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**Structural and metamorphic inheritance controls strain partitioning during orogenic shortening
(Kalak Nappe Complex, Norwegian Caledonides).**

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Caledonides; Shear-parallel folds

Abstract

The occurrence of pre-collisional structural and metamorphic fabrics may control the development of new structures during subsequent orogenic deformation. Structural, petrological and geochronological analyses have been performed on selected samples collected along a NW-SE cross section of the Kalak Nappe Complex (KNC) exposed on Kvaløya Island (Finnmark, Norway), in order to define pre-Caledonian or Caledonian affinity of deformation fabrics. Nappes within the KNC experienced different pre-collisional tectonometamorphic histories, resulting in contrasting pre-Caledonian fabrics, which in turn controlled orogen-scale strain partitioning and metamorphic re-equilibration during Caledonian shortening. Caledonian deformation during top-to-SE-directed thrusting occurred at 550-675°C and 0.8-1.0 GPa in the presence of fluid. Suitably-oriented pre-collisional fabrics were firstly exploited as zones of localized shearing internal to the Nappe and subjected to metamorphic re-equilibration during shortening. Fold geometry during Caledonian thrusting was also controlled by the orientation of pre-Caledonian fabrics. SE-verging asymmetric folds were developed after minor tilting of pre-Caledonian upright folds with orogen-parallel hinge in the hinterland consistently with top-to-SE shearing. Shear-parallel folds displaying orogen-perpendicular hinge lines resulted from top-to-SE general shearing of pre-collisional upright folds showing pre-collisional orogen-perpendicular hinge lines. Caledonian metamorphism appears to have been accompanied by infiltration of radiogenic ^{40}Ar -rich fluids, which affected the Ar isotopic system in synkinematic micas.

1. Introduction

Pervasive ductile deformation in the middle and lower crust controls the evolution of the deep portions of orogenic wedges and the accommodation of deep crustal shortening during large-

scale thrusting and nappe stacking and folding (Escher and Beaumont, 1997; Williams and Jiang, 2005; Beaumont et al., 2006; Culshaw et al., 2010; Bastida et al., 2014; Wex et al., 2017). During orogenesis, thick-skinned tectonics involves the deformation of crystalline basement units that are commonly characterized by a multi-stage pre-collisional tectonometamorphic history (Audet and Bürgmann, 2011; Faber et al., 2019). The prolonged deformation and metamorphic history of basement units is reflected in the development of multiple and variably oriented fabrics. The occurrence of multiple different fabrics formed under different conditions at different times makes untangling the tectonometamorphic history of basement units very difficult, however this is critical for constraining the different spatial and temporal tectonic processes that take place during either (multiple) orogenic cycles or progressive deformation during the same orogenic cycle. These basement units provide an ideal natural laboratory to analyse how pre-collisional inherited deformation fabrics influence strain accommodation and partitioning during a subsequent orogenic episode (Audet and Bürgmann, 2011; Mouthereau et al., 2013).

Structural inheritance has been shown to affect orogenic shortening both at brittle upper crustal levels (Butler et al., 2006; Massironi et al., 2011; Beltrando et al., 2014; Fossen et al., 2017), as well as at ductile, mid- to lower-crustal conditions (Vauchez and Barruol, 1996; Jammes and Huismans, 2012; Mouthereau et al., 2013). Similarly, pre-collisional metamorphic history may strongly influence the behaviour of basement units during later continental collision, especially those typically characterized by dry and rheologically strong lithologies (Yardley and Valley, 1997; Austrheim, 2013). The definition of the pre-collisional tectonometamorphic history of basement units and related deformation-metamorphic fabrics is therefore of fundamental importance for the analysis and interpretation of strain partitioning and accommodation processes during continental collision. Careful investigations of low-strain domains within nappe complexes can provide information on the different P-T conditions and

68 timing of fabric development, as well as on the geometry of strain. Such analyses are crucial
69 to the understanding of the evolution of polyorogenic basement units and of the role of the pre-
70 collisional history on the architecture of mountain belts (Ridley, 1989; Babist et al., 2006;
71 Kirkland et al., 2006b; Manzotti and Zucali, 2013; Gasser et al., 2015; Faber et al., 2019). In
72 addition, petrological and geochronological analysis of regional-scale fabrics are pivotal for
73 the correlation of deformation stages, the correct interpretation of geochronological age dating
74 and for the inference of orogen-scale tectonic processes (Warren et al., 2012; Skipton et al.,
75 2018).

76 Here we present the results of field structural, petrological and in-situ $^{40}\text{Ar}/^{39}\text{Ar}$
77 geochronological analysis on a NW-SE cross section of the Kalak Nappe Complex (KNC) of
78 the Norwegian arctic Caledonides in the Kvaløya Island (Finnmark, Norway). This cross
79 section exposes polyorogenic units of the KNC that were deformed under mid-lower crustal
80 conditions during the Caledonian orogeny. The units were only partially re-equilibrated and
81 reworked during Caledonian shortening, and therefore preserve large-scale low-strain domains
82 (similar to those reported by Gasser et al., 2015). The studied section is parallel to the
83 Caledonian top-to-SE thrusting direction, and provides an ideal natural laboratory for
84 investigating how pre-collisional fabrics affected the accommodation of increasing strain
85 during shortening. We integrated field observations and structural analysis of different pre- and
86 collisional fabrics with P-T-fluid condition estimates in order to define: (i) the metamorphic
87 evolution of the KNC in the study area, and (ii) how the strain distribution and the geometric
88 style of shortening of a polyorogenic basement nappe depend on the orientation and
89 metamorphic history of pre-collisional fabrics. We find that the KNC nappes underwent two
90 different cycles of tectonometamorphic evolution prior to the Caledonian orogeny. The
91 orientation of the previous fabric affected how strain and metamorphism occurred in the KNC
92 units during the Caledonian collision. The study area shows an abrupt change in orientation of

a stretching lineation from *orogen-parallel* to *orogen-perpendicular* towards the foreland. We show that this switch is due to the different orientation of pre-collisional fabrics and of the resulting Caledonian folds, with shear-parallel folds dominating in the foreland part of the section. Finally, we infer that in-situ $^{40}\text{Ar}/^{39}\text{Ar}$ dates of synkinematic micas from both pre-collisional and collisional fabrics do not directly reflect the timing of crystallization, deformation or cooling related to fabric development or tectonic exhumation. Instead, they appear to have been affected heterogeneously by Ar-rich fluid infiltration during Caledonian metamorphism.

2. Geological setting

The Scandinavian Caledonides formed by the convergence and continental collision between Baltica and Laurentia, which followed the subduction and closure of the Iapetus Ocean, during the Ordovician to Devonian (Roberts, 2003). Ocean closure and continental collision resulted in the stacking of different allochthonous nappes with, from bottom to top, Baltica, Iapetus and Laurentia affinity (Roberts, 2003). Traditionally, the nappe stack has been subdivided into Lower, Middle, Upper and Uppermost Allochthon units (Roberts, 2003; Gee et al. 2008). The deep erosional level of the hinterland of the Scandinavian Caledonides provides direct access to middle- and lower crustal sections subjected to intense collisional deformation and metamorphism in an orogen of Alpine-Himalayan style (Gee et al., 2008).

The geology of the Scandinavian Caledonides in Finnmark, northern Norway, consists of windows of Baltica basement with its metasedimentary autochthonous units, overlain by parautochthonous metasediments (Fig. 1a) (Roberts, 2003). Above the parautochthonous units, the stack of allochthonous nappes that were thrust eastward over Baltica is dominated by the Kalak Nappe Complex (KNC), a composite nappe pile consisting of several different thrust

117 sheets telescoped onto Baltica during the Caledonian Orogeny (Corfu et al., 2007; Kirkland et
118 al., 2007b; 2008b). The KNC represents a section of reworked middle and lower continental
119 crust that had previously experienced several Neoproterozoic events prior to the Caledonian
120 Orogeny (Sturt et al., 1978; Daly et al., 1991; Kirkland et al., 2005; 2006a; 2007a, 2007b;
121 2008a; 2008b; Corfu et al., 2011; Gasser et al., 2015; Gee et al., 2017), when it was subjected
122 to pervasive deformation and metamorphism during nappe stacking (Gasser et al., 2015; Faber
123 et al., 2019).

124 *2.1. Geology of the Kalak Nappe Complex*

125 The KNC is composed of ortho- and paragneisses, metasediments of psammitic and pelitic
126 composition and variably affected by migmatization, minor schists and marbles, and felsic and
127 mafic intrusive rocks (Zwaan and Roberts, 1978; Rice, 1990). These lithologies are variably
128 grouped and distributed in two distinct polyorogenic crustal sections that form the lower and
129 the upper nappe of the KNC (Kirkland et al., 2006b). The two nappes are further subdivided
130 into different internal units and thrust sheets (Kirkland et al., 2008b).

131 The lower nappe includes the Fagervik gneissic complex, predominantly composed of quartzo-
132 feldspatic gneisses and amphibolites, and the overlying metasediments of the Sværholt
133 succession (Kirkland et al., 2008b). Detrital zircon ages of 1948 ± 17 Ma reveal a
134 Paleoproterozoic age for the protolith of the Fagervik gneisses (Kirkland et al., 2008b). Partial
135 melting and emplacement of granitic intrusions in the Fagervik complex occurred at 1796 ± 3
136 Ma. These ages are consistent with the origin of the Fagervik complex as Baltica basement
137 (Kirkland et al., 2008b). The depositional age of the Sværholt succession is bracketed by
138 detrital U-Pb zircon ages between 1030 and 980 Ma. The sediments were affected by late
139 Grenvillian metamorphism, deformation and partial melting at 980-960 Ma (Kirkland et al.,

140 2006a; 2007b). The contact between the two units is probably of tectonic origin, as supported
141 by recent studies on zircon provenance (Kirkland et al., 2007b, 2008b).

142 The upper nappe is composed of paragneisses and metasediments of the Sørøy succession,
143 which includes the Eidvågeid series (dominated by migmatitic paragneisses), the Klubben
144 psammities, and the Storelv schists (Kirkland et al., 2005). The Sørøy succession was deposited
145 between 910-840 Ma (Kirkland et al., 2007b), and was deformed, metamorphosed and intruded
146 by granitic melts during the Porsanger Orogeny at c. 850-820 Ma and during the Snøfjord event
147 at c. 710 Ma (Kirkland et al., 2006a, 2006b, 2007b; Corfu et al., 2007; Gasser et al., 2015). The
148 Sørøy succession was also intruded and locally migmatized and deformed between 580-520
149 Ma by the Seiland Igneous Province (SIP), a series of mafic to ultramafic and alkaline
150 intrusions related to the rifting of the Iapetus Ocean (Daly et al., 1991; Elvevold et al., 1994;
151 Roberts et al., 2006; Menegon et al., 2011).

152 The exact timing and the origin of the juxtaposition between the lower and the upper nappe of
153 the KNC are still debated (e.g. Corfu et al., 2007). It has been suggested that the original
154 unconformity (now tectonized) between the underlying Sværholt succession and the overlying
155 Sørøy succession is preserved on Hjelmsøy (Kirkland et al., 2008b), and that the juxtaposition
156 was pre-Caledonian, as both successions were affected by the c. 710 Ma Snøfjord
157 tectonomagmatic event (Kirkland et al., 2006a).

158 The internal structure of the KNC has been traditionally described to result from several
159 discrete deformation stages ("5 or 6 folding events" of Zwaan and Roberts, 1978; Rhodes and
160 Gayer, 1977; Rice, 1998) during Neoproterozoic and Caledonian orogenesis. Gayer et al.
161 (1985) and Kirkland et al. (2006b) identified 5 deformation stages ($D_1 - D_5$) based on fold
162 geometry and orientation, and on crosscutting relationships between fabrics and granitic
163 intrusions of known age. Whilst D_1 is only very rarely preserved, D_2 is widely preserved in

both the lower and upper nappe of the KNC (Kirkland et al., 2006a). U-Pb zircon dating of magmatic intrusions, and their structural relationship with the D₂ deformation fabrics, suggest that D₂ deformation was diachronous and occurred at different times within each nappe of the KNC (Kirkland et al., 2006a). D₃ is generally referred to as the main Caledonian deformation stage in the KNC, which resulted in the formation of the regional foliation during the collisional stage of the orogeny (i.e. the Scandian stage: Roberts, 2003; Gasser et al., 2015; Faber et al., 2019). D₄ and D₅ represent late-Caledonian crenulation and gentle folding of the main regional foliation.

However, regional correlation of structures and their attribution to regional scale, discrete deformation stages is difficult without accurate geochronological and petrological constraints on the age and metamorphic conditions of fabric development (Fossen et al., 2019). In addition, several of the traditionally described “deformation stages” deduced from the different fold orientation and from the superposition of fold geometries may effectively result from progressive deformation during a single tectonic event (Fossen et al., 2019). Therefore, in the present work, the observed structural features are first described in terms of their geometry, orientation and metamorphic mineral assemblages, and then their possible allocation to regional-scale tectonic events is discussed.

3. Methods

Petrographic and microstructural analysis were performed using polarized light- and scanning electron microscopy (SEM) on oriented polished thin section cut parallel to the stretching lineation and perpendicular to the foliation. SEM analysis was conducted with a JEOL 6610

SEM at the Electron Microscopy Centre of the University of Plymouth. Electron microprobe analyses were performed at the Open University (Milton Keynes, UK) and at the Department of Lithospheric Research of the University of Vienna (Austria) with a WDS CAMECA SX 100 equipped with five WDS spectrometers.

Sample preparation and bulk chemical XRF analyses were performed at the Consolidated Radio-isotope Facility (CoRIF) at University of Plymouth with a WDS XRF PANalytical Axios Max spectrometer (fused bead prepared using a PANalytical Eagon 2 fusion system).

