NGU REPORT 2017.031

History of exploration of the nickel resources of the Råna Intrusion, Nordland, Norway

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REPORT

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Title:
History of exploration of the nickel resources of the Råna Intrusion, Nordland, Norway

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Geological Survey of Norway

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Deposit name and grid-reference: Bruvann EU89-UTM Zone 33 X-koord:580099 m. Y-koord: 7581150 m	**Number of pages:** 34 **Price (NOK):** 390,- **Map enclosures: 4**

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Summary:

The report gives a history of the discovery and exploration of the Råna layered mafic/ultramafic intrusion in Nordland county, with particular emphasis on the Bruvann Ni-Cu-Co mineralisation, in the NW part of the intrusion, which consists predominantly of disseminated sulphides in layers of peridotite. The tonnage and grade were calculated in 1975 to be 43.6 Mt grading 0.33% Ni_s, 0.08% Cu and 0.015% Co (cut-off 0.15% Ni_s). The Bruvann ore bodies also include lesser, irregular bodies of massive sulphide containing up to 3-4% Ni. The exploration of the Bruvann area prior to the opening of a mine in 1989 included seven drilling campaigns of which the largest, managed by NGU on behalf of Stavanger Staal, encompassed 91 drill holes with a total core length of 24,427.7m (3 of the holes were later extended by a total of 880m.) Brief mention is made of small massive sulphide mineralizations in the Rånbogen area, on the N contact of the intrusion NE of Bruvann, and in Eiterdalen in the SE part of the intrusion.

The report summarizes the results of mapping and petrological studies which form the basis for concepts of the evolution of the intrusion and its mineralizations. The intrusion was emplaced in the Early Silurian (U-Pb date on zircons: 436.9 +1/-2 Ma): in part it shows features typical of classical layered mafic/ultramafic intrusions but the current form of the intrusion is that of a folded chamber with a steep, possibly overturned NW limb, NW of a marked SW-NE trending deformation zone. Further structural complexities are indicated by the marked asymmetry of certain features in the intrusion E and W of the N-S trending valley, Råndal, which is occupied by the lake, Storvann.

The defined tonnage remaining in the Bruvann deposit is over 9 Mt at approximately the grades indicated above, i.e. a larger tonnage than that found in any of the historically mined Ni deposits in Norway which have been re-investigated within the last 40 years. Peridotites are known to exist at depth in two areas, down to 2km below sea level along the coast in the NW part of the intrusion and at levels below sea level W and SW of, and possibly beneath the western part of the Bruvann ore body. The mine was closed in 2002 before it was possible to investigate the Ni potential of the deep-lying peridotites close to the mine.

Keywords: nickel	copper	platinum metals
olivine	aggregate	

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1. Preface

The first author, Carl Olaf Mathiesen, was born in NewYork in 1929 to parents from Norway. After schooling and college studies in the USA he served in the United States Army in post-War Europe. His military service allowed him to take advantage of a scholarship scheme for ex-soldiers which enabled him to study geology at the University of Oslo in the mid-1950s. In 1958 he was appointed as a geologist in the state company, Kautokeino Kobberfelter, which had been created in order to investigate the copper ores at Bidjovagge and in other parts of the region now known as the Kautokeino Greenstone Belt. This project was followed by others related to metallogenic provinces, including, after his appointment to the Geological Survey in 1969, the investigations of the nickel deposits in the Råna intrusive (information from obituaries written by H. Barkey and I. Lindahl, January, 2013).

Mathiesen retired from the Geological Survey in 1997. His papers included a manuscript (in Norwegian) for a report on the history of investigations of the Bruvann nickel deposit, the main metallic resource in the Råna intrusion, covering early investigations and, especially, the period 1970-79. A draft of the manuscript was read and commented on by the second author and others, but the report was not completed before Mathiesen's retiral and subsequent death: his widow provided the second author with the draft which forms a key part of this report. The following adjustments relative to Mathiesen's original have been made by agreement with NGU's management:

- The content of the report has been expanded to cover summary descriptions of exploration, mining and academic projects subsequent to those of the 1970s and early 1980s.
- The report has been written in English so that it is more readily accessible to companies from outside Norway.

The second author considers that the results achieved during the 1970s and early 1980s were, in large part, due to Mathiesen's systematic approach, which he shared with the key NGU geophysicist, Per Singsaas, and for his positive attitude to new methods which could further understanding of the Bruvann ores and their host rocks.

A summary description of the intrusion, as viewed after the first, intensive period of exploration in the 1970s, adapted from Boyd & Mathiesen (1978), with minor adjustments, is as follows:

The Råna synorogenic Caledonide intrusion in north Norway contains one known major nickel deposit, near the lake, Bruvann, in the NW part of the intrusion. The mineralization consists of pyrrhotite, pentlandite, chalcopyrite and pyrite, occurring interstitially to olivine and orthopyroxene in peridotite and grading up to 0.8% sulphide-bound nickel. Locally, associated with certain deformation zones, interstitial sulphide dissemination passes into massive mobilized sulphide with up to 5% nickel. Resources are 43 million metric tons with 0.33% sulphide-bound nickel, 0.08% copper and approximately 0.0l5% cobalt. The Råna intrusion consists of a peripheral zone of norite containing bands and lenses of peridotite and pyroxenite, and a core mainly of quartz norite (Figures 1 and 3). The Råna intrusion thus has a gross stratigraphy that conforms to the pattern of many layered intrusions, but primary structures have, in many parts of the intrusion, been disturbed by later Caledonian fold phases which also involved local over-thrusting; these movements resulted in an infolding and thrusting of units of semipelitic and calc-silicate gneiss and black schist into the intrusion. The body has the form of an inverted, possibly truncated cone with its axis plunging north-westwards at a moderate angle. The presence of sulphide-bearing black schists on or close to the contacts of the intrusion and emplaced within it along shear zones, and the occurrence of graphite within sulphide disseminated in peridotite suggest assimilation of sulphur from the country rocks. Sulphur isotope studies do not, however, offer confirmation of the hypothesis that an external source of sulphur has had more than very local significance at Råna.

Sections 2 to 7 of this report focus on the successive stages of exploration of the Bruvann and other mineralizations in the intrusion, up to and including the period of mining from 1987 to 2002. Parallel with, and generally linked to individual explorations projects, there have been several projects which have focussed on the geology and petrology of specific components of the intrusion or of its mineralizations. These are summarised in sections 8 and 9 and constitute an attempt to describe the development of understanding of the intrusion and its components from the first descriptions almost 100 years ago by State Geologist Steinar Foslie and up to the present.

This report focuses exclusively on the nickel mineralisations/potential of the Råna intrusion: other resources in the intrusion which have been exploited include:

- The Keiploftet quartz deposit is located at 380 m a.s.l. NE of the mouth of Eiterdalen (Figure 3). The deposit was discovered in 1910 and was exploited from 1949 to 1966 by Meråker Smelteverk. For further information see Blomlie (2012).
- Muscovite was quarried especially in the period 1925-30 from two pegmatites on Simlefjell, the westernmost peak in the main part of the intrusion (Foslie, 1941) and from pegmatite in pits on the N side of Rånkjeipen (Figure 3) before and during World War II (Blomlie, 2012).
- Noritic and pyroxenitic rocks E and N of the exposed parts of the Bruvann ores were quarried as aggregate by Ballangen Aggregates from 2004 – 2007: there is currently (June, 2017) interest in the potential for renewed aggregate production.

2. Discovery of the Råna Intrusion and its nickel mineralisations

The Råna intrusion is a deformed layered ultramafic-mafic intrusion covering an area of ca. 70 km^2 on the S side of Ofotfjord, WSW of Narvik. Information in the Geological Survey archives indicates that the intrusion was discovered by geologist O. A. Corneliussen during a traverse in August, 1874, from Råna, on its northern margin, via the valley Eiterdal in the southeastern part of the intrusion, to Skjomenfjord (Foslie, 1941) (Figure 1). A rough outline of the intrusion is shown on Tellef Dahll's geological map of Northern Norway (Dahll, 1879). The intrusion is hosted within the Narvik Nappe Complex which forms part of the Upper Allochthon of the Scandinavian Caledonides (Melezhik et al. (2014)). It has been dated, using U-Pb in zircon from norite, at 436.9 +1/-2 Ma (Tucker et al., 1990).

Copper/zinc/pyrite mineralizations associated with graphite schists and amphibolite in the region to the south and west of the Råna intrusion attracted attention as early as the middle of the 17^{th} C (Foslie, 1941). The largest, the Bjørkåsen pyrite-Cu-Zn deposit, was discovered in 1876 and was mined, with some breaks, from 1917 to 1964. The Melkedalen Cu-Zn deposit, 9 km S of Bjørkåsen, was mined on a pilot scale from 1899 to 1913. Numerous smaller deposits and showings have been discovered and examined in prospect pits, including those in the Botneidet Cu deposit, ca. 2 km W of the southern end of Storvann (Figure 1): records described by Foslie (1941) indicate that this deposit was worked in 1672-73. The earliest prospecting activity in the Råna intrusion (in the 1880s) was focussed on copper-bearing showings.

State Geologist Steinar Foslie mapped an extensive area south of Ofotfjord, including the Råna intrusion, in the period 1912-13. His mapping was aimed at production of map sheet Tysfjord at 1:100 000 scale (Foslie 1941) and of the southern part of map sheet Ofoten to the north. His detailed studies of the Råna intrusion in 1913 revealed its potential for nickel-copper mineralisation and led to two publications (Foslie, 1920, in Norwegian) and in 1921, "Field Observations in Northern Norway Bearing on Magmatic Differentiation" published in the University of Chicago publication, Journal of Geology. The general distribution of mafic and ultramafic lithologies documented by Foslie in Figure 1 is close to that acquired fifty years later with a range of modern aids and the capacity to map in detail (see section 4). The map shows that Foslie registered the presence of nickel mineralizations at 10 localities in the intrusion, all close to its northern margin except for the Eiterdal mineralization, close to Klubviktind in its southeastern corner.

Foslie (1921), building on theories suggested by Bowen (1915, 1919), proposed that the distribution of lithologies in the Råna intrusion was caused by crystallization of the magma under the influence of lateral orogenic pressure, in a closed system, without a significant role for gravitational settling. His description of the geological map sheet Tysford (1:100 000) (Foslie, 1941) which includes the central and southern parts of the intrusion contains comprehensive descriptions of the magmatic lithologies and their distribution, and more limited consideration of their interaction with units of meta-sedimentary wall rock. The specific topics to which he gives attention include (on p.170) a description of three types of occurrence of graphite:

- On fractures in both norite and peridotite
- As impregnation in norite
- As locally rich impregnation in pentlandite-pyrrhotite-chalcopyrite mineralization (see illustration in Ramdohr, 1969)

He describes four locations W of Storvann at which these types of occurrence can be found.

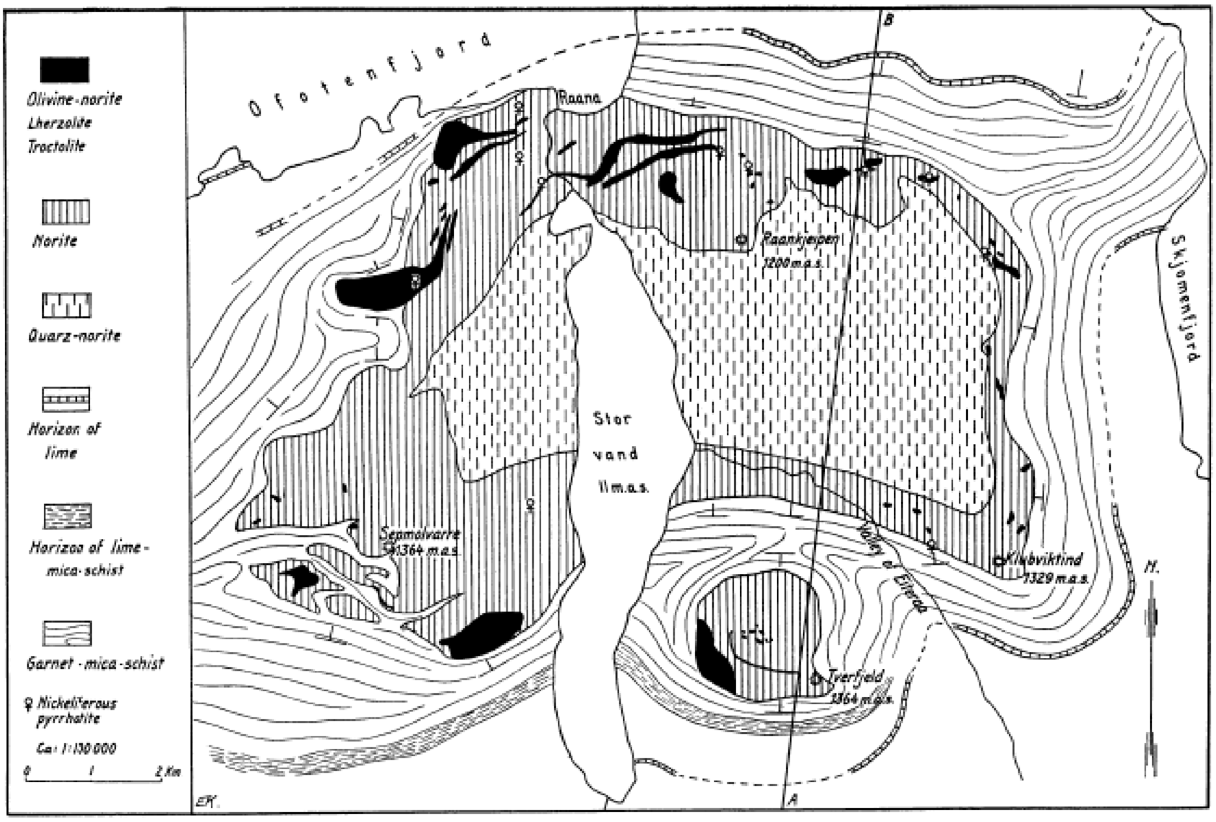


Figure 1: Map of the Råna norite field (Foslie, 1921)**.**

3. Discovery of the Bruvann Ni-Cu-Co deposit and its earlier investigation, up to 1970

The chronology of events in exploration of the metallic deposits in the Råna intrusion can be listed as follows:
1911: Claims, based on their copper content, on mineralizations outcropping on the ridge 500m W of Råna.

1912: Discovery of the mineralization in Eiterdalen, below the peak of Klubviktind in the SE corner of the intrusion. This mineralization was also initially considered to be a copper mineralization.

1913: Foslie recognized that the Eiterdalen mineralization was primarily a nickel mineralization and, by implication, that the intrusion as a whole was a nickel-copper province.

1913-15: Pilot production at Eiterdalen on behalf of lawyer Ludvig Lumholz. 135 t of ore was exported to Germany from a pier just E of Råna, in 2015.

1913-20: Ringerike Nikkelverk and Kristiansand Nikkelraffineringsverk were, as well as Lumholz, involved in further investigations at Eiterdalen.

1913-18: Bjørkåsen Gruber established pilot-scale production of copper, and later, of nickel, in the Bruvann area (Blomlie, 2012): their operations included building a dam at the NW corner of Bruvann.

1914: Mining engineer Hunger wrote a report on the nickel mineralizations in the northern part of the intrusion.

