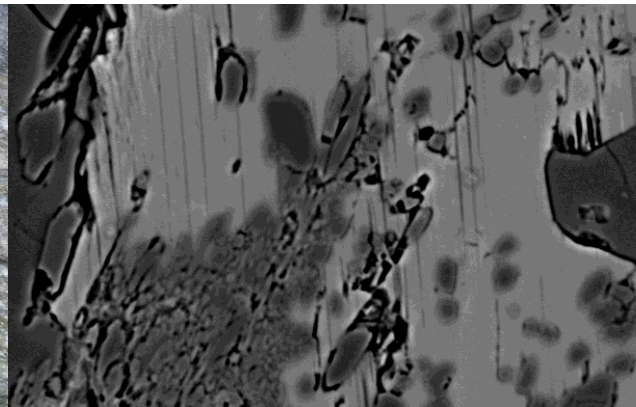
Mg-K-Fe fluid producing mineral reactions, metasomatism and microfabric development during formation of nodular sillimanite-gneiss in the middle crust

Ane K. Engvik
Geological Survey of Norway
Claudia Trepmann
Department of Earth and Environmental Sciences, Ludwig-Maximilians-Universität München
Håkon Austrheim
Department of Geosciences, University of Oslo





Motivation - Metamorphic reactions and deformation

- Important processes in modification and formation of crust
- Metasomatism - Metamorphism - involving fluids - changes in rock chemistry
- Element transport
- New rocks with new mineralogy and structure
- Bamble lithotectonic domain (Norway) – Metasomatism regional extensive

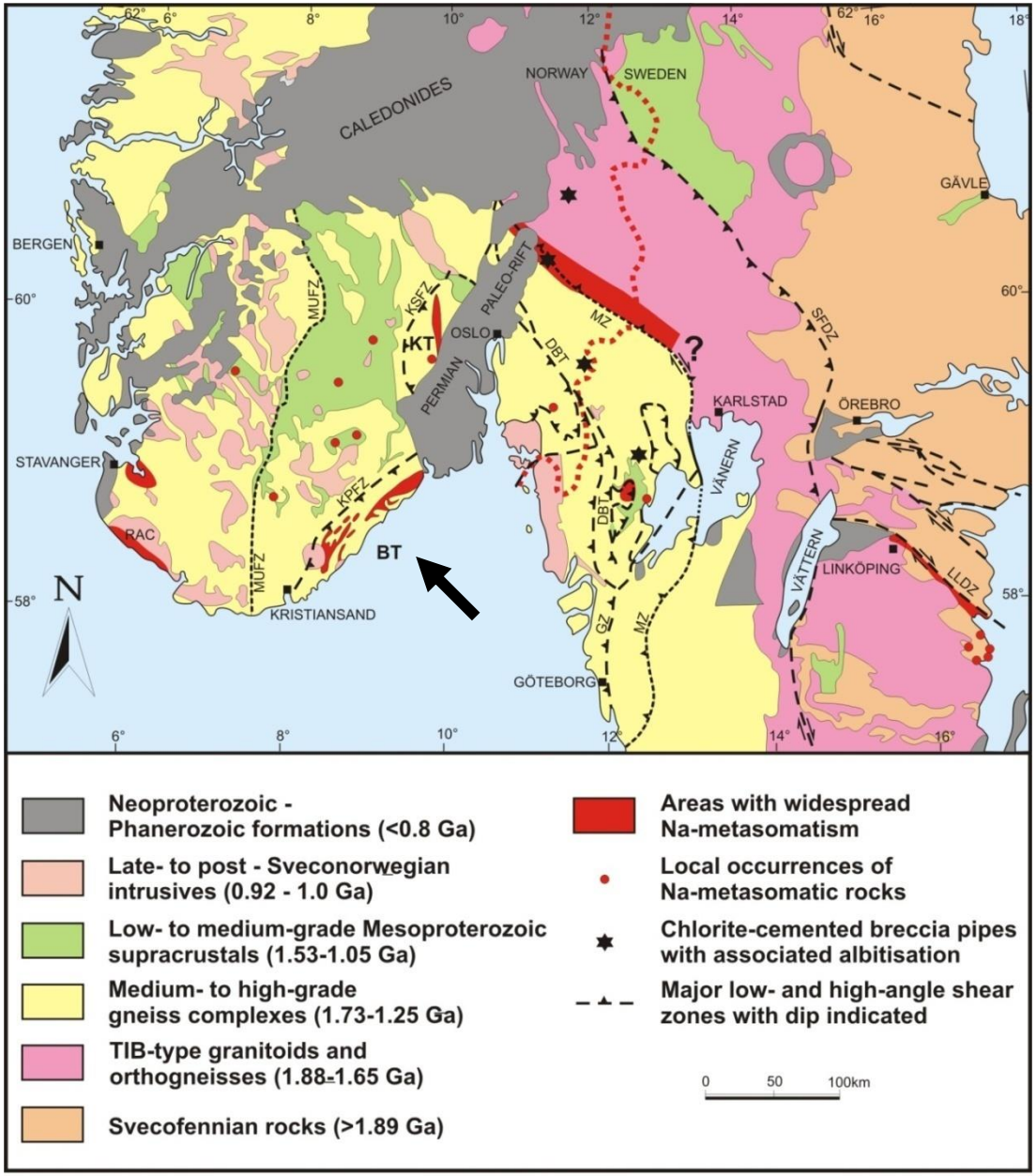
Our study on sillimanite-nodular gneisses

- Field studies
- Mineral replacement analysis (Optical microscopy, EDS, EMP)
- Microfabric - EBSD