P-T conditions of selected samples were estimated by calculating phase diagram sections with Perple_X (Connolly, 2005) using the internally consistent thermodynamic database of Holland and Powell (2011). The pseudosection were calculated for the $\text{MnO}_2\text{-Na}_2\text{O-CaO-K}_2\text{O-FeO-MgO-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$ chemical system. Table SM1 reports the list of solid solution models used and the independent end-members with abbreviation from Perple_X. Modal proportion and chemical compositions of solid solutions were defined as follows: (i) albite component of Pl(h) model, $X_{\text{Ab}} = \text{Na}/(\text{Na}+\text{Ca})$; (ii) Mg# of Bi(W), Mica(W), Gt(W): $\text{Mg\#} = \text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ in molar proportions; Ti, Fe^{3+} and Mn components of biotite were neglected; (iii) molar fractions of grossular, spessartine, almandine of garnet as X_{Grs} , X_{Sps} and X_{Alm} components of Gt(W) solid solution and $\text{Mg\#} = \text{Mg}/(\text{Mg}+\text{Fe}^{2+}+\text{Mn})$. Amphibole-plagioclase geothermobarometry was applied to pairs of amphibole and plagioclase grains in contact with each other to estimate the temperature and pressure of fabric development using the methods of Holland and Blundy (1994) and Bhadra and Bhattacharya (2007).

In-situ UV Laser $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology was carried out at the Open University, UK, on polished 200 μm -thick polished sections from samples 240 and 251. Analyses were carried out on a Nu Instruments Noblesse Mass Spectrometer coupled to a Photon Machines Excite 193 nm laser. Analysis involved ablation of 65 μm to 85 μm spots in the biotite and muscovite

grains, after which gases were cleaned with 2 SAES AP-10 getters running at 450°C and room temperature. Detailed description of analytical conditions and data processing for all analytical techniques can be found in the Supplementary Material.

4. Field observations: the Kalak Nappe Complex on Kvaløya

4.1. Lithologies and tectonostratigraphy

The map of the study area (Fig. 1b) is a revision of existing map material (1:50000 Hammerfest sheet: Jansen et al., 2012) based on our field observations. The lower nappe on Kvaløya (Fig. 1b-c) is mainly composed of: (i) the Fagervik gneissic complex, (ii) metasediments of the Sværholt succession (metapsammites/metapelites), and (iii) an undifferentiated banded gneiss unit, composed predominantly of high-grade metapelites, amphibolites and metapsammites. The Fagervik complex (Fig. 2a-b) is characterized by distinctive banded quartzo-feldspathic gneisses intercalated with amphibolites and with rare ultramafic layers and pods. Quartzo-feldspathic gneisses include paragneisses, and orthogneisses, locally showing mylonitic fabrics. Up to 2 metres thick bands of garnet-rich amphibolites are common (Figs. 2b, SM1a). The metasediments of the Sværholt succession are dominated by metapsammites and minor biotite-rich metapelites (Fig. SM1b). The banded gneiss unit has a distinctive rusty colour on outcrop and includes different lithologies arranged in bands that range in thickness from < 5 cm to 1-2 m (Fig. 2c). The most common lithologies of this unit are quartzites, psammites, high-grade (aluminosilicate-bearing) micaschists, migmatitic garnet- and biotite-rich schists, and garnet-rich amphibolites (Fig. SM1c). The banded gneiss unit is laterally discontinuous, and it is observed at both contacts between the lower- and the upper nappe (Fig. 1b).

The Fagervik complex is the lowermost unit of the area and represents the base of the lower nappe. We grouped the “rusty” banded gneiss unit together with the Fagervik complex, based on the occurrence of distinctive layers of garnet amphibolites of similar thickness in the two

units (Fig. SM1a,c), and on the consistent structural style displayed by all lithologies (see next chapter). Furthermore, the Fagervik gneisses and the banded gneiss units show a strong lithological affinity with the Fennoscandian (Baltica) basement, such as the West Troms Basement Complex as described in Bergh et al. (2014) and Gee et al. (2017).

In the study area, the upper nappe is dominated by the migmatitic paragneisses of the Eidvågeid Series (Rice and Roberts, 1988; Rice, 1990; Corfu et al., 2007; Gasser et al., 2015; Faber et al., 2019), with minor bands of psammites tentatively correlated with the Klubben psammite (Fig. 1b). Stromatic migmatites are defined by up to 10-20 cm thick quartzo-feldspatic leucosomes alternating with biotite-sillimanite-rich melanosome. The migmatites contain large clusters and individual crystals of dark pink garnet (up to 10 cm in diameter), typically surrounded by thin (< 1 cm thick) feldspar-rich rims. The unit also contains intercalated minor bands of calcsilicates and marbles, as well as several pegmatitic intrusions predominantly discordant to the stromatic banding. Towards the boundary with the lower nappe, migmatitic paragneisses make transition to muscovite-rich paragneisses and minor schists. These rocks contain up to 2-3 cm long mica-fish of muscovite and dark pink garnet porphyroclasts. The stromatic migmatites and the muscovite-rich paragneisses are intercalated with more psammitic bands ranging in thickness from ≤ 5 m to about 50 m.

4.2. Structural domains

Along the analysed NW-SE cross section in Kvaløya, the KNC can be subdivided in three main areas, where the lower- and the upper nappe show different structures and internal deformation features (Fig. 1b, d). In northern Kvaløya, the lower nappe is characterized by NE-SW trending folds and by subhorizontal NE-SW trending stretching lineations parallel to fold axes (Lower nappe North, Fig. 1d). The upper nappe is exposed in central Kvaløya, where foliations are

generally also striking NE-SW and contain NE-SW-trending stretching lineations (Upper nappe, Fig. 1d). The lower nappe occurs again in southern Kvaløya, where it is characterized by a dominant shallowly NW-dipping foliation that envelops low-strain domains where NW-SE-trending upright folds are observed (Lower nappe South, Fig. 1d). The contact zone between the upper nappe and the lower nappe is exposed near the localities of Rypefjord (northern contact zone, NCZ in Fig. 1b) and, more continuously, at Grotnes (southern contact zone, SCZ in Fig. 1b). The SCZ develops over a distance of 1 km and consists of a high strain zone with a foliation shallowly dipping to the NW. Our observations and analysis of the contact zone predominantly come from this area.

4.3 Structures in the lower nappe

In the lower nappe the main foliation is defined by a gneissic banding (S_G), which is folded by upright, NE-SW trending, open to tight mesoscopic folds that form the dominant structural pattern of the lower nappe in northern Kvaløya (Figs. 2a-b, SM1a-b). No axial plane foliation is associated with upright folds. Elongated trails of white mica and amphibole, and feldspar- and quartz-rods, delineate a fold-axis parallel stretching lineation (Figs. 1d, 2b). The average orientation of the stretching lineation is $06^\circ/045^\circ$ (plunge/trend), and this will be referred to as *orogen-parallel* stretching lineation hereafter (Fig. 1d). This stretching lineation is locally associated with a dextral kinematics (Fig. 2d).

Locally, upright folds display a weak top-to-SE tilting (see the dispersion of poles to axial plane in Fig. 1d; Figs. 2a, SM1b). ANW-SE-trending stretching lineation locally develops on NW-dipping fold limbs (average orientation: $39^\circ/310^\circ$; see scatter red dots in stereonet Lower Unit North in Fig. 1d). Mesoscale fold asymmetry is consistent with the occurrence of a regional

scale SE-vergent synform (β -axis: $04^\circ/247^\circ$; fold axial plane: $44^\circ/333^\circ$, dip/dip direction) (Fig. 5a-b; Sturt et al., 1978; Akselsen, 1982).

On southern Kvaløya, the lower nappe is characterized by a dominant shallowly NW-dipping foliation (S_{main} : $27^\circ/312^\circ$), wrapping around local low-strain domains (Figs. 1d, 3a-e). The main foliation locally shows mylonitic fabric, with the development of sheath folds (Fig. 3b), and kinematic indicators indicating top-to-SE transport (Fig. 3c). Within low-strain domains, NW-SE-trending upright folds with subhorizontal fold axis are preserved and are similar to the upright folds cropping out on northern Kvaløya. However, upright folds on southern Kvaløya are oriented almost normal (fold axis orientation: $10^\circ/340^\circ$) to the upright folds on northern Kvaløya (Fig. 1d). In the low-strain domains, Type-3 refolded fold geometries (Ramsay, 1962; Grasemann et al., 2004) are observed. The extent of refolding of upright folds within low-strain domains varies from gentle (with the development of crenulated upright folds with subhorizontal axial planes: Fig. 3d) to tight (with the development of tight, recumbent folds: Fig. 3e). In all cases, the fold axis of re-folded folds is almost parallel to the stretching lineation developed on the main foliation planes (fold axis: $15^\circ/322^\circ$; stretching lineation: $26^\circ/329^\circ$, Fig. 1d) and defined by elongated trails of white mica, amphibole and biotite, and by rods of quartz and feldspar. Thus, the re-folded folds in southern Kvaløya can be classified as *shear-parallel* folds (Xypolias et al., 2013). In summary, the main foliation is axial planar to re-folded folds and contains a NW-SE trending stretching lineation associated with a top-to-SE kinematics (Figs. 1d, 3b-c). This stretching lineation in Southern Kvaløya is hereafter referred to as *orogen-perpendicular* lineation.

4.4. Structures in the upper nappe

The NNE-SSW-trending stromatic migmatite banding defines the oldest fabric in the Eidvågeid Series (S_{mig}). It is mostly steeply dipping, but the dip angle can vary to define small and large-scale NE-SW trending folds (Figs. 1d, 4a). Mylonitic shear zones are frequent in the Eidvågeid migmatites, and appear as fine-grained, light purple rocks with cm-sized euhedral dark pink garnets surrounded by quartzo-feldspathic rims (Fig. 4b). The main mylonitic foliation S_m (shallowly NNW-dipping) is a mm-cm scale compositional banding between alternating biotite-sillimanite-rich layers and quartzo-feldspathic domains (Fig. 4b). S_m contains a NE-SW-trending stretching lineation L_m (parallel to the axis of the NE-SW trending folds) defined by rodding of feldspar and quartz and by elongate trails of sillimanite. In relatively low-strain domains, S_m represents a crenulation cleavage foliation from folding of the S_{mig} in the stromatic migmatites, locally defining an anastomosing pattern of shear zones with a strong stretching lineation (“coaxial network” of shear zone of Fossen and Cavalcante., 2017) (Fig. 4c). No consistent systematic shear sense indicators have been observed in the mylonitic shear zones, and both dextral and sinistral kinematics exist.

4.5. The Contact Zone

The NCZ between the lower and the upper nappe dips to the NW from shallowly to steeply and juxtaposes a sequence of banded gneisses with the muscovite-rich Eidvågeid paragneisses (Fig. 1b). This geometry results from parasitic folding to the regional-scale SE-vergent synform (Fig. 5a-b). The stretching lineations are invariably subhorizontal and oriented NE-SW in both units, parallel to the fold axes in the area (Fig. 1d).

The SCZ (Fig. 1b) is characterized by a sequence of different lithologies that includes, from north to south: (i) Eidvågeid migmatites with a mylonitic foliation (S_m), intercalated with psammitic layers; (ii) fine-grained banded mylonites with metapelitic Grt + Wm + Sill layers alternating with amphibolite bands, locally including symmetric boudins of pegmatites; (iii) muscovite-rich Eidvågeid paragneisses with large (up to 3 cm) Wm fishes and dark pink garnet; (iv) micaschists, amphibolites and garnet amphibolites presumably belonging to the banded gneiss unit. Foliations are consistently shallowly NW-dipping in the southern contact zone ($27^\circ/311^\circ$). Lithology (i) display the *orogen-parallel* L_{sm} lineation. Lithology (ii) marks the sharp onset of the occurrence of *orogen-perpendicular* NW-SE trending lineation associated with top-to-SE kinematic indicators (lineation: $26^\circ/329^\circ$; Figs. 1d, 4d-e). The stretching lineation is subparallel to the fold axis preserved in low strain domains between mylonitic high-strain zones (Fig. 3a). Lithology (ii) is interpreted as a tectonic sliver of the lower nappe incorporated into the original contact zone between the two nappes.

5. Microstructure and P-T conditions of fabric development

Based on the structural and tectonostratigraphic constraints derived from the field observations, we selected the following samples for the determination of the P-T conditions of fabric development (Figs. 1b and 5a-b):

- Sample 360 (marked as 1), representative of the pre-Caledonian main fabric in the ‘rusty’ banded gneiss unit of the Fagervik complex (lower nappe). The foliation is oriented $42^\circ/304^\circ$ and contains a subhorizontal NE-SW stretching lineation ($05^\circ/036^\circ$).

- Sample 240 (marked as 2), representative of the pre-Caledonian S_m fabric in the mylonitic Eidvågeid Series (upper nappe). S_m in sample 240 is oriented $40^\circ/311^\circ$ and contains a stretching lineation oriented $03^\circ/042^\circ$.
- Sample 251 (marked as 3), representative of the main fabric associated with Caledonian top-SE deformation in the muscovite-rich Eidvågeid paragneisses (upper nappe - SCZ). The main foliation is oriented $12^\circ/307^\circ$ and contains a stretching lineation oriented $24^\circ/304^\circ$.
- Samples 372 and 367 (marked as 4 and 5, respectively), representative of the main fabric associated with Caledonian top-SE deformation in the Fagervik complex (lower nappe). The main foliation in sample 372 dips $35^\circ/306^\circ$ and contains a stretching lineation oriented $24^\circ/356^\circ$. The main foliation in sample 367 is oriented $25^\circ/320^\circ$ and the lineation plunges shallowly to the NW ($17^\circ/341^\circ$).

Sample locations are reported in Table SM2. XRF bulk rock compositions are reported in Table 1. Mineral compositions obtained from EMP analysis are reported in Table 2. P-T pseudosections were calculated for the metasediment samples 240, 251, and 360. Amphibole-plagioclase geothermobarometry was applied to constrain the conditions of fabric re-equilibration in amphibolites from the Fagervik complex (samples 367 and 372). Results are reported in Table 3. Mineral abbreviation after Whitney and Evans (2010).

