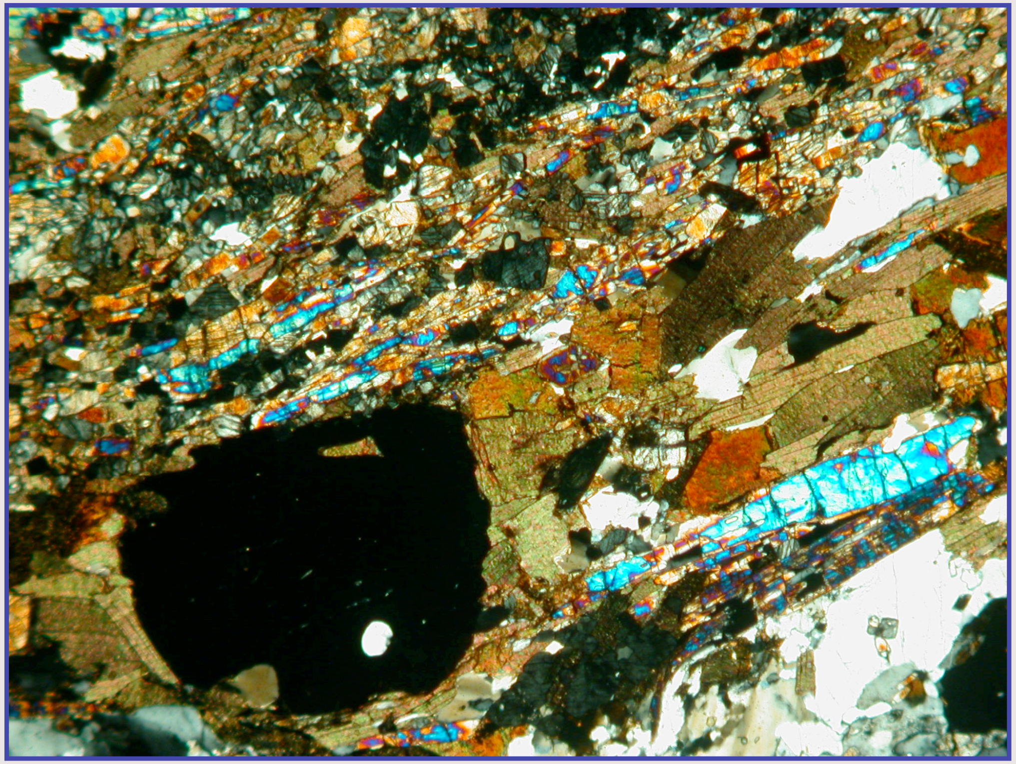
AFM diagram for the staurolite zone: Grt+Chl= St+Bt

