

Dynamic Recrystallization in the Sveconorwegian Frontal Wedge, Småland, southern Sweden

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Cover Picture: Metagabbro from Ryssbysjön, which shows a fully metamorphosed mineral assemblage consisting of plagioclase, hornblende, biotite, opaque minerals, quartz, and zircon.

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Abstract: South-central Sweden hosts a tectonic boundary region which traditionally has been called the Protogine Zone. It acts as the boundary between rocks which have escaped Sveconorwegian deformation and metamorphism to the east, and rocks affected by the Sveconorwegian orogeny to the west. North of lake Vänern, the boundary zone is nowadays referred to as the Sveconorwegian Frontal Deformation Zone. The term Sveconorwegian Frontal Wedge is adopted in this study for the continuation of the boundary zone south of lake Vättern. Investigation into the tectonic boundary zone in an area south of Lake Vättern was performed through sampling of rocks in a transect across the deformation zone, petrographic analysis, and Zr-in-titanite thermometry. Petrographic data were then related to previously documented structural trends in the area. The results show that rocks from two sub-areas within the deformation zone (Ryssby and Bor), experienced epidote amphibolite-facies conditions with local late greenschist-facies overprint. In contrast, the sub-area east of the deformation front (Lammhult), experienced greenschist- to low amphibolite-facies conditions. Zr-in-titanite thermometry was performed using LA-ICP-MS-analysis on titanite in two metagabbroic and two metagranitic samples from the two western sub-areas. Temperature estimations of very fine-grained titanite grains (50-100 μm) in metamorphic aggregates from these four samples resulted in temperature estimates ranging from 650 to 686 $^{\circ}\text{C}$, at an assumed pressure of 0.6 GPa. These results are suggested to be overestimates due to Zr-zonation within the titanite grains. The metamorphic conditions cannot have exceeded a suggested 600–650 $^{\circ}\text{C}$ at 0.6 GPa, demonstrated by the lack of evidence for partial melting. Larger (circa 500 μm) titanite grains in one sample of granitic gneiss recorded a temperature estimate of 759 $^{\circ}\text{C}$ at 0.3 GPa, which is suggested to reflect an igneous granitic crystallization temperature. The contrast in metamorphic conditions between sub-areas in the study area is suggested to reflect that rocks in the east have escaped Sveconorwegian metamorphism. The findings are supported by different trends of foliations that are on average N-S striking in the west and ESE-WNW striking in the east. Sveconorwegian greenschist- or amphibolite-facies deformation zones in the easternmost part of the Frontal Wedge, such as is reported for the Sveconorwegian Frontal Deformation Zone in the Karlskoga-Kristinehamn area, have not been documented.

Keywords: Protogine Zone, Sveconorwegian Frontal Wedge, petrography, Zr-in-titanite thermometry

Supervisors: Charlotte Möller, Tomas Næraa

Subject: Bedrock Geology

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Dynamisk rekristallisation av mineral i de frontala delarna av den Svekonorvegiska provinsen i Småland

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Sammanfattning: I de centrala delarna av södra Sverige finns ett tektoniskt gränsområde som traditionellt sett har kallats Protoginzonen. Det har agerat som gränsen mellan bergarter vilka undkommit svekonorvegisk deformation och metamorfos i öster, och bergarter som upplevt den svekonorvegiska bergskedjebildningen till väster. Norr om Vänern kallas detta gränsområde numera Sveconorwegian Frontal Deformation Zone (fritt översatt Svekonorvegiska Frontala Deformationszonen). Termen Sveconorwegian Frontal Wedge används i detta arbete avseende den sydliga fortsättningen av deformationszonen, söder om Vättern. En undersökning angående detta gränsområde utfördes genom provtagning av bergarter i ett transekt genom deformationszonen, petrografisk analys, samt Zr-i-titanit-termometri. Petrografiska data relaterades sedan till tidigare dokumenterade strukturer i området. Resultaten visade att bergarter från två underområden (Ryssby och Bor) utsattes för metamorfos i epidot-amfibolitfacies med lokala avtryck av senare metamorfos i grönskifferfacies. I kontrast till detta har bergarterna i området öster om deformationsfronten (Lammhult) utsatts för metamorfos i grönskiffer- till låg-amfibolitfacies. Masspektrometri (LA-ICP-MS) utfördes för att bidra med isotopdata till Zr-i-titanit-termometri för två metabasiska och två metagranitiska bergartsprover. Temperaturuppskattningar utfördes på små titanitmineral (50-100 μm) lokaliserade i metamorfa aggregat i dessa fyra prover, vilket resulterade i uppskattningar mellan 650–686°C vid 0.6 GPa. Dessa tros vara överskattningar sprungna ur av zonering av zirkonium i titanitmineralen. De verkliga förhållanden i proven tros inte ha överstigit 600–650°C vid 0.6 GPa då inga bevis för delsmälta observerats. Ett granitiskt prov innehöll större titanitmineral (kring 500 μm), vilka estimerades ha bildats vid en temperatur på 759°C vid 0.3 GPa. Detta föreslås vara provets magmatiska kristallisationstemperatur. De kontrasterande metamorfosgraderna, vilka de olika bergarterna utsatts för, föreslås vara orsakade av att bergarterna i de östra delarna undkom Svekonorvegisk metamorfos. Detta styrks av skillnaden i uppmätta strykningsriktningar av foliation i området, vilka i genomsnitt stryker N-S i delområdena till väst, samt ONO-VSV i området till öst. Vidare har studien inte observerat deformationszoner som upplevt grönskiffer- eller amfibolitfacies på grund av svekonorvegisk omvandling i de östra delarna av den svekonorvegiska fronten, såsom tidigare rapporterats för den svekonorvegiska frontala deformationszonen i området kring Karlskoga-Kristinehamn.

Nyckelord: Protoginzonen, Svekonorvegiska fronten, petrografi, Zr-i-titanit-termometri

Handledare: Charlotte Möller, Tomas Næraa

Ämnesinriktning: Berggrundsgeologi

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1 Introduction

The tectonic boundary zone classically known as the Protogine Zone is 15-30 km wide and stretches roughly N-S from southern Sweden northwards until it disappears beneath the Caledonian thrust front (Andréasson & Rodhe 1990). A limited number of studies done during the last few decades have investigated various aspects of this zone. A geological map produced by Wikman (2000) has been used as a basis for the sampling for this study. Wahlgren et al. (1994) performed mapping and structural analysis in the region around Karlskoga and Kristinehamn, north of Lake Vänern. Jarl (2002) conducted U-Pb dating of the Vaggeryd syenite, south of Lake Vättern. Later work on the Vaggeryd syenite and adjacent intrusions involved Pb-Pb-dating (Söderlund & Ask 2006). Notable is the absence hitherto of quantitative pressure- and/or temperature-estimates of the metamorphism in the Protogine Zone.

The definition of the term Protogine Zone (PZ) has been discussed (Rodhe 1992), and other names for the boundary zone have been suggested. Wahlgren et al. (1994) suggested the term Sveconorwegian Frontal Deformation Zone (SFDZ) for the easternmost boundary zone of deformation, which is located east of the traditional Protogine Zone, north of Lake Vättern. In addition, the term Frontal Wedge (Möller et al. 2015; Ulmius et al. 2015) and “boundary zone” (Ulmius et al. 2018) have also been used. For this study the term Frontal Wedge will be used, referring to the position in the Sveconorwegian litho-tectonic province.

One way of better understanding the Frontal Wedge (FW) is to characterize the deformation-structures and the metamorphic conditions under which they formed. The present study has tested the application of a recently developed trace-element thermometer based on the zirconium content in titanites (Hayden et al. 2008), and present a documentation of the metamorphic deformation fabrics in the south-central part of the zone.

2 Geological background of southern Sweden

2.1 Proterozoic bedrock east of the Sveconorwegian Province

The Fennoscandian shield is mainly composed of Paleoproterozoic rocks consisting of calc-alkaline and alkali-calcic meta-plutonic and meta-volcanic rocks referred to as Svecofennian and Transscandinavian Igneous Belt rocks, respectively (Fig. 1). These Paleoproterozoic rocks range in age from 1.96-1.66 Ga (Lahtinen et al. 2005; and references therein), with the youngest rocks towards the south and west (Stephens & Andersson 2015). Accretion along an active continental margin is a proposed mechanism for the crustal growth (eg. Hermansson et al. 2008 and Stephens & Andersson 2015). The Blekinge-Bornholm region, in the southernmost Fennoscandian shield, experienced an orogenic event during the Mesoproterozoic called the Hallandian, alternatively the Danopolonian orogeny (Ulmius et al. 2015; and references therein). Gra-

nitic intrusions and deformation associated with their emplacement occurred at 1.47-1.44 Ga (Čečys et al. 2002; Johansson et al. 2006; Zariņš & Johansson 2008; Ulmius et al. 2015) in the older bedrock, dated at 1.82-1.74 Ga (Čečys et al. 2002; Johansson et al. 2006; Zariņš & Johansson 2009; Ulmius et al. 2015).

2.2 The Sveconorwegian Province

The Sveconorwegian Province consists of five litho-tectonic units (Bingen et al. 2008). These are the Telemarkia, Bamble, Kongsberg, and Idefjorden Terranes, and the Eastern Segment. Of these, the Eastern Segment is lithologically and geochemically continuous with the Proterozoic bedrock in the east and dominated by granitic intrusive rocks 1.73-1.66 Ga old (Möller et al. 2007; Möller et al. 2015; Petersson et al. 2015; and references therein). Occurrences of Hallandian metamorphism, deformation and magmatism in the southern Eastern Segment have been dated at 1.47-1.38 Ga (Christoffel et al. 1999; Söderlund et al. 2008; Hansen et al. 2015; Piñán Llamas et al. 2015; Ulmius et al. 2015; and references therein). In southernmost Sweden, the Hallandian metamorphic grade reached low-pressure granulite-facies, estimated at 700-750°C and 0.4-0.5 GPa. The tectonic setting is not known but has tentatively suggested as an active continental margin analogous to the modern-day Andes (Ulmius et al. 2015). Younger bimodal magmatism at 1.22 Ga has been proposed to be related to extension (Söderlund & Ask 2006). Two major tectonic boundaries delimit the Eastern Segment to the west and east. The Mylonite Zone is the boundary to the west, at the overlying Idefjorden Terrane (Fig. 1.) The eastern, low-grade, limit of Sveconorwegian deformation is termed the or Sveconorwegian Frontal Deformation Zone (Wahlgren et al. 1996) or the Sveconorwegian Front (Möller et al. 2015). The tectonometamorphic evolution in the different Sveconorwegian terranes has been recorded as stages from 1.14 Ga to 0.9 Ga (Bingen et al. 2008), but metamorphism and deformation in the Eastern Segment is constrained at 0.99-0.96 Ga (Möller et al. 2015). The Eastern Segment can be divided into three subsections: the internal section, the transitional section, and the frontal wedge (Möller et al. 2015) of which the latter corresponds to the zone traditionally termed the Protogine Zone (Rodhe 1992).

2.3 Phanerozoic sedimentary basins and the Sorgenfrei-Tornquist Zone

The Sorgenfrei-Tornquist Zone (STZ) is a 20-50 km wide, NW-SE trending, tectonic lineament stretching from the North Sea towards Poland where it extends into the Teisseyre-Tornquist Zone (Eugeno-S Working Group 1988; Erlström et al. 1997). Volcanic activity marked the onset of rifting during the Late Carboniferous (Michelsen & Nielsen 1991). Repeated activism is described from the Triassic to Paleogene (Michelsen & Nielsen 1991; Bergerat et al. 2007; and references therein). During the Cretaceous to Early Paleogene, inversion tectonism occurred within the Tornquist Zone (Erlström et al. 1997). Brittle reactivation during the Permian of is suggested to have formed the Lake Vättern, possibly as a splay from the STZ (Månsson, 1996). Fragments and crack-fillings of quartzite occur

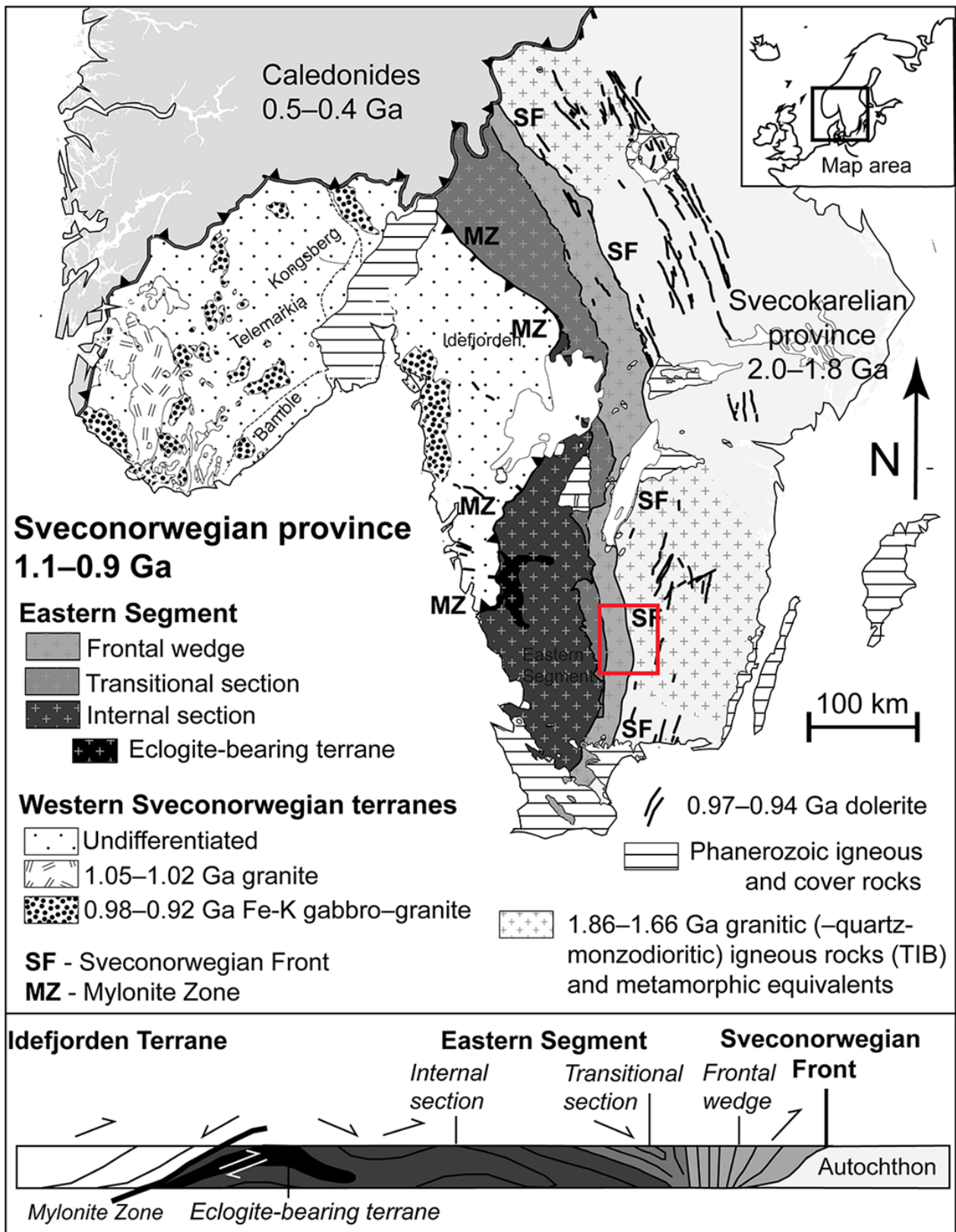


Fig. 1. Schematic regional tectonic map of the Sveconorwegian province. The red box marks the study area. Original map published by Möller et al. (2015) and based on data from the Geological Surveys of Sweden and Norway. Schematic cross-section of the Eastern Segment from Möller et al. (2015).

in the study area, suggested to belong to the Almesåkra group of sediments (Wikman 1998).

3 The Sveconorwegian Frontal Wedge

3.1 Rock types

The study area comprises rocks of a wide variety, which are described by (Wikman 2000) and summarized as follows. Supracrustal rocks include volcanic porphyries (eg. Smålandsporfyrr), ignimbrites, and agglomerates. The composition of these rocks is mainly rhyolitic, but andesitic and basaltic compositions are common. Amongst the intrusive rocks, granitic rocks are the most abundant, and include tonalite, granodiorite, quartz-monzonite, and quartz-monzonodiorite along with basic rocks, mainly gabbro. Dolerite and pegmatite dikes are also found in the study area. A variety of the dolerite dikes, containing dark plagioclase grains, are called hyperite dolerites. In addition, magmatic rocks which show signs of mingling or mixing of felsic and mafic magmas are common in the region. Metamorphic varieties of these rocks include gneisses and amphibolites.

3.2 Deformation structures

The Sveconorwegian Frontal Deformation Zone has been mapped out to be 40-50 km wide in the Karlskoga-Kristinehamn area (Wahlgren et al. 1994). It has been explained as a fan-like configuration in the aforementioned area, with a proposed increase in metamorphic grade from east to west (Wahlgren et al.

1994). South of lake Vättern, the Frontal Wedge (née Protogine Zone) forms a 20-30 km wide boundary zone between rocks affected by the Sveconorwegian deformation, and rocks with an TIB-related east-west trending foliation (Andréasson & Rodhe 1990; Söderlund et al. 2004). Aeromagnetic data show the tectonic boundary, where the deformation front is seen striking approximately NNW-SSE in an anastomosing fashion (Fig. 2). Rocks occurring in the Frontal Wedge show both ductile and brittle deformation fabrics (Andréasson & Rodhe 1990; Wikman 2000). The brittle fabrics have been proposed to have been formed either during Sveconorwegian uplift (Andréasson & Rodhe 1990), and/or later during Permian (Månsson, 1996). Intrusive features such as dolerite dikes and bimodal intrusions occur in the FW and approximately a hundred km east of it, occurring along-strike to the Sveconorwegian Front; and are suggested to be characterizing for the FW (Patchett & Bylund 1977; Jarl 2002; Söderlund & Ask 2006). Hydrothermal activity involving metavolcanics aluminous gneisses were stated to be a characterizing feature for the Protogine Zone (Andréasson & Rodhe 1990), but these features have lately have been explained by other means (Larsson 2001; Piñán Llamas et al. 2015; Ulmius et al. 2015).

