Modelling melt-bearing systems

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Intro: Systematics of melting equilibria

Intro: Physical behaviour of melt-bearing systems

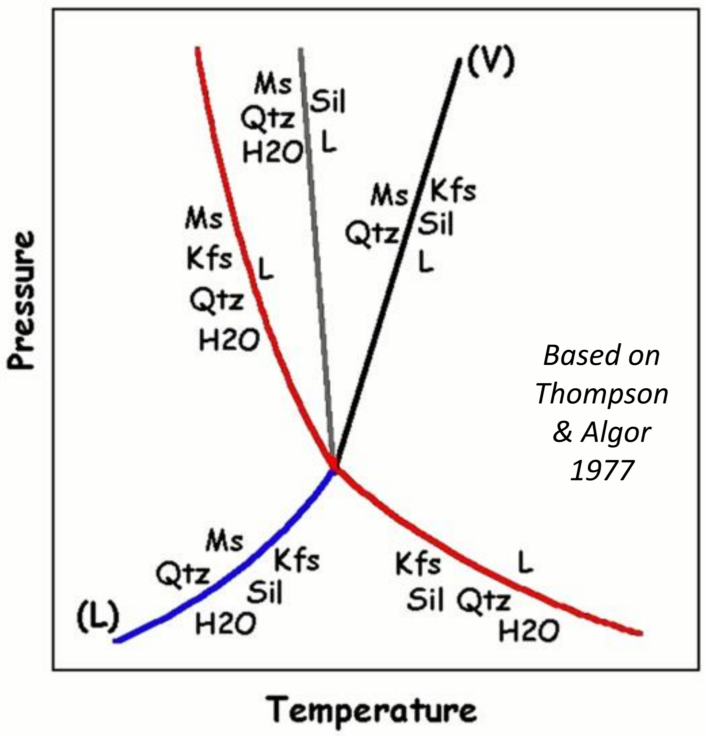
Approaches to modelling:

1. Forward modelling of melting relations
2. Migmatites: H_2O-saturated vs dehydration melting
3. Dealing with melt loss in migmatites and granulites

Systematic phase relations of melting equilibria

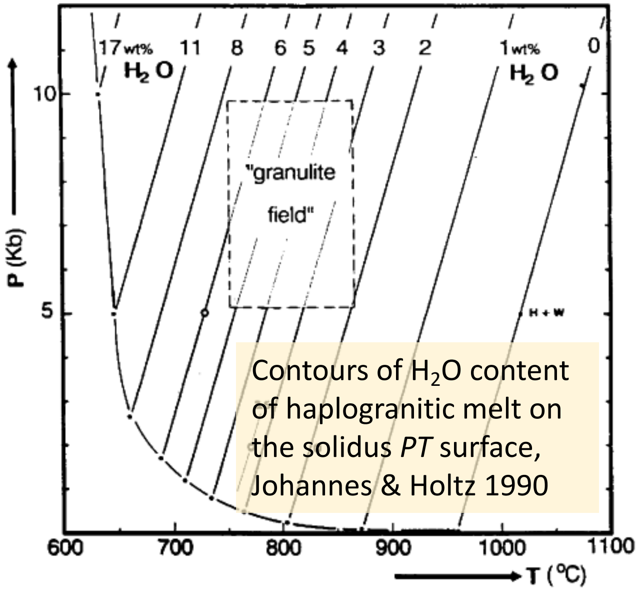
Vapour-present and vapour-absent (dehydration-) melting reactions [generic bundle, but drawn for muscovite]

- Red curves define the **H_2O-saturated solidus**
- Intersection of subsolidus dehydration reaction (L) generates other, incongruent melting curves (solid products)
- One of these is the **vapour-absent dehydration melting** reaction (V)



Based on Thompson & Algor 1977

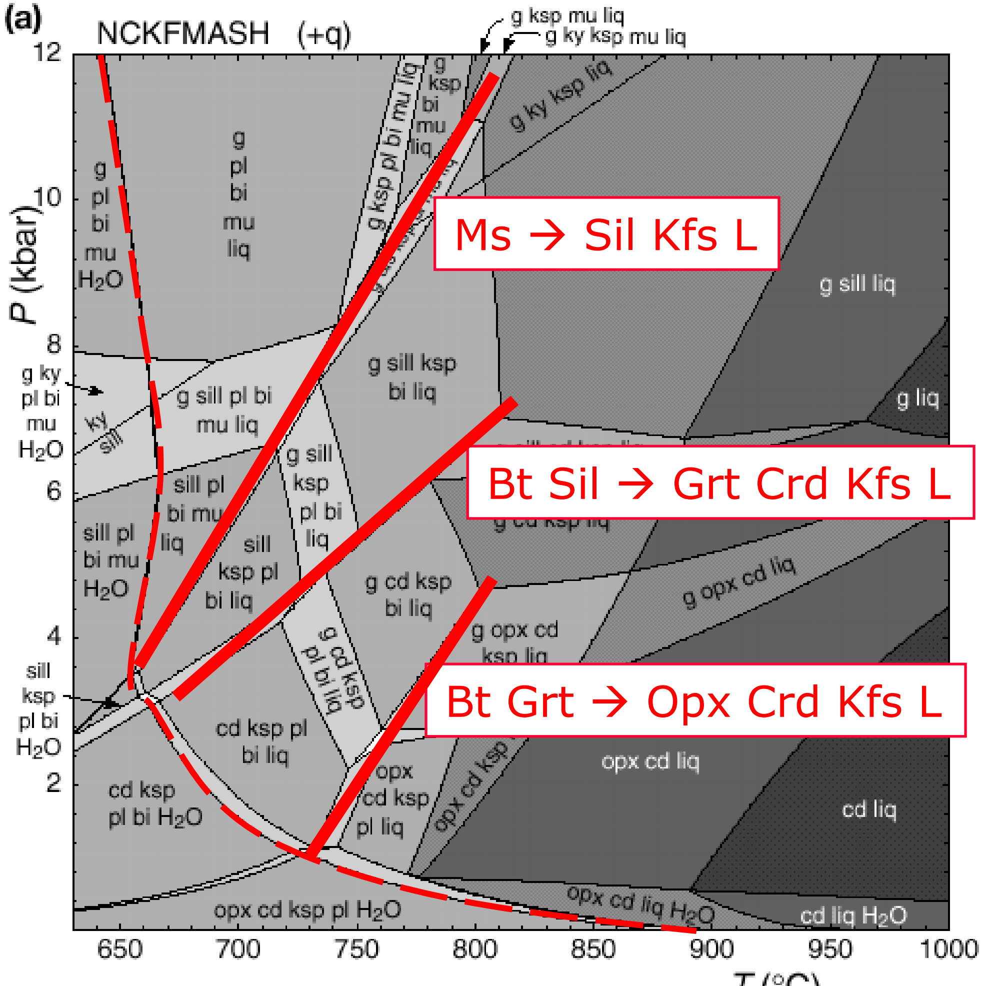
Decrease with *T* in water content of melt in system with fixed H_2O content leads to increase in melt volume



