CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

REPORT 79-27

MINERALOGY OF SAMPLES FROM THE LAC DES ILES AREA, ONTARIO

L.J. CABRI AND J.H. GILLES LAFLAMME

MINERALS RESEARCH PROGRAM
MINERAL SCIENCES LABORATORIES

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

AUGUST 1979

Available by mail from:

Printing and Publishing
Supply and Services Canada,
Ottawa, Canada K1A 0S9

CANMET
Energy, Mines and Resources Canada,
555 Booth St.,
Ottawa, Canada K1A 0G1

or through your bookseller.

Catalogue No. M 38-13/79-27
ISBN 0-660-104030-X

Price: Canada: $1.00
Other countries: $1.20

Price subject to change without notice.

En vente par la poste:

Imprimerie et Édition
Approvisionnements et Services Canada,
Ottawa, Canada K1A 0S9

CANMET
Énergie, Mines et Ressources Canada,
555, rue Booth
Ottawa, Canada K1A 0G1

ou chez votre libraire.

N° de catalogue M 38-13/79-27
ISBN 0-660-104030-X

Prix: Canada: $1.00
Autres pays: $1.20

Prix sujet à changement sans avis préalable.

MINERALOGY OF SAMPLES FROM THE LAC DES ILES AREA, ONTARIO†

by

Louis J. Cabri* and J.H. Gilles Laflamme**

ABSTRACT

Samples from the Lac des Iles area, Ontario, were investigated as part of a study to determine the mineralogy and distribution of the platinum-group elements from different areas and rock types. The samples contain low-grade disseminated Cu-Ni sulphides, with trace arsenides and sulpharsenides, all highly variable from sample to sample. The principal minerals are pentlandite, pyrite, chalcopyrite and pyrrhotite, but one sample had no pyrrhotite and some had variable amounts of millerite (NiS). Although chalcopyrite is the principal source of copper, nickel is distributed among 13 opaque minerals, exclusive of the platinum-group minerals; nevertheless, more than 95% of the nickel is estimated to occur in pentlandite. The platinum-group minerals in decreasing order of frequency are: braggite series [(Pd,Pt)S] $\geqslant$ kotulskite (PdTe) > isomertieite ($Pd_{11}As_2Sb_2$) > merenskyite ($PdTe_2$) > sperrylite ($PtAs_2$) plus three other rarer minerals. Palladium also occurs as a solid-solution in pentlandite, gold and melonite ($NiTe_2$). These findings, together with data on mineral associations and size variations, should be helpful in guiding more detailed mineralogical studies and beneficiation tests.

*Research Scientist and **Mineralogical Technician, Mineralogy Section, Physical Sciences Laboratory, Mineral Sciences Laboratories, Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada, Ottawa, Canada.
†Minerals Research Program, Processing Contribution Number 117.

MINERALOGIE D'ECHANTILLONS DE LA REGION DU LAC DES ILES, ONTARIO†

par

Louis J. Cabri* et J.H. Gilles Laflamme**

RESUME

Des échantillons provenant de la région du Lac des Iles en Ontario furent examinés dans le cadre d'une étude sur la minéralogie et la distribution des éléments du groupe du platine provenant de différentes régions et types de roches. Les échantillons contiennent des disséminations appauvries de sulfures de Cu-Ni avec des quantités minimes d'arséniures et de sulfoarséniures, et varient fortement d'un échantillon à l'autre. Les minéraux principaux sont: pentlandite, pyrite, chalcopyrite et pyrrhotine, sauf un échantillon où la pyrrhotine ne s'est pas révélée, et quelques-uns où les quantités de millerite (NiS) étaient variables. Bien que la chalcopyrite soit la source principale de cuivre, le nickel est distribué dans plus de 13 minéraux opaques, excluant les minéraux du groupe du platine; néanmoins, on a évalué à 95% la quantité de nickel provenant de la pentlandite. Les minéraux du groupe du platine sont, par ordre décroissant en terme de fréquence: série du braggite [(Pd,Pt)S] ≥ kotulskite (PdTe) > isomertieite ($Pd_{11}As_2Sb_2$) > merenskyite ($PdTe_2$) > sperrylite ($PtAs_2$) de même que trois autres minéraux plus rares. Le palladium se présente aussi en solution-solide dans la pentlandite, dans l'or et dans la melonite ($NiTe_2$). Ces découvertes en plus des données sur les associations et variations granulométriques de ses minéraux devraient être très utiles pour des études minéralogiques et minéralurgiques plus détaillées.

