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Evaluation of Ni-Cu occurrences in the Uppermost Allochton of the Scandinavian Caledonides of Nordland, I: Field relationships

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Summary:

The report gives a description of the geology and field relationships of Ni-Cu mineralisation in 7 ore fields that occur in the Uppermost Allochthon (UmA) of the Scandinavian Caledonides in Nordland, where they are associated with a variety of metamorphosed and/or metasomatically altered mafic-ultramafic rock units. The occurrences in Markafjell in Brønnøy municipality, Esjeholmene in Lurøy municipality and Utvikåsen in Bodø municipality are associated with ultramafic rocks in dismembered ophiolites whereas the ore-bearing ultramafic intrusion at Tverrbrennfjellet in Bodø municipality comprises pyroxenites that have become "gabbroic" by mingling with a tonalitic magma. Mineralisation hosted by gabbroic intrusions are comprised by the Høgsetdalen showing in Gildeskål municipality and the Lilleålegden deposit in Beiarn municipality, as well as the Måløy deposit in Steigen municipality. The latter two deposits have been the sites of small-scale mining in the past due to high-grade ores exceeding 1 wt. % (locally massive pentlandite with ca. 33 wt. % Ni). The Steinåga mineralisation in Beiarn municipality, comprising low-grade base metal pyrrhotite mineralisation (< 0.1 wt % Ni or Cu), is hosted by ultramafic amphibolites possibly representing meta-volcanites.

The investigations are part of a joint project on 50/50 basis between Nordland fylkeskommune (NOK 400,000) and Norges geologiske undersøkelse. The aim of the project is to investigate Ni-Cu deposits and occurrences in the Scandinavian Caledonides of Nordland in relation to their geology and economic potential, the latter based on their dimensions and contents of potentially exploitable metals such as Ni, Cu, Co, PGM and Au. The discovery of economically interesting mineralisation types and deposits is important in regard to land-use planning work carried out in the individual municipalities and for NGU, in advocating for an extension of the Mineral Resources in North-Norway program (MINN) and for semi-regional geophysical ground surveys on the most interesting occurrences.

Preliminary assessments of the individual occurrences are so far based on their bedrock and ore geology, as well as on analyses of Ni, Cu, Co, Pt, Pd and Au in the NGU Ore Database. These data suggest that there are several mineralisations on which follow-up work is justified. These include the Markafjellet mineralisation which has the potential of representing a large, low-grade Ni deposit in a body of meta-peridotites that may have its counterparts among the dismembered ophiolites elsewhere in the Velfjord district. The high-grade to very high-grade Ni-Cu mineralisations with enhanced contents of PGM are hosted by small gabbroic bodies at Høgsetdalen, Måløy and Lilleålegden. These are of no economic importance. However, their restricted size, their ore fabric and the ratio of sulphides to silicates indicate that the gabbros were intruded as two immiscible liquids derived from an external Ni-rich source. Gravity surveys should, in order to search for this source magma of possible economic interest, be conducted in these three areas in order to find any significant mafic-ultramafic-hosted ore bodies.

The mineralisations at Esjeholmene, Utvikåsen, Steinåga and Tverrbrennfjellet are generally of low grade and with restricted dimensions. None of them appears to represent interesting mineralisation types with a economic potential. They would be of no importance in land use planning in the relevant municipalities.

Keywords: Field report	Ni-Cu occurrences	Scandinavian Caledonides
Nordland	Geological setting	Ore geology
Field relationships		

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SAMMENDRAG

Rapporten gir et sammendrag av resultatene fra feltundersøkelser av 7 felter med nikkel-kopper mineraliseringer som opptrer i Øverste Dekkeserie i de skandinaviske Kaledonider i Nordland. Arbeidet gjøres innenfor prosjektet:

Evaluering av nikkel-kobber forekomster i Nordland i et malmletings- og arealplan-perspektiv.

Prosjektet vil søke å kartlegge det økonomiske potensialet av de kjente forekomstene av nikkel i disse feltene i Nordland ut fra deres størrelse og innhold av utnyttbare metaller (nikkel, kobber, kobolt, platinagruppe metaller og gull). Denne vurderingen gjøres på basis av internasjonalt aksepterte geologiske kriterier for dannelsen av økonomiske nikkelforekomster og geologien i felter med slike forekomster. Resultatene av denne evalueringen vil gi viktige insitamenter til bruk i kommunenes arealplanlegging, samt innspill for bedømningen av de mineraliserte områdenes prospekterbarhet og valg av malmletningsmetoder, inkludert geofysiske luft- og bakkemålinger. Påvisning av økonomisk interessante mineraliseringer vil også kunne gi argumenter for videreføring av programmet Mineralressurser i Nord-Norge (MINN). Dessuten vil utnyttelsen av nikkel-kobber forekomster i et større perspektiv kunne skape nye arbeidsplasser i de angjeldende områder i Nordland.

De undersøkte nikkelsulfid mineraliseringene opptrer i tilknytning til en rekke forskjellige typer av metamorfe og/eller metasomatisk omvandlete mafisk-ultramafiske bergartsenheter. Disse omfatter ultramafiske enheter i fragmenterte ofiolittkomplekser slik som på Markafjellet i Brønnøy kommune, Esjeholmene i Lurøy kommune og Utvikåsen i Bodø kommune. Nikkel-kobber mineraliseringer i ultramafiske intrusjoner av pyroksenitt finnes i landskapsvernområdet på Tverrbrennfjellet hvor store partier har et gabbroisk utseende grunnet at pyroksenittsmelten har blitt gjennomtrengt av et tonalittisk magma. Magnetkismalmen ved Steinåga i Beiarn kommune skiller seg ut fra de andre typene av ultramafiske vertsbergarter ved å bestå utelukkende av amfibol og ha lavt innhold av nikkel og kobber, samt andre base-metaller. Denne ultramafiske amfibolitten som danner en lagparallell enhet i glimmerskifre opptrer sammen med tilsvarende enheter av serpentinitt, noe som kan antyde opptreden av magnesium-rike meta-vulkanitter.

Forekomster rike på både nikkel og kobber samt til dels platinagruppe metaller finnes i tilknytning til intrusive kropper av gabbroisk sammensetning. Disse omfatter

mineraliseringen i Høgsetdalen i Gildeskål kommune og malmkroppene i de gamle gruvene på Lilleålegden i Beiarn kommune og Måløy i Steigen kommune. De to sistnevnte forekomstene leverte på 1890-tallet håndskeidet malm med flere vektprosent nikkel. Malmen i Lilleålegden førte lokalt partier av nesten massiv pentlanditt med opptil 33 vektprosent nikkel.

Foreløpige vurderinger av de enkelte mineraliseringer er basert på lokalområdets geologi og malmens geologiske oppbygning og kjemiske sammensetning. Det siste er hvor mulig hentet fra analyser av nikkel, kobber, kobolt, platina, palladium og gull i NGUs Malmdatabase. Resultatene av disse viser at flere av de mineraliserte områdene er økonomisk interessante og dermed fortjener videre oppfølgning. Dette gjelder de to undersøkte meta-peridotitene i Markafjellet som fører et jevnt fordelt innhold av finkornet magnetkis (1-5 %) med assosiert pentlanditt. De mineraliserte peridotittkroppene er store og indikerer muligheter for en stor lavgehaltig nikkelsulfid forekomst. Dessuten finnes det også andre steder i Velfjord-Tosen dekkekompleks tilsvarende kropper som kan ha potensial. De nikkel- og kobber-rike forekomstene på Høgsetdalen, Måløy and Lilleålegden gir også prøver med forhøyet innhold av platina og/eller palladium. Forekomstene er dessverre tonnasjemessig for små til å være av økonomisk interesse. Men disse forekomstenes begrensete størrelse sammen med malmens spesielle oppbygning når det gjelder forholdet mellom silikatmineraler og sulfider, samt deres høye metallinnhold indikerer at de mineraliserte gabbroene representerer en injeksjon av to ikke-blandbare smelter, hvorav en silikat-rik og en sulfid-rik, som stammer fra et annet utenforliggende nikkel-rikt magma. En slik tung malmførende mafisk-ultramafisk kildebergart av mulig økonomisk interesse kan muligens påvises gjennom gravimetriske bakkemålinger områdene forutsatt at den ligger på dypet.

Mineraliseringene på Utvikåsen, Steinåga, Esjeholmene, og Tverrbrennfjellet har meget begrensete dimensjoner med generelt lavt innhold av nikkel og kobber. Ingen av disse synes å være av økonomisk interesse og vil derfor ikke komme i konflikt med annen bruk av landområdet til for eksempel landskapsvern slik som i Tverrbrennfjellområdet.

1. INTRODUCTION

The report gives a short review of the main geological features of registered nickel (Ni) occurrences in Nordland which were surveyed in the summer of 2017 by senior geologist Peter M. Ihlen and assistant. The survey was implemented in NGU project 376700 which received financial support from Nordland County Council (Regional Economic Development Fund) in the amount of NOK 400,000.

10 sub-areas containing old prospects and pilot mines were planned to be surveyed by five project members. Two of the members, unfortunately, became ill and thus the total amount of work in each sub-area was reduced, including the postponement of mapping the Aunvatn layered nickeliferous gabbro west of Mosjøen. The locations of the surveyed sub-areas are shown in Figure 1. They are all located in the Uppermost Allochthon (UmA) of the Caledonides and comprise from north to south in zone 33 W (Table 1):

1. Måløy, Steigen municipality, EU89-UTM coordinates: 486470 7521291
2. Utvikåsen, Bodø municipality, EU89-UTM coordinates:504723 7456286
3. Tverrbrennfjellet, Bodø municipality, EU89-UTM coordinates: 499263 7432107
4. Høgsetdalen, Gildeskål municipality, EU89-UTM coordinates: 454759 7429906
5. Lilleålegden, Beiarn municipality, EU89-UTM coordinates: 486035 7430262
6. Steinåga, Beiarn municipality, EU89-UTM coordinates: 481810 7405300
7. Esjeholmene, Lurøy municipality, EU89-UTM coordinates: 394149 738259
8. Markafjellet 1, Brønnøy municipality, EU89-UTM coordinates: 390614 7243747
9. Markafjellet 2, Brønnøy municipality, EU89-UTM coordinates: 390107 7245424

The different sub-areas will be described below according to a subdivision based on the type of mafic-ultramafic rock hosting the mineralisation, i.e. ophiolite-type ultramafic rocks, ultramafic intrusions, gabbroic intrusions and ultramafic meta-volcanites. Descriptions of the collected samples are given in Appendix 1 and their locations in the deposits are shown in the figures in the text.

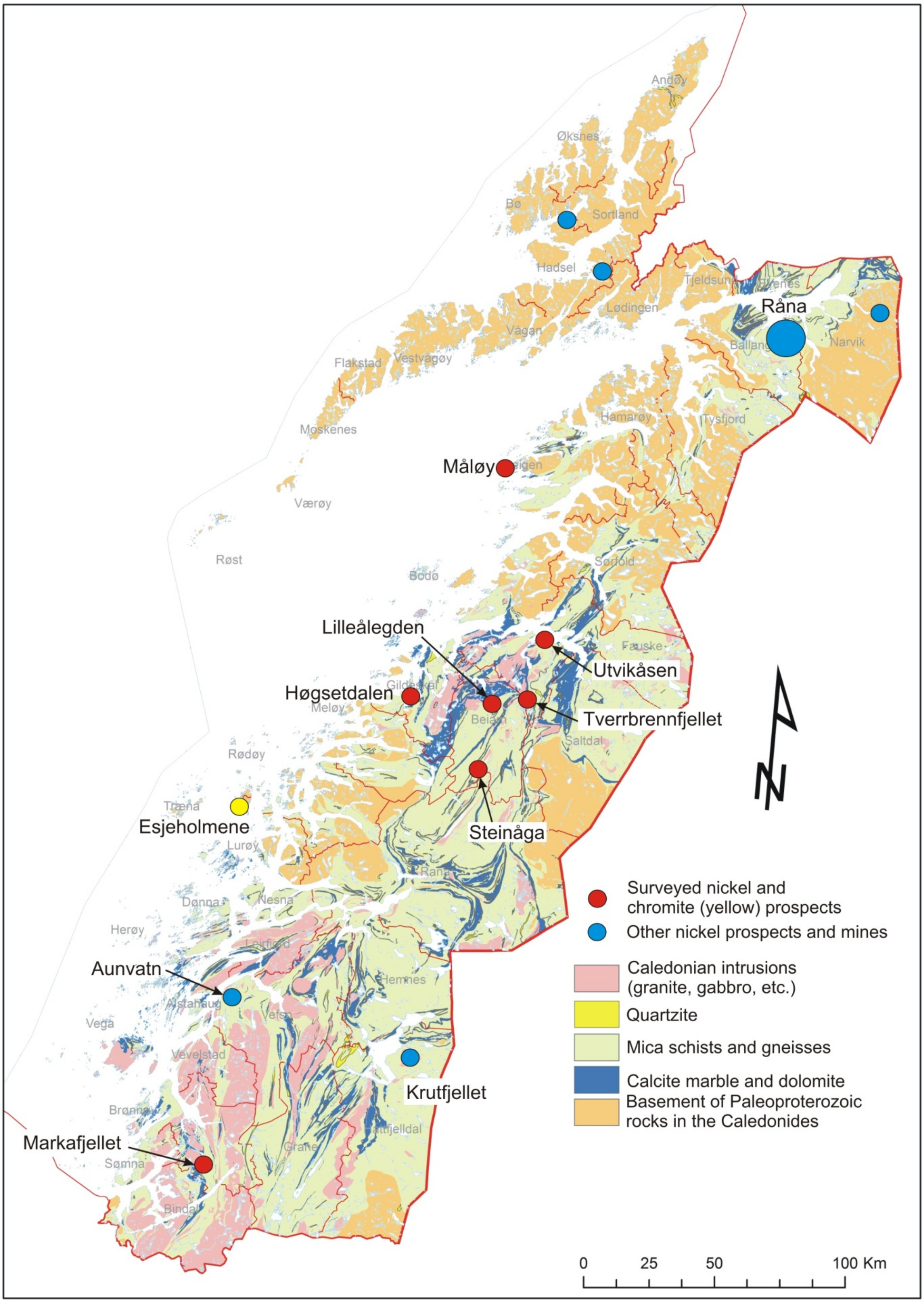

Figure 1. Simplified geological map of Nordland showing the distribution of the surveyed nickel sulphide occurrences.

Table 1. Tectonostratigraphic position of the investigated occurrences and their mineralisation types. Abbreviations for the structural units are; BN = Beiar Nappe, GN = Govddestind Nappe, HNC = Helgeland Nappe Complex, MG = Meløy Group (lower part of RNC), RNC = Rødingsfjell Nappe Complex and VTN = Velfjord-Tosen Nappe.

OCCURRENCE	MINERALISATION TYPE	UPPERMOST ALLOCHTHON			
		HNC	RNC		
		VTN	MG	BN	GN
Utvikåsen	Ophiolite-type ultramafic rocks			X	
Markafjellet	Ophiolite-type ultramafic rocks	X			
Esjeholmene	Ophiolite-type ultramafic rocks		X		
Tverrbrennfjellet	Ultramafic intrusion			X	
Høgsetdalen	Gabbroic intrusions			X	
Lilleålegden	Gabbroic intrusions				X
Måløya	Gabbroic intrusions		X		
Steinåga	Ultramafic amphibolites			X	

2. OCCURRENCES IN OPHIOLITE-TYPE ULTRAMAFIC ROCKS

Two mineralised ultramafic bodies connected to dismembered ophiolite complexes were investigated at Utvikåsen in the Skjerstad area of Bodø municipality and at Markafjellet in the Velfjord area of Brønnøy municipality, respectively. The ophiolite-type ultramafic rocks at Esjeholmene off the southern shore of Nesøya island in Lurøy municipality were anticipated to contain sulphides, according to Korneliussen (1976, 1977). The surveyed ultramafic rocks, described in order of decreasing sulphide content, have experienced multiple episodes of metamorphism and retrogression with peak metamorphism occurring during the Scandian continent-continent collision in the Silurian. Most of them show metamorphic mineral assemblages typical of lower- to upper-amphibolite facies metamorphism with the highest grades in the west. The Scandian peak metamorphic mineral assemblages in most of these solitary ultramafic bodies show an isotropic mineral intergrowth texture. However, late stage post-peak-metamorphic deformation has often, in varying degrees, affected the marginal parts of the bodies along which hydration (talc-, amphibole-, serpentine- and/or chlorite-formation) has occurred, together with development of a penetrative foliation. The Utvikåsen body represents a typical example of this type of late-stage development.

2.1 The Utvikåsen mineralisation

The old workings are situated near the top of a steep escarpment facing Skjerstadfjord towards the northeast (Figures 2, 3 and 4). The mineralistion is most easily reached by following a strongly vegetated 1 km-long tractor road up the escarpment (Figure 3). The tractor road takes off towards the SSE from the main road (F 554) between Skjerstad and Breidvik about 1.25 km E of the creek running into the innermost part of Eirvika bay (Figure 3). At the top of the escarpment, where the tractor road turns W towards the lake, Sandnesvatnet, a 5 m high wooden tower used in elk hunting is found. Continue from the tower to the E along a shallow valley and, when crossing the ridge on top of the valley, after about 600 m, turn SSE and continue along the hillside for about another 600 m (ridge shown in the upper left corner of Figure 4). The mineralised area, with the old workings, is situated about 100-150 m S of the electric power line to Breidvik.

2.1.1 Present and previous work

Two rainy days were spent on Utvikåsen and surrounding areas in 2017, in order to sample the trial workings and search for other ophiolite fragments in addition to those already registered by Farrow (1974). One of these days was used for collecting samples for analysis and for doing detailed studies.

In contrast to several of the other Ni occurrences in the Salten district there are few, if any century-old reports covering the Utvikåsen deposit, i.e. from the time of the first exploration periods, with pitting, trenching and exploration adits and sinks. Information which may exist from the then mine-superintendent is therefore difficult to look up, if such at all exists.

The most relevant information on the deposit therefore originates from the Ni exploration campaigns by Sulitjelma AS in the 1970s (e.g. Cole and Langley 1970a,b) and from the detailed descriptions in the NGU Ore database (based on field work by R. Wilberg). There are five mixed ultramafic rocks including amphibolite-hosted working points situated at the northern, altered end of the mantle peridotite.

2.1.2 Geological setting

The Utvikåsen deposit is situated in the northern end of an up-to 150 m wide and 850 m long tabular ultramafic body which has a NNW-SSE trend (Figures 3 and 4). The body, called Steinnakken by Farrow (1974), is part of a 15 km long crescent-shaped string of tabular ophiolite fragments occurring between Misvær and Breidvik on the shore of Skjerstadfjord in the north (Figure 2). It occurs parallel to the foliation and mineral banding of the country rocks which dip moderately (30°-50°) to the WSW. The ultramafic bodies are hosted by a thick sequence of micaceous gneisses and schists containing thin, subordinate units of marble and amphibolite (Venset Group, Farrow, 1974; Solli et al., 1992). These gneisses are part of the Beiar Nappe (BN) which overlies the Rödingsfjäll Nappe Complex (RNC) in the Uppermost Allochthon of the Caledonides (Figure 2). The BN is comprised by variable types of micaceous schist and gneisses interlayered with thick units of calcite and dolomite marbles which are truncated by numerous plutons of diorite, tonalite, granodiorite and granite, as shown in Figure 2.

Cross-cutting relationships indicate that these plutons were mainly emplaced subsequent to intrusion of peridotites, pyroxenites and gabbros occurring along the eastern margin and lower part of the BN. Some of these are nickeliferous (Figure 2) whereas the alkali-pyroxenite massif immediately south of Misvær contains carbonatite dykes and is rich in apatite (Ihlen et al., 2014).

Four phases of folding were recognised by Farrow (1974) in the rocks associated with the Utvikåsen deposit. The F_1 and F_2 folds are mostly isoclinal, whereas the F_3 folds are open to tight, being affected by late broad F_4 warps. Peak metamorphism under amphibolite-facies conditions occurred shortly after F_1 at 5.5 Kb pressure and temperatures of 600-640°C (Farrow, 1974).

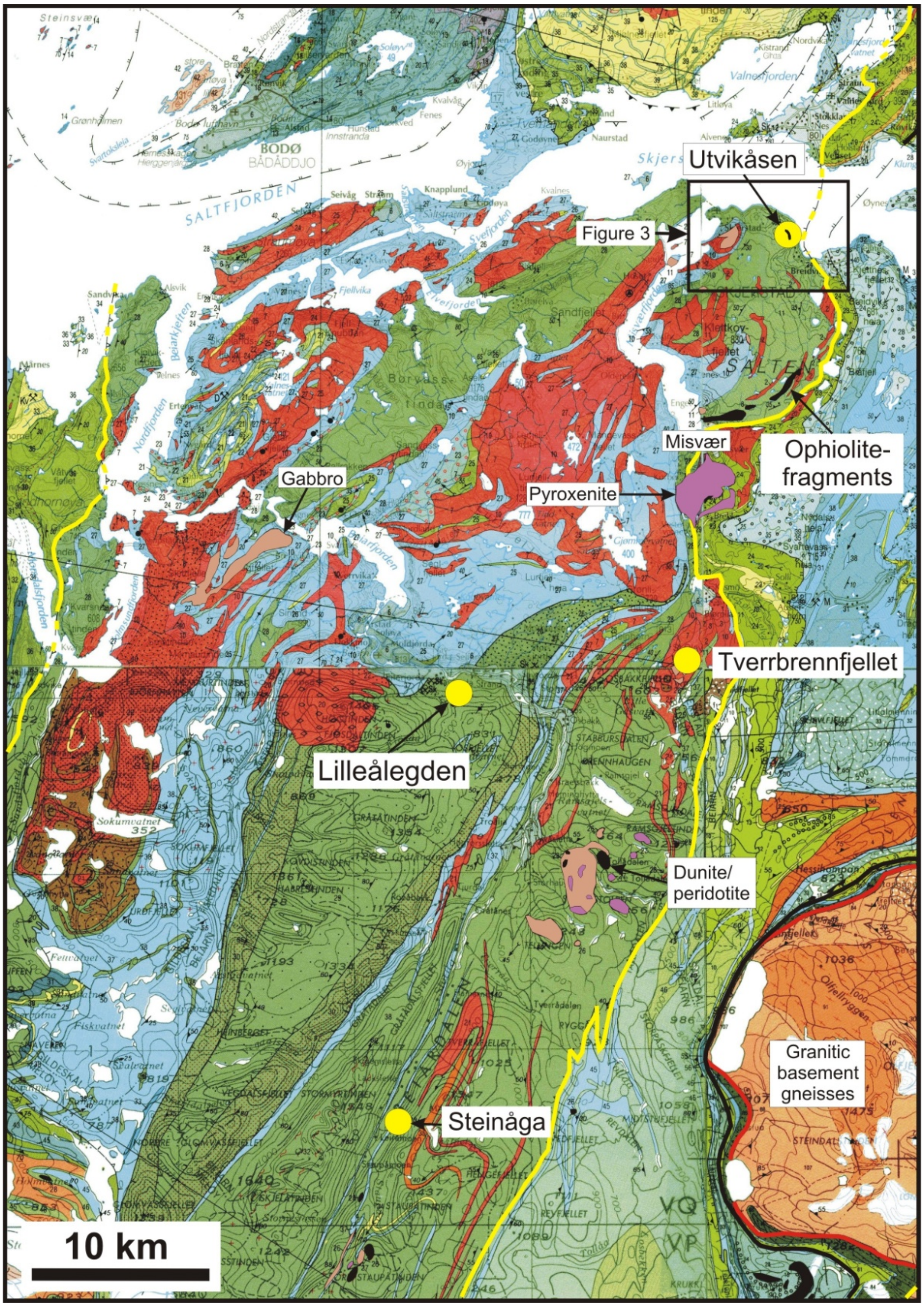

Figure 2. Geological map of the Uppermost Allochthon in Beiarn, Bodø, Saltdal and Fauske municipalities showing the distribution of the investigated Ni-sulphide mineralisations shown as yellow filled circles. Black bodies = peridotites and dunites, Black thick line = basal thrust of the RNC in the Uppermost Allochthon, Blue = marbles, Brownish = diorite and granodiorite, Greenish = micaceous schists and gneisses, Purple bodies = pyroxenite intrusions, Reddish = granitoids, Red thick red line = the basal thrust of the Upper Allochthon, Yellowish = quartzites, and Yellow thick line = basal thrust of the Beiar Nappe within the Rødingsfjell Nappe Complex (RNC). Compilation made from the 1:250000 map sheets Bodø (Gustavson and Blystad, 1995), Sulitjelma (Gustavson, 1996), Mo i Rana (Gustavson and Gjelle (1991) and Saltdal (Gjelle, 1988).

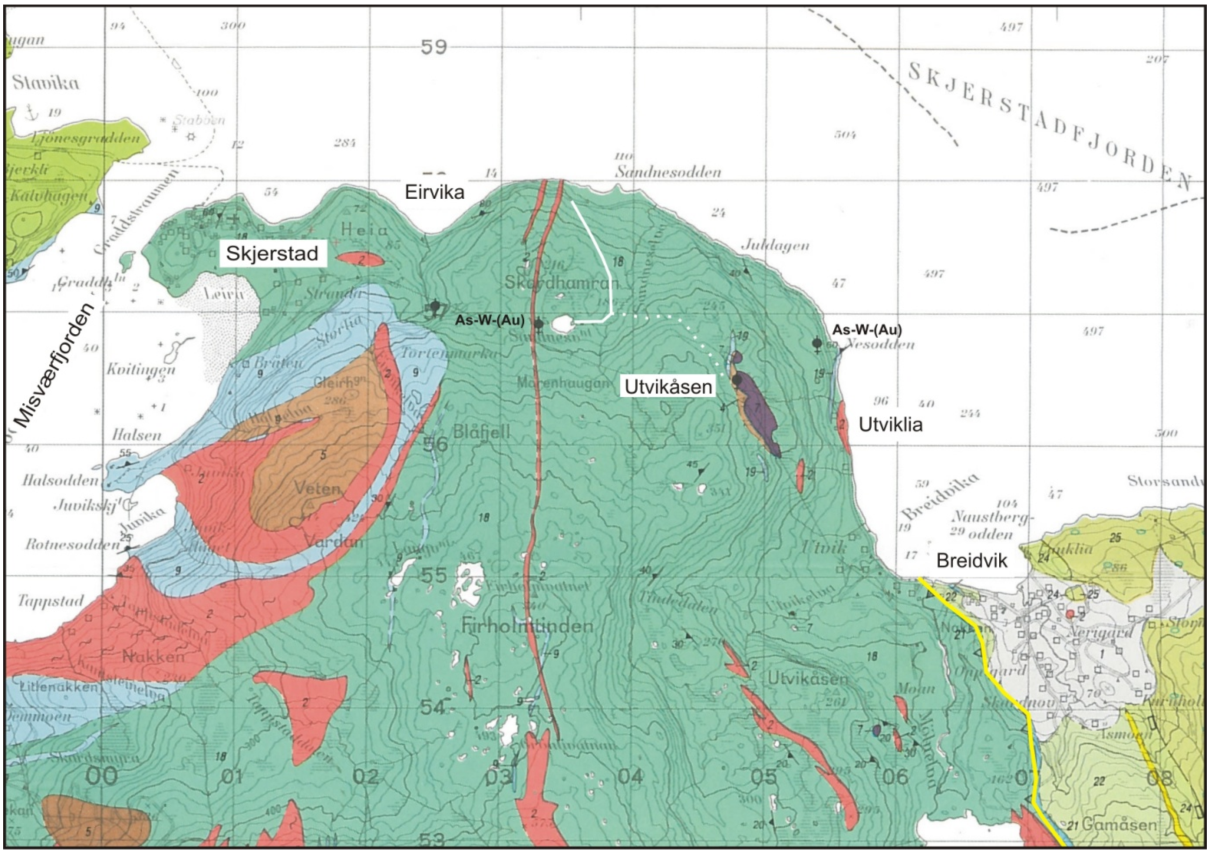

Figure 3. Enlargement of the area between Skjerstad and Breidvik shown in Figure 2. The locations of the tractor road and foot path towards Utvikåsen are shown by white solid and dotted lines, respectively. The lithologies comprise marbles in blue, mica schists and gneisses in green colours, carbonate conglomerates in yellowish green (25), granite intrusions in red, gabbros in brown and ultramafic rocks in purple. The thick yellow line represents the basal thrust of the Beiar Nappe, overlying the Fauske Nappe in the lower part of the Rödingsfjäll Nappe Complex. Compilation based on bedrock map Misvær, 1:50 000 (Solli et al., 1992).

The Utvikåsen ultramafic body was tectonically emplaced during the F_1 nappe-stacking in the Uppermost and Upper Allochthons, prior to the emplacement of the post-F_2 granitoid plutons. One of these granites yields a Rb-Sr age of 440±30 Ma which falls within the age range of other comparable calc-alkaline to alkali-calcic granitic batholiths of late Ordovician and early Silurian age found elsewhere in the Uppermost Allochthon of northern Norway (Tørudbakken and Brattli, 1985; Barnes et al., 2011, and references therein). These allochthons (and batholiths) are assumed to have amalgamated outside Baltica and to have been tectonically emplaced onto Baltica during continent-continent collision in the late Silurian (Barnes et al., 2011).

