Rapport nr. 90.065
NTNF project no. MB10.20346

GEOCHEMISTRY OF PLATINUM METALS IN OPHIOLITES IN NORWAY

FINAL REPORT

VOL. 1

NORGES GEOLOGISKE UNDERSØKELSE

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RAPPORT

Rapport nr. 90.065	ISSN 0800-3416	Åpen/~~Fortrolig~~

Tittel:

NTNF project no. MB10.20346 Geochemistry of platinum metals in ophiolites in Norway, Final report.

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Fylke: Troms, Nordland, N-Trøndelag, S-Trøndelag, Sogn og Fjordane, Rogaland	**Kommune:** Lyngen, Rødøy, Hattfjelldal, Leka Røros, Vik, Karmøy
Kartbladnavn (M. 1:250 000) Nordreisa, Vega, Mosjøen, Røros, Odda, Haugesund	**Kartbladnr. og -navn (M. 1:50 000)** 1634 IV Lyngstuva, 1828 II Rødøy, 1926 II Hattfjelldal 2026 III Krutfjell 1725 III Leka, 1720 III Røros, 1316 IV Myrkdalen, 1113 I Haugesund, 1113 II Skudeneshavn
Forekomstens navn og koordinater:	**Sidetall:** Vol.1: 44 Vol.2: 220 **Pris:** kr. 300,- **Kartbilag:**

Feltarbeid utført:	Rapportdato:	Prosjektnr.:	Seksjonssjef:
	31.03.90	67.2437.00/67.1889.79	[signature]

Sammendrag:

The project has documented the existence of several previously unknown platinum group element (PGE) mineralizations in Norwegian ophiolites, of a type previously not well-documented anywhere, i.e. stratiform platinum-palladium-gold mineralization in ultramafic cumulates in ophiolites. PGE-bearing podiform chromitite and high level Ni-Cu sulphide mineralizations have also been studied. It has been documented that PGE-enrichment in the ultramafic bodies hosting the podiform chromitites is confined to the chromitite bodies. Both the podiform chromitite and Ni-Cu sulphide mineralizations are of such limted tonnage that they have no economic interest. The stratiform PGE mineralizations found so far, in the Leka and Lyngen ophiolites are submarginal but are sufficiently rich and of sufficient dimensions that they are considered to indicate a possible potential for mineralizations of economic interest in these complexes and in all others with well developed, laterally extensive sequences of olivine-rich cumulates. This conclusion has relevance for prospecting in general for PGE-mineralizations, and could be particularly important if the present supply-demand situation for the PGE were to change.

Emneord	Petrologi	
Platinametaller	Malmgeologi	
Geokjemi		

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1. INTRODUCTION

1.1 Project concept and organization

The current project was preceded by a pilot project entitled: Geochemistry of platinum metals in rocks and ores in Norway: Pilot Project (Barnes et al. 1987). The pilot project involved the analysis of 385 samples from a range of geological environments for platinum group elements (PGE) and gold. The environments included Ni-Cu deposits, of which two in oceanic crustal rocks, chromite deposits in ophiolitic rocks and chromite-bearing rocks from ophiolites.

The most important conclusion reached during the pilot project was that: "Results from only one of the geotopes sampled, ophiolites and related rocks, give an indication of possible economic interest." The following recommendations for further work in this respect were made: "The specific targets located so far considered to merit further study are:

- chromite-olivine cumulates in the Leka ophiolite
- chromite-bearing harzburgites forming isolated ultramafic bodies, i.e. Osthammeren, Skamsdalen, Aurtand and Ørnstolen
- the potential for further Cu-Ni-PGE mineralizations of the Fæøy type in the Karmøy ophiolite.

Critical topics to be examined in the Leka ophiolite will be the lateral and vertical extent of the Os-Ir-Ru enrichment, geochemical variations within the enriched zone, the mineralogical residence of the PGE and the processes leading to their concentration.

In the isolated harzburgite bodies the critical question in an economic evaluation will be whether the PGE are exclusively linked to chromite. All the chromite mineralizations found to date are very small."

The present project was formulated with the aims of examining these topics. It encompasses an evaluation of the processes leading to PGE enrichment, in both petrological and economic-geological contexts.

Organization

Much of the project was carried out through collaboration between the Geological Survey of Norway (NGU) and the Geological Institute, Div. A, University of Bergen (UiB). The project was led from NGU and carried out by workers from NGU (R. Boyd and L.-P.Nilsson) and UiB (R.-B. Pedersen and G.M. Johannesen). The project has thus been able to benefit from the considerable expertise on ophiolites which has been built up at UiB over the last 10-15 years. During the lifetime of this project NGU has carried out work on three scientifically related but organizationally unrelated projects, on parts of the Lyngen ophiolite (T.Grenne), on PGM in heavy mineral concentrates from the Raudberget talc deposit, Vik, Sogn (S.Bakke, T.Boassen, L.-P. Nilsson) and on the Lillefjellklumpen Ni-Cu-PGE mineralization in N-Trøndelag (A.Grønlie): these projects are also covered in this report for the increase in scientific completeness which they allow.

The project has also involved collaboration with geoscientists from the Geological Institute at the University of Trondheim (NTH); Dept. of Earth Sciences, Open University, England; Sciences de la Terre, Universite du Quebec, Canada; Dept. of Earth Sciences, Memorial University of Newfoundland, Canada. Most of the analytical work for PGE and gold was carried out by Sheen Analytical Services, Perth, Australia because methods with the detection levels and precision required were/are not available on a commercial basis, and probably not from research laboratories either, in Europe. Further analytical work was carried out by Caleb Brett Laboratories, St.Helens, UK (Pt,Pd and Au analyses in the pilot project) and by X-Ray Assay and Chemex Laboratories, Toronto, Canada (PGE and Au analyses on Lillefjellklumpen). Control analyses were carried out at Memorial University of Newfoundland.

Scope of the project

The project has, in its broadest sense, i.e. including work not financed by NTNF, encompassed studies of the following:

- isolated ultramafic complexes and related chromitite mineralizations, mainly in the Røros area and in Nordland (Nilsson)
- heavy-mineral fractions from the Raudberget talc deposit,Vik, Sogn (Bakke, Boassen,Nilsson)
- chromitites in dunite/pyroxenite lenses, dykes and veins in the Leka ophiolite (Pedersen, Johannesen)
- ultramafic cumulates and related chromite, sulphide and arsenide enrichments in the Leka ophiolite (Pedersen, Johannesen)
- a reconnaissance of several ultramafic pods and of ultramafic/mafic cumulates in the Lyngen ophiolite (Grenne)
- the Lillefjellklumpen Ni-Cu-PGE mineralization in the Gjersvik island arc complex (Grønlie)
- the PGE geochemistry of the volcanic suites in the Karmøy ophiolite (Pedersen). The Fæøy Cu-Ni-PGE mineralization which is part of the dyke complex in the Karmøy ophiolite was not studied because it is currently the topic of a thesis being carried out at Memorial University.

The location of the areas studied is shown on a tectonostratigraphic base map (modified from Roberts & Gee 1985 and Furnes, Roberts, Sturt, Thon and Gale 1980) in Fig.1 and their position in an idealized ophiolite pseudo-stratigraphy in Fig.2. Fig. 2 also shows the position of certain types of gold mineralization being considered in a parallel NTNF project led by Professor F.M.Vokes, geologisk inst., NTH.

Almost all of the subprojects indicated above will result in manuscripts for publication in scientific journals, some already have. The report has therefor, in order not to delay this process, been compiled largely from manuscripts in varying degrees of readiness for publication. The report has been written in English for this reason, and in order to make the report itself readily accessible to the international prospecting industry. Volume 1 gives brief descriptions of the work carried out, with emphasis on the conclusions reached: the complete papers/manuscripts are given in Volume 2. For certain subprojects such manuscripts have not yet been completed (Karmøy and Lyngen).

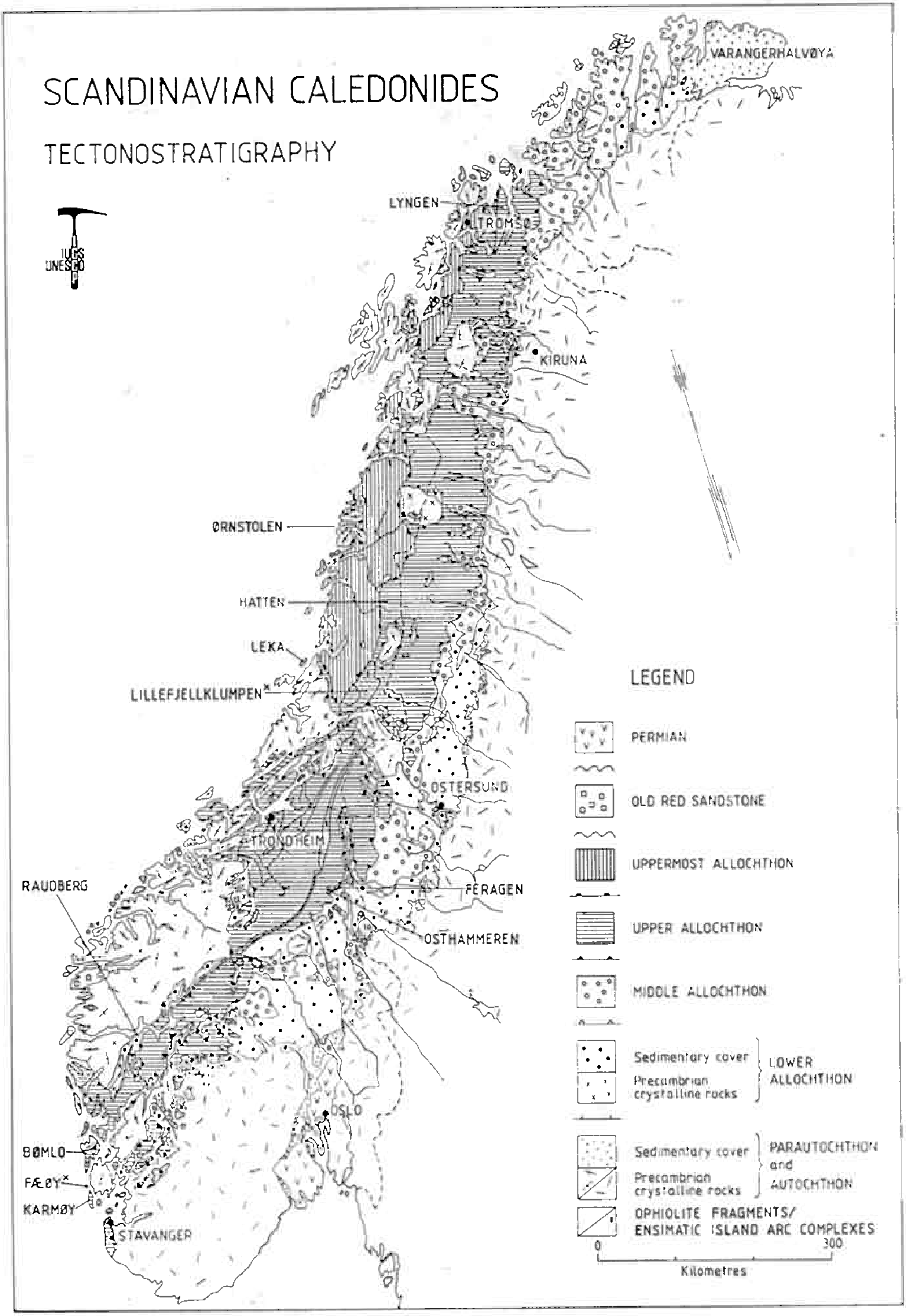


Fig. 1: Tectonostratigraphic map of the Scandinavian Caledonides (Roberts & Gee 1985), showing major ophiolite and ensimatic island arc complexes (modified from Furnes et al. 1980). Complexes/deposits in which noble metal concentrations have been studied are named.

