Faculty of Science and Tecnology

Department of Geosciences

Tectono-metamorphic evolution of metasedimentary host rocks of ultramafic rocks in the Heidal/Sel Group, Trondheim Nappe Complex, Folldal: mineralogical and micro-textural changes during the Scandian thrusting

Christian Baug

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Acknowledgements

More than five years at the department of geosciences are over. It feels good.

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“School’s out forever”, Alice Cooper.

Christian Baug

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Abstract

Several ultramafic outcrops are located along a specific tectono-stratigraphic unit in the Trondheim Nappe Complex, Central Scandinavian Caledonides. The relative timing and kinematics of these rocks are investigated by the use of structural, petrographic and mineralogic data from its host rocks. The metasedimentary host rocks are part of the Sel and Heidal Groups of the Røros and Remsklepp Nappe Complex, in the Upper and Middle Allochthon. The investigated area is located in Folldal and Dovre municipalities, 145 km south of Trondheim, in Hedmark County, in the southern Trondheim Region Caledonides.

A geological map compiling data from petrographic and field observations show a wide range of mainly metasedimentary rocks hosting the ultramafic rocks. The most dominant host rocks are garnet-mica schists and quartz mylonites, but the various amount of mica and quartz generates several similar rock types, such as quartzites and metapsammites. After mica and quartz, garnets and chlorite are the most abundant minerals.

The dominant fabric in the area is the main foliation, with a gentle, general dip toward southwest, referred to as S1 and a result of a D1 deformation event. Porphyroblasts of garnet and amphibole are interpreted to be from this phase. Mylonites, with amphibolite facies mineral assemblage are prominent at the contacts of the thrust nappes, indicating they formed during peak metamorphism, just before or during the D2 event. The metasedimentary rocks further away from the thrust nappes show greenschist facies assemblage without any obvious kinematic indicators, indicating less strain. Presence of chlorite indicates retrograde metamorphism from the D3 event. The ultramafic rocks are altered through serpentinization, with soapstone at some local sites. The serpentinites contain various amounts of chromite and magnetite and locally large amounts of talc. They have a sharp contact with the host rocks, and no sign of contact metamorphism or partial melting is observed, indicating the ultramafic rocks were tectonically placed on top of the Heidal Group in the late Precambrian or early Palaeozoic, before sedimentation of the Sel Group.

Table of Contentsv

List of Figures

1 Introduction and aim of thesis

This thesis started as a cooperation with the NGU (Geological Survey of Norway/ Norges Geologiske Undersøkelse) in Trondheim, with the intention to investigate a series of ultramafic rocks in the Folldal area. The study area is located in Folldal and Dovre municipalities, 145 km south of Trondheim, in Hedmark County, in the southern Trondheim Region of the Central Scandinavian Caledonides (figure 1). The area of main interest, Raudhamran is situated 17 km to the east of the village of Dovre, in the Rondane National Park. There is a walking distance of about 3 km from the road to the ultramafic outcrops at Raudhamran.

The main objective of this master thesis is to examine the tectono-stratigraphic setting for the ultramafic bodies and to explore their structural architecure by mapping structures in the field and analysing the mineralogical and micro-textural changes during deformation in the surrounding rock units.

According to Nilsson et. al, (1997), dismembered parts of oceanic crust, and ultramafic mantle fragments of the prehistoric Iapetus Ocean were thrusted up and eastwards, between, and together with two sedimentary units, the Sel Group and Heidal Group (figure 2), during the formation of the Caledonides. This is the setting that will be explained below (see chapter 1.1).

The study involved fieldwork and laboratory work with petrographic studies. The first chapter gives an overview of the regional geology before closing in on the local geology and previous work. The results are presented with a revised geological map, petrographic data and thin section overviews. Interpretations of the results are based on petrographic studies of selected ultramafic rocks, and petrographic, mineralogical and micro-textural studies of the hosting meta-sedimentary and mylonitic shear zone rocks of the studied nappe units, in order to discuss the tectono-metamorphic evolution.

The aim was to examine the origin and evolution of the ultramafic rocks, as part of an ongoing project by NGU, called GEARS (GEologisk Arv i indre Skandinavia). The GEARS-project was established to map and explore different geological localities for evaluation of the geological heritage value. The Folldal area is one of three core areas for the GEARS project, also including the Fulufjell area and the Siljan meteoritic crater in Sweden. The rationale for studying the ultramafic rocks is their geological setting forming a series of isolated bodies in various metasedimentary units. On a regional scale the bodies form variable sized reddish coloured knolls, crags and small pinnacles and for people farming, hunting and hiking in these areas, it is one of the most frequent questions asked: what kind of rock is this and how was it formed? For geologists it is moreover a question of how the ultramafic bodies got there. This thesis will shed light on some of these questions, forming a base for subsequent dissemination to the public both in the form of animations, tourist guiding, posters and folders. The master thesis was initially intended to focus on the knolls and crags of the Folldal and Grimsdalen areas, but due to a thin but pervasive quaternary cover, the study area was moved further west and into higher altitudes to the area of Hornsjøhøe and Haverdalen. Raudhamran is a relatively larger body of utramafic rock situated close to the main hiking path between the cabins of Grimsdalhytta and Høvringen and being observed by many hikers and hunters every summer. The area was examined briefly in 2017 and in more detail in 2018. Several bodies of ultramafic rocks were found and mapped and most of these displayed outcrops of the best location for mapping, with contact relationships to the metasedimentary host rocks. Additionally, the best exposed ultramafic outcrops was Randhamran and 4-5 related smaller bodies. Shear zones, faults and folding in the wall rock are far better exposed here than in the Folldal and Grimsdalen areas.

1.1 Regional geology

The Scandinavian Caledonides are remnants of an old mountain range exposed over large parts of Norway and western Sweden. The Caledonian orogeny was initiated by the collision between two continents; Laurentia and Baltica (Roberts and Gee, 1985). Before the collision, in the late pre-Cambrian, the two continents were separated by the Iapetus Ocean, an equivalent to the present day Atlantic Ocean (Corfu et al., 2014). The orogeny is characterized by various nappes, conventionally divided into four allochthonous units or nappe complexes (figure 1): the Lower, Middle, Upper and Uppermost Allochthons (Roberts and Gee, 1985). Lower and Middle Allochthon are inferred to comprise sedimentary rocks derived from Baltica. Upper Allochthon consists of oceanic crust with diverse arc and basin associations, and the Uppermost Allochthon is the most exotic part, believed to have affinities with Laurentia (Roberts, 2003).

Parts of Baltica and Laurentia were eventually translated eastward over the Precambrian crystalline rocks of the Fennoscandian shield together with sheets of oceanic crust (ophiolites) and arc terranes, derived from the Iapetus Ocean (Roberts, 2003). The Scandian phase in Silurian times was the main thrusting event of the Caledonian orogeny. Zwart (1974) describes the peak metamorphism to be after the first folding phase (=F1), where the rocks were carried to depth, and before the second folding phase (=F2) when the rocks were thrust towards the surface. Remains of oceanic crust and ophiolitic rocks from the Iapetus Ocean are present all along the coast from Karmøy in the southwest to Lyngen in the northeast (Slagstad et al., 2014), mostly within the Upper and Uppermost allochthonous nappe units. Ophiolites are represented both as complete sequences, fragments and/or mainly as gabbro and ultramafic rocks along thrust boundaries of the initial Iapetus Ocean and island arc sequences (Slagstad et al., 2014).

Dewey & Bird (1971) explains the origin of ophiolites to be from either beneath or behind subduction zones or from obduction zones. They give a reason why this study is the right approach to reach the aim when they point out that the metamorphic relationships within and around ophiolite complexes probably reflect processes involved in both genesis and emplacement.

1.1.1 South central Norway

The Caledonian nappes in South Central Norway consist of several different terranes and lithological units of various origin (Corfu et al., 2014). The Köli Nappe and the Seve Nappe are terms used for large parts of Upper Allochthon and Middle Allochthon, respectively (figure 1) (Gee et. al., 2008), but they are redefined several times. Zwart (1974) describe the Seve Nappe Complex as a major unit of metasedimentary and meta-igneous rocks of unknown age. It is metamorphosed in the amphibolite facies and stretches from northern parts of Sweden to central parts of Sweden and Norway. He describes Köli as a sequence above Seve, consisting of sedimentary and volcanic rocks metamorphosed in the greenschist facies. This thesis will refer to the Seve Nappe as the upper part of the Middle Allochthon and the Köli Nappe as the lowest part of Upper Allochthon. In the Köli Nappe three foldsets are distinguished by Zwart (1974): The first set (F1) is characterized by isoclinal folds with varying attitude of axial planes and fold axis du to later folding. The second set (F2) refolds the F1 folds and often causes a crenulation cleavage (=S2) but also larger folds up to several hundreds of metres. The axial planes have a general dip towards west, although there are considerable local variations. The third set (=F3) forms open folds, folding the S2 crenulation cleavage. These folds have steep to vertical axial planes and directed N/NW, sub-parallel to the Caledonian trend. Seve rocks show similar features as Köli according to Zwart (1974).

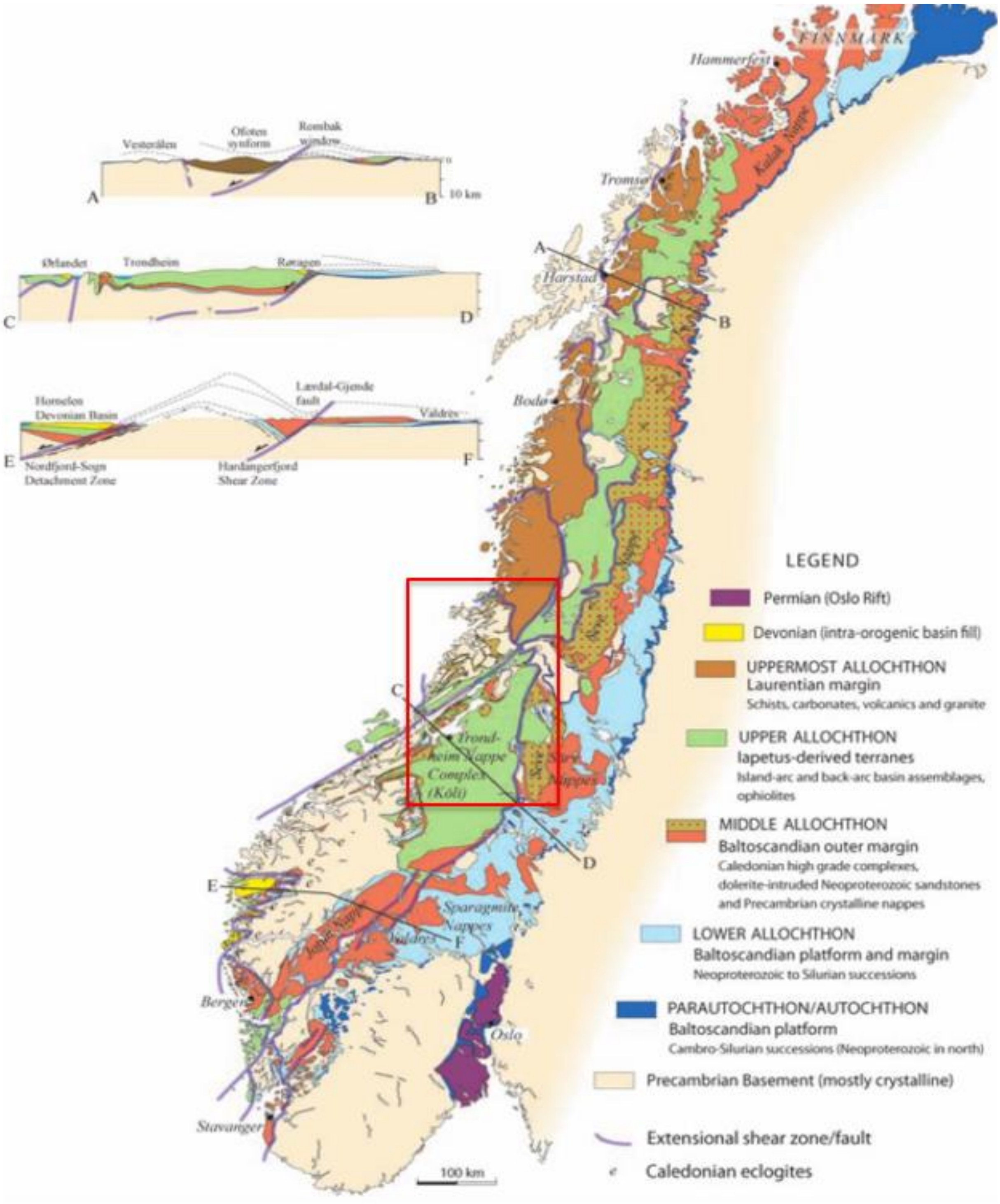

Figure 1: Map of the Scandinavian Caledonides with the central part of the Trondheim region marked with red square, and Seve and Kölo within the square (reworked from Gee, Fossen, Henriksen, & Higgins, 2008).

The Trondheim region of the Central Scandinavian Caledonides is largely dominated by a major slab of the Upper Allochthon (Ramsay & Sturt, 1998), but also significant parts of the Middle Allochthon. Nilsen and Wolff (1989) have compiled the different tectonostratigraphic models and names proposed for the area through the years, in a 1:250 000 map. In this context, the study area of this work is located at the border of the Røros Nappe Complex (Köli Nappe) and the Remsklepp Nappe Complex (Seve Nappe).

According to Nilsen (1988) the history of the relevant area in the Trondheim region was former sea-floor (parts of Köli Nappe) obducted onto metasedimentary rocks (Seve Nappe) with a following uplift and erosion before extensive sedimentation took place. This, in short explains the geological setting before the Caledonian folding and metamorphism commenced.

1.1.2 The Folldal area

In the area between Folldal and Røros, several ultramafic intrusions (pods and lenses) can be traced in a certain tectono-stratigraphic level along strike of the metamorphic nappe rocks (figure 2). These intrusions are interpreted to be a part of the Vågåmo Ophiolite, which stretches from Otta in the southwest to Feragen in the northeast (Nilsson et al., 1997). This ophiolitic terrane is believed to have been "…thrusted onto rocks of the supracrustal Heidal Group, uplifted and deeply eroded before the deposition of the sedimentary and volcanic Sel Group" (Nilsson et al., 1997), resulting in an unconformity between the two groups. Both of these groups and the contact between them can be seen in the studied area near Folldal (figure 3).

The Støren Nappe, Gula Nappe and Meråker Nappe dominate the northern part of the Trondheim Nappe Complex (Nilsen, 1988), the southern part is described below.

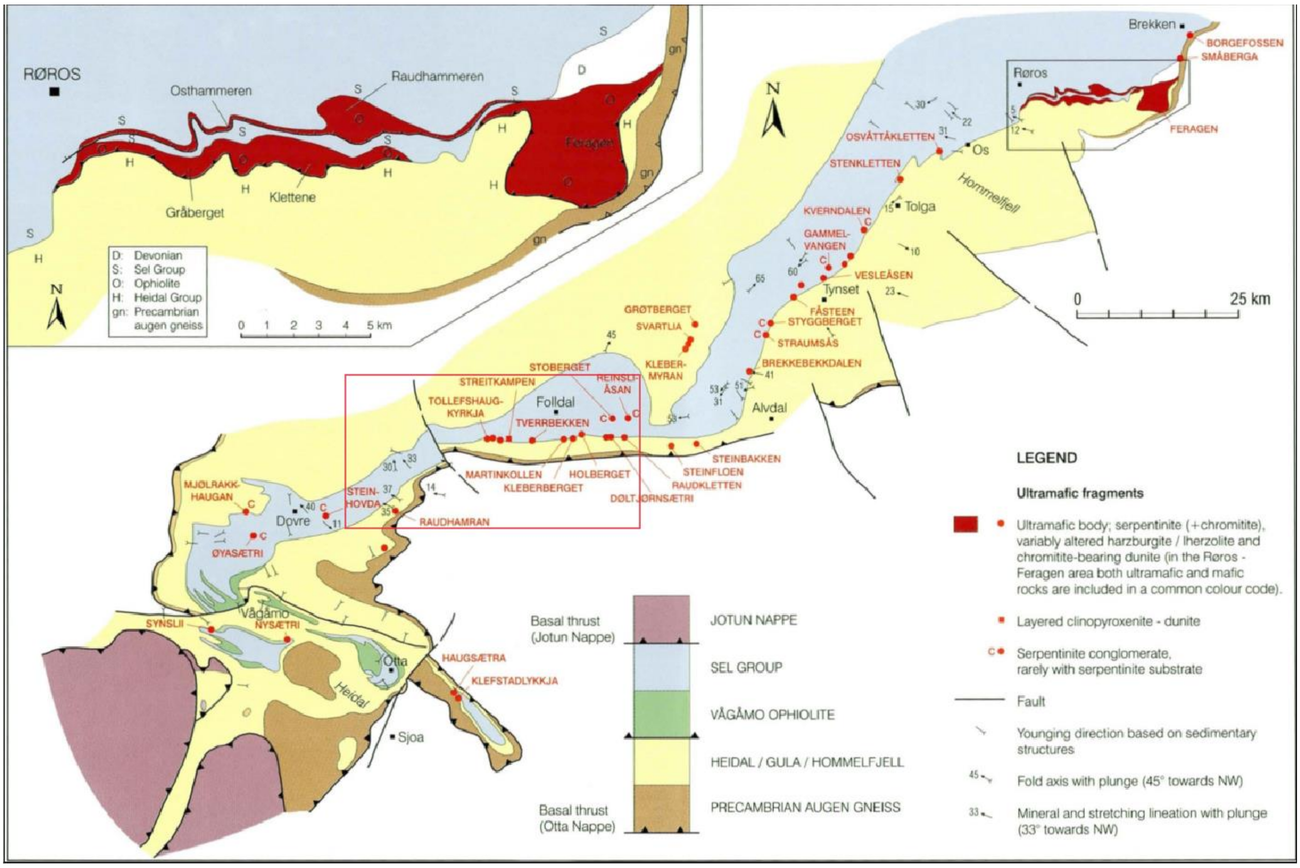

Figure 2: Geological map of the Røros-Gudbrandsdalen area, with locations of ophiolitic fragments (Nilsson et al., 1997). Folldal is framed in central parts of the map.

