4 continued: The effect of metamorphism

There are three main driving forces for metamorphism: Pressure, Temperature and Stress. These can act on their own, but more commonly, will work in unison to transform a protolith into a metamorphic rock

The main effects on the protolith are:

- A change in mineralogy
- Development of a metamorphic structure (fabric, banding, etc.)
- Change in composition

What about the impact of the protolith composition ?

Effects of metamorphism - bulk composition

The effect of metamorphism on a rock does not only depend on the amount of pressure, temperature and stress exerted, but also on the bulk composition:

bulk composition ≈ susceptibility to metamorphic change

key rock types subjected to metamorphism include:

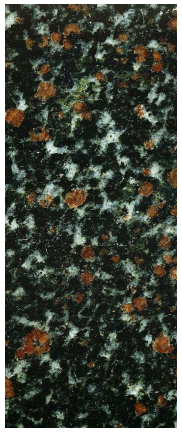
- pelite (clay-dominated sediment)
- basalt (e.g. oceanic crust)
- granite and other felsic igneous rocks
- other sediments: sandstone, limestone, marl, evaporites, BIF
- ultramafic rocks
- ore deposits

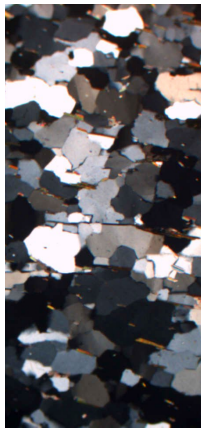
Clearly a sandstone will be able to show very little change, whereas a pelite or basalt will show a characteristic set of mineralogical and textural changes

The effect of bulk composition on metamorphism


meta-BIF


meta-pelite


meta-basalt


meta-quartzite

Naming of metamorphic rocks (Winter chapter 22)

Metamorphic rock names include parts from all three effects that metamorphism can have on a rock: mineralogy, composition and fabric

composition terms: meta-pelite; meta-granite; meta-basalt

add mineralogy: garnet-staurolite meta-pelite; hornblende-plagioclase meta-basalt

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fabric related naming terms (see Winter for more elaborate definitions):

- slate - a fine-grained low-grade rock with perfectly developed phyllo-silicate foliation
- schist - medium-grained rock displaying strong preferred orientation of minerals
- gneiss - meta rock displaying mineral segregation into gneissic banding
- migmatite - meta rock showing partial melting
- granofels - a metamorphic rock lacking fabric
- mylonite - rock formed by grainsize reduction due to intense ductile deformation
- augen mylonite - mylonite with distinct crystals or fragments wrapped by foliation
- crenulation cleavage - micro-folding of the foliation

4

4-2

Naming of metamorphic rocks

Metamorphic rock names include parts from all three effects that metamorphism can have on a rock: mineralogy, composition and fabric

composition terms: meta-pelite; meta-granite; meta-basalt

add mineralogy: garnet-staurolite meta-pelite; hornblende-plagioclase meta-basalt

add fabric name: slate; gneiss; granofels

final name includes all three (if known):

- garnet-staurolite meta-pelite schist
- hornblende-plagioclase meta-basaltic gneiss
- garnet-pyroxene migmatite
- plagioclase augen mylonite

5

5

Naming of metamorphic rocks

Of course, as in all branches of geology, there are many more metamorphic rock names, often for very specific rocks. The most important of these are:

- greenschist - green-coloured schist with colour due to e.g. chlorite, actinolite, epidote
- greenstone - as greenschist, but without the schistosity
- blueschist - schistose rock whose blue colour resulting from glaucophane (sodic amp)
- amphibolite - mafic meta rock dominated by plagioclase and >40% amphibole
- hornfels - contact metamorphic rock lacking fabric, often fused
- eclogite - high-pressure rock composed of garnet and pyroxene and plag-free
- restite - mainly a compositional term; defines a rock that is the residue of melting

Note: greenschist, blueschist, amphibolite and eclogite are not just rock names, but also names of metamorphic facies

6

6

Lecture 5: Mineral assemblage and paragenesis

Metamorphism is about changing a protolith's mineralogy, composition and/or texture and these changes are the result of changes in *P*-*T*-σ conditions

Minerals have a limited stability; when conditions get too high, they will react to something else: prograde path. Same if conditions are too low: retrograde. But: reaction rates slow down at low *T*: can preserve metastable mineral relicts.

Not all minerals in a metamorphic rock will be in equilibrium and metamorphic rocks therefore generally contain multiple mineral parageneses, which give information on its journey through the Earth

7

7

Mineral assemblage and paragenesis

Not all minerals present in a (metamorphic) rock are necessarily in equilibrium

an *assemblage of minerals in mutual equilibrium* is called a mineral paragenesis and a rock or thin-section can contain multiple equi assemblages or parageneses as relicts, overgrowths, inclusions, partial replacements etc. etc.

