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

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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
Granulite facies metamorphism

**U-Pb zircon age 1139 ±11 Ma**

\[ P = 1.03 \pm 0.17 \text{ GPa} \]
\[ T = 838 \pm 112 \text{ °C} \]

(Thermocalc, version 333, Powell & Holland 1994)

Engvik, Bingen, Solli 2016 Lithos
Regional setting - metasomatism

Bamble lithotectonic domain
Kongberg-Modum lithot. domain
Mylonite Zone

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

Albitites
Scapolite metagabbros
Orthoamph-crd rocks
Sillimanite gneisses

Mineral deposits:
Rutile
Apatite
Fe-ores
Carbonate
Mg-Al-Si-rich lithologies

Orthoamphibole-cordierite rocks
Sillimanite-nodular gneisses

Kragerø area – Bamble lithotec. domain
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 H₂O

3 K(Mg,Fe)₃(AlSi₃O₁₀)(OH)₂ => KAl₂(AlSi₃O₁₀)(OH)₂ + 9 (FeO, Mg²⁺) + 2 K⁺ + 6 SiO₂ + 2 H₂O

Production of K, Mg, FeO, quartz and H₂O
**Mineral reactions:** K-feldspar $\rightarrow$ muscovite $\rightarrow$ sillimanite

\[
3 \text{K-feldspar} + \text{H}_2\text{O} \rightarrow \text{muscovite} + 6 \text{quartz} + 2 \text{K}
\]

\[
3 \text{KAlSi}_3\text{O}_8 + \text{H}_2\text{O} \rightarrow \text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2 + 6 \text{SiO}_2 + 2 \text{K}^+
\]
Mineral reactions: K-feldspar => muscovite => sillimanite

3 K-feldspar + H₂O => muscovite + 6 quartz + 2 K

3 KAlSi₃O₈ + H₂O => KAl₂(AlSi₃O₁₀)(OH)₂ + 6 SiO₂ + 2 K⁺

2 muscovite => 3 sillimanite + 3 quartz + 2 K + 2 H₂O

2 KAl₂(AlSi₃O₁₀)(OH)₂ => 3 Al₂SiO₅ + 3 SiO₂ + 2 K⁺ + 2 H₂O

Production of sillimanite, quartz and K
First crystallisation of sillimanite as radiation needles

Mica grains with strongly sutured phase boundaries - surface energy not important
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 in 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-SiO₂-rich rocks – sillimanite-nodular gneisses
- Mineral deposits (Fe-ores, rutile, apatite, carbonate)

Sillimanite-nodular gneisses

K-feldspar => muscovite => sillimanite: K- and SiO₂ producing reactions

Biotite => muscovite               K-Mg-Fe, SiO₂ and H₂O 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