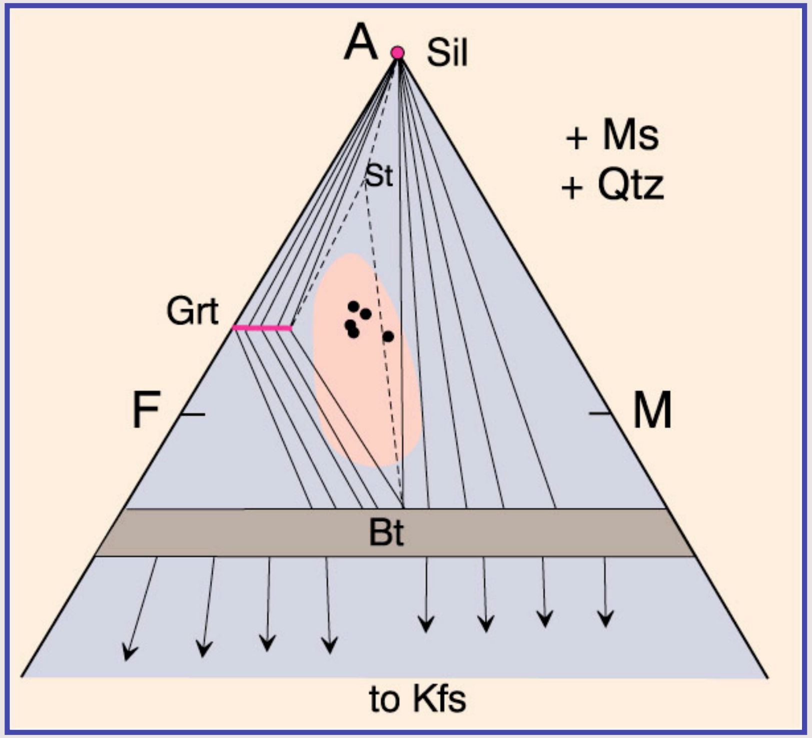




Metapelites

AFM projection above the sillimanite and "*staurolite-out* isograds, sillimanite zone, upper amphibolite facies. St (+Ms+Qtz)= Grt+Bt+Als+H_2O (kinzigite gneiss)