Contours of H_2O content of haplogranitic melt on the solidus *PT* surface, Johannes & Holtz 1990

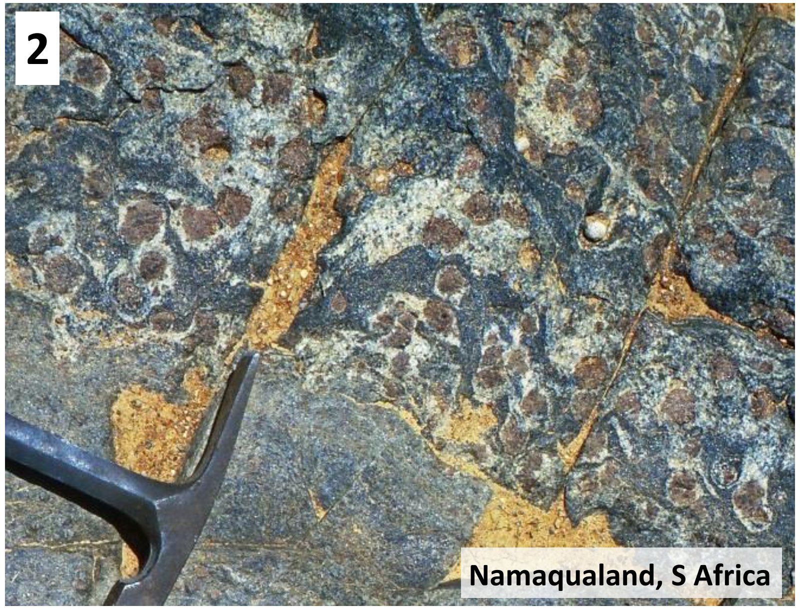
Diagram for 'average pelite', H_2O-absent suprasolidus assemblages.

- Narrow bands mark low-variance dehydration melting reactions
- But dehydration melting also occurs up-T in other fields with micas



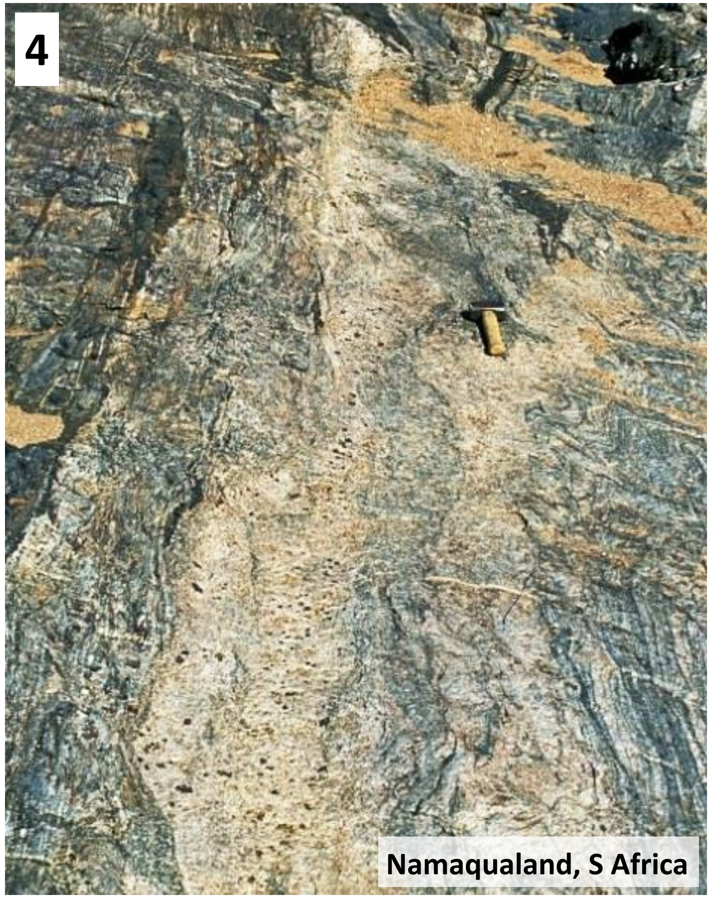
White et al. 2001, JMG

Physical behaviour of melt-bearing systems



Connectivity established ~7–10 vol% (Brown 2007)

Deformation assists melt migration



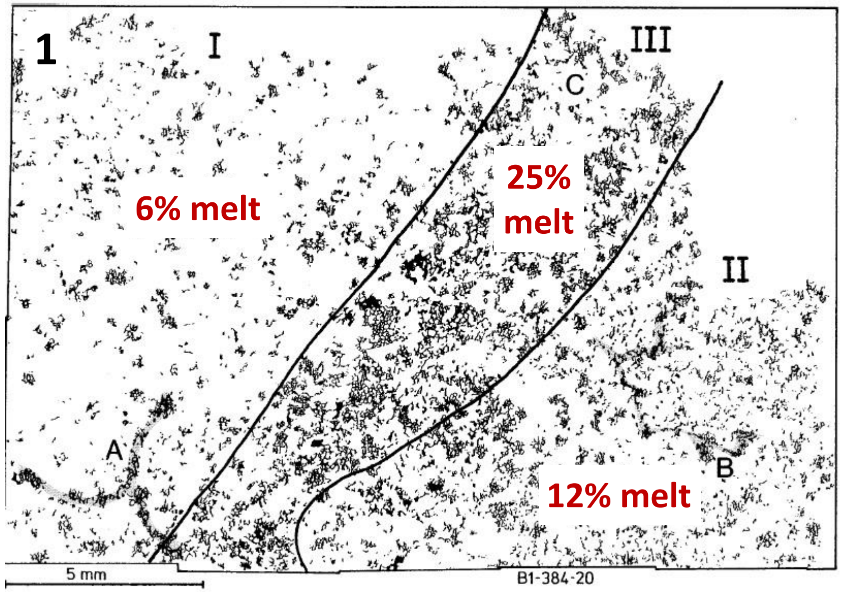
1. Stromatic migmatite; leucosomes have melt composition (probably H_2O-saturated)
2. Dehydration melting of biotite, first melt forming around existing garnet
3. Continuous neosomes with peritectic Grt and local melt accumulation
4. Sheet of Grt-bearing leucogranite (melt migration with entrained crystals)

