Metamorphism

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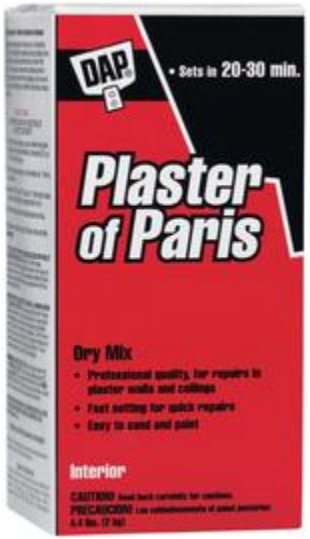
Gypsum, $Ca\ SO_4\ .2H_2O$
Naica mine, Mexico

Just add heat =

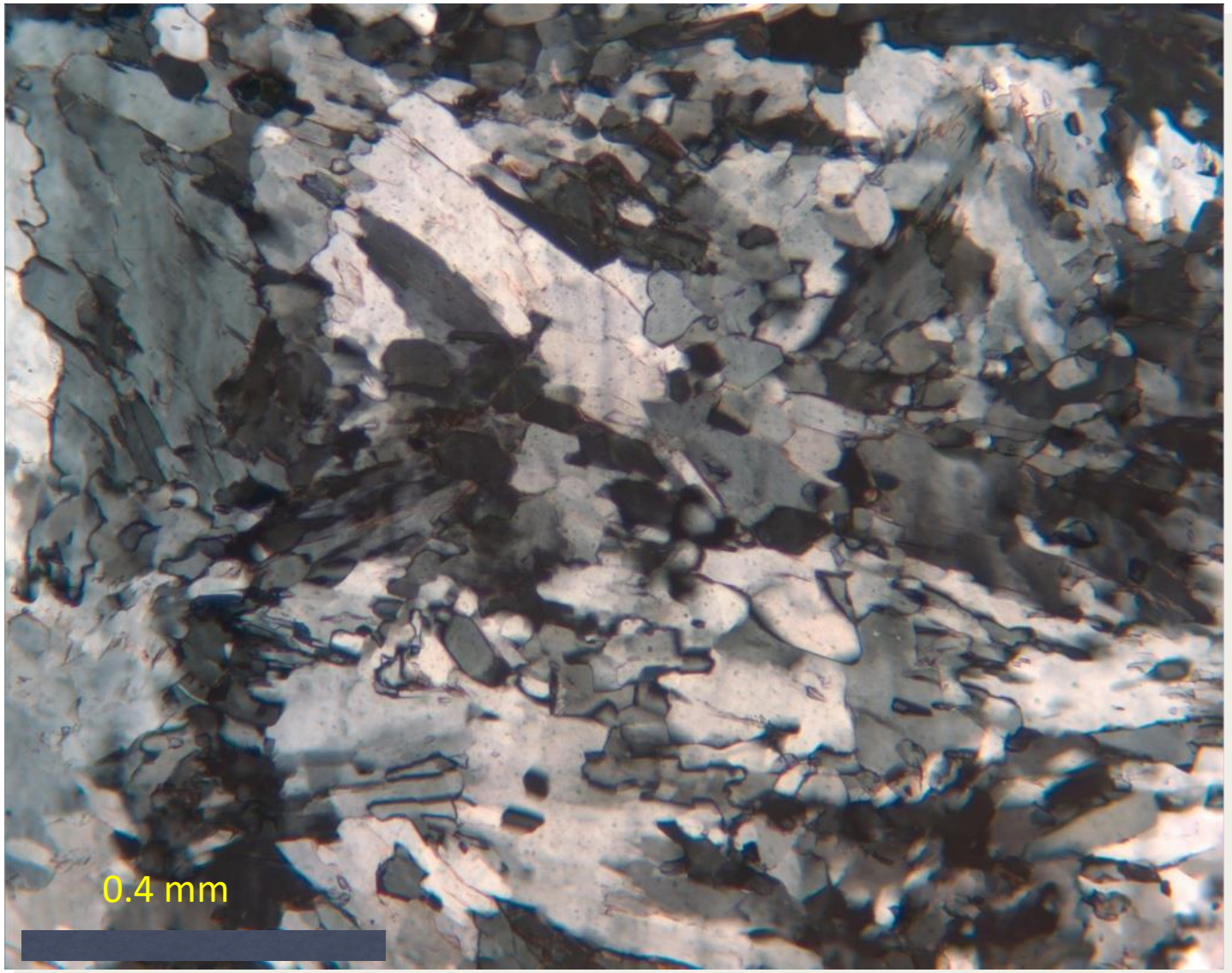


Bassanite, $CaSO_4 .0.5H_2O$
Most DIY shops, Almost Anywhere

+

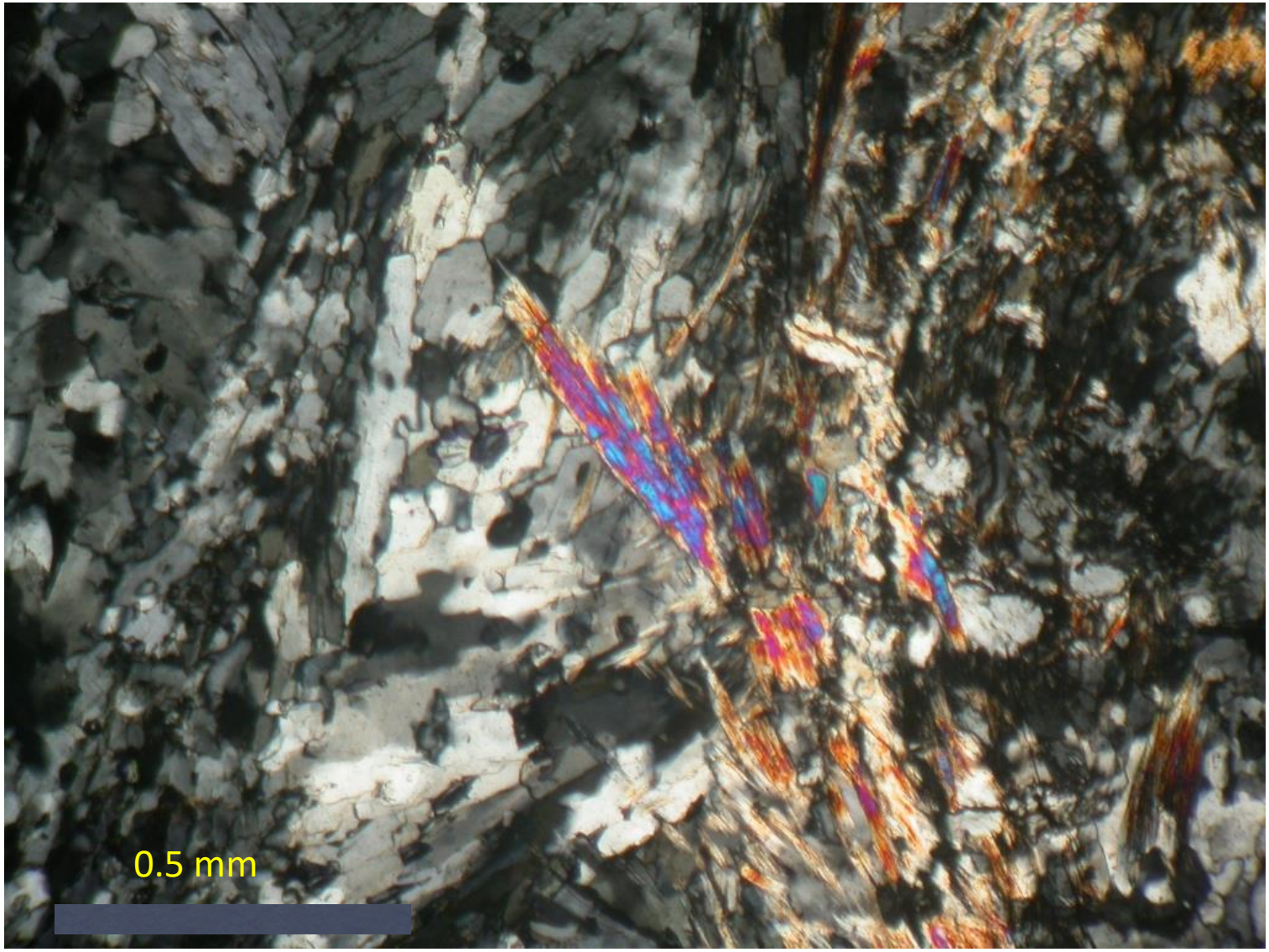
Water, H_2O
Most taps, Almost Anywhere

Volterra gypsum $Ca\ SO_4\ .H_2O = Ca\ SO_4\ .0.5(H_2O) + 1.5\ H_2O$



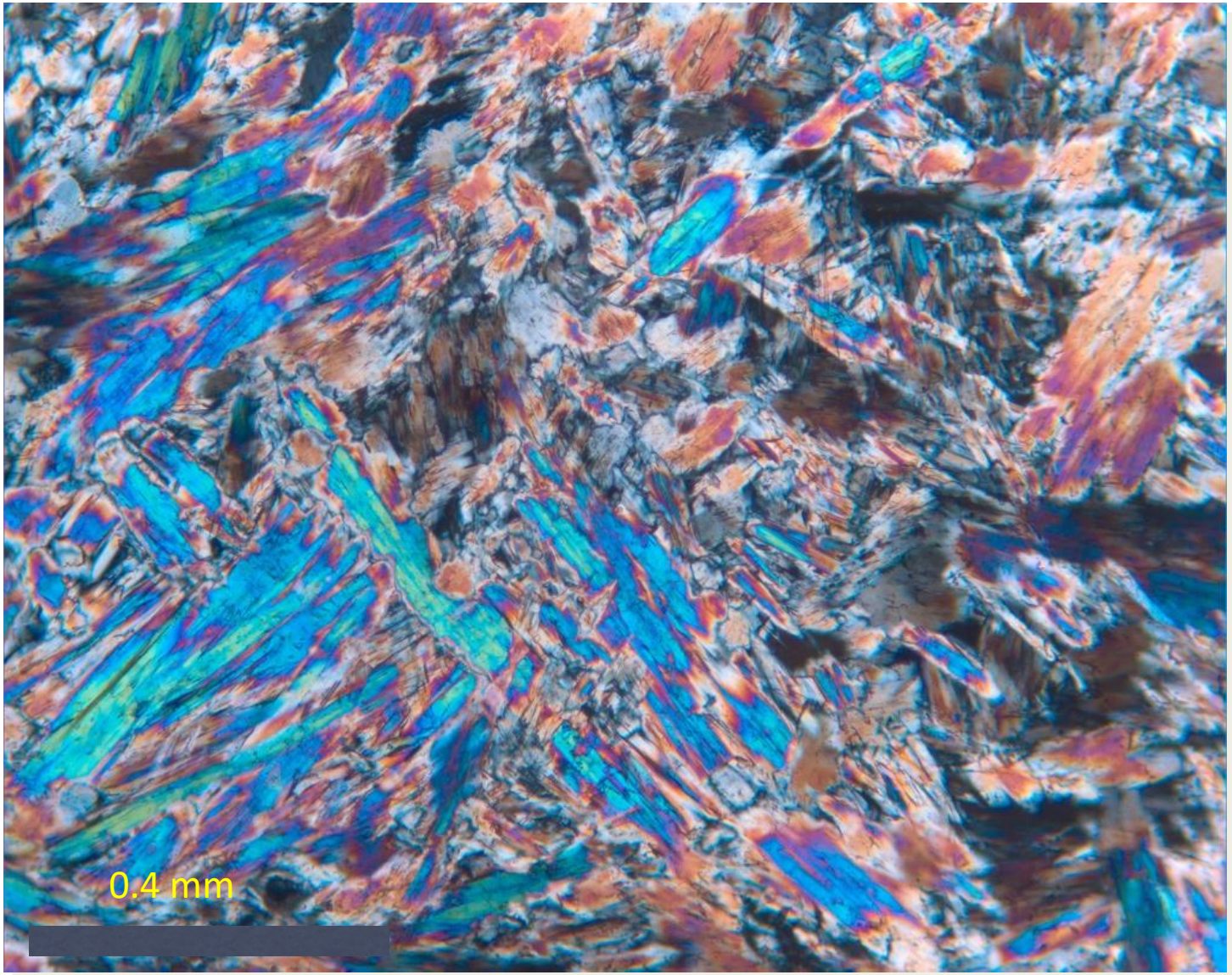
- gypsum in partially dehydrated specimen (gyp48)

Experiments: microstructure



- bassanite and gypsum in partially dehydrated specimen (gyp65)

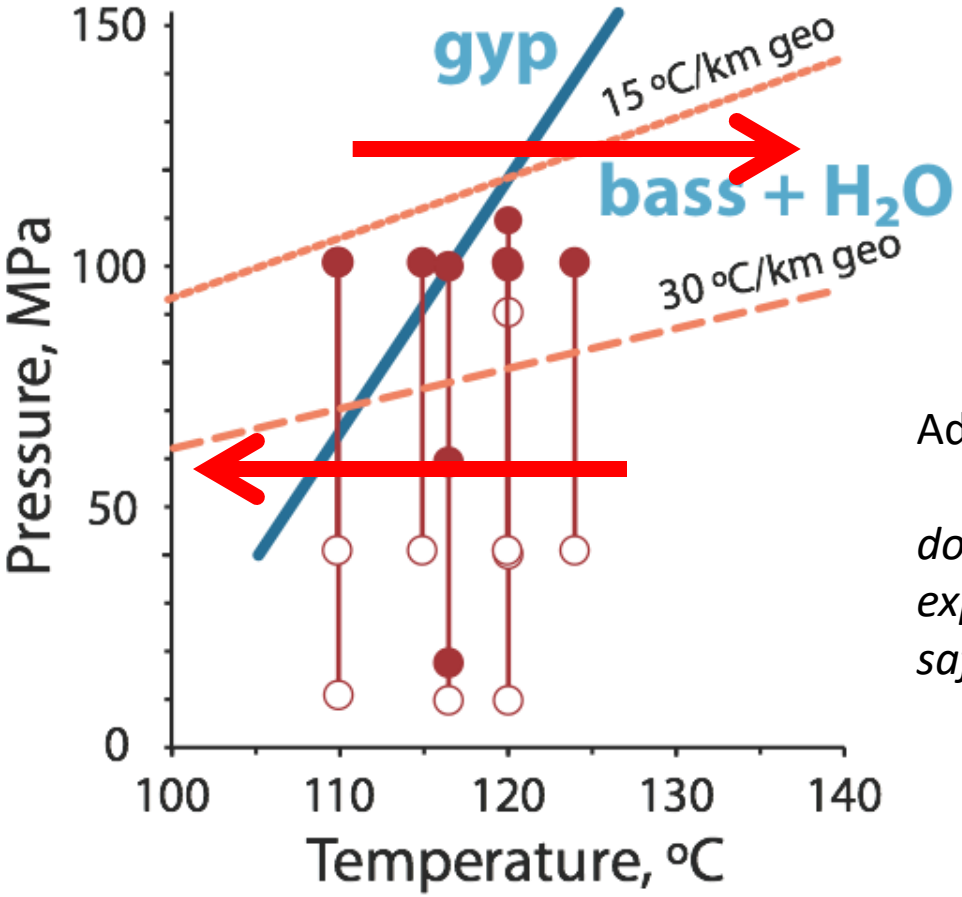
Experiments: microstructure



- bassanite in fully dehydrated specimen (gyp64)