5.1. Main foliation with top-to-NE kinematics in the lower nappe

The mineral assemblage consists of quartz (Qtz), plagioclase (Pl), K-feldspar (Kfs), biotite (Bt), white Wm (Wm), sillimanite (Sill), garnet (Grt), titanite (Ttn) (Fig. 6a). The main Bt + Wm foliation envelops isolated asymmetric Wm fish and Kfs porphyroclasts that indicate a dextral sense of shear (Fig. 6a). Relict grains of sillimanite elongate parallel to the foliation are replaced by white Wm (Fig. 6b). Recrystallized Pl in the matrix has a homogeneous

composition (Ab₇₉₋₈₁). Mg# in Bt ranges between 0.46 and 0.49. Mg# and Si content of Wm in the recrystallized matrix ranges between 0.62-0.65 and 6.29-6.35, respectively. Wm fish display homogeneous composition (Si=6.27 a.p.f.u., Mg#=0.60). Idioblastic Grt shows homogeneous composition (Alm₇₅₋₇₇ Grs₇₋₈ Prp₁₂₋₁₄ Sps₂; Mg# = 0.14-0.16) and it grows in isolated pockets, showing commonly euhedral rims and Qtz + Ttn + Bt + Sill inclusion-rich cores.

The P-T pseudosection was calculated using a H₂O amount of 1.78 wt%, as obtained from LOI measurement. The phases identified in the sample are not predicted to be stable at any P-T conditions within the investigated range (Fig. 7a). Considering Kfs and Sill porphyroclasts as relict/metastable phases, the stable mineral assemblage should include Qtz + Pl + Wm + Bt + Grt. This mineral paragenesis is stable over a wide range of P-T conditions. However, Pl (X_{Ab}) and Grt isopleths (Mg#, X_{Grs}) suggest that Grt growth occurred at T=500-550°C and P=0.62-0.72 GPa. The stable mineral assemblage at these conditions consists of Qtz + Grt + Bt + Pl + Wm ± kyanite (Ky) ± staurolite (St) (Fig. 7a-b). Ky and St are expected to occur in very low amounts (<2 vol%). Mg# of both Bt and Wm are calculated to be stable at similar pressure conditions but slightly higher temperature. Sill and Kfs are stable together only at higher temperature (>650°C) and pressures <0.7 GPa; where the aluminosilicates content becomes significant (~10 vol%).

5.2. *S_m fabric in the upper nappe: mylonitic Eidvågeid migmatite*

The mineral paragenesis consists of Qtz + Pl + Bt + Grt + Kfs + rutile (Rt) + oxides (Ox) + zircon (Zrn) + monazites (Mnz) (Fig. 6c). The sample displays a coarse-grained (50-100 µm) Qtz + Bt + Kfs mylonitic foliation, with sub-mm-size plagioclase porphyroclasts and garnet

porphyroblasts (Fig. 6c-d). Kfs is mainly observed as interstitial phase forming thin films around Pl and Grt crystals (Fig. 6e). Recrystallized Pl in the matrix has a homogeneous composition (Ab_{61-66}). $\text{Mg\#}$ in Bt ranges between 0.53 and 0.56. Grt shows a homogeneously distributed large inclusions of Qtz, Bt and Rt. Grt rim compositions are slightly enriched in grossular (Alm_{65-74} Grs_{10-16} Prp_{14-19} ; $\text{Mg\#} = 0.16-0.20$) compared to the more pyrope-rich core compositions (Alm_{67-73} Grs_{4-6} Prp_{20-25} ; $\text{Mg\#} = 0.21-0.26$).

P-T pseudosection for sample 240 has been calculated for a constant H_2O amount of 0.51 wt%, as obtained from LOI measurements. The observed mineral paragenesis is stable over a large range of P-T conditions. However, the intersection of Bt, Pl isopleths and the composition of Grt cores suggests the likely stability of this paragenesis at 725-750°C and 0.62-0.83 GPa (Fig. 7c-d). The stable mineral assemblage at these conditions consists of Melt + Qtz + Bt + Pl + Kfs + Grt + Sill. The lack of Wm indicates that deformation occurred at pressure <0.78 GPa. X_{Grs} -rich Grt rims suggest lower temperature and higher pressure conditions for re-equilibration (T~500-700°C, P~0.72-1.08 GPa), although this Grt composition is not stable with the measured compositions of Bt and Pl. Considering a bulk H_2O content of 0.51 wt%, H_2O is not expected to be stable as a free phase in the wide range of P-T conditions modelled here (Figs. 7c-d).

5.3. Main foliation with top-SE kinematics in the upper nappe: muscovite-rich *Eidvågeid* paragneiss

The sample is characterized by a coarse-grained (100 μm) mylonitic matrix with large (up to mm-sized) Wm fish and Grt porphyroclasts/-blasts. The mineral paragenesis consists of Qtz + Pl + Bt + Wm + Grt $\pm$ epidote (Ep) (Fig. 6f). Recrystallized Pl in the matrix has a homogeneous

composition ($X_{Ab} = 0.69-0.75$). Bt Mg# ranges between 0.38 and 0.42. Wm occurs as mm-size Wm fish or dispersed in the foliation, where it locally forms intergrowths with Bt (Fig. 6g). Wm shows a continuum spread in composition in the range Si = 6.09-6.34 a.p.f.u. and Mg# = 0.50-0.60 (Fig. 10e) with Wm fish compositions showing lower Si and Mg# (Si = 6.09-6.14 a.p.f.u. and Mg# = 0.50-0.53). Grt shows a core-rim zoned texture: (i) the core is rich of fine-grained Qtz inclusions, (ii) the inclusion-free rim displays euhedral facets. However, the composition of Grt is fairly homogeneous from core to rim (Alm₅₉₋₆₅ Grs₂₃₋₃₀ Prp₆₋₇; Mg# = 0.09-0.10).

The P-T pseudosection has been calculated at H₂O-saturated conditions, as results from preliminary T-M_{H₂O} pseudosection calculations (not reported here) have shown that the H₂O content derived from LOI measurements is larger than the amount of H₂O required to saturate the system. The assemblage Qtz + Bt + Pl + Grt + Wm + H₂O is stable over a wide range of P-T conditions between 550°C and 750°C and < 0.4 – 1.2 GPa. Bt Mg#, Pl X_{Ab} , Wm isopleths for Mg# and Si and Grt composition constrain the deformation conditions at 600-650°C and 0.8-0.9 GPa (Fig. 7e-f).

5.4. Main foliation with top-SE kinematics in amphibolites from the lower nappe

Sample 372 has a mylonitic fabric defined by alternating bands of amphibolite and metapelite. The amphibolite paragenesis consists of amphibole (Amp) + Pl + Bt + Ttn + Ep + Grt + Qtz ± Cpx (Fig. 8b). Cpx is mainly observed as rare relict phase. Grt + Bt + Ep paragenesis is mainly observed along amphibolite selvages in contact with metapelitic layers (Fig. 8b). Two generations of Amp have been identified based on different compositions and textures. Coarse Amp₁ porphyroclasts show a fairly homogeneous composition (Mg-hornblende; Si=6.85-7.01 a.p.f.u.; Mg#=0.68-0.7; low Al₂O₃ content). Amp₁ porphyroclasts are mantled by Amp₂ grains with lower Si and Mg# (K-Fe-pargasitic hornblende; Si=6.2-6.4; Mg#=0.58-0.61; high Al₂O₃

content). Recrystallized Pl₂ has a homogeneous composition of X_{Ab}=0.65. A few grains, possibly belonging to a former generation of Pl₁, have a slightly An-rich composition of X_{Ab}=0.57. Pl₁ and Pl₂ grains do not show any systematic textural relationship, and they are both occurring in the fine-grained amphibolite matrix. Amp-Pl geothermobarometry calculated on Amph₂-Pl₂ pairs yields T= 670°C ± 20 °C and P=0.98 GPa ± 0.04 GPa (Table 3).

Sample 367 is an amphibolite from tight- to isoclinal shear-parallel folds with top-to-SE sense of shear in southern Kvaløya (Fig. 3c). The mineral paragenesis consists of Amp (Si= 6.31-6.53 a.p.f.u.; Mg#= 0.57-0.63) + Pl (X_{Ab}=0.81-0.88) + Qtz + Ep + Ttn ± Rt (Fig. 8d-e). BSE images indicate that Amp is rather homogeneous in composition and does not show any core-rim zoning (Fig. 8e). Pl usually shows darker rims along grain boundaries, fractures and cleavage planes, characterized by porous aggregates of Ab-rich plagioclase (Pl₂, X_{Ab}=0.95) + Kfs + Chl (Fig. 8f). Coarse Ep shows a zoning pattern, with Fe-rich cores. Amp – Pl geothermobarometry applied to Amp – Pl mineral pairs yields consistent P-T conditions of metamorphic re-equilibration at T=650°C ± 30°C and 0.77 GPa ± 0.07 GPa.

6. ⁴⁰Ar/³⁹Ar Ages

In-situ UV Laser ⁴⁰Ar/³⁹Ar geochronological measurements were carried out on synkinematic micas on samples of: (1) the mylonitic Eidvågeid migmatite (S_m foliation in the upper nappe, sample 240) (Figs. 4b, 6c, SM2a), and (2) the muscovite-rich Eidvågeid paragneiss (main foliation with Caledonian top-to-SE kinematics in the upper nappe, sample 251) (Figs. 4e, 6f, SM2b-d). In particular, synkinematic Bt was analysed in sample 240; whereas, Bt and Wm were analysed in sample 251. The results are shown in the form of frequency diagrams in Fig. 9a-c and Table 4. The geochronology work was limited to samples of the Eidvågeid series, because the very similar bulk XRF composition between samples 240 and 251 suggests that

the muscovite-rich paragneisses represent the retrograded and hydrated variety of the mylonitic Eidvågeid gneiss. Thus, we attempted to track the timing and P-T conditions of the Caledonian overprint on the Neoproterozoic fabric in samples that we considered representative of originally the same lithological unit.

6.1. Sample 240 - mylonitic Eidvågeid migmatitic gneiss

$^{40}\text{Ar}/^{39}\text{Ar}$ data were collected in-situ from Bt aggregates in strain shadows around garnet porphyroblasts. Biotite shows no significant chemical variation (Fig. 9f). The resulting dates, as shown in the frequency distribution diagram of Fig. 9a, show a rather narrow peak resembling a (left-skewed) normal distribution centred at 423.9 ± 6.5 Ma. The dates range between 551 ± 50 Ma and 372 ± 24 Ma. No relationship between date and biotite microstructure was observed.

6.2. Sample 251 - muscovite-rich Eidvågeid paragneiss

$^{40}\text{Ar}/^{39}\text{Ar}$ data were collected in-situ from Bt and Wm in two different textural positions: (i) fine-grained Wm (<mm-sized) lamellae in the recrystallized matrix, where muscovite is commonly intergrown with Bt (Fig. 6g); (ii) large (mm-sized) Wm fish. The chemical composition of Wm in the two different textural positions is rather different (Fig. 9e). A frequency distribution diagram shows a large spread in dates, ranging from 915 ± 87 Ma to 437 ± 10 Ma, and several scattered peaks (Fig. 9b-c). Fine-grained Bt mats yield the oldest dates (900-800 Ma). Dates between 800-500 Ma were obtained from small grains in the recrystallized matrix and from Wm grains intergrown with Bt. A population of consistently younger dates, showing a well-defined frequency peak around 489 Ma (Fig. 9c), was yielded by coarser Wm lamellae and small 'fish' parallel to the main mylonitic foliation.

488

489 **7. Discussion**

490 *7.1. Structural and metamorphic evolution of the lower and upper nappe*

491 Our structural analysis confirms that the lower- and upper nappe of the KNC underwent two
492 different sequences of deformation and metamorphic events, resulting in the formation of
493 different pre-Caledonian fabrics that were overprinted during the Caledonian continental
494 collision (Fig. 5a). In the following discussion, we present our interpretation of the structural
495 and metamorphic evolution of the two nappes prior and during the Caledonian orogeny.

496 *7.1.1. Pre-Caledonian deformation in the lower nappe*

497 Analysis of sample 360 indicates that the main gneissic banding in the Fagervik complex
498 developed at 500-550°C and 0.7 GPa. As there is no evidence of a dextral fabric in the upper
499 nappe, we consider the dextral fabric in the lower nappe older than 710 Ma (minimum age of
500 the juxtaposition between lower- and upper nappe, Kirkland et al., 2006a). An earlier, higher
501 T fabric is locally preserved as relict grains of Kfs and Sill.

502 The main gneissic banding has then been folded by upright folds without the development of
503 an associated axial plane foliation. The different orientation of upright folds in northern- and
504 southern Kvaløya suggests that upright folding was probably followed by a regional-scale
505 bending of the fabric, and we speculate that this might have occurred during an orocline
506 formation event (Fig. 5a) (see section 7.3.1).

507 The tectonometamorphic history of the lower nappe units has not been addressed in detail so
508 far, although geochronology constraints are abundant (Kirkland et al., 2007a, 2007b). Given
509 the lack of metamorphic constraints on the development of upright folds and the discontinuous

exposure of the lower nappe between northern and southern Kvaløya, attributing the upright folding event either to pre-Caledonian discrete deformation phases or to progressive deformation in a complex regional strain field is rather difficult (Fossen et al., 2019).

This bent structural grain has been sheared during top-to-SE Caledonian thrusting, developing a heterogeneous NW-dipping foliation and different folding geometries in the northern and southern Kvaløya sections of the lower nappe.