---

*Minéralogiste et **technicien, Section de la minéralogie, Laboratoire des sciences physiques, Laboratoires des sciences minérales, CANMET, Ministère de l'Energie, des Mines et des Ressources, Ottawa, Canada.

†Programme de recherche sur les minéraux, Contribution n° 117.

MINERALOGY OF SAMPLES FROM THE LAC DES ILES AREA, ONTARIO

TABLE OF CONTENTS

	Page
ABSTRACT	i
RESUME	ii
INTRODUCTION	1
SAMPLES AND METHOD OF INVESTIGATION	1
MINERALOGY	4
Opaque minerals, exclusive of PGM	4
The platinum-group minerals	10
DISTRIBUTION OF METAL VALUES	15
CONCLUSIONS	17
ACKNOWLEDGEMENTS	18
REFERENCES	19

TABLES

1.	Synthetic standards and X-ray lines used for electron probe analyses	3
2.	Chemical analyses and metal ratios	4
3.	Distribution and content of Pd in pentlandite	5
4.	Electron probe analyses of ferroan siegenite and cobaltoan violarite	5
5.	Electron probe analyses of palladian gold, palladoarsenide, stillwaterite and unnamed Pd_5As_2	9
6.	Electron probe analyses of kotulskite, merenskyite, moncheite and melonite	10
7.	Number, size, range and distribution of PGM	11
8.	Electron probe analyses of braggite - vysotskite	12
9.	Electron probe analyses of isomertieite	14
10.	Metal distributions	16

FIGURES

		Page
1.	Location map of Lac des Iles	2
2.	Fine-grained pyrite-pentlandite intergrowth	7
3.	Ferroan siegenite-millerite intergrowth	7
4.	Vysotskite and associated sulphides	7
5.	Kotulskite inclusion in pyrrhotite	7
6.	Moncheite and sperrylite inclusions in kotulskite	7
7.	Moncheite and kotulskite included in pentlandite	7
8.	Kotulskite inclusions in isomertieite	7
9.	Stillwaterite and unnamed Pd_5As_2 associated with chalcopyrite	7
10.	Violarite-siegenite analyses plotted in the Ni_3S_4-Fe_3S_4-Co_3S_4 composition triangle	8
11.	Cooperite, braggite and vysotskite analyses plotted in the PtS-PdS-NiS composition triangle . . .	13

INTRODUCTION

Samples from the Lac des Iles area, 80 km N of Thunder Bay (Fig. 1), were received in 1974 and 1975 for mineralogical study. These samples are of interest because of their content of platinum-group elements (PGE). Drill-indicated reserves of 35000 t/m (vertical) at a grade of 6.33 g PGE, 0.68 g Au, and 0.22% (Cu + Ni) were reported for one section (Anon., 1976)[1]. Results of the mineralogical investigations were presented orally by Cabri and Laflamme[2] in 1976 and specific details about the samples were reported by Cabri (1978)[3] and Cabri et al. (1978)[4]. The geology and platinum-group mineralization of the property from which they came have been described by Dunning (1979)[5] and Watkinson and Dunning (1979)[6].

SAMPLES AND METHOD OF INVESTIGATION

Six samples had been sent on behalf of J.P. Sheridan of Sheridan Geophysics Limited, Toronto, and were received in the form of partly crushed drill core. A seventh sample is a polished section provided by J.M. Franklin, then at Lakehead University, and is referred to in the report as "J.M.F". The sample referred to as "Composite" was one of two composites prepared by the Research Centre of Placer Development Limited, Vancouver, from 23 drill core samples weighing approximately 58 kg. This sample weighed 1123 g and consisted of minus 212 µm plus 150-µm (minus 65 plus 100-mesh) material. Four samples came from portions of drill hole No. P-14 (14-7, 14-8, 14-11, 14-17) and one from part of drill hole No. P-23. These five samples weighed 856, 748, 949, 762 and 1,047 g, respectively.