Metapelites

Granulite facies

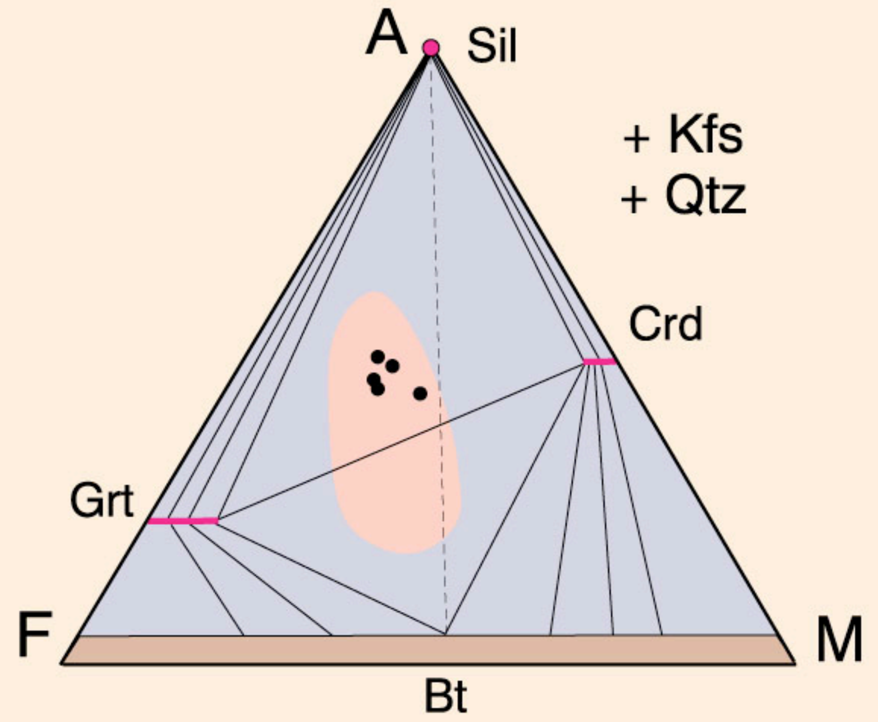
-Ms out

$Ms+Qtz=Kf+Sil+H_2O$

-Bt out

$Bt+Sil=Grt+Crd+H_2O$

$Bt+Qtz=Opx+Kf+H_2O$

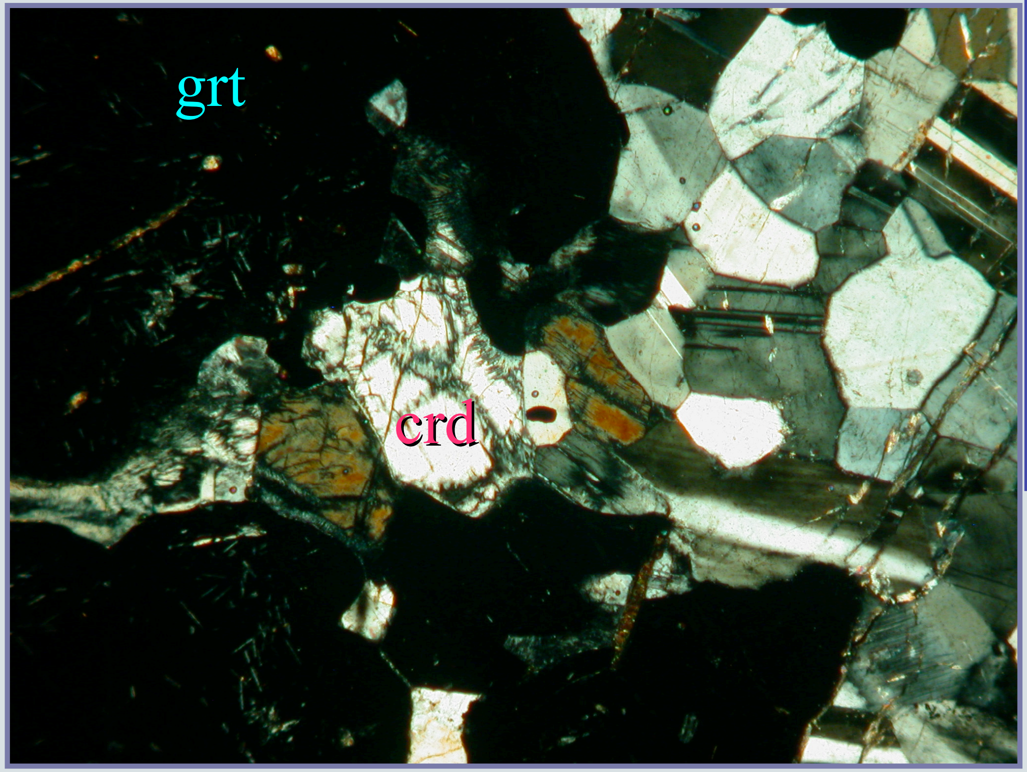


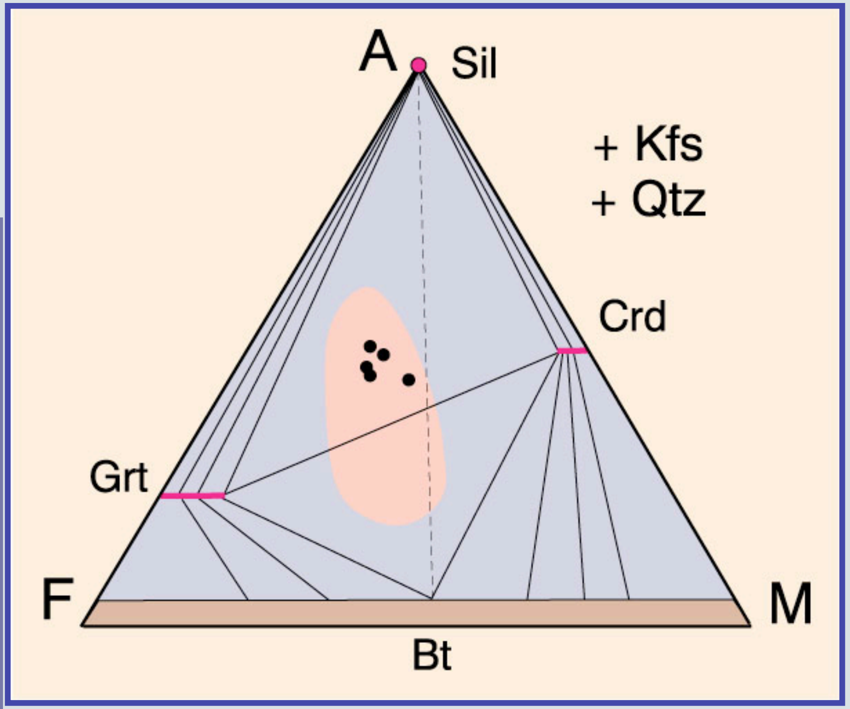
AFM diagram (projected from K-feldspar) above the cordierite-in isograds, granulite facies. The dashed Sil-Bt tie-line is lost and the Grt-Crd tie-line forms (after Winter, 2001)