Mineral assemblage and paragenesis

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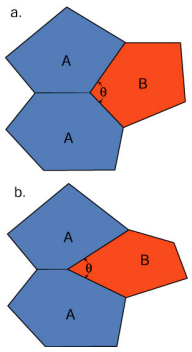
Indicators of equilibrium:

- minerals in direct contact, contacts are sharp and with correct crystal faces
- mutual inclusions of A in B and B in A
- ideal inter-mineral angles
- …

Mineral assemblage and paragenesis

Surface tension (or interfacial energy) generates a characteristic contact angle between minerals, also called the dihedral angle:



When $E_{int}(A) = E_{int}(B)$, the angle is 120°

When $E_{int}(A) > E_{int}(B)$, the angle is less 120° so as to minimize the A-A interface length

figures from Winter (chapter 23)

Mineral assemblage and paragenesis

Surface tension (or interfacial energy) generates a characteristic contact angle between minerals, also called the dihedral angle

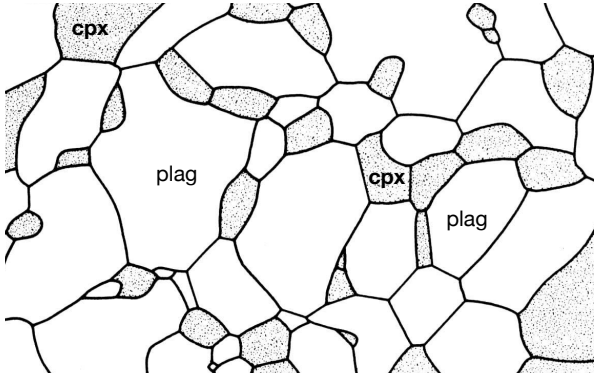
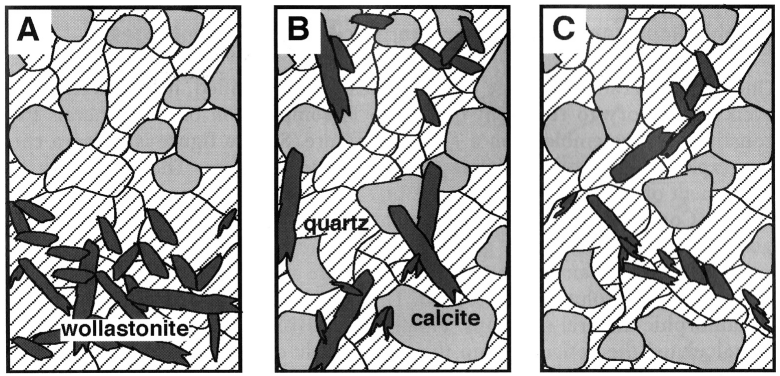


figure from Winter (chapter 23)

Assemblage and paragenesis



two assemblages = two parageneses

one assemblage = one paragenesis

one assemblage = two parageneses

from Bucher and Frey 2002 12

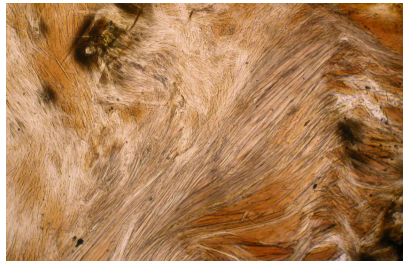
12

Mineral assemblage and paragenesis

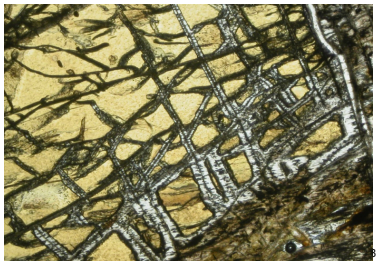
This is a very important concept, because the succession of mineral paragene-ses provides information on the history of the rock and its metamorphic path

preservation of multiple generations of equilibrium mineral assemblages results from lower reaction rates resulting from a combination of lower temperatures, solid state reactions, lack of a fluid phase etc.