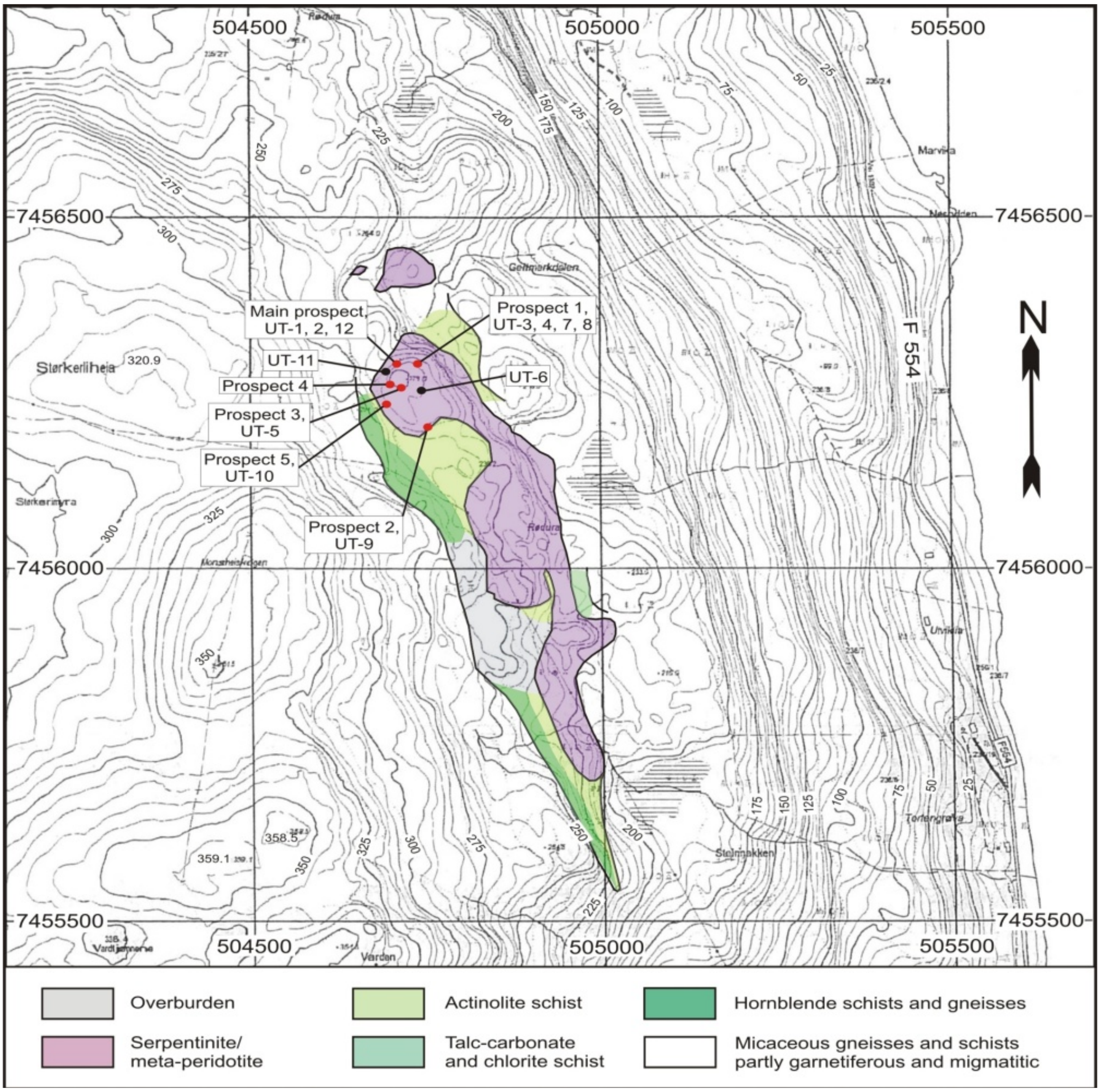

Figure 4. Sketch of the ultramafic body at Utvikåsen showing the distribution of prospects with sample numbers (red dots) and the location of samples outside the prospects (black dots). The geology is taken from Farrow (1974). The distance between the grid lines is 500 m and they are shown with EU89-UTM coordinates in metres within zone 33. The altitude contours are at 5 m intervals.

2.1.3 Ore geology

The mineralisation at Utvikåsen is situated in the northernmost part of the tabular ultramafic body (Figure 4) which is dominated by grey to dark grey, fine-grained (< 1 mm) foliated ultramafic rocks. The steep foliation and fracture cleavage in the ultramafic rocks dip inwards towards the centre of the ultramafic body which consists of massive fine-grained and light-greenish to grey enstatite-bearing peridotite (sample UT-6 in Figure 4).

Figure 5. Massive enstatite-bearing peridotite criss-crossed bylight grey talc, tremolite and/or carbonate veins. Sample UT-6 inFigure 4 and Appendix 2.

Figure 6. Vertical bands of fine-grained, semi-massive magnetite and thin magnetite veinlets which are cut obliquely by the shear foliation outside Prospect 3.

The peridotite has a light brownish weathered surface, criss-crossed by thin veins of talc, tremolite and/or carbonate (Figure 5). The foliated ultramafic rockss are composed predominantly of amphibole, magnetite, chlorite, talc, pyroxene, titanite and/or minor garnet according to quantitative XRD (Appendix 2).

The foliated ultramafic rocks appear to have been formed by metasomatic alteration of the peridotites as indicated by schistose soapstone and the introduction of abundant magnetite (15-30 % mode) in contrast to the peridotites which are nearly barren of magnetite (~1 % mode). Magnetite is thus a characteristic mineral which occurs as dense dissemination and thin veinlets as well as in locally semi-massive bands which are cut by the foliation (Figure 6). Colour-banding caused by variable contents of the different mafic silicates is also found locally.

The mineralisation that was prospected in the past is located at the northern end of the ultramafic body where the workings occur within rusty weathered zones at the margin of the ultramafic body (Main prospect, Prospect 1 and Prospect 2, Figures 7 and 8) and inside scattered rusty patches (Prospect 3-5, Figure 9) of the foliated ultramafic rocks. The rust is caused by weathering of pyrrhotite occurring as fine-grained dissemination and massive stringers along the foliation together with magnetite, chalcopyrite and accessory pyrite.

Figure 7. Adit at the Main prospect intersecting mixed foliated and banded ultramafic rocks, quartzites and felsic gneisses rich in magnetite and dense dissemination and foliation-parallel stringers of pyrrhotite. The wooden stick is 2 m long.

The Main prospect and Prospect 1 are situated at the western and eastern ends, respectively, of the main mineralisation which forms an oval, E-W-trending lens-shaped rusty zone which is up to 20 m wide and 40 m long. The mineralization occurs in an imbricated sequence of foliated and altered mantle peridotites and overlying ocean-floor volcanites with zinc-rich cherty exhalites.

The Main prospect comprises a 5 m long cutting ending in a 7 m long SE-trending adit which transects a more than 12 m wide rusty zone composed of a mixture of sheared ultramafic rocks and fine-grained thinly-banded quartzites and mafic gneisses (Figure 8). The rocks in the cutting and the adit contain magnetite-rich and low-grade sulphide dissemination together with pyrrhotite-rich veinlets along the foliation planes.

Prospect I is located ca. 25 m E of the adit and close to the eastern end of the lens-shaped rusty ore zone. A 2 m-thick ore zone has been worked in the cliff around the entrance of a 6 m-long inclined shaft (cross-section 2 m x 3 m) plunging 20° to the SW (Figure 8). The mineralisation is comparable to that found in the

Figure 8. Strongly sulphidic and rusty magnetite-rich rocks in the main ore zones around the inclined shaft at Prospect 1. The wooden stick is 2m long.

Figure 9. A small working on a 1-2 m wide and a few metre- long steeply dipping rusty zone in the cliff at Prospect 3. The rusty zones are brecciated and filled with black to dark grey amphibole aggregates as seen at the top of the 2 m long wooden stick.

adit although boulders with fist-sized “durchbewegt” or sheared lenses of semi-massive pyrrhotite and chalcopyrite are commonlyfound on the dumps which have a volume of ca. 20 m^3.

Prospect 2 represents an additional example of mineralization occurring in the sequence covering the mantle peridotites. It consists of a 2 m wide and 10 m long pit, located at the base of a cliff of rusty magnetite-bearing talc-rich schistose ultramafic rock which carries mainly low-grade pyrrhotite - chalcopyrite dissemination and minor foliation-parallel sulphide veinlets. The talc-rich ultramafic rock occurs in contact with a black ultramafic amphibolite ”black wall” occurring as a rim against the semi-pelitic wall rocks.

Prospect 3 is a representative of the patchy mineralisation which occurs in Prospects 4 and 5. It is located in a 4 m high vertical cliff on which a ca. 20 m^2 rusty area contains very coarse-grained, blackish-green amphibole aggregates along a breccia zone (Figure 9). The rusty serpentinite is recognised by weak dissemination of pyrrhotite and high concentrations of disseminated magnetite, partly occurring as semi-massive vertical bands (Figure 6).

Prospect 4 comprises a small working on a 1-2 m wide and a few metre- long steeply dipping rusty zone in a cliff (Figure 10). The rusty zone contains a variablydense dissemination of magnetite, pyrrhotite and minor chalcopyrite and locally contains small, semi-massive pyrrhotite lenses parallel to the foliation.

Prospect 5 represents a spherical, rusty area where some blasting has been done, near the western margin of the foliated serpentinite e (Figure 10). The mineralisation comprises a weak dissemination mainly of pyrrhotite.

Figure 10. Rusty patch with disseminated pyrrhotite engulfed in foliated light grey weathered magnetite-amphibole-chlorite-talc rock occurring at Prospect 5. The rust zone at Prospect 4 is seen in the back-ground.

2.1.4 Preliminary assessment

The mineralisation is confined to rusty areas within foliated talc-rich magnetite-bearing ultramafic rocks. Magnetite is, in general, a common mineral in retrogressed dunites and peridotites and is, in most cases, caused by breakdown of olivine to serpentine and magnetite and, in some cases, further altered to talc and carbonates. However, the presence of fine-grained magnetite as banded units in quartzitic rocks at the Main prospect and inProspect 1, where semi-massive to massive sulphide lenses are common, may indicate formation by volcanic exhalative processes. This interpretation is possibly also supported by high Zn-values given in the NGU Ore Database for samples from the main ore zone (up to 0.17 wt. % Zn in samples from the Main prospect and up to 2.03 wt. % Zn in samples from Prospect 1). Analyses of 6 sulphide-rich samples exceeding 11.87 wt.% S in the Database yield an average of 19.07 wt. % S, 0.46 wt. % Ni, 0.53 wt. % Cu, 0.43 wt. % Zn and 0.28 wt. % Co. However, in contrast to this style of mineralisation there are erratically distributed rusty patches at Prospects 3, 4 and 5 which appear to represent structurally controlled mineralisation along local shear zones. These occurrences are generally low in sulphides, as in Prospect 4 where a sulphide-poor ultramafic rock contains 3.95 wt. % S, 0.11 wt. % Ni, 0.18 wt. % Cu, 0.02 wt. % Zn and 0.04 wt. % Co.

The deposit is somewhat abnormal in comparison with other Ni-deposits in Nordland due to its high contents of Zn. The Utvikåsen Co-Ni-Cu-Zn-Fe-S deposit can be classified as an ultramafic rock-hosted metallogenetically complex sulphide deposit the nature of which is, as yet, far from sufficientlyunderstood. It appears, however, natural to compare and contrast it with e.g. the very large and famous Outokumpu deposit in Finland as well as with a number of similarminor ophiolitic peridotite-hosted sulphide occurrences in Norway. The distinct Co-(As) enrichment characterising the Utvikåsen deposit may be due to a metallogenic interaction or overprint from a number of nearby located As-W-(Au) mineralisations hosted by quartz breccia veins (from W to E: Eirvikelva - Sandnesvatnet - Utviklia) the array of which crosses the Utvikåsen peridotite lens. This is, however, but one of a series of possible solutions for explaining the complexity of the metal assemblage.

The genesis of the deposit is thus somewhat enigmatic. Most likely it developed prior to peak metamorphism by buoyancy-driven diapiric ascent of hydrated mantle peridotites into overlying ocean-floor volcanites with interlayered sulphidic and oxidic exhalites. Extraction of nickel from olivine during influx of sulphate-rich sea water may have generated the nickeliferous sulphide ores.

The relatively low Ni and Cu contents are not the main obstacle in generating an economic deposit. In the present case, the main obstacles are the low areal extents of the main ore zone and of the mineralised rusty patches. The deposit is thus of no economic importance at present, though a few more days of detailed mapping of the ultramafic rock body are needed in order to finally ascertain this conclusion.

2.2 The Markafjellet mineralisation

Three ultramafic bodies occur on the western hillside of Markafjellet immediately south of Lake Sausvatn in the Velfjord district of Brønnøy municipality (Figures 11 and 12).

2.2.1 Present and previous work

Two of the ultramafic bodies were sampled. One body is exposed in road cuttings (Skogrud crossing) along the Tosen road (R 76) between Brønnøysund and the E6-Mosjøen to the east whereas the other occurs along a dirt road leading through Gunnardalen to the farms at Nordfjellmark (Figure 12). The geology of the ultramafic bodies and their country rocks were previously described by Thorsnes and Løseth (1991) whereas Nilsson and Sturt (1994) gave a description of the ore mineralogy in both the ultramafic rocks and their psammitic cover sequence. The present authors, because the geology was rather well known from these previous investigations, focussed on sampling the mineralised parts of the ultramafic rocks. Twelve grab samples with varying sulphide contents were collected in less than a day.

The Markafjellet mineralisation is not a registered Ni-sulphide occurrence in NGU's Ore database, but a notable spin-off result from an idea developed by Professor B. A. Sturt to test a supposed fossil, lateritic paleo-surface for eventual detrital noble-metal mineral enrichments/accumulations derived from the ophiolitic substrate of ultramafic composition (Nilsson and Sturt, 1994, 1995). Two of Sturt's graduate students made a detailed account of the geology of the basement-cover sequences in the Velfjord-Tosen area in their cand. scient. theses. The results of their investigations were given in Thorsnes and Løseth (1991).

The noble-metal part of the study by Nilsson and Sturt (1994) turned out to be negative, since no enrichments were recorded during the testing of a number of sites.

However, two unexpected spin-off results proved to be unusual and, in isolation, worth following up. These are:

1) Pyrrhotite (po) with Co-pentlandite exsolution lamellae containing 8 % Co was first recorded in the mantle peridotite and later in the meta-psammite immediately overlying (i.e. deposited onto) the peridotite. This confirms that the *po* had survived both erosion with decomposition and removal of its ultramafic host mineral assemblage, transport as minor, but free, detrital grains, re-deposition,

burial diagenesis and subsequent metamorphism in a completely "foreign" psammitic environment basically consisting of quartz, feldspar and mica. This observation is notable in itself, especially taken into account the very unstable nature of most *po* during atmospheric conditions.

2) Mantle-peridotite-hosted *po* inspected in reflected light was shown to be fairly homogeneous, but microprobe investigations showed uncommon and interesting mineralogical features. The apparently homogeneous *po* was shown to be hexagonal *po* (*hpo*) with thin, parallel and slightly irregular low-temperature (< 139°C) exsolution lamellae of stoichiometric, pure troilite (*tr*), a very rare Fe-sulphide. Primary and significantly coarser, sub-parallel pentlandite veins and patches (*ptl*-1) occur perpendicular to the *tr*-lamellae. As *ptl*-1 is not in equilibrium with the late-formed *tr* a new *ptl* (*ptl*-2) formed, preferentially by interaction with the *tr*. This secondary, *tr*-hosted, and distinctly flame-shaped *ptl*-2 is richer in Fe, but poorer in Ni and Co than the primary *ptl* (ptl). Formation of *tr* is usually a rare phenomenon in Ni-sulphide deposits and may here be caused by a distinct surplus of available Fe v. S in this specific restite harzburgite (restite after mantle melting) and possibly also more generally in such depleted mantle peridotite environments. See further comments on this in section 2.2.4.

The above results have previously been shown only as an internal NGU poster presentation and published as an extended abstract, not showing the original back-scattered electron images (Nilsson and Sturt, 1995). This work has thus not attracted any attention from the potentially interested part of the geologic community. For that reason this is an opportunity to revitalize and deepen understanding of the genesis of the Markafjellet magmatic sulphides.

It is finally important to note that the studied thin sections of the meta-peridotites from the Markafjellet area contain up to 5- 10 vol. % sulphides and that chalcopyrite is not part of the sulphide assemblage at all. This is probably a mantle sulphide mineralisation in a meta-harzburgite representing a mantle peridotite restite and not a sulphide mineralisation formed in, and hosted by a mafic and/or ultramafic silicate melt.

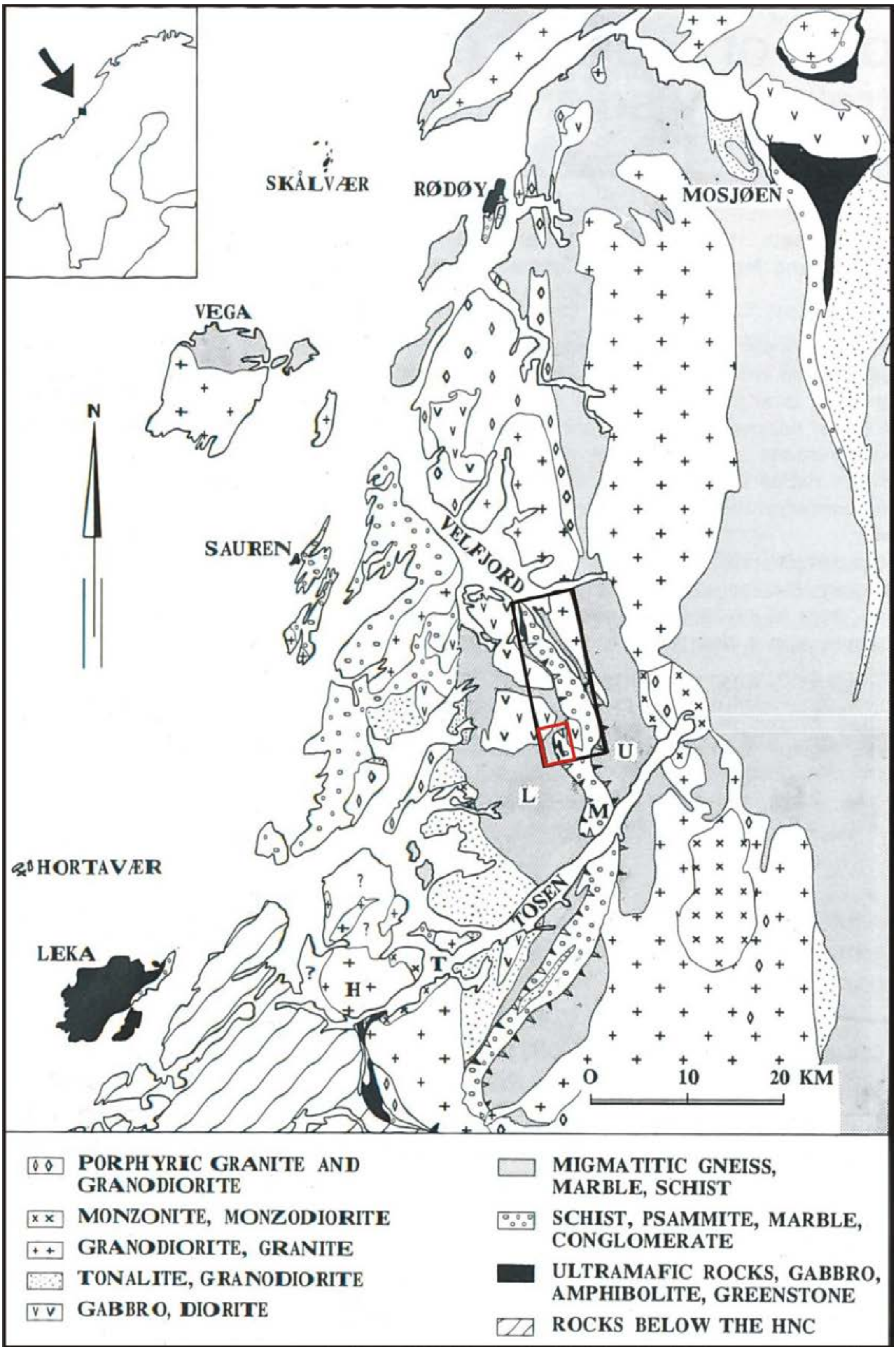

Figure 11. Simplified geological map of the HNC and the Bindal Batholith showing the position of the sampled sulphide occurrences at Markafjellet as shown in Figure 12 (red square) and the longitudinal section of the Velfjord-Tosen Nappe (VTN) shown in Figure 13 (black rectangle). Redrawn from Thorsnes and Løseth (1991).

2.2.2 Geological setting

These ultramafic bodies representing ophiolite fragments occur at several localities within the Helgeland Nappe Complex (HNC) of the UmA (Figure 11; Thorsnes and Løseth, 1991). The HNC is characterised by the presence of a multitude of granitic intrusions collectively termed the Bindal Batholith which also includes hornblende diorites and monzodiorites as west of Lake Sausvatn and in Markafjellet hill (Figure 12). They were emplaced during the Late Ordovician and Early Silurian, subsequent to nappe stacking outside Baltica and prior to the Scandian phase of continent-continent collision in the Middle Silurian to Early Devonian (Barnes et al., 2011).

The amphibolite facies nappes in the HNC can be subdivided lithologically into two main groups: 1) nappes composed largely or entirely of meta-sedimentary rocks such as marbles, mica schists, quartzites and migmatitic biotite gneisses and 2) nappes characterised by mafic and ultramafic igneous rocks of ophiolite/immature arc affinity. Some of these comprise, as in the Velfjord-Tosen area, a basement of meta-gabbro and various types of ultramafic rock that are unconformably overlain by cover sequences of polymict mafic conglomerates, psammites, calcareous schists and/or thin marbles (Figure 13; Thorsnes and Løseth, 1991). The basement-cover sequences in the Markafjellet area which occur within two separate nappe units represent, collectively, a specific sub-unit within the HNC (Figure 11). It is here informally termed the Velfjord-Tosen Nappe (VTN).

The nature of the cover sequence indicates that the ophiolites were uplifted and eroded prior to nappe stacking. The igneous basement rocks at Markafjellet area comprise 3 bodies of variably serpentinised meta-harzburgite. The north-western body is termed Skogrudkrysset, the north-eastern Mølnhusbekken and the southern Gunnardalen.

All of these rest on the basal thrust zone of the VTN and are possibly derived from the upper mantle in an immature arc setting comparable to the Leka ophiolite which has yielded a late Cambrian U/Pb age (497±2 Ma) for a trondhjemite associated with a gabbro and sheeted dykes (Dunning and Pedersen, 1988; Furnes et al., 1988).

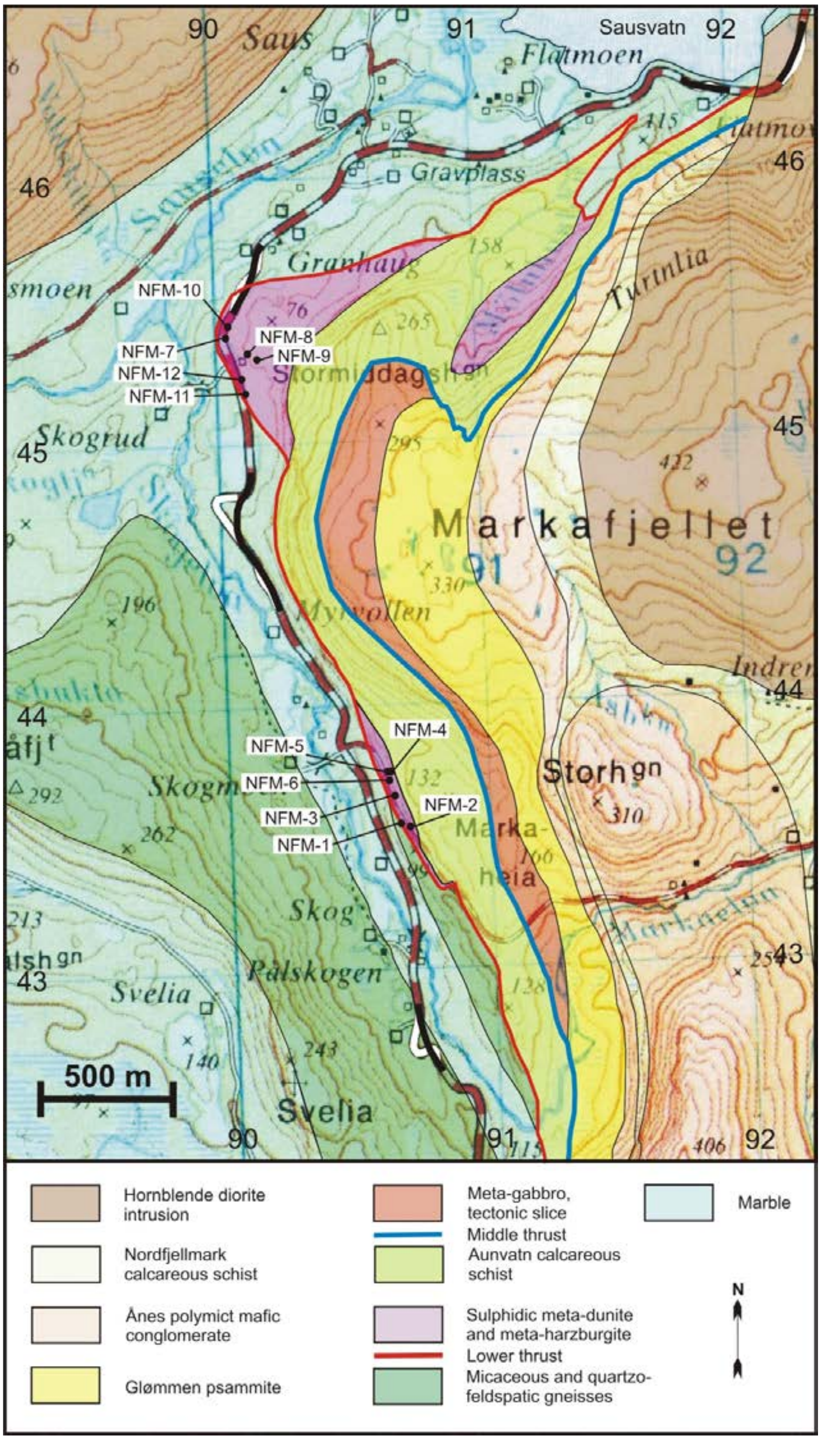

Figure 12. Geological map of the Markafjellet area showing the distribution of ultramafic bodies and collected grab samples. The samples in Gunnardalen (NFM 1-6) and the Skogrudkrysset bodies (NFM 7-12) are shown schematically. White and black sections along the road indicate the courses of the old and new roads, respectively. The numbers alongthe frame represent UTM grid lines 1000 metres apart in zone 33 of WGS84 in map sheet Velfjord (1825-IV) of the M 711 series published by Statens Kartverk. Sample numbers NO-NFM-17-1, NO-NFM-17-2, etc. in Appendix 1 are abbreviated to NFM 1, NFM 2, etc. in the Figure. Compilation based on Thorsnes and Løseth (1991).

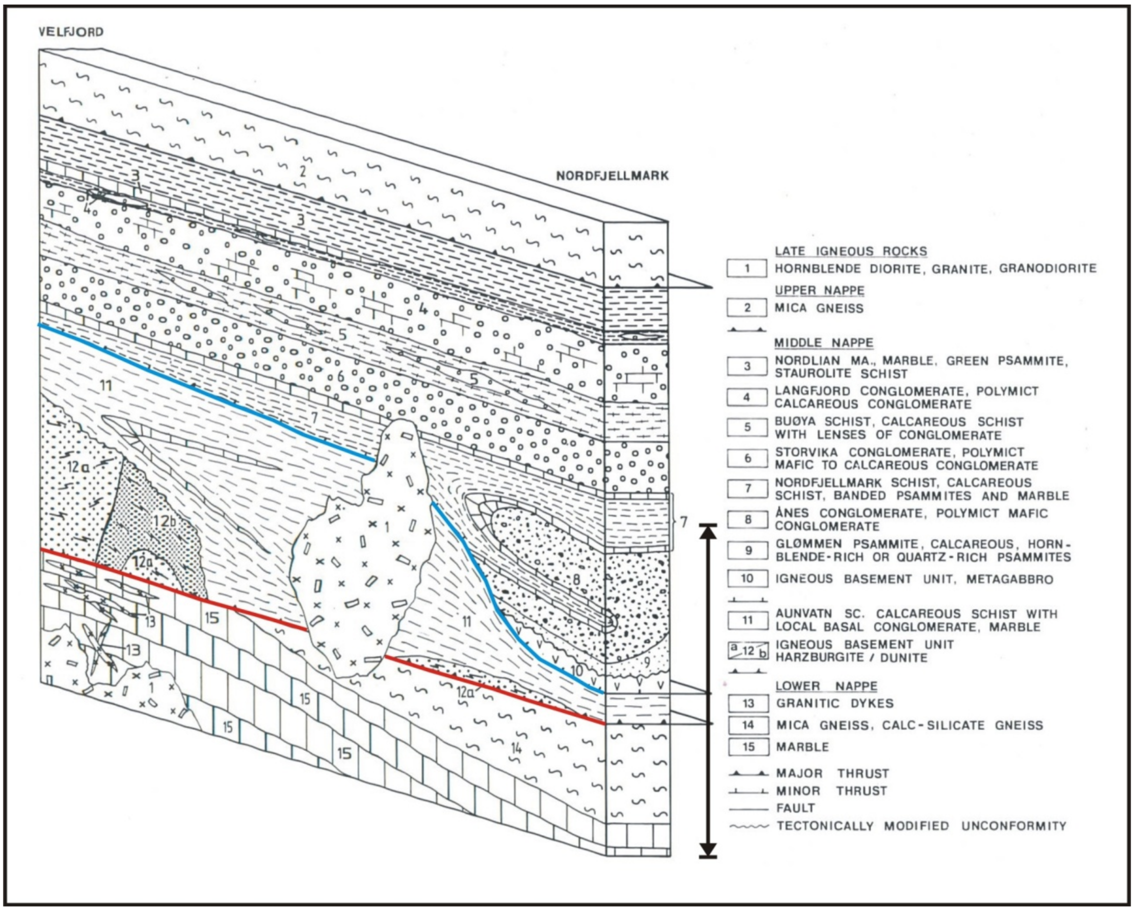

Figure 13. Longitudinal section of the Velfjord-Tosen Nappe (VTN). The stratigraphic section in the Markafjellet area is indicated by black arrows. Red and blue lines, as shown, in Figure 12 are thrust planes. Figure redrawn from Thorsnes and Løseth (1991).

Some of the igneous basement units show, according to Thorsnes and Løseth (1991), evidence of several phases of deformation which appear to have occurred prior to deposition of the overlying sedimentary cover rocks. Four phases of deformation (D1-D4) can be recognised in the latter rocks, with peak metamorphism at amphibolite facies during D2. Structures assumed to be related to D1 are largely obliterated by the penetrative S2 foliation developed as a consequence of thrusting and isoclinal folding during D2. Later, retrograde metamorphism with open folds and warps occurred during D3 and D4 during which the present attitude of the rocks was produced, i.e. primary sedimentary layering, metamorphic mineral banding and foliation dipping 40°-60° ENE.

2.2.3 Ore geology

The two ultramafic bodies are composed of pyrrhotite, chlorite, amphibole, brucite, talc, serpentine and forsterite in order of increasing abundance (Table 1). The bodies have a dark brown weathering surface caused by presence of Fe-sulphides whereas the unaltered light greenish-grey meta-harzburgites have a lighter brown weathering surface with 5-10 mm enstatite crystals (similar to that in Figure 6). Both types of ultramafic rocks contain fine-grained dissemination of sulphides, but this is more easily recognised in the dark grey matrix of the talc-serpentine-altered types than in the pale grey matrix of the meta-harzburgite (see NFM 1 and NMF 9 in Appendix 2). They also appear to be low in magnetite when compared with the altered meta-peridotites at Utvikåsen which are characterised by patchy dissemination of sulphides separated by barren areas.

A total of 12 grab samples were collected from the meta-dunites (9), meta-harzburgites (2) and gabbroic amphibolite (1). The Gunnardalen ultramafic body situated along the road to thw Nordfjellmark farms in the east comprises an up to 50 m wide tabular meta-dunite body dipping 60°-70° ENE. It contains up to a total of about 25 % modal serpentine, talc, chlorite, amphibole and brucite. Signs of strong ductile shearing and locally hydrothermal brecciation are found near sample locations NFM-2 and NFM-4 (Figure 12). Sample NFM-5 was collected from a 3 m wide zone of sheared gabbroic amphibolite. All the samples from Gunnardalen contain accessory to subordinate amounts of very fine-grained disseminated pyrrhotite, usually less than a few percent. Sample NFM-4, a few metres away from the sheared hanging-wall contact, contain 5-10 % sulphides which occur as evenly distributed dissemination and as 5-10 mm wide linear zones with dense dissemination.