Experiments: PT space

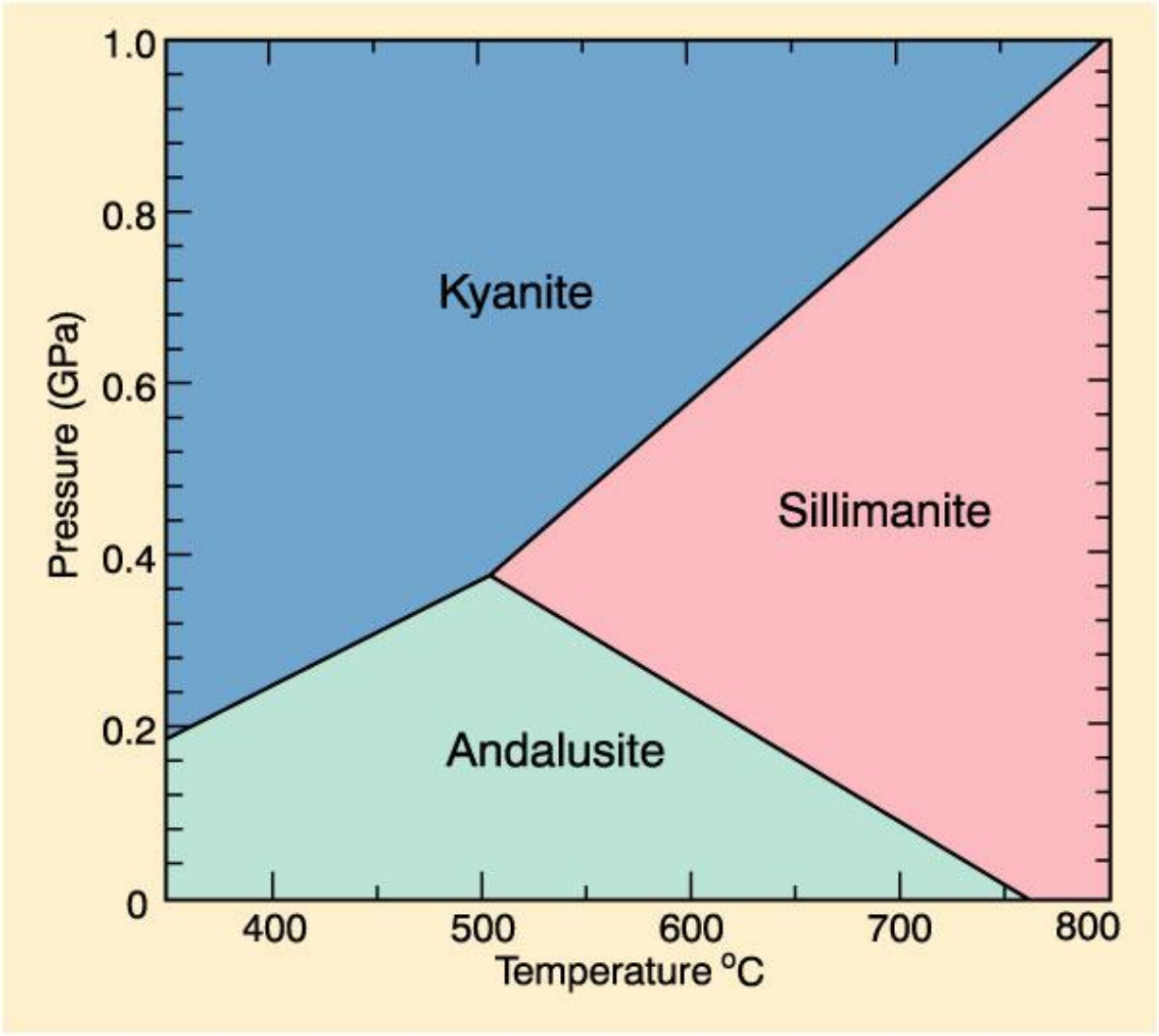
Bassanite-in (metastable) after McConnell et al 1987

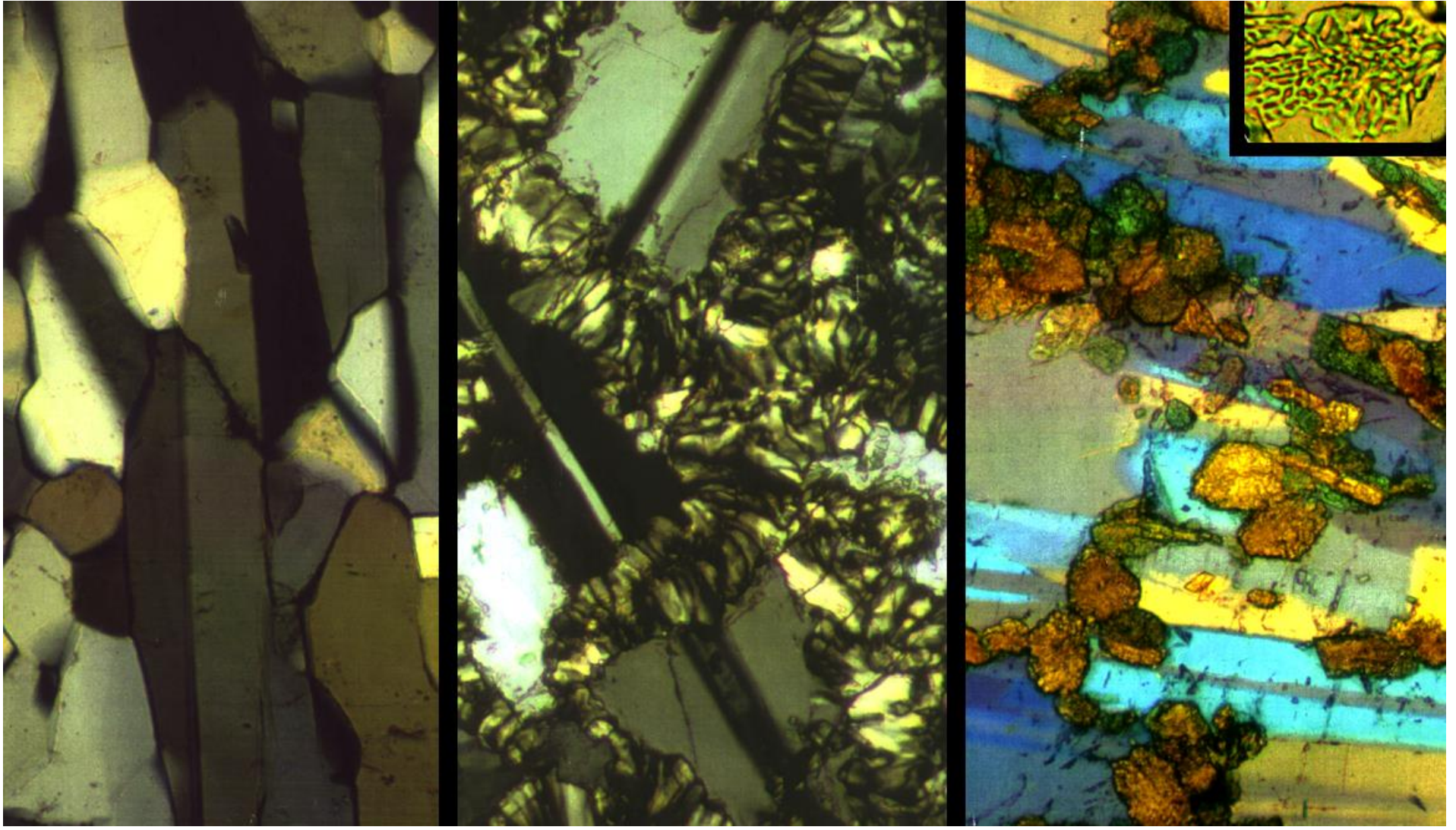


Add heat, water given off

Add water, heat given off

do not do this without expert advice, there are safety risks


1.0
0.8
0.6
0.4
0.2
0
Pressure (GPa)
Kyanite
Sillimanite
Andalusite
400
500
600
700
800
Temperature °C



Starting material Dry Wet

Albite $\rightarrow$ Jadeite + Quartz

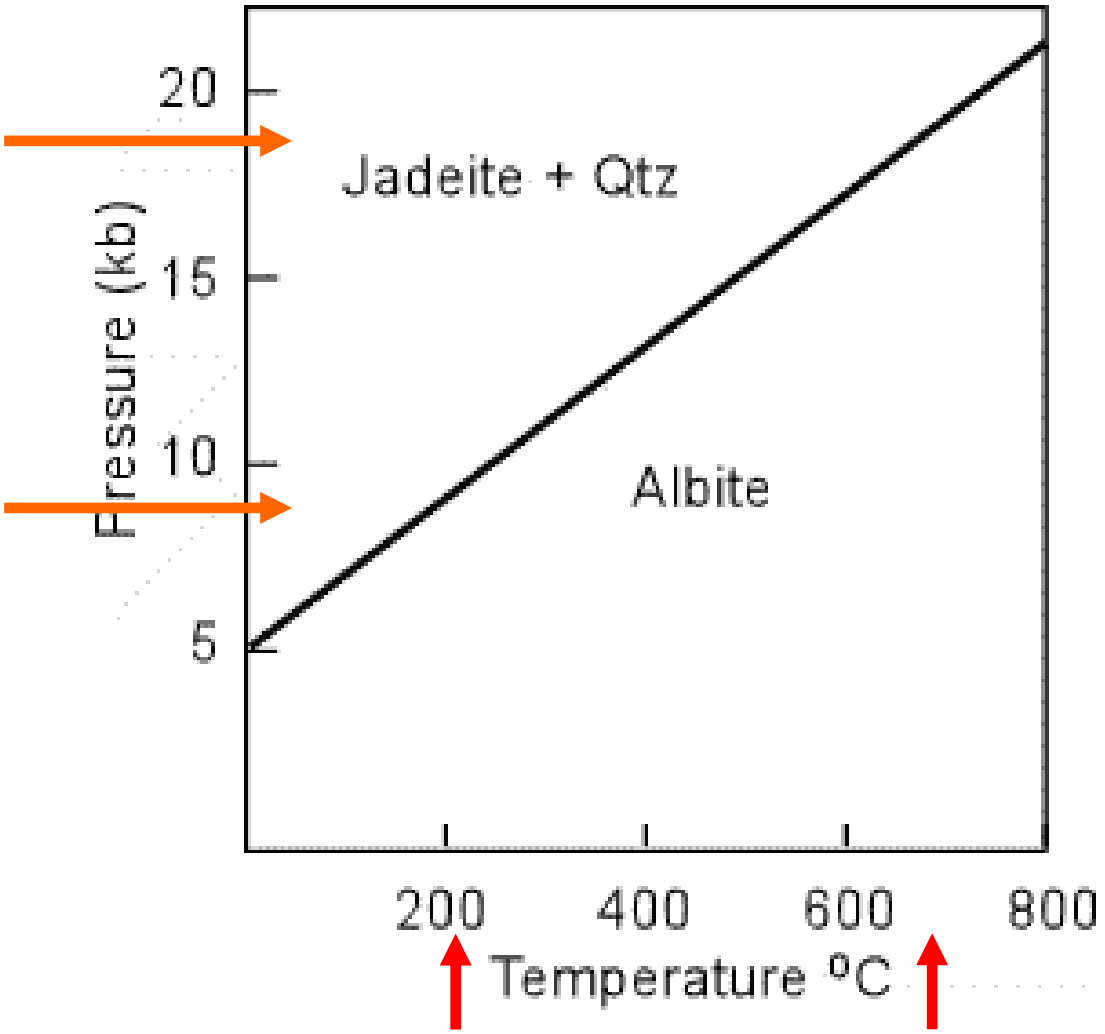
$NaAlSi_3O_8$ = $NaAlSi_2O_6$ + SiO_2

Albite Jadeite Quartz

About 60 km burial depth

When you find crustal rocks at such pressures, rocks have undergone burial due to tectonics and/or sedimentation

About 30 km burial depth, base of normal thickness continental crust



Domestic oven

Some rocks begin to melt

Unfinished reaction – because metamorphic kinetics (reaction rates) are not very fast

Garnet (pink) forming from pyroxene (black) and plagioclase (white)

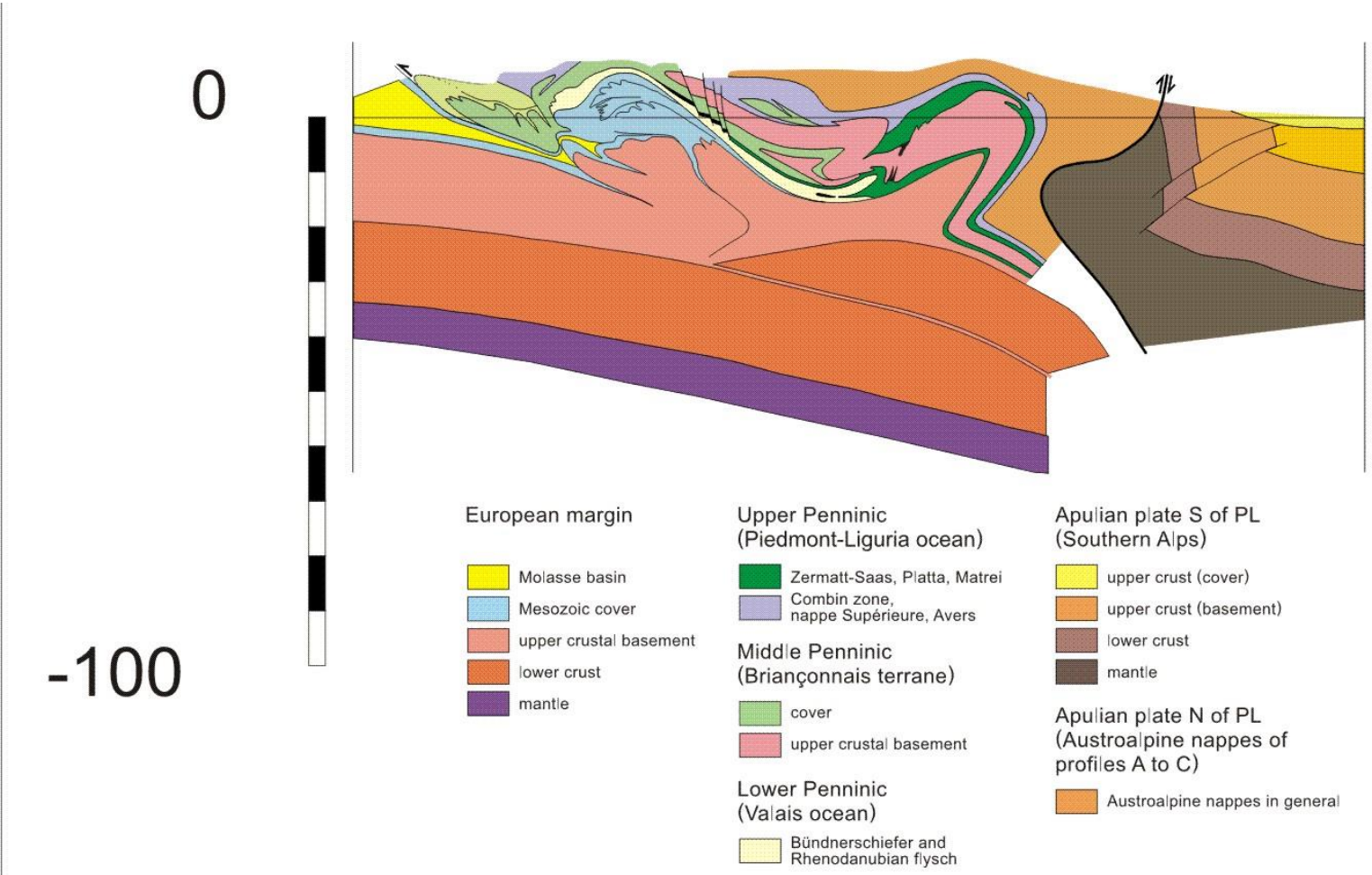
Regional metamorphism: minerals and textures

Cross section through the Alpine mountain belt

Shortening thickens the crust and buries rocks, increasing the pressure (Cretaceous, Tertiary)

Cold rocks now at depth warm up with heat from below, increasing the temperature

Pervasive deformation creates foliations: slates, schist, gneisses



Caledonian Orogeny metamorphic zones characterised by index minerals and separated by isograds (formed in Ordovician). These reflect the different P and T conditions experienced at different places.

