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		Nikkel og Olivin AS	Prospekteringsstøtte 1998	

Tittel

The Nikkel og Olivin AS Exploration Projekt, Years 1996-1998, Final Report

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Råstoffgruppe	Rastofftype
Malm/metall	Ni

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

En kortfattet rapport over de geologiske, geofysiske og geokjemiske arbeidene samt kjerneboringer som er utført i Rånafeltet i årene 1996-1998. Alle kart og bilder i svart/hvitt. Kjernelogger mangler.

0408/00 Nei

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15.02.00

Att: Bjarne Lieungh

The Nikkel og Olivin AS - Exploration Project 1996 - 98

Viser til telefonsamtale med vår Markus Ekberg.

Vedlagt oversendes tekstdelen av sluttrapporten for prosjektet..

Vi håper dette er i samsvar med dine ønsker.

Med hilsen
Nikkel og Olivin AS

Vidkun Henriksen

Rapport BV 4621

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BASE METALS
BUSINESS AREA

outokumpu

BILAG TIL JR.NR. 0408/00

090/NORWAY/KTK/1999

THE NIKKEL OG OLIVIN AS EXPLORATION PROJECT

YEARS 1996-1998

FINAL REPORT

By Tapio Karppanen
Pertti Lamberg
Risto Pietilä

Outokumpu 30.3. 1999

Tapio Karppanen
Exploration manager

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1. SUMMARY

The Nikkel og Olivin Exploration Project was launched in February 1996 as an attempt to discover new, better quality ore reserves in order to improve the economy and lifetime of the mine. The scheduled duration of the project, 1.5 years, was later extended by one year for some additional investigations.

NGU material from the 1970's as well as recent geological information from the mine served as a basis for the work. Exploration was delimited to a segment comprising ca.18 km² in the NNW part of the Råna intrusion, with particular emphasis on the vicinity of the operating mine.

Various geophysical, lithogeochemical, mineralogical and geological approaches were applied in the course of the Project. The geophysical methods utilized were systematic ground magnetics and EM, ground and down-hole Protem and Mise-á-la-Masse, semisystematic gravimetrics with DGPS positioning, and an airborne survey with helicopter covering the Project area.

The lithogeochemical study coincided and became integrated with the GeoNickel project of EC. In GeoNickel, the Bruvann ultramafic block is a key case in the development of APE, a program for creating a magmatic and structural model for intrusions and their ore formation processes.

The R&D work of APE and the accumulation of lithogeochemical data in the N&O Project occurred simultaneously. Hence the method could not yet be fully utilized at the culmination of the Project, when most of the drilling took place.

After integrating the results of geophysics, lithogeochemistry and geology, and taking into account the operating mine and infrastructure, eight exploration objects were identified in the area, ranked as follows: 1) Bruvann SW, 2) Rikmalmen, 3) Arnes, 4) Rånbogen, 5) Arneshesten, 6) Brudalen, 7) Råna and 8) Råntindvann.

Drilling concentrated on the SSW extensions of the Bruvann ultramafics underlying a gneiss cover and a major part of Lake Bruvann, i.e. Bruvann SW and Rikmalmen. Drilling here comprised 18 surface holes and four underground holes. One hole was drilled outside the two targets, viz. at Råna.

At Bruvann SW the ultramafics were demonstrated to plunge and extend southwestwards under a gneiss cap, and to be open to the west below the sea level. Due to inadequate rig capacity the surface holes did not reach the ore-bearing horizon in the ultramafic package, but met cumulates depleted in nickel, representing the type currently overlying the Vestmalmen ore horizon. However, the continuation of the Vestmalmen "ore type cumulates" was caught in underground holes. The alleged main mineralized body was interpreted by down-hole Protem to lie downdip to the south.

In the Rikmalmen area (eastern half of Lake Bruvann) a blind lobe of ultramafics protruding south from Østmalmen has locally abundant sulfides, yet with low Ni in the sulfide phase.

Promising intersections of massive and semimassive Ni-rich sulfides were encountered in peridotite and contact rocks in a synform between the lobe and the main ultramafic body.

The ore-bearing, most primitive cumulate in the middle of megacyclic unit 1, interpreted in the lithogeochemical results as a later pulse of magma, can by geological evidence be explained to represent a typical basal unit, which is isoclinally folded together with a slice of crustal substratum into the megacyclic unit. This is an important idea from the exploration point of view which needs verification through a separate tectonic study.

The Project failed to find mineable orebodies. Due to long drillholes needed and a limited budget only nearby targets south and southwest of the mine were investigated properly. The terrain at the most attractive targets that remained unstudied (Arnes, Rånbogen, Arneshesten, Brudalen) also presented challenges in accessibility.

2. GENERAL

The Nikkel og Olivin Exploration Project was launched after Outokumpu Harjavalta Metals Oy acquired a majority in Nikkel og Olivin AS in late 1995. The need for additional and better quality ore reserves had already been realized for some time when Outokumpu was operator of the mine. At the time of acquisition there were ore reserves for four years of operation at an incredibly low average grade of 0.5 percent Ni. All exploration during the mine operation had been limited to the very mine site.

The Exploration Project was officially commissioned in February 1996. (The Project had a jump start already in late 1995 with a ground geophysical survey which was left outside the budget.) The duration was scheduled for 18 months, starting in April 1996. A budget of NOK 5 million was shared by the owners Outokumpu Harjavalta Metals Oy (70%) and Nordlandsbanken, based in Bodø (30%). NB decided to withdraw from the Project in 1997.

A "support group" was appointed at the onset of the Project, including

Dr Rognvald Boyd, NGU - geology and previous exploration of the area
Pertti Lamberg, ORC - lithogeochemistry and mineralogy
Risto Pietilä, OM - geophysics
Tapio Karppanen, N&O - geology, project manager

Lamberg and Pietilä have worked intimately in the Project in their special fields, applying the latest technology and methods in Outokumpu exploration. Dr Boyd has acted as a geological adviser. Aimo Hattula (OM) worked briefly as a geophysicist at the outset of the Project. Jussi Aarnisalo (OM) processed image composites of the airborne geophysical survey.

Lasse Telstø (University of Oslo) did bedrock mapping and assisted in core logging in summers 1996 and 1997. Antti Saarelainen (freelance) was hired for a short-term mapping period at Rånbogen in autumn 1997.

An interim report was compiled in May 1997. It was realized that field contracts had rapidly eroded the Project funds, while the Project work was far from completed. Another NOK 1 million was allocated to drilling in January 1998. This phase 2 of the Project was brought to an end in August 1998.

The extensive and well-documented work of the Geological Survey of Norway (NGU) in the 1970's provided a steady basis for the Project. Because of the time and budget frame the Project was delimited to comprise the northwestern segment of the intrusion including the ultramafic blocks of Bruvann, Arnes/Rånbogen (Fig. 2.1). This area hosts the operating nickel mine, an infrastructure with reasonable accessibility and most of the previously recorded nickel sulfide occurrencies.

The realization of the Project quite naturally took two courses right at the start. One was - in order to get the project running - to drill geologically attractive geophysical anomalies. The drilling was started already in April 1996. Also the following drilling stages were guided by geophysics and geological reasoning. To facilitate target ranking the area was covered with a helicopterborne geophysical survey (Fig. 2.2).

The other course, sampling and assaying (XRF) of intrusive lithologies in old and new drillholes as well as outcrops was carried out continuously in order to create an extensive lithogeoghemical database. The aim was to establish a model for the magmatic development of the intrusion and the associated ore formation, and to use this information for locating new orebodies. This coincided with the start-up of the GeoNickel project of the European Commission, in which the Råna intrusion was included as a case study target in Task 1.1 of WorkPackage 1 ("Mineralogy and modelling of Ni deposits related to mafic and ultramafic intrusions").

The build-up of the geochemical database takes a lengthy time, and the results could hardly be expected to be at hand at an early phase of the project. Therefore, the selection and prioritization of targets were updated from time to time. Contrary to geophysics, this exercise has been fed by drilling, rather than vice versa.

3. PREVIOUS EXPLORATION

The following is a brief review of the exploration history of the Råna intrusion.

- First systematic geological mapping of the Råna intrusion 1912-1921 by S. Foslie (reports/publications in 1919, 1922, 1923, 1941 etc.)
- First description of the bedrock and mineralisation by J. H. L. Vogt (1916)
- First nickel occurrences found, and claims made in the Råna intrusion 1912-1914
- 693 meters of drifting and 29 diamond drillholes during the German occupation by Erzstudiengesellschaft of Berlin 1940 to 1942 (T Horvath 1946)
- Electromagnetic ground survey of the Bruvann deposit in 1946 by state-owned Geofysisk Malmleting (GM 1946)
- Additional studies including drilling by Norsk Bergverk in 1954 to 1960
- Geophysical and geological work in the NW margin of the intrusion (P Singsaas and B Flood 1964, P Singsaas 1966, 1973)
- Geochemical studies in areas of nickel mineralisation in 1971 (J.R. Krog 1973)

- In the early 1970's Stavanger Staal A/S started an extensive exploration campaign using NGU expertise in geophysics and geology. The work included amongst others an electromagnetic ground survey of the area between Bruvann and Råna (P Singsaas et al. 1972), geological mapping of the Råna intrusion in 1973 (R Boyd 1974), a gravity survey around Råna in 1976 (NGU report 1538, 1977), combined potential (P Eidsvik 1972) and VLF surveys (P Singsaas 1978) at Bruvann, and mapping of the Bruvann area in 1 : 2 000 as well as over 30 000 m diamond drilling in 1971-1978 (R Boyd and C. O. Mathisen 1979, R Boyd 1980).

Most of the NGU drilling was carried out in the Bruvann deposit as vertical inventory drilling, mainly with 50 or 100 m centers. The Vestmalmen ore horizon was discovered in 1972. A few individual deep exploratory holes were drilled in the area between Bruvann and Råna.