Increase understanding of mineral- and rock-forming process,

important for modeling crustal building and geological history

Regional setting - Bamble lithotectonic domain, South Norway



Gneiss formation 1570-1300 Ma

Sveconorwegian reworking

and magmatism 1200-920 Ma

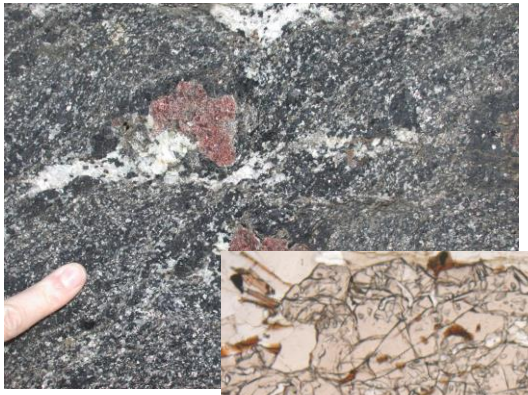
Metamorphism

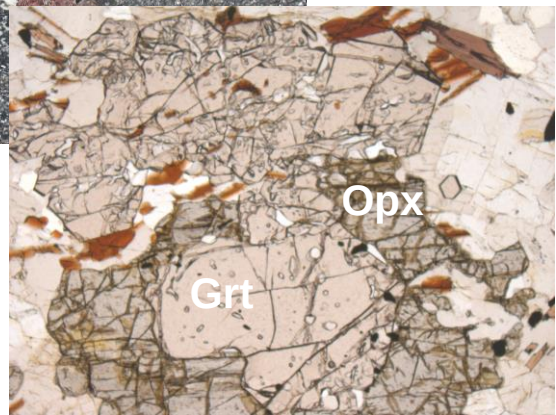
- regional scale deformation

Amphibolite facies gneisses

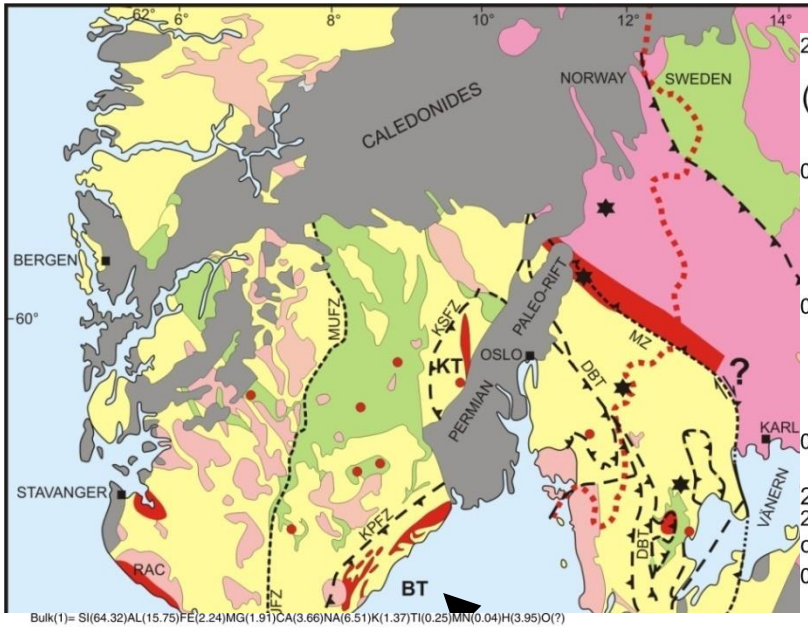
Local granulite facies domains:

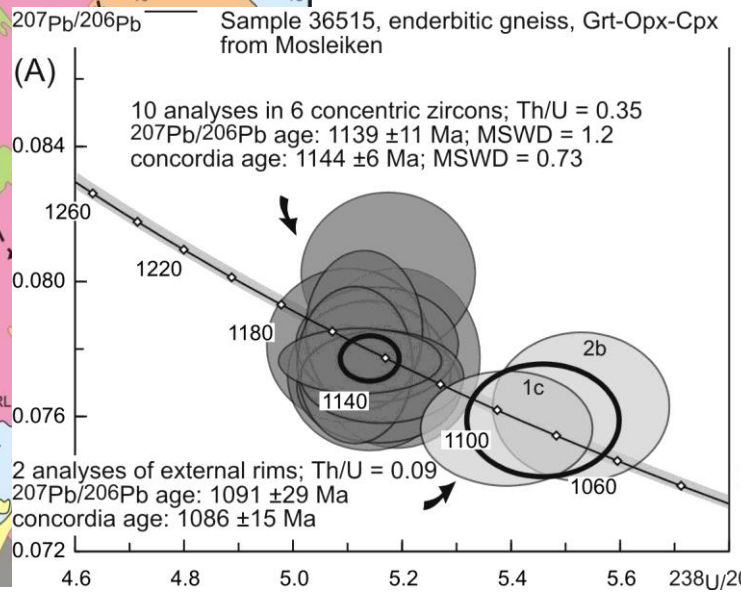
Grt-bearing charnockitic gneiss

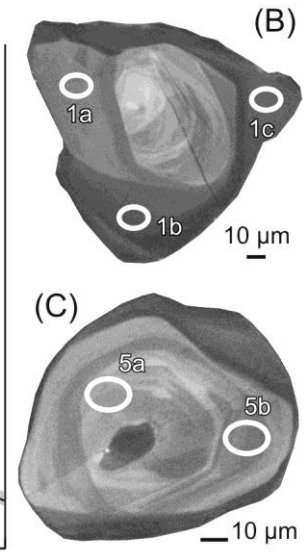


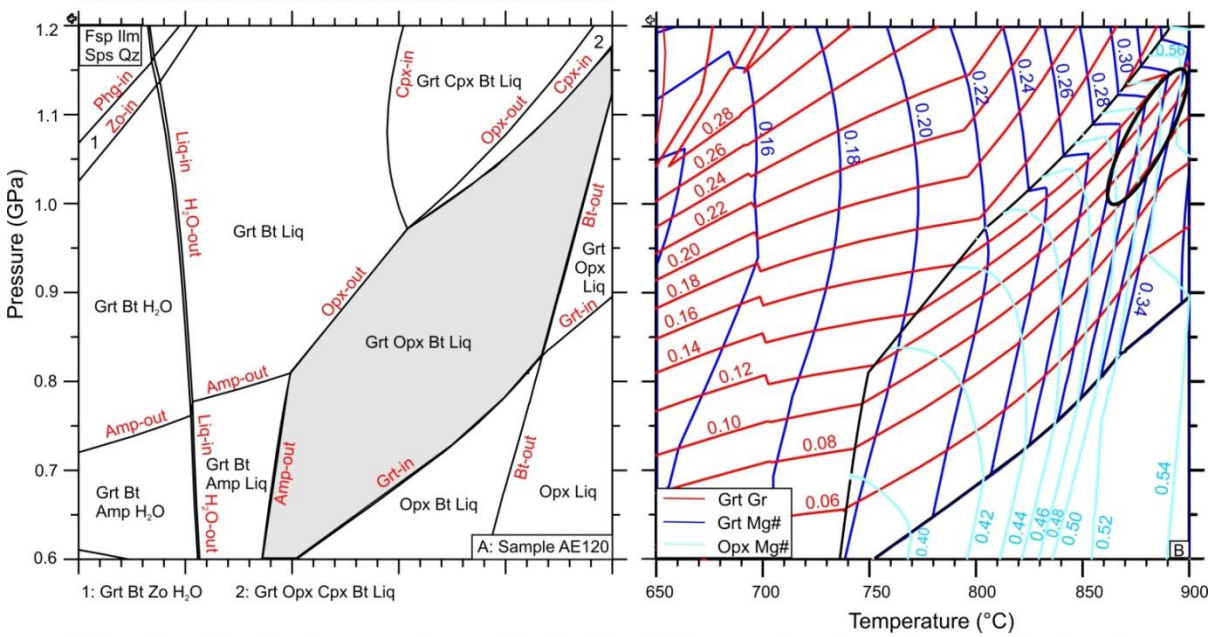


Regional setting - Bamble lithotectonic domain, South Norway









(Theriak-Domino software)

Granulite facies metamorphism

U-Pb zircon age 1139 ±11 Ma

P= 1.03 ±0.17 GPa

T= 838 ±112 °C

(Thermocalc, version 333, Powell & Holland1994)