All samples, except J.M.F., were crushed further and sieved. Samples P-14 and P-23 were divided into four fractions: minus 300 µm plus 212 µm (minus 48 plus 65 mesh), minus 212 µm plus 150 µm (minus 65 plus 100 mesh) and minus 150 µm plus 106 µm (minus 100 plus 150 mesh). The composite sample was divided into minus 212 μm plus 180-μm (minus 65 plus 80-mesh) and minus 180 μm plus 150-μm (minus 80 plus 100-mesh) fractions. All fractions

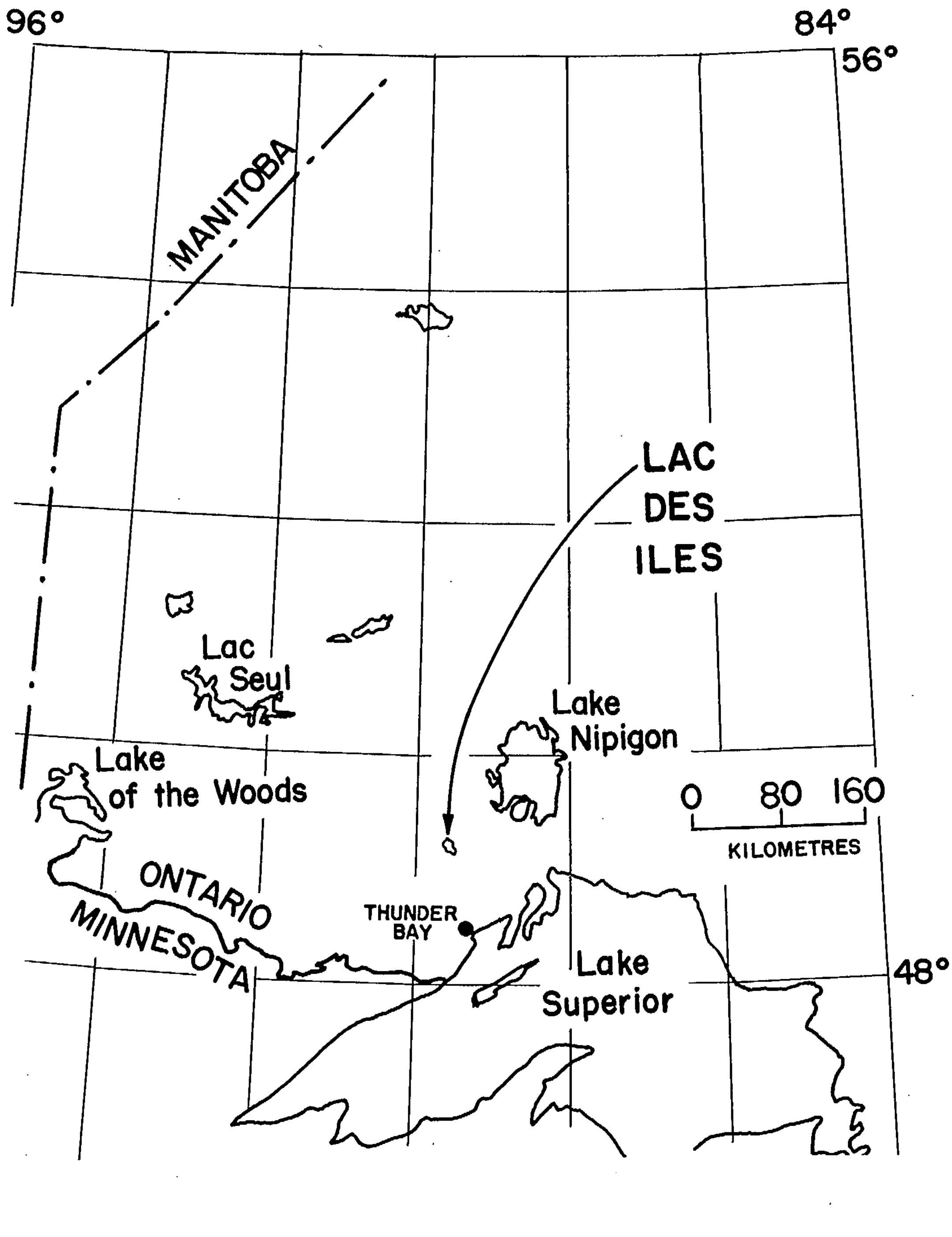

Fig. 1. Location map of Lac des Iles

(Note that the location is misspelled as "Lac des Isles" in references 2, 3 and 4).