prograde replacement

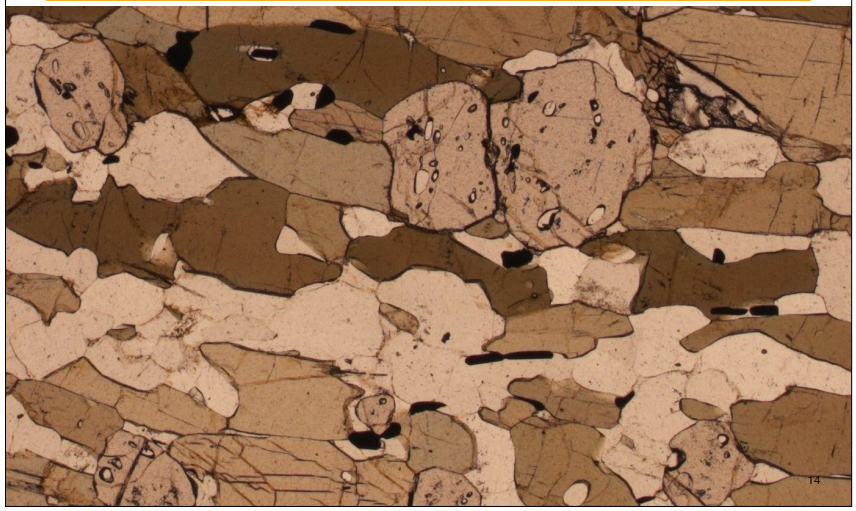


retrograde replacement



13

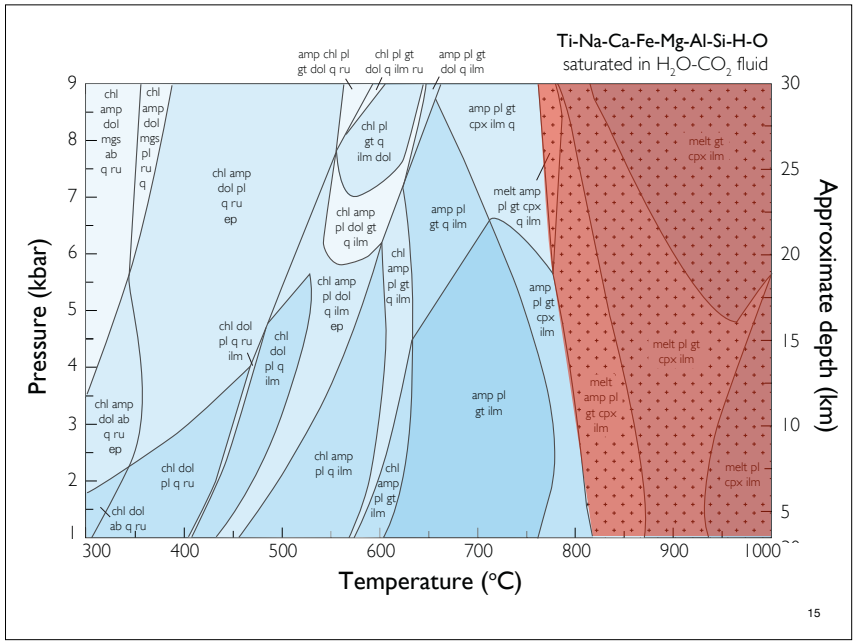
Mineral assemblage and paragenesis: an example



