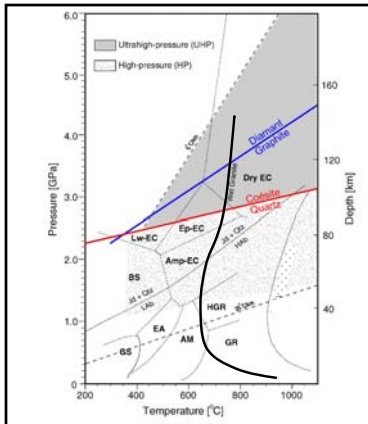
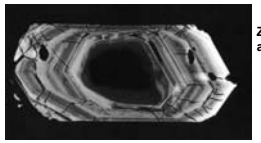
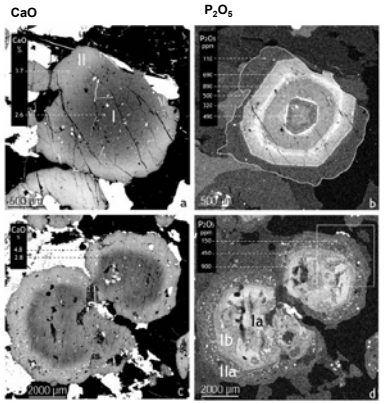
Melting of crustal materials at high pressure





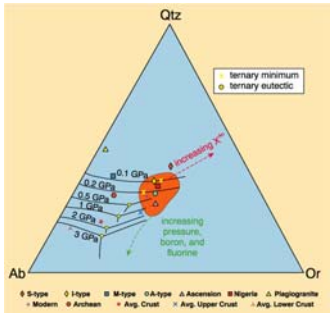
Zircon from a HP granite

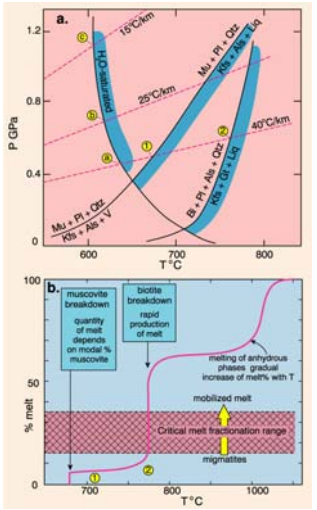


HP-HT garnets from Massif Central (Vielzeuf et al. 2005)

Melting in the crust:
the traditional low pressure view

→ to be applied to HP





Winter (2001) Magmatic and Metamorphic Petrology

Chapter 18: Granitoid Rocks

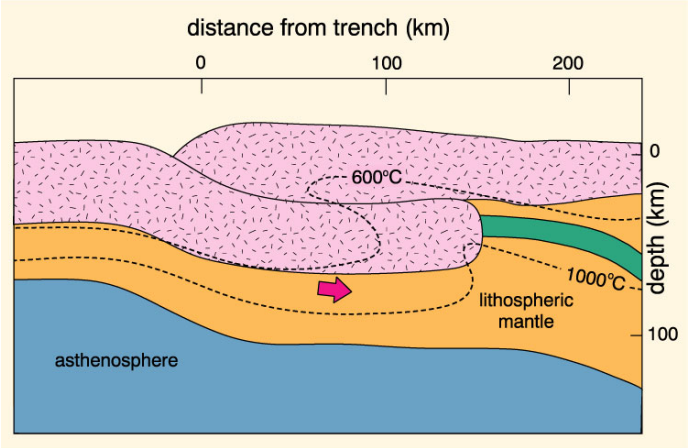


Figure 18-6. A simple modification of Figure 16-17 showing the effect of subducting a slab of continental crust, which causes the dip of the subducted plate to shallow as subduction ceases and the isotherms begin to "relax" (return to a steady-state value). Thickened crust, whether created by underthrusting (as shown) or by folding or flow, leads to sialic crust at depths and temperatures sufficient to cause partial melting. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Chapter 18: Granitoid Rocks

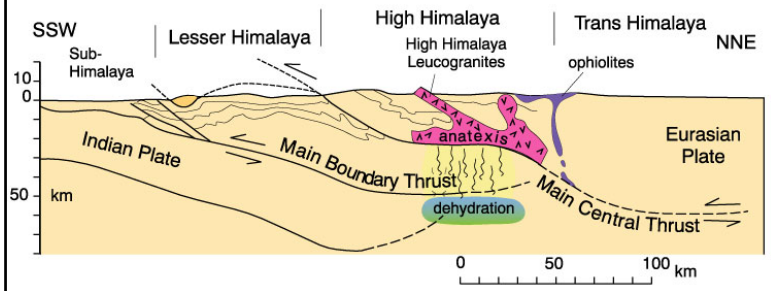
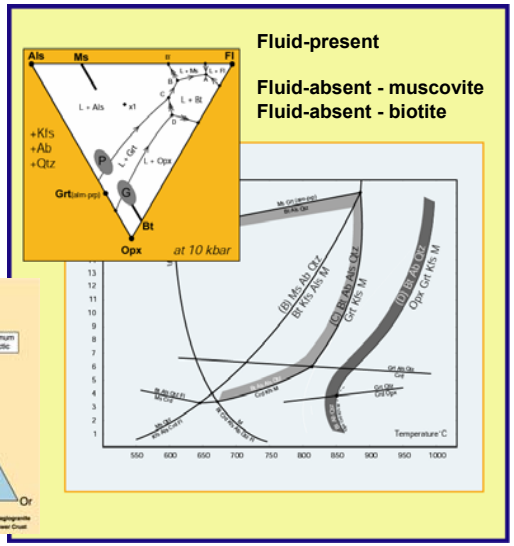