coarser than 150 μm (100 mesh) were separated into magnetic and non-magnetic portions and then subjected to mineral separation as described by Cabri and Laflamme (1976)[7]. One to three polished sections were made from the heaviest fractions for a total of 36 polished sections which were examined by ore microscopy. All platinum-group mineral (PGM) identifications were confirmed by electron-probe analysis and some PGM, sulphides and sulpharsenides were also analyzed quantitatively. Standards and X-ray lines used for most of the electron-probe analyses, using techniques described by Cabri and Laflamme (1976)[7], are given in Table 1. The standard and X-ray line used for pyrrhotite and

TABLE 1. SYNTHETIC STANDARDS AND X-RAY LINES USED FOR ELECTRON PROBE ANALYSES

X-ray line	Braggite series	Kotulskite	Merenskyite	Stillwaterite and unnamed Pd_5As_2	Palladoarsenide	Palladian gold	Isomertieite	Siegenite and Violarite	Pentlandite
PdLα	PdS	PdTe	$Pd_{0.9}Ni_{0.1}Te_{1.9}$	Pd_8As_3	Pd_2As	Pd	$Pd_{11}As_2Sb_2$	-	syn457
PtLα	$Pt_{0.7}Pd_{0.3}S$	$PtTe_2$	$PtTe_2$	-	PtSn	-	-	-	-
NiKα	Ni	Ni	$Pd_{0.9}Ni_{0.1}Te_{1.9}$	-	Ni	-	-	syn457*	syn457
CuKα	-	-	-	$Pd_{4.85}Cu_{0.15}Sb_2$	-	-	-	-	-
FeKα	-	-	-	-	-	-	-	syn457	syn457
CoKα	-	-	-	-	-	-	-	Co_3S_4	$(Fe_{0.99}Co_{0.01})S_{1.0}$
AuLα	-	-	-	$Au_{0.12}Ag_{0.88}$	-	Au	Au	-	-
AgLα	-	-	-	-	-	$Au_{0.69}Ag_{0.31}$	-	-	-
BiLα	-	PdBiTe	PdBiTe	-	-	-	-	-	-
TeLα	-	PdTe	$Pd_{0.9}Ni_{0.1}Te_{1.9}$	PdTe	PdTe	-	Pd_3HgTe_3	-	-
SbLα	-	PdSb	PdSb	$Pd_{4.85}Cu_{0.15}Sb_2$	$Pd_{4.85}Cu_{0.15}Sb_2$	-	$Pd_{11}As_2Sb_2$	-	-
AsKα	-	-	-	Pd_8As_3	Pd_2As	-	$Pd_{11}As_2Sb_2$	-	-
SKα	PdS	-	-	-	-	-	-	Co_3S_4	syn457

* syn457 = $(Fe_{4.0}Ni_{4.95}Pd_{0.05})\ S_{8.0}$

pyrite are: $Fe_{0.99}Ni_{0.01}S_{1.0}$ and NiKα, respectively. Bulk analyses were made for all samples except J.M.F. for Pt, Pd and Au; most also were analyzed for soluble Cu and Ni, total S and Ag, Rh and Cr at the Chemical Laboratory, CANMET (Table 2). Sample P-14-8 was also analyzed for total Ni. It had 0.07% insoluble Ni, occurring in silicates or oxides or in both.