Metapelites

Granulite facies-Bt out: $Bt+Sil=Grt+Crd+H_2O$

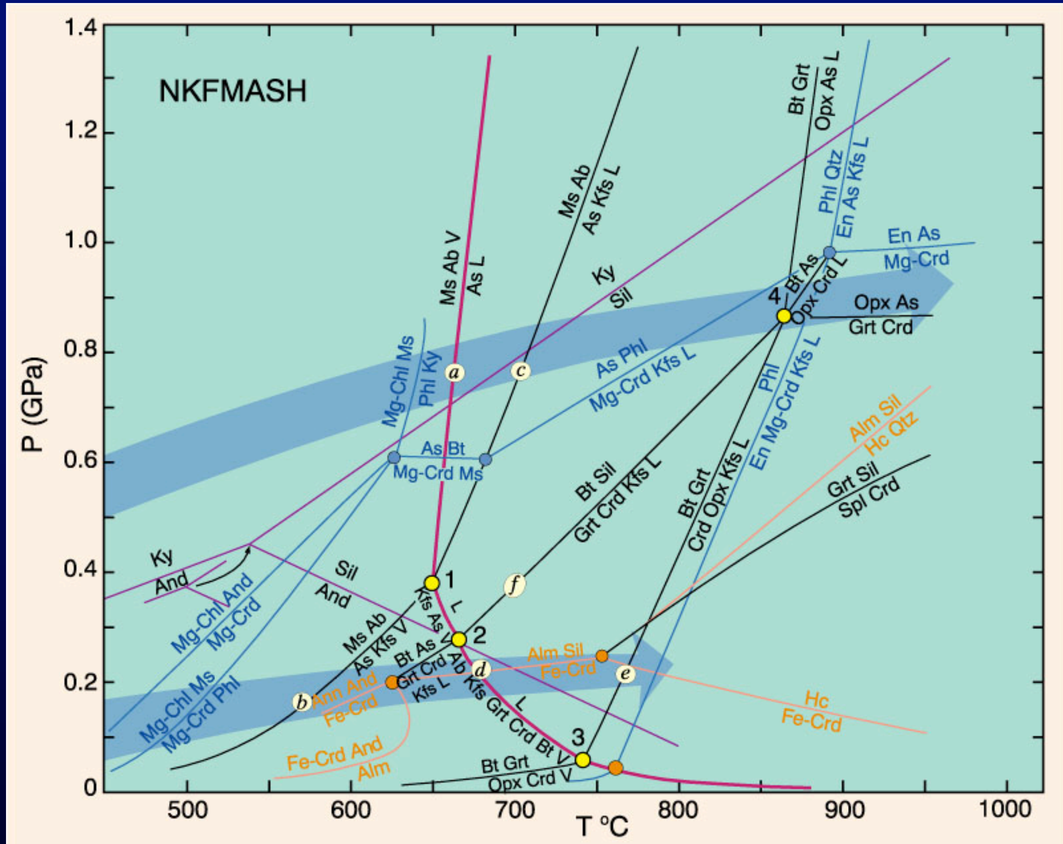
$Bt+Qtz=Opx+Kf+H_2O$





Partial melting of pelites: Migmatites

- Along the medium P/T metamorphic field gradient the first major melting reaction occur at point ***c***
  Ms+Ab+Qtz=Al_2SiO_5+Kf+Liq
- Along the low P/T metamorphic field gradient significant melt production occur at point ***e*** by biotite breakdown
  Bt+Grt+Qtz=Crd+Opx+Kf+Liq
- At slightly higher P, significant melting is generated at point ***f*** via the rection
  Bt+Sil+Qtz=Grt+Crd+Kf+**Liq**



High-temperature petrogenetic grid showing the location of selected melting and dehydration equilibria in the NKFMASH system (after Winter, 2001)