The Skogrudkrysset body is composed of meta-harzburgites and meta-dunites which have been irregularly altered to a maximum of nearly 25 % modal serpentinite and minor amount of talc, amphibole, chlorite and brucite The dark grey fine- to medium-grained serpentine-rich locally contains 5-10 mm aggregates of fine-grained forsterite in 10 cm wide zones (NFM-7) and 2-8 mm long crystal lathes of talc (NFM-12). Both the meta- harzburgites and meta-dunites almost invariably carry low concentrations of evenly distributed grains of fine- and extremely fine-grained pyrrhotite, normally about 1-2 %.

2.2.4 Preliminary assessment

The Skogsrudkrysset ultramafic body is large and exceeds 20 Mt to a depth of 100 m down dip. The sulphides appear to be evenly distributed in the sampled types, yielding a rather homogeneous ore type, which may have low, but sufficiently high grades of Ni, Cu, Co and/or PGE to be of economic interest.

. The results of the field investigations in the Markafjellet area gave no clear answere regarding how they were formed, only that they appear to represent sulphidic mantle peridotites showing rather low degree of serpentinitisation, even along their tectonic margin. Thus the assessment of the mineralisation in the Markafjellet area must await the results of detailed microscope investigations and chemical analyses. Nevertheless the discoveriesmade this summer are very promising and other sulphide-bearing meta-peridotite bodiesare possibly present elsewhere in the VTN, represent an interesting exploration target.

2.3 The Esjeholmene ultramafic complex

The chromite-bearing ultramafic rocks on the Esjeholmene islets are situated immediately south of the southern shore of the Nesøya island in Lurøy municipality (Figure 14). The Esjeholmene islets were sampled in connection with another ongoing NGU project (370700) the aim of which is to investigate potentially apatite-rich pyroxenites intruding Paleoproterozoic paragneisses and mangerites on Nesøya to the north. The islands in the area have also been investigated for the presence of potentially Li-bearing pegmatites of Devonian age (Ihlen, 2004). The interest for the ultramafic rocks on these islets stems from the description of patchy sulphide mineralisation given in Korneliussen (1976, 1977) and the possibility of extending the group of sulphidic mantle peridotites defined by the occurrences at Utvikåsen (Ch. 2.1) and Markafjellet (Ch. 2.2).

2.3.1 Present and previous work

The Esjeholmene islands include Storesjeholmen, Litlesjeholmen with two closely neighboring islets as well as two tiny islets with a lighthouse 1 km to the west. Half a day was spent on 4 of 6 of these islands in sunny weather in July 2017 (Figure 15). All of the main types of ultramafic rocks shown in Figures 16-20 were sampled.

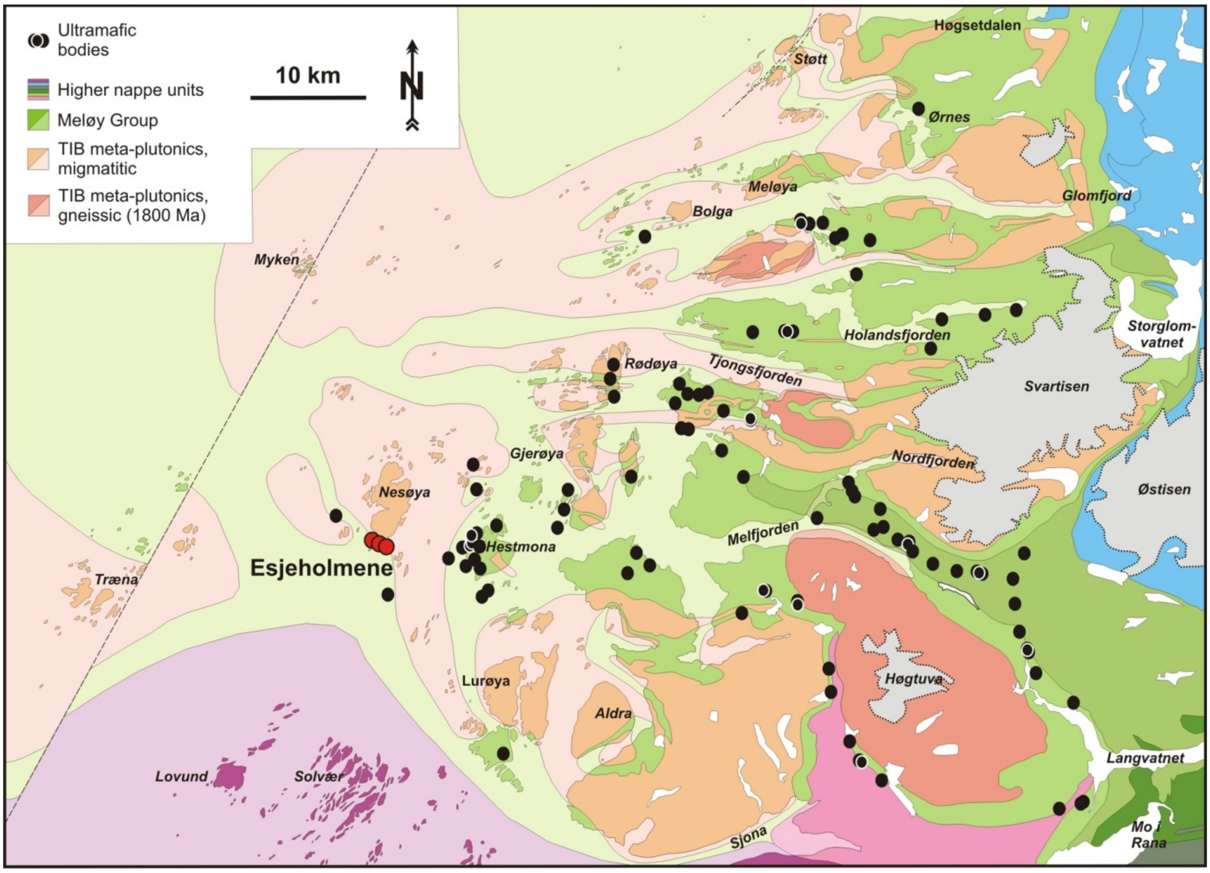

Figure 14. Simplified geological map of northern Helgeland showing the distribution of altered mantle peridotites commonly containing chromite ore as on Esjeholmene islets in the central western part of the area. Compilation mainly based on Gustavson and Gjelle (1991) and on the NGU Ore Database.

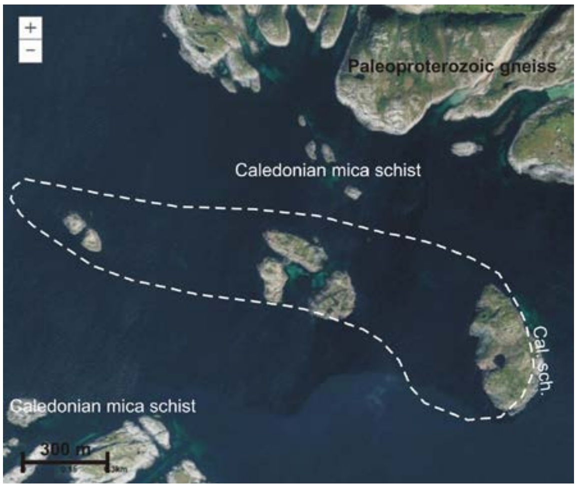

Figure 15. Map showing the outline of the ultramafic complex on the Esjeholmene islets. Sample localities of the main rock types on the eastern islands are shown in Figures 16 a,b. Image taken from https://www.norgeibilder.no/

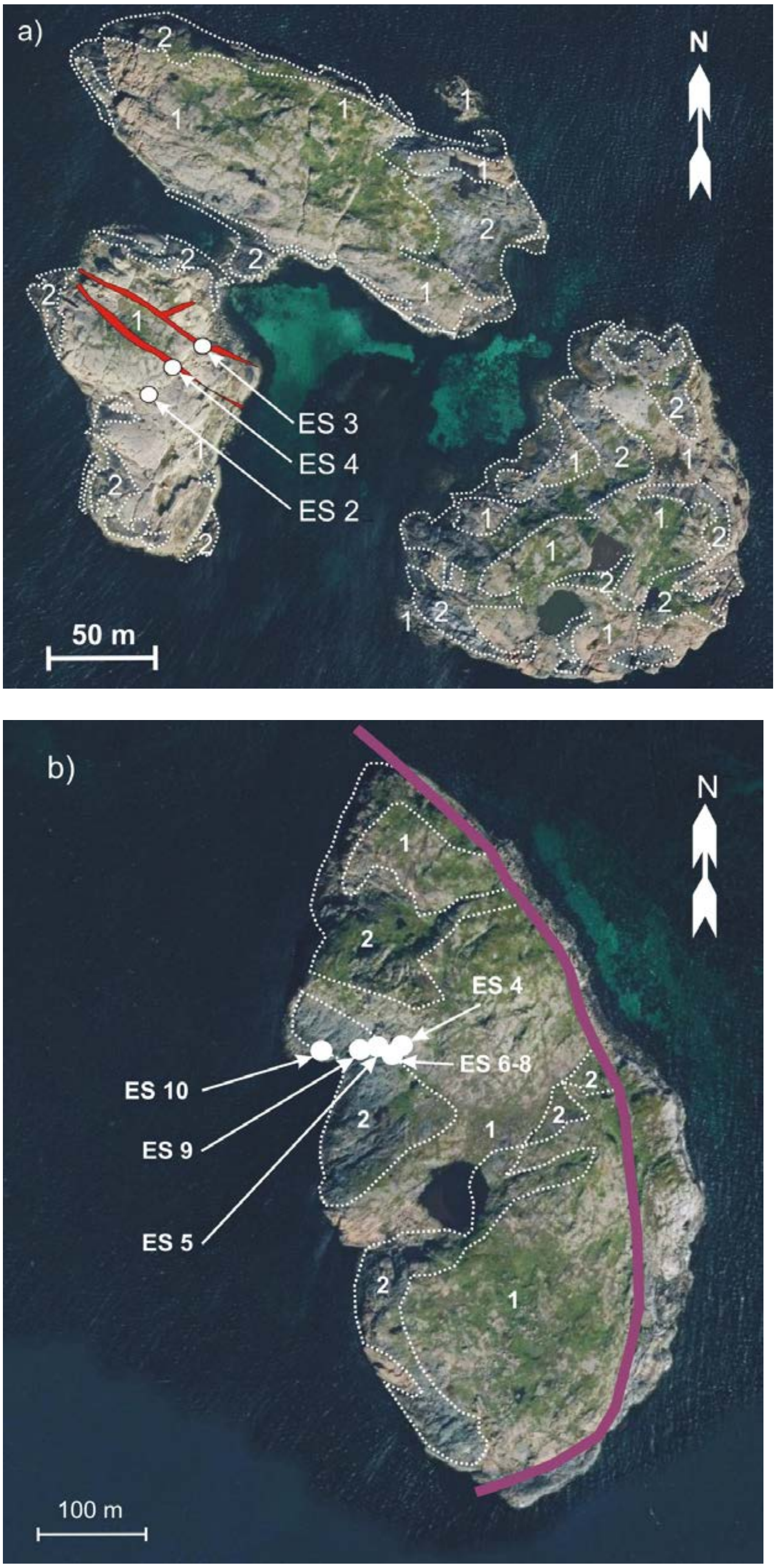

Figure 16. Distribution of the major types of ultramafic rock decribed in the text together with the location of collected samples; Lille Esjholmene islets and **b)** Store Esjeholmen islet. 1 = pale brownish-weathered enstatite-forsterite rock, 2 = dark grey weathered metamorphic hornblendite (pargasite), light grey is a mixture of type 1 and type 2 and red dykes in Figure 16a = type 3, very coarse-grained rock with radiating enstatite aggregates. Compilation based on images from https://www.norgeibilder.no/

The ultramafic bodies occurring both on the mainland and on the islands, islets and skerries in the central Nordland archipelago were recognised by geologists in the early stages of regional bedrock mapping (Rekstad, 1912). They also reported the widespread occurrence of chromite mineralisation.

A number of small pits and trial workings were thus, over time, excavated by prospectors, including one on the Esjeholmene Islets (Korneliussen 1976, 1977). Korneliussen, in his 1977 report, described patchy sulphide enrichments in some of the peridotites and chromitites, both those on the mainland and on some of the islands and islets in the archipelago. He describes pyrrhotite as the primary sulphide mineral with subordinate pyrite, pentlandite, mackinawite ($(Fe, Ni)_{1+x}S$) and chalcopyrite. On Esjeholmene he found scattered cm- dm-sized rusty, sulphide-bearing patches and 5 - 30 cm wide and up to 4 m long rusty zones or schlieren in the ultramafic rocks. These sulphide enrichments, containing at most 15-20 % of disseminated sulphides, appear to have no "preference" for any specific host rock type.

However, this description of sulphide-bearing ultramafic rocks is not confirmed by any of the 10 analyses of grab samples given in Korneliussen (1977), in whch the analytical values do not exceed 0.01 % Ni and < 0.01 % Cu. One sample of chromite mineralisation, however, from a small working on the northwestern islet of Little Esjeholmene, yielded 4.0 % Cr, 0.45 % Ni and 0.52 % Cu. None of these samples was analysed for sulphur, so the amount of sulphide-bound nickel cannot be assessed.

The sulphide enrichments described by Korneliussen (1976, 1977) have not attracted any subsequent attention though a more thorough treatment, including modern analyses of the samples is clearly desirable, not least for comparison with other sulphide-bearing ophiolitic meta-peridotites such as Markafjellet and Utvikåsen. This is the background for the visit to the Esjeholmene islets.

2.3.2 Geological setting

The ultramafic rocks on Esjeholmene are assumed to represent fragments of strongly dismembered ophiolite complexes that have been tectonically emplaced into the sequence of mica schist and migmatitic biotite gneisses of the Meløy Group. This Group, which is part of the Rödingsfjäll Nappe Complex of the UmA, comprises an upper amphibolite facies sequence of predominantly meta-sedimentary rocks including variably migmatitic pelitic to semi-pelitic gneisses, psammites, banded gneisses, calc-silicate gneisses and subordinate marbles. Meta-eclogites are found locally in these paragneisses, at Træna just west of the Esjeholmene islets (Larsen et al., 2002). The Meløy Group characteristically contains abundant lenses, sheets and slices of granitic orthogneisses of Paleoproterozoic age (Larsen et al., 2002). These orthogneisses which commonly carry neosome veins may possibly represent the source of anatectic melts generating the Nord-Helgeland pegmatite district (Ihlen, 2004). These pegmatites yielding U-Pb ages in the range 401-409 Ma occur widespread in central and north central Norway. They are considered to be related to metamorphism and decompression melting during the latest Scandian exhumation in the Early Devonian (Eide et al., 2002; Larsen et al., 2002 and Nordgulen et al., 2002).

The ultramafic rocks in the coastal area are composed of metamorphic mineral assemblages comprising enstatite + forsterite + tremolite or pargasite + chlorite ± spinel, typical of metamorphic conditions in the PT-ranges 680-780°C and 9-10 kbar (Bucher-Nurminen, 1988, 1991). A later overprint resulted in the formation of magnesite and late talc according to the latter author.

2.3.3 The ultramafic rocks

The ultramafic rocks on the Esjeholmene islets comprise three major types (Figure 15) which include, in order of decreasing abundance:

Type 1: Coarse-grained to very coarse-grained brownish weathered rocks composed of various proportions of enstatite, tremolite, magnesite, chlorite (Al), spinel (Al) and/or magnetite (Table 1; Figure 17) which, according to Bucher-Nurminen (1988), are characteristic for this part of the Caledonides. They locally contain dunitic zones (Figure 18) and lenses of chromitite (Figure 19) as well as being transected by 1-20 cm wide magnesite veins (Figure 20).

Type 2: Coarse-grained dark grey to black ultramafic rock composed of pargasite [$NaCa_2Mg_4Al_3Si_6O_{22}(OH)_2$]- and enstatite-forming sheets and irregular enclaves inside type 1 (Figure 21).

Type 3: Very coarse-grained, greyish rock composed of nearly monomineralic enstatite occurring as up to 20 cm long sheaves and radiating aggregates with minor interstitial talc, forsterite and/or magnesite (Figures 16a and 22).

Figure 17. Radiating aggregates of enstatite in a matrix of forsterite, talc and minor quantities of magnesite, tremolite and chlorite.

Figure 18. Small, 5-10 cm long, black lenses of chromitite in coarse-grained enstatite-forsterite rock (pale brownish on the left side) with light greenish yellow dunite to the right.

Figure 19. Folded, broken chromitite lens in coarse-grained forsterite-enstatite-magnesite rock.

Figure 20. Magnesite-chlorite veins in enstatite-forsterite-magnesite rock (meta-peridotite).

Figure 21. Contact between brown enstatite-forsterite-magnesite rock and dark grey to black metamorphic pargasite-rich rocks.Such contact zones are shown as light grey areas in Figure 16.

Figure 22. Close up of enstatite composed of radiating sheaves of enstatite (10-15 cm long) constituting up to 20 m wide and more than 100 m long linear zones.

The type 1 and 3 assemblages are, according to Bucher-Nurminen (1988), related to metasomatic alteration of forsterite to magnesite and enstatite by interaction with CO_2-rich fluids. Type 3 rocks, which occur as 10-20 m wide linear zones in type 1 rocks, appear to possibly represent structurally controlled fluid conduits in originally dunitic rocks. The type 2 rocks are of enigmatic origin. They may possibly be related to interaction with neighbouring calcareous supracrustal rocks.

2.3.4 Preliminary assessment

All the different types of ultramafic rock carry accessory sulphides, but none of those in the investigated areas (Figure 15) were found to contain sulphides in the amounts described by Korneliussen (1976, 1977). The enrichment of sulphides must thus be of very limited extent.

None of the investigated ultramafic rocks contain more than accessory grains of pyrrhotite and pyrite. This result is supported by the 10 semi-quantitative analyses of ultramafic rocks from the Esjeholmene islets yielding ≤ 0.01 Wt. % Ni, i.e. the detection limit for the atomic absorpsion method used at the NGU lab (Korneliussen, 1977). In his review of the geochemistry of chromite ore in the coastal area of Central Nordland Korneliussen (1977) reports that one sample from the northern islet of Litle Esjeholmene islets contains 0.45 % Ni. However, the restricted dimensions of this and similar chromite mineralisation combined with low grades in the ultramafic rocks indicate strongly that further exploration for Ni-Cu ores should be halted.

3. OCCURRENCES IN ULTRAMAFIC INTRUSIONS

Ni-Cu occurrences hosted by mafic-ultramafic intrusions such as the intraorogenic mantle-derived Råna intrusion SW of Narvik appear to be rather rare in the UmA of the Scandinavian Caledonides. (Boyd and Mathiesen, 1979). Such an ultramafic intrusion is found in pyroxenite enclaves at Tverrbrennfjellet in Bodø municipality where the present authors as well as earlier geologists have struggled to define the correct terminology for both the host and wall rock lithologies in addition to understand how they were formed.

3.1 The Tverrbrennfjellet mineralisation

The workings at Tverrbrennfjellet are also named St. Olav, Tverbrændfeltet, or Tverbrennskjerpene in old reports. The mineralisation is situated above the tree line in the southernmost part of Bodø municipality and close to the border with Beiarn municipality. It comprises 5 small open pits situated shortly north of the top of Mount St. Olav (707 m a.s.l.). The prospects are reached by following a foot path starting at the parking place situated 1.6 km NE of the road tunnel at the highest point of county-road F 813 (Figure 23). The foot path crosses the areas north of Lake Steinheivatn and Lake Brennfjellvatn and reaches, after about 1.5 km, the Brennfjellstua cabin to the SE where the foot path bifurcates with one branch leading to Mount St. Olav, 1.5 km to the NE.

3.1.1 Present and previous work

Two full days were spent on the mineralised area and on the lithologies constituting the xenoliths along the footpath leading to Mount St. Olav where the sulphide mineralisation was sampled.

Old reports (filed in the NGU Bergarkivet) covering the first exploration phase after the 1903 discovery of nickel sulphide mineralisation provide interesting information and often the typically optimistic, but correspondingly weakly justified expectations for the commercial viability of the discovery (Bugge, 1907). The first pitting in the best and most rusty spots in pyroxenitic rocks gave very promising results, with up to 3.75 % Ni and 1.65 % Cu (Dalset 1904). Later, detailed sampling (Thorkildsen 1915) of what was termed "the north pit" or "north sink" gave particularly interesting grades with up to 4.50 % Ni, 0.35 % Cu and correspondingly only 12.1 % insoluble residual, i.e. the silicate gangue fraction. As many as 8 of the 13 analyses originating from the north pit showed > 2.0 % Ni (on average: 2.41 % Ni, 0.18 % Cu and 32.63 % insoluble residue, n = 13). This indicates high-grade, massive to semi-massive sulphide ore, at least for the best analyses. Samples from the other locations in the top area, e.g. "the south pit"," the northern trench", "the top sink" and "western trench" all gave considerably lower grades (Thorkildsen 1915). Two years later Mørch-Olsen (1917) made a similar inspection trip on behalf of Raffineringsverket and came to a clear, negative conclusion as to exploitability, due to the general scarcity of ore and the large spread of the few rusty sulphide spots encountered.

Band (1977), in his key report on the Tverrbrennfjellet mineralisation, states that no further work had been carried out on the showings after 1917 except for a few inspection visits. These include:

Ursin (1938) gave quite unrealistic hopes for the area, in a short report, in strong contrast tothe views of the other geologists. According to Bøckman (1953) there are 4-5 small, blasted pits in the top area of the Tverrbrennfjellet plateau. These pits show poor pyrrhotite dissemination in a green, rusty “gabbro” as well as in associated "olivine stone". The whole top area consists of a mosaic of gabbro varieties interwoven with white dykes and veins of granite and pegmatite. The gabbro-hosted sulphide impregnations seem to be spatially confined to the gabbro/granite contact areas according to Bøckman. Poulsen (1954) points to the "highly irregular sulphide mineralisation" and concludes that the occurrence must be regarded as uneconomic. He, like several of the others, concluded that he "would certainly discourage any outlay for further investigations".

The inspection by Skofteland and Færden (1969) did not give much new information. They observed a "partly rusty olivine gabbro transected by dykes of Misvær-granite, the same rock that encloses the gabbro". They had a negative overall impression of the potential of the mineralisation, but opened for detailed mapping of the olivine gabbro as well as sampling of the mineralisations.

The inspection by Larsen (1969) did not give much new information either. Larsen emphasized that a body of coarse-grained, brown gabbro in the top area of the mountain strikes SW - NE and dips to the NW, with a 3-5 m thick "ore zone" located in the central part of the gabbro and oriented parallel to its strike direction. The coarse grained brown ore-bearing gabbro is transitional, towards the NW, into a green-white, non-mineralised amphibolite. In one of the prospect pits (the north pit?) the gabbro is clearly brecciated and interwoven with thin injected granite veins. The mineralisation is composed of semi-massive sulphides, rusty at the surface and in this way being different from the grayish barren gabbro in the wall rock (Larsen, l.c.).

Kollung (1972, p. 6), regarding the composition of the Tverrbrennfjellet gabbro, writes that large portions of the upper parts of the gabbro are strongly rusty and altered. A thin section of fresh gabbro from the area, however, showed plagioclase and mafic minerals in similar amounts. The mafic minerals are pale hornblende, both monoclinic and rhombic pyroxene as well as sphene and the retrograde minerals chlorite and epidote. The plagioclase is very basic (ca. An_{60}). Kollung (1972, p. 9-10) further emphasizes that there are small bodies of ultramafic rocks within the pale (light) gabbro and that these ultramafic rocks are partly more strongly mineralised than the gabbro. He visited and sampled the three small pits west of the top point from which he reports:

Eastern pit: Olivine orthopyroxenite with rich sulphide impregnation, ca. 2/3 orthopyroxene, the rest olivine and hornblende with ca. 5 % sulphide minerals

Central pit: Similar rock but poorer in disseminated sulphides

Western pit: Dunitic rock with ca. 80% olivine, some retrograde chlorite and talc and impregnation of ca. 10 % pyrrhotite + pentlandite + chalcopyrite.

Kollung (1972) regards the high Ni content in the westernmost pit (0.65 and 0.70 %, respectively) as being due to lattice-bound Ni in the olivine. No sulphide impregnation may be seen in the gabbro, but the gabbro is more strongly rusted (weathered) and the sulphides are therefore "diluted" compared to their content in the ultramafic rocks.

The Swedish company Terratest conducted helicopter-borne geophysical surveys (EM and magnetics) in the Misvær - Skjerstad - Beiarn area in 1970 on contract for Sulitjema Bergverk A/S. The survey did not yield significant EM or magnetic anomalies worth following up in the Tverrbrennfjellet area (Löfberg 1971), but one should, however, still have in mind a small, but very strong and well defined magnetic anomaly located ca. 1.75 km t SE of the top point (707 m a.s.l.) on Tverrbrennfjellet (M.T. Styles in: Roberts and Taylor, 1974). This anomaly, situated within a large area of foliated diorite (Gjelle, 1980), does not seem to have been properly followed up on the ground. Styles (op.cit.) writes that it is "probably due to numerous amphibolite rocks that occur in that area". Resampling and analysing of the same "north-pit and trench" by Sulfidmalm (Band, 1977, fig. 4) gave lower grades than the 1915 analyses (Thorkildsen, l.c.), but still interesting values (on average: Ni = 0.78 %, Cu = 0.20 %, n = 10 samples) than the initial analyses from 1915.

A 1:2,500 scale simplified outcrop map of the plateau based on aerial photo coverage was made by A. Park (fig. 3 in Band 1977). The map shown in Figure 29 of this report emphasises the irregular borders between the moderately NW-dipping gabbro body and the acid (granitic) gneisses. The gabbro itself is back-veined by a large number of irregular acid dykes. Similar gabbro caps the ridges immediately west of Tverrbrennfjellet, and also the Elsenakken ridge, 1.5 km to the east (Band, 1977, p. 4). The ground geophysics carried out by Sulfidmalm: magnetic, VLF and mise-á-la-masse surveys did not show any significant anomalies. Band (op.cit., p. 6) concluded that "the Tverrbrennfjellet mineralisation is so dispersed as to be essentially non-conductive, as is also indicated by the very weak VLF anomalies obtained over the showing".

The main conclusion drawn by Sulfidmalm after its exploration campaign in this fairly large area was that "it appears that there is little potential for the discovery of significant nickel mineralisation in the Beiarn - Skjerstad area" (Band 1977, p. 14).

3.1.2 Geological setting

The deposit is located a short distance above the basal thrust of the Beiar Nappe (BN in the UmA) which outcrops ca. 3 km to the east (Figure 2 and 23). The BN is predominantly composed of micaceous schists and gneisses, locally containing sillimanite, as well as thick units of marbles. The meta-sedimentary sequence is punctured by abundant granitoid intrusions which, in the Tverrbrennfjellet area, contain 18 xenoliths assumed to represent a somewhat older phase of mafic-ultramafic intrusions which are termed the St. Olav Complex. The xenoliths are distributed within an elliptical area which is up to 1 km wide and 3.5 km long and with the longest axis trending NE-SW (Figure 23). The mineralisation is situated inside the northernmost and largest of the xenoliths shown in the bedrock map by Solli et al. (1992). It measures 400 m x 850 m and is centred on Mount St. Olav (Figure 24). It was termed gabbro by the latter authors, but is best described as a tonalitic intrusion breccia comprising fine-grained tonalites carrying a variety of differently sized, shaped and spaced inclusions of coarse-grained pyroxenites, peridotites and gabbros (partly altered to amphibolites) (Figure 25). Xenoliths of dunitic rocks carrying sheeted asbestos veins, are commonly encountered in the low-altitude south-western part of the St. Olav Complex. The field relationships shown in Figures 26-27 are difficult to interperate, although they indicate a blend of two rock-types of tonalitic and mafic-ultramafic composition. The ultramafic patches commonly show a rusty surface colour caused by the presence of accessory grains of pyrrhotite and chalcopyrite.

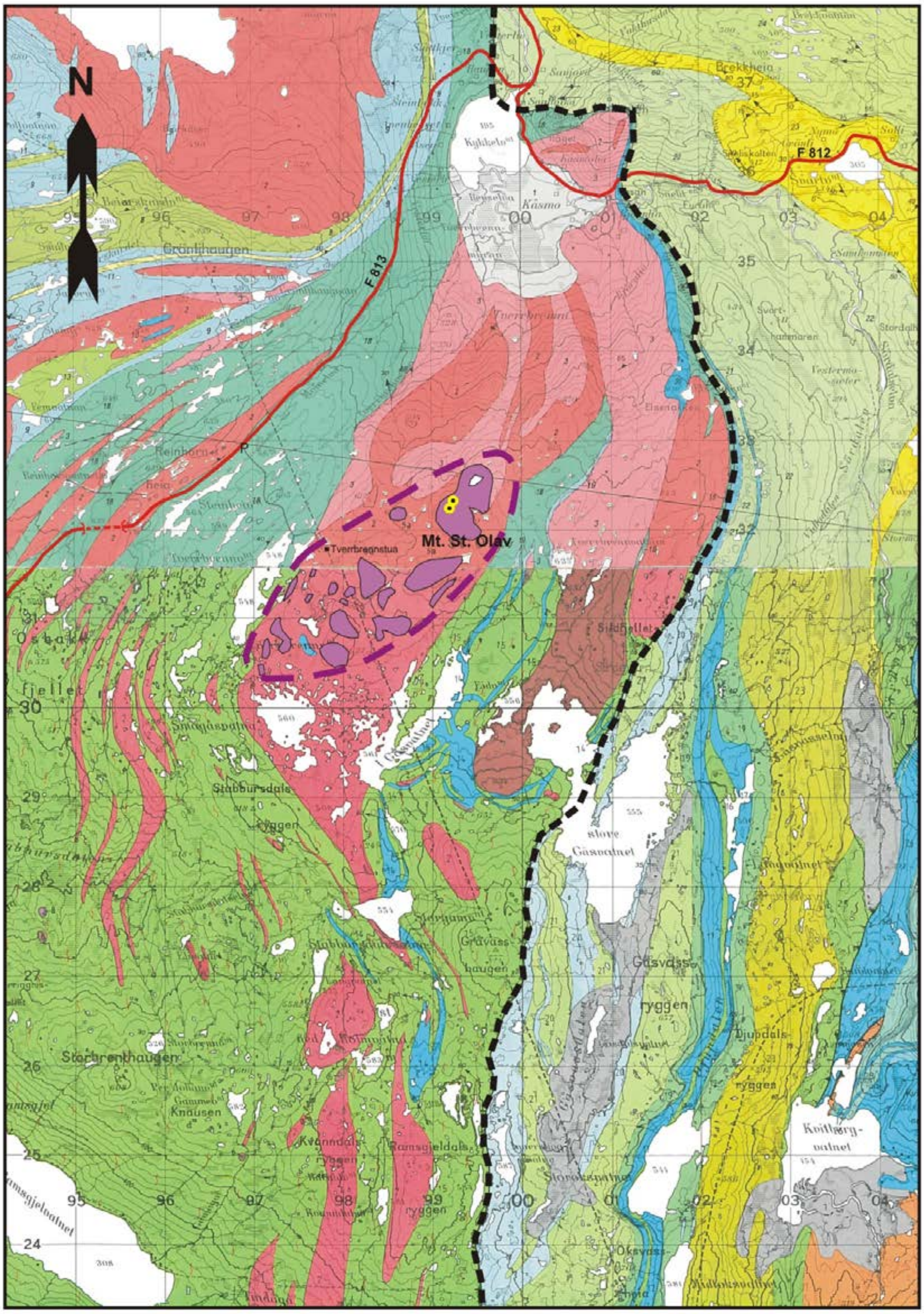

Figure 23. Bedrock geology of the area around St. Olav based on compilation of segments from the bedrock map sheets (1:50000) Beiardalen (2028-1; Gjelle, 1980) and Misvær (2029-2; Solli et al., 1992). The black stippled line represents the basal thrust of the Beiar Nappe and the purple stippled line the outline of the dismembered St. Olav mafic-ultramafic complex composed of 18 xenoliths shown in purple. The northernmost xenolith contains the Tverrbrennfjellet prospects shown as black dots in yellow spots. The country rocks comprise: Granites (2) in red, tonalites and quartz diorites (3) in pink, diorite (4) in brown, micaceous schists and gneisses in greenish colours, marbles in bluish colours and quartzites and quartz schists in yellow. 1 km distance between the grid lines in the UTM ED 50 system

This type of rusty weathering is characteristic for the upper part of Mount St. Olav, except where it is cut by dykes extending from the surrounding massif of polyphase granitoid intrusions (Figure 28).