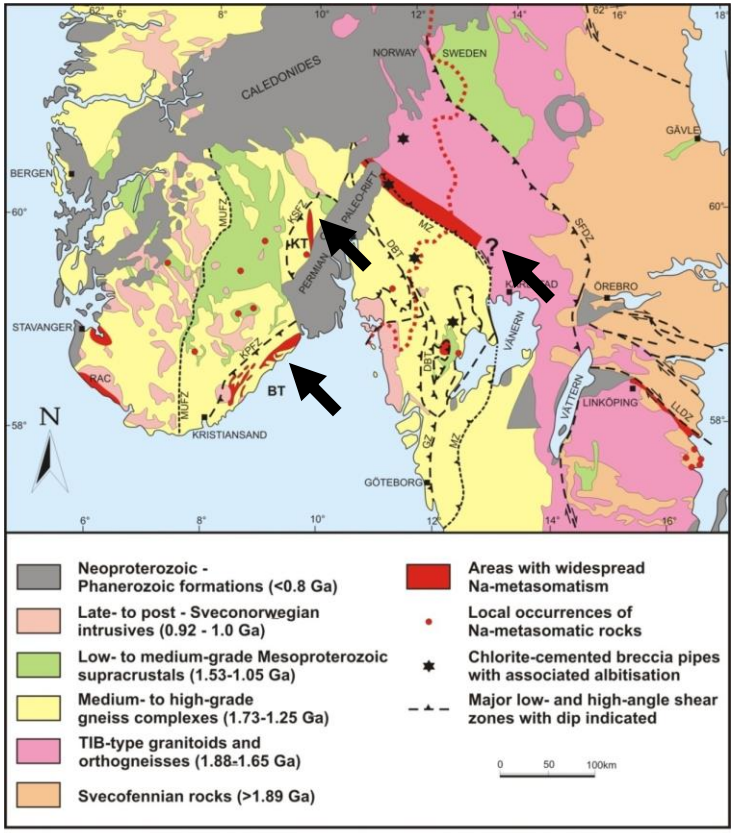
Engvik, Bingen, Solli 2016 Lithos

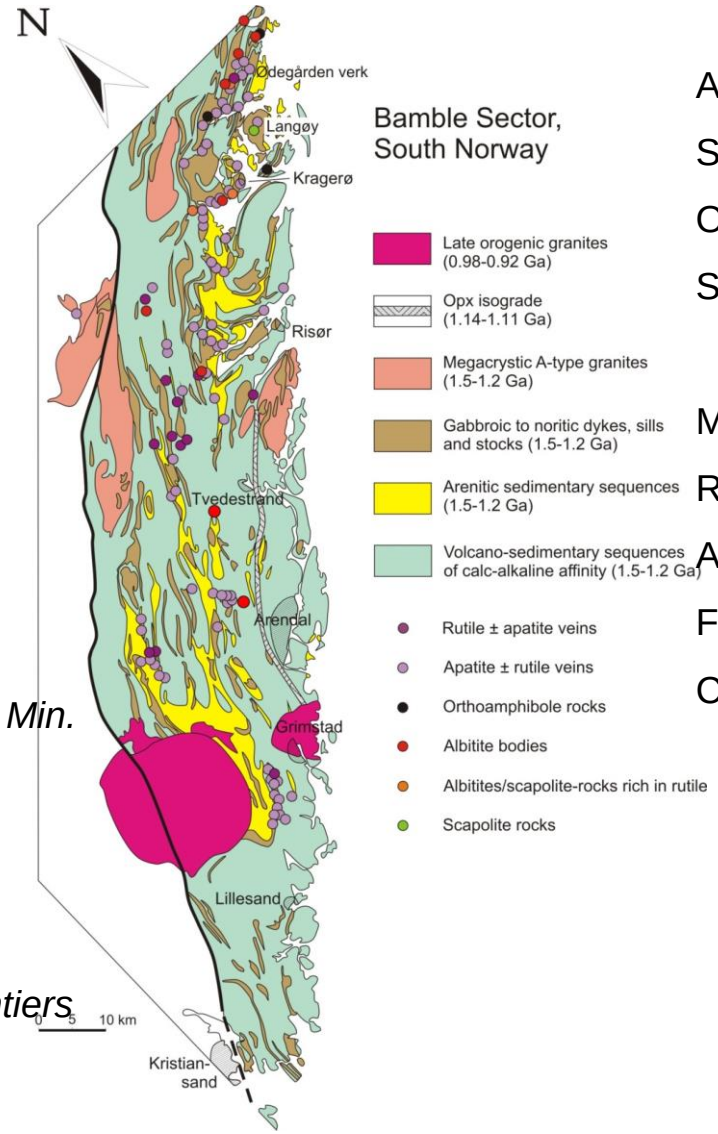
Regional setting - metasomatism

Bamble lithotectonic domain

Kongberg-Modum lithot. domain

Mylonite Zone





Albitites

Scapolite metagabbros

Orthoamph-crd rocks

Sillimanite gneisses

Mineral deposits:

Rutile

Apatite

Fe-ores

Carbonate

Engvik, Putnis, FitzGerald, Austrheim 2008 Can. Min.

Austrheim, Putnis, Engvik, Putnis 2008 CMP

Engvik, Golla-Schindler et al. 2009 Lithos

Engvik & Austrheim 2010 Terra Nova

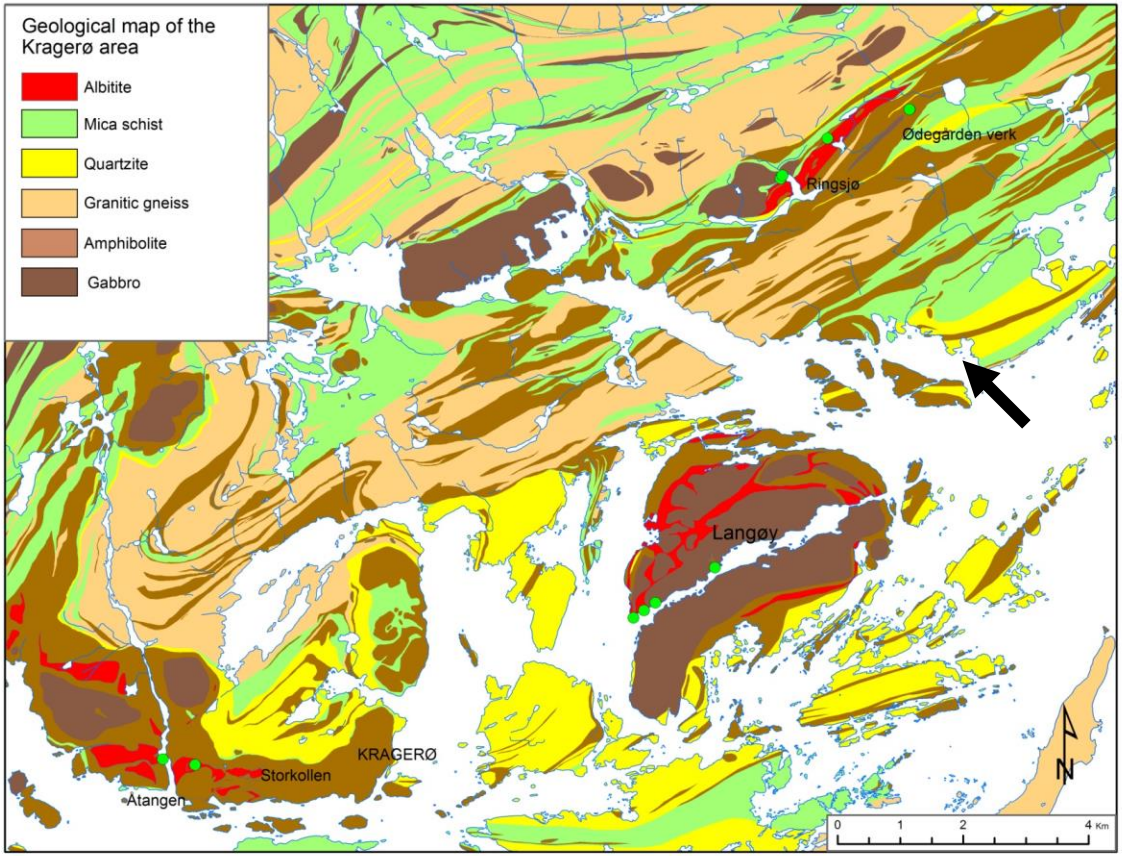
Engvik, Mezger et al. 2011 J. Met. Geol.