Figure 18-7. Schematic cross section of the Himalayas showing the dehydration and partial melting zones that produced the leucogranites. After France-Lanord and Le Fort (1988) *Trans. Roy. Soc. Edinburgh*, 79, 183-195. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Liquid compositions of crustal melting:

project from >90% i.e. from plag+kfsp+ qz



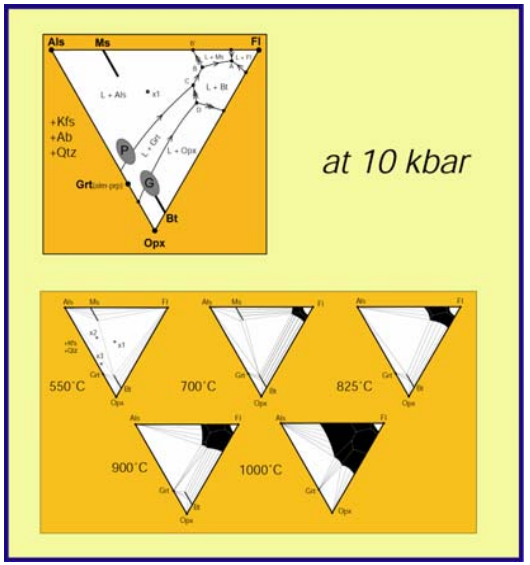
Fluid-present

Fluid-absent - muscovite

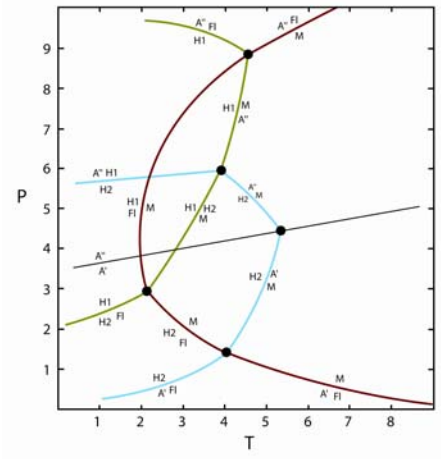
Fluid-absent - biotite

Liquid compositions of crustal melting:

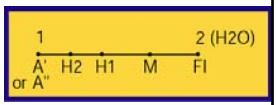
project from >90% i.e. fsp's + qz

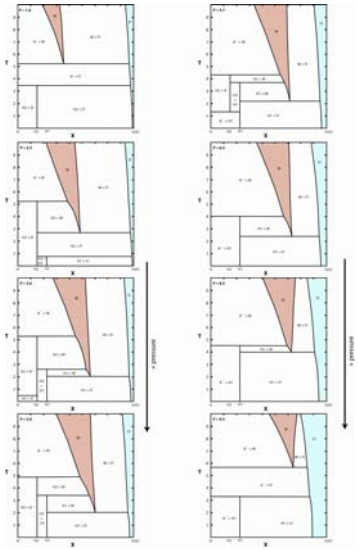


High pressure melting: Two Hydrous phases and S-shaped solidi



red: wet solidus
blue: stability of hydrous phase 1
green: stability of hydrous phase 2





Some motivation:

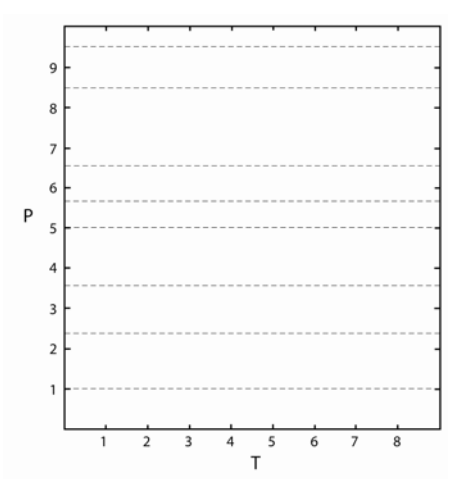
The resulting topology and shape of solidi is general for crustal rocks.

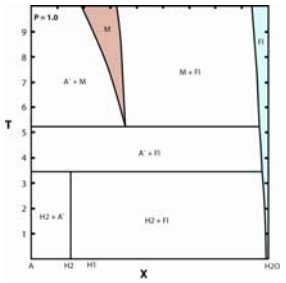
In metabasalts H1 and H2 are amphibole and epidote/zoisite

In metasediments H1 and H2 are biotite and phengite

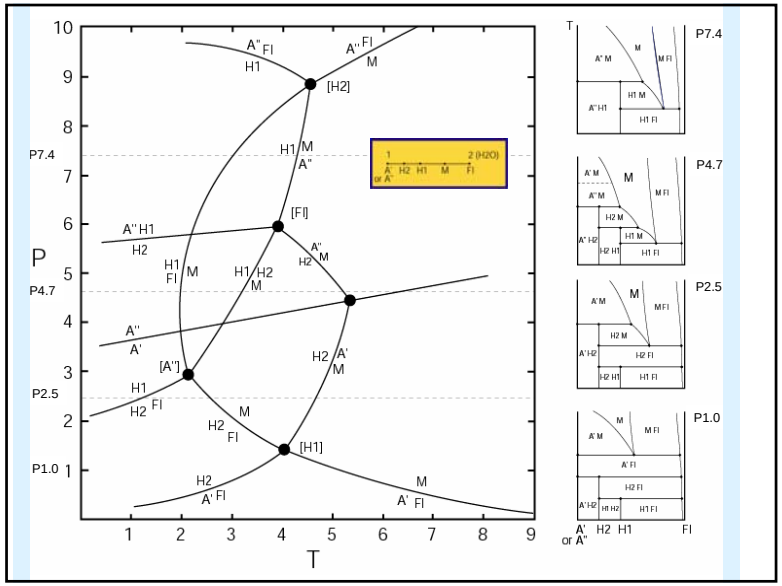
A` = A`` could be:
cordierite - garnet
albite - jadeite
plag - omphacite
garnet-in
...

