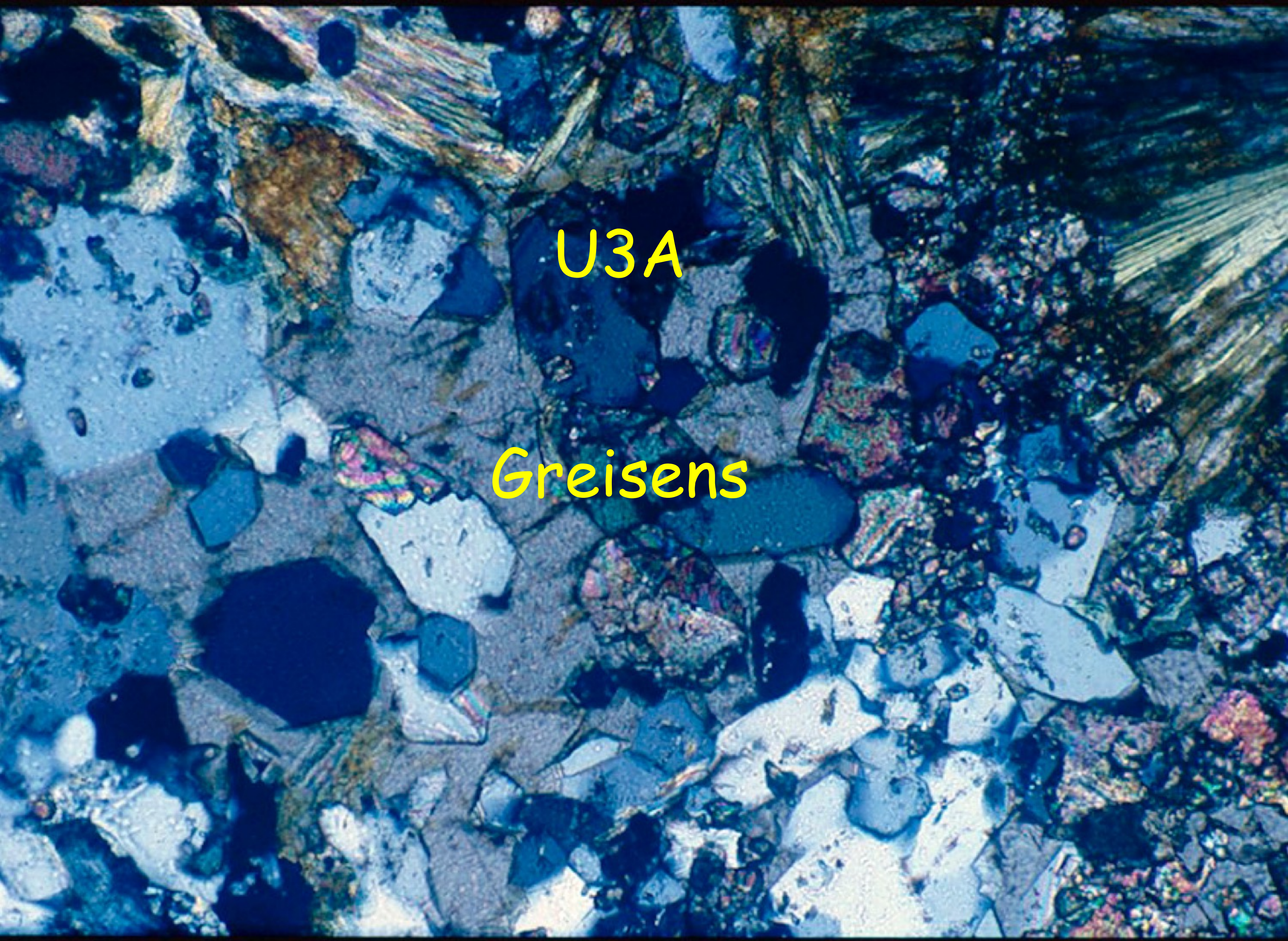

U3A
Greisens

Introduction

- Greisens → metasomatic altered rocks formed by the action of high temperature pneumatolitic-hydrothermal fluids (rich in H_2O, F and B)
- form in apical domes of granite intrusions, in exocontact zones and in veins
- generally quartz-mica rocks commonly with topaz, tourmaline, fluorite and metal sulphides (pyrite, pyrrhotite, chalcopyrite etc)
- ores include Sn, W, Be, Mo, Cu, Zn, As, Bi, Ta, Nb and rare earth minerals
- attracted Romans to Britain to exploit greisen-hosted Sn deposits in Cornwall

Greisenisation

- Greisenisation involves the high temperature (300-500°C) post magmatic transformation of rocks under the influence of acid residual solutions, high in silica and volatiles (H_2O, F, B,H_2S)

- the process is typically associated with intrusion of acidic and ultra-acidic magmas emplaced at shallow depths (1-4km) in the crust

- the process of *greisenisation* begins with the leaching of ions from rock-forming minerals and their replacement by quartz, sericite, muscovite, tourmaline, topaz, fluorite and other minerals.

- initial alteration involves the hydrolysis of K-feldspar

$$3KAlSi_3O_8 + 2H_2O \rightarrow KAl_2[Si_3AlO_{10}](OH)_2 + 2KOH + 6SiO_2$$

orthoclase muscovite quartz

Greisens

- Greisens have been formally described as:
  " Metasomatic rocks that are essentially quartz-mica in composition , often with topaz, fluorite, tourmaline, feldspar and ore minerals"

- definition misleading as some types of greisen (e.g. qtz-topaz greisen contain no micas

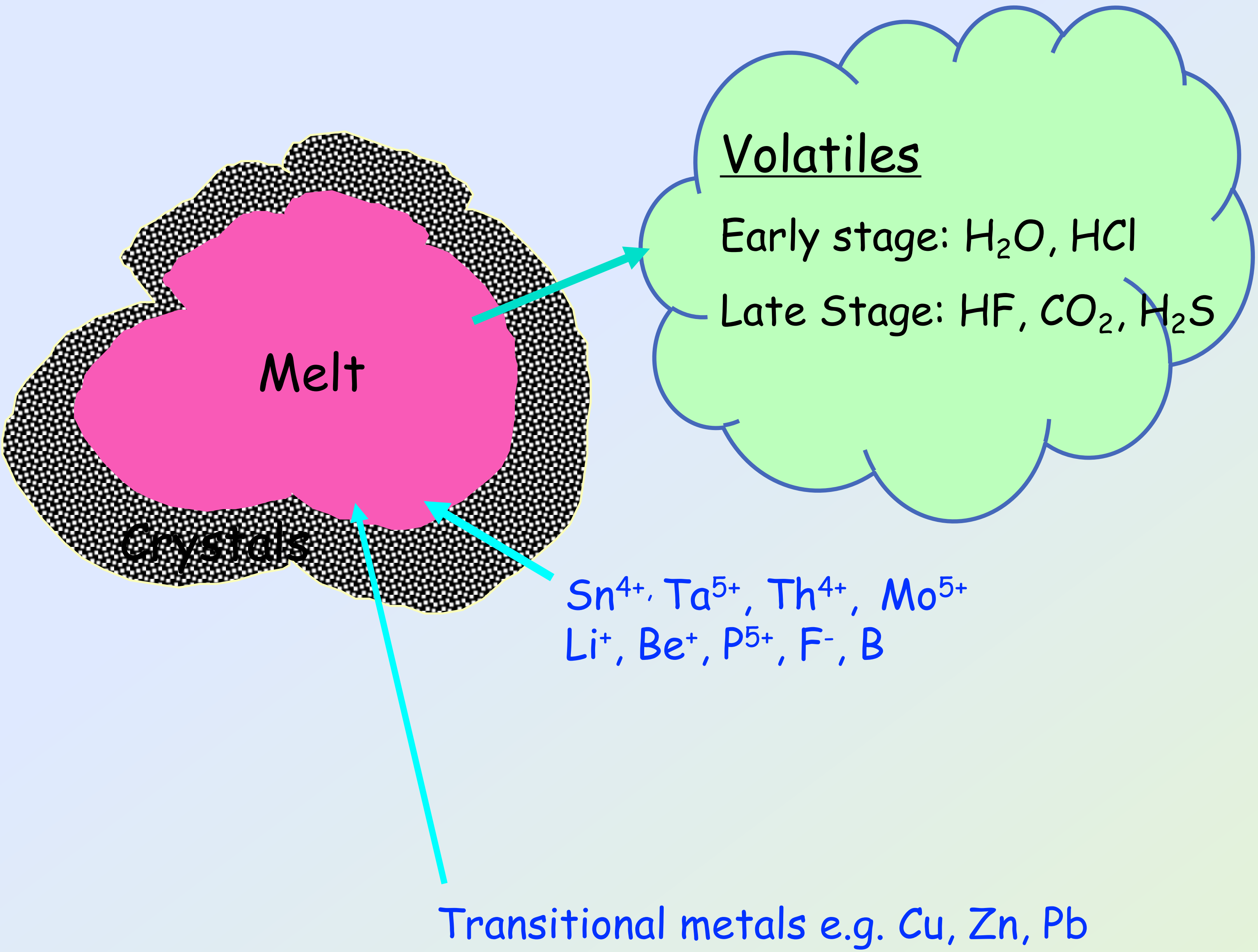
- qtz-mica rocks can form without experiencing greisenisation

- major difference between the two → white micas in greisens have higher F and Li contents

Granites associated with greisenisation

- Granites associated with greisenisation are typically biotite-muscovite granites (S-types using the classification scheme of Chappell and White)
- depth of granite intrusion relatively shallow (1-4km) where large volumes of fluids and other volatiles can evolve
- boiling may occur during greisenisation but is not essential for the process to occur
- the presence of relatively high concentrations of fluorine and boron in the melt, lowers the solidus by more than 100°C and prolongs crystallisation → late fluids enriched in Sn,Th, Cu etc

Element partitioning in crystallisation



Nature of greisens

Location

Form in apices and along flanks of shallow intrusions (1-4km), along margins of veins in endo and exocontact zones

Geometry

Endocontact: veins, pipe-like bodies, sheets, breccia pipes, irregular, massive

Exocontact: brittle styles (veins, stockworks, pipes, replacement bodies).

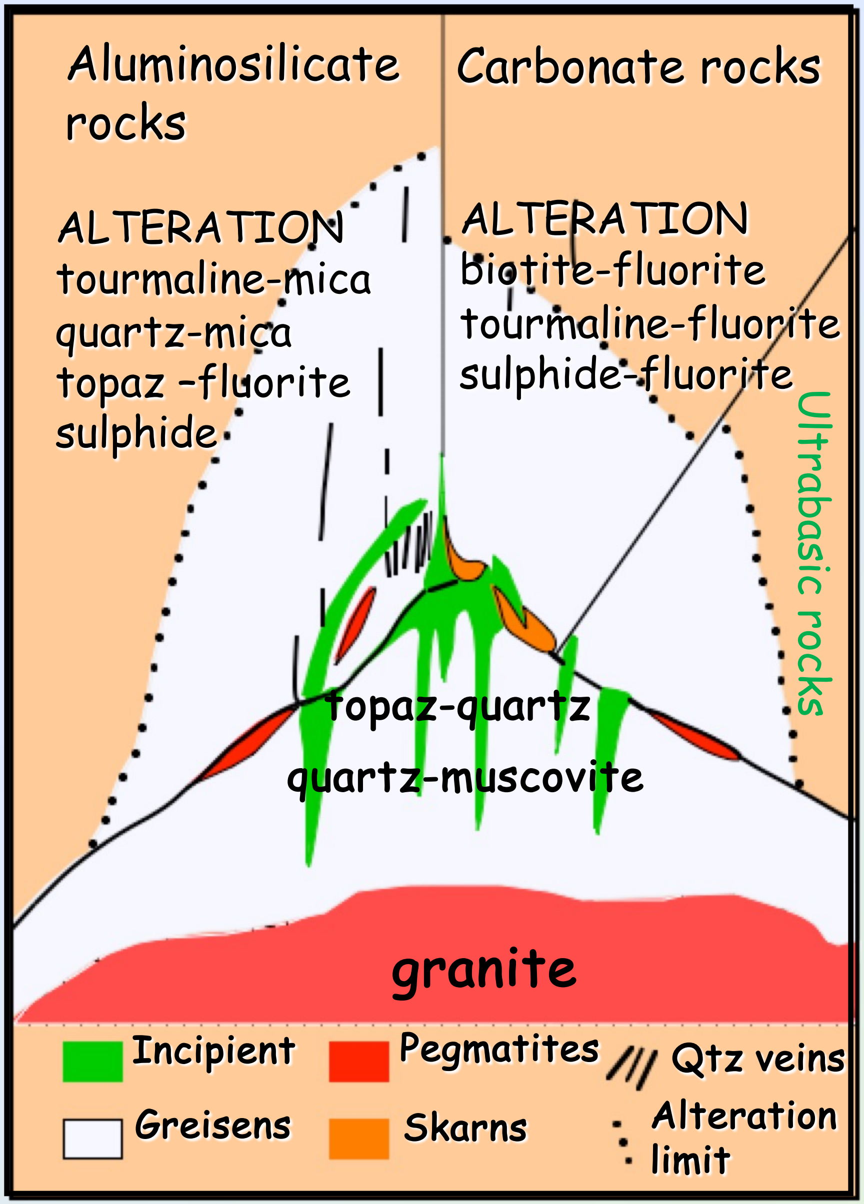
Endogreisen - autometasomatic replacement (replacing itself)

Exogreisen - greisen assemblages superimposed on rocks peripheral to the intrusion.

Greisen veins -infilled fissures by greisen fluids/leachates

There is a distinct temporal and spatial variation in greisen facies

Generalised greisen model (After Shcherba 1970)



Greisen facies in aluminosilicate rocks

Facies	Main minerals	Minor minerals
greisenised granite	quartz, sericite, muscovite, chlorite	topaz, fluorite
quartz-muscovite	quartz (50%), muscovite (40%)	topaz, fluorite
muscovite	muscovite (90%)	quartz
quartz-topaz	quartz, topaz	muscovite, fluorite, sulphides
topaz	topaz	quartz, sulphides
quartz-tourmaline	quartz, tourmaline	topaz sulphides
quartz	quartz	topaz

Ore minerals: cassiterite, wolframite, molybdenite, beryl, helvite, monazite, columbite ($[Fe, Mn][Nb,Ta]_2O_6\}$), zinnwaldite

Greisen fluids in carbonate rocks

- Carbonate rocks near or adjacent to intrusions that evolve greisen fluids are subject firstly to contact metamorphism and skarn formation prior to greisenisation
- early formed acid hydrothermal fluids partially dissolve carbonate rocks → create dissolution cavities
- interconnecting cavities greatly increase fluid permeability
- cavities infilled by minerals
- restricted movement of fluids → increases fluid pressure → fracturing → fluids move along fractures and along grain boundaries

Greisenised skarn and carbonate rocks

- Limestone lenses are skarnised then greisenised to form ore bodies
- greisenisation can be imposed directly onto carbonate rocks that have not been skarnised e.g. B south, Cleveland deposit
- magnetite and scheelite form during skarn stage
- onset of K metasomatism begins greisenisation → muscovite, biotite then later F and B-rich fluids → fluorite → tourmaline
- ore minerals formed in exogreisen include cassiterite, stannite (Cu_2FeSnS_4), wolframite, molybdenite and Cu and Zn sulphides

Skarn-carbonate greisen deposits

Ore deposits in skarn-carbonate greisen deposits show distinct stages in the paragenesis.