7.1.2. Pre-Caledonian deformation in the upper nappe

The stromatic migmatite layering S_{mig} has been sheared and folded during the development of the coaxial shear zone pattern. The S_{m} foliation with *orogen-parallel* stretching lineation in the mylonitic Eidvågeid migmatites developed at 725-750°C, 0.65-0.8 GPa, H₂O-poor (<0.5 wt%) and melt-present conditions (Figs. 7c-d). Microstructures indicative of the former presence of melt during deformation are the Kfs films around Grt porphyroclasts and completely enveloping Pl grains (Fig. 6e, see also Menegon et al., 2011). We interpret these P-T estimates to be representative also of the conditions of S_{mig} formation in the Eidvågeid Series, as the mineral assemblages in S_{mig} and S_{m} are the same. Similar fabrics and microstructures indicative of high-grade, melt-present deformation in the upper nappe have been reported from many other localities of the KNC and related to the ca. 710 Ma Snøfjord event (Akkarfjord in Kvaløya: Corfu et al., 2007; Snøfjord: Kirkland et al., 2006a; Eidet: Gasser et al., 2015), indicating a pre-Caledonian age for the migmatization and mylonitization events and related structures accommodating an overall NE-SW lengthening in the lower crust. Despite the similar orientation of pre-Caledonian lineations in the upper- and in the lower nappe (subhorizontal, NE-SW, Fig. 1d), they are associated with different P-T conditions and with different deformation kinematics (Fig. 10c). This is consistent with the available geochronological constraints that indicate that the two nappes experienced different pre-

Caledonian tectono-metamorphic histories (Kirkland et al., 2005, 2007a, 2007b, 2008b; Corfu et al., 2007, 2011).

7.1.3. Caledonian evolution of the KNC

The main foliation in the lower nappe is kinematically compatible with the mylonitic foliation in the upper nappe observed at the contact zone, both showing top-to-SE kinematics. In the upper nappe, top-to-SE shearing related to Caledonian thrusting was localized exclusively in muscovite-rich Eidvågeid paragneisses. Thus, most of the upper nappe escaped the Caledonian tectonometamorphic overprint. The main foliation in muscovite-rich Eidvågeid paragneisses developed at amphibolite-facies conditions of 550-675°C, 0.8-1.0 GPa. These conditions largely overlap with the results of Amp-Pl geothermobarometry on the main mylonitic fabric developed in the lower nappe (sample 372: 650-700°C, 0.9-1.0 GPa; sample 367: 625-675°C and 0.7-0.8 GPa) (Fig. 10c). Gasser et al. (2015) obtained comparable metamorphic conditions (ca. 600-700°C, 1.0-1.2 GPa) from pseudosection analysis of the top-to-SE Caledonian fabric developed in muscovite-rich paragneisses of the KNC at the Eidet locality (Figs. 1a, 10c), which was tentatively correlated with the Eidvågeid Series. At the Eidet locality, this tectonometamorphic event has been dated at 440-430 Ma by U-Pb dating of syn-kinematic titanite (Gasser et al., 2015) and has been related to the Scandian nappe thrusting stage. As also reported by Gasser et al. (2015), the enrichment in grossular in the Grt rim compositions of the pre-Caledonian fabric in metapelitic rocks from the lower nappe is consistent with a pressure increase during Scandian overprint of the pre-Caledonian fabric (Fig. 7c-d). U-Pb titanite ages of 428.1 ± 1.6 Ma were obtained also from a Grt-Bt amphibolite the SCZ just north of Grotnes in Kvaløya (Corfu et al., 2011), the same locality of our sample 372 from the banded gneiss unit of the lower nappe, in which the main Caledonian foliation developed at 650-700°C and

0.9-1.0 GPa. Thus, we interpret the development of the main NW-dipping foliation in the lower- and upper nappes to represent the Scandian overprint during Caledonian thrusting of the KNC at P of 0.7-1.0 GPa and T of 600-700°C (Figs. 5, 10b-c).

The similarities of XRF bulk compositions and pseudosections between samples 240 and 251 suggest that the muscovite-rich Eidvågeid paragneisses might represent the product of retrogression and hydration of the Eidvågeid migmatites, which deformed under relatively dry conditions during the pre-Caledonian melt-present deformation. Comparing the pseudosection results from sample 240 (Pre-Caledonian S_m fabric in upper nappe) and sample 251 (Caledonian fabric in the upper nappe), we can infer that deformation during Caledonian overprint occurred at H₂O-saturated conditions, therefore probably involving fluid-infiltration in the upper nappe units along inherited pre-collisional tectonic nappe boundaries. Fluid infiltration along tectonic boundaries during Caledonian nappe stacking and metamorphism in the KNC has been suggested by Kirkland et al. (2009) for the explanation of zircon and monazite growth stages in the Hjelmsøy shear zone, and by Gasser et al. (2015) to account for the increased amount of Wm in the Caledonian fabric compared to the pre-Caledonian one in the Sørøy succession.

7.2. Effects of Caledonian metamorphism on $^{40}\text{Ar}/^{39}\text{Ar}$ ages

The mineral paragenesis in sample 240 equilibrated at high-grade ($T > 700^\circ\text{C}$), dry (H₂O-undersaturated) metamorphic conditions in the Neoproterozoic (maximum age of ca. 710 Ma as obtained from U-Pb zircon dating, Corfu et al., 2007; Kirkland et al., 2008b). This age and metamorphic conditions likely represent the crystallization event of the dated biotite grains. The Eidvågeid Series subsequently resided at high-T, lower crustal conditions for at least 200 Ma prior to the Caledonian orogeny (Gasser et al., 2015). Such long-lasting high-T conditions

are theoretically sufficient to completely reset the isotopic system in biotite in an open system where a sink such as a grain boundary fluid is available for the released argon (Skipton et al., 2018). We therefore interpret the $^{40}\text{Ar}/^{39}\text{Ar}$ date of 423.9 ± 6.5 Ma obtained from the mylonitic Eidvågeid sample 240 as relating to the timing of cooling during the late stages of the Caledonian orogeny. This age is comparable within analytical uncertainty with other in-situ $^{40}\text{Ar}/^{39}\text{Ar}$ laser ablation biotite ages determined from paragneisses in the basement units of the Kalak and Magerøy Nappes in Finnmark (Kirkland et al., 2007a). However, we cannot exclude the possibility that contamination from excess radiogenic ^{40}Ar affected sample 240 to some degree during its tectonometamorphic (Caledonian?) history, with the effect of making the yielded date artificially too old (as also discussed by Kirkland et al., 2008a).

The development of the Caledonian fabric in muscovite-rich Eidvågeid paragneisses occurred under amphibolite facies conditions ($T > 550^\circ\text{C}$), at temperatures high enough to completely reset the isotopic system of Ar both in Wm and Bt at these pressures (Harrison et al., 2009; Warren et al., 2012). Importantly, Caledonian metamorphic re-equilibration involved significant fluid influx and hydration of previously dry granulitic rocks. Broad ranges of Wm and Bt $^{40}\text{Ar}/^{39}\text{Ar}$ ages have also been reported from other localities in the KNC on Sværholthavøya and Nordkinnhalvøya ($^{40}\text{Ar}/^{39}\text{Ar}$ laser ablation geochronology; Kirkland et al., 2008a). In that study, a narrow frequency peak of Wm dates occurring around 500 Ma was interpreted by Kirkland et al. (2008a) as a Wm cooling age after a Mid-Late Cambrian tectonometamorphic event. The occurrence of older Bt ages was explained as likely due to contamination from excess radiogenic Ar in Bt from metamorphic fluids. Accordingly, similar conclusions can be drawn considering the broad date ranges reported here. Small Bt and Wm grains might have been contaminated by excess ^{40}Ar , likely related to metamorphic fluids, whereas at least the cores of the larger grains appear not to have been (Warren et al., 2012). This contamination may have occurred at relatively low temperatures ($400 - 450^\circ\text{C}$), or during

a short lived infiltration event: at such temperatures, the Ar isotopic system in Wm is less sensitive to contamination than in Bt (Kirkland et al., 2008a; Warren et al., 2011; Skipton et al., 2018), leading to the very much older ages in Bt compared to Wm. The effect of such contamination seems to be proportional to the amount of metamorphic re-equilibration experienced by the nappes during Caledonian collision. Bt in sample 240 might have been affected by the same fluid-infiltration event, but in a very minor amount as compared to the effect on Bt in sample 251 (which was totally re-equilibrated at Caledonian metamorphic conditions).

Our results strengthen the hypothesis that a significant regional-scale fluid-infiltration event that resulted in micas being contaminated with excess ^{40}Ar , occurred during, or shortly after, peak Caledonian metamorphic conditions were reached in the KNC (Kirkland et al., 2008a). Further geochronological analyses using different isotopic systems are needed to determine whether the obtained dates reflect the age of some regional-scale orogenic process such as metamorphic recrystallization or cooling.

7.3 Structural inheritance in the KNC during Caledonian orogenic shortening

Two puzzling structural features of the KNC in Kvaløya are (1) the different deformation style and fold orientation in the lower nappe in northern- and southern Kvaløya (Figs. 2a, 3d, 5, 10), and (2) the abrupt change in orientation of the pre-Caledonian linear fabrics, from subhorizontal NE-SW trending (*orogen-parallel*) to shallowly NW-plunging (*orogen-perpendicular*) (Fig. 1b, d). Here, we interpret both features to result from the pre-Caledonian bending of the gneissic banding in the lower nappe of the KNC.

7.3.1. *Structural inheritance and the origin of orogen-parallel and orogen-perpendicular lineations*

Different tectonic models have been proposed to explain a similar switch in orientation of the stretching lineation observed elsewhere in the KNC, and underlying (Laksefjord) and overlying (Magerøy) nappes. Models involve either oblique tectonics during late-stage Caledonian collision (Kirkland et al., 2006b), or shearing-related rotation of pre-existing linear fabrics (Rhodes and Gayer, 1977; Williams, 1978; Rice, 1984, 1998). The bending is most evident comparing the orientation of stretching lineations and fold axes in northern Kvaløya and in low-strain domains in southern Kvaløya, where they occur in an *orogen-parallel* and in an *orogen-perpendicular* orientation, respectively (Fig. 10a-b). The change in orientation clearly affects the lower nappe, but it is unclear if (and to what extent) it also affects the upper nappe. A similar switch in orientation of linear fabrics has been already reported from other localities within the KNC, and it has been attributed to the progressive reorientation of the fold axes of pre-Caledonian folds (generally oriented N-S to NE-SW) into the thrusting direction (Ramsay and Sturt, 1973; Rhodes and Gayer, 1977; Williams, 1978; Ramsay, 1979; Rice, 1984, 1987, 1998; Gayer et al., 1985). This reorientation is most evident and localized in the hanging wall of thrust zones and close to high-strain zones in the lowermost portions of the KNC (Zwaan and Roberts, 1978; Rice, 1987, 1998; see also Xypolias and Alsop, 2014). Conversely, in Kvaløya, the change in orientation of linear fabrics is abrupt, occurring close to the SCZ, and persistent throughout the whole investigated km-scale southern section of the nappe. Gradual re-orientation would imply a spread in the orientation of fold axes preserved in different low-strain domains, which is not observed in Kvaløya. Gradual re-orientation would also imply the development of sheath-like folds (Xypolias and Alsop, 2014), which are only locally and rarely observed in high-strain zones in Kvaløya (Fig. 3b). Therefore, we attribute the abrupt switch in orientation of the lineation to a regional-scale bending of the pre-Caledonian gneissic

banding that resulted in the fold axes being oriented subparallel to the Caledonian transport direction in southern Kvaløya (Figs. 1a-b, d). Thus, the Caledonian folds in southern Kvaløya initiated with hinges parallel to the transport direction, and the abrupt change in orientation from *orogen-parallel* to *orogen-perpendicular* lineation reflects a structural inheritance during top-SE shearing of a bended pre-Caledonian structural grain.

We note that regional-scale bending of the schistosity resulting in upright folds trending from ca. NW-SE to ca. NE-SW is common in large-scale outliers of Baltica basement west of the Scandinavian Caledonides in northern Norway, such as in the West Troms Basement Complex (WTBC, Bergh et al., 2010, 2014). Granitoid rocks of ca. 1800 Ma age found in the Fagervik complex (Kirkland et al., 2006, 2008) are common also in the WTBC (Corfu et al., 2003; Bergh et al., 2010). As the Fagervik complex is interpreted as a sliver of Baltic Shield (Kirkland et al., 2008b), we infer that its southeastern transport during the Caledonian nappe stacking involved the overprint of pre-collisional folds trending both parallel and perpendicular to the Caledonian orogeny, which are preserved in e.g. the exhumed Baltica basement of the WTBC.

7.3.2. Structural inheritance vs transpressive shear during thrusting of the KNC

Strain partitioning during oblique continental collision commonly results in the development of distinct lineations related to the partitioning between orogen-parallel shear and orogen-perpendicular thrusting (Dewey et al., 1998; Goscombe et al., 2005; Viola and Henderson, 2010). Generally, sinistral transpressive shear coupled to extensional deformation coeval with the latest stages of thrusting in Late Silurian – Early Devonian time has been widely recognised in the Scandinavian Caledonides (Roberts, 2003), and typically resulted in orogen-parallel folding in the footwall of regional-scale extensional detachments (Chauvet and Séranne, 1994; Krabbendam and Dewey, 1997; Fossen, 2000). N-S to NE-SW trending, roughly *orogen-parallel* mineral lineations and fold hinges have been reported from several Caledonian nappes,

including the Bergsdalen nappe in southwestern Norway (Fossen, 1993), and the KNC itself (Kirkland et al., 2006b). They have been interpreted to result from WNW-directed nappe translation prior to the development of Devonian basins in SW Norway (Fossen, 1993), and from constrictional strain during Scandian lateral escape tectonics (Kirkland et al., 2006b). However, in such a transpressive tectonics scenario, the *orogen-parallel* and the *orogen-perpendicular* lineation should be broadly coeval, develop at similar P-T conditions, and be associated with a dominant strike-slip and reverse dip-slip (top-to-SE) shearing, respectively. The results of our P-T estimates indicate that the *orogen-parallel* dextral shear in the lower nappe occurred under lower conditions than the Caledonian top-to-SE deformation in the same unit (Figs. 10c). Furthermore, neither of the kinematics associated with the *orogen-parallel* stretching lineations in the KNC is consistent with a late-Caledonian sinistral transpressive event.