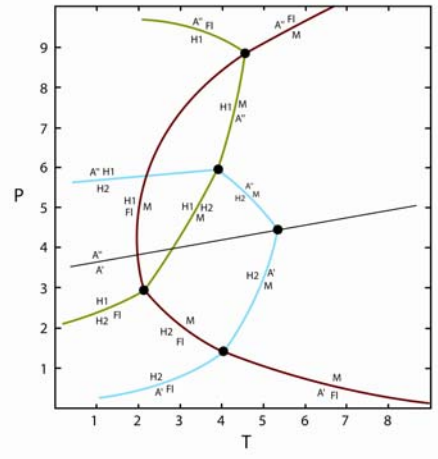
Of course combinations of all the above occur, e.g. in metatonalites and Ca-rich greywackes





subsolidus reactions to 7 GPa have flat positive slopes, above flat negative slopes



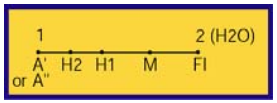


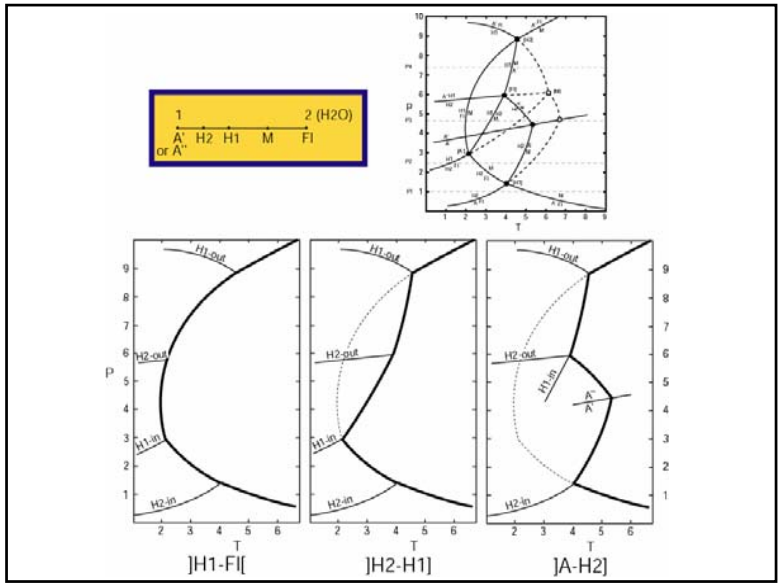
Exercise 2:
find the relevant solidus for

A) a rock which contains more H_2O than H1

B) a rock that has a H_2O content between H1 and H2

C) a rock that has a H_2O content between A and H2

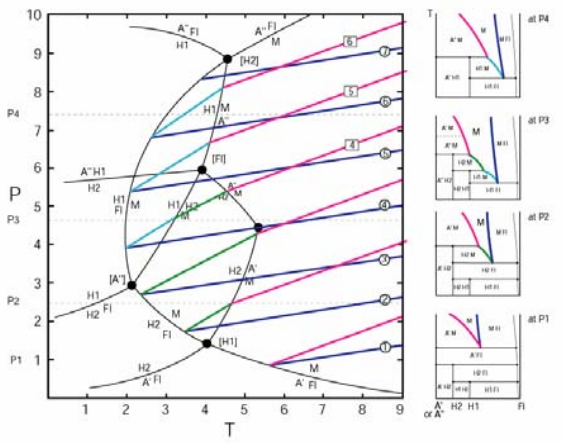


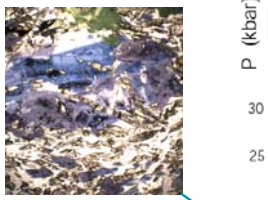


Considering systems saturated with Als and quartz

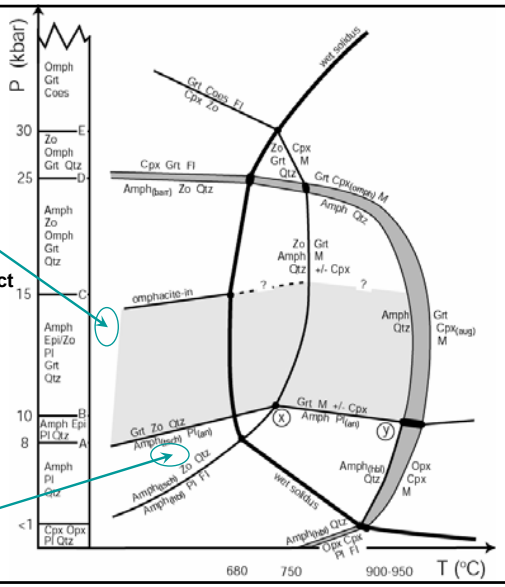
A	*A'*	*Reaction*
Anorthite	*Grossular*	*An = Grs + Als + Qtz*
Cordierite	*Garnet*	*Crd = Grt + Als + Qtz*
Orthopyroxene	*Garnet*	*Opx + Als = Grt + Qtz*

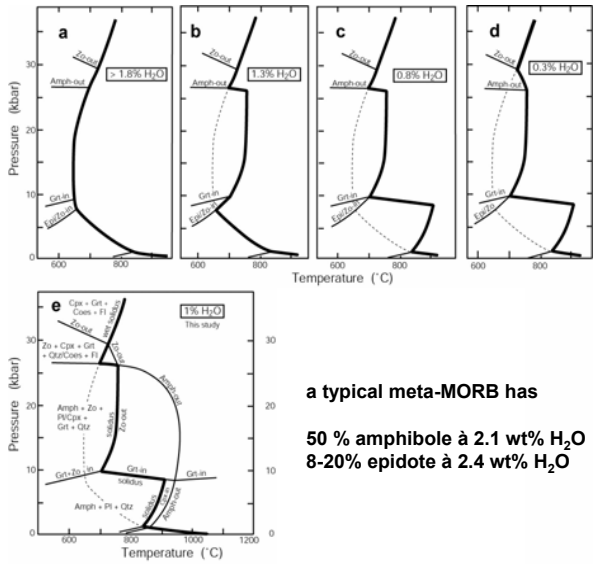
Isopleth of H_2O content in the melt





The constructed diagram and the solidi have a direct equivalent in metabasalts where H1 and H2 are zoisite/epidote and amphibole