Partial melting of pelites: Migmatites

Biotite dehydration melting reaction:
Bt+Sil+Qtz+Pl=
Grt+Crd+Kf+Liq

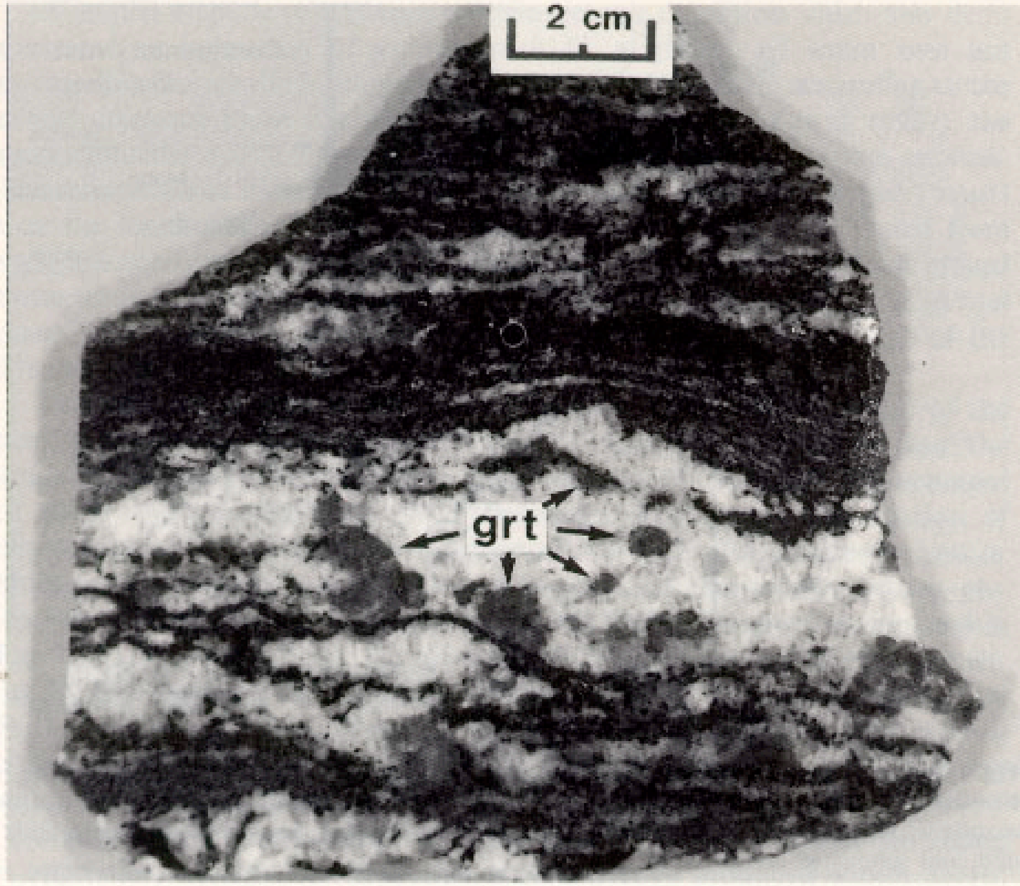


Fig. 1.10. Handspecimen showing formation of leucosome and restitic garnet (*grt*) due to the breakdown of biotite during dehydration melting in a metapelite from Turku area, Finland. (Meier 1992)

(after Johannes & Holtz, 1996)

Migmatiti

- Definizione
- Classificazione
- Modelli genetici

Approfondimenti in:

Ashworth J.R.(Ed) 1985: Migmatites. New York, Chapman and Hall

Sawyer E.W. (Ed) 2008: Working with Migmatites. MAC, Short Course Series Vol.38

Sawyer E.W. (Ed) 2008: Atlas of Migmatites. The Canadian Mineralogist Special Publication 9