Engvik, Ihlen, Austrheim 2014 Geoscientific Frontiers

Engvik, Corfu, Solli, Austrheim 2017 Prec Res

Engvik, Taubald et al. 2018 Geofluids

Mg-Al-Si-rich lithologies



Kragerø area – Bamble lithotec. domain

Orthoamphibole-cordierite rocks

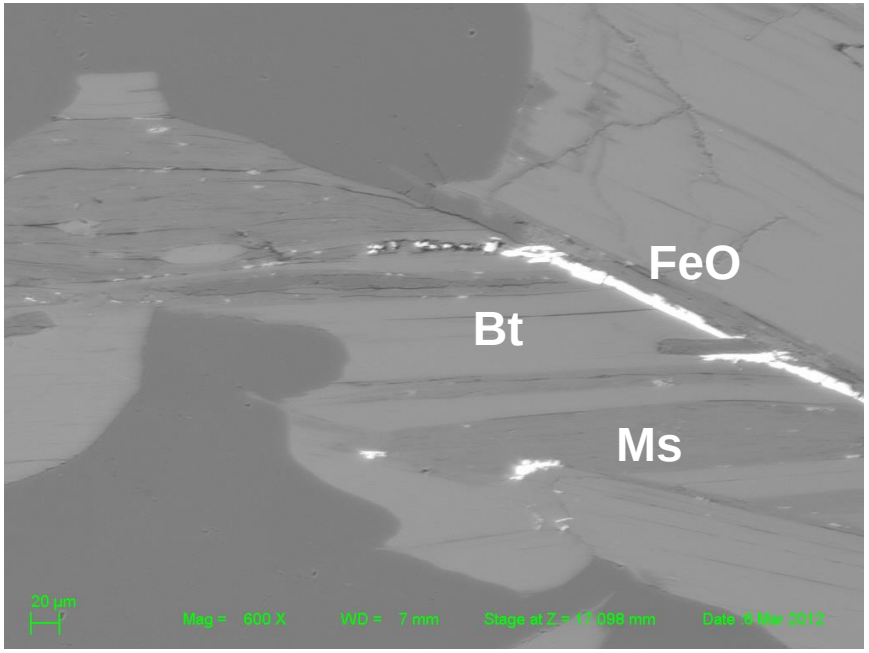
Sillimanite-nodular gneisses

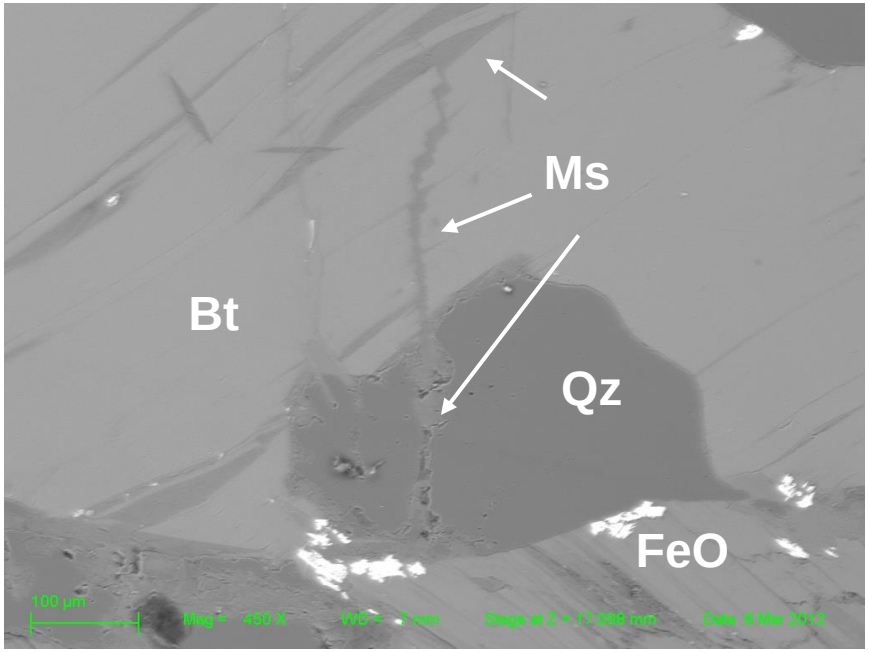
Sillimanite-nodular gneisses

Foliated sillimanite gneisses

Host K-feldspar-mica gneisses

Mineral reactions: Biotite breakdown



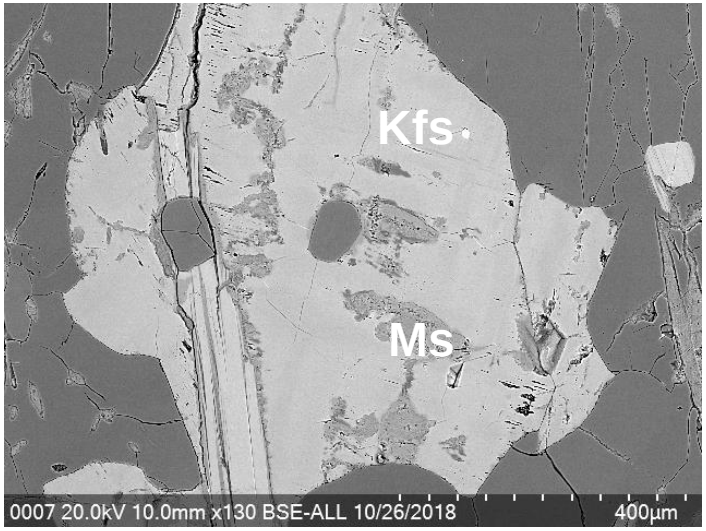


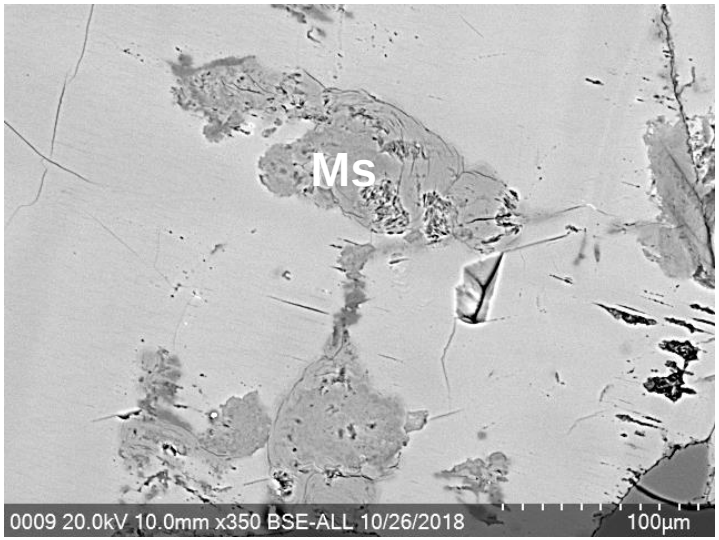
3 Biotite => muscovite + 9 Fe-oxide and Mg + 2 K + 6 quartz + 2 H_2O

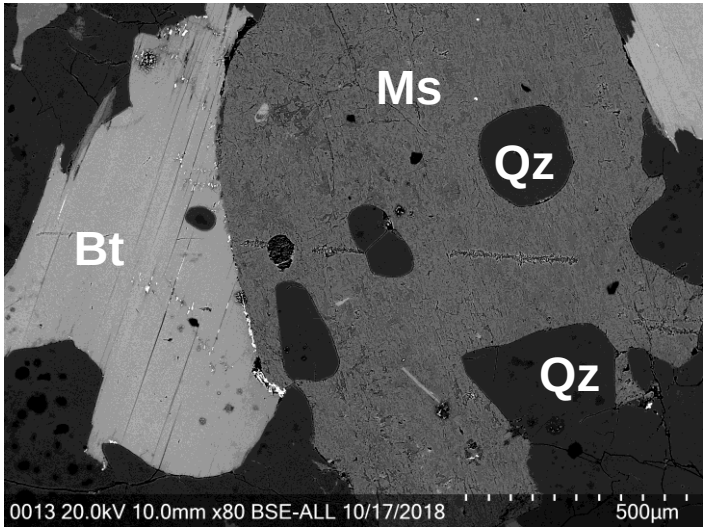