The syn-collisional buttressing and lateral escape model proposed by Kirkland et al. (2006b) is based on the strain analysis of metaconglomerates with a strong N-S stretching lineation from the Magerøy nappe (structurally above the KNC), and on $^{40}\text{Ar}/^{39}\text{Ar}$ dating of biotite that defines the N-S lineation. This model assumes that the development of *orogen-parallel* and *orogen-perpendicular* lineations occurred at comparable ages and metamorphic conditions in the Magerøy nappe. The KNC on Kvaløya presents *orogen-parallel* lineations oriented NE-SW (different from the N-S, orientation reported from the Magerøy nappe), which (1) developed at different metamorphic conditions in the lower and upper nappes (Fig. 10c), and (2) are associated with distinct kinematics (dextral in the lower nappe vs. coaxial deformation in the upper nappe). Therefore, even though the Magerøy and the KNC nappe were already stacked during the syn-collisional Scandian lateral escape (Kirkland et al., 2006b), there is no evidence in the KNC for the occurrence of such lateral escape tectonics. The lateral escape might have

affected only the overlying Magerøy nappe, suggesting a sort of orogen-scale strain partitioning between nappes.

7.3.3. Structural inheritance and orogen-scale strain partitioning during Caledonian deformation

The upper and the lower units show a different tectonic style during Caledonian overprint. The upper nappe was largely unaffected by Caledonian deformation, except at its southern margin (SCZ), where muscovite-rich Eidvågeid paragneisses are optimally oriented (shallowly NW-dipping) to localise top-to-SE shearing (Fig. 4e). The Caledonian high-strain zone at the southern contact zone represents an internal thrust within the KNC (Fig. 10a-b) and exploits the terrane boundary between the upper and lower nappes (see also Kirkland et al., 2006b).

The hangingwall of the internal thrust (northern and central Kvaløya, Figs. 1b, 5b, 10a-b) extensively preserves pre-Caledonian *orogen-parallel* fabrics, suggesting that the intensity of the Caledonian tectonic overprint was low there. Thus, we interpret northern and central Kvaløya as a Caledonian low-strain domain. The weak Caledonian overprint in the lower nappe resulted in a tilting of the NE-SW-trending upright folds to produce slightly asymmetric SE-verging folds. Caledonian stretching lineations developed only on fold limbs that were progressively tilted from subvertical to NW-dipping, and then optimally oriented for top-to-SE shear localization (Akselsen, 1982). In central Kvaløya, the upper nappe behaved as an orogen-scale “porphyroclast” during Caledonian deformation. This behaviour is typical of lower crustal, dry, granulitic terranes that can survive metastably during the Wilson cycle if they are not infiltrated by aqueous fluids and weakened (Yardley and Valley, 1997; Austrheim, 2013). Indeed, fluid-infiltration, metamorphic re-equilibration and weakening probably occurred at

the boundary between upper- and lower nappe, developing the muscovite-rich Eidvågeid paragneisses, on which Caledonian shearing had preferentially localized.

The Caledonian overprint was more pervasive in the footwall of the internal thrust, towards the foreland. In southern Kvaløya, the pre-Caledonian fabric in the lower nappe was not suitably oriented to localize Caledonian shearing, given that axes of upright folds were parallel to the top-to-SE tectonic transport direction. Caledonian folds initiated with hinges subparallel to the stretching lineation and evolved (Fig. 11a, c), with progressively higher strain, into the development of recumbent folds with a new, Caledonian axial planar foliation with top-to-SE kinematic indicators. Upright folds were progressively vertically flattened with strain (Fig. 11b, d). Flattening and hinge-parallel shearing lead to the development of “curtain folds” (Xypolias et al., 2013) and Type-3 re-folded structures (Grasemann et al., 2004) that progressively evolved into recumbent folds with a shallowly NW-dipping axial plane (Fig. 11e-f). Thus, the pervasive Caledonian foliation in the lower nappe in southern Kvaløya developed as an axial plane foliation from the transposition of previous upright folds. This evolution of fold geometry highlights the strong strain partitioning between the low-strain domains, where pure-shear component is mainly partitioned, and the enveloping Caledonian S_3 foliation, where the top-to-SE simple-shear component is accommodated (Fig. 11g).

8. Conclusions

This study highlights the pivotal role of integrated field, microstructural, petrological and geochronological analysis in untangling the tectonometamorphic history of polyorogenic nappe systems. Geochronological and petrological analysis are fundamental for discerning between pre- and/or syn-collisional fabrics and structures with similar orientation, which might otherwise be related to a common tectonometamorphic event. For example, in the KNC there

is evidence for at least three different deformation events (two pre-Caledonian and one Caledonian) associated with orogen-parallel stretching lineations.

The definition of the tectonometamorphic history and related fabrics in the KNC has clarified how pre-collisional fabrics controlled strain partitioning during Caledonian shortening. The structural character (massive vs layered) and the metamorphic history of the pre-collisional fabrics strongly influenced partitioning of both strain intensity and geometry during Caledonian shortening. The top-to-SE thrusting component of Caledonian general shear was initially partitioned onto inherited, optimally-oriented pre-collisional tectonic boundaries between the upper and lower nappe. These structures were hydrated and weakened during Caledonian shortening and metamorphic re-equilibration. Strain intensity increased towards the south east with the development of suitably-oriented fabric during initially flattening-dominated general shear of the lower nappe in southern Kvaløya.

Fluid-related contamination of excess ^{40}Ar appears to have influenced the dates recorded in synkinematic micas of the Caledonian fabric. Our results and those available in the literature suggest that Arctic Caledonides $^{40}\text{Ar}/^{39}\text{Ar}$ mica dates should be carefully interpreted in relation with their Caledonian metamorphic evolution, since fluid-related radiogenic Ar contamination appears widespread. We suggest that our approach provides a suitable framework for disentangling the complex poly-orogenic tectonometamorphic evolution of lower crustal nappes in the Caledonides and elsewhere. However, further studies involving different geochronological methods are needed to provide more robust temporal constraints.

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Figure Captions

Figure 1: Geological map and structural orientation data obtained from field survey. Geographical coordinate system WGS84. (a) Geographical location and geological map of Finnmark, northern Norway (redrawn from Gayer et al., 1987; Kirkland et al., 2007a, 2008a; Gasser et al., 2015). DTM base layer elaborated from USGS Aster GDEM database (<https://earthexplorer.usgs.gov/>). (b) Tectonostratigraphic column showing the interpreted units belonging to the upper and lower nappes observed in Kvaløya. The Contact Zone (faint wavy curve) is interpreted here as a tectonically re-elaborated tectonic contact. (c) Geological map of Kvaløya. The map shows also the location of analysed samples (encircled numbers from 1 to 5) and the trace of the interpreted cross section shown in Fig. 5b. (d) Equal area, lower hemisphere projection of structural orientation data from the identified structural domains and nappes exposed in Kvaløya; left column reports poles to foliation and lineations; right column reports fold axes and poles to axial plane. Dashed grey great circles represent the orientation of the mean girdle distribution of foliation calculated from lineation distribution. Black dashed great circles represent the average orientation of fold axial plane. Beta-axes and calculated average orientation of linear fabrics are reported (grey-filled squares and triangles for beta/fold-axes and lineations, respectively). Abbreviations: S_G : gneissic banding in the lower nappe; L_{SG} : stretching lineation of the gneissic banding; L_{Smain} : stretching lineation of the NW-dipping main foliation; S_m : mylonitic foliation in the upper nappe; L_{Sm} : stretching lineation on the mylonitic foliation of the upper nappe.

Figure 2: Lower nappe structure in northern Kvaløya. (a) Symmetrical upright folds in the Fagervik banded gneisses on the northern slope of Rypefjell. Field of view: 40 m. (b) Slightly SE-vergent upright fold refolding the main geissic banding in the Fagervik gneisses. The gneissic banding is here defined by the alternation of pegmatitic gneiss layers (Pegm),

1036 paragneisses (Para-gns) and amphibolite (Amph) layers. The hinge zone of an upright fold is
1037 exposed, showing the parallelism between crenulation L_C and stretching L_S lineations. (c)
1038 Typical outcrop of the Rusty Unit on the southern slope of Rypefjell. Note the succession of
1039 cm-thick layers of metapelites, quartzite and a thick layers with mafic composition. On the
1040 right side of the outcrop, it is possible to see the typical “rusty”-like alteration of this unit. (d)
1041 Top-to-NE (dextral) shear-sense indicator (amphibolite lense) in the banded gneiss unit.
1042 Norwegian krone coin for scale. Orientation of filed images is usually vertical, where not
1043 otherwise specified.

1044 **Figure 3:** Lower nappe structure in southern Kvaløya. (a) Sheared and re-folded gneissic
1045 banding (black lines) enveloped by the NW-dipping foliation (white lines) in a pelitic facies of
1046 the banded gneiss unit close to the SCZ. (b) Sheath-like fold geometry (gneissic banding
1047 sheared and re-folded within dominant NW-dipping foliation – white lines) observed in the
1048 fine-grained mylonitic facies of the banded gneiss unit close to the SCZ. (c) Asymmetric
1049 boudinage in a competent amphibolite layer of the Fagervik gneiss complex indicating top-to-
1050 SE shearing along the main foliation (sample 367, locality 4 in Figs. 1b, 5b). (d) Overprinting
1051 fabrics in the Sværholt Psammities (Southern Kvaløya). Inferred top-to-SE kinematic is shown
1052 on the main foliation. A lensoid low-strain domain, preserving at its interior the upright folds,
1053 is enveloped by shallowly NW-dipping foliation. (e) Tight shear-parallel fold in the banded
1054 gneiss unit in the “Southern Contact Zone”. The tightly re-folded and flattened pre-Caledonian
1055 fabric is marked by black lines.

1056 **Figure 4:** Fabrics of the Eidvågeid Paragneisses in the Upper Nappe. (a) Typical outcrop of
1057 the Eidvågeid Migmatitic facies showing the stromatic banding of melanosomes and
1058 leucosomes. (b) Mylonitic facies of Eidvågeid showing the characteristic dark pink garnets. No
1059 clear shear sense indicators are observed. (c) Crosscutting relationships between the subvertical

1060 S_{mig} fabric (dashed white curves) of the migmatitic facies and the subhorizontal S_{m} (solid white
1061 lines) mylonitic facies of Eidvågeid. (d) Outcrop of the muscovite-rich Eidvågeid NW-dipping
1062 foliation overprinting the mylonitic Eidvågeid S_{m} fabric (location close to the SCZ). (e)
1063 Muscovite-rich Eidvågeid showing top-to-SE kinematic indicators (feldspar sigma-clast in
1064 this case).

1065 **Figure 5.** (a) Annotated sketches that summarize the deformation history of the KNC in
1066 Kvaløya inferred from field observations (see text for explanation). (b) Geological cross section
1067 of Kvaløya along the profile A-A' of Fig. 1b and sample locations.

1068 **Figure 6.** Petrography and microstructures of the analysed samples. (a) Optical image (crossed
1069 polarizers) of the microstructure of sample 360 – banded gneiss unit showing top-to-NE
1070 kinematics and orogen-parallel lineations. (b) Detail of the microstructure of sample 360
1071 showing Sill porphyroclasts embedded in white Wm (optical microscope, crossed polarizers).
1072 (c) Optical image (crossed polarizers) displaying the microstructure of sample 240 – Mylonitic
1073 Eidvågeid showing the banding defined by Qtz and Qtz + Kfs + Bt layers embedding Pl
1074 porphyroclasts and Grt porphyroblasts. (d) BSE image of the microstructure of sample 240. (e)
1075 Detail of the microstructure of sample 240 showing thin Kfs layers around Pl porphyroclasts
1076 interpreted as former melt layers (BSE image). (f) Optical image (crossed polarizers) of sample
1077 251 – muscovite-rich Eidvågeid showing Wm fish embedded in Wm + Bt foliation. (g-h) BSE
1078 image of sample 251 microstructure showing the occurrence of Pl porphyroclasts, WM fish
1079 and Wm-Bt intergrowths along the foliation.

1080 **Figure 7.** P-T Phase diagram sections and summary of P-T conditions obtained from
1081 petrological analysis of other outcrop of the KNC. (a) (c) (e) P-T pseudosections for sample
1082 360, 240, 251, respectively, showing the observed stable metamorphic assemblage and the P-
1083 T field (red polygons) refined by isopleths analysis. (b) (d) (f) P-T pseudosections for sample

360, 240, 251, respectively, showing the Mg# and XGrs isopleths adopted in each sample for the P-T conditions refinement. In each diagram are reported the most relevant mineral-in and/or -out reactions and XGrs and Mg# isopleths for garnet. In (c-d), the inferred conditions of formation of Grt rims of sample 240 and relevant X_{Ab} and Bt Mg# isopleths are reported.

Figure 8. Microstructure of amphibolite samples of the banded gneiss and Fagervik Units (a) Sample 372 – Mylonitic facies of banded gneiss unit showing asymmetric Pl porphyroclasts suggesting top-to-SE kinematics. (b) Optical microphotograph of amphibolite sample 372 from the banded gneiss unit (Sample 4 of Fig. 5). (b) SEM-BSE image of the white box reported in (b). (d) Optical microphotograph of amphibolite sample 367 from the Fagervik gneisses (Sample 5 of Fig. 5). (e) SEM-BSE image of the white box reported in (d). (f) BSE image of a detail of the microstructure of sample 367 showing the local nucleation of Ab and Chl.