The Heidal Group is a separate unit of the Hummelfjellet Nappe in the Remsklepp Nappe Complex, located in the upper part of the middle allochthon (Sturt et al., 1995). It consists of metasedimentary and volcanic rocks thrust over the Precambrian Baltica bedrock during the Caledonian orogeny in the Early Ordovician (Sturt et al., 1995). The Sel Group is considered the lower part of the upper allochthon and is part of the Essandsjø Nappe in the Røros Nappe Complex (Nilsen & Wolff, 1989). This nappe complex appears to have been thrusted E/SE together with the Heidal group and the ophiolitic remnants in between, as one unit (Sturt et al., 1995). Both groups consist mainly of meta-sedimentary rocks like mica schists, phyllites, meta-psammites and para-gneisses. The Heidal group also has a large part of quartz-rich rocks believed to be derived from the Baltica bedrock (Sturt et al., 1995). Metamorphic minerals show an increase in temperature and pressure from east to west, i.e. increase from lower to upper/uppermost allochthon (Dallmeyer, 1990) and therefore, the Sel Group (greenschist facies) and the Heidal group (amphibolite facies) are distinguished by their different metamorphic grades. This opposite directed temperature- and pressure-increase mentioned by

Dallmeyer (1990), has been interpreted and explained by the nappes in the area having an inverted position (Nilsen, 1988).

1.2 Previous work

Ultramafic rocks of the Scandinavian Caledonides are present in two main tectono-stratigraphic associations: in the Precambrian Basal Gneiss Region in SW Norway and in the area of the metamorphosed Upper/Middle Allochthon boundary (Qvale & Stigh, 1985). According to the specified characteristics mentioned by Qvale & Stigh (1985, p.696), “Alpine-type” ultramafic rock, in the Upper/Middle Allochthon boundary is the category that fits best for the Folldal area. The origin of the ultramafic rocks there have been debated for several decades, and the rocks are usually altered into serpentinites and occasionally to soapstone (Wolff, 1967). The ultramafic rocks are considered as the lowest part of the Vågåmo-ophiolite, which extends from Vågå in the SW to the Røros tract in the NE (Nilsson et al., 1997). This belt of ultramafic bodies can be traced along the SE margin of the Trondheim Region and is also interpreted by Qvale & Stigh (1985) to be a tectonically dismembered part of an ophiolite.

Geochemical, geochronological and isotopic data available from the northern and western part of the Trondheim region ophiolites and associated rocks suggest that they formed in a suprasubduction-zone setting close to a continental or microcontinental margin (Slagstad et al., 2014). This applies to the ophiolites of Bymarka, Løkken, Vassfjellet and Leka. The relatively close ophiolitic segments of southern and eastern Trondheim region on the contrary, are considered to have formed a part of the ocean floor of an extended seaway that developed between the Gula microcontinent and the passive margin of Baltica (Nilsson & Roberts, 2014).

Parts of the area have been mapped by several geologists and compiled into two different maps that overlaps in the area, the Lillehammer map (figure 3B) by Siedlecka et. al. (1987) and the Røros & Sveg map (figure 3A) by Nilsen & Wolff (1989), both in 1:250 000.

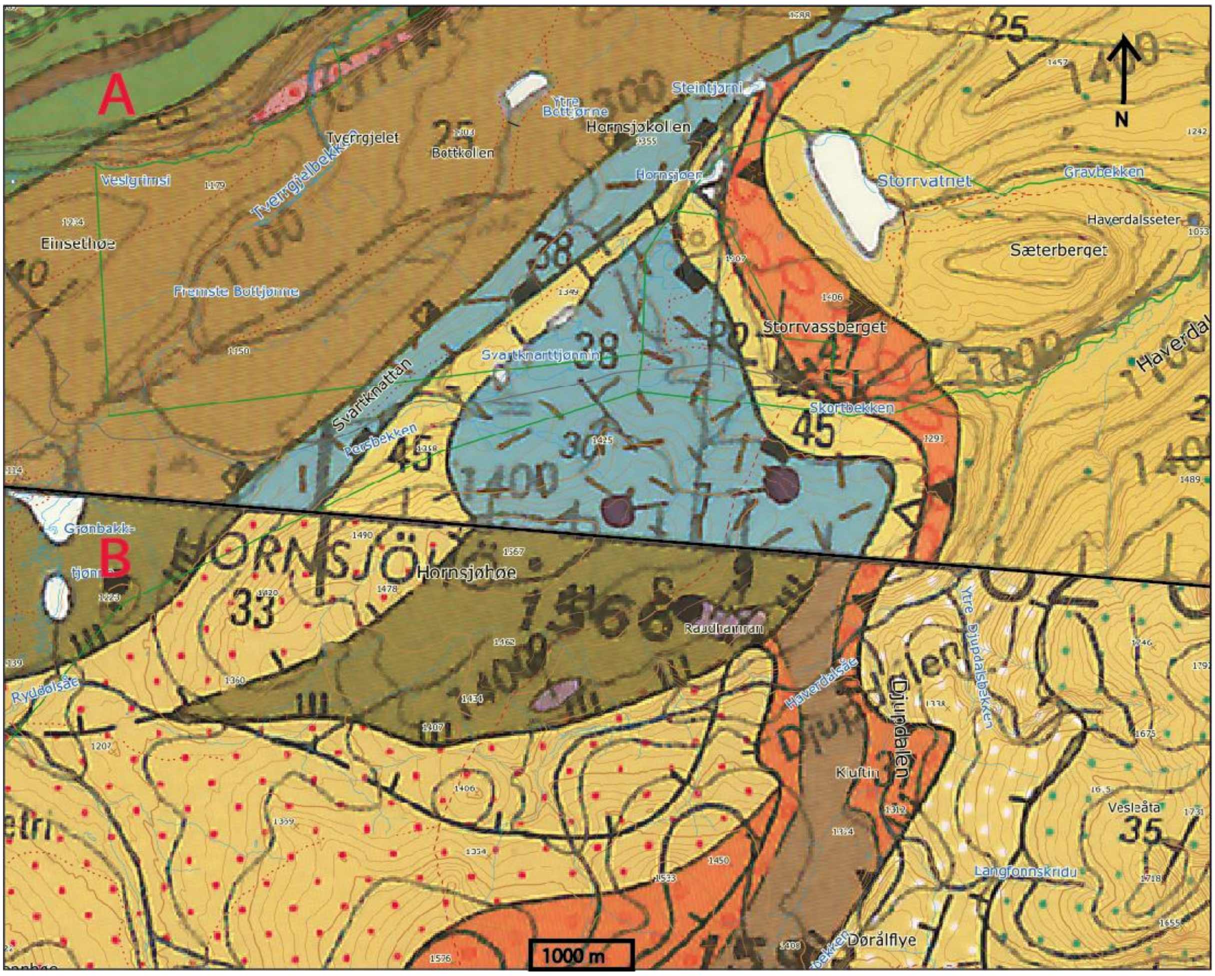

Figure 3: Geological maps linked together from the investigated area. A) Nilsen & Wolff (1989), B) Siedlecka et. al. (1987). Subhorizontal line in the middle of the map divides the two maps.

1.3 Litho- and tectono-stratigraphic subdivision of Folldal area

Different names have been used on similar lithological sequences at different areas in the region. Sturt et al (1997) proposed a revised stratigraphy (figure 4) for the Otta-Røros area, which constitutes the essential parts of the investigated area. The Otta nappe is regarded as the southern end of the major Trondheim Nappe Complex (TNC) (Ramsay & Sturt, 1998), and the division for the TNC is included in this study in order to get an understanding of the geological setting in the Folldal area.

1.3.1 Heidal Group

Ramsay & Sturt (1998) gives a thorough description of the Heidal Group: The lower and middle part is dominated by meta-psammite- and quartzites with local intercalations of polymict meta-conglomerate. The middle part shows an increase in lime content manifested in growth of calcium-rich hornblende. The upper part of the Heidal Group is characterized by graphitic mica schists interbanded with white quartzites and a top sequence dominated by black schist. The metamorphic grade of the Heidal Group rocks is overall, medium grade (amphibolite facies).

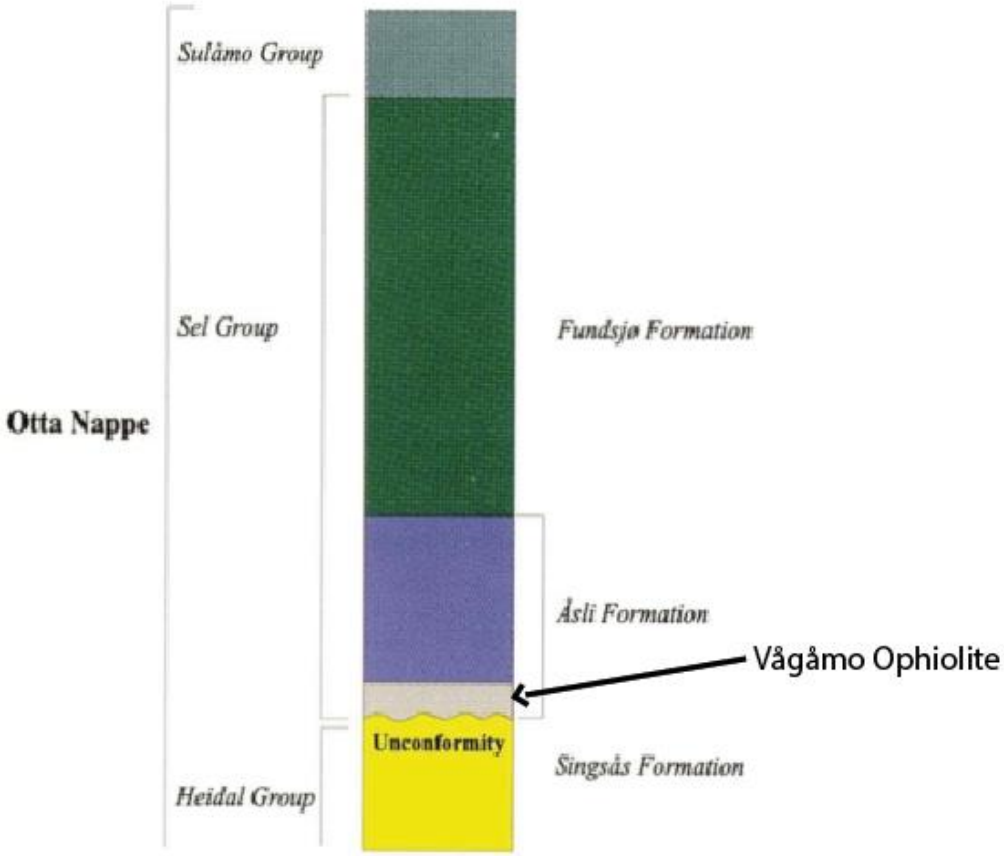

Figure 4: Revised stratigraphy of the Otta-Røros tract (Sturt et al,1997)

The Singsås Formation is the upper part of the Heidal Group and is considered equivalents to the enigmatic Gula Complex, which is dominated by two lithologies: Staurolite-garnet-kyanite-biotite schists and gneisses (Engvik et al., 2014).

1.3.2 **Sel Group**

The Sel Group is a phyllite-dominated sequence with local developments of conglomerate, turbidites and sandstones (Ramsay & Sturt, 1998). It comprises the Fundsjø Formation on the top, Åsli Formation in the middle and the ophiolitic remntants called the Vågåmo Ophiolite. The metamorphic grade is lower than in the Heidal Group rocks, largely greenschist facies (Ramsay & Sturt, 1998). Ramsay & Sturt (1998) have outlined the existence of a major tectono-thermal hiatus with the Heidal Group pre-dating the unconformity at the base of the Sel Group. Sturt et. al. (1995) have identified what they describe as "…a perfect example of the unconformity between the Heidal Group and serpentine conglomerate". The serpentine conglomerate is a local part of the lower Sel Group.

The Vågåmo Ophiolite was thrusted over the already folded and metamorphosed rock of the Heidal Group in early Ordovician times (Sturt et al., 1997), before it was uplifted and deeply eroded prior to the deposition of the Sel Group (Nilsson et al., 1997). Nilsson et al. (1997) consider ultramafic/mafic lenses along the thrust boundary of the Sel and Heidal Groups to have a common origin and represent the lower part of a once continuous ophiolite sheet (The Vågåmo Ophiolite). Serpentinite conglomerate, derived from the ultramafic part of the Vågåmo Ophiolite, occurs in the lower part of the Sel Group (Nilsson et al., 1997).

Mapping of the Folldal area (Bjerkgård & Bjørlykke, 1994) shows clearly that the Fundsjø Formation volcanites are an integral part of the Sel Group and are not separated from either the structurally underlying or overlying rocks by thrust planes (Sturt et al., 1997).
The Folldal Trondhjemite intrudes the Heidal Group and the Sel Group in the Folldal area, and is dated to U-Pb zircon age of 488 +/- 2 Ma. The first deformation phase in the area has affected the intrusion; this gives a minimum tectonic age of the Sel Group with its intercalated ultramafic rocks (Bjerkgård & Bjørlykke, 1994).

The Åsli Formation (like Singsås Formation), is characterized by porphyroblastic staurolite. West of this schist is a garnet-muscovite schist, characterized by porphyroblastic garnet (Engvik et al., 2014). Åsli and Singsås correlates with the Gula Group in the Folldal area (Bjerkgård & Bjørlykke, 1994).

1.3.3 Sulåmo Group

Above the Folldal Volcanics, stratigraphic above the Sel Group, is the black phyllite – grey sandstone sequence of the Sulåmo Group (Wolff, 1967). Wolff (1967) describe the extension of the Sulåmo Group, but focus on the northern part of the group because the southern extension is "…somewhat dubious". Thus are the information about this group poor.

2 Methods of study

The methods used in this thesis include literature studies and reading of articles and geological maps prior to fieldwork, in order to establish the right prerequisites and overview of the area of interest.

The fieldwork was done during 10 days of September 2017 of regional survey and 5 days of August 2018 focused on the Raudhamran area. Compass with clinometer and level, GPS, camera, magnet pencil, magnifier, hammer and measuring tape were used for petrographic and structural mapping.

The orientation of foliation and lineation was measured applying the right-hand rule, on the host rock and other relevant rock formations close to the ultramafic rocks. The key minerals and mineral association from hand specimens were investigated on site with magnifier and magnet. Representative samples were collected from selected locations for petrographic and thin-section studies. Several photos were taken from each locality. GPS-points were registered for all structural measurements and hand samples. Some locations were tracked with GPS for marking of larger areas of similar lithology. Also a Tough book including all the existing geological information displayed in ArcGIS was provided by NGU. The bedrocks in the Folldal area are generally poorly exposed due to glacial sediments, which in some cases made the fieldwork challenging.

Five samples from the area Raudhamran, were selected for making thin sections. These represent the host rock surrounding the ultramafic lenses. The samples were cut into cubes (~1.5*2.0*3.0 cm), before they were prepared and polished by the employees in the laboratory at the Department of Geoscience, UiT.

Microscopy of the thin sections was done using the microscope Leica DM4500P. Both transmitted light and reflected (for the opaque sulphides) light were used together with plane- and crossed-polarized light to determine minerals and microtextures of the rocks sampled. All thin sections contain various amounts of silicates and small amounts of sulphides. Representative photos were taken of each thin-section. Abbreviations used for mineral names are taken from Kretz (1983).

3 Results

This chapter presents the results of all observations from the fieldwork carried out in the Raudhamran area.

3.1 Tectonostratigraphy and structural overview

The data collected during the fieldwork are combined and summarized in a revised geological map, including an interpreted cross section (figure 6).

Lenses of various sized ultramafic rocks have been mapped in the studied area (figure 6), some with soapstone at the margins (figure 5).

Figure 5: Two representative lenses of ultramafic rock, with some hundred meters apart, located west to northwest of Raudhamran.

Metasedimentary rocks such as quartzites and quartz-schist, garnet-mica-schist and augen gneiss in addition to amphibolite, dominate the area surrounding the Raudhamran outcrop and other ultramafic rocks (figure 6). Augen gneiss is located in between meta-sandstone rocks. The two latter units are separated in the map by a major thrust fault inside the Essandsjø Nappe. The highly strained mylonitic rocks inside the Hummelfjell Nappe, marked in the map, are placed farther west towards Raudhamran. It separates the Røros Nappe Complex in the west and the Remsklepp Nappe Complex in the east. The latter shows internally, strong deformation, tight to isoclinal folds, and mylonitic rocks with lenses of disintegrated host rocks.

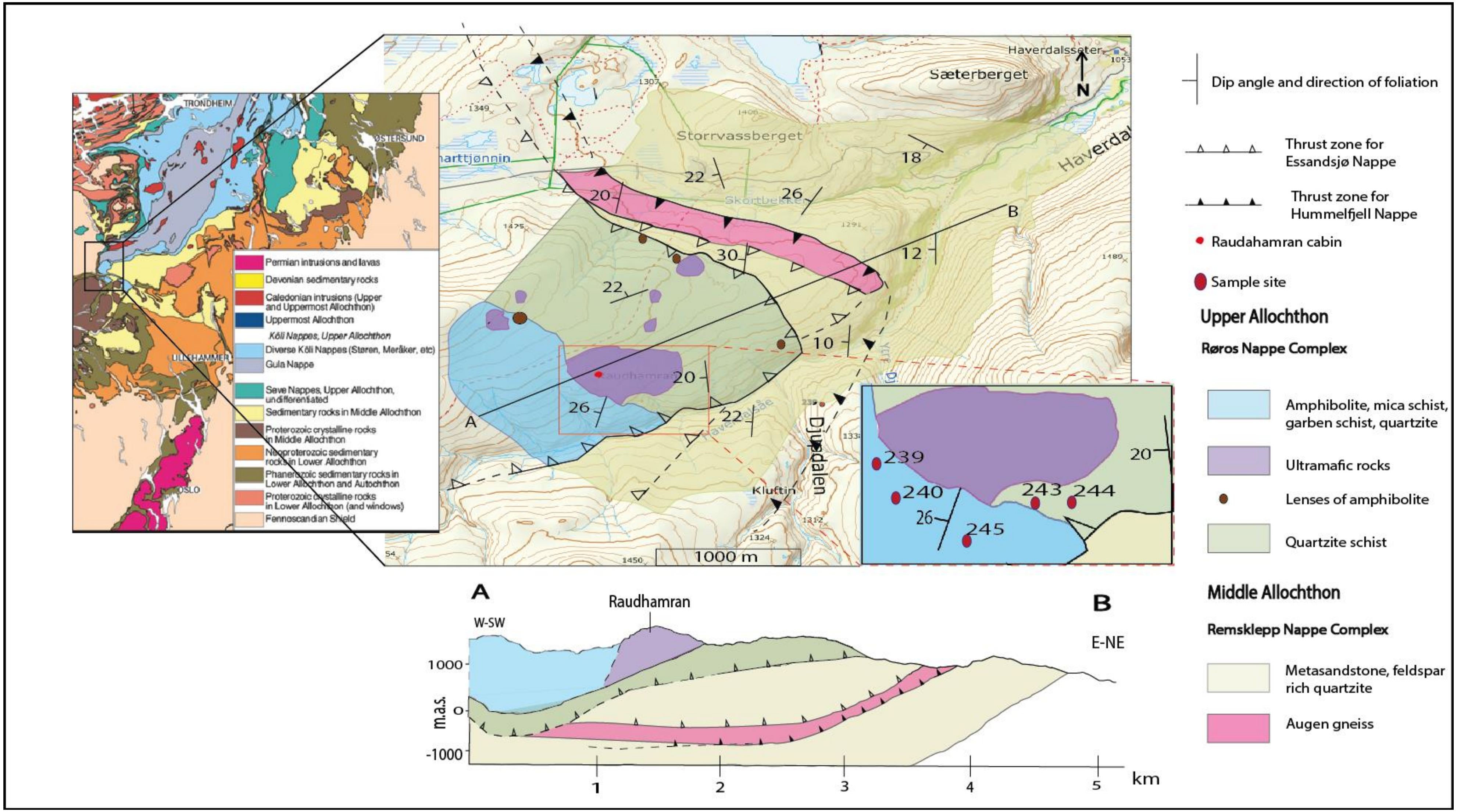

Figure 6: Geological map from the field study. The location of the cross section A-B (bottom of page) is marked on the map by a line and is vertically exaggerated. The Raudhamran ultramafic pod with related cabin is used as a geographic reference point.