TABLE 2. CHEMICAL ANALYSES AND METAL RATIOS

Sample No.	Cu	Ni	S	Cr	Pt	Pd	Rh	Au	Ag	Cu/ Cu+Ni	S/ S+Cu+Ni	Pt/ Pt+Pd	Au/ Au+Pt+Pd
Composite	0.149*	0.101*	-	-	0.43	7.43	-	0.40	-	0.60	-	0.06	0.05
P-14-7	0.05	0.07	0.07	0.07	1.79	12.87	nd	0.25	10.36	0.42	0.37	0.12	0.02
P-14-8	0.14	0.23	0.36	0.09	1.96	12.35	nd	0.86	4.87	0.38	0.57	0.14	0.06
P-14-11	0.47	0.48	1.19	0.06	2.51	21.61	<0.1	0.12	3.50	0.49	0.56	0.10	0.05
P-14-17	0.30	0.29	0.74	0.04	1.79	9.61	nd	0.69	2.06	0.51	0.56	0.15	0.06
P-23	0.03	0.07	0.02	0.07	1.24	10.54	nd	0.42	2.75	0.30	0.17	0.08	0.03

Cu, Ni, S & Cr in wt %, Pt, Pd, Rh, Au & Ag in ppm. * Values from Placer Development Limited, Vancouver.
nd = not detected.

MINERALOGY

Opaque minerals, exclusive of PGM

The major opaque minerals at approximately >20% each are pentlandite, pyrite, chalcopyrite and pyrrhotite, except for sample P-23 which contains no pyrrhotite. Proportions of the major minerals vary among the samples. A fine-grained myrmekitic-like intergrowth of pyrite and pentlandite is characteristic of four samples: P-14-8, -11, -17 and P-23 (Fig. 2).

Twenty-three randomly selected pentlandite grains, representing all seven samples, were quantitatively analyzed. These had variable compositions. Ni content ranged from 41.9% to 34.0% and averaged 36.1%. Co content ranged from 1.5% to 0.20% and averaged 0.65%. Twenty-one of these pentlandites contained small amounts of Pd ranging from 0.02% to 0.60%, with an average of 0.19%, the detection limit being 0.02% Pd. Pt and Rh were not detected, but their detection limits were higher at 0.035 and 0.07%, respectively. An additional 289 spot analyses of pentlandite for Pd, Pt and Rh gave similar results, but these data are thought to be skewed because they include a large number of spot analyses with <0.02% Pd in the non-representative sample J.M.F. (Table 3).

Twenty-two randomly selected grains of pyrrhotite from samples "composite", P-14-8 and P-14-17 had a range of 0.22 to 1.20% Ni and averaged 0.50%. Pyrite proved even more variable in Ni content: 23 randomly selected grains from samples "composite", P-14-11 and P-14-17 averaged 0.56% Ni and ranged from nil to 2.46%. Detailed examination of sample P-23 showed its pyrite to have a Ni content ranging from nil to 0.15% for eight grains, with an average of 0.02%.

TABLE 3. DISTRIBUTION AND CONTENT OF Pd IN PENTLANDITE

Sample No.	No. Spot Anal.	Pd* Distribution in wt.% units <0.02	0.02-0.10	0.10-0.25	0.25-0.50	0.50-0.75
J.M.F.	26	69%	31%(0.08)**	-	-	-
Composite	57	-	25%	70%	5%(0.31)	-
P-14-8	56	9%	29%	51%	-	11%(0.65)
P-14-11	50	10%	20%	28%	42%(0.41)	-
P-14-17	50	-	42%	56%	2%(0.26)	-
P-23	50	24%	72%	4%(0.12)	-	-

* Pt and Rh sought for but not detected at 0.035 and 0.07%, respectively.
** Numbers in parentheses represent maximum wt.% determined.

The more common minor or trace opaque minerals in all samples except P-23 are galena, magnetite and sphalerite. Millerite is also a minor constituent in samples P-14-7, P-14-11 and P-23 (Fig. 2 and 3). Ferroan siegenite [(Co,Fe)(Ni,Fe)$_2$S$_4$] and cobaltoan violarite [(Fe,Co)(Ni,Fe)$_2$S$_4$] are present in small quantities in sample P-23, together with minor millerite and galena. Analyses of seven grains of violarite-siegenite revealed that six are ferroan siegenite and one is cobaltoan violarite (Table 4). Nickel (1973)[8] reported that cobalt-rich violarite occurs in hypogene deposits whereas relatively cobalt-poor violarite commonly forms