1915: Seventy claims on these mineralizations were registered by lawyer Schølberg, Bodø.

1918: Three holes (total 369m) were drilled by A/S Bjørkåsen Gruber (then in German ownership) in the eastern part of the Bruvann area (Figure 3).

1919: Foslie, at the request of A/S Bjørkåsen Gruber, carried out an investigation of all the nickel mineralizations W of Storvann and N of Bruvann, and E of Storvann between Rånbogen and Rånkjeipen. His report (registered as Bergarkiv Rapport nr. 1121, in all 30 pages) includes analytical data on core from the above-mentioned drillholes and detailed descriptions of the field relationships observed in the Bruvann area and at other exposed mineralizations to the NE, including those near Kringelvann (the northernmost, small lake in Råndal) and those on Rånkjeipen. He describes three mineralizations near Kringelvann, one of which, (no.1) had been drilled by Bjørkaasen Gruber in 1918. He makes particular mention of the high concentrations of graphite in mineralization no. 2 and in parts of mineralization no. 1. The occurrence of graphite in sulphide mineralizations in the Råna intrusion is illustrated on p. 385 of Ramdohr's standard work: "The Ore Minerals and their Intergrowths (Ramdohr, 1969).

Figure 2: Klubviktind and, outlined in red, the location of the Eiterdalen mineralizations. The deposit is located ca. 200m above the floor of the valley. Five adits were driven into the deposit over a strike length of 180m. Selected samples (Barnes, 1986) gave the following ranges: 340-7730 ppm Ni, 11-3846 ppm Cu, 75-716 ppm Co, <7-19 ppb Pt, <5-22 ppb Pd, 1.7-14 ppb Au.

Photograph from Wikipedia (http://www.skatterifjell.no/wiki/index.php?title=Eiterdalen)

1936-37: Nine holes (total 930m) were drilled by Kristiansand Nikkelraffineringsverk in the eastern part of the Bruvann area. Much of the core from these two drilling campaigns was analyzed. The core analyses led to a calculation (Hornemann, 1937) of the ore as being a minimum of 2 Mt grading 0.53% Ni_{tot} and 0.12% Cu.

1940-46: Extensive studies of the eastern part of the Bruvann area were made in this period (the western, down-faulted continuation of the mineralization was not discovered until 1972).

1940: An adit was driven 420 m. in an ESE direction from an altitude of 400 m a.s.l. (Figure 3). A 204 m. cross-cut to the S was driven from a point 76m. into the adit and from its termination, a 35 m.-long adit to the E. This work was implemented by Fangel & Co. on behalf of Erzstudiengesellschaft in Berlin. The cross-cut intersected an ore zone, exposing mineralization which, in part, was described as quite rich.

1940-45: Thirty-two holes, totalling ca. 4035m, were drilled from the adit, in various directions, by A/S Malmundersøkelser on behalf of Erzstudiengesellschaft. Most of the N-directed holes are in footwall rocks and the S-directed holes are mainly at a small angle to the dip of the mineralized zone. Weakly mineralized core was not analyzed. These factors limited the knowledge gained on the geometry of, and internal variations within the mineralized zone. Flotation tests were carried out on ore samples by a company in Oslo (Ferdinand Egeberg) and by Krupp and I. G. Farben in Germany: the tests included production of both sulphide and olivine concentrates.

1944: A report by the Hungarian geologist, F. Horvath, on the above investigations was released. He concluded that the Bruvann deposit, as then known, contained 4 Mt, grading 0.5% Ni_{tot}. He also considered the results from the flotation tests and made proposals for developing the deposit for mining.

1946: Electromagnetic measurements, carried out by Geofysisk Malmleting A/S with government funding, defined the basal contact of the known mineralization and confirmed that it dipped southwards (Singsaas and Brekken, 1947).

1953: A/S Norsk Bergverk, following flotation tests on Bruvann ore in Germany, sent a sample of concentrate to Canada to test application of the Sheritt Gordon process (extraction of Ni, Cu and Co using ammonia as a solvent). The concentrate, containing 9.0% Ni, 2.04% Cu and 0.39% Co yielded Ni+Co with 99.9% purity, Cu with 76.5% purity and ammonium sulphate with 25.1% S. Recovery percentages were: Ni – 95%, Cu – 96%, Co – 86% and S – 45% (Bjørlykke & Færden, 1961).

1956-57: Geological mapping by A/S Norsk Bergverk.

1960: Three holes (total 750 m) were drilled by NGU, two from the innermost part of the cross-cut driven into the Bruvann ore in 1940 and one from the surface in the same area.

1961: Bjørlykke & Færden (1961) calculated the ore between 275 and 400m a.s.l. as follows: Probable ore: 1.1 Mt grading 0.6% Ni_{tot} or 1.7 Mt grading 0.5% Ni_{tot}, Possible ore: 0.78 Mt.

1964: Geophysical and geological investigations were carried out along the northern contact of the intrusion, E of Råna, and in Eiterdal (Singsaas, 1964: Singsaas & Flood, 1964). A number of conductive zones were found south of Store Saltvikvann within the outer contact of the norite: these are related to variable, generally weak contents of sulphide, but also to the presence of graphite. Samples from prospect pits generally gave grades of 0.5 – 1.0% Ni with a maximum of 1.91% Ni. Eight holes were drilled in Eiterdalen, at levels 10 – 40m above the adits with the aim of intersecting the continuation of the mineralisation found in the adits (see profiles in Flood (1964). The cores showed however, that the mineralised norite in the adits did not continue into the mountain and that it probably represented a "pocket" of norite, "isolated" due to erosion combined, possibly, with primary intrusive and/or tectonic features.

1970: An overview of all existing claims was prepared by NGU for Stavanger Staal.

4. Exploration by Stavanger Staal/Geological Survey of Norway (NGU)

1970-76: Stavanger Staal

Stavanger Staal, on 16th March, 1970, entered into an agreement with the Ministry of Industry for rental of the Norwegian government's claims (83 in all) in the Råna area for the period to 1976. The company specialized in production of nickel-bearing steel and had experienced problems in acquiring nickel in 1969 due to strikes in the mining industry in Canada: the company wanted to secure a domestic source of nickel and the Råna area was, at that time, the only major prospective nickel province in Norway in which claims were open for rental. Stavanger Staal did not, however, have the necessary ore-geological expertise and subcontracted NGU for the tasks of planning and implementation of the necessary studies in the period 1970-76. By far the largest part of the project was carried out in the Bruvann area, though supplementary surface investigations were also carried out elsewhere, including geological mapping of the whole intrusion. Senior engineer Torvid Grønlie represented Stavanger Staal in coordination of the project.

Stavanger Staal's contract with NGU involved the following components:

- Preparation, by A/S Fjellanger Widerøe, of full topographic coverage of the intrusion in five sheets at a scale of 1:10,000 and of the whole intrusion, in one sheet at a scale of 1:20, 000. A sheet at a scale of 1:2,000 was prepared for the Bruvann area. This work was completed early in 1972. The basis for the topographic coverage included a complete, new set of aerial photographs of the intrusion, in colour. The colour aerial photographs were very useful at higher altitudes, with good exposure, such as the higher parts of the Tverrfjell outlier in the SE part of the intrusion (see Figure 8).
- Grid for observations and drilling: The ore body in the Bruvann area, as known in 1970 strikes E-W and dips S: N-S profiles would thus be suitable for illustrating many of its features. Part of the reason for the map constructions described above was to provide a basis for a precise N-S, E-W grid in which the coordinates for all observations, sampling and drill holes could be linked to a national coordinate system. This grid was established with the setting up of a base-line marked with bolts early in 1972, with other bolts precisely located in other positions. The base-line was the starting point for a grid established on the ground by NGU geophysicists: N-S profiles in the grid contained wooden pins at 50m intervals, with the coordinates marked on aluminium strips stapled to the pins. The grid had critical importance for coordinated interpretation of geological, geophysical and drilling data from all the investigations from 1972 onwards.

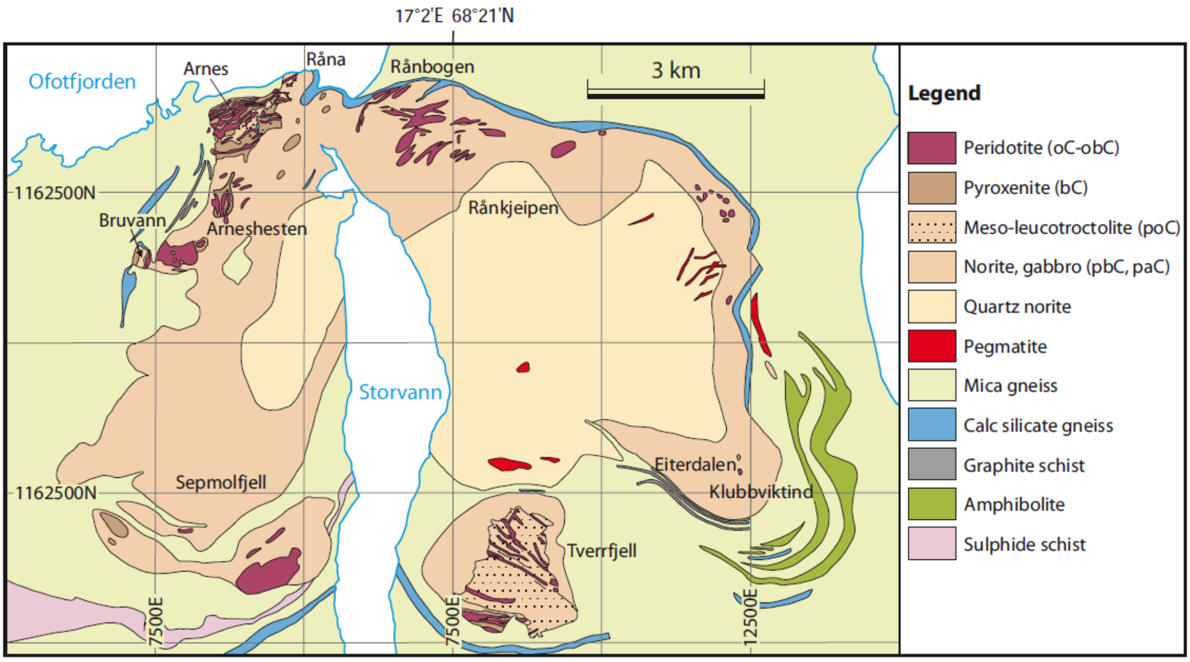


Figure 3: Geology of the Råna intrusion, from Lamberg (2005) after Boyd & Mathiesen (1979), Barnes (1986) and Karppanen et al. (1999)

- Geochemical sampling was carried out in 1970-71. A brief reconnaissance stream-sediment sampling programme was carried out in 1970 in the streams draining the areas N and S of Bruvann and one which drains the Arneshesten area. The programme in 1971 encompassed: 1) stream-sediment sampling of most of the streams draining the intrusion as far as the terrain permitted, 2) a limited number of water samples and 3) soil sampling in two profiles northwards from the Bruvann area. The results showed that most of the outcropping peridotite bodies did not contain significant concentrations of sulphides.

- An aeromagnetic survey was carried out in 1971. The contents of magnetite in the rocks of the intrusion are low but the data indicate that the intrusion as a whole has a plunge to the N of 35^o.
- An electromagnetic survey covering the Bruvann area and its surroundings to the S and N was carried out in 1972 (Singsaas, 1973). It revealed weak anomalies in the westernmost extension of the intrusion near Bruvann and clear anomalies indicating the presence of graphite-bearing zones in the country rock to the S, W and N. The survey also indicated the presence of a conductive zone at depth, around the SW corner of the Bruvann area beyond the surface contact of the mafic complex. Subsequently, charge potential and conductivity measurements were carried out in drillholes which intersected massive sulphides close to the southern margin of the main mineralized zone at Bruvann. The results were complex (as is the geology revealed in the drillcores) and did not lead to clear conclusions.
- A gravity survey was carried out along all the roads intersecting the intrusion in 1976, and was supplemented in 1977 (Sindre & Boyd, 1977). It provided information on the 3D geometry of the intrusion, most particularly that ultramafic rocks extend along parts of its northern margin to a depth of ca. 2 km below sea level.
- Geological mapping (1:10 000) of the NW part of the intrusion was carried out and a reconnaissance of the whole of the northern contact zone as far as 10 000E (Figure 3) in 1972. This was followed up by helicopter-supported mapping of the whole intrusion in 1973, based on three camps – S of Tverrfjell, S of Sepmolfell and E of Rånkjeipen (Figure 3): the main focus in the geological mapping was on the outer, noritic zone and the ultramafic bodies within it. This resulted in the production of four 1:10 000 sheets, Arneshesten, Sepmolfjell, Rånkjeipen and Tverrfjell which were combined to produce a 1:20 000 sheet covering the whole intrusion. These maps were supplemented by further mapping in 1974 in addition to which a 1:10 000 sheet Saltvikfjell (north of the eastern part of the intrusion) was produced (Boyd, 1973, 1974). The geological mapping gave much information on the magmatic and structural evolution of the intrusion and revealed that the Tverrfjell outlier showed a relatively undeformed sequence of the magmatic rocks at lower levels in that part of the intrusion.

  Mapping in the SW part of the intrusion indicated a clear asymmetry relative to the SE part of the intrusion. In contrast to the quite "open" structure on Tverrfjell the mafic and ultramafic rocks S of Sepmolfjell are located in tight to isoclinal fold structures with N- to NW-dipping axial planes. This zone of deformation and its associated lithologies are not visible E of Storvann but appear to change in trend to a northwesterly dip on the steep, largely scree-covered slopes down towards Storvann. These features should be considered in context with the interpretation of tectonic features in the NW part of the intrusion described on p. 26 in Section 9
- Diamond drilling in the Bruvann area commenced in 1971 and, in this period of investigation, continued until 1975. Ninety-one drillholes, totalling 24,472.7 m. were completed: 45 of the holes were drilled by NGU's drilling team and 46 by the Bjørkaasen Grube team. The drillholes were sited according to the above-mentioned grid (top of p.10). In the eastern part of the mineralization the holes were drilled at 50m intervals in profiles 100m apart, whereas in the area W of the fault shown in Figure 4 the distance between holes is generally 100m. The holes are numbered according to the first three digits in the map coordinate system. Where it was found appropriate to drill an additional, oblique hole within the profile this is indicated by the letter B, e.g. hole 235-160B at the coordinates 2350E-1600N.