1. Anhydrous skarn stage - garnet, pyroxene, wollastonite
2. Hydrous skarn stage - amphibole, magnetite, scheelite
3. Pre-ore greisen stage - mica-quartz exogreisens
4. Ore greisen stage - quartz-mica-fluorite-wolframite -molybdenite. quartz-tourmaline-fluorite exogreisens. cassiterite, sulphide formation.
5. Post greisen stage - carbonate, chlorite alteration

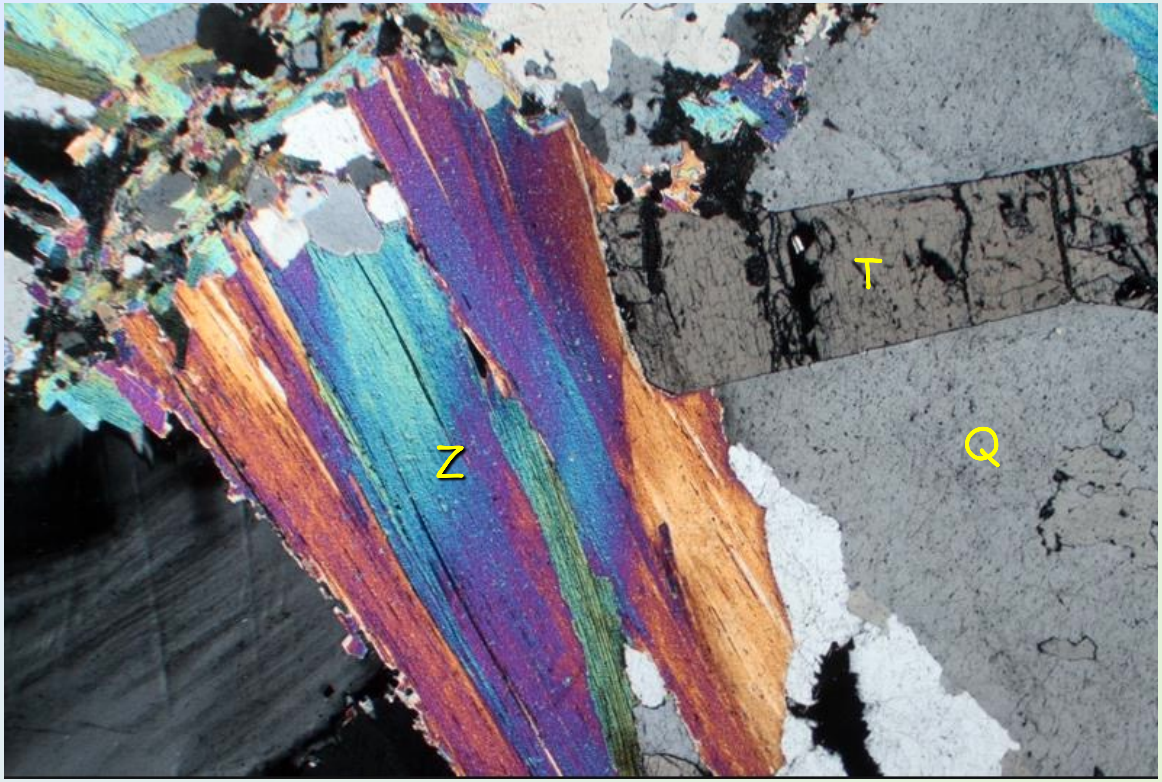
Greisen facies imposed on skarns and carbonate rocks

Facies	Main minerals	minor minerals
mica-fluorite	biotite, fluorite, quartz, siderite, phlogopite	sulphides, sellaite (MgF_2)
topaz-fluorite (rare)	fluorite, topaz, quartz, sulphides	white mica, sellaite, graphite
tourmaline-fluorite	tourmaline, fluorite, siderite, sulphides	quartz, sellaite
microcline-fluorite	quartz, muscovite, fluorite, microcline	tourmaline, sulphides

Ore minerals: cassiterite, wolframite, scheelite, molybdenite, powellite, helvite, phenacite, sulphides of Sn, Bi, Cu, Pb, Zn

Greisen veins

- Exchange reactions between greisen fluids and granite leach chemical species from wallrock that add to those originating at fluid source
- leachates may form vein minerals or precipitate in the country rocks



Greisen vein containing zinnwaldite, topaz and quartz
Photomicrograph, crossed polars

Effect of fluorine in greisenisation

(1) In skarn overprinted exogreisens, fluorite and fluoro-apatite are the only stable Ca-minerals.

With a high F activity calcic amphiboles alter to grunerite.

$$Ca_2Fe_5Si_8O_{22}(OH)_2 + 4HF + 2Fe^{2+} \rightarrow Fe_7Si_8O_{22}(OH)_2 + 2CaF_2 + 4H^+$$

ferrohastingsite → grunerite, fluorite

(2) Scheelite that is found as an ore mineral in some calcic skarns e.g. King Island, is unstable in the presence of F-rich greisenising solutions.

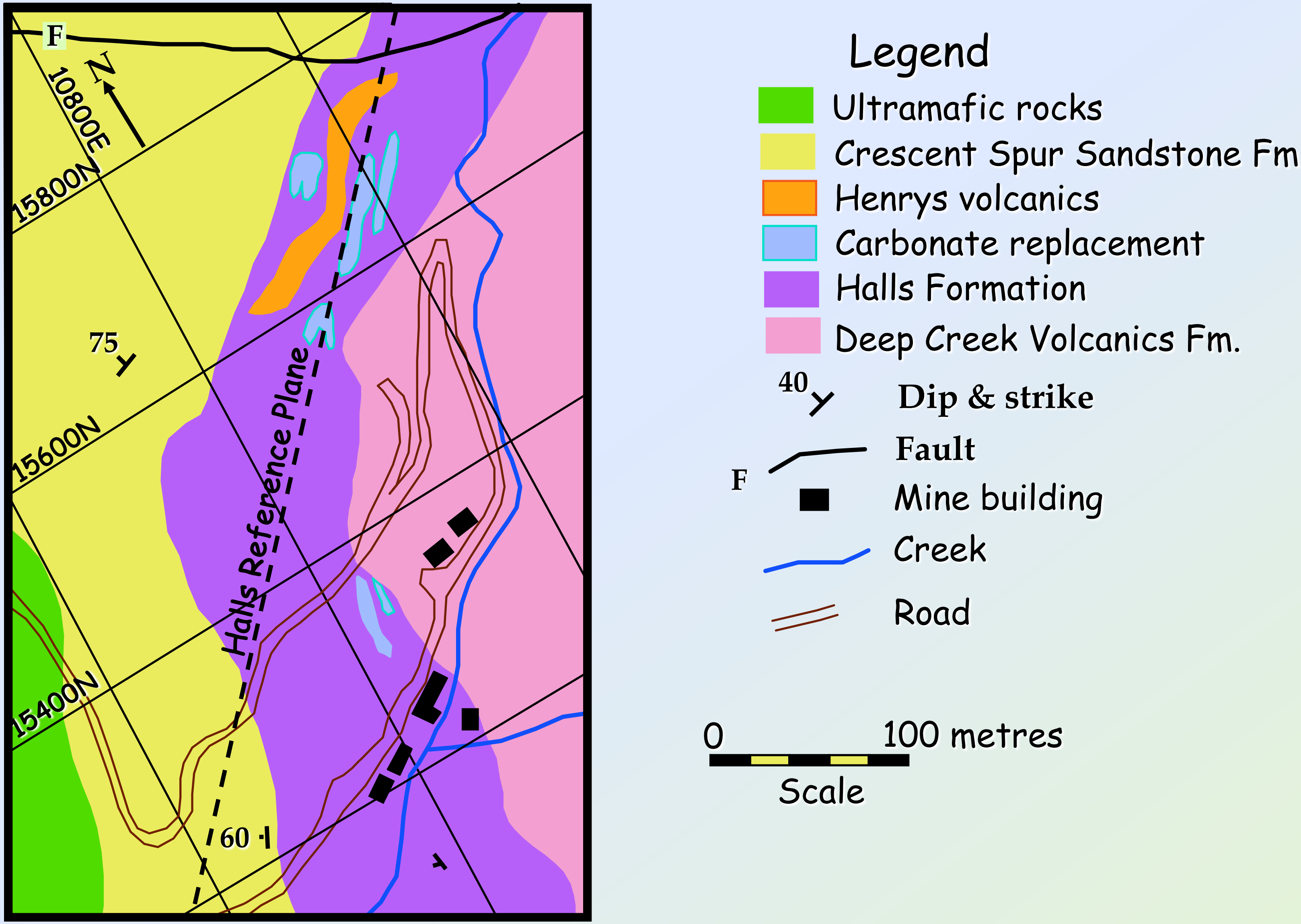
$$CaWO_4 + Fe^2 + 2HF \rightarrow FeWO_4 + CaF_2 + 2H^+$$

scheelite → wolframite, fluorite

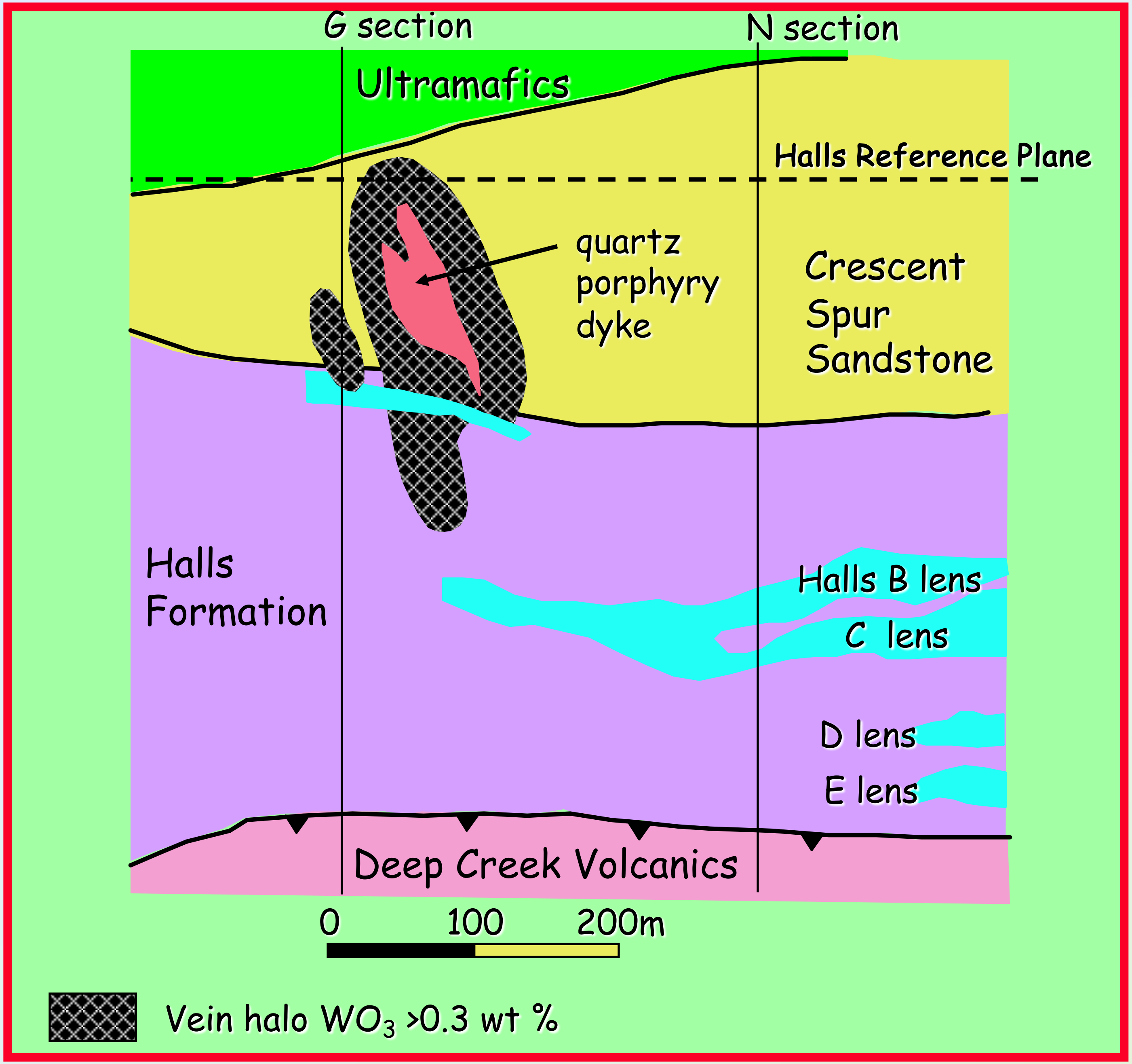
Cleveland Sn deposit

- Located 10km west of Waratah, NW Tasmania
- Mineralisation in the deposit is hosted by carbonate lenses in steeply dipping sedimentary, volcanic and volcaniclastic rocks of the Crimson Ck Formation
- a hydrothermal greisen altered quartz-porphyry dyke intrudes the mine sequence but does not outcrop at the surface
- Three styles of mineralisation occur in the mine:
    1. Endogreisen and stockwork in quartz-porphyry dyke
    2. greisenised skarn in replaced carbonate rocks
    3. vein mineralisation enveloping dyke

Interpretation of the surface geology of the Cleveland Mine, Tasmania



Plan of level RL800 Cleveland Mine



Greisenised quartz porphyry dyke

- The quartz porphyry dyke at the Cleveland mine was a major conduit for fluids that produced several styles of endogreisen in the dyke
- a close inspection of the dyke rocks shows a high degree of fracturing providing permeability for fluid flow
- fluids precipitated minerals in fractures → veins, altered country rocks surrounding dyke, infiltrated distal carbonate lenses
- there is a clearly defined zonation in greisen facies within dyke
- highest Sn grades in the dyke occur in qtz-topaz greisen

Alteration sequence in the quartz porphyry dyke Cleveland Mine, Western Tasmania (Jackson 1993)

quartz-feldspar porphyry

STAGE 1 ↓

incipient greisen

STAGE 2 ↓

quartz-muscovite greisen

STAGE 3 ↓

quartz-topaz greisen

STAGE 4 ↓

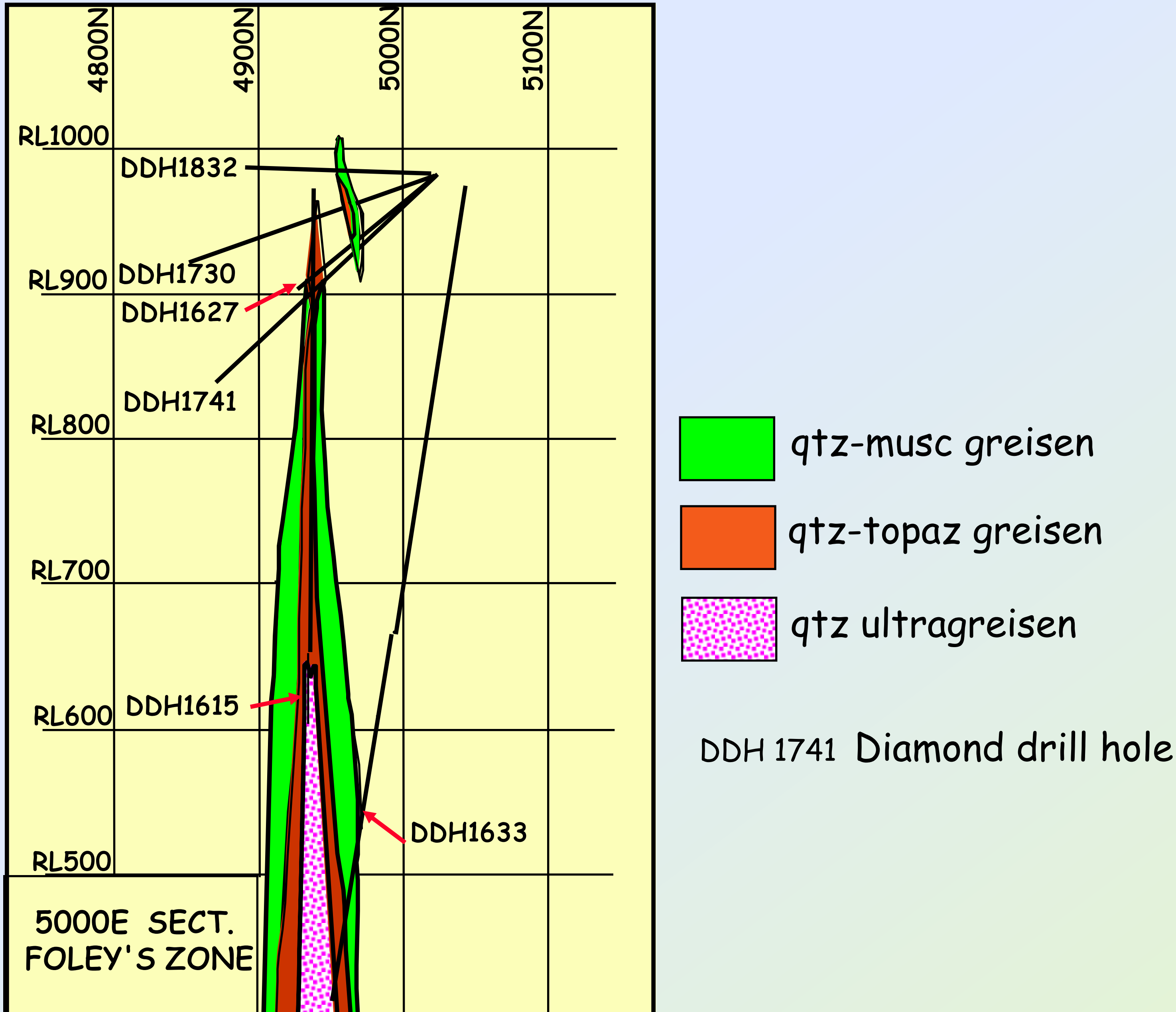
quartz ultragreisen

STAGE 5 ↓

carbonate alteration (low temperature)