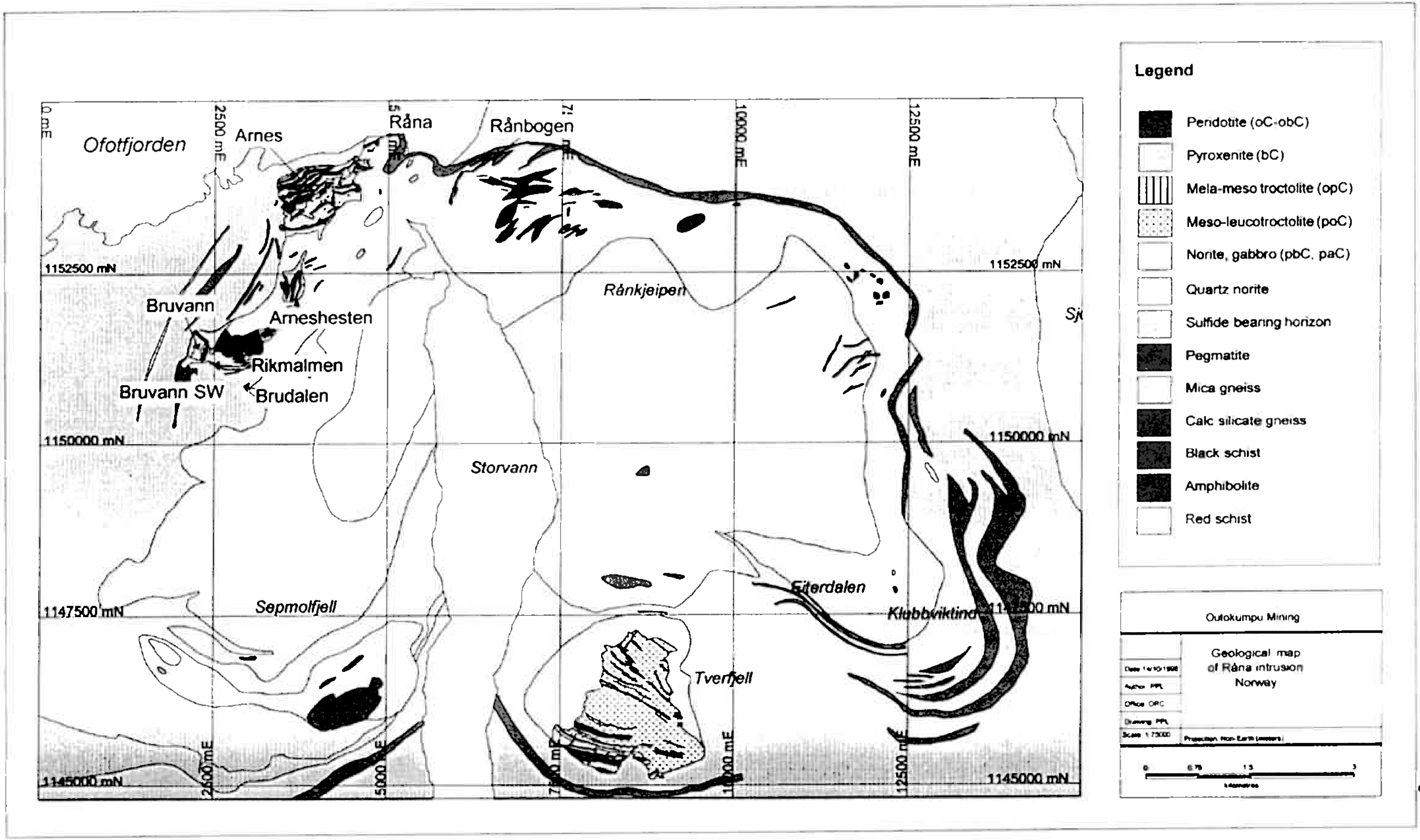
4. GEOLOGICAL SETTING

The Råna intrusion is a mafic-ultramafic intrusion located in the Narvik Nappe Complex in the Caledonides, roughly 20 km south of Narvik. The Narvik Nappe Complex consists of several nappes, all at the middle to upper amphibolite facies metamorphic grade. The complex has experienced six deformations, the latest five of which have affected the Råna intrusion (Hodges 1985). The emplacement of the intrusion took place 437+/-2 Ma ago, or is early Silurian of age (R D Tucker; R Boyd; S-J Barnes 1990).

The intrusion measures 70 km^2 on the surface (Fig. 2.1). It has a roughly concentric structure with a core of quartz (gabbro)norite (over 1000 m at its thickest), (gabbro)norite around the core (300-2000 m), and an outer zone of (gabbro)norite with irregular bodies of ultramafic rocks (0-800 m). The shape of the intrusion has been interpreted to be that of an inverted cone with an axis plunging NW and steepening in that direction (Boyd 1974). Gravity data indicate an increase of ultramafics with depth northwestwards in the intrusion (Sindre and Boyd 1977). Depositional layering has been recorded only in the Tverrfjell outlier in the southeastern part of the intrusion (R D Tucker, R Boyd and S-J Barnes 1990). Whether the Råna intrusion is a layered intrusion (which it isn't *sensu stricto*), or a normal one, is still debatable.

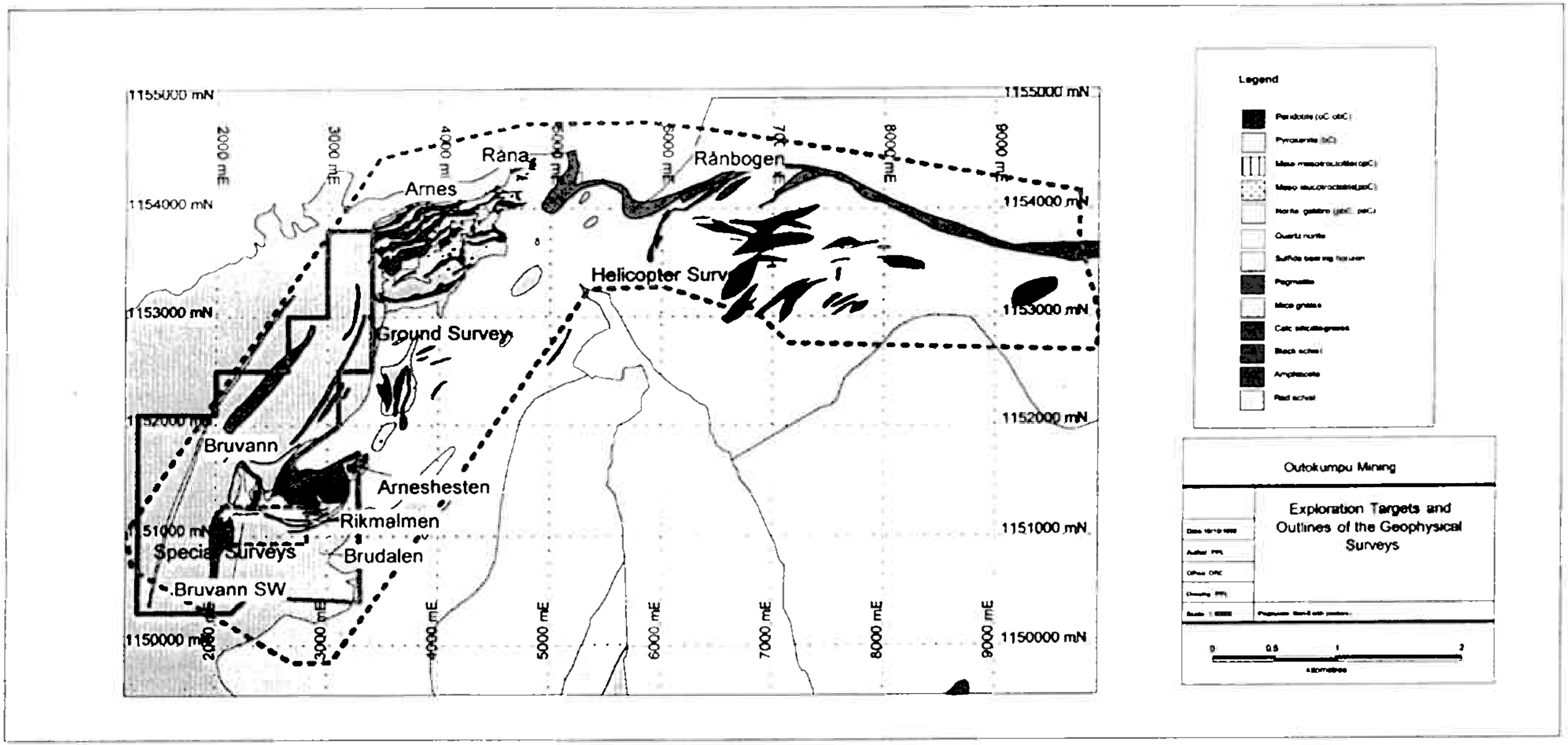
In spite of the location of the Eiterdalen nickel deposit in the SE part of the intrusion, the NW segment including the Bruvann, Arnes, Rånbogen and Råntindvann ultramafic bodies is considered the most prospective area (Fig. 2.2).

At the Bruvann ore deposit the disseminated sulfides occur in tabular lenses of variable thickness in the geochemically most primitive units within the ultramafic package. At least part of the repetition of these lenses can be attributed to deformation in several phases, which is manifested in folding, shear zones, faulting, emplacement of mafic dykes and intrusion of norites etc. The Østmalmen orebodies have an average gentle plunge to the west with southerly dip in the east, turning flat or slightly northerly in the west. The Vestmalmen orebodies are more scattered with a generally gentle plunge to the south.