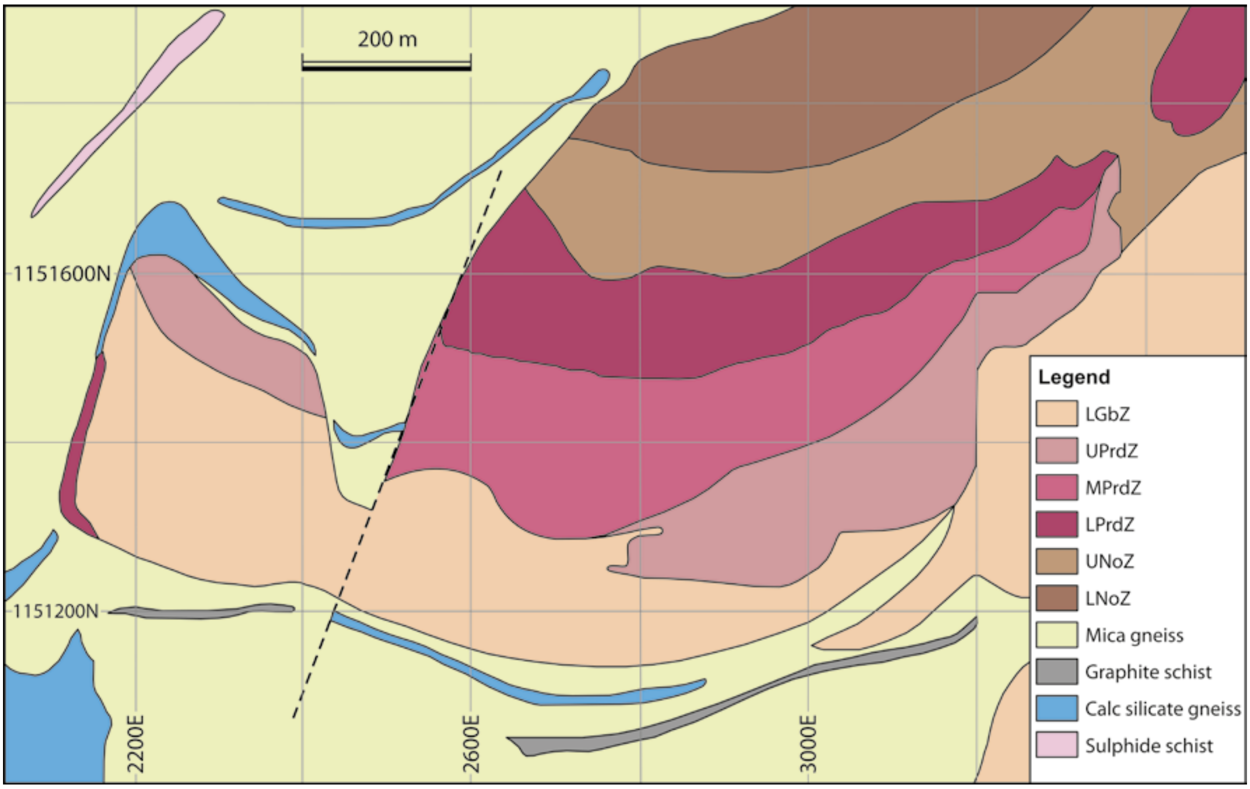


Figure 4: Geological map of the Bruvann area (Lamberg 2005, modified after Boyd & Mathiesen 1979 and Karppanen et al. 1999) (Gb= gabbro, Prd= peridotite, No= norite)

The merits of drilling, primarily vertical, holes in a grid pattern are clear when compared with the difficulties of interpreting the drillholes from earlier periods:

- Many of the older holes intersect the ore at small angles
- Many of the holes are described as having large and improbable deviations
- For many holes the only analyses are for the richer zones of mineralization.
- The descriptions of the core are inadequate and, in some cases, have been lost.

Major discoveries in the drilling campaign were:

- The discovery of the first intersection of the "blind" western ore body in drill hole 235-150 in 1972: continued drilling in the western ore body confirmed the presence of the hinge fault and of increasing downward displacement to the north, west of the fault.
- The discovery of massive sulphides in several holes in the southern part of the eastern ore body (profile 1250N) in 1974.

The standard procedure for logging the core was as follows: the core was stored in core boxes holding 10m: a preliminary description of all core drilled in the previous 24 hours was made in the field. After the core boxes were full they were transported to a store in the former fire station in Bjørkåsen. The store was equipped with a wooden stand on which the core boxes could be mounted, with a spotlight focussed on the core. A more refined description was made and every core box was photographed, firstly while dry and then wet, so as to remove dust and reveal textures more clearly. Samples for reference purposes and for thin sectioning were removed .The descriptions were subsequently finalised, after analytical data was available, by examining the colour slides of the core boxes, placed on a light table using a binocular microscope.

Figure 5: The eastern part of the Bruvann area viewed from close to the lake. The ridge on the left (northern part of the skyline) corresponds to the norite units, LNoZ and UNoZ in Figure 4.

Descriptions of the core and a volume of profiles were issued in 1975 (Mathiesen, 1975, 1976). A later report (Boyd, 1980), including results from holes drilled in 1977 and 1978 with extra funding from the Ministry of Industry, includes interpreted N-S profiles utilising all the core data in the Bruvann area, at 100m intervals, E-W profiles, mainly at 50m intervals and interpreted horizontal sections at 50m intervals from sea level to 600m a.s.l. The cores are illustrated with the recorded lithologies and histograms of Ni_S contents (see below), and are, where significant deviation has been recorded, projected into the profiles. Three profiles in A2 format are included (at the back of the report) as illustrations of the description of the main structural features of the Bruvann area:

- Profile 2600E is based on the logs and analytical data from 9 drill holes: the northernmost, 260-170, is located north of the hinge fault which separates the western part of the Bruvann ore from the eastern part (see Figure 4). The drillholes at 50m intervals, from 260-145 to 260-115, show mineralised intersections of ca. 35m in peridotite and olivine pyroxenite in holes 260-145 and 260-140 and sporadic mineralisation within intersections of the same thickness in holes 260-135, 260-130 and 260-125, including the richest mineralisation in the profile, hosted by a unit of olivine pyroxenite which, in holes 260-130 and 260-125, coincides with the base of the mineralisation. The intersections from 260-245 to 260-125, considered along with the intersecting E-W profiles, indicate that the mineralised horizon strikes approximately E-W in this area and dips at ca. 40^o. The southernmost two holes in the profile, 260-120 and 260-115 indicate that the mineralised horizon is thinner (≤ 20 m), is hosted in peridotite and overlying norite and forms a shallow synform. These two holes indicate complex interaction between norite and the ultramafic units and between units of wall rock, gneiss and calsilicate gneiss and the mafic and ultramafic rocks. Two slices of metasedimentary rock appear to extend >100 m into the magmatic sequence, a type of feature observed on the surface, further east (see Figure 4). The major gneiss intersections in drillhole 260-115, down to a depth of ca. 250 m, may be connected to the main body of gneiss on the surface and underlying the lake, Bruvann. Karppanen et al. (1999) indicate that much of the northwestern part of Bruvann (W of the hinge fault shown on Figure 4) is underlain, at depth, by ultramafic rock: available data indicates that a smaller ultramafic body is found E of the hinge fault >100 m below the surface, where it extends, only just, to profile 2600E at a depth of ca. 200 m below the surface, close to profile 1000N.

- Profile 2350E is based on the logs and analytical data from 7 initially vertical drill holes: the whole of the profile as interpreted, lies W of the hinge fault shown on Figure 4 (which intersects the profile on the surface at ca. 1125N). The northernmost holes, 235-180, 235-170 and 235-160 are drilled from gneiss, through a band of calcsilicate gneiss and, after a deviation which increases with the length of core in the country rock, into the mafic rocks. The profile shows intersections through two major blocks of mineralized peridotite separated by an obliquely oriented slice of pyroxenitic and noritic rock, almost without mineralisation. Each of the two blocks shows a quite thick northernmost intersection of mineralised peridotite, respectively ca. 100 m (northern block) and ca. 80 m (southern block), interrupted only by a unit of 5-6 m of unmineralised peridotite. The mineralised peridotite units form wedge-shaped sections, thinning southwards, those in the northern block with an apparent dip to the north and those in the southern block, apparently form a shallow synform (see the above description of profile 2600E). Smaller lenses of mineralisation are found above and below these two blocks. The uppermost major unit of mineralised peridotite and the underlying units of pyroxenite, norite and peridotite are terminated to the north against a body of norite and olivine norite, a juxtaposition which may be a downfaulted continuation of the relationship found on the surface E of the hinge fault, where the outcropping, partially mineralised peridotite abuts on a ridge of norite to the north (Figure 4).

  The uppermost 100 m of the southernmost drillhole, 235-120 is dominated by a wedge of calcsilicate gneiss against which the mafic units of the above-mentioned "uppermost" block terminate. Karppanen et al. (1999) show that gneiss and calcsilicate gneiss extend to a depth of ca. 150 m in profile 1000 N in this profile: Beneath the metasediments there is, in the continuation of profile 2350E under the northwestern part of Bruvann, a unit of peridotite with a vertical intersection of min. 300 m of peridotite, in which there is a unit of norite, 20-100m thick, with an apparent dip to the W: these ultramafic-mafic units have been proved by drilling to be terminated at the hinge fault.

- Profile 1400N is based on the logs and analytical data from 11 drill holes. Three of the holes are west of the hinge fault which intersects the profile just W of 2500E and which is marked by the presence of a wedge of gneiss and calcsilicate gneiss (see Figure 4). The profile shows the lowermost mineralised peridotite units W of the fault (see description of profile 2350E above). These units and the mineralised peridotite E of the fault are both underlain by min. 80 m of peridotite without mineralisation, a factor which suggests that they may have been continuous prior to downfaulting of the western units by ca. 260 m. Above the mineralised periodotites, with an intervening "break" in the magmatic "stratigraphy" there are two layers of pyroxenite, separated by a unit of peridotite and with weakly mineralised peridotite above the uppermost pyroxenite. These features also suggest original continuity. The eastern mineralised peridotite is cut off to the east against a structural "break" on parts of which there are slices of gneiss: this feature appears also to cut the two overlying pyroxenite units. A slice of gneiss is exposed on the surface in the profile at ca. 3120E and a major wedge of gneiss extends northeastwards into the intrusion south of this profile, which it intersects east of the end of the profile. Two lenses of mineralised peridotite were intersected "beneath" the above-mentioned structural "break": their form suggests that are sstructurally bounded fragments of the main horizon.

Analytical procedure: Sections of core prioritised for analysis were split and 2m sections were crushed and bagged for sending to the NGU Chemical Division for analysis. Remaining core was stored in four vacant buildings at Bjørkåsen. The analytical routines were:

- Semi-quantitative analysis of bulk Ni content using XRF.
- All samples with Ni contents > 0.1% were analysed using wet chemical methods. In 1971-72 the method used was solution of the samples in a 3:1 mixture of nitric acid and hydrochloric acid ("lungesvæske". This process gave a value for bulk nickel content, both sulphide- and silicate-bound (the latter mainly in olivine).
- Reconnaissance microprobe analyses of olivine revealed Ni contents of up to 1500 ppm
- The laboratory, beginning in 1973, used a development of the bromine-water solution method developed by the Finnish geochemist Aulis Häkli (Häkli, 1971): this method gave reliable figures for sulphide-bound nickel, which was the critical parameter in economic assessment of the mineralisation. All previously analysed samples were reanalysed using the bromine water method.

The analytical data for core drilled in the period 1971-75 are provided in NGU Report 1326G (Mathiesen, 1975) which also includes a description of the bromine-water analytical method.

Reserve/resource calculations: Successively updated calculations of the tonnage and average grades of the intersected ore zones were calculated in 1973, 1974 and 1975 (NGU Reports 1173C, 1250C and 1326C). These calculations were based on the principle that each intersection in a drillhole represents an ore volume which is the sum of the intersections multiplied by a rectangular area extending half way to the neighbouring drillholes in N-S and E-W profiles. The cut-off employed was 0.15% Ni_S. Ore zones exceeding 6m thickness are included and wall rock zones exceeding 6m thickness are excluded. Intersections of massive ore in zones of disseminated ore are included at a grade of 1% Ni_S in order to avoid a disproportionate influence on zones dominated by disseminated ore. The mineralizations are delimited in all directions except at depth in the southwestern corner of the western part of the Bruvann limb of the intrusion (see Karppanen et al., 1999). (Figure 4): The total numbers of holes from which intersections are included in the calculation are 41 in the eastern ore and 16 in the western ore. The calculation for the eastern ore, which is more densely drilled and has a greater degree of regularity, is probably more reliable than that for the western ore. The final calculation in 1975 showed the figures shown in Table 1.

Eastern ore (E of the fault shown in Figure 4):	19.6 Mt grading 0.33% Ni_S
Western ore – upper zone:	9.9 Mt grading 0.29% Ni_S
Western ore – lower zone:	14.1 Mt grading 0.35% Ni_S
SUM:	**43.6 Mt grading 0.33% Ni_S**

Table 1: Calculation of Ni tenor in the main components of the Bruvann mineralisation

Geostatistical calculations were carried out in 1974 and 1977 (Sinding-Larsen, 1977). The results given by these were problematic – it is thought because of effects due to the oblique orientation of the actual ore blocks, relative to the statistical method which assumed that the blocks were horizontal.

Ore-dressing tests: Numerous ore-dressing tests on Bruvann ore were carried out at the Norwegian University of Technology (then NTH) in the period 1972-75. The results are described in 9 reports, one by Professor M. Digre and the others by Professor K. L. Sandvik. A bench test yielded a concentrate containing 7.5% Ni, 2% Cu, 0.29% Co and 39% S. A pilot test yielded a concentrate containing 5.96% Ni, 1.48% Cu and 29.95% S.

Stavanger Staal had, at a later stage (1977), a dialogue with Sulfidmalm/Falconbridge (see below): several ore-dressing tests were conducted at Lakefield Laboratories. The most interesting results were achieved using a basic pulp and a then, new gangue depressant (CMC): the result was a cleaned concentrate containing 10-11% Ni and with 80-85% recovery. Experience, it was said, indicated that adjustment of the process would give a concentrate of 10% Ni and ca. 88% recovery.

Dialogue between Stavanger Staal and other companies:
Stavanger Staal's intention was to complete the field and analytical investigations and then to seek a partner for planning and establishing a mining operation. Two companies were approached: A/S Sydvaranger and A/S Sulfidmalm/Falconbridge, the latter then one of Canada's two major nickel-copper mining companies. A/S Sydvaranger carried out a new resource/reserve calculation, using two alternative models for selective mining. These models gave total tonnages of 26.9 Mt (grading 0.33% Ni_S) and 29.1 Mt (grade not recorded).

A/S Sulfidmalm/Falconbridge carried out five alternative resource/reserve calculations, as follows:

CUT-OFF, %Ni_S	RESOURCE/RESERVE Mt	AVE. % Ni	TON Ni
0.6	3.6	0.77	27,720
0.5	8,6	0.63	54,180
0.4	12.7	0.57	72,390
0.3	26.6	0.42	111,720
0.13	44.0	0.33	145,200

Table 1: Alternative results for calculations by A/S Sulfidmalm/Falconbridge

A/S Sulfidmalm had, during the 1960s and 1970s, investigated the potential of all the major nickel deposits known in Norway, and had been responsible for several new discoveries. Negotiations relating to the Bruvann deposit were ultimately terminated.

Conclusion of Stavanger Staal's project:
Stavanger Staal experienced increasing financial difficulties through the 1970s and terminated its agreement with NGU as of the end of January, 1976, though the company nevertheless supported further gravity measurements in 1976 on roads within and around the Råna intrusion.