↕ sulphidation (quartz-topaz greisen to quartz ultragreisen)

Section 5000E through Foley's Zone



Greisenized quartz porphyry dyke

Ore minerals in the Cleveland deposit

Ore minerals in endogreisen and greisen veins

Cassiterite (SnO_2), wolframite ($FeWO_4$), molybdenite (MoS_2), chalcopyrite ($CuFeS_2$), stannite (Cu_2FeSnS_4), bismuth

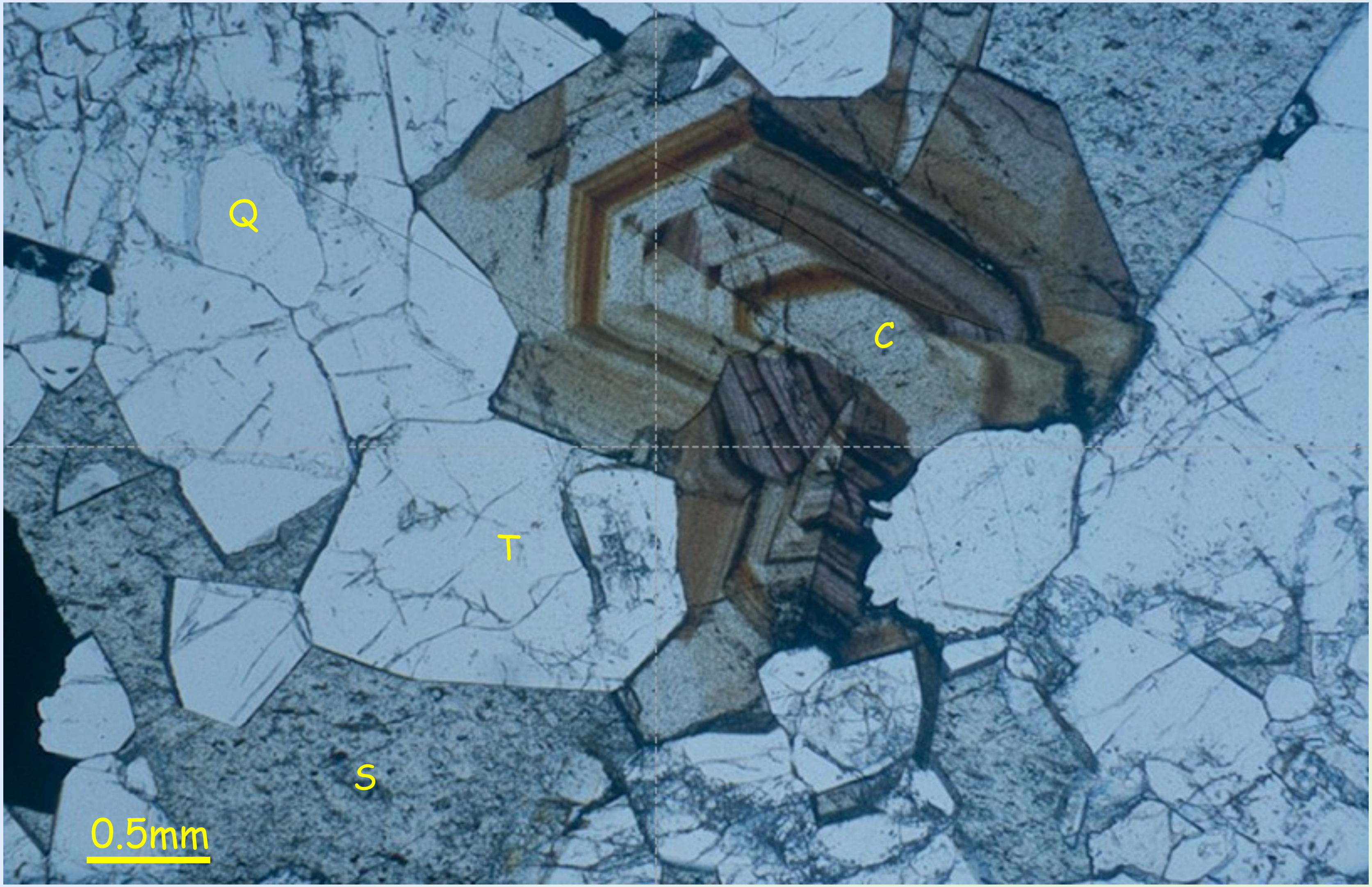
Ore minerals in greisenised skarn

cassiterite, magnetite, scheelite, wolframite, danalite [($Be_3Fe_4(SiO_4)S$] , chalcopyrite, stannite, sphalerite (ZnS)

Cassiterite + topaz + siderite

Growth zoned cassiterite with topaz and siderite in endogreisen.

Photomicrograph, PPL



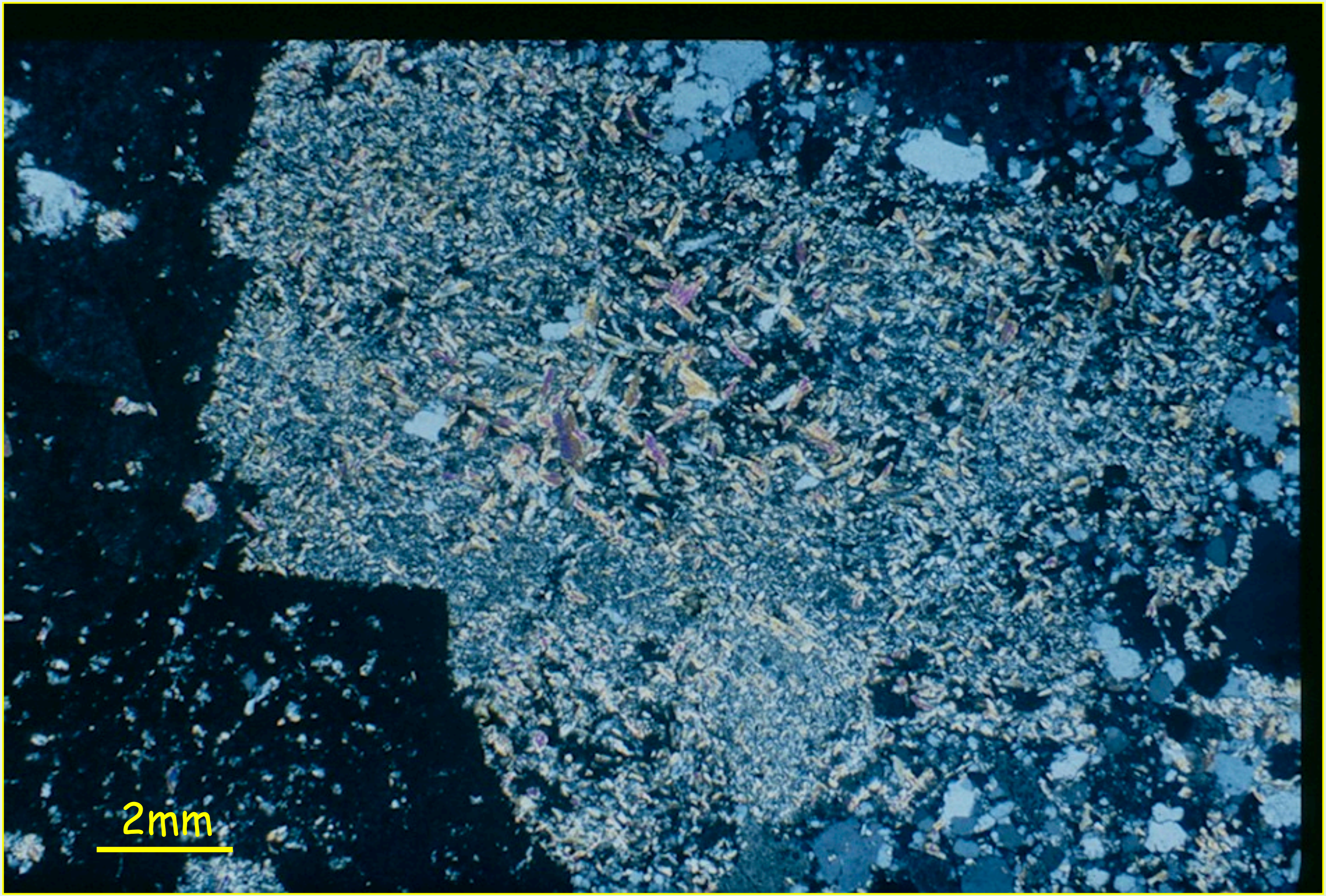
Incipient greisenisation

Primary texture is preserved

Greenish yellow colouration is due to the presence of pyrophyllite.

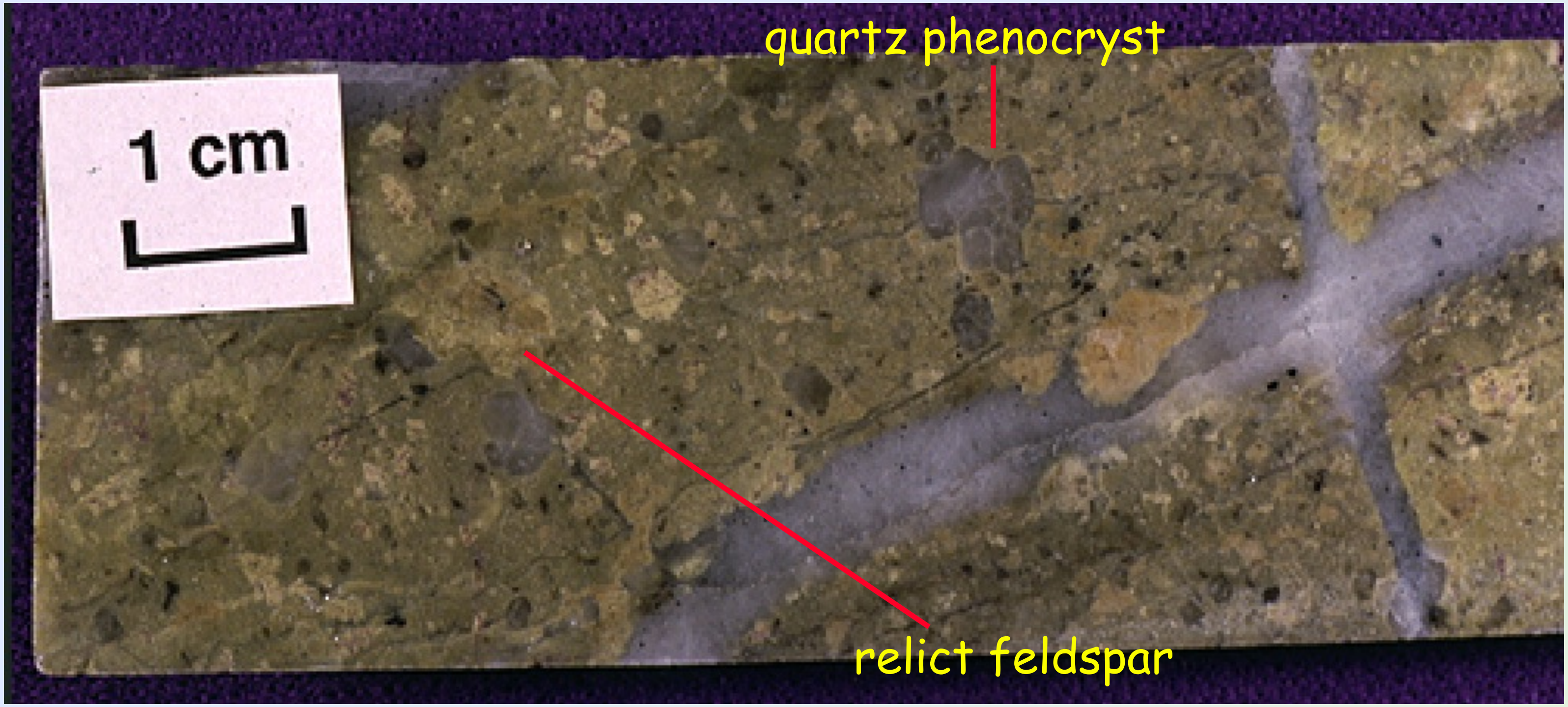
Incipient greisenisation

Rectangular shaped crystals are feldpars that are largely altered to sericite (high birefringence). Photomicrograph, PPL



Quartz-muscovite greisen

Note that the primary texture has been mostly obliterated. Quartz phenocrysts are obvious but only ragged, relict feldspars are evident.