TABLE 4. ELECTRON PROBE ANALYSES OF FERROAN SIEGENITE AND COBALTOAN VIOLARITE

Anal. No.	Weight per cent Ni	Co	Fe	S	Total*	Atomic proportions** Ni	Co	Fe	Σ	S
1	34.B	11.8	11.9	42.1	100.6	1.79	0.60	0.64	3.03	3.96
2	35.2	12.1	10.5	41.3	99.1	1.84	0.63	0.58	3.05	3.95
3***	33.4	13.9	10.8	42.3	100.4	1.72	0.71	0.58	3.01	3.98
4	33.3	13.4	11.3	41.0	99.0	1.74	0.70	0.62	3.06	3.93
5	32.4	17.5	8.3	41.2	99.4	1.69	0.91	0.46	3.06	3.94
6	31.9	17.6	8.3	41.0	9B.8	1.68	0.92	0.45	3.05	3.94
7	31.8	18.5	7.6	41.1	99.0	1.67	0.97	0.42	3.06	3.94

* Pd, Cu, and Se sought for but not detected. ** calculated on the basis of 7 atoms. *** Grain X-rayed.
All analyses from sample P-23.

Fig. 2 Fine-grained pyrite-pentlandite (2) intergrowth; millerite (1) only on right side; specimen carbon-coated All scales represent micrometers

Fig. 3 Ferroan siegenite-millerite (lighter) intergrowth

Fig. 4 Vysotskite (1) partly intergrown with pentlandite (2) and pyrrhotite (3); minor pyrite (4) also present

Fig. 5 Rounded inclusion of kotulskite in pyrrhotite which also contains a few lamellae of pentlandite (1)

Fig. 6 A complex intergrowth of sperrylite (2) and moncheite lamellae (1) in kotulskite (4), itself included in pentlandite (3) with fine pyrrhotite lamellae (darker)

Fig. 7 Moncheite (1) and kotulskite (2) included in pentlandite (3) and associated with minor chalcopyrite (4)

Fig. 8 Isomertieite (1) with numerous blebs of kotulskite inclusions, the finest of which are less than one micrometre and not visible in this photomicrograph; associated with chalcopyrite (2) and pentlandite (3)

Fig. 9 Unnamed Pd_5As_2 (1) and stillwaterite (2) attached to chalcopyrite (3) which exhibits twinning; crossed nicols

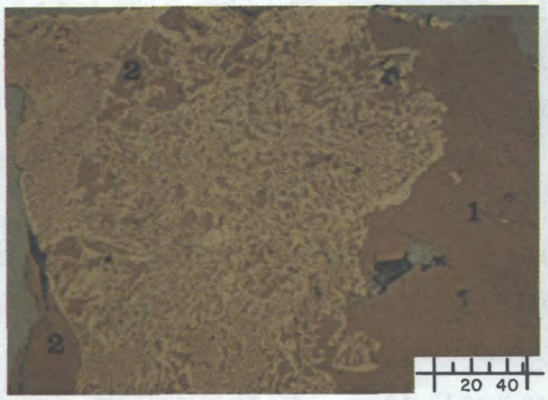

Fig. 2.

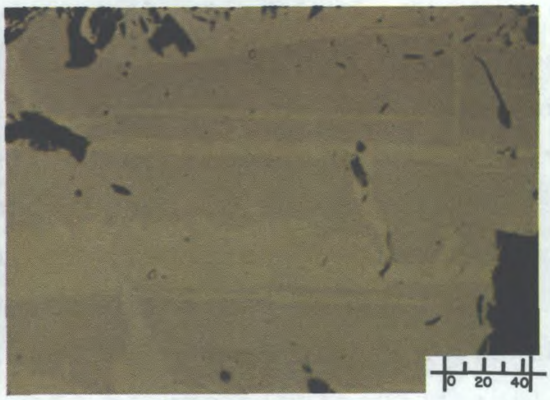

Fig. 3.

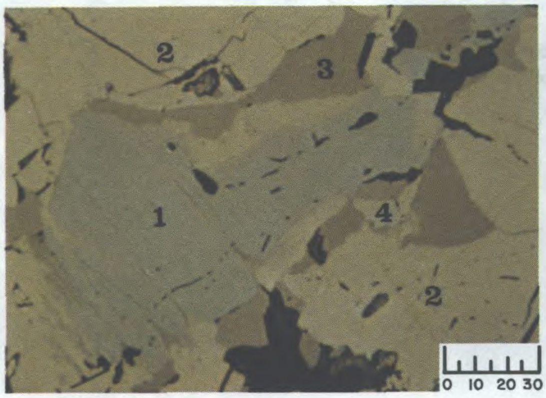

Fig. 4.