Legend
Peridotite (oC-obC)
Pyroxenite (bC)
Mela-meso troctolite (opC)
Meso-leucotroctolite (poC)
Norite, gabbro (pbC, paC)
Quartz norite
Sulfide bearing horizon
Pegmatite
Mica gneiss
Calc silicate gneiss
Black schist
Amphibolite
Red schist
Outokumpu Mining
Geological map
of Råna intrusion
Norway
Ofotfjorden
Arnes
Råna
Rånbogen
Rånkjeipen
Bruvann
Arneshesten
Rikmalmen
Bruvann SW
Brudalen
Storvann
Sepmolfjell
Eiterdalen
Klubbviktind
Tverfjell
0 mE
2500 mE
10000 mE
12500 mE
5000 mE
1152500 mN
1150000 mN
1147500 mN
1145000 mN

Fig. 2.1



1155000 mN
1154000 mN
1153000 mN
1152000 mN
1151000 mN
1150000 mN
2000 mE
3000 mE
4000 mE
5000 mE
6000 mE
7000 mE
8000 mE
9000 mE
Rana
Arnes
Rånbogen
Helicopter Surv
Ground Survey
Bruvann
Arneshesten
Rikmalmen
Special Surveys
Brudalen
Bruvann SW
Legend
Outokumpu Mining
Exploration Targets and Outlines of the Geophysical Surveys

Fig. 2.2

A minor share of the sulfides occur as massive and semimassive ore. In Østmalmen it appears to be located as a fragmented horizon at or close to a tongue of calcsilicate gneiss extending from the gneiss synform in the south. Massive and semimassive sulfides also occur as stringers and offsets in hornfelsic gneiss and hybrid contact rocks around the same interface. These features indicate a syngenetic origin for the massive and semimassive sulfides.

In Vestmalmen on the other hand the massive ore is very coarse grained, with irregular shapes in more or less vertical position subparallel to the main hinge fault. It is clearly cutting across the general structure and later lithologies, viz. mafic dykes and norite. The features refer to an epigenetic origin.

5. EXPLORATION METHODS

5.1. GEOPHYSICS

5.1.1. DATA ACQUISITION

The Project used SMOY (Suomen Malmi Oy) as a contractor to carry out both ground and down hole geophysics. SMOY has provided logistical reports and digital data, which are stored and filed in Outokumpu's data base system.

NGU carried out the magnetic and electromagnetic helicopter survey.

5.1.2. DATA PROCESSING

All geophysical data were processed and interpreted by using software packages like GEOSOFT, MODELVISION and EMVISION. Systematic ground surveys were imaged and plotted as multicolour maps. 3-D modelling was applied to test geological interpretations and to interpret down hole surveys.

5.1.3. GEOPHYSICAL METHODS

The entire Bruvann area and part of the Arnes area were covered by **systematic magnetic and electromagnetic** measurements. The purpose of the survey was to get decent structural information as well as to map and classify electrical conductors. The specifications are as follows:

Magnetics:	Line spacing 50-100 m, Station interval 10m Equipment: Scintrex Envi-Mag proton
Electromagnetics:	Line spacing 50-100 m, Station interval 20 m Coil separation 100 m, frequencies 220 Hz, 1760 Hz and 7040 Hz. Equipment: APEX MaxMin I

Semi-systematic **gravity** surveys were carried out at Bruvann and mining area to map the distribution of mafic and ultramafic rocks. Gravimetric data gives valuable information of the structure and volume of the ore bearing lithology. The survey was done as part of the GeoNickel development work practically without costs for the Project. Gravity stations form a grid of approx. 100 m by 100 m. The total number of measured stations was 260.

The elevation and location of each gravity station was determined by **differential GPS** (accuracy +/- 3-5 cm for X, Y and Z). The gravity meter was Scintrex AutoGrav.
Other ground methods were **Protem** and **Mise-a-la-Masse.** Both these methods are applied in down hole work as well. Protem is an electromagnetic method which is reasonably good in depth penetration when used in ground mode (can be hundreds of metres by fixed loop config.). It is also a good down hole tool to pick up a conductor if drilling has missed the target. In the case of a good conductor (like a massive orebody) Protem gives the first estimate for the size of the body.

Mise-a-la-Masse is a galvanic method which is usually very effective when following up conductors both underground and on the surface.

Because of the rough terrain a **helicopter survey** was flown to cover the NE corner of Råna intrusion. A total of 150 line kms of helicopter borne magnetic and electromagnetic measurements was carried out.

5.2. LITHOGEOCHEMISTRY AND MINERALOGY

Lithogeochemistry and mineralogy were applied in exploration to find answers to the following questions, which have a direct impact on exploration:

1. Why doesn't the Ni ore at Bruvann seem to be located next to the contact of the country rocks, as it according to most of the ore formation models should, and as it in practice often is?

2. What is the internal structure of the intrusion (basically known) and especially that of the Bruvann block (where is the original bottom, what is "up")?

3. What has triggered the ore formation and what is the source of sulfur?

4. What is the genesis of massive ore, or are there several types of massive ores and do they have different origins?

5. Are there several cyclic units at Bruvann as there are in the Tverfjell block? And if there are,
5a) which one of the units is mineralized?
5b) how can they be identified?

6. What is the potential for additional Ni mineralizations, ores, and massive ores at Bruvann and in other parts of the intrusion?

7. What are the Ni exploration methods to be applied?

The research work at Bruvann has been funded by the GeoNickel project of the European Commission. Results are summarized in the Final Technical Report of WorkPackage 1.

In the GeoNickel project several methods were developed to utilize whole rock chemistry for unravelling the primary magmatic mineralogy. The study showed that from the exploration and mineralogical point of view a 10-20 cm long drill hole sample is adequate for a representative analysis. In the Nikkel og Olivin Project XRF analyses on this type of samples were used. Some longer samples in selected intervals were collected and analysed (AAS) at the laboratory of the mine. All mineralogical features were estimated and calculated from the whole rock analyses using the APE (Advanced Petrological Explorer) program developed in the GeoNickel project.

5.3. GEOLOGY

Background information was obtained largely from NGU reports of the 1970's. The mine has also produced a good deal of new information in three dimensions on the relationships between lithologies and ore, as well as the complex structures involved.

The aim of the Project was to track down extensions of the concealed mine ultramafics and the associated ore-bearing horizon southwestwards of the mine, and to sample all available ultramafic units for lithogeochemical studies. This included **relogging and sampling old diamond drillholes**, mainly from the NGU period, **drilling new ones** and **mapping and sampling** outcropping ultramafics.

A few representative old holes were relogged and sampled at Løkken, where most of the old holes are stored, already before the Project was officially started. This was the birth of the lithogeochemical XRF database of the N&O Project, which was included as one of the case study targets in the GeoNickel project.

The total amount drilled in the Project is 7 276 m (Table 6.1.). In 1996 drilling comprised 9 holes at Bruvann SW, totalling 2 969 m. In 1997 the target area was Rikmalmen with another 9 holes and a total of 2 863 m from the surface and 2 holes with 230 m from the mine. Phase 2 of the Project in 1998 was restricted to 2 holes from the mine at Bruvann SW with 835 m and one hole at Råna with 379 m. In addition to the above figures come two short holes planned by the Project but executed at a later stage by the mine's rig from level -230 in Østmalmen, totalling 114.40 m.

Terje Holmen AS from Kautokeino was drilling contractor in 1996. Their rig with T-46 bit size was sled-mounted and rather underpowered for holes over 250 m in length. The hole diameter didn't allow insertion of PVC casing for the protection of down hole probes.

The 1997 surface drilling contract was awarded to Suomen Malmi Oy from Espoo. The rig was a Diamec 700 with hydraulic traction and T-56 bit size, sufficient to fit PVC casing. Most of the drilling took place from the ice of Lake Bruvann. All the planned holes were angled which presented a major challenge in positioning and anchoring the casing in locally over 20 m deep water. For the same reason the mounting of PVC casing failed in some of the holes so that down hole surveys couldn't be done.

The plan was to utilize the winter capabilities of SMOy's rig to drill at the Arnes and Brudalen targets, but this couldn't be done due to rough terrain.

Tekobor AS drilled two upward underground holes from -100 level towards Rikmalmen. These holes were not surveyed geophysically.

The 1998 drilling was carried out by Terje Holmen Diamantboring AS, now part of Geodrilling AS based in Namsos. Bit size TT-56 was used, but due to caving, the installation of PVC casing failed in one of the underground holes.

The location, azimuth and inclination of nearly each hole collar were measured with a theodolite after the hole was completed; those which weren't include two short holes on the west side of the intrusion, a few holes from the ice - the casings had to be removed once the hole was drilled - and the holes on the east side of L. Bruvann which got unrealistic azimuth readings. This was probably due to bending of the above-collar part of inserted PVC casings buried in deep snow at the time of measuring.

Hole inclinations were read at regular depth intervals, whereas azimuth deflections were not measured in the holes.

Geological mapping in 1 : 5 000 scale was carried out in the Arnes block in 1996 and 1997, and at Råna, Arneshesten and Rånbogen in 1997. Ultramafics were sampled for XRF assays. Magnetic susceptibility was measured. An attempt was made to trace the anomalies of the airborne survey on the ground with a Gefinex 200 device. A portable DGPS array was used for positioning in 1997.

6. RESULTS AND INTERPRETATIONS

6.1. GEOLOGY AND DRILLING

The drillholes, their parameters and intersections of ultramafics are listed in Table 6.1. The geologic sections including the Project drillholes are depicted in Appendices 3.1. to 3.13.

6.1.1. BRUVANN SW

Drilling in 1996 was aimed at targets of geophysical and geological interest outside the outcropping SW flank of the Bruvann intrusives (App.1). The first three about 200 m long holes P-1, P-2 and P-3-96 were placed in a distinct N-S chain of anomalies roughly along profile Y 2000 (Apps. 3.6., 3.4. and 3.1.). The anomalies proved to originate from Fe sulfides and graphite in country rocks; hence hole P-4-96 planned further south in the chain was cancelled. Hole P-1-96 met the W-dipping peridotite deeper down.