3 $K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$ => $KAl_2(AlSi_3O_{10})(OH)_2$ + 9 (FeO, Mg^{2+}) + 2 K^+ + 6 SiO_2 + 2 H_2O

Production of K, Mg, FeO, quartz and H_2O

Mineral reactions: K-feldspar => muscovite => sillimanite



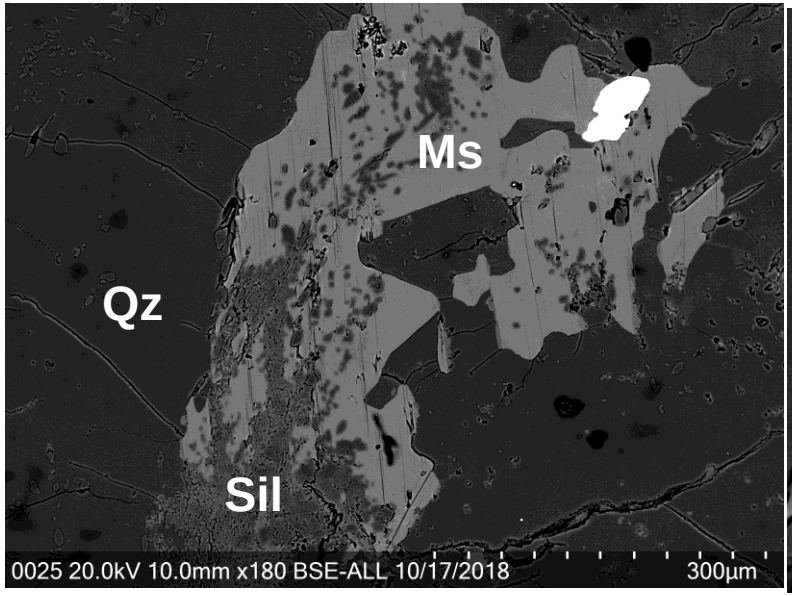


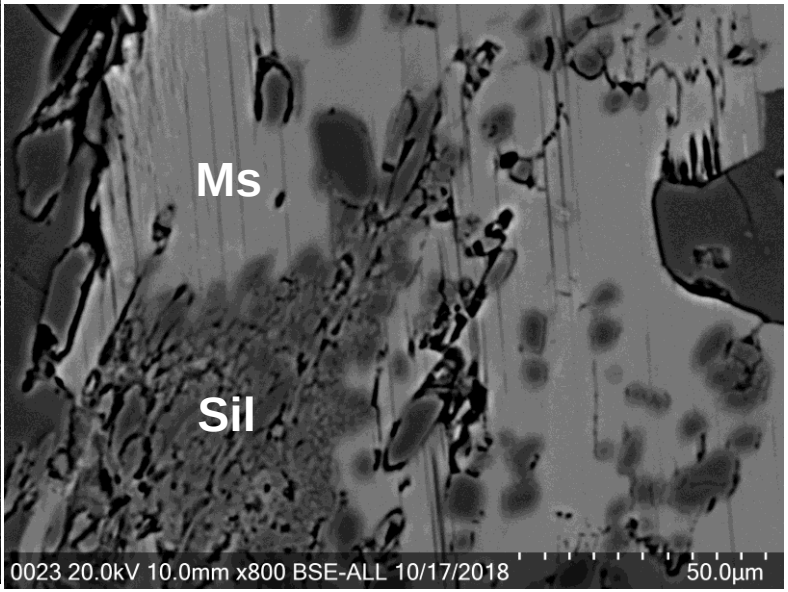


3 K-feldspar + H_2O => muscovite + 6 quartz + 2 K

$3\ KAlSi_3O_8 + H_2O \Rightarrow KAl_2(AlSi_3O_{10})(OH)_2 + 6\ SiO_2 + 2\ K^+$

Mineral reactions: K-feldspar => muscovite => sillimanite





3 K-feldspar + H_2O => muscovite + 6 quartz + 2 K

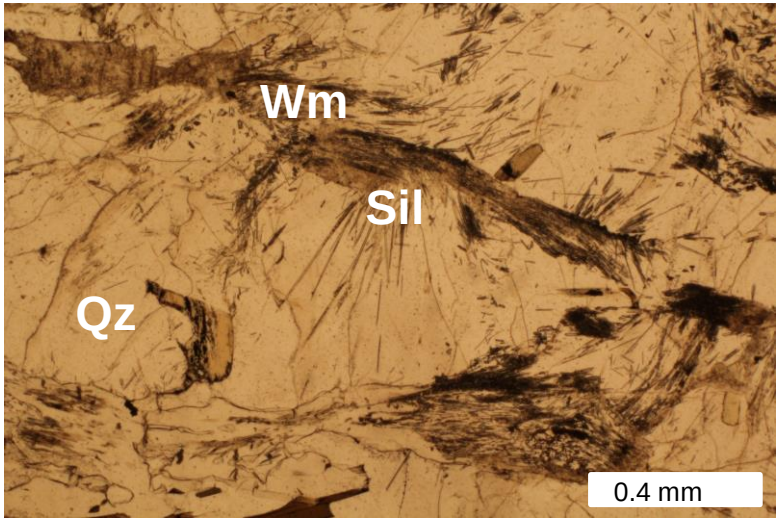
$3\ KAlSi_3O_8 + H_2O \Rightarrow KAl_2(AlSi_3O_{10})(OH)_2 + 6\ SiO_2 + 2\ K^+$