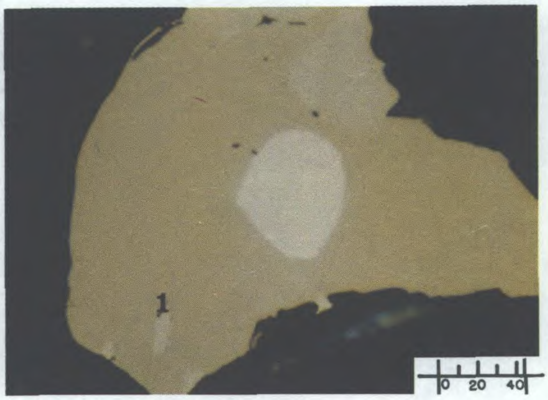

Fig. 5.

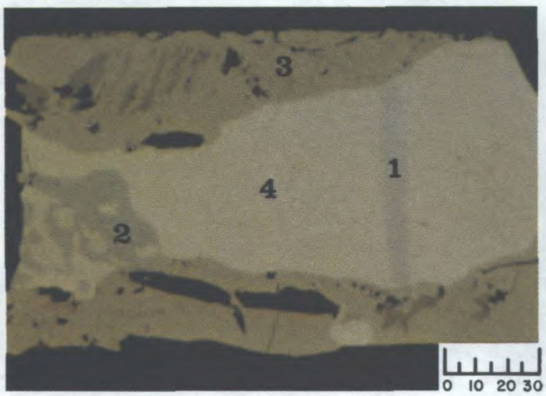

Fig. 6.

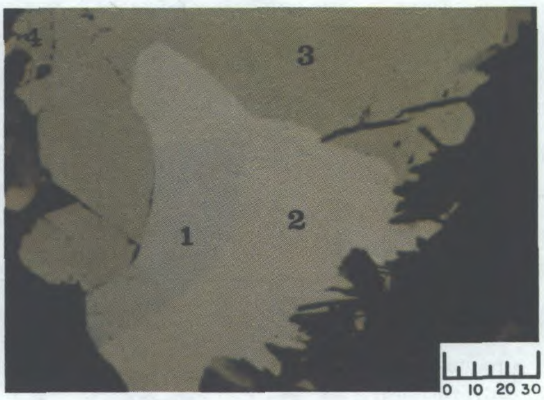

Fig. 7.

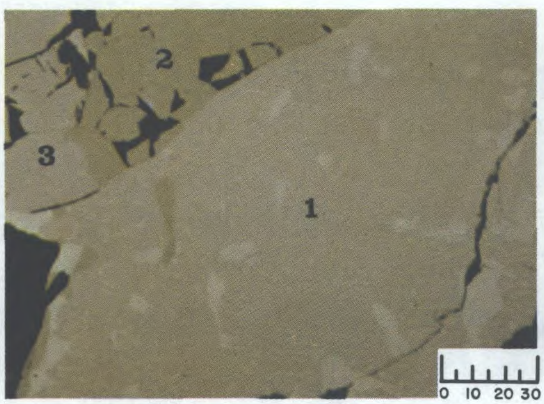

Fig. 8.

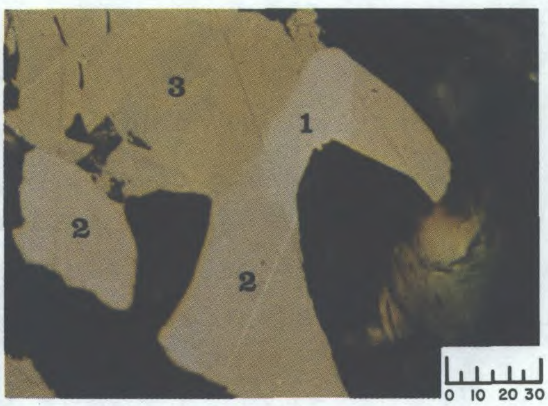

Fig. 9.