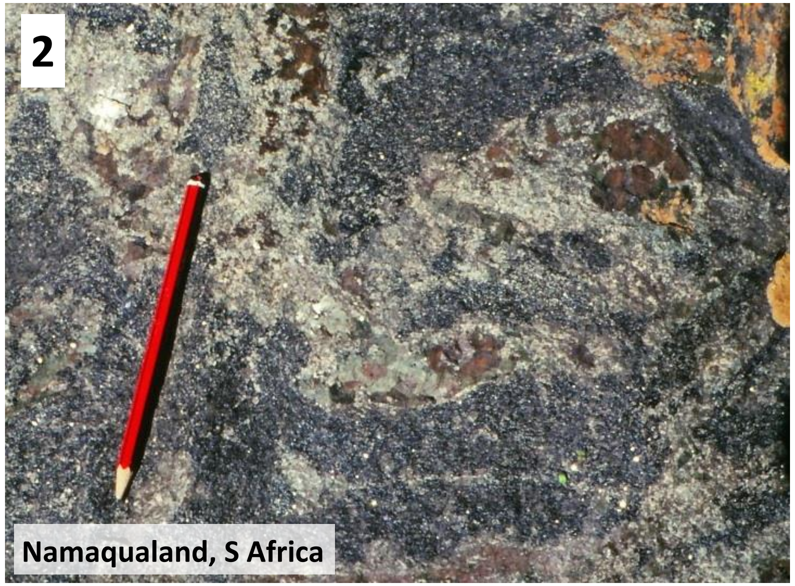
Physical behaviour of melt-bearing systems

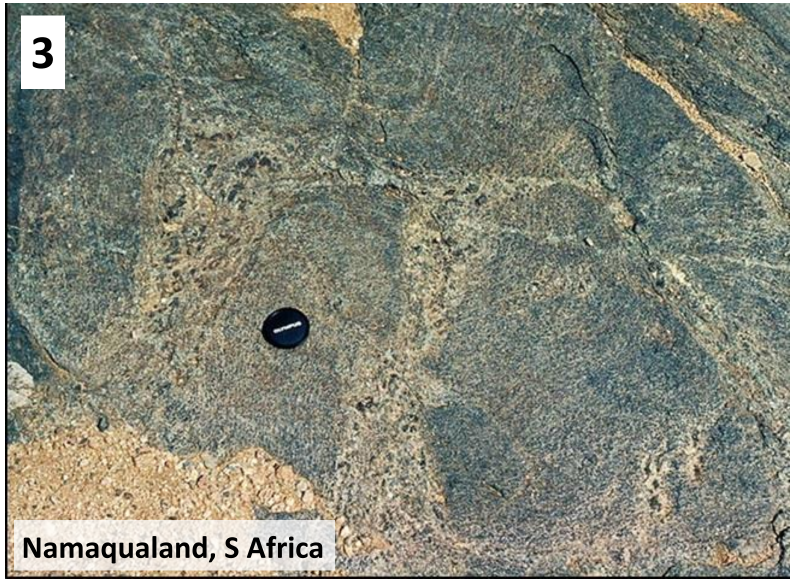
1. Melt connectivity, melt proportion at thin-section scale (Sawyer, 2001)

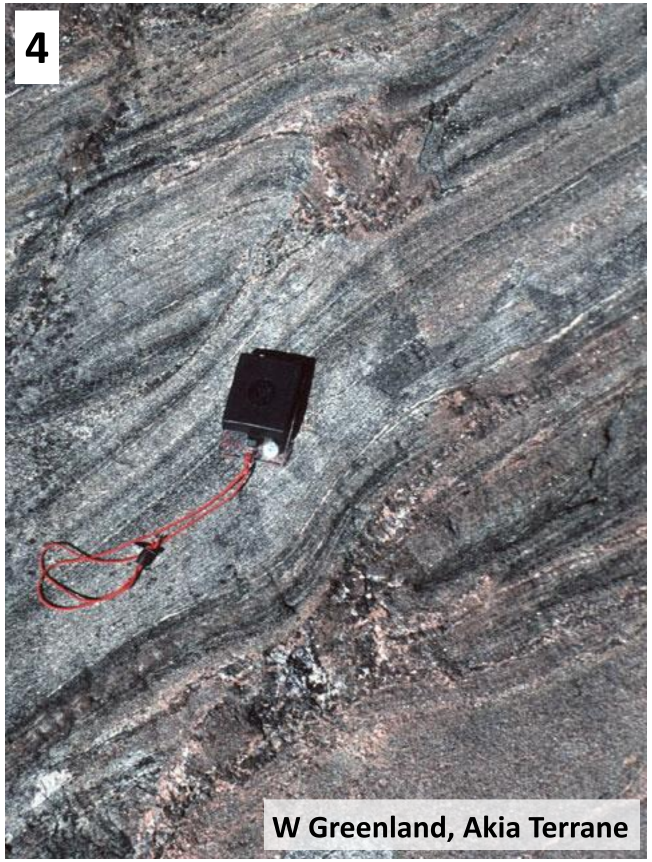
Melting features in outcrop, metabasites

2. Peritectic pyroxene in neosomes
3. Interconnected neosomes
4. Deformation, boundinage, melt migration









Loss of coherence in diatexites at critical melt fraction – convective instability in larger bodies, at 30–50 vol% melt. Not often achieved if melt drains off at lower melt fraction.