Local bending of the foliation can be seen along strike of the thrusts (figure 6). Although, the main foliation of the host rock in the area generally dip gently to the west. However, both strike and dip angle vary within the area. Differences are usually not of any significant character (within 10% of the main measurements), but they correspond to the observed folds in the field. Observed changes in strike and dip directions of the main foliation are mainly due to presence of different macro scale limbs of open folds. Open to asymmetric macro- and meso-scale kink folding of the main foliation have been observed, and such folds trend N-S and plunge gently south, indicating a shortening from W-E.

3.1.1 Metapsammites

Various types of meta-psammites and quartz-rich schists constitute the main part of the Remsklepp Nappe Complex. These rocks extend outside the mapped area, farther north and eastward into the Rondane massif. Quartz dominates these rocks, with variable amounts of mica, feldspar and carbonates. Porphyroclasts of red K-feldspar are found locally, and the amount increases close to contacts with the augen gneisses. The main texture is the distinct foliation, but possible, relict cross-bedding have been observed some places, indicating a primary sedimentary structure (figure 7A). Large open folds locally fold the foliation of the metapsammites, but also micro folds and crenulations are found (figure 7B). The fold axis trends N-S and plunges gently S, whereas the axial surface in general strikes N-S and dips gently toward W-SW. The fold axis lineations of meso-scale folds are observed some places (figure 8). The mineralogy of the lineations are hard to determine to due its weathered surface and massive appearance.

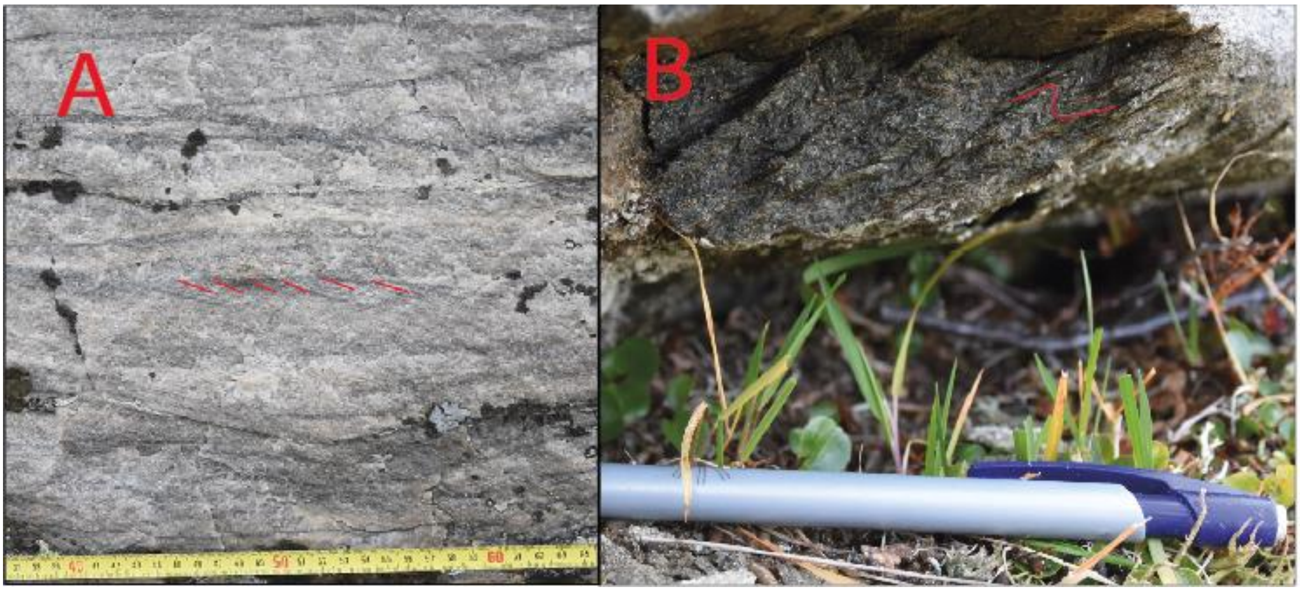

Figure 7: Metapsammites with A) very high quartz content and relics of primary sedimentary cross-bedding marked with red lines and, B) meta-psammite with higher content of mica and small-scale folds/crenulations.

Figure 8: Meso-scale lineations of the fold axis in metapsammites, marked with walking poles.

3.1.2 Augen gneisses

Lenses of augen gneiss are found between the meta-psammites. Such lenses are limited by thrust faults with a general dip toward S-SW. Large, red crystals of K-feldspar (up to 5-10 cm in dimensions) contributes to the distinct appearance that is characteristic for augen gneiss (figure 8A). The matrix of the gneiss is fine-grained, and tiny foliated. Minerals in the matrix are mainly feldspar and quartz, with some amount of white mica, biotite and hornblende. Close to the fault where shortening strain likely was higher, the red feldspar crystals are fragmented and aligned into mm size and smaller grains, along with the interstitial flaky matrix minerals (figure 8B).

Figure 9: A) Augen gneiss with large red K-feldspar crystals, and B) augen gneiss with fragmented K-feldspar crystals close to the fault.

3.1.3 Amphibolites, garben schists, quartzites and mica schists

A separate unit of various amphibolites, garben schists, meta-psammites and mica-schists are found to the south and west of the ultramafic rocks in Raudhamran. The meta-sedimentary (schistose) rocks are present stratigraphically above of the mafic rocks (amphibolites) that are likely remnants of ophiolites. In some parts, the schists are easily weathered foliated quartz and mica-rich schist with an overall high content of carbonate. It is fine-grained with a characteristic ductile lamination that is locally folded by open folds (figure 9). Their internal boundaries are difficult to locate due to the limited degree of outcrop.

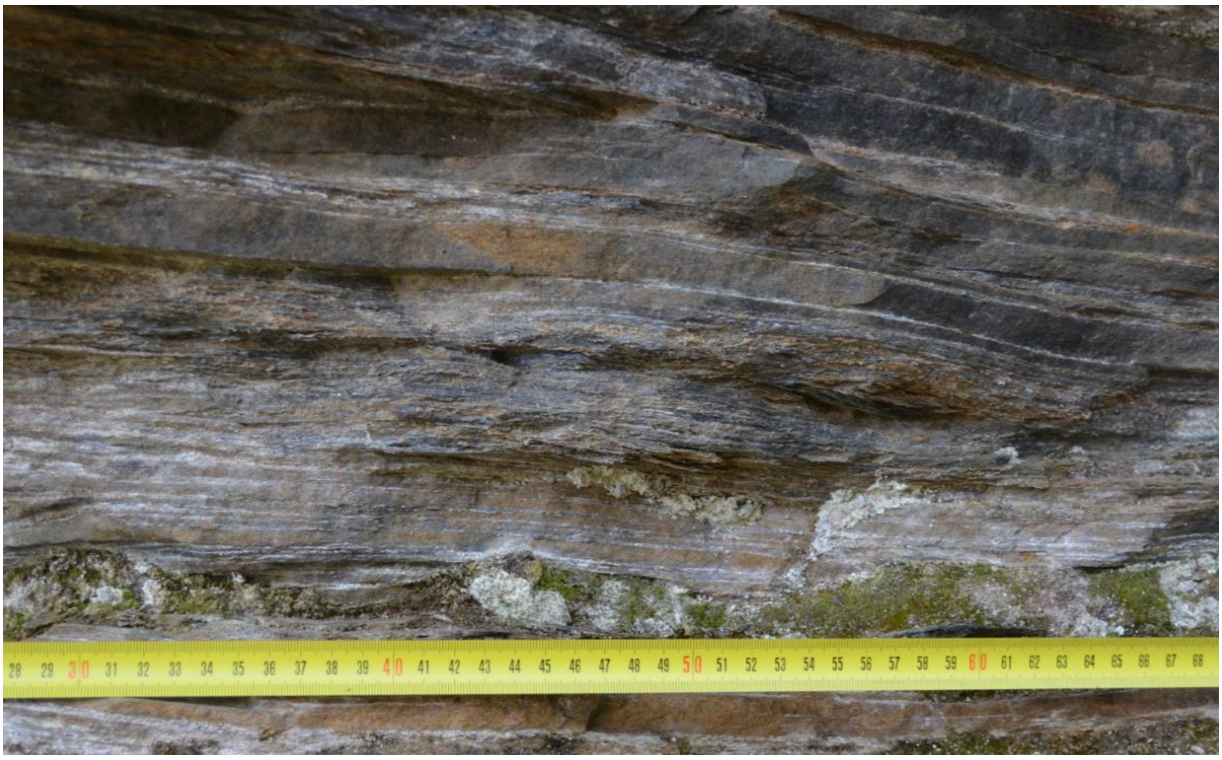

Figure 10: Fine-grained, schistose rock with high content of carbonate. Fine lamina characteristic for this unit.

3.1.4 **Ultramafic rocks**

The ultramafic rocks are massive and have a characteristic yellowish/brownish weathering surface, indicating weathering of olivine. The pristine minerals, olivine and pyroxene, are altered, at least in near-surface outcrops. Alteration reaction has formed serpentinite, brucite and dispersed euhedral grains of chromite. In general, the ultramafic rocks are magnetic, indicating the presence of magnetite, which is a common mineral after serpentinization. Some of the relatively small bodies and some of the rims of large bodies have been metamorphosed into soapstone composed of varying amounts of talc. There is no clear observation of primary magmatic layering in any of the ultramafic bodies examined. Internal folding is observed (figure 11A), but it is not clear whether the folding is a relict primary magmatic flow structure or secondary folding at a stage where the ultramafic rock was in solid state able to plastically deform. Characteristic cracks and veins are a dominant feature, in particular for the least metamorphosed parts of the bodies (figure 10).

Figure 11: Overview of parts of the ultramafic rock at Raudhamran, showing the typical irregular vein and crack system. Hammer for scale.

A fresh cut shows the internal, massive texture and non-oxidated, dark green rock colour of a typical ultramafic rock at Raudhamran (figure 11B). The rocks are not geochemically analysed, but observed to consist of at least serpentine, brucite, chromite and magnetite.

Figure 12: Field observations of ultramafic rocks. A) hint of a ductile deformed section. B) a look into a fresh cut section with the thin, characteristic weathering skin.

3.2 Petrographical and micro-textural descriptions

In this section, the five representative samples of the host rocks to the ultramafic rocks in Raudhamran will be described with respect to mineralogy and micro-textural observations. The sample localities are highlighted in the geological map (figure 6). The samples and the related thin-sections will be described in the order of what is interpreted to be from lowest metamorphic grades and less deformed rocks to those that are most highly deformed. None of the thin-sections are oriented and the mineral assemblages are described separately and linked to the main deformation structures applying Winkler (1979). There are no replacement textures, coronas, compositional zoning or other obvious disequilibrium textures found.

3.2.1 Amphibolite, garben schist, mica schist, quartzite unit

The samples 239, 240 and 245 are described from thin-section. They are taken from the schistose unit (figure 6), close to the ultramafic rocks in Raudhamran. Four lithologies are observed in this unit: amphibolite, garben schist, quartzite and mica-schist, but only the two latter were sampled for thin-section studies.

Sample 239: Quartzite

The sampled rock is located several hundred meters north of the thrust fault that separates Remsklepp Nappe- and Røros Nappe Complex. This is a fine-grained, leucocratic rock composed almost entirely of quartz (>90%) and show conchoidal fractures. The remaining 10% is mainly dark mica and garnet. This massive quartzite has a penetrative foliation. Thick veins (>10 cm) of massive quartz are found some places (figure 12).

Figure 13: Quartzite with inclusions of quartz veins.

Thin section description: This thin section is dominated by a matrix of foliated quartz (>90%)(figure 13A&B). Quartz grains are fine-grained, elongated and with well-developed triple-point junctions and ~120° interfacial angle. Garnet porphyroblasts (up to 1mm in size) encloses and surround the quartz grains. Fractured garnets (figure 13C&D) are widely dispersed and the second most abundant mineral in the rock (~5%). The garnet porphyroblasts have a xenomorphic, sigmoidal shape, indicating a dextral motion when viewed in section parallel to foliation (figure 13C&D). They are surrounded by muscovite (~3%) and biotite (~1%) which define the main fabric of the rock, and which bends around the garnet. Both micas are mainly found as thin bands along foliation. Sulphide (~1%) minerals, possibly pyrrhotite, are found as very small crystals. They are xenomorphic to idiomorphic and mainly elongated. Some elongated sulphide crystals included in the garnets, are also rotated along with the sigmoidal shaped garnet (figure 13C).

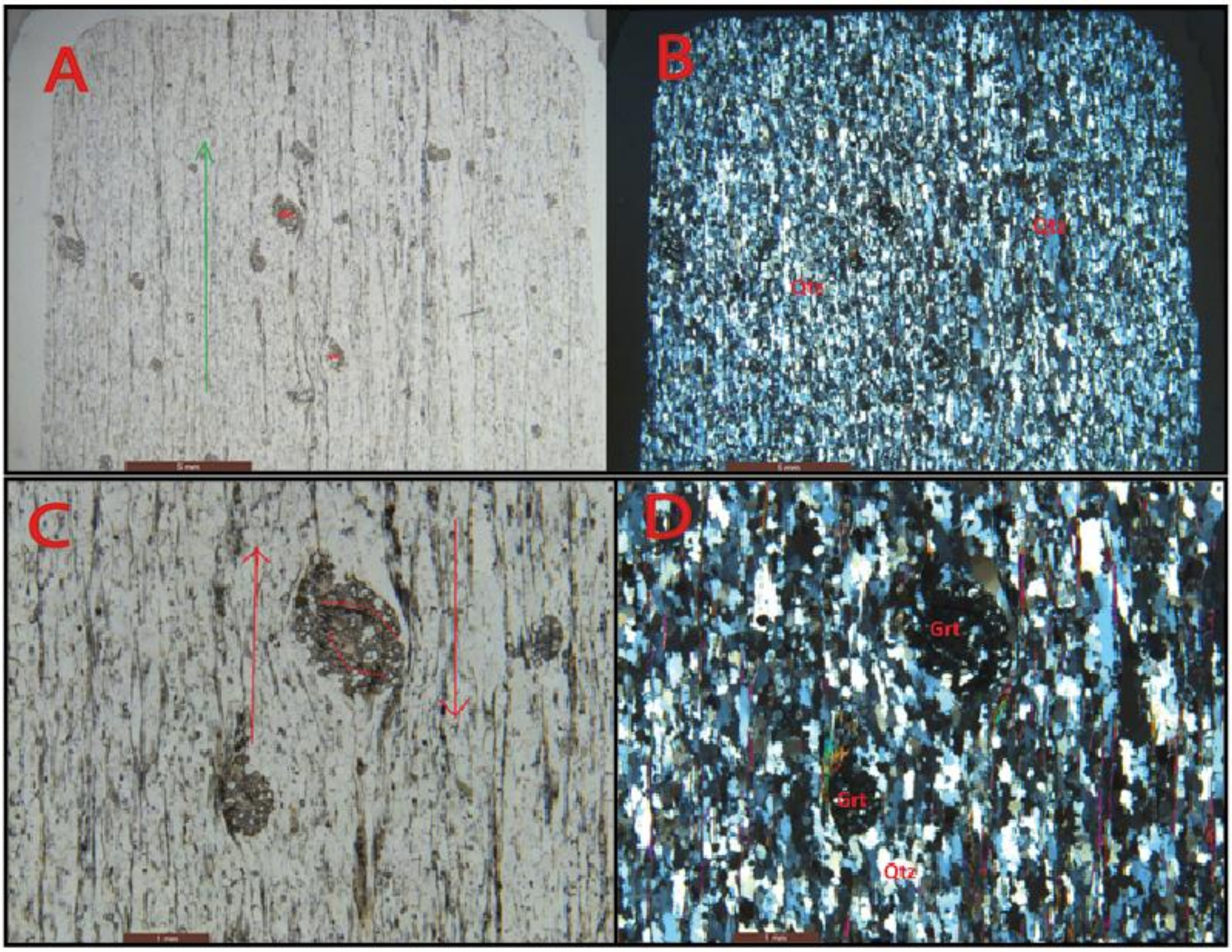

Figure 14: Photos of thin-sections from quartzites with a well-developed foliation (A). Rotated sigmoidal garnet with a dextral motion (C). The other pictures show the relationship of the mineral assemblage in the sample. PPL left and XPL right. Green arrow showing direction of motion

Sample 240: Garnet-mica schist

The sample is taken from the gorge SW of Raudhamran cabin. It is a fine-grained and shaly rock with foliated, white mica as the most abundant mineral in the rock (figure 14). Lenses and veins of quartz are found in some places. There are few, but large garnets and presence of a green mineral in the shadows of some garnets, most likely chlorite. Amphibole is seen as dark, greenish-colored flaky minerals, finely distributed in the schist.

Figure 15: Garnet-mica schist, representative for this part of the unit. With visible large garnets.

Thin section description: The rock consists of uniform layers with quartz-rich and mica-rich domains parallel to the main foliation or schistosity of the rock (figure 15A&B). Fine-grained, flaky intergrowths of muscovite dominate the rock (~50%). The quartz grains are fine- to medium-grained and the second most abundant mineral (~35%). Both minerals make up the foliation, which is locally and internally folded by open folds and bend around the garnets (~10%). Garnets are subidiomorphic with mainly irregular inclusion cracks, although some appear to be perpendicular to the main foliation. The internal cracks of the garnets are filled with biotite (figure 15 C&D). Pressure shadows filled with chlorite are commonly observed in relations with garnet (figure 15 C&D). Sulphide (<1%) form small, elongated grains aligned with foliation. In some garnets, the sulphides are aligned parallel with the orientation of the main foliation (figure 15C).