Some older models explained the Protogine Zone as a suture zone (Burke et al. 1977; Baer 1981). Later reports found that rocks found both sides of the deformation zone did not differ in lithology but only in tectonic reworking (Wahlgren et al. 1994; Wahlgren et al. 1996; Söderlund et al. 1999). Extensional tectonism is preferred by Andréasson & Rodhe (1990) with formation of half-graben complexes followed by

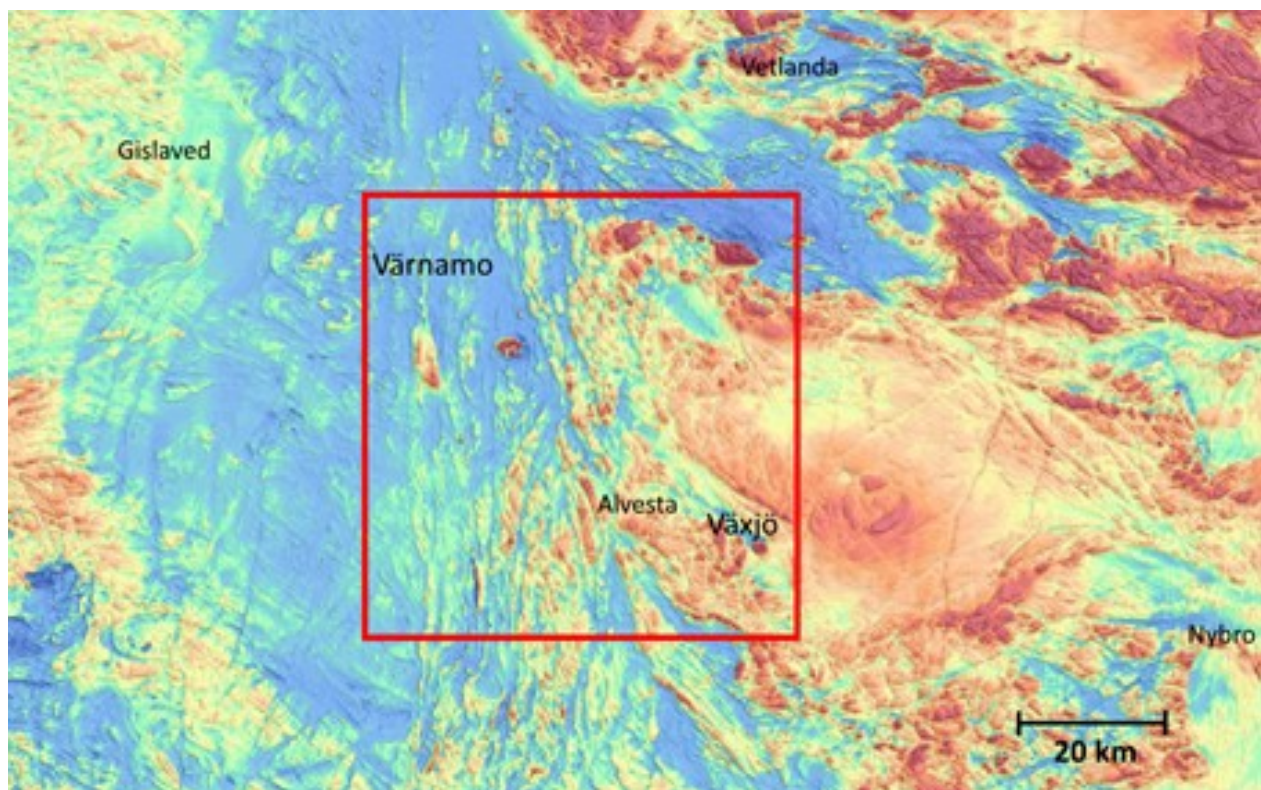


Fig. 2. Airborne magnetic anomaly map (source SGU). Blue = low and red = high magnetic field. Red box marks the study area.

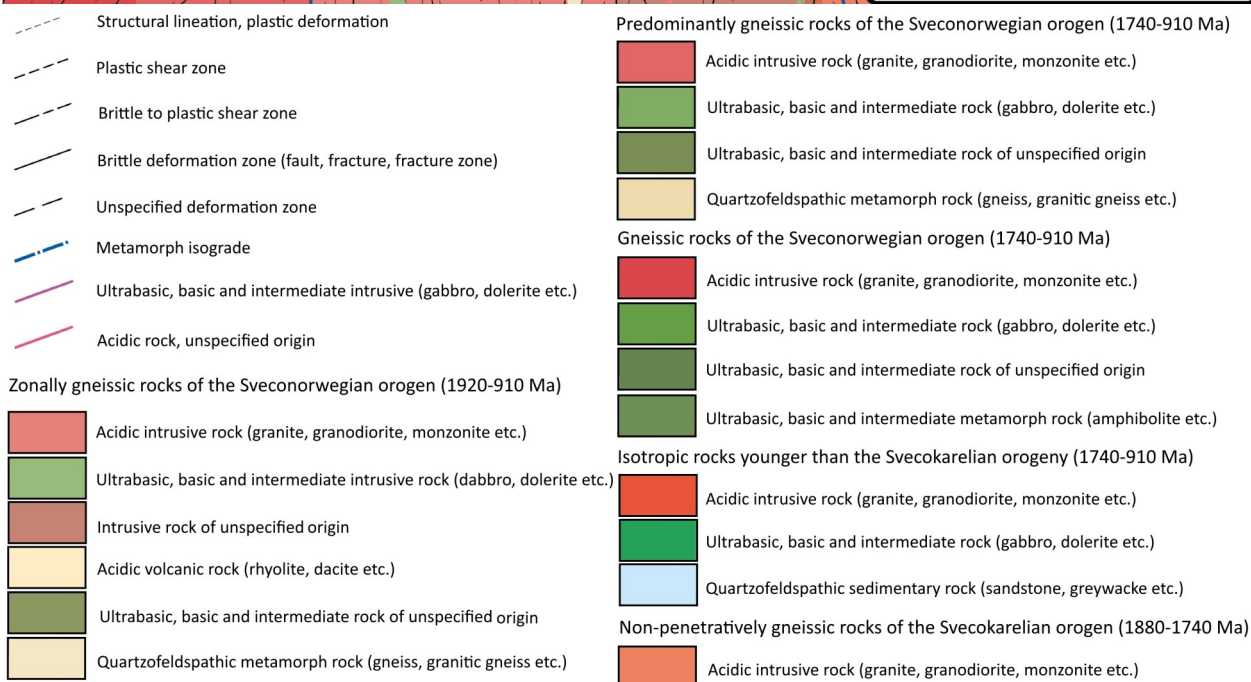
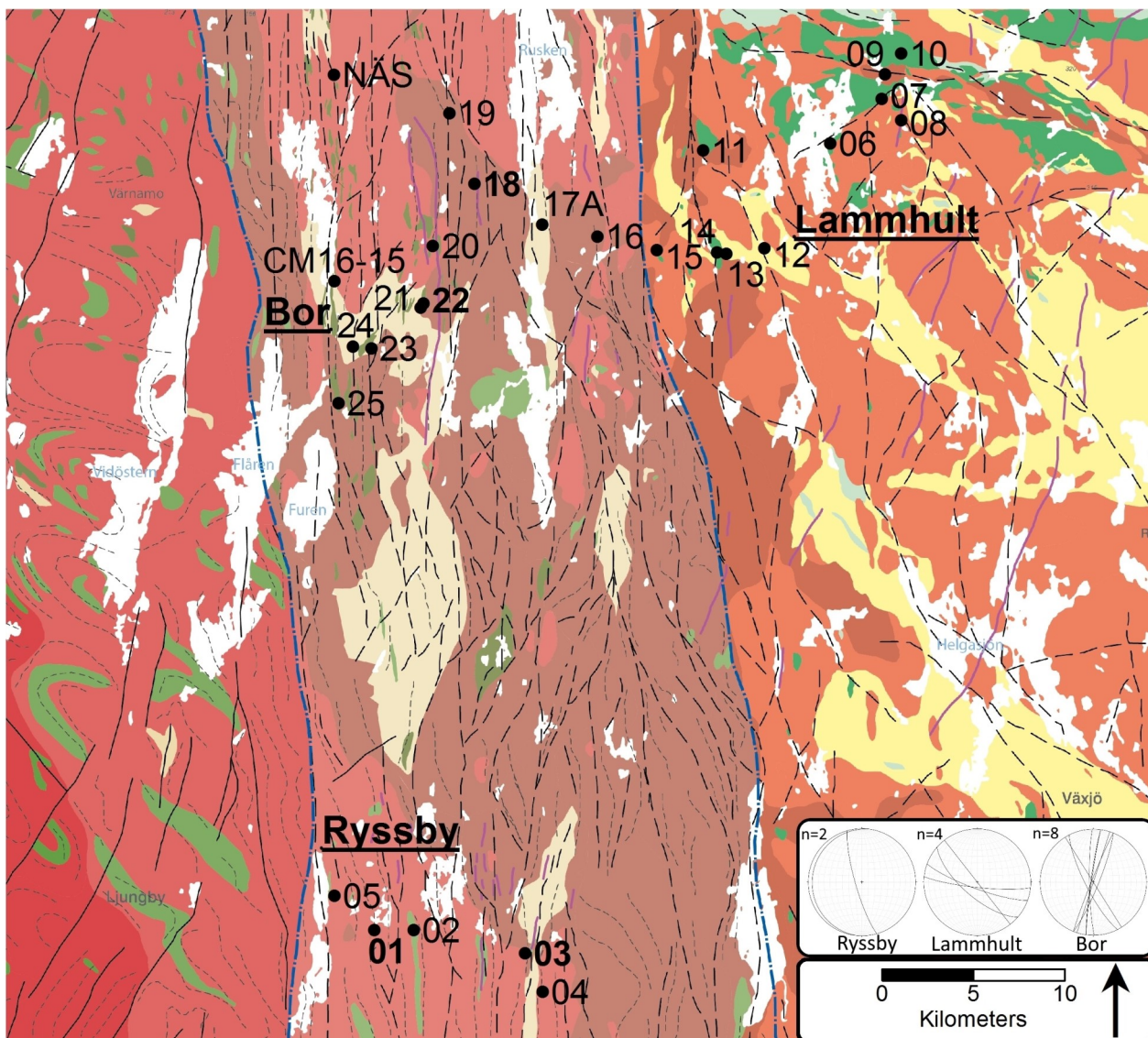


Fig. 3. Previous page. Bedrock map (modified from SGU source). Legend shows structural elements and geological units (modified from SGU source). Sample locations from JP-16-series abbreviated to serial number only. Samples collected by Charlotte Möller abbreviated as NÄS and CM16-15. The three sub-areas (Ryssby, Lammhult and Bor) are shown underlined. The inset shows the stereoplots for the three sub-areas.

isostatic rebound and associated uplift of granulite terrains to the west. Extensional activity is also believed to explain the occurrence of dolerite and syenite dikes found in relation to the Frontal Wedge (Söderlund et al. 2005; Söderlund & Ask 2006). It is also suggested that rapakivi magmatism at 1.57 Ga may have caused the crustal weaknesses which later reactivated to form the Protogine Zone and determined the spatial distribution of dikes emplaced in relation to the zone from 1.22 Ga and onwards (Söderlund & Ask 2006). Wahlgren et al. (1994) favor a two-stage model for the deformation occurring north of Lake Vänern. Their model explains the deformation via the formation of an imbricate thrust-stack followed by a rotation during the Sveconorwegian - resulting in a fan-like structure with steep westward-dipping foliation in the east with a gradual switch to eastward-dipping foliation in the west.

3.3 Geochronology

The Transscandinavian Igneous Belt, in which the Frontal Wedge is located, is made up of rocks emplaced at 1.85-1.65 Ga (Högdahl et al. 2004; and references therein). Intrusive rocks emplaced into the Scandinavian crust at approximately 1.57 Ga may have contributed to form crustal weaknesses later to be reactivated (Söderlund & Ask 2006). Two dolerite samples, located in the semi-penetratively deformed part of the SFDZ, show ductile deformation which restricts the timing of the deformation to at the earliest 1.57 Ga (Wahlgren et al. 1996). Extensional magmatism at circa 1.22 Ga and 1.2 Ga emplaced the Vaggeryd complex suite of rocks (located south of Lake Vättern), of which the Vaggeryd syenite is transected by ductile deformation of the FW and thus predates the deformation-event (Jarl 2002; Söderlund & Ask 2006). Dating of muscovite from rocks showing ductile deformation attributed to the PZ resulted in $^{40}\text{Ar}/^{39}\text{Ar}$ -cooling through $375\pm 25^\circ\text{C}$ at 965-955 Ma (Andréasson & Dallmeyer 1995). In intensely deformed rocks, muscovite was dated at 940 Ma (Andréasson & Dallmeyer 1995). These ages are suggested to date the exhumation of the Sveconorwegian Eastern Segment, west of the Sveconorwegian Front. Rocks from the Rommelåsen horst in Scania, which show non-penetrative deformation of greenschist- to amphibolite-facies attributed to the Frontal Wedge, were recently dated to 882-902 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$ muscovite) and 892-906 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$ biotite), recording cooling and exhumation through 530-330°C (Ulmius et al. 2018). The $^{40}\text{Ar}/^{39}\text{Ar}$ -cooling ages were stated to be related to extensional tectonism accommodated by shear zones along the Frontal Wedge (Ulmius et al. 2018). Måansson (1996) suggests that the brittle reactivation of ductilely deformed rocks formed Lake Vättern during the Permian as an extension from the Sorgenfrei-Tornquist Zone - possibly analogous to the Oslo rift.

4 Methods

4.1 Sampling and sample preparation

Sampling and structural measurement in the field were carried out in collaboration with supervisor Charlotte Möller during three days in November 2016. SGU's bedrock maps 5E Växjö NV and 5E Växjö NO with descriptions (Wikman 2000) were used as a basis for finding appropriate sampling localities of felsic and mafic rocks. Twenty-six samples were collected at this occasion and seven samples (NÄS1, NÄS2, NÄS3, NÄS4, CM16-14, CM16-15A and CM16-15B) had been collected at earlier occasions; and were provided by Charlotte Möller. Sample locations are shown in Fig.3, and coordinates in Table 1. Altogether 33 samples were sawed prepared for thin section preparations. Samples with distinguishable lineation were cut both parallel and perpendicular to the lineation (eg. JP16-22P and JP1622V, respectively). Of these, three samples (JP16-26, CM16-14, and NÄS4) from the Bor area proved to be heavily affected by very fine-grained low-grade brittle-ductile deformation. They were to be omitted during the petrographic microscopy analysis.

4.2 Polarized microscopy

Petrographic investigation of 43 thin-sections from 33 samples was made using a standard polarizing microscope (Nikon Eclipse E400) at the Department of Geology, Lund University. Three samples (JP16-26, NÄS4, and CM16-14) were omitted during the analyses due to them being heavily affected by low-grade brittle-ductile deformation causing the grain-size to be too fine for optical microscopical investigation. Five thin-sections containing sufficient quantities of titanite were chosen for further analysis using scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS).

4.3 Scanning Electron Microscopy (SEM)

The five thin-sections (JP16-01, JP16-03, JP16-18, JP16-22P, and JP16-24P) chosen for further analysis were analyzed using a Tescan Mira3 FE-SEM equipped with an EDS analyzer (Oxford Instruments X-MaxN 80), at the Department of Geology, Lund University. Samples were carbon-coated (20-30µm) before analysis and an acceleration voltage of 15 kV was used. The focus of the analysis was threefold. Firstly, to locate micro-domains with titanite- and zircon-grains for further LA-ICP-MS analysis. Secondly, to identify mineral species in these micro-domains using EDS. Finally, to produce an internal ^{43}Ca -standard for titanites in each sample by means of EDS-analysis.

4.4 LA-ICP-MS analysis

Five samples (JP16-01, JP16-03, JP16-18, JP16-22P, and JP16-24V) were analyzed using a Bruker Aurora Elite ICP-MS equipped with a 193 nm Cetac Analyte

Table 1. Sample numbers with corresponding place names and coordinates in SWEREF 99TM.

Sample ID	Name	X (SWEREF 99 TM)	Y (SWEREF 99 TM)
Ryssby area			
JP16-01	Boarydsvägen, Målaskog	6298080	452180
JP16-02	Intersection Boarydsvägen at Målaskogsberg	6298086	454338
JP16-03	Mjöhult	6296818	460421
JP13-04	Vislanda	6294703	461397
JP16-05	Ryssbysjön	6299970	449995
Lammhult area			
JP16-06	Bergö, Allgunnen	6341152	477142
JP16-07	Västra Göl/Lönelid	6343590	479950
JP16-08	NW of Sjöända	6342430	481014
JP16-09	Svältestorp	6344940	480128
JP16-10	Yggersryd	6346067	481027
JP16-11	Röbarkarmossen	6340770	470187
JP16-12	Anebodavägen	6335400	473528
JP16-13	Lammhultsvägen, Skärslund	6335119	471457
JP16-14	Skärslund	6335194	470940
JP16-15	Möcklehult	6335300	467635
Bor area			
JP16-16	Grunnen	6336055	464386
JP16-17	Kalvsjön	6336715	461360
JP16-18	Os	6338936	457670
JP16-19	Skärsjön	6342812	456287
JP16-20	Glimmarp	6335544	455387
JP16-21	Skaverås 1	6332170	454703
JP16-22	Skaverås 2	6332390	454870
JP16-23	Gällarydsvägen	6329933	452012
JP16-24	Bor	6330040	450999
JP16-25	Furen	6326925	450225
NÄS1	Näsbyholm	6344903	449959
NÄS2	Näsbyholm	6344903	449959
NÄS3	Näsbyholm	6344903	449959
CM16-15A	Hindsen	6333616	449984
CM16-15B	Hindsen	6333616	449984

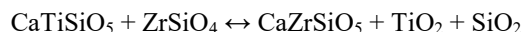
G2 excimer laser. The practical execution of the analysis was performed by Tomas Næraa (Department of Geology, Lund University), based on titanite micro-domain locations chosen during SEM-analysis. More information on methodology can be found in Appendix, Table A. Spot-sizes were chosen to be 90 μm^2 , e.g. 30x30 μm or 20x45 μm for elongate grains; for samples JP16-01, JP16-22P and JP16-24V. For samples JP16-03 and JP16-18, 20x20 μm spot-sizes were used. Laser output was set at 19.2%, fluence at 1.53J/cm², repetition rate at 8 Hz, and shot count at 240. Titanite standards used were MKED1 (Spandler et al. 2016), ONT2 and Khan. Elements measured were ⁴³Ca, ⁴⁷Ti, ⁵⁷Fe, ⁸⁸Sr, ⁸⁹Y, ⁹⁰Zr, ⁹¹Zr, ¹³⁹La, ¹⁴⁰Ce,

¹⁴⁶Nd, ¹⁴⁷Sm, ¹⁶³Dy, ¹⁷²Yb, ¹⁷⁸Hf, ¹⁸¹Ta. Data reduction was mainly performed by Tomas Næraa. The data was then calculated using an internal standard for ⁴³Ca for each sample which was calculated from SEM EDS-data gathered in the previous step, shown in Table 2 (Section 5.4.6). A mix-up of thin-sections caused JP16-24V to be analyzed instead of JP16-24P, resulting in data unusable for Zr-in-titanite thermometry for that sample.

4.5 Zr-in-titanite thermometry

Hayden et al. (2008) found that the zirconium content in titanite show a systematic relationship with tempe-

rature and pressure. This relation was used to produce a thermobarometer with an approximate uncertainty of $\pm 20^\circ\text{C}$ at a pressure-temperature range of 0.1-2.5 GPa and 600-1000°C. The thermobarometer is based on the substitution between Ti^{4+} and Zr^{4+} , illustrated by the following reaction:



Providing that the Zr-content in titanite is low enough, Henry's law may be applied, the activity of zirconium is related to the mole fraction and thus can be experimentally analyzed. Calculation of the crystallization temperature is made using the equation:

$$T(^{\circ}\text{C}) = [7708 + 960P] / [10.52 - \log(a\text{TiO}_2) - \log(a\text{SiO}_2) - \log(\text{ppm Zr-in-titanite})] - 273$$

In addition to the experimental uncertainties, the activities of TiO_2 and SiO_2 affect the result. For rutile-bearing and rutile-absent amphibolite, rutile-activities of 0.92 ± 0.12 and 0.75 ± 0.26 respectively, were suggested by Kapp et al. (2009). For ilmenite-bearing but rutile-absent amphibolite the suggested value is $0.95 + 0.05 / -0.25$ and 0.8 ± 0.20 for rutile-absent metapelite (Chambers & Kohn 2012). The activity of SiO_2 is dependent on the structural state of quartz. The thermometer is calibrated for α -quartz, but for samples which equilibrated in the β -quartz stability field, the activity is 0.97 at 1 GPa and 1000°C; and higher for lower temperatures at the same pressure (Hayden et al. 2008). Estimating the temperature using the thermometer requires pressure-values to be given or estimated. The thermometer is shown to be insensitive to REE and F-Al substitution, but sensitive to pressure effects. The common occurrence of sector zoning formed by growth entrapment, representing a kinetic disequilibrium feature, must also be considered. For titanites with sector zoning, sectors with low Zr-content are suggested to represent the equilibrium concentration, suitable for using in thermometry (Hayden et al. 2008).

5 Petrography

Samples were collected from three areas: Ryssby in the southwest (5.1), Lamnhult in the northeast (5.2), and Bor in the northwest (5.3); shown in Fig. 3.