Holes P-5 to P-9-96 (Apps. 3.2. to 3.5. and 3.8.) were drilled in anomalies of lower magnitude between Y 2000 and the main hinge fault. The purpose of hole P-10-96 (App. 3.7.) was to test the dip and nature of ultramafics on the W flank. All holes met ultramafics

Table 6.1.

PROJECT DRILLHOLES IN 1996 TO 1998								
Hole ID	Section	East (Y)	North (X)	A.s.l. (Z)	Azim(g)	Incl (deg)	Length (m)	Ultramafics
P - 1-96	X 1350	2007.77	1349.86	420.00	104.2 (E)	52.9	200.1	97.00-183.70
P - 2-96	X 1100	1875.83	1100.70	441.11	96.8 (E)	52.0	207.15	-
P - 3-96	X 700	1950.00	700.00	473.00	100 (E)	51.8	189.00	-
P - 5-96	X 1100	2052.88	1100.26	436.24	93.7 (E)	50.5	456.25	197.10-244.00 371.30-437.90
P - 6-96	Y 2250	2250.00	1050.00	425.30	000 (N)	71.4	329.55	67.20-140.00 262.85-329.55
P - 7-96	X 1200	2049.89	1200.75	434.49	101.0 (E)	51.0	503.35	288.00-364.00 384.70-431.85 445.70-503.35
P - 8-96	X 1000	2091.33	1000.04	431.74	101.7 (E)	56.6	423.65	277.15-359.85 372.40-415.25
P - 9-96	X 900	2197.57	900.10	425.47	93.6 (E)	67.9	417.00	258.65-269.40
P -10-96	X 1450	2000.00	1450.00	403.00	100 (E)	50.6	243.20	145.00-215.95
P -11-97	X 1100	2650.31	1099.83	431.74	300 (W)	49.7	389.05	174.90-230.00 283.15-389.05
P -12-97	Y 2500	2499.87	1000.23	426.02	1.39 (N)	73.4	269.65	163.10-175.20 234.85-254.30
P -13-97	X 1100	2648.69	1099.88	431.53	300 (W)	71.4	282.60	141.85-157.90 184.25-241.75
P -14-97	X 1000	2710.43	1001.88	430.12	300 (W)	51.7	348.55	-
P -15-97	Y 2500	2500.00	1070.00	425.70	000 (N)	71.3	322.30	177.55-184.60 205.20-264.50
P -16-97	X 1100	2500.00	1100.00	425.70	100 (E)	77.5	282.45	136.50-170.90 200.10-242.15
P -17-97	Y 2450	2449.82	1050.00	425.20	000 (N)	68.4	303.30	212.00-221.40 288.00-303.30
P -18-97	Y 2450	2450.23	998.82	425.30	4.96 (N)	72.0	372.45	183.40-195.20 232.75-278.15
P -19-97	Y 2575	2577.14	1242.82	434.89	203.44(S)	61.9	292.50	7.50-39.30 214.40-278.90
PG-1-97	oblique	2406.61	1175.08	141.52	164.80	-39.9	119.90	31.00-55.50 68.35-73.00 98.30-101.10
PG-2-97	oblique	2406.31	1175.41	141.64	138.17	-50.9	110.00	29.30-83.15 96.25-97.85
PG-3-98	X 1140	2344.97	1140.82	86.51	302.12(E)	24.7	400.50	0.00-45.00 100.50-377.30
PG-4-98	oblique	2345.20	1139.98	85.89	267.55	39.5	434.60	0.00-162.65 254.20-268.20 287.75-291.80
P -20-98	Y 4860	4861.02	4488.55	8.25	195.88(S)	50.3	378.70	many thin ones
bh-899-98	Y 2450	2450.39	1152.37	224.98	177.9	15.9	57.7	9.45-13.65
								25.1-27.85
bh-900-98	Y 2450	2450.43	1152.42	224.3	173.32	41.75	56.7	8.95-10.30
								11.85-13.65

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with minor sulfides. The best intersection, a formerly unknown mineralised body, was obtained in P-7: 344.75 to 349.70 m (4.75 m) at 0.73% Ni and 0.12% Cu.

The main ultramafic horizon lies beneath a cap of gneisses and amphibolites. The upper contact dips gently westwards from appr. 200 m's depth at the hinge fault. Southwards it seems that the fault has lifted the otherwise south-dipping ultramafic block up to that same level at between X 1000 and 1100 under Lake Bruvann (section Y 2250). The extension of

the Bruvann ultramafics far beyond where they earlier were thought to terminate was established (App.1).

Lamberg shows in this report that the Bruvann orebodies are associated with certain cyclic units in the megacyclic unit 1 of ultramafics. Their host rock differs geochemically in several respects from the other units. One would expect the same succession of units to exist at Bruvann SW as well; it is hard to imagine any mechanism there that would have eroded the ore-hosting units.

The ultramafics encountered at Bruvann SW correspond geochemically to those currently overlying the ore horizon at Bruvann, which ever way the stratigraphic succession is. The ore-hosting units were not intersected with the surface holes, chiefly due to drillrig capacity reasons. The holes were up to 503 m long, which is about what the rig was capable to do. The drillrig chosen was planned for substantially shorter hole lengths when the drilling contract was negotiated.

It was calculated from the thicknesses of ultramafic rock types in Vestmalmen that the approximate level of ore horizon at Bruvann SW would be around 100 m below the sea level. This target was best reached by drilling from a drift on level -80 in the mine, although at an adverse angle. The two holes drilled from there, PG-3 and PG-4-98 (App. 3.4.), did not find ore at the target, but are highly informative both geochemically and geophysically. Both holes start with "ore horizon" olivine-sulfide mesocumulate, which in fact represents the extension of the Vestmalmen host rock (P Lamberg 1, 1998). The rest of the ultramafics in both holes are geochemically of the "depleted in Ni" type.

Isolated 15 cm "lithogeochemical" samples from the "ore horizon" give XRF assays of up to 1.08 % Ni , while the "mine method" composite samples of 3 to 5 m lengths give AAS values of up to 0.68 % Ni.

The geophysical down-hole Protem survey in PG-3 indicates a continuation of the "ore horizon" to the south with a plunge of appr. 40 degrees. The anomaly is interpreted as being caused by sulfide dissemination (see Apps. 5.5.2 and 5.5.3). Continuation of the anomaly below the sea level and possible massive ore there are outside the range of the survey.

An off-hole Protem anomaly in PG-3 at 230 m is related to a sulfide-rich zone in the overlying gneiss. The zone is intersected by hole P-7-96 and is clearly anomalous in both ground Protem and Max-Min surveys. On the NGU geological map the zone is labeled as "conductor zone at greater depth."

6.1.2. RIKMALMEN

Geophysical ground and down-hole surveys suggest that there are possibilities for small massive mineralizations south of Østmalmen, in a zone roughly SSE-wards from the so-called Elefantmalmen under the lake and the east shore of Lake Bruvann. This area called Rikmalmen was tested with nine surface holes (P-11 to P-19-97), five of which were drilled from reinforced ice of the lake, and four from the shore (App. 1). In addition, two holes (PG-1 and PG-2-97), were drilled from underground (120 Fo2). The corresponding sections are in Apps. 3.3., 3.4., 3.9., 3.10. and 3.11.

A bulge projecting from the Bruvann mafic-ultramafic body was intersected with seven of the surface holes, some of them containing rather abundant sulfide mineralization around the contact with the gneiss. Although appearing syngenetic, the sulfides proved to be quite low in nickel.

Hole P-17, which hit the synform between the intrusion and the lobe, had an intersection of 0.55 m of massive sulfides in core at 2.42% Ni and 1.41% Cu. The true width can't be determined due to contact irregularity. The host rock is a hybrid between chilled intrusion margin and country gneisses, frequently enveloping the intrusion, or a kind of hornfels. The intersection is not far from the Elefantmalmen orebody (App. 3.9.). Hole PG-1 approached the same area from Vestmalmen level -140 along peridotite, and intersected 0.15 m of similar massive sulfides at the same level. This time the host was calcsilicate gneiss.

The phase 2 program included drilling of two short holes from the access drift to Elefantmalmen at level -220. This was postponed pending site preparation, but was carried out with the mine's rig after closing the Project proper. The two holes had both to be stopped at less than 60 m due to hitting water under pressure. Hole 899-98 reportedly had following intersections (AAS): peridotite from 9.45-13.65 m, 4.2 m at 1.57% Ni, peridotite from 25.10-29.15 m, 4.05 m at 1.09% Ni, and calcsilicate gneiss from 50.00-51.15 m, 1.15 m at 1.86% Ni. The other hole 900-98 hit sulfides in norite-pyroxenite-peridotite from 4.85-10.30 m, 5.45 m at 0.98% Ni, and in peridotite from 11.85-13.10 m, 1.25 m at 1.13% Ni. Some of the intersections coincide with those in holes P-17 and PG-1.

6.1.3. ARNES

The Arnes block, located in the NW corner of the intrusion, is the largest of the outcropping ultramafic bodies (Figs. 2.1, 2.2. and App. 2.1). It is characteristically composed of WSW-ENE oriented alternating peridotite and pyroxenite megalayers with steep northerly dips. Whether the layering is depositional or related to deformation is still debatable.

The block was regarded favorable already at the outset of the project by virtue of its volume of peridotites and persistent occurrence of Ni sulfides. The project results, especially in lithogeochemistry, not only confirmed but boosted this impression.

The Arnes block was mapped and sampled in detail in 1996 (App.2.1.). Remapping and repositioning of observation points with DGPS was done in 1997 in connection with an attempt to locate the aerogeophysical anomalies in the field with a portable Gefinex 200 instrument. The latter failed due to a cover of loose rock thicker than the range of the device. The old NGU drillhole BH-345-400B (App. 3.12.) was relogged and sampled for XRF whole rock assays.