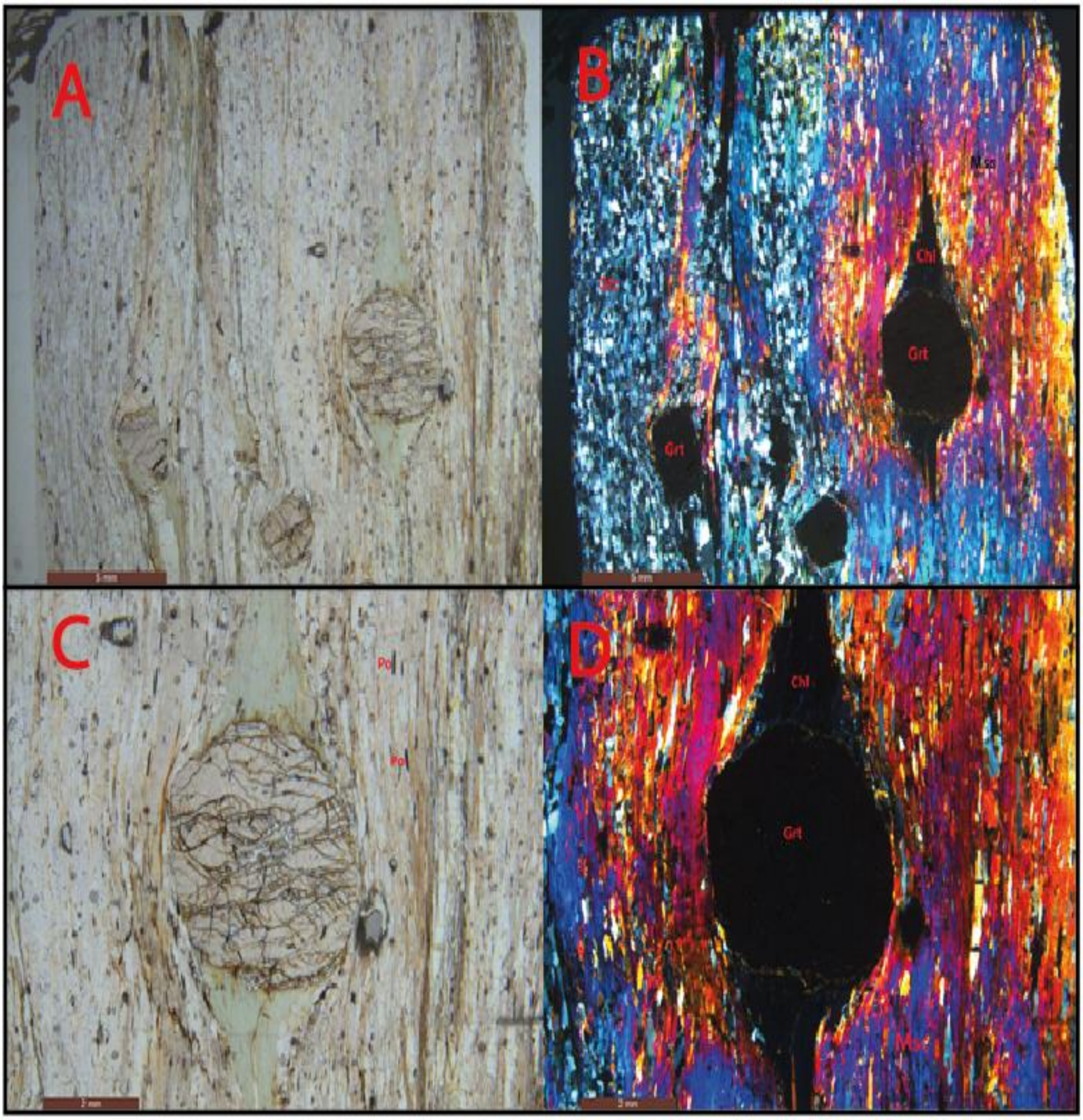

Figure 16: Thin-sections of garnet-mica schist with biotite and sulphide (opaque). Note garnet with a pressure shadow of chlorite (best seen in picture C). B illustrates the quartz-rich and mica-rich domains, D show a close up on the mica-part. PPL left and XPL right.

Sample 245: Garnet-mica schist

The sample is taken approximately 5-10 meters from the ultramafic outcrop. Micas dominate the rock, with quartz as the second most abundant mineral. Some parts are almost completely massive, whereas others are weakly and irregularly foliated defining lenses and ductile sheets along the main foliation (figure 16). The rock is fine-grained with flaky chlorite in the foliation and garnet porphyroblasts visible. Some parts of the irregular foliation have been folded by open folds with tight folds with subsidiary, smaller-scale tight folds on the limbs.

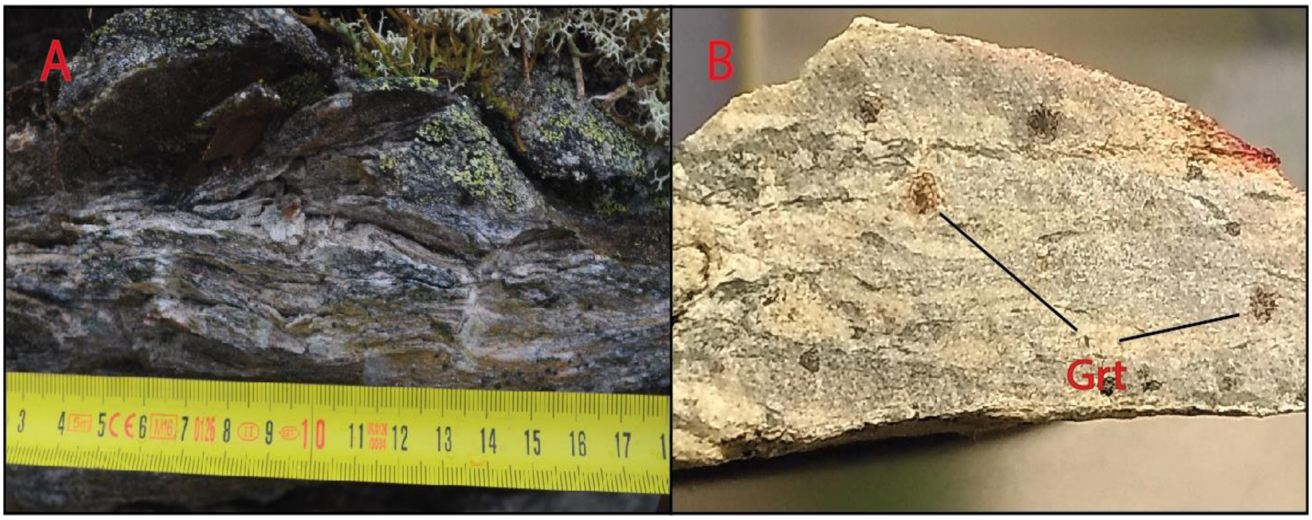

Figure 17: Samples of garnet-mica schist. A) Weathered surface from the sample location. B) Hand specimen thin section, with garnets highlighted.

Thin section description: The rock consists mainly of very fine-grained white mica (>50%). Biotite (~2%) exists as thin, flaky aligned bands along foliation. The mica-rich foliation have been variously folded, by both open folds and more asymmetric, tight crenulations (figure 17F). Chlorite (~5%) is seen as short elongated bands in the main foliation, parallel to biotite. The second most abundant mineral (~30%) is fine-grained, layered quartz that show no clear evidence of folding in the thin section. Close to the more rigid quartz are a few larger grains of sulphide that still have preserved the original cubic shape (figure 17A&C). Small sulphide and biotite grains are found as inclusions in garnet. Garnets are large (figure 17A) and exist as xenomorphic to subidiomorphic crystals with small inclusions of mica and quartz in an irregular vein system.

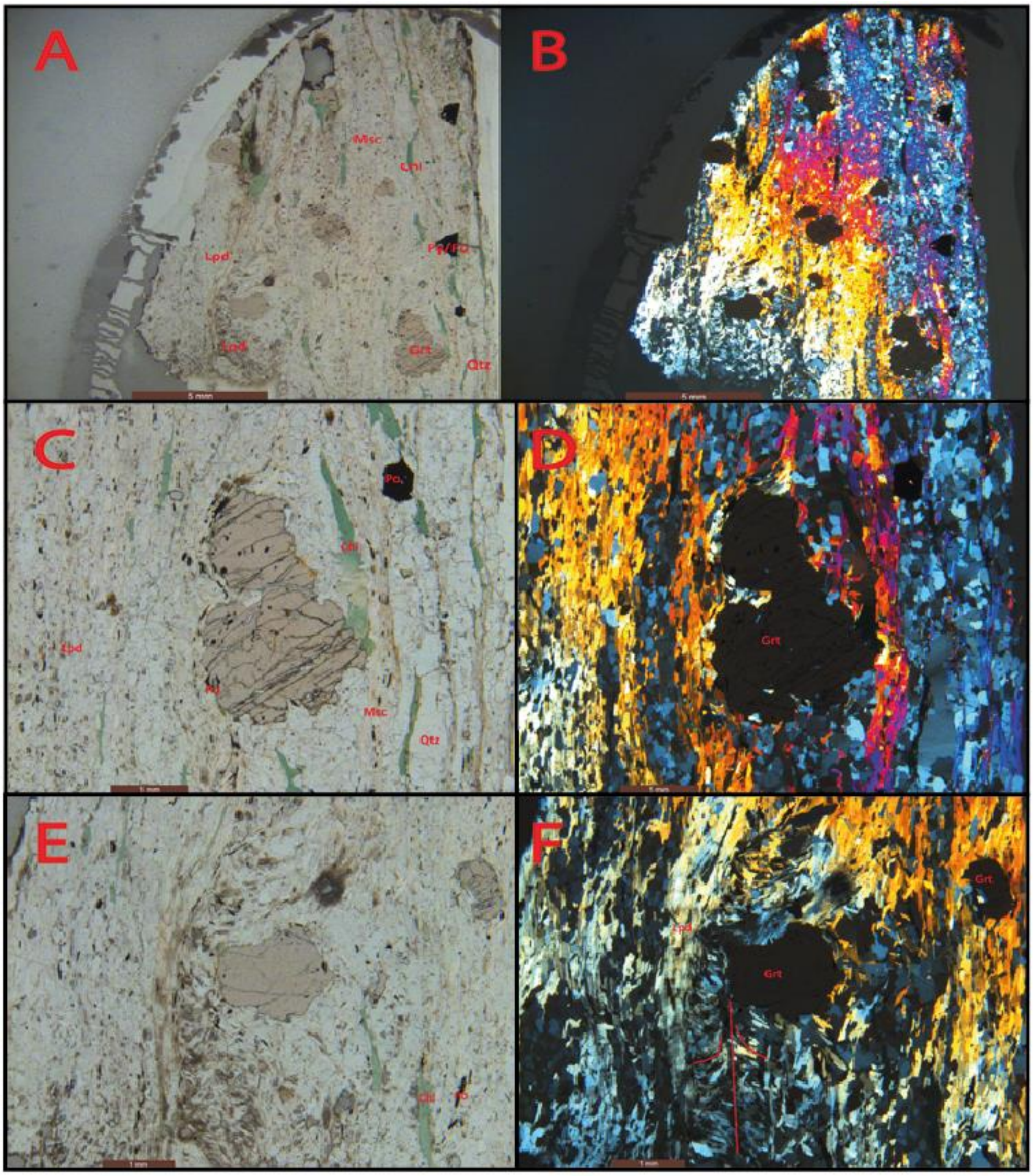

Figure 18: Thin-section of garnet-mica-schist with about 30% quartz and large garnets (C & D). Crenulation can be observed in the mica (F). Note the subidiomorphic garnet with very few internal fractures (E).

3.2.2 **Quartzite schist/mylonite**

The two samples below are taken from the unit with quartzite schists east of the ultramafic lens at Raudhamran (figure 6). The rock is foliated and characterized by high amount of fine-grained quartz that has undergone relatively high degree of deformation and recrystallization. Traces of lens-shaped porphyroblasts of garnet and amphibole are observed (figure 19A&B),

indicating the rock is a mylonite found close to the thrust fault where shortening strain has been largest.

Sample 244: Quartz mylonite (1)

The sample is collected just south of the Raudhamran outcrop. It appears mylonitic in character as the matrix is fine grained, banded and as the matrix content, mainly quartz, make up more than 50% of the rock. It is a fine-grained rock with numerous folds with variable sizes, likely also parasitic folds (figure 18). Thin lenses and veins of quartz and amphibole units are found dispersed in the rock. These lenses contain small garnets and white mica.

Figure 19: Highly deformed, fine-grained, mylonitic rock, containing mainly quartz (>50%).

Thin section description: Fine-grained aligned quartz dominates the foliation of the rock (>50%). Large crystals of quartz are seen as smaller parts of a large lens (figure 19B). Small crystals of quartz are found as inclusions in porphyroblasts of garnet and amphibole. A major part of the rock is mica (~25% muscovite and ~3% biotite), found as the dominant mylonitic foliation alternating with aligned quartz. Chlorite (~10%) is observed as a mineral located in pressure shadowns of amphibole and garnet (figure 19 C&D). Amphibole (~10%) is present as large porphyroblasts overprinting both the foliation and the other minerals. The garnets

(~1%) are up to 1mm in size, subidiomorphic and grow across muscovite in the foliation. The crystals are fractured with irregular oriented cracks.

Sulphide (<1%) minerals are found as elongated grains in the main foliation and as inclusions in garnet. Some are dispersed around as rounded grains.

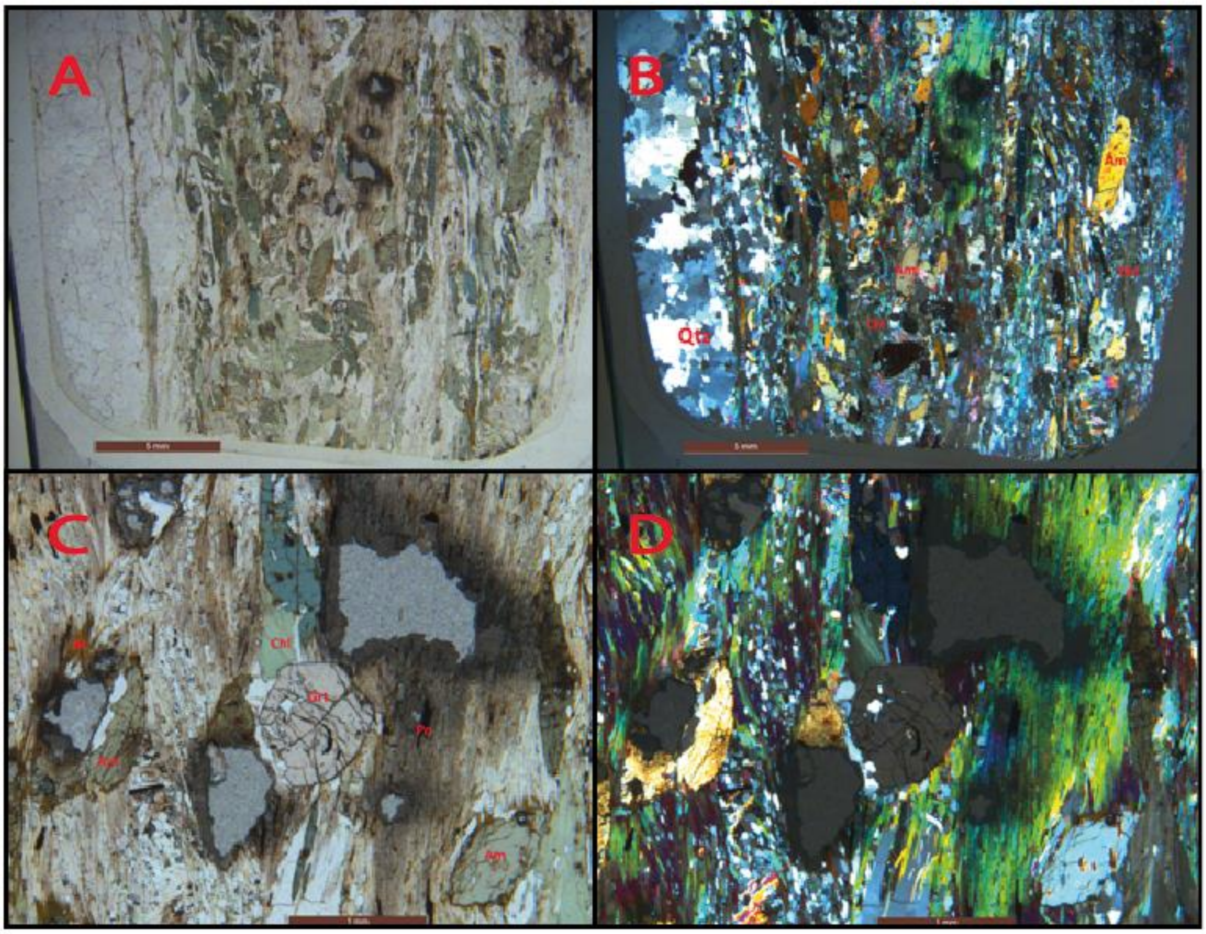

Figure 20: Thin-sections of quartz-mylonite with a foliation made up of quartz, mica, chlorite, amphibole and garnet as the dominating minerals (A and B). Large crystals of garnet, chlorite and amphibole are prominent in part C and D. PPL left and XPL right.

Sample 243: Quartz mylonite (2)

Another sample of quartz-mylonite (figure 20) is taken from the south side of Raudhamran cabin, close to the ultramafic rock. It appears mylonitic, with more than 50% matrix of mainly quartz. The rest of the matrix is fine-grained with white mica, carbonate and chlorite. Foliation-parallel quartz veins are abundant. Small amounts of amphibole are observed dispersed as single crystals. The rock is highly folded with small isoclinal folds having axial surfaces parallel to the main mylonitic foliation, whereas larger open folds (figure 20A) refold the main foliation.