5.1 The Ryssby area

Five outcrops (JP16-01 to JP16-05) were sampled in the area around Ryssby, between Ljungby and Vislanda (Fig. 3). The deformation is non-penetrative with N-S-striking and steeply dipping amphibolite-facies fabrics. At two localities, the deformation fabrics have a shallowly plunging linear component, 8-20 degrees to the south.

5.1.1 JP16-01 Boarydsvägen, Målaskog, east of Ljungby

The rock, sampled at a road-cut on Boarydsvägen, is a metagabbro which has a relict coarse- to medium-grained texture (Fig. 4A-B). Remnant igneous plagioclase laths (1-2 mm long) are present. Fe-Ti-oxide and apatite grains are possibly remnant igneous grains.

Except for these minerals, the rock is recrystallized and dominated by the metamorphic minerals hornblende, plagioclase, biotite, quartz, apatite, titanite, calcite, and epidote. Hornblende is the dominating mineral, pleochroic with bluish-green to green-beige color. Poikiloblastic hornblende grains are up to 1 mm large, with addition of smaller subhedral grains. Quartz is abundant within the poikiloblastic hornblende. The dark minerals (hornblende, biotite, opaques and some titanite) form a domainal texture, likely being pseudomorphs after igneous pyroxene and Fe-Ti-oxide. Titanite grains form thin rims around the opaque grains. Zircon grains are seen where halos have formed in hornblende and biotite. The light-colored domains are mainly composed of lath-shaped plagioclase, smaller polygonal plagioclase, quartz, and rod-shaped apatite. The lath-shaped plagioclase grains commonly have plenty of inclusions, of which epidote and biotite were identified.

5.1.2 JP16-02 Intersection Boarydsvägen at Målaskogsberg

The rock sampled at a road-cut at Målaskogsberg is a dark, seemingly unmetamorphosed, coarse- to medium-grained diabase with isotropic texture (Fig. 5A-B). The thin section shows that the texture and minerals are dominantly magmatic with olivine, pyroxene, opaque minerals, biotite, and plagioclase. Fine-grained, possibly metamorphic, minerals form coronas up to 5 mm wide around olivine and opaques. The olivine grains have two coronas, where the inner corona consists of a clear mineral dusted with small opaque grains. The outer corona consists of a lightly bluish to green amphibole. Locally, fine-grained garnet is present in this type of corona. The opaque grains in this sample are often rimmed by biotite. The pyroxene grains are dusty grey in plain polarized light with medium relief and 2nd order birefringence. Plagioclase-laths comprise roughly half of the rock. Accessory apatite grains are common.

5.1.3 JP16-03 Mjöhult

The Mjöhult sample is a light reddish granitic gneiss of medium grain-size (Fig. 6A-B). The sample consists mainly of quartz, tartan-twinned K-feldspar, and plagioclase. The grains are generally equidimensional and have interlobate grain boundaries. Undulose extinction is observed in both feldspars and quartz. Subgrains are common in quartz. The dark foliae consist of dark mineral aggregates of: hornblende, biotite, allanite, epidote, zircon, titanite, garnet, and opaque minerals. The hornblende is dark green in color and the grains are anhedral in shape. Colorless to light brown titanite grains occur as rims around the opaque minerals.

5.1.4 JP16-04 Vislanda

The sampled outcrop consists of a dark, medium to coarse-grained, metagabbro with spaced deformation lineation fabric. The sample is from an undeformed section, characterized by comparatively well-preserved igneous texture and minerals (Fig. 7A-B). The magmatic minerals are pyroxene, plagioclase, biotite, apatite, quartz, and opaque minerals. Metamorphic minerals are very fine-grained rims and small grains of biotite and hornblende. The igneous pyroxene grains are

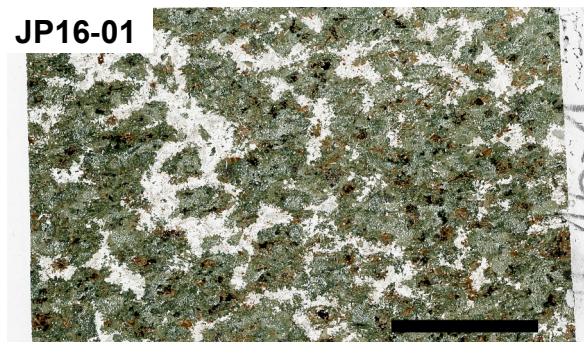
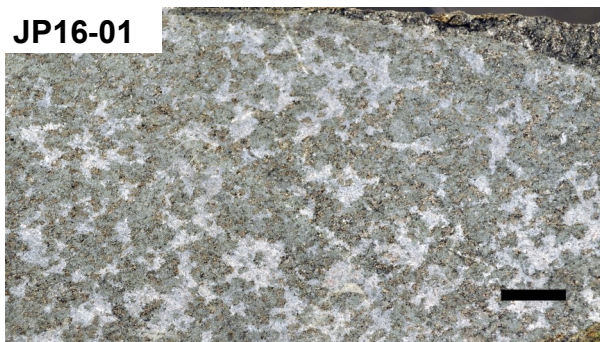


Fig. 4. Undeformed metagabbro from Boarydsvägen, Målaskog (sample JP16-01). Scale-bars are 1 cm. **(A)** Hand specimen showing the relict medium- to coarse-grained texture. **(B)** Scanned thin-section illustrating texture and metamorphic recrystallization. Dark domains consist of fine-grained aggregates of hornblende, biotite, oxides and minor titanite. Light-colored domains consist of remnant igneous plagioclase laths (with inclusions of epidote and biotite) and fine-grained polygonal aggregates of plagioclase, quartz, and apatite.

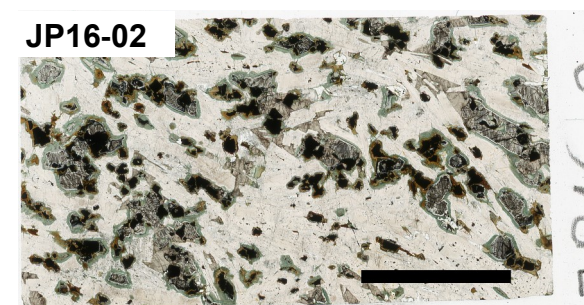


Fig. 5. Unmetamorphosed diabase from intersection Boarydsvägen at Målaskogsberg (sample JP16-02). Scale-bars are 1 cm. **(A)** Wet hand specimen showing the isotropic magmatic texture. **(B)** Thin-section scan showing light-colored and lath-shaped plagioclase grains along with dusty grey pyroxene grains, opaque minerals, biotite, and olivine.

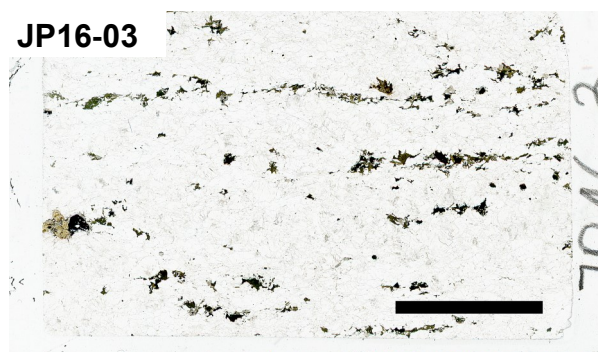
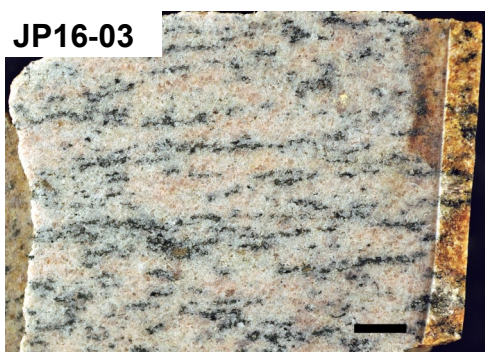


Fig. 6. Light-reddish granitic gneiss from Mjöhult (sample JP16-03). Scale-bars are 1 cm. **(A)** Hand sample showing the gneissic texture. **(B)** Scanned thin-section. The light-colored domains consist of quartz, K-feldspar and plagioclase. The dark foliae consist of aggregates of hornblende, biotite, allanite, epidote, titanite, garnet, and opaque minerals.

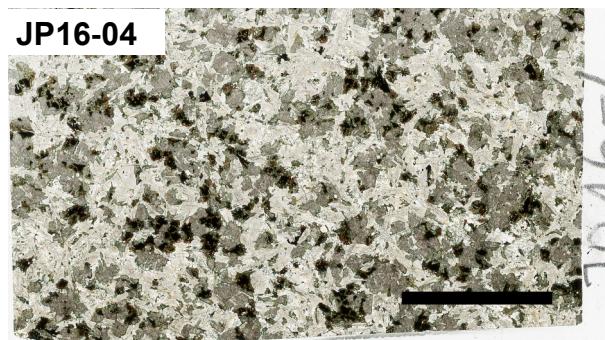
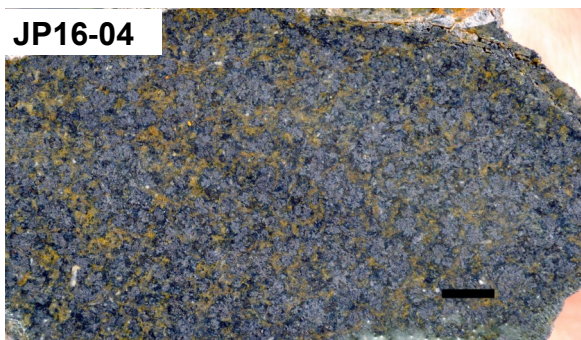


Fig. 7. Metagabbro at Vislanda (sample JP16-04). Scale-bars are 1 cm. **(A)** Wet hand specimen shows a medium- to coarse-grained relict texture. **(B)** The thin-section scan shows the relict texture where magmatic minerals comprise pyroxene, plagioclase, biotite, apatite, quartz, and opaque minerals. Fine-grained metamorphic rims of biotite and hornblende are apparent around opaque grains and pyroxenes.

dusty grey with no apparent pleochroism, medium relief; twinning can be seen in some grains. Plagioclase grains are somewhat dusty and lath-shaped; twinning and zoning are seen, along with a slight undulatory appearance. The opaque grains are often rimmed by biotite. Hornblende form blueish green rims on either the opaque grains or pyroxene grains. Anhedral quartz with sub-grains and undulations are observed, together with rod-shaped apatite grains.

5.1.5 JP16-05 Ryssbysjön

The sample at Ryssbysjön is a metagabbroic rock with LS-fabric defined by deformed light-colored plagioclase domains and dark mineral domains, suggesting a previous igneous medium- or coarse-grained texture (Fig. 8A-C). The rock is completely recrystallized into a metamorphic assemblage consisting of plagioclase, hornblende, biotite, opaques, quartz, and zircon. The green hornblende is either anhedral and poikiloblastic; or consists of subhedral grains. The opaques and biotite are predominantly within the hornblende domains. The light-colored domains consist mainly of polygonal plagioclase grains, which are variably sericitized. Small accessory apatite grains occur within the plagioclase domains.

5.2 The Lammhult area

Ten outcrops (JP16-06 to JP16-15) were sampled around Lammhult (Fig. 3). The foliation in this area strike roughly ESE-WNW with steep dips (68-90 degrees, SSW). Deformation fabrics range from greenschist- to lower amphibolite-facies.

5.2.1 JP16-06 Bergö, Allgunnen

At Allgunnen, a metagabbro was sampled. The rock is medium to coarse-grained, with an isotropic texture (Fig. 9A-B). The rock contains abundant saussuritized laths of relict magmatic plagioclase and olive-green hornblende. Accessory minerals are apatite and opaques. Fine-grained metamorphic minerals identified are epidote, chlorite, white mica and minor titanite.

5.2.2 JP16-07 Västra Göl/Lönelid

A medium-grained metagabbro was sampled at a road-cut at Västra Göl. This rock contains relict magmatic light-green clinopyroxene (partly amphibolitized), olive-green hornblende, and partly saussuritized lath-shaped plagioclase grains (Fig. 10A-B). Accessory minerals are biotite, opaques, quartz, and apatite. Metamorphic minerals are epidote (in plagioclase) and blue-green amphibole (replacing clinopyroxene)

5.2.3 JP16-08 NW of Sjöända

This sample of fresh-looking gabbro was sampled from an outcrop, two kilometers from Sjöända, and has a medium- to coarse-grained texture with a predominantly magmatic mineral assemblage (Fig. 11A-B). It contains two types of pyroxene, one which is comparatively clear and pale reddish brown (twinning can be seen in some grains), and the other which is heavily altered into very fine-grained minerals. Anhedral opaque grains are common. Somewhat saussuritized and lath-shaped plagioclase grains make up an approximate half of the rock. Both twinning and zoning are observed in plagioclase along with a slight undulatory

extinction. Accessory minerals are euhedral apatite grains, small grains of biotite, olive-green hornblende and some quartz. The only metamorphic mineral identified is chlorite, of which lesser amounts are present locally.

5.2.4 JP16-09 Svältestorp

The sample was collected from a road-cut at Svältestorp, and is a leucocratic, fine-grained foliated rock with sparse rounded 1-3mm porphyroclasts of tartan-twinned K-feldspar and quartz (Fig. 12A-B). Sutured quartz, K-feldspar and plagioclase (saussurized/sericitized) form the matrix; both feldspars and quartz show an undulating extinction. Lesser amounts of biotite, muscovite, opaque minerals, chlorite, and a brown unknown mineral (possibly secondary) were observed.

5.2.5 JP16-10 Yggersryd

A sample of foliated metagabbro, of fine to medium grain-size, was collected at a road-cut near Yggersryd. The dominating mineral observed in thin-section is green to blue-tinted green hornblende, 1-3 mm large (Fig. 13A-B). These hornblende grains are anhedral in shape and have opaque minerals as inclusions, possibly a sign of magmatic origin. Finer hornblende grains occur along their margins and among the surrounding felsic minerals. Biotite has been partly altered into light-brown micaceous minerals with 1st order interference colors, possibly chlorite. Light-colored minerals in the thin-section are plagioclase and quartz, with undulose extinction and recrystallization into very fine grains along the margins; sericitization and saussuritization are common. Small titanite grains are observed, from anhedral to euhedral in shape, with a light pinkish-orange color, some have grown around opaque minerals. Zircon grains occur as inclusions in hornblende or micas; a few grains of allanite were found. Metamorphic minerals include scattered grains of muscovite, epidote, and chlorite.

5.2.6 JP16-11 Röbbarkarmossen

The sample from Röbbarkarmossen, 6 km NW of Lammhult, is a strongly deformed, dark metabasic rock with elongated plagioclase grains (Fig. 14A-B). Pale hornblende with a slightly blue-green tint, along with apatite, form larger fractured grains that are surrounded by fine-grained foliae of micaceous nature (muscovite, and pale chlorite). A few small, anhedral, opaque minerals occur as accessory minerals.

5.2.7 JP16-12 Anebodavägen

A sample of schistose metabasic rock with a slightly undulatory foliation (Fig. 15A-B) was taken from a road-cut at the junction between Lammhultsvägen and Anebodavägen. Bluish-green hornblende is the most abundant mineral in this sample. The elongated hornblende grains vary from larger, anhedral, poikiloblastic in many places zoned; to smaller and subhedral grains. The opaque minerals are commonly rimmed by high-relief minerals; either titanite, epidote or both. The colorless domains consist of fine-grained anhedral grains of quartz with undulatory extinction, saussuritized plagioclase and epidote. Some small needles of muscovite can be identified within the fine-grained material. Discrete micro-shear zones <1 mm wide,

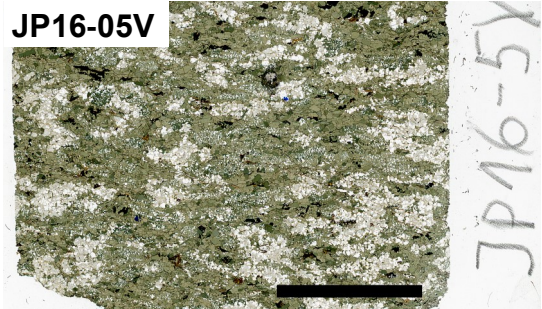
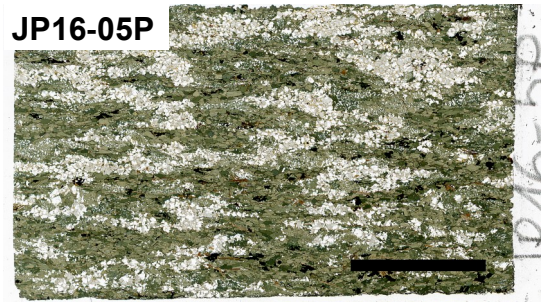
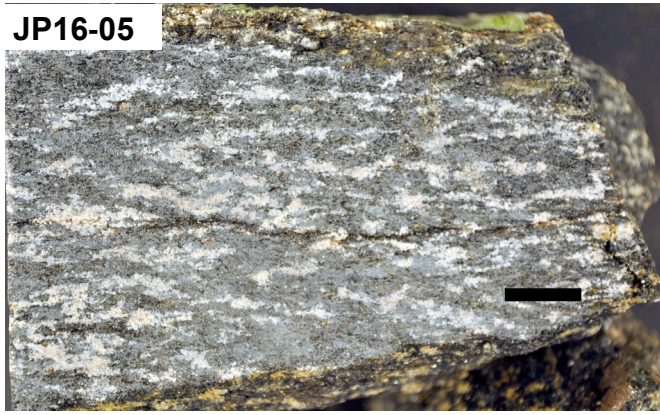


Fig. 8. Metagabbro from Ryssbysjön (sample JP16-05). Scale-bars are 1 cm. **(A)** Hand sample shows deformed plagioclase-domains. **(B)** Scan of thin-section cut parallel to the lineation, showing elongate light-colored aggregates of polygonal plagioclase and quartz. Dark-colored domains consist of green hornblende, biotite, and opaque minerals. **(C)** Scan of thin-section cut perpendicular to the lineation.

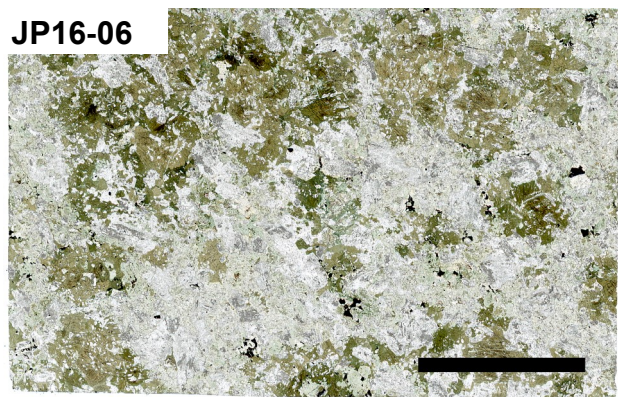
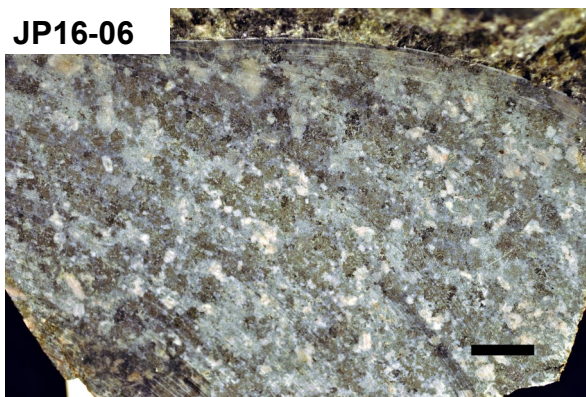


Fig. 9. Metagabbro from Bergö, at Allgunnen (sample JP16-06). Scale-bars are 1 cm. **(A)** Hand sample depicting the medium- to coarse-grained isotropic texture. **(B)** Thin-section scan showing light-colored domains of saussuritized magmatic plagioclase. The colored domains consist of olive-green hornblende.