as a secondary mineral after pentlandite, pyrrhotite or millerite. Hudson and Groves (1974)[9] described hypogene violarite from the disseminated sulphide mineralization at Black Swan, Western Australia and, in addition to its cobalt-rich nature, they stressed that it may also be distinguished from supergene violarite by its smooth, nonporous surface. The Black Swan thiospinels range over the major part of the solid-solution series between violarite ($FeNi_2S_4$) and polydymite (Ni_3S_4), whereas compositions of the Lac des Iles thiospinels are in the central part of the solid-solution series between violarite and siegenite ($CoNi_2S_4$) (Fig. 10). However,

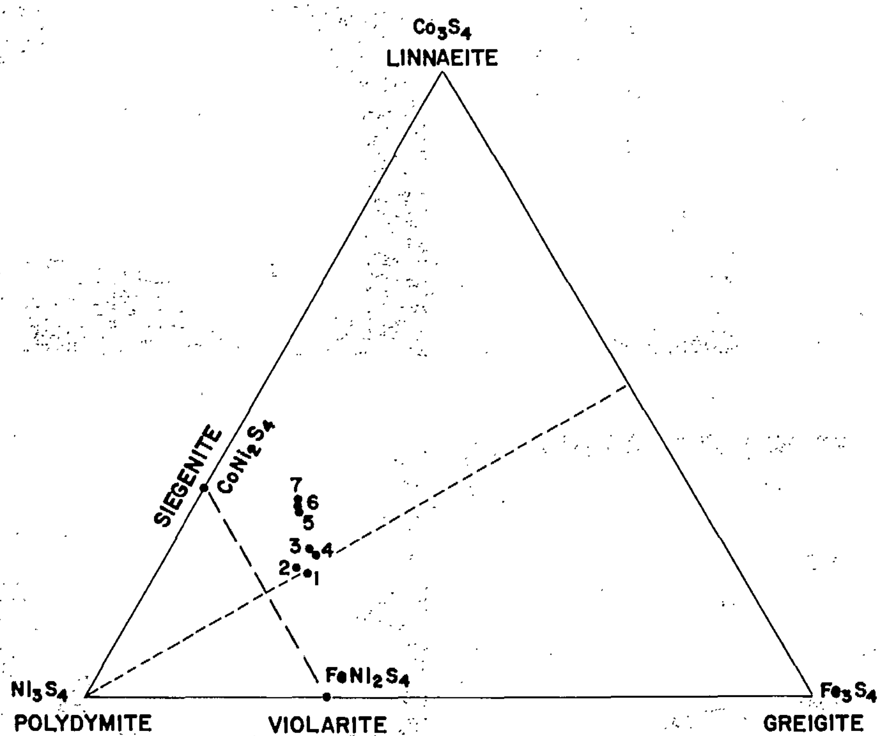

Fig. 10 Violarite-siegenite analyses plotted in the Ni_3S_4-Fe_3S_4-Co_3S_4 composition triangle. The numbers refer to analyses in Table 4.

the high cobalt contents and smooth appearance in polished surface are characteristic of both the Black Swan and Lac des Iles hypogene thiospinels (Fig. 3).

Opaque minerals, exclusive of the PGM, occurring in trace quantities are the sulpharsenides arsenopyrite (FeAsS), cobaltite (CoAsS), and gersdorffite (NiAsS), the arsenides loellingite ($FeAs_2$), skutterudite ($CoAs_3$) and nickeline (NiAs), the copper sulphides cubanite ($CuFe_2S_3$), bornite ($CuFe_4S_5$), and covelline (CuS), and molybdenite (MoS_2), marcasite (orthorhombic FeS_2), native silver, ilmenite ($FeTiO_3$), palladian gold (Au,Ag,Pd), palladian and platinian melonite [$(Ni,Pd,Pt)(Te,Bi)_2$], and cassiterite (SnO_2). Twenty-eight spot analyses on six grains of cobaltite-gersdorffite, and 14 spot analyses on three skutterudite grains, showed Pd, Pt and Rh to be below the detection limits of 0.02, 0.035 and 0.07%, respectively. The three grains of palladian gold have Pd contents (Table 5) slightly less than reported for palladian gold from the

TABLE 5. ELECTRON PROBE ANALYSES PALLADIAN GOLD, PALLADOARSENIDE, STILLWATERITE AND UNNAMED Pd_5