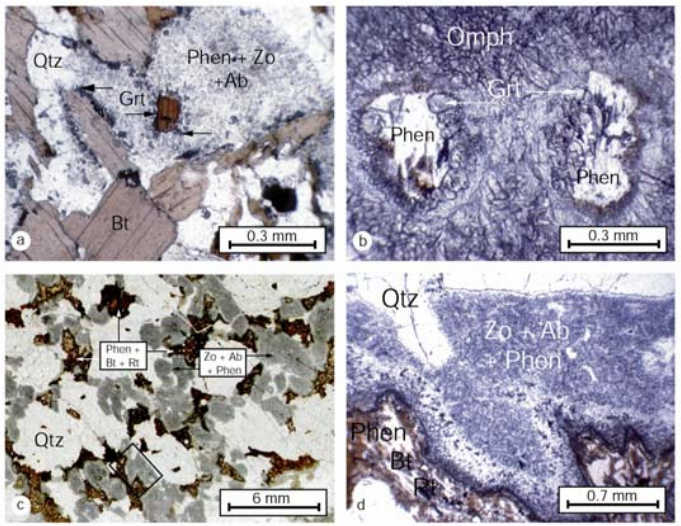


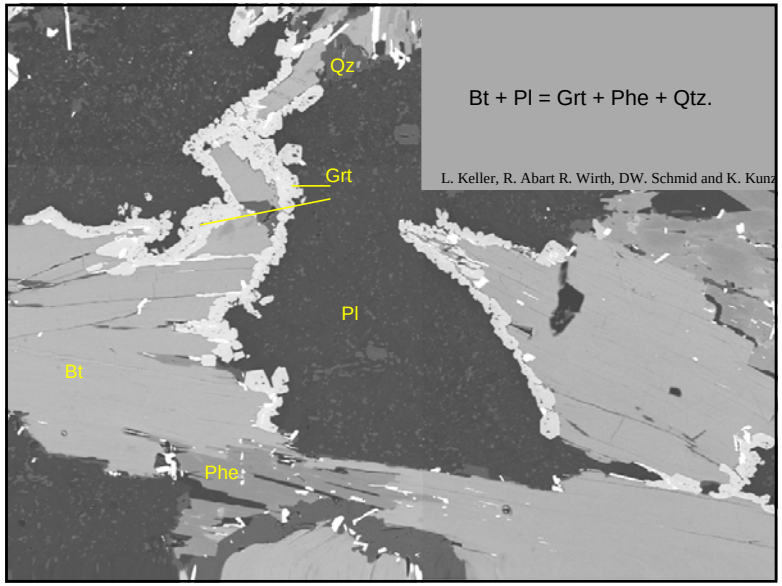


a typical meta-MORB has

50 % amphibole à 2.1 wt% H_2O
8-20% epidote à 2.4 wt% H_2O

What about meta-granites/greywackes/pelites ?



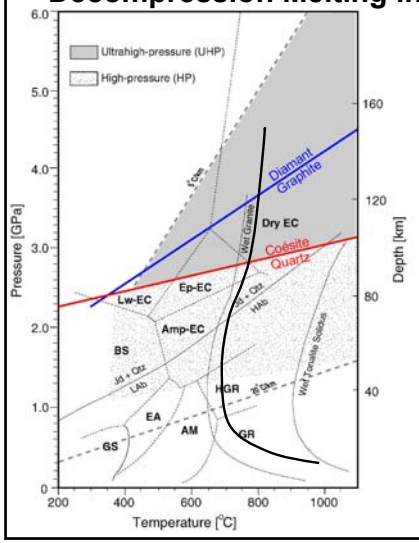


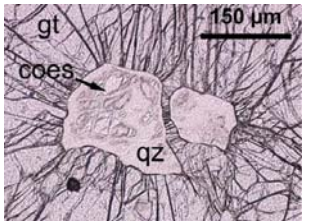
Bt + Pl = Grt + Phe + Qtz.

L. Keller, R. Abart R. Wirth, DW. Schmid and K. Kunz

- The shape and location of the solidus changes as a function of the bulk H_2O content.
- There are remarkable analogies in melting behaviour of metapelites, metagreywackes and metabasalts

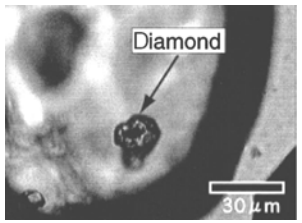
Decompression Melting in the continental crust





(Chopin, 2004)

Katayama et al. (2000)

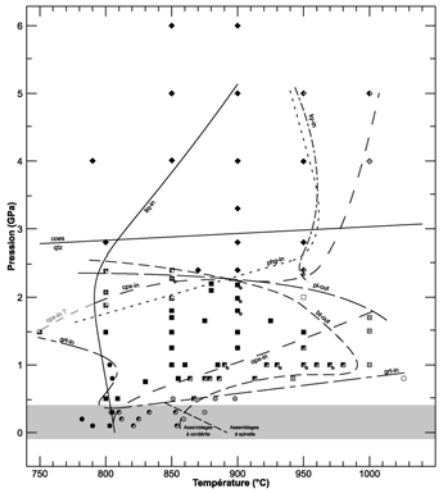


Experimental Conditions

- Metagreywacke Composition
- Biotite + Plagioclase$_{(An20)}$ + Quartz
- Fine mineral powder (<5µm)
- Pressure range 5-80 kbar
- 3 isothermal sections (800, 850, 900°C)

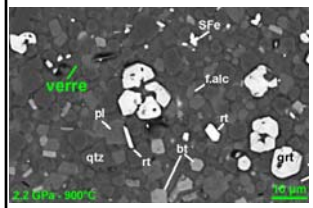
10 major phases :

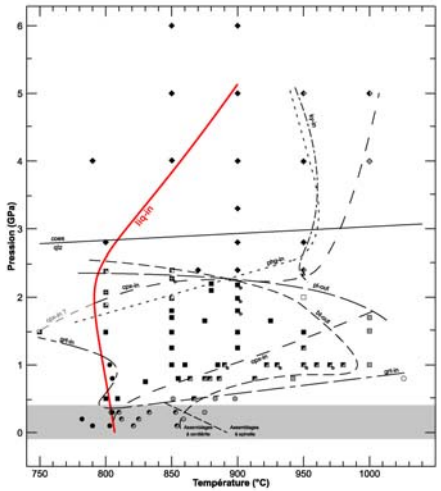
Quartz / coesite : always present
Biotite
Plagioclase
(K-feldspar)
Orthopyroxene
Garnet
Phengite
Clinopyroxene
Kyanite
Silicate melt