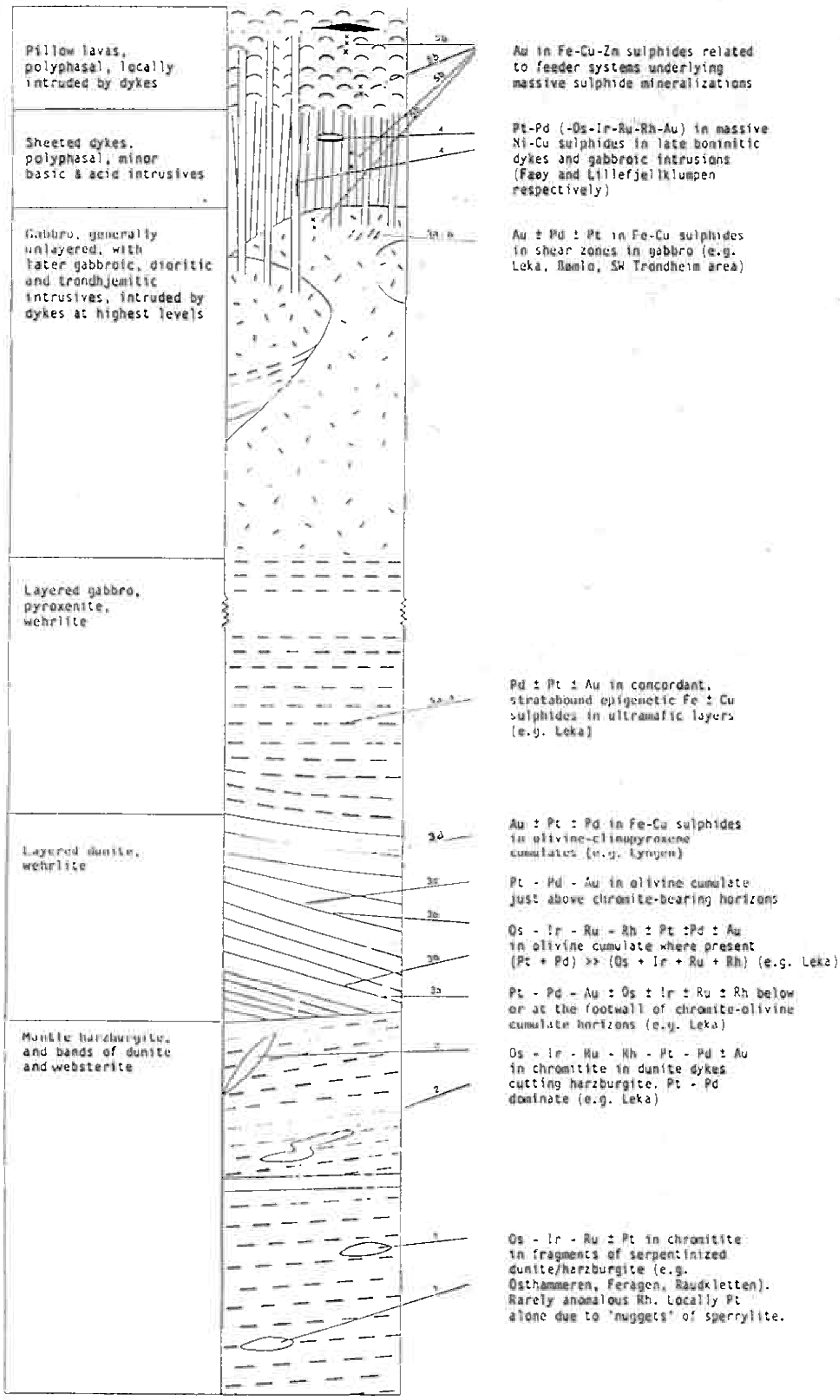


Fig.2: Ophiolite pseudostratigraphy showing the generalized location of noble metal mineralizations found in Norwegian complexes to date.

1.2 Background information on the platinum metal geochemistry of ophiolites

Until the advent of the Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) in the latter half of the 1980s the technology for analysis of all the PGE and gold at, or close to background levels in the rocks of ophiolite complexes was not readily available. Thus Crocket (1981), in an exhaustive survey of the literature to that date, could present only very limited data on the Os,Ru and Rh contents of chromite-free ultramafic rocks in ophiolites and no data for the contents of these elements in sulphide-free mafic rocks in ophiolites. Barnes et al. (1988) presented a summary of analytical data on the PGE-content of several suites of volcanic rocks, showing that the contents of these elements was still only loosely constrained in boninites and ocean floor basalts, both at the lower and upper levels of the assumed range of concentration.

A summary of the data available on the PGE and Au contents of chromite-/sulphide-free rocks from oceanic crustal environments is given in Table 1.

ROCK TYPES	Os	Ir	Ru	Rh	Pt	Pd	Au	n
Boninites	-	<0.01-0.1	-	-	-	6.9-35	0.68-3.3	12
MOR-basalts	<0.086	0.0011-0.116	-	-	-	<0.1-6.29	-	12
Mafic cumulates	0.02	0.017-0.033	-	-	4.5	3.0-3.1	0.17	11
U.mafic cumulates	0.02-0.21	0.05-2.4	-	-	17-28	0.9-29	0.52-2.2	35
Harzburgite	3.95-6.7	2.2-7.29	-	-	4.99-10	2.04-9.5	0.33-1.8	35
Mantle ave.	4.2	4.4	6	2	9.2	4.4	1.4	114

Table 1: PGE and Au contents of rocks in oceanic crustal environments (from Barnes et al.1985: Barnes et al. 1988)

The harzburgites which are assumed to represent tectonized mantle have PGE and Au concentrations of the same order of magnitude as the mantle values which is as to be expected if they can be regarded as undepleted,if tectonized mantle. The ultramafic and mafic cumulates which are specifically not chromite-bearing, are depleted in Os and Ir (and probably also in Ru), i.e.the sub-group of the PGE known as IPGE, which can be explained by the prior fractionation of chromite, in which these elements are enriched.

MOR-basalts are also characterized by a high ratio of PPGE (Rh+Pt+Pd) to IPGE which is again consistent with prior removal of chromite. However normal models for the formation of MORB indicate 10-20% melting of the mantle which would suggest that all sulphide would have melted, with all the PPGE partitioning into the sulphide. This would give a content of PPGE one to three orders of magnitude higher than that which is observed (Barnes et al. 1985). Possible explanations are (Barnes et al. 1985):

- retention of some sulphide (and PPGE) in the mantle.
- prior depletion of PPGE from the mantle from which the MORB melted.

- removal of sulphides from MORB before its extrusion (Czamanske & Moore 1977).

The work done within this project tends to confirm the feasibility of the third explanation.

Available data indicates that boninites have PGE concentrations of the same order of magnitude as MORB but that they are depleted in Cu, Au and possibly Ni relative to MORB (Barnes et al. 1988) which could indicate a prior melting event (Hamlyn et al. 1985). Hypothetical primary magmas of boninitic character have been considered as one of the two magma types involved in the formation of the Bushveld and Stillwater layered intrusions (Irvine & Sharpe 1982)

1.3 Known platinum metal mineralizations in ophiolites

The literature contains documentation of several types of PGE-bearing mineralization in ophiolite complexes. These are:

- podiform chromitites in mantle harzburgite (many examples)
- stratiform chromitite in ultramafic cumulates (two examples)
- stratiform sulphide in ultramafic cumulates (two examples)
- stratiform sulphide in mafic cumulates (one example)
- hydrothermal sulphide/arsenide mineralizations at various levels (several examples)
- massive sulphides at higher levels in ophiolites (several examples).

Podiform chromitites in mantle harzburgite

Among the areas/ophiolite complexes in which podiform chromitites have been analyzed for PGE are southwest Oregon (Page 1969: Page et al. 1975), the Semail Ophiolite, Oman (Page et al. 1979), New Caledonia (Page et al. 1982) and Morocco (Fischer et al. 1988). Chromitites from a number of ophiolites in the Caledonian orogen have been analyzed for PGE: these include the Bay of Islands and White Hills complexes on Newfoundland (Page & Talkington 1984) and the Unst ophiolite on Shetland (Gunn et al. 1985:Prichard et al. 1986). In almost all cases these mineralizations are enriched in IPGE with total PGE rarely exceeding 1 ppm: in a study involving 323 samples from deposits in California and Oregon 10% of the samples were found to have more than 0.17 ppm Ir, 0.32 ppm Ru, 0.026 ppm Rh, 0.064 ppm Pt and 0.01 ppm Pd (Page et al. 1986): the richest individual sample reported from the same study contained 2.93 ppm Ir, 4.93 ppm Ru, 0.074 ppm Rh, 1.18 ppm Pt and 0.005 ppm Pd. The Cliff mineralizations on Unst are an exception in relation to all podiform chromitites described so far in the literature as regards their absolute concentration of PGE (up to >70 ppm PGE) and the predominance of PPGE in relation to IPGE (Pd/Ir ratios of 10-12 while 'normal' podiform chromitites have Pd/Ir ratios of 0.01-0.1).

Numerous papers have described the platinum group minerals (PGM) in podiform chromitite deposits (Chang et al. 1973: Talkington et al. 1984: Legendre & Auge 1986: Prichard et al. 1986: Auge 1988 among others): these show that most deposits, the Cliff type obviously being an exception, are dominated by laurite (RuS_2), IPGE alloys and IPGE arsenides.

Few papers give information on the economic significance or otherwise of the PGE content of the chromitite deposits, some of which reach a size of two million tons (Auge 1988). An exception is Page et al. (1986) who conclude that the potential supply of by-product PGE from mining podiform chromite deposits is small: their estimate of the total world resource of Pt in podiform chromite deposits was roughly one-sixth of the quantity imported annually to the United States. World annual consumption of the IPGE which are predominant in most podiform chromite deposits is met by by-product production from Pt-Pd and Ni-Cu deposits and would probably not justify any additional capacity even if the deposits had tonnages of sufficient grade to be of theoretical interest in relation to the metal prices. An exception again would be mineralizations of the Cliff type, because of their high content of Pt and Pd, if these could be found with an adequate tonnage: indications are that the mineralizations on Unst itself are much to small to be of economic interest in themselves.

Stratiform chromitite in ultramafic cumulates

The first example of this type of mineralization to be described is in the Acoje block of the Zambales Ophiolite in the Philippines (Abrajano & Bacuta 1982: Bacuta et al. 1988). The mineralization was earlier known purely as a stratiform Ni-Cu sulphide mineralization with by-product Pt (Hulin 1950: Parangit 1975). Unfortunately both of the first-mentioned references are abstracts only. The mineralization is described as being a visible Ni-Cu sulphide mineralization associated with stratiform chromitite in dunite-wehrlite cumulates. Its PGE content is given as 30-460 ppb Ir, 830-1100 ppb Ru, 2.6-759 ppb Rh, 2.8-5958 ppb Pt and 2.3-8351 ppb Pd: no indication is given as to values which could be regarded as representative of the deposit as a whole but it is indicated indirectly that the deposit has considerable dimensions and that it is of potential economic interest.

PGE-enrichment in chromite cumulates has also been described from the 3.5 Ga-old Jamestown Ophiolite Complex in S. Africa (de Wit & Tredoux 1988). The mineralization is reported to be enriched in PPGE but it is of extremely limited extent (20-30 cm thick with a strike length of 10m).

Stratiform sulphide in ultramafic cumulates

Orberger et al. (1988: 1989) also describe PPGE enrichment associated with Ni-Cu sulphides in the Acoje block of the Zambales ophiolite: they describe this mineralization however as being independent of any chromite accumulation. It is not entirely clear whether this is a separate mineralization from that described by Bacuta et al. (1988). Afurther example, in the Wadi Onib-Hamisana ophiolite, Sudan, is mentioned in an abstract by Abdelrahman & Matheis (1990): no grades are given.

Stratiform sulphide in mafic cumulates

The one definite example known to the authors is in the Semail ophiolite and was described in a recent abstract by Lachize et al. (1990). It occurs in gabbronoritic cumulates and includes disseminated and massive (30-40%) sulphides. An analysis of "one of the richest layers" gives <8ppb Os, <3ppb Ir, 32 ppb Ru, 4 ppb Rh, 37 ppb Pt, 130 ppb Pd and 150 ppb Au. This implies that the contant of PGE+Au in total sulphides is fairly low; at four times the absolute values it would be 1.4 ppm.

Hydrothermal sulphide/arsenide mineralizations at various levels

This group includes several types of mineralization:

- cobolt-arsenide mineralization in carbonate lenses in serpentinized harzburgite in the Bou-Azzer Ophiolite, Morocco (Fischer et al. 1988): this mineralization is rich in gold (>10 ppm) and generally contains < 100 ppb PGE but locally has values of Pt up to > 2 ppm.
- Cu-Ni-Co sulphide at the periphery of podiform chromite bodies in the Othris Ophiolite (Economou & Naldrett 1984): the analyses show values up to 256 ppb Pt, 213 ppb Ru and 525 ppb Au. Pd is >10 ppb and the high Pt/Pd ratio coincident with a high Cu/Ni ratio is among the factors indicating a hydrothermal origin. The mineralizations are small (the chromite deposits do not exceed 40,000 tons).
- Cu-sulphide in chloritite in shear zones in the Troodos and Leka ophiolites (Vokes 1987). The mineralizations at Leka contain up to 240 ppb Pd (Vokes pers. comm. 1989) but have Au values up to 4.2 ppm.

Massive sulphides at higher levels in ophiolites

Deposits of this type include the Lillefjellklumpen deposit in the Gjersvik Island Arc Complex (Grønlie 1988), the Fæøy deposit in the Karmøy Ophiolite (Boyd et al. 1988) and the Illinois River deposit in Oregon (Foose 1986). All of these are Cu-Ni sulphide deposits with up to several ppm of both Pt and Pd in massive sulphides though they occur at differing positions in the pseudostratigraphy, the Illinois River deposit in mafic cumulates, the Fæøy deposit as a lens in a sheeted dyke complex and the Lillefjellklumpen deposit in a small high-level gabbroic intrusion. All three are small.

2. PLATINUM METALS IN ISOLATED ULTRAMAFIC BODIES AND PODIFORM CHROMITITES

2.1 Summary

Samples of chromitite mineralization and host rock from 39 isolated ultramafic complexes have been analyzed for PGE and Au (Tables 2-5). The anomalous PGE values found are confined to samples from the chromite mineralizations the size of which is such that they are not of economic interest even with the theoretical added value of their PGE-content.