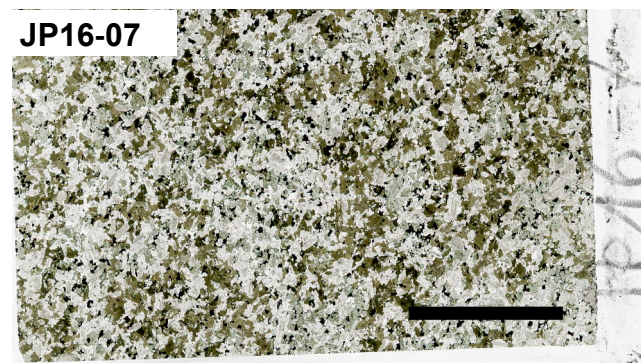
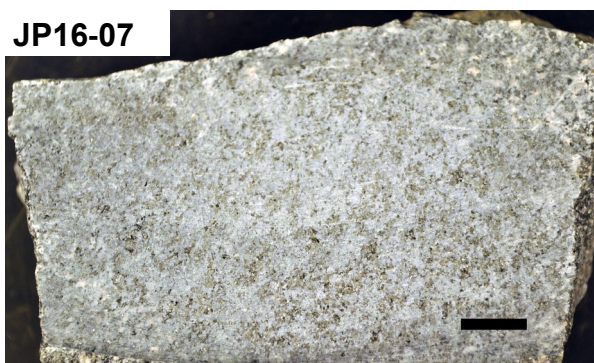


Fig. 10. Metagabbro from Västra Göl/Lönelid (sample JP16-07). Scale-bars are 1 cm. **(A)** Hand specimen showing the medium-grained isotropic texture. **(B)** Scan of thin-section. Magmatic clinopyroxene (light-green), hornblende (olive-green) and lath-shaped plagioclase are shown along with accessory biotite, opaque minerals, quartz, and apatite. Metamorphic amphibole has (partly?) replaced clinopyroxene and epidote-grains are found within plagioclase.

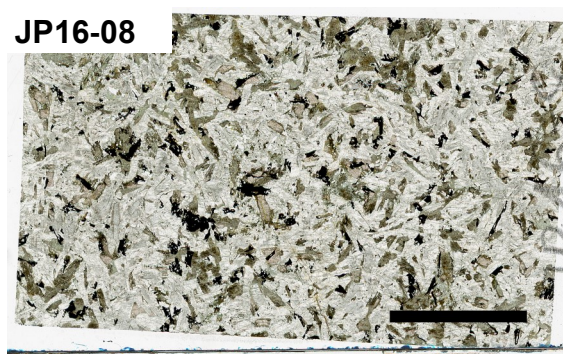
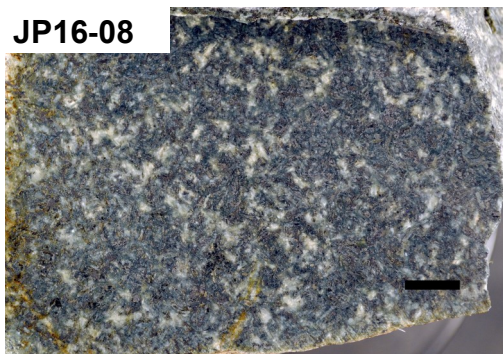


Fig. 11. Gabbro collected 2 km NW of Sjöända (sample JP16-08). Scale-bars are 1 cm. **(A)** Wet hand specimen showing a medium- to coarse-grained texture, predominantly magmatic. **(B)** Scanned thin-section shows light-colored lath-shaped plagioclase and pale reddish brown pyroxene along with olive-green hornblende, biotite, and opaque minerals. Metamorphic chlorite is locally present.

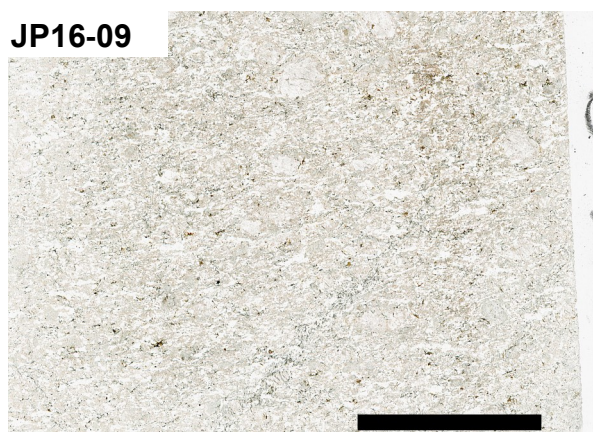
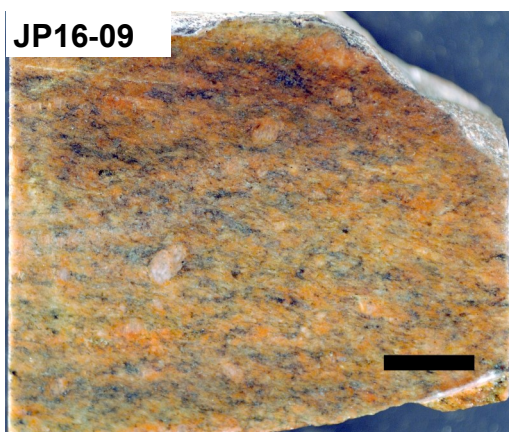


Fig. 12. Fine-grained leucocratic sample from Svältestorp (JP16-09). Scale-bars are 1 cm. **(A)** The fine-grained texture with small, 1-3mm, K-feldspar and quartz porphyroclasts seen on wet surface of the hand specimen. **(B)** Scan of thin-section: quartz, K-feldspar and plagioclase dominates the sample. Small elongate quartz-domains can be seen. Accessory minerals include biotite, muscovite, opaque minerals and chlorite.

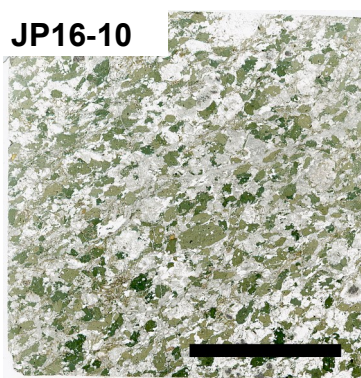
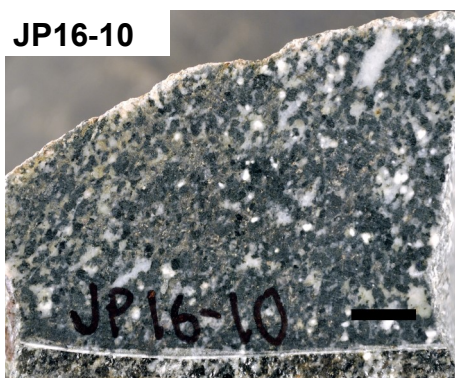


Fig. 13. Foliated metagabbro from Yggersryd (sample JP16-10). Scale-bars are 1 cm. **(A)** Hand sample showing the fine- to medium-grained texture with wet surface for greater recognition of details. **(B)** Green hornblende dominates the rock, as seen in the thin-section scan. The light-colored minerals are mainly plagioclase and quartz. Accessory minerals are biotite and opaque minerals. Scattered grains of metamorphic minerals include muscovite, chlorite, epidote, and allanite.

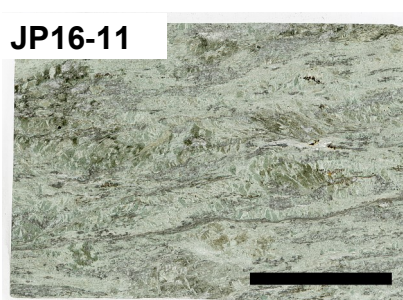
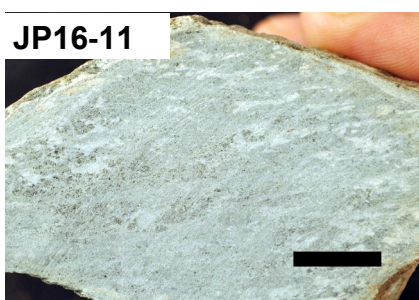


Fig. 14. Deformed metabasite from Röbbarkarmossen (sample JP16-11). Scale-bars are 1 cm. **(A)** Hand specimen illustrates the deformed texture with elongated plagioclase domains. **(B)** Thin-section scan further shows the deformed texture. Colorless domains consist of plagioclase and green to blue-green domains are hornblende with accessory opaque minerals. A foliation trail can be seen in the lower half of the thin-section consisting of muscovite and chlorite.

with very fine-grained material cut the foliation at high angles.

5.2.8 JP16-13 Lammhultsvägen, Skärslund

A mesocratic, grey rock with fine-grained matrix and centimeter-sized plagioclase phenocrysts (Fig. 16A-C) was sampled at Skärslund, west of Lammhult. The plagioclase phenocrysts are anhedral, contain inclusions, and have partly sericitized cores. Quartz, K-feldspar, and smaller metamorphic plagioclase grains form the matrix along with small amounts of saussuritized or sericitized material. Feldspars and quartz show an undulating extinction and vary in shape, from sutured to polygonal. Blue-tinted hornblende, biotite and opaque minerals form the foliation. Opaque minerals, epidote, zircon and titanite occur as accessory phases.

5.2.9 JP16-14 Skärslund

A relict medium-grained, leucogabbroic rock (Fig. 17A-C) was sampled from a road-cut at Skärslund, west of Lammhult. Fine-grained basic inclusions were observed in field. The sample is dominated by very fine-grained material, particularly in the former plagioclase domains. The matrix is rich in white mica and zoisite. Pale, anhedral, amphibole grains are present in the dark-colored domains.

5.2.10 JP16-15 Möcklehult

At Möcklehult, a foliated meta-granite, with relict medium- to coarse grain-size was sampled (Fig. 18A-C). The foliated granitic rock has a steeply west-dipping foliation (LS-fabric) defined by elongated quartz domains and aggregates of dark minerals. Aggregates of weakly recrystallized K-feldspar and plagioclase occur as augen. Dark minerals include green hornblende, brown biotite, opaques and reddish brown titanite. Quartz-grains are strained (undulose extinction) and show grain size reduction by recrystallization. Plagioclase and K-feldspar grains show signs of sericitization and saussuritization. Accessory phases, in addition to opaque minerals, are zircon, apatite, and epidote.

5.3 The Bor area

Eleven samples (JP16-16 to JP16-26) were collected from the area around Bor, east of Värnamo (Fig. 3). Seven samples (NÄS1, NÄS2, NÄS3, NÄS4, CM16-14, CM16-15A and CM16-15B) collected at an earlier occasion was provided by Charlotte Möller. Three samples (JP16-26, CM16-14, and NÄS4) from this area were omitted as they were heavily affected by very fine-grained low-grade brittle-ductile deformation, (too fine-grained for the scope of this study). Where deformed, rocks show a steeply dipping foliation (78-90 degrees) striking roughly N-S. The metamorphic grade is amphibolite-facies.

5.3.1 JP16-16 Grunnen

The rock was sampled on a small hill north of the small lake Grunnen. It is a dark medium-grained partly metamorphosed dolerite with an isotropic texture (Fig. 19A-B). Magmatic phases include pyroxene, plagioclase, some olivine and opaque minerals. The plagioclase has a pinkish tint in thin-section and a slightly undulating extinction. The pyroxenes are dusty grey in plain polarized light and seem to have been affected by

low-temperature metamorphism. Some small cores of olivine are observed, although most of the olivine grains have been recrystallized into very fine-grained minerals. Accessory minerals are biotite, quartz, and apatite. Biotite occur as rims around the opaque grains. Small interstitial areas are filled by quartz. Apatite grains occur as small needle-shaped grains.

5.3.2 JP16-17A Kalvsjön

Near lake Kalvsjön, a light-red granitic gneiss was found which is strongly foliated in a NNW-SSE striking and steeply dipping orientation (78 degrees). Three samples were taken, of which one (JP16-17A) was chosen for thin-section preparation. The rock has cm-sized dark foliae between light-colored domains consisting of K-feldspar and plagioclase (sericitized and/or saussuritized), quartz and muscovite (Fig. 20A-B). The quartz occurs as polygonal grains, situated between the feldspars and micas. Occasional muscovite grains show a west-up sense of shear. The darker, mica-rich, bands are dominated by larger grained muscovite with minor amounts of quartz-ribbons and elongated epidote grains.

5.3.3 JP16-18 Os

Reddish grey granitic gneiss was sampled 2 km west of Os. The granitic gneiss is relict medium- to coarse-grained with centimeter-sized grains of K-feldspar and foliation anastomosing around feldspar augen (Fig. 21A-B). The thin-section shows that most of the augen are made up of feldspar aggregates with sutured grain boundaries, suggesting recrystallization. Only a few large, 3-6 mm sized, grains of K-feldspar and plagioclase are observed. Elongated quartz-domains consist of near-polygonal grains with weak undulose extinction indicating grain coarsening after deformation has ceased. The feldspars are rich in very fine-grained inclusions and commonly show signs of sericitization and saussuritization. The anastomosing dark mineral foliae are defined by biotite (largely chloritized) and titanite, together with accessory epidote, opaque minerals and zircon. The titanite grains have cores which are tinted orange-brown, and rims which are pale greyish brown. The few larger K-feldspar grains and the colored titanite cores are interpreted as relict igneous grains.

5.3.4 JP16-19 Skärsjön

Granitic augen-gneiss was sampled from an outcrop near Skärsjön. The granitic gneiss has a steep to vertical foliation and is medium- to coarse grained with K-feldspar augen, indicating a west-side-up sense of movement (Fig. 22A-C). Quartz form elongated lenses and ribbons; individual quartz grains show weak undulose extinction and have sutured grain boundaries indicative of grain coarsening after deformation has ceased. Plagioclase and K-feldspar have sutured grain boundaries and neoblasts, showing dynamic recrystallization. The larger plagioclase grains have abundant fine-grained inclusions of epidote and muscovite. K-feldspar grains in many places show undulose extinction. Thin anastomosing foliae are defined by muscovite, biotite (largely chloritized), epidote, and titanite. The titanite grains are light-brown to colorless; larger grains (possibly relict igneous) are dusty

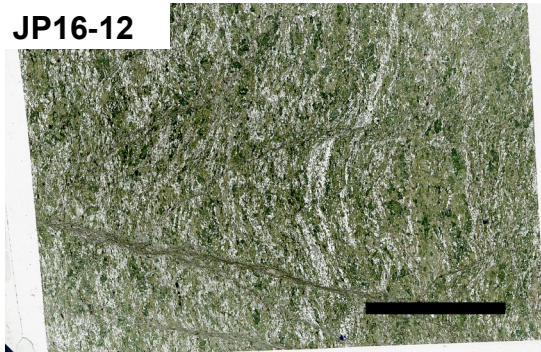
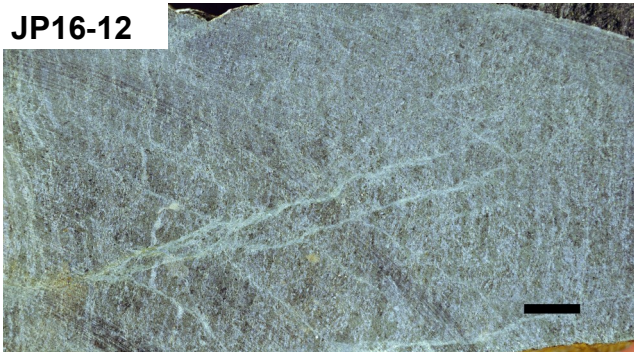


Fig. 15. Schistose metabasite collected at Anebodavägen (sample JP16-12). **(A)** The schistose fabric is visible in hand-specimen, along with cross-cutting micro-shears. **(B)** Blueish-green hornblende dominates the sample with colorless domains of quartz, plagioclase, and epidote in-between. Opaque minerals occur, having rims of titanite or epidote.

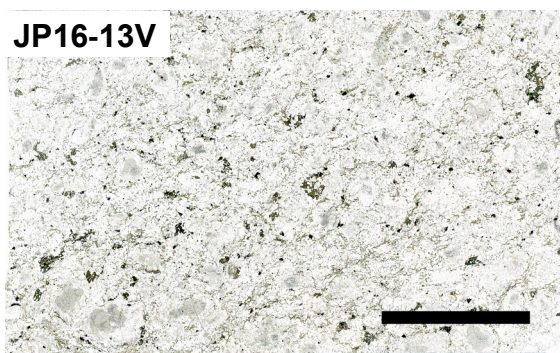
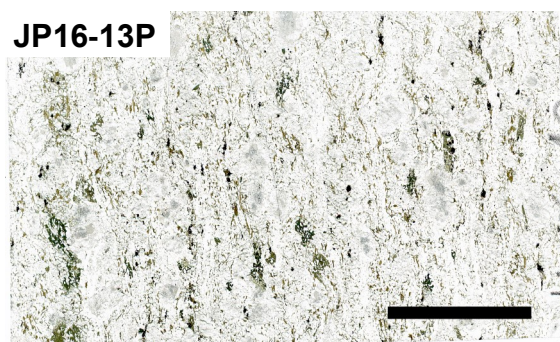


Fig. 16. Plagioclase phenocrystic mesocratic rock from Lammhultsvägen at Skärslund (sample JP16-13). **(A)** The wet hand sample shows plagioclase phenocrysts, elongate silica-rich domains and a foliated texture. **(B)** Scan of thin-section cut parallel to the lineation, showing foliae of hornblende, biotite, and opaque minerals. The matrix surrounding the plagioclase phenocrysts consist of quartz, K-feldspar and metamorphic plagioclase. **(C)** Scan of thin-section cut perpendicular to the lineation.

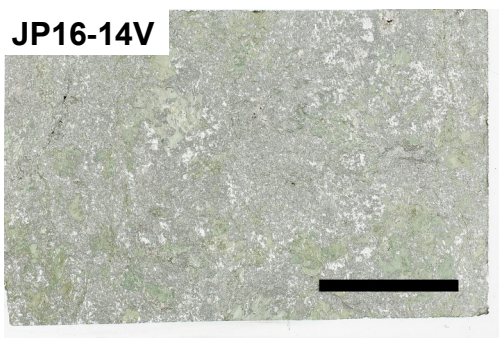
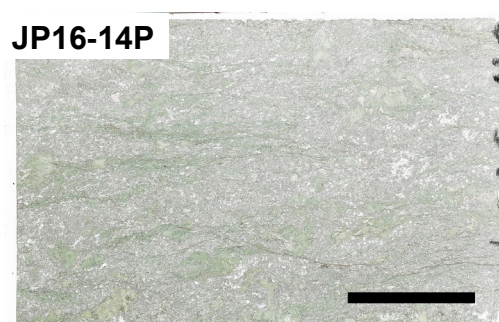
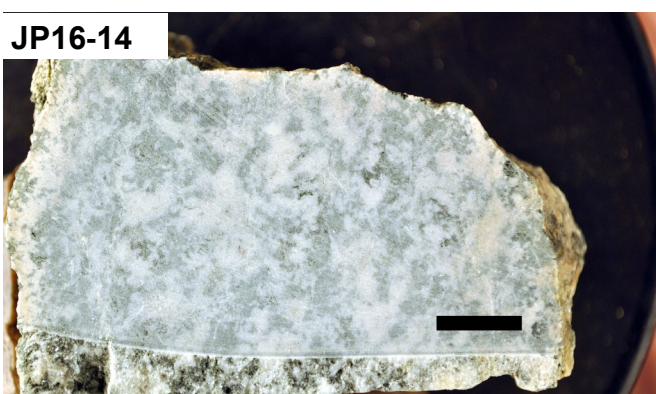


Fig. 17. Leucogabbroic sample collected at Skärslund (sample JP16-14). **(A)** The relict texture is visible as seen in hand specimen. **(B)** Thin-section scan cut parallel to the lineation. The former plagioclase domains consist of very fine-grained material, mainly white mica and zoisite. The darker domains consist of pale amphibole, forming the lineation? in the rock. **(C)** Thin-section scan cut perpendicular to the lineation, further showing the abundance of fine-grained material in the sample.