Migmatiti

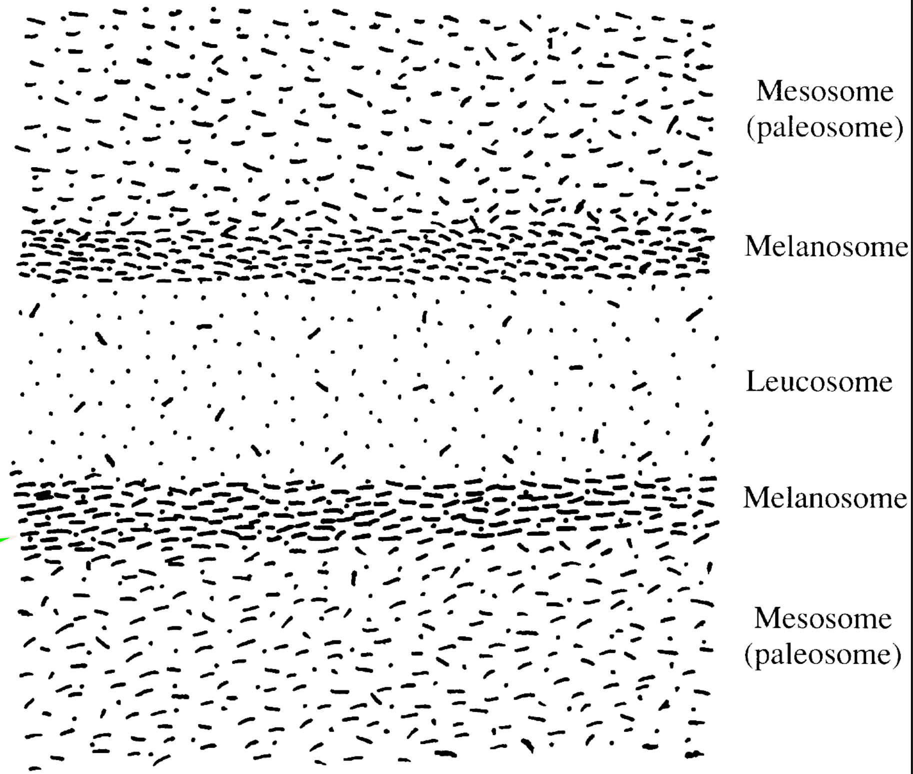
Il termine migmatite (dal greco migma = mescolanza) è stato coniato da Sederholm (1907) per indicare una roccia silicatica composita ("roccia mista") costituita da parti di colore scuro e aspetto metamorfico (mesosoma /paleosoma) e parti leucocratiche di aspetto granitico s.l. (leucosoma/neosoma)

Paragneiss migmaticici
(*stromatiti)*,Milazzo (Sicilia)

Migmatiti

✓I contatti leucosoma-mesosoma possono essere *netti o graduali*

✓Al contatto ci può essere un accumulo di minerali femici⇒*melanosoma* (*mafic selvage*)



15.15 Schematic segregation of felsic and mafic (dashes) minerals in a migmatite resulting from *in situ* partial melting. **Mesosome** is a descriptive term for rock intermediate in composition between mafic **melanosome** and **leucosome**, whereas **paleosome** is a genetic term for the protolith.

Migmatite resulting from *in situ* partial melting

Migmatiti: classificazione e *modelli* genetici

Classificazione

- I terreni migmatitici presentano una *grande variabilità strutturale* anche su piccole distanze

- Le migmatiti vengono classificate sulla base delle *caratteristiche strutturali* (Menhert, 1968)