Melt

Solidus
P = 0.5 à 2.4 GPa :
Negative slope
P = 2.4 à 5.0 GPa :
Positive slope

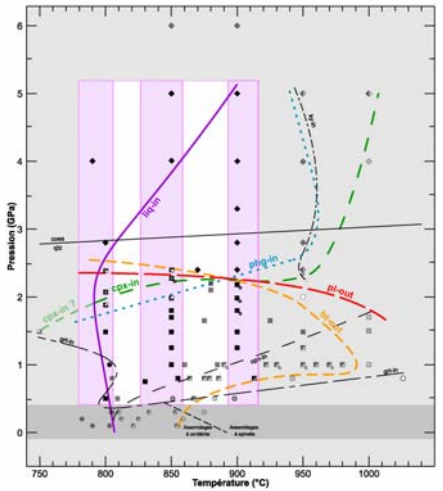


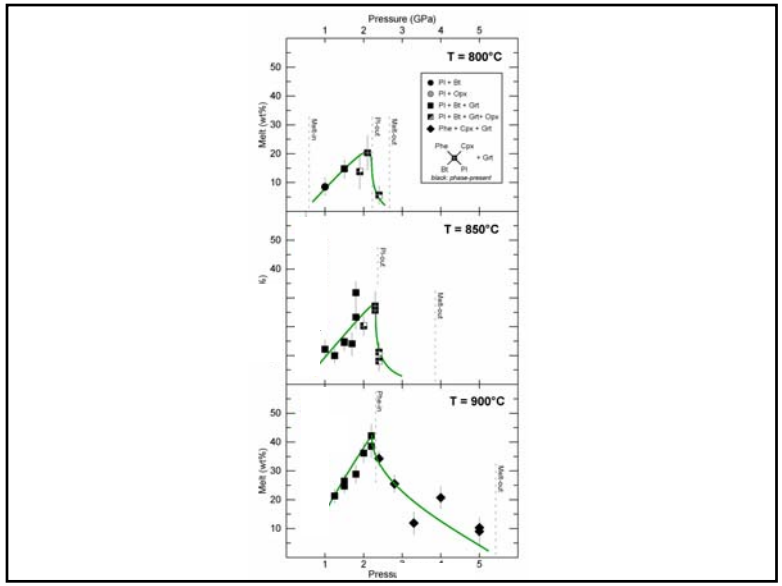


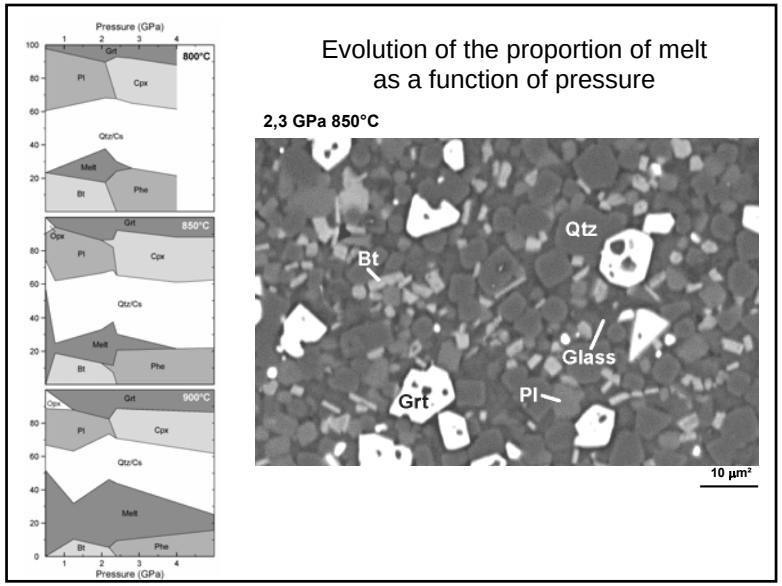
HP domain
No Bt, Pl, Opx
qtz/coes + phg + cpx + grt ± glass

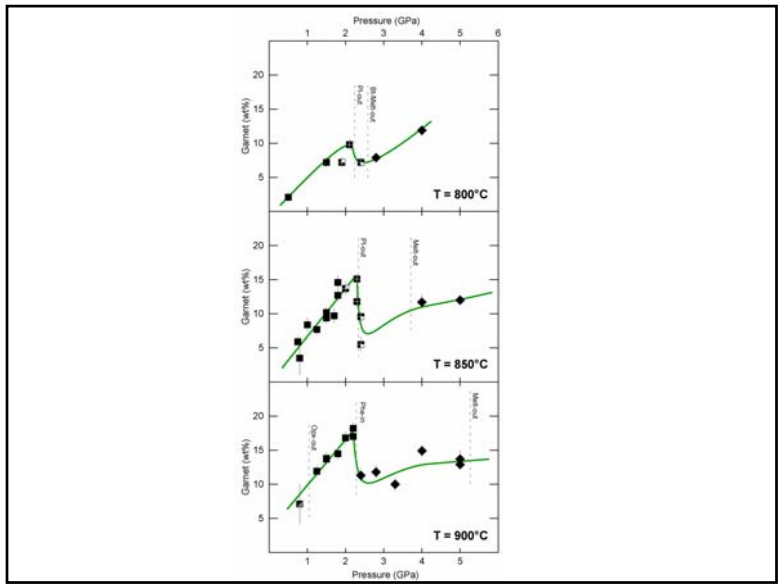
Intermediate domain
qtz + bt + phg ± cpx ± pl + grt + glass

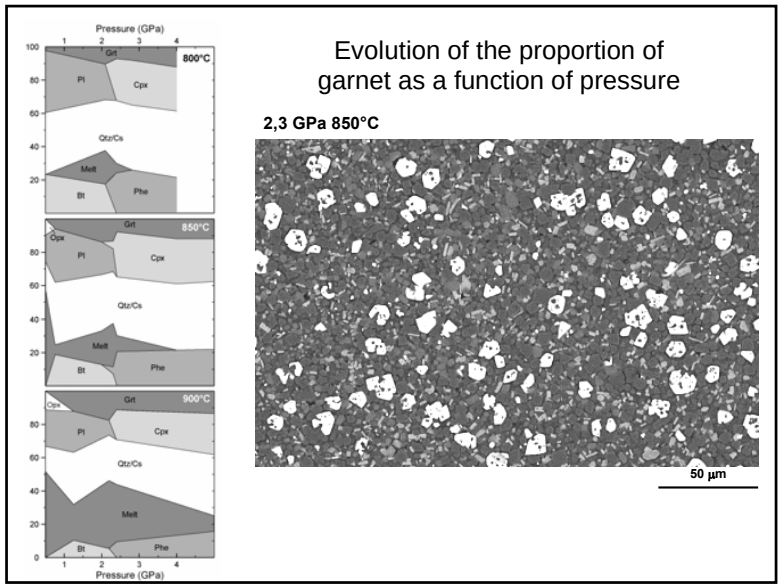
LP domain
No Phg, Cpx
qtz + bt + pl + grt ± verre
qtz + bt + pl + grt + opx + verre