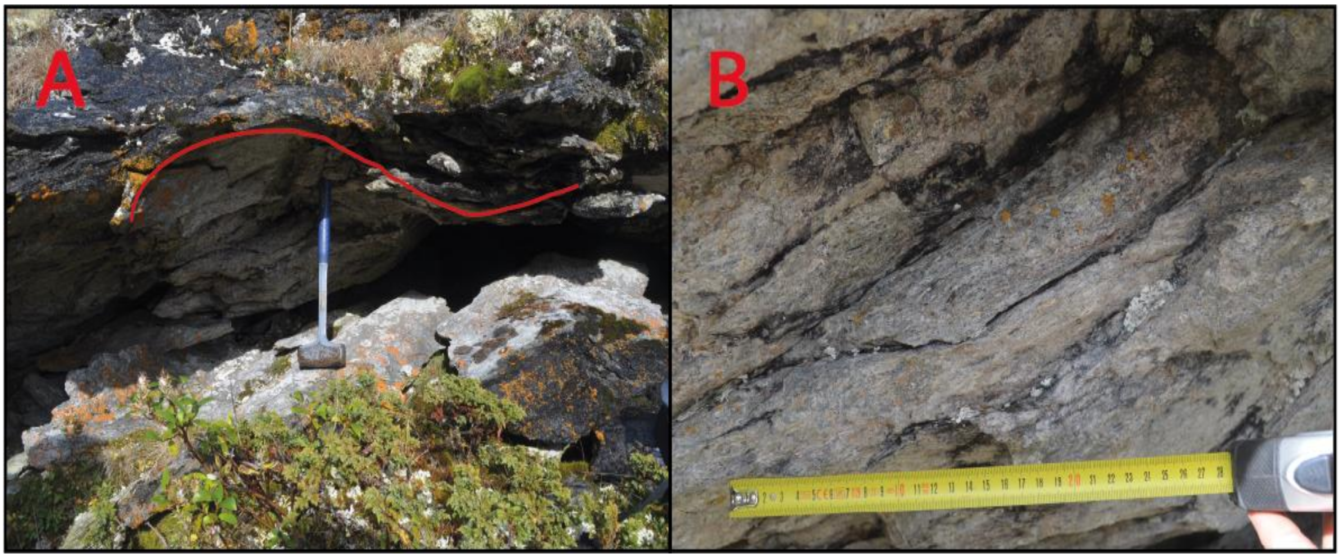

Figure 21: Quartz mylonite. A) open folds. B) close up on the mylonite from same location as photo A.

Thin section description: Quartz dominates the rock (~60%) as alternating fine-grained and medium-grained mylonitic layers (figure 21A&B). A large part of the rock is mica (~20% muscovite and ~3% biotite), defining a fine-grained foliation together with quartz. Some places the mica is clearly folded with tight to isoclinal folds (figure 21D). Sulphide crystals are arranged parallel to the layers and folded together with the mica layers (figure 21C&D).

Small quartz crystals with triple-junctions are found as inclusions in porphyroblasts of garnet and amphibole. Garnets are large (up to 1mm) and subidiomorphic to idiomorphic, but less common in thin section (~2%)(figure 21E&F). Only one large amphibole crystal is found, with main axis perpendicular to main foliation. It is surrounded by chlorite and biotite.

Carbonate (~5%) exist as large, elongated crystals (up to 1mm) with no apparent oriented grain distribution, surrounded by and with inclusions of quartz and mica.

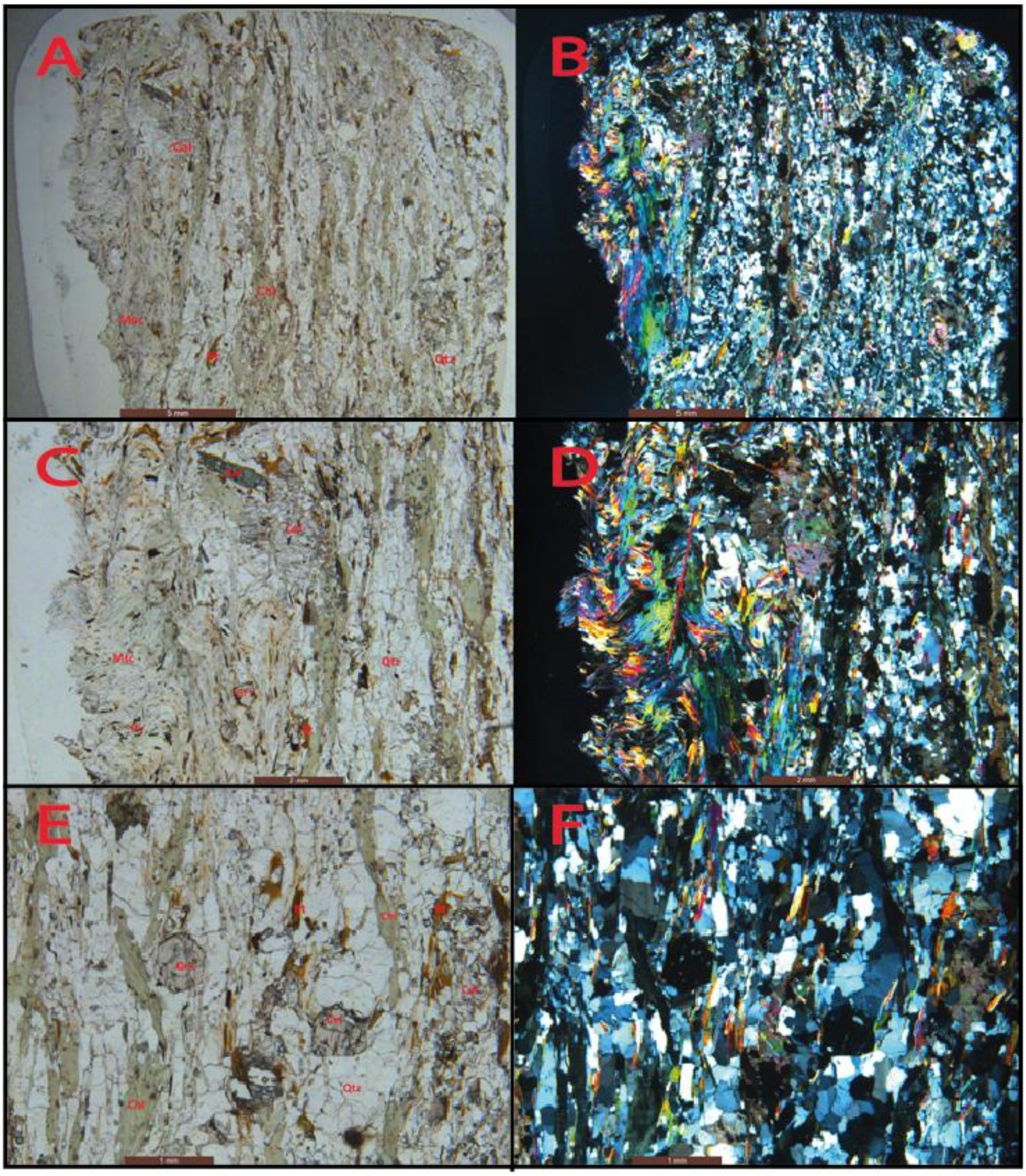

Figure 22: Micro-photographs of quartz-mylonite (A and B) giving an overview of the constituents in the rock. Red line marking isometric kink folds, probably F2 (D). Note how sulphide is aligned with the folds in photos C and E. PPL left and XPL right.

4 Discussion

The results presented in chapter 3 will be used as a frame to interpret the tectono-metamorphic evolution of the Heidal/Sel Group. Petrographic, mineral and micro-textural observations reveal a complex and polyphase history of the Caledonian bedrocks in the study area. Understanding of the tectono-metamorphic history of the meta-sedimentary host rocks may contribute to understand the tectonic framework of the ultramafic rocks.

4.1 Discussion of tectono-stratigraphy and macro-scale structures of the Folldal area

The geological map (figure 6) summarize the interpreted tectono-stratigraphy with macro-scale structures in the Folldal area. Three mylonitic thrust zones are detected; two of them are located on both sides of the augen gneisses with metapsammites stratigraphically found above and beneath. Nilsen & Wolff (1989) interpret these two units to a part of the Remsklepp Nappe Complex in the Middle Allochthon. At the boundary of the metasedimentary host rocks is the last thrust zone, marked by quartz mylonites and with traces of red K-feldspar believed to be derived from the close laying augen gneisses. The stratigraphically higher metasedimentary rocks cut the augen gneisses (see figure 6), causing the interaction to be visible as red feldspatic remnants in the rocks at the boundary. These metasedimentary rocks are interpreted to be the Sel and Heidal Groups, of the local nappe name Otta (Sturt et. al., 1997). The ultramafic remnants of the Vågåmo Ophiolite are placed between the two former mentioned groups, and together they are believed translated eastward, placed on top of the Remsklepp Nappe Complex. According to Nilsen & Wolff this last thrust zone, called the Essandsjø Nappe thrust zone, also marks the boundary of the Middle and Upper Allochthon of the Scandinavian Caledonides.

4.2 Discussion of petrography and origin of the host rocks

All rock samples used for thin section are interpreted to be of a sedimentary origin, containing mainly mica and quartz in varying amounts, with garnet and chlorite as the most abundant secondary constituents. The metamorphic grade varies from greenschist facies to amphibolite facies. The original depositional environment for the sedimentary rocks might be a vast area where the different minerals prefer to settle under special conditions. E.g. a marine delta that creates a huge distribution area where the heaviest minerals settle first.

The ultramafic rocks originated from ophiolites where the upper sections with layered gabbro and different intrusive and extrusive rocks are eroded, so that only the bottom layer is left.

However, as seen in the geological map (figure 6) there are lenses of amphibolite dispersed in the area, which may be mafic remnants of the stratigraphic level above the ultramafic rocks. The amphibolites seem to follow the trend in close relation with the augen gneisses, and neither the ultramafic or the amphibolitic rocks are observed east of the augen gneisses. This suggests that both the interpreted ophiolitic rocks are part of the same nappe located in the Upper Allochthon.

The lower Sel Group is said to locally contain conglomerates with inclusions of pebbles and cobbles, derived from the Heidal Group (Sturt et al., 1997). Internal fabrics in these inclusions suggests polyphase deformation of the Heidal rocks prior to uplift, erosion and deposition of the rocks of the Sel Group (Bøe et al, 1993). According to Sturt et al (1995) the Sel Group also includes continental, fan-deltaic and marine sediments, which indicates a large area of deposition for the original sediments. This, of course, has the potential to generate a vast range of grain sizes, and rock and mineral combinations, and explains the sometimes-diffuse differences in the host rocks.

4.3 Discussion of mineralogical, micro-textural/structural and metamorphic data

The presence of garnet and amphibole porphyroblasts, heavily folded and sheared mylonitic rocks, and mineralogical alterations and replacements (e.g. of amphibole with chlorite, etc.) suggests both polyphase tectonic, and prograde versus retrograde metamorphic evolution of the rocks. Inclusions of small quartz grains in garnet porphyroblasts demonstrates that garnet grew on top of pre-existing fine-grained quartz, whereas the main foliation of the rock grew at different metamorphic conditions (Trouw & Passchier, 2005).

An attempt to use garnet porphyroblasts as kinematic indicators in the mylonites was done combining the common, sigmoidal garnet shape and the presence of asymmetric strain shadows (figure 15). Strain shadows of newly grown mineral phases or fragmented grains are formed near some garnets (described in Bos, 2000). The abundance of garnet and associated biotite and white micas, indicate a medium grade metamorphism. The xenomorphic shape of garnets indicate rapid growth, conditions that are likely to occur in a ductile shear zone with potentially, large amounts of fluids circulating through the rock (Frisch et. al., 2011).

Mica tends to be less resistant to shortening strain than quartz, and traces of deformation will stand out more clearly in mica-schists. Although crystallization of quartz with triple-junction indicate that the quartz-rich schists are metamorphosed and fully recrystallized (Trouw &

Passchier, 2005). Isoclinal folds in mica-schists are observed in some thin sections (figure 21), and since they have their axial surfaces subparallel to the main foliation (S1) they are interpreted as the oldest generation of micro-folds (F1). These folds are observed to be refolded by younger, open to asymmetric kink-folds (F2-folds), with axial surfaces (S2) oblique to the main foliation. Small-scale crenulation folds and oblique cleavages/kink bands were only observed in one thin section 243 (figure 21), but at several locations in the field. Carbonates appear unaffected by the F2 folding phase, and therefore are younger than the folds (figure 21B&D)

The metamorphic grade in the studied rocks seem to have changed during the Caledonian folding events. This is supported by changing mineral assemblages of inclusions in garnet porphyroblasts versus mineral growth in the matrix, and by alteration /replacement of e.g. amphibole by chlorite and biotite by white micas. The dominant mineral assemblage of inclusions (pre-S1) in garnet porphyroblasts are biotite + quartz + chlorite. Whereas the main minerals of the host rock foliation are muscovite, quartz, garnet and amphibole, indicating prograde metamorphism from low grade (greenschist facies) conditions at the beginning of the garnet growth to medium grade (amphibolite facies) when the main foliation formed. Presence of small amphibole and biotite grains in the mylonitic foliations (figure 21C) with surrounding chlorite, and garnets with chlorite in pressure shadows, and locally, post-tectonic growth of chlorite across the main foliation, indicate greenschist facies mineral replacement and a retrograde metamorphism post-dating the main foliation-forming event. This retrograde metamorphism may be due to uplift of the crust, and/or increased fluid content in the thrust system, which usually accompanies regional scale folding and thrusting. Chlorite is a common metamorphic mineral, usually indicative of low-grade metamorphism. The close relationship with biotite indicate a breakdown of biotite to chlorite (Barker, 1998). The observed kink folding (F2) of micas in the main foliation may have taken place at this stage.

No new growth of minerals or fabrics are seen in the fold hinges, or along the F2-fold axial surfaces, indicating the metamorphic conditions remained more or less constant during this late event. Although garnets have inclusions of pre-existing quartz and the associated retrograde metamorphism, the constant metamorphic conditions during the F2 event suggests that garnets have grown prior to this.

The studied ultramafic rocks seem to have been subjected to the same prograde-retrograde tectono-metamorphic events as the surrounding host rocks according to observations, and these events may have caused serpentinization (alteration).

Fluid flow through a shear zones readily leads to the retrogression of the primary, igneous ultramafic assemblage to give serpentinites (figure 23). Talc is stable at 310 °C to 670 ° if the fluid is very H2O-rich (Barker, 1998). The presence of talc in soapstone, at the periphery of the ultramafic rocks places it at the same metamorphic setting as the mentioned host rocks.

$$\underset{\text{forsterite}}{2Mg_2SiO_4} + 3H_2O = \underset{\text{serpentine}}{Mg_3Si_2O_5(OH)_4} + \underset{\text{brucite}}{Mg(OH)_2} \qquad (1)$$

and

$$\underset{\text{enstatite}}{3MgSiO_3} + 2H_2O = \underset{\text{serpentine}}{Mg_3Si_2O_5(OH)_4} + \underset{\text{silica}}{SiO_2} \qquad (2)$$

Figure 23: "Metamorphic reactions where olivine (1) and pyroxene (2) are serpentinized. From Barker (1998)"

The presence of magnetite is caused by oxidation during the process of serpentinization (Barker, 1998), which explain the magnetism of the ultramafic rocks. The irregular vein and crack systems at the surface of the ultramafic rocks are due to the common expansion of the rocks during serpentinization.

Pyrrhotite is a common trace mineral in some rocks, especially mafic igneous rocks. All thin sections show some amount of a very small sulphide mineral. Some crystals are still close to the original cubic shape. However, most minerals are deformed to rounded or elongated grains. The elongated crystals are layered with the main foliation or bending with the folds (figure 21C). Since only a few undeformed, euhedral sulphide minerals are preserved, it supports the ultramafic bodies were subjected to thrusting and mylonitization at high shortening strain in a similar manner as the host rocks.

4.4 Tectono-metamorphic evolution and structural implications

The structural data discussed above suggests a complex and polyphase tectono-metamorphic evolution of the studied Caledonian rocks hosting the ultramafic lenses in the Folldal area.

A low-angle foliation with a general dip to the W-SW, is the dominant fabric in the area. This foliation is referred to as S1, and is a result of a deformation event that may have involved the rocks being carried to depth (D1) before crustal shortening and thrusting of nappes (D2). Porphyroblasts, like garnet may have started to grow during the D1 event, and they grew across the fine-grained S1-fabric. The main foliation (S2) is seen in the most highly deformed rocks as a mylonitic foliation and may have formed in nearby ductile shear zones during thrusting. Internal, isoclinal folds (F1/F2), sigmoidal garnet porphyroblasts, shear bands and transposed fabrics are all observed in the mylonitic rocks, and indicate strong ductile shearing (thrusting) at medium grade (amphibolite facies) metamorphic conditions. These structures in the Folldal nappes are interpreted to reflect the main Scandian thrusting event (Gee et al., 2008).

The D3 deformation event is represented by open macro- and meso-scale folds, smaller-scale crenulations and mineral lineations (all F3 structures), and characterized by growth of low-grade metamorphic minerals such as muscovite and chlorite in the host rock and talc in the ultramafic rocks, implying retrograde metamorphism. The majority of retrograde metamorphism require hydration or carbonation, therefore the presence of a fluid phase is essential for this type of metamorphism to take place (Barker, 1998). The mylonite zones and the different folding phases described in this thesis corresponds with the regional implications made by Zwart (1974), mentioned in sections 1.1 and 1.1.1. He refers to the Seve and Köli Nappes further east of the Folldal and Dovre area but he calls the structures Caledonian trends. It is therefore nearby to assume that Zwarts data can be correlated further west as well.

The sharp contact between the ultramafic rocks and the meta-sedimentary host rocks, indicate that a tectonic process emplaced the ultramafic rocks at the current location. Considering the tectono-thermal hiatus mentioned in section 1.3.2., the ultramafic rocks must have been emplaced as the lower part of an oceanic crust, which has been uplifted and deeply eroded. Only the most resistant ultramafic parts were left on top of the Heidal Group when the sediments of the Sel Group were deposited. The rheology of the ultramafic rocks are very different from the host rocks and they will behave as relatively hard bodies in a more easily deformed host rock. They will be torn into pieces rather than deformed plastically. In that case, they will appears as beads on a string, stretched out and away from its original place of formation.

With the intrusive Folldal Trondhjemite yielding an age of ~488, and the tectono-thermal hiatus before deposition of the Sel Group, the Heidal Group rocks might be as old as of late pre-Cambrian or early Cambrian age. According to Nilsen & Wolff (1989), both Remsklepp-and Røros Nappe Complex are assumed to be from late Proterozoic /Cambrian to Ordovician time. The augen gneisses dated to 1600 Ma it does not help to determine the timing of all the events, it rather illustrates the complexity of the area.

4.5 Regional comparison and implications

The present study describes and analyses the ultramafic lenses in metasedimentary host rocks that are part of the Sel and Heidal Groups of the Røros and Remsklepp Nappe Complexes, in the Upper and Middle Allochthon (Nilsson et. al., 1997). The Sel and Heidal Groups were previously thought to differ in metamorphic grade, i.e. greenschist facies rocks characterizing the Sel Group whereas amphibolite facies rocks characterized the Heidal Group (Ramsay & Sturt, 1998). Considering these assertions, one could infer that both groups are represented in the study area. My study show that both amphibolite and greenschist facies metamorphic conditions affected the Sel and Heidal Groups, during D1/D2 and D3 events, respectively. Presence of amphibole and garnets in the most deformed samples, and replacement by chlorite support this statement. If both groups of rock are present in the study area, this fits well with the article from Sturt et al. (1997), which states that the ultramafic rocks of the Vågåmo Ophiolite lie aling a tectonic contact in bestween the Sel Group and Heidal Group.