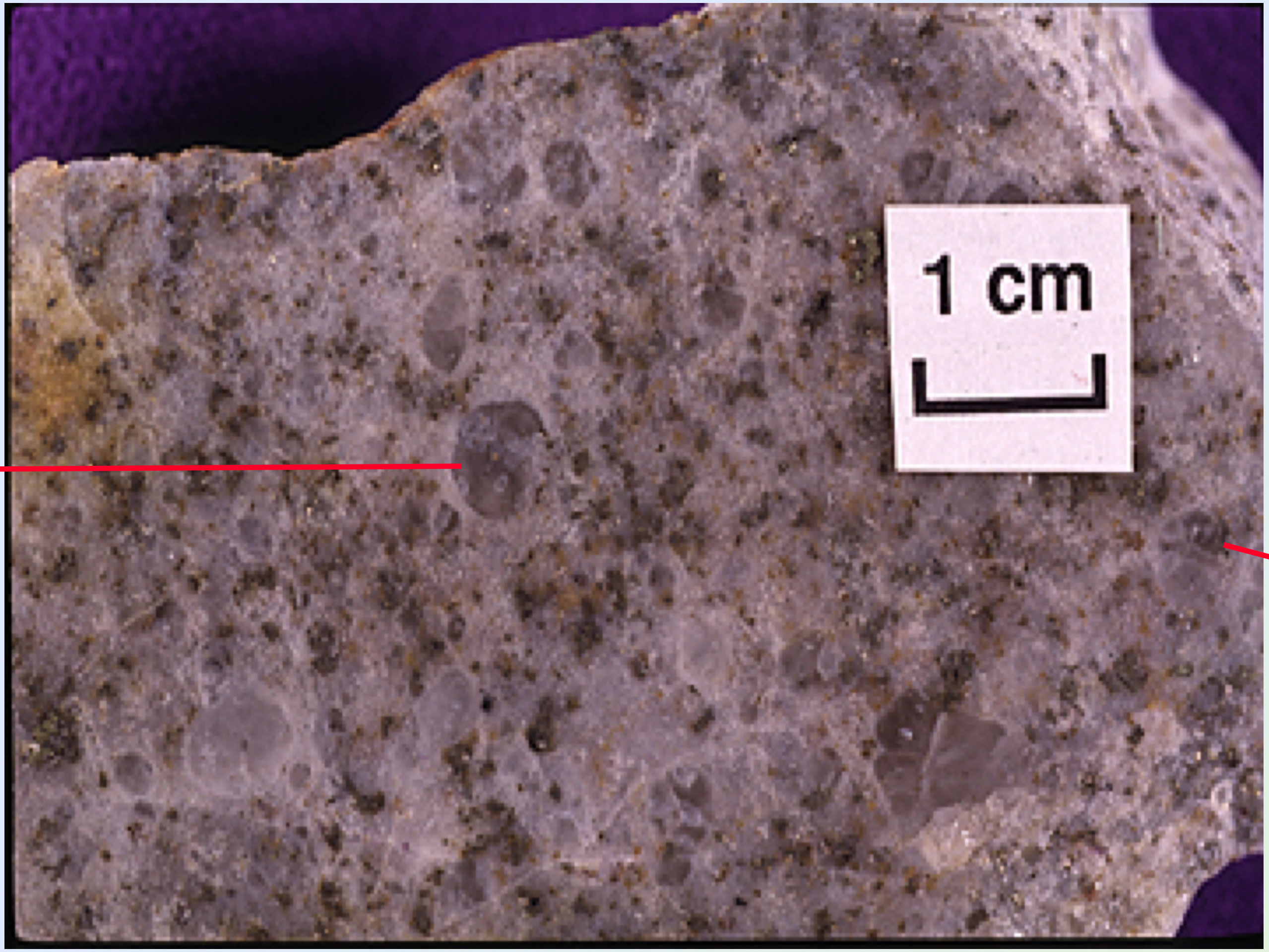


Quartz-muscovite greisen

Photomicrograph (crossed polars) contains quartz, muscovite, zircon

Quartz-topaz greisen

quartz phenocryst

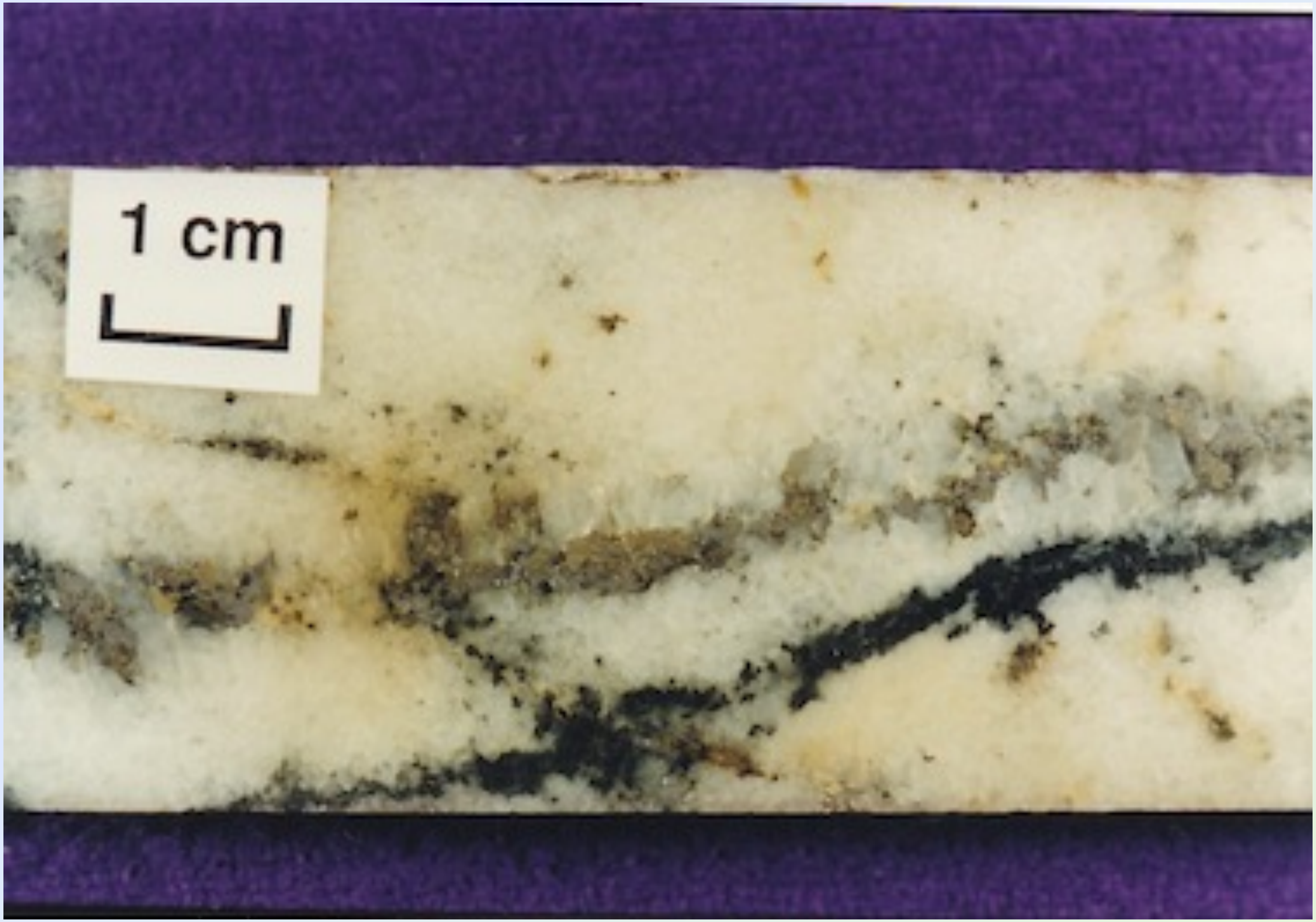


pyrite

Fine-grained matrix comprises quartz and topaz

Quartz ultragreisen

Completely recrystallised to form a quartz rock. A relict late stage sulphide-bearing vein is defined by tourmaline vein selvages.



Greisen reactions

Quartz-muscovite formation

$$3KAlSi_3O_8 + 2H^+ \rightarrow KAl_2(Si_3Al)O_{10}(OH)_2 + 2K^+ + 6SiO_2$$

K-feldspar — muscovite — quartz

$$3CaAl_2Si_3O_8 + 2K^+ + 4H^+ \rightarrow 2KAl_2(Si_3Al)O_{10}(OH)_2 + 3Ca^{2+} + 3SiO_2$$

anorthite — muscovite — quartz

$$3NaAlSi_3O_8 + K^+ + 2H^+ \rightarrow KAl_2(Si_3Al)O_{10}(OH)_2 + 3Na^+ + 6SiO_2$$

albite — muscovite — quartz

Greisen Reactions

Quartz-topaz formation

$$2KAl_3Si_3O_{10}(OH)F + HF + 2H^+ \rightarrow 3Al_2SiO_4(OH)F + 3SiO_2 + H_2O + 2K^+$$

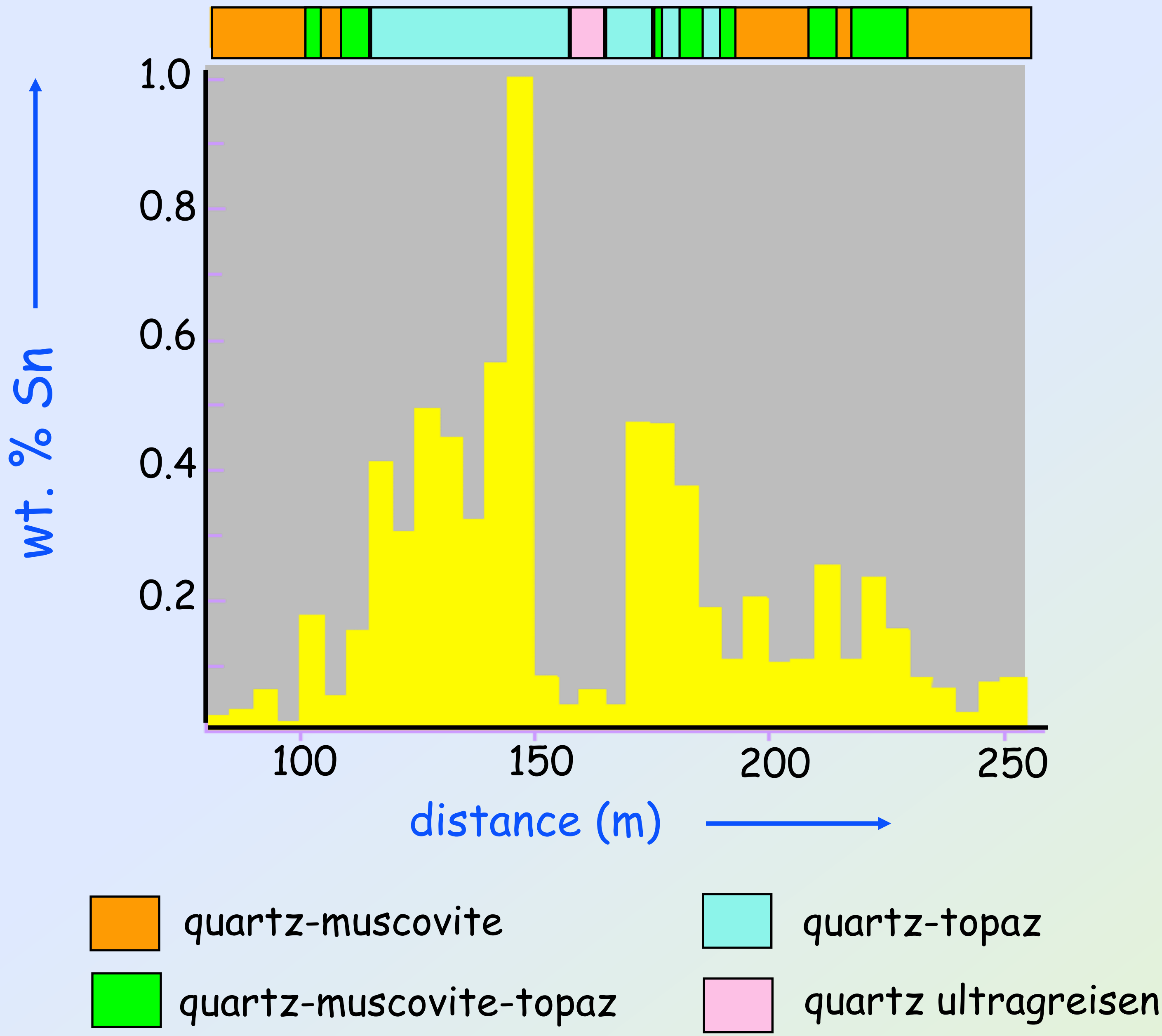
muscovite — topaz — quartz

Quartz ultragreisen formation

$$Al_2SiO_4(OH)F + 5HF \rightarrow 2AlF_{3(aq)} + SiO_2 + 3H_2O$$

topaz — quartz

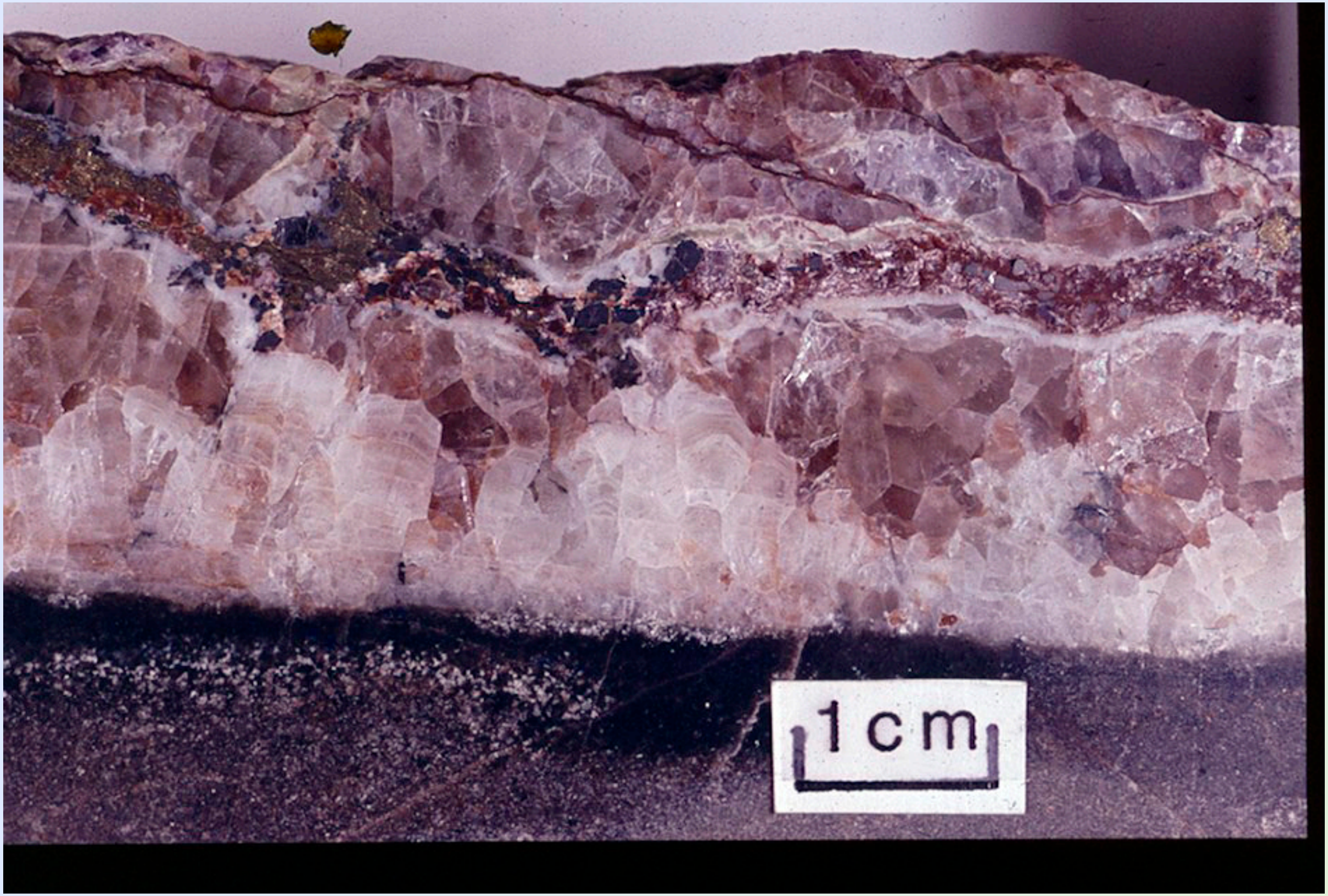
Sn values (wt. %) from drill hole 1615 Cleveland Mine, Tas.