Pressure (GPa)
T = 800°C
T = 850°C
T = 900°C
Melt (wt%)
Pl + Bt
Pl + Cpx
Pl + Bt + Grt
Pl + Bt + Grt+ Cpx
Phe + Cpx + Grt
Phe
Cpx
+ Grt
Bt
Pl
black: phase-present


Pressure (GPa)
800°C
850°C
900°C
Grt
Pl
Cpx
Qtz/Cs
Melt
Bt
Phe
Evolution of the proportion of melt as a function of pressure
2,3 GPa 850°C
Qtz
Bt
Glass
Grt
Pl
10 µm²


Pressure (GPa)
Garnet (wt%)
T = 800°C
T = 850°C
T = 900°C


Pressure (GPa)
800°C
850°C
900°C
Grt
Pl
Cpx
Qtz/Cs
Melt
Bt
Phe
Evolution of the proportion of garnet as a function of pressure
2,3 GPa 850°C
50 µm

P = from 2.3 to 5,0 GPa

Solidus

Solidus :

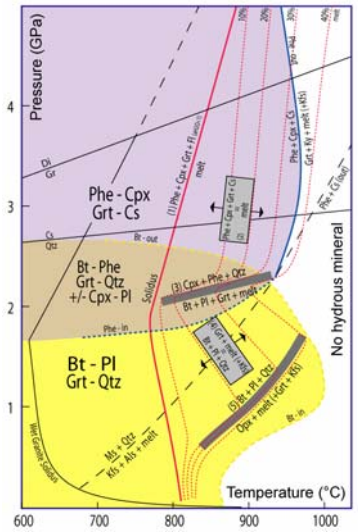
phg + cpx + grt + fl = liq

Experiments:
a_{H2O} <1 in the fluid phase.

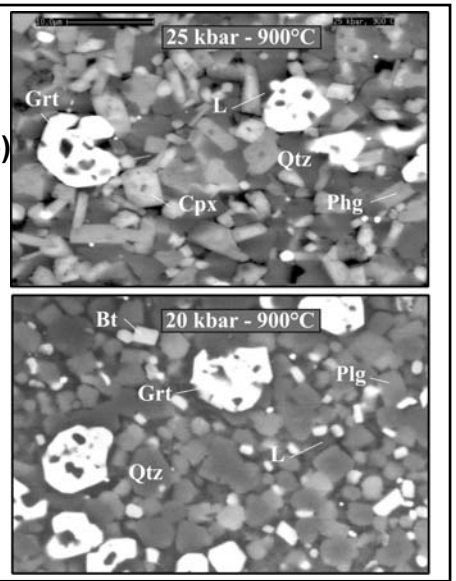
UHP rocks :
Fluid inclusions with a_{H2O} <1 *(Xiao et al., 2000; Philippot et al., 1995)*

Under UHP conditions, partial melting with ($^{fluide}a_{H2O}$<1) is likely.

Under UHP conditions, temperatures around 800-850°C are sufficient to generate significative amounts of partial melt.
The ingress of a fluid rich in H_2O is not required.



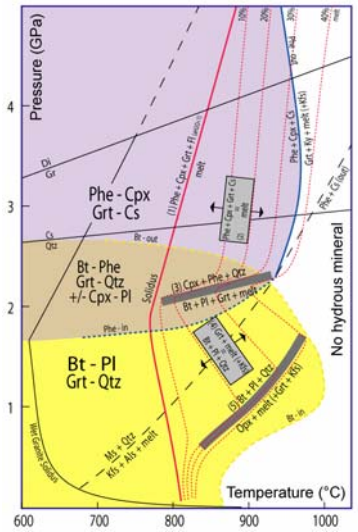
Eclogite- to amphibolite (granulite) facies transition



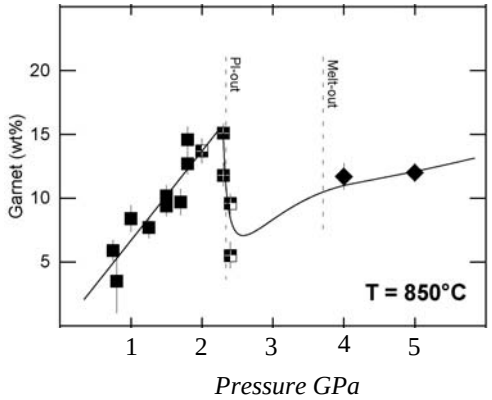
P ≈ 1.8 à 2.5 GPa

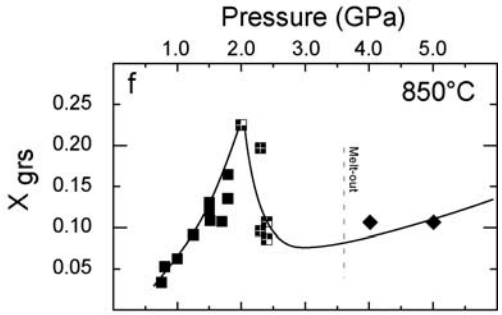
cpx + phg + qtz = bt + pl + grt + melt

45 Phe + 49.9 Cpx + 5.1 Qtz
=
35.7 Bt + 42.2 Pl + 5 Grt + 17.2 M



To lower pressures





P < 2,0 GPa

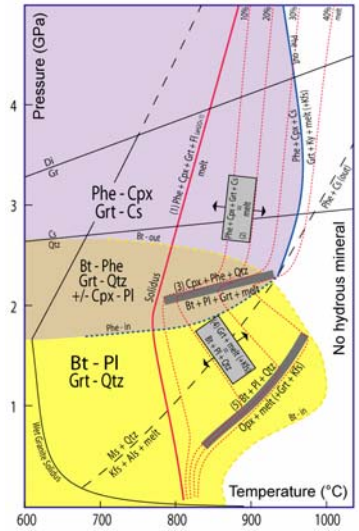
Pressure decrease
grt + melt (+ Kfs) = bt + pl$_{(an)}$ + qtz