Approaches to modelling: 1a. Forward modelling of melting relations

Melting of greywackes (Johnson et al. 2008)

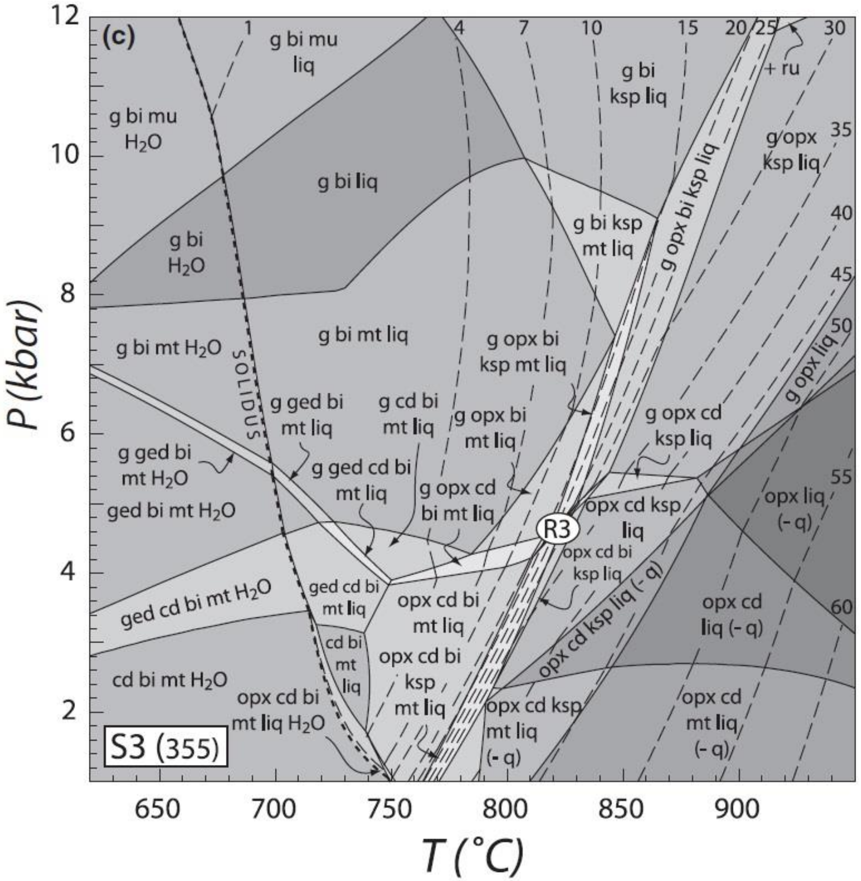
Melt vol% contours show small fractions at T <800°C.

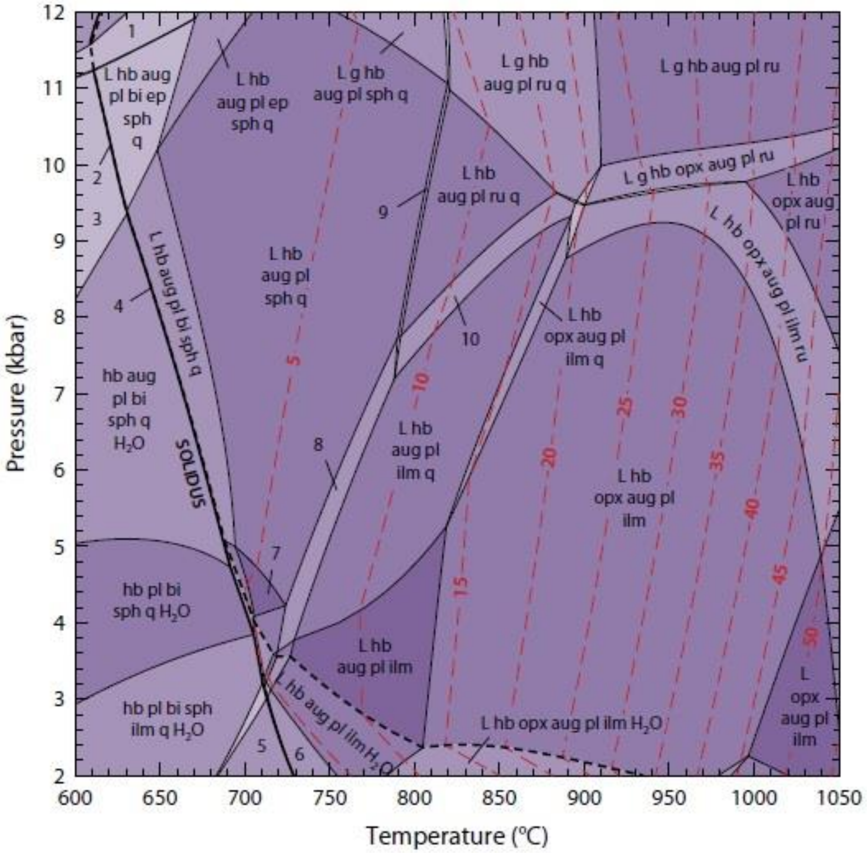
In this composition (but not in all), there is a marked melt-producing reaction (R3) at final breakdown of biotite

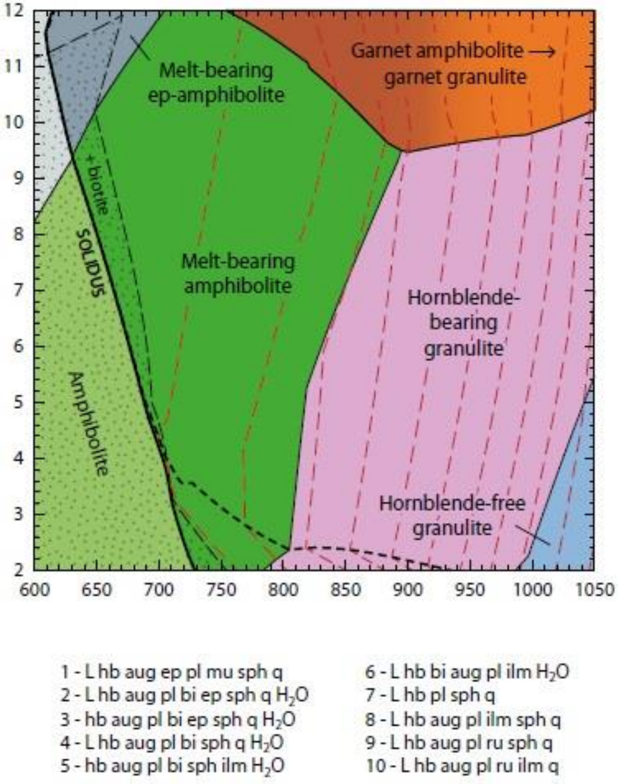
Melting of mafic rocks (Palin et al. 2016)

Diagrams shown are for MORB composition

Note: steadily increasing melt fraction with T; persistence of hornblende to high T







Approaches to modelling: 1b. Forward modelling of melting relations

Melting on ‘clockwise’ P-T paths (Groppo et al 2012)

R1 = muscovite dehydration melting

R2 = biotite dehydration melting

Paths 1 – 4 have different implications for melting behaviour (e.g. in ‘Himalayan Metamorphic Core’)