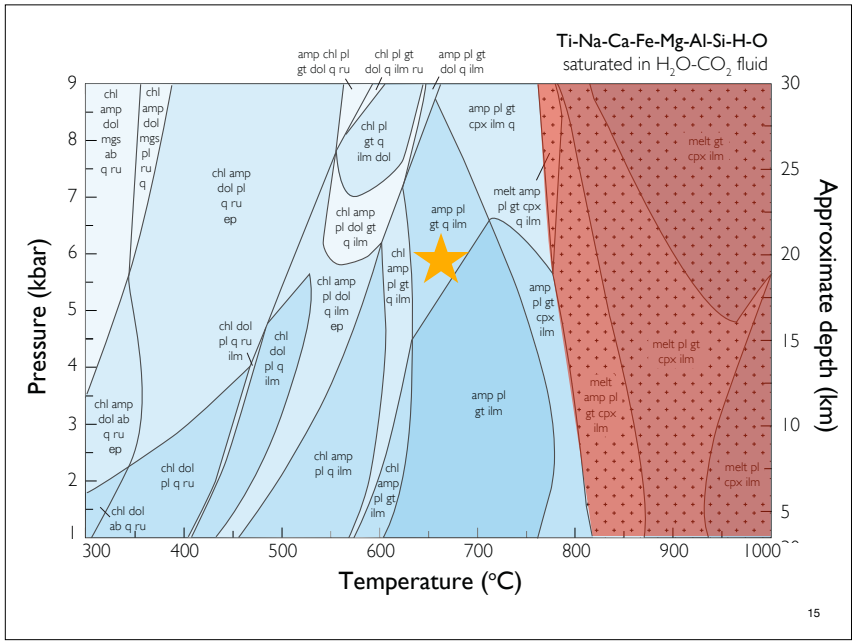
14-1

Mineral assemblage and paragenesis: an example

14-2

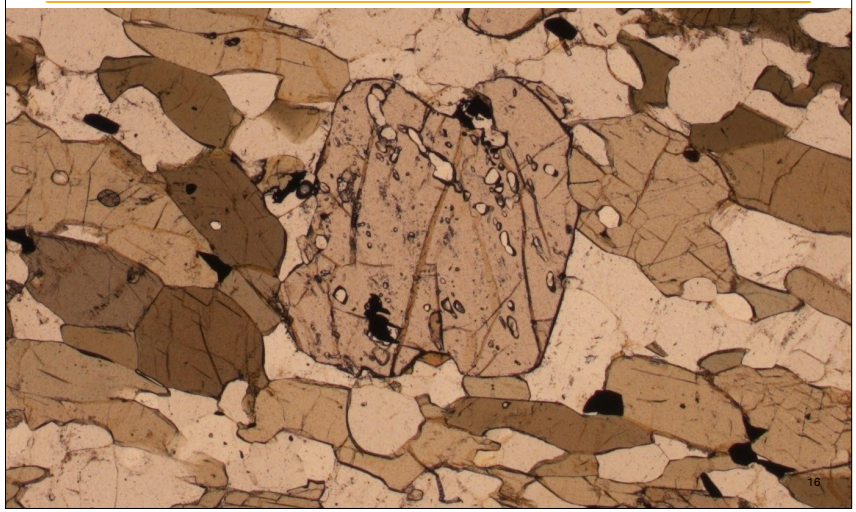


15-1



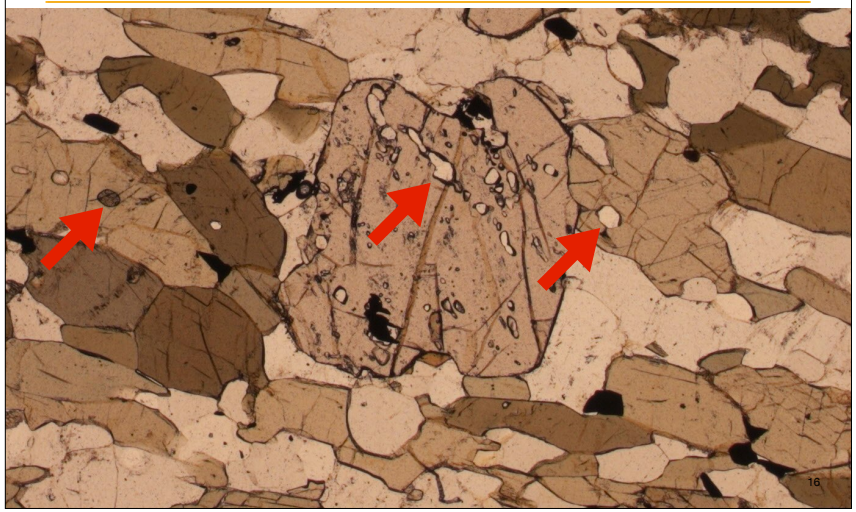
15-2

Mineral assemblage and paragenesis: an example



16-1

Mineral assemblage and paragenesis: an example

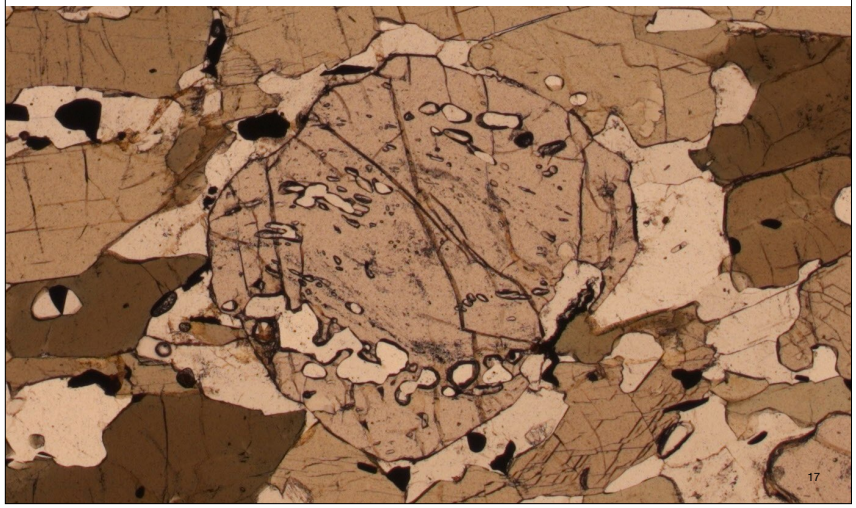


16-2

Mineral assemblage and paragenesis: an example