Migmatites

Some structures of migmatites

a. Breccia structure in *agmatite*

b. Net-like structure

c. Raft-like structure

d. Vein structure

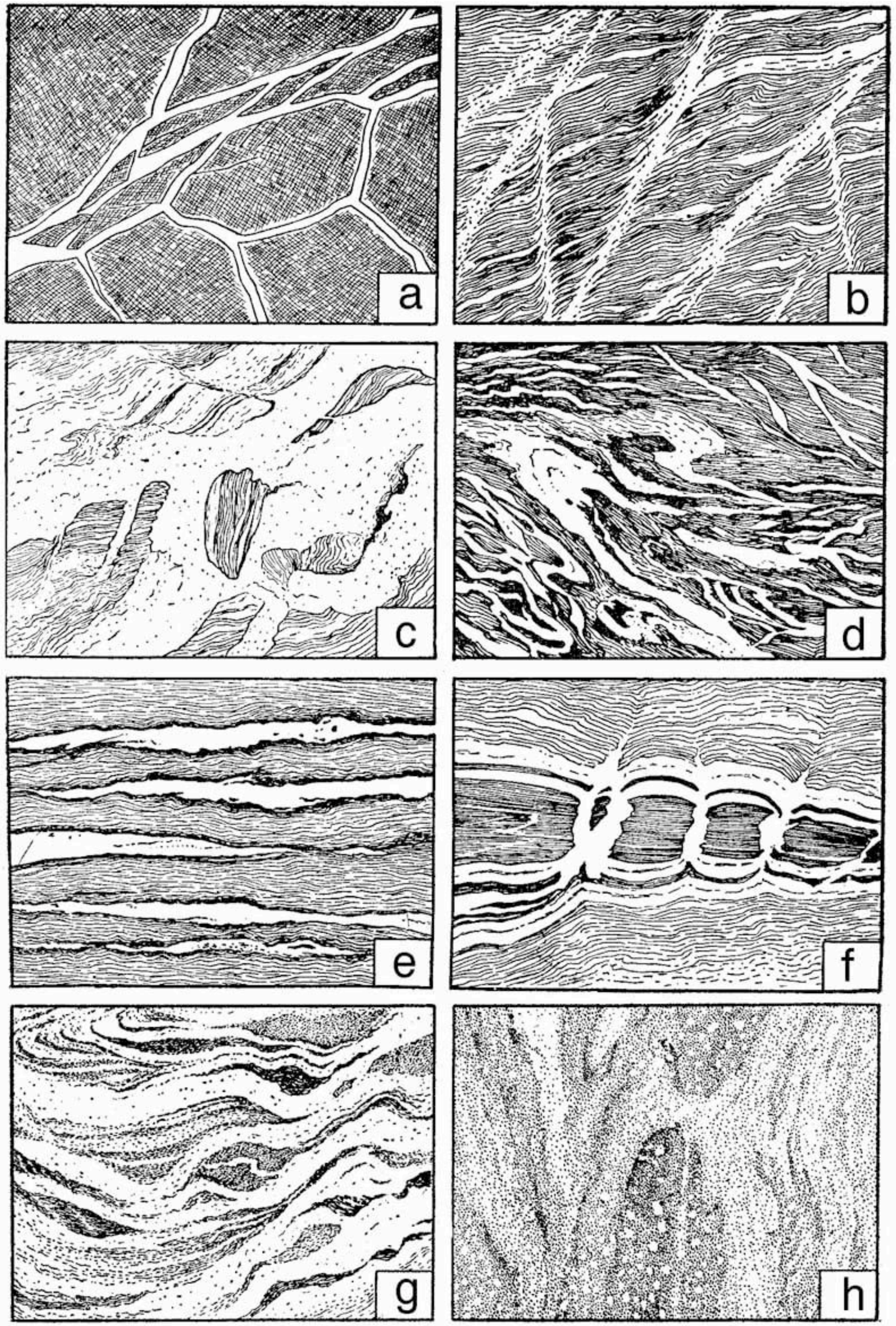
e. *Stromatic*, or layered, structure

f. Dilation structure in a boudinaged layer

g. *Schlieren* structure

h. *Nebulitic* structure

From Mehnert (1968) Migmatites and the Origin of Granitic Rocks. Elsevier.