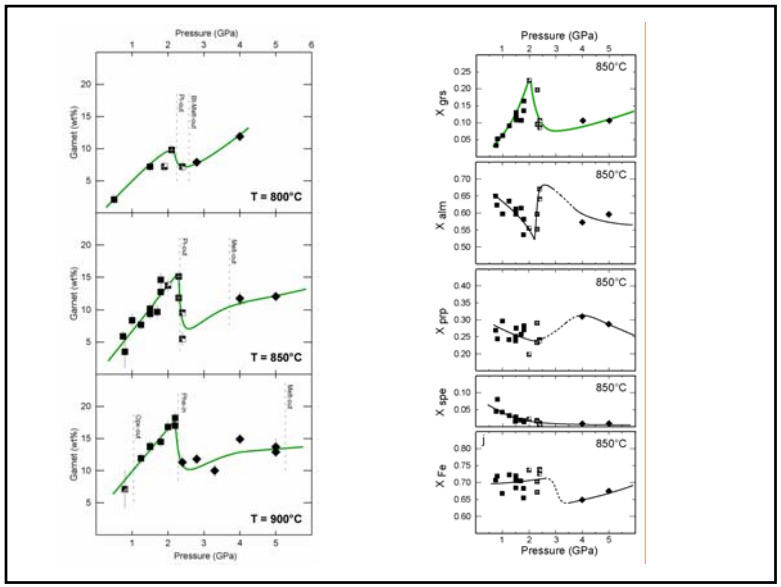
Garnet zoning during decompression

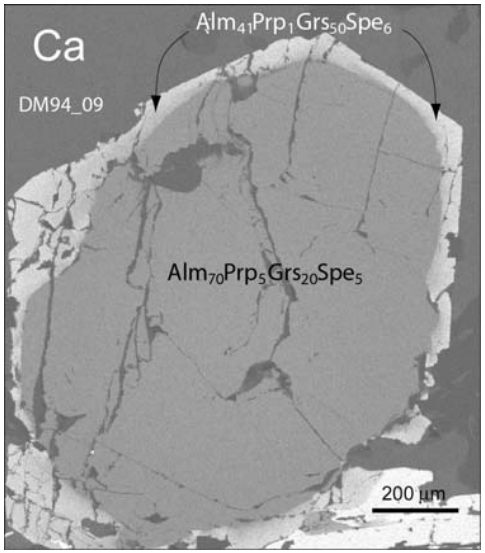
Crystallization of a Grs-rich garnet at the eclogite/amphibolite transition (garnet overgrowth)

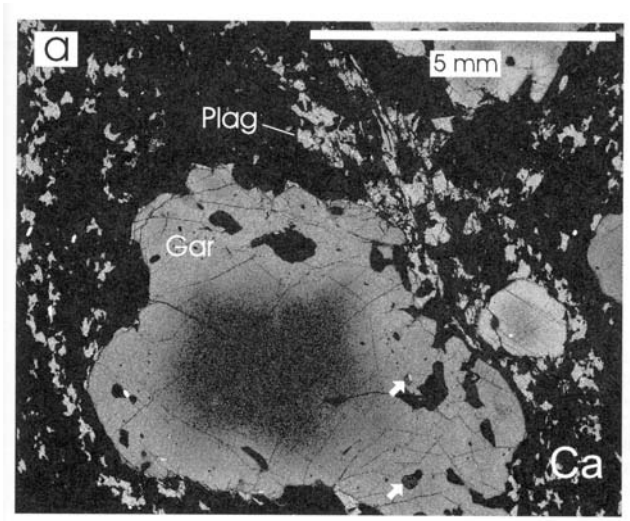
Breakdown of garnet below (resorption surfaces)

In HP subducted rocks, grossular-rich zones in garnet are not necessarily indicative of highest P during the metamorphism.









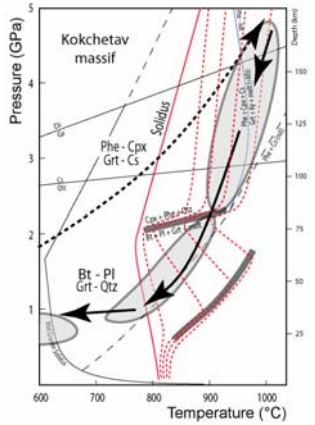
Terry et al. Am. Mineral. 2000

Partial melting during the exhumation of UHP metamorphic units

Kokchetav massif - Kazahhstan

Indications of partial melting

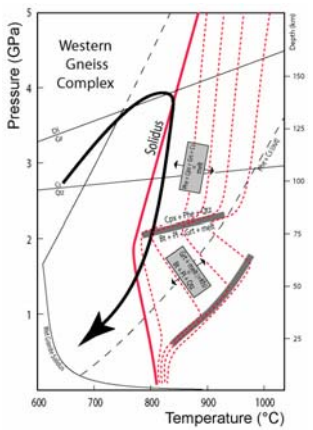
- Diamond gneisses depleted in K, Na, Si, LREE *(Shatsky et al., 1995)*
- Zoned zircons (UHP, BP) crystallized from a granitic melt saturated in Zr *(Hermann et al. 2001)*
- UHP : 528 ± 4 Ma *(Hermann et al. 2001)*
  migmatite : 523 ± 4 Ma *(Ragozin et al., 2005)*
- P-T path crossing the solidus *(Shatsky et al., 1995; Hermann et al., 2001)*
- Garnet rims enriched in grossular *(Shatsky et al., 1995; Hermann et al., 2001)*



Western Gneiss Region, Norvège

Indications of partial melting

- Migmatization "modest but widespread" in the UHP gneissic unit *(Labrousse et al., 2002)*
- post-éclogitization partial melting during the exhumation (*Labrousse et al., 2002*)
- P-T path crossing the solidus *(Terry et al., 2000)*
- Garnet rims enriched in grossular *(Terry et al., 2000)*