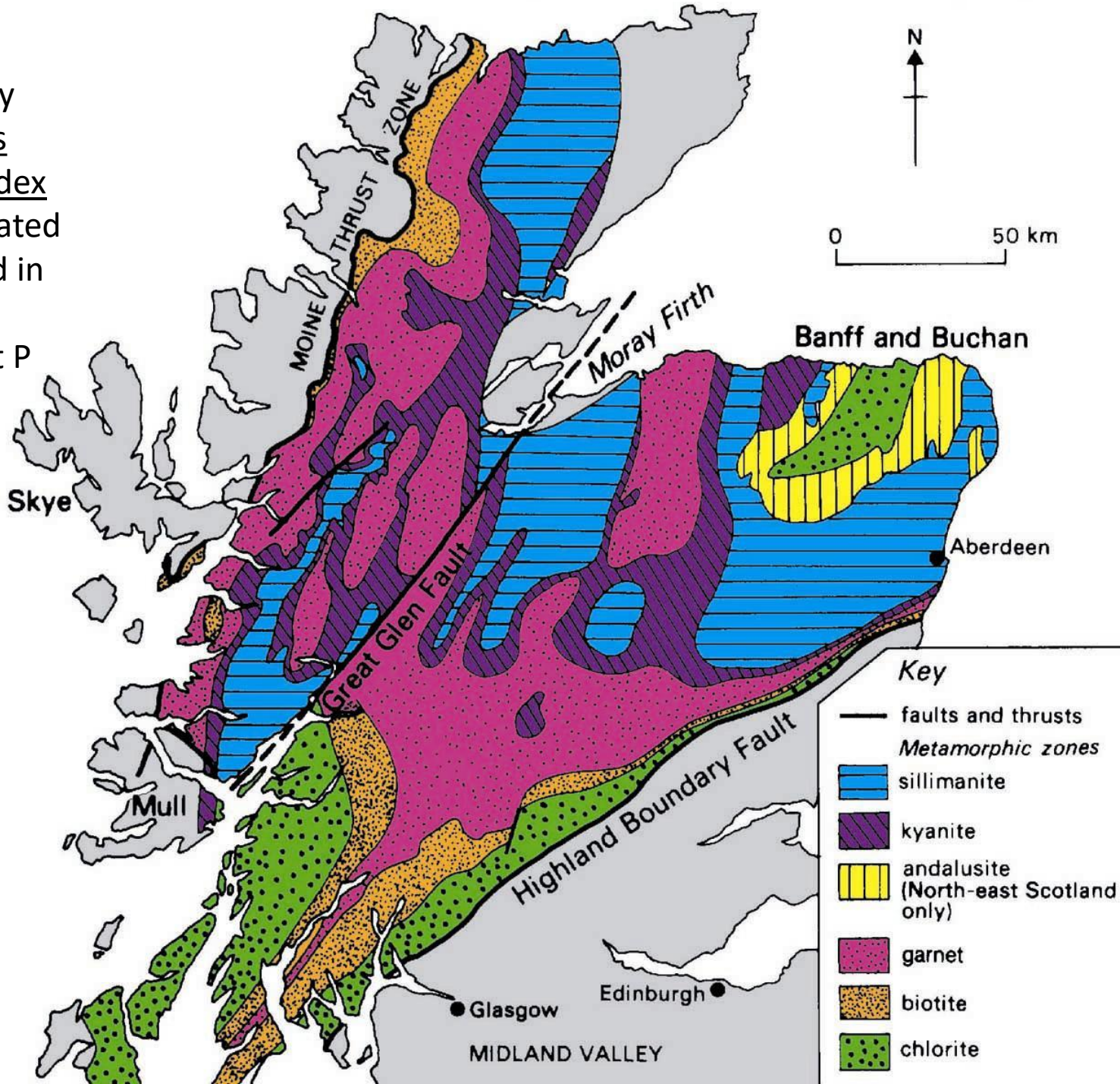
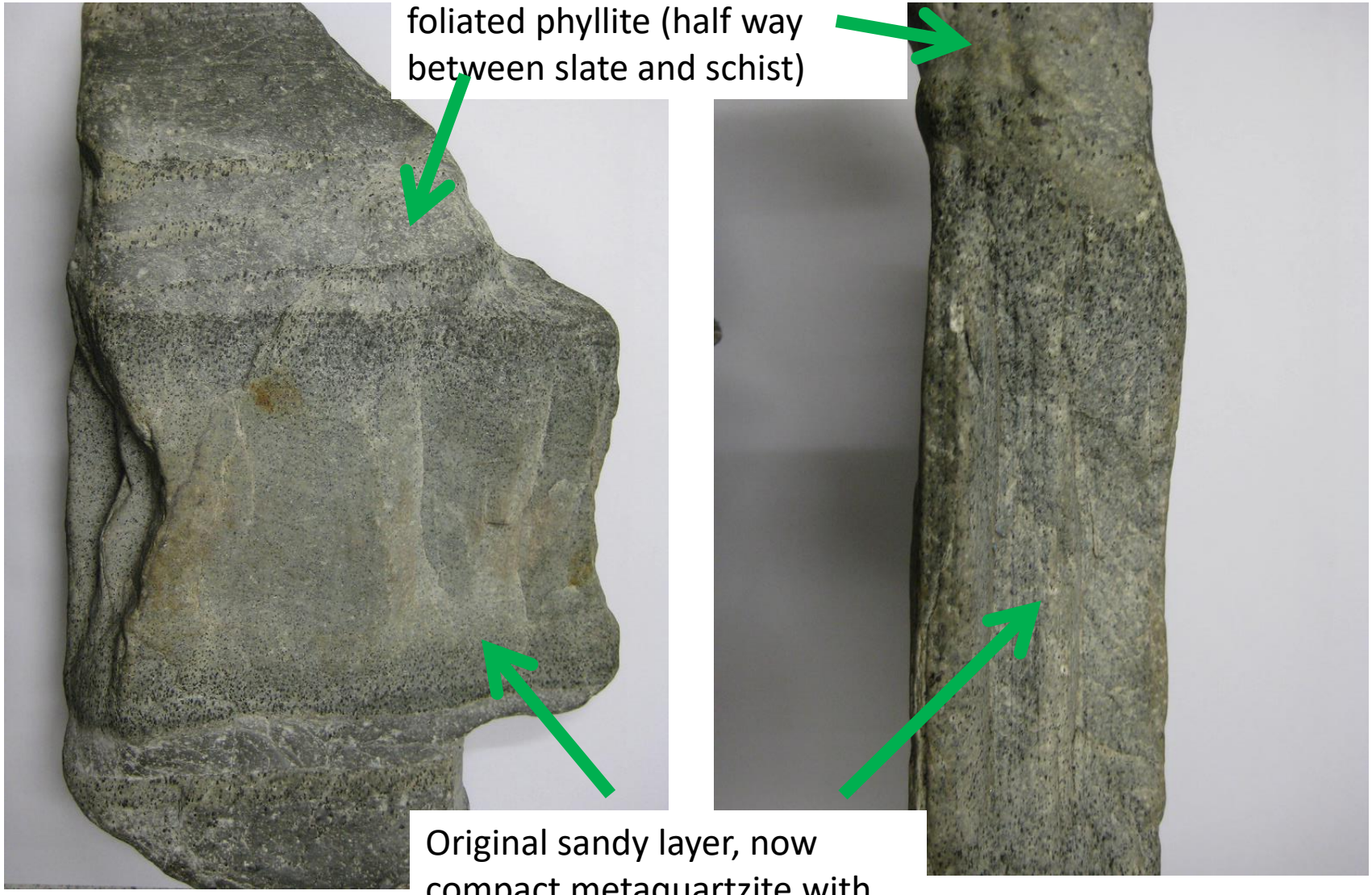
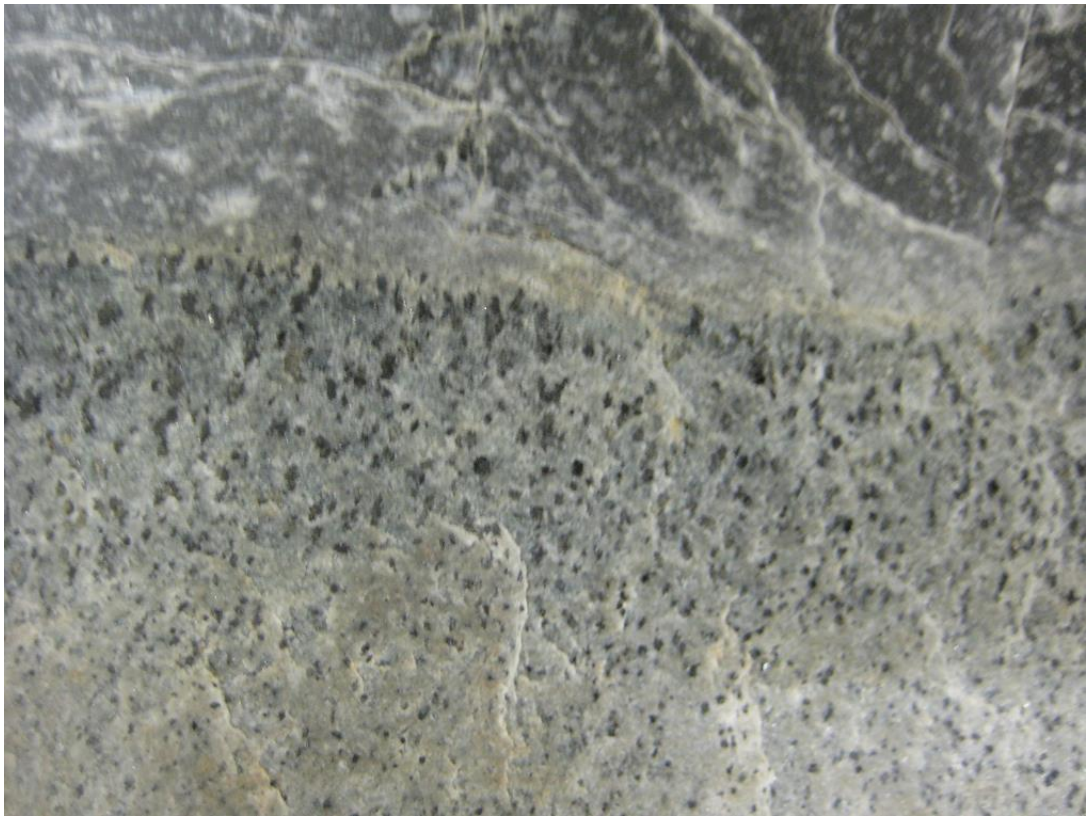
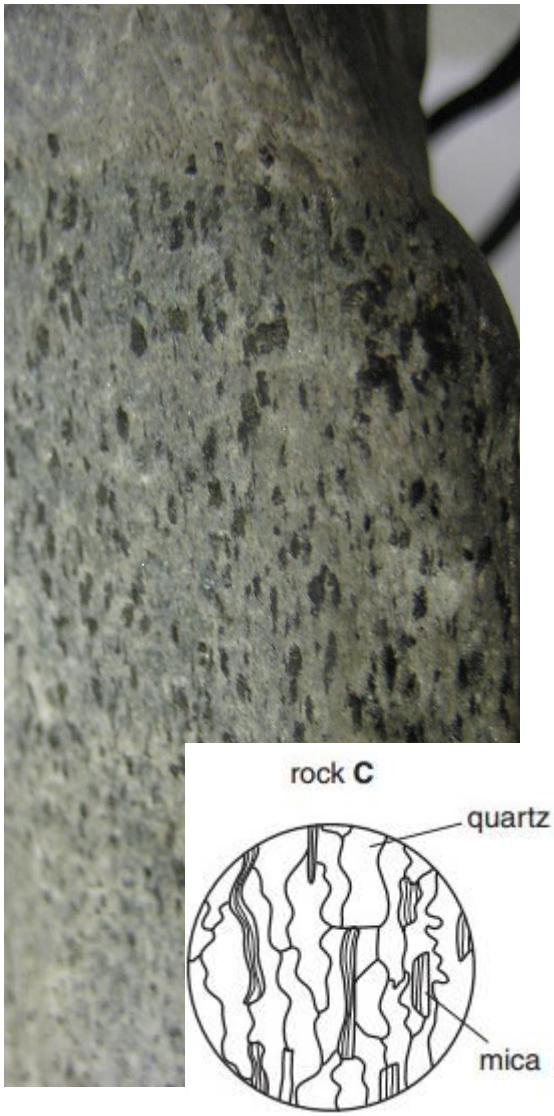


Figure 21-8. Regional metamorphic map of the Scottish Highlands, showing the zones of minerals that develop with increasing metamorphic grade. From Gillen (1982) *Metamorphic Geology. An Introduction to Tectonic and Metamorphic Processes*. George Allen & Unwin. London.

Low grade metamorphism
Slate, French Alps
Deformed to create foliation (in this case, slaty cleavage). The white spots were originally circles. Note bedding still visible.


Original muddy layer, now foliated phyllite (half way between slate and schist)
Original sandy layer, now compact metaquartzite with interlocking quartz grains, but showing some foliation



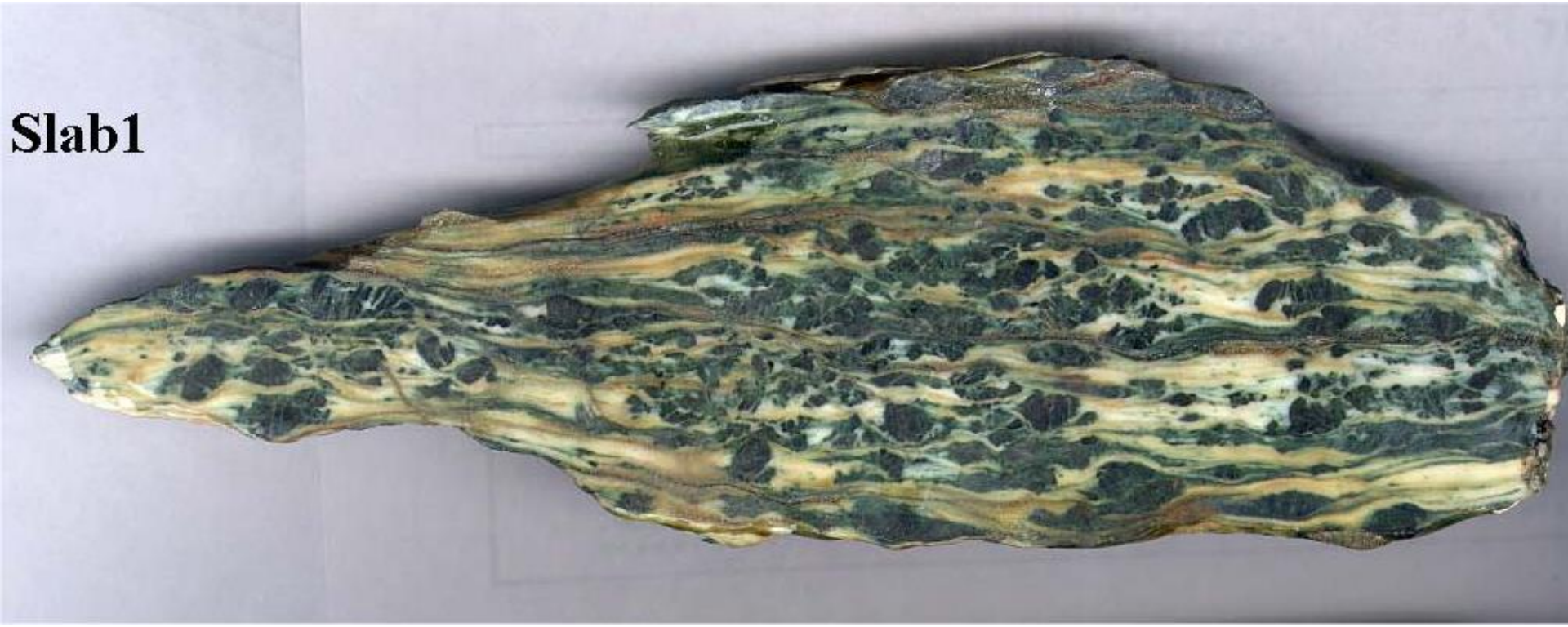


Biotite flakes grow at original muddy margin of sandstone layer; aligned in foliation