Vein system

- The bulk of the vein system is hosted by the Crescent Spur Sandstone
- there is lesser veining in Hall's Formation
- veins infill fractures contemporaneously with the evolution of hydrothermal fluids
- at least 14 vein generations have been identified
- vein densities are parallel to the surface of the quartz-porphyry dyke

Topaz-fluorite vein



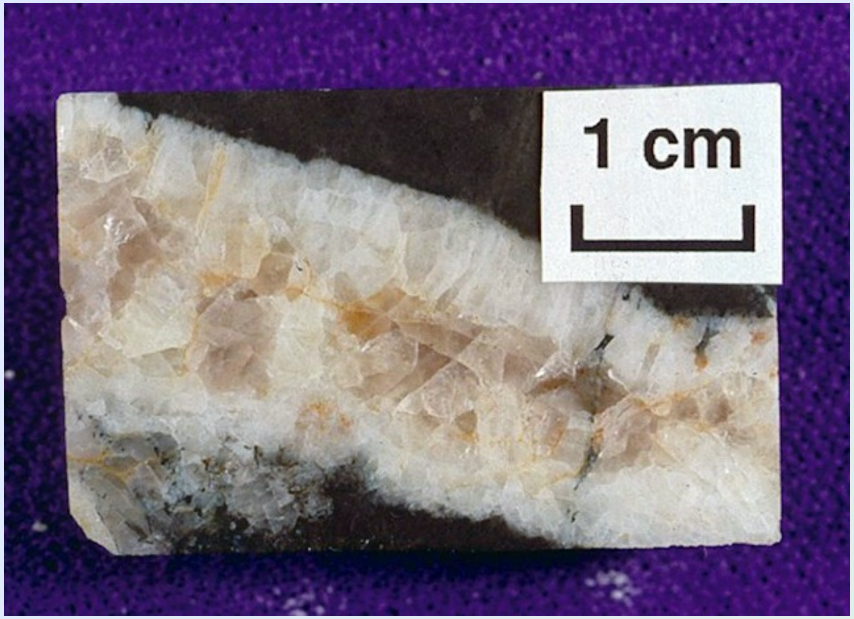
Vein paragenesis

Vein stage	Distinctive vein characteristic	Vein generations
STAGE 1 (Siliceous stage)	Qtz dominant veins, minor other minerals Wallrock alteration → biotite	I,II,III
STAGE 2 (Greisen I stage)	Veins enriched in micas, feldspar wolframite and molybdenite ↑ towards end of stage wallrock alteration → muscovite, biotite, tourmaline	IVA,IVB,VIC VA, VB,VIA, VIB
STAGE 3 (Greisen II stage)	Topaz/fluorite rich veins. Wolframite and molybdenite abundant early. Late sulphide stages wallrock alteration → moderate/strong tourmaline	VII, VIIA, VIIIB IX, XA, XB, XI1A
STAGE 4 (Carbonate stage	Carbonate and fluorite bearing veins	XIII, XIV

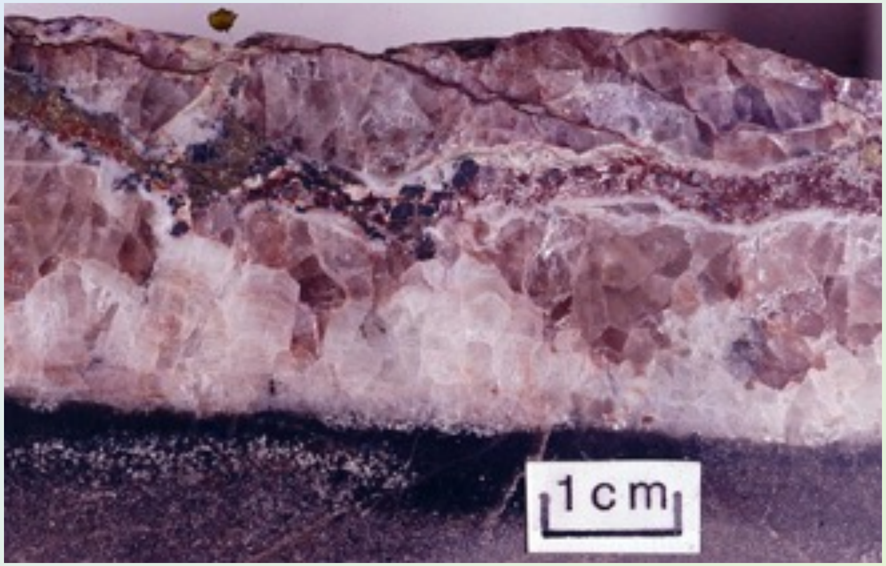
Some vein types

qtz-K-feldspar veins

qtz-biotite veins

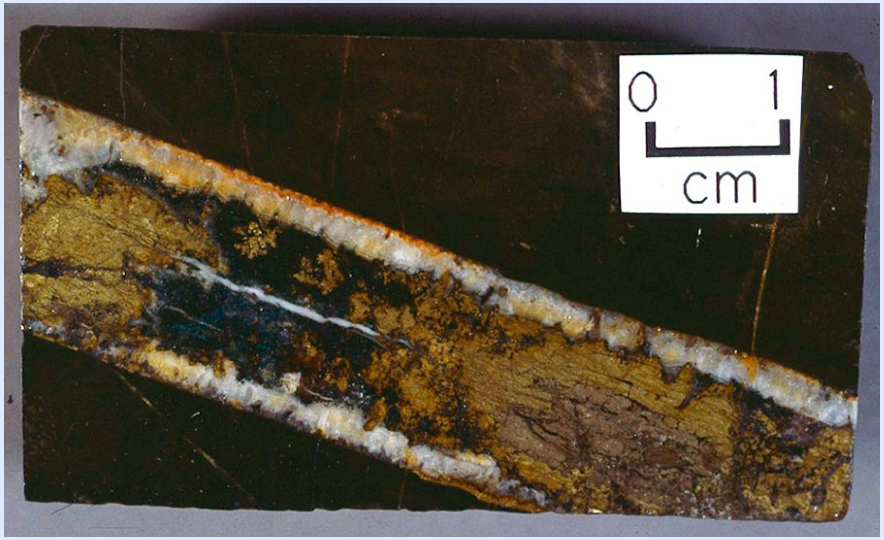


qtz-fluorite vein



Crustified qtz-topaz-fluorite-sulphide vein

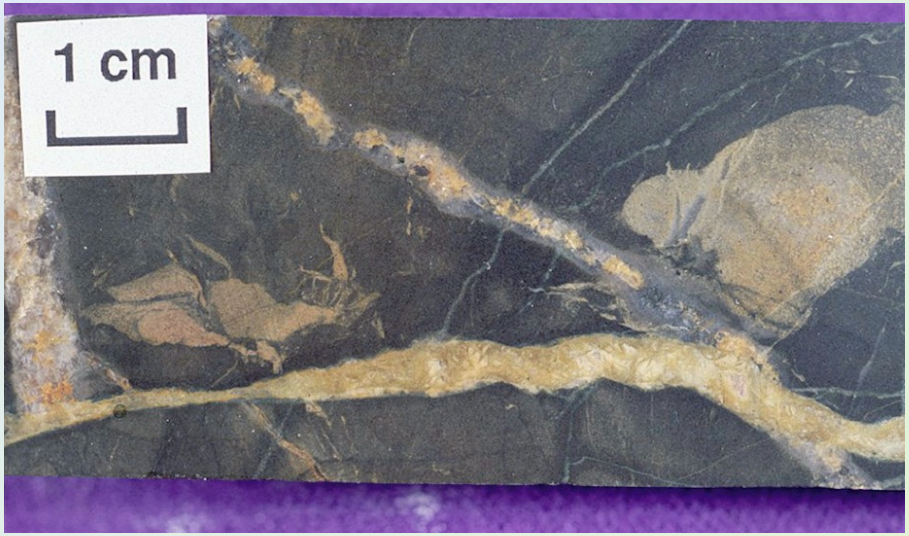
Some vein types



qtz-sulphide-tourmaline vein

wolframite-siderite vein in qtz-topaz greisen

fluorite-siderite vein in endogreisen

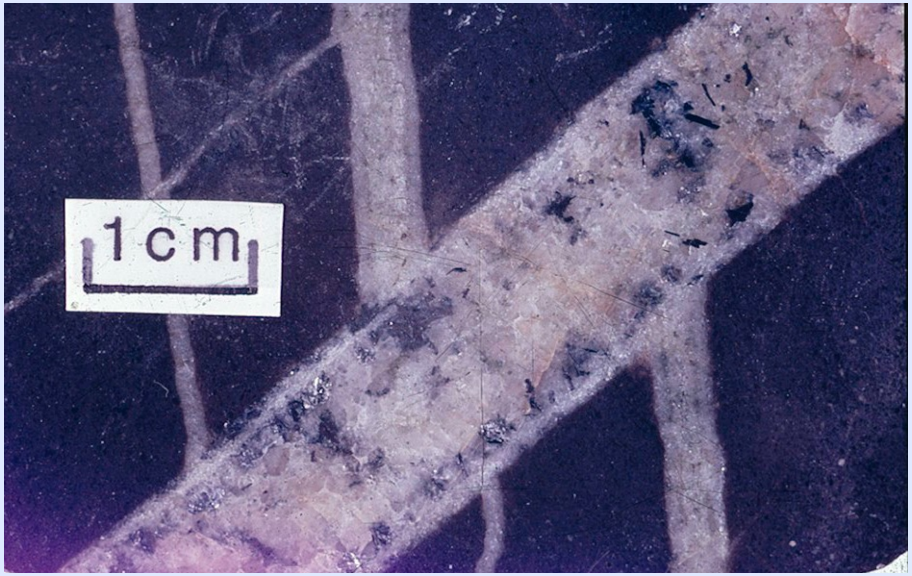


carbonate veins in shale

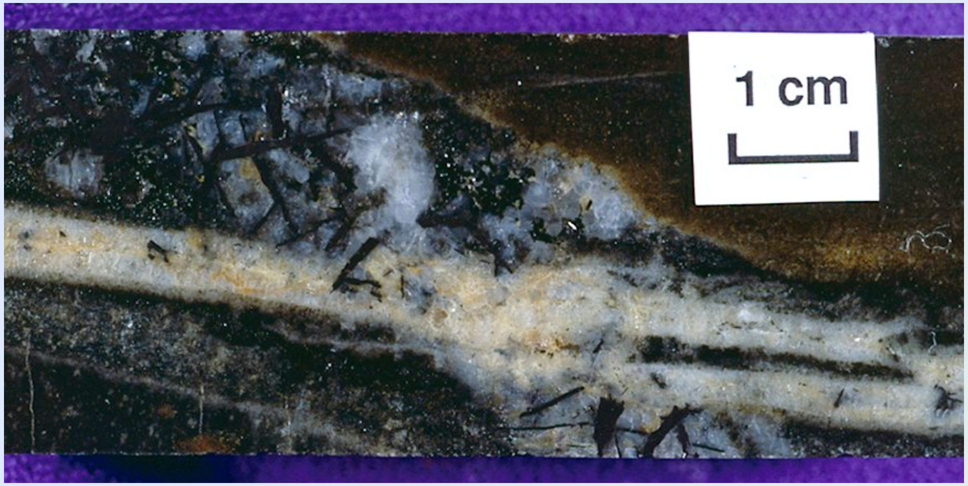
Cross-cutting vein relationships

- The composition of evolved fluids changes over time as crystallisation and fluid fractionation progresses
- late forming fluids have a different composition and transport different ionic species than early formed fluids
- this results in changes in vein mineral composition for various stages in the evolution of the deposit
- by studying cross-cutting vein relationships you can determine the paragenesis of the vein system

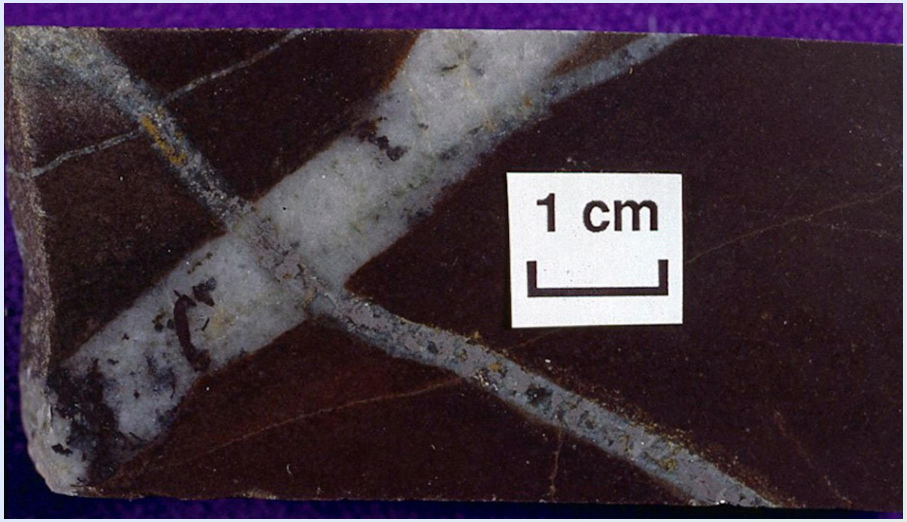
Vein cross-cutting



qtz-wolframite vein X-cutting qtz-feldspar veinlets



qtz-fluorite veinlet x-cutting qtz-biotite vein



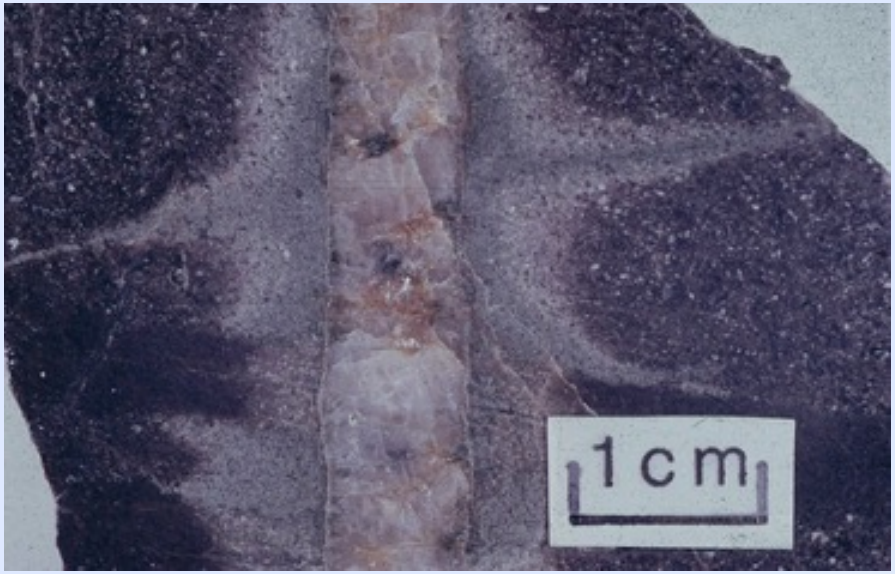
Arsenopyrite veinlet x-cutting qtz-wolframite vein

siderite-fluorite vein x-cutting qtz-wolframite vein

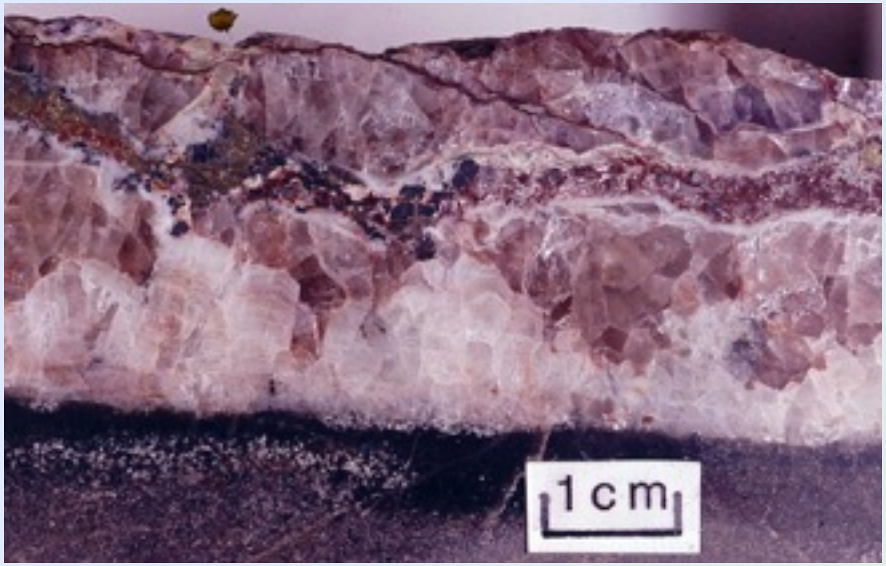
Wallrock alteration enveloping veins

- Wallrock alteration along vein margins indicates a change in fluid composition over time
- early veins may show chlorite alteration followed by biotite wallrock alteration in later veins and still later stage → tourmaline alteration
- wallrock alteration also provides evidence for element species contemporaneous with those in the vein but not present in the vein
- boron in late stage fluids infiltrates the wallrock to react with Fe-silicate minerals → tourmaline wallrock alteration