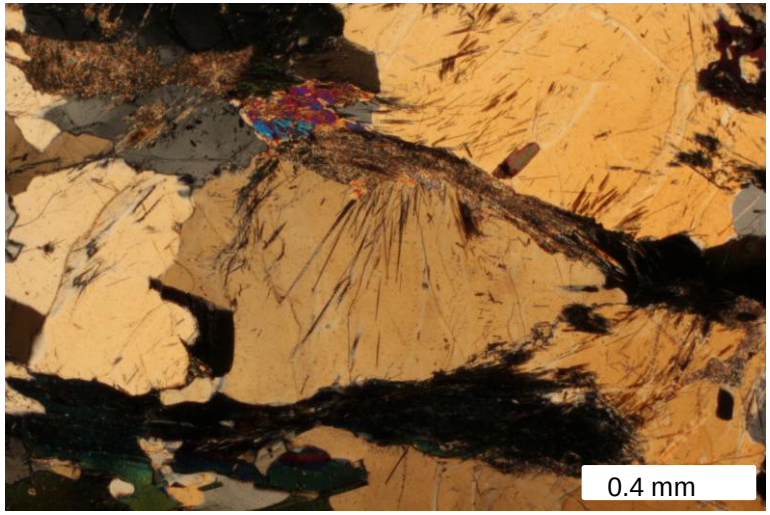
2 muscovite => 3 sillimanite + 3 quartz + 2 K + 2 H_2O

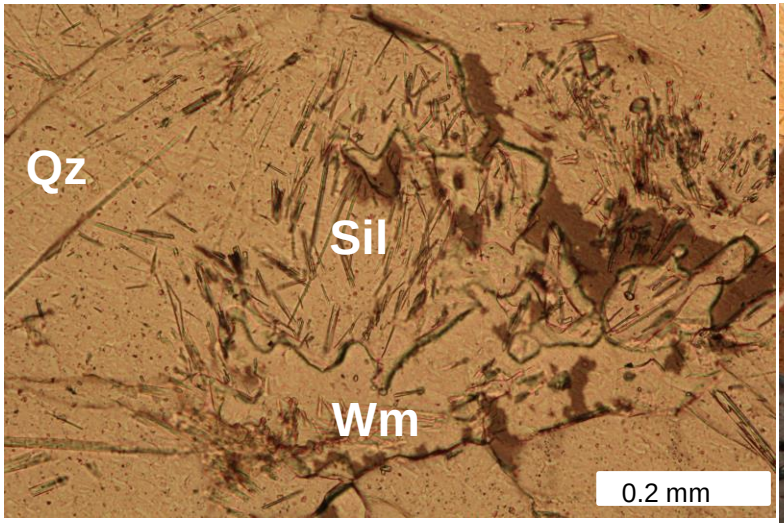
$2\ KAl_2(AlSi_3O_{10})(OH)_2 \Rightarrow 3\ Al_2SiO_5 + 3\ SiO_2 + 2\ K^+ + 2\ H_2O$