16-3

Mineral assemblage and paragenesis: an example

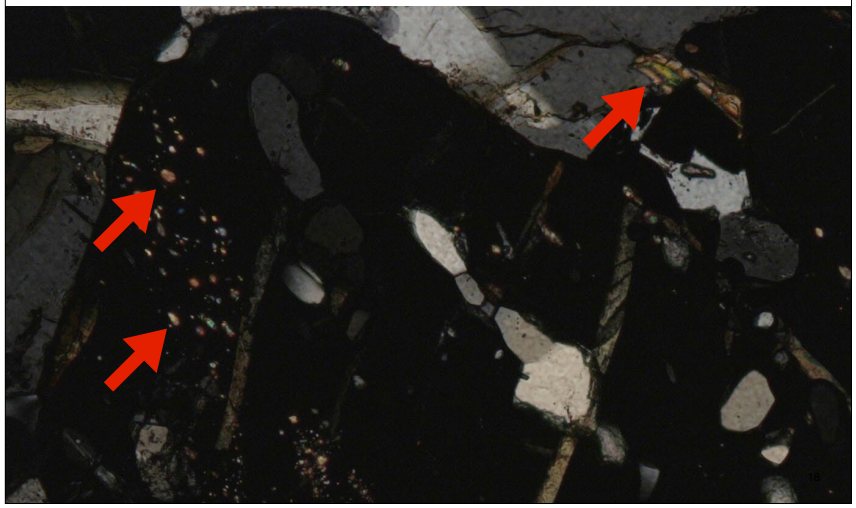


17-1

Mineral assemblage and paragenesis: an example

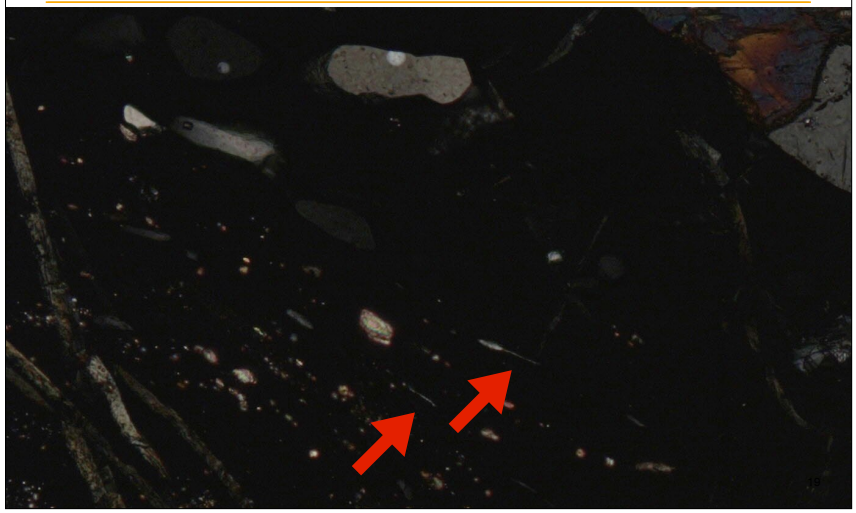
17-2

Mineral assemblage and paragenesis: an example

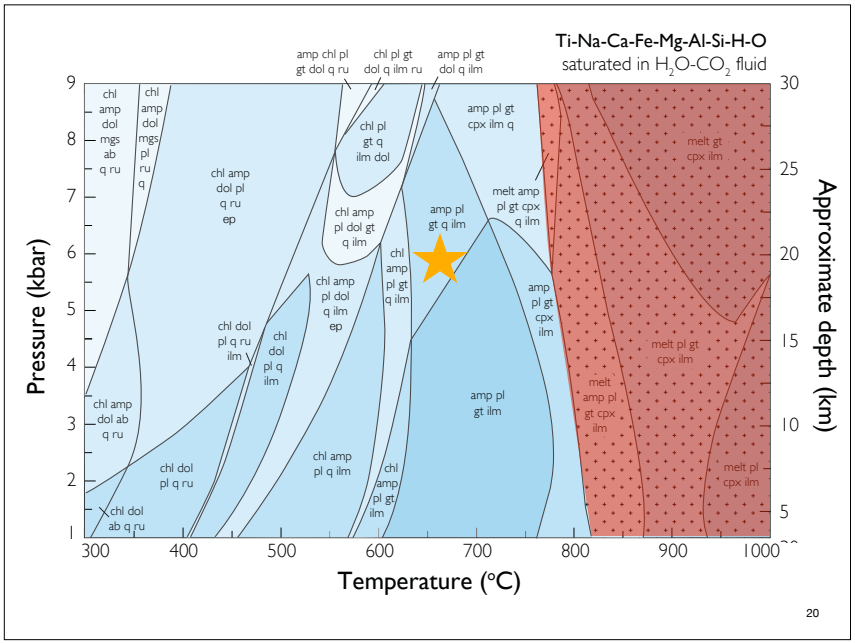


18

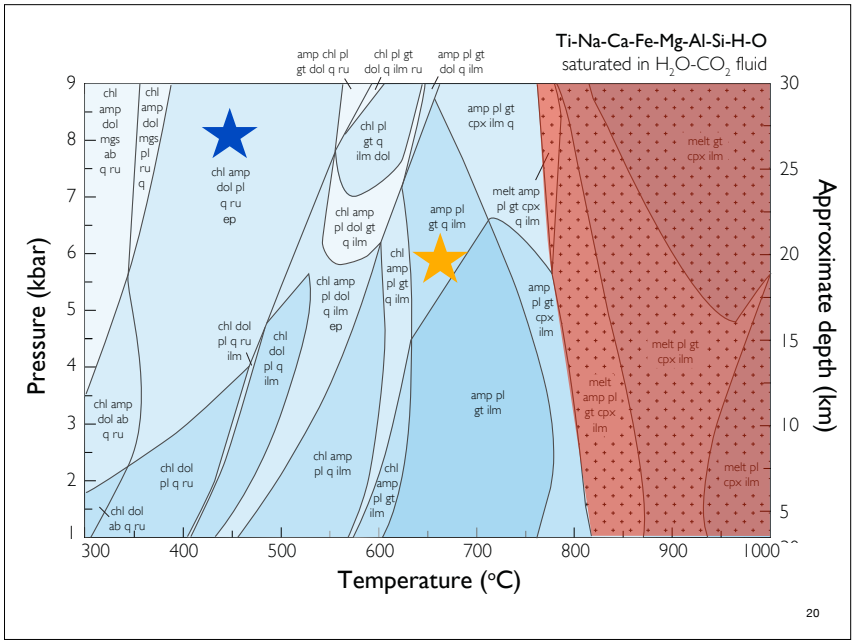
Mineral assemblage and paragenesis: an example