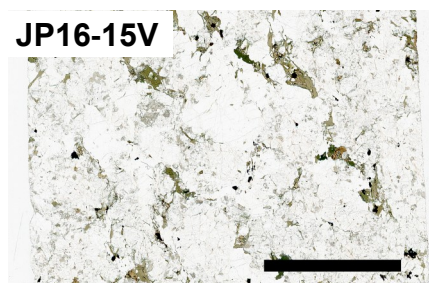
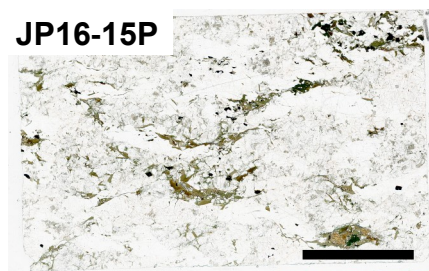


Fig. 18. Meta-granite from Möcklehult (sample JP16-15). Scale-bars are 1 cm. **(A)** Hand specimen of the rock illustrating the relict medium to coarse grain-size with dark foliae. **(B)** Scanned thin-section cut parallel to the lineation. Elongate augen of K-feldspar and plagioclase are surrounded by foliae of hornblende, biotite, opaques, and titanite. Zircon, apatite, and epidote occur as accessory phases. **(C)** Scanned thin-section cut perpendicular to the lineation. The plagioclase and K-feldspar augen are more visible from this angle.

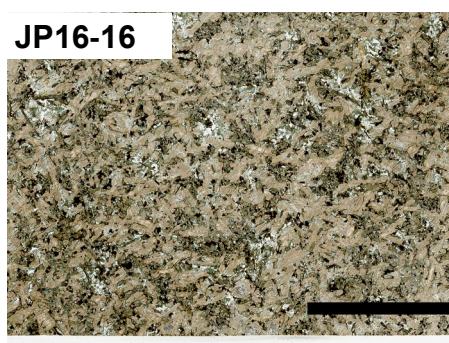
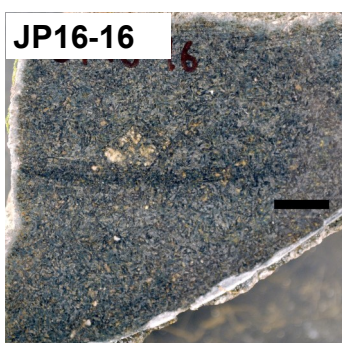


Fig. 19. Partly metamorphosed dolerite collected near lake Grunnen (sample JP16-16). Scale-bars are 1 cm. **(A)** Image of wet hand sample, showing the medium-grained relict texture. **(B)** Scanned image of thin-section showing light-pinkish plagioclase and dusty grey pyroxenes along with opaque minerals rimmed by biotite. In addition, the sample contains small cores of olivine, apatite, and interstitial quartz.

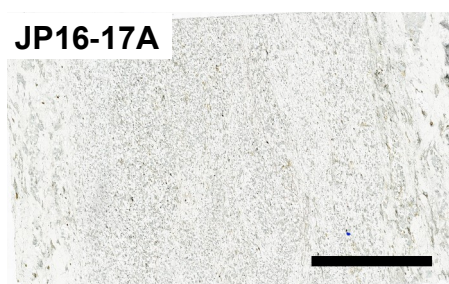
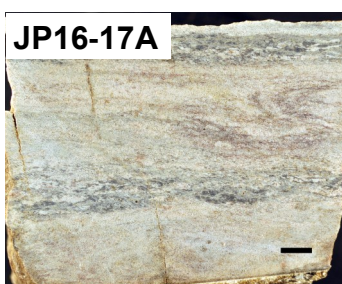


Fig. 20. Granitic gneiss sampled near lake Kalvsjön (sample JP16-17A). Scale-bars are 1 cm. **(A)** Hand specimen illustrates the dark mica-rich bands which show the foliation in-between light-colored domains. **(B)** Scanned image of thin-section with light-colored domain in the middle, consisting of K-feldspar, plagioclase, polygonal quartz and muscovite. The mica-rich domains, seen on the left and right fringes of the thin-section, contain larger muscovite grains along with quartz-ribbons and elongate epidote grains.

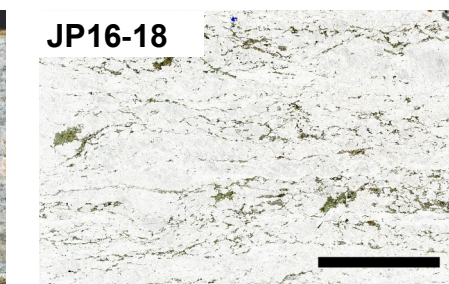
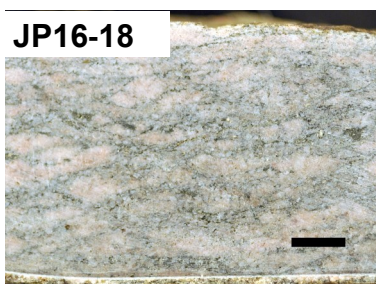


Fig. 21. Granitic gneiss reddish-grey in color, sampled 2 km west of Os (sample JP16-18). Scale-bars are 1 cm. **(A)** Hand specimen illustrating the relict medium- to coarse-grained texture containing feldspar-augen. **(B)** Scan of thin-section showing light-colored domains of K-feldspar, plagioclase and quartz. The dark mineral foliae consist of chloritized biotite, epidote, titanite and opaque minerals.

with abundant fine-grained opaque inclusions. Small anhedral opaque minerals occur as an accessory phase.

5.3.5 JP16-20 Glimmarp

Strongly foliated amphibolite (metagabbro) was sampled at a road-cut near Glimmarp, between Bor and Os. The amphibolite has undergone complete metamorphic recrystallization and consists dominantly of bluish-green hornblende and with elongated plagioclase-rich domains (Fig. 23A-B). The individual hornblende grains are subhedral, elongated, and define the foliation together with biotite and opaque mineral grains. Within the hornblende, metamict halos are observed, suggesting zircon inclusions. In-between the hornblende-rich domains, the light-colored domains consist of small polygonal grains of quartz and plagioclase, both showing slight undulose extinction. The plagioclase grains do not show twinning, but some are slightly sericitized. Small high-relief epidote grains are common within the plagioclase-rich domains.

5.3.6 JP16-21 Skaverås 1

A light reddish, leucocratic, granitic gneiss with thin dark streaks forming a strong subvertical linear fabric was sampled at Skaverås. The grain size is fine- to medium and the rock seems to have undergone complete metamorphic recrystallization (Fig. 24A-C). Quartz appear as elongate aggregates or ribbons, as mainly granoblastic grains with weak undulose extinction, indicative of grain coarsening. Plagioclase and K-feldspar are the other two main phases. The plagioclase grains have inclusions of epidote and muscovite. K-feldspars show an undulose extinction in many places. Feldspars are strongly uneven-grained with sutured grain boundaries, suggestive of dynamic recrystallization by neoblast formation and grain boundary migration. The fabric is defined also by muscovite and biotite (chloritized and green), the latter which contain occasional zircons. Anhedral titanite grains are observed both related, and unrelated to the mafic streaks. Opaque minerals, epidote, and garnet occur as accessory phases.

5.3.7 JP16-22 Skaverås 2

Strongly foliated amphibolite of fine-grain-size (Fig. 25A-C) was also sampled at Skaverås approximately 275 meters from the gneiss locality. Blueish-green hornblende is the major mineral. The hornblende grains are subhedral, elongated, and define the foliation together with biotite and opaque minerals. The hornblende grains contain metamict halos, suggesting small zircon inclusions. In-between the hornblende-domains, light-colored domains are made up by small polygonal grains of quartz and plagioclase which show slight undulose extinction. The plagioclase grains do not show twinning, but some are slightly sericitized. Small high-relief epidote grains occur in trails together with small, subhedral, light-colored titanite grains.

5.3.8 JP16-23 Gällarydsvägen

Gray-red relict coarse-grained granitic gneiss, of fine- to medium grain-size and with a strong anastomosing foliation (Fig. 26A-B) was sampled in a road-cut at Gällarydsvägen east of Bor. Quartz form elongate domains and ribbons that are composed of polygonal

grains and with slight undulose extinction suggesting grain coarsening. K-feldspar is the second-most abundant phase in the sample. The K-feldspar grain-size varies from <0.1 mm to 7 mm, with larger grains having sutured grain boundaries suggesting dynamic recrystallization involving neoblast formation and grain boundary migration. Anhedral to sutured plagioclase grains are also observed. Aggregates of dark minerals form foliation trails, defined by mainly biotite (largely chloritized), together with small anhedral grains of allanite, opaque minerals, epidote, titanite, and a few grains of garnet. Scattered grains of muscovite occur. The opaque minerals are occasionally rimmed by a reddish-brown unknown mineral, possibly late alteration.

5.3.9 JP16-24 Bor

A fine-grained and strongly foliated amphibolite was sampled in a road-cut near small town of Bor. Bluish-green hornblende is the most abundant mineral (Fig. 27A-B). The amphibole grains are subhedral to anhedral and very elongated, defining the foliation together with biotite, opaques, and light-colored mineral aggregates of plagioclase and quartz. Within some hornblende grains signs of metamictization can be seen, suggesting small zircon inclusions. The opaque minerals are rimmed by nearly colorless titanite. Quartz and plagioclase occur as polygonal grains with weak undulose extinction. The plagioclase grains contain a large amount of very fine-grained inclusions of epidote and biotite. The rock is completely recrystallized into a metamorphic assemblage.

5.3.10 JP16-25 Furen

The sample, taken just north of Lake Furen, is a highly schistose metabasite, in which bluish-green subhedral elongated hornblende defines the foliation together with biotite and opaque minerals (Fig. 28A-B). Within the hornblende and biotite grains, halos from metamictization can be seen, suggesting zircon inclusions. The light-colored domains are dominated by polygonal grains of quartz or plagioclase with weak undulose extinction. The plagioclase grains rarely show twinning, but some are slightly saussuritized and some contain very fine-grained inclusions of epidote. A few larger, anhedral, plagioclase grains are rich in inclusions including epidote and may be remnants of magmatic grains.

5.3.11 NÄS1-3 Näsbyholm

Five samples of metabasic rocks were provided by C. Möller from a quarry at Näsbyholm. Two of these samples (NÄS4 and CM16-14) show abundant brittle deformation along with epidote formation. Three samples (NÄS1-3) are varieties of the same deformed and amphibolitized gabbroic rock from the gate of the quarry and are described below.

Sample NÄS1 of amphibolite at Näsbyholm has a fine - medium-grained domainal texture consisting of hornblende-rich and light-colored domains, respectively (Fig. 29A-B). Blue-green hornblende occurs together with anhedral opaque grains surrounded by biotite. Metamict halos and zircons are observed within the hornblende. The colorless domains contain plagioclase and quartz. Some plagioclase grains are larger with

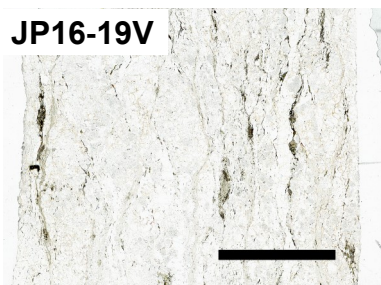
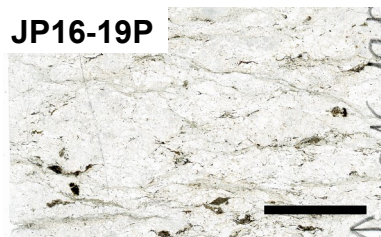
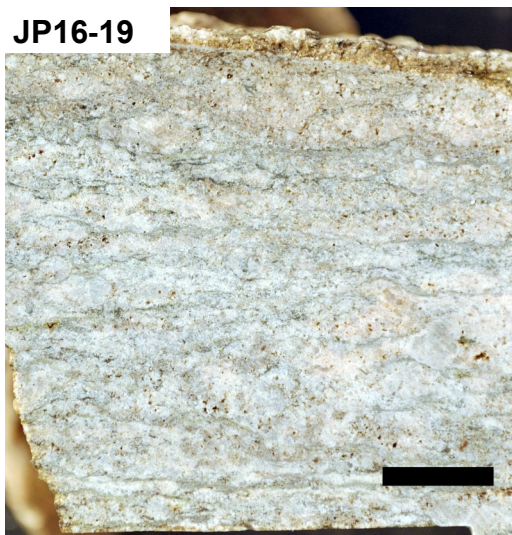


Fig. 22. Granitic augen-gneiss from Skärsjön (sample JP16-19). Scale-bars are 1 cm. **(A)** Hand specimen showing the feldspar augen and the anastomosing foliation. **(B)** Scan of thin-section cut parallel to the lineation showing the anastomosing foliation consisting of muscovite, chloritized biotite, epidote, and titanite. **(C)** Scan of thin-section cut perpendicular to the lineation. Light-colored domains contain K-feldspar, elongate and ribbon-like quartz, along with plagioclase containing fine-grained epidote and muscovite.

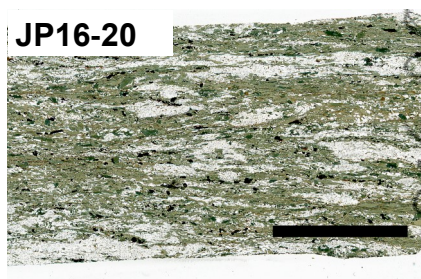
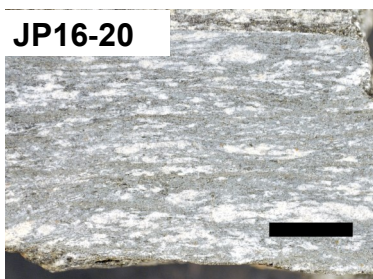


Fig. 23. Amphibolite metagabbro from road-cut near Glimmarp (sample JP16-20). Scale-bars are 1 cm. **(A)** The deformed texture with elongate plagioclase-rich domains as seen in hand specimen. **(B)** Thin-section scan of the sample showing blue-green hornblende as the dominating mineral species. Biotite and opaque grains occur together with the hornblende. The colorless domains contain polygonal quartz, partly sericitized plagioclase, and small epidote grains.

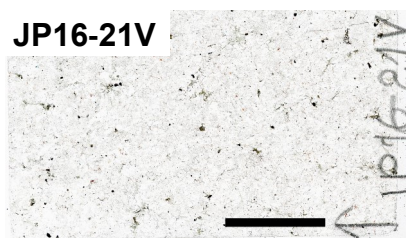
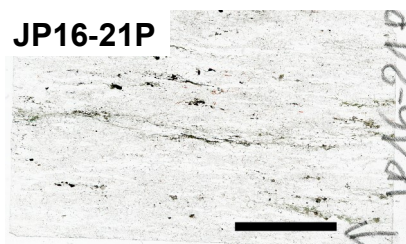


Fig. 24. Leucocratic granitic gneiss from Skaverås (sample JP16-21). Scale-bars are 1 cm. **(A)** Wet hand specimen showing silica-rich domains of plagioclase and K-feldspar with thin dark lineaments. **(B)** Scan of thin-section cut parallel to the lineation, showing the dark streaks defined by muscovite and biotite (chloritized). The colorless minerals in thin-section are elongate or ribbon-like quartz, plagioclase (with muscovite and epidote inclusions), and K-feldspars with sutured boundaries. Additional mineral species include titanite, garnet, and zircon. **(C)** Scan of the thin-section cut perpendicular to the lineation.

plenty of inclusions whereas most are smaller and polygonal. Accessory minerals are apatite and minor epidote.

Sample NÄS2 has a stronger foliation than sample NÄS1, with centimeter-sized elongated plagioclase-rich domains (Fig. 30A-B). Hornblende, bluish- to light-green, is the most abundant mineral where individual grains are subhedral to anhedral and occur together with biotite (partly chloritized), and opaque grains. Metamict halos can be seen within hornblende, biotite and chlorite, implying the presence of small zircon inclusions. The light-colored domains are made up of aggregates of plagioclase, quartz and minor biotite. The plagioclase grains do not show twinning, but some are slightly saussuritized. Apatite occurs as an accessory mineral. On the fringe of the sample, a section where chlorite is the dominating species, is observed. A small-scale shear can also be seen in the thin-section.

Sample NÄS3 is a fine-grained metabasic rock, dominated by light green anhedral hornblende and chlorite (Fig. 31A-B). The chlorite is intergrown with biotite. Metamict halos can be seen within hornblende, biotite and chlorite, showing zircon inclusions. Light-colored domains in the sample include plagioclase-rich lenses and a folded quartz vein. Accessory minerals are opaque grains, and apatite.

5.3.12 CM16-15A & B Hindsen

Two samples of metabasic rocks were provided by C. Möller from the southern end of Lake Hindsen.

Sample CM15-15A is a fine- to medium-grained amphibolite with centimeter-sized deformed and recrystallized plagioclase domains (Fig. 32A-C). The hornblende-rich domains consist of mostly fine-grained anhedral grains of bluish-green hornblende, biotite, and opaque minerals. Quartz and plagioclase grains are uneven-grained, polygonal or with sutured grain-boundaries. The plagioclase grains are locally saussuritized. A few mm-sized grains of garnet are present.

CM16-15B is strongly foliated, with elongated plagioclase aggregates visible in hand specimen (Fig. 33A-B). In thin-section, the sample has a domainal texture of colorless or hornblende-dominated domains. The foliation is defined by anhedral grains of light-green to bluish hornblende, biotite and anhedral opaque minerals. Halos, caused by metamictization are common in these two minerals, suggesting presence of small zircon grains. The colorless domains consist of plagioclase and quartz. Brittle fracturing is observed, cutting across the foliation, causing sericitization of plagioclase near the fractures. In addition, apatite occurs as an accessory mineral.

5.4 Scanning Electron Microscopy of titanite-bearing micro-domains

Five samples were chosen for SEM-EDS analysis. Micro-domains with titanite, identified by petrographical microscopy, were targeted to identify the micro-textures associated with titanite grains. EDS-analysis was used to measure the ^{43}Ca -content in titanite, as a preparation for the LA-ICP-MS analysis. Minerals located in micro-domains containing titanite were also identified.

5.4.1 JP16-01, metagabbro at Boarydsvägen, Målaskog, east of Ljungby

The metagabbro-sample has a relict texture with dark- and light-colored domains. The dark domains consist of titanite, hornblende, biotite, ilmenite, and pyrite. Titanite-grains occur as polycrystalline rims around anhedral remnants of ilmenite grains (Fig. 34). Tiny zircon grains, up to a few tens of μm long, occur within titanite, ilmenite, or in grain boundaries of these. Hornblende occur as poikiloblastic grains along with small subhedral grains. Quartz occur within these poikiloblastic hornblende. In addition, subhedral biotite and pyrite occur within these dark-colored domains. Light-colored domains consist of lath-shaped plagioclase, smaller polygonal plagioclase, subhedral to polygonal quartz and equidimensional apatite grains.

5.4.2 JP16-03, light reddish granitic gneiss at Mjöhult

The sample of granitic gneiss from Mjöhult consists of light-colored domains of equidimensional grains of quartz, K-feldspar and plagioclase with interlobate grain boundaries. Dark mineral aggregates form foliae. These aggregates consist of hornblende, titanite, ilmenite, biotite, muscovite, and apatite. Titanite occurs as polycrystalline rims around cores of anhedral remnants of ilmenite (Fig. 35). Hornblende, biotite, and muscovite occur as anhedral grains. Subhedral to anhedral zircon grains (up to 200 μm -long) occur both in relation to, and unrelated to the foliae. In addition, small subhedral apatite grains occur as an accessory mineral within the ilmenite grains.

5.4.3 JP16-18, granitic gneiss at Os

The sample of granitic gneiss from Os is relict medium- to coarse-grained with cm-sized grains of K-feldspar with foliae anastomosing around. The dark-colored domains consist mainly of titanite, apatite, biotite, Fe-oxide, epidote, and zircon (Fig. 36). The titanite grains have got cores of a lighter shade, and rims of a slightly darker shade (as seen in SEM). In comparison, the cores are darker, when observed in a petrographical microscope. These titanite cores have a patchy appearance due to metamorphic alteration processes. Along with titanite, the foliae consist of anhedral grains of Fe-oxide, epidote, biotite, and apatite. The light-colored domains consist mainly of anhedral grains of K-feldspar, plagioclase and quartz with sutured grain boundaries.