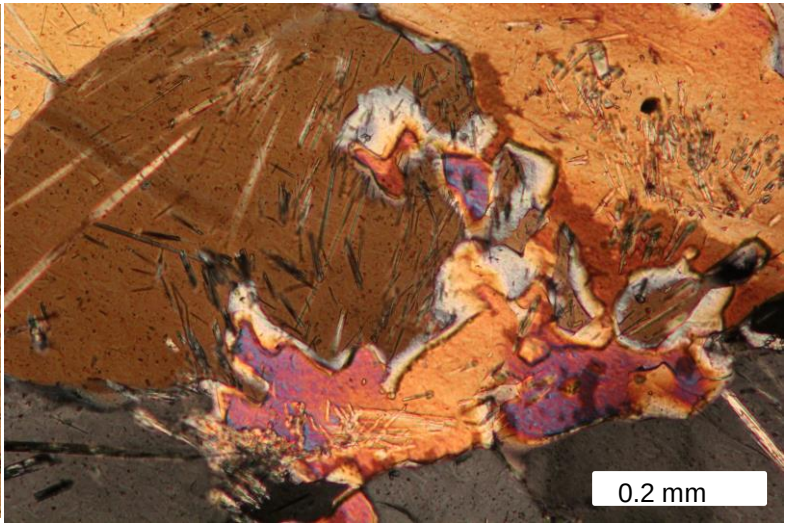
Production of sillimanite, quartz and K

Microfabric





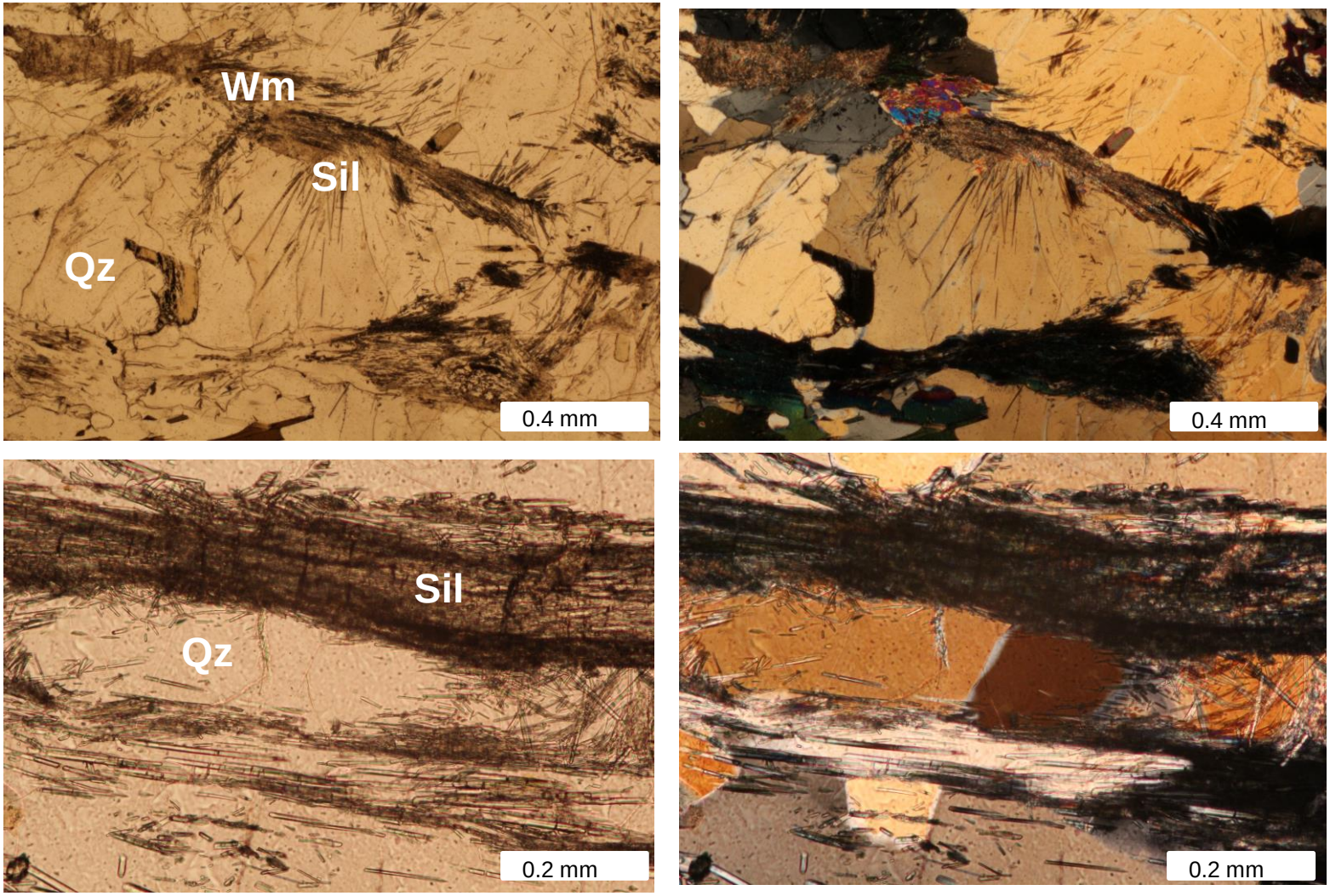




First crystallisation of sillimanite as radiation needles

Mica grains with strongly sutured phase boundaries - surface energy not important