In the Folldal area, Bjerkgård & Bjørlykke (1994) describes the Singsås formation to “show typically a rhythmical variation in quartz and mica content as well as grain size, 0.5 – 2 m scale, from nearly pure quartzites to mica schists”. This description of the uppermost part of the Remsklepp Nappe, in the uppermost part of the Middle Allochthon, corresponds to the findings in this thesis. Bjerkgård & Bjørlykke (1994) also mention garnet and amphibole porphyroblasts to be common, and the existence of primary sedimentary structures are found other places in the Singsås unit, e.g. the Røros area. All of these features are observed in the study area, which is located close to a thrust contact that can be traced all the way to Røros along strike within the corresponding Remsklepp and Røros Nappe Complexes.

However, a direct link of the two map sheets that cover the study area cannot be made (see figure 24). These maps include made the Røros & Sveg (R&S) map (Nilsen & Wolff, 1989) and the Lillehammer (L) map made by Siedlecka et al (1987). As seen in the map (figure 24A), there are large differences in the interpretation of the overlapping area for the maps, where the map sheet boundary is located.

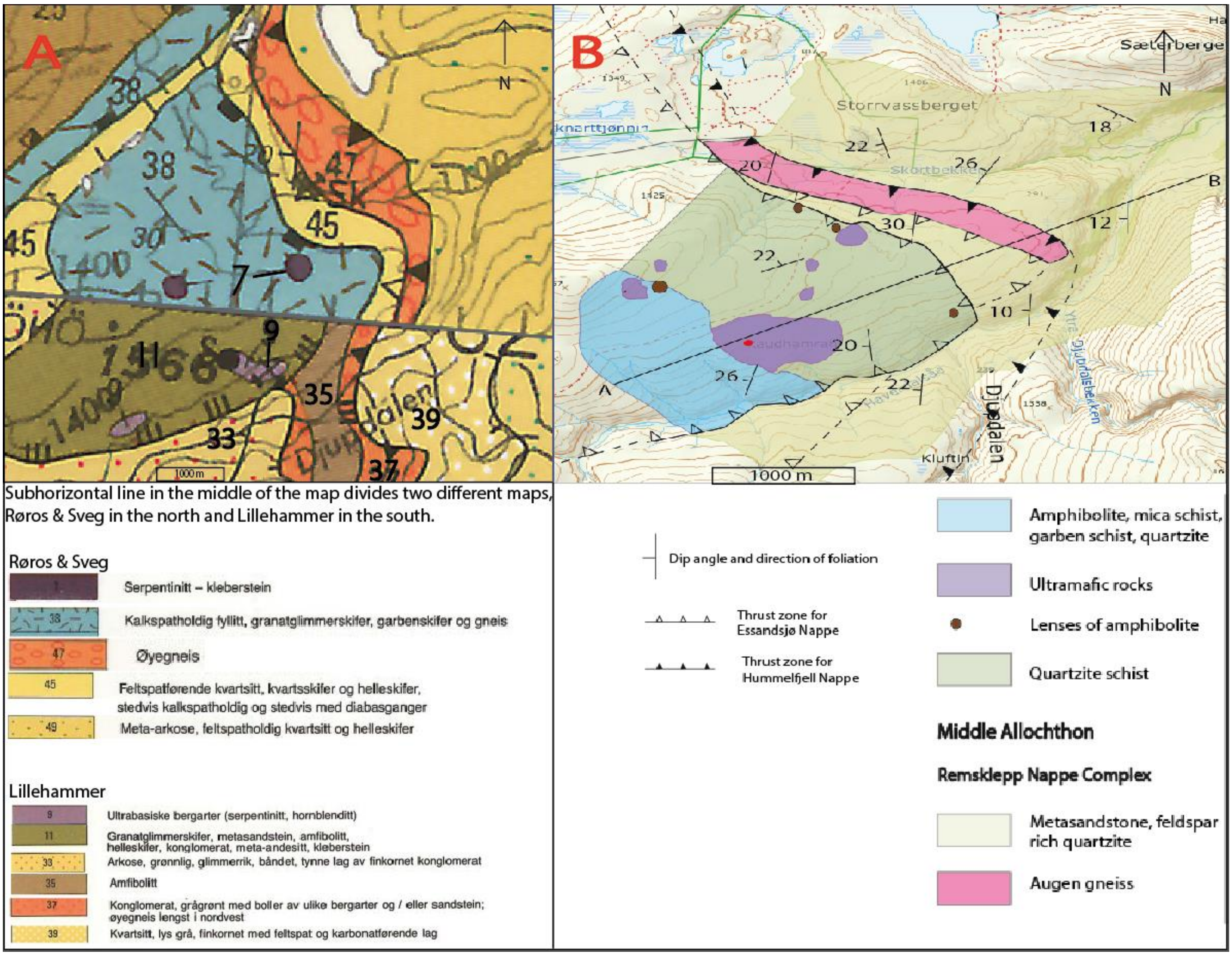

Figure 24: Section of geological maps. A) Section of Røros & Sveg and Lillehammer divided by subhorizontal line in the middle of the map, the latter map south of line. B) Revised geological map based on field studies for this thesis.

The augen gneisses (#47(number of the unit in the map)(R&S) and (#37(L)) follow more or less the same trend in both maps. But the Lillehammer map shows a lens of amphibolite (#35(L)) located between the augen gneisses and the metasedimentary rocks to the west, whereas the Røros & Sveg map states that it is feldspatic quartzite, quartz-schist and with local suits of diabase (#45(R&S)). The augen gneisses have been radiometric dated to c. 1600 Ma (Nilsen & Wolff, 1989). The rocks formerly described as the host rocks of the ultramafic rocks in this thesis, are in R&S called phyllite, garnet-mic-schist, garbenschist and gneiss, while in the L- map they are referred to as garnet-mica-schist, metasandstone, amphibolite, conglomerate, meta-andesite and soapstone. Siedlecka et. al. (1987) have divided the different lithologies into more units and the extension of the augen gneisses and the amphibolite deviates from that of the R&S- map. The differences of lithology in the units of the two maps might be due to the diffuse changes and transitions in mineralogy, already pointed out in this thesis. The thrust zones fits well, although the grid location of the units and the thrust faults seem to be a bit offset. There are no 1:50 000 maps and no detailed survey of the area available so far.

The revised geological map (figure 6) for this thesis is a result of mapping several in a limited area, which might clear up some of the differences and give a new understanding of the already established interpretations. The Otta Nappe boundary truncates the amphibolite seen in the L- map. This thesis has shown the presence of amphibolite lenses, rather than extensive units of amphibolite. It indicates that the map by Siedlecka et. al. (1987) is more accurate in this area than the map by Nilsen & Wolff (1989). Traces of mylonitic augen gneisses are observed subparallel to the Essandsjø thrust zone, which suggests that both maps locate the Essandsjø thrust zone too far east.

A strike-slip fault might be located just south of Raudhamran (figure 6). It could explain the location of the ultramafic bodies relative to each other and the contours of such a fault is visible in aerial photos. Siedlecka (1981) has made an unpublished observational map from the area where different fault are marked, and it might correlate with a strike-slip fault as pointed out. Faults of similar type and strike direction is typical for the region (Bjerkgård et. al., 2002)

Next step for further scientific research would be radiometric dating of the ultramafic rocks, in addition to geochemical investigations of both the ultramafic rocks and the host rocks. More detailed field mapping, than for this thesis and of what Siedlecka (1981) had available is required to improve the understanding of the region.

Presently, there is ongoing research from the University in Oslo, led by Johannes Jacob, where they investigate ultramafic rocks along strike from Bergen to Røros. Although the research from Oslo is not done before this thesis is out, it would be interesting to compare the two at a later stage.

4.6 The GEARS-project

The assessment form used for evaluating geological sites is enclosed at the end as appendix 3. It is worked out in cooperation between the NGU and its Swedish counterpart, equivalent to the NGU. Because of this fact, the form is only available in Norwegian/Swedish language. The form suggests an approach of mapping before, documentation during and evaluation after fieldwork. As this part was a secondary assignment, the idea was to make the assessment based on the results of the field study, without considering it too much before or after fieldwork. Although, the preparation and the actual fieldwork of this GEARS-project does not deviate much from an ordinary geological field study.

4.6.1 Evaluation

The Raudhamran outcrop, with its distinct ultramafic rocks is the subject of this evaluation. Its location within a national park contributes to keep it protected from any destructive human interventions. During the interwar years, a man prospected for chromite at Raudhamran and in that context raised a cabin there. In close vicinity, there is evidence of extraction of soapstone vessels. For scientific research, it is interesting because of its presence close to the contact between Upper and Middle Allochthon in the Caledonides. Despite a great prevalence of sediment covers in the region, some sites are good for study of this boundary. The historical value of this site has some potential. According to the guest book inside, this cabin is often used by hikers. Even though it is passed by a marked tourist trail and several hunters frequents the area during autumn, the damage potential is estimated to be minimal.

There are several similar outcrops found spread around in most parts of the Scandinavian Caledonides. Many of them shows a history of different kinds of mining. The Tollevshaugkyrkja outcrop located in Grimsdalen, is one set closer to the road, thus better suited also for tourism. The scenic view can clearly be compared to that of Raudhamran, which might be the biggest advantage of Raudhamran. Some outcrops probably have better visibility to the mentioned allochthonous boundary, since a large amount of this type of ultramafic rock are located along strike at the same tectono-stratigraphic level. Based on these criteria the uniqueness is not remarkable. Its almost monumental size and shape, along with the distinct colour, gets the curiosity going amongst people passing by, and an information board could be appropriate to place beside the cabin.

As concluding remarks, the Raudhamran ultramafic outcrop is a lovely place to visit, with local history documented inside the cabin related to it. But there are better locations more suitable for tourism, dissemination, etc. Besides the mentioned information board, no further steps are recommended in regard to the GEARS-project.

5 Conclusion

- The host rocks are part of the Sel and Heidal Groups, in the Røros Nappe Complex, Upper Allochthon at the boundary of the Middle Allochthon. The rocks are subjected to polyphase prograde-retrograde tectono-metamorphic events.
- The first phase of deformation (D1) observed in the host rocks involved a deep burial of the Otta Nappe, creating isoclinal folds (F1) and initiating growth of porphyroblasts. The second deformation event (D2) was the eastward thrust of the nappe in a ductile shear zone. It caused the refolding of F1-folds, evolving of porphyroblasts, crenulation cleavages (F2) and mylonites close to the shear zones. The main foliation (S1) possibly originate from both D1 and D2. The third phase of deformation (D3) was due to tectonic uplift, which made the macro- to meso-scale folds (F3), mineral lineations and initiated the process of retrograde metamorphism.
- The ultramafic rocks must have gone through a disfragmentation from their original ophiolitic setting upon tectonic emplacement on to the sedimentary/meta-sedimentary rocks of the Heidal Group. The unconformity between the Sel and Heidal Groups, the sharp contact and the metamorphic similarities between the ultramafic rocks and the host rocks suggests a simultaneous translation during the Caledonian thrusting events. This infers that the ultramafic rocks have gone through the same phases of Caledonian deformation processes as its host rocks.

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Appendix 1 – Petrographic reports

Sample 239: Quartzite
Rock name: Quartzite

The *Quartz* (>90%) is fine-grained and foliated.

Garnets (~5%) are small (up to 1mm), xenomorphic with up to 50% inclusions of the groundmass mineral quartz. Irregular oriented veins are filled with biotite. Sigmoidal shape with inclusions of sulphide (figure XXxxXX) in some garnets.

Muscovite (<3%) exist as thin elongated bands between quartz layers and bends around garnet.

Chlorite (<0,5%) exist only as single fine-grained, elongated crystals between quartz layers and near muscovite or biotite. There are very small amounts in the rock.

Biotite (<1%) behave as muscovite, with elongated bands between quartz layers and bends around garnet.

Sulphide (<1%), opaque in thin section, occur between quartz layers. Sulphide mineral act as both cubic and elongated grains rotated with garnet. It is found as inclusions in garnet and along with the foliation.

Sample 240: Garnet-mica schist

Mineral assemblage: garnet-biotite-muscovite-chlorite-quartz

Rock name: Garnet-mica schist

Muscovite (~50%) is the dominant mineral in the thin section and occur as very fine-grained coherent layers in elongated bands. It bends around garnet where these occur. Tendencies of undulose extinction under cross polarized lights.

Different layers of elongated *Quartz* (<35%) of varying size (few microns – almost 1mm). Mostly coherent layers but individual grains are observed in muscovite layers as elongated grains. Clusters of quartz are found in shadow of garnet and in the layers bending around garnet.

Garnets (<10 %) in thin section are relatively large (few mm) and subidiomorphic. The main cracks show tendencies of being aligned perpendicular to main foliation (figure XXXxxx).

Chlorite (~2%) is mainly seen in the shadow of garnets (figure X), but few thin bands between muscovite and quartz to.

Biotite (~2%) are found as elongated bands in layers of quartz and muscovite or as infill in veins in garnet.

Sulphide (<1%) act as small, elongated grains aligned with foliation. In some garnets, the sulphides have similar shape and an orientation parallel to foliation.

Sample 245: Garnet-mica schist

Mineral assemblage: Muscovite-Chlorite-Quartz-Garnet

Rock name: Garnet-mica schist

Mica (~50%) is seen as thin penetrative bands along foliation, softly bending around garnets. It is in close contact with all minerals in the section. Possible *Lepidolite* (a lithium rich mica) (figure 3) appear as grey/yellow with diffuse texture. The interference colors and other optical features suggest Lepidolite, but more laboratory investigations (e.g. SEM (Scanning Electron Microscopy)) need to be carried out to be certain. It is the most abundant type of mica in the sample

Quartz (~30%) is the second most abundant mineral the thin section. Clusters of small quartz rather than elongated grains, although larger elongated grains can be observed in foliation. Small, angular fragments are found as inclusions in garnet (figure X).

Garnet (~5%) exist as s. Partly irregular fracture system. The main orientation of the most markedly fractures appear to be perpendicular to the main foliation.

Chlorite (~5%) is seen as short elongated bands in the main foliation, parallel to biotite.

Sulphide (~2%), most likely pyrrhotite, are found as small, opaque grains aligned with foliation and randomly placed inside garnet, and as larger subidiomorphic grains (possibly pyrite) in a specific horizon/layer of the sample (figure XX).

Biotite (~2%) is seen as thin bands in relation with muscovite, as small inclusions in garnet and at the rim of garnets.

Muscovite (~2%) is the same as biotite above

Sample 244: Quartz mylonite
Mineral assemblage: Biotite-chlorite-quartz → Amphibole

Rock name: Quartz mylonite

Quartz (~50%) is dominating the thin section with medium grains to the left (figure X) and fine grains to the right, polygonal shape and sharp boundaries. Quartz to the left in section act as a monomineralic layer (figure 1). Fine quartz found as inclusions in amphibole and chlorite. Slightly undulose foliation.

Muscovite (~25%) dominantly found as thick layers, but as elongated bands between quartz and as inclusions in amphibole too.

Chlorite (<10%) is found at the boundaries of amphibole and garnet, stretched out along the main foliation.

Amphibole (<10%) is seen as medium sized grains elongated along main foliation. With different colours in thin section and only some show the specific 60°/120° cleavage, because the crystals are cut in different directions relative to main axis. Amphibole are in close contact with biotite and quartz along the edges of the crystal and as small inclusions. It has overgrown all other textures and minerals.

Biotite (~3%) found as small inclusions and at the edges of larger grains of amphibole and garnet. The larger grains are elongated in foliation and some have a polygonal shape.

Garnets (<1%) are small, subidiomorphic and deformed, closely surrounded by or in contact with quartz, biotite, chlorite and amphibole. It has grown on top of muscovite in foliation. Crystals are fractured with irregular oriented cracks.

Sulphide (<1%) is found as elongated grains in the main foliation and as inclusions in garnet, but some are also located more randomly as circular grains.

Sample 243: Quartz mylonite
Mineral assemblage: Carbonate-garnet-biotite-chlorite-quartz

Rock name: Quartz mylonite

Quartz (~60%). Size vary from fine grained quartz up to about 0,5mm with triple junctions. Quartz is found as inclusions in larger grains, e.g. carbonate.

Muscovite (~20%) is dominating the left side of the thin section (see figure X) but is also found in thin bands all over the specimen. Figure X show heavily folded muscovite with kink folds.

Chlorite (>5%). Elongated grains in the quartz matrix, in close contact with small amounts of biotite and muscovite.

Carbonate (~5%) exist as large grains (up to 1mm) surrounded by quartz and mica. It shows deformation with inclusions of mica and quartz. Grains are elongated with no apparent uniform direction of grain distribution. Cleavage is more or less perpendicular to foliation. Carbonate appear unaffected by F2.

Biotite (~3%) is seen in the whole section as small, elongated grains up to 0,1mm. Especially seen at the edges of carbonate and chlorite crystals (figure XXXxXX). It has also grown over carbonate.

Garnets (~2%) are small (<1mm), xenomorphic to subidiomorphic, and few in thin section. Deformed with irregular veins of tiny amounts of biotite and inclusions of quartz. Garnets lay in a matrix of quartz and in close relationship with grains of biotite and chlorite.

Amphibole (<1%), only one large grain found, perpendicular to main foliation, surrounded by chlorite and biotite.

Sulphide (~1%) crystals appear original to the sediment as it bends with the folded mica.