- **1977-80: Geological Survey (NGU) continuation of the project**

NGU applied, in 1977, for additional funding (NOK 2,165,000), in order to carry out diamond drilling in the northernmost part of the intrusion, NE of the Bruvann area. This resulted in an allocation of NOK 2,000,000 from the Ministry of Local Government (KD) and NOK 165,000 from Stavanger Staal. The basis for the application (for funding of a total of a further 6,000 m of diamond drilling) was the discovery of E-W gravity anomalies along the N margin of the intrusion: the anomalies indicated a source extending to a depth of 2 km below sea level and were of a nature which indicated that the source consisted predominantly of peridotite, the rock type which is the predominant host for the sulphides in the Bruvann area. A further NOK 970,000 was allocated by KD in advance of the 1979 field season. The following sub-projects were carried out in this period:

Geophysics

- VLF measurements in April, 1977, on the ice covering Bruvann: these measurements allowed mapping of a zone of pyrrhotitic graphite schist which underlies the lake from its NE corner, continuing westwards until, as shown by these measurements, it is cut off by the NE-SW trending fault which displaces the western part of the Bruvann limb of the intrusion obliquely downwards, relative to the eastern part. VLF measurements were also carried out W of Bruvann, in order to acquire more information on the form of sulphidic gneiss units.
- IP and VLF measurements in the northernmost part of Råndal, one WSW-ENE profile S of Kringelvann and five between Kringelvann and Råna. The purpose of these measurements was to

check the surroundings of known, exposed mineralizations, including some of the earliest discoveries, for more extensive mineralizations at deeper levels. Conductive horizons were discovered but there were no indications of Bruvann-type mineralizations.

- Turam- and VLF-measurements in the Rånbogen area (Singsaas, 1978), from Råndal eastwards as far as ca. profile 7500E. These measurements (and supplementary geological mapping) were carried out in 1977 using a grid, established in the same manner as that in the Bruvann area (see above). The Rånbogen area includes numerous irregular lenses of peridotite, some of which contain weak sulphide dissemination but also contains extensive lenses of massive sulphide and rich disseminated mineralization, mainly enveloped in shear zones. Exposures of this type of mineralization can be found in a gully in Rånbogen at ca, 6100E at 100 – 150m. a.s.l. The massive sulphides have, compared to the Bruvann mineralization, a low nickel tenor – 2-2.5% Ni_S.
- Audiomagnetotelluric measurements (AMT) were carried out by Sulitjelma Gruber, on contract to NGU as follows:
  - A long E-W profile (1200N) and a long N-S profile (4100E) on Arneshesten showed resistivity contrasts at depths of - 400m (below sea level) to -1600m.
  - A conductive zone could be observed in the eastern part of profile 1200N, rising from sea level (approximately) at 2450E to ca. 400m. a.s.l. at 2800E.
  - Measurements at 2600E/1250N did not give any signal which could be related to the massive mineralization found in the drill hole at this location.
  - Measurements were carried out in profile 2500E from 1250N to 3000N. A conductor was found at depths between sea level and 200m a.s.l. at the southernmost point in the profile: this could possibly be related to massive sulphides found in drill hole 245-125. Contrasts were found between -800m and -1600m at 1600N, 2000N, 2200N and 3000N but there were no such indications from 2500N to 2700N.
  - Measurements in the western part of the Bruvann area on E-W profile 1400N and N-S profiles 2150E and 2250E gave consistent resistivity contrasts between 100 and 200m a.s.l. which corresponds, in general, to mineralizations found in drill holes.
  - Measurements W of Arneselv, in profiles 1400N and 1500N, between 1750E and 2000E, show effects only at deep levels – ca.1100m b.s.l.
  - Measurements were also carried out in the area of Kringelvann (see above): these did not give results of significance in relation to mineralizations, possibly due to disturbance caused by power- and telephone lines.

<u>Drilling</u>:

- <u>Extensions of drillholes in the Bruvann area</u>:
  - Drillhole 235-130 was originally 522.2m long, terminating in a section of 8.5m of norite: the extension showed a further 46m of norite, containing graphite in the lowermost 4m, below which the hole intersects gneiss, probably part of the unit forming the southern margin of the Bruvann limb of the intrusion.
  - Drillhole 235-160 was originally 218.9m long and was extended to a length of 802m. The extension intersected a 10m mineralised peridotite zone found also in hole 235-170, below which the mineralized peridotite zone appears to be "cut" by a body of pyroxenite (see NGU Rapport 1582A III, Boyd, 1980). Below the pyroxenite the hole enters another major unit of peridotite in which there is weak mineralization from 438m – 450m.: this zone can be found at a similar level in hole 235-150. The host peridotite can be followed in drillholes to hole 235-120 but without mineralization in its lower levels in the southernmost holes,
  - Drillhole 225-160 was originally 432.3m long and was extended to 683.2m in an attempt to locate a continuation of the mineralized peridotite found at, or just above sea level in the drillholes to the S and in holes 235-150 and 235-160. No such continuation was found: the extension showed a complex sequence of interbanded norite, olivine norite, pyroxenite and peridotite, without mineralization: a similar sequence is found in the lowermost 150m of core in drill hole 235-160.

- Drilling on and N of Arneshesten:
  - Drillhole 360-160 was drilled vertically from close to the top of Arneshesten. The hole intersected norite with minor units of unmineralized peridotite to a depth of just over 200m after which it intersected ca. 70m of gneiss before the hole was terminated after a further 40m in norite. The gneiss intersection is probably a continuation of the wedge of gneiss which extends eastwards and then northeastwards from the NE corner of Bruvann (see Figure 4): further to the northeast, towards Råna, this structure appears to continue as a number of thin NW-dipping bands of sulphidic schist which give clear geophysical anomalies (see the map of the Arneshesten area in vol.1 of Boyd (1980). These bands may represent a thrust zone along which the Arneshesten "block", extending from Bruvann to Råna, was thrust upwards to the southeast (see Figure 3)
  - Drillhole 310-218B (drilled from the base of the NW slope of the mountain at S60^{o}E with an inclination of 45^o) penetrated the intrusion after ca. 180m in gneiss, indicating that the NW margin of the Arneshesten block is subvertical in this area. The remaining ca. 290m is dominated by norite with three thin zones (ca. 10m) of peridotite/olivine-pyroxenite and two thin zones of gneiss. A profile showing the drillholes 360-160 and 310-218B relative to the surface geology is included in vol.1 of Boyd (1980): the profile indicates that the contact between norite and gneiss NW of Arneshesten is close to vertical.
  - Drillhole 345-400 was drilled from close to the contact of the intrusion at Arnes, at S30^{o}E with an inclination of 45^o, in order to provide a section through the banded sequence exposed at the surface. The hole was drilled to 259m in the autumn of 1977 and extended to 694m the following spring. The lithologies are similar to those exposed on the surface but tectonic disturbances and the vertical gap make correlation speculative. Three intersections in peridotite show mineralization: 274 - 284m (0.15% Ni), 298 - 318m (0.17% Ni) and 442 - 462m (0.1/% Ni).
  - Drillhole 300-360A was drilled on country rock, SW of the previous hole, in order to investigate whether the intrusion, potentially peridotite-bearing, could be penetrated at depth. The hole was drilled to 645m. At the surface the gneisses dip steeply NW and the schistosity is cut at a narrow angle throughout, approximately, the uppermost half of the core. The schistosity is, however, approximately normal to the core axis throughout the lower half of the core: this may indicate that an extension would have penetrated the intrusion but there was no available basis for estimating at what depth.
- Drillhole 475-447, NW of Råna: this drillhole was located in an aggregate quarry on the S side of the E6, approximately 500m NW of the bridge at Råna. The hole was located to test the rocks coincident with part of the gravity anomaly (see above) which extends along the northern margin of the intrusion and which indicates the presence of dense rocks, probably peridotite, to depths of ca. 2 km below sea level. The uppermost 100m of the core consists of three major units of norite uppermost, followed by peridotite and another norite unit. This is followed by 200m of core containing numerous intersections of norite and pyroxenite, mainly < 10 m thick but with one 20m intersection of norite: within the 200m there are also seven intersections with gneissic wall rock up to ca. 20m thick. From ca. 280m to 562m the hole intersects major units of peridotite and norite with traces of sulphide in the lowermost peridotite at 480-520m. The lowermost part of the core intersects calcsilicate gneiss (?5m) and finally 50m of gneiss, which may represent part of the structure underlying the upthrust Arnes block (see NGU Rapport 1582A I, Boyd, 1980 and the interpretation of drillhole 360-160 above.)
- Rånbogen: Two holes were drilled, 645-413B towards the S at 45^o inclination and 645-413C towards the N at 60^o inclination. A previous attempt to intersect the mafic rocks from a hole placed N of the outer contact (6330E-4240N) had to be abandoned because of the depth of overburden. The cores (respectively 456.1m and 207.4m) showed less peridotite than indicated by surface mapping and almost no sulphide content.
- Kringelvannet: Hole 597-246 was drilled to a depth of 393 m. to test the source of an AMT anomaly (see above): the core was almost entirely norite and no significant mineralisation was found.

5. Assessment by the Preparatory Råna Committee/Forberedende Rånautvalg (1980-81)

The results of the investigations described above could legitimately be considered to indicate that the Råna intrusion and specifically, the Bruvann deposit, was one of the most promising metallic deposits known and systematically documented in Norway in the late 1970s. The information compiled also indicated potential in addition to the documented sulphide-bearing zones in the Bruvann area. The calculations and assessments made by and for Stavanger Staal were, however, for various reasons, incomplete: e.g. they did not consider:

- Exploitation of reserves accessible only with underground mining, nor beneficiation using selective flotation.
- Mining of higher-grade reserves in the initial, cost-intensive period.
- Assessment of co-products in addition to sulphide concentrate.

The above conclusions are taken from a memorandum written by C. O. Mathiesen in January, 1977, which formed part of the basis for the funding for additional investigations granted by the Ministry of Local Government (KD) in 1977, and for the subsequent establishment of the Preparatory Råna Committee (PRC) in June, 1980. The PRC had the following members:

Chairman:	Docent Knut L. Sandvik, NTH
Members:	Director Ottar Brekke, Rana Gruber
	State Geologist Rognvald Boyd, NGU
Secretary:	State Geologist Carl O. Mathiesen, NGU

The mandate for the PRC was as follows:

1. Preparation of a plan for further assessment, including a proposal for the professional composition of the Committee.
2. Preparation of a proposal for the mandate for the Assessment Committee.
3. Preparation of a budget estimate for the work of the Assessment Committee.

The conclusions of the PRC report, submitted in March, 1981, can be summarised as follows:

- <u>Potential products:</u>
  - <u>Sulphide concentrate</u>: Microprobe data indicate that ≥95% of the total content of sulphide-bound nickel (Ni_S) is in pentlandite, the remainder being in exsolved flames of pentlandite in pyrrhotite. It is important to assess the potential for selective flotation of the pentlandite, both in relation to the value of the concentrate, the cost of its transport to a smelter and the optimalisation of the metallurgical process to be applied.
  - <u>Olivine</u>: The PRC noted that there had, in recent years, been heightened interest in iron-ore pellets containing magnesium silicates as an additive (i.e. olivine or olivine+orthopyroxene). Chemical requirements for the additive are: < 0.1 % K_2O, and total alkali < 0.3 %. The host rock of the Bruvann mineralisation is peridotite, in which the dominant silicates are magnesium-rich olivine and pyroxene. The tailings from flotation of the ore could be considered to be suitable as an additive in iron-ore pellets.
  - <u>Magnesium</u>: Olivine is acid-soluble and could, potentially, be used for production of magnesium metal: Norsk Hydro had, however, shown that olivine would not be a competitive source for magnesium for the then foreseeable future.
  - <u>Aggregate</u>: The dominant rocks in the Bruvann extension of the Råna intrusion are: peridotite, pyroxenite and norite. Earlier tests had shown that all of these meet the requirements of the road authorities for crushed rock in asphalt. Peridotite meets the requirement, but norite is of very good

quality in relation to this application and pyroxenite exceptionally good. Both of the latter rocks are pale green in colour and are potentially of interest in other aggregate markets, especially in Nordland and Troms counties (in which few deposits of high-quality aggregate were then known).

- Economically viable operation
  Realistic assumptions were made regarding product price levels, investment costs and production volumes, based on open-cast mining of the eastern part of the Bruvann mineralization. It was concluded that viable operation could be achieved if one or more of the following results could be achieved:
  - Olivine could be produced as a co-product, with a payable tonnage at a payable price.
  - The stipulated price for Ni concentrate is increased, either by improved processing or by negotiating a better price than so far stipulated by Outokumpu (50% payment for the metal content of the concentrate).
  - Preferential mining of rich ore in the amortisation period.
  - An increase, with further prospecting, in the reserves of rich dissemination and massive mineralisation.

- Components in a feasibility study
  The following components were considered necessary:
  Process studies, laboratory tests and market investigations:
  - Flotation: Tests have to be carried out with the aim of proving that it is possible to produce an acceptable sulphide concentrate and an olivine(-orthopyroxene) concentrate, "in parallel" from the same ore. This required detailed information on variations in Ni:S ratios and in the compositions of olivine and orthopyroxene. Bench tests must be followed by pilot-scale tests. This also applies to assessment of the tailings in relation to the chemical requirements for a pellets additive.
  - Pelletisation: Preliminary investigations suggest that there is interest in an olivine-orthopyroxene product for use in iron-ore pellets and that such a product could add significantly to income from mining the Bruvann deposit. Necessary steps include: systematic information on the composition of the silicates, bench- and pilot-flotation tests and pelletisation tests.
  - Concentrate – alternative processes: A quotation had been received from Outokumpu for smelting of a concentrate containing 7.5 – 11% Ni. Possibilities for improving the concentrate by selective flotation or the terms by negotiation should be followed up. Hydrometallurgical processing of the concentrate as an alternative to smelting, should also be considered (Falconbridge, then, could carry out the necessary tests.)
  - Aggregate: The volume of the relevant rock types in a projected mineable volume should be calculated and appropriate tests in relation to market requirements carried out. Market studies should also be carried out.
- Bulk sampling: This can be carried out from the cross-cut in the underground workings at Bruvann but this will necessitate acceptable securing of the adit opening and the underground workings, and improvement of the road from the E6 to Bruvann. Larger samples can be acquired from the surface.
- Analytical studies: The following were considered necessary:
  - Analysis of S in core previously analysed only for Ni.
  - Analysis of the alkali content in representative core samples
  - Analysis of the Fe:Mg ratio in the above cores and, by microprobe, in representative grains of olivine and orthopyroxene within them (*carried out in 1980-82*).
  - Analysis of the contents of gold and platinum metals in representative samples of the mineralization (*carried out in 1985: Boyd et al., (1986, 1987*).
- Reserve calculation: The following were considered necessary:
  - The existing reserve calculation was based on the statistical hypothesis that each ore intersection in a core was representative for a block extending half the distance to the nearest intersections in

"neighbouring drillholes" in N-S and E-W profiles. The PRC recommended that plans for an open-pit and underground mine should be based on a geological interpretation of the form of the ore zones and their internal grade variations. This would provide the basis for defining mineable blocks. (*The geological interpretation was produced in 1980*: *NGU Report 1582A, Boyd, 1980*).

- Calculation of the tonnage of co-products.

6. LKAB: Evaluation and olivine production, 1982 - 1987

Consideration of a product based on olivine-dominant tailings from a future mine at Bruvann (see above) made it logical to consult LKAB – both as source of information on the quality requirements for the olivine, and as a potential user of an olivine concentrate, and because of the ideal logistical location of the deposit in relation to the LKAB railhead in Narvik and the availability of rail capacity to transport an olivine concentrate to Kiruna.