The majority of chromitite deposits sampled and analyzed for all PGE would appear to have weakly or, less commonly, strongly anomalous concentrations of IPGE. A few have, at least locally, anomalous concentrations of PPGE: these include the Osthammeren and Ørnstolen mineralizations which have been studied in detail. The richest single analysis is from a sample of chromitite from the Osthammeren body in the Røros area: it contains 11 ppm total PGE, of which 9.3 ppm Pt. The average of 12 samples from Osthammeren is 1.5 ppm total PGE which is also the highest average for any single field of chromitite deposits.

The chromitites are, in some cases, of considerable mineralogical interest. Numerous platinum group minerals not previously reported in Norway have been found: several of these appear not to have been recorded elsewhere either. The mineralogical studies allow the division of the PGM into primary magmatic or late magmatic/hydrothermal minerals and secondary hydrothermal minerals and increase our knowledge of the degree of solid solution between the PGE-sulpharsenides.

2.2 Platinum-group mineral inclusions in chromitite from the Osthammeren ultramafic tectonite body; south central Norway

This subproject has involved a study of the PGE-geochemistry of the Osthammeren chromitite mineralization and its host serpentinite and a detailed examination of the platinum group minerals: the latter is the main topic of a brief paper which is in press (Nilsson 1990), of which a fuller version, as submitted for publication in Norsk Geologisk Tidsskrift, is included in Vol. 2 of this report.

Twelve samples of chromitite from Osthammeren and ten of the host serpentinite have been analyzed for all the PGE and Au (Table 6), in addition to the initial analysis for Pt, Pd and Au in the pilot project. The average content of PGE+Au in the serpentinite samples was 39.6 ppb while the chromitite samples averaged 1500 ppb. This strong indication that significant PGE enrichment is confined to the chromitite rules out any economic potential in this mineralization.

The contents of the PGE and Au found in the serpentinite are within, or close to the ranges reported for the contents of these elements in mantle harzburgite by Barnes et al. (1985) except for Au which is 3.5 ppb higher at Osthammeren. The contents of the individual PGE in the average of the results from Osthammeren are similar to those reported from several chromitites described in the literature, e.g. Skyros (Economou 1986) and Harold's Grave, Unst (Prichard et al. 1986: Gunn 1989)(see Fig. 9 in the paper in Vol.2). The single sample containing 9.3 ppm Pt is atypical in relation to the other samples.

Table 2

Content of Au, Pt and Pd (ppb) in chromitite from ophiolite fragments and solitary ultramafic complexes, central Norway.
A compilation of datafrom the pilot project.

Location	Sample No.	Au	Pt	Pd	Ore type
Rødøya ophiolite fragment, Vefsn district:					
1. "Karoline" claim, close to Rødøygårdene	LP 1	28	43	110	massive, with little gangue
2. Top of Rødøyfjellet	LP 2	13	5	12	medium-grained moderate impregnation
Velfjord ophiolite fragment, South Helgeland district:					
3. Claim SW of Nævernes	LP 3	9	9	<2	medium-grained moderate impregnation
4. Claim SW of Nævernes	LP 4	2	22	5	massive ore/very strong impregnation
5. Holmen claim	LP 5	7	26	16	weak impregnation
6. Stort Haab mine	LP 6	2	13	<2	medium-grained strong impregnation
7. Fire Søskende claim	LP 7	2	12	<2	fine-grained impregnation
8. Haabet claim	LP 8	5	16	4	medium-grained strong impregnation
Feragen solitary ultramafite, Røros district:					
9. Forsøket mine	LP 9	41	7	<2	leopard
10. Geitsjøgruva mine	LP 10	5	24	11	massive
11. Skalgruva mine	LP 11	8	<3	<2	massive (very little gangue)
12. Loc. no. 70, mine	LP 12	5	13	5	massive
13. Rødtjerngruva mine	LP 13	5	<3	<2	massive/very strong impregnation
14. Leighgruva mine	LP 14	2	6	<2	fine-grained strong impregnation
15. Røragsgruva mine	LP 15	5	11	<2	leopard (scattered)
16. Loc. 18	LP 16	4	4	<2	leopard (dense)
17. Skalgruva mine	LP 17	4	6	<2	pique-ore
18. Jakobine mine	LP 18	5	<3	<2	fine-grained weak impregnation
19. Amalie mine	LP 19	5	4	<2	schlieren impregnation
20. Rødtjerngruva mine	LP 20	4	<3	<2	fine-grained impregnation/leopard ore
21. Jacobine (?) mine	LP 21	5	<3	<2	pique ore (3 parallel bands)
22. Jacobine (?) mine	LP 22	2	8	<2	fine-grained impregnation/pique-ore
23. Stampen mine	LP 23	5	10	<2	medium-grained strong impregnation/pique ore (dense)
Raudhammeren ultramafite, Røros district:					
24. Loc. 118	LP 24	3	<3	<2	medium-grained strong impregnation/leopard ore
25. Loc. 119	LP 25	16	31	<2	massive ore (cross-cut by late cabonate-serpentine veins)
26. Loc. 121	LP 26	32	15	<2	massive ore
27. Loc. 124	LP 27	3	6	<2	patchy/banded impregnation (very uneven)
28. Loc. 124	LP 28	4	36	2	massive ore
29. Loc. 125	LP 29	2	8	<2	banded ore (mm-cm thick bands)
Storgråberget ultramafite, Røros district:					
30. Loc. 132	LP 30	2	4	<2	massive ore/impregnation ore (very uneven)
31. Loc. 135	LP 31	2	<3	<2	massive ore
Osthammeren ultramafite, Røros district:					
32. Loc. 132	LP 32	8	760	<2	massive ore (very little gangue)
Brorhaugen ultramafite, Røros district:					
33. Loc. 141	LP 33	152	79	<2	massive ore (from vein)
Klettene ultramafite, Røros district:					
34. Loc. 145	LP 34	2	12	3	fine-grained impregnation/patches/ schlieren (very uneven)
35. Loc. 146	LP 35	4	4	<2	massive
36. Loc. 147	LP 36	4	4	<2	massive ore (strongly brecciated by late magnesite-serpentine veins)
Tollefshaugen ultramafite, Grimsdalen,					
37. Loc. 185	LP 37	6	<3	<2	medium-grained patchy/banded impregnation
Raudhamran ultramafite, Haverdalen, Dovre district:					
38. Loc. 186	LP 38	3	5	<2	medium-grained impregnation ore
39. Loc. 187	LP 39	3	<3	2	fine-grained/patchy impregnation in bands
40. Loc. 187	LP 40	2	7	<2	medium-grained patchy impregnation
41. Loc. 190	LP 41	<1	6	<2	fine-grained/medium-grained impregnation
Skamsdalen ultramafite, Lesja district:					
42. Skamsdalen mine	LP 42	4	88	26	medium-grained strong impregnation/massive ore
43. Skamsdalen mine	LP 43	120	178	156	massive ore
Nysetri ultramafite, Lesja district:					
44. Nysetri mines, Loc. 97	LP 44	3	16	<2	medium-grained impregnation ore
45. Nysetri mines, Loc. 95	LP 45	3	16	3	fine-grained to medium-grained patchy impregnation
46. Nysetri mines, Loc. 95	LP 46	3	11	<2	fine-grained to medium-grained patchy impregnation

Table (2) cont.

Location	Sample No.	Au	Pt	Pd	Ore type
Lesjehorrungane ultramafites, Lesja district:					
47. Aurtand (= Sjong) mine	LP 47	2	13	2	fine-grained to medium-grained impregnation ore
48. Aurtand (= Sjong) mine	LP 48	5	427	104	medium-grained strong impregnation
49. Severine claim	LP 49	4	<3	<2	medium-grained strong impregnation
50. Severine claim	LP 50	3	12	2	rel. weak impregnation ore/leopard ore
51. Halvfarhøi mine	LP 51	2	4	<2	strong, patchy impregnation ore
Dørkampen ultramafite, Skjåk district:					
52. Dørkampen, loc. 66	LP 52	3	13	<2	impregnation/leopard ore
53. Dørkampen, loc. 68	LP 53	4	9	<2	impregnation/leopard ore
54. Dørkampen, loc. 69	LP 54	2	9	<2	medium-grained strong impregnation/ (compact ore)
Krosshø ultramafite, Grotli area, Skjåk district:					
55. loc. 61	LP 55	3	7	<2	medium-grained impregnation
Feragen ultramafite, Røros district:					
56. Mynta mine	LP 56	<1	<3	<2	leopard ore (coarse patches)
57. Falkestien mine	LP 57	<1	<3	<2	pique ore
58. Skalgruva mine	LP 58	<1	<3	<2	pique ore/leopard ore (dense)
59. Svinet mine	LP 59	<1	<3	<2	medium-grained strong impregnation/pique ore
60. Leigruva mine	LP 60	1	3	<2	leopard ore/banded ore
61. Leigruva mine	LP 61	5	<3	<2	leopard ore (very coarse chr-patches)
62. Liegruva mine	LP 62	2	7	6	pique ore (very weak); i.e. scattered)
63. Rødtjerngruva mine	LP 63	3	3	<2	leopard ore
64. Liegruva mine	LP 64	1	7	3	massive (very little gangue)
Glupen ultramafite, Sunndal district:					
65. Glupen mine	LP 65	<1	6	<2	leopard ore (coarse patches within fine-grained impregnation)
Ørnstolen ultramafite, Selsøy, Rødøy kommune, North Helgeland district:					
66. Ørnstolen claims, loc. 1	AK 1	32	22	74	
67. Ørnstolen claims, loc. 2	AK 2	138	6	<2	
68. Ørnstolen claims, loc. 3	AK 3	11	56	63	
69. Ørnstolen claims, loc. 4	AK 4	718	299	1391	
70. Ørnstolen claims, loc. 5	AK 5	10	7	10	

of the 70 samples 66 are:
non-anomalous to weakly anomalous

	Au	Pt	Pd
Arithmetic mean (n = 66)	9.92	12.02	6.15
Geometric mean (n = 66)	3.80	6.66	1.80

where <x is calculated as $\frac{x}{2}$

Anomalous samples (No. 32, 43, 48 and 69 are excluded)

Analyst: Caleb Brett Laboratories Ltd., St. Helens, UK (28-07-1986)

Method: Fire Assay and atomic absorption spectrometry.

Content of platinum-group elements (PGE) and Au in ppb in 4 anomalous chromitite samples from a pilot study comprising 70 chromitite samples (ref. Table). In addition analysis of host serpentinite from Osthammeren (sample LPN78-139.

Location	Sample No.	Os	Ir	Ru	Rh	Pt	Pd	Au
1. Osthammeren, Røros district	LPN78-139	5.5	5.2	6.2	0.9	1.7	1.7	11.8
2.	LP32	174.2	674.4	841.	65.2	323.4	2.9	4.9
3.	LPN32-REP	166.3	659.2	835.8	64.9	316.1	3.0	5.2
4. Skarnsdalen, Lesja	LP43	37.2	47.8	128.1	21.7	265.3	157.0	56.2
5.	LP43-REP	36.1	46.7	120.2	20.6	252.6	149.7	52.8
6. Aurtand, Lesja	LP48	20.2	51.8	67.9	36.1	88.9	29.3	6.1
	LP48-REP	20.5	50.4	64.3	34.1	83.5	27.6	8.4
7. Ørnstolen, Selsøy, Rødøy	AK4	10.5	25.0	40.9	9.7	397.7	1621.0	832.4

Analyst: Memorial University of Newfoundland, St. John's, Newfoundland, Canada (ca. Dec. 1987?).
Method: Fire Assay and ICP-Mass Spec'

Table 3

Content of platinum-group elements (PGE) and Au* in ppb in chromitite and host rocks and copper-magnetite mineralizations from solitary ultramafites, central Norway. A compilation of data.