A drilling program comprising two 250 m holes was compiled on the basis of geology, lithogeochemistry and airborne geophysics. The steep terrain and drillsite elevation - 300-350 m - would have called for helicopter transport for the rig, crew and supplies - a rather costly exercise. At this stage the project had used nearly all the budgeted funds on drilling targets close to the mine, and failing to arrange the needed financing had to drop the case.

6.1.4. ARNESHESTEN

Arneshesten (App. 2.3.) is a small peridotite body on the NE extension of the Bruvann orebodies at an elevation of about 650 m asl. It is regarded an important exploration target as it is assumed to represent the extension of the Østmalmen ultramafics to the east, detached from it by faulting. Sulfides were recorded in mapping by NGU, and there is a ground magnetic anomaly on the target.

The body was mapped in detail and sampled in summer 1997. The main purpose of the mapping, finding evidence of faulting between the ultramafics, didn't bring anything new to the NGU work. On their map the more or less N-S trending faults and thrusts are located between the Østmalmen and the Arneshesten target, as well as between Arneshesten and the more intense anomaly to the east.

Arneshesten was put forward as a drilling target in the 1997 and 1998 exploration proposals. An existing road on the mountainside could have been utilized for the job, planned to be done with an underground rig. This was never materialized due to lack of funds.

6.1.5. RÅNA

The target (App. 3.1.) emerged geophysically as an airborne magnetic and an associated electromagnetic anomaly together with an earlier gravimetric survey by NGU, which indicated the ultramafics (and the intrusion channel) to plunge northwestwards beneath the Ofoten fjord in the very area. A vertical hole (BH-475-447), drilled by NGU in the vicinity had abundant ultramafics, but it had deviated away from the MAG/EM anomaly. Mapping in 1997 showed that the anomaly area comprised mainly norite and gabbro which are not capable of creating those anomalies. It was assumed that they were associated with ultramafics lying at shallow depth.

The target was included in the phase 2 of the exploration program in 1998, with one 400 m hole (P-20-98, App. 3.20.) to be drilled with a southerly azimuth and inclination of 50 degrees from the verge of highway E6. The hole was surveyed by down-hole EM equipment (Protem). The final length is 378.70 m.

In the hole peridotites occur sporadically among the predominantly noritic to gabbroic intrusives, without significant sulfides. Semimassive to impregnated sulfides are located in two zones: 1 meter at 88 m and a swarm of veins between 291 and 297.5 m. In the Protem survey they proved to have extensive lateral continuity. AAS assays made on the sections richest in sulfides gave discouragingly low nickel values, the best being 0.44% Ni. The low nickel to sulfur ratio drops the target's attraction notably.

6.1.6. RÅNBOGEN

Based on the work of NGU the area located east of Råndalen on the northern rim of the intrusion was known to contain relatively abundant sulfides. Many peridotite bodies were also recorded in the area. However, the sulfides are usually hosted by norites, and the nickel content of sulfide phase is low. Two holes (645-413 B and C), which were never logged, and the three test pits made by NGU in a sulfidic zone reportedly had low nickel values.

A peridotite body named Rånbogen was picked up as one of the four aerogeophysical Bruvann analogies in the airborne image processed derivative maps. A restricted area around it was mapped in October 1997 before lasting snow cover (App. 2.2). The richest sulfides occur in early shear zones in norite with massive to semimassive vein-type sulfides, with values of up to 1.6% Ni and 28% S (XRF) in mapping samples. Olivine norite or plagioclase peridotite - a transitional rocktype between norite and peridotite - often hosts disseminated sulfides interpreted to have cumulate textures, with values of up to 0.3% Ni and 7% S (XRF).

A 400 m hole was planned to be drilled into the anomaly: Y=6650E, X=4500N, Z~75 asl, Az=200^{g}, Incl=50deg. However, the restricted funds of the project didn't allow the exercise. On the other hand, access to the drillsite might have caused some problems.

6.1.7. BRUDALEN

The target is mainly represented in ground geophysics. There is a subtle chain appr. 500 m in length of magnetic and EM anomalies starting from the SE corner of Lake Bruvann and fanning out to the east. The zone also comes out in the gravimetric survey of 1997. The roughly E-W oriented anomalies seem to originate from below the overlying folded gneisses, lying approximately in their axial plane.

The only way to get samples from the zone is to drill through the gneisses. One hole at X=2700, Y= 700, northerly azimuth and inclination of 50 deg was planned to start with, but the self-propelled rig available for the work could not manage the combination of a hilly terrain and thick soft snow.

6.1.8. RÅNTINDVANN

This is the easternmost of the four Bruvann-analogies on the derivative aeromagnetic map. The anomaly originates from an oval 450 by 160 m peridotite body mapped earlier by NGU. There is no record of sulfides in their report.

The altitude is 500 m asl. The nearest road - highway E6 - is over 3 km away as the crow flies. Further examination of the body would best be started by light methods, detailed mapping/sampling, ground geophysics etc.

6.1.9. ØSTMALMEN - A KEY TO STRUCTURE

Lamberg writes in this report (see 6.3.1.2), based on his lithogeochemical observations, that the most primitive cumulate unit, carrying disseminated ore, sits 100-300 meters above the basal contact, or in megacyclic unit 1, and that the semimassive to massive ore is always adjacent to that. He further notes that the (semi)massive ore carries crustal fragments, and in fact is often hosted by hybrid contact rock or calcsilicate gneiss. Also crustal contamination is evident, interpreted to have taken place at two stages - first deep in the crust while the magma was ascending, and later in situ.
The same structural and lithological relationships have been observed in drillcore, in the development drifts of Østmalmen, and can also be envisaged in sections Y2450, Y2500 and Y2575 (Apps. 3.9 to 3.11), where a synform of crustal and contact rocks develops and pushes a wedge into the intrusion, as one moves to the east. Massive sulfides of high Ni grade are located on both sides of the contact and as stringers in the crustal rocks.

Lamberg regards the Bruvann ultramafics as a single overturned series of magmatic pulses, where the ore-bearing horizon - with both disseminated and massive sulfides - lies in the middle of megacyclic unit 1 (MCU 1). This is interpreted to mean that the basal massive ore typically associated with these has not been encountered in the series. In spite of counting the sequence as overturned, the significance of tectonics within it is ignored.

The above features - the most primitive cumulate adjacent to massive ore, which is in contact with and sends stringers into the crustal and hybrid rocks, crustal clasts of hornfels gneisses and black schist in the ore, as well as the in situ contamination - are all characteristics typically associated with the base of a mafic/ultramafic intrusion. In fact, they shouldn't exist at higher levels of crystallisation.

Assumed that this is the basal unit, a complex tectonic history is needed to result in the present array and configuration of cumulates in MCU 1, as well as the whole ultramafic package. This complexity can easily be seen in the surrounding contorted country rocks and - particularly in the mine galleries - the tectonic zones and dykes of various ages and compositions in the intrusives, and the structural relationships between these. This is no surprise, as it has been shown that the intrusion has gone through five (D_{2-6}) of the six deformation phases which the Narvik Nappe Complex has suffered (Hodges 1985).

It seems likely that the ultramafic package (MCU 1 at least) has been isoclinally folded. Part of the basal unit with its underlying crust was wrapped and preserved as a wedge in the middle of MCU 1, while the rest was offset by deformation or perhaps obliterated by invading norites. The extensions of the basal unit proper - the Rikmalmen target - were not found in the drilling campaign, but some untested objects have been picked up with ground and down-hole geophysics on the east side of Lake Bruvann.

Part of the cyclicity seen in the lithogeochemistry can also be attributed to isoclinal folding, tectonic slicing, or even leaching in shearzones.

The complexity and importance of tectonics at Bruvann were realized too late in order to study it as an essential part of the Project. Anyhow, many key areas in the mine are still available for structural studies, if found sensible. This work would not turn out very costly, so it is highly recommended.

6.2. GEOPHYSICS

6.2.1. PETROPHYSICS

Creating the petrophysical database was part of the GeoNickel project. Geological sections used in GeoNickels's mineralogical studies were sampled for petrophysics also. Magnetic properties, density and electrical resistivity values were determined from core samples. Table 6.2.1. shows the distribution of magnetic susceptibility and density for measured samples.

Rock type	Mean /Susc.	Mean /Dens.	Median /S	Median /D	Stdev /S	Stdev /D	Min/ S	Min /D	Max/ S	Max/ D	N
Sulphides incl.*	**282**	3.45	**141**	3.33	462	0.42	0	2.97	**1 856**	4.65	29
Dunites	**131**	3.29	115	3.31	44	0.07	83	3.11	**279**	3.41	32
Gabbros	33	3.02	34	2.99	13	0.14	7	2.76	49	3.19	9
Norites	68	3.08	51	3.06	51	0.12	22	2.86	288	3.36	70
Peridotites	**125**	3.28	**116**	3.3	51	0.05	62	3.09	**341**	3.38	61
Clinopyrox.	56	3.2	44	3.2	27	0.05	41	3.12	116	3.3	7
Orthopyrox.	99	3.22	81	3.21	51	0.06	65	3.11	228	3.3	9

* ore plus all samples with anomalous sulphide content

Table. 6.2.1. Descriptive statistics for magnetic susceptility and density. Mag. susc. x 10exp(-5) and density g/cm3.

Sulphidic samples, dunites and peridotites are the most magnetic and dense rock types. The intensity of magnetic susceptibility is quite low however. The diagram in appendix 5.6.1. highlights the electrical properties of host rocks and mineralisation as against other nickel deposits studied in GeoNickel. BFIN stands for Bruvann fine grained massive ore, BDIS disseminated ore and BCOA coarse grained massive ore respectively. The diagram also includes black schist samples (BLSCH) to demonstrate the overlapping of magnetic and electrical parameters (a.) for massive ore and black schist.