Appendix 2 - Symbols for rock-forming minerals

KRETZ: SYMBOLS FOR ROCK-FORMING MINERALS

Table 1. Mineral Symbols

Acm	acmite	Elb	elbaite	Ntr	natrolite
Act	actinolite	En	enstatite (ortho)	Ne	nepheline
Agt	aegirine-augite	Ep	epidote	Nrb	norbergite
Ak	åkermanite	Fst	fassite	Nsn	nosean
Ab	albite	Fa	fayalite	Ol	olivine
Aln	allanite	Fac	ferroactinolite	Omp	omphacite
Alm	almandine	Fed	ferroedenite	Oam	orthoamphibole
Anl	analcite	Fs	ferrosilite (ortho)	Or	orthoclase
Ant	anatase	Fts	ferrotschermakite	Opx	orthopyroxene
And	andalusite	Fl	fluorite	Pg	paragonite
Adr	andradite	Fo	forsterite	Prg	pargasite
Anh	anhydrite	Gn	galena	Pct	pectolite
Ank	ankerite	Grt	garnet	Pn	pentlandite
Ann	annite	Ged	gedrite	Per	periclase
An	anorthite	Gh	gehlenite	Prv	perovskite
Atg	antigorite	Gbs	gibbsite	Phl	phlogopite
Ath	anthophyllite	Glt	glauconite	Pgt	pigeonite
Ap	apatite	Gln	glaucophane	Pl	plagioclase
Apo	apophyllite	Gt	geothite	Prh	prehnite
Arg	aragonite	Gr	graphite	Pen	protoenstatite
Arf	arfvedsonite	Grs	grossularite	Pmp	pumpellyite
Apy	arsenopyrite	Gru	grunerite	Py	pyrite
Aug	augite	Gp	gypsum	Prp	pyrope
Ax	axinite	Hl	halite	Prl	pyrophyllite
Brt	barite	Hs	hastingsite	Po	pyrrhotite
Brl	beryl	Hyn	haüyne	Qtz	quartz
Bt	biotite	Hd	hedenbergite	Rbk	riebeckite
Bhm	boehmite	Hem	hematite	Rds	rhodochrosite
Bn	bornite	Hc	hercynite	Rdn	rhodonite
Brk	brookite	Hul	heulandite	Rt	rutile
Brc	brucite	Hbl	hornblende	Sa	sanidine
Bst	bustamite	Hu	humite	Spr	sapphirine
Cam	Ca clinoamphibole	Ill	illite	Scp	scapolite
Cpx	Ca clinopyroxene	Ilm	ilmenite	Srl	schorl
Cal	calcite	Jd	jadeite	Srp	serpentine
Ccn	cancrinite	Jh	johannsenite	Sd	siderite
Crn	carnegieite	Krs	kaersutite	Sil	sillimanite
Cst	cassiterite	Kls	kalsilite	Sdl	sodalite
Cls	celestite	Kln	kaolinite	Sps	spessartine
Cbz	chabazite	Ktp	kataphorite	Sp	sphalerite
Cc	chalcocite	Kfs	K feldspar	Spn	sphene
Ccp	chalcopyrite	Krn	kornerupine	Spl	spinel
Chl	chlorite	Ky	kyanite	Spd	spodumene
Cld	chloritoid	Lmt	laumontite	St	staurolite
Chn	chondrodite	Lws	lawsonite	Stb	stilbite
Chr	chromite	Lpd	lepidolite	Stp	stilpnomelane
Ccl	chrysocolla	Lct	leucite	Str	strontianite
Ctl	chrysotile	Lm	limonite	Tlc	talc
Cen	clinoenstatite	Lz	lizardite	Tmp	thompsonite
Cfs	clinoferrosilite	Lo	loellingite	Ttn	titanite
Chu	clinohumite	Mgh	maghemite	Toz	topaz
Czo	clinozoisite	Mkt	magnesiokatophorite	Tur	tourmaline
Crd	cordierite	Mrb	magnesioriebeckite	Tr	tremolite
Crn	corundum	Mgs	magnesite	Trd	tridymite
Cv	covellite	Mag	magnetite	Tro	troilite
Crs	cristoballite	Mrg	margarite	Ts	tschermakite
Cum	cummingtonite	Mel	melilite	Usp	ulvöspinel
Dsp	diaspore	Mc	microcline	Vrm	vermiculite
Dg	diginite	Mo	molybdenite	Ves	vesuvianite
Di	diopside	Mnz	monazite	Wth	witherite
Dol	dolomite	Mtc	monticellite	Wo	wollastonite
Drv	dravite	Mnt	montmorillonite	Wus	wüstite
Eck	eckermannite	Mul	mullite	Zrn	zircon
Ed	edenite	Ms	muscovite	Zo	zoisite

Appendix 3 – The GEARS-project, assessment form

1. Kartlegging (før feltarbeid)

1.1 Velge perspektiv

- Earth System
- Prosessbasert beskrivelse Geosystemtjenester
- Områdebeskrivelse

1.2 Studere publisert informasjon

- Litteratur
- Kart

1.3 Studere tilgjengelig informasjon som kan supplere publisert informasjon

- LiDAR, hvilke strukturer vi ikke kjenner til kan ses på nye LiDAR-data?
- Geofysikk, hva kan sees av anomalier?
- Intervju med fagfolk som har jobbet i området
- Intervju med lokalkjente (ikke nødvendigvis med geologisk kompetanse): hva er spektakulært, hva lurer folk på?
- Klargjøre 3D modell hvis det finnes tilgjengelige data

1.4 Konklusjon før dokumentasjon (feltarbeid)

- Valg av perspektiv
- Rammeverk: Hvilke viktige hendelser eller miljø karakteriserer området som skal vurderes?
- Tidslinje (berggrunn): Hva kjennetegner området som skal undersøkes, hvilke typer lokaliteter kan vi forvente å finne?
- Kvartær/ geomorfologi: Hva slags landskapsmiljø finner vi, hvilke spor kan vi forvente å finne?
- Bruttoliste over steder som kan tenkes å vise/representere variasjonen i områdets geologiske historie (berggrunn)
- Bruttoliste over steder som kan tenkes å vise/representere landskapsmangfold og spor etter istiden (kvartærgeologi)

2. Dokumentasjon (I felt)

Fylle ut skjema /database med følgende tema

2.1 Hva forventer vi å se og hva ser vi?

Fritekst

Sammenstilling (sammanfattning) av de geologiska huvuddragen utifrån bergarter, jordarter, stratigrafi, mineral, fossil, strukturer, relationer, geomorfologiska element och terrängformer samt geopaleomiljö.

Verdistatus (värdestatus):

Eksisterende (befintlig) kunskap om verdi (värde) /signifikans med begrunnelse. Angi om det finns kända typsektioner, utpekade värden eller uppmärksammade element och kvaliteter

Tidligere undersøkelser/referanser

Kunnskapsgrunnlag		middels	godt	Meget godt	Svært god	
		Dokumentation och rapporter har gjorts om området	Dokumentation, abstracts och rapporter har gjorts om området	Artiklar publicerade i **nationella** vetenskapliga tidskrifter	Artiklar publicerade i **internationella** vetenskapliga tidskrifter	

Vernestatus

- Hvilken type vern;
- Er geologi eventuelt en del av grunnlaget for vern?

2.2 Type geologisk lokalitet (mest aktuelt for berggrunn)

Fagområde	**Forklaring**	
Stratigrafi	hendelser, sekvenser, typesnitt, stratigrafiske grenser	
Geomorfologi	Landformer og landskap, grotter, karstlandskap, fluvial, kyst, glasial, periglasial	
Sedimentologi	Løse avleiringer, deres avsetningsmiljø, klassifikasjon og omdanning til faste bergarter	
Paleontologi	Makro- og mikrofossiler, utvikling	
Mineralogi	Forekomster av mineraler, mangfold og prosesser	
Paleomiljø	Indikatorer på fortidens klima, paleoforvitring, fossiler, sedimentasjon, paleoøkologi	
Hydrogeologi	kilder, vannfører, hydrologisk karst og speleothemer	
Struktur (tektonisk)	Folder, forkastninger, skjærsoner, plastisk og sprø deformasjon, forflytning, skyveretning, tektonisk setting	
Magmatisk	vulkanske og plutoniske bergarter, ganger, magmatiske prosesser, magmatisk petrologi	
Metamorfose	Metamorphic indicators eller prosesser, metamorf petrologi	
Geobiosfære	Geologi som kilde til variasjon for økosystemer, spesielle livsforhold og biodiversitet knyttet til geologi	
Geokronologi	Steder for geokronologiske dateringer, alder, tidslinje?	
Submarin	Områder på havbunn eller submarint kystmiljø, f.eks. dyner, korallrev, hydrotermale skorsteiner, submarine skred	
Geofare	Bevis for nyere tids massebevegelser f.eks. skred, jordskjelv, vulkanske utbrudd, tsunami	
Georessurs	Historisk eller moderne betydning som råvare (mineraler, bergarter)	
Geokultur	Historisk eller moderne bergkunst, og historiske eller moderne steinbygninger eller bygninger med knytting til geologi, geosteder av (religiøs) andakt	
Vitenskapelig historisk	Områder av betydning for den historiske utviklingen av geologi som vitenskap	

Tillegg: Hvilket punkt (eller punkter) i tidslinjen vil dette stedet representere?

2.3 Type geologisk miljø (mest aktuelt for kvartærgeologi, ikke uttømmende liste)

Notera typ av geologisk miljö				
Häll, hällområde	Kanal	Lerflata	blockstrand	tjärn
Bergsplatå	Tidvattenområde	Saltäng	Klippkust	Flod, älv
Täkt, grop	Vik	Sanddyner	Ö eller vattenomslutna klippor	Dräneringsdike
Skärning	Bukt	Sandstrand	Hav	mosse
grotta	Flodmynning	Klapperstrand	Sjö	Moränform
tunnel	Sandflata	Klapperfält	Dämning	dalgång
Rasbrant	Delta	morän	Ås	Fjord
Etc.				

Alternativ (N): Naturtype landform i henhold til Natur i Norge (NIN)

- Avsetningsformer knyttet til breer/glacierer
  (*Dødisgrop, dødisterreng, drumliner, ende- og sidemorener, esker, flyttblokk, iskjernemorene)*
- Avsetningsformer knyttet til rennende vann
  (*Delta, elvebanke, elveslette, elvevifte leirslette levé)*
- Breformer:
  Botnbre, dalbre, dalsidebre, kalvende bre, platåbre, regenerert bre, sammensatt bre
- Erosjonsformer knyttet til breer
  (*Botn, bruddform, dalende, dalklype, fjorddal, hengende dal, marint basseng P-form, rundsva, skuringsstripe, tind, U-dal)*
- Elveløpsformer
  (Blind dal, forgreinet elveløp kroksjø meander, underjordisk elveløp bekkekløft)
- Erosjonsformer knyttet til rennende vann
  (Erosjonskant gjel jettegryte jordpyramide ravine (bresjø eller leire) spylerenne V-dal)
- Landformer knyttet til frostprosesser
  (Forvitringsblokkmark/ forvitringsgrusmark, pingo, steinbre, strukturmark)
- Landformer knyttet til jordas indre krefter
  (Glintrand, havbunnsskorstein, kalkrygg, mudderdiapir, muddervulkan, sprekkedal, utstrømningsgrop vulkan ***med flere)***
- Kjemiske oppløsningsformer (*Doline, dryppstein kalkgrotte karstoverflate kalktuff)*

- Landformer knyttet til kystprosesser (*Kystgrotte kystklippe rauk, strandlinje, strandvoll)*
- Landformer knyttet til massebevegelse på land (*Flytjordsvalk, fjellskredur, flomrasvifte, jordskred, leirskred (grop) protalus, snørasvoll, talus)*
- Landformer knyttet til marine strøm- og skredprosesser
- Landformer knytet til vindprosesser
- **Andre (*F. eks. Landformer knyttet til forvitringsprosesser (Etseflate, strandflate) mfl.*)**

Berggrunn: Robusthet/Rehologi -> Mineral sammensetning og deformasjonsgrad -> Metamorfosegrad, mineralvekst -> sprø/duktil setting -> fold og forkastning, skjærsone.

2.4 Typologi

Typologi	**Forklaring**	
Punkt	Små, isolerte områder *(Forslag: ikke større enn 1 ha.)*	
Seksjon	Kronologiske sekvenser og/eller områder som har utstrekning som en linje	
Areal	Store områder som inneholder kun en type av interesse	
Utsiktpunkt	Et utsiktpunkt omfatter to ulike elementer: et stort areal med geologisk interesse og et punkt hvor det området kan sees fra.	
Komplekst areal	Større områder som omfatter flere punkter, seksjoner, arealer og/eller utsiktpunkter.	
Landskap	Større områder med spesifikke geologiske eller geomorfologiske egenskaper.	
2D profil i z retning	Kronologiske sekvenser eller områder som har utstrekning i to dimensjoner	
3D kropp	Et volumområde i 3 dimensjoner	

2.5 Formidlingspotensial

Potensielt bruk

- Vitenskap
- Undervisning
- Reiseliv/besøksnæring
- Samling (Samlande)
- Rekreasjon

Kan stedet tenkes å være egnet for undervisning og/eller reiseliv (ikke ekskluderende)

UNDERVISNING		BESÖKSMÅL			FORVALTNING
Tydlighet	**Mångfald**	**Skönhet/ visuella kvaliteter**	**Andra värden inom eller nära området**	**Företeelsernas möjlighet till poularisering och tolkning**	**Verdisatt lokalitet**
Visar företeelser klart	Många olika, tydliga företeelser	Platsen	Biologi	Intuitivt begripliga	
Visar processer klart	Många kopplade, tydliga företeelser	Området	Historia	Stora	
Visar relationer och geologiska sammanhang klart		Företeelserna	Arkeologi	Sällsynta	
Visar fenomen som kan användas för flera olika nivåer i undervisning		Objekt	Kultur	Distinkta	
			Museum, Naturum, besökscentrum	Rekord: Det äldsta, första, bästa, ...	

			Andra sevärdheter		
				Spektakulära	

- **Samlet vurdering av formidlingspotensial: Svak – Moderat - Sterk**

2.6 Tilstand:

Sikkerhet. Angi flere ved behov:

Säkerhetsfaktorer för besök	**Ange hur och vad**	**Sd**	**D**	**M**	**G**	**IR**	**IU**
Finns räcken, staket, trappor, ... i tillräcklig grad?							
Är skärning säkrad för ras?							
Passeras riskabla områden eller partier på väg till det geologiskt intressanta området?							

Sd: Svært dårlig/ farlig D: Dårlig: M: Middels: G:god: IR: Ikke relevant, IU: Ikke undersøkt

Kommentar sikkerhet

Bruksbegrensninger (Användningsbegränsningar) og logistikk. Angi flere ved behov:

Begränsande faktorer för tillgänglighet och besök	**Ange hur och vad**	**SD**	**SV**	**M**	**ST**	**IR**	**IU**
Parkeringsmöjlighet							
Parkeringskapacitet							
Avstånd från parkeringsplats							
Information på plats							
Information på turistbyrå/besökscentrum/Naturum							

Sd: Svært dårlig/ SV Svak M Moderat, ST: Sterk IR: Ikke relevant, IU: Ikke undersøkt

Kommentar bruksbegrensninger

Föreliggande hot/trusler. Skadande verksamhet. Ange flera vid behov:

Naturliga processer	**Mänsklig verksamhet**	**Hinder**	**Saknade faktorer**
Överväxning, beskogning	Mineralutvinning, muddring, sprängning, schaktning, grävning	Motstående intressen inom området hindrar beslut	Platsdokumentation saknas
Förändring av nat. processer: vattenytehöjn/sänkn, älvlopp byter fåra, uttorkning, ...	Igenfyllning, schaktmassor, tippning	Markägarkonflikt: tillträde begränsat, provtagning begränsad	Förmedling av geologiskt värde saknas (för vetenskap, undervisning eller turism)
Pågående nat. processer: erosion, deposition, vittring, ras, skred, ...	Expansion/utveckling av infrastruktur: väg, järnväg, bebyggelse, anläggningar, ...	Befintligt naturskydd begränsar användning av plats	Förmedling av kopplingar till andra värden saknas (biologi, kultur, historia, arkeologi, ...)
Försämring/nedbrytning av blottning, skärning, landform eller landskap	Älvkonstruktioner, kanaler	Lovhinder: Krav på tillståndsansökan för tillträde eller användning	Sparade sektioner i täkter eller skärningar saknas
Havsytestigning	Kustskyddskonstruktioner		Skötsel/underhåll saknas
Översvämning	Förändring av fluviala processer: dämning, reglering, omledning, ...		Resursbrist
	Militära övningar		
	Rekreation, friluftsliv, camping, golf, ...		
	Volyminös provtagning av stuffer, material eller borrkärnor, översamling av fossil, mineral, bergart, mineralisering.		

	Plats föremål för andra mål och strategier		
	Hög befolkningstäthet i relation till platsens sårbarhet		

Markanvändning inom område. Ange flera vid behov:

Huvudsaklig markanvändning				
Naturvård		Betande djur		
Friluftsliv				
Inga aktiviteter		Skogsbruk, odling		
Väg				
Bebyggelse		Vetenskap, undervisning		
Täkt	Industri	Vetenskap, provtagning		
Jakt, fiske	Soptipp	Pedagogisk lokal, allmänhet		

- **Samlet vurdering av robusthet: Sterk – Moderat – Svak**

2.7 Tiltak (åtgärd)

	Høy	**Medium**	**Lav**	**Ikke vurdert**
Grad av bevaring	Godt bevart i naturlig tilstand	Delvis forvitret av menneskelig aktivitet eller forvitring/erosjon	Kraftig skadet av menneskelig aktivitet eller forvitring/erosjon	
Bevaringsbehov Behovet for aktive bevaringstiltak	Sterke bevaringstiltak nødvendige	Middels bevaringstiltak nødvendige	Ingen bevarings behov	
Behov for fredning	Stort behov for fredning	Kan være behov i fremtiden eller deler av området bør vernes	Ingen behov nødvendig	

Skjøtselsforslag:

- Hugga ner skog
- Rensa vegetation
- Sätta upp skyltar
- Skydda området

Annen info, råd og anbefalinger tilrettelagt for forvaltningsorganer

3. Vurdering (etter felt):

- Sammenstilling
- Diskusjon mellom alle som har kartlagt/registrert i området
- Vurdering av **representativitet**
- Vurdering av **sjeldenhet**
- Vurdering av **sårbarhet**
- Råd for formidlingsstrategier
- Råd for forvaltningsstrategier

3.1 Generelt

Her kan vurderingen(bedömningen) skje fra ulike perspektiv avhengig av formålet (syftet) enten det er vitenskap, undervisning, besøksnæring, eller generell miljøkartlegging (naturvärdesinventering i allmänhet). Vurderingen (bedömningen) kan gjøres dels ut fra kvantitative faktorer (grunder) og dels fra kvalitative faktorer. De kvantitative faktorene kan reflektere mangfoldet og dets betydning for landskapet mens de kvalitative tar utgangspunkt i en sammenligning mellom ulike plasser og hvor bra de representerer delene i et geologisk rammeverk. Her presenterer (redovisar) vi de kriteriene som vi anser er viktige å ta stilling til.

3.2 Vurdering av sjeldenhet

Kriterium	**Stort antall**	**Middels**	**Middels**	**Sjelden**	**Ikke vurdert**
Sällsynthet/Sjeldenhet i et gitt område	Förekommer i stort antal/präglar området.	Förekommer på flera platser inom området.	Förekommer på enstaka platser inom området.	Sällsynt inom området.	