LKAB carried out a supplementary drilling programme in the eastern part of the Bruvann deposit in 1982: records available at NGU indicate that the programme included 17 drillholes to depths of up to 80m, but the number may have been larger. Pilot-scale production of olivine from an open-pit was carried out from 1982 to December 1985 (Krogh & Lindahl, 1988). The company was, in November 1985, granted a concession for production of up to 200,000 t/a of olivine. Production was increased to 85,000 t in 1986, but was reduced to 45,000 t in 1987, due to a requirement for a more magnesian olivine as additive to the pellets produced in Kiruna. Subsequently, after a period during which olivine was purchased from A/S Olivin, LKAB (through its daughter company, Minelco) acquired and developed the Seqi olivine deposit on the W coast of Greenland as a source of olivine.

7. Nikkel og Olivin (LNS)/Outokumpu, 1987 - 2002

The company Nikkel og Olivin AS was established in 1987 on the basis of a concession for production of sulphide- and olivine concentrates from the Bruvann deposit. The main owner of the company was Leonhard Nilsen og Sønner, who had extensive experience from contract mining (including cooperation with Outokumpu) and tunnelling. Outokumpu Oy took over the major shareholding and operational responsibility from 1992. Outokumpu was the logical recipient for concentrate from Bruvann and also had interests in other sulphide mines in Norway.

Outokumpu Harjavalta Metals established, in February 1992, an exploration project aimed at extension of the reserves available and, if possible, improvement of their grade. The project applied a range of geophysical, geochemical and geological methods on topics with a direct impact on exploration (Karppanen et al., 1999): it was supported by the European Commission's GeoNickel Project. (The second author was a member of a "support group"). Key questions were related to the genesis of the intrusion and its sulphides and the current geometry of its primary structures.

Key conclusions included:

- The Bruvann ore is direct evidence of ultramafic-related ore formation.
- Lithogeochemistry similar to that at Bruvann has been found in other localities and mineralisations may, by drilling, be discovered in further areas.
- Applied geophysical methods have located abundant structures considered favourable for ore occurrences.

Eight targets were identified and ranked.

The geophysical survey conducted in the Bruvann area by NGU (Singsaas et al., 1973) indicated the presence of a conducting zone at greater depth W of the NW corner of Bruvann and continuing northwards, W of the western contact of the Bruvann limb of the intrusion at the surface. Outokumpu (Karppanen et al., 1999) tested this anomaly, beginning in 1996, and proved the presence of ultramafic rocks at depth under the northern half of the lake, Bruvann, and in a zone 200m wide, along the western contact as far N as 1151500N (Figure 4). Several drillholes reached ultramafic rocks in these areas: comparison with the magmatic sequence in the defined ore bodies indicated that potential continuations of mineralized peridotite zones could be found at levels below sea level.

Outokumpu (Karppanen et al., 1999) drilled 13 holes within or close to the southern contact of the eastern ore body at Bruvann in a search for massive or rich sulphides. Several intersections, up to 4.2m thick contained > 1.5% Ni and >1% Cu: several of the holes had to be terminated due to their meeting water under pressure. Karppanen's report can be understood to imply that there is further potential

Outokumpu Oy decided, in 2000, to focus its operations in the Nordic countries on stainless steel and to withdraw from mining in Norway and Finland (though retaining ownership of the Kemi chromite mine). The Nikkel og Olivin mine at Bruvann was closed in 2002 after thirteen years of operation. Scandinavian Highlands (2013), who subsequently held the rights to the deposit (see below), cited Nikkel og Olivin as stating that "*the Bruvann Ni-Cu-Co mine ... has a remaining inferred resource of 9.15 Mt grading 0.36% Ni (0.3% cut off), 0.1% Cu and 0.02% Co*".) It has been estimated that the annual production had a Ni metal content of 3,000 t. Scandinavian Highlands have also stated that: "*The total mined tonnage from 1989 to 2001 was 8.2 Mt with a grade of 0.52% Ni and a cut off in the range 0.43−0.47 depending on the nickel price."*(http://scandinavian-highlands.com/projects/bruvann-nickel-copper-cobalt-deposit.aspx)

8. Scandinavian Highlands

Scandinavian Highlands, a Danish company, established several prospecting projects in Northern Norway (and in Germany and Sweden) in 2004-2005: these included a project focussing on the northern part of the Råna intrusion, from Bruvann to Rånbogen, held by a subsidiary company, ApS. The company focussed on the northern part of the intrusion, specifically the Arnes and Rånbogen areas.

Exploration work in the prioritised area included:

- Geochemistry: surface rock sampling (400), stream sediment sampling (50) and topsoil sampling (4000).
- Airborne geophysics: two SkyTEM surveys (185 line km) with Maxwell modelling of the data.
- Ground geophysics: 2 km^2 magnetic survey and 1.5 km^2 EM survey, on targets areas.
- Diamond drilling: 16 holes, totalling 4,000m, with analysis of the core by ICPMS.

The company presented a key conclusion at the CIM meeting in Vancouver in 2013 as follows: *"Based on 2006 and 2007 surface drilling an inferred resource of 58 Mt grading 0.25% Ni, 0.04% Cu and 0.01% Co is situated surface near along the marginal zone of the intrusion".* A link to the presentation is given in the reference list.

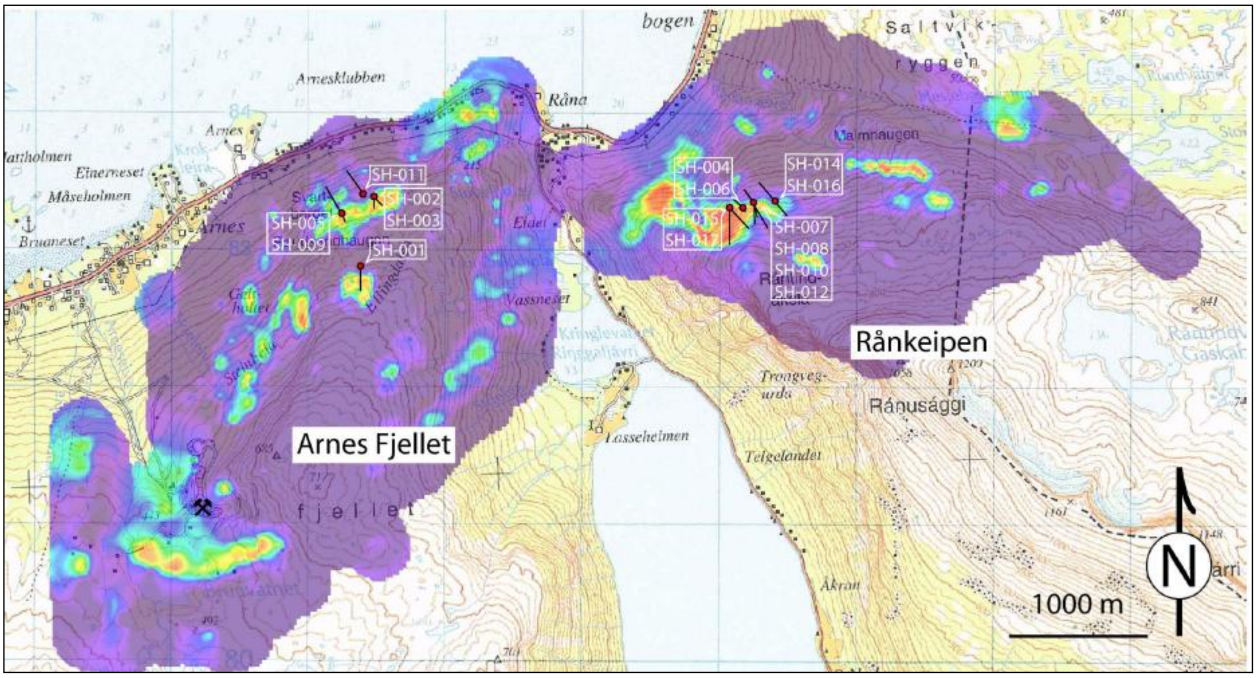


Figure 6: Results from SkyTEM survey and location of holes drilled by Scandinavian Highlands in 2006 - 2007 (from a presentation at CIM meeting in Vancouver, 2013)

Ten holes were drilled at a level of ca. 500 m a.s.l. at the northern margin of a geophysical anomaly NW of Rånkjeipen. Data on sulphide-bound nickel are available for two of these holes: one shows grades of Ni_S of predominantly ca. 3% for sulphide contents of up to 20%, but mainly 2 – 5%: the other shows tenors ranging from 1-7% for sulphide contents predominantly from 2 – 5%. These tenor values are similar to those found in the core from the holes drilled in Rånbogen in 1979 by NGU. The claims once held by Scandinavian Highlands are now held by Ofoten Minerals, a Danish-owned company, listed on the Perth stock exchange in W. Australia: this company also has it main focus on the northern margin of the intrusion.

Scandinavian Highlands contracted NGU, in 2007, to prepare an assessment of the results from a number of their drillholes and of the prospectivity of different parts of the Råna intrusion: the report (see abstract below) was confidential until 31.12.2010:

Boyd, R., 2007: Ni-Cu-PGE potential of the Råna Intrusion: 2006 drilling program. NGU Report 2007.078
The abstract of the report is as follows:
This report considers: 1) The prospectivity of different parts of the Råna intrusion: 2) Data sets generated from core drilled in 2006 (and relevant core drilled by Outokumpu and NGU) and possible correlations indicated by the geology of the cores, 3) The significance of microprobe data from different parts of the Råna intrusion and 4) Possible targets for further work.

Key conclusions/proposals include:
- Variations in the assemblage of cumulate minerals suggest that there may be lateral variations in the Ultramafic Series, which explain some of the contrasts between the rocks seen at Arnes, at Bruvann and in Rånbogen.
- The cumulates intersected by the SH holes at Rånbogen may be part of a sequence which is not seen at Arnes or Bruvann: they contain very little clinopyroxene.
- The Ultramafic Series in the southern part of the intrusion reveals part of the overall differentiation sequence (carrying olivine with lower Fo content), which is not exposed on the northern periphery of the intrusion. Though there is limited mineral-chemical data from the core of the intrusion, it may also be that the Mafic Series, as exposed, is also incomplete, parts of the chamber having been displaced by tectonic instability during crystallization (as indicated by the dykes in Rândal – see figure below).
- Amounts of nickel, which are significant in low-grade disseminated mineralization, enter into olivine and lesser amounts into orthopyroxene. Sulphide-bearing core should therefore be analyzed for sulphide-bound Ni, Cu and Co

(bromine-methanol). As a check it would be useful to have a student do a microprobe project on the trace metal contents of olivine and opx in key zones.

- It could be useful to present certain problems to an expert on high-precision gravity surveys, e.g. Brudalen, the section between Bruvann and Arnes, possibly a wider area.
- The SH team could consider looking at the Saltvik area, where mineralizations investigated in pits and short adits may be linked by a weak EM anomaly 1000m long in norite (scattered samples show ~2% Ni_S) (Singsaas & Flood, 1963). It is not certain that the most sulphidic samples have the highest Ni_S. This could be an analogue for the mineralizations drilled in Rånbogen.
- Targets at Brudalen, Bruvann SW, Saltvik and possibly between Arnes and Bruvann W should be considered.
- The conclusion still stands that it is unlikely that the Bruvann mineralization is the richest in the complex. The gravity data indicate that the lowermost portions of the northern part of the complex, down to c. 2 km below sea level along its NW periphery, are dominated by ultramafic rocks. Investigation of this volume of rocks, even at a reconnaissance level, would require several deep drillholes. Application of the most sophisticated geophysical methods available would be a logical precursor to drilling.

The report includes the following figure depicting the range of the Mg-end members in orthopyroxene and olivine in different parts of the intrusion.

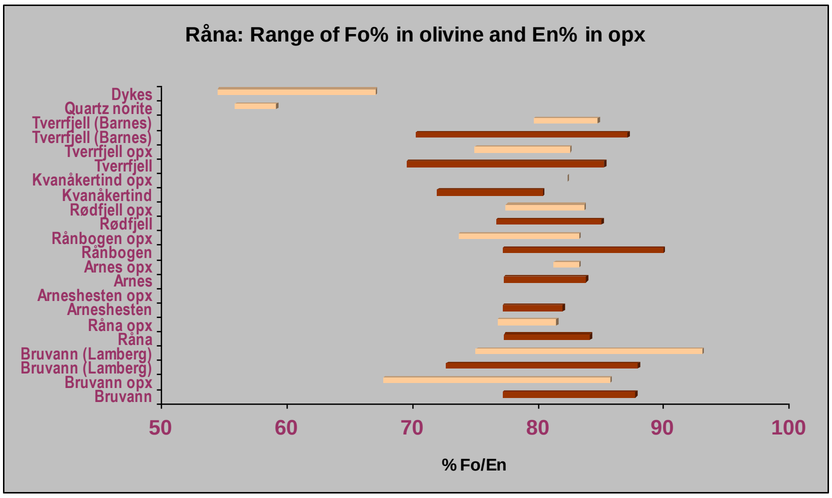


Figure 7: Range of olivine and orthopyroxene compositions in different sectors of the Råna intrusion (from Boyd, 2007), including data from Barnes (1986) from Tverrfjell and from Lamberg (2005) from Bruvann. Data for olivine are in brown and for orthopyroxene in fawn

9. Geological publications relating to the Råna intrusion

- Foslie, S., 1921: Field observations in Northern Norway bearing on magmatic differentiation

  This 19-page paper was published in the University of Chicago Press journal, Journal of Geology, late in 1921. It presents the geology and mineralogy of the Råna intrusion in the context of the then current understanding of the phase petrology of this type of intrusion as proposed by Bowen (1915, 1919). Foslie rejects the theory that the intrusion formed by "gravitative differentiation" in a "magma basin" and was subsequently "thrown down in an inverted fold". He maintains that "the norite body forms a lens in its normal position between the schists, with a mean dip of about 30^o, and the basic border zone is quite as well developed in the upper as in the lower part of the lens." Foslie, following one of Bowen's theories, envisages that olivine (and orthopyroxene) crystallized to form an outer zone within the magma-filled lens with interstitial magma being gradually squeezed into the core of the lens as the lens was compressed by orogenic processes – "the squeezing theory" of Bowen (1915). Comparison of Figures 1 and 3 indicates that the distribution of the mafic and ultramafic rocks shown by Foslie (Figure 1) has not been changed dramatically. Our understanding of the tectonic context of the intrusion, at regional and local scales, has, however, changed dramatically. The presence of slices of wall rock within the northern and southern parts of the intrusion, the delimitation of its north-western part, from Bruvann to Råna, by a wedge of wall-rock which thins in a north-easterly direction and intrusive relationships between different magmatic components indicate a much more complex evolution than that advocated by Foslie.

Foslie (1941), in his description of the geology of 1:100 000 map-sheet Tysfjord, as well as describing the part of the Råna norite within that sheet (approximately two-thirds), describes the Sørfjord norite, a klippe SW of the Sørfjord arm of Tysfjord: further east there are a further three, smaller klippen. Foslie describes the Sørfjord rocks as being "quite identical" with those in the basal parts of the Råna intrusion. The underlying lithologies suggest that the Råna and Sørfjord bodies were emplaced at similar tectonostratigraphic levels. Crowley (1989) describes a gabbroic complex, the Marko Complex at a similar tectonostratigraphic level, over 30 km to the east, 5-10 km over the border with Sweden.