6.2.2. GROUND GEOPHYSICS

Appendix 5.1. is an index map which shows all geophysical ground surveys implemented during the Project.

Ground magnetic and electromagnetic measurements were carried out to cover the surroundings of the mine and the contact lithology to the north, towards Arnes and Råna. However, the rugged terrain set limits so that the coverage at Arnes is incomplete.

The magnetic map (App. 5.2.1.) shows 2 major anomaly patterns. Narrow and continuous, ribbon type anomalies at SW Bruvann are related to country rocks anomalous in Fe sulphides and graphite. The other anomaly pattern is like the one at mine site i.e. clusters of anomalies forming bigger blocks, all related to ultramafics. The interpretation of anomaly A suggests that the host intrusion could extend to the south being overlaid by a gneiss cap (approx. 100 m thick, appendix 5.5.1.). It is quite likely that gradient B reflects the ultramafic block under the gneiss cover. Modelling profile 5.5.1. illustrates section 1000N where dark greyish bodies demonstrate peridotites and pyroxenites which are the most magnetic rocks in the intrusion, excluding the ore.

The most significant electromagnetic anomalies (App. 5.2.2.) are related to country rocks and calcsilicate rocks rich in Fe sulphides. Fixed loop Protem (App. 5.1.) surveys were carried out to discover conductors at depth. Also in the case of Protem, all conductors were related to Fe sulphides embedded in country rocks.

GPS Gravity survey covered the Bruvann area only (App. 5.2.3). Other target areas are too steep in topography to get reliable results. Gravity data indicates a high density and large volume of ultramafic rocks at Bruvann. Bouguer anomaly coincides well with magnetic data (App. 5.2.4.).

Mise-a-la-Masse was used as a surface tool also. Several locations for the current electrode were used to test the continuation of different mineralised zones. The most frequently used ones are listed in Table 6.2.1. Generally all systems gave similar results if the current was entered into the ore body (App. 5.2.5.). Surprisingly System 2 caused an anomaly coincident with magnetic anomaly A (Triangle symbol on App. 5.2.6.), which suggests that the ore bearing structure continues to the south.

The current seems to spread out to the eastern side of the fault zone (App. 5.2.6.) concentrating on the Østmalmen.

System	Location of C1	
1	Hole R245-125 at 157 m	C2: 3250N, 1750E (shore line)
2	Vestmalmen +300 level	REF:
3	Østmalmen	
4	Hole P12 164.5 m	

Table 6.2.2. Mise-a-la-Masse configuration

6.2.3. HELICOPTER SURVEY

It was the steep topography at Arnes and Råna that favoured a helicopter-borne survey instead of a ground one. NGU contracted the survey during November 1996. The total area covered 150 line kilometers at a nominal line spacing of 100 m and 60 m flight altitude. The equipment in the survey included one magnetometer and a multi-frequency electromagnetic system (Aerodat system).
Appendix 5.3.1. illustrates the total magnetic intensity over the area. It is noteworthy to mention that magnetic anomalies are very low in intensity. The maximum value exceeding the mean level is of the order of **75 nT**. However, the target areas are distinctively anomalous popping up as magnetic highs. Appendix 5.3.2. depicts an apparent resistivity distribution based on 4551 Hz (co-axial) EM data. The most interesting, untested conductors are situated at Arnes and Rånbogen. Appendices 5.3.3. and 5.3.4. show derivative maps processed at Outokumpu's image processing laboratory, Espoo. The former shows enhanced magnetic anomalies produced by using an in-house filtering technique. Ultramafic rocks are expressed as greenish or black colour patterns. App. 5.3.4. illustrates a colour composite image of magnetic and EM data. Magnetic anomalies are presented in green-blue colour palette and EM anomalies (apparent resistivity) in magenta. Black polyline indicates the location and strike of a conductive zone.

6.2.4. DOWN HOLE GEOPHYSICS

6.2.4.1. Down hole Protem

Down hole Protem was carried out in SW Bruvann (holes PG-3 and -4), in Rikmalmen area (holes P-11 - P-16) and in Råna area (hole P-20).

A distinct off-hole anomaly was recorded in P-11 (App. 5.4.1.) and P-13. According to the filament inversion (Fig. 5.4.2.) the edge of the target is approx. 20 m to the north from the section. Later on, at the end of 1998, the anomaly was tested by underground drilling. Drill hole 899-98 intersected patches of massive/semi-massive nickel mineralisation (Ni 1.29-1.86 %) approx. at the target area. Protem interpretation suggests that the intersected mineralisations are narrow projections of a bigger conductor located to the east and slightly deeper down.

Appendices 5.4.3. and 5.4.4. illustrate Protem result in hole PG-3 and the corresponding interpretation. Comments are included in Chapter 6.2.1. Hole PG-4 was blocked.

6.2.4.2. Mise-a-la-Masse

Mise-a-la-Masse was used as a down hole tool to follow up ore zones. Appendices 5.4.7. and 5.4.8. illustrate Mise-a-la-Masse sections X=1100 and Y=2500. Results show clearly how the ultramafic system is dipping to the north and plunging to the west. See also magnetic modelling in App. 5.5.1. which indicates a structure similar to Mise-a-la-Masse. Appendix 5.4.9. shows how the current is concentrated at Østmalmen but spreads out towards Vestmalmen despite the fault zone.
The current distribution is more or less conformable with the known ore bodies excluding the anomaly to the south, below Lake Bruvann (anomaly A). See also chapter 6.1.2.

6.3. LITHOGEOCHEMISTRY AND MINERALOGY

6.3.1. BRUVANN

The Bruvann ore formation process was studied in the GeoNickel project that lasted for three years. A total of 226 samples were collected. Polished thin sections were prepared, their mineralogy was studied microscopically and the composition of mafic silicates determined in selected samples. Whole rock analyses were done for all the samples. REE analyses and Sm/Nd, C, and S isotope work was done on selected samples in order to study contamination. The results are collected in the Final Technical Report of WorkPackage 1, GeoNickel ("Final Technical Report. WorkPackage 1. Mineralogy and Modelling of Ni Ore Deposits").

The most important results of the GeoNickel study of Bruvann are summarized in the following chapters.

6.3.1.1. Structure of Bruvann (see App.4, Figs. 4.1.1-4.1.9)

In the Bruvann block the intrusion is overturned (stratigraphic top is downwards). This conclusion is based on interpreting the magmatic differentiation: Generally cumulates develop gradually more evolved downwards as illustrated in Figs. 4.1.1 and 4.1.2 (drillhole 235-160). Only in the first 100 meters the differentiation is reversed.

Two major units can be identified: megacyclic unit 1 (MCU1) and megacyclic unit 2 (MCU2). The former is about 320 m thick and the latter (overlying) is at least 400 m thick. MCU1 is characterized by the crystallization series olivine - orthopyroxene - plagioclase - clinopyroxene. In MCU2 the crystallization series is olivine - clinopyroxene - plagioclase - orthopyroxene. The appearance of clinopyroxene as a major cumulus mineral characterizes MCU2 (see Fig. 4.1.1). By naked eye the difference is often hard to recognize. Both units consist of several cyclic units.

In MCU1 the ideal cyclic unit contains the following cumulates: olivine cumulate, olivine - orthopyroxene cumulate, orthopyroxene cumulate, orthopyroxene - plagioclase cumulate, and plagioclase cumulate (thus peridotite, orthopyroxenite, norite). Frequently the succession is incomplete, i.e. beheaded, which means that some of the last cumulates are missing. The thickness of a cyclic units varies from 10 to 100 m. In the (stratigraphically) lowest cyclic units differentiation may be reversed, or olivine cumulates in the following cyclic units are more primitive. At about 100 m above the basal contact differentiation turns to normal: each of the successive cyclic units are more evolved.

In MCU2 the cyclic units are generally thinner than in MCU1. The cumulate sequence is ideally olivine (ortho) cumulate, olivine-clinopyroxene cumulate, clinopyroxene - plagioclase ± orthopyroxene cumulate (thus peridotite, clinopyroxenite, gabbro).

The observations and the division of the intrusion into two megacyclic units are in harmony with the work of Barnes (1985) in the Tverfjell block.

6.3.1.2. Ni ore (Fig. 4.2.1-4.2.8)

The ore is located stratigraphically some 100-300 meters above the basal contact, thus in MCU1. Two ore types exist: (1) Disseminated ore and (2) semimassive ore. Characteristic features of the ore are summarized in Figs. 4.2.1-4.2.8.

The disseminated ore is hosted by the most primitive olivine cumulate unit (forsterite content 80-88%), which is relatively thick (30-100 m). The semimassive ore is hosted by orthopyroxene cumulate (pyroxenite), orthopyroxene - plagioclase cumulate (norite) or hybridic rock containing crustal fragments. The semimassive ore is always located close to the most primitive olivine cumulate layer.

Both ore types show clear contamination features: (a) presence of gneiss and black schist inclusions and xenoliths inside or close to the ore, (b) graphite in massive ore, (c) anomalously high lithophile element contents adjacent to the ore. Contamination was confirmed by isotope studies, which resulted in that sulphur is mainly from the mantle, while carbon is crustal. Sm/Nd isotopes indicate, that the Bruvann magma has experienced contamination at two stages: first overall assimilation at a deeper level and a later in-situ assimilation, which is associated with the ore formation.

A high V content and the presence of graphite refer to black schist contamination. The conclusion is that black schist contamination has elevated especially the SiO_2 and S contents of the magma, which have caused 1) the crystallization series to drift to the olivine-orthopyroxene-plagioclase route instead of olivine-clinopyroxene-orthopyroxene series, and 2) sulfide saturation and segregation.