Garnet schist, Sgurr Mor, Scotland

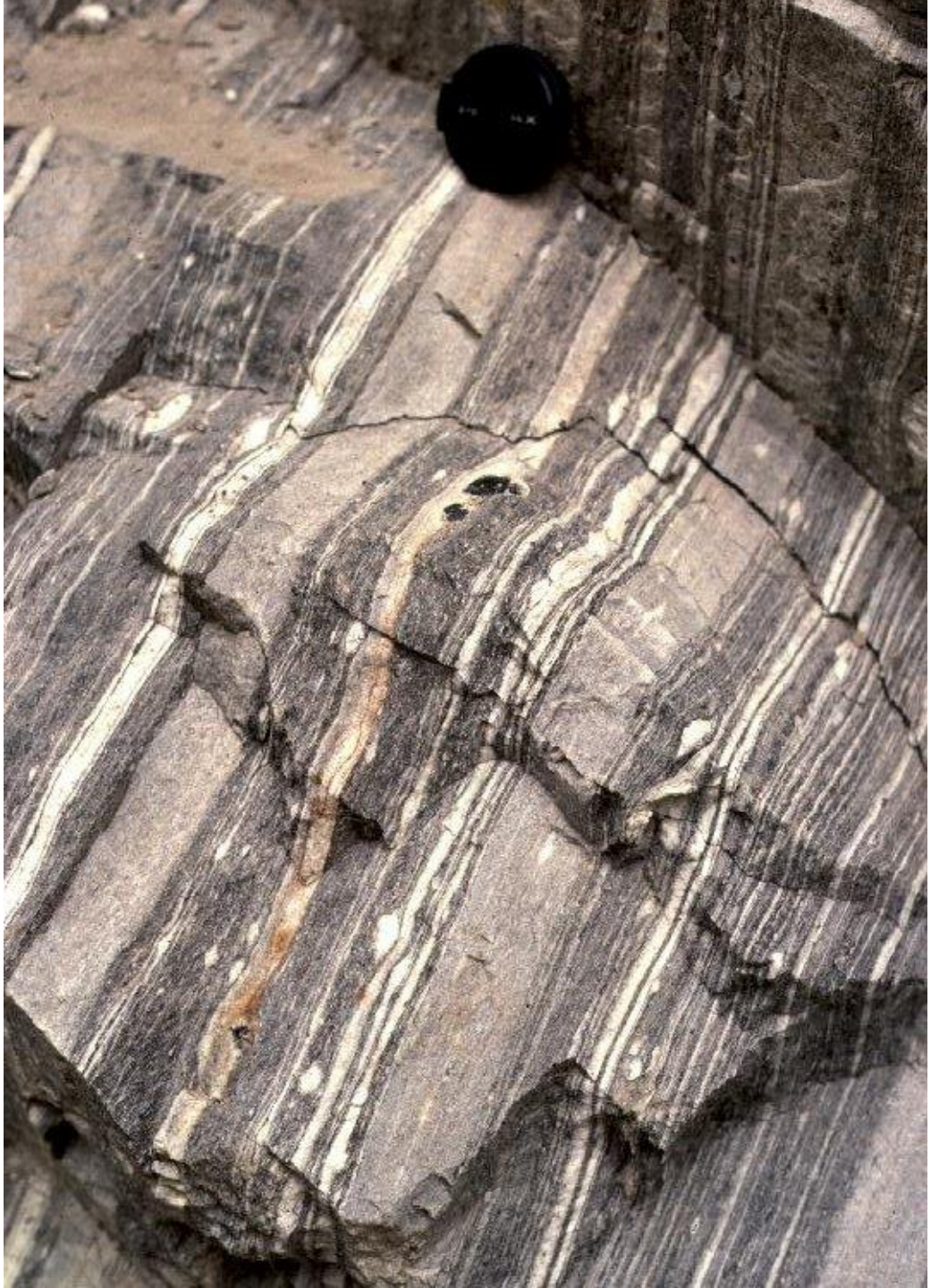
Calcareous mica schist, Alps

Deformed basic igneous rock, Alps



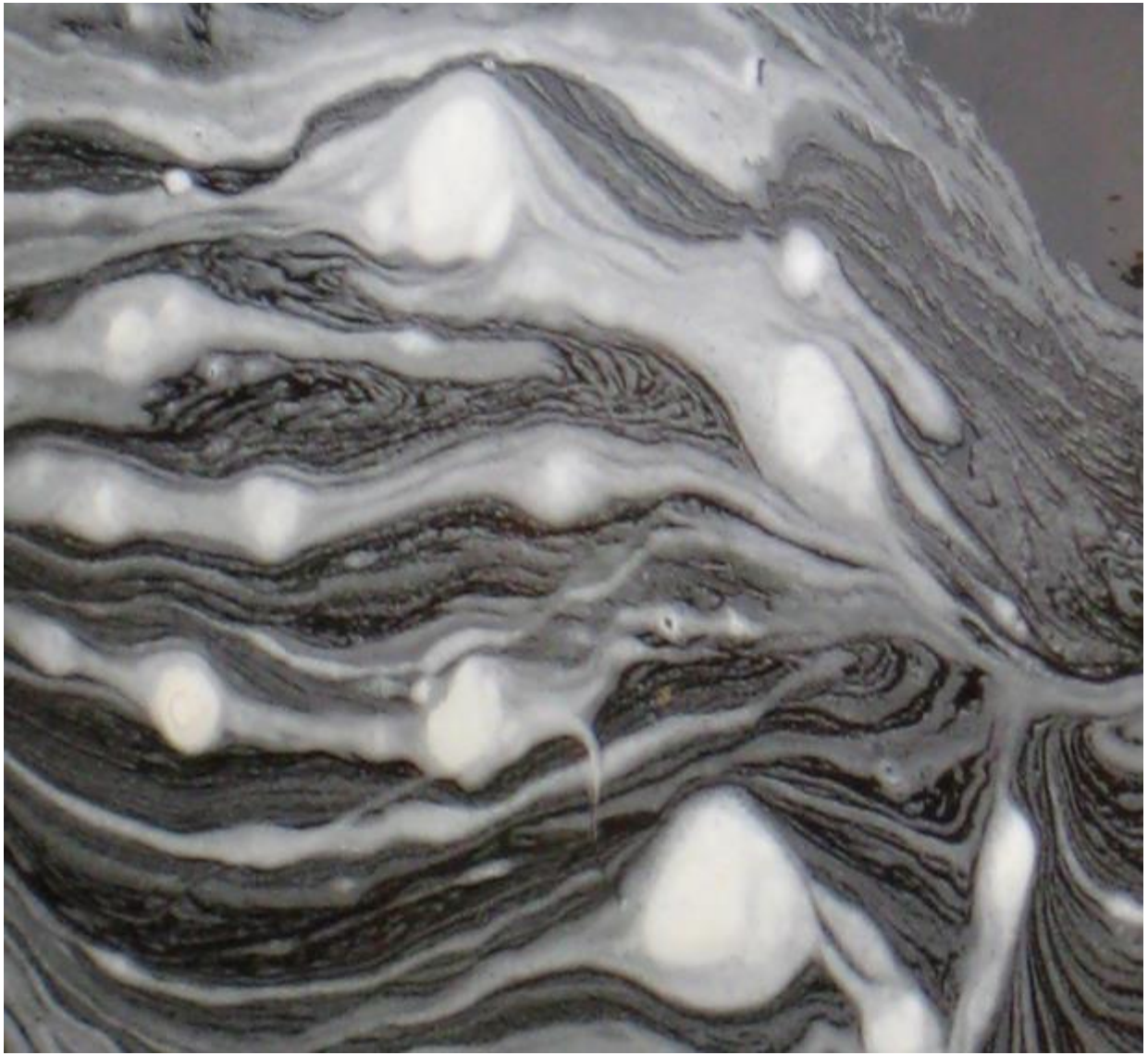
High grade gneiss, Himalayas

Note intense gneissose banding



Augen gneiss, Scotland.

Augen are original objects (in this case phenocrysts) not yet stretched out to form gneissose banding

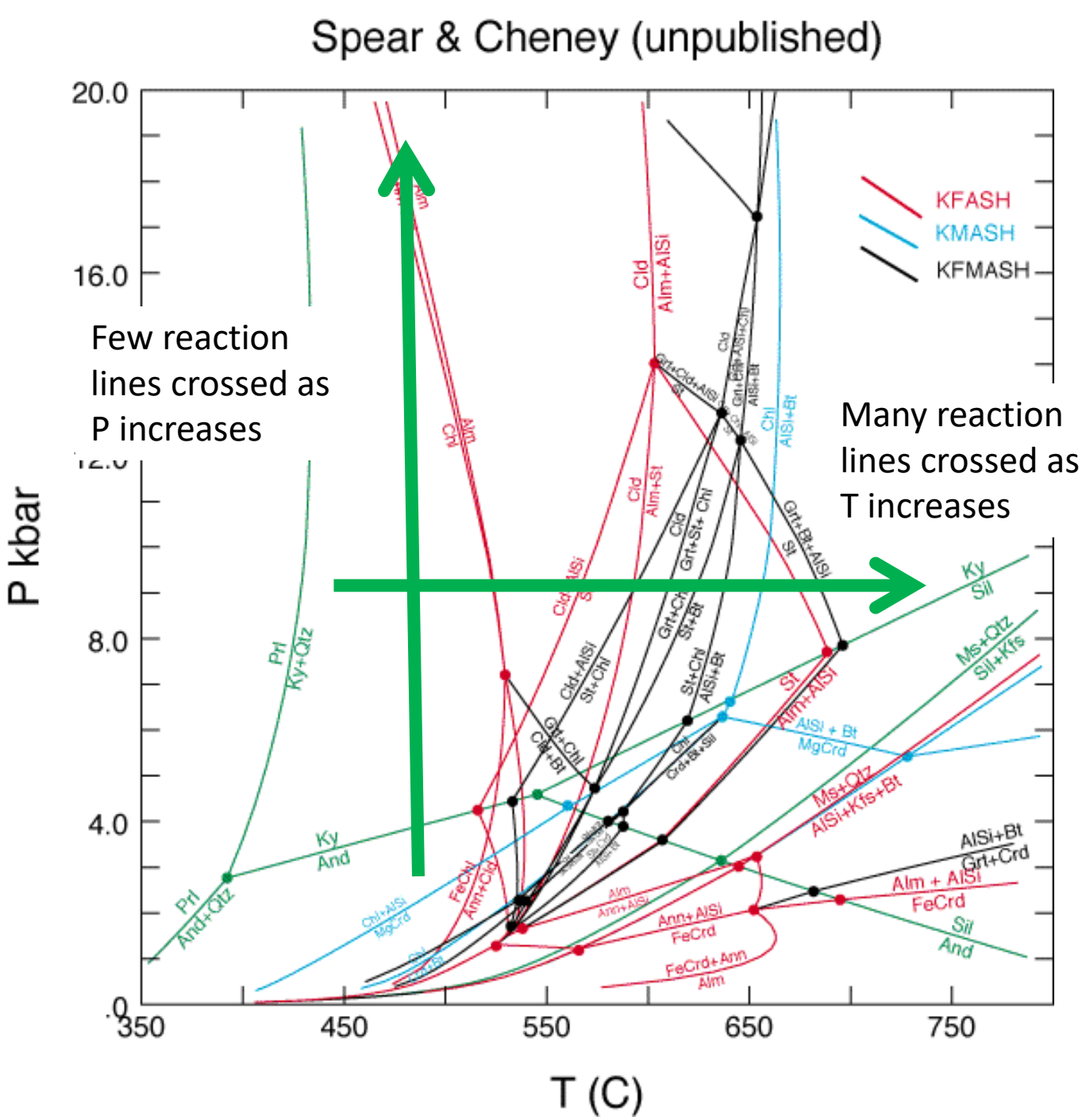


Foam blobs and streaks in a river – deformation of the water stretches out some of the foam blobs into streaks; other blobs survive.

That is how augen gneiss forms

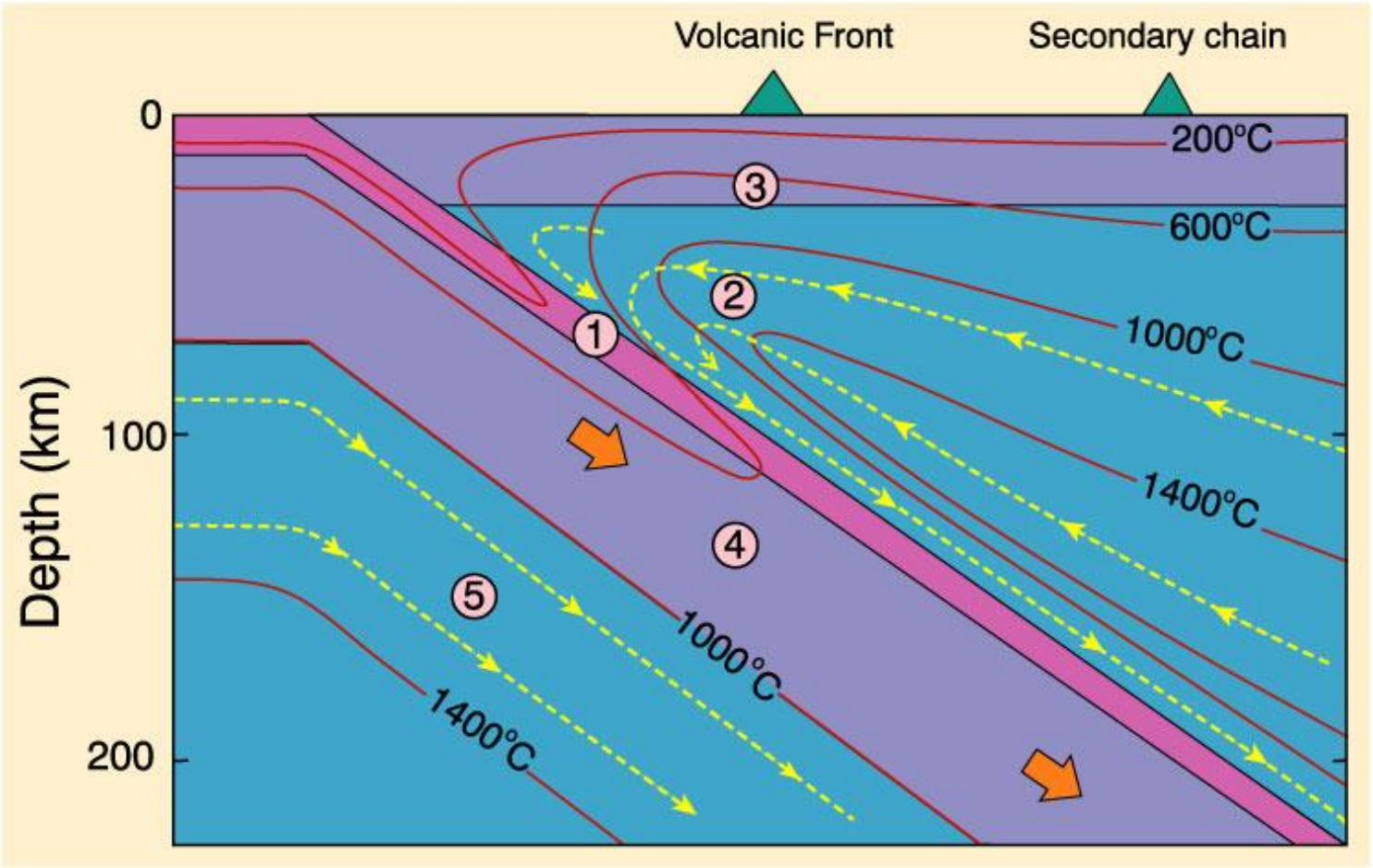
Migmatite, Alps: partial melting

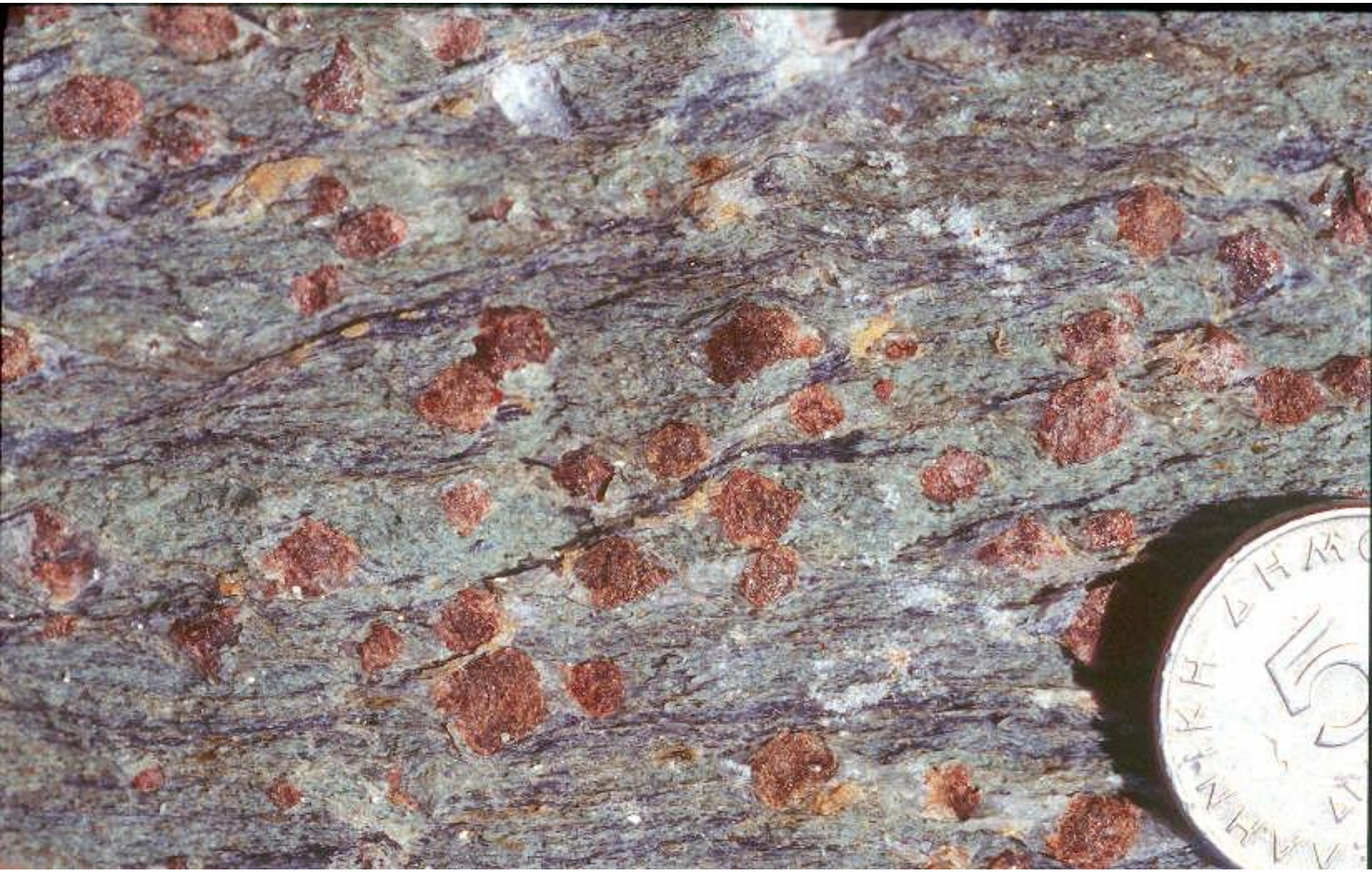
Migmatite, Alps: partial melting



Temperature dependence of metamorphism

Metamorphism occurs in subduction as well as in continental collision – rocks buried by the downward movement





Blueschist, Aegean islands, from L. Jolivet

Blueschist, Corsica, from L. Jolivet

Contact Metamorphism: minerals and textures

- This is simpler to understand (usually no deformation)
- In real examples, though, contact metamorphism around large intrusions is commonly *superimposed* on regional metamorphism