Foslie's description forms the basis of a brief description of the intrusion in the volume on "Caledonian Rocks of Igneous Origin" within the Caledonides in S. Troms and Ofoten published by Gustavson (1969). Gustavson includes a section on comparison of older and younger mafic intrusive in the Caledonides of N. Norway and supports the observation of similarities between the Råna intrusion and the Haldit intrusion in N. Troms (Hausen, 1942) which were shown, by later work (Tucker et al, 1990; Vaasjoki & Sipilä, 2004) to be, within error margins, of the same age.

- <u>IGCP Project 161: Sulfide Deposits in Mafic and Ultramafic Rocks: Participation, cooperation (on S. Isotopes and PGE) and scientific papers</u>

Falconbridge/Sulfidmalm, during their assessment of the Bruvann deposit in 1977, engaged, as a consultant, Professor Anthony J. Naldrett of the University of Toronto, one of the world's most renowned experts on the geology of Ni-Cu-PGE mineralisations. The second author was a guide during an excursion in the Råna intrusion. The Bruvann mineralisation created interest for a number of reasons, one of them being its location in what many geologists would have considered as a "synorogenic" mafic intrusion (i.e. emplaced contemporaneously with orogenic deformation). Later work (see below) suggests that "intraorogenic" is more appropriate (i.e. emplaced during a possibly extensional episode between compressional phases). Contact with Professor Naldrett and other participants in the IGCP project led to the following:

- An invitation to present a paper on the Råna intrusion at an IGCP Project 161 symposium in Toronto in October, 1978, the paper to be published in Canadian Mineralogist (Boyd & Mathiesen, 1979).
- An invitation to participate in IGCP Project 161: Sulfide Deposits in Mafic and Ultramafic Rocks. This ultimately led to the project's second "Nickel Sulfide Field Conference 1980" being held in the Nordic countries with field trips to Råna, nickel deposits in the Umeå region and most of the nickel mines and prospective areas for Ni-Cu-PGE in Finland. The conference attracted thirty participants from universities and geological surveys in numerous countries and from industry (INCO, Falconbridge, Outokumpu and Western Mining).
- Contact with Geochron Laboratories who carried out sulphur isotope analyses on sulphide from 46 samples including different types of mineralization within the Bruvann deposit (35) and from bands of blackschist both within and outside the intrusion (4 and 7 samples). The results were reported in Boyd & Mathiesen (1979) and are summarised in the section below on that paper.
- Contact with a group of specialists at the United States Geological Survey who undertook analyses of the platinum metals in the Bruvann mineralization (see: Boyd, McDade, Millard & Page, 1987).

- Boyd, R. & Mathiesen, C.O., 1978: The nickel mineralization of the Råna mafic intrusion, Nordland, Norway, Canadian Mineralogist 17, 287-298. This paper presents an understanding of the intrusion in relation to the field relationships as shown in Figure 3 (above). Important advances in knowledge of the surface geology relative to the map in Foslie's 1921 paper are:
    - Definition of the northwestern (Arneshesten) block of the intrusion by a wedge of gneiss extending from S of Bruvann and the top of Arneshesten and continuing, in the form of several shear zones, north-eastwards to Råna: the shear zones include several lenses of metasedimentary rocks and are marked by EM anomalies indicating the presence of graphite. Surface observations, the form of the geophysical anomalies and one drillhole intersection (hole 360-160) indicate that the zone is a continuous feature and that it dips, in the uppermost 150m, at ca. 45^o NW.
    - Recognition of a steep-to vertical SW-NE-trending fault along which the western part of the Bruvann limb of the intrusion is displaced downwards by ca. 300m (Boyd, 1980, Volume IV)
    - Recognition of curvilinear shear zones which define the eastern margin of the Bruvann area, the southern and eastern margins of the block dominated by ultramafic rocks at Arnes and the block, predominantly of noritic rocks immediately W of the bridge at Råna.
    - Recognition of the northward extent of gneissic rocks on the W side of Storvann as far as the 0 base line (Figure 3).
    - More precise information on the SE part of the intrusion, both of the form and extent of the gneissic country rocks and of the spectacularly layered mafic and ultramafic rocks on the Tverrfjell plateau.

  Further important features include:
    - The presence of an E-W-trending block of ultramafic rocks, indicated by gravity data as extending below the surface from Arnes to Råna with dimensions of 1km N-S, to a depth of ca. 2km.
    - Complex interleaving of magmatic rocks and wall rocks along the southern margin of the Bruvann limb of the intrusion: these features can be seen in several drillhole profiles.
    - Close to tight folds of norite/metanorite including lenses of ultramafic rocks in the SW part of the intrusion, S of Sepmolfjell (see Figure 4). These structures are not necessarily "in situ" relative to the "marginal" norite on Sepmolfjell and have no obvious continuation E of Råndal.
    - The spectacular primary magmatic layering on the Tverrfjell outlier which could clearly represent the basal sequence on the outer thin, "rim" of an originally funnel- shaped intrusion.

  The sulphur isotope study showed that the isotopically lighter sulphur of the type found in the black schists, also as slices within the intrusion, had very local, limited importance in massive sulphides which were also graphite-bearing. The results from disseminated mineralization in different host rocks clearly indicate that the sulphur in these originated in an uncontaminated magma from a deep-seated source: the only exceptions are four samples from dissemination in norite which also contains graphite.

  The general conclusions from these and other observations were that the intrusion has a gross stratigraphy which conforms to the pattern of many petrologically similar intrusions, but which has been deformed and disrupted by Caledonian folding and local thrusting. The body has the form of an inverted, possibly truncated funnel, the axis of which plunges to the NW at a moderate angle, but which has been disrupted by SE-directed thrusting (the Bruvann-Arnes block) and later bock faulting. The up-thrusting of the NW part of the intrusion exposes a much deeper level of the original intrusion that that seen in the westernmost part of the intrusion between Bruvann and Sepmolfell and along the eastern contact N of Klubbviktind.

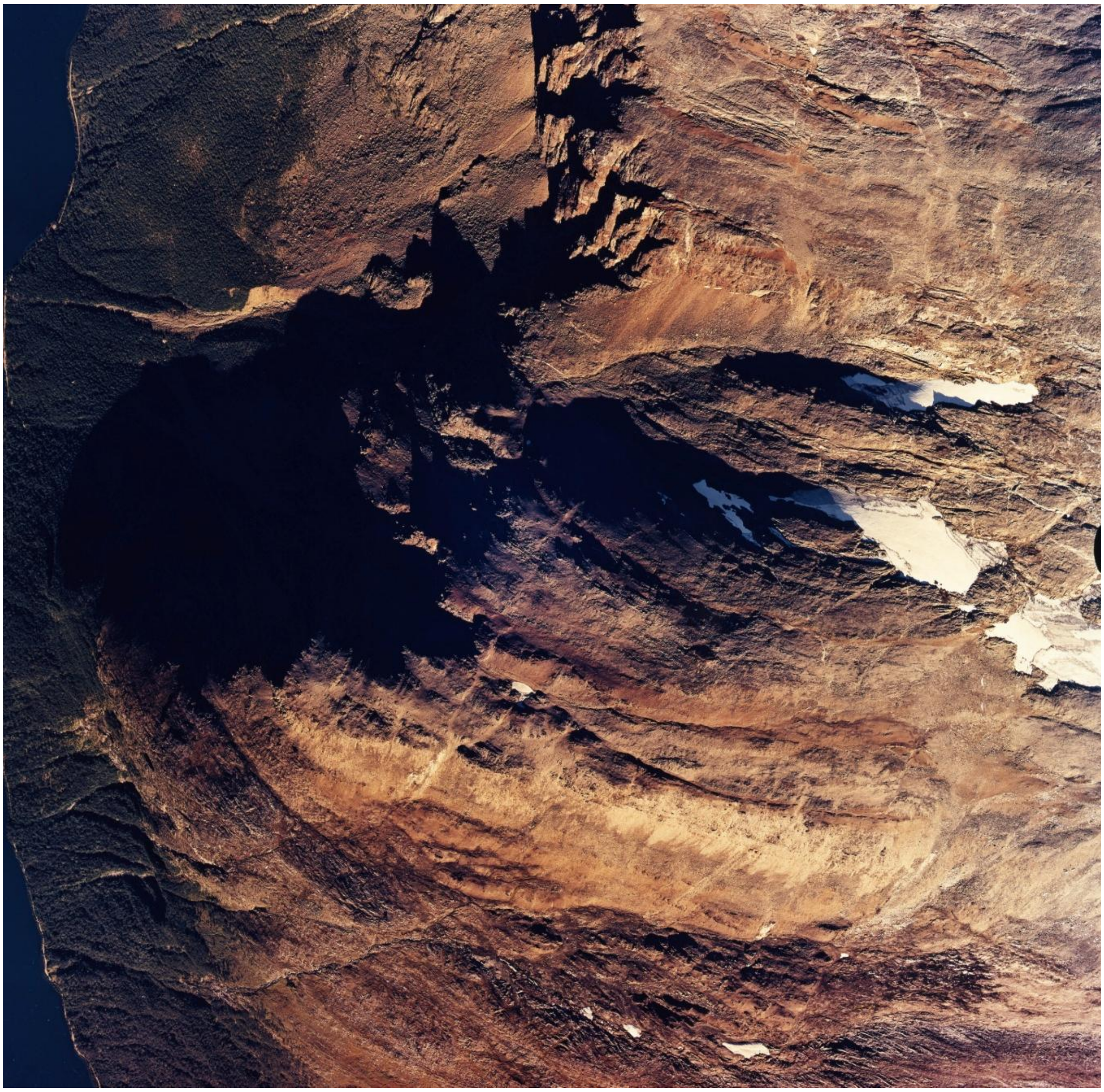


Figure 8: Aerial photograph of the Tverrfjell plateau. The southern contact of the intrusion is marked by a shallow gully at the base of buff-coloured weathered mafic rocks, magmatic layering, marked by reddish weathered olivine cumulates and displacement of layers along faults in the northern part of the plateau**.**

The Tverrfjell "klippe" shows numerous cyclic units including basal zones of peridotite overlain by pyroxenite and norite. The ultramafic layers are much thinner than those found in the NW part of the intrusion, which suggests, by analogy with many well-documented intrusions of a similar type, that the units on Tverrfjell formed on, or close to the base of a thinner, peripheral part of the original magma chamber.

- Barnes, S.J., 1986: Investigation of the potential of the Tverrfjell portion of the Råna intrusion for platinum group element mineralization, NGU report 86.021.

  The IGCP Project 161 field trip in 1980 included an excursion to the southern margin of the Tverrfjell klippe. The 30 participants were flown, in perfect weather, by helicopter from Narvik to a horizontal area just N of the contact. The sequence of cumulus minerals in the intrusion in general (olivine – orthopyroxene – plagioclase in the "basal" levels) and, in part, at Tverrfjell has some features in common with some of the most famous layered intrusions known, several of which contain major platinum-metal mineralizations. The lowermost part of the cumulate sequence shows spectacular layering and features formed by sedimentary processes in the magma chamber such as current bedding. These created a great deal of enthusiasm among the participants and a consensus among several that the area should be studied in greater detail. Consultations with Professor A.J. Naldrett, University of Toronto, and Dr. Roger Eckstrand, Geological Survey of Canada, contributed to the conclusion that the petrology of the Tverrfjell area could be a suitable topic for a post-doctoral fellowship. A proposal for such a fellowship was granted financial support by LKAB, NTNF (Science and Technical Research Council of Norway) and the Geological Survey of Norway: Dr. Sarah-Jane Barnes (Ph.D., Toronto) was appointed to a three-year fellowship which was carried out in the period 1984-86.

The following is a summary of her final report:

"Nickel sulphides from the Bruvann nickel sulphide deposit in the Råna Layered Intrusion are extremely depleted in platinum group elements (PGE). This observation and the similarities in mineral chemistry and crystallization order between the intrusion and the Bushveld and Stillwater layered intrusions led to the suggestion that there might be a Merensky Reef-like platinum deposit elsewhere in the Råna Layered Intrusion. The Tverrfjell portion of the intrusion was selected for a detailed investigation for such a deposit. The area was mapped on a scale of 1:5,000 and over 150 samples were collected along three traverses across the stratigraphy. These samples were investigated petrographically; over 2000 microprobe analyses of the minerals were made, 146 of the samples were analysed for major and trace elements and 136 for noble metals and 46 for REE.

The principle conclusions of the study are as follows:

- There is no noble metal deposit in this portion of the intrusion. The highest Pt values obtained were 30-50 ppb, the average was 6 ppb. Reconnaissance work at two other localities in the intrusion, Eiterdalen and Rånbogen, also indicated low Pt values. Therefore it seems unlikely that the intrusion contains any Pt deposit.

- As in the case of the Bruvann rocks, if the analyses are recalculated to 100% sulphides the calculated sulphides are depleted in platinum group elements relative to Ni and Cu. The recalculation of the analyses to 100% sulphides assumes that all the noble metals are in sulphides and that the presently observed sulphur values in the rocks represent the igneous values. Both of these assumptions are questionable, so instead of considering the 100% sulphide normalized values, this report has considered the whole rock values for Cu and Ni (base metals). The whole rock compositions at Bruvann, Rånbogen, Tverrfjell and Eiterdalen are anomalous in terms of high Cu/Ir (447-2380 x 1000) and at all four localities in terms of high Ni/Ir (2795-13333 x 1000) ratios. Similarly, the Cu/Pd (84-214 x 1000) and Ni/Pd ratios (302 – 1200 x 1000) are very high compared with igneous rocks from the literature. At all localities the Ni/Cu ratios (3.5 – 6.3) are primitive. Pt exhibits a similar behaviour to Pd. If these ratios are the result of igneous processes, then the magma that formed the Råna Layered Intrusion was depleted in platinum group elements relative to base metals.

- The whole rock geochemistry and mineral analyses suggest that the liquid from which the Tverrfjell rocks crystallized was a primitive olivine tholeiite with an MgO content of the order of 12%. The initial liquid has affinities with E-MORB or ocean island tholeiites. The most forsteritic olivines found in the intrusion are found at Rånbogen, which indicates that the Tverrfjell sequence does not include the stratigraphically "lowest" part of the magmatic stratigraphy of the intrusion. One possible reason for the unusual base-metal to PGE ratios at Råna is that the mantle which melted to produce the Råna magma was depleted in platinum group metals by a previous melting event. The initial liquid at Råna was not depleted in highly incompatible elements such as Cs, Rb and LREE and therefore it seems unlikely that it was derived from depleted mantle. However, this hypothesis cannot be ruled out entirely because the exact nature of E-MORB is still a controversial subject. Some models suggest that E-MORB is derived from depleted mantle and then contaminated to produce the enrichment of highly incompatible elements. Isotope work will be necessary to rule out this option completely. A single-stage partial melting event of primitive mantle could not produce such high base-metal to PGE ratios and the restite of such an event would have lower base-metal to PGE ratios than primitive mantle, therefore melting of depleted mantle will not produce a magma with high base-metal to PGE ratios.