6.3.1.3. Applicable exploration methods

A GeoNickel study outcome is that it is possible to use lithogeochemistry and mineralogy in order to rank Ni exploration targets on the basis of the following factors:

- primitivity of parental magma,
- crystallization series,
- internal structure of intrusion,
- contamination features,
- sulfide segregation features, and
- openness of the system

The orthopyroxene/(orthopyroxene+clinopyroxene) ratio is proposed for a contamination measure (index) (see the GeoNickel report). Sulfide segregation features can be identified in the non-Ni-depleted nature of olivine and the scattered pattern in the Ni vs. forsterite diagram. In addition, high sulfide contents in cumulates indicate segregation of sulfides at early stages of crystallisation. The concentration process required is more effective in open, continuously recharged systems. Therefore, targets which lack repetitive olivine cumulate layers are more favorable for sulfide concentration. At Bruvann targets having the thickest olivine cumulates close to (or preferentially at) the basal contact are the most favourable ones for an effective concentration process.

6.3.2. COMPARISON OF TARGETS

In the following the exploration targets are compared to Bruvann using the petrological key figures determined on the basis of lithogeochemical and mineralogical data: primitivity of the magma, crystallization series, contamination features, sulfide segregation features, internal structure of the intrusion and openness of the magmatic system.

The table below gives the number and distribution of samples included in the investigation.

Target	n
Bruvann	226
Bruvann SW	179
Arnes	125
Arneshesten	29
Råna	15
Rånbogen	14

TOTAL 588

3.2.1.6. Primitivity of magma

According to magma primitivity the targets can be put in the following order of favorableness (see Figures 4.3.1 and 4.3.2):

Target	Max MgO_n%	Max Fo% of ol, interpreted (calculated)	Ni of olivine max Fo (calculated)
Arnes	43.9	86.9 (84.0)	250
Bruvann	41.5	86.7 (83.8)	900
Rånbogen	40.2	84.5 (81.5)	400
Bruvann SW	37.2	83.6 (83.4)	900
Råna	37.0	83.6 (80.6)	800
Arneshesten	38.6	83.5 (80.5)	400

Each of the targets has olivine cumulates, which are chemically and mineralogically similar to the ones hosting disseminated ore at Bruvann (see Fig. 4.3.3). At Arnes they are most voluminous.

6.3.2.2. Crystallization series

The crystallization series favorable for ore formation, typified by Bruvann, is olivine-orthopyroxene-plagioclase (ol-opx-pl). Bruvann is the only target, where the MCU2 unit with crystallization series ol-cpx-opx-pl was detected. At Arnes a specific orthopyroxene-clinopyroxene cumulate has been encountered.
The high orthopyroxene/pyroxenes ratio shown in Fig 4.3.4 confirms that in each of the targets exploration (and sampling) was concentrated on the right part of the intrusion, on megacyclic unit 1 (MCU1).

Target	Favorable series	max ol in oC	max opx in bC	Thickness of thickest bC
Arnes	Yes	oMC (91%)	bMC (88%)	Thick
Bruvann	Yes	oMC (90%)	bMC (76%)	Thick
Rånbogen	Yes	oMC (80%)	bMC (35%)	??
Arneshesten	Yes	oMC (80%)	bMC (78%)	??
Bruvann SW	Yes	oMC (78%)	bOC (75%)	Lacking?
Råna	Yes	oMC (74%)	obC (41%)	Lacking?

Olivine mesocumulates (similar to those hosting the disseminated Ni ore at Bruvann) were encountered in all the targets. At Bruvann the orthopyroxene mesocumulates always occur close to the ore, and that rocktype was encountered at all the other targets except Råna and Rånbogen (see Figs. 4.3.5 and 4.3.6)

6.3.2.3. Contamination features

The most important process leading to ore formation is crustal contamination. At Bruvann the favorable contaminant has been sulfidic graphite schist. The black schist is relatively rich in vanadium, therefore contamination tends to increase the V content of the magma, and cumulates thereafter will be richer in vanadium. A normal gneiss or calc-silicate rock is rich in lithophile elements. Especially elevated zirconium and yttrium in contaminated magma will be reflected in the cumulates thereafter.

Arnes as a whole is anomalously rich in vanadium, which may indicate a high amount of contaminated black schist (see Fig. 4.3.7). Bruvann SW is anomalously rich in zirconium, yttrium, titanium and also potassium (see Figs. 4.3.8-4.3.9). This indicates that the magma has assimilated crustal material, but no black schist.

The following table summarizes the contamination features of each target.

Target	Black schist contamination	Evidence	Other crustal contamination	Evidence
Arnes	Yes	Graphite, high V (n=42)	Weak	high Y in some samples
Bruvann	Yes	Graphite, high V (n=12)	?	
Rånbogen	Probably	high V (n=3)	?	
Arneshesten	Probably	high V (n=6)	?	
Bruvann SW	Possibly	high V (n=1)	Clear, strong?	high Zr, Ti, Y,
Råna	No?	-	?	

Olivine cumulates associated with Ni ore are anomalously rich in manganese at Bruvann. Rånbogen is in general rich in manganese, but the most primitive olivine cumulate is not anomalously rich in Mn. Especially manganese rich olivine cumulates are also encountered at Arnes and Arneshesten (see Fig. 4.3.11 and 4.3.12). Anomalous manganese contents in sulfide rich cumulate samples (similarly as in Bruvann) are encountered at Bruvann SW and Rånbogen.

6.3.2.4. Sulfide segregation features

Segregation of sulfides is liable to deplete magma in chalcophile elements. In the Råna intrusion this is not very clearly visible, because of replenishment of the system by new pulses of magma (which tend to normalize the composition of magma with respect to chalcophile elements). However, calculated delta Ni values of drill hole 235-160 shown in Fig. 4.1.2 are lower (stratigraphically) above the ore than below. Thus, cumulates above the ore are slightly depleted compared to the ones below the ore. This can be seen in other Bruvann drill holes as well, but usually depletion extends only tens of meters stratigraphically above the ore. Ni vs. forsterite content of olivine shown in Fig. 4.3.15. demonstrates the scattered nature of Bruvann samples indicating significant sulfide segregation in places and, on the other hand, that the system has been open and divided into several subsystems (units). Statistics of Delta Ni values calculated after Bruvann SW model curve, shows (Fig. 4.3.16) that the composition of olivine is scattered at Arnes (as it is at Bruvann). Arneshesten is slightly less scattered, but the trends in other targets are well defined and follow closely the Bruvann SW model curve.

Target	Olivine Fo-Ni figure	Conclusion
Arnes	Scattered	Highly prospective
Bruvann	Scattered	Ore features
Rånbogen	Uniform	Depleted
Arneshesten	Scattered	
Bruvann SW	Coherent	Slightly depleted
Råna	Coherent	

6.3.2.5. Openness of the system

The presence of one-mineral adcumulates is evidence of a flowing system, where intercumulus liquid is constantly removed and replaced by flowing fresh magma. If sulfide segregation occurs, the enrichment process required for ore formation may take place. On the other hand, if there are peaceful periods in the magma chamber and the recharge is episodic, sulfide enrichment traps will be destroyed by overlaid cumulates. Sulfide saturation and segregation will in those cases produce ore horizons in "hanging positions". The best sulfide enrichments are encountered frequently at or close to the basal contact. This type of ore has not been found at Bruvann, but all the orebodies lie stratigraphically 50-200 m from the basal contact. The best location for such an orebody would be stratigraphically below the most primitive, thick olivine adcumulate next to the country rock contact. The target most favorable in that respect is Arnes, which hosts olivine adcumulate more primitive than that of Bruvann. However, this rock type is not in direct contact with the country rocks.

Orthopyroxene cumulate is an indication of favorable contamination. At Bruvann relatively thick orthopyroxene mesocumulate lies above or on both sides of the ore horizon. Such a cumulate unit has been encountered at Arnes, Arneshesten and Bruvann SW.

The table below lists the targets in the order of favorableness as to openness of the system.

Target	max ol% in oC	Thickness of thickest oAC or oMC	max opx in bC	Thickness of thickest bMC
Arnes	oAC (93%)	??	bMC (88%)	Thick
Bruvann	oAC (93%)	Thick	bMC (76%)	Thick
Rånbogen	oMC (81%)	??	bMC (62%)	??
Arneshesten	oMC (78%)	Thin	bMC (77%)	??
Bruvann SW	oOC (70%)	Thin	bOC (70%)	??
Råna	oOC (72%)	Thin	obC (40%)	??

6.3.2.6. Overall ranking

When summing up the ranking of each of the above parameters the targets can be ranked overall as follows:

1) Arnes, 2) Rånbogen, 3) Arneshesten, 4) Bruvann SW and 5) Råna.

6.3.3. WHAT DO THE ORE GRADE SAMPLES TELL?

Ore grades (Ni(XRF)>0.5%) were encountered at Arnes (n=4), Arneshesten (n=1), Bruvann SW (n=14), and Råna (n=1). All semimassive ore types from Arnes, Arneshesten and Bruvann SW and the sulfide rich samples from Rånbogen and Råna show anomalous Mo and V contents referring to black shist contamination (Figs. 4.4.1-4.4.2). Several samples regarded as epigenetic have anomalous V and Mo contents referring rather to the existence of graphite schist inside the intrusion.

The Ni and Cu contents of sulfide phase are dissimilar in semimassive and disseminated ores at Bruvann, as illustrated in Fig. 4.4.3. Most of the "semimassive ore" type of samples from other targets (Arnes, Arneshesten, Rånbogen) are depleted in nickel, indicating that there the ore formation process has been small-scale and local. One sample from Rånbogen and several from Bruvann SW are in terms of Ni and Cu contents of sulfide phase similar to the "semimassive ore" at Bruvann.

The disseminated sulfide samples encountered at Arnes, Bruvann SW and Råna are similar to the disseminated ores in Bruvann in terms of mineralogy and chemistry (see Figs. 4.4.5 - 4.4.8). A better quality sulfide phase (higher Ni content) was encountered at Arnes and Bruvann SW.