5.4.4 JP16-22P, foliated amphibolite at Skaverås 2

The amphibolite-sample from Skaverås is dominated by subhedral hornblende, which along with titanite, epidote, and biotite form the foliation of the rock. Titanite occurs as subhedral grains in clusters, where the individual grain-size up to 100 μm (Fig. 37). Anhedral grains of biotite and epidote occur along with the titanite. Minute zircons, less than 20 μm large, occur within titanite and/or epidote grains, as well as on their grain boundaries. Larger epidote grains have a zoned appearance. Silica-rich domains consist mainly of polygonal grains of plagioclase and quartz.

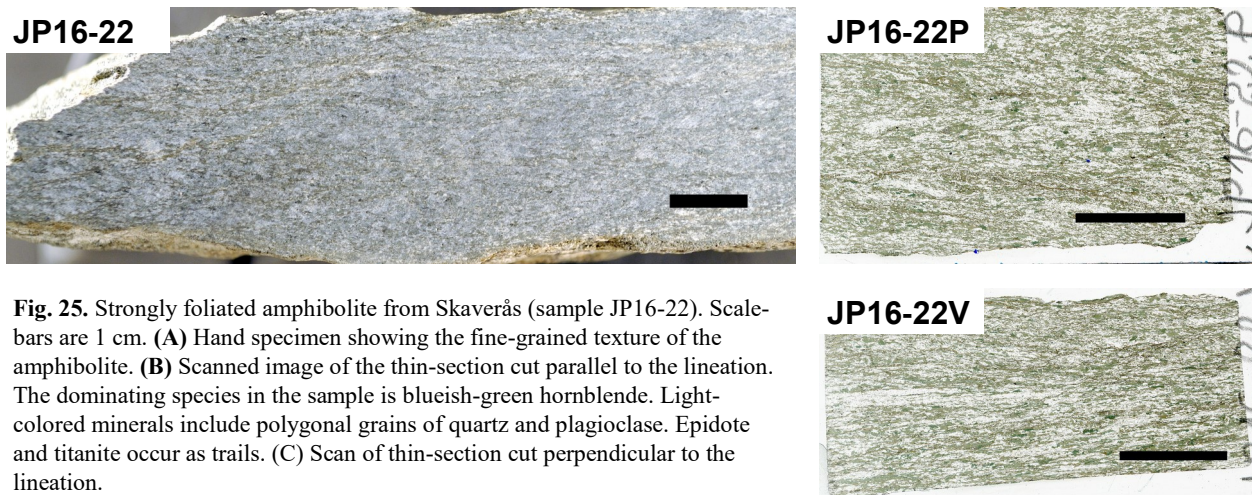


Fig. 25. Strongly foliated amphibolite from Skaverås (sample JP16-22). Scale-bars are 1 cm. **(A)** Hand specimen showing the fine-grained texture of the amphibolite. **(B)** Scanned image of the thin-section cut parallel to the lineation. The dominating species in the sample is blueish-green hornblende. Light-colored minerals include polygonal grains of quartz and plagioclase. Epidote and titanite occur as trails. **(C)** Scan of thin-section cut perpendicular to the lineation.

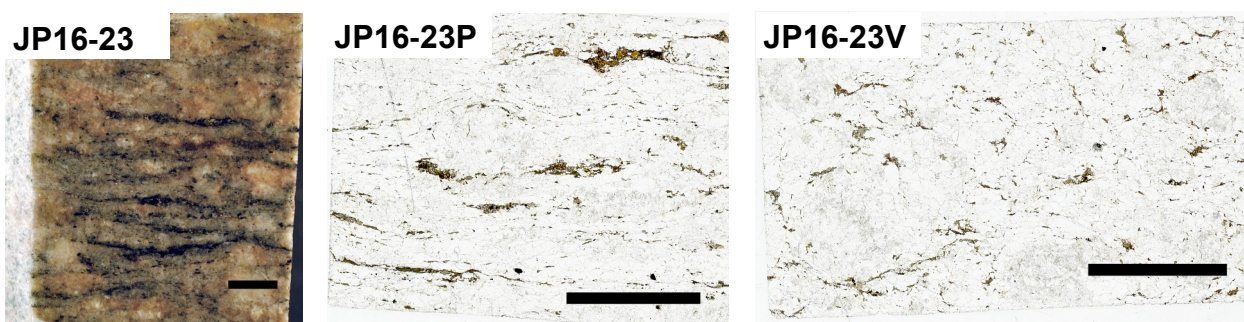


Fig. 26. Gray-red granitic gneiss with fine- to medium-coarse relict grain-size sampled at Gällarydsvägen east of Bor (sample JP16-23). Scale-bars are 1 cm. **(A)** Wet hand sample illustrating the anastomosing foliation wrapping the felsic aggregates. **(B)** Scan of thin-section cut parallel to the lineation. The foliae are defined by chloritized biotite, allanite, epidote, titanite, opaque minerals and occasional garnet grains. Quartz, K-feldspar, and plagioclase make up the colorless domains. **(C)** Scan of thin-section cut perpendicular to the lineation.

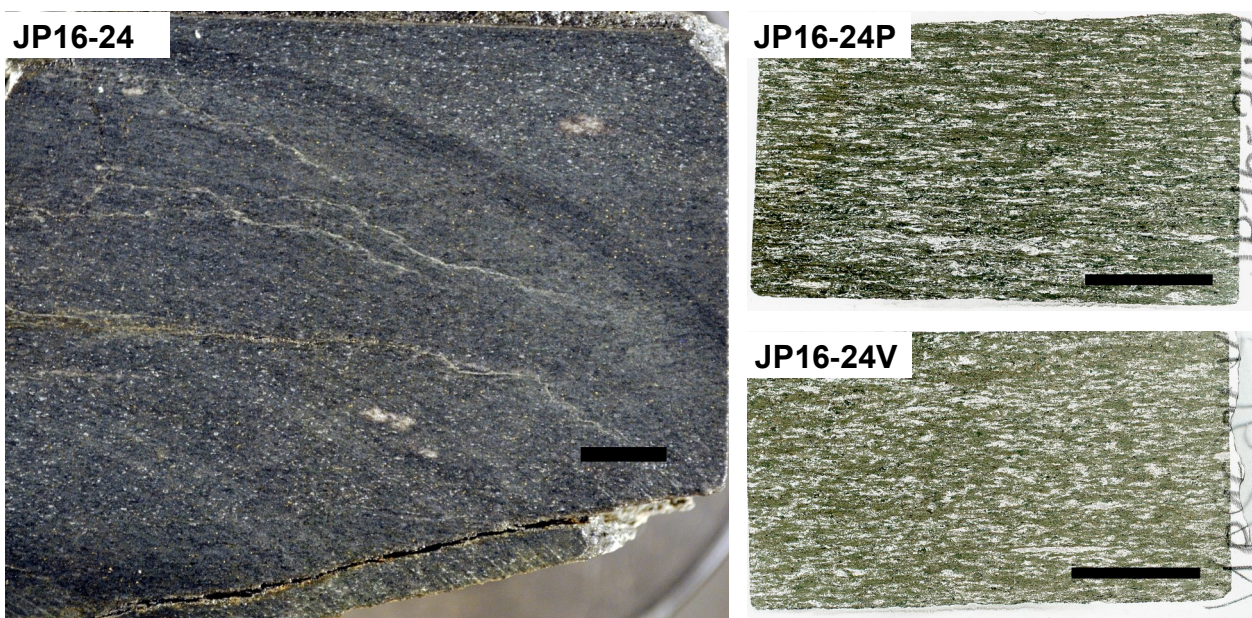


Fig. 27. Strongly foliated amphibolite sample near Bor (sample JP16-24). Scale-bars are 1 cm. **(A)** Hand sample of the fine-grained amphibolite with a wet surface. **(B)** Thin-section scan of the amphibolite cut parallel to the lineation, showing the abundance of blueish-green hornblende. Biotite occurs along with opaque grains, which are rimmed by colorless titanite. The colorless domains consist of polygonal quartz and plagioclase which contain fine-grained inclusions of epidote and biotite. **(C)** Thin-section scan of the sample cut perpendicular to the lineation.

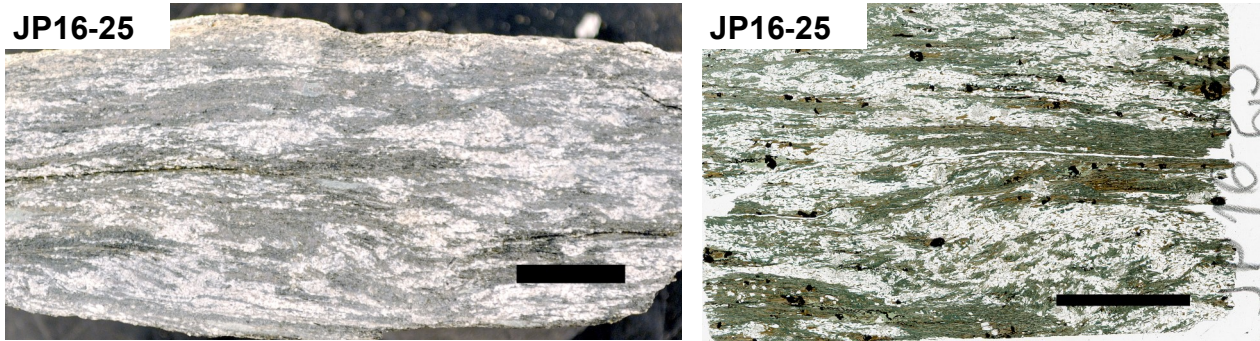


Fig. 28. Schistose metabasite sampled near Lake Furen (sample JP16-25). Scale-bars are 1 cm. **(A)** Hand specimen showing the schistose texture with elongate plagioclase-rich domains. **(B)** Scanned image of the thin-section. The dark-colored domains consist mainly of blueish-green hornblende, along with biotite and opaque mineral grains. The colorless domains contain mainly polygonal plagioclase and quartz, with a few larger grains of plagioclase (rich in inclusions) as possible relict magmatic grains.

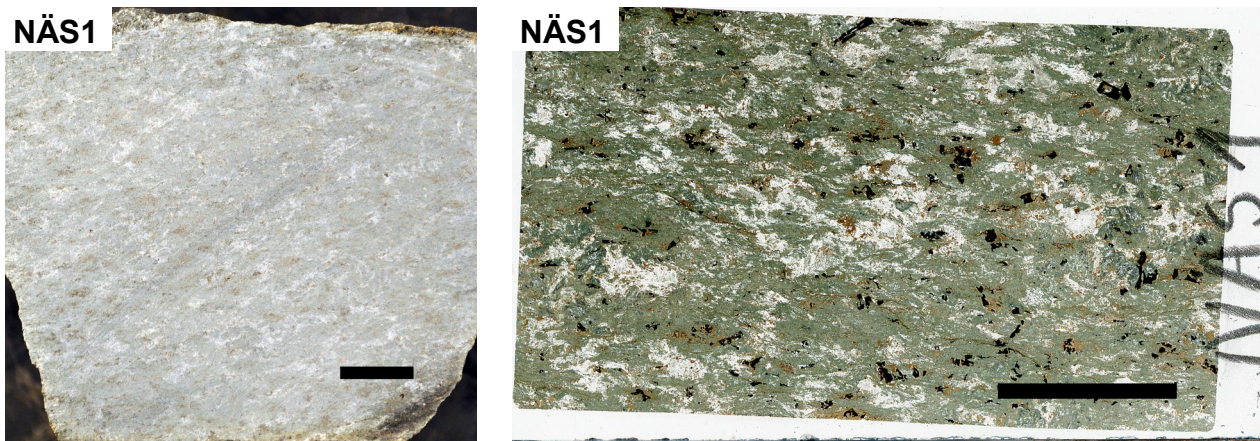


Fig. 29. First amphibolite sample from the Näsbyholm quarry (sample NÄS1). Scale-bars are 1 cm. **(A)** The hand specimen shows the medium- to fine-grained domainal texture. **(B)** The scanned thin-section image illustrates that blue-green hornblende dominates, and that opaque minerals are surrounded by biotite. The colorless domains consist of quartz and plagioclase (both small polygonal and larger grains with plenty of inclusions). Apatite and epidote are accessory phases.

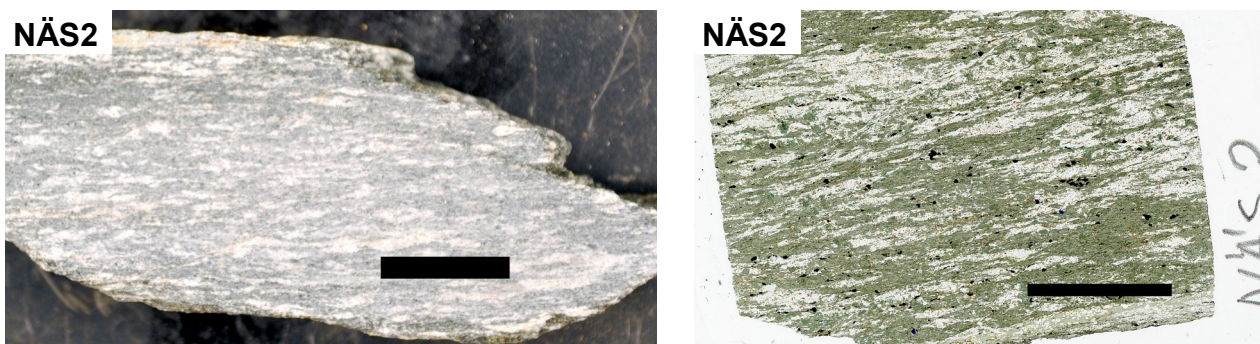


Fig. 30. Second amphibolite sample from Näsbyholm quarry (sample NÄS2). Scale-bars are 1 cm. **(A)** The hand sample shows a more deformed texture (with elongate plagioclase domains) than the previous sample from the same location. **(B)** Scan of the thin-section. Blue-green hornblende is the dominating mineral. The other colored minerals are biotite (partly chloritized) and opaque minerals. The colorless domains consist of aggregates of plagioclase, quartz and minor biotite. A small-scale shear is visible through the upper-middle part of the thin-section. On the bottom-right, a band dominated by chlorite occurs. Accessory apatite is also observed.

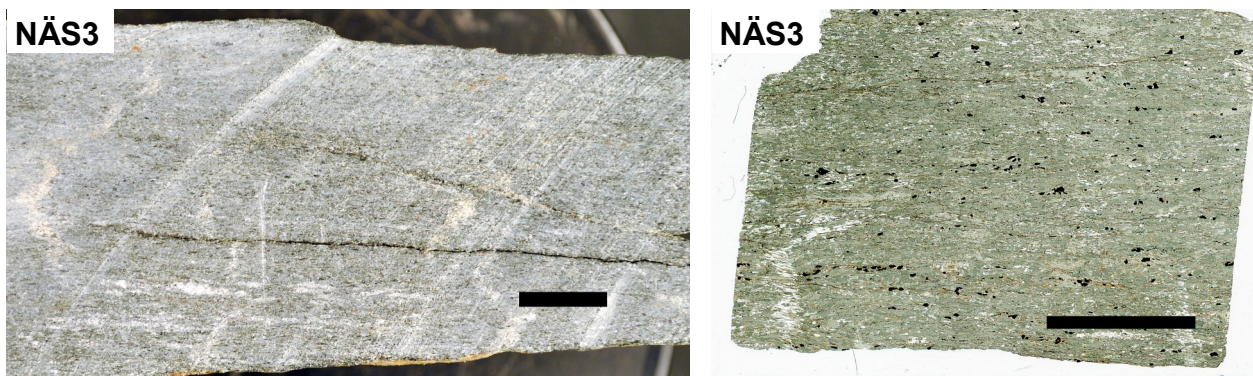


Fig. 31. The third sample from Näsbyholm quarry is a fine-grained metabasite (sample NÄS3). Scale-bars are 1 cm. **(A)** The hand specimen shows the fine-grained texture. **(B)** Scanned thin-section image. The rock is dominated by green hornblende, along with biotite-chlorite intergrowths and opaque grains. The light-colored minerals are plagioclase, quartz and apatite.

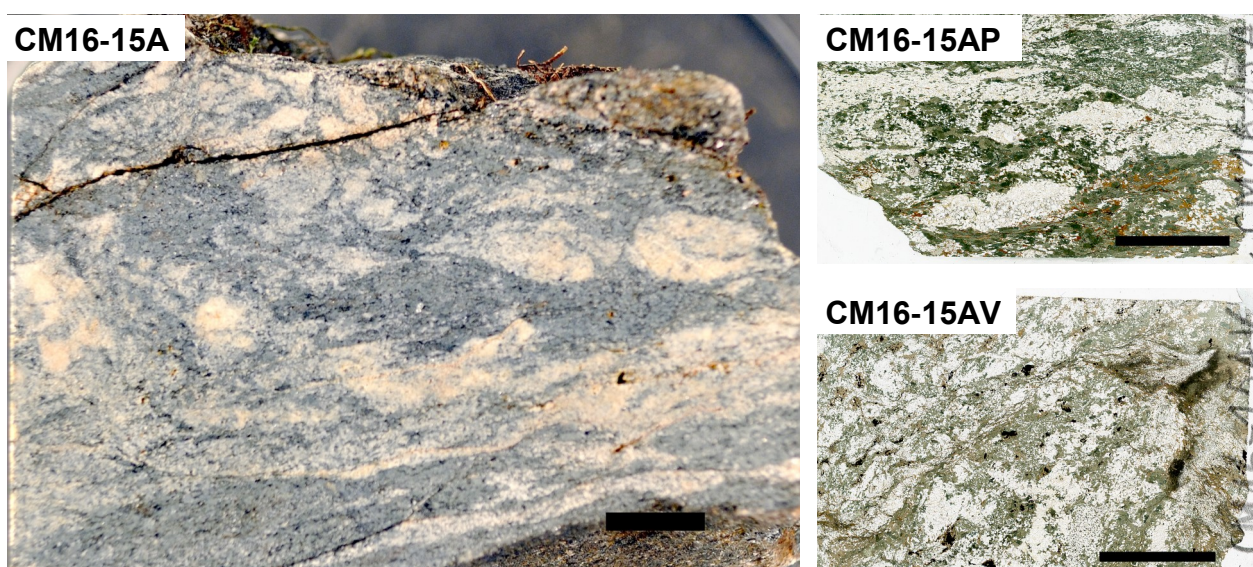


Fig. 32. Fine- to medium-grained amphibolite from Hindsen (sample CM16-15A). Scale-bars are 1 cm. **(A)** Image of the hand sample illustrating the amphibolite with centimeter-sized plagioclase-rich domains. **(B)** Scan of thin-section cut parallel to the lineation. Colored domains contain mainly blueish-green hornblende, along with biotite and opaque minerals. The light-colored domains consist of plagioclase (partly saussuritized) and quartz grains, both with polygonal to sutured grain boundaries. **(C)** Scan of thin-section cut perpendicular to the lineation.