Figure 9. Linear probability plot of dates resulting from Wm and Bt in-situ $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. Plotted dates have 95% confidence and are presented in ascending order from left to right. Box heights (error bars) are 2σ . Dates presented in blue bars were rejected. (a) Age spectra resulting from in situ analysis on Bt from Mylonitic Eidvågeid S_m fabric. (b) Whole age spectra resulting from in situ analysis on white Wm from muscovite-rich Eidvågeid main fabric. (c) Age spectra of the younger population obtained from in situ analysis on white Wm from muscovite-rich Eidvågeid shown in (b). (d) Age absolute frequency diagram of sample 251 compared to selected age spectra from Kirkland et al. (2008a). (e) Si vs Mg# diagram for Wm of sample 251. (f) Si vs Mg# diagram showing the composition of Bt in sample 251 and 240.

Figure 10. Block diagrams representing the pre- and collisional fabrics in the KNC. (a). Pre-collisional (post-bending) structural setting and fabrics in the KNC. The lower nappe presents the upright symmetric folds with different orientation in northern and southern Kvaløya. The

1108 upper nappe is characterized by the migmatitic and mylonitic fabrics. (b) Structural setting and
1109 fabrics developed during the Caledonian shortening. The block diagram shows the increasing
1110 intensity of strain accommodated toward the foreland. The pre-collisional fabric in the lower
1111 nappe is tilted toward SE in northern Kvaløya; whereas it is flattened and then sheared in
1112 southern Kvaløya. The pre-collisional fabric in the upper nappe is exploited only where it is
1113 favourably oriented along the pre-collisional nappe contact (orange layers). The exploitation
1114 of such pre-collisional contact gave rise to a zone of localized shearing internal to the nappe
1115 during Caledonian shortening. (c) P-T diagram summing up the metamorphic conditions
1116 obtained from this work and compared to the P-T estimates published in the literature for other
1117 outcrops of the KNC (Gasser et al., 2015; Faber et al., 2019). Numbers in parenthesis refers to
1118 the sample (1-5) reported in this work.

1119 **Figure 11.** Development of shear-parallel folds. See text for explanation.

1120

1121 Tables

1122 **Table 1.** Bulk compositions of the rock samples as obtained from XRF analyses and adopted
1123 for pseudosection calculation .

1124 **Table 2.** Mineral phase compositions of the rock samples as obtained from EMP analysis.

1125 **Table 3.** Mineral phase compositions of Amp and Pl as obtained from EMP analysis on
1126 amphibolite samples 372 and 367 with the respective calculated standard deviations. Pressure
1127 and temperature results are reported as obtained from Amp-Pl geothermobarometry applied to
1128 selected Amp-Pl pairs.

1129 **Table 4.** In situ UV laser ablation $^{40}\text{Ar}/^{39}\text{Ar}$ of synkinematic micas analysed in the Samples
1130 240 and 251.

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Sample	360	240	251
SiO ₂	63.91	69.40	66.42
TiO ₂	1.01	1.01	0.80
Al ₂ O ₃	18.55	13.91	14.75
FeO	5.43	5.15	5.82
MnO	0.08	0.10	0.14
MgO	1.60	1.52	1.77
CaO	0.89	2.27	2.20
Na ₂ O	1.49	2.34	2.77
K ₂ O	3.91	2.80	2.83
P ₂ O ₅	0.14	0.09	0.22
Total	97.00	98.59	97.71
LOI	1.74	0.12	0.78
SO ₃	0.003	-0.004	-0.002
V ₂ O ₅	0.018	0.015	0.015
Cr ₂ O ₃	0.008	0.005	0.005
SrO	0.003	0.008	0.009
ZrO ₂	0.038	0.064	0.035
BaO	0.094	0.112	0.076
NiO	0.003	0.003	0.002
CuO	BDL	BDL	0.003
ZnO	0.014	0.008	0.018
PbO	0.004	0.009	0.006
HfO ₂	0.001	0.001	BDL

Unit	Lower Nappe (North) - Rusty Unit				Upper Nappe - Mylonitic Eidvågeid				Upper Nappe - Wm-bearing Eidvågeid			
Sample	1 - 360				2 - 240				3 -251			
Mineral phase	Pl	Bt	Wm	Grt	Pl	Bt	Grt (core)	Grt (rim)	Pl	Bt	Wm	Grt
Number of point analysis	8	10	14	10	18	29	8	19	16	19	50	9.00
Component												
Na ₂ O	9.30	0.14	0.53	0.00	7.41	0.15	0.07	0.06	8.52	0.11	0.31	0.09
MgO	0.00	9.94	1.02	3.53	-0.02	10.73	5.82	4.32	0.01	7.74	1.42	1.85
Al ₂ O ₃	23.28	18.07	33.93	21.07	25.50	18.31	21.64	21.65	23.74	17.62	32.31	21.51
SiO ₂	63.12	36.12	47.56	37.59	59.39	36.38	37.76	37.62	61.95	35.92	47.79	37.43
K ₂ O	0.03	8.21	9.63	-0.02	0.22	9.81	0.00	0.00	0.27	9.27	10.31	0.00
CaO	4.46	0.04	-0.01	2.66	7.24	0.04	1.66	4.81	5.16	0.04	0.01	9.52
TiO ₂	-0.02	2.23	1.21	0.05	0.01	3.85	0.03	0.02	0.00	3.67	1.11	0.05
Cr ₂ O ₃	-0.05	0.02	-0.03	0.03	0.00	0.06	0.00	0.00	0.00	0.02	0.02	0.00
Mno	-0.04	0.00	-0.04	1.10	0.00	0.02	0.90	0.87	0.00	0.13	0.00	1.66
FeO	0.02	19.60	1.10	34.71	0.05	15.98	32.56	30.95	0.06	20.49	1.90	28.45
Totale	100.08	94.35	94.90	100.70	99.79	95.33	100.44	100.31	99.71	94.99	95.17	100.55
Si	2.79	5.51	6.30	3.00	2.65	5.45	2.97	2.97	2.75	5.51	6.37	2.97
Ti	0.00	0.26	0.12	0.00	0.00	0.43	0.00	0.00	0.00	0.42	0.11	0.00
Al	1.21	3.25	5.30	1.98	1.34	3.23	2.01	2.02	1.24	3.18	5.08	2.01
Cr	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Fe ²⁺	0.00	2.50	0.12	2.31	0.00	2.00	2.15	2.05	0.00	2.63	0.21	1.89
Mn	0.00	0.00	0.00	0.07	0.00	0.00	0.06	0.06	0.00	0.02	0.00	0.11
Mg	0.00	2.26	0.20	0.42	0.00	2.40	0.68	0.51	0.00	1.77	0.28	0.22
Ca	0.21	0.01	0.00	0.23	0.35	0.01	0.14	0.41	0.00	0.01	0.00	0.81
Na	0.80	0.04	0.13	0.00	0.64	0.04	0.01	0.01	0.25	0.03	0.08	0.01
K	0.00	1.60	1.63	0.00	0.01	1.87	0.00	0.00	0.73	1.81	1.75	0.00
Totale	5.01	15.43	13.81	8.01	5.00	15.44	8.02	8.02	4.98	15.38	13.89	8.03
Mg#		0.47	0.62	0.15		0.43	0.24	0.19		0.32	0.57	0.10
X _{Ab}	78.90				64.12				73.72			
X(Prp)				13.82			22.55	16.85				7.22
X(Alm)				76.26			70.83	67.73				62.36
X(Sps)				2.44			1.98	1.94				3.68
X(Gr _s)				7.48			4.64	13.48				26.74

1141 **Table 3.**

Sample	372		367	
Amphibole	Amp₂		Amp	
	N=11	St Dev	N=28	St Dev
SiO ₂	42.35	0.36	42.96	0.46
TiO ₂	0.93	0.07	0.65	0.32
Al ₂ O ₃	15.30	0.35	12.38	0.43
FeO*	13.07	0.38	16.77	0.26
MgO	10.41	0.31	9.98	0.24
MnO	0.05	0.01	0.31	0.02
CaO	12.07	0.08	11.12	0.21
Na ₂ O	1.37	0.05	1.97	0.16
K ₂ O	1.47	0.09	0.75	0.06
Sum	97.02	0.20	97.10	0.27
Plagioclase	Pl₂		Pl	
X _{Ab}	0.63	0.03	0.84	0.02
X _{An}	0.37	0.03	0.16	0.02
T(°C)	670	13	644	16
P(kbar)	0.98	0.03	0.77	0.04

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	⁴⁰ Ar	± 1σ	³⁹ Ar	± 1σ	³⁸ Ar	± 1σ	³⁷ Ar	± 1σ	³⁶ Ar	± 1σ	⁴⁰ Ar ^a / ³⁹ Ar	± 1σ	Age	± 2σ	% error
Sample 240															
Biotite															
J values	bk1a =	9.08530E-05		bk2a =	8.99830E-05										
mcm115 bk1a	3231.53	176.89	128.21	5.97	2.35	0.98	19.90	17.98	-1.41	1.25	25.21	1.81	372.00	24.22	6.51
mcm115 bk1a	6361.78	130.14	230.52	6.53	3.16	0.67	9.05	9.24	-0.50	1.50	27.60	0.96	403.63	12.76	3.16
mcm115 bk1a	9278.25	313.63	334.80	8.65	3.73	0.83	19.15	6.00	-0.58	2.27	27.71	1.18	405.14	15.54	3.84
mcm115 bk2a	26670.60	604.51	947.70	13.79	11.76	1.79	171.60	12.64	5.35	3.19	28.14	0.76	407.23	9.99	2.45
mcm115 bk2a	77870.46	296.92	2757.76	41.13	33.35	1.58	32.96	17.00	7.92	1.68	28.24	0.43	408.45	5.92	1.45
mcm115 bk2a	63351.16	274.78	2234.32	38.21	29.67	1.33	71.48	17.02	6.01	1.42	28.35	0.50	409.97	6.72	1.64
mcm115 bk2a	17360.39	187.26	611.80	12.09	7.72	0.96	41.92	17.05	0.19	1.34	28.38	0.64	410.25	8.46	2.06
mcm115 bk2a	10035.02	190.36	352.96	9.09	5.44	1.02	53.12	17.05	0.86	1.42	28.43	0.91	410.96	11.90	2.90
mcm115 bk1a	1203.43	38.06	42.72	2.79	0.85	0.37	9.89	4.95	-1.58	1.02	28.17	2.05	411.10	26.76	6.51
mcm115 bk1a	2893.92	177.59	101.45	3.79	0.78	0.84	13.70	18.00	-0.74	1.33	28.53	2.05	415.76	26.73	6.43
mcm115 bk2a	32001.32	600.48	1106.36	14.76	16.94	1.91	419.26	12.63	4.62	3.19	28.92	0.67	417.34	8.78	2.10
mcm115 bk2a	94346.06	733.55	3254.13	28.38	45.26	2.22	66.60	12.62	7.14	3.29	28.99	0.34	418.21	4.74	1.13
mcm115 bk1a	14284.85	125.74	497.38	9.33	6.20	1.23	16.35	6.43	0.75	1.13	28.72	0.60	418.28	7.96	1.90
mcm115 bk1a	6455.00	130.39	224.15	6.99	3.96	0.67	23.89	9.23	1.01	1.61	28.80	1.07	419.28	14.03	3.35
mcm115 bk1a	14892.39	310.29	513.53	9.47	7.57	0.84	54.62	6.00	-0.65	2.30	29.00	0.81	421.91	10.63	2.52
mcm115 bk2a	100490.70	455.52	3400.04	30.42	42.40	1.76	34.22	17.00	5.22	1.77	29.56	0.30	425.45	4.25	1.00
mcm115 bk2a	61107.78	229.21	2020.24	21.69	27.05	1.58	102.64	17.02	2.39	1.51	30.25	0.34	434.30	4.80	1.10
mcm115 bk1a	19431.66	70.60	644.42	9.99	9.55	0.80	27.73	4.93	3.11	1.03	30.15	0.48	436.82	6.47	1.48
mcm115 bk1a	11768.46	122.38	382.13	9.14	5.38	1.22	25.46	6.42	1.94	1.18	30.80	0.80	445.07	10.48	2.35
mcm115 bk2a	18467.24	711.76	587.68	4.93	8.17	1.73	1.73	12.64	0.38	3.11	31.42	1.24	449.24	15.81	3.52
mcm115 bk1a	11671.73	123.08	371.39	8.10	6.36	1.27	20.90	6.42	1.92	1.27	31.43	0.76	453.13	9.92	2.19
mcm115 bk1a	17112.09	247.57	527.23	9.72	10.47	0.82	100.57	9.25	13.44	1.95	32.46	0.76	466.20	9.85	2.11
mcm115 bk1a	2443.29	165.62	74.79	2.80	0.50	0.29	-2.02	1.39	-3.15	0.69	32.67	2.53	468.91	32.03	6.83
mcm115 bk1a	13660.16	417.71	400.73	7.90	5.12	0.56	1.73	4.94	1.42	0.97	34.09	1.24	486.73	15.67	3.22
mcm115 bk1a	2263.26	117.10	65.68	3.04	1.09	1.15	-12.47	6.43	-0.31	1.09	34.46	2.39	491.35	29.93	6.09
mcm115 bk1a	3258.07	314.61	82.81	4.13	2.78	0.76	52.34	6.00	1.30	2.32	39.34	4.28	551.34	51.69	9.38
Sample 251															
White mica															
J values	bk3b =	8.86780E-05		bk4b =	8.78080E-05										
mcm115 bk3b	41056.91	937.25	1334.68	20.68	13.04	1.19	21.34	26.87	-13.97	3.82	30.76	0.85	437.06	10.88	2.49
mcm115 bk4b	66927.69	1044.87	2085.36	34.29	25.53	1.35	41.47	34.49	4.93	3.87	32.09	0.73	449.87	9.25	2.06
mcm115 bk4b	14665.49	813.71	438.79	9.17	6.39	1.00	53.83	34.55	-4.22	3.77	33.42	1.98	466.28	24.45	5.24
mcm115 bk4b	56278.05	824.24	1667.37	16.81	18.27	1.24	36.13	34.51	-0.54	3.91	33.75	0.60	470.33	7.65	1.63
mcm115 bk3b	159177.46	974.75	4701.88	32.35	49.54	2.27	32.29	26.80	5.48	4.53	33.85	0.31	475.66	4.38	0.92
mcm115 bk4b	29315.27	815.51	852.57	11.06	9.97	1.11	61.53	34.54	-3.84	3.77	34.38	1.06	478.07	13.06	2.73
mcm115 bk4b	74985.93	836.44	2159.38	32.34	27.37	1.60	45.39	34.45	3.66	3.91	34.73	0.65	482.23	8.18	1.70
mcm115 bk3a	305747.25	924.15	8778.45	74.31	95.19	2.19	30.19	23.28	1.37	2.89	34.83	0.31	487.67	4.40	0.90

mcm115 bk3a	264769.25	551.75	7540.60	35.32	82.89	1.99	47.96	23.29	1.75	2.09	35.11	0.18	491.14	3.08	0.63
mcm115 bk3a	281590.87	809.45	7963.65	45.08	85.05	2.17	17.41	12.39	0.17	2.01	35.36	0.22	494.16	3.49	0.71
mcm115 bk3a	191408.57	571.68	5412.50	37.30	60.21	2.08	127.54	12.39	6.80	2.01	35.36	0.27	494.22	3.90	0.79
mcm115 bk3a	271125.36	1034.19	7628.04	46.05	86.72	2.35	28.36	12.40	1.32	1.85	35.54	0.25	496.40	3.78	0.76
mcm115 bk4b	106629.52	831.94	2943.87	22.62	35.23	1.60	69.81	34.47	6.33	3.91	36.22	0.40	500.36	5.26	1.05