It can be concluded, that an ore horizon similar to the one at Bruvann was located at Bruvann SW in drill holes PG-3 and PG-4-98. The mineralized samples from Arnes and Rånbogen are so similar to the Bruvann ores and refer to the possibility of a larger scale Ni ore formation process, that their existence in the vicinity is highly prospective.

7. BUDGET AND EXPENDITURE

The original budget compiled in February 1996 by M Ekberg was made for a duration of 1.5 years with an expenditure of NOK 5 million. The costs were distributed very front-weightedly, NOK 4 million in 1996 and NOK 1 million in 1997. The budget was revised in September 1996 when equal shares of NOK 2.5 million were allocated for each year. The costs vs. budget are given in Table 7.1.

Unexpectedly high costs occurred in drillsite preparation and other supportive fields, as well as in the use of ground and down-hole geophysics, which forced to cut down the amount of drilling in order to stay within the frames of the budget. The geophysical helicopter survey (NOK 170 000) in November 1996 was approved by the N&O board outside the budget.

The decision to continue the project beyond September 1997 in expectation of public support expanded the expenditure substantially. Moreover, these expectations urged to compile an even bigger budget for 1998, only to prove over-optimistic already in January, when the costs for the rest of the project (phase 2) were limited to NOK 1 million. The hunt for public support continued, however, and eventually materialized later on, when the state (Bergvesenet) allocated funds for 50 % of a single hole (P-20-98) drilled at Råna.

Table 7.1.

COSTS OCCURRED COMPARED WITH THE BUDGET (1000NOK)

	1996		1997		1998		TOTAL	
	Actual	Budget	Actual	Budget	Actual	Budget	Actual	Budget
Drilling	1 180	1 350	1 467	1 700	601	2 570	3 248	5 620
Ground and downhole geophysics	339	150	184	115	86	140	609	405
Airborne geophysics	170	0	0	0	0	0	170	0
Personnel costs	525	450	690	450	297	637	1 512	1 537
Assays and consultancy	85	50	144	110	303	205	532	365
Travelling and representation	46	0	119	88	48	65	213	153
Other costs	140	500	359	52	221	258	720	810
Support from government	0	0	0	0	-152	0	-152	0
TOTAL	2 485	2 500	2 963	2 515	1 404	3 875	6 852	8 890

Drilling is by far the largest single cost item. Costs of the two short holes drilled at a later stage by the mine are not included. Direct costs for drilling in 1996 were kNOK 1180 or NOK 397.2 per meter, for 1997 kNOK 1467, or NOK 474.3 per meter, and for 1998 kNOK 601, or 495.1 NOK per meter. Underground drilling was performed in 1997 (2 holes, 230 m) and in 1998 (2 holes, 835 m).

8. CONCLUSIONS

The ultimate objective of the Project - finding additional mineable reserves - did not materialize. When regarding the volume of work done in relation to the size of the project area, much remains untested. In the course of the Project a handful of targets were picked up, based on geology, lithogeochemistry and geophysics.

The intrusion has proved to be favorable for the occurrence of Ni sulfides for the following reasons:

- The existence of ore at Bruvann is direct evidence of an ultramafic-related ore formation process. Similar lithologies are common on the northern rim of the intrusion
- Lithogeochemistry similar to Bruvann has been encountered in other localities and is likely to be found in several others by drilling
- The applied geophysics: ground, down-hole and airborne methods have located abundant lithologies and structures favorable for ore occurrence

The targets were ranked geochemically according to a system developed in the GeoNickel project. The following factors were studied and evaluated: (1) primitivity of the parental magma, (2) crystallization series, (3) internal structure of the intrusion, (4) contamination features and (5) sulfide segregation features. Compared to other intrusions studied in the GeoNickel project, Bruvann equates with Stormi (Vammala) and Laukunkangas (Enonkoski) intrusions, both hosts to nickel mines.

The geophysical helicopter survey registered four anomalous targets corresponding to the Bruvann area. Some of these coincided with the lithogeochemical targets. A few of the ground survey anomalies were tested by drilling, but several remained untested, or need reinterpretation. Gravimetry proved successful and was in accord with the other methods on the surveyed relatively flat ground around the mine, but may be problematic to interpret if performed in steeper terrain.

Considering the operating mine and infrastructure, and after summing up the results of lithogeochemistry, geophysics and geology, the targets were ranked as follows: 1) Bruvann SW, 2) Rikmalmen, 3) Arnes, 4) Rånbogen, 5) Arneshesten, 6) Brudalen 7) Råna and 8) Råntindvann.

Drilling concentrated on the S-SW periphery of the existing mine. At Bruvann SW it was confirmed that the ultramafics plunge southwestwards. The ore horizon of Vestmalmen was caught in the beginning of drillhole PG-4 (and PG-3). Based on the downhole EM survey, the mineralized horizon plunges at 40 degrees to the south-southwest. The ultramafics are open to the west below the sea level. At the Rikmalmen target some attractive intersections of massive and semimassive sulfides were obtained in hornfelsic gneisses and hybrid contact rocks close to Østmalmen.

In the lithogeochemical modelling of the Bruvann deposit the ore-bearing, most primitive unit sits in the middle of MCU I. This is reluctantly taken as evidence that it is not a typical basal unit. However, the unit has other basal characteristics - crustal clasts, offsets of massive ore in the "underlying" hornfels gneiss and hybrid contact rock, crustal contamination in situ - which shouldn't occur at higher levels of crystallisation. The location can be explained by isoclinal folding of the basal unit together with a wedge of crustal basement into MCU I, as one or several of the five deformation events (D_{2-6}) which the intrusion has suffered. Identifying this deposiitional interface on the extensions of the Bruvann block or elsewhere in the intrusion would be a major step towards finding additional ore. This is a hypothesis that should be verified by a proper structural study in the mine.

Several promising targets remained untested: Arnes (lithogeochemical, favorable lithologies with sulfides, geophysical indications), Arneshesten (favorable lithologies, structurally on the continuation of Østmalmen, sulfides encountered, geophysical indications), Rånbogen (geophysical indications, sulfides, favorable lithology). No samples are available from Brudalen (ground geophysics, covered by gneiss cap) or Råntindvann (airborne geophysics, remote location).

Regarding the big size of the intrusion and the abundant untested ultramafics involved, it is likely that orebodies of better quality still remain to be discovered.

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9.4. INCIDENTAL PROJECT PHOTOGRAPHS

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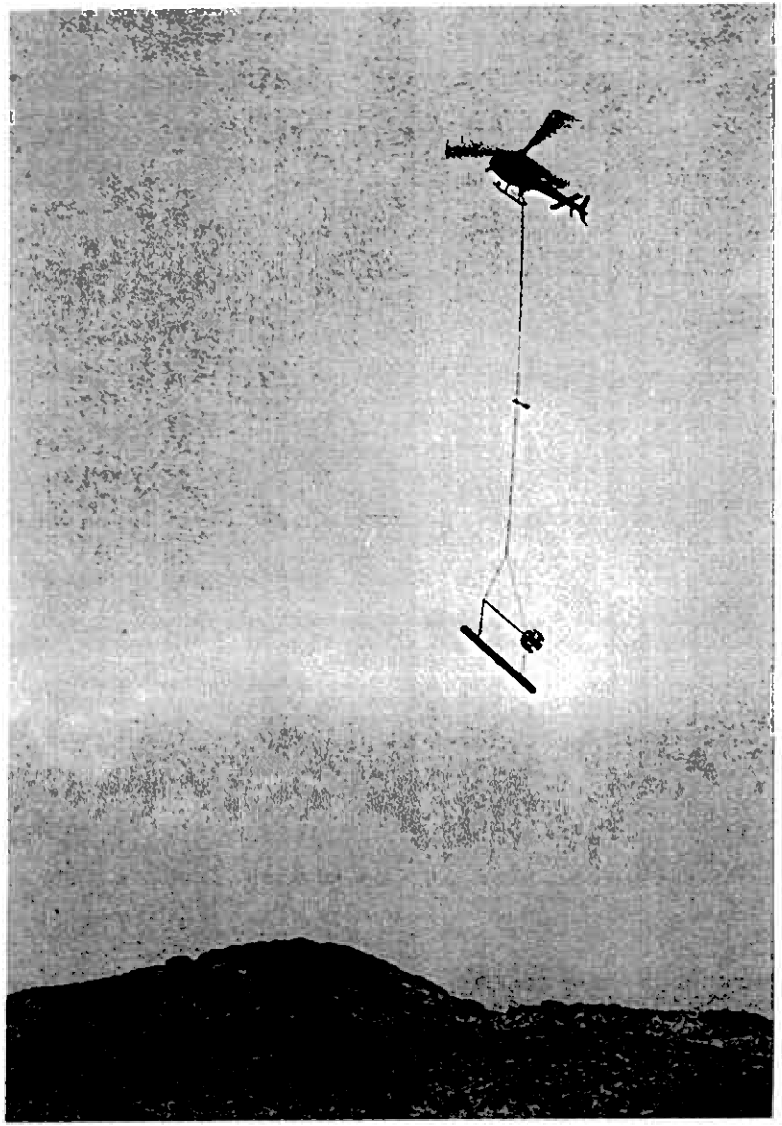

Helicopter survey, November '96

Testing the Protem equipment. Risto Pietilä (left) and Mauri Kesonen (operator)

Lowering the Protem probe in an old NGU drillhole

Mise-á-la-Masse survey by boat (lower right) across Lake Bruvann

Pertti Lamberg sampling for XRF analyses

Compositional banding in pyroxenite.
Arnes block (above)

Measuring magnetic susceptibility on
a shear zone. Arnes block (right)

Creeks are favorable for bedrock exposure. Tapio Karppanen (left) and Pertti Lamberg. Storelva, Arnes block

A view along Råndalen towards Storvann and Tverrfjellet

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