Vein wallrock alteration



Chlorite wallrock alteration



Tourmaline wallrock alteration

Zoned biotite wallrock alteration

Unaltered limestone Hall's B lens

Cleveland greisenised skarn paragenesis

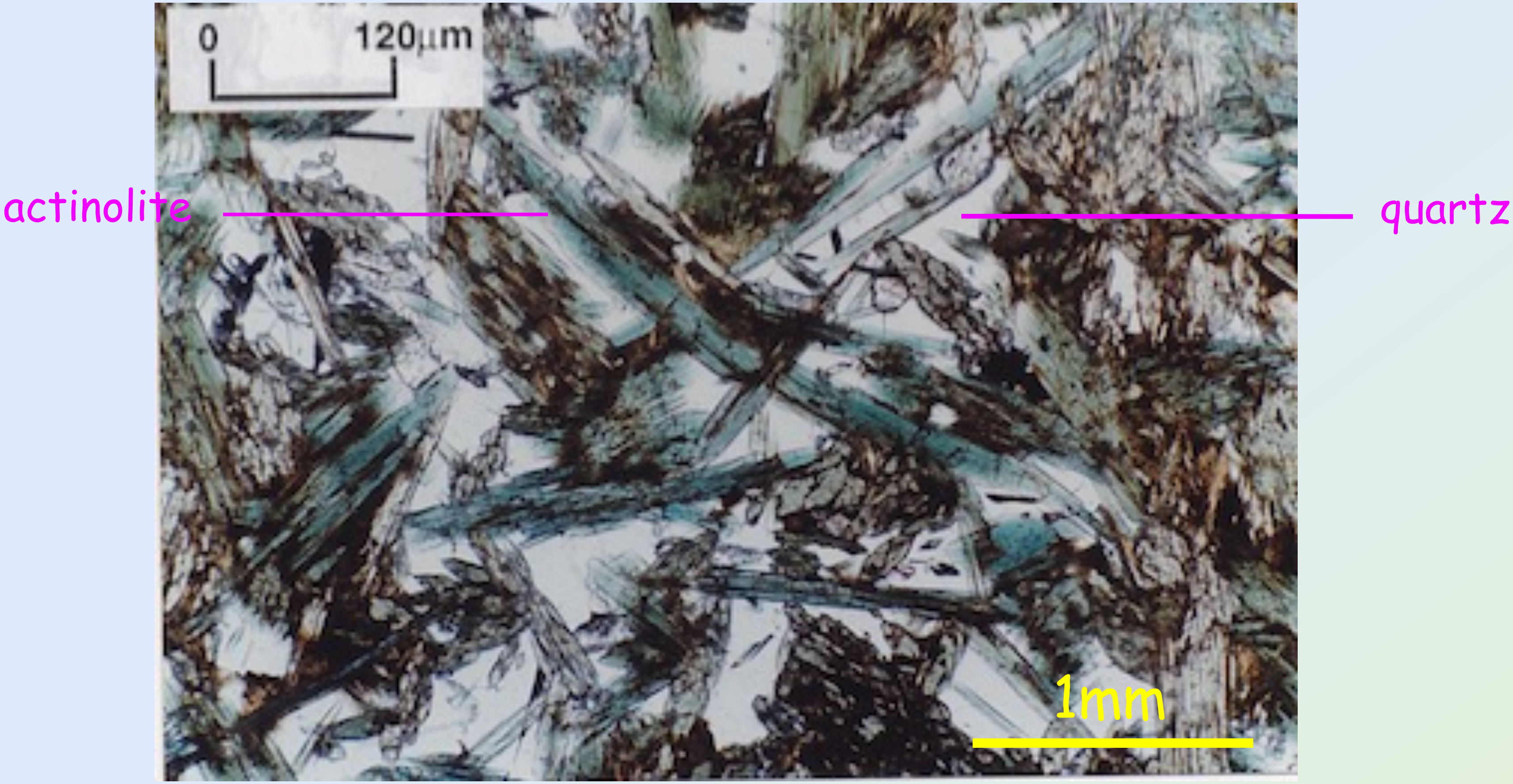
Exogreisen in carbonate replacement shows a clear paragenesis with disrupted zonation. There is no obvious evidence of an anhydrous skarn stage, perhaps because it was completely overprinted

1. Anhydrous skarn stage (?) - garnet, pyroxene, wollastonite
2. Hydrous skarn stage - amphibole, chlorite, magnetite, scheelite
3. Pre-ore greisen stage - biotite-quartz exogreisen
4. Ore greisen stage - quartz-mica-fluorite, quartz-tourmaline- fluorite greisen. Sulphide formation
5. Post greisen stage - carbonate, marcasite alteration

Amphibole skarn

Proximal skarn comprising actinolite + quartz

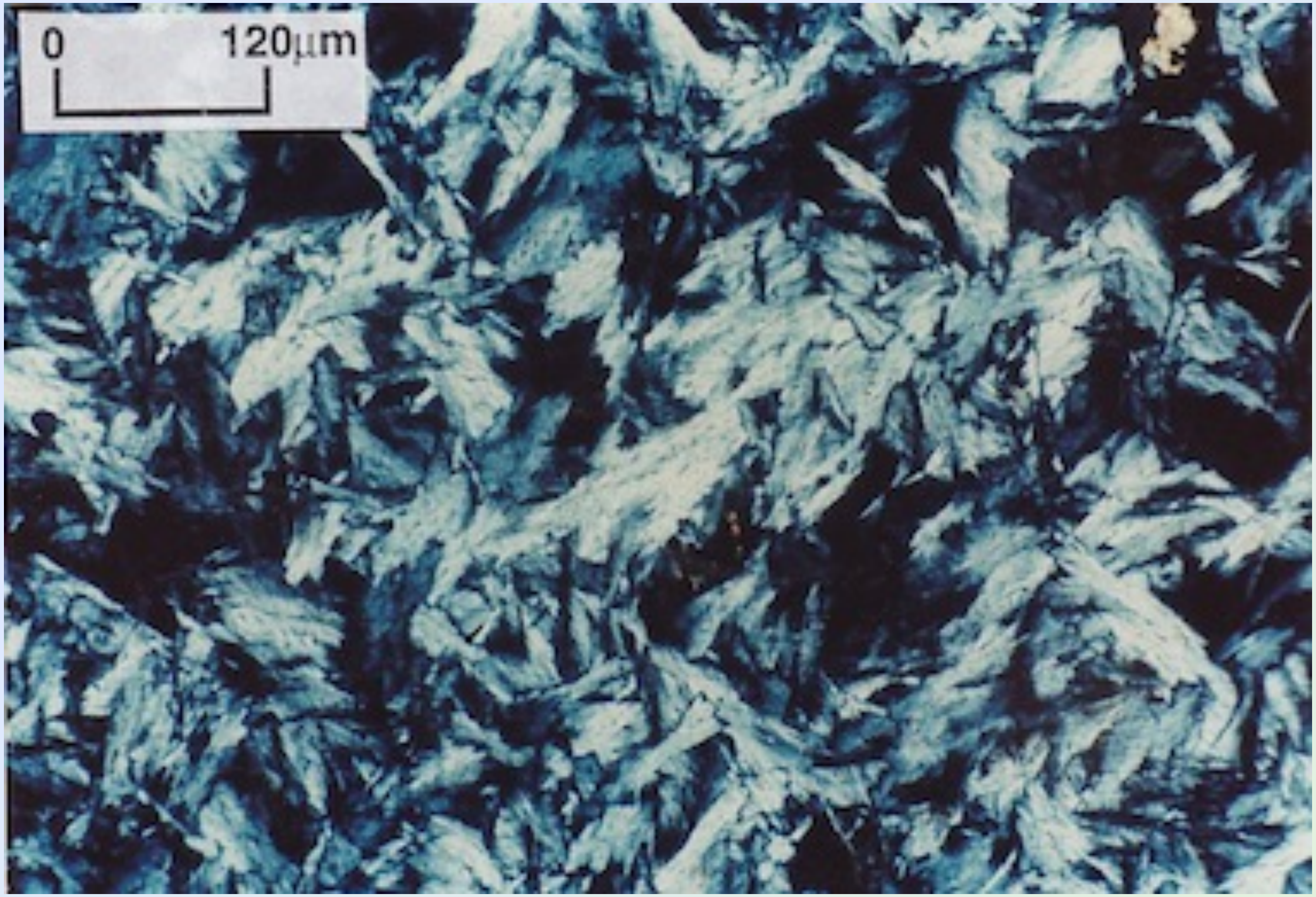
Photomicrograph, PPL



Chlorite skarn

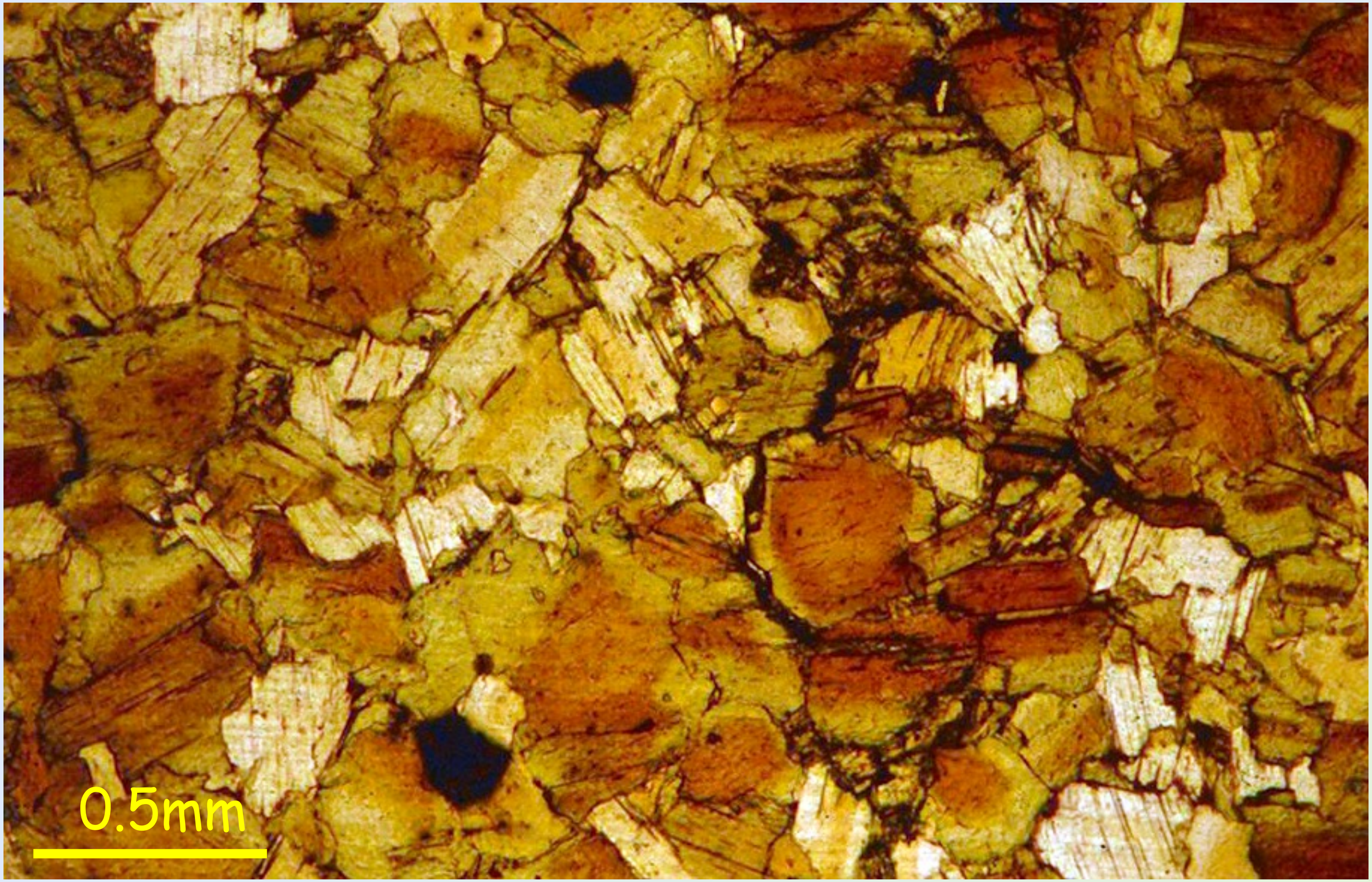
Distal skarn with the assemblage: chlorite + quartz + calcite

Photomicrograph, crossed polars.