Location	Sample	Os	Ir	Ru	Rh	Pt	Pd	Au	Ore type/host rock
1. Svartåsen, Røros district	Svart-1	40	31	66	6.5	2.5	9.0	4	impregnation ore
2. Kjemsjøfjell, Alvdal v.fjell	Kjems-1	66	37	84	8.5	18	22	<2	strong impregnation, compact ore
3. Raudkletten, Folldal district	Raudk-1	160	100	240	9.0	8.0	15	12	massive ore in small pods
4. " , "	Raudk-2	96	160	230	25	99	5	8	massive ore in small pods
5. " , "	Raudk-4	10	19	53	6.5	1.5	11	<2	massive ore/dense leopard ore
6. Tolgenkletten,Tolga,N-Østerdal	Tolge-1	10	7.0	16	2.5	1.0	13	2	schlieren impregnation
7. Fåsteen,Tynset,N.-Østerdal	Fåste-1	34	24	60	18	980	15	16	fine grained strong impregnation
8. " , " , "	Fåste-3	54	38	98	15	84	42	2	massive ore in schlieren
9. " , " , "	Fåste-4	60	31	100	4.5	6.0	9.5	<2	massive ore in schlieren
10. David claim, Feragen,	David-1	450	240	540	19	1.0	9.5	4	massive ore
Røros district	David-1 D	460	210	440	18	1.5	6.0	<2	" "
11. Vinkelen mine, " " Røros district	Vinke-1	24	22	80	6.5	2.5	16	6	massive ore
12. Elev claim, " " Røros district	Elev-1	20	17	57	5.5	2.0	7.5	4	massive ore
13. Bakos mine, " " Røros district	Bako-1	54	30	110	7.0	0.5	9.0	2	massive ore
14. Pikhågen, Selsøy, Rødøy	Pikhå-1	24	21	56	7.5	47	54	<2	impregnation/compact ore
15. Ørnstolen, Selsøy, Rødøy	Ørnst.-1	12	12	42	5.5	4.0	7.0	12	fine-grained impregnation ore
16. " , " , "	Ørnst.-3-1	38	36	54	8.5	160	77	10	fine grained impregnation ore
17. " , " , "	Ørnst.-3-2	10	5.5	25	3.5	16	14	8	serpentinite-tremolite rock
18. " , " , "	Ørnst.-3-3	4	<0.5	6.5	0.5	2.0	12	10	tremolite rich ultramafic rock
19. " , " , "	Ørnst.-3-4	32	27	73	12	5.0	13	4	strong impregnation/ compact ore
20. " , " , "	Ørnst.-6	2	<0.5	2.5	<0.5	3.5	32	2	ultramafic rock
21. " , " , "	Ørnst.-9	62	31	68	9.0	72	32	10	impregnation/compact ore
22. " , " , "	Ørnst.-14	4	<0.5	7.5	1.0	0.5	12	6	ultramafic rock
23. Ørnstolen, Selsøy, Rødøy	Ørnst.-17	<2	<0.5	4.0	2.5	15	37	4	hornblendite
24. Hatten, Hattfjelldal	Hatt-1	2	2.0	<0.5	1.5	160	11	250	copper-magnetite ore
	Hatt-1 D	(100)	(10)	2.0	2.5	120	6.5	240	"
25. " , "	Hatt-2	2	1.0	2.0	2.5	<0.5	17	550	"
	Hatt-2 D	(100)	(9)	4.5	4.0	7.5	12	530	"
26. " , "	Hatt-5	<2	0.5	4.0	1.5	2.0	12	200	"
	Hatt-5 DUP	(80)	8.5	4.5	3.5	4.5	11	190	"
27. " , "	Hatt-7	4	2.0	15	1.0	7.0	7.0	6	serpentinite (altered dunite)
28. " , "	Hatt-8	4	2.0	10	2.0	4.5	7.0	<2	" (" harzburgite)
29. Røddiken (Tuva), Hattfjelldal	Rødd-1	6	5.0	4.0	<0.5	2.0	6.0	<2	Cumulate impregnation ore

Analyst: Analytical Services (W.A.) PTY.LTD. Perth, Western Australia (24-05-1988)
Method: Fire Assay and ICP-Mass Spec'.
* Recovery of Au is not quantitative at levels below 500 ppb.

Table 4

Content of platinum-group elements (PGE) and Au* in ppb in chromitite and sulphide mineralizations (No. 14 and 33) from solitary ultramafites, central and northern Norway. A composition of data

Location	Sample No.	Os	Ir	Ru	Rh	Pt	Pd	Au	Ore type/host rock
1. Svarthølhaugen, Oppdal district	-501 B	20	18	35	11	2.5	7.0	<2	impregnation ore
2. " , " "	-501 C/2	36	19	40	9.0	3.5	5.5	2	impregnation ore
3. Vindalskammen, " "	-502 A/6	150	64	250	35	17	32	54	massive ore
4. " , " "	-502 B/2	34	27	45	12	3.0	20	<2	massive ore
5. Koppungen, Sunndal district	-503 A	16	19	24	9.5	3.0	4.0	<2	massive ore
6. Grønvoldsteinen, Sunndal district	-504 A	50	33	82	21	3.0	7.5	<2	massive ore (coarse grained)
7. " , " "	-504 C	760	260	760	41	600	34	58	massive ore (fine grained, strongly magnetic)
8. Storskarhø, " "	-505 C/2	12	17	28	11	4.5	5.5	8	massive/strong impregnation ore
	-505 C/2 DUP	14	17	30	11	4.0	5.0	8	" "
9. " , " "	-505 C/3	6	12	20	6.0	4.0	2.5	8	" "
10. Tronfjell (N-slope), Alvdal	-508 (A)	26	23	38	12	2.0	3.0	<2	strong impregnation/massive ore
11. " ("), "	-508 B	2	5.0	6.0	2.0	8.0	5.0	4	serpentinite/serp.dunite
12. " (Grytåa, SE of top) Alvdal	-509	<2	5.0	4.0	1.5	2.0	3.0	<2	serpentintie/serp.dunite
13. " (S of top) "	-510	<2	2.5	1.5	1.0	0.5	1.5	<2	olivingabbro
14. Hjelmkona, Halsa, Nord-Møre	-511	(62)	8.5	5.5	3.0	11	10	100	sulphide-impregnation (strongly weathered)
15. " , " , "	-512	32	20	40	9.5	6.0	14	6	strong fine grained impregnation/massive ore
16. " , " , "	-513	26	12	26	7.0	4.5	6.5	8	coarse grained, uneven, impregnation ore
17. Sjømæingen, Gjemnes, Nord-Møre	-514 D	44	24	43	11	5.0	5.0	<2	coarse-grained impregnation/ massive ore
18. " , " , "	-514 C/2	6	14	40	9.0	18	18	4	" "
	-514 C/2 DUP	4	12	44	11	22	19	8	" "
19. Holberget, Kolletholen, Folldal	-515 B	50	42	69	18	2.0	2.5	<2	massive ore
20. Rødøya (NE of Skarvhammeren),Vefsn	-516 A	10	13	22	8.0	1.0	4.0	<2	medium grained impregnation ore
21. Rødøya (Rødøyvågen), Vefsn	-516 B	16	4.0	20	7.5	5.5	12	<2	impregnation / massive ore
22. " ("), "	-521 B	8	2.0	12	4.5	10	18	4	massive ore
23. " ("), "	-522	26	14	51	23	9.0	13	6	massive ore
24. " ("), "	-525	12	4.0	22	8.0	6.0	18	<2	massive ore
25. " ("Karoline")	-527	18	5.5	35	15	4.0	12	<2	massive ore
26. Forhågen, Kvaløya, Tromsø	-529	4	1.5	6.0	2.0	2.5	6.0	<2	weak impregnation in serpentinite
27. " , " , "	-531	3	5.5	30	6.5	4.5	10	<2	strong impregnation in serpentinite
28. Kalvholmen, Hestmannoy area	JHLV-1	150	22	78	33	240	630	26	massive ore
29. Raudholmen, "	JHLV-2	6	3.5	16	6.0	5.5	15	24	massive ore
30. Lille Esjeholmen, Nesøy area	JHLV-3	8	3.5	13	6.5	4.5	15	6	massive ore
31. Ramberget, Hestmannøy	AK86-Kr 1B	10	2.0	6.5	3.5	10	15	16	impregnation ore
	" , DUP	12	2.0	7.0	4.0	11	17	10	"
32. " , "	AK86-Kr 2	4	5.0	2.0	7.0	5.5	3.5	4	massive ore
33. "Harsjø"-boulder, Harsjø-farms,	K (ca. 1946)	44	7.0	18	7.0	11	12	10	sulphide boulder with 12 % Cu and 2 % Ni

Analyst: Sheen Analytical Services LTD, Perth, Western Australia (14-04-1989)
Method: Fire Assay and ICP-Mass Spec'.
Recovery of Au is not quantitative at levels below 500 ppb.

Table 5

TABLE A6

Content of PGE and Au in ppb in chromitites and host serpentinite from the Osthammeren ultramafic tectonite body.

Sample no.	Location (claim no./ loc. no. ref. to Fig. 3)		Os	Ir	Ru	Rh	Pt	Pd	Au	TOT	Ore-type/ host rock	Analyst analytical method
LPN78-138/2	9						760	<2	8		massive ore (PGM-anomalous sample)	
-138/2	9		174.2	674.4	841.0	65.2	323.4	2.9	4.9		massive ore (PGM-	
		DUP	166.3	659.2	835.8	64.9	316.1	3.0	5.2		anomalous sample)	
										2068.5	Average of two analyses	
-139			5.5	5.2	6.2	0.9	1.7	1.7	11.8		serpentinite	
LPN87-1/1	1		62	41	100	8.0	25	9.0	10		transition dissemination -	
		DUP	54	39	100	9.0	7.5	30	10		massive ore	
-2	2		130	160	160	130	9300	79	200		massive ore	
		REP	380	73	150	22	39	6.5	8			
		REP	86	79	170	28	49	8.5	12			
-3	3		62	58	140	31	83	11	2		massive ore	
-4/1	4		140	130	230	19	79	28	6		massive ore in veins	
		DUP	130	110	190	28	120	6.0	6		and schlieren	
-4/3	4		120	110	180	17	84	5.0	2		massive ore	
-5	5		530	510	640	63	470	7.0	6		massive ore in vein	
		DUP	130	110	750	78	480	11	10			
-6/1	6		50	54	100	21	1000	19	20		massive ore in vein	
		REP	270	43	97	11	22	10	2			
		REP	44	44	130	13	24	40	2			
-8/1	8		92	90	170	18	72	28	4		transition dissemination -	
		DUP	70	73	150	26	68	27	4		massive ore in fine veins	
-9/1	9		550	420	590	34	160	22	12		massive ore in veins	
		REP	560	290	610	32	120	9.0	6			
		REP	560	430	550	35	190	34	8			
-9/2	9		670	490	640	50	430	20	2		massive ore in veins	
-10/1	10		570	470	520	27	210	8.5	10		massive ore in veins	
-10/2	10		1400	810	1400	73	350	6.0	30		massive ore	
		DUP	1100	610	1100	54	230	8.0	32			
			346	243	396	35	449	17	14	1500	Average of samples 1/1 to 10/2 n = 12	
-1/2	1		6	5.0	4.0	<0.5	2.0	6.0	<2		serpentinite	3
-4/2	4		6	6.5	8.0	1.0	<0.5	8.5	4		"	
-6/2	6		4	3.5	14	1.0	2.5	21	6		"	
-8/2	8		2	4.0	5.5	1.0	7.0	5.5	4		"	
-9/3	9		4	1.5	8.0	2.0	4.5	19	<2		"	
-12	12		2	2.0	5.5	1.0	1.5	4.5	2		"	
-13	13		2	6.0	12	1.5	3.0	15	2		"	
-14	14		2	2.5	35	1.5	7.5	6.0	<2		"	
-15	15		6	4.0	7.0	1.0	3.0	14	24		"	
-16	16		4	3.0	11	1.0	3.0	12	8		"	
			3.8	3.8	11.0	1.1	3.4	11.2	5.3	39.6	Average of samples -1/2 to 16 n = 10	

Analyst:	Method:
1 Caleb Brett Laboratories Ltd., St. Helens, UK	Fire Assay and atomic absorption spectrometry
2 Memorial University, St. John's, Newfoundland, Canada	Fire Assay and ICP-Mass Spec
3 Analytical Services (W.A.) PTY.LTD, Perth, Western Australia	Fire Assay and ICP-Mass Spec

The mineralogical studies have revealed the following two assemblages:

1. Os-,Ir-,Ru- and, to a lesser extent, Pt-bearing minerals in primary magmatic, euhedral-subhedral, small (under 20 microns) inclusions in fresh unaltered chromite. These consist of mainly single-phase inclusions of Os-free laurite, Os-laurite, osmiridium and a Pt-Ir-Os-Fe alloy. A few of the inclusions are associated with small blebs of Na-bearing hornblende or phlogopite, indicating the presence of volatiles at an early stage in the formation of the PGM.

2. Secondary PGM occurring as anhedral-subhedral, texturally complex grains or grain-aggregates up to 70 microns across and always found in cracks in chromite, usually in association with ferrite-chromite, a hydrothermal alteration product of chromite. These contain up to eight PGM plus Ni-sulphide and Ni-arsenide. The phases found include Os-free laurite, Os-laurite, erlichmanite, Ir-rich erlichmanite, native Os, iridosmine, osarsite, irarsite, hollingworthite, Rh-rich platarsite, Ru-rich platarsite, sperrylite, (Ir,Rh)SbS, IrSbS, Pd-antimonide (probably stibiopalladinite), $(Ir,Pt,Pb)S_2$ (possibly a new mineral) and the associated phases, pentlandite, heazlewoodite and niccolite.

2.3 Inclusions of platinum group minerals (PGM), base-metal sulphides (BMS) and sulpharsenide in chromitite and host rocks from the Ørnstolen ultramafic tectonite body, north central Norway

Five chromitite samples from the Ørnstolen ultramafic body were analyzed for Pt, Pd and Au in the pilot project (Table 2). Three samples contained 100-200 ppb Pt+Pd+Au while one contained 299 ppb Pt, 1391 ppb Pd and 718 ppb Au, values later confirmed by reanalysis at Memorial University.

The subproject reported here has included further whole-rock analyses of PGE and Au contents and a mineralogical study. Both are reported in full in a draft manuscript included in Vol. 2 of this report.