19

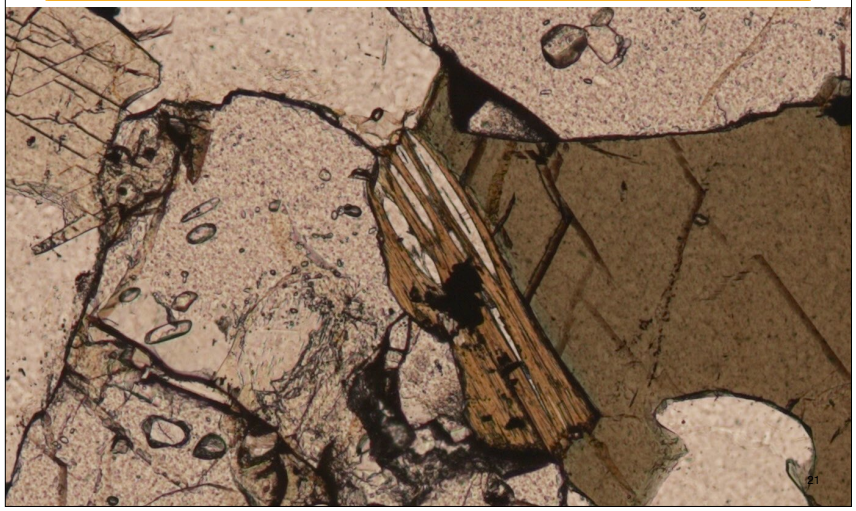


20-1



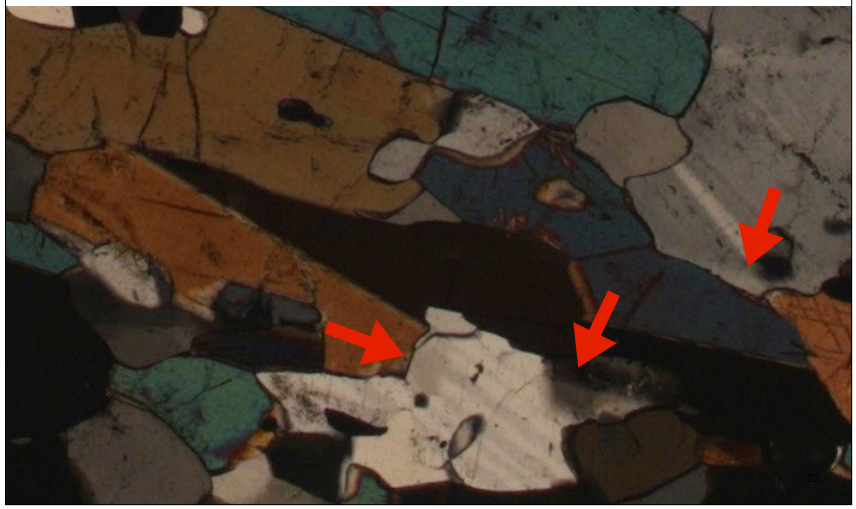
20-2

Mineral assemblage and paragenesis: an example



21

Mineral assemblage and paragenesis: an example



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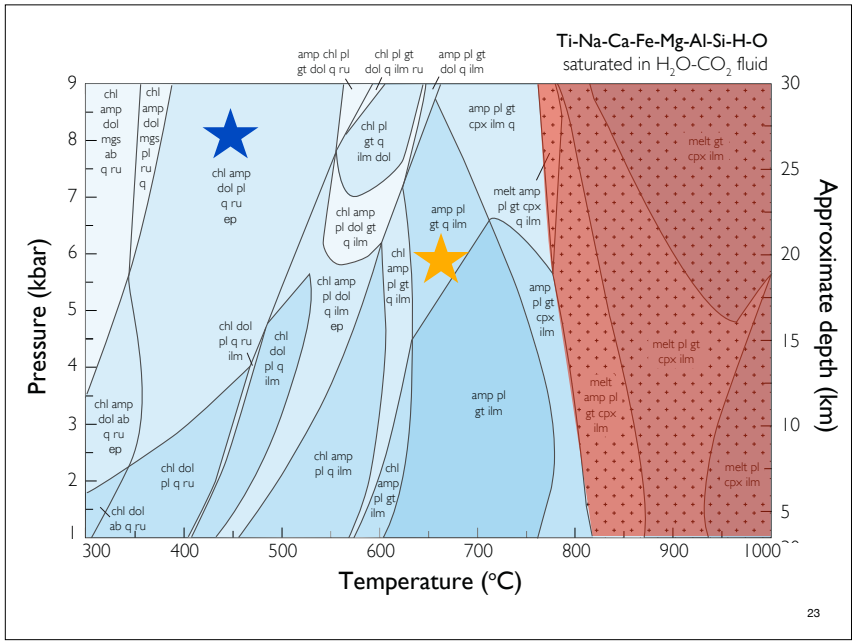
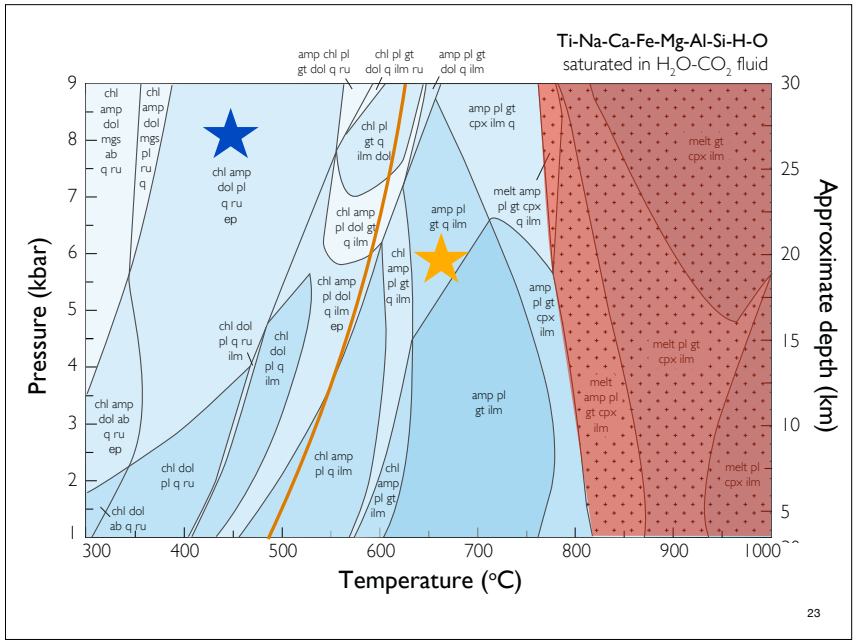
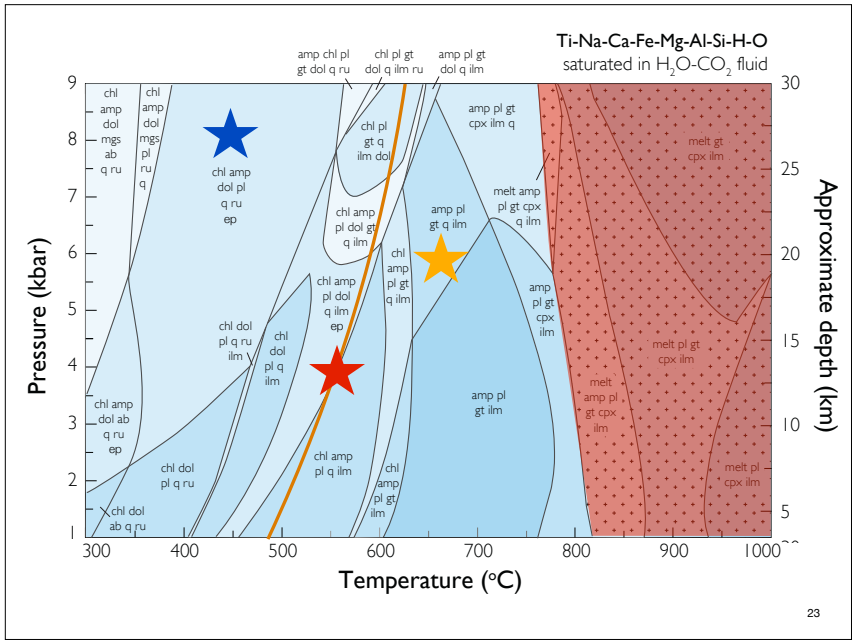


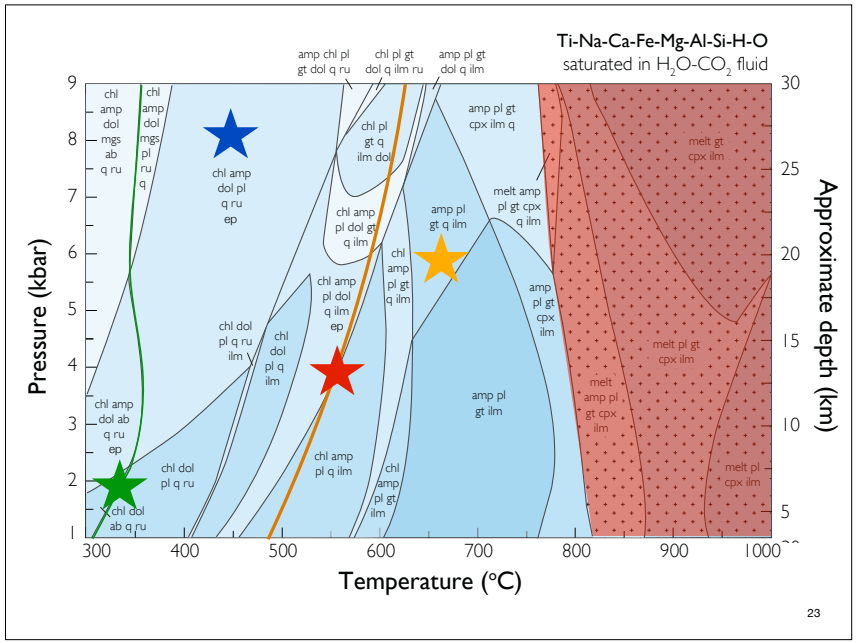
23-1



23-2



23-3



23-4

Mineral assemblage and paragenesis

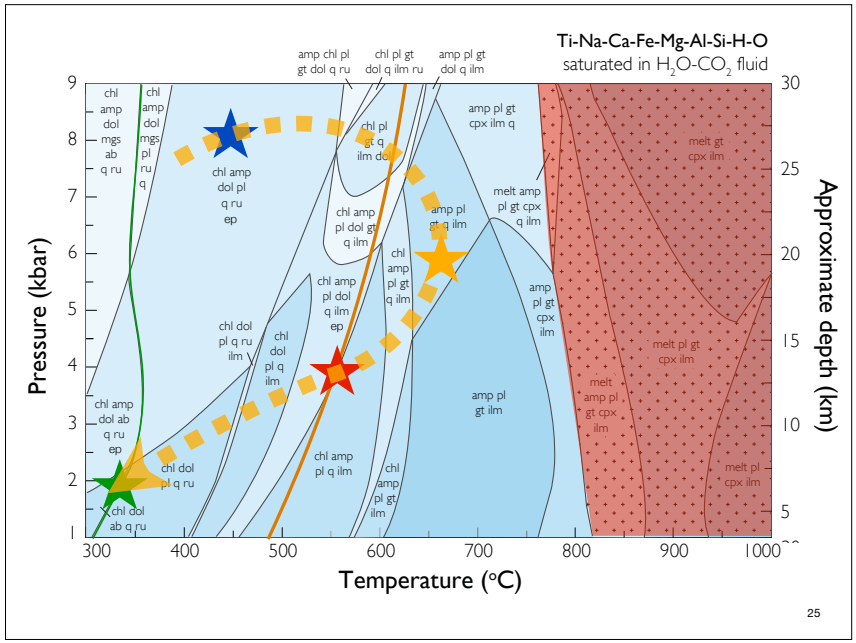
Sequence of metamorphic mineral parageneses in one thin-section:

1. Present as inclusions in garnet: amphibole + rutile + epidote
2. Main mineral stage: garnet + amphibole + ilmenite + quartz + plagioclase
3. Replacement at grain edges: amphibole to biotite
4. Locally on plagioclase grains: plagioclase going to albite

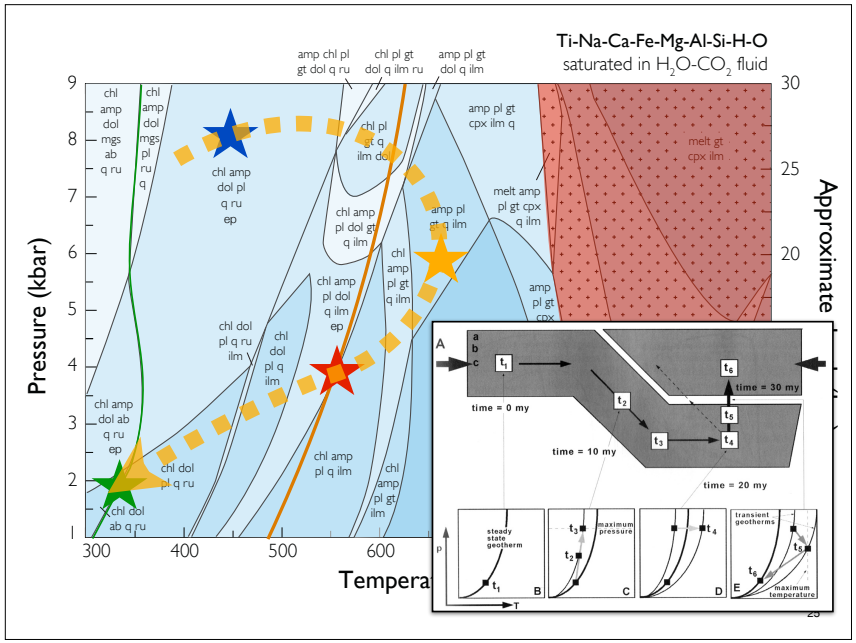
A metamorphic P-T path reconstructed from prograde, peak and retrograde mineral parageneses, all of which are subsets of the rock mineral assemblage

24

24



25-1



25-2