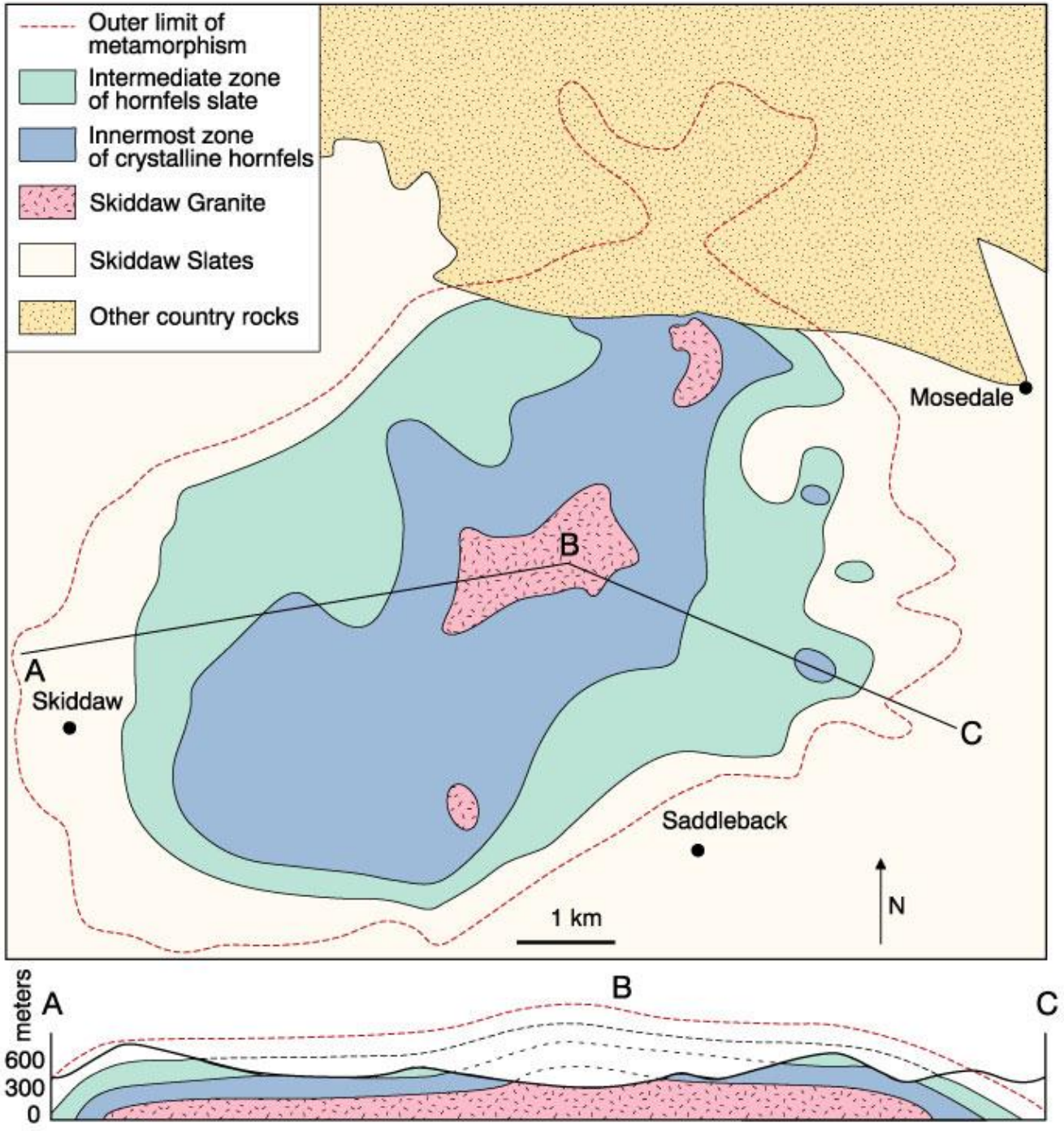


Figure 21-14. **Geologic Map and cross-section of the area around the Skiddaw granite, Lake District, UK. After Eastwood et al (1968). *Geology of the Country around Cockermouth and Caldbeck*. Explanation accompanying the 1-inch Geological Sheet 23, New Series. Institute of Geological Sciences. London.**

Contact Metamorphism of original mudstone in the Skiddaw Aureole, UK

- Middle zone: slates (formed from mudstone) quite thoroughly recrystallized, contain biotite + muscovite + cordierite + andalusite + quartz

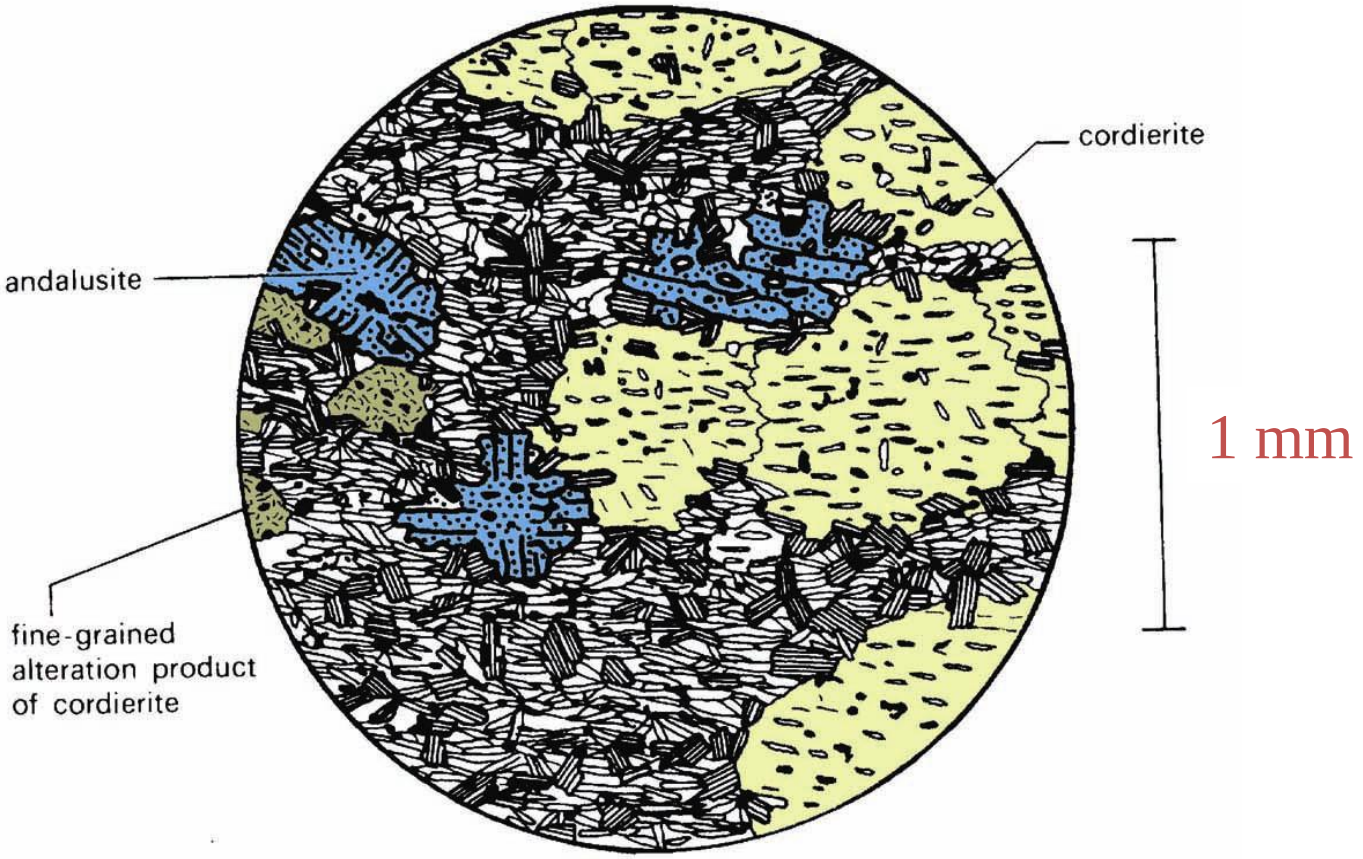
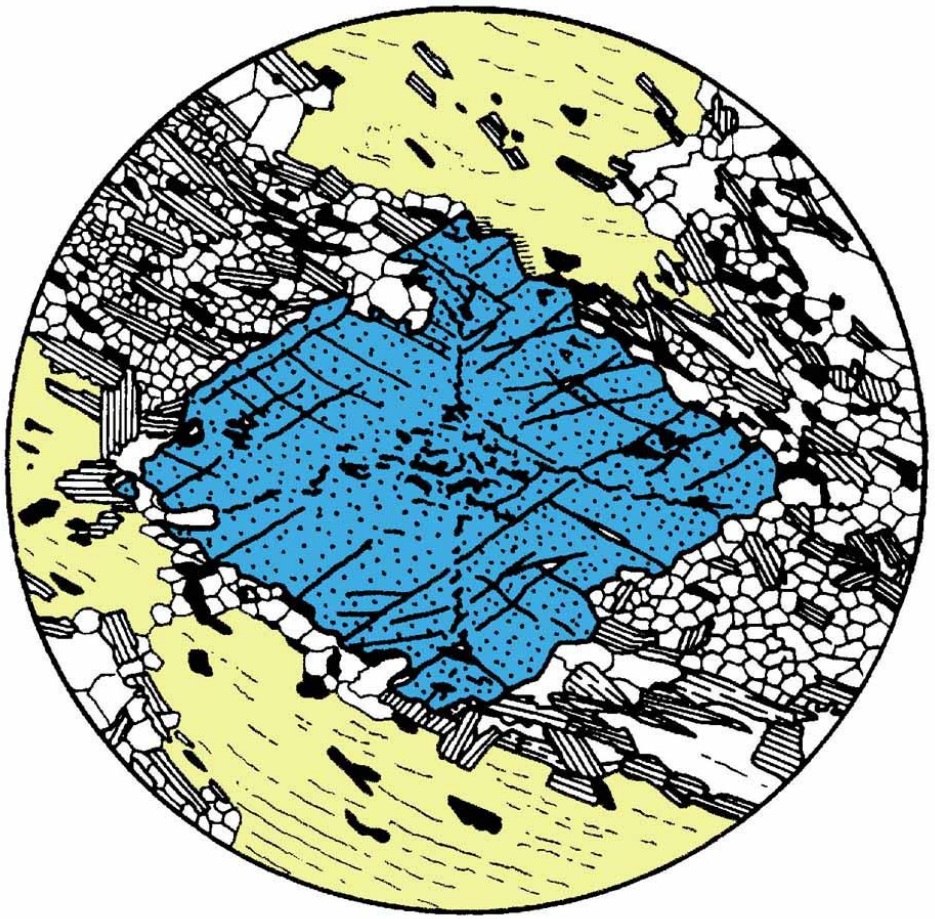


Figure 21-15. Cordierite-andalusite slate from the middle zone of the Skiddaw aureole. From Mason (1978) *Petrology of the Metamorphic Rocks*. George Allen & Unwin. London.

Contact Metamorphism of original mudstone in the Skiddaw Aureole, UK



1 mm

Inner zone:

Thoroughly recrystallized

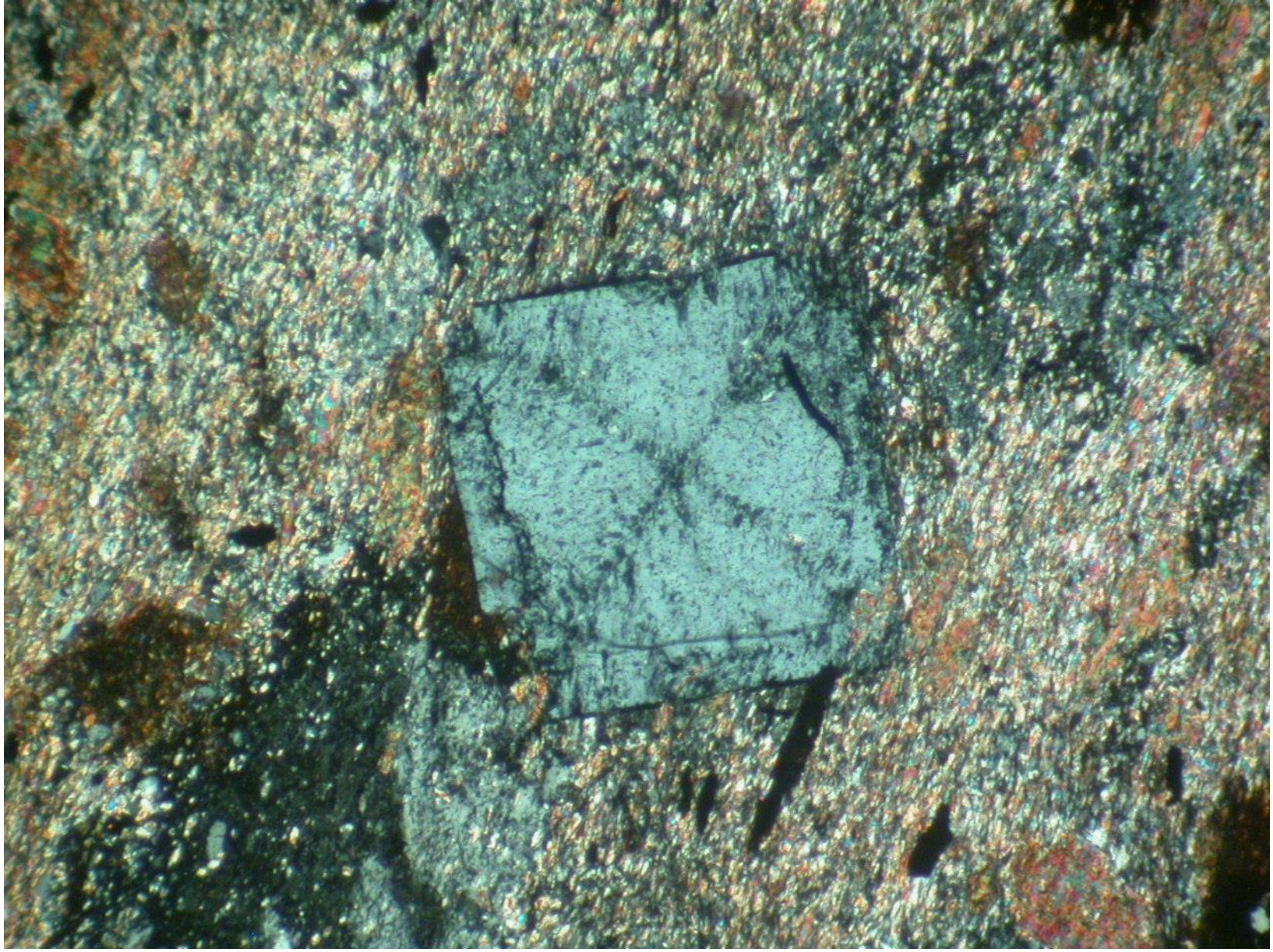
Lose foliation

Figure 21-16. **Andalusite-cordierite schist from the inner zone of the Skiddaw aureole. Note the chiastolite cross in andalusite (see also Figure 22-49). From Mason (1978) *Petrology of the Metamorphic Rocks*. George Allen & Unwin. London.**

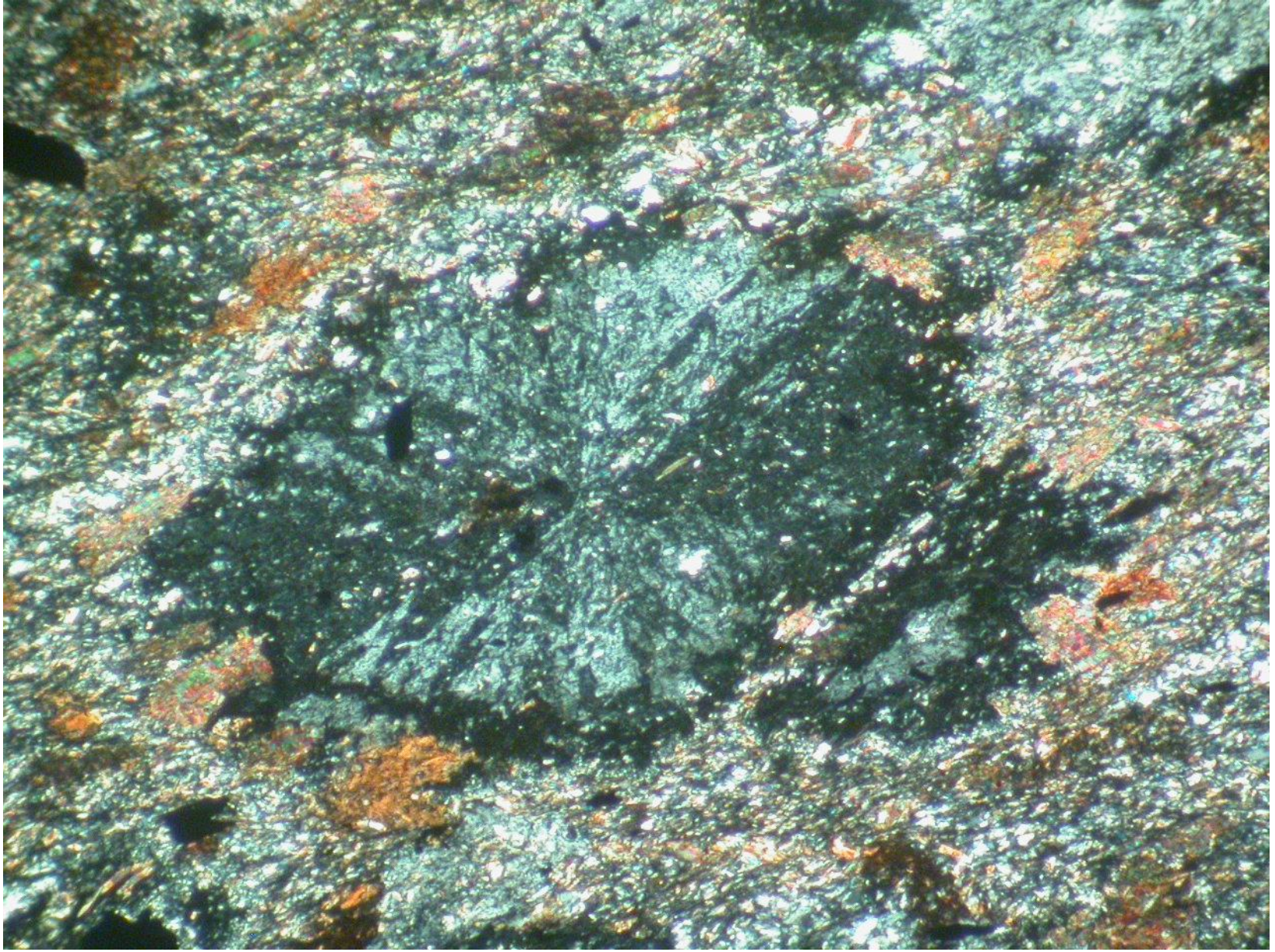
Andalusite needles (porphyroblasts)
in what *was* slate