A further nine samples were analyzed in the course of this project, four chromitite samples and five samples of the host metaperidotite (see paper in Vol.2). The host rocks contain a prograde metamorphic assemblage consisting mainly of olivine, enstatite and tremolite, the only primary phase being chromite. The metaperidotites proved to have low contents of the IPGE, with an Ir content under half the estimated mantle average (Barnes et al. 1988), while Pt-, Pd- and Au-values, while still low (all single values <100 ppb) are significantly higher than the values reported for mantle harzburgite by Barnes et al.(1985), by a factor of two for Pt and Pd, and a factor of four for Au. None of the chromitite samples yielded values comparable to the richest sample analyzed in the pilot project, the highest values found being 383.5 ppb total PGE+Au, of which 160 ppb Pt. The average of the five chromitite samples is 223.2 ppb total PGE+Au. The strong enrichment in Pt, Pd and Au found in one sample analyzed during the pilot project must be very local. The restriction of the anomalous values to the chromitite precludes any economic potential in the area.

A few small PGM inclusions have been found in chromite grains in the chromitite samples: the PGM found are laurite, Os-laurite and irarsite. The occurrence of an arsenic-bearing phase in what appears to be an inclusion in chromite is unusual (they are common in later-formed hydrothermal assemblages). A Pd-Bi-bearing phase was found in a sample of metaperidotite. Details of the base metal sulphides and sulpharsenides found are given in the complete report in Vol. 2.

2.4 Hydrothermal gold-enriched iron and iron-copper occurrences in the Hatten ultramafic tectonite lens, Hattfjelldal

Chromitite samples from the Hatten ultramafic body in Hattfjelldal are reported in the literature (Lunde & Johnsen 1928) as containing 0.83 ppm Pt. A reconnaissance of the area was therefore carried out in order to obtain samples of the chromitite: neither the locations nor the dimensions of the chromitite showings are, however described in the above reference and the mineralizations could not be found in the time available. Mineralizations containing magnetite and copper- and iron-sulphides, and located on shear zones, as described by Corneliussen (1891) and Vogt (1894) were however found and sampled.

The mineralizations sampled are of such limited extent that they have no economic significance: they are probably of the same type as the mineralizations described from the Troodos and Leka ophiolites by Vokes (1987), these also, so far as is known of quite limited size. The possibility of finding larger mineralizations of this type in other ophiolite complexes should not be excluded.

Of five samples analyzed for all the PGE+Au three contain Au values between 195 and 540 ppb, one of these also containing 140 ppb Pt (see paper in Vol.2 for complete analytical data): we have no explanation for the elevated Os and Ir contents reported for the three samples which were re-analyzed. Au values are available for a further twelve samples (see Table 3 in the report in Vol. 2): ten of these have values >100 ppb with a maximum of 3260 ppb. An examination of the mineralogy of the samples is in progress.

2.5 Platinum group minerals (PGM), gold and associated minerals in the Raudberg field ultramafic tectonites, Vik, Sogn og Fjordane, western Norway

The Raudberg area contains several ultramafic lenses with a combined surface area of just over 3 sq.km.: they are concentrically zoned from metadunite cores to serpentinite and then soapstone on their margins. The soapstone is being evaluated as a source of talc. The soapstone contains small amounts of sulphide and because of the ease with which these could be beneficiated their mineralogy and chemistry has been studied despite their low abundance.

Seventeen whole rock samples have been analyzed for all the PGE and gold. The results show erratic weak enrichment in several of the elements (see paper in Vol. 2 for complete analytical data). The richest single sample contains 46 ppb Os, 13 ppb Ir, 170 ppb Ru, 41 ppb Rh, 7 ppb Pt, 17 ppb Pd and 2 ppb Au. The highest single values for Pt, Pd and Au are found in a sample with 20, 62 and 16 ppb respectively. Samples of concentrate prepared by relatively simple methods give enrichment of at least an order of magnitude, the richer of two concentrates giving 2.38 ppm PGE+Au, of which 350 ppb Pt, 580 ppb Pd and 340 ppb Au.

Because of the sparsity of the ore minerals, and of the noble metal-bearing phases within these, the mineralogical studies have been carried out on concentrates and therefore do not include any consideration of textural relationships between ore minerals and silicate matrix. The predominant ore minerals, in addition to chromite, are heazlewoodite and cobaltite in the metadunite, gersdorffite, heazlewoodite, cobaltite and pentlandite in the serpentinite and pentlandite in the soapstone, indicating decreasing As and Ni and increasing S contents from the cores of the bodies outwards. Most of the PGM found, except for irarsite, are alloys of Pt with other PGE. One PGE-telluride, michenerite, has been found and small amounts of non-PGE-bearing tellurium minerals are common.

3. PLATINUM METALS IN PODIFORM CHROMITITE IN DUNITE/PYROXENITE LENSES/DYKES/VEINS IN MANTLE HARZBURGITE IN THE LEKA OPHIOLITE

The mineralizations considered in the above chapter occur in isolated ultramafic lenses most of which are thought to have originated in sub-oceanic mantle or lowermost oceanic crustal rocks (i.e. ultramafic cumulates if they can be identified). By their nature it is not possible to reconstruct their geological environment and their degree of alteration /metamorphism often makes it difficult to determine their original character. The presence of a complete ophiolite stratigraphy with excellent exposure permits a much better understanding of the nature and origin of the mineralizations on Leka.

The lowermost part of the Leka Ophiolite Complex (LOC) consists of mantle harzburgite with a clear tectonic fabric and containing tabular dunite bodies and dykes and veins of dunite and pyroxenite. The latter contain, in many cases, a central zone, generally of disseminated chromite, but locally with massive chromitite zones 10-20 cm thick. These mineralizations do not have dimensions which give them any direct economic significance but they are important for an understanding of the processes controlling the distribution of the PGE in the complex.

Eighteen samples of chromite-free harzburgite, dunite and pyroxenite have been analyzed for all the PGE+Au. They all yielded low values <80 ppb total PGE+Au, compatible in general with the mantle average given by Barnes et al. (1988), except for a slight positive Ru anomaly which could possibly be an analytical artifact. Sixteen chromite-bearing samples were analyzed: they revealed a range from mantle concentration levels up to 8510 ppb, of which 4600 ppb Pt and 2700 ppb Pd. Comparison with Cr analyses shows a strong positive correlation between Cr-content and total PGE+Au-content and PPGE/IPGE exemplified by the Pt/Ir ratio (see Figs. 6 and 7 in the full manuscript in Vol. 2). The enriched samples have PGE contents atypical in relation to most podiform chromitites for which PGE-data is available in their enrichment in PPGE: the distribution pattern of the PGE resembles that found at the Cliff mineralization on Unst though at almost an order of magnitude lower absolute concentration (Fig. 3).

The correlation with Cr-contents indicates that chromite is important for the enrichment of the PGE though probably through the physical process of accumulation rather than through solid substitution in chromite. The two richest samples are from chromitite in pyroxenite dykes while almost all the low-PGE chromitite samples are from dunites: this may indicate that differentiation of the magma in the mantle is important for the formation of PPGE-enriched chromitites in this type of deposit.

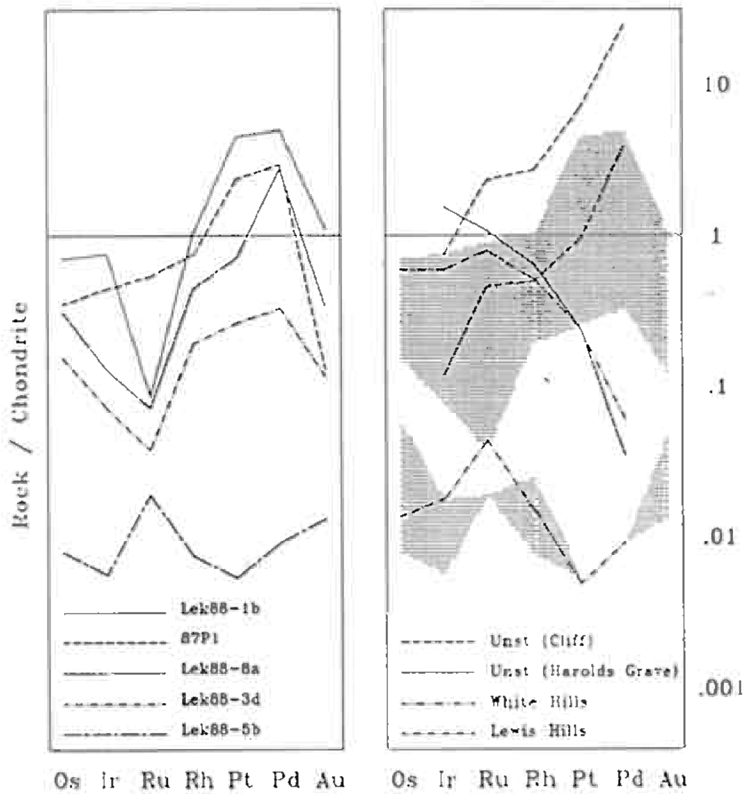


Fig.3: A) Chondrite-normalized PGE patterns of chromitites in dunitic bodies in mantle harzburgite in the Leka ophiolite.
B) Comparison of these with corresponding data from Unst (Prichard et al. 1986) and Bay of Island (Talkington & Watkinson 1986).

4. PLATINUM METALS IN ULTRAMAFIC CUMULATES

4.1 Summary

The platinum metal geochemistry of parts of the sequences of ultramafic cumulates in the Leka and Lyngen ophiolites has been examined. In the case of Leka this study had the advantage of building on a very detailed knowledge of the field geology, mineralogy and petrology of the rocks: the work done on Lyngen must be regarded as a reconnaissance. That stratiform enrichments of Pt,Pd and Au, albeit at subeconomic levels, were found in both complexes after examination of relatively limited parts of them, would seem to indicate a potential for richer mineralizations in both areas and a clear potential for PGE-mineralizations in ultramafic cumulates in ophiolites in general. The paper in Vol. 2 concludes with a model for the formation of the type of PGE-enrichment found on Leka and gives criteria which should be useful in a search for further mineralizations of this type, either in the LOC or other ophiolites. These criteria include association with reversals in the trend of cryptic variation in olivine composition, the actual composition of the cumulus olivines and a stratigraphic position above chromite-bearing horizons.

The stratiform mineralizations found on Leka are:

- Os-Ir-Ru-enriched chromitite with up to 500 ppb PGE+Au
- Pt-enriched olivine adcumulate with up to 1 ppm PGE+Au over 0.5 m
- Pd-enriched olivine adcumulate with up to 1 ppm PGE+Au over 0.5 m and up to 3 ppm in hand samples.

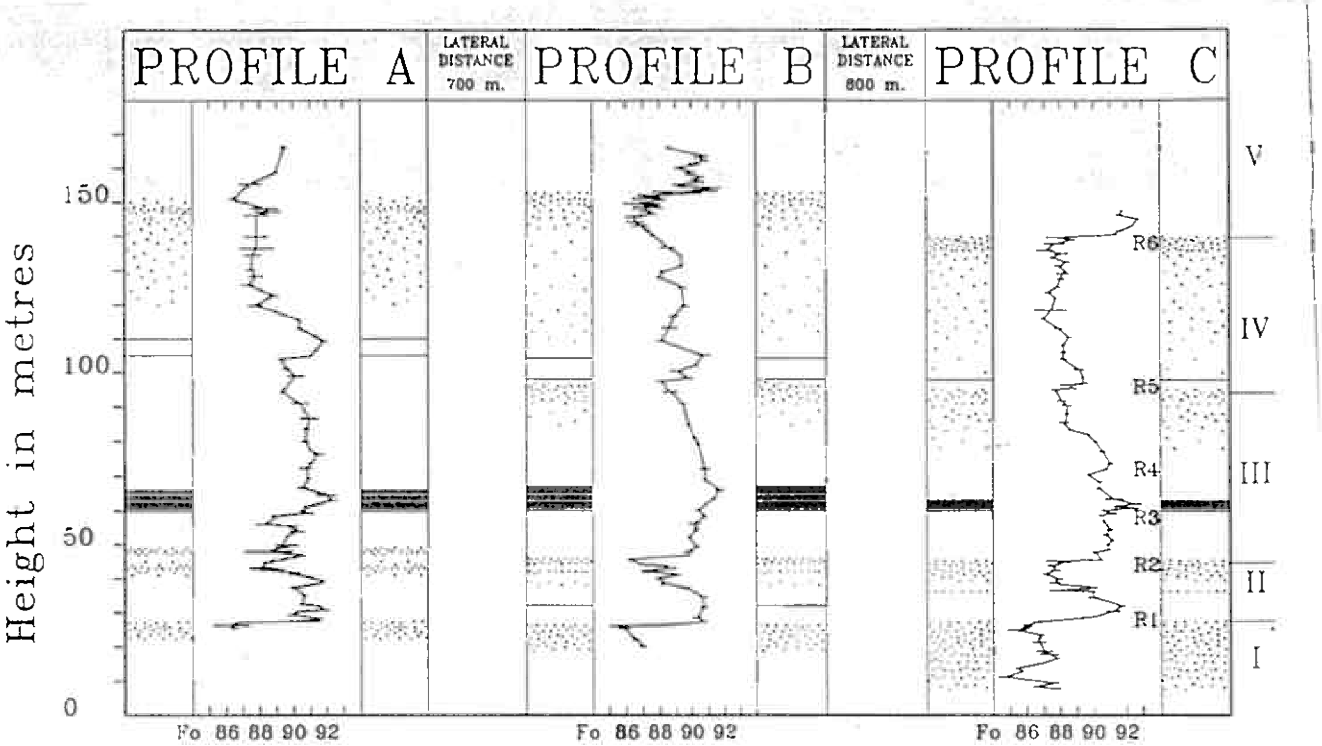
The mineralizations have been followed over a strike length of 1500m and have a probable total strike length of about 3000m. Hand samples from mineralized horizons outside the area studied in detail have also proved to be enriched in Pt, Pd and Au.