3.1.3 Ore geology

Larger enclaves of massive coarse-grained pyroxenite (3-10 mm grain size) do exist and three of these contain more high-grade sulphide mineralisation that has been worked in the past (Figures 29-30).

Figure 24. View towards the north from the mountside of St. Olav. The grey weathered surfaces represent tonalites whereas the brownish and rusty surfaces comprise of mafic-ultramafic intrusion breccias. The lake and the small mountain top are shown in the northern part of Figure 29.

Figure 25. Outcrop of intrusion breccia near the top of St. Olav. It is composed of fine-grained tonalitic rock with scattered irregular patches of rusty pyroxenite with subordinate dissemination of pyrrhotite. Close ups in Figures 26 and 27.

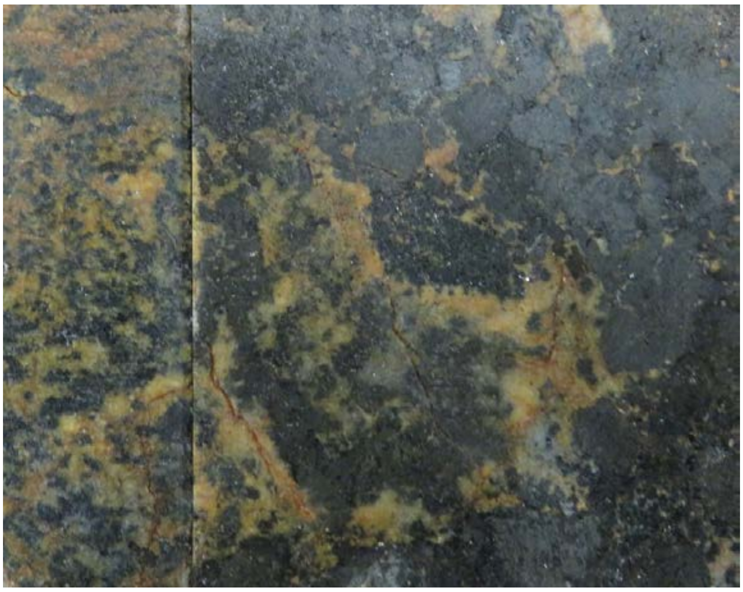

Figure 26. Cut surface of a sample of the border between a pyroxenite enclave and "gabbro". The enclave is composed of coarse-grained pyroxene (dark grey) with minor interstitial tonalite (right side). Towards the left the pyroxenite grades into fine-grained light grey tonalite with small, fine-grained pyroxenite/amphibolite patches and areas with evenly distributed amphibole-altered pyroxene crystals (by the authors termed "tonalitic gabbro"). The short side of the picture is 6 cm.

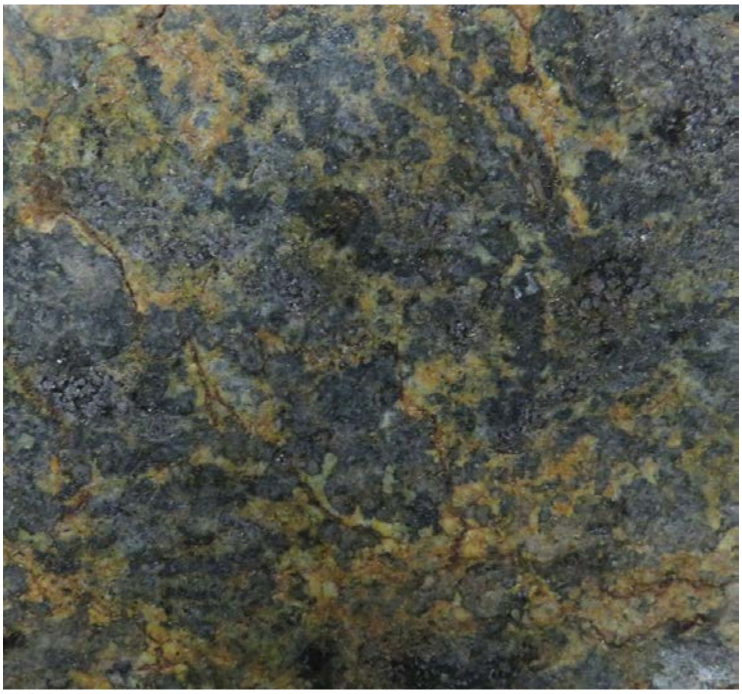

Figure 27. Photo of another slab of a mixture of felsic and ultramafic segregations, i.e. single crystals and aggregates of pyroxene scattered in a matrix of fine-grained tonalite which is possibly recrystallized in the lower part of the picture. The long side of the picture is 8 cm.

Figure 28. Picture of a E-W trending granite dyke cutting the mineralised ultramafic rocks at the central and eastern pits, 100 m northwest of the summit of Mount St. Olav. The pits are worked on 10 m^3 bodies of mainly pyroxenites situated in a rusty tonalitic intrusion breccia containing accessory pyrrhotite. (see also Figure 29). Photo taken at the central pit towards the east.

The Northern pits are situated in the scree-covered northern slope of Mount St. Olav. The lower part of the slope, where the workings are situated, can be covered by snow for most of the year. They comprise a 2-3 m wide and 10 m long cutting driven towards the south into an outcrop of rusty pyrrhotite-bearing pyroxenite. The cutting ends in a 4 m high wall with minor underground extensions towards the east where a small shallow open pit is situated (Figure 30). The rich ore samples which were collected on the approximately 100 m^2 spoil heap comprise coarse-grained pyroxenite with coarse interstitial aggregates and an intergranular network of fine-grained nickeliferous pyrrhotite and minor chalcopyrite. The sulphides are rimmed by amphibole aggregates towards the adjacent 1 cm long pyroxene crystals.

The Central and Eastern pits, visited in the summer of2017, are situated closer to the summit of Mount St. Olav. They comprise two small, 1 m-deep open pits located 21 m apart in an E-W direction (Figure 28). The eastern one is located about 80 m away from the Northern pits in a NNE direction and measures 1 m x 1 m whereas the western one is 1 m x 2 m. The two pits have been worked on two small enclaves of massive, coarse-grained (5-15 mm), sulphide-bearing pyroxenite comparable to that in the Northern pits. The pyroxenite enclaves in both workings are surrounded by variably mixed ultramafic and tonalitic rocks which are cut by a 2 m wide and E-W trending granite dyke that appears to split the pyroxenite enclaves into two segments as shown in Figure 28.

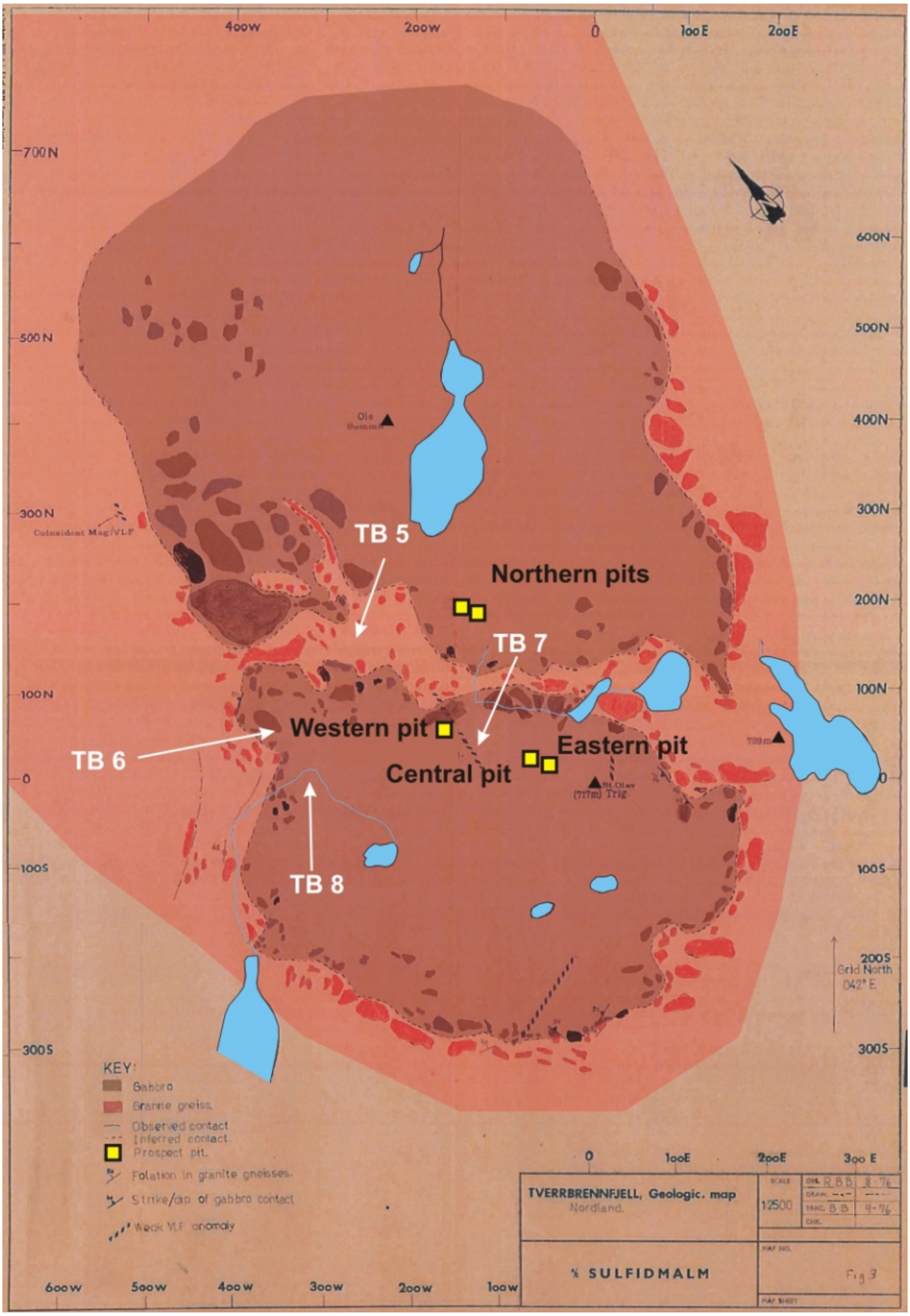

Figure 29. Simplified geological map showing the location of the Tverrbrennfjellet pits in the Olav xenolith which is separated into two by a narrow tonalite dyke. Black triangle = mountain summit shown in Figure 24, Blue = lakes, Brown = tonalitic intrusion breccia with mafic-ultramafic inclusions, Red = granite and tonalite, the latter north and east of the northernmost xenolith and Yellow filled squares = pits. Map redrawn from Band (1977) who reported the mapping done by A. Park.

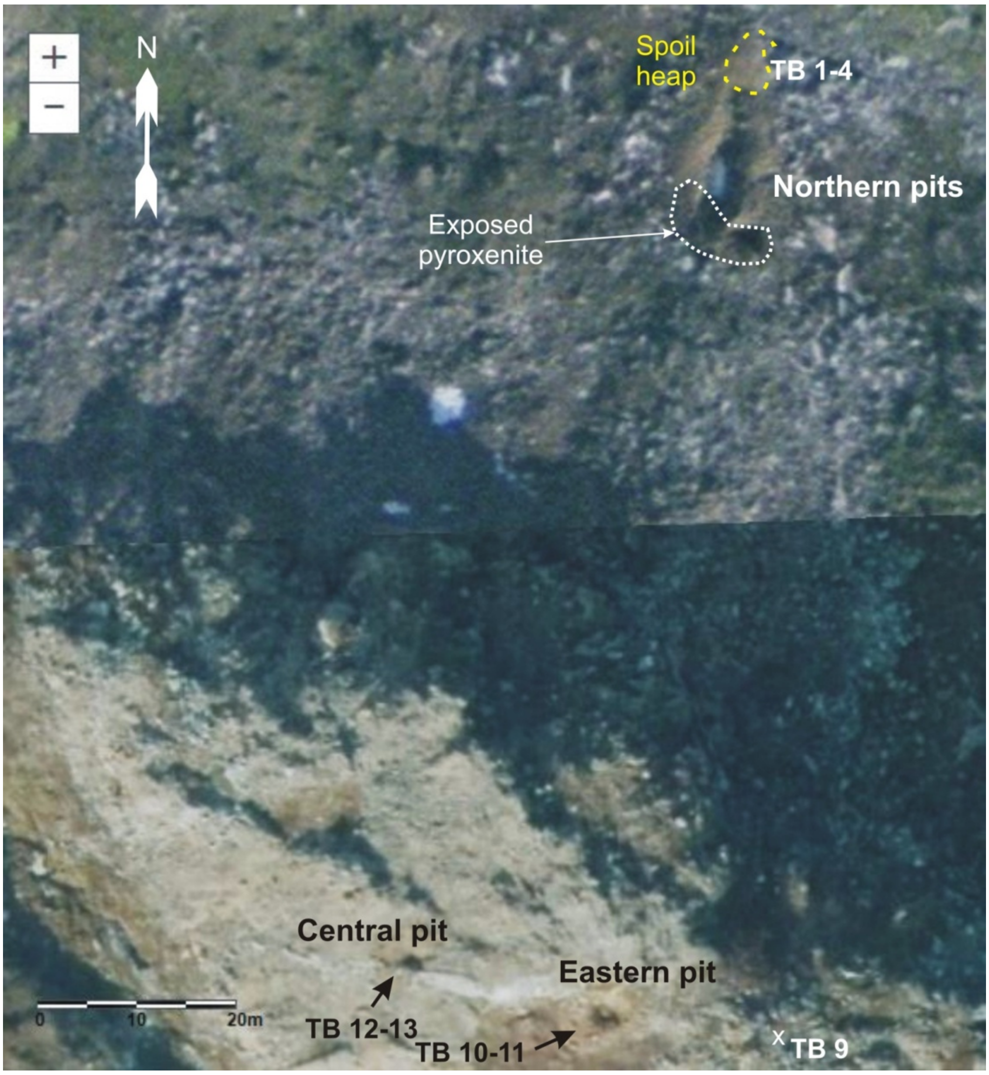

Figure 30. Aerial photograph of the northern scree-covered slope of Mount St. Olav showing the pits visited in the summer of 2017. The pits represent trial mining of pyroxenites carrying disseminated nickeliferous pyrrhotite and chalcopyrite. The pyroxenite at the Northern pits covers an area of about 60 m^2. Notice the granite dyke cutting the intrusion breccia between Central pit and Eastern pit as shown in Figure 28. Compilation based on images from https://www.norgeibilder.no/

3.1.4 Preliminary assessment

Previous analyses of pyroxenite samples collected in the pits yielded Ni values mostly in the range 0.2-0.6 wt %, together with low values of Cu and Co, as well as very low values of PGE (NGU Ore Database, Appendix 3). Although the formation of the "tonalitic gabbro" and breccias is not well understood the amount of sulphide-free tonalite in the intrusion breccia is far too large to generate potential host rocks. The tonalitic phase would probably, in most cases, have a strong bulk diluting effect on any Ni-Cu mineralisation occurring in the mafic and ultramafic phases. No mineralisations other than the already known ones were found during the two days of investigation in this well-exposed area so we doubt that further study of the area will generate positive results, except for those of purely scientific interest.

The St. Olav Complex is part of a linear train of mafic-ultramafic intrusions which can be followed from the outer part of Misværfjord in the north, via the Misværdal clinopyroxenite massif (Ihlen and Furuhaug, 2012; Ihlen et al., 2014) and the Tollådalen gabbro-pyroxenite complex (Gjelle, 1980) to around Steinåga in the south, where small pyroxenite and serpentinite bodies occur together with ultramafic amphibolites and sills of alkaline granites (Figure 2). Typical of these bodies is that they contain large proportions of clinopyroxenites and show signs of mingling between felsic and mafic magmas crystallising as granites and clinopyroxenites, respectively. The mafic magmas appear to be generally low in sulphides. Some of them, however, are rich in phosphorus as is the Misværdal massif which, based on 419 samples, contains an average of 2.27 % P_2O_5 or 5 vol.% apatite over an area of 8 km^2 (Ihlen and Furuhaug, 2012).

4. OCCURRENCES IN GABBROIC INTRUSIONS

The type of nickeliferous intrusion which is presently known in the UmA carries mineralisation that is relatively rich in Ni and Cu, but have highly variable contents of Pt and Pd that reach 1156 ppb in the Høgsetdalen mineralisation. The three known mineralisations, at Høgsetdalen, Lilleålegden and Måløy, occur in association with intrusions ranging in composition from gabbro via melanocratic gabbros to sulphide-rich ultramafic rocks (Appendix 2). They are, unfortunately, of very limited areal extent. The possibility that these nickeliferous intrusions may have originated from a much larger volume of magma at depth cannot be excluded and is thus of major interest from both economic and scientific viewpoints.

4.1 The Høgsetdalen mineralisation

This deposit is located on the shoreline of Sørfjorden in Gildeskål municipality. It is reached by following county-road F 475 to Forstranda and then by driving southwards on the dirt-road to the abandoned farm at Høgsetdalen where a footpath leads down to a cabin and further on to a boathouse located about 300 m SSE of the farm houses and 50 m NE of the prospect (see Figure 32). Only minor work has been conducted on the deposit which is partly flooded at high tide.

4.1.1 Previous and present work

Two days were spent on sampling the mineralisation and its wall-rocks and searching the surrounding areas for larger bodies of mafic and/orultramafic intrusions, and for possible gabbroic differentiates in the dioritic orthogneisses shown in Figures 31 and 32. Unfortunately, the sampling of the ore zone was not conducted due to a misunderstanding between the two investigators which left the mineralisation unsampled. Supplementary sampling will be undertaken at the earliest opportunity. Thus the assessment of ore chemistry will possibly rely on samples collected during previous ore-database registrations that are stored at NGUs Geodata Centre at Løkken.

There are no reports referring to earlier exploration work on this occurrence and the only work conducted seems to be some minor blasting carried out about a century ago (1 m^3 has been blasted out). This indicates that previous prospectors have regarded the deposit too small to spend any money on.

4.1.2 Geological setting

The deposit is situated at the base of the Beiar Nappe within the Rødingsfjell Nappe Complex of the UmA (Figures 31 and 32). The structural geology of the area is described by Wells and Bradshaw (1970) whereas the regional bedrock geology is covered in maps by Gustavson and Gjelle (1991) and Gustavson (2003). These authors documented the presence of a stacked sequence of meta-sedimentary rocks separated by numerous slides and thrusts which are truncated by several granitoid intrusions of Late Ordovician-Early Silurian age. The rocks are affected by multiple episodes of isoclinal folding and up to kyanite-grade metamorphism.

The Beiar Nappe consists of the Sokumfjell- and Saura Group marbles as well as the Sundsfjord Group mica schists and gneisses (Figures 31 and 32). The Saura Group in the Sørfjord area comprises, in addition to calcite marbles, subordinate units of various mica schists and gneisses within an overturned synform. The Sokumfjell Group is intruded in the east and northeast by numerous dioritic to granitic intrusions, as well as containing scattered gabbroic bodies (Figure 31).

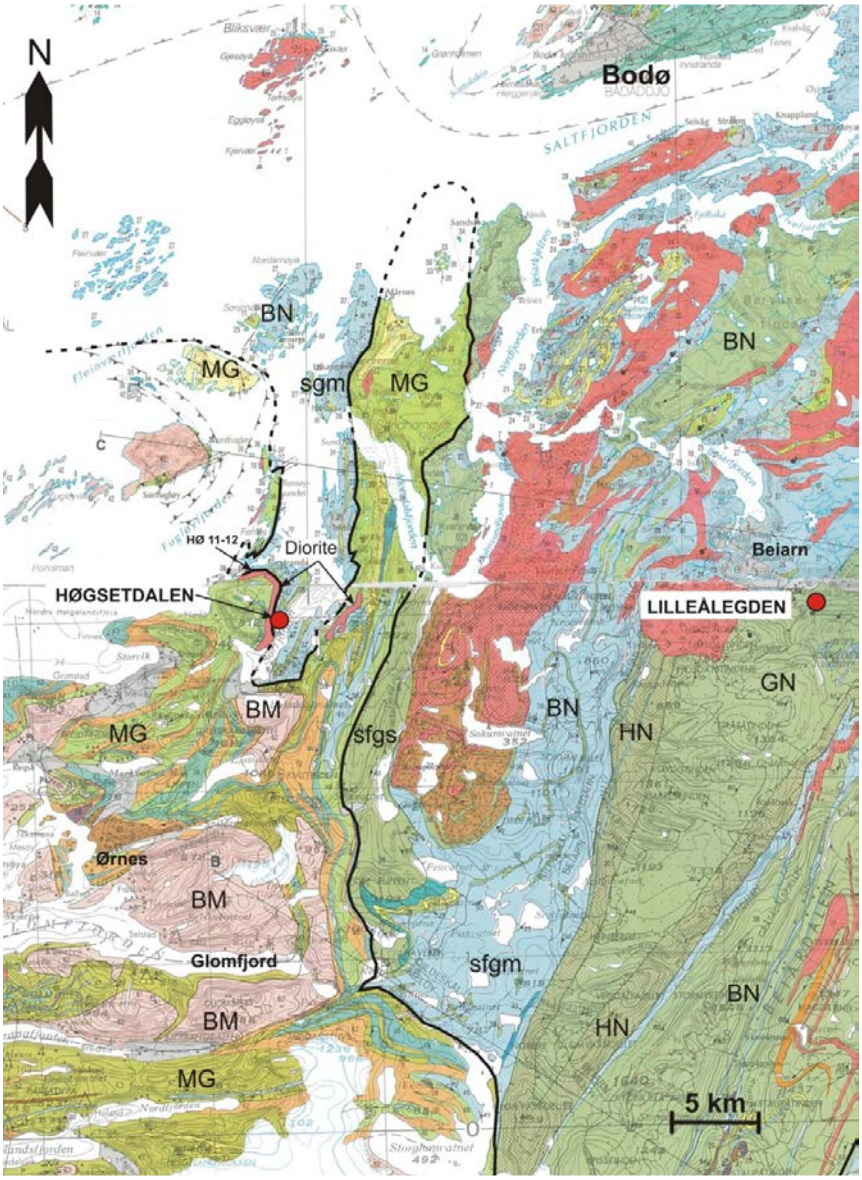

Figure 31. Regional geological map of the southwestern part of the Salten region showing the location of the Høgsetdal and Lilleålegden Ni-deposits and the main lithotectonic units in the RNC of the UmA. These are, in order, from bottom to structural top: BM = basement gneisses, MG = Meløy Group, BN = Beiar Nappe, HN = Habresåga Nappe, and GN = Govddestind Nappe. The basal thrust of the BN is shown with a thick black line. The main lithologies include: Bluish = marbles, Brownish Early Palaeozoic diorite, Greenish = micaceous schists and gneisses, Pink = granitic orthogneisses of Paleoproterozoic age in the basement, Reddish = Early Paleozoic granitoids, sfgm = Sokumfjell Group marbles, sfgs = Sundsfjord Group schists, sgm = Saura Group marbles and Yellowish to orange = quartzites and arkosic gneisses. Compilation based on Gustavson (2003), Gustavson and Blystad (1995), Gustavson and Gjelle (1991).

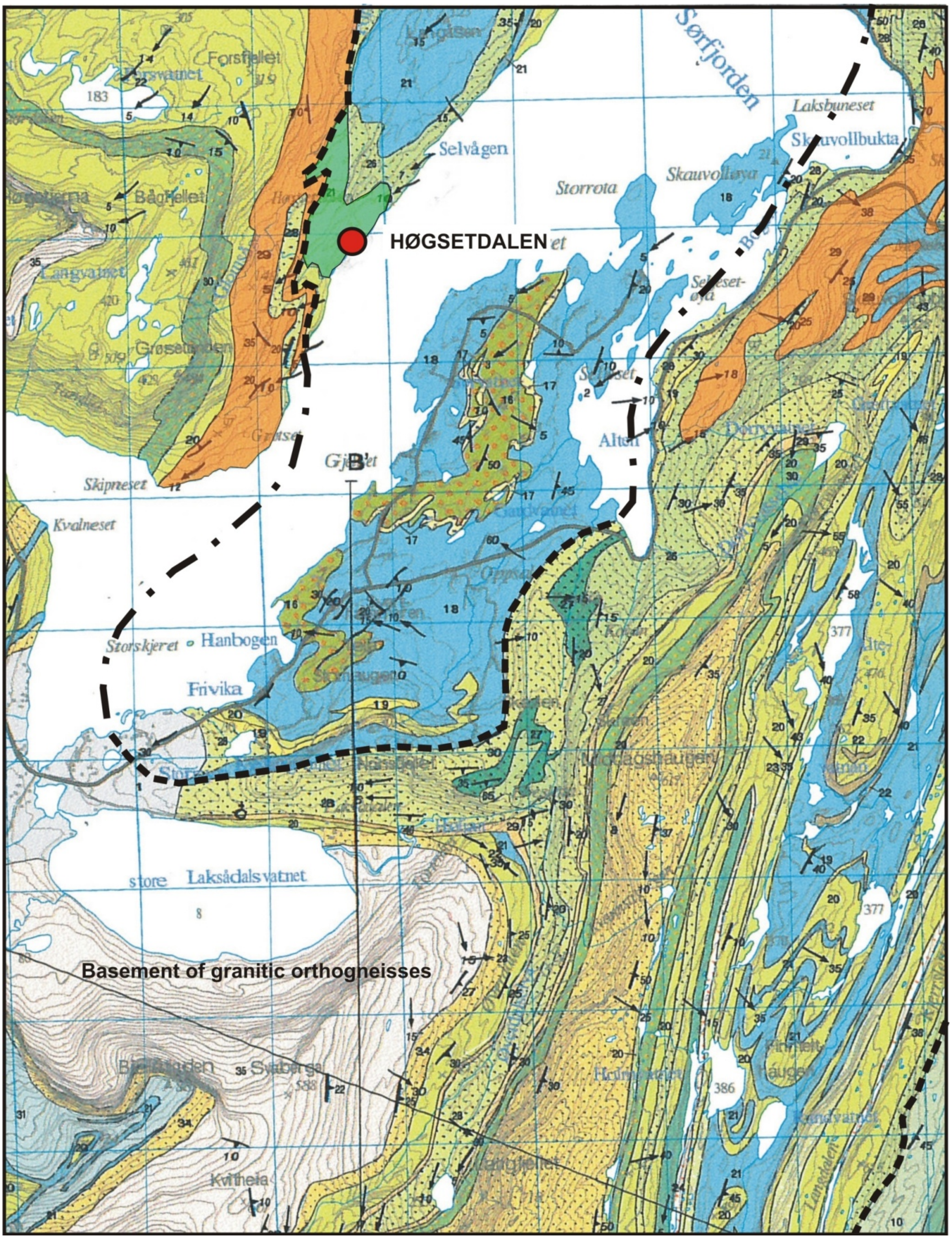

Figure 32. Geological map of the Sørfjorden area in Gildeskål municipality showing the location of the Høgsetdal Ni-Cu mineralisation and the basal thrust of the Beiar Nappe (Thick black stippled line). Segment of bedrock map sheet Glomfjord (1:50 000, Gustavson (2003). The main lithologies include: Marbles in blue colours, different types of mica schist and gneisses in greenish colours grading into yellowish by increasing amount of quartz and feldspar. The diorite intrusions shown in orange was investigated for the presence of gabbroic phases

The lower part of the Rødingsfjell Nappe Complex is characterised by meta-sedimentary sequences carrying abundant tectonic lenses of Paleoproterozoic basement gneiss of granitic composition as in the Laksådalen tectonic window 5-6 km south of the deposit (Figure 32). These meta-sedimentary rocks, which are termed the Meløy Group, are composed predominantly of pelitic to semi-pelitic mica schists and gneisses as well as psammitic rocks.

They also contain additional amounts of garnet, kyanite and/or carbonate. Minor units of marble, quartzite and hornblende-biotite orthogneiss represent additional members of this group. The latter orthogneisses appear to represent deformed diorite intrusions forming extensive sills with a tectonic contact (thrust) towards the overlying rocks of the Saura Group in the Beiar Nappe (Figure 33). The diorites in the Sørfjord area were searched for gabbroic differentiates, but without any success.

Figure 33. Dioritic orthogneiss outcropping along the county-road (F 475) at Forstrand.

Figure 34. The hanging-wall sequence of the gabbro-bearing quartzite. Grey biotite gneisses with quartz stringers along the foliation intercalated with thin units of calcite marbles. See location in Figure 35.

Figure 35. The large northern and small southern domes of melanocratic meta-gabbro (MMG) in rusty quartzite. The upper limit of the seaweed indicates the water level at high tide. The photo in Figure 34 is taken in the cliffs in the background to the right.

Figure 36. Banded semi-pelitic to psammitic biotite gneiss comprising the foot-wall sequence of the gabbro-bearing quartzite at the boat house in Figure 37. Location for sample HØ 10.

4.1.3 Ore geology

The Høgsetdalen mineralisation is situated within the rocks of the Saura Group which, in the mineralised area, comprises a mixed sequence of mica schists and gneisses carrying thin units of quartzites and marbles (Figures 34 and 36). The mineralisation occurs in the contact zone of two closely spaced elliptical and dome-shaped protrusions of melanocratic meta-gabbro (Appendix 2) locally grading into ultramafic amphibolite. They occur within, or cross-cut a thin unit of quartzites dipping 10-50° NW (Figures 35 and 37). The southern dome of meta-gabbro, with the longest axis trending N88°E, measures 1.2 m x 2.5 m (Figures 35 and 38).