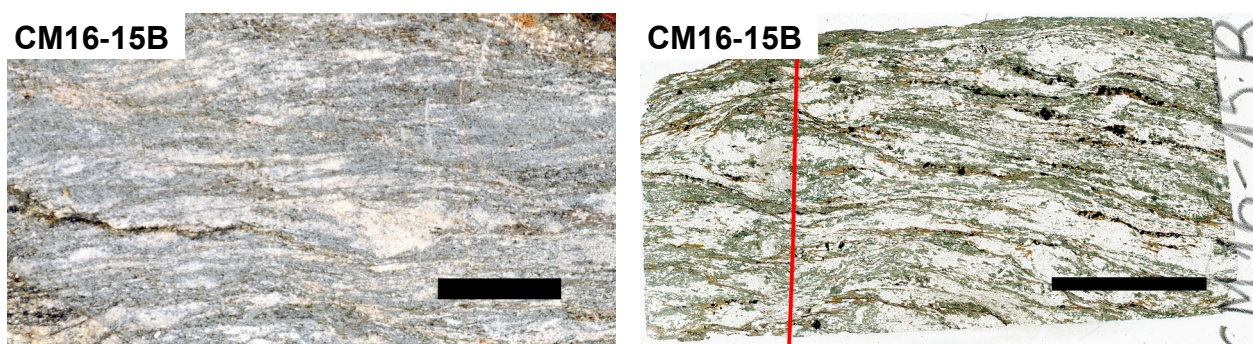


Fig. 33. Second amphibolite sample from Hindsen (sample CM16-15B). Scale-bars are 1 cm. **(A)** Hand specimen shows the deformed texture with elongate plagioclase-rich domains. **(B)** Thin-section scan illustrates the deformed texture. Hornblende, biotite, and opaque minerals comprise the foliae of the sample. Plagioclase and quartz make up the colorless domains. Apatite occurs as an accessory mineral. A minute brittle fracture cuts across the foliation on the left side of the thin-section (approximately outlined by the red line) and is associated with sericitization of plagioclase along the fracture.

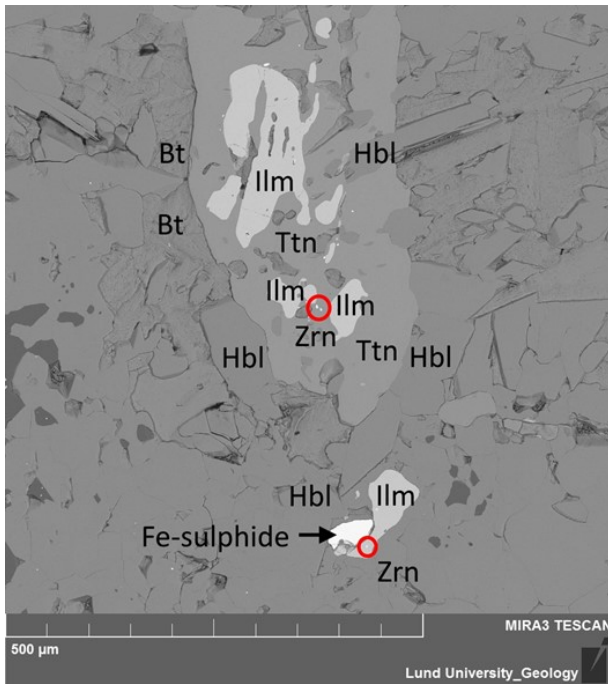


Fig. 34. Back-scatter electron image of metagabbro with relict magmatic texture from Boarydsvägen, Målaskog (sample JP16-01). Anhedronal remnants of an ilmenite grain (center) is surrounded by titanite with tiny grains of zircon (red circle). The titanite pseudomorph after ilmenite is surrounded by a matrix of hornblende and biotite with minor plagioclase and Fe-sulphide (arrow).

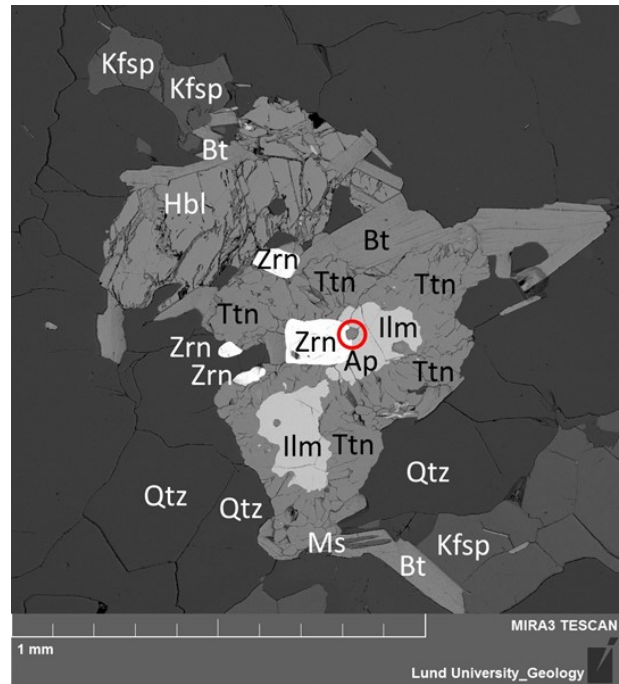


Fig. 35. Back-scatter electron image of a granitic gneiss from Mjöhult (sample JP16-03). Anhedronal ilmenite (center), intergrown with zircon (bright white), is surrounded and partly pseudomorphed by an aggregate of fine-grained titanite. Amphibole, biotite, apatite (red circle), allanite, garnet, and muscovite occur around the titanite-aggregates. The surrounding matrix consists of quartz, K-feldspar, and plagioclase.

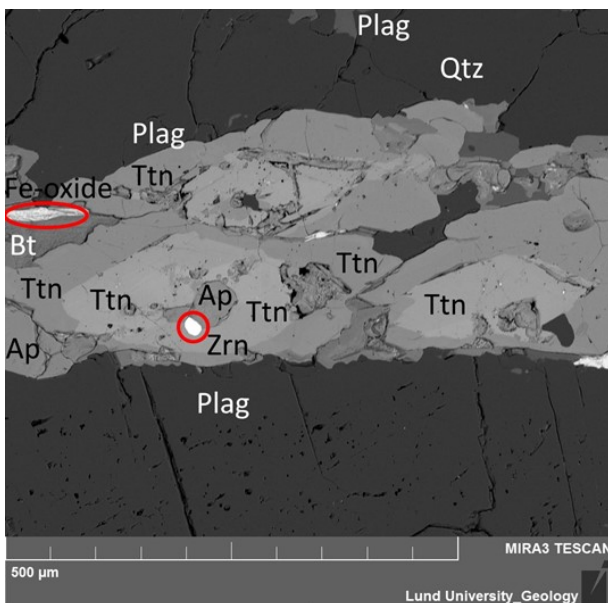


Fig. 36. Back-scatter electron image of a granitic gneiss with relict medium- to coarse-grained texture, sampled 2 km west of Os (sample JP16-18). The center of the image shows the and elongated aggregate, made up of titanite, biotite, epidote, Fe-oxide (red oval), and zircon (red circle). The titanite grains have lighter-colored cores and darker rims in BSE. The surrounding matrix consists of quartz, K-feldspar (top), and sericitized plagioclase (bottom).

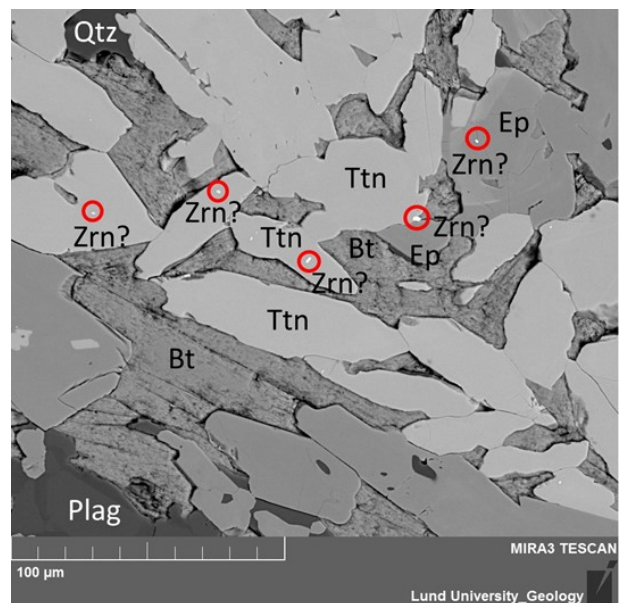


Fig. 37. Back-scatter electron image of a strongly foliated amphibolite sampled at Skaverås (sample JP16-22). An aggregate of subhedral titanite (light grey) grains with minute zircon grains encircled in red. Anhedronal biotite is seen filling the space in-between the titanite grains. Zoned, anhedronal epidote is seen top-right in the picture.

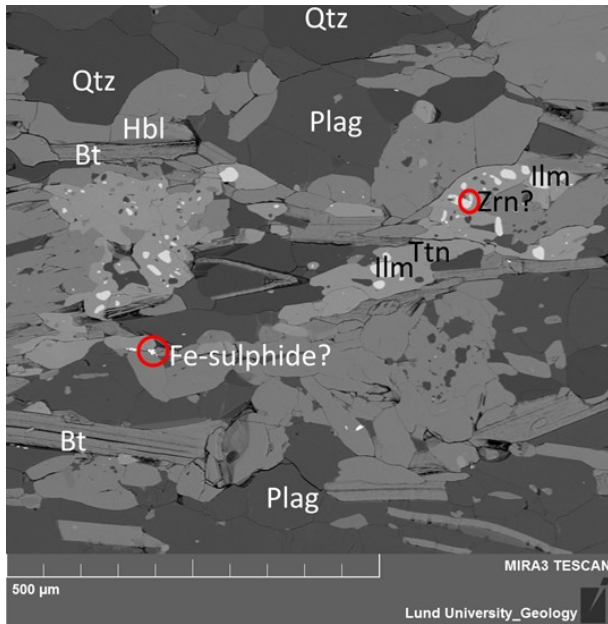


Fig. 38. Back-scatter electron image of a fine-grained and foliated amphibolite sample, from Bor (sample JP16-24). Subhedral titanite aggregates with bright-grey ilmenite-remnants are seen in the middle of the image. Elongate grains of hornblende and biotite surround the titanite aggregates. Minute zircon grains occur within titanite, biotite and hornblende, of which one is encircled red. At the top and bottom of the image, polygonal grains of plagioclase and quartz can be seen (dark-grey). Accessory Fe-sulphide is seen circled in red in left-center of the image.

5.4.5 JP16-24P, foliated amphibolite at Bor

The foliated amphibolite sample from Bor is dominated by an abundance of amphibole. The amphibole grains are subhedral to anhedral, and form the foliated fabric along with biotite, titanite, and ilmenite. Titanite occurs as polycrystalline grains, formed as rims around remnant cores of ilmenite. Minute zircons, less than 10 µm large, occur within the titanite grains (Fig. 38). Anhedral biotite grains are elongated, aligned with the foliae. Quartz and plagioclase grains are polygonal and make up the silica-rich domains of the sample. Anhedral grains of apatite, epidote and pyrite occur as accessory minerals.

5.4.6 Calcium content in titanite

During the SEM investigation, EDS-analysis of calcium content within titanite grains was carried out. Samples JP16-01, JP16-13, and JP16-22P contained titanite with apparently homogenous compositions. Sample JP16-18 contained titanite grains with cores of

Table 2. Calcium-content (wt-%) in titanite minerals, measured in each sample by EDS-analysis.

Sample	JP16-01	JP16-03	JP16-18 rim	JP16-18 core	JP16-22P
⁴³ Ca wt%	20,53	20,68	20,73	20,12	20,60
Data points	5	22	9	14	14

Table 3. Results of temperature estimates calculated using the Zr-in-titanite thermometer, for four samples and three chosen pressures. Estimates for JP16-18 are split into two analyses of titanite-cores and -rims. Temperature-estimates for each sample are shown based on lowest, mean and maximum estimates. Internal analytical error is ±1°C and external analytical error-values based on the MKED1 titanite standard accounts to ±32-46°C

Pressure 0.3 GPa			
Sample (nr. of spots)	Min. T [°C]	Mean T [°C]	Max. T [°C]
JP16-01 (11)	643	652	657
JP16-03 (21)	581	618	642
JP16-18 rim (14)	632	653	666
JP16-18 core (4)	757	759	761
JP16-22P (10)	626	650	672
Pressure 0.6 GPa			
Sample (nr. of spots)	Min. T [°C]	Mean T [°C]	Max. T [°C]
JP16-01 (11)	676	685	691
JP16-03 (21)	612	650	675
JP16-18 rim (14)	664	686	700
JP16-18 core (4)	794	796	798
JP16-22P (10)	658	683	706
Pressure 0.9 GPa			
Sample (nr. of spots)	Min. T [°C]	Mean T [°C]	Max. T [°C]
JP16-01 (11)	709	719	724
JP16-03 (21)	643	682	708
JP16-18 rim (14)	697	720	734
JP16-18 core (4)	832	833	836
JP16-22P (10)	690	716	740

a brighter color than the rims. The distinction between core and rims of the titanites promoted the decision to separate the analysis of titanites in JP16-18 into two: JP16-18 rim and JP16-18 core. Results showing the calcium content in the samples are shown below, in Table 2.

5.5 LA-ICP-MS Zr-in-titanite thermometry

Out of the five samples, four (JP16-01, JP16-03, JP16-18, and JP16-22P) provided data useful for Zr-in-titanite thermometry. Table 3 shows the results of Zr-in-titanite thermometry. The results are for TiO_2 -activity of 0.95, based on activity values for ilmenite-bearing, rutile-absent amphibolite (Chambers & Kohn 2012). SiO_2 -activity was set to 1, as all samples were estimated to be within the α -quartz stability field. Pressures used for calculating the temperature are 0.3, 0.6, and 0.9 GPa. Table 4 and 5 shows further information on the analyses such as the measured concentrations for a selection of elements.

6 Interpretation and discussion

6.1 Petrography

6.1.1 The Ryssby area

The five samples from the Ryssby area comprise four mafic samples and one felsic sample, all within an area characterized by N-S-trending and non-penetrative deformation (Fig 2B-C). All mafic samples contain metamorphic hornblende and biotite, and two of them (JP16-01 and JP16-05) neoblasts of metamorphic plagioclase. Sample JP16-01 also contains metamorphic quartz, titanite, calcite, and epidote. Very fine-grained garnet occurs in some of the coronae in coronitic metagabbro (JP16-02). The felsic sample (JP16-03) contains metamorphic biotite, hornblende, epidote, titanite, and minor garnet. The interlobate to polygonal grain boundaries of quartz, plagioclase, and K-feldspar suggest dynamic recrystallization into static recrystallization. Epidote occurs in two samples (JP16-01 and JP16-03) whereas hornblende occurs in all the samples in this area, suggesting that the metamorphic conditions reached epidote amphibolite-facies. The partly preserved igneous fabric in metagabbro (JP16-01 and JP16-02) complete recrystallization did not occur.

6.1.2 The Lammhult area

The ten samples from the Lammhult area consists of seven mafic, one intermediate, and two felsic samples. The foliation strikes E-W to SE-NW, and dips steeply (68-90 degrees to the south). Of the mafic samples, three contain what was interpreted as metamorphic hornblende. All the mafic samples contain one or several of the metamorphic minerals commonly found in greenschist-facies assemblages, such as chlorite, epidote and muscovite. Four samples contained recrystallized plagioclase grains (JP16-07, JP16-10, JP16-11, and JP16-14) Metamorphic titanite is apparent in two

samples (JP16-06 and JP16-10), and possible in two additional samples (JP16-12 and JP16-13), occurring as minute grains or rims around opaque minerals. Zoisite was found in one sample (JP16-14). The mesocratic sample (JP16-13) contained metamorphic plagioclase, quartz, hornblende, and epidote. The felsic sample JP16-09 contains metamorphic biotite, muscovite, and chlorite along with sutured quartz-grains possibly formed by bulging recrystallization. Also felsic, sample JP16-15 contains metamorphic epidote along with quartz-grains which show grain size reduction by recrystallization. In total four samples contained metamorphic hornblende (suggestive of amphibolite-facies), but none contained an exclusively amphibolite-facies assemblage of minerals. The metamorphic grade of the Lammhult area is suggested to be greenschist-facies to lower amphibolite-facies.

6.1.3 The Bor area

The fifteen samples from the Bor area consist of ten mafic samples and five felsic samples. The rocks show a steeply dipping foliation (78-90 degrees) which trends approximately N-S. Nine of the mafic samples have mineral assemblages formed by metamorphic recrystallization. These amphibolite-samples have metamorphic assemblage consisting of hornblende, biotite, plagioclase and quartz. Metamorphic zircon occurs in five samples (JP16-20, JP16-22, JP16-24, JP16-25, and NÄS2), and metamorphic titanite in two samples (JP16-22 and JP16-24). Metamorphic epidote occurs in five samples (JP16-20, JP16-22, JP16-24, JP16-25, and NÄS1). Sample NÄS2 contains chloritized biotite and a band of chlorite; and NÄS3 from the same location is dominated by both hornblende and chlorite. Sample JP16-16 has a mainly magmatic mineral assemblage with signs of low-grade metamorphism in the pyroxene and olivine grains, where the olivine has been replaced by fine-grained minerals. The five felsic samples contain polygonal quartz grains and quartz ribbons suggestive of grain coarsening. The plagioclase and/or K-feldspar grains in these five samples have sutured grain boundaries with neoblast formation showing dynamic recrystallization. Metamorphic epidote and muscovite is present in four of the samples (JP16-17A, JP16-19, JP16-21, and JP16-23), of which two have foliation defined by muscovite (JP16-17A and JP16-19). Chloritized biotite occurs in five samples (JP16-18, JP16-19, JP16-21, JP16-23, and NÄS2). Garnet occurs in two samples (JP16-21 and JP16-23) and allanite occurs in one sample (JP16-23). Two of the felsic samples (JP16-17A and JP16-19) contain shear sense indicators suggesting a west-side-up sense of shear. The muscovite-bearing mineral assemblages of these felsic samples along with the signs of recrystallisation and grain coarsening suggest low- or middle-amphibolite-facies. Considering the mafic samples, these clearly show an amphibolite-facies mineral assemblage with minor epidote- and titanite (where secondary chlorite is interpreted as formed from biotite during post-deformational fluid infiltration). Based on these observations, the Bor area is suggested to have experienced epidote amphibolite-facies metamorphism.

Table 4. LA-ICP-MS analyses of titanite minerals in samples JP16-01 and JP16-03 including sample information, internal standard and calculated concentrations of a selection of elements.