Biotite and biotite/white mica intergrowth

J values	bk3a =	8.91130E-05	bk3b =	8.86780E-05	bk4a =	8.82430E-05									
mcm115 bk3a	51851.66	286.76	1322.80	46.89	15.15	1.03	52.14	14.17	1.80	1.43	39.20	1.41	540.49	16.92	3.13
mcm115 bk4a	19698.77	99.21	451.65	9.80	4.91	0.62	-0.91	7.05	-0.35	1.27	43.61	0.97	587.42	11.45	1.95
mcm115 bk4a	13965.32	92.54	309.11	6.79	3.26	0.47	-0.35	7.04	1.85	1.12	45.18	1.04	605.32	12.08	2.00
mcm115 bk4a	18144.70	223.98	375.30	9.16	3.90	0.68	3.92	6.65	0.13	1.11	48.35	1.32	641.02	15.00	2.34
mcm115 bk4a	3029.93	88.03	61.61	1.94	0.65	0.42	2.31	7.06	-0.31	1.11	49.18	2.11	650.24	23.58	3.63
mcm115 bk3a	4476.46	413.58	91.92	4.52	3.41	1.05	290.23	12.42	2.77	1.78	48.70	5.10	650.28	57.22	8.80
mcm115 bk4a	16214.71	95.00	329.28	7.47	3.65	0.52	9.09	7.06	-1.11	1.25	49.24	1.15	650.98	13.09	2.01
mcm115 bk3a	9148.36	251.46	185.01	6.75	2.17	0.57	44.87	23.35	-1.26	1.83	49.45	2.26	658.65	25.35	3.85
mcm115 bk4a	33380.67	236.05	660.61	10.81	7.07	0.82	-0.53	6.63	0.04	1.19	50.53	0.90	665.21	10.30	1.55
mcm115 bk3a	108384.42	359.08	1990.27	18.86	23.17	1.32	240.01	23.32	2.70	1.95	54.46	0.55	713.70	6.61	0.93
mcm115 bk3b	82468.81	962.76	1508.97	32.35	14.87	1.15	50.15	26.86	-9.23	3.94	54.65	1.33	715.82	14.72	2.06
mcm115 bk4a	7203.05	89.74	130.12	4.95	1.38	0.47	2.09	7.06	0.70	1.13	55.35	2.22	717.57	23.90	3.33
mcm115 bk3a	68926.96	210.81	1240.31	14.99	15.76	0.96	100.81	21.16	2.04	1.83	55.57	0.69	725.74	8.02	1.11
mcm115 bk3a	70480.76	229.34	1250.89	14.03	25.97	1.20	30.75	21.16	0.92	1.83	56.34	0.66	734.02	7.66	1.04
mcm115 bk3a	97414.54	271.97	1728.87	16.90	20.97	1.11	31.41	21.18	1.77	1.76	56.35	0.57	734.03	6.83	0.93
mcm115 bk3a	107507.70	295.27	1902.78	42.12	23.75	1.11	50.57	21.19	-0.81	2.73	56.50	1.26	735.69	13.81	1.88
mcm115 bk4a	42187.30	186.98	714.28	10.96	7.08	0.65	9.86	5.27	0.57	1.07	59.06	0.94	756.79	10.35	1.37
mcm115 bk4a	32621.54	235.31	551.43	9.16	6.44	0.74	16.15	6.65	0.16	1.17	59.16	1.07	757.79	11.62	1.53
mcm115 bk3b	80366.68	519.26	1354.74	52.79	14.92	1.02	44.84	31.61	0.44	2.51	59.32	2.34	765.62	24.84	3.24
mcm115 bk3a	94735.65	301.62	1591.60	15.03	27.40	1.32	71.33	23.33	2.90	1.95	59.52	0.59	767.71	6.97	0.91
mcm115 bk3b	28864.94	429.58	480.34	8.89	5.50	0.81	32.38	31.71	-2.93	2.31	60.09	1.43	773.70	15.27	1.97
mcm115 bk3a	331574.29	794.32	5493.61	29.49	74.34	2.19	118.56	23.31	5.19	2.09	60.36	0.35	776.45	4.87	0.63
mcm115 bk4a	19960.87	116.91	324.90	7.18	3.67	0.51	8.76	7.03	2.51	1.13	61.44	1.40	781.48	14.84	1.90
mcm115 bk4a	28659.64	232.49	466.25	8.58	5.66	0.76	29.42	6.64	-0.15	1.13	61.47	1.24	781.79	13.14	1.68
mcm115 bk3b	46774.61	444.88	756.82	22.55	6.48	0.74	5.07	31.70	-1.52	2.29	61.80	1.93	791.52	20.29	2.56
mcm115 bk4a	26554.57	107.44	423.03	8.64	5.47	0.64	2.27	7.04	2.42	1.17	62.77	1.31	795.21	13.77	1.73
mcm115 bk4a	3768.84	219.48	59.07	2.11	0.71	0.54	14.36	6.65	1.14	0.96	63.80	4.36	805.73	44.51	5.52
mcm115 bk3a	4285.40	413.11	67.61	4.16	1.04	1.06	85.89	12.44	-1.91	1.57	63.39	7.25	807.87	74.55	9.23
mcm115 bk3b	170066.90	991.68	2664.04	20.68	29.56	1.53	70.61	26.85	-3.15	4.03	63.84	0.62	812.49	7.14	0.88
mcm115 bk4a	26073.32	242.44	400.92	3.70	4.09	0.68	-2.54	6.63	-0.58	1.15	65.03	0.85	818.23	9.23	1.13
mcm115 bk3a	593071.79	1790.69	9044.95	44.11	102.68	2.62	107.68	12.40	6.50	2.25	65.57	0.38	830.14	5.06	0.61
mcm115 bk4a	28845.26	227.53	431.37	8.77	4.23	0.67	11.17	6.64	-0.03	1.13	66.87	1.46	836.70	14.98	1.79
mcm115 bk3b	273335.66	1073.61	4073.29	28.45	46.13	1.90	198.87	26.83	7.24	4.18	67.10	0.54	845.65	6.38	0.75
mcm115 bk3b	79109.49	458.16	1178.88	14.77	13.24	0.98	55.41	31.68	1.16	2.40	67.11	0.93	845.67	9.91	1.17
mcm115 bk3a	6669.88	172.28	98.73	3.99	2.39	0.73	323.91	21.20	1.22	1.76	67.56	3.24	850.21	32.70	3.85
mcm115 bk3a	2432.02	171.58	35.31	3.61	-2.26	0.97	17.14	21.23	-0.63	1.70	68.88	8.56	863.43	85.37	9.89
mcm115 bk4a	68908.12	234.43	947.76	19.66	11.04	0.74	15.42	5.26	0.38	1.13	72.71	1.53	894.21	15.23	1.70
mcm115 bk4a	3928.96	167.41	54.00	3.89	0.22	0.30	3.50	5.27	-1.52	0.91	72.76	6.08	894.68	59.10	6.61
mcm115 bk3b	412982.38	1322.26	5699.37	32.35	68.50	1.80	59.45	26.76	11.52	4.13	72.46	0.47	898.76	5.81	0.65
mcm115 bk3b	339370.09	1184.85	4636.05	30.40	52.54	1.80	63.59	26.78	8.14	4.24	73.20	0.54	905.98	6.38	0.70

mcm115 bk4a	17211.40	174.64	230.72	6.43	3.15	0.47	17.83	5.27	-0.72	0.93	74.60	2.21	912.46	21.55	2.36
mcm115 bk3b	3801.43	428.09	51.24	2.43	1.72	0.70	521.46	31.64	3.91	2.46	74.18	9.07	915.51	87.82	9.59

Sample	360	240	251
SiO ₂	63.91	69.40	66.42
TiO ₂	1.01	1.01	0.80
Al ₂ O ₃	18.55	13.91	14.75
FeO	5.43	5.15	5.82
MnO	0.08	0.10	0.14
MgO	1.60	1.52	1.77
CaO	0.89	2.27	2.20
Na ₂ O	1.49	2.34	2.77
K ₂ O	3.91	2.80	2.83
P ₂ O ₅	0.14	0.09	0.22
Total	97.00	98.59	97.71
LOI	1.74	0.12	0.78
SO ₃	0.003	-0.004	-0.002
V ₂ O ₅	0.018	0.015	0.015
Cr ₂ O ₃	0.008	0.005	0.005
SrO	0.003	0.008	0.009
ZrO ₂	0.038	0.064	0.035
BaO	0.094	0.112	0.076
NiO	0.003	0.003	0.002
CuO	BDL	BDL	0.003
ZnO	0.014	0.008	0.018
PbO	0.004	0.009	0.006
HfO ₂	0.001	0.001	BDL

Table 1

Unit	Lower Nappe (North) - Rusty Unit				Upper Nappe - Mylonitic Eidvågeid				Upper Nappe - Wm-bearing Eidvågeid			
Sample	1 - 360				2 - 240				3 - 251			
Mineral phase	Pl	Bt	Wm	Grt	Pl	Bt	Grt (core)	Grt (rim)	Pl	Bt	Wm	Grt
Number of point analysis	8	10	14	10	18	29	8	19	16	19	50	9.00
Component												
Na ₂ O	9.30	0.14	0.53	0.00	7.41	0.15	0.07	0.06	8.52	0.11	0.31	0.09
MgO	0.00	9.94	1.02	3.53	-0.02	10.73	5.82	4.32	0.01	7.74	1.42	1.85
Al ₂ O ₃	23.28	18.07	33.93	21.07	25.50	18.31	21.64	21.65	23.74	17.62	32.31	21.51
SiO ₂	63.12	36.12	47.56	37.59	59.39	36.38	37.76	37.62	61.95	35.92	47.79	37.43
K ₂ O	0.03	8.21	9.63	-0.02	0.22	9.81	0.00	0.00	0.27	9.27	10.31	0.00
CaO	4.46	0.04	-0.01	2.66	7.24	0.04	1.66	4.81	5.16	0.04	0.01	9.52
TiO ₂	-0.02	2.23	1.21	0.05	0.01	3.85	0.03	0.02	0.00	3.67	1.11	0.05
Cr ₂ O ₃	-0.05	0.02	-0.03	0.03	0.00	0.06	0.00	0.00	0.00	0.02	0.02	0.00
Mno	-0.04	0.00	-0.04	1.10	0.00	0.02	0.90	0.87	0.00	0.13	0.00	1.66
FeO	0.02	19.60	1.10	34.71	0.05	15.98	32.56	30.95	0.06	20.49	1.90	28.45
Totale	100.08	94.35	94.90	100.70	99.79	95.33	100.44	100.31	99.71	94.99	95.17	100.55
Si	2.79	5.51	6.30	3.00	2.65	5.45	2.97	2.97	2.75	5.51	6.37	2.97
Ti	0.00	0.26	0.12	0.00	0.00	0.43	0.00	0.00	0.00	0.42	0.11	0.00
Al	1.21	3.25	5.30	1.98	1.34	3.23	2.01	2.02	1.24	3.18	5.08	2.01
Cr	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Fe ²⁺	0.00	2.50	0.12	2.31	0.00	2.00	2.15	2.05	0.00	2.63	0.21	1.89
Mn	0.00	0.00	0.00	0.07	0.00	0.00	0.06	0.06	0.00	0.02	0.00	0.11
Mg	0.00	2.26	0.20	0.42	0.00	2.40	0.68	0.51	0.00	1.77	0.28	0.22
Ca	0.21	0.01	0.00	0.23	0.35	0.01	0.14	0.41	0.00	0.01	0.00	0.81
Na	0.80	0.04	0.13	0.00	0.64	0.04	0.01	0.01	0.25	0.03	0.08	0.01
K	0.00	1.60	1.63	0.00	0.01	1.87	0.00	0.00	0.73	1.81	1.75	0.00
Totale	5.01	15.43	13.81	8.01	5.00	15.44	8.02	8.02	4.98	15.38	13.89	8.03
Mg#		0.47	0.62	0.15		0.43	0.24	0.19		0.32	0.57	0.10
X _{Ab}	78.90				64.12				73.72			
X(Prp)				13.82			22.55	16.85				7.22
X(Alm)				76.26			70.83	67.73				62.36
X(Sps)				2.44			1.98	1.94				3.68
X(Grs)				7.48			4.64	13.48				26.74