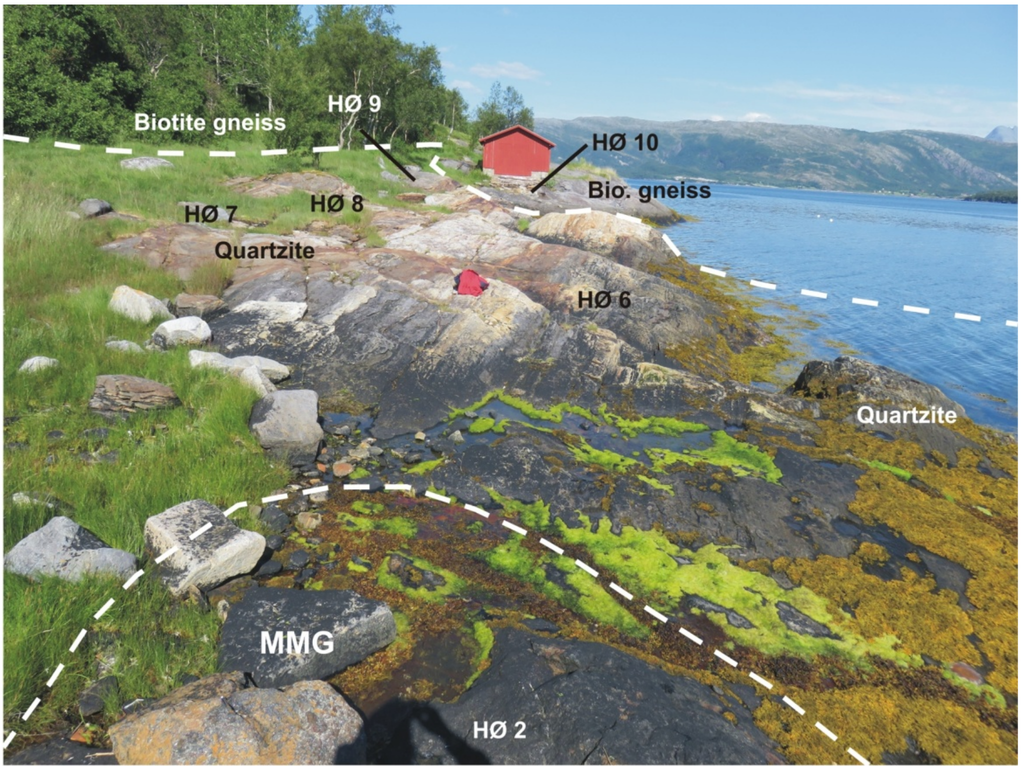

Figure 37. Quartzite with rusty zones viewed northwards towards the boat house where the west-dipping quartzite wedges out. High tide indicated by the uppermost limit of the seaweed. MMG = the margin of the large northern dome of melanocratic meta-gabbro.

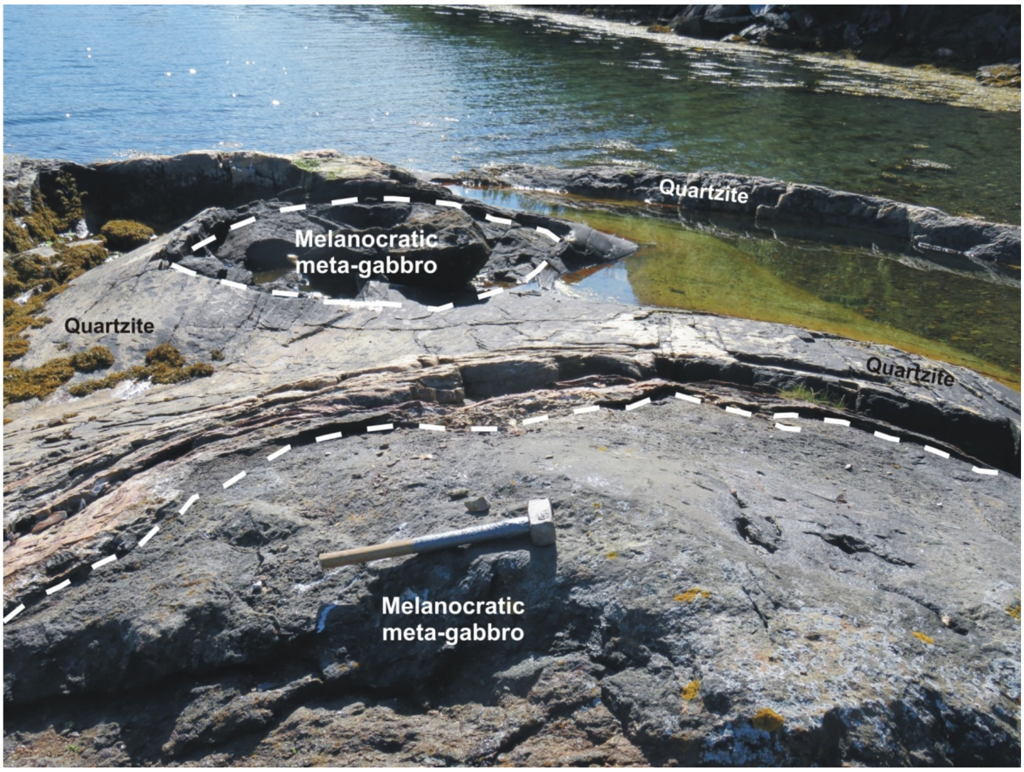

Figure 38. The domes of melanocratic meta-gabbro viewed towards the south. The length of the hammer is 60 cm.

The other gabbro dome, with a centre situated 6 m towards the NE, has an axial trend of N 38°E and axes measuring 4.5 m and 6.5 m (Figures 35 and 39). The quartzites carry several rusty zones caused by minor dissemination of very fine-grained Fe-sulphides (Figure 37). A calcite marble, 20-50 cm thick and isoclinally folded, occurs at the contact with the footwall biotite gneisses at the boat house.

The weakly schistose melanocratic meta-gabbro is exposed and mineralised to a maximum depth of about 1 m below the contact with the overlying quartzite (northern dome). The mineralisation in the meta-gabbro comprises dissemination and minor intergranular net-veining of pyrrhotite occurring in the contact zone towards the overlying quartzite.

The latter carries a 10-20 cm contact zone with pyrrhotite stripes along shear planes. The richest mineralisation occurs as aggregates at the margin of narrow quartz and pegmatite veins locally cutting the melanocratic meta-gabbro. This type of mineralisation with up to 8.62 wt. % S contains 1.24 wt. % Ni, 0.32 wt. Cu, 0.03 wt. % Co, 146 ppb Pd and 1010 ppb Pt (NGU Ore Database and Appendix 3). The latter value is probably a nugget effect since it is a single high Pt value only, i.e. not reflected by the remaining analyses. The anomalous Pd content is, however, repeated in the other analyses.

4.1.4 Preliminary assessment

The ore grade is acceptable, but not the apparent extension of the mineralisation which is difficult to determine. The deposit is rather enigmatic since it is not possible to determine whether the outcropping meta-gabbros represent a boudinaged sill parallel to the banding of the quartzite (Figures 39 and 40) or the top of an altered stock-shaped melanocratic gabbro intrusion (Figure 41). This could be tested by doing a gravimetric survey in the area in order to define the shape of the gabbro body or bodies.

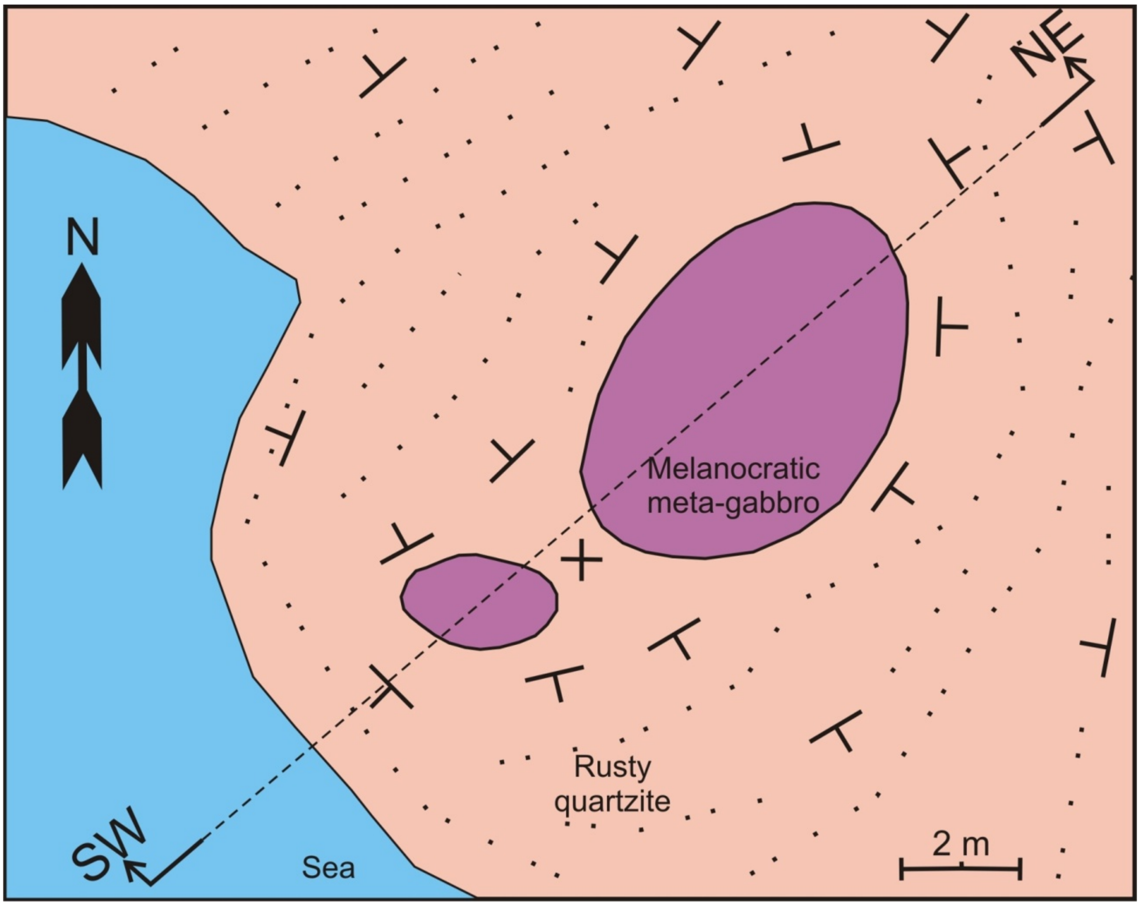

Figure 39. Simplified sketch of the amphibolite domes showing the section line viewed in Figures 40 and 41 towards the northwest.

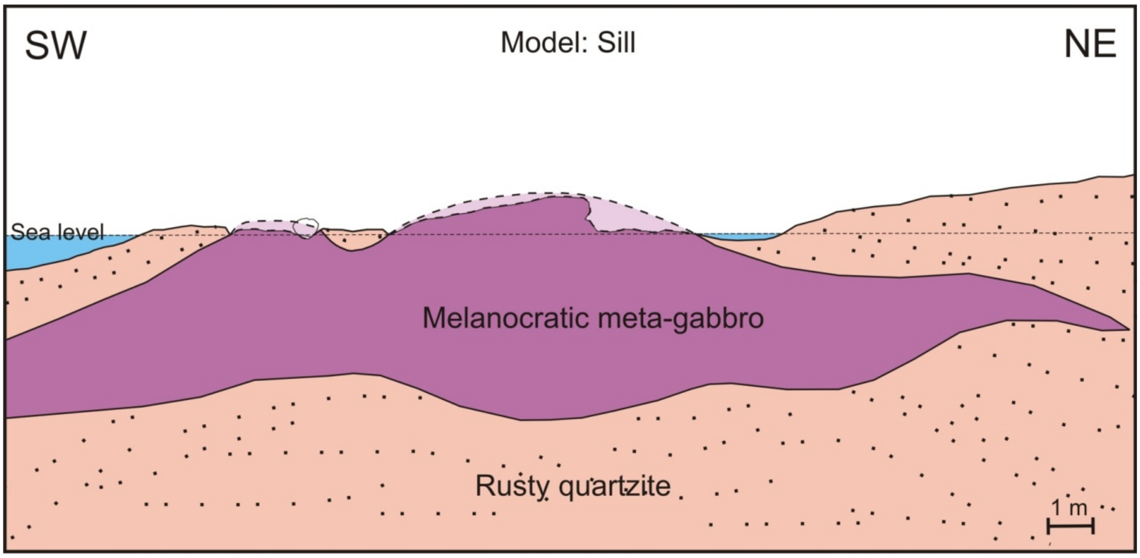

Figure 40. Potential model of the domes formed by boudinage of a roughly foliation-parallel melanocratic meta-gabbro sill. Sea level at high tide.

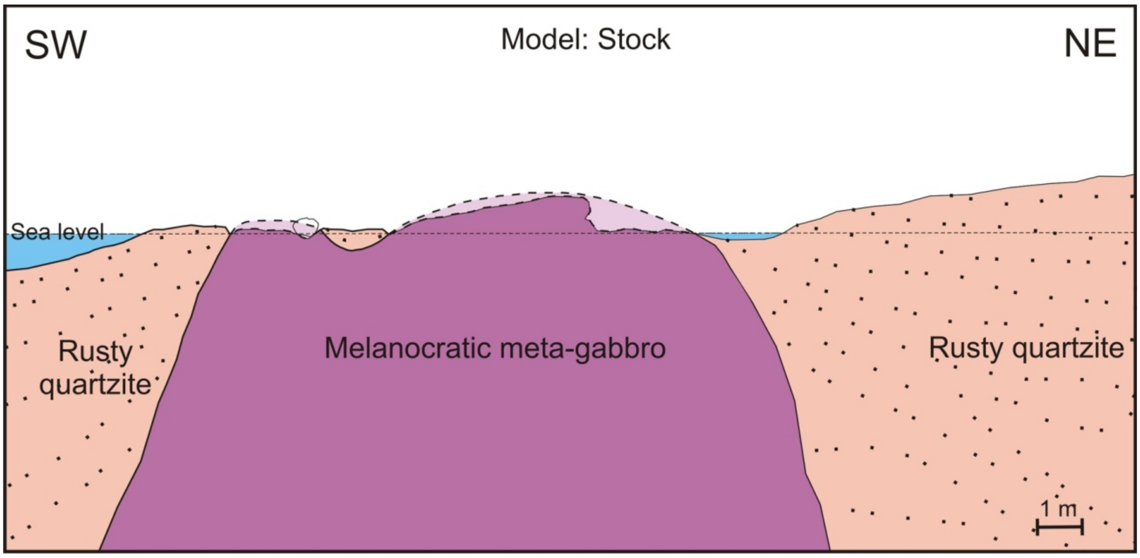

Figure 41. Potential model of the domes formed by late stage diapiric rise of a stock-shaped melanocratic meta-gabbro. Sea level at high tide

4.2 The Lilleålegden mineralisation

The mine has different names in old reports including Lilleåleiden, Lille-Leiden, and Eiterjord. It is situated on the eastern bank of Lilleåga River at the southern slope of Beiardalen Valley (Figures 2, 31 and 42). It is reached by following a tractor road which takes off from the main road along the southern bank of Beiarelva River about 800 m southeast of Eiterjord farm (outside Figure 42). The tractor road winds up the densely forested mountainside to an altitude of 155 ma.s.l. where it ends at the spoil heap on the western bank of the Lilleåga River (Figure 43).

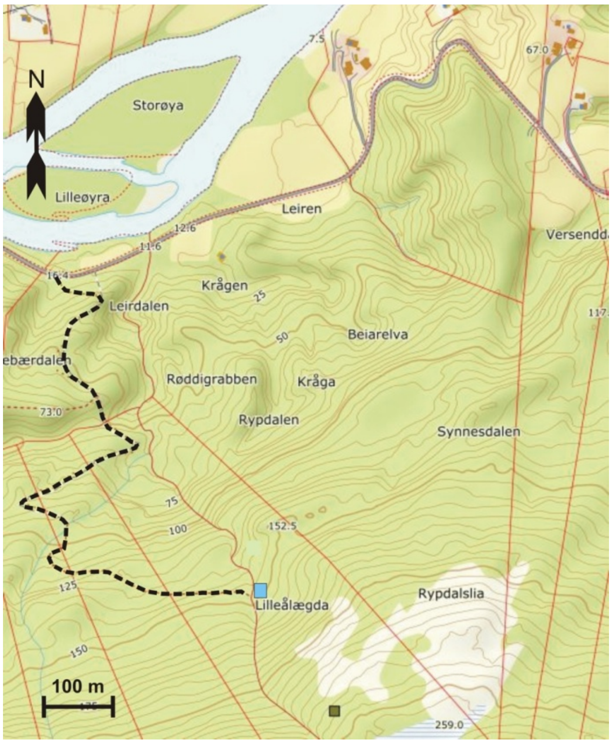

Figure 42. Topographic map showing the location of the tractor road (black stippled line) ending at the Lilleålegden mine (blue square).

4.2.1 Present and previous work

Two days were spent on mapping the geology of the mineralised gabbro as well as collecting samples of the main lithologies and ore types. In addition, one day was used to do some preliminary investigations of the geology of the ore zone along strike in both directions.

The ore body at Lilleålegden was discovered in 1891 possibly due to outcrops occurring along the Lilleåga River that runs across the ore zone. The ore was shown to be unusually rich in nickel and therefore soon attracted attention, especially from Professor J.H.L. Vogt who addressed the deposit in several contemporary papers (Vogt 1892, 1901, 1902). A number of analyses of massive sulphide ore showed very high grades (between 4.7 and 19.3 wt % Ni and even up to 33.35 wt. % Ni which represents pure pentlandite (Vogt 1892, p. 18-20 and 1901, p. 16).

Figure 43. a) Left: picture viewed towards the east. It shows the rust-brown spoil heap where the tractor road ends outside the mine entrance with a white arrow. The entrance and the grey spoil heap at a distance are situated on the east side of the river. **b)** Right: the picture shows the entrance to the open pit immediately east of the Lilleåga River in the foreground.

The high grade ores was possibly mined out already in 1891-92 yielding 685 metric tons with an average of around 6-7 wt-% Ni in hand-cobbed first-class ore (Vogt 1901, p. 16, 1902, p. 9, Henriksen 1897, 1898). Most of the first-class ore was shipped to harbours abroad whereas lower-grade ores and most of the fines were left untouched after hand sorting (Henriksen 1897).

The mineralisation is confined to a poorly exposed meta-noritic body assumed to be about 15 x 40 m in outcrop. However, the high amount of amphibole in the rock indicates alteration of clinopyroxene rather than orthopyroxene (see Appendix 2). The mined length of the ore body is ca. 25 m whereas the width of rich ore varies between 0.25 and 1 m in outcrop (Vogt 1892, p. 17). The ore body was mined from a 23 m long, up to 4 m high and 5 m wide horizontal cutting with an entrance immediately east of the Lilleåga River (Figures 43, 44).

In the central part of the open pit there is a 4.5 m deep vertical shaft with a cross section of 3 m x 5 m. It gives entrance to underground galleries extending to a depth of 19 m below the sole of the cutting and for more than 14 m along the strike of the ore zone (Figure 45). The latter is also intersected by short transverse drifts (Henriksen 1897,1898, Puntervold 1910, Flood 1941).

Figure 44. a) Left picture showing the cutting viewed towards the east. The dark area in the lower central part is the water-filled entrance to the underground gallery. **b)** The cutting viewed towards the west. The white area in the upper central part is the reflection from the water surface on the sole of the cutting.

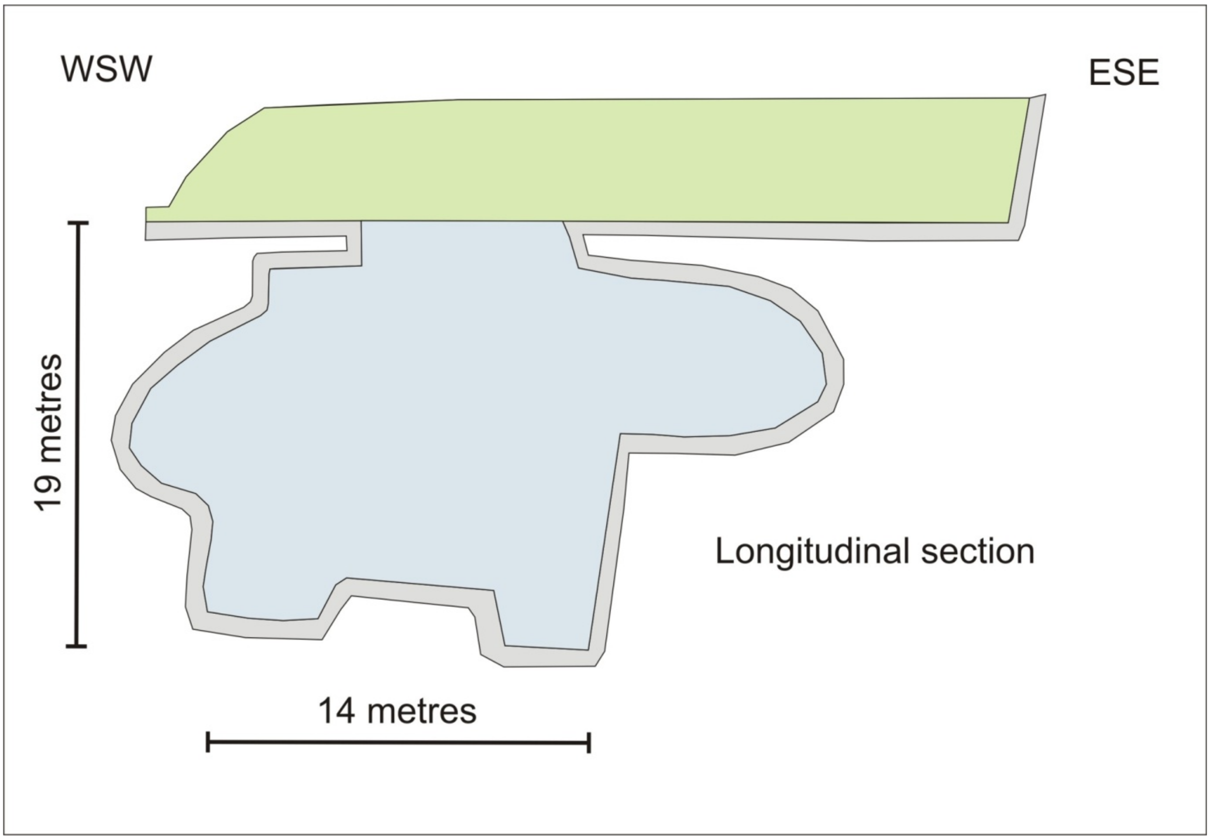

Figure 45. Sketch of the longitudinal section of the Lilleålegden mine. The light green area represents the cutting and the light blue area the underground, now water-filled, gallery. Based on the not-to-scale drawing given by Rosenlund and Borthen (1916).

On the bottom sole of the underground gallery the width of the zone carrying rich ore has been measured as 15 - 70 cm in the western part, but only 1 - 10 cm in the eastern part (Henriksen 1897, 1898), indicating a possible plunge of the ore body (bodies) towards the west. At a point 5 m to the east of the cutting's eastern end, a shallow 15 m-long exploration trench has been driven to the NW, across the area, cutting through the NE part of a gabbro (Henriksen 1898; Rosenlund and Borthen 1916). Recent inspection has shown that this is not the ore-bearing gabbro but a separate, barren amphibolite body. During the mining period the miners noted that the ore seemed to be concentrated in a number of connected or disconnected minor massive ore lenses (Flood 1941). Several shallow exploration trenches have been dug through the moraine down to in-situ bedrock in the area around the mine but these do not show sulphide ore or even gabbroic host rocks (Figure 46 and 48). All these shallow and very irregular test trenches show metapsammites only, according to Rosenlund and Borthen (1916, p. 3-4). This may indicate that these "wild-cat" trenches were made at an early stage of the exploration.

Figure 46. Collapsed and strongly vegetated exploration trench in the extreme northeast part of the mining area.

The ore consists of pyrrhotite-pentlandite-chalcopyrite, some millerite (NiS) (Holmsen 1932) plus accessory titano-magnetite or magnetite. The gangue contains amphibole as a major mineral (>10 %) plus subordinate (1-10 %) pyroxene, biotite and quartz, the latter partly as nodules, as well as accessory garnet (< 1%). Holmsen (l.c.) further mentions hypersthene, labradorite and anorthite as the main constituents of the host intrusive, indicating a possible noritic composition for the rock.

Neither modern exploration efforts, including airborne geophysics, (e.g. Löfberg 1971a,b, Band 1977) nor general bedrock mapping (Brattli and Tørudbakken 1987, Gjelle 1980) have revealed additional mineralized norite lenses of similar type in the Beiarn - Beiardalen area.

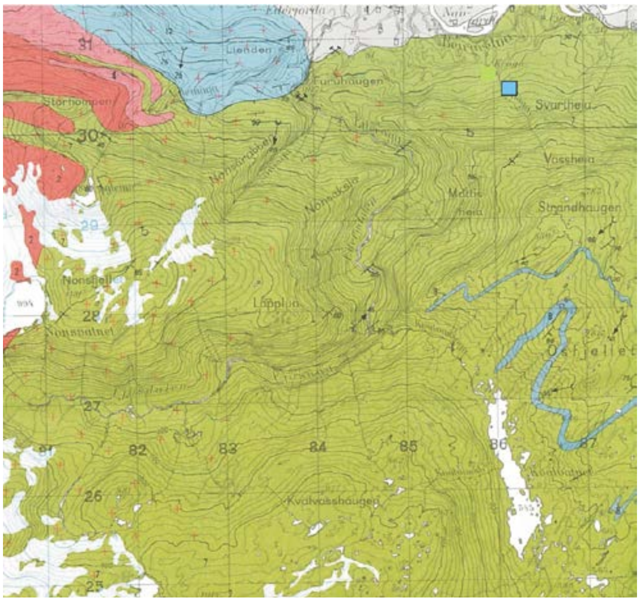

Figure 47. Bedrock map showing the location of the Lilleålegden deposit (blue square) in the Govddestind Nappe structurally overlying the Sokumfjell marbles (12) of the Beiar Nappe. The Govddestind Nappe is composed predominantly of dark garnetiferous mica schist alternating with light grey quartz-muscovite schist (7) and scattered units of calcite marbles (8) and amphibolites. The red areas in the northwest represent red porphyritic granites of the Høgtind pluton (2) and tonalites (pink 4). Segment of the bedrock map made by Brattli and Tørudbakken (1987).

4.2.2 Geological setting

The deposit is situated within the Govddestind Nappe in the uppermost part of the Rødingsfjell Nappe Complex in the UmA (Figures 2 and 31). The Govddestind nappe is situated above the Beiar Nappe from which it is separated by the Habresåga Nappe (Brattli and Tørudbakken, 1987). The thrusts separating these nappes are truncated by the Høgtind granite intrusion which yielded a nine-point Rb/Sr isochron of 440 ± 30 Ma, i.e. early Silurian (Tørudbakken and Brattli, 1985). This indicates that the amalgamation of the nappes occurred prior to the emplacement of the granite batholith which was deformed during the Scandian orogenic phase of continent-continent collision at about 425 Ma.

The Govddestind Nappe is composed of mm- to several metre- thick bands and zones of mainly dark grey two-mica schists and light grey quartz-muscovite schists containing subordinate units of calcite marbles, amphibolites and banded psammites (Figures 47 and 48).

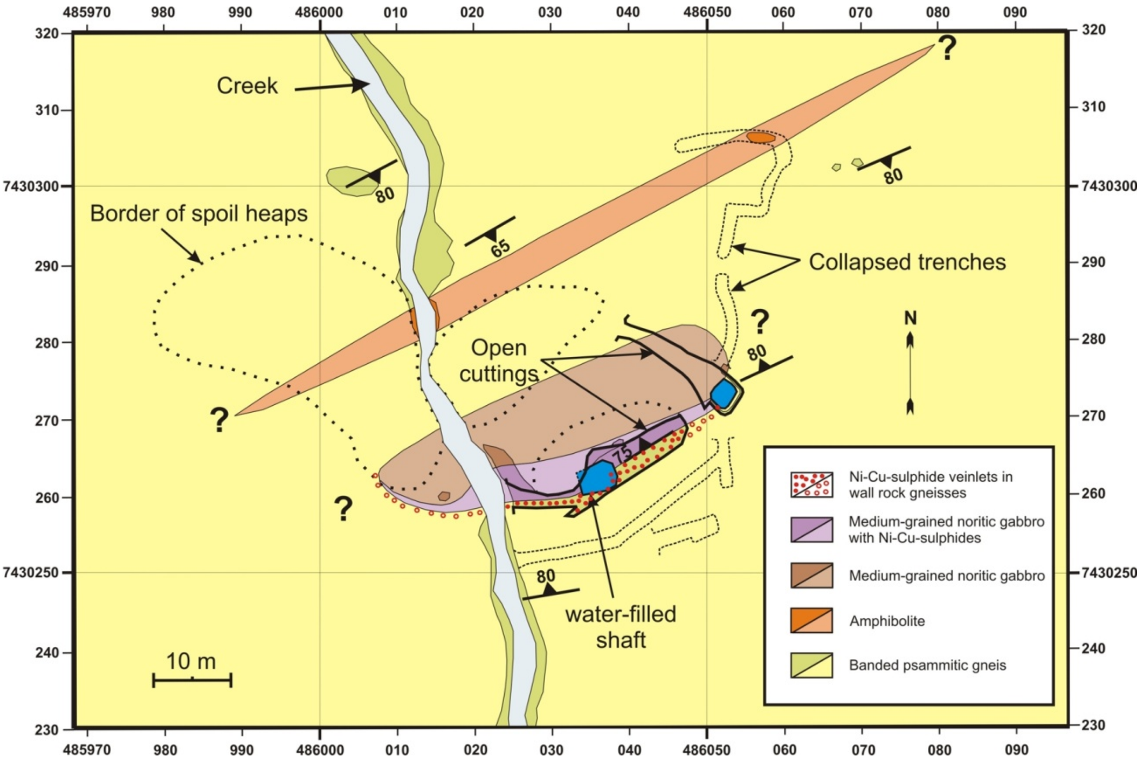

Figure 48. Geological map of the Lilleålegden mining field. Dark colours shown on the left half of the rectangles in the legend and in the drawing represent exposed rocks in contrast to the pale colours to the right representing till-covered rocks. The outline of the poorly exposed gabbroic intrusion is drawn according to the statement by Rosenlund and Borthen (1916) that the trenches only showed psammitic gneisses.

4.2.3 Ore geology

The deposit is confined to a gabbroic intrusion which outcrops over a distance of about 45 m along strike and 10 m across strike (Figure 48). The poorly exposed intrusion is possibly lens-shaped (15 m wide and 45 m long) and occurs parallel to the NE-SW striking and steeply dipping dark grey wall-rock gneisses (Figure 49). The Ni-Cu mineralisation is located in the south-eastern contact zone of the NW-dipping body striking 70°ENE that appears to be situated in the hinge zone of an isoclinal synform. The sulphide-bearing part of the medium-grained (2-5 mm) gabbro has a characteristic grey colour whereas the barren part of the gabbro contains black mafic aggregates interstitial to light grey plagioclase laths. With the exception of some narrow zones along the contact of the gabbro, where a faint foliation is developed, both gabbro types generally show an isotropic texture in contrast to the 4 m wide amphibolite zone northwest of the gabbro. The amphibolite which is conformable with the banding in the psammitic wall rocks is composed of foliation-parallel stripes of feldspar and amphibole. This relationship is important since it shows that the formation of the Ni-Cu mineralisation occurred subsequent to the deformation of the amphibolites and at a late stage in the tectonomagmatic evolution of the Goddvestind Nappe. The gabbro was possibly emplaced coeval with the granite batholith plutons towards the west where gabbros also occur (Figure 31).