JP16-01	Calculated concentrations [ppm]											
Spot #	Ti	2σ	Zr	2σ	La	2σ	Ce	2σ	Nd	2σ	Hf	2σ
Spot 1	2,5E+05	4,9E+03	65,3	1,5	48,8	1,1	374,0	11,0	628,0	16,0	5,3	0,1
Spot 2	2,4E+05	2,0E+03	80,6	1,1	60,8	0,7	432,1	4,5	630,7	6,3	5,7	0,1
Spot 3	2,4E+05	2,8E+03	76,0	1,8	55,4	0,8	406,1	6,7	630,0	10,0	5,5	0,2
Spot 4	2,3E+05	3,6E+03	80,7	2,1	59,1	1,4	415,4	8,3	615,0	12,0	5,6	0,2
Spot 5	2,4E+05	8,7E+03	68,7	3,5	53,1	2,7	414,0	16,0	707,0	27,0	5,9	0,3
Spot 6	2,4E+05	1,7E+04	80,2	5,3	63,8	5,2	498,0	21,0	754,0	31,0	6,7	0,5
Spot 6a	2,5E+05	2,8E+03	80,9	1,2	60,6	0,8	461,9	6,4	814,1	8,8	7,1	0,2
Spot 7	2,4E+05	2,4E+03	80,5	1,2	61,1	0,9	440,3	5,2	715,3	8,8	6,7	0,1
Spot 8	2,4E+05	5,0E+03	84,3	2,2	69,4	1,5	541,0	11,0	854,0	18,0	5,8	0,2
Spot 9	2,4E+05	2,0E+03	83,9	1,3	61,1	0,8	465,9	5,3	772,6	8,8	5,7	0,1
Spot 10	2,4E+05	2,5E+03	88,8	1,6	68,7	1,1	499,0	7,5	780,0	13,0	5,9	0,1

JP16-03	Calculated concentrations [ppm]											
Spot #	Ti	2σ	Zr	2σ	La	2σ	Ce	2σ	Nd	2σ	Hf	2σ
Spot 1	2,0E+05	2,1E+03	63,2	1,6	10,7	0,2	106,8	1,6	350,6	4,0	4,9	0,1
Spot 2	1,9E+05	2,2E+03	41,1	0,8	5,0	0,1	78,4	1,0	327,8	4,1	3,3	0,1
Spot 3	1,8E+05	4,3E+03	40,8	1,2	7,9	0,3	99,7	2,8	404,0	10,0	3,7	0,1
Spot 4	2,0E+05	2,6E+03	48,3	1,0	7,4	0,1	103,5	1,3	395,0	5,0	4,1	0,1
Spot 5	1,9E+05	2,9E+03	42,3	1,0	4,4	0,2	64,3	1,2	318,5	5,0	3,5	0,1
Spot 6	1,9E+05	2,2E+03	32,3	0,9	3,0	0,1	51,6	0,8	282,0	3,9	2,9	0,1
Spot 7	2,0E+05	1,9E+03	67,5	2,1	10,7	0,5	112,7	1,6	362,2	3,8	5,3	0,2
Spot 8	1,7E+05	2,4E+03	19,9	0,6	0,7	0,0	14,3	0,4	114,5	2,8	2,7	0,1
Spot 9	2,0E+05	4,8E+03	36,7	1,4	2,4	0,1	44,4	1,5	311,0	10,0	4,4	0,2
Spot 10	1,8E+05	1,8E+03	15,1	0,7	1,7	0,2	14,4	0,8	92,8	3,8	2,2	0,1
Spot 12	2,0E+05	2,9E+03	44,2	1,0	12,8	0,2	109,7	1,7	297,7	4,8	3,9	0,1
Spot 13	2,0E+05	2,2E+03	33,5	0,7	8,0	0,3	70,0	1,5	200,0	3,5	3,0	0,1
Spot 14	2,0E+05	3,1E+03	26,8	0,9	5,1	0,2	45,2	1,0	134,1	3,5	2,4	0,1
Spot 15	1,9E+05	3,6E+03	24,9	0,9	5,6	0,2	46,7	1,5	136,7	4,3	2,3	0,1
Spot 18	1,9E+05	2,1E+03	26,6	0,6	4,7	0,2	46,8	1,3	134,5	3,0	2,1	0,1
Spot 19	2,0E+05	2,3E+03	37,6	0,9	8,8	0,3	76,8	1,9	201,4	4,9	3,3	0,1
Spot 20	2,0E+05	3,0E+03	36,4	1,0	3,4	0,1	53,1	1,6	266,0	7,6	3,4	0,1
Spot 21	1,9E+05	3,2E+03	29,0	1,1	3,6	0,2	45,7	2,0	238,4	9,6	2,7	0,1
Spot 22	2,0E+05	2,6E+03	35,9	1,1	3,7	0,1	52,5	1,6	257,4	6,7	3,2	0,1
Spot 23	2,1E+05	2,9E+03	44,3	1,3	5,6	0,1	78,8	1,7	387,0	6,6	4,1	0,1
Spot 24	1,9E+05	3,0E+03	33,1	1,1	4,1	0,2	55,6	1,8	286,0	8,3	3,0	0,1

Table 5. LA-ICP-MS analyses of titanite minerals in samples JP16-18 (split into two sets of titanite-cores and -rims) and JP16-22P including sample information, internal standard and calculated concentrations of a selection of elements.

JP16-18												
Calculated concentrations [ppm]												
Spot #	Ti	2 σ	Zr	2 σ	La	2 σ	Ce	2 σ	Nd	2 σ	Hf	2 σ
Spot 25	2,2E+05	2,8E+03	100,3	2,0	10,7	0,3	71,3	1,4	130,3	2,6	8,6	0,2
Spot 26	2,2E+05	2,8E+03	85,6	2,0	6,7	0,2	43,5	0,9	76,4	1,4	7,0	0,2
Spot 27	2,2E+05	4,6E+03	89,9	2,7	8,9	0,3	59,7	1,5	105,6	2,6	7,9	0,2
Spot 32	2,2E+05	2,7E+03	101,6	1,8	15,0	0,3	110,7	1,7	218,8	3,7	9,8	0,2
Spot 33	2,3E+05	3,0E+03	91,2	1,8	13,0	0,3	91,1	1,6	169,3	2,5	8,6	0,3
Spot 34	2,2E+05	5,1E+03	58,2	2,1	4,2	0,2	30,7	1,0	60,8	1,7	6,5	0,2
Spot 35	2,2E+05	4,1E+03	73,9	2,3	6,1	0,2	42,9	1,5	81,8	2,6	7,3	0,2
Spot 38	2,2E+05	3,3E+03	50,6	1,1	14,9	1,9	72,1	6,8	77,6	3,8	5,5	0,2
Spot 39	2,2E+05	2,6E+03	73,8	1,6	5,4	0,2	35,4	0,7	63,0	1,2	7,0	0,2
Spot 40	2,2E+05	3,4E+03	88,6	1,9	9,5	0,3	64,7	2,0	115,8	3,7	7,9	0,2
Spot 41	2,3E+05	4,0E+03	107,1	2,5	25,5	1,6	159,0	5,3	270,7	5,6	9,9	0,3
Spot 42	2,3E+05	3,2E+03	85,7	1,6	23,8	0,6	162,4	2,8	293,6	3,5	8,3	0,2
Spot 43	2,2E+05	3,0E+03	65,1	1,2	4,9	0,1	32,7	0,7	57,0	1,1	6,3	0,2
Spot 46	2,2E+05	3,4E+03	56,5	1,5	4,1	0,1	27,8	0,5	49,7	1,0	5,9	0,2

JP16-18												
Calculated concentrations [ppm]												
Spot #	Ti	2 σ	Zr	2 σ	La	2 σ	Ce	2 σ	Nd	2 σ	Hf	2 σ
Spot 36	2,3E+05	3,3E+03	619,0	12,0	2813,0	48,0	7970,0	180,0	5680,0	75,0	54,4	0,8
Spot 37	2,3E+05	2,8E+03	605,0	12,0	2883,0	52,0	7790,0	160,0	5501,0	71,0	53,0	0,8
Spot 44	2,3E+05	4,2E+03	619,0	13,0	2803,0	60,0	7700,0	190,0	5689,0	96,0	53,0	1,0
Spot 45	2,3E+05	3,8E+03	646,0	11,0	2652,0	40,0	7570,0	130,0	5680,0	74,0	58,3	0,9

JP16-22P												
Calculated concentrations [ppm]												
Spot #	Ti	2 σ	Zr	2 σ	La	2 σ	Ce	2 σ	Nd	2 σ	Hf	2 σ
Spot 11	2,4E+05	4,3E+03	79,2	2,0	3,4	0,1	27,6	0,8	49,9	1,5	6,6	0,2
Spot 12	2,4E+05	2,3E+03	120,7	2,3	9,7	0,3	75,6	2,3	134,8	3,6	10,0	0,1
Spot 13	2,4E+05	3,7E+03	66,9	2,8	1,8	0,1	13,2	0,6	25,3	1,0	5,9	0,2
Spot 14	2,4E+05	3,0E+03	76,6	2,4	1,8	0,1	14,7	0,5	28,1	1,0	6,9	0,2
Spot 17	2,4E+05	2,6E+03	76,0	1,6	3,9	0,1	31,6	1,1	61,0	2,1	7,2	0,2
Spot 18	2,4E+05	2,4E+03	61,7	1,9	2,2	0,1	16,8	0,5	32,4	0,9	6,2	0,2
Spot 19	2,4E+05	2,3E+03	44,1	2,4	2,0	0,1	16,0	1,0	31,9	1,7	4,4	0,2
Spot 20	2,4E+05	3,5E+03	57,2	1,4	2,8	0,2	24,0	1,5	52,6	2,7	6,0	0,1
Spot 21	2,4E+05	2,6E+03	88,4	1,7	2,4	0,1	18,5	0,5	37,0	0,7	8,1	0,1
Spot 22	2,4E+05	2,7E+03	85,8	1,6	4,4	0,1	34,8	0,9	70,6	1,5	8,9	0,2

6.1.4 Interpretations from the petrography

The petrographic analysis shows that the main differences between the samples occur between samples from Bor and Ryssby versus the samples from Lammhult.

The samples from Bor and Ryssby consist of epidote amphibolite-facies assemblages. Chlorite replacing biotite occurs as a minor constituent, indicating that the rocks underwent late-stage local greenschist-facies fluid infiltration. Garnet was observed in five samples, from Bor (JP16-02, JP16-03, CM16-15A) and Ryssby (JP16-21, JP16-23), of which JP16-02 and CM16-15A are mafic and situated in the westernmost part of the study area. The rocks from Bor and Ryssby show a general trend in foliation of approximately N-S. The N-S striking foliation of the Ryssby and Bor areas is interpreted as formed during Sveconorwegian deformation and metamorphism. The amphibolite-facies rocks seem to be limited to areas where the foliation strikes roughly N-S. Petrographic observations of the samples from Bor and Ryssby show that there is no clearly distinguishable difference in metamorphic grade from east to west within these two sub-areas.

The samples from Lammhult show a relatively consistent greenschist-facies assemblage locally however with metamorphic hornblende. Three of the samples from around Lammhult (JP16-09, JP16-11, JP16-14) contain amphiboles which are very pale as seen in the petrographical microscope, a feature which were not observed in any samples from the other two areas. The pale amphiboles could reflect a host rock more Mg-rich than those prevalent in the Ryssby and Bor areas. Alternatively, some of these pale amphiboles may possibly be igneous remnants or formed during pre-Sveconorwegian metamorphism. Samples from the Lammhult area more commonly have metamorphic epidote, muscovite and chlorite in comparison to Bor and Ryssby samples. Garnet was not found in samples from the Lammhult area. The titanite-grains observed in rocks from Lammhult were too small for analysis with LA-ICP-MS, occurring as minute grains or rims. This suggests that either the chemical composition of the rock did not allow for formation of significant amounts of titanite, or that the pressure-temperature conditions needed for formation were not met. The foliation in the Lammhult area is roughly ESE-WNW with steep southerly dips. The greenschist-facies rocks are delimited to the Lammhult area, corresponding with the east-westerly foliation. They are interpreted to have escaped the Sveconorwegian overprint, and instead show earlier, possibly Paleoproterozoic, deformation.

6.2 LA-ICP-MS

6.2.1 Results and interpretations

The temperature estimates (Table 3) for the titanite cores in sample JP16-18 show elevated values, circa 100 °C higher than the other samples. The Zr-content is prominently higher in comparison to the other samples (605-646 ppm versus 15-121 ppm). Rare-earth elements such as ^{139}La , ^{140}Ce , ^{146}Nd and ^{178}Hf are elevated from one to three orders of magnitude in the titanite cores in comparison to the titanite rims, and

also in comparison to the other samples (see Table 4 and 5). The resulting temperature estimates from the titanite-cores in sample JP16-18 are therefore suggested to reflect the igneous crystallization of the granite. This could then be in agreement with Söderlund et al. (1999), who found that brown titanites from the SFDZ were igneous, whereas colorless titanites from the same area produced ages which were related to Sveconorwegian reworking.

Out of the remaining four samples, three (JP16-01, JP16-18 rims and JP16-22P) yield temperature estimates which are close: 650-653°C at 0.3 GPa, based on mean values (Table 3), with JP16-03 yielding an estimate of 618°C at 0.3 GPa.

For each increment (0.3 GPa) of increased pressure the resulting temperature increase is between 32-37°C. Another variable important for the calculation of temperatures are the TiO_2 -activity. The estimated temperatures were calculated using a TiO_2 -activity of 0.95, as suggested for ilmenite-bearing but rutile-absent amphibolite (Chambers & Kohn 2012). The activity was chosen since ilmenite was identified in SEM-EDS in JP16-01 and JP16-03. For JP16-18 and JP16-22, opaque minerals suggested to be ilmenite were seen in optical microscopy but were not identified during the SEM-analysis. A decrease in TiO_2 -activity to 0.75, suggested for rutile-absent amphibolites (Kapp et al. 2009), would result in 9-14°C lower temperature estimates. The analytical error of the LA-ICP-MS is calculated to be $\pm 1^\circ\text{C}$, based on internal 2σ -error values. Error values based on the MKED1 titanite standard accounts to ± 32 -46°C.

Sector zoning may be a factor in calculating the estimated temperature values when using the Zr-in-titanite method. During optical microscopy and SEM-analysis only the sample JP16-18 showed obvious zonation in the titanite grains, which is the reason why temperature estimates for the sample is split into two: titanite cores and rims, which are interpreted as magmatic and metamorphic, respectively. The other three samples contain titanite grains which were too small to perform pinpoint-analysis on eventual zonation. As such, the values are possibly mixed if sector zoning is present. Hayden et al. (2008) showed that the use of Zr-enriched sectors resulted in temperature-overestimations of approximately 48°C at an actual temperature of 600°C for crystals which were zoned with a threefold increase in Zr-concentrations. The Zr-concentrations do differ for analyzed spots for each sample, as seen in Table 4 and 5. The felsic sample JP16-03 shows the greatest relative difference between measured ^{91}Zr -values, ranging from 15.14 ppm to 63.2 ppm. Temperature estimates based on the lowest ^{91}Zr -values measured instead of mean values would decrease the estimated values by 9-37°C (see Table 4). The thermometer adds another $\pm 20^\circ\text{C}$ of approximate uncertainty (Hayden et al. 2008).

The P-T-estimates for samples JP16-01, JP16-03, JP16-18 rims, and JP16-22 corresponds to amphibolite-facies. In contrast, the petrography shows that the metamorphic conditions were epidote amphibolite-facies. Using lowest possible estimations, the results corresponds to amphibolite-facies, although closer to epidote amphibolite-facies. If the metamorphism experienced would have been medium to high amphibolite-

facies, evidence for partial melting of particularly the felsic rocks would have been expected. No evidence for such were observed in this study. The actual temperature experienced is thus expected to be below the solidus for a water-saturated granite. The PT-conditions corresponding to most of the temperature estimates (for 0.6 and 0.9 GPa) end up past the solidus for a water-saturated granite. As such, partial melting could be expected in the felsic samples, which was not observed. The higher temperatures needed to melt mafic rock can explain the absence of partial melt in the mafic samples. An explanation for the discordance between petrographical observations of the felsic samples and corresponding PT-estimates could be that these rocks were not water-saturated and thus did not form any partial melt. Another explanation is overestimation due to analytical methods, such as the sector zoning in titanites. The sample which shows closest agreement between petrographic observations and PT-estimates is JP16-03 (612°C at 0.6 GPa). This estimate combines a high pressure enough for epidote amphibolite-facies together with a temperature below the granite wet solidus. Since the three other metamorphic samples yield approximately 50°C higher estimates, the true pressure and temperature is probably in between these. The suggested PT is 600-650°C at 0.6 GPa. The Zr-in-titanite thermometer was previously used to investigate the pressure-and temperature conditions of a gabbro from Herrestad, located within the transitional section of the Sveconorwegian Province, by another student at the Lund University (Filippa Karlstedt). The resulting estimates were 667-722°C at 0.9 GPa. These were correlated to pseudosection modeling and geothermobarometry; and suggested to reflect actual PT-conditions of approximately 610°C at 0.9 GPa. PT-estimates from the internal section of the Sveconorwegian Province for amphibolites are 680-750°C at 0.85-1.06 GPa (Wang & Lindh 1996). For granulites within the internal section, the estimates are 705°C at 0.81 GPa and 700-800°C at 0.85-1.17 GPa (Johansson et al. 1991; Wang & Lindh 1996). The results from this study show lower PT-conditions which may suggest that the metamorphic grade increases to the west. Both in this and a previous master thesis the Zr-in-titanite thermometer resulted in estimates which are suggested to be overestimations. It is therefore important to correlate the technique by other means, such as petrography in this study.

Further PT-modeling by means of geothermobarometric or pseudosection modeling are needed to corroborate the results in this study. Especially pressure estimates are needed to be used in tandem with the Zr-in-titanite geothermometer.

6.3 Structural implications

There is a difference in metamorphic conditions and trend of deformation between the epidote amphibolite-facies in the two western sub-areas, Ryssby and Bor; and the greenschist- to amphibolite-facies sub-area in the east, Lammhult.

The metamorphism associated with deformation in the Frontal Wedge is confined to the western sub-areas, and characterized by epidote amphibolite-facies conditions with only local greenschist-facies overprint. The sub-areas of Ryssby and Bor expose shear-zones

related to the Frontal Wedge in the study area. Movements along these shear-zones may have facilitated the uplift required to expose these rocks from an approximate depth of 20 km (0.6 GPa). Two mafic samples containing garnet were found in the western part of the Frontal Wedge, possibly indicating a higher grade of metamorphism towards the western part of the FW.

Within the Lammhult area it has not been possible to identify Sveconorwegian amphibolite- or greenschist-facies deformation zones such as reported for the SFDZ in the Karlskoga-Kristinehamn transect (Wahlgren et al. 1996). Instead, the metamorphism shows deformation trending ESE-WNW, suggested to be Paleoproterozoic in origin.

7 Conclusions

- Rocks from a transect within the Frontal Wedge show no obvious gradation in metamorphic facies from east to west, with the possible exception of two garnet-bearing mafic rocks.
- In the study area, the metamorphic facies associated with N-S trending deformation of the Sveconorwegian Frontal Wedge is epidote amphibolite-facies, with local greenschist overprint.
- Zr-in-titanite thermometry yielded temperature/pressure estimates of 650-686°C at 0.6 GPa, which are suggested to reflect real temperatures of 600-650°C at 0.6 GPa.
- Sveconorwegian amphibolite- or greenschist-facies deformation zones were not identified in the Lammhult area, such as for the SFDZ in the Karlskoga-Kristinehamn region. The metamorphic facies associated with the ESE-WNW trending deformation east of the Frontal Wedge is greenschist- to lower amphibolite-facies.

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10 Appendix

Table A. Additional information on methodology on the LA-ICP-MS analysis performed at Lund University.

Laboratory & Sample Preparation	
Laboratory name	Department of geology LA-ICP-MS laboratory
Sample type / mineral	Titanite
Sample preparation	Thin section
Laser ablation system	
Make, Model & type	Photon machines, Analyte G2 excimer laser
Ablation cell & volume	HelEx 2 sample cell
Laser wavelength	193 nm
Pulse width	<4 ns
Fluence	2 (S1) and 1.5 (S2) J/cm ²
Repetition rate	8 Hz
Spot size	20x20 (S1) 30x30 (S2) 90 µm
Sampling mode / pattern	Single spot analyses
Carrier gas	He gas with Ar make-up gas combined using a Y-connector downstream from sample chamber
Background collection	30 seconds
Ablation duration	30 seconds
Wash-out delay	2 seconds
Cell carrier gas flow	0.75 l/min He
ICP-MS Instrument	
Make, Model & type	Bruker Aurora Elite Quadrupole ICP-MS
Sample introduction	Via conventional tubing with insert “squid”
RF power	Ca. 1300 W
Make-up gas flow	Ca. 0.95 l/min Ar
Detection system	Single collector discrete dynode electron multiplier or DDEM
Masses measured (all 10 milliseconds dwell time)	⁴³ Ca, ⁴⁷ Ti, ⁵⁷ Fe, ⁸⁸ Sr, ⁸⁹ Y, ⁹⁰ Zr, ⁹¹ Zr, ¹³⁹ La, ¹⁴⁰ Ce, ¹⁴⁶ Nd, ¹⁴⁷ Sm, ¹⁶³ Dy, ¹⁷² Yb, ¹⁷⁸ Hf, ¹⁸¹ Ta
Total scan time	181 milliseconds
Data Processing	
Gas blank	30 seconds
Calibration strategy	MEKD1 (Spandler et al., 2016) as primary standard reference, Khan (Heaman, 2009) and ONT2 (Spencer et al., 2013) as secondary standard reference
Internal standard	⁴³ Ca with following concentrations: MKED (20.3 wt.%), Khan (20 wt.%)
Reference Material info	MKED1 - (Spandler et al., Chemical Geology 425 (2016) 110–126), Khan - (Heaman, Chemical Geology 261 (2009) 43–52)
Data processing	Iolite software (Paton et al. Journal of Analytical Atomic Spectrometry 26 (2011) 2508–2518)

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