Table 2

Sample	372		367	
<u>Amphibole</u>	Amp₂		Amp	
	N=11	St Dev	N=28	St Dev
SiO ₂	42.35	0.36	42.96	0.46
TiO ₂	0.93	0.07	0.65	0.32
Al ₂ O ₃	15.30	0.35	12.38	0.43
FeO*	13.07	0.38	16.77	0.26
MgO	10.41	0.31	9.98	0.24
MnO	0.05	0.01	0.31	0.02
CaO	12.07	0.08	11.12	0.21
Na ₂ O	1.37	0.05	1.97	0.16
K ₂ O	1.47	0.09	0.75	0.06
Sum	97.02	0.20	97.10	0.27
<u>Plagioclase</u>	Pl₂		Pl	
X _{Ab}	0.63	0.03	0.84	0.02
X _{An}	0.37	0.03	0.16	0.02
T(°C)	670	13	644	16
P(kbar)	0.98	0.03	0.77	0.04

Table 3

	⁴⁰ Ar	ε Ĉl	³⁹ Ar	ε Ĉl	³⁸ Ar	ε Ĉl	³⁷ Ar	ε Ĉl	³⁶ Ar	ε Ĉl	⁴⁰ Ar* ³⁹ Ar	ε Ĉl	Age	ε Ĉl	% error
Sample 240															
Biotite															
J values	bk1a =	9.08530E-05		bk2a =	8.99830E-05										
mcml15 bk1a	3231.53	176.89	128.21	5.97	2.35	0.98	19.90	17.98	-1.41	1.25	25.21	1.81	372.00	24.22	6.51
mcml15 bk1a	6361.78	130.14	230.52	6.53	3.16	0.67	9.05	9.24	-0.50	1.50	27.60	0.96	403.63	12.76	3.16
mcml15 bk1a	9278.25	313.63	334.80	8.65	3.73	0.83	19.15	6.00	-0.58	2.27	27.71	1.18	405.14	15.54	3.84
mcml15 bk2a	26670.60	604.51	947.70	13.79	11.76	1.79	171.60	12.64	5.35	3.19	28.14	0.76	407.23	9.99	2.45
mcml15 bk2a	77870.46	296.92	2757.76	41.13	33.35	1.58	32.96	17.00	7.92	1.68	28.24	0.43	408.45	5.92	1.45
mcml15 bk2a	63351.16	274.78	2234.32	38.21	29.67	1.33	71.48	17.02	6.01	1.42	28.35	0.50	409.97	6.72	1.64
mcml15 bk2a	17360.39	187.26	611.80	12.09	7.72	0.96	41.92	17.05	0.19	1.34	28.38	0.64	410.25	8.46	2.06
mcml15 bk2a	10035.02	190.36	352.96	9.09	5.44	1.02	53.12	17.05	0.86	1.42	28.43	0.91	410.96	11.90	2.90
mcml15 bk1a	1203.43	38.06	42.72	2.79	0.85	0.37	9.89	4.95	-1.58	1.02	28.17	2.05	411.10	26.76	6.51
mcml15 bk1a	2893.92	177.59	101.45	3.79	0.78	0.84	13.70	18.00	-0.74	1.33	28.53	2.05	415.76	26.73	6.43
mcml15 bk2a	32001.32	600.48	1106.36	14.76	16.94	1.91	419.26	12.63	4.62	3.19	28.92	0.67	417.34	8.78	2.10
mcml15 bk2a	94346.06	733.55	3254.13	28.38	45.26	2.22	66.60	12.62	7.14	3.29	28.99	0.34	418.21	4.74	1.13
mcml15 bk1a	14284.85	125.74	497.38	9.33	6.20	1.23	16.35	6.43	0.75	1.13	28.72	0.60	418.28	7.96	1.90
mcml15 bk1a	6455.00	130.39	224.15	6.99	3.96	0.67	23.89	9.23	1.01	1.61	28.80	1.07	419.28	14.03	3.35
mcml15 bk1a	14892.39	310.29	513.53	9.47	7.57	0.84	54.62	6.00	-0.65	2.30	29.00	0.81	421.91	10.63	2.52
mcml15 bk2a	100490.70	455.52	3400.04	30.42	42.40	1.76	34.22	17.00	5.22	1.77	29.56	0.30	425.45	4.25	1.00
mcml15 bk2a	61107.78	229.21	2020.24	21.69	27.05	1.58	102.64	17.02	2.39	1.51	30.25	0.34	434.30	4.80	1.10
mcml15 bk1a	19431.66	70.60	644.42	9.99	9.55	0.80	27.73	4.93	3.11	1.03	30.15	0.48	436.82	6.47	1.48
mcml15 bk1a	11768.46	122.38	382.13	9.14	5.38	1.22	25.46	6.42	1.94	1.18	30.80	0.80	445.07	10.48	2.35
mcml15 bk2a	18467.24	711.76	587.68	4.93	8.17	1.73	1.73	12.64	0.38	3.11	31.42	1.24	449.24	15.81	3.52
mcml15 bk1a	11671.73	123.08	371.39	8.10	6.36	1.27	20.90	6.42	1.92	1.27	31.43	0.76	453.13	9.92	2.19
mcml15 bk1a	17112.09	247.57	527.23	9.72	10.47	0.82	100.57	9.25	13.44	1.95	32.46	0.76	466.20	9.85	2.11
mcml15 bk1a	2443.29	165.62	74.79	2.80	0.50	0.29	-2.02	1.39	-3.15	0.69	32.67	2.53	468.91	32.03	6.83
mcml15 bk1a	13660.16	417.71	400.73	7.90	5.12	0.56	1.73	4.94	1.42	0.97	34.09	1.24	486.73	15.67	3.22
mcml15 bk1a	2263.26	117.10	65.68	3.04	1.09	1.15	-12.47	6.43	-0.31	1.09	34.46	2.39	491.35	29.93	6.09
mcml15 bk1a	3258.07	314.61	82.81	4.13	2.78	0.76	52.34	6.00	1.30	2.32	39.34	4.28	551.34	51.69	9.38
Sample 251															
White mica															
J values	bk3b =	8.86780E-05		bk4b =	8.78080E-05										
mcml15 bk3b	41056.91	937.25	1334.68	20.68	13.04	1.19	21.34	26.87	-13.97	3.82	30.76	0.85	437.06	10.88	2.49
mcml15 bk4b	66927.69	1044.87	2085.36	34.29	25.53	1.35	41.47	34.49	4.93	3.87	32.09	0.73	449.87	9.25	2.06
mcml15 bk4b	14665.49	813.71	438.79	9.17	6.39	1.00	53.83	34.55	-4.22	3.77	33.42	1.98	466.28	24.45	5.24
mcml15 bk4b	56278.05	824.24	1667.37	16.81	18.27	1.24	36.13	34.51	-0.54	3.91	33.75	0.60	470.33	7.65	1.63
mcml15 bk3b	159177.46	974.75	4701.88	32.35	49.54	2.27	32.29	26.80	5.48	4.53	33.85	0.31	475.66	4.38	0.92
mcml15 bk4b	29315.27	815.51	852.57	11.06	9.97	1.11	61.53	34.54	-3.84	3.77	34.38	1.06	478.07	13.06	2.73
mcml15 bk4b	74985.93	836.44	2159.38	32.34	27.37	1.60	45.39	34.45	3.66	3.91	34.73	0.65	482.23	8.18	1.70
mcml15 bk3a	305747.25	924.15	8778.45	74.31	95.19	2.19	30.19	23.28	1.37	2.89	34.83	0.31	487.67	4.40	0.90
mcml15 bk3a	264769.25	551.75	7540.60	35.32	82.89	1.99	47.96	23.29	1.75	2.09	35.11	0.18	491.14	3.08	0.63
mcml15 bk3a	281590.87	809.45	7963.65	45.08	85.05	2.17	17.41	12.39	0.17	2.01	35.36	0.22	494.16	3.49	0.71
mcml15 bk3a	191408.57	571.68	5412.50	37.30	60.21	2.08	127.54	12.39	6.80	2.01	35.36	0.27	494.22	3.90	0.79
mcml15 bk3a	271125.36	1034.19	7628.04	46.05	86.72	2.35	28.36	12.40	1.32	1.85	35.54	0.25	496.40	3.78	0.76
mcml15 bk4b	106629.52	831.94	2943.87	22.62	35.23	1.60	69.81	34.47	6.33	3.91	36.22	0.40	500.36	5.26	1.05
Biotite and biotite/white mica intergrowth															
J values	bk3a =	8.91130E-05		bk3b =	8.86780E-05		bk4a =	8.82430E-05							
mcml15 bk3a	51851.66	286.76	1322.80	46.89	15.15	1.03	52.14	14.17	1.80	1.43	39.20	1.41	540.49	16.92	3.13
mcml15 bk4a	19698.77	99.21	451.65	9.80	4.91	0.62	-0.91	7.05	-0.35	1.27	43.61	0.97	587.42	11.45	1.95
mcml15 bk4a	13965.32	92.54	309.11	6.79	3.26	0.47	-0.35	7.04	1.85	1.12	45.18	1.04	605.32	12.08	2.00
mcml15 bk4a	18144.70	223.98	375.30	9.16	3.90	0.68	3.92	6.65	0.13	1.11	48.35	1.32	641.02	15.00	2.34
mcml15 bk4a	3029.93	88.03	61.61	1.94	0.65	0.42	2.31	7.06	-0.31	1.11	49.18	2.11	650.24	23.58	3.63
mcml15 bk3a	4476.46	413.58	91.92	4.52	3.41	1.05	290.23	12.42	2.77	1.78	48.70	5.10	650.28	57.22	8.80
mcml15 bk4a	16214.71	95.00	329.28	7.47	3.65	0.52	9.09	7.06	-1.11	1.25	49.24	1.15	650.98	13.09	2.01
mcml15 bk3a	9148.36	251.46	185.01	6.75	2.17	0.57	44.87	23.35	-1.26	1.83	49.45	2.26	658.65	25.35	3.85
mcml15 bk4a	33380.67	236.05	660.61	10.81	7.07	0.82	-0.53	6.63	0.04	1.19	50.53	0.90	665.21	10.30	1.55
mcml15 bk3a	108384.42	359.08	1990.27	18.86	23.17	1.32	240.01	23.32	2.70	1.95	54.46	0.55	713.70	6.61	0.93
mcml15 bk3b	82468.81	962.76	1508.97	32.35	14.87	1.15	50.15	26.86	-9.23	3.94	54.65	1.33	715.82	14.72	2.06
mcml15 bk4a	7203.05	89.74	130.12	4.95	1.38	0.47	2.09	7.06	0.70	1.13	55.35	2.22	717.57	23.90	3.33
mcml15 bk3a	68926.96	210.81	1240.31	14.99	15.76	0.96	100.81	21.16	2.04	1.83	55.57	0.69	725.74	8.02	1.11
mcml15 bk3a	70480.76	229.34	1250.89	14.03	25.97	1.20	30.75	21.16	0.92	1.83	56.34	0.66	734.02	7.66	1.04
mcml15 bk3a	97414.54	271.97	1728.87	16.90	20.97	1.11	31.41	21.18	1.77	1.76	56.35	0.57	734.03	6.83	0.93
mcml15 bk3a	107507.70	295.27	1902.78	42.12	23.75	1.11	50.57	21.19	-0.81	2.73	56.50	1.26	735.69	13.81	1.88
mcml15 bk4a	42187.30	186.98	714.28	10.96	7.08	0.65	9.86	5.27	0.57	1.07	59.06	0.94	756.79	10.35	1.37
mcml15 bk4a	32621.54	235.31	551.43	9.16	6.44	0.74	16.15	6.65	0.16	1.17	59.16	1.07	757.79	11.62	1.53
mcml15 bk3b	80366.68	519.26	1354.74	52.79	14.92	1.02	44.84	31.61	0.44	2.51	59.32	2.34	765.62	24.84	3.24
mcml15 bk3a	94735.65	301.62</

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Solid solution name	Abbreviation of s.s. model	Abbreviation in the main text	End-members	References
Plagioclase	Pl(h)	Pl	abh, an	Newton et al. (1981)
K-feldspar	San	Kfs	san, abh	Waldbaum and Thompson (1968)
Biotite	Bi(W)	Bt	Ann, Phl, mnbi	White et al. (2014)
White Mica	Mica(W)	Wm	mu, pa, ma1_dqf, cel, fcel, fmu	White et al. (2014)
Epidote	Ep(HP11)	Ep	cz, fep	Holland and Powell (2011)
Garnet	Gt(WPH)	Grt	spss, alm, py, gr, andr_i	White et al. (2007)
Amphibole	cAmph(G)	Amp	Tr, Ts, Parg, Gl, Cumm, Grun, mrbG, Kprg, Tts	Green et al. (2016)
Chlorite	Chl(W)	Chl	daph, f3clin, ames, afchl, clin, mnchl	White et al. (2014)
Staurolite	St(W)	St	mstt, msto, fst, mnst, mst	White et al. (2014)
Cordierite	Crd(W)	Crd	mnocrd, fcrd, crd, hcrd	White et al. (2014)
Chloritoid	Ctd(W)	Ctd	ctdo, fctd, mctd	White et al. (2014)
Clinopyroxene	Cpx(HP)	Cpx	esn, ccrts, cats, jd, acm, hed, di	Holland and Powell (1996); Zeh et al., (2005)

Table SM1

Sample	Unit	GPS Coordinates (UTM WGS84)
1	L.N. Banded gneiss	70°39'17.8"N 23°44'0.5"E
2	U.N Mylonitic Eidvågeid	70°36'17.3"N 23°73'38.2"E
3	U.N. Wm-bearing Eidvågeid	70°34'30.6"N 23°41'31.6"E
4	L.N. Banded gneiss	70°34'45.6"N 23°41'25.8"E
5	L.N. Fagervik Gneiss	70°32'23.5"N 23°44'14.6"E

Table SM2

Figure SM1

Figure SM2