Dabie Shan - Sulu, Chine

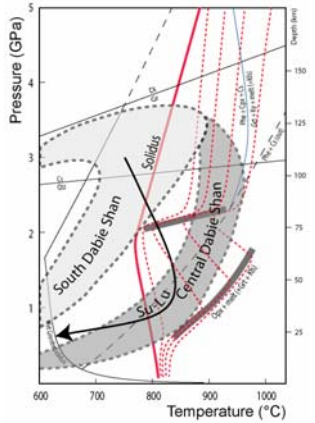
Dabie Shan

Indications of partial melting

- Foliated garnet-bearing granites (no coesite) in UHP gneissic units *(Zhong et al., 1999, 2001; Zhang et al., 2001)*
- UHP : 220-240 Ma
  Foliated granites : 227-234 Ma *(Zhang et al., 2001)*
- P-T trajectories

Dabie Shan sud : may cross the solidus *(Faure et al. 2003)*

Dabie Shan centre : crosses the solidus but … *(Faure et al. 2003)*



Sulu, China

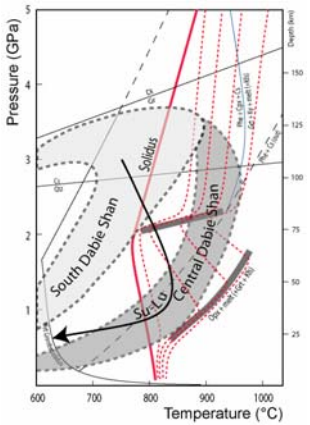
Sulu

Indications of partial melting

- Granitic dykes rich in Kfs *(Wallis et al. 2005)*
- UHP : 214-234 Ma *(Li et al., 1999)*
  dykes : 200-230 Ma *(Wallis et al. 2005)*

- P-T trajectories crossing the solidus

(Wang et al., 1993)



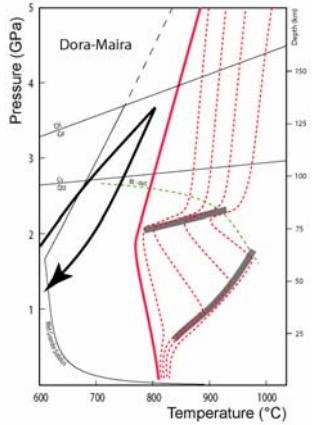
Dora Maira, Italia

Indications of partial melting

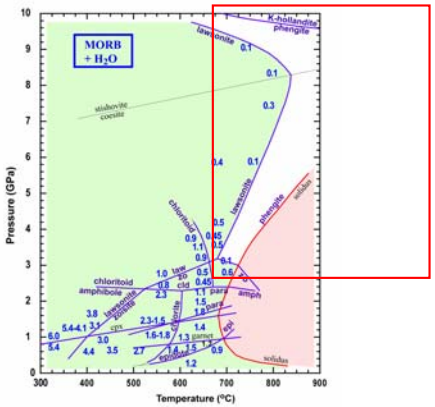
- Incipient melting in UHP gneisses *(Schertl et al., 1991)*

- P-T trajectory not crossing the solidus

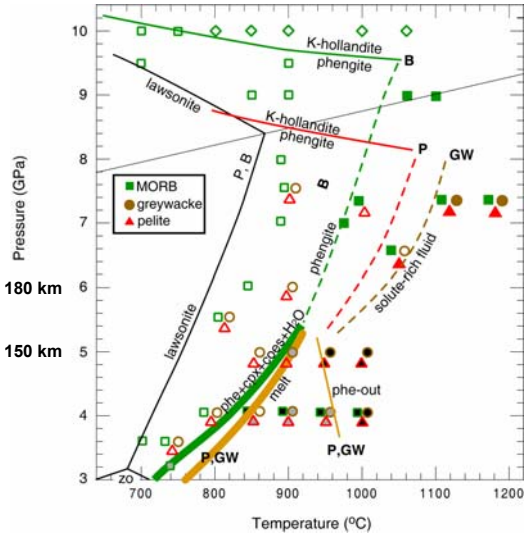
(Schertl et al., 1991)



Hydrous phases in MORB and peridotite
and H_2O-contents stored in hydrous phases



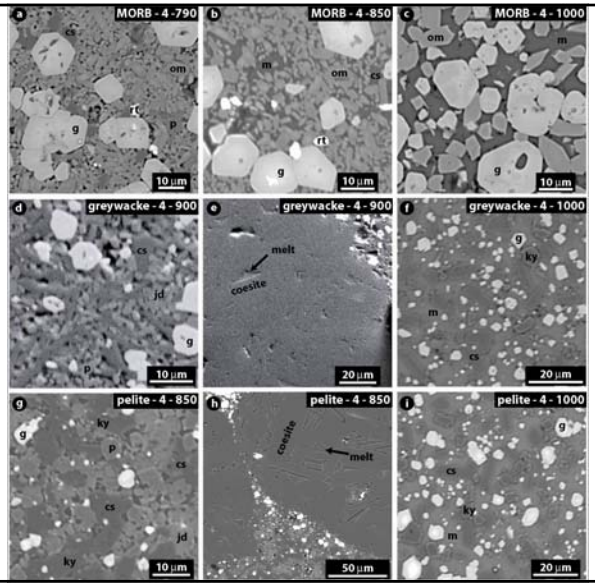
next slide



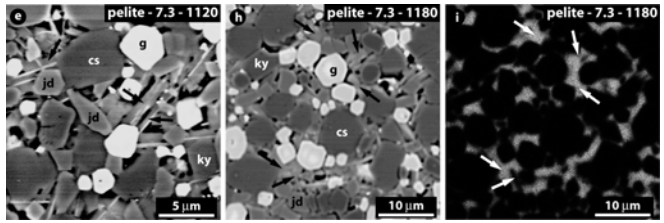
At > 100 km, clastic sediments and basaltic rocks have the same eclogitic mineralogy:

garnet+cpx+phengite +rutile+quartz

between 150 and 180 km depth, the solidus ceases to exist



Clay at 7.3 GPa (220 km), 1120-1180 °C



A high pressure pelite should have 25 % mica !

garnet – clinopyroxene (jd) – coesite – kyanite – rutile
+ supercritical melt

Mobile phase:

at low pressure aqueous fluid or melt, depending on P-T-conditions;
at high pressure chemical continuum (supercritical melt);

→ there is no solidus, i.e. no “melting temperature” at high pressure !!