The mineralizations found in the Lyngen complex would appear to be of a slightly different type, occurring higher up in the cumulate stratigraphy, in association with Cu-dominated sulphides and without any, even indirect association with chromitite enrichments. They do not appear to have the same stratigraphic regularity as the mineralizations found on Leka. The highest concentration found was 551 ppb, of which 150 ppb Pt, 240 ppb Pd and 150 ppb Au.

4.2 Platinum metal abundances in the ultramafic cumulates of the Leka ophiolite

The examination of part of the sequence of ultramafic cumulates in the LOC represents the largest single subproject reported here. It has built on the work of H. Furnes and R.B.Pedersen and their colleagues at the University of Bergen (see paper in Vol. 2 for reference list) but has involved considerable additional hand sampling, the drilling of over 20 shallow drill holes (down to a maximum depth of 30 m), the analysis of several hundred samples for the PGE and Au, of a lesser number for other elements and a mineralogical study of the PGE-enriched horizons which is still in progress.

Analysis of hand samples collected at intervals of a few metres proved the existence of relatively weak enrichments of the IPGE (of the order of a few hundred ppb) in association with the most prominent chromitite horizon



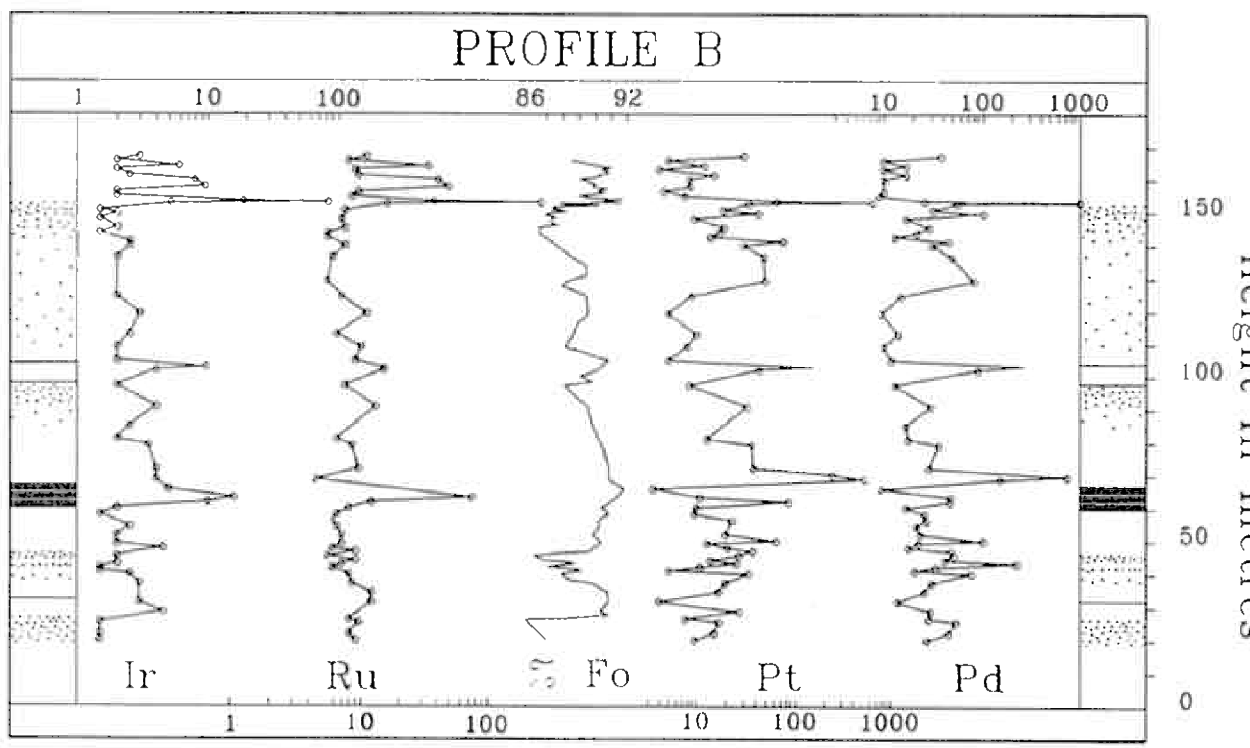


Fig.4: A) Cryptic variation of olivine across part of a sub-zone of olivine cumulates: profiles A,B and C are separated by 700 and 800 m respectively. Cyclic units which can be defined in the field are marked by Roman numerals. Reversals in cryptic variation are marked R1, R2, etc.

B) Variation of PGE content with height in Profile B.

in the sequence (Fig. 4), and with a chromite-bearing horizon at the base of a cyclic unit 100 m higher up in the stratigraphy (R6). The hand samples also indicated the existence of three horizons enriched in the PPGE, of which two contained >1000 ppb Pt+Pd. One of these was found immediately above the main chromitite while the two others were found at the bases of higher cyclic units.

In order to obtain complete intersections of the enriched horizons a number of drillholes (max. depth 30 m) were drilled in three profiles, the profiles having separations of 700 and 800 m (Fig. 5). Analysis of the drillcore (0.5 m lengths) confirmed the existence of the PPGE-enrichment just above the main chromitite (Figs. 4,5), showing that it consisted of two horizons, and showed the presence of PPGE-enriched horizons associated with the bases of the cyclic units immediately below (R2) and immediately above (R4) the main chromitite (itself characterized as R3). The enrichment associated with R6 was also found but the core samples had a maximum content of PGE+Au of 228 ppb, suggesting that the hand sample from this horizon, which contained over 2.2 ppm was collected from the richest part of the horizon. The enrichment found to be associated with R5 from the analysis of the hand samples was not intersected by any of the drillholes.

The richest drillhole intersection is in drillhole 87A1, across the lowermost enrichment above the main chromitite (R3) in profile B (Figs. 4,5). It contains 0.5 m of core with 1099 ppb PGE+Au, of which 140 ppb Pt, 780 ppb Pd and 170 ppb Au, and averages 609 ppb PGE+Au over 1.5 m of core. The last 0.5 m of drillhole 88B1 (Fig. 5) contains 966.5 ppb PGE+Au, associated with the enrichment at R4, and averages 680 ppb PGE+Au over the last 1.5 m of the hole: we do not know the average composition at this locality because the hole stops in the middle of the mineralized zone. Hole 88B2 intersected the PPGE enrichment above R2, which gave 801 ppb PGE+Au, of which 390 ppb Au, over 0.5 m: the following seven samples representing 3.5 m of core averaged over 370 ppb Au but showed only very weak enrichment of Pt and Pd: this Au enrichment is thought to be hydrothermal.

The Pt-Pd-enriched horizons have a PGE-geochemistry similar to that found in stratiform PGE mineralizations such as the Merensky and Johns-Manville reefs, found in large layered intrusions in cratons, though at somewhat lower absolute concentrations (Fig. 6). Further features in common with these mineralizations are very limited thickness, large lateral extent and a close relationship to the bases of cyclic units, i.e. pointing to a genetic link with influx of fresh magma pulses and mixing of these with the magma resident in the chamber. The Leka mineralizations contrast with those mentioned above in that they occur much deeper in the cumulate stratigraphy, in association with olivine adcumulates, while the well-known reefs occur after the crystallization of cumulus plagioclase commences. The variations in composition of the mineralizations on Leka indicate that the Pt-enriched horizons occur just below those that are enriched in Pd and that the former are well-developed close to the presumed magma feeder while the reverse is the case for the Pd-enriched horizons.

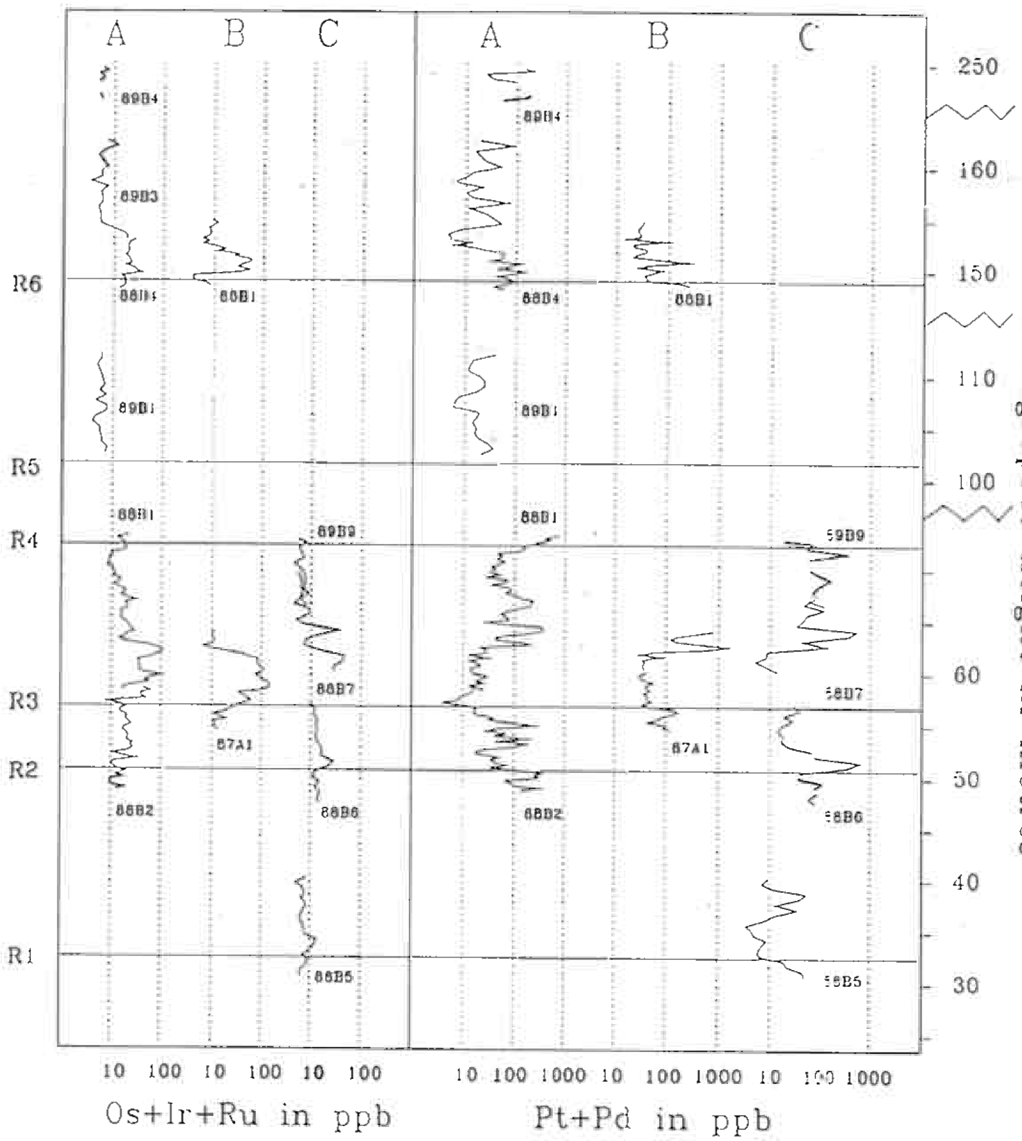


Fig. 5: Relative positions of drillcores through PGE+Au mineralizations in the ultramafic cumulates at Leka with data on IPGE- and PPGE+Au contents.