- Cu, Pt, Pd and Au are not incorporated into silicate minerals to any large degree therefore silicate crystal fractionation will not change the Cu to Pt, Pd and Au ratios. Sulphide accumulation decreases the base- to noble-metal ratios therefore cumulate processes in primitive magma will not produce rocks with high base- to noble-metal ratios. However, removal of a small amount of sulphide prior to the emplacement of the magma pulses to their present position would increase the base-metal to PGE ratios in the silicate melt sufficiently to generate rocks similar to those observed at three of the localities. In order to account for the base-metal/PGE ratios observed at Tverrfjell, sulphide and olivine fractionation prior to separation and emplacement of the magma pulse from which these rocks crystallized is necessary.

See also:

Barnes S.-J., 1987: Unusual nickel and copper to noble-metal ratios from the Råna layered intrusion, northern Norway. Norsk Geologisk Tidsskrift, 67, 215-231.

Barnes S.-J., 1989: Sulphide-segregation history of the Tverrfjell portion of the Rana Layered Intrusion. In: Prendergast, M.D., Jones, M.J. (Eds.), Magmatic sulphides-the Zimbabwe volume. Institution Mining Metallurgy, 229-239.

- Tucker, R.D., Boyd, R. & Barnes, S.-J., 1990: A U-Pb zircon age for the Råna intrusion, N. Norway: New evidence of basic magmatism in the Scandinavian Caledonides in Early Silurian time. Norsk Geologisk Tidsskrift 70, 229-239.

  Abstract: Four morphologically distinctive zircon types from quartz-bearing gabbronorite in the Råna intrusion in the Narvik Nappe Complex yield coincident and concordant U-Pb analyses indicating a crystallization age of 437 +1/-2 Ma. The intrusion, which consists of ultramafic and mafic cumulates derived from a high MgO tholeiitic parental magma, was emplaced into argillaceous sediments within a probable marginal basin or back-arc setting prior to its tectonic emplacement onto the Baltoscandian Shield. The age of the Råna intrusion, together with other zircon ages from similar layered mafic intrusions and ophiolites in Norway, provides evidence for a distinct and possibly short-lived period of back-arc spreading and mafic plutonism in the upper part of the Upper Allochthon and in the Uppermost Allochthon of the Scandinavian Caledonides in Early Silurian time. The intrusion was emplaced during a period of regional crustal extension that post-dates the local D_1 deformational phase and pre-dates phases D_2 - D_6. The main period of regional metamorphism in the Narvik Nappe Complex post-dates emplacement of the Råna intrusion, and it is concluded that these latest deformational phases are probably related to the medial Silurian Scandian orogeny and not to the Cambrian-Early Ordovician (?) 'Finnmarkian' orogeny, as previously supposed. Several of the "similar layered mafic intrusions and ophiolites" are listed by Andreasson et al. (2003).

- De Vries, P.R., 1993: Relationships of chromian spinel and olivine compositions with Ni-orebody forming processes at the Råna intrusion, North Norway. M. Sc. Thesis, University of Utrecht (the initiative for this thesis project was taken by Professor Adrian van der Veen, who was a participant in the above-mentioned IGCP Project.)

  Abstract: "The Råna intrusion (North Norway) mainly consists of norites, pyroxenites and (lherzolitic) peridotites. The peridotites are the host rocks for several (sub-) economic nickel deposits. Symplectitic coronas around olivines, amphibolitized pyroxenes and several other mineral alterations suggest that the rocks went through a long and complicated history of cooling and metamorphism. The mineralizations consist of pyrrhotite, pentlandite and chalcopyrite. The sulphides mainly occur as net-texture sulphides interstitially to early silicates. Chromian spinel only rarely occurs. The Zn chromian spinel ore-guide (Groves et al., 1976) appears to be ineffective to predict nickel mineralizations in the Råna intrusion. Both the Ni-Fo% oreguide of Naldrett et al. (1984) and the chromian spinel ore-guide of Johan (1979) turn out to be excellent tools to predict Ni-sulphide mineralizations in (ultra)mafic rocks. Furthermore these two ore-guides can be applied to investigate the genesis of the sulphide mineralizations. For the Bruvann area of the Råna intrusion a batch equilibrium sulphide segregation is suggested that took place shortly before or during the silicate crystallization. For the Rånbogen area a more fractional segregation seems likely to have taken place. The suggestion of Barnes (1986) that the rocks of the Tverrfjell outlier represent the depleted melt that was left over after the formation of the Bruvann nickel deposits is confirmed in this report by the chromian spinel ore-guide."

- Karppanen, T., Lamberg, P. & Pietilä, R., 1999: The Nickel og Olivin exploration project, years 1996-1998. Final Report, Outokumpu

- This report provides detailed information of exploration in the Bruvann area in the period 1996-98. The exploration concepts are, in most cases, described in P. Lamberg's doctoral thesis (see below), which is in the public domain. A summary of the main concepts and conclusions in the thesis is included below.

- Lamberg, P., 2005: From genetic concepts to practice – lithogeochemical identification of Ni-Cu mineralised intrusions and localisation of the ore. Geological Survey of Finland Bulletin 402, 264 pp (doctoral thesis).

The Bruvann mineralisation is one of three mined Ni-Cu deposits considered in Lamberg's thesis, which also describes three sub-economic deposits/intrusions and three barren intrusions: Part III of the thesis focuses on parameters which are indicative of processes which may be critical in the formation of economic sulphide deposits and on use of these and other factors in analysing the prospectivity of the intrusions for, as yet, unknown mineralisations.

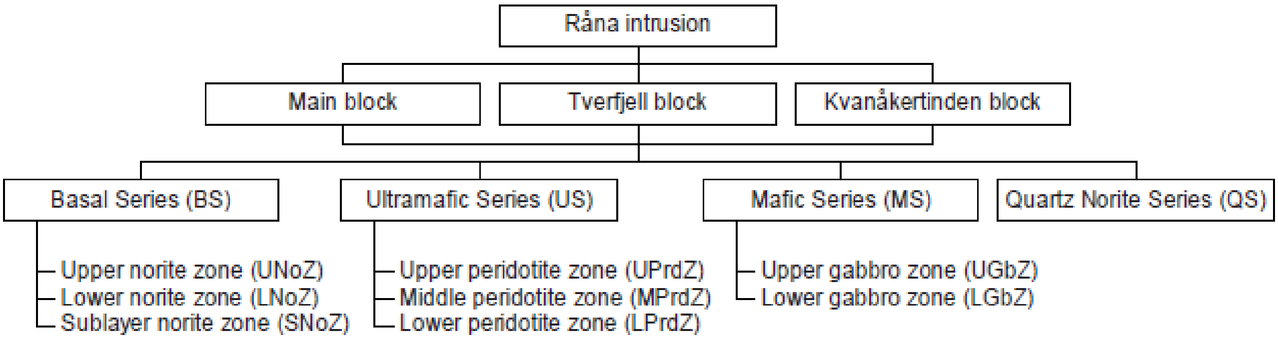


Figure 9: Subdivision of the Råna Intrusion into three blocks and four series (Lamberg, 2005)

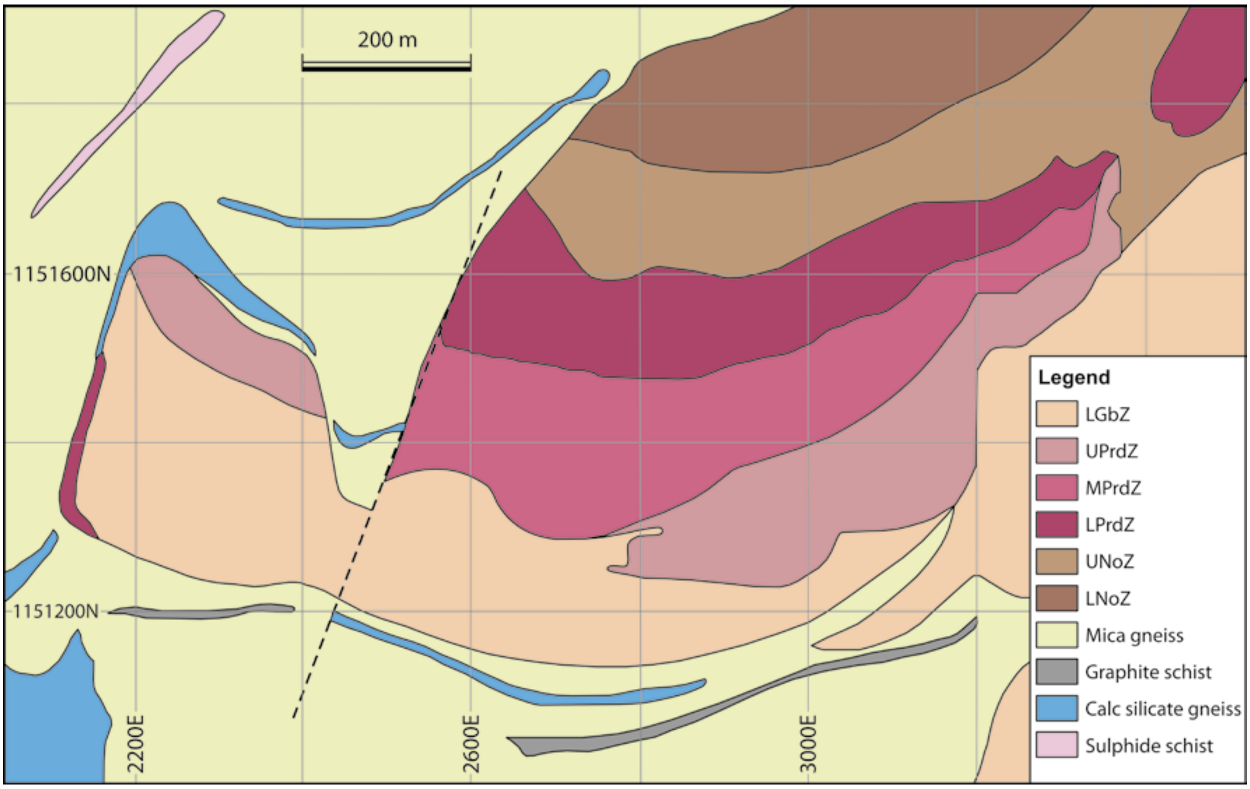


Figure 10: Geological map of the Bruvann area (Lamberg 2005, modified after Boyd & Mathiesen 1979 and Karppanen et al. 1999) (Gb= gabbro, Prd= peridotite, No= norite)

Figures 9 and 10 illustrate Lamberg's subdivision of the Råna intrusion into four series of which the lowermost three are:

- Basal Series, consisting of three norite zones, Upper, Lower and Sublayer
- Ultramafic Series, consisting of Upper, Middle and Lower Peridotite zones

- Mafic Series, consisting of Upper and Lower Gabbro zones

The Sublayer norite zone is described as consisting of "norite veins within the country rocks" and consisting of "plagioclase-orthopyroxene cumulates".

All the units, from the Lower Norite to the Lower Gabbro zones are exposed in the Bruvann area: their surface expressions indicate that their relationship is not that of an undisturbed pseudostratigraphical sequence. This is even more clearly shown in interpretations of drillhole profiles in Lamberg (2005) (N-S sections 2350E and 2600E) and in profiles in Boyd (1980), (12 N-S profiles and 12 E-W profiles at a scale of 1:2000). Lamberg indicates that the Basal Series is locally absent on the "basal" contact, in which areas the Ultramafic Series is in contact, probably tectonic, with gneisses. The Middle Peridotite is plagioclase-free and contains the most voluminous mineralized zones. The Ultramafic Series is cut by veins of norite and granite and also commonly contains inclusions of gneiss.

The Bruvann mineralization is located predominantly in the Ultramafic Series with local mineralization in the uppermost metres of the Basal Series. The deposit is separated into Western and Eastern bodies by a subvertical NNE-trending hinge fault the throw of which (downwards to the west) increases north-eastwards from 130-200m in the area close to Bruvann.

Lamberg (2005) defines seven targets within the intrusion: Tverfjell, Arneshesten, Rånbogen, Bruvann, Lake Bruvann (SW of the main western part of the deposit), Arnes and Råna: he assesses these (p. 201) in relation to the Overall Discrimination Index (OD) developed in the thesis. Within a range from 0 to 7.000 the mineralizations at Bruvann and Lake Bruvann have values of 5.000 while those at Arnes and Råna have values of 6.000: with reference to Karppanen et al. (2000) he states that drilling in the Arnes area did not reveal significant sulphide mineralisations but that thin intersections with high contents of Ni and Cu were found. Two of his key statements are:

- "the fertility analysis succeeds to point the north and northwest sections of the Råna intrusion as the most interesting parts" (p. 201)
- "in the Råna intrusion, the most primitive and base-metal non-depleted cumulates are located in all the targets quite far away from the primary contact, which forecasts that if sulphide enrichment is encountered, it is either of low grade, i.e. disseminated type, or small in size and thus not very interesting." (p. 202)

- Petersen, C.M., 2015: Petrogenesis of the sulphide mineralizations of the Råna intrusion, Nordland, Norway. Cand. Scient thesis, University of Copenhagen, 117 pp.

  Abstract: " The mafic 70 km^2 Råna intrusion is located at approximately UTM32 05.84000; 75.8000, some 20 km southwest of Narvik, Nordland, Norway. It has been the focus of extensive exploration since the ore potential was first discovered in 1880 and has been mined for Ni Co sulphides in the Bruvann mine from 1989 to 2002. The mineralizations mainly consist of pyrrhotite and Ni-Co pentlandite which has recrystallized during the 6-7 kb and 600 – 700^{o}C metamorphosis of the intrusion and its country rock. K/P ratio and sulfur isotopic evidence indicate that country rock assimilation played a role in the later formation of sulphides fractionated in situ due to magma-mixing or silicate assimilation. Forsterite versus Ni ppm in olivine place the intrusion together with a number of fertile intrusions and world class Ni sulphide deposits. The presence of massive sulphides formed at an early stage of fractionation indicates the possibility of a formation of massive ore at the base contact of the intrusion where only minor of the reported exploration has been focused so far.

  This study indicates the intrusion has a potential for a Ni-Co sulfide ore yet to be found."

  (RB comment: No other study, including those of Lamberg (2005) and Scandinavian Highlands (2013) has indicated that cobalt is a more important component in the Råna mineralizations than copper.)

10. Selected conclusions and observations

The remaining tonnage of the originally calculated reserve for the Bruvann Ni-Cu-Co mineralization is: 9.15 Mt grading 0.36% Ni (0.3% cut off), 0.09% Cu and 0.01% Co (see section 7. Nikkel og Olivin (LNS)/Outokumpu). This tonnage is considerably higher than that which has been documented for the tonnage remaining in other nickel deposits in Norway, e.g. in the individual deposits at Espedalen and Ertelien. The exploration carried out by Nikkel og Olivin/Outokumpu in the 1990s (see section 7) clearly indicates a potential for further ore-grade mineralisation in the Bruvann area, towards the southern margin of the eastern ore and at depth, both to the south and west of the western ore.