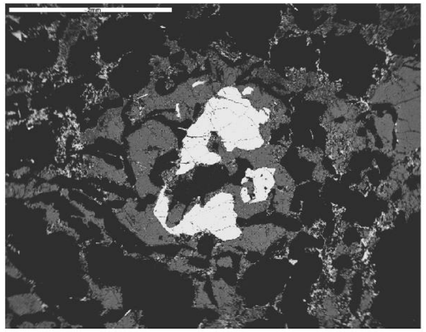
Also, dehydration melting is an endothermic process

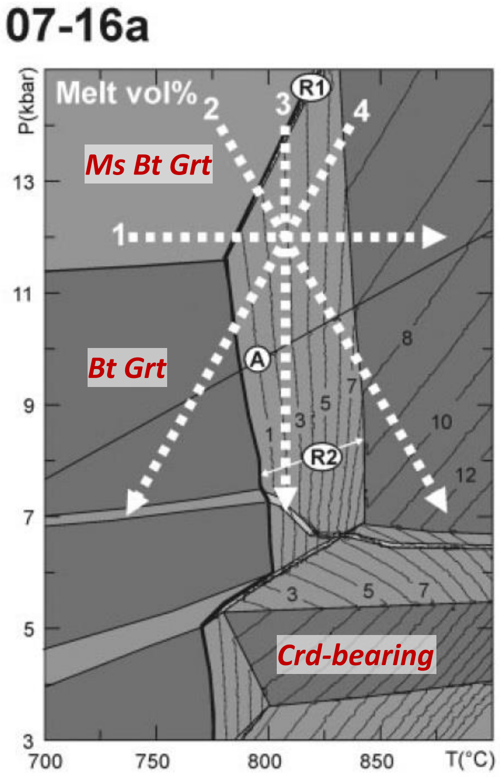
Cordierite-bearing migmatites at Nanga Parbat

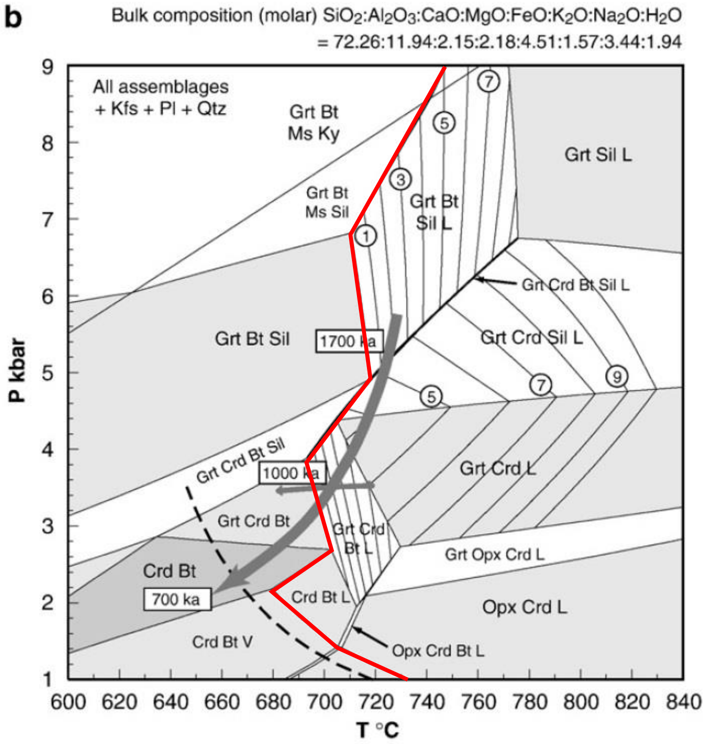
(NW Himalaya, Crowley et al 2009)

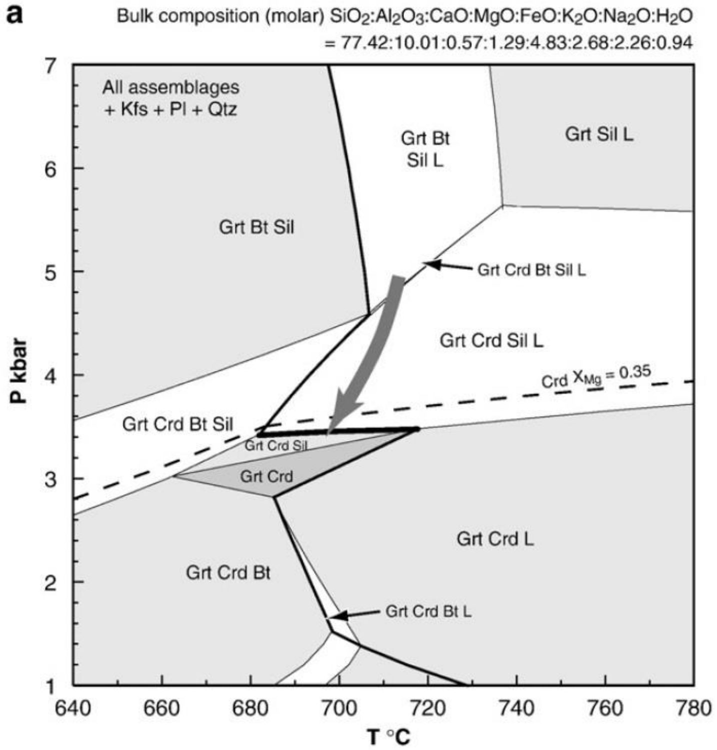
Clockwise path of melting and crystallisation

- Reaction of garnet to cordierite removes H_2O from melt
- This can cause certain melt compositions to freeze
- This behaviour allowed a detailed chronology of melt evolution and crystallisation on the exhumation path