Slaty cleavage obliterated

Andalusite needles cut in various orientations – note darker inclusion rich cores – this is a called chiastolite texture

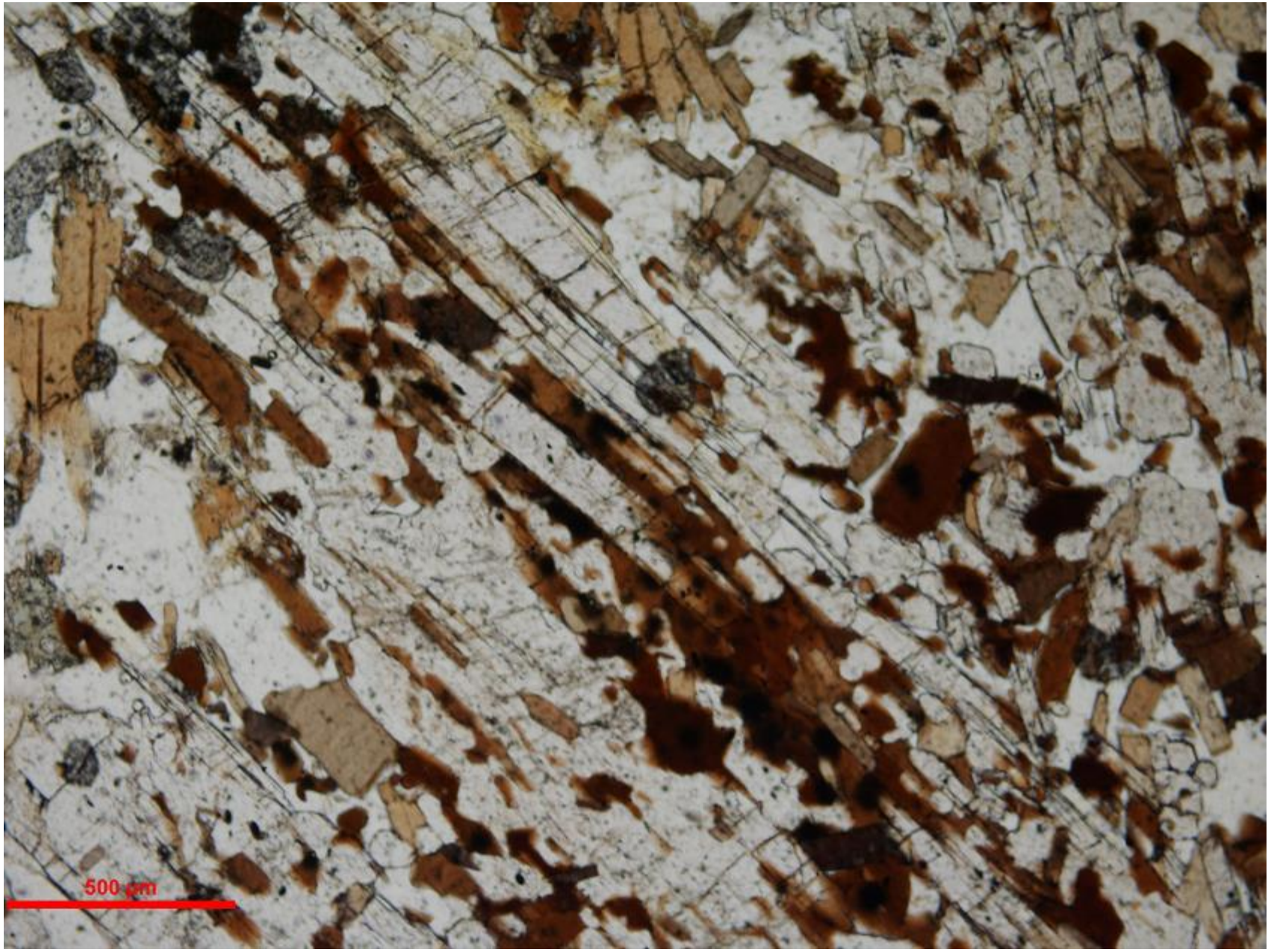


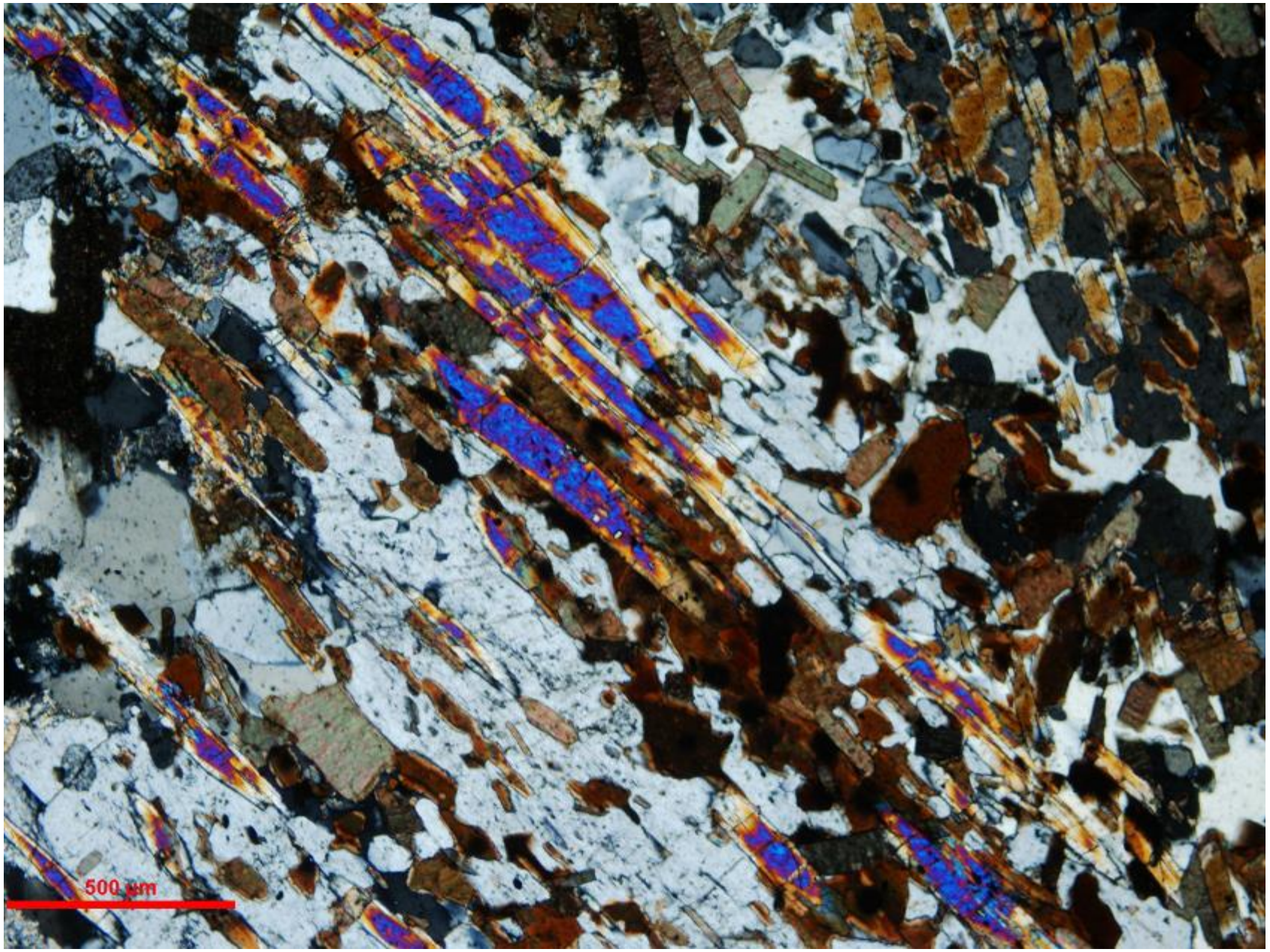
461-41: cross-section through andalusite prism in centre. Pattern of inclusions is “chiastolite cross”. Note foliated matrix. XPL.



461-41: cordierite showing ill-defined radial “sector twinning” and a poorly developed corona of pinite (isotropic, i.e. black here). XPL.

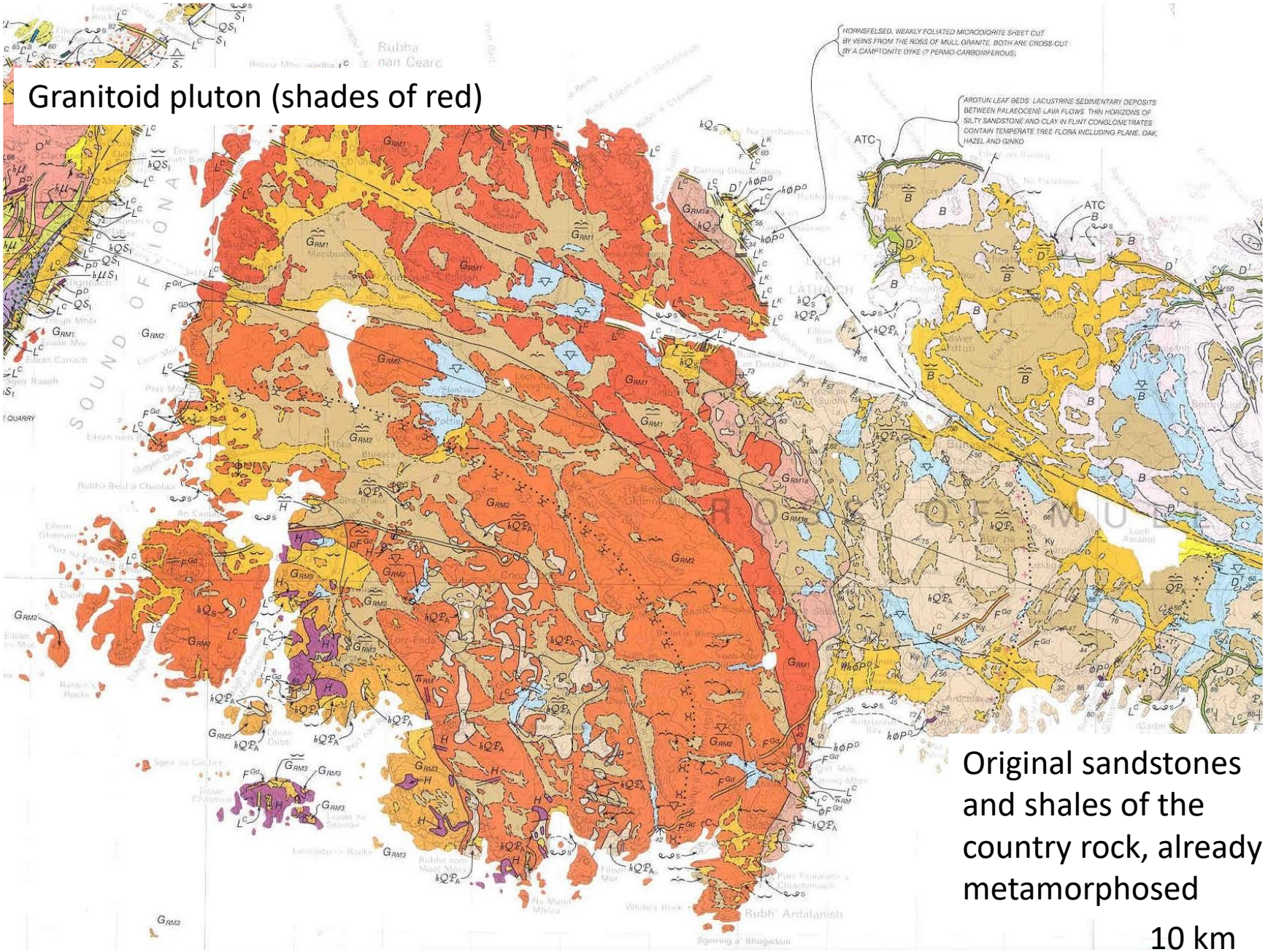
Hornfelsed – foliation lost; interlocking grains