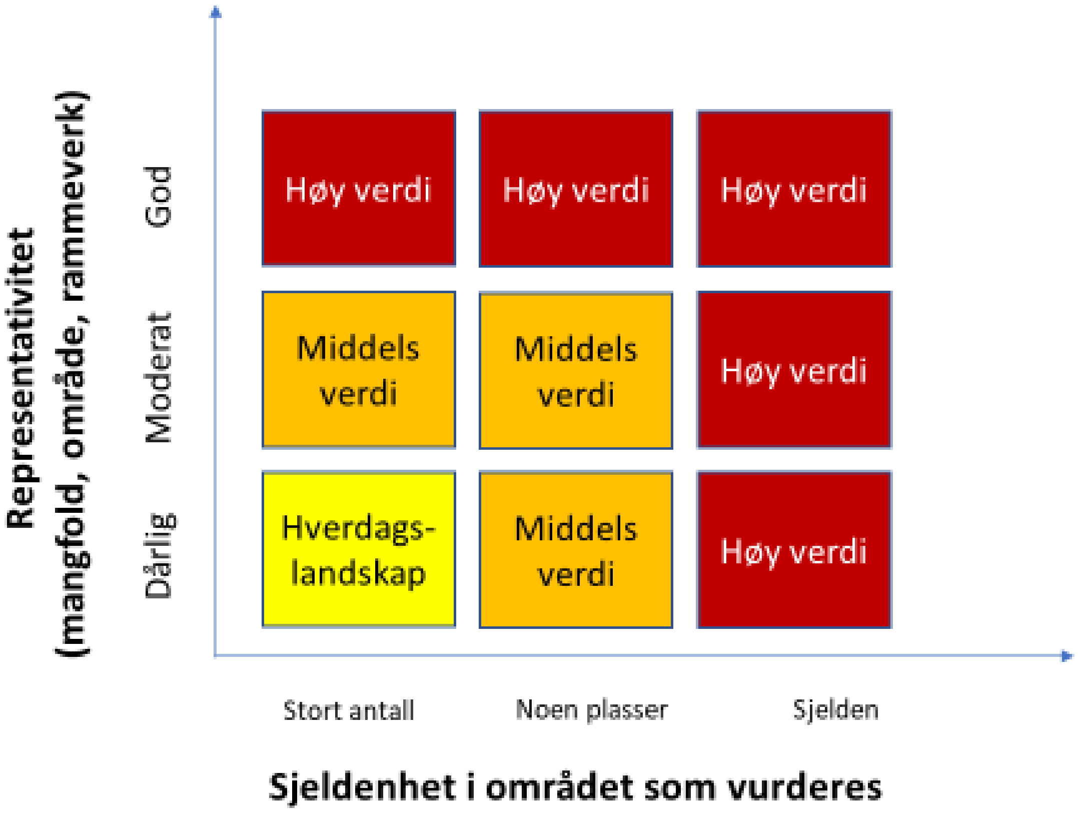
3.3 Vurdering av representativitet

Kriterium	**Hverdagslandskap**	**Dårlig**	**Moderat**	**Moderat**	**God**	**Ikke vurdert**
Representativitet, rammeverk (Viktighet) Område med dokumentert betydning innen geofag og visning av geologiske prosesser		Representativ för tema, process, företeelse eller utveckling på lokal nivå utifrån det geologiska ramverket *(Av betydning for å beskrive og forstå det lokale geologiske rammeverket og/eller en bestemt geologisk prosess)*	Representativ för tema, process, företeelse eller utveckling på regional nivå utifrån det geologiska ramverket (*Av betydning for å beskrive og forstå det geologiske rammeverket for en region*)	Representativ för tema, process, företeelse eller utveckling på nationell nivå utifrån det geologiska ramverket (*Av betydning for å beskrive og forstå geologiske prosesser på nasjonal skala*)	Representativ för tema, process, företeelse eller utveckling på internationell nivå utifrån det geologiska ramverket (*Av betydning for geologi som en vitenskap,* *Enestående global betydning*)	
Begrunnelse/Motivering till ovan:						
Representativitet, mångfald Område som viser et geologisk fenomen som er representativt for andre fenomener i den samme kategorien		Representativ på område-nivå	Representativ på et regionalt nivå	Representativ på et nasjonalt nivå	Representativ på et internasjonalt nivå	
Begrunnelse/Motivering till ovan:						
Representativitet, område (sjekkes i felt)		Någorlunda exempel på tema, process, företeelse eller utveckling inom området utifrån det geologiska ramverket	Bra exempel på tema, process, företeelse eller utveckling inom området utifrån det geologiska ramverket		Mycket bra exempel på tema, process, företeelse eller utveckling inom området utifrån det geologiska ramverket	

Begrunnelse/Motivering till ovan:	

Problem: Hvordan sammenfatte vurderingen av representativitet til en verdi? Gjerne i klassene: Dårlig – moderat – god. Finne klassen med høyest verdi eller bruke gjennomsnitt, dersom flere enn én type representativitet er aktuell?

3.4 Vurdering av verdi



	Stort antall	Noen plasser	Sjelden
God	Høy verdi	Høy verdi	Høy verdi
Moderat	Middels verdi	Middels verdi	Høy verdi
Dårlig	Hverdags-landskap	Middels verdi	Høy verdi

Modifisert etter Evju et al. 2017

Kommentarer til aksen for representativitet:

En samlet vurdering av representativitet i forhold til:

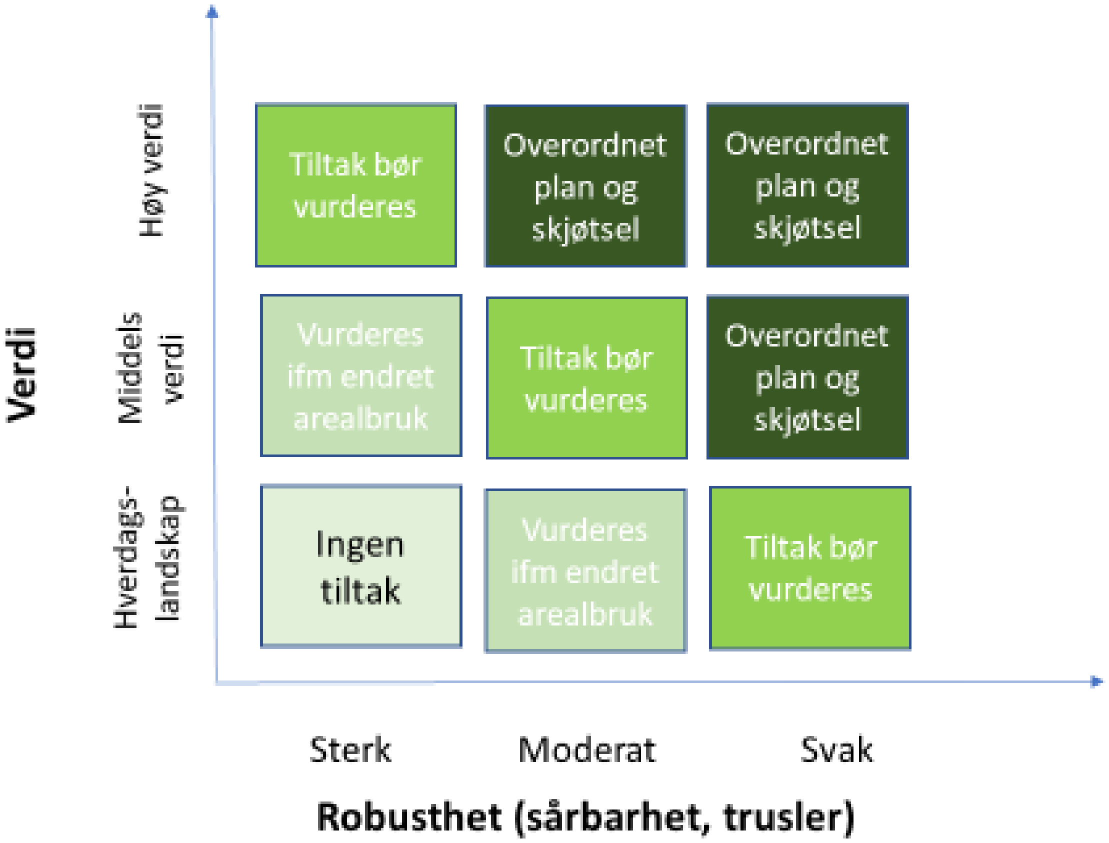
- Mangfold)
- Geografisk område
- Rammeverk (de geologiske temaene som er aktuelle for dette området)

Kommentarer til aksen for sjeldenhet:

Med sjeldenhet menes: Område som er unikt på grunn av det geologiske fenomenet som vises eller fordi det inneholder sjeldne mineraler, bergarter eller fossiler.

- Stort antall: Forekommer i stort antall/preger (präglar) området
- Middels: Forekommer på flere steder / enkelte steder (enstaka platser) i området.
- Sjelden: Sjelden (Sällsynt) i området

3.5 Forvaltningsråd

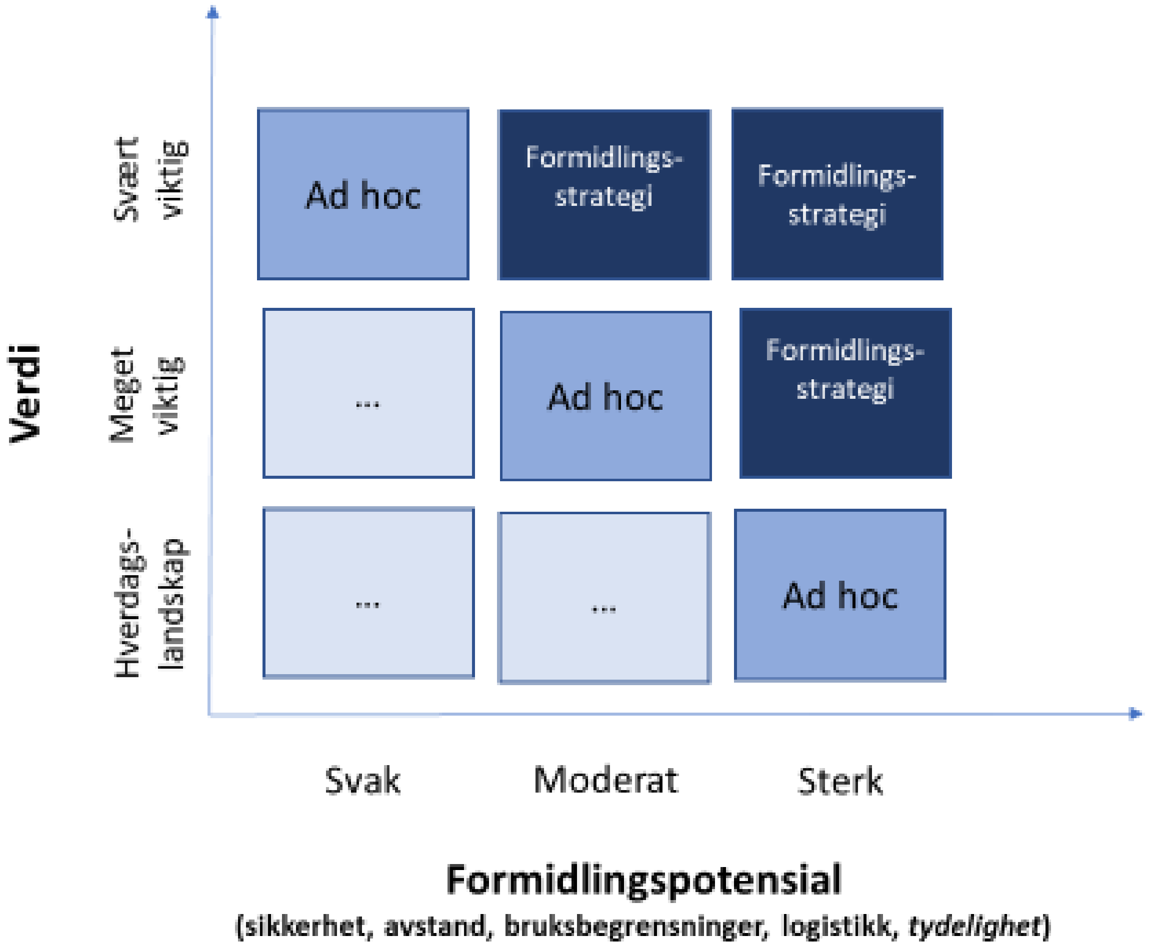


Kommentarer til aksen for robusthet:

Samlet vurdering av:

- Sårbarhet for naturlig nedbrytning
- Sårbarhet for menneskelig påvirkning
- Sannsynlighet for framtidige trusler
- Bevaringsgrad?

3.6 Formidlingsråd



Aksen for formidlingsegnethet:

Samlet vurdering av:

- Sikkerhet
- Tydelighet (intuitivt begripelig),
- Mangfold,
- Visuelle kvaliteter,
- Mulighet til popularisering
- Bruksbegrensninger, logistikk

Formidlingsråd må deretter ses i sammenheng med forvaltningsstrategier, besøksstrategier etc.

Referanse:

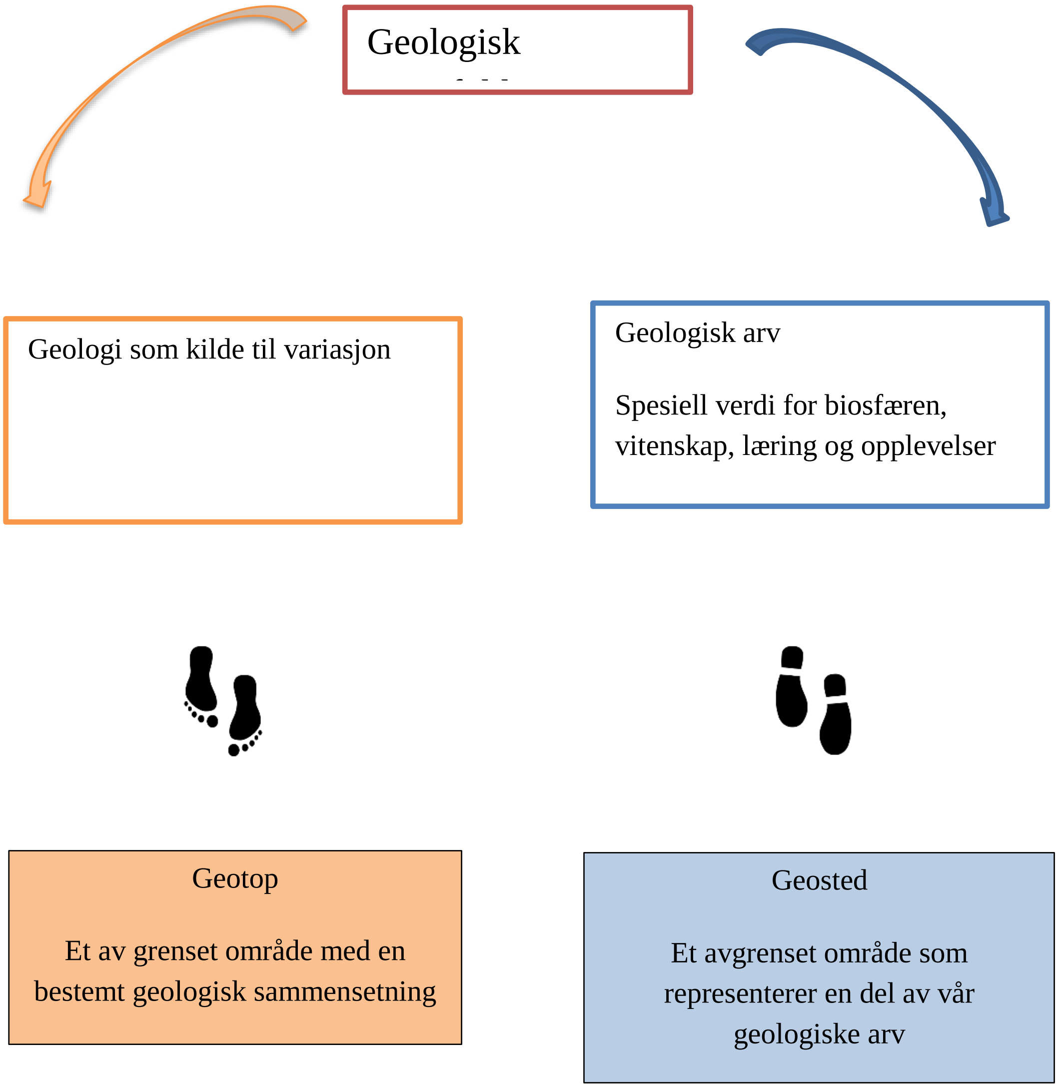
Evju, M., Blom, H., Brandrud, T. E., Bär, A., Lyngstad, A., Øien, D.- I. & Aarrestad, P. A. 2017. Naturtyper av nasjonal forvaltningsinteresse. Revidert forslag til vurdering av lokalitetskvalitet. - NINA Rapport 1428. 95 s

Arbeidsflyt, kartlegging og analyse av geologisk mangfold

Visjon for bruk av database for geologisk mangfold

- Vern og ivaretakelse
- Tilgjengeliggjøring av kunnskap
- Naturforvaltning

- Betydning og verdi
- Belyse trusler



Geologisk

Geologi som kilde til variasjon

Geologisk arv

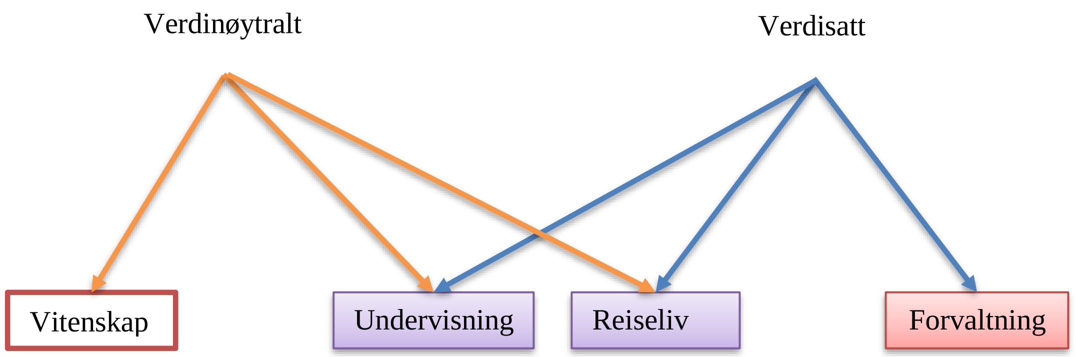
Spesiell verdi for biosfæren, vitenskap, læring og opplevelser

Geotop

Et av grenset område med en bestemt geologisk sammensetning

Geosted

Et avgrenset område som representerer en del av vår geologiske arv


Verdinøytralt
Verdisatt
Vitenskap
Undervisning
Reiseliv
Forvaltning