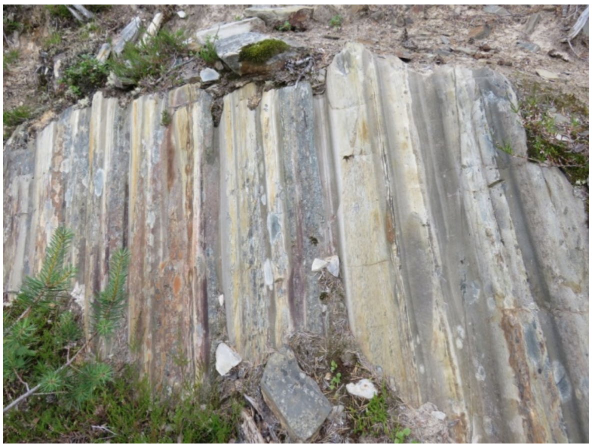

Figure 49. a) The left picture shows fine-grained diffusely banded siliceous biotite gneiss at the creek 20 m below the mine entrance; **b)** The right picture shows fine-grained banded (1-10 cm wide) dark and light grey psammitic gneiss and schist on the tractor road at 100 ma.s.l. (Figure 42). The gneisses dip steeply to the southeast.

Sampling for ore geochemistry has shown that the richest mineralisation in the deposit occurs along the steep foot-wall contact of the gabbro where it comprises coarse-grained massive to semi-massive sulphide ore with a high Ni-content (Figure 50). Some of these massive sulphide ores have a cataclastic fabric ("durchbewegt") caused by fragments of hydrothermal quartz and wall-rock gneisses engulfed in the sulphide mass. The sulphide contents and the amount of visible, coarsely crystalline pentlandite decrease away from the contact. The mineralisation which is hosted by a grey medium-grained (2-3 mm), altered gabbro comprises, along the ore contact, a combination of massive segregations and veinlets, a dense intergranular network and strong dissemination of sulphides. Further away from the contact the mineralisation gradually becomes dominated by disseminated mineralisation and changes into weak dissemination and accessory sulphide when the mineralisation "dies out", about 4 m away from the contact towards the NW. The wall-rock gneisses carry up to cm-thick massive pyrrhotite-chalcopyrite-pentlandite veins both along and across the foliation, up to a distance of 2 m away from the contact of the intrusion.

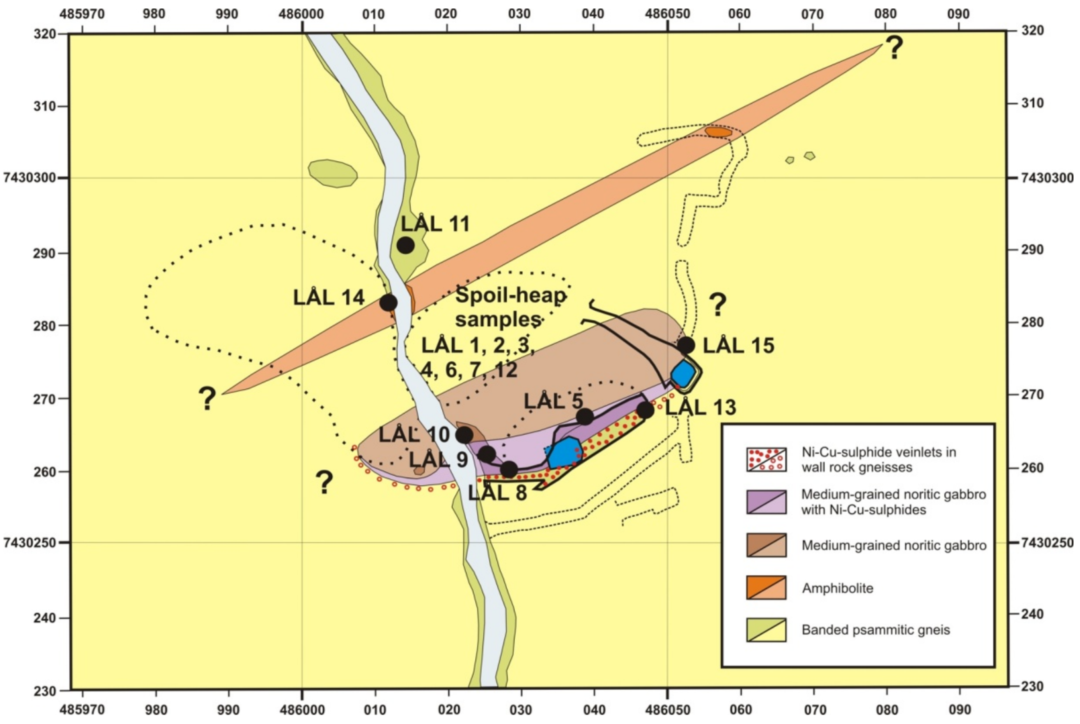

Figure 50. Geological map of the Lilleålegden mining area showing the locations at which samples were collected.

4.2.4 Preliminary assessment

The sulphide-mineralised zone is about 50 m long and 2.5-5 m thick, Parts of this zone, especially along the gabbro/gneiss contact carry mineralisation which is rich to extremely rich in Ni and Cu, but low in PGE. However, the exposed dimensions of the gabbroic intrusion and the ore zone are far too small to be of any economic interest. Since the area is totally covered in both strike directions an excavator would be needed to investigate possible extensions by digging trenches both along and across strike. Secondly, a gravimetric ground survey and an airborne TEM survey should be considered on the basis of the possible presence of a large, Ni-enriched, dense mafic-ultramafic body at depth. The accessible part of the deposit is, however, so extraordinarily rich in nickel that it, together with the minor, but possibly genetically similar nickel occurrences at Måløy and Høgsetdalen, deserves a thorough scientific study regardless of theinitial assessment of its economic potential. It is enigmatic that such a rich ore body (or clustering of minor ore lenses) is hosted by such a seemingly small volume of an Mg-poor and olivine-free mafic host rock. It is well worth focusing on the uncommonly efficient nickel-enrichment process(es) involved in this case.

4.3 The Måløy mineralisation

The mineralisation occurs in the cliff above the shore of a small bay at the SE side of the island Måløya which is located off the coast of Steigen about 60 km N of Bodø. Other names and spellings used for the mine include Moløen, Maalø, Måløy, Stegen, Steigen, Lædingen and Store Fugleberg. The grass-covered and poorly forested island is 1 km wide and 3.5 km long in a SW-NE direction (Figure 51). A number of abandoned farms are found in the central part of the island where the farm houses are now used for vacation purposes. The main harbour on the island is situated on the north-western side ca. 1.7 km north-east of the mine along the foot path (Figure 51). The nearest harbour on the mainland, in Steigen municipality, is Nordskot where a boat can be hired. From the quay at Måløya a grass-covered tractor road can be followed due southwards for 700 m where the road turns west after passing a courtyard at a farm. After another 250 m the tractor road bifurcates. The road turning left and due westwards should be followed for exactly 300 m. Shortly, after passing a large sallow tree a vague foot path takes off into the grass towards the south. The foot path again becomes more distinct when approaching a small valley that leads down to the mine, which is located in a steep cliff at the sea shore (see Figure 52).

4.3.1 Present and previous work

Three days were spent on the island, including transport back and forth to the farm house on the island. One and a half day was devoted to mine surveying, geological mapping and sampling in the mine area and one day to reconnaissance on the geology elsewhere on the island. Sampling of the ore zone was difficult due to its smooth surface and the fact that the best parts were out of reach without a ladder. Most of the samples were collected at the 10 m x 20 m spoil heap outside the adit. The sample localities are shown in Figures 53 and 54.

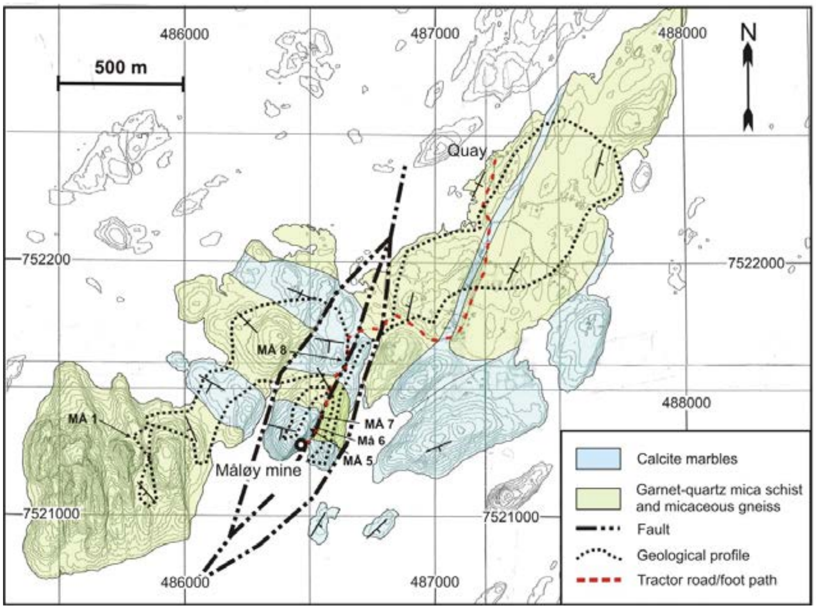

Figure 51. Geological sketch map showing the distribution of different lithologies met with and seen at a distance under the few regional profiles (dotted line) made on Måløya island. The red stippled line shows the tractor road and foot path from the quay to the mine. Partly based on Rekstad (1929) and Gustavson and Blystad (1995). Numbers (MÅ 1, etc.) refere to litho-samples. The locations of ore samples given in Figure 54.

Figure 52. The Måløy mine, located at the shore to the left, in a sequence of grey banded calcite marbles containing narrow and boudinaged dark grey amphibolites. Some of them are indicated by arrows. The mine openings comprise the entrances to the Lower drifts to the left, the Central adit (4 m high) and the Upper drifts to the right. The ore zone is recognized by the brown stain in the middle and upper parts of the drifts and adit.

The Måløy nickel ore body has long been regarded as an odd, genetically unusual marble-hosted mineralisation in several of the exploration reports and other geological literature. This is the case despite the fact that mine superintendents A.S. Bachke in 1884 and P. Mortensen in 1890-91 pointed to "gabbro" (and not marble) as the probable host rock of the ore, in Mortensen's case after he recognized blocks of gabbro-hosted nickel ore on the mine dumps.

The Måløy deposit was discovered in 1883 and contemporary analyses of the sulphide ore revealed a Ni content in the order of 5 - 6 %, a fact that immediately attracted much attention and local optimism. Test mining therefore commenced immediately and the district mine-superintendent, A.S. Bachke in his annual report for 1883 (DsC 1883), reported a 14 m-long adit mined along the strike of the ore body from which "abundant nice copper ore as well as Ni-bearing pyrrhotite ore has been mined". An analysis showing 8 % Ni is reported, but the width of this first mined ore was very variable, from stripes measuring just a few inches up to 0.5 m thick lenses.

More regular mining took place in 1884-86 when hand-sorted primary ore grading 7 wt.% Ni and secondary ore grading 2 wt.% Ni were produced from up to 1 - 1.5 m thick pyrrhotite ore lenses associated with 0.2 - 1 m thick chalcopyrite ore in the mine (DsC 1884-86). The ore zone was reported, in the bottom of the mine, to be 1.5 m thick, of which 0.80 m was massive pyrrhotite ore. The remaining 0.70 m must therefore have been sulphide-impregnated ore from which the hand-sorted secondary 2 % Ni concentrate was derived. This implies that the original ore body consisted of both massive Ni-Cu sulphide ore as well as disseminated Ni-Cu sulphides in a mafic host rock. It is interesting to note from the report that the ore in the bottom section of the mine gradually changed from pyrrhotite ore to pyrite ore. The mine therefore seems to have been forced to closure both due to problems with frequent flooding from the nearby sea, changes in ore composition (from pyrrhotite to pyrite ore), reduced ore grades and reduced widths of ore lenses. According to analysis of the most representative "general sample" of the first class, hand-sorted ore produced in 1884-86 this contained 5.60 % Ni and 0.61 % Co. Further, an equivalent analysis of the secondary hand-sorted ore showed 2.10 % Ni and 0.16 % Co, and finally, 17 tons of hand-cobbed copper ore showed as much as 14.19 % Cu in the general analysis (Schütz and Hasselbom 1891, Vogt 1902, p. 9). Total production from the Måløy deposit (1883, 1884-86 and 1897-98) was probably somewhat more than 100 tons according to old reports. About 2/3 of this tonnage was calculated as first class ore according to the reports from the mine superintendents.

The ore zone on Måløy attracted new attention during the German occupation 1940-45 (anonymous 1942(?)) and later during a nickel exploration campaign in the 1970s that included both geological, geophysical and geochemical surveys as well as two "Winkie" drill holes in 1973 (Band 1977). The outcome of the latter seems to have been limited and did not result in any follow-up activities.

Altogether some 5-600 m^3 of rock, plus ore, was mined from small, but fairly complex underground workings comprising several short, but interconnected adits, drifts and sinks (Figures 52, 53 and 54). Mortensen (1890, 1891) gives, in two reports from his inspection journey in 1890, detailed information about the mining activities and the field occurrence of the ore within the mine.

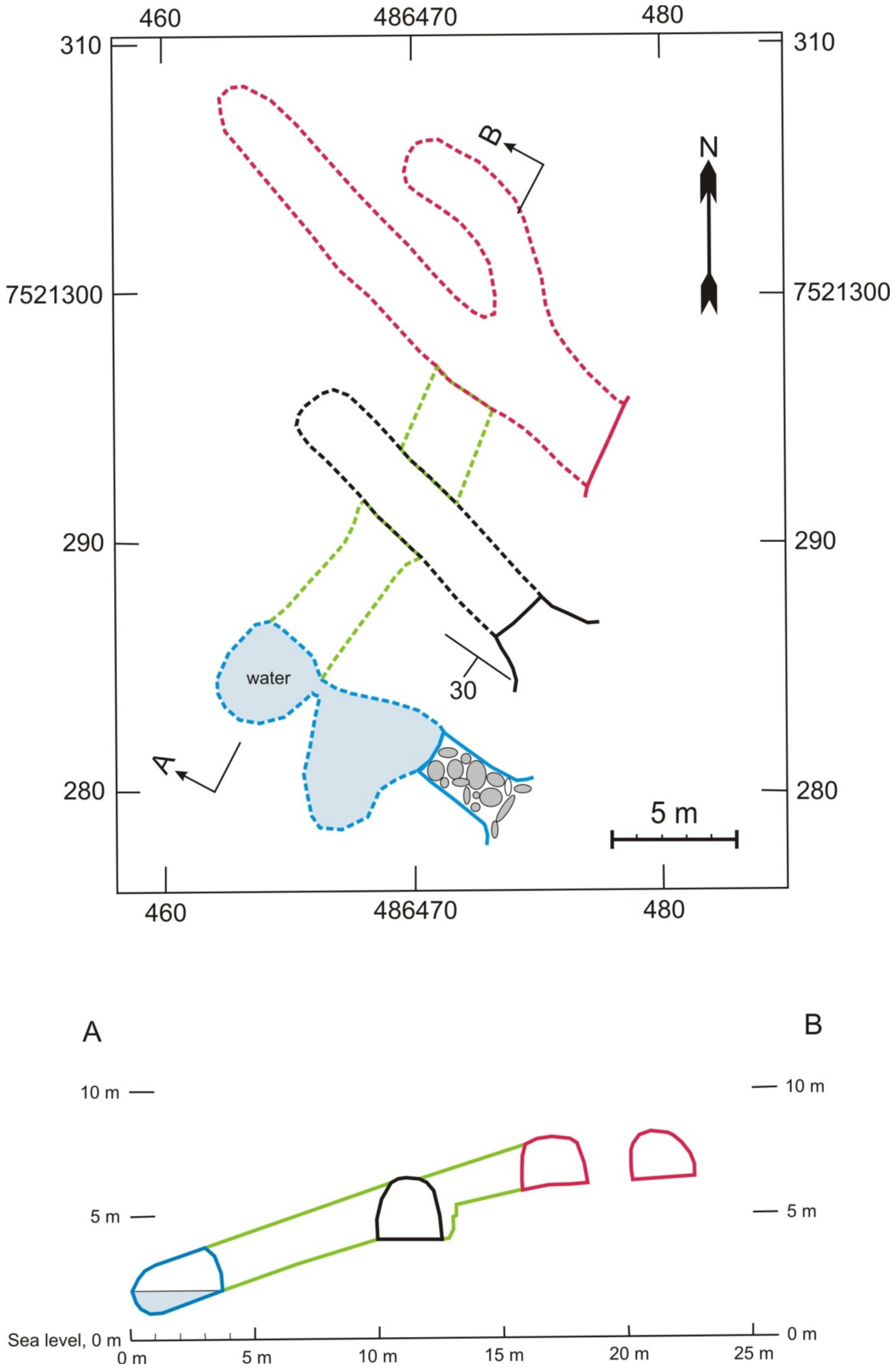

Figure 53. Horizontal projection of the Måløy mine together with a vertical section along the western wall of the inclined shaft in the lower part of the figure. Green lines show the location of the inclined shaft connecting the Central adit with the Lower (blue line) and Upper drifts (red line). Stippled lines in the horizontal projection represent underground workings whereas full lines show the location of cuttings at surface.

The ore can be followed ca. 20 m along strike and 25 m along dip, where it typically occurs as minor ore lenses and irregular globules (for example 30 x 100 cm and 18 x 60 cm respectively) probably interconnected by thin strips of ore (1 - 5 cm thick). The ore zone is roughly concordant along both dip and strike with the enclosing calcite marble which dips 25-30° to the SSW. Mortensen (1890) calculated the ore acquired from the last mining period (based on the remaining ore at the dump as well as the total amount of rock excavated) to some 65 tons of ore grading 5 wt. % Ni, i.e. the remaining ore at the dump constitutes ca. 2.5% of the total excavated amount of ore and wall rock.

According to E. Flood (1942) the hand-sorted (first class) Måløy nickel ore bears a strong visual resemblance to the equivalently treated Lilleålegden nickel ore. A number of analyses carried out on high-grade ore showed ore-grades at a level of 6 - 7 wt-% Ni with some additional Cu and Co.

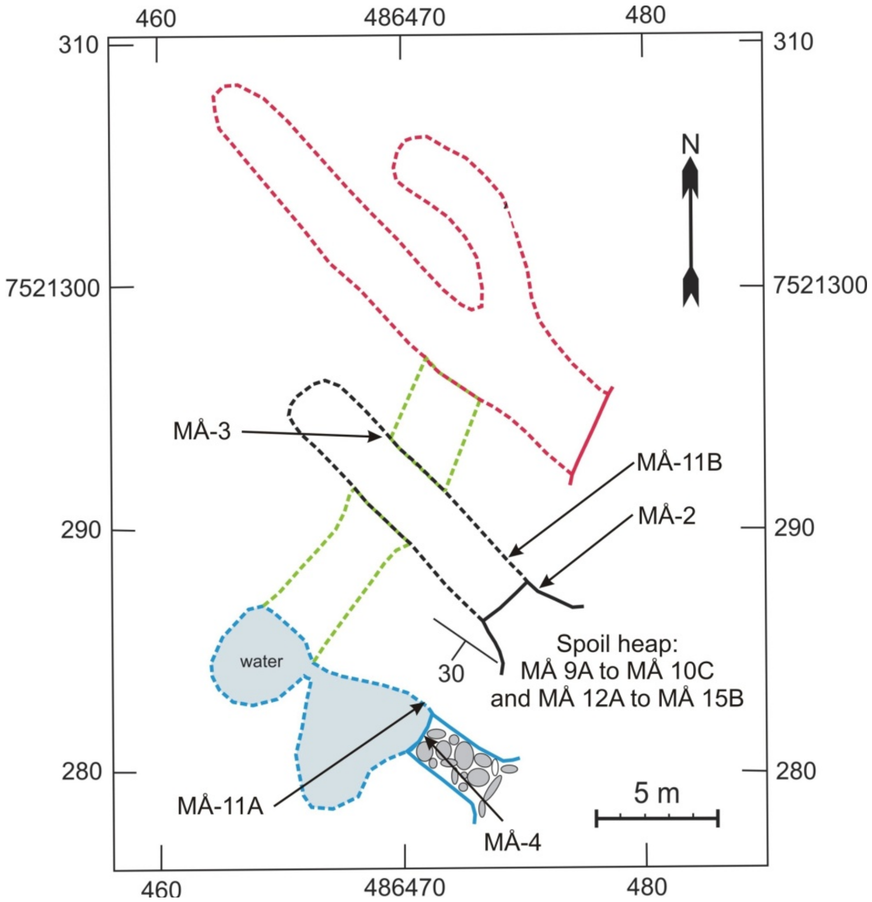

Figure 54. Horizontal projection of the mine with the location of collected samples (e.g., MÅ 4).

It should further be noted that patchy, "fist-sized" Ni mineralisation has been observed "here and there" in the vicinity of the mine and further away on the island, but nowhere in such concentrations that it has attracted further attention (Dahl, 1895; Flood, 1942). It should also be mentioned here that similar "carbonate-hosted" Ni mineralisation has been discovered in "Harstadhavn" in Trondenes, but this discovery was inaccessible to the mine superintendent during his visit to the place in 1885 according to his annual report for that year.

4.3.2 Geological setting

The deposit is situated in marbles of the Meløy Group a short distance above the basal thrust of the Rødingsfjell Nappe Complex of the UmA (Figure 55). The thrust separates granitic basement gneisses of assumed Paleoproterozoic age from structurally overlying meta-sedimentary rocks which represent the bedrock on the island. The bedrock is predominantly composed of different types of pelitic and semi-pelitic micaceous schists and gneisses that are commonly garnetiferous and locally migmatitic. They carry a few thick units of banded calcite marbles which are characterised by the presence of conformable units of amphibolite (Figures 52 and 56). There are, on Engeløya island off the northern coast of Steigen towards Vestfjorden, a number of gabbroic intrusions in the Meløy Group meta-sedimentary rocks (Rekstad, 1929; Gustavson, 1996).

4.3.3 Ore geology

The ore zone is developed in pale-grey banded calcite marbles which, in the mine area, contain abundant 0.01-0.5 m thick amphibolite units that are penetratively foliated, often necked and locally carrying thin neosome stringers. The up to 2 m thick ore zone occurs parallel with and sub-concordant to the banding in the marble which strikes/dips about N122°E/20-30°. The ore zone is about 25 m long and 15 m wide along dip and strike, respectively. It comprises a system of one or several gabbroic veins, millimetres to decimetres thick, carrying different proportions of sulphide, grading from nearly massive sulphides to weak dissemination. The abundance and thickness of the veins appear to decrease both up and down dip from the central adit and towards the WNW as shown in Figures 57, 58 and 59. The mineralised gabbros are weakly deformed and include types with an isotropic fabric as well as types showing signs of ductile shearing and local development of lineated gabbros and dykes showing chaotic folds related to ductile flow in the marbles (Figure 57).

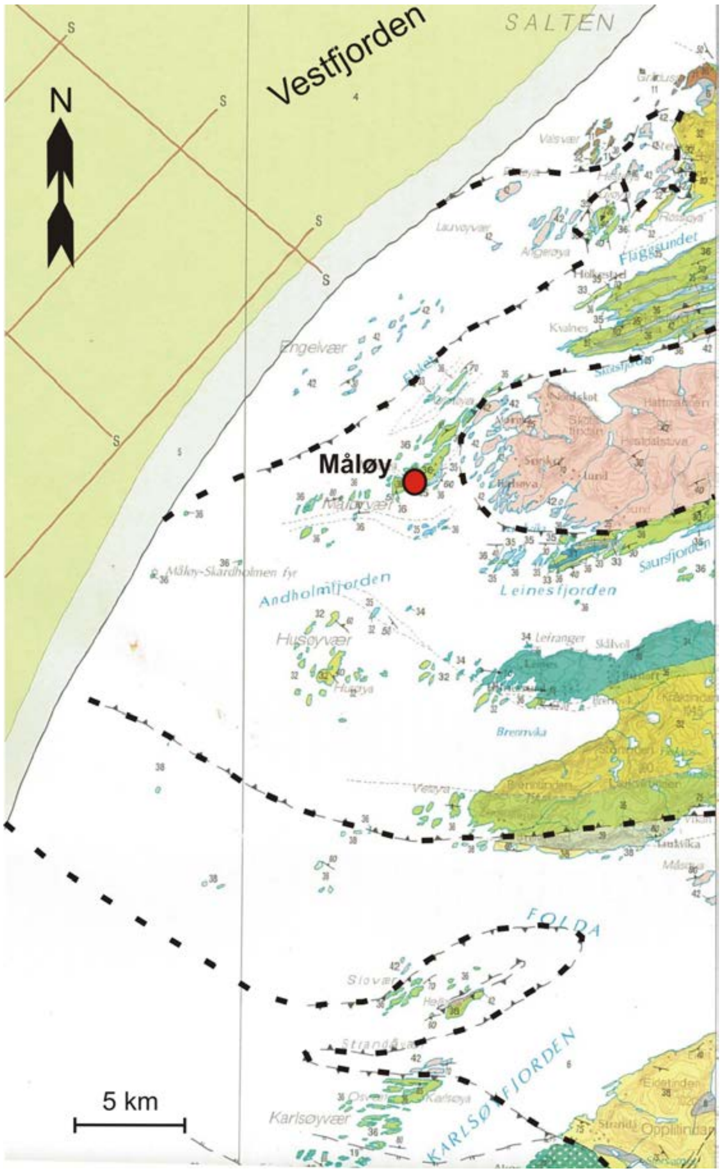

Figure 55. Geological map showing the location of the Måløy mine (red filled circle) in Steigen municipality between Vestfjorden and Bodø Town, 30 km south of the lower left corner of the figure. The Måløy deposit is hosted by marbles of the Meløy Group within the Rødingsfjell Nappe Complex of the UmA. The Meløy Group comprises different types of micaceous schist and gneiss (greenish, and more yellowish for quartz-feldspar rich types and more bluish for carbonate-bearing types) with narrow intercalations of marble (blue) and quartzite (yellow). Black stippled lines represent the basal thrust of the RNC separating the Meløy Group from the underlying Paleoproterozoic basement gneisses (greenish, 38, 39; pinkish, 42).

Figure 56. 2-10 m thick folded amphibolite zones (dark grey) in marbles (light grey) 200 m up dip (NNE) from the mine

Figure 57. The ore zone is composed of irregular pyrrhotite-rich gabbro dykes (10 cm thick) intruding laminated grey and beige-stained calcite marbles. The photo is from the roof of the Central adit at its entrance.

Figure 58. 5-10 cm thick linear gabbroic dyke with dissemination of Fe-Ni- and Cu-sulphides situated in the western wall of the inclined shaft between the Central adit and the Upper drifts, 12 m in from the entrance tothe Central adit. The dyke is roughly concordant with the banding in the grey marble. Notice the pronounced necking of the 10 cm thick amphibolite zone and the unnecked state of the about 2 m long mineralised gabbroic dyke.

Figure 59. The inner western wall (16 m in) of the Central adit where the ore zone has thinned out to a 1 cm thick vein of massive sulphides containing only minor silicates.

Bedrock mapping has shown that the formation of the narrow NE-SW-trending valley east of the mine is caused by a fault zone which is suggested by the dextral displacement of the border between mica schists and marbles (Figure 51). The marbles on the eastern side of the valley are characterised by containing only a few scattered amphibolite units when compared with the marbles on the western side around the mine where they occur abundantly as thin zones of necked amphibolites which become thicker and more voluminous on metre- to 10- metre scales as well being strongly folded (Figure 56). The limited thickness of the amphibolite zones, commonly down to a few centimetres, but commonly up to over 100 m in length, may indicate that the amphibolite units represent basaltic tuffs, rather than meta-gabbroic sills, possibly extending from a magmatic centre in the southern part of the marble zone shown in Figure 56.

4.3.4 Preliminary assessment

The Måløy nickel deposit is uncommonly rich in nickel and resembles in that context the Lilleålegden and possibly also the Høgsetdalen occurrences. This is particularly true in regard to the weak tectonothermal overprint on the gabbros in these occurrences when compared to the strongly foliated amphibolites in the wall rocks. It thus appears that the deposits which are associated with the gabbroic intrusions represent a late stage in the tectonomagmatic evolution of the Caledonides, i.e. possible in the early Silurian and coeval with the formation of the Råna layered intrusion and its Ni-Cu deposits,dated at 436.9 Ma(Tucker et al., 1990).

The ore zone is far too small to be of any economic interest but it carries high-grade ores of Ni and Cu as well as yielding moderately anomalous analytical values for Pt and Pd (Appendix 3). The vein-type gabbroic intrusion may be structurally bound and was possibly formed by emplacement of a mixed sulphide and silicate magma that ascended along the fault zone and migrated outwards along the strike of the deformed marble towards the west. If this points to the possible existence of a Ni-Cu-rich mafic source magma at depth this could be tested by gravimetric ground surveys and airborne TEM-type electromagnetic investigations.

5. OCCURRENCE IN ULTRAMAFIC AMPHIBOLITES

Amphibolites containing more than 90 volume % metamorphic amphibole are termed ultramafic amphibolites. They are rather uncommon and may represent metamorphosed pyroxenitic intrusions or meta-volcanites of komatiitic or picritic composition. One example found in the UmA is the Steinåga occurrence situated in Beiardalen valley (Figure 2).

5.1 The Steinåga mineralisation

The deposit is located on a densely forested mountain slope about 300 m due east of the bridge across Beiarelva River. The bridge is reached about 600 m south of Steinåmoen farm in Beiardalen Valley (Figures 2 and 60). It is reached by following a densely vegetated tractor road starting about 50 m north of the bridge. The tractor road should be followed for about 200 m along the eastern side of the Beiarelva River and up along the northern side of the tributary Steinåga River until a NE-trending cleft is reached (Figure 60). Turn left and follow the top of the NE-trending ridge along the north-western side of the cleft (which represents an old river valley, Gammelsteinågafaret gully). The terrain becomes flatter after 200m along the rather steep ridge and the valley turns towards the east. Continue to the NE for another 80 m before reaching the pit in an area covered by ablation till and large boulders between large pine trees and clusters of birch trees.

5.1.1 Present and previous work

The deposit was found according to the description given in the NGU Ore Database. The free text of the latter also contains a description of other mineralised amphibolites occurring on the banks of Steinåga River and in the Gammelsteinågafaret Gully. Those at Steinåga River were found during the present survey but could only be seen at a distance since they were inaccessible due to flooding of the river.

The host rock is an ultramafic amphibolite lens concordant with its host mica-schist. Extensive trenching has been carried out through thick ablation moraine cover some 200 m down the valley slope beneath the pitting site.

According to Bugge (1907), extracting from the mine superintendents' annual reports for the period 1901-1905, pitting has occurred on the farm Leiråmo in Beiarn on a pyrrhotite - chalcopyrite mineralisation occurring in garnet-rich portions of an amphibole schist. It continues as a sulphide-impregnated band along strike, passing Steinåmo to Kjeldsåslet ca. 3 km to the NNE.