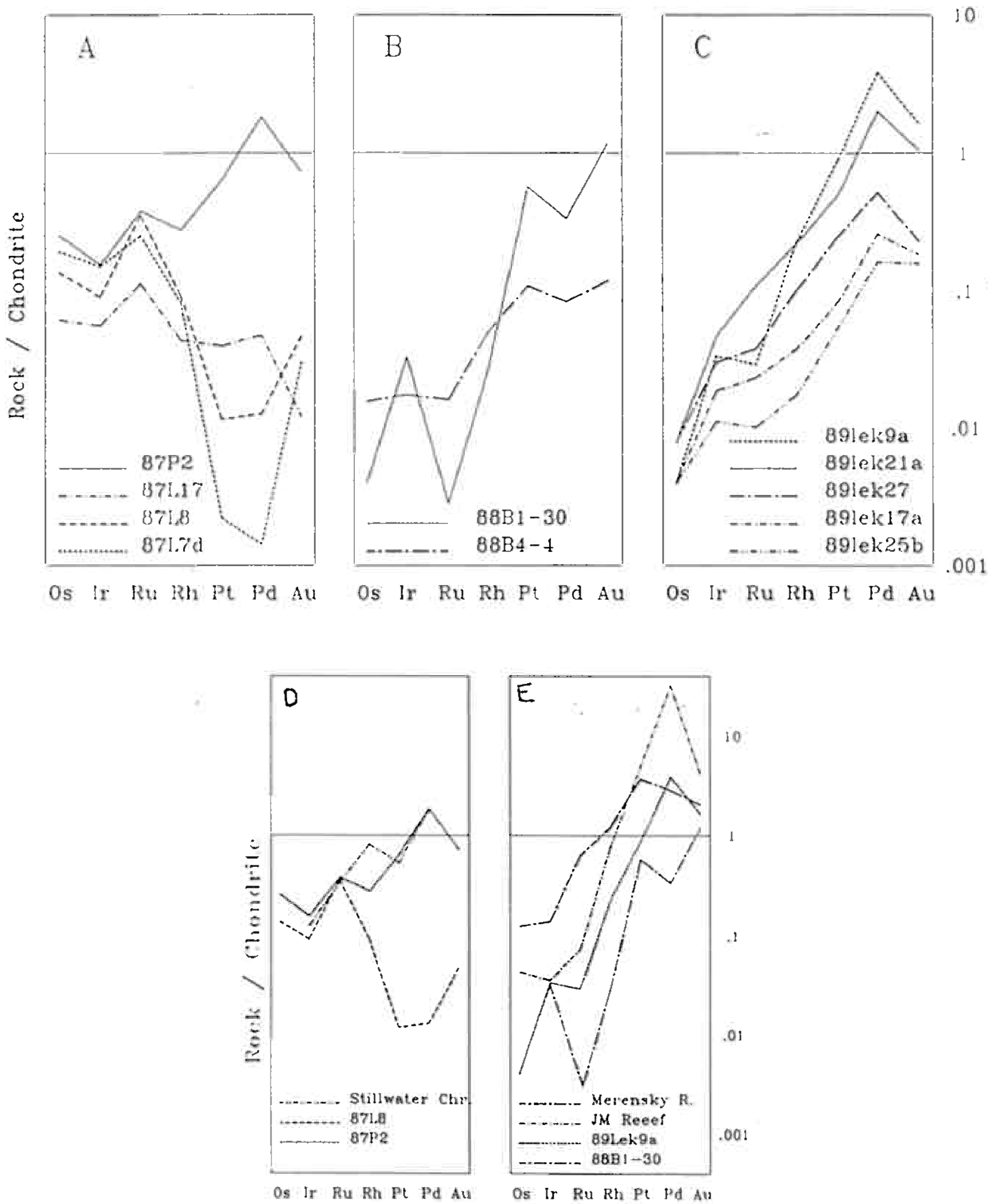


Fig. 6: Chondrite-normalized patterns of PGE and Au contents for: A) IPGE-enriched chromitites, B) Pt-dominated enrichments, C) Pd-dominated enrichments and for D) the IPGE-enriched chromitites and Stillwater chromitites (Page et al. 1976) and for E) the PPGE-enriched horizons and the Merensky and Johns-Manville Reefs (von Gruenewaldt 1979: Barnes & Naldrett 1985).

The occurrence of the PPGE enrichments is related to the mixing of a primitive magma in equilibrium with olivine of composition Fo93-92 with a slightly more evolved magma (in equilibrium with Fo90-85): mixing of the two magmas facilitated the preciptation of both chromite and sulphides /arsenides, a model which builds on the work of Irvine (1977), Campbell et al. (1983) and Naldrett & von Gruenewaldt (1989). Nd-isotope studies of the PGE-enriched cumulates show that they crystallized from a magma with MORB/IAT affinity: calculation of its probable original PGE content suggests that it would be of roughly the same order as that of the boninitic parental magmas postulated for the Bushveld and Stillwater intrusions (Davies & Tredoux 1985: Zientek et al. 1986).

The model should enable the prediction of which type of cyclic unit in the ultramafic cumulates of ophiolites should be favourable for the occurrence of PPGE-enriched horizons: it is probable that further horizons of this type can be found in the Leka ophiolite. It is regarded as highly probable that many such horizons will be found in ophiolite complexes with well-developed sequences of ultramafic cumulates, particularly when the PGE geochemistry of the parts of cyclic units immediately above the chromite horizons or the bases of cyclic units in general, whether marked by chromite enrichment or not, are studied. Among the complexes in which the preconcitions for mineralizations of this type would seem to be present are the Semail ophiolite in Oman (Lippard et al. 1986), the Bay of Islands ophiolite in Newfoundland (Dunsworth et al. 1986) and, of less well-known examples, the Pozanti-Karsanti ophiolite in Turkey (Rahgoshay et al. 1987), which is reported as containing chromite-bearing olivine cumulates over a 2 km thickness with several dm-thick chromitite horizons for every metre.

4.3 Platinum metal abundances in ultramafic cumulates in the Lyngen ophiolite

A reconnaissance of ultramafic bodies in the more accessible parts of the Lyngen ophiolite was carried out in 1987-88 as a collaborative project between Norges geologiske undersøkelse and Troms fylkeskommune. The Lyngen ophiolite is by far the largest in Norway, with a total strike length of over 80 km, but it is also disrupted and strongly deformed and has an incomplete stratigraphy. Mantle harzburgite and ultramafic cumulates are present, but as tectonically emplaced pods of which the largest, at Russelv in the northernmost part of the Lyngen peninsula, is about 6 km long. The ophiolite is delimited to the west by a tectonically disturbed erosional unconformity which is overlain by a sedimentary sequence which contains a series of serpentinite lenses at a specific level just over 1 km above the unconformity.

133 samples from ultramafic bodies on each side of Kjosen, east of Russelv (Fig. 7) and from the serpentinite lenses in the sedimentary sequence overlying the ophiolite were analyzed for PGE+Au. The 9 serpentinite samples gave uniformly low values, <30 ppb total PGE+Au. 73 samples from metadunitic budies, probably originally cumulates, at Kjosen yielded values predominantly <50 ppb PGE+Au, with a maximum of 106.5 ppb PGE+Au, of which 83 ppb Pt. The weak enrichment found in these rocks is consistently of Pt. 51 samples of metamorphosed olivine- and olivine-clinopyroxene cumulates from the Russelv ultramafic body gave more positive results: these rocks locally contain visible chalcopyrite-pyrrhotite

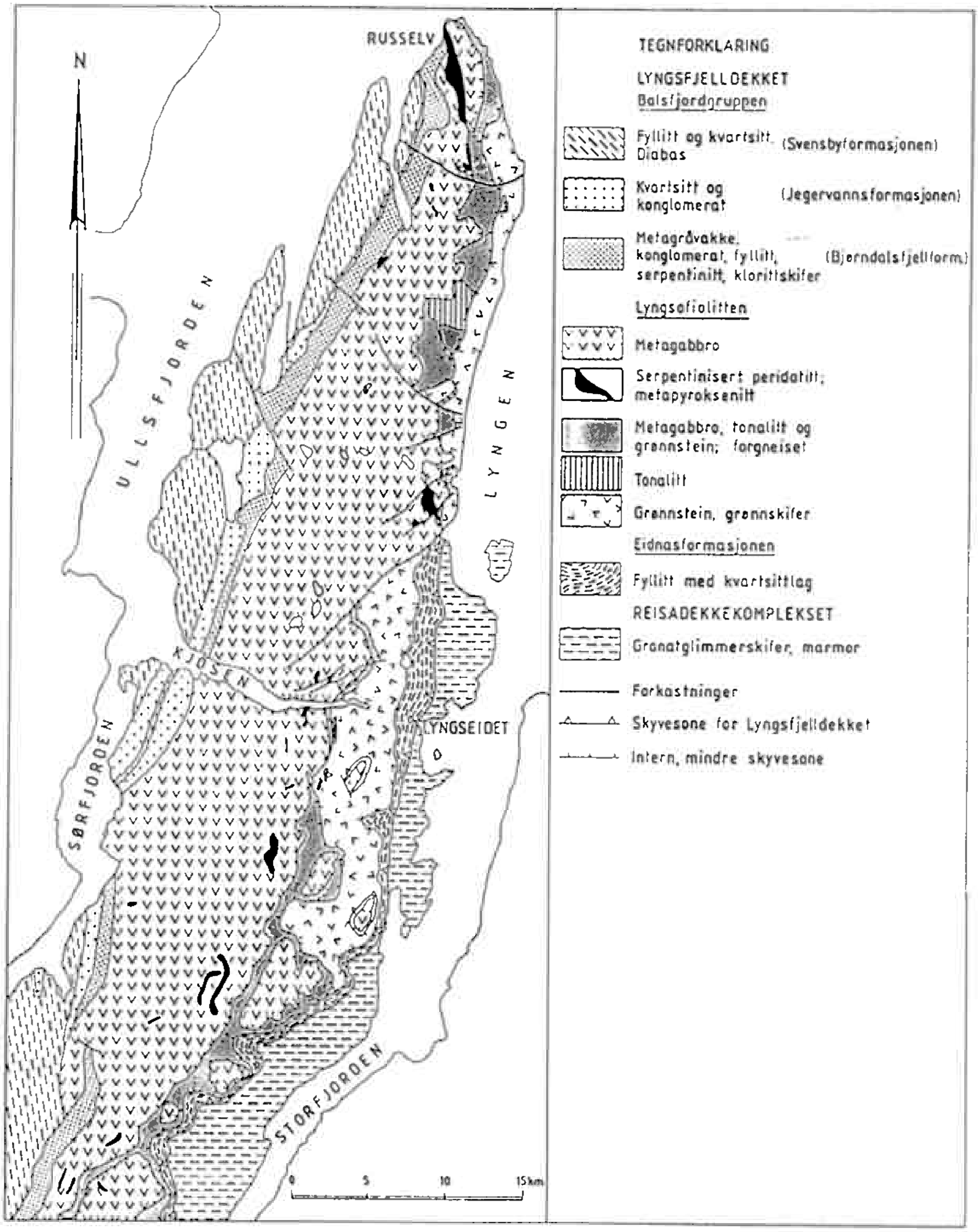


Fig. 7: Geology of the Lyngen peninsula (based on Boyd & Minsaas 1983 a,b)

dissemination, altered to bornite and digenite: there is a positive correlation between noble metal content and sulphide content. The richest samples contain over 100 ppb each of Pt, Pd and Au, with a maximum of 550 ppb PGE+Au. The samples from Russelv have higher Au/Pt and Pd/Pt ratios than those from the Kjosen area. The absolute grades are similar to those reported from a mineralization in mafic cumulates in the Semail ophiolite by Lachize et al. (1990) but the latter has a much higher modal % of sulphides which indicates that the Lyngen mineralization in which the actual volume of sulphides is only a few percent at most, would have a much higher grade of noble metals on 100% sulphide, a frequently quoted parameter (e.g. Naldrett 1981).

The discovery of noble metal enrichments after such a limited reconnaissance of a small part of the complex indicates that a potential for finding further horizons of this type, possibly at higher levels in the stratigraphy is present and that the possibility of finding richer concentrations cannot be ruled out.

5. PLATINUM METALS IN HIGHER LEVEL MINERALIZATIONS

All the Norwegian ophiolite complexes which have been studied petrologically in any detail have been shown to contain components formed in island arc environments, and are regarded as supra-subduction ophiolites (Pedersen et al. 1988). If the definition of ophiolite is broadened to include predominantly island arc-derived copmlexes, with lesser components formed at ridges, then we have two high level PGE-bearing mineralizations in ophiolites in Norway, the Fæøy deposit in the Karmøy ophiolite, and the Lillefjellklumpen deposit in the Gjersvik island arc complex. Both are deposits of massive Ni-Cu sulphides with associated PGE and small amounts of Au. For both deposits the samples analyzed average 1.8 ppm Pt: the values from Fæøy for Pd average 4.76 ppm while the corresponding average for Lillefjellklumpen is 3.07 ppm. Gold contents average 101 and 219 ppb respectively. The Lillefjellklumpen mineralization is tiny and that at Fæøy, small - its probable original tonnage was of the order of 40,000 tons: no further deposits of this type have been found in Norway and deposits with similar characteristics in ophiolites in other parts of the world also seem to be of very limited size: there would not seem to be a potential for deposits of this type with economically interesting dimensions but should this conclusion prove to be wrong, grades of Pt and Pd of the level found in the two deposits in Norway would make deposits of even a modest size economically attractive.

The Lillefjellklumpen deposit is located in the Gjersvik island arc complex, north-east of Grong in N-Trøndelag (see paper by Grønlie in Vol.2). The host complex is interpreted as an ensimatic island arc, the mineralization itself being associated with a small gabbroic intrusion at the base of the volcanic level of the complex. The mineralization consists of massive sulphide, dominated by pyrrhotite, pyrite, pentlandite and chalcopyrite, with an average grade of 3.6% Ni and 1.2% Cu (Grønlie 1988). The averages of eight samples analyzed for all the PGE+Au are 139 ppb Os, 170 ppb Ir, 189 ppb Ru, 214 ppb Rh, 1799 ppb Pt, 3068 ppb Pd and 219 ppb Au. These values compare closely with those for typical mineralizations at Sudbury (Naldrett 1981). The PGE are hosted in merenskyite, sperrylite, moncheite and temagamite, the mineralization being very unusual in having merenskyite as the dominant platinum group mineral.