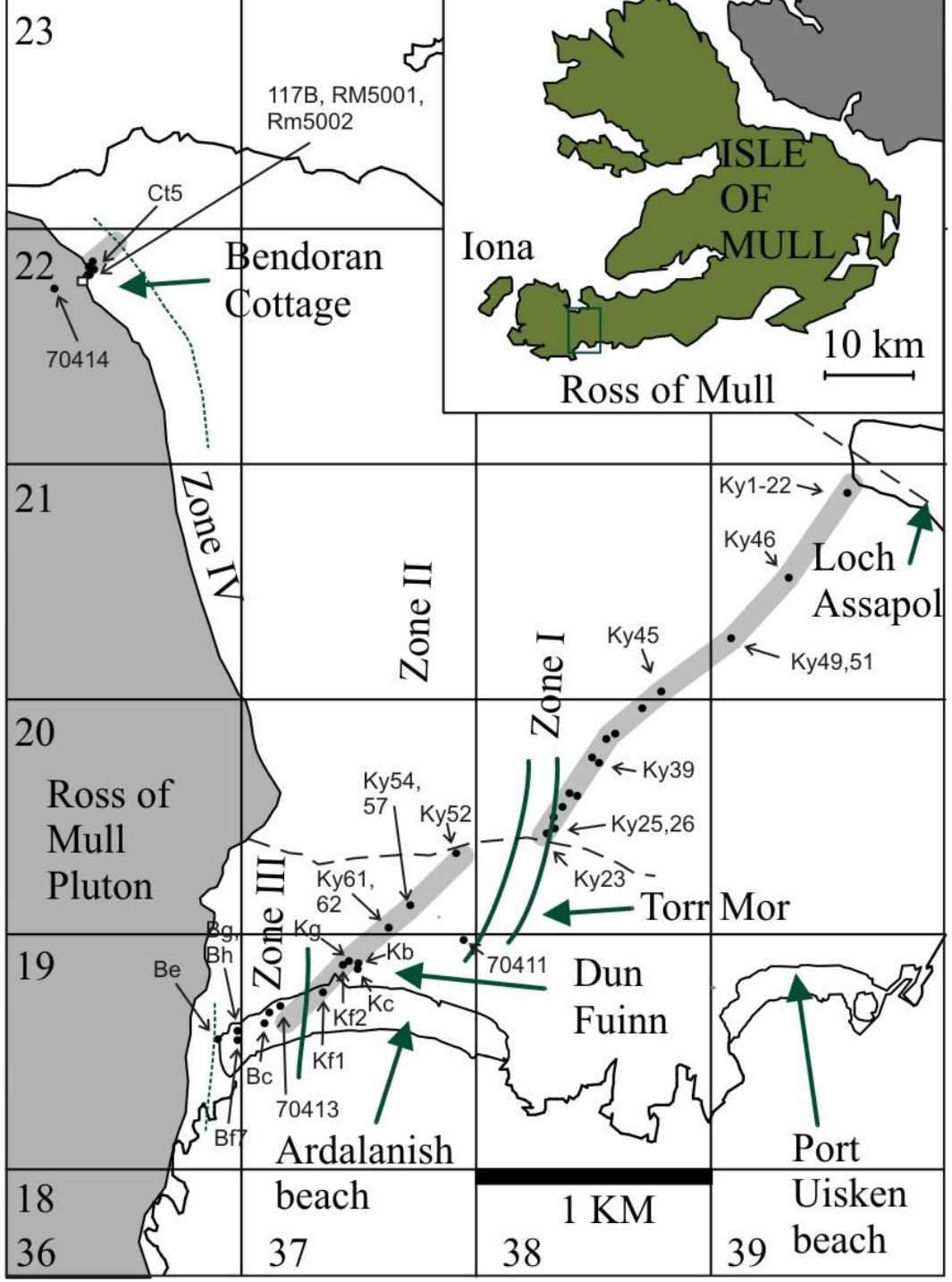

500 µm


500 µm

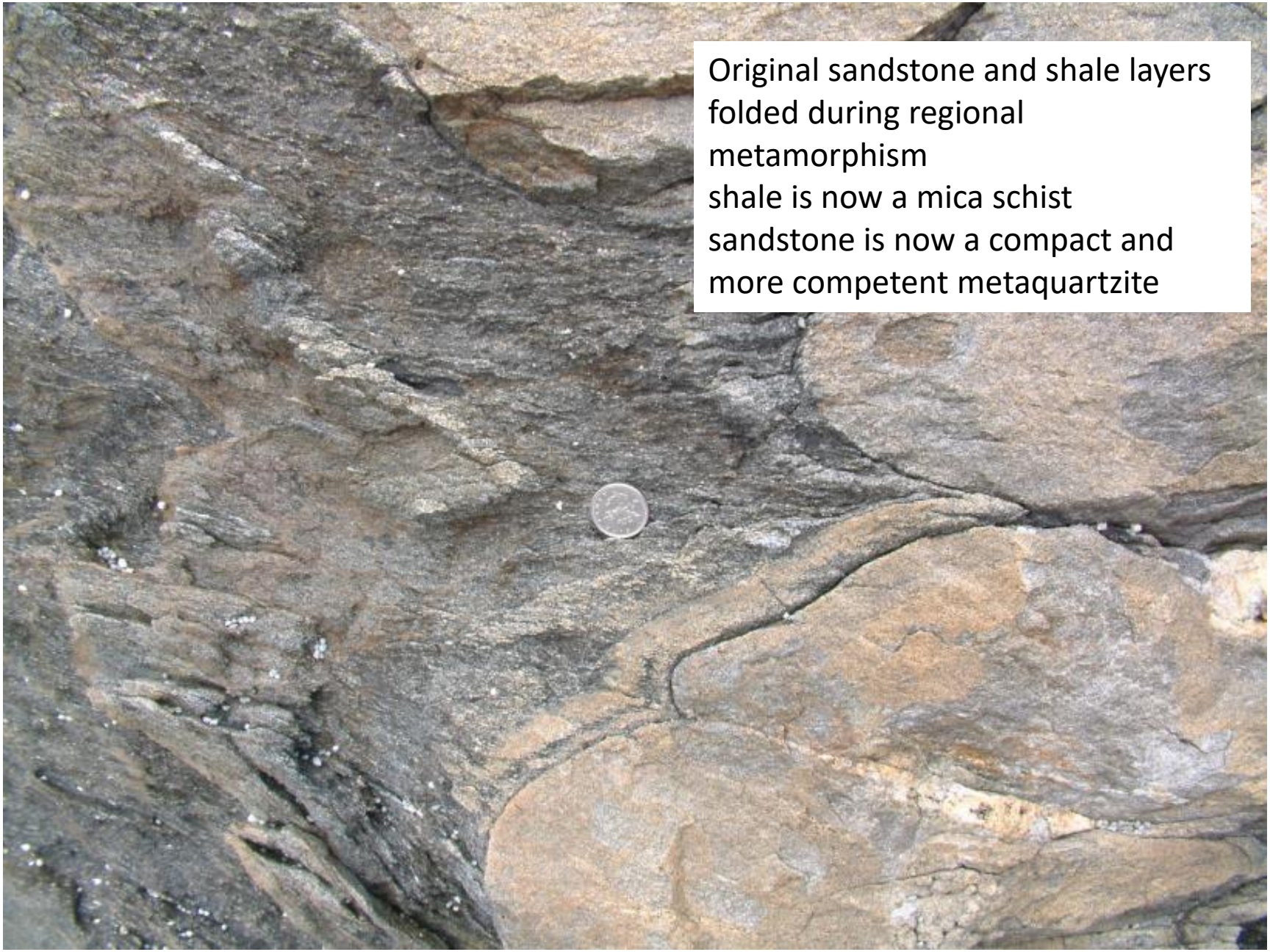
Contact metamorphism case study

Ross of Mull granite aureole

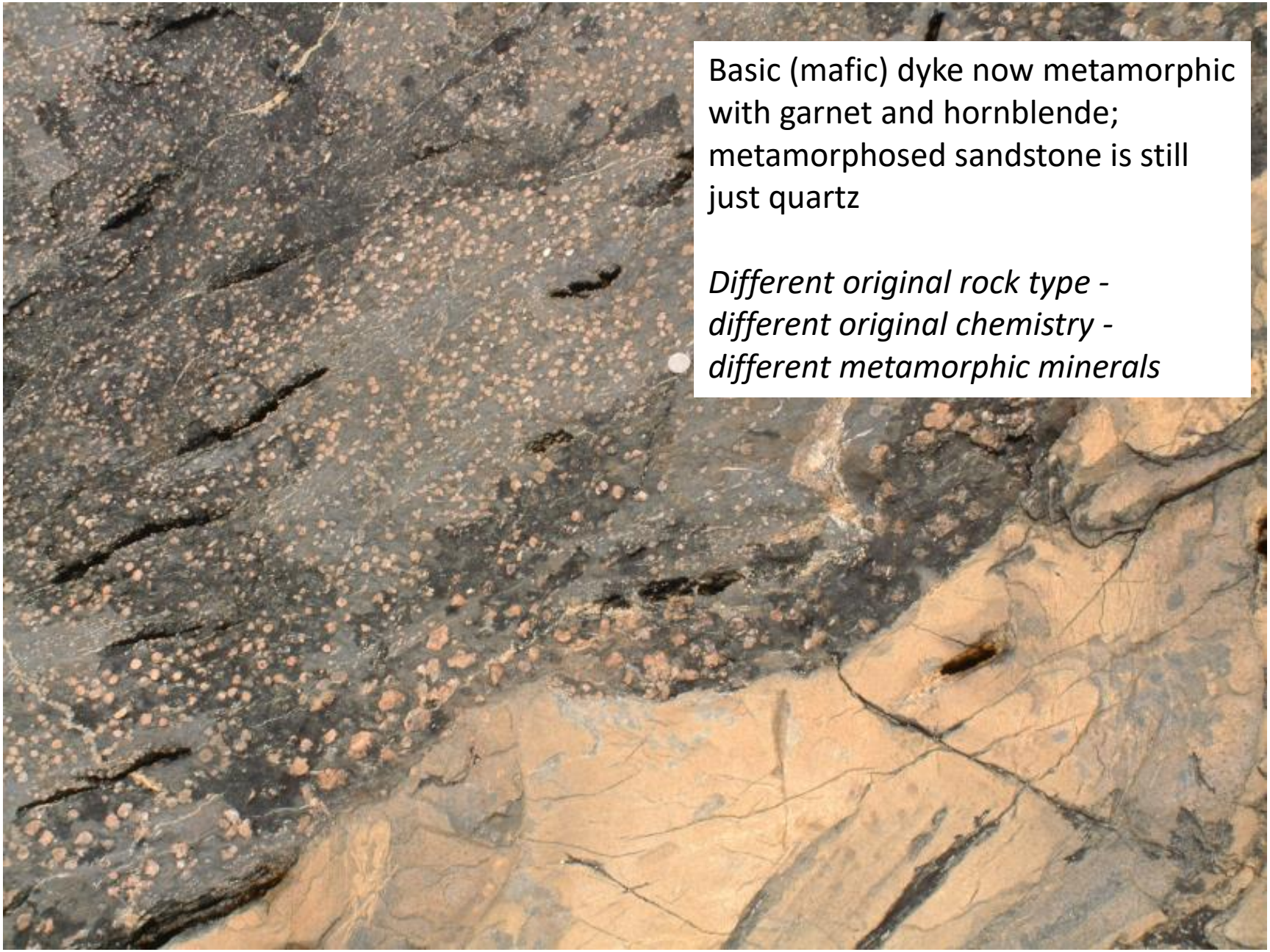

Granitoid pluton (shades of red)
HORNFELSED, WEAKLY FOLIATED MICRODIORITE SHEET CUT BY VEINS FROM THE ROSS OF MULL GRANITE, BOTH ARE CROSS-CUT BY A CAMPTONITE DYKE (? PERMO-CARBONIFEROUS)
ARDTUN LEAF BEDS: LACUSTRINE SEDIMENTARY DEPOSITS BETWEEN PALAEOCENE LAVA FLOWS. THIN HORIZONS OF SILTY SANDSTONE AND CLAY IN FLINT CONGLOMERATES CONTAIN TEMPERATE TREE FLORA INCLUDING PLANE, OAK, HAZEL AND GINKO
ATC
Original sandstones and shales of the country rock, already metamorphosed
10 km


23
117B, RM5001,
Rm5002
Ct5
22
Bendoran
Cottage
70414
ISLE
OF
MULL
Iona
10 km
Ross of Mull
21
Zone IV
Zone II
Zone I
Ky1-22
Ky46
Loch
Assapol
Ky45
Ky49,51
20
Ross of
Mull
Pluton
Ky54,
57
Ky52
Ky39
Ky25,26
Ky23
Ky61,
62
Torr Mor
Zone III
Bg,
Bh
Be
Kg
Kb
Kc
Kf2
Kf1
Bc
70413
Bf7
70411
Dun
Fuinn
19
Ardalanish
beach
Port
Uisken
beach
1 KM
18
36
37
38
39

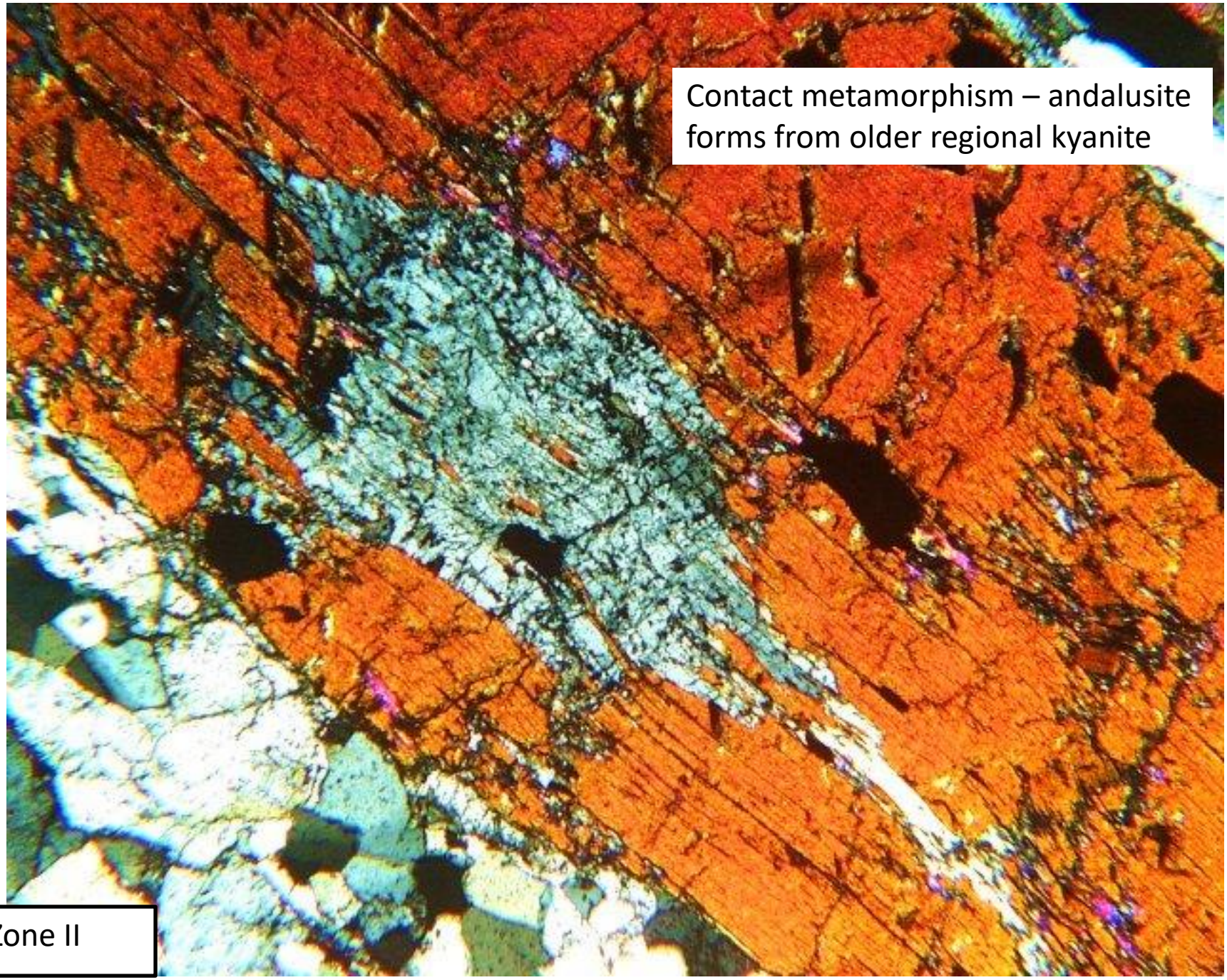

Original sandstone and shale layers folded during regional metamorphism

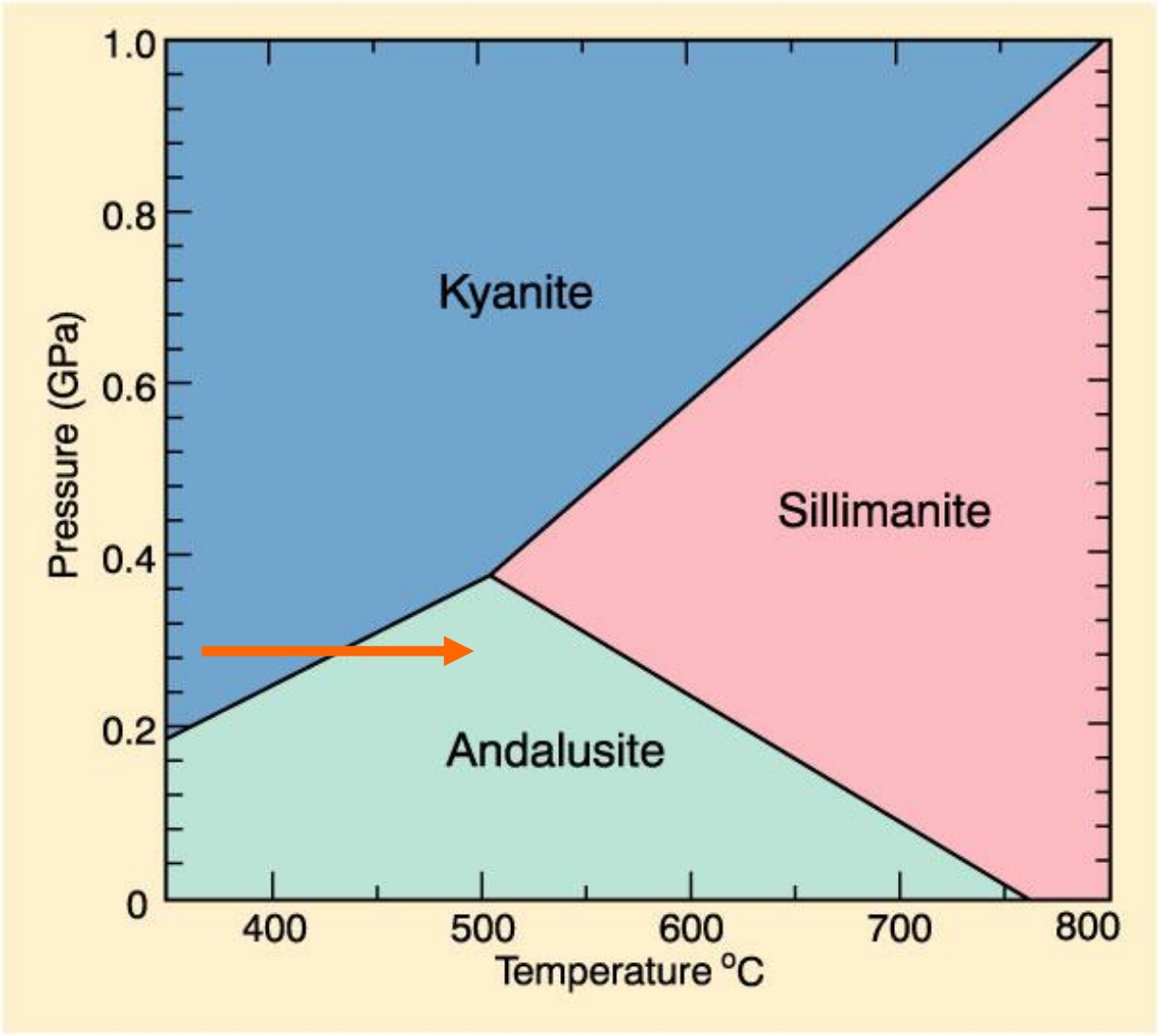

Original sandstone and shale layers folded during regional metamorphism
shale is now a mica schist
sandstone is now a compact and more competent metaquartzite