Skofteland and Færden (1969), with the help of a local guide, managed to find four of the sulphide mineralised locations, all of them situated within a few hundred metres from the confluence of the stream Steinåga with the River Beiarelva (= River Storåga). The area is strongly covered by tallus (boulder field), partly with very large blocks. The following sub-areas are presented:

Loc. 1) The stream, Steinåga, cuts through a 3 m thick, N-S striking and steeply eastward-dipping gabbro lens which is rusty ("rust burned") with stripes of sulphide and graphite (Black circle in Figure 60). The adjacent wall rocks are muscovite schist to the east and chlorite schist to the west.

Loc. 2) A steep wall with an impregnation zone is located 50 m to the east of Loc. 1. From west to east: gabbro - 0.5 m greenstone, 1.5 m impregnation zone and finally muscovite mica schist. The steeply dipping zone strikes N-S.

Loc. 3) There is, in a cutting near Steinåga, 50 m west of Loc. 1, a 0.5 - 1 m thick rusty and garnetiferous zone in a metagabbro with amphibolite on its footwall side.

Loc. 4) Ca. 125 m north of Loc. 1 there is a cutting showing alternating gabbro and amphibolite, both partly rusty, but none of them are "particularly rusty". Some serpentinite was also located there, but it could not be determined if this was in situ bedrock or very large boulders. If the latter is the case serpentinite would also occur "in situ" higher up on the steep slopes towards the east.Skofteland and Færden (l.c.) concluded, from this, that a follow-up investigation in this terrain would involve great difficulties and that it was therefore not worth following up the rust zones based on the quality of the four locations examined. They suggested, however, a follow-up study searching for mafic and ultramafic rocks in the area.

Band (1977, p. 8-9), referring to this area, wrote that the series of small sulphide showings extends from the farm Staupåmo in the SSW to the farm Kjeldåslett in the NNE, a distance of 4.5 km on the eastern side of the upper part of Beiardalen. He further wrote that the mineralisation appears to be confined to a gneiss horizon in the dominant mica schists. The main period of exploration activity in this area was around 1910, the target, then beingcopper. The company A/S Sulitjelma Gruber was active in the area in the period 1971-1974 according to Band (l.c.). Three handpicked samples from the main showing at Steinåga showed quite low assays: 0.02, 0.09 and 0.45 % Ni and 0.15, 0.09 and 0.17 % Cu respectively. Stream sediment samples, mostly collected from the streams draining the western side of the valley did not give anomalous results (ca. 20 ppm Ni). It was possible to sample only a very limited number of streams draining the east side of the valley. These showed higher values (ca. 60 ppm Ni), but this probably reflects the influence of the more mafic gneiss horizon according to Band (l.c., p. 9 and fig. 11).

In contrasting to the above report, Søyland-Hansen and Harrison (1975), in their field report and reconnaissance map to A/S Sulitjelma Gruber, emphasised a massive greenstone as the chalcopyrite-pyrite ore-bearing rock and don't mention gabbro at all. In the mineralised zones the greenstones appear as coarse-grained garnet amphibolites in which garnet may constitute up to 50 % of the rock in addition to some olivine and biotite. In addition Søyland-Hansen and Harrison (1975) show, on their 1:5,000 scale map, several serpentinite outcrops as bosses as well as more elongated bodies spread out on both sides of the Steinåga stream and near the farm Steinåmo. They have, in addition, mapped the lower part of the Steinåga stream in great detail along two continuous sections. They have, if their map is correct, contributed significantly to understanding of the geology (lithology) of the Steinåmo area. The serpentinite bodies, conformable with the enclosing schists and occurring at several levels of the stratigraphical succession, contain both coarse-grained, fibrous talc as well as olivine in a fine-grained black ground mass. Søyland-Hansen and Harrison (1975) also measured 3 VLF-test profiles, but with negative results.

5.1.2 Geological setting

The Steinåga deposit is confined to a zone of ultramafic amphibolites situated in the Stabbursdal Group in the lower part of the Beiar Nappe inside the Rødingsfjell Nappe Complex of the UmA (Figures 2 and 43). The isoclinally folded country rocks which are dominated by micaceous schists and gneisses contain narrow units of dominantly calcite marble and alkaline granitic gneiss (Figure 61; Brattli and Tørudbakken, 1987). The micaceous schists and gneisses are partly banded and migmatitic and contain zones and bands rich in garnet, kyanite and staurolite as well as locally Fe-sulphides. The upper part of the Stabbursdal Group where the mineralisation are found comprise abundant lenses and layer parallel units of serpentinites and ultramafic amphibolites, commonly garnetiferous.

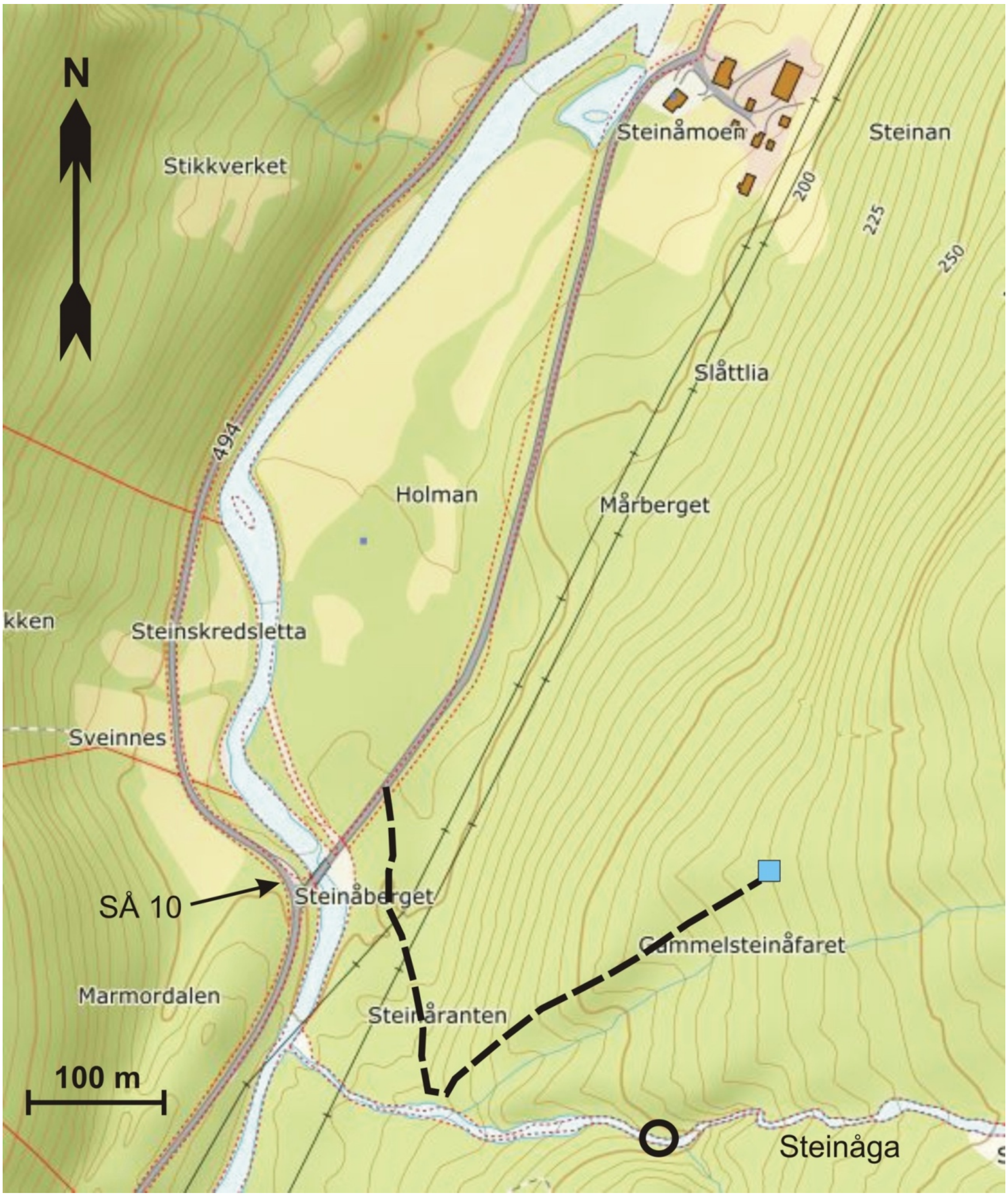

Figure 60. Topographic map showing the location of the Steinåga deposit (blue filled square) and the area with narrow amphibolite zones (open black circle, Skofteland and Færden,1969). The best route to the deposit is shown with a stippled line. SÅ 10 is the location of a sample of rusty banded micaceous meta-psammite.

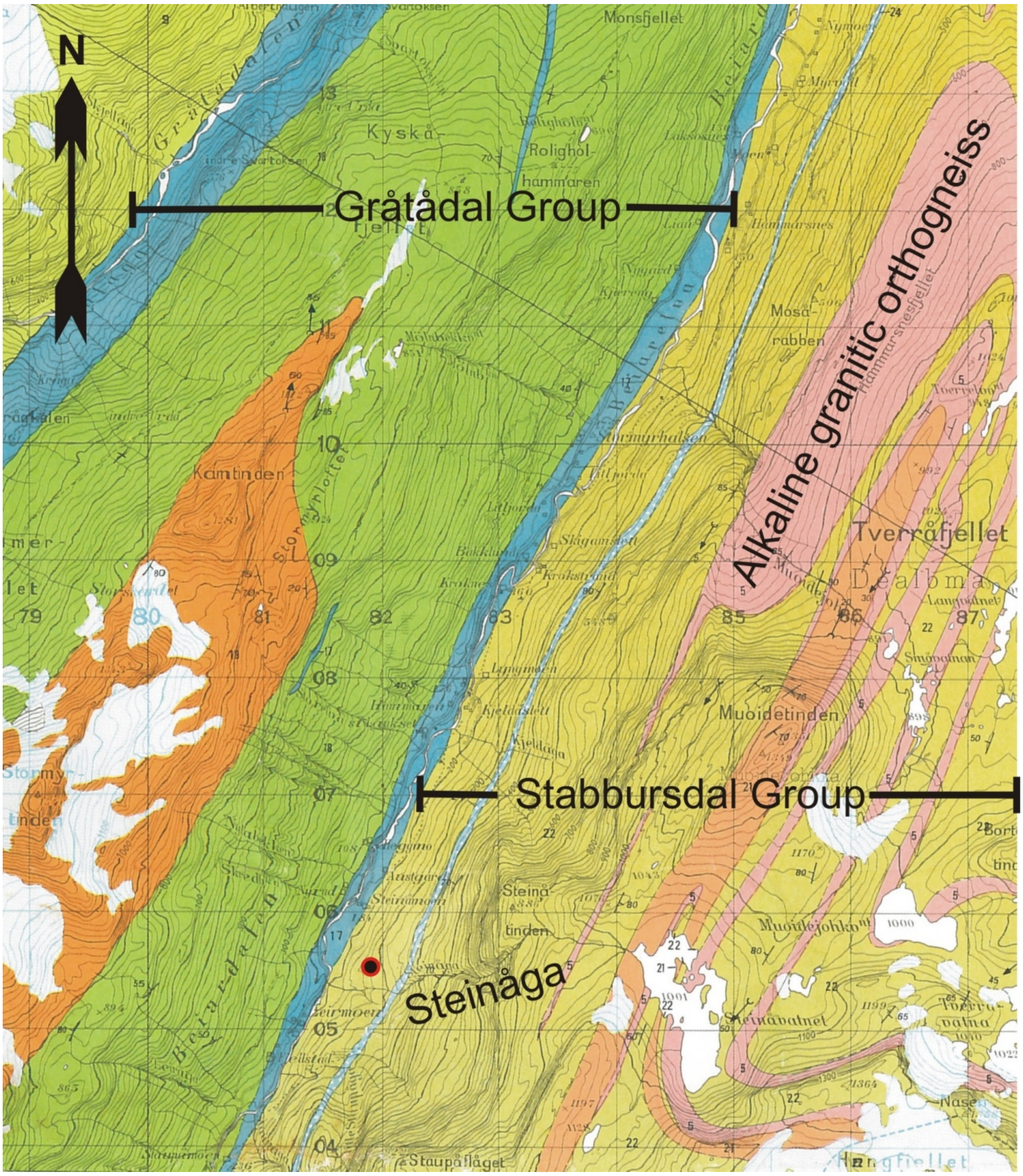

Figure 61. Geological map showing the setting of the Steinåga deposit (black filled circle with red rim). Lithologies: Greenish = micaceous schist and gneiss (18, 22), Orange = mica gneiss, banded gneiss and augen gneiss and Bluish = predominantly calcite marble.

5.1.3 Ore geology

The mineralisation occurs in the central part of a 500 m wide amphibolite-serpentinite belt which is bordered by marbles in the uppermost part of the Stabbursdal Group in Beiardalen valley (Søyland-Hansen and Harrison, 1975). The mineralised ultramafic amphibolite occurs in an area with few outcrops and those that are exposed occur around the margin of the water-filled pit. The pit which is 1-2 m deep to the water table is five-sided or sub-circular with a diameter of about 5 m (Figure). A small outcrop of quartz-muscovite schists occur 2 m north of the pit margin showing that the mineralised ultramafic rocks strikes NE-SW and dips moderately to the SE (N70°E/40°). The ultramafic rocks are only exposed along the margin of the pit, especially in its north-eastern and south-eastern walls. Except for the small outcrop of mica schist in the north no outcrops are found outside the pit. The ultramafic unit must thus exceed 5 m in width. It has a fabric which is banded on a cm - dm scale due to alternating bands of fine-grained ultramafic amphibolite and bands composed of randomly oriented coarse-grained hornblende crystals (5-15 mm long), locally altered to chlorite or intergrown with biotite. The fine-grained bands are locally garnetiferous and may contain up to 20 cm wide bands of massive reddish garnetite. The coarse-grained ultramafic bands are possibly formed by a late recrystallisation of the fine-grained type due to influx of metamorphic fluids post-dating the dominating ENE-trending fabric. Both of these ultramafic rocks carry dissemination of pyrrhotite and minor chalcopyrite with grain sizes varying with the grain size of the host rock. The fine-grained ultramafic bands also carry semi-massive sulphide stringers and veins parallel to the foliation.

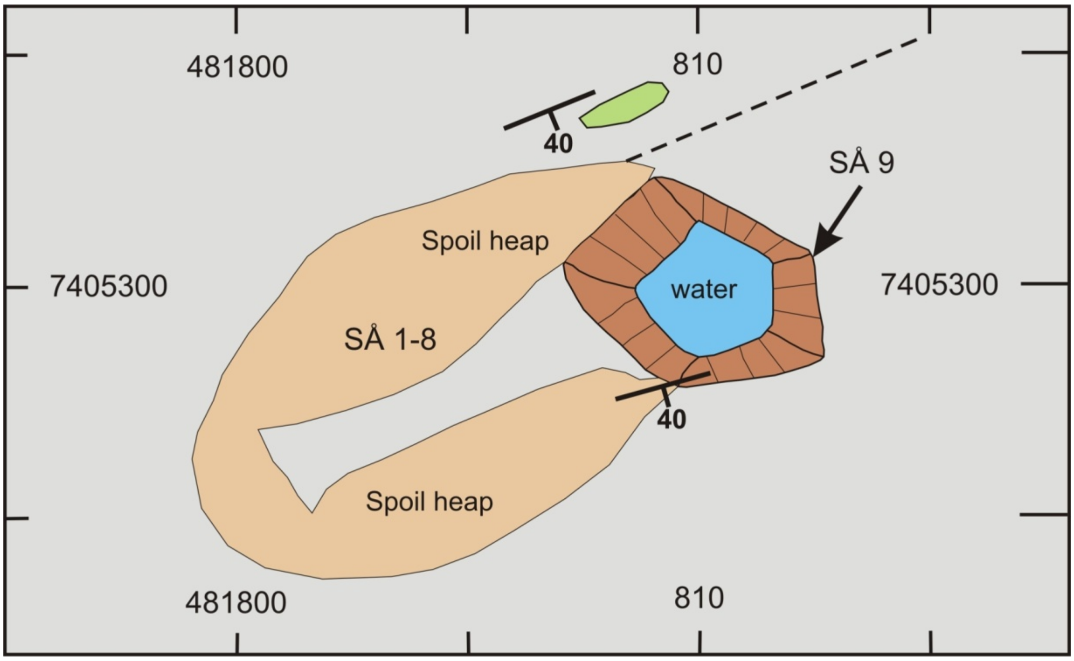

Figure 62. Water-filled pit on the Steinåga deposit showing the location of collected samples. Scattered outcrops of amphibolites (brown) on the inclined walls of the pit and one small outcrop of mica schist (light green) in the ablation till (grey). UTM EUREF 89 coordinates in metres. East coordinates on the X axes.

5.1.4 Preliminary assessment

The mineralisation is generally far too low in Ni and Cu (both ≤ 0.11 wt. %) to be of economic interest. In addition, it may represent an epigenetic mineralisation hosted by a hydrothermally altered fine-grained amphibolite which would not be expected to carry Ni-rich ores. However, prospecting for pyrrhotite and chalcopyrite hosted by amphibolites has, according to Bugge (1907), been conducted over a distance of 2.5 km in the Stabbursdal Group between Kjeldåslett and Leiråmo north and south of the Steinåga mineralisation, respectively. Given that the Lilleålegden deposit, which is very rich in Ni, occurs in similar country rocks it cannot be excluded that the amphibolite-bearing micaceous schists and gneisses may contain more interesting types of Ni-mineralisation. This is suggested by the work by Søyland-Hansen and Harrison (1975) who defined a number of other localities with mineralised garnetiferous and ultramafic amphibolites, as well as elongated to stock-shaped intrusions of serpentinite which, at one locality, contain inclusions of mica schist. Thus it appears that the serpentinised meta-peridotites may represent intrusions rather than dismembered ophiolite-type mantle peridotites. These intrusions may be part of the belt of pyroxenites and peridotites that can be followed from Misværdal via Tollådalen to south of Steinåga where large bodies of similar rocks are marked on the 1:250 000 Mo i Rana (see Figure 2 and 4.1.4 Tverrbrennfjellet; Gustavson and Gjelle, 1991).

It would, in order to reach a firmer conclusion regarding the ore potential of the Stabbursdal Group, be appropriate to make a two-day traverse along the Steinåga River and others running through the Stabbursdal Group in order to sample sulphide-bearing mafic-ultramafic units. In addition, the 1:5,000 scale outcrop map compiled by Søyland-Hansen and Harrison (1975) should be carefully assessed in the field, with sampling of all sulphide-bearing units..

6. CONCLUSIONS

The surveyed Ni-Cu occurrences within the project area are all located within the Uppermost Allochthon of the Scandinavian Caledonides as shown in Table 1. The individual mineralisations can be subdivided into different types according to their host rocks including ophiolite-type ultramafic rocks (Utvikåsen, Markafjellet and Esjeholmene), ultramafic intrusions (Tverrbrennfjellet), gabbroic intrusions (Høgsetdalen, Lilleålegden and Måløy) and ultramafic amphibolites (Steinåga). Prior to the initiation of the project it was clear that the generally high degree of exposures in Nordland would not favour the possible discovery of economic deposits at the surface among investigated mineralised areas and occurrences (in brackets above). Nevertheless the project members thought it was important to initiate the collection of field data and rock samples for a long-term and up-to-date scientific investigation and modelling of the ore-forming processes in order to evaluate the possible presence of blind ore bodies or previously overlooked potential.

In addition, the definition of both economically interesting and uninteresting mineralisation would give important information to those involved in land use planning both at the municipality level and at higher administrative levels, e.g. various land protection planning like national parks.

The assessment of the economic potential of the individual mineralisations is, of course, preliminary since it is solely based on geological parameters and bulk ore chemical data from the NGU Ore Database. A full evaluation has to await mineralogical and chemical analyses of the ores and igneous rocks, including analyses of Ni-Cu-PGE contents in the sulphide phase.

Presently, the most interesting mineralisation occurs associated with variably serpentinised and then prograde metamorphosed mantle peridotites at Markafjellet in Brønnøy municipality. These large, low-grade peridotite bodies which are widespread in the Velfjord-Tosen district, and possibly also in the Bindal district, should be followed up if the analyses of the collected samples yield positive analytical values for Ni. The generally small, but rich Ni-Cu mineralisations associated with gabbroic intrusions at Høgsetdalen, Lilleålegden and Måløy are, as such, of no economic interest. However, it appears that they represent intrusions of a special Ni-rich magma possibly composed of a mixture of two immiscible melts, i.e. silicate and Ni-sulphide rich melts which were possibly extracted from an external Ni-rich mafic-ultramafic source magma. If such an external magmatic body exists at depth it can be tested by gravimetric ground surveys in the area around the mineralisation.

The mineralisation in the ophiolite-type ultramafic rocks at Utvikåsen and Esjeholmene, together with those associated with ultramafic intrusions and amphibolites at Tverrbrennfjellet and Steinåga, have, respectively, either too small dimensions and/or too low nickel grades to be of any economic interest. However, the possibilities of finding blind ore bodies in these mining fields cannot be totally excluded and will certainly increase as the geophysical, geological and geochemical surveys proceed.

7. PLANS FOR FURTHER WORK

Dependent on the results of the forthcoming chemical analyses and ore petrographic work the following mineralisations appear, so far, to have revealed the need for follow-up work.

- Mantle peridotites in the Velfjord-Tosen Nappe Complex: The Skogsrudkrysset body should be systematically sampled for sulphide analyses. In addition, other sizeable bodies of peridotite known to occur between Velfjord and Tosenfjord as well as further north to Rødøy should be surveyed for sulphides and sampled.
- Høgsetdalen: Re-sampling of the mineralisation and search for other outcrops of mafic-ultramafic rock along the shores of Sørfjorden in Gildeskål.
- Lilleålegden: Re-sampling the mineralisation and search for other outcrops of mafic-ultramafic rocks along creeks in the mountain side.
- Måløy: Sampling, with improved equipment, of the mineralised gabbroic dykes in the presently inaccessible parts of the mine. Secondly, to make a bedrock map of the island and sampling of the main rock types for lithogeochemical and petrographic studies, as well as for petrophysical measurements (e.g. density) needed for the modelling of gravimetric data. Finally, the marble units should be searched for other occurrences of Ni-pyrrhotite ores which, according to old reports, should exist outside the mine area.
- Gravimetric surveys should be conducted in the areas covering the mineralisations at Høgsetdalen, Lilleålegden and Måløy.

- Steinåga: A short survey of outcrops of ultramafic rocks along tributaries to the Beiarelva river and the outcrops shown on the map given by Søyland-Hansen and Harrison (1975). This is done to get a clearer picture of the ultramafic rocks and mineralisation described in the report by Søyland-Hansen and Harrison (1975).

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Appendix 1. List of nickel ore and rock samples collected during the field season 2017. The samples are listed in numerical order (NGU No.) with locality,field no., UTM coordinates and sample description.Available in excel format on request.

NGU No	Locality	Field No	UTM coordinates (WGS 84) Zone 33		Sample description
			X	Y	
194001	Lille Esjholmene, W, outcrop	NO-ES-17-1	394158	7382665	**Metapsammite**, massive, rel. fine- to medium-grained Plag-(Bt) dominated rock. Very fine-grained dissem. of po-(ptl)
194002	Lille Esjholmene, W, outcrop	NO-ES-17-2	394149	7382659	**Enstatite(?)** as radiating fan with radius ca. 10 cm, associated matrix mass of forsterite, talc and magnesite
194003	Lille Esjholmene, W, outcrop	NO-ES-17-3A	394171	7382671	**Magnesite** in 5 cm wide vein, greyish, with mm-size black chlorite lists
194004	Lille Esjholmene, W, outcrop	NO-ES-17-3B	394171	7382671	**Metaperidotite**, medium-grained (1-5 mm), greenish grey with 3-7 mm phlogopite flakes
194005	Store Esjholmen, outcrop	NO-ES-17-4	394924	7382473	**Enstatite-forsterite** rock, medium- to coarse-grained, dark greyish green with 0,5-1 cm tremolite laths
194006	Store Esjholmen, outcrop	NO-ES-17-5	394914	7382478	**Enstatite-forsterite** rock, medium-to coarse-grained, dark greenish grey, with subordinate, fine-grained tremolite
194007	Store Esjholmen, outcrop	NO-ES-17-6	394918	7382472	**Contact-zone min. assembl**. of banded black/brownish weathered rock of black amphibole (Hbl) + green smaragdite (Act-Tr)
194008	Store Esjholmen, outcrop	NO-ES-17-7	394918	7382472	**Forsterite-amphibole** rock, brownish weathered
194009	Store Esjholmen, outcrop	NO-ES-17-8	394918	7382472	**Meta-clinopyroxenite**, represents strongly amphibole-altered clinopyroxenite, medium-gr., black, occurs in two varieties
194010	Store Esjholmen, outcrop	NO-ES-17-9	394896	7382479	**Forsterite**-dominated rock, dense, fine-grained, pale yellow-green, superimposed by fine-grained tremolite
194011	Store Esjholmen, outcrop	NO-ES-17-10A	394863	7382486	**Meta-clinopyroxenite**, medium-grained (1-2 mm), greygreen, repr. strongly Am-alt. clinopyroxenite, Am/Px ratio ca 5/1
194012	Store Esjholmen, outcrop	NO-ES-17-10B	394863	7382486	**Meta-clinopyroxenite**, DO, but less altered than 17-10A, slightly more Px than Am in sample, in addition ca. 8 % Olivine
194013	Gunnardalen, outcrop	NO-NFM-17-1	390670	7243546	**Meta-arenite,** massive, rel. fine- to medium grained Plag-(Bt) dominated rock. Very fine-grained dissemination of po-(ptl)
194014	Gunnardalen, outcrop	NO-NFM-17-2	390685	7243525	**Metadunite**, fine-gr., blackish-grey, prograde Fo-Tlc assembl. strongly repl. precursor Srp. Very fine-grained dissem. of po-ptl
194015	Gunnardalen, outcrop	NO-NFM-17-3	390611	7243667	**Serpentinite**, fine-grained, medium coke-grey, with opx-pseudomorphoses and other alteration minerals, sulphide dissemin.
194016	Gunnardalen, outcrop	NO-NFM-17-4	390614	7243747	**Gabbroic amphibolite**, foliated, blackish grey, strongly biotite-altered, Subordinate felsic veining, scarcity of visible sulphides
194017	Gunnardalen, outcrop	NO-NFM-17-5	390611	7243742	**Serpentinite**, fine-grained, coke grey, with cm-wide zones of disseminated opx crystals, much fine-grained sulphides
194018	Gunnardalen, outcrop	NO-NFM-17-6	390593	7243730	**Serpentinite**, fine-grained, greyblack, with 3-8 mm opx crystals, rich in fine-grained disseminated sulphides
194019	Skogrudkrysset, outcrop	NO-NFM-17-7	390041	7245398	**Serpentinite**, coke grey w. pale prograde forsterite aggreg., scattered 2-5 mm opx cryst., magnetite and rich in sulphides
194020	Skogrudkrysset, outcrop	NO-NFM-17-8	390107	7245424	**Forsterite** rock, fine- to medium-grained, greyish, with scattered enstatite crystals, scattered sulphide dissemination
194021	Skogrudkrysset, outcrop	NO-NFM-17-9	390164	7245334	**Metadunite**, equigranular, fine- to medium-gr. grey, metam. forsterite(Fo)-Srp-Tlc rich rock w. fine-gr. dissem. po-ptl
194022	Skogrudkrysset, outcrop	NO-NFM-17-10	390042	7245429	**Serpentinite**, massive, fine- to medium-gr.,w. scattered opx crysts, rich sulphide dissem, partly selectively Srp-hosted
194023	Skogrudkrysset, outcrop	NO-NFM-17-11	390086	7245204	**Serpentinite**, dense, fine-grained, coke-grey rock with sulphides on fine fissures and as even dissemination
194024	Skogrudkrysset, outcrop	NO-NFM-17-12	390082	7245238	**Serpentinite**, fine-grained, greyish black with scattered talc laths, rich fine-grained sulphide dissemination
194025	Utvikåsen, Main adit, dump	NO-UT-17-1	504723	7456286	**Talc-serpentine** altered non-magnetic metaperidotite, fine-grained, grey, schistose, with stripes and aggregates of chalcopy.
194026	Utvikåsen, Main adit, dump	NO-UT-17-2	504723	7456286	**Semi-massive po-ore** with dark gangue schlieren, unevenly distributed cp-stripes and -aggregates
194027	Utvikåsen,Prp. 1, dump	NO-UT-17-3	504746	7456283	**Semi-massive chalcopyrite-pyrrhotite-magnetite ore**, durchbewegt, partly with sulphides in cm amphibole bands
194028	Utvikåsen,Prp. 1, dump	NO-UT-17-4	504746	7456283	**Semi-massive po-dominated ore**, fine-grained, shear-deformed (ductile deformation) with felsic schlieren
194029	Utvikåsen,Prp. 3, outcrop	NO-UT-17-5	504 714	7456253	**Amphibole-veined breccia rock**, coarse-grained, with quite subordinate sulphides
194030	Utvikåsen, Point 1, outcr.	NO-UT-17-6	504744	7456258	**Fo-En metaperidotite**, bownish weathered, grey, medium-gr. rock w. coarser En porphyroblasts and scattered laths of Ath/Tlc
194031	Utvikåsen, Prp. 1, outcrop	NO-UT-17-7	504746	7456283	**Semi-massive po ore with cp stripes**, dark, shear deformed (schlieren deformed), partly in Am-rich zones