The mineralisations identified in other parts of the northern margin of the intrusion, at Arnes and Rånbogen, have been of limited size and with a tenor much lower than that found in the main mineralisation at Bruvann. The remaining target for Bruvann-type mineralisation is the block of ultramafic rocks indicated by the gravity anomaly in the Arnes-Råna area (Sindre & Boyd, 1977), part of which was tested by drillhole 475-447 (see above). The gravity data indicate that the ultramafic rocks extend to a depth of 2 km over a N-S extent of 1 km and a probable E-W extent of 2 km. In the absence of geophysical methods which could enable differentiation of mineralised zones within this target, its investigation would require a major expense in drilling costs and overcoming the practical difficulty that the main highway, the E6 runs along the shore of Ofotfjord above the ultramafic block. The later discovery of ultramafic rocks below sea level at the W end of the Bruvann area re-opens the question of the extent of ultramafic rocks at depth in the Bruvann area and between the Bruvann area and Arnes: this could almost certainly be documented by a systematic gravity survey.

The organisations and the individuals whose results form the basis of this report represent, in some cases, world-class expertise in their fields, which range from the petrology of nickel deposits and their host rocks (Sarah-Jane Barnes, Pertti Lamberg) to the exploration and mining technology needed to quantify and exploit them (Outokumpu). The second author believes that there will be further interest in the Råna intrusion and that new generations of geologists, with new technology and ideas, especially if related to structural geology, will further advance our knowledge of the intrusion and its mineralisations.

References:

Andréasson, P.G., Gee, D. G., Whitehouse, M.J. & Schöberg, H., 2003: Subduction-flip during Iapetus Ocean closure and Baltica - Laurentia collision, Scandinavian Caledonides, Terra Nova 15, 362-369.

Barnes, S. - J. 1986: Investigation of the potential of the Tverrfjell portion of the Råna intrusion for platinum group element mineralization. NGU report 86.201, 169p..

Barnes, S.-J., 1986: Unusual nickel and copper to noble-metal ratios from the Råna Layered Intrusion, northern Norway. Norsk Geologisk Tidsskrift 67, 215-231.

Barnes, S.-J, 1989: Sulphide segregation history of the Tverrfjell portion of the Råna Layered Intrusion. In: Magmatic Sulphide – the Zimbabwe Volume, M.D. Prendergast & M. J. Jones (eds.), 107-116.

Barnes, S.-J, Boyd, R., Korneliussen, A., Nilsson, L.-P., Often, M., Pedersen, R. B. & Robins, B., 1988: The use of mantle normalization and metal ratios in discriminating the effects of partial melting, crystal fractionation and sulphide segregation in platinum group elements, gold, nickel and copper: examples from Norway. In: Prichard, H., Bowles, J. & Potts, P. (eds.) Geoplatinum '87 Symposium Volume, Elsevier, 113-144.

Bjørlykke, H. & Færden, J., 1961: Rapporten over undersøkelsene ved Bruvannstollen, Råna nikkelmalmfelter 196 - 1961 - BA 3151

Blomlie, T., 2012: Treasure in the Mountains. A guide to the mining and quarrying history of Ballangen, Evenes, Narvik and Tysfjord, Museum Nord, 128 pp.

Bowen, N.L. 1915: The later stages of the evolution of the igneous rocks. Journal of Geology 23, 1-91.

Bowen, N.L., 1919: Crystallization-differentiation in igneous magmas. Journal of Geology 27, 393-430.

Boyd, R., 1973: Geologisk kartlegging av Rånamassivet. NGU-rapport 1173 A.

Boyd, R., 1974: Geologisk kartlegging av Rånamassivet. NGU-rapport 1250 A.

Boyd, R., 1980: Geologisk oversiktsrapport, Bruvannsfeltet, Ballangen kommune, Nordland. NGU-rapport 1582 A, 4 bind.

Boyd, R., 2007: Ni-Cu-PGE potential of the Råna Intrusion: 2006 drilling program. NGU Report 2007.078 (on contract for Scandinavian Highlands, open access from 31.12.2010).

Boyd, R. & Mathiesen, C.O., 1979: The nickel mineralization of the Råna mafic intrusion, Nordland, Norway. Canadian Mineralogist 17, 287-298.

Boyd, R., McDade, J.M., Millard, H.T. & Page, N.J., 1986: Platinum and palladium geochemistry of the Bruvann nickel-copper deposit, Råna, North Norway. Terra Cognita 6, 559-560.

Boyd, R., McDade, J.M., Millard, H.T. & Page, N.J., 1987: Platinum metal geochemistry of the Bruvann nickel-copper deposit, Råna, North Norway. Norsk Geologisk Tidsskrift 67, 205-213.

Boyd, R., Barnes, S.-J. & Grønlie, A., 1988: Noble metal geochemistry of some Ni-Cu deposits in the Sveconorwegian and Caledonian orogens in Norway. In: Prichard, H., Bowles, J. & Potts, P. (eds.) Geoplatinum '87 Symposium Volume, Elsevier, 145-158.

Crowley, P.D., 1989: The tectonostratigraphy and structural evolution of the Sitas area, North Norway and Sweden (68^{o} N), Norges geologiske undersøkelse Bulletin 416, 25 – 46.

Dahll., T., 1879: Geologisk Kart over Det nordlige Norge, Norges geologiske undersøkelse.

Foslie, S., 1919: Rapport over nikkelfeltene ved Raana og Arnes i Ofoten, BA 1121.

Foslie, S., 1921: Field observations in Northern Norway bearing on magmatic differentiation. Journal of Geology 29, 701 – 719.

Foslie, S., 1941. Tysfjords geologi. Beskrivelse til det geologiske gradteigskart Tysfjord., Norges geologiske undersøkelse, Bulletin 149, 298 pp.

Groves, D.I., Barret, F.M., Binns, R.E. & McQueen, K.G., 1977: Spinel phases associated with metamorphosed volcanic-type iron-nickel sulfide ores from Wetern Australia. Economoc Geolpgy 72, 1224 – 1244.

Gustavson, M., 1969: The Caledonian mountain chain of the southern Troms and Ofoten areas, Part Il. Caledonian rocks of igneous origin. Norges Geologisk Undersøkelse Bulletin 261, 110 pp.

Hornemann, N. 1937: Bericht uber die von Christiansand Raffineringsverket 1937 ausgefuhrten Unt - 1937 - BA 3275

Horvath, F., 1944: Ausbauplan fur die Nickelgrube Råna bei Ballangen, Nord-Norge. - 1944 - BA 1183

Häkli, T. A. 1971: Silicate nickel and its application to the exploration of nickel ores. Bull. Geol. Soc. Finland 43, 247—263.

Johan, Z., 1979: Possibilité de discrimination des massifs basiques Mineralises en nickel et cuivre etd es massifs steril par l'étude christallochimique des spinelles. Memoire du BRGM 97, 203-218.

Karppanen , T., Lamberg, P. & Pietilä, R . 1999: The Nikkel og Olivin AS Exploration Project. Years 1996-1998. Final Report. Unpublished internal report of Outokumpu Base Metals, 30. March 1999, 33 p.

Krogh, S. & Lindahl, I., 1988: Perspektivanalyse på bergindustrien i Nordland, NGU report 88.062.

Lamberg, P., 2005. From Genetic Concepts to P ractice – Lithogeochemical Identification of Ni-Cu Mineralised Intrusions and Localisation of the Ore. Geological Survey of Finland, Bulletin 402, 264 pp.

Mathiesen, C. O., 1975: Diamantboringer i Bruvannsfeltet 1971-1975. Kjernebeskrivelser. – 1975, NGU rapport 1326 E

Mathiesen, C. O., 1975: Beregning av tonnasje og gehalter i Bruvannsfeltet etter boringene i 1974-75,NGU rapport 1250 C

Mathiesen, C. O., 1976: Kart- og profilhefte for Bruvannsfeltet. – 1976, NGU rapport 1326 F

Melezhik, V. A., Kuznetsov, A. B., Pokrovsky, B. G., Solli, A., Gorokhov, I. M.. Fallick, A. E., Lindahl, I., Konstantinova, G. V. & Melnikov, N. N., 2014: Chemostratigraphic insight into deposition of the Melkedalen Marble, Narvik Nappe Complex, North-Central Norwegian Caledonides, Norwegian Journal of Geology 94, 35-52.

Naldrett, A.J., Duke, J.M., Lightfoot, P.C. & Thompson, J.F.M., 1984: Quantitative modelling of the segregation of magmatic sulfide: an exploration tool, CIM Bulletin 77, No. 864, 45 – 56.

Pedersen, R.B., Furnes, H. and Dunning, G., 1991. A U/Pb age for the Sulitjelma Gabbro, North Norway: further evidence for the development of a Caledonian marginal basin in Ashgill–Llandovery time. Geological Magazine 128, 141–153.

Petersen, C.M., 2015: Petrogenesis of the sulfide mineralizations in the Råna intrusion, Nordland, Norway, Unpublished M.S. thesis, University of Copenhagen.

Ramdohr, P., 1969: The Ore Minerals and their Intergrowths, Elsevier, 1192pp.

Scandinavian Highlands, 2013: Presentation at CIM meeting, Vancouver, 2013: http://scandinavian-highlands.com/media/12579/r%C3%A5na%20vancouver%202013.pdf

Sinding-Larsen, R., 1977: Geostatistisk malmberegning for A/S Stavanger Staal av en 60 m til 100 m mektig liggsone i Bruvannsfeltet, Råna. NGU Rapport 1611.

Sindre, A. & Boyd, R, 1977: Tyngdemålinger Råna. NGU Rapport 1538.

Singsaas, P., 1964. Geofysiske undersøkelser Råna Nikkelmalmfelter, Eiterdalen Nikkelgrube NGU-rapport 515 B, 6s.

Singsaas, P., 1973. Elektromagnetiske bakkemålinger Bruvann, Råna. NGU-rapport 1110, 13s.

Singsaas, P., 1977: VLF-forsøksmålinger Bruvannsfeltet, 1977, NGU-rapport 1525.

Singsaas, P., 1978: Turam- og VLF-målinger, Råna nikkelmalmfelter: Rånbogen. NGU-rapport 1580A.

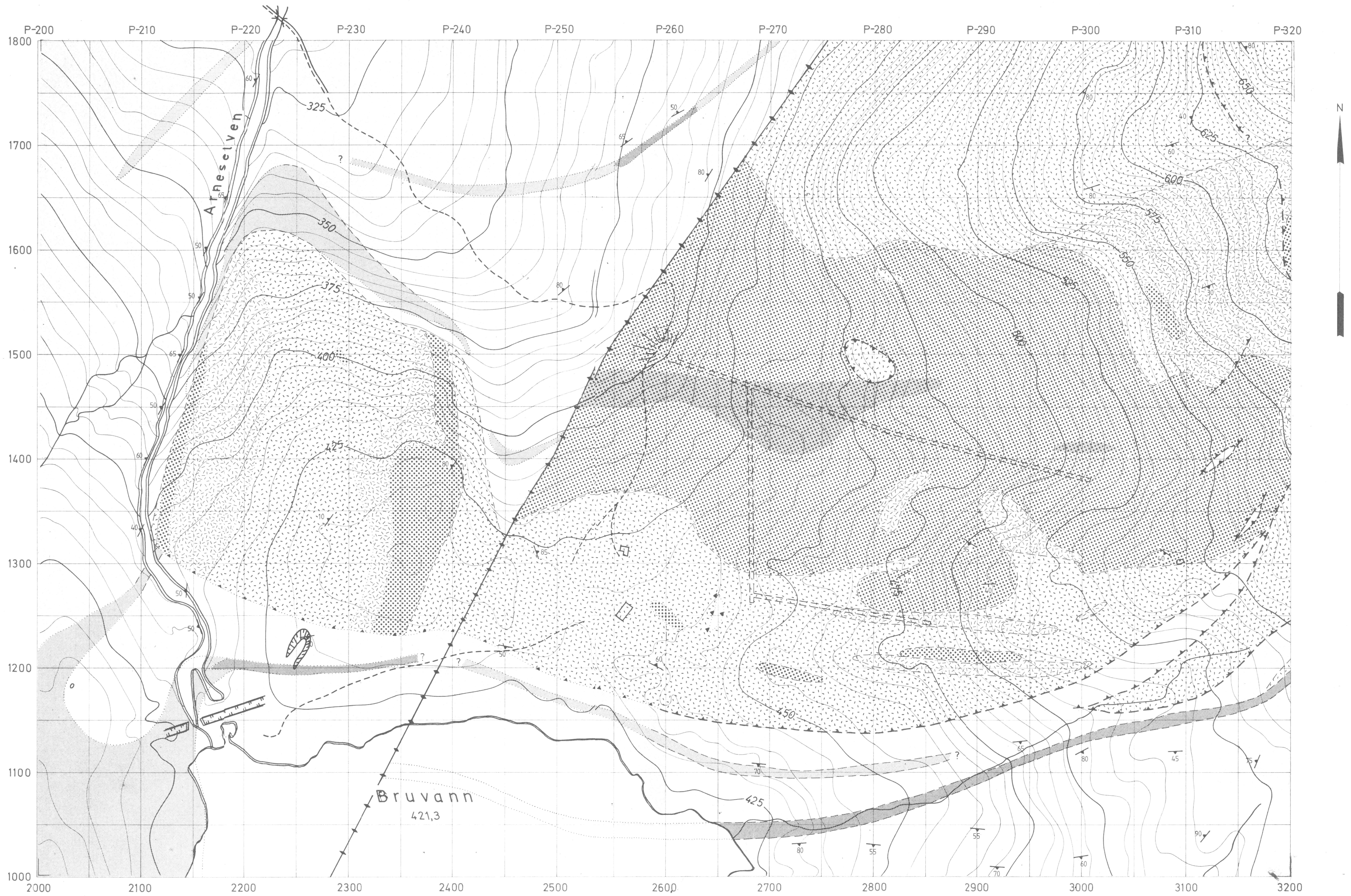
Singsaas, P. & Brækken, H., 1947: Elektromagnetiske forsøksmålinger Råna Nikkelforekomsten, NGU rapport 52.

Singsaas, P. & Flood B., 1964. Geofysiske og geologiske undersøkelser Råna Nikkelmalm-felter, Saltvikfeltet. NGU-rapport 515 C, 25s.

Tucker, R.D., Boyd, R. & Barnes, S.-J., 1990: A U–Pb zircon age for the Råna Intrusion, northern Norway: new evidence of basic magmatism in the Scandinavian Caledonides in Early Silurian time. Norwegian Journal of Geology 70, 229–239.

Vaasjoki, M. & Sipilä , P., 2001. U–Pb isotopic determinations on baddeleyite and zircon from the Halti-Ridnitsohkka intrusion in Finnish Lapland: A further constraint on Caledonide evolution. In: *Radiometric Age Determinations from Finnish Lapland and Their Bearing on the Timing of Precambrian Volcano-Sedimentary Sequences* (M.Vaasjoki, ed.). Geological Survey of Finland Special Paper 33, 247–253.

deVries, P. R., 1993: Relationships of chromian spinel and olivine compositions with Ni-orebody forming processes at the Råna intrusion, North Norway, Unpublished M. S. thesis, University of Utrecht.



TEGNFORKLARING

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- PYROKSENITT
- NORITT
- GNEIS
- KALKSILIKATBERGART / SVARTSKIFER
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- FORKASTNING / OVERSKYVNING
- SKIFRIGHET
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Enkelte deler av kartet er basert på resultatene a EM og VLF målinger foretatt av P.Singsaas. (NGU Rapporter 1110, 1525 og 1580 B).

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