Detailed study of the Fæøy deposit has not been given high priority because it has been the topic of an M.Sc. thesis being carried out by a student from Memorial University, Newfoundland: unfortunately the completion of this project has been delayed. The mineralization is a massive sulphide deposit located in the dyke complex of the Karmøy ophiolite. It outcrops at sea-level and most of the workings from mining activity early in this century and late in the last are under water. It is a Cu-Ni deposit but with highly variable Cu/(Cu+Ni) ratios, varying from 0.3 to 0.75. The average of six samples analyzed for PGE+Au is 234 ppb Os, 195 ppb Ir, 219 ppb Ru, 244 ppb Rh, 1794 ppb Pt, 4760 ppb Pd and 101 ppb Au.

6. PLATINUM METAL GEOCHEMISTRY OF SUCCESSIVE MAGMA TYPES IN THE KARMØY OPHIOLITE

The upper levels of the Karmøy ophiolite include volcanic rocks of several different types - mid-ocean ridge basalts (MORB), island arc tholeiites (IAT), boninites, calcalkaline and alkaline basalts. Investigation of the PGE geochemistry of these rocks allows the following conclusions to be drawn:

1) The boninites and calcalkaline basalts have higher PGE-contents than the other series.
2) The boninites show a bimodal distribution of PGE abundance. The PGE-enriched boninites have chondrite-normalized PGE patterns similar to those found in boninites in modern island arcs, while the PGE-depleted boninites have patterns resembling those in the other series (MORB, IAT, alkaline).
3) The bimodal distribution of PGE abundance in the boninites is probably related to sulphur saturation and enrichment of PGE in the sulphides, the Fæøy mineralization probably being a product of this process.
4) The considerable variations in ENd ratio in the boninites indicate that the magma did not differentiate in a large steady-state magma chamber, as did the MORB/IAT series. It would thus seem to be unlikely that large layered intrusions of boninitic parentage and containing stratiform PGE enrichments will be found in the Karmøy or other ophiolite complexes.
5) The apparent difference in PGE-content between MORB/IAT magmas and the PGE-enriched boninites is also ascribed to later sulphur saturation in the latter.
6) Rock complexes with boninitic parental magmas in ophiolites should not be regarded as particularly favourable for PGE-enrichment in relation to others with MORB/IAT parental magmas.

7. CONCLUSIONS

The most important finding within the project is the discovery and documentation of stratiform PPGE mineralizations in ultramafic cumulates in the Leka ophiolite and of indications of similar mineralizations at a stratigraphically higher level in the Lyngen ophiolite. The Leka mineralizations are of a type the existence of which in ophiolites has not been (well) documented before and which has several characteristics in common with stratiform PGE enrichments in large layered intrusions. Though subeconomic, the mineralizations indicate a possible potential for horizons with higher PGE-contents in the two ophiolites examined and a clear potential for PPGE mineralizations in ophiolites with well-developed sequences of ultramafic cumulates in general. The model developed for the mineralizations in the Leka ophiolite (see paper in Vol.2) gives criteria which should assist in the selection of ophiolite complexes with PGE-potential and the location of targets within them.

Samples from numerous podiform chromitite mineralizations have been analyzed and several of the deposits have been studied in detail. Several deposits, including those on Leka, have proved to be enriched in PPGE, unlike most of the examples described in the literature which are enriched in IPGE. The PGE enrichment is confined to chromite-bearing rocks and, at least on Leka, shows a postive correlation with Cr-content: the small size of the chromitite mineralizations precludes any economic potential in the Norwegian examples. The largest examples described in the literature are also relatively small (<5 million tons) which suggests that only the very largest podiform chromitites could be interesting targets for PGE-exploitation and then only if they were enriched in PPGE.

The PGE-enriched massive Cu-Ni sulphide and hydrothermal Cu-sulphide mineralizations examined are also too small to have economic importance.

Studies of the isotope- and PGE-geochemistry of the different volcanic suites in the Karmøy ophiolite and of the cumulates in the Leka ophiolite suggest that rock suites with boninitic parentage should not be regarded as particularly favourable for PGE-enrichment in relation to suites with parental magmas of MORB/IAT affinity.

The project has demonstrated that the availability of new analytical technology (ICP-MS) which allows the rapid analysis of all the PGE at a reasonable cost, can lead to the discovery of new mineralizations and potentially to new mineralizations of economic significance. It shows further the advantages which a well-developed, well-exposed ophiolite complex has as a natural laboratory for the study of the processes controlling PGE-enrichment (as opposed to many layered intrusions in cratons) in that potential magma source rocks, feeder channels and the end products of the magmatic evolution can be sampled as well as the immediate host rocks and the mineralizations themselves.

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NTNF
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Søknadsskjema

Søknad datert. . . . .

1 Søker: Norges geologiske undersøkelse

NTNF-komite:

NTNF-nr.:

Postadr.:
Postboks 3006
7001 Trondheim

Tlf.:

Prosjekttittel (maks. 64 anslag):
Geokjemi av platinametaller i
norske ofiolitter

Søkers kontaktperson: Avd.direktør S. Krogh, SINTEF

Faglig hovedansvarlig: forsker R. Boyd, NGU

2 Emneord (4 emneord som karakteriserer prosjektet): Platinametaller/geokjemi/petrologi/malmgeologi

3 Er eller vil det bli søkt om prosjekt-støtte fra annen kilde enn NTNF?
[X] Ja
[ ] Nei
Hvis ja: Gi opplysninger i pkt. 5 eller i prosjektbeskrivelse

4 Mål
1) Å gjennomføre en første vurdering av potensialet for platinametaller i ofiolitter i Norge
2) Å studere prosessene som styrer fordelingen av platinametallene
3) Å undersøke et fåtall prioriterte områder nærmere

5 Bevilgninger/budsjett for hele prosjekttiden (Alle beløp i 1000 kr.)

	Bevilgninger		Budsjett			
	Tidligere år	I år	Søknadsår	Etterfølgende år		
Første år med NTNF-støtte 19 / Planlagt siste år med NTNF-støtte 19	19 –19	19	19 87	19 88	19 89	19 – 19
NTNF-midler			400	600	400	
Industrimidler			150	150	150	
Offentlige midler			600	600	600	
Andre midler (spesifisert i vedlegg)						
SUM			1150	1350	1150	

6 Kostnader i søknadsåret (Alle beløp i 1000 kr.)

Nr.	Delprosjekttittel	Ansvarlig	Direkte lønn og felleskostn.	Direkte matr. og utlegg	Kostnader i egne laboratorier	SUM
1)	Rekognoserende undersøkelse m.h.p. platinametaller i norske ofiolitter	R. Boyd NGU-medarb. stipendiat	350	185	160	695
2)	Oppfølgende undersøkelser i utvalge områder	R. Boyd NGU-medarb. stipendiat	150	75	80	305
SUM			500	360	290	1150
NTNF-andel			230	170		400

7 Prosjektsammendrag

Kfr. veiledningen
Skal kunne publiseres direkte i prosjektkatalog

Prosjektet omfatter en vurdering av platinametallinnholdet i bergartskomplekser og malmtyper i ofiolitter i Norge. Prosessene som fører til anriking av platinametaller vil bli studert ut fra både vitenskapelige og økonomisk-geologiske synspunkter. Utvalgte områder vil bli vurdert nærmere. Prosjektet vil være et viktig skritt mot den første moderne oversikt over platinemetaller i berggrunnen i Norge. Arbeidet vil omfatte samarbeid med universiteter og andre geofaglige institusjoner både i inn- og utland.

8 Bakgrunn, behov og nytteverdi

Bakgrunn. Flere geologiske miljø i Norge kan ha et potensial for platinametaller. Disse er: ofiolitter, lagdelte intrusiver, Alaska-type ultramafiske intrusiver og svartskifre. Fra nikkelprospektering, forskning på ofiolitter og kartlegging ellers er det kjent flere ofiolittkomplekser som muligens har potensiale for anriking av platinemtaller. Nylig er platinamineralisering blitt oppdaget i Shetland-ofiolitten som er av samme alder og type som flere norske komplekser.
Behov. EF har gitt prospektering etter platinametaller høy prioritet, og det er interesse for prosjektet i prospekteringsindustrien. Datagrunnlaget som er nødvendig som utgangspunkt for et prospekteringsprogram mangler, bortsett fra i noen få områder.
Nytteverdi. Prosjektet vil føre til en vesentlig utbygging av datagrunnlaget og til forskning basert på resultatene. Dette vil tillate en første vurdering av potensialet for platinametaller i ofiolittmiljøet i Norge. En vesentlig del av innsatsen i prosjektet blir gjennomført av en stipendiat, noe som vil medføre oppbygging av norsk kompetanse på dette området.

9 Brukerkontakt og informasjonstiltak

NGU har uformell kontakt med brukergrupper i industri i Norge og har en utstrakt kontakt med institusjoner som er aktive i forskning innenfor dette området i Europa og ellers. Falconbridge Nikkelverk, Kristiansand vurderer å yte et bidrag på kr. 150.000 til prosjektet.

Resultatene vil bli offentliggjort i form av rapporter, publikasjoner og foredrsag.

10 Organisering av prosjektet

Prosjektledelse, samarbeid, eventuelt kontakt – eller styringsgruppe

Prosjektet tilhører et program som ledes av en styringsgruppe, hvor NGU, SINTEF, industri og universitetene er representert. Prosjektet skal ledes av en person tilknyttet NGU. Innen prosjektet er det tatt kontakt med Universitetetet i Bergen, NTH, Open University, Imperial College og British Geological Survey som ønsker å samarbeide i prosjektet. Det vil videre bli tatt kontakt med universitetene i Aten, København og Southampton og med Grønlands Geologiske Undersøgelse (GGU).

Søkerens underskrift | Faglig hovedansvarlig

Vedlegg: Prosjektbeskrivelse (nye prosjekter)/Framdriftsrapport (igangværende prosjekter)

LIST OF PAPERS PUBLISHED/PRESENTED ON THE TOPICS OF THE PROJECT

Papers published:

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 between the effects of partial melting, crystal fractionation and sulphide-segregation on platinum-group elements, gold, nickel and copper: examples from Norway. In: Prichard, H.M., Potts, P.J., Bowles, J.F.W. & Cribb, S.J. (eds.) Geo-Platinum 87, Elsevier, London, 113-144.

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.M., Potts, P.J., Bowles, J.F.W. & Cribb, S.J. (eds.) Geo-Platinum 87, Elsevier, London, 145-158.

Grønlie, A. 1988: Platinum-group minerals in the Lillefjellklumpen nickel-copper deposit, Nord-Trøndelag, Norway. Norsk. geol. tidsskr. 68,

Nilsson, L.P. 1990: Platinum-group mineral inclusions in chromitite from the Osthammeren ultramafic tectonite body; south central Norway. Mineral. & Petrol.

Papers presented orally or as posters:

Barnes, S.-J., Boyd, R. & Grønlie, A.: Edelmetallgeokjemi av noen norske Ni-Cu forekomster. NGFs landsmøte, Trondheim, 16-18.01.87.

Barnes, S.-J., Boyd, R. & Grønlie, A.: Noble metal geochemistry of some Ni-Cu sulphide deposits in Norway. EUG IV, Strasbourg, 13-16.04.87, and Geoplatinum 87, Milton Keynes, 23-24.04.87.

Barnes, S.-J., Boyd, R., Korneliussen, A., Nilsson, L.-P., Often, M., Pedersen, R.B. & Robins, B.: The use of mantle normalization and metal ratios in discriminating between the effects of partial melting, crystal fractionation and sulphide-segregation on platinum-group elements, gold, nickel and copper: examples from Norway.Geoplatinum 87, Milton Keynes, 23-24.04.87.

Boyd,R., Pedersen, R.B., Vokes, F.M., Grenne, T., Grønlie, Nilsson, L.P. & Rundhovde, E.: Noble metal mineralizations in Lower Palaeozoic ophiolites in Norway. 5th International Platinum Symposium, Helsinki, 1-3.08.89 and 19. Nordiske Geologiske Vintermøte, Stavanger, 6-9.01.90.

Nilsson, L.P.: Platinum-group mineral inclusions in chromitite from ophiolitic tectonites in the Caledonides of Norway. Troodos 87 Ophiolites and Oceanic Lithosphere, Nicosia, 4-10.10.87.

Nilsson, L.P.: Inneslutninger av platina-gruppe mineraler (PGM) i kromitt fra Osthammeren og Ørnstolen - to ofiolittiske tektonitter i de norske Kaledonider. 18. Nordiske Geol. Vintermøte, København, 12-14.01.88.

Nilsson, L.P.: Tre eksempler på opptreden av platina-gruppe elementer (PGE). Malmgeologisk symposium, Løkken, 12-13.02.88.

Nilsson, L.P.: Platinum-group mineral inclusions in ophiolitic chromitite from the Osthammeren tectonite body, Norway. 5th International Platinum Symposium, Helsinki, 1-3.08.89.

Pedersen, R.B.: PGE-geochemistry of boninitic and basaltic rocks of the Karmøy ophiolite complex, western Norway. 5th International Platinum Symposium, Helsinki, 1-3.08.89.

Pedersen, R.B. & Boyd, R.: PGE-geochemistry of the ultramafic rocks of the Leka ophiolite complex, Norway. 5th International Platinum Symposium, Helsinki, 1-3.08.89.