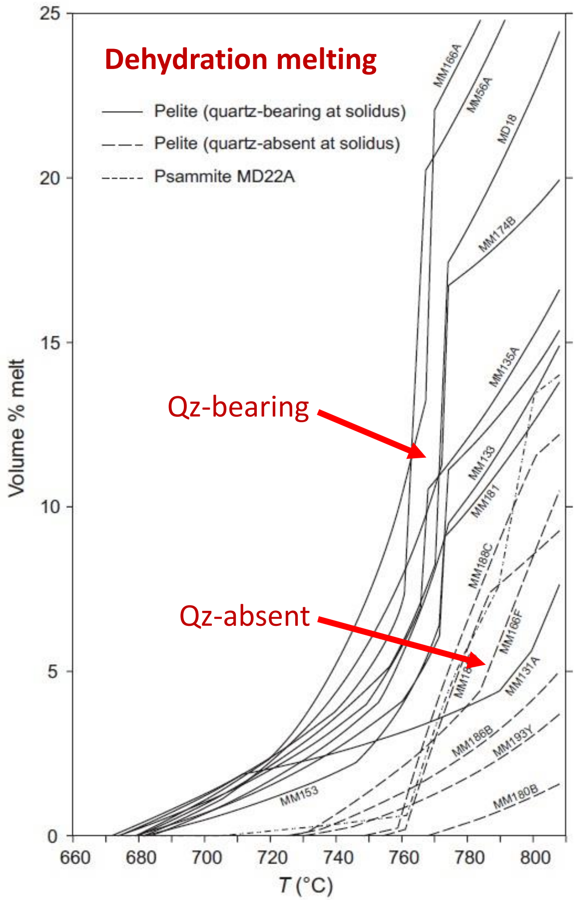


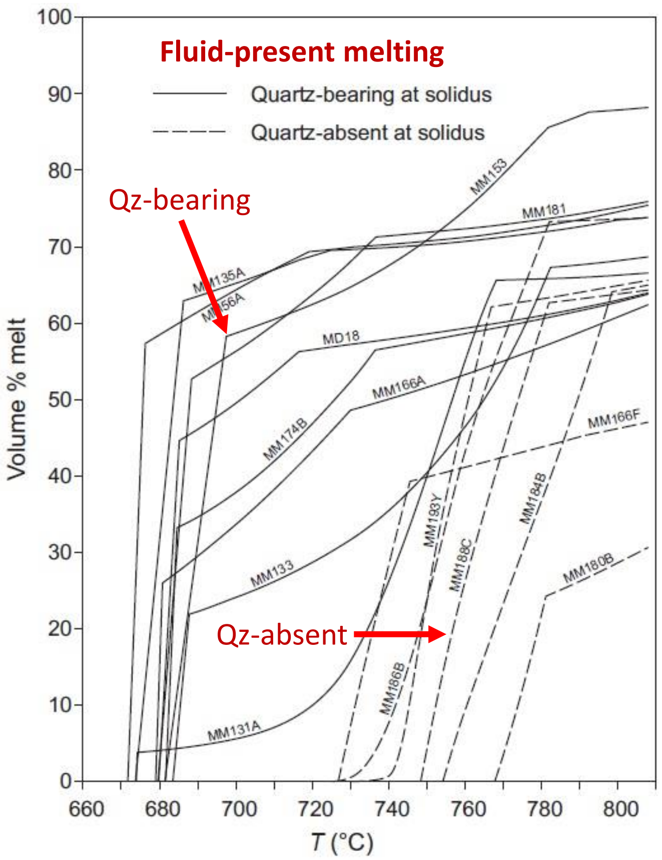




Droop & Brodie (2012) compared dehydration melting and fluid-present melting.

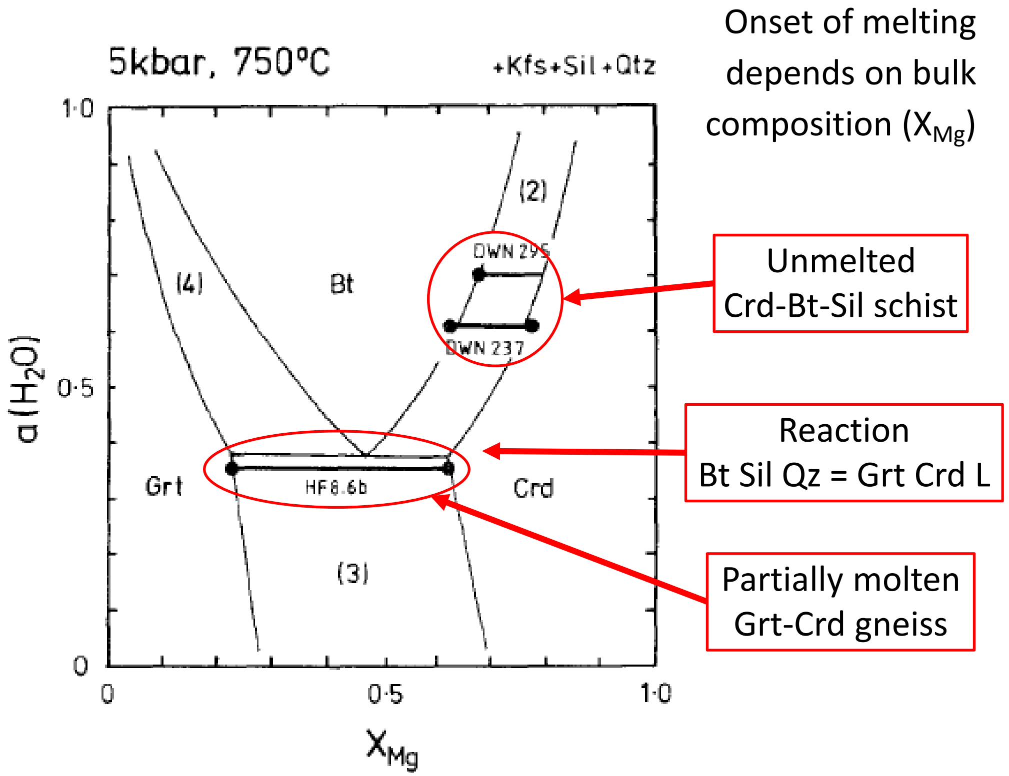
They also considered effects of H_2O transfer from adjacent dehydrating lithologies into melt-bearing rocks





Contrast in $a(H_2O)$ between melted and unmelted rocks at the amphibolite–granulite facies transition, Namaqualand, S Africa. [Waters & Whales (1984)]

This is a projection, not a phase diagram – curves are calculated mineral compositions, based on experimental studies in pelitic systems



Forward modelling with Theriak

Calculate along a *P-T* path
(see p 11 and p 48 of the Theriak-Domino User's Guide)

These diagrams were calculated for muscovite melting at 8 kbar, using the 'muscovite-biotite schist' composition of Patiño Douce & Harris (1998)

Fractionation of H_2O is used to safely approach and to locate the just-saturated solidus *T,* for modelling dehydration melting

Fractionation of melt can be used to simulate melt loss at particular stages, or at each calculation step.