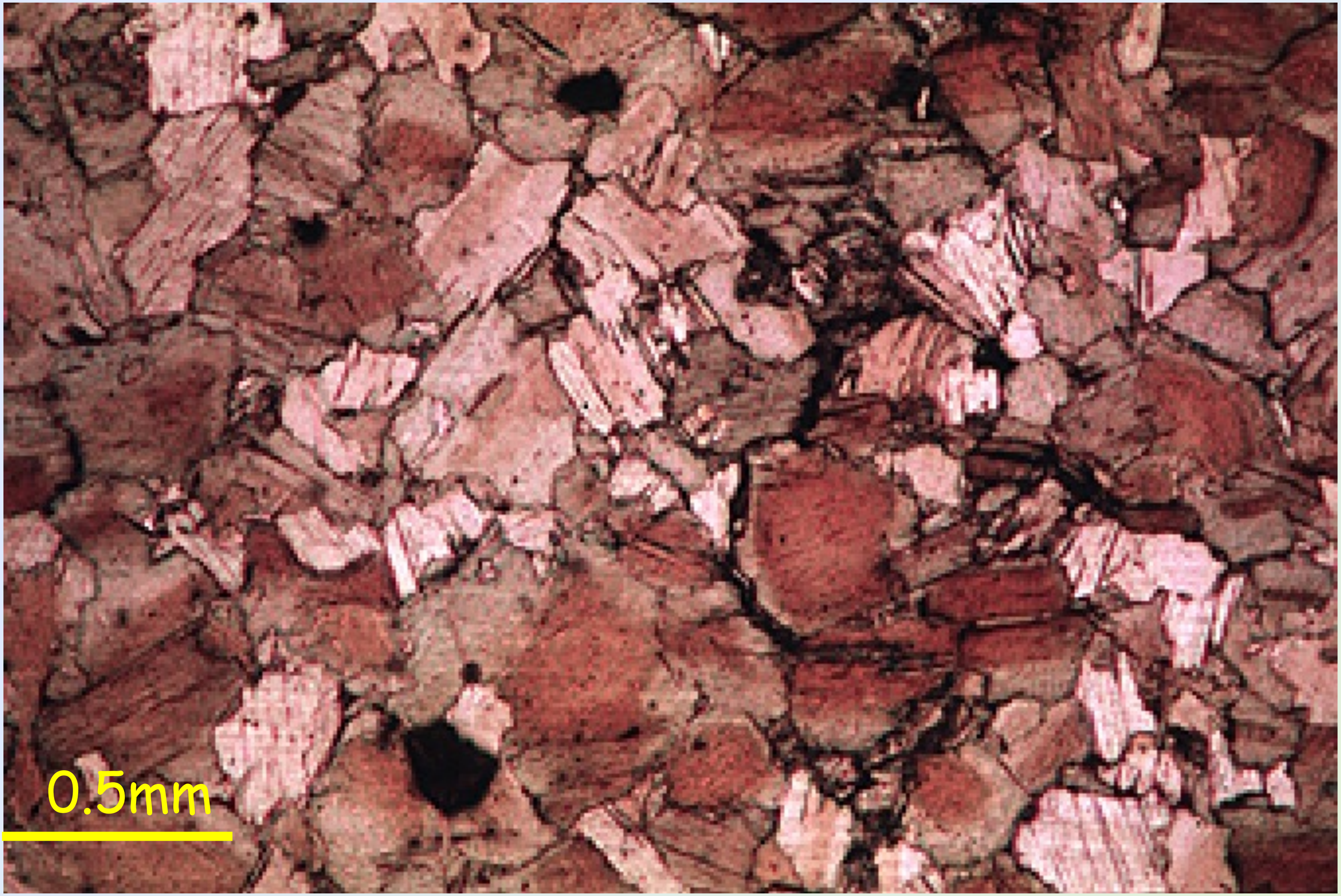
Biotite exogreisen

Biotite alters primary skarn and marble. Photomicrograph, PPL



Biotite exogreisen

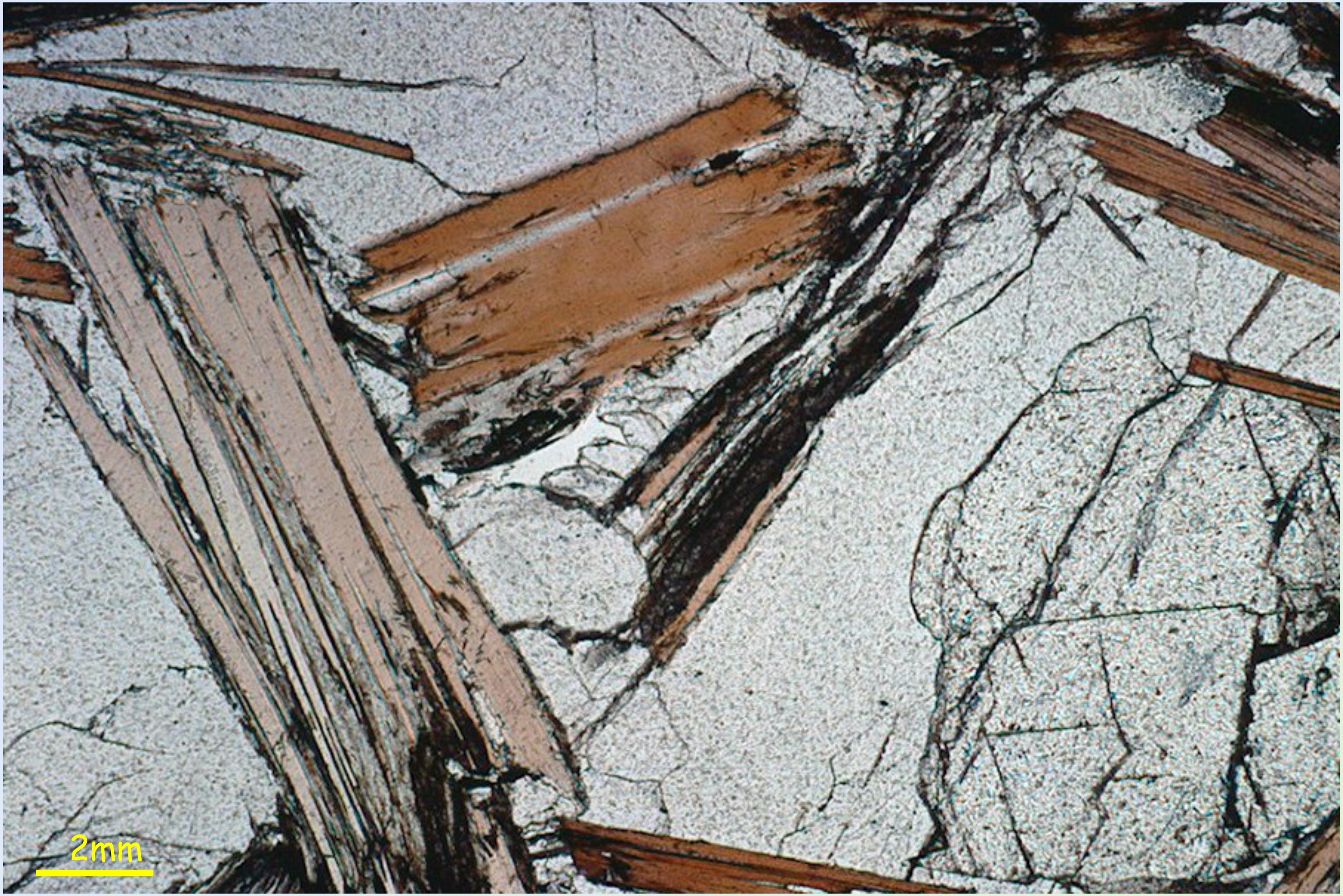
Brown biotite in biotite exogreisen. PPL



Biotite in fluorite, biotite-fluorite exogreisen

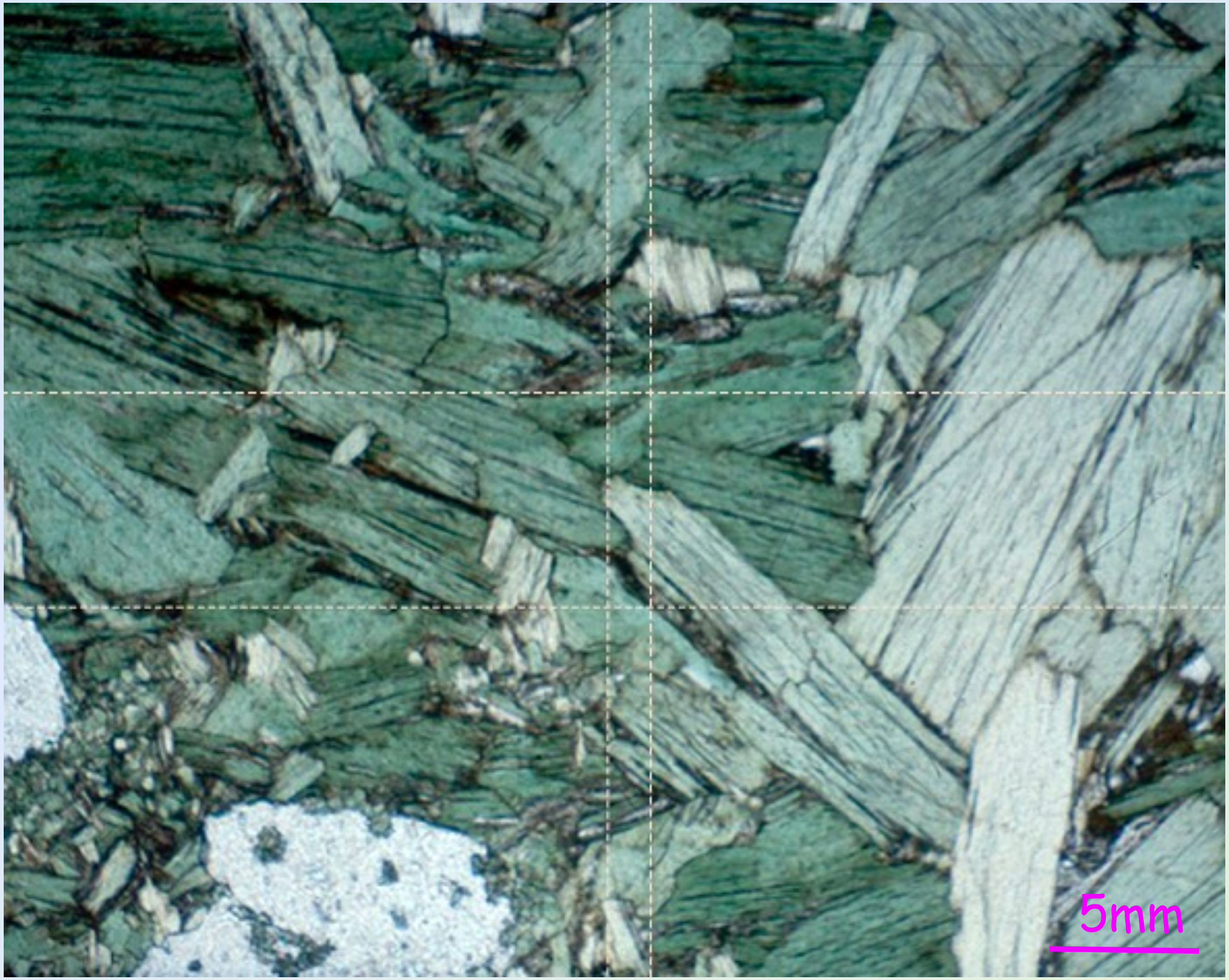
Biotite flakes enclosed in fluorite, biotite-fluorite exogreisen

Photomicrograph, PPL



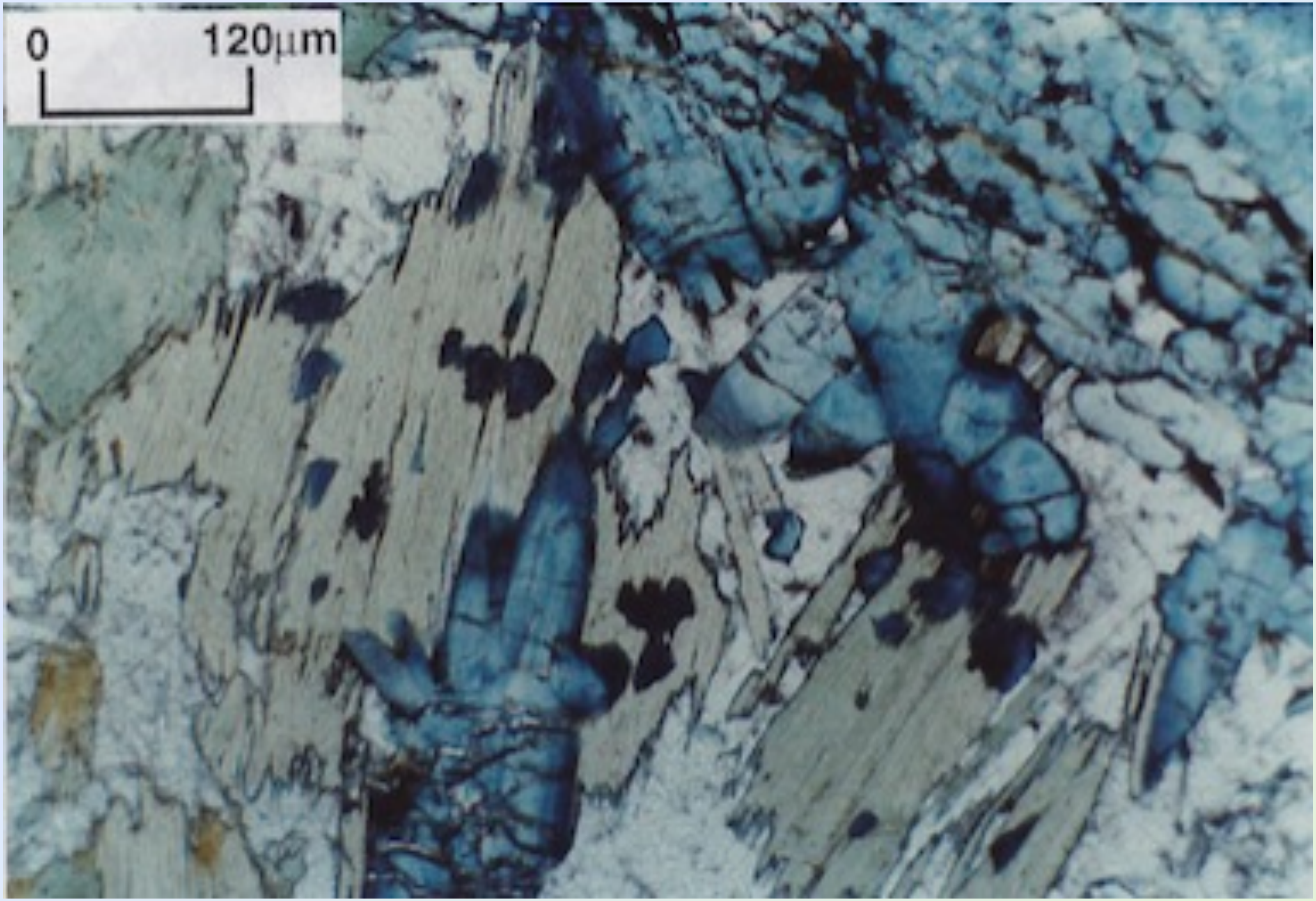
Green biotite exogreisen

Green biotite in biotite exogreisen. PPL



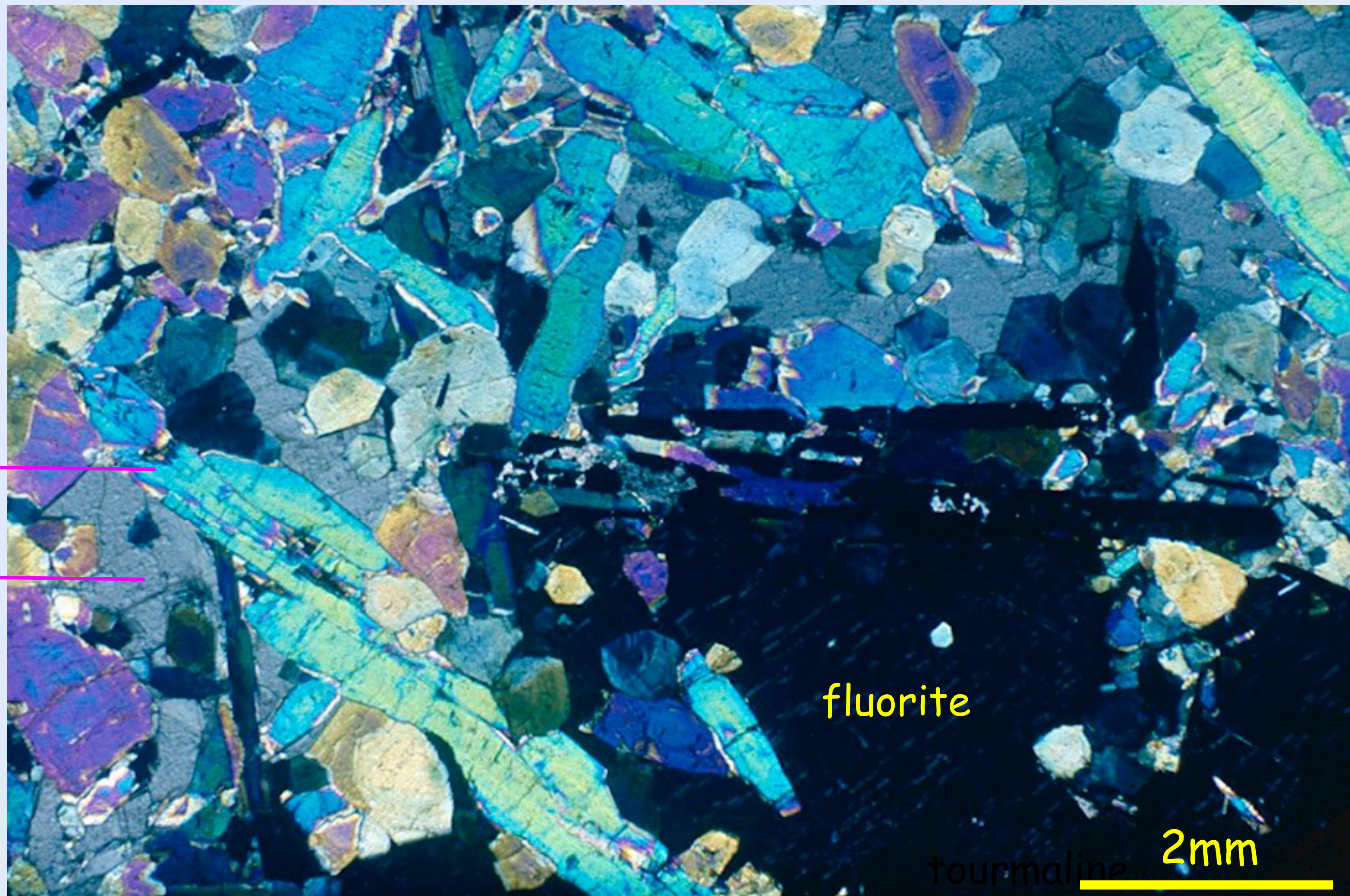
Tourmaline partially replacing green biotite in exogreisen.