194032	Utvikåsen, Prp. 1, dump	NO-UT-17-8	504746	7456283	**Po-Cp-Mt rich ore**, durchbewegt texture, pale, fine-grained and dark grey striped, mm-banded
194033	Utvikåsen, Prp. 2, outcrop	NO-UT-17-9	504751	7456196	**Ultramafic amphibolite**, black, non-magnetic, without visible sulphides (black wall)
194034	Utvikåsen, Prp. 5, dump	NO-UT-17-10	504696	7456237	**Magnetite-rich reaction zone assemblage**: Mt-Ttn-Tlc-(Am)-(Chl)-(Px) assembl, fine-gr., strongly foliated with black schlieren
194035	Utvikåsen, point 2, outcrop	NO-UT-17-11	504691	7456278	**Talcified serpentinite**, fine-grained, pale greyish yellow-green
194036	Utvikåsen, Main adit, outcr.	NO-UT-17-12	504723	7456286	**Pyrrhotite schlieren ore**, shear-deformed, with pale fine-grained bands alternating with dark magnetite-rich bands
194037	Høgsetdalen, outcrop	NO-HØ-17-1	454758	7429903	**Muscovite schist**, medium-grained, pale grey with scattered biotite flakes, 0.5 cm fine-grained quartz bands
194038	Høgsetdalen	NO-HØ-17-2			*Sample missing*
194039	Høgsetdalen, outcrop	NO-HØ-17-3	454760	7429906	**Melanocratic schistose meta-gabbro, biotite-amphibole-bearing**, medium-grained (1-2 mm)
194040	Høgsetdalen, outcrop	NO-HØ-17-4	454760	7429905	**Melanocratic, weakly foliated, amphibole meta-gabbro** , 1-2 mm w. 0.1-1 mm white spots, mafic/felsic min.ratio ca. 80/20
194041	Høgsetdalen, outcrop	NO-HØ-17-5	454750	7429893	**Quartzite**, fine-grained, greyish white and rust spotted
194042	Høgsetdalen, outcrop	NO-HØ-17-6	454766	7429909	**Muscovite schist**, rusty brown with scattered biotite laths
194043	Høgsetdalen, outcrop	NO-HØ-17-7	454775	7429916	**Quartzite**, grey, fine-grained with rust-brown bands and muscovite-rich zones
194044	Høgsetdalen, outcrop	NO-HØ-17-8	454780	7429923	**Quartz-mica schist**, rust-brown, muscovite-rich
194045	Høgsetdalen, outcrop	NO-HØ-17-9	454789	7429933	**Quartzite** bands, fine-grained, greyish white, alternating with greyblack biotite-rich bands
194046	Høgsetdalen, outcrop	NO-HØ-17-10	454804	7429934	**Gneiss**, foliated, grey, fine-grained with scattered 1-2 mm garnet porphyroblasts
194047	Høgsetdalen, outcrop	NO-HØ-17-11	454108	7432761	**Dioritic gneiss** with 1-2 x 3-5 mm feldspar augen (porphyroblasts) and innermost biotite and epidote-altered feldspar
194048	Høgsetdalen, outcrop	NO-HØ-17-12	454258	7432723	**Dioritic gneiss**, grey with 1-2 x 5-8 mm feldspar augen and interstitial biotite
194049	Tverrbrennfjellet, dump	NO-TB-17-1	499263	7432107	**Serpentinite**, fine-grained, dark grey with diffusely delineated, irregularly shaped, pale orange areas
194050	Tverrbrennfjellet, dump	NO-TB-17-2	499263	7432107	**Olivine-pyroxenite**, partly amphibole-altered, Px crystals 2-5 mm with greygreen Am rim and interstitial po dissemination
194051	Tverrbrennfjellet, dump	NO-TB-17-3	499263	7432107	**Pyroxenite** with local dense dissemination and intergranular aggregates (1-3 mm) of po ± cp
194052	Tverrbrennfjellet, dump	NO-TB-17-4	499263	7432107	**Pyroxenite** with 3-8 mm Px crystals surrounded by Am-rim and interstitial po aggregates
194053	Tverrbrennfjellet, outcrop	NO-TB-17-5	499138	7432157	**Pyroxenite**, medium-grained, with some interstitial po between 1-3 mm pyroxene crystals
194054	Tverrbrennfjellet, outcrop	NO-TB-17-6	499019	7432134	**Pyroxene crystals** (3-10 mm), dark green, in greyish green, fine-grained matrix with some disseminated po
194055	Tverrbrennfjellet, outcrop	NO-TB-17-7	499167	7432095	**Amphibolite schlieren**, dark green, fine-grained (2-10 mm), unevenly distributed in pink fine-grained ground mass
194056	Tverrbrennfjellet, outcrop	NO-TB-17-8	499011	7432060	**Aplite**, texture, pink, fine-grained, undefined texture, black grid of veins and aggregate of amphibole
194057	Above upper Tverrb.fjellet, o.c.	NO-TB-17-9	499248	7432032	**D.O.**, but aplitic mass quite subordinate at the expense of dark 2-5 mm Am crystals clustered in 1-2 cm large aggregates
194058	Upper Tverrb.fjellet, East, o.c	NO-TB-17-10	499223	7432029	**Feldspar matrix**, medium-grained (1-2 mm), greyish green to pink, abundantly with black dots in dissemination (0.5 mm)
194059	Upper Tverrb.fjellet, East, o.c.	NO-TB-17-11	499223	7432029	**Olivine-pyroxenite**, medium-grained, dark green with 1-5 mm Px crystals with Am-rim against interstitial po+py aggregate
194060	Upper Tverrb.fjellet, West, o.c.	NO-TB-17-12	499208	7432031	**D.O.**, abundantly with up to 1 cm aggregates of py+po in retrogressed pyroxenite
194061	Upper Tverrb.fjellet, West, o.c.	NO-TB-17-13	499208	7432031	**D.O.**, but relatively scarcely occuring po in weakly retrogressed pyroxenite
194062	Steinåga, dump	NO-SÅ-17-1	481810	7405300	**Ultramafic amphibolite**, fine- to medium-grained, dark green with bands of randomised biotite, hornblende and talc in schlieren
194063	Steinåga, dump	NO-SÅ-17-2	481810	7405300	**Ultramafic amphibolite**, fine-grained, blackish green, foliated
194064	Steinåga, dump	NO-SÅ-17-3	481810	7405300	**Ultramafic amphibolite**, foliated with dark, semi-massive, fine-grained po-garnet band
194065	Steinåga, dump	NO-SÅ-17-4	481810	7405300	**Hornblende porphyroblasts** (3-10 mm), randomised in dark green bands, innermost po-dissemination and po-aggregates
194066	Steinåga, dump	NO-SÅ-17-5	481810	7405300	**Ultramafic band**, dark green, consisting of randomised hbl laths with some disseminated sulphides
194067	Steinåga, dump	NO-SÅ-17-6	481810	7405300	**Garnet band** (3-4 cm), consisting of red, fine-gr. Grt, against band consisting of randomised hbl (5-15 mm) w. interstit. Grt+po
194068A	Steinåga, dump	NO-SÅ-17-7A	481810	7405300	**Amphibolite**, selective cut of fine-gr. amphibolite in dark green, banded um of fine-gr. Am + med-gr. randomised Hbl (3-10mm)
194068B	Steinåga, dump	NO-SÅ-17-7B	481810	7405300	**Hornblende**, selective cut of med-gr Hbl + dark green, banded um of fine-gr amphibolite + med-gr randomised Hbl (3-10mm)
194069	Steinåga, dump	NO-SÅ-17-8	481810	7405300	**Pyrrhotite** as weak dissemination in ultramafic bands consisting of randomised hornblende (2-10 mm)
194070	Steinåga, outcrop	NO-SÅ-17-9	481812	7405301	**Ultramafic amphibolite**, fine- to medium-grained, schistose, scattered 1 mm garnets

194071	Beiarndalen, outcrop	NO-SÅ-17-10	481460	7405319	**Mica gneiss (psammite - semi-pelite)**, fine-grained, grey to dark grey, diffusely banded (1-2 cm)
194072	Lilleålegden, dump	NO-LÅL-17-1	486035	7430262	**Sulphide impregnation ore**, much po+cp as dissemination in medium-grained (1-3 mm) greyish, altered olivine-gabbro/norite
194073	Lilleålegden, dump	NO-LÅL-17-2	486035	7430262	**Sulphide impregnation ore**, fine-grained, greyish green mass of altered rock with net-vein textured and disseminated po+cp
194074	Lilleålegden, dump	NO-LÅL-17-3	486035	7430262	**Sulphide impregnation ore**, po-aggregates (1-3 mm) evenly distributed in dark grey gangue
194075	Lilleålegden, dump	NO-LÅL-17-4A	486035	7430262	**Gneiss-breccia ore**, sulphide veined, with dark grey, fine-grained fragments of semi-pelite, cf. sample LÅL-17-13
194076	Lilleålegden, dump	NO-LÅL-17-4B	486035	7430262	**Massive sulphide ore** (5-25 mm) without gangue. Mainly altered po (85 %), ptl/bravoite (15 %) with only minor cp
194077	Lilleålegden, outcrop	NO-LÅL-17-5	486039	7430267	**Metagabbroic rock**, fine-grained (1 mm), equigranular, greyish green, with weak dissemination of very fine-grained po
194078	Lilleålegden, dump	NO-LÅL-17-6	486035	7430262	**Gabbroic rock**, ophitic, fine- to medium-grained, equigranular, partly altered and without visible sulphides
194079	Lilleålegden, dump	NO-LÅL-17-7	486035	7430262	**Noritic chill zone**, fine-grained (1 mm), dark grey, with weak dissemination and net-veining pyrrhotite
194080	Lilleålegden, outcrop	NO-LÅL-17-8A	486027	7430261	**Gabbroic rock**, fine-grained, dark grey with relatively strong dissemination of single grains and aggregates of po+ptl
194081	Lilleålegden, dump	NO-LÅL-17-4C	486035	7430262	**Sulphidic quartz-breccia ore** with 1-10 mm glassy Qtz fragments
194082	Lilleålegden, outcrop	NO-LÅL-17-9	486025	7430262	**Metagabbroic rock**, melanocratic, amphibole-altered, even-grained (2 mm), grey with weak po-dissemination
194083	Lilleålegden, outcrop	NO-LÅL-17-10	486022	7430265	**Metagabbroic rock**, melanocratic, amphibole-altered, pale-colored, medium-grained (2-4 mm)
194084	Lilleålegden, outcrop	NO-LÅL-17-11	486014	7430292	**Psammitic gneiss**, schistose, fine-grained with cm wide darker bands enriched in biotite
194085	Lilleålegden, dump	NO-LÅL-17-12A	486035	7430262	**Net-vein textured ore**, fine-gr., dark grey gangue with intergranular net-vein textured mt+ptl as well as large cp segregations
194086	Lilleålegden, dump	NO-LÅL-17-12B	486035	7430262	**Sulphide dissemination**, dense dissemination of fine-grained po+ptl plus subordinate veins of cp in fine-grained grey gangue
194087	Lilleålegden, dump	NO-LÅL-17-12C	486035	7430262	**Metagabbroic rock**, medium-grained (1-3 mm) with disseminated grains and disseminated zones of po+ptl, 5 mm ptl
194088	Lilleålegden, dump	NO-LÅL-17-12D	486035	7430262	**Banded gneiss**, dark grey, fine-grained, with cm-wide amphibole-rich bands
194089	Lilleålegden, dump	NO-LÅL-17-12E	486035	7430262	**Metagabbroic rock**, medium-grained, with relatively much irregularly distributed po+ptl (1-2 mm)
194090	Lilleålegden, dump	NO-LÅL-17-12F	486035	7430262	**Metagabbroic rock**, medium-grained (1-2 mm), grey, with dense impregnation of po+ptl with some cp-filled fissures
194118	Lilleålegden, dump	NO-LÅL-17-12G	486035	7430262	**Massive sulphides** with dark ultramafic gangue as well as gneiss fragments
194091	Lilleålegden, outcrop	NO-LÅL-17-13	486047	7430268	**Psammitic gneiss**, grey, fine-grained, with zoned semi-massive sulphide veins (po-cp-ptl) parallel foliation in gneiss
194092	Lilleålegden, outcrop	NO-LÅL-17-14	486012	7430283	**Amphibolite**, plagioclase-striped, medium-grained with traces of garnet
194093	Lilleålegden, dump	NO-LÅL-17-15	486052	7430276	**Gabbroic rock**, medium-grained (1-2 mm), dark grey, weakly retrogressed, without sulphides
194094	Måløy, outcrop	NO-MÅ-17-1	485708	7521299	**Mica schist**, medium-grained with scattered 1 mm red garnets
194095	Måløy, outcrop	NO-MÅ-17-2	486475	7521288	**Calcite marble**, fine- to medium-grained, pale greyish, banded
194096	Måløy, outcrop	NO-MÅ-17-3	486469	7521294	**Amphibolite**, boudinaged, 3-4 cm wide in pinkish grey, fine- to medium-grained marble
194097	Måløy, outcrop	NO-MÅ-17-4	486471	7521282	**Garnet-amphibolite**, fine-grained, plagioclase-striped, with some mm-thick leucosome areas
194098	Måløy, outcrop	NO-MÅ-17-5A	486519	7521346	**Amphibolite**, fine- to medium-grained, feldspar striped
194099	Måløy, outcrop	NO-MÅ-17-5B	486519	7521346	**Amphibolite**, fine-grained, plagioclase-striped
194100	Måløy, outcrop	NO-MÅ-17-6A	486527	7521360	**Amphibolite**, fine striped with some 1-3 mm wide neosome veins
194101	Måløy, outcrop	NO-MÅ-17-6B	486527	7521360	**Amphibolite**, fine striped with some 1-3 mm wide neosome veins
194102	Måløy, outcrop	NO-MÅ-17-7	486541	7521389	**Amphibolite**, fine-grained, striped, with 1-3 mm garnet aggregates, no penetrative foliation
194103	Måløy, outcrop	NO-MÅ-17-8	486639	7521619	**Amphibolite**, distinctly lineated, rich in garnet (1-2 mm)
194104	Måløy mine, dump	NO-MÅ-17-9A	486470	7521291	**Metagabbroic** amphibolite, retrogressed, foliated, 1-2 mm grain size, with pyrrhotite-stripes
194105	Måløy mine, dump	NO-MÅ-17-9B	486470	7521291	**Amphibole pseudomorphs**, 2-5 mm grain size, dark green, with interstitial net-veining of po-aggregates
194106	Måløy mine, dump	NO-MÅ-17-9C	486470	7521291	**D.O.**, but richer in pyrrhotite
194107	Måløy mine, dump	NO-MÅ-17-10A	486470	7521291	**Ultramafic amphibolite**, foliated with 1-2 cm wide semi-massive po and cp dominated bands
194108	Måløy mine, dump	NO-MÅ-17-10B	486470	7521291	**Metagabbro**, melanocratic, weakly foliated with 1-3 mm prismatic amphibole aggregates and interstitial pyrrhotite
194109	Måløy mine, dump	NO-MÅ-17-10C	486470	7521291	**Semi-massive pyrrhotite ore**, with some dissemination of 1-3 mm prismatic amphibole aggregates
194110A	Måløy mine, outcrop	NO-MÅ-17-11A	486472	7521283	**Semi-massive sulphide mineralisation** with Pl-rich gangue. Unaltered po-ptl assemb. in veins and dissem. in calcite marble
194110B	Måløy mine, outcrop	NO-MÅ-17-11B	486472	7521283	**Calcite marble** with veins and dissemination zones of po, py and a little cp (clean cut marble)

194111	Måløy mine, dump	NO-MÅ-17-12A	486470	7521291	**Gabbro**, melanocratic, grain size 5-30 mm, with cm-wide zones of po and po+cp
194112	Måløy mine, dump	NO-MÅ-17-12B	486470	7521291	**Semi-massive ore**, po-dominated, with 0.1-0.5 mm amphibole crystals in fine-grained ultramafic amphibolite (1 mm)
194113A	Måløy mine, dump	NO-MÅ-17-13A-1	486470	7521291	**Pyrrhotite schlieren** in matrix dominated by amphibole prisms/-augen, occurring as 3-5 cm wide rust band in marble
194113B	Måløy mine, dump	NO-MÅ-17-13A-2	486470	7521291	**Calcite marble**, clean cut, (host rock to rust band in MÅ-17-13A-1)
194114	Måløy mine, dump	NO-MÅ-17-13B	486470	7521291	**Metagabbro,** grain size 1-5 mm, with abundant pyrrhotite aggregates interstitial to amphibole-aggregates
194115A	Måløy mine, dump	NO-MÅ-17-14A	486470	7521291	**Marble** with enclosed rust zone (in MÅ-17-14B)
194115B	Måløy mine, dump	NO-MÅ-17-14B	486470	7521291	**Rust zone**, medium-grained garnet(1-5 mm)-amphibolite with some disseminated pyrrhotite (in marble in sample MÅ-17-14A)
194116	Måløy mine, dump	NO-MÅ-17-15A	486470	7521291	**Amphibole aggregates**, prismatic, 1-3 mm grain size, in pyrrhotite matrix
194117	Måløy mine, dump	NO-MÅ-17-15B	486470	7521291	**Metagabbro**, with 1-3 mm prismatic amphibole aggregates and interstitial po aggregates

Appendix 2. Semi-quantitative mineral content in investigated samples of Cu-Ni sulphide ore and associated rocks from investigated occurrences. In addition to the listed minerals occurs minor to trace amounts of ilmenite, brucite, garnet and/or dolomite occur in several of the samples. Data in excel fomat is available up on request.

Location	Sample No.	Lithology	Ol	Srp	Brc	Tlc	Chl	Amf	Px	Qtz	Pl	Bt	Po	Cp	Mt	Tt	Ilm	Gt	Dol / Ank	Other
Esjeholmene																				
Lille Esjholmene, W, outcrop	NO-ES-17-2	**Pyroxene (enstatite?)** as radiating fan with radius ca. 10 cm, associated matrix mass of forsterite, talc and magnesite	2			2			95						1					
Store Esjholmen, outcrop	NO-ES-17-7	**Forsterite-amphibole** rock, brownish weathered	64	2		2		13	19											
Store Esjholmen, outcrop	NO-ES-17-8	**Meta-clinopyroxenite**, represents strongly amphibole-altered clinopyroxenite, medium-grained, black, occurs in two varieties	tc					80	17						3					
Store Esjholmen, outcrop	NO-ES-17-10A	**Meta-clinopyroxenite**, medium-grained (1-2 mm), greygreen rock, repr. strongly Am-alt. clinopyroxenite, Am/Px ratio ca 5/1						83	15						2					
Store Esjholmen, outcrop	NO-ES-17-10B	**Meta-clinopyroxenite**, DO, but less altered than 17-10A, slightly more Px than Am in sample, in addition ca. 8 % Ol	8	tc			3	40	47						2					
Markafjellet																				
Gunnardalen, outcrop	NO-NFM-17-1	**Meta-arenite,** massive, rel. fine- to medium-grained Plag-(Bt) dominated cover rock. Very fine-grained dissem of po						2	2	2	71	23								
Gunnardalen, outcrop	NO-NFM-17-2	**Metadunite**, fine-gr., blackish, prograde Fo-Tlc assembl. strongly repl. precursor Srp. Very fine-gr dissem. of po-ptl	65	19	6	7		2					1							
Gunnardalen, outcrop	NO-NFM-17-3	**Serpentinite**, fine-gr, medium coke-grey, with opx-pseudomorphoses and other alteration minerals, sulphide dissem.	77	2	tc	2	2	1	12				4							
Skogrudkrysset, outcrop	NO-NFM-17-12	**Serpentinite**, fine-grained, greyish black with scattered talc laths, rich fine-grained sulphide dissemination	45	23	3	14	5	5					5							
Utvikåsen																				
Utvikåsen, Point 1, outcrop	NO-UT-17-6	**Fo-En metaperidotite**, bownish weathered, grey, med.-gr. rock w. coarser En porphyrobl. and scattered laths of Ath/Tlc	48	tc		2	7		42						1					
Utvikåsen, Prp. 1, outcrop	NO-UT-17-7	**Semi-massive po ore with cp stripes**, dark, shear deformed (schlieren deformed), partly in Am-rich zones					11	56					11	2	17				3	
Utvikåsen, Prp. 1, dump	NO-UT-17-8	**Po-Cp-Mt rich ore**, durchbewegt texture, pale, fine-grained and dark grey striped, mm-banded						12					25	1	39				23*	
Utvikåsen, Prp. 5, dump	NO-UT-17-10	**Magnetite-rich reaction zone assembl.**: Mt-Ttn-Tlc-(Am)-(Chl)-(Px) assembl, f.-gr., strongly foliated with black schlieren		*tc*		*16*	*11*	*13*	*9*				*3*		*31*	*17*				
Utvikåsen, Main adit, outcr.	NO-UT-17-12	**Pyrrhotite schlieren ore**, shear-deformed, with pale fine-grained bands alternating with dark magnetite-rich bands				6	6	37	9				25	1	14					
Høgsetdalen																				
Høgsetdalen, outcrop	NO-HØ-17-3	**Melanocratic schistose meta-gabbro, biotite-amphibole-bearing**, medium-grained (1-2 mm)					5	64				31								
Høgsetdalen, outcrop	NO-HØ-17-4	**Melanocratic, weakly fol., amphibole meta-gabbro** , 1-2 mm w. 0.1-1 mm white spots, maf/fels min.ratio ca. 80/20						63		10	12	15								
Høgsetdalen, outcrop	NO-HØ-17-12	**Dioritic gneiss**, grey with 1-2 x 5-8 mm feldspar augen and interstitial biotite						10		24	52	10							Tc?	alkfsp 4
Tverrbrennfjell																				
Tverrbrennfjellet, dump	NO-TB-17-2	**Olivine-pyroxenite**, partly amphibole-altered, Px crystals 2-5 mm with greygreen Am rim and interstitial po dissem.	35	tc		1	5	32	22				5							
Tverrbrennfjellet, outcrop	NO-TB-17-6	**Pyroxene crystals** (3-10 mm), dark green, in greyish green, fine-grained matrix with some disseminated po				6	16	52	2	8	8	8								Tc rutil
Above upper Tverrb.fjellet, o.c.	NO-TB-17-9	**Aplite**, but aplitic mass quite subordinate at the expense of dark 2-5 mm Am crystals clustered in 1-2 cm large aggr.					8	40		3	38	7				4				

Upper Tverrb.fjellet, East, o.c.	NO-TB-17-11	**Olivine-pyroxenite**, medium-grained, dark green with 1-5 mm Px crystals with Am-rim against interstitial po+py aggr.	9			3	6	16	61				4	1						
Upper Tverrb.fjellet, West, o.c.	NO-TB-17-13	**Olivine-pyroxenite**, but relatively scarcely occuring po in weakly retrogressed pyroxenite	11			tc	2	20	63				4							
Steinåga																				
Steinåga, dump	NO-SÅ-17-4	**Hornblende porphyroblasts** (3-10 mm), randomised in dark green bands, innermost po-dissemination and po-aggr.					9	79		5			7						tc	
Steinåga, dump	NO-SÅ-17-5	**Ultramafic band**, dark green, consisting of randomised hbl laths with some disseminated sulphides					5	82		4	5					2	1		1	
Steinåga, outcrop	NO-SÅ-17-9	**Ultramafic amphibolite**, fine- to medium-grained, schistose, scattered 1 mm garnets					2	79		18							1			
Lilleålegden																				
Lilleålegden, dump	NO-LÅL-17-1	**Sulphide impregn. ore**, much po+cp as dissem. in medium-grained (1-3 mm) greyish, altered olivine-gabbro/norite				4	10	38	20				24	1						Valle-riite* 3
Lilleålegden, dump	NO-LÅL-17-3	**Sulphide impregnation ore**, po-aggregates (1-3 mm) evenly distributed in dark grey gangue					3	61			23	3	6			3	1			
Lilleålegden, dump	NO-LÅL-17-4A	**Gneiss-breccia ore**, sulphide veined, with dark grey, fine-grained fragments of semi-pelite, cf. sample LÅL-17-13								10			77							ptl 13
Lilleålegden, dump	NO-LÅL-17-4B	**Massive sulphide ore** (5-25 mm) without gangue. Mainly altered po (85 %), ptl/bravoite (15 %) with only minor cp											85							ptl 15
Lilleålegden, outcrop	NO-LÅL-17-8A	**Gabbroic rock**, fine-grained, dark grey with relatively strong dissemination of single grains and aggregates of po+ptl					9	71	7		1	4	6							ptl 2
Lilleålegden, outcrop	NO-LÅL-17-9	**Metagabbroic rock**, melanocratic, amphibole-altered, even-grained (2 mm), grey with weak po-dissemination					3	67		1	24	3								
Lilleålegden, outcrop	NO-LÅL-17-10	**Metagabbroic rock**, melanocratic, amphibole-altered, pale-colored, medium-grained (2-4 mm)					2	70	2	1	21	3								
Lilleålegden, dump	NO-LÅL-17-15	**Gabbroic rock**, medium-grained (1-2 mm), dark grey, weakly retrogressed, without sulphides						60		2	30	5		1		2				
Måløy																				
Måløy, outcrop	NO-MÅ-17-4	**Garnet-amphibolite**, fine-grained, plagioclase-striped, with some mm-thick leucosome areas						36		16	30	8				3	4	3		
Måløy mine, dump	NO-MÅ-17-10A	**Ultramafic amphibolite**, foliated with 1-2 cm wide semi-massive po and cp dominated bands					4	62		4	6	3	19	2						
Måløy mine, dump	NO-MÅ-17-10B	**Metagabbro**, melanocratic, weakly foliated with 1-3 mm prismatic amphibole aggregates and interstitial pyrrhotite					6	60	5	3	15	2	8							
Måløy mine, dump	NO-MÅ-17-10C	**Semi-massive pyrrhotite ore**, with some dissemination of 1-3 mm prismatic amphibole aggregates					5	49		7	14	2	23	tc						
Måløy mine, outcrop	NO-MÅ-17-11A	**Semi-massive sulph. min.** with Pl-rich gangue. Unaltered po-ptl assemb. in veins and dissem. in calcite marble								4	18		60							ptl 18
Måløy mine, dump	NO-MÅ-17-12A	**Gabbro**, melanocratic, grain size 5-30 mm, with cm-wide zones of po and po+cp					3	40	6	4	17	5	21	4						
Måløy mine, dump	NO-MÅ-17-13A-1	**Pyrrhotite schlieren** in matrix dominated by amphibole prisms/-augen, occurring as 3-5 cm wide rust band in marble					tc	52	4	8	6	6	20	1						
Måløy mine, dump	NO-MÅ-17-14B	**Rust zone**, med.-gr. garnet(1-5 mm)-amphibolite with some disseminated pyrrhotite (in marble in sample MÅ-17-14A)					3	21		29	16	4		3		10		14		
Abbreviations used in the table:																				
Ol: olivine, Srp: serpentine, Tlc: talc, Qtz: quartz, Bt: biotite,Po: pyrrhotite,	Brc: brucite, Cp:chalcopyrite	Chl: chlorite, Amf: amphibole, Px: pyroxene, Pl: plagioclase Mt: magnetite, Tt: titanite, Ilm: ilmenite, Gt: garnet, Dol: dolomite,																		
Ank: ankerite, En: En: enstatite,	Hbl: hornblende	Alkfsp: alkalifeldspar																		

Appendix 3. Content of Ni, Cu, Co, Zn, Fe, S, Pt, Pd and Au in mineralised samples from investigated Ni-Cu occurrences. Data from NGU's Ore database and from Boyd & Nixon (1985). Samples sorted by decreasing S content for each deposit. Data from several of the Råna deposits included for comparison. Finally the average grades for the 43 million metric tons of the Bruvann deposit given by Mathiesen and Boyd (2017).

DBORE		wt-%	wt-%	wt-%	wt-%	wt-%	wt-%	ppb	ppb	ppb
DEP_NAME	SAMPLE_NO	Ni %	Cu %	Co %	Zn	Fe%	S%	Pt	Pd	Au
Ni-Cu-(Co) mineralisation in gabbroic intrusions										
Lilleålegden	Boyd and Nixon 1985	**5,50**	0,80				30,25			
Lilleålegden	NO0550.07	**2,00**	1,91	0,04	0,00	16,15	13,85	26	60	25
Lilleålegden	NO0550.08	0,85	5,85	0,03	0,01	13,53	13,04	124	163	44
Lilleålegden	NO0550.06	**2,26**	0,26	0,05	0,00	16,17	12,68	16	25	12
Lilleålegden	NO0550.05	**2,45**	2,12	0,06	0,00	13,90	12,59	141	49	19
Lilleålegden	NO0550.03	0,73	1,48	0,02	0,01	11,13	6,02	19	94	207
Lilleålegden	Boyd and Nixon 1985	0,90	0,30				4,25			
Måløy	Boyd and Nixon 1985	**5,50**	0,28	0,11			36,60			
Måløy	Boyd and Nixon 1985	**3,00**	0,40	0,08			15,70			
Måløy	NO0477.01	**2,31**	3,68	0,05	0,01	18,03	10,02	95	184	60
Måløy	NO0477.02	**1,93**	0,72	0,04	0,01	15,79	8,75	235	72	7
Høgsetdalen	NO0561.03	**1,24**	0,32	0,03	0,01	12,17	8,62	**1010**	146	43
Høgsetdalen	NO0561.04	**1,20**	0,16	0,03	0,00	11,17	8,39	10	131	7
Høgsetdalen	NO0561.01	0,53	0,41	0,01	0,01	6,36	4,14	4	115	9
Høgsetdalen	NO0561.02	0,57	0,15	0,01	0,00	6,38	3,91	42	48	5
Ni-(Cu)-(Co) mineralisation in ultramafic intrusion (pyroxenite)										
Tverrbrennfjellet	NO0549.11	**1,22**	0,19	0,07	0,00	13,72	10,61	8	11	7
Tverrbrennfjellet	NO0549.10	0,58	0,28	0,03	0,00	8,32	6,54	6	17	1
Tverrbrennfjellet	NO0549.05	0,34	0,10	0,02	0,00	6,39	3,91	6	3	2
Tverrbrennfjellet	NO0549.09	0,43	0,11	0,02	0,00	8,76	3,82	4	7	3
Low base metal mineralisation in ultramafic amphibolites										
Steinåga	NO0021.03	0,11	0,11	0,04	0,00	33,51	25,77	3	83	6
Steinåga	NO0021.02	0,04	0,55	0,02	0,01	15,45	10,12	3	8	9
Steinåga	NO0021.01	0,02	0,08	0,01	0,01	7,71	3,82	4	11	15
Co-Cu-Ni-Zn-Fe-S mineralisation associated with altered mantle peridotite										
Utvikåsen	NO0548.07	0,78	0,55	0,48	0,04	43,68	29,06	5	4	4
Utvikåsen	NO0548.05	0,50	0,86	0,29	0,06	42,62	21,50	4	6	12
Utvikåsen	NO0548.04	0,49	0,54	0,32	0,07	42,41	21,41	6	7	6
Utvikåsen	NO0548.08	0,44	0,70	0,26	0,25	37,24	17,09	12	10	8
Utvikåsen	NO0548.09	0,30	0,34	0,19	2,03	33,26	13,49	15	4	4
Utvikåsen	NO0548.06	0,27	0,22	0,16	0,12	46,60	11,87	3	3	2
Utvikåsen	NO0548.10	0,24	0,50	0,16	0,03	16,60	10,16	53	3	8
Utvikåsen	NO0548.03	0,18	0,27	0,10	0,17	31,56	7,79	6	6	3
Utvikåsen	NO0548.12	0,11	0,18	0,05	0,02	13,55	3,95	7	4	3
Utvikåsen	NO0548.02	0,14	0,10	0,05	0,05	15,61	3,85	5	6	3
For comparison:										
Various Råna Ni-Cu-Co ore deposits										
Sukkertoppen	NO0259.01	0,72	0,16	0,11	0,00	32,90	15,90	3	32	9
Eiterdalen	NO0320.03	**1,10**	0,16	0,09	0,00	24,29	15,15	4	13	2
Råntindaksla	NO0307.02	0,35	0,22	0,08	0,00	18,53	12,52	-3	5	9
Eiterdalen	NO0320.01	0,52	0,20	0,04	0,00	12,22	9,18	-3	6	3
Raudfjellet	NO0260.01	0,31	0,27	0,06	0,00	17,50	7,96	3	49	7
Råntindaksla	NO0307.01	0,21	0,16	0,05	0,00	12,16	7,61	62	12	18
Storvatnet	NO0261.01	0,23	0,16	0,06	0,00	13,80	6,74	3	16	12
Eiterdalen	NO0320.04	0,26	0,07	0,03	0,00	9,68	5,34	-3	6	-2
Eiterdalen	NO0320.02	0,18	0,15	0,01	0,00	5,18	2,62	3	70	65
Bruvann deposit	Mathiesen & Boyd 2017	0,33	0,08	0,015						
	(sulphide-bound Ni)									

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