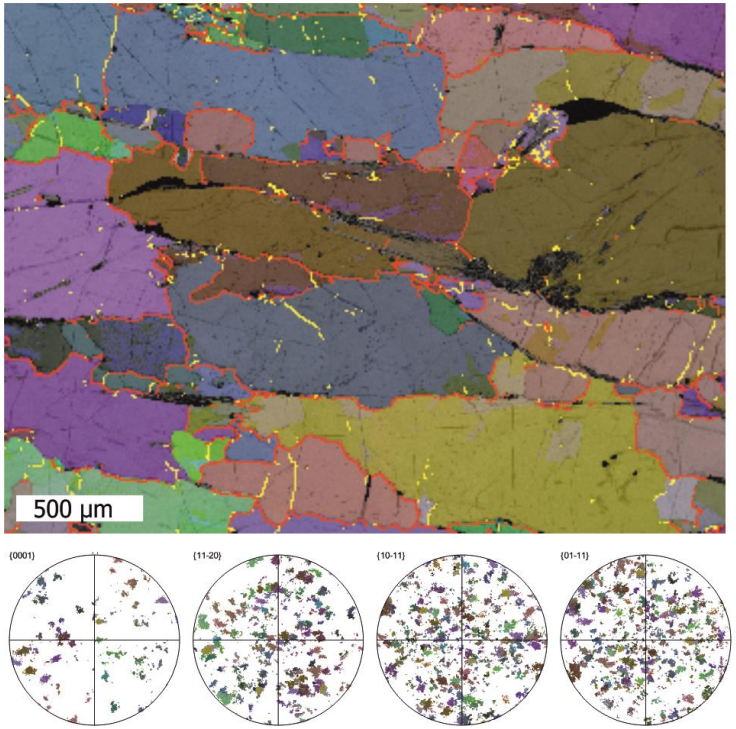
Microfabric

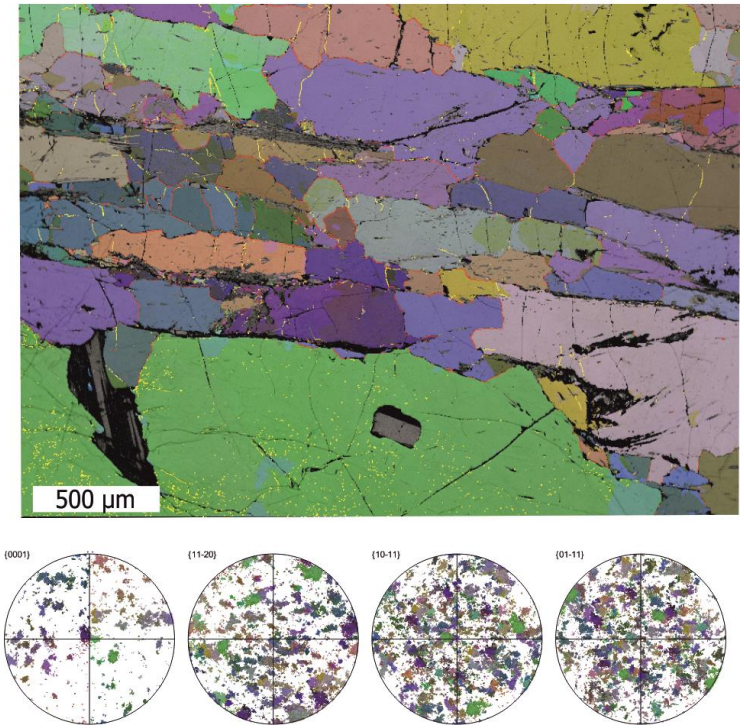


Foliated sillimanite gneisses: Shape-preferred orientation of quartz

Crystallographic preferred orientation of evolved sillimanite crystals

Microfabric EBSD data – quartz, mica, sillimanite

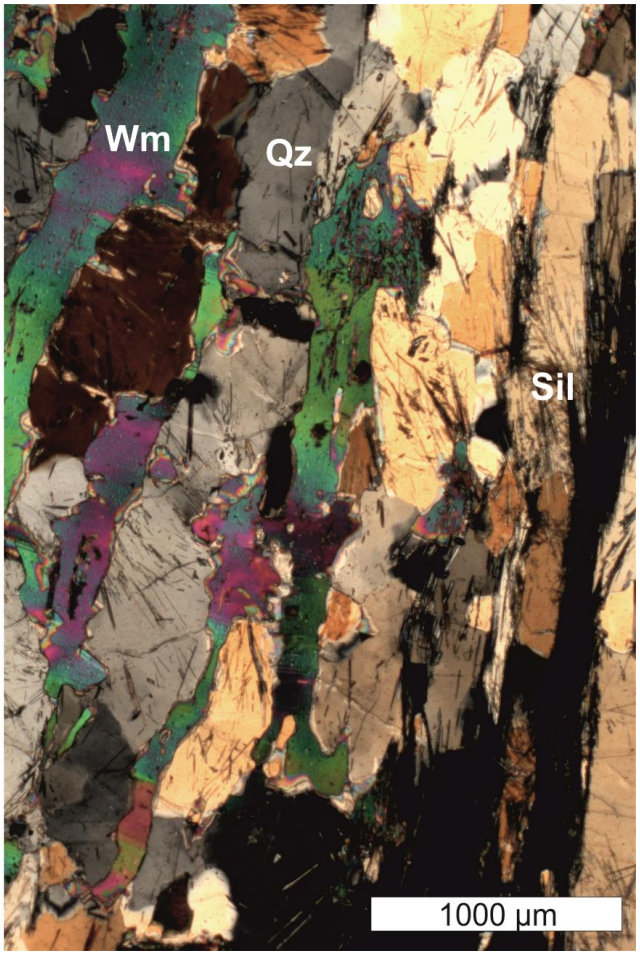


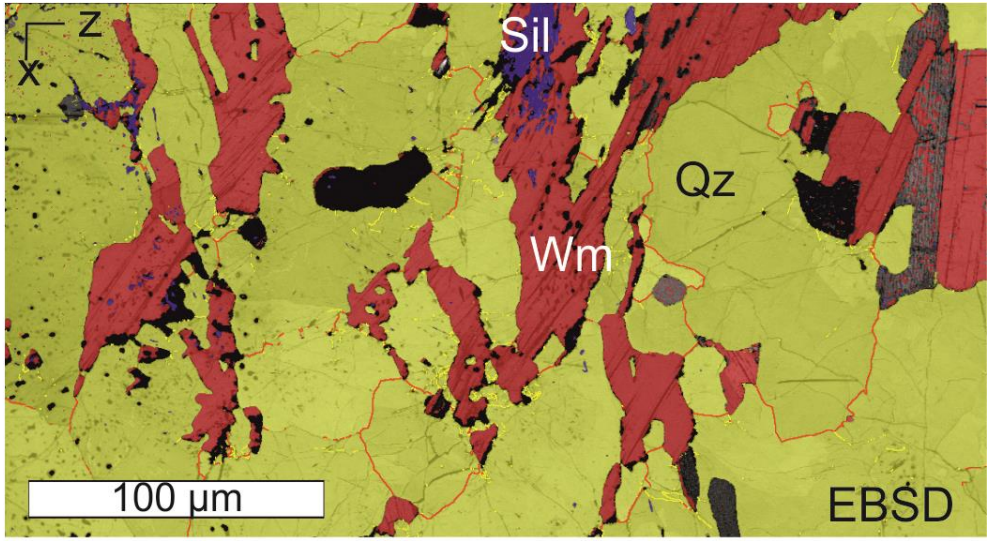


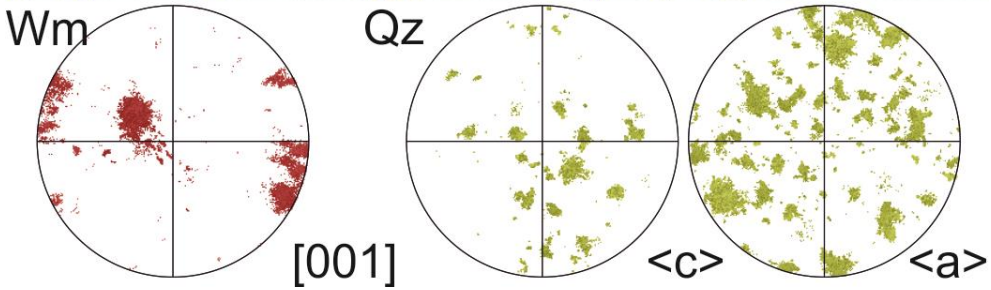
Quartz – Shape preferred orientation

No obvious crystallographic preferred orientation

Microfabric EBSD data – quartz, mica, sillimanite





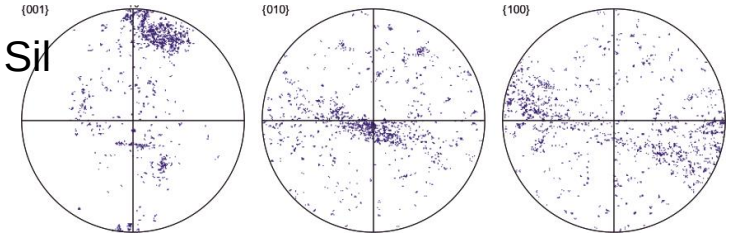


Mica Crystallographic preferred orientation

Coarse with few different orientations - low nucleation rate

No obvious crystallographic relationship between quartz-mica

Sillimanite Crystallographic preferred orientation



Summary

Sveconorwegian (1200-920 Ma) tectonothermal event i middle crust

Strongly metasomatised crustal rocks:

Scapolitisation (Increase in **K-Mg**-Na-P-Cl-B - depletion of **Fe**)

Albitisation (**Na**-enrichment – depletion in **Fe**-Mg-Ca)

Mg-Al-SiO_2-rich rocks – sillimanite-nodular gneisses

Mineral deposits (Fe-ores, rutile, apatite, carbonate)

Sillimanite-nodular gneisses

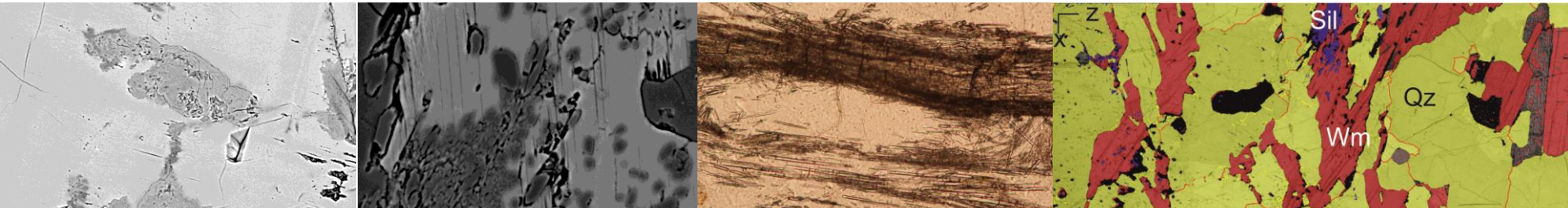
K-feldspar => muscovite => sillimanite: K- and SiO_2 producing reactions

Biotite => muscovite K-Mg-Fe, SiO_2 and H_2O producing reactions

Reactions at non-isostatic stress conditions: Shape-preferred orientation of elongate Qz

Mica with sutured phase boundaries

Crystallographic preferred orientation for mica and sillimanite



Concluding remark

Mineral reactions and deformation forming Al-Si-rich rocks; sillimanite quartzite and gneisses

one small piece in a complex crustal picture

Source for the extensive K-Mg metasomatism (scapolitisation); Fe-depletion and Fe-deposition

Mineral reactions and deformation produce rocks with a new mineralogy and structure

- increase understanding of mineral- and rock-forming process
- important for modeling crustal building and geological history