The command file ('directive' or .drv file) used for diagram (c) was:

```
REMOVE  LIQtc  90
TP      670    8000
TP      770    8000    50
```

… i.e., fractionate 90% of the melt produced at each step

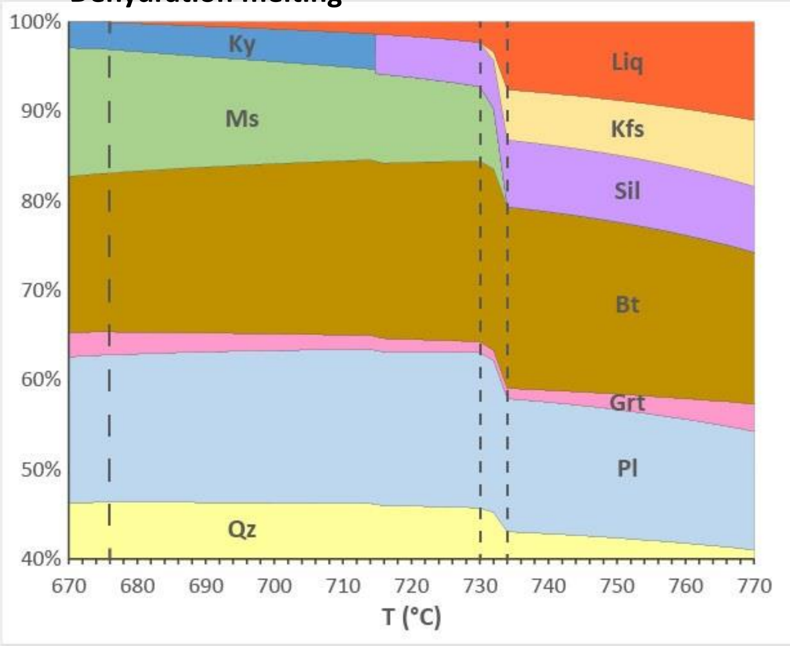
a. Dehydration melting
b. H_2O in excess
c. H_2O in excess, melt fractionated

Long-dashed line: wet solidus

Short-dashed lines: muscovite dehydration-melting interval

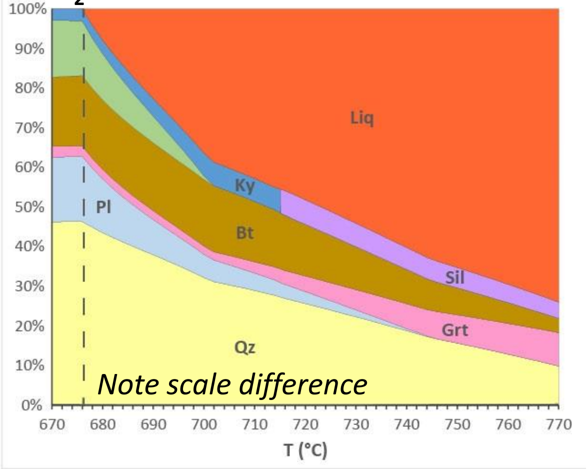
Dehydration melting

a



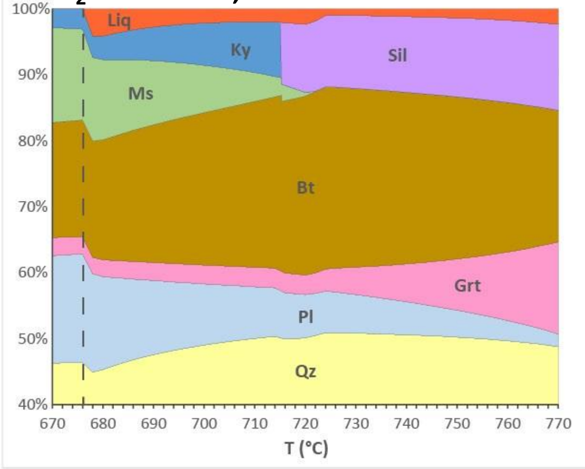
H_2O in excess

b



H_2O in excess, melt fractionated

c



Approaches to modelling: 3a. Dealing with melt loss in migmatites and granulites

- Basic approach (Waters 2019)

Modelling the rock 'as seen', on basis:

Composition represents situation at 'peak' *P-T* after loss of excess melt

At this peak, current assemblage was at its solidus

- Locating H_2O-saturated solidus

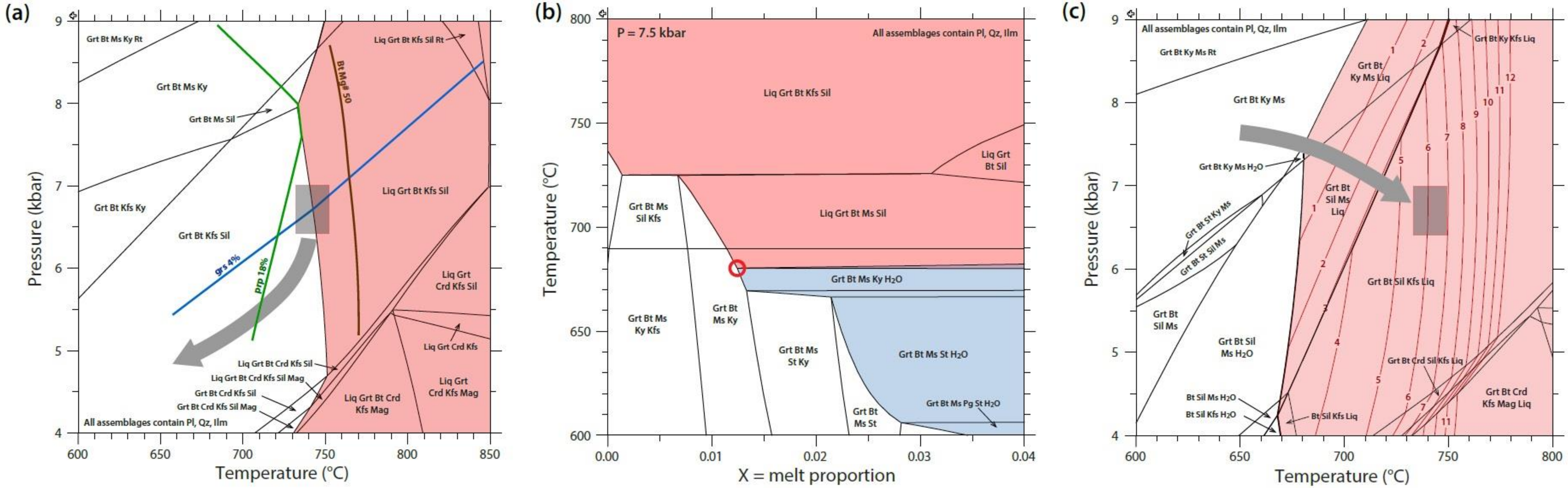
Make a *T*–*X* diagram where X = melt proportion added. Use suitable model melt composition.