Migmatiti: *Modelli* genetici
origine ignea (anatessi) vs. origine metamorfica

- Migmatiti di iniezione: iniezione di fusi leucocratici/granitici in rocce metamorfiche preesistenti (questo modello non spiega la natura melanocratica e il carattere restitico dei melanosomi
- Migmatiti di anatessi: fusione parziale *in situ* con il *fuso* che va a formare il *leucosoma* e il *residuo* di anatessi (parte *restitica*) che va costituire il melanosoma
- Migmatiti di origine metasomatica e/o di differenziazione

Migmatiti: Modelli genetici

origine ignea (anatessi) vs. origine metamorfica

- ✓ L'origine *ignea* vs. *metamorfica* delle migmatititi è stata per lungo tempo controversa, anche in considerazione del fatto che la composizione dei leucosomi è più comunemente *leucotonalitica/trondhjemitica* (qtz+pl) piuttosto che *granitica* (qtz+pl+kf: *minimum melt)*

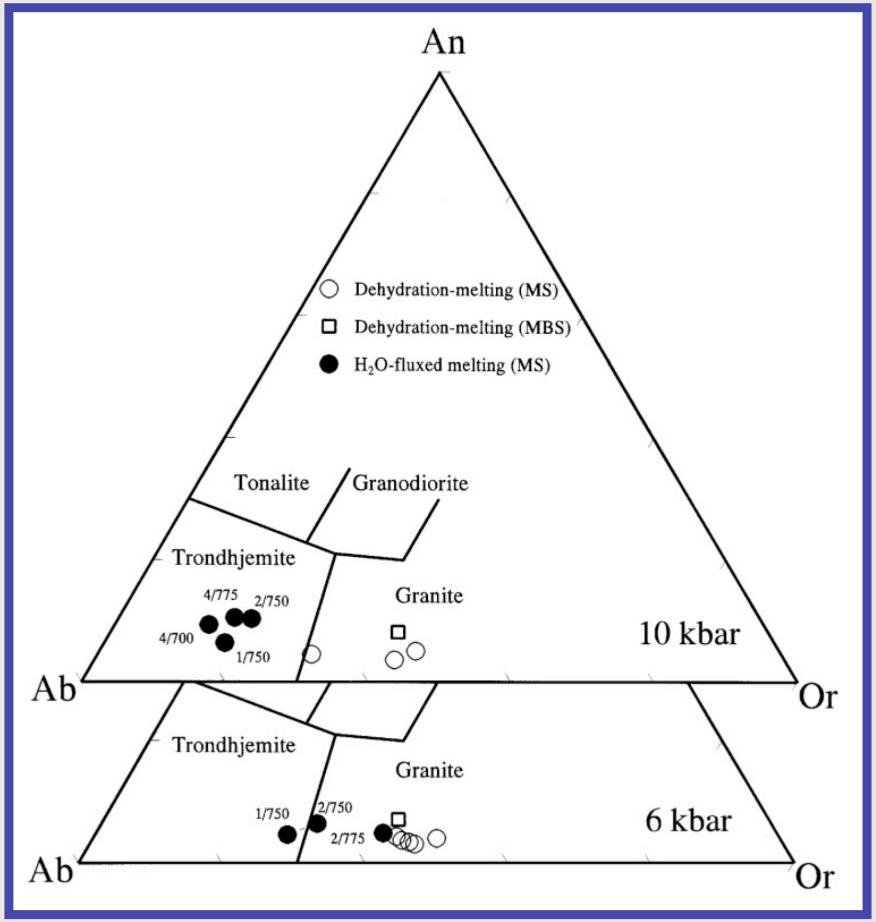
Migmatiti: modelli genetici

origine ignea (anatessi) vs. origine metamorfica

✓ Risultati sperimentali recenti (Patino Douce & Beard, 1996; Patino Douce & Harris, 1998) hanno messo in evidenza che composizioni *granodioritiche e trondhjemitiche* si possono formare

i) in presenza di una fase fluida libera (fusione di *qtz+pl* con scarso coinvolgimento della Ms)

ii) ad alta P



Patino Douce & Harris (1998): Experimental constraints on Himalayan Anatexis. J. Petrol., 39, 689-710.

Migmatiti: modelli genetici

origine ignea (anatessi) vs. origine metamorfica

✓ Composizioni trondhjemitiche e granodioritiche si possono formare anche attraverso processi di frazionamento sol/liq: ➡ *accumulo di plagioclasi* di prima cristallizzazione con formazione di *frazionati ricchi in Kfeldspato* (Sawyer et al., 1999)