Photomicrograph, PPL



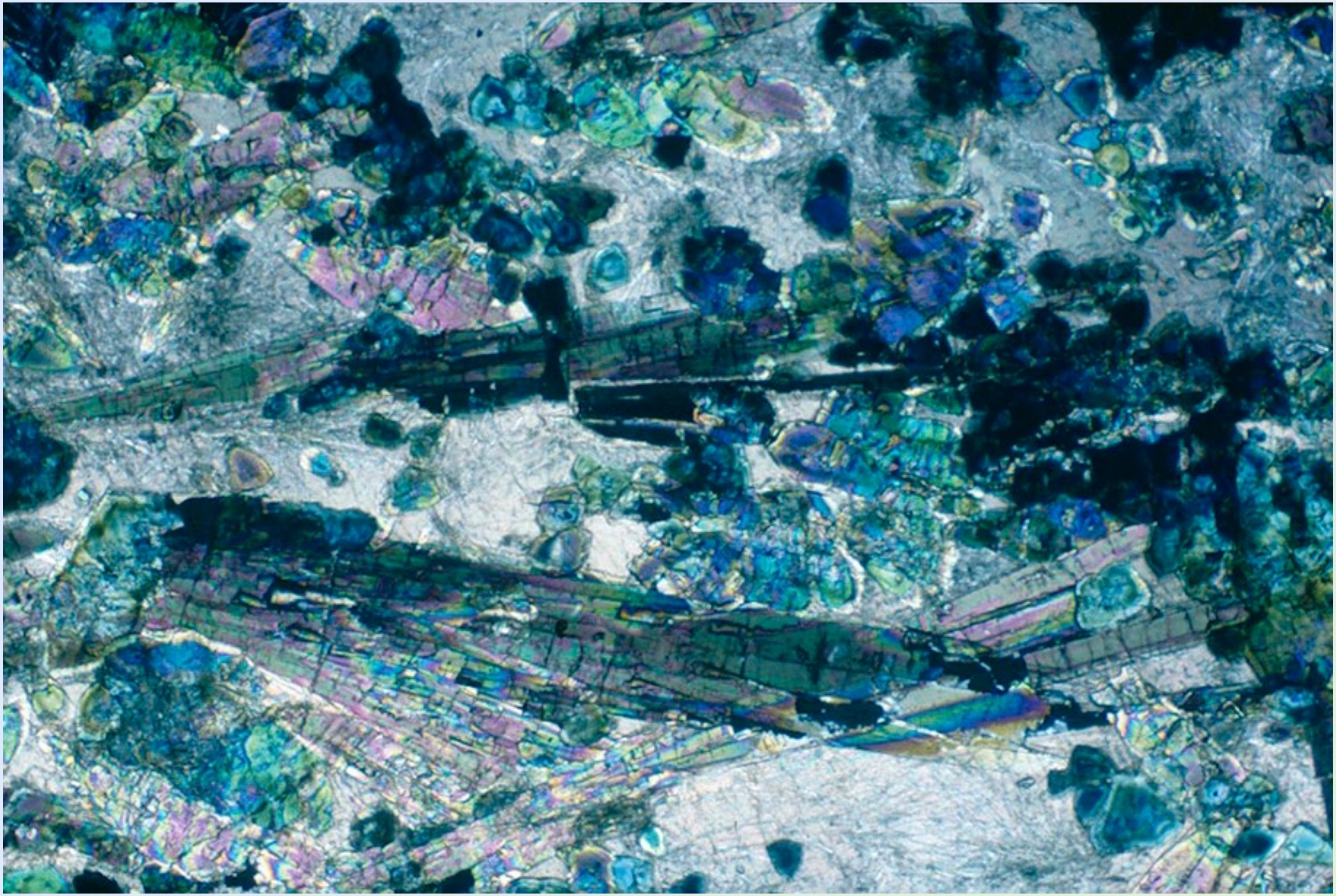
Tourmaline-fluorite exogreisen

Can form through the alteration of skarn or greisen or it may replace marble. Photomicrograph, crossed polars.



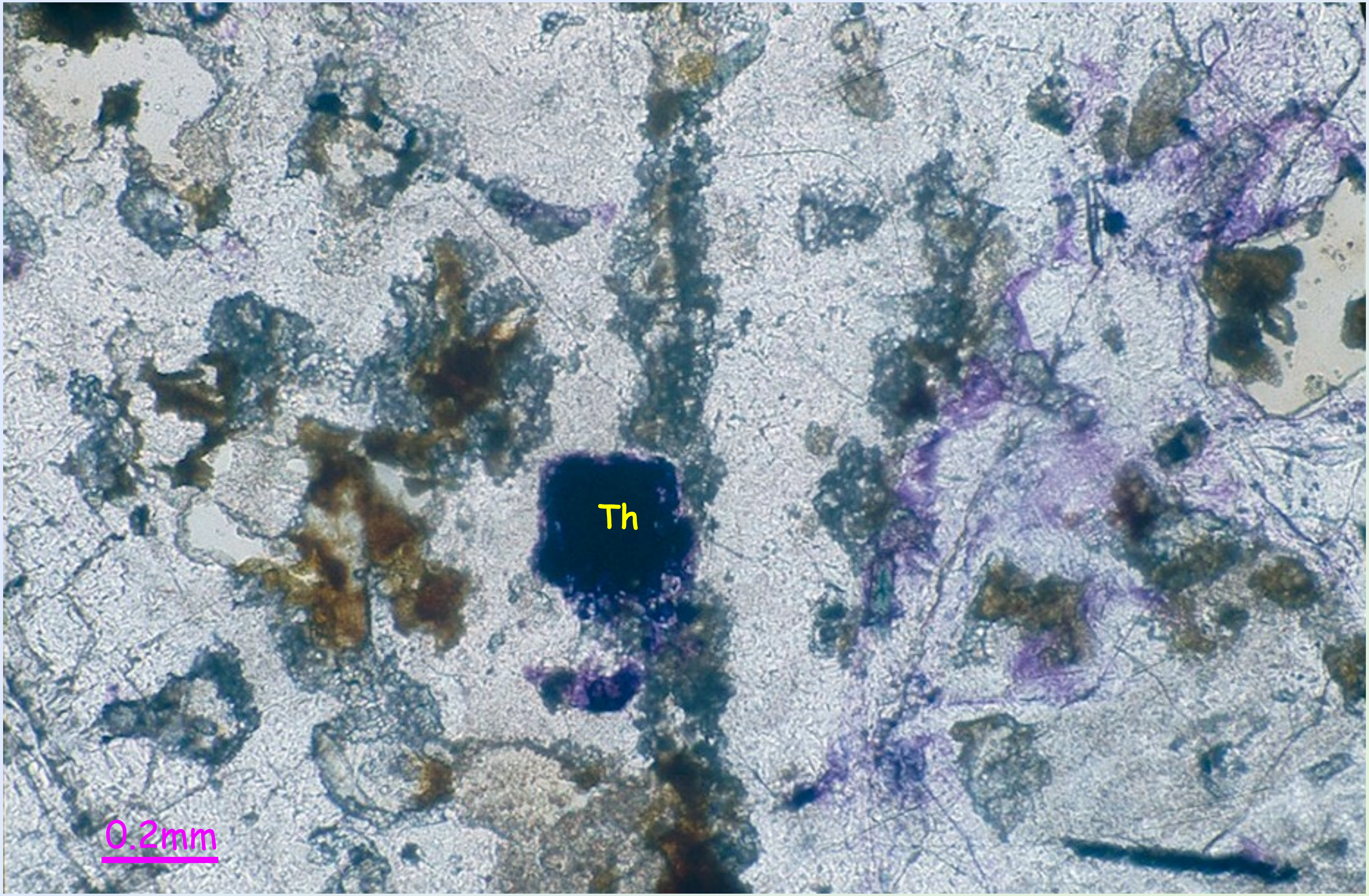
Tourmaline in carbonate , upper zone, endogreisen

Tourmaline replacing carbonate in the upper zone of the carbonate lens. Photomicrograph, PPL



Thorianite in fluorite-tourmaline exogreisen

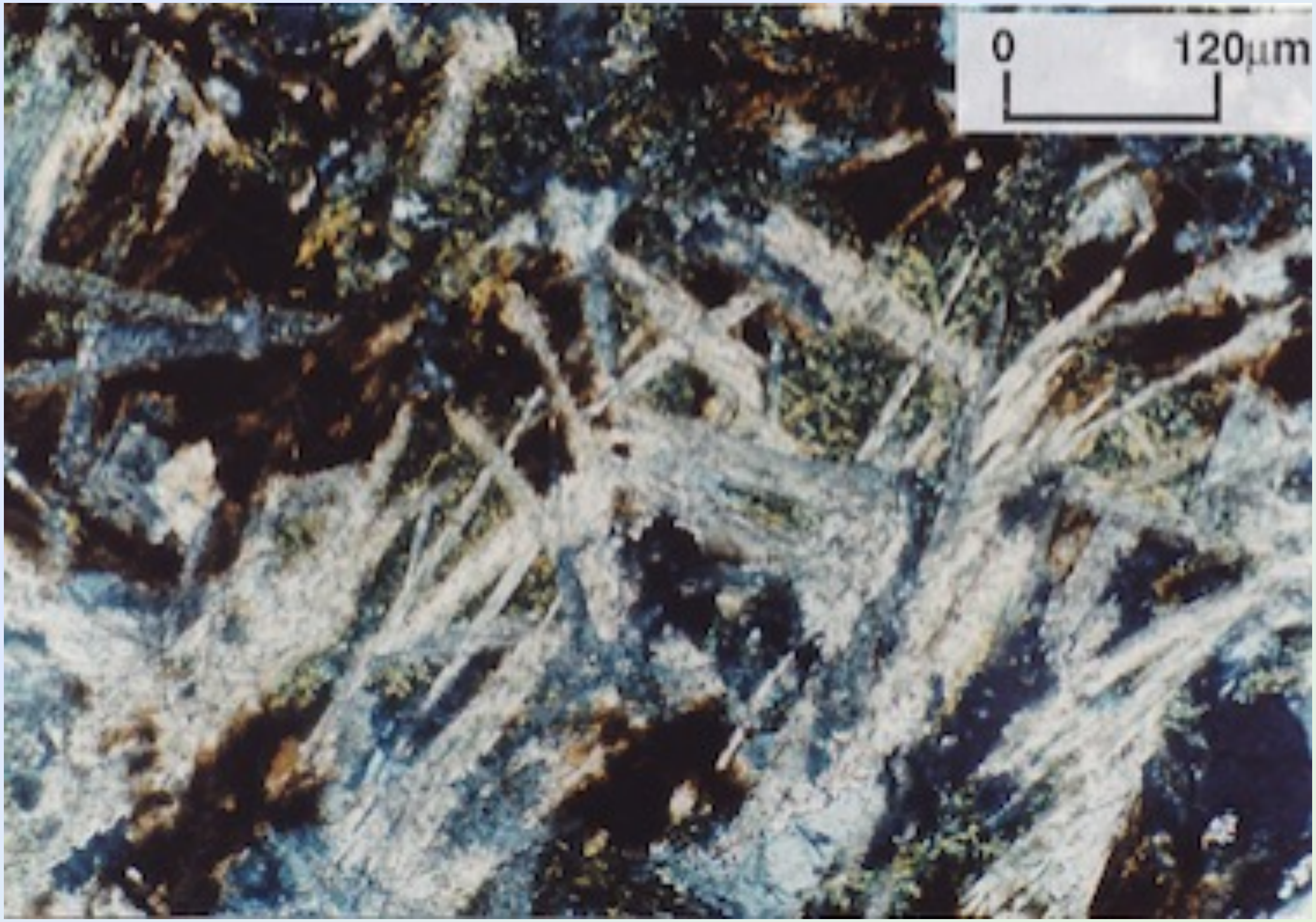
Photomicrograph, PPL



Late carbonate stage

Carbonate pseudomorphs after amphibole

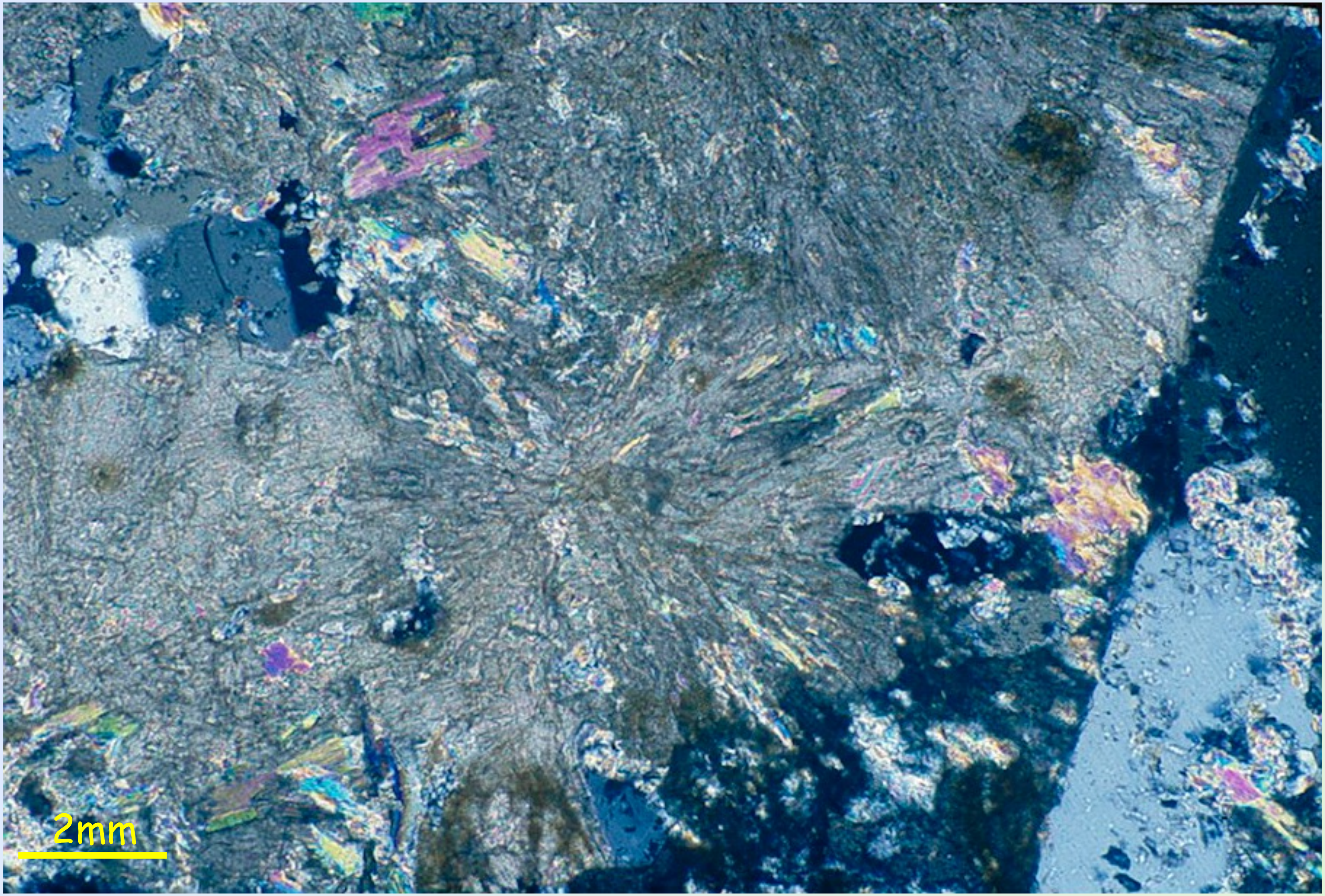
Photomicrograph, crossed polars.



Carbonate replacing muscovite

Late carbonate replacement of muscovite by carbonate

Photomicrograph, crossed polars



Lost River Alaska

Lost River deposit, Alaska described as a Sn-F-W-Be-Zn-Pb-Cu-Ag skarn.

Within the carbonate-replaced bodies are five principal assemblages:

(1) andradite garnet

(2) magnetite + vesuvianite + fluorite

(3) biotite + fluorite + tourmaline + cassiterite

(4) sulphides

(5) carbonate + chlorite

- significant feature of the deposit atypical of skarns, is the potassic overprint which is reflected by the presence of abundant biotite.
- another feature is the strong development of endogreisen in the granite
- the association of greisen and Sn mineralisation is universal.