Blue areas are H_2O-saturated, red areas contain melt, small red circle marks the just-saturated solidus

- Reintegrate melt, new diagram

Add appropriate amount of melt to the original bulk composition, recalculate diagram.

Solidus crossed at 7.5 kbar (relict Ky), rock experienced both muscovite- and biotite-dehydration melting, generated 6–7 vol% melt



Approaches to modelling: 3b. Dealing with melt loss in migmatites and granulites

Forward-modelling melt loss: Johnson et al. 2008

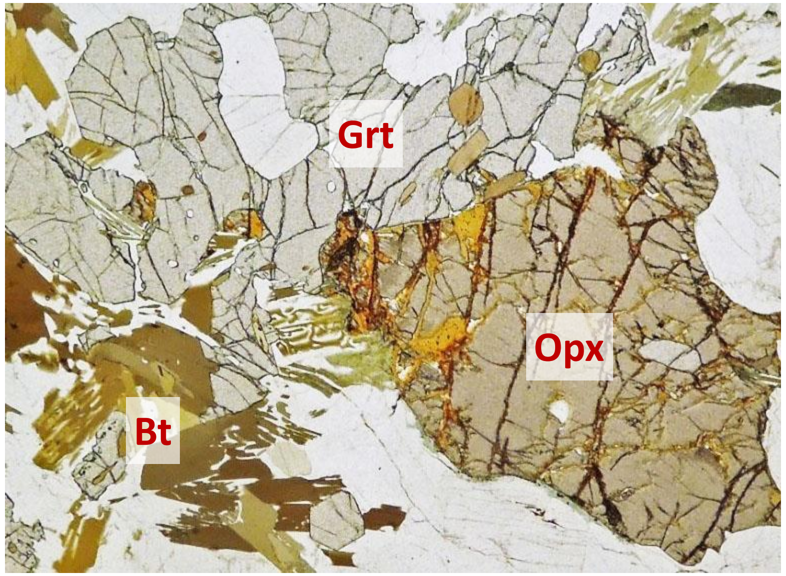
Isobaric section at 7 kbar, X = proportion of melt lost

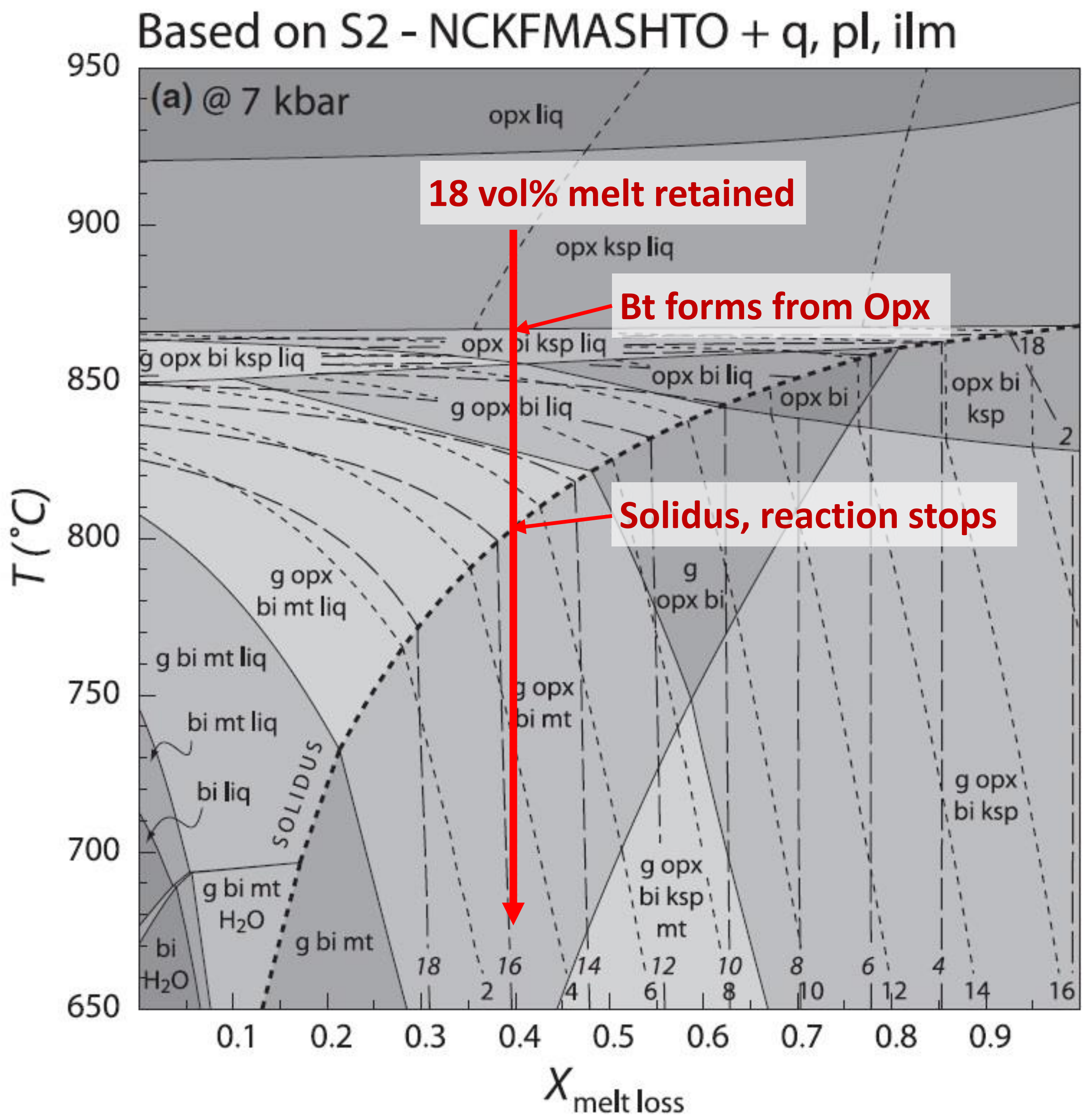
Total volume of melt at ~900°C was 30 %.

Diagram shows predicted assemblage changes on isobaric cooling after partial melt loss, largely through back-reaction with melt. Below the solidus there will be very little change.

Contours: mol% biotite (long dash), orthopyroxene (short dash)

One of my own specimens, showing this process





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