Original basic dyke cut the sediments


Basic (mafic) dyke now metamorphic with garnet and hornblende; metamorphosed sandstone is still just quartz
Different original rock type - different original chemistry - different metamorphic minerals


Contact metamorphism – andalusite forms from older regional kyanite
Zone II


Contact metamorphism – andalusite forms from older regional kyanite
Zone II


1.0
0.8
0.6
0.4
0.2
0
Pressure (GPa)
Kyanite
Sillimanite
Andalusite
400
500
600
700
800
Temperature °C

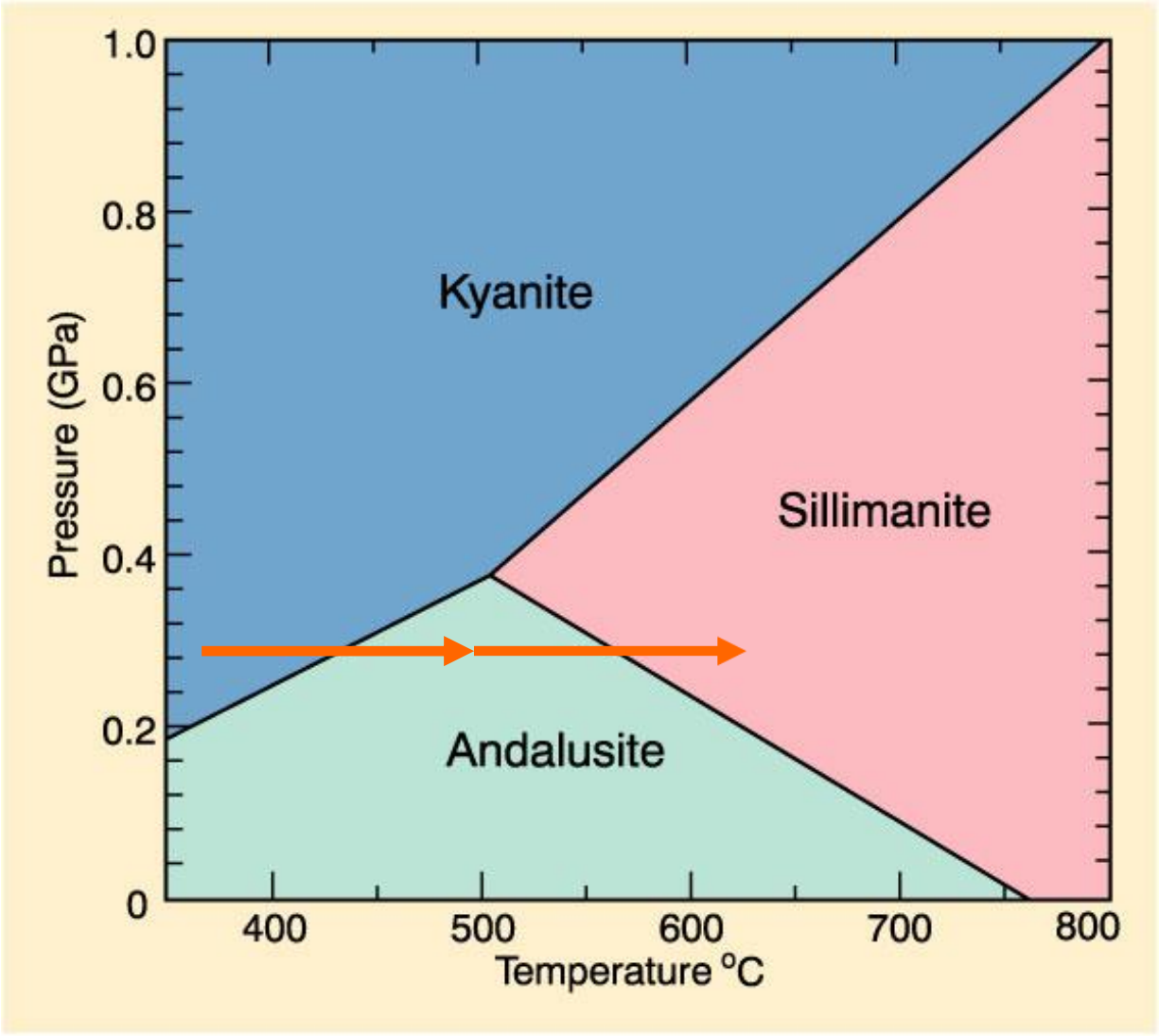
Contact metamorphism – kyanite now totally broken down to andalusite, cordierite, mica: the shapes are *pseudomorphs* after kyanite

Zone II

Zone IV

Close to granite sillimanite forms –
and tiny new garnets

Zone IV


1.0
0.8
0.6
0.4
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Pressure (GPa)
Kyanite
Sillimanite
Andalusite
400
500
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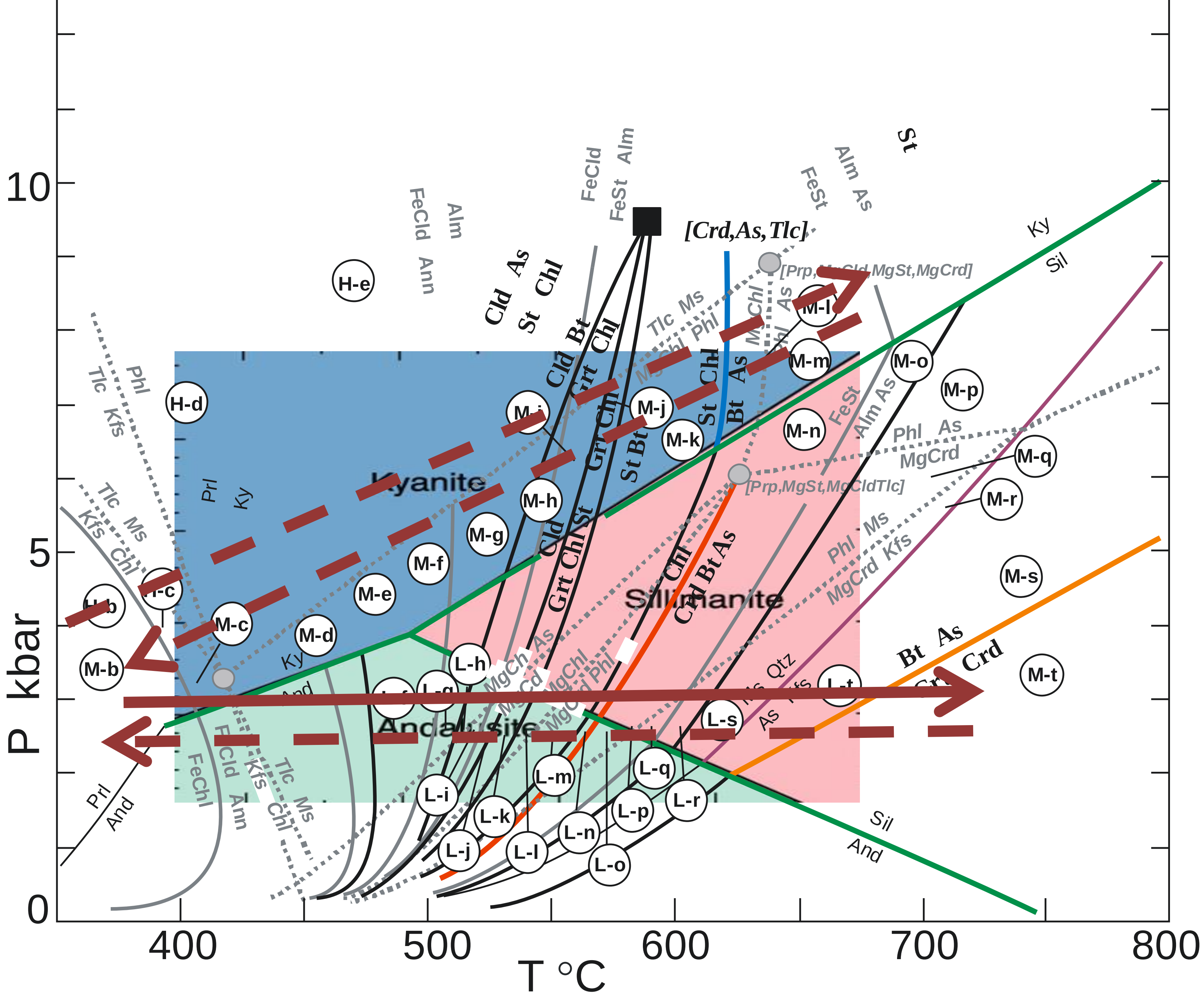
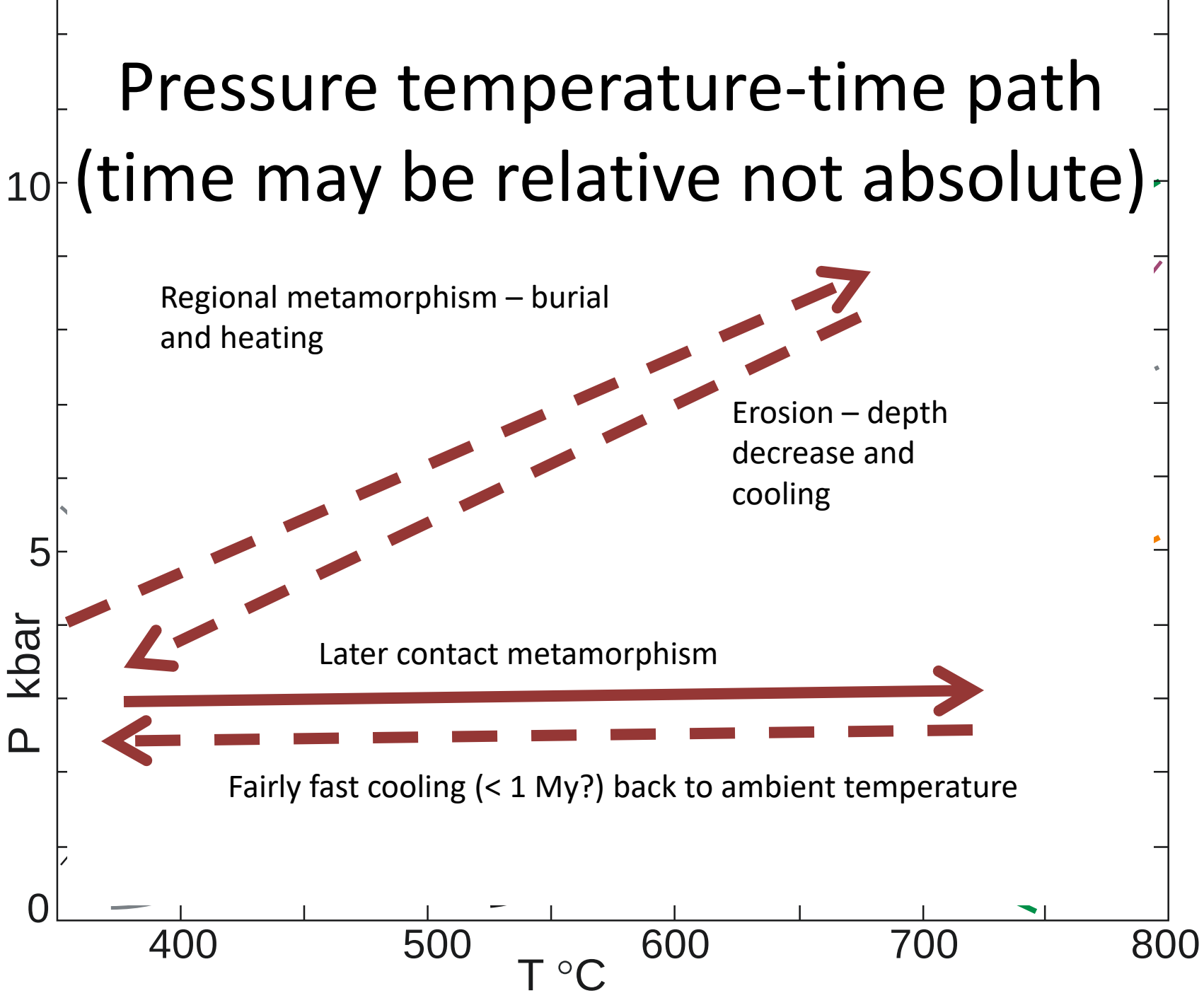
700
800
Temperature °C



P kbar
T °C
0
5
10
400
500
600
700
800
Kyanite
Sillimanite
Andalusite
[Crd,As,Tlc]
[Prp,MgSt,MgCldTlc]
Ky
Sil
And
Bt As
Crd

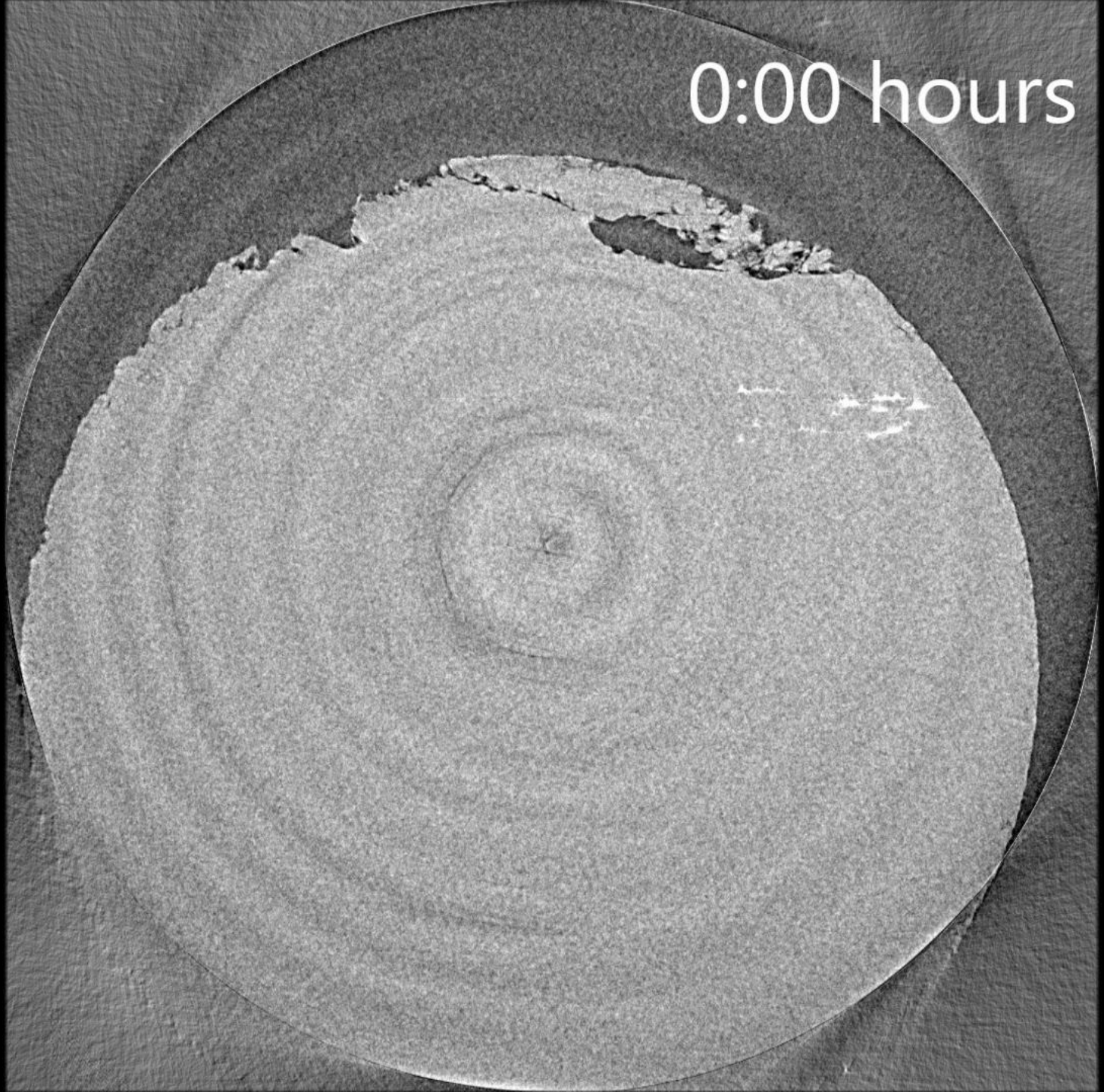
Pressure temperature-time path (time may be relative not absolute)



Most of the Earth is metamorphic

Finally

- First ever movie of an actual metamorphic reaction
- Made using X ray tomography on a synchrotron in Chicago
- My colleagues John Bedford, Henri Leclere, Florian Fusseis


0:00 hours

Geology at Liverpool

- https://www.liv.ac.uk/earth-ocean-and-ecological-sciences/geology-and-geophysics-programmes/
- Apologies I have to leave soon to catch a flight
- If you have further questions email me on johnwh@liv.ac.uk – you may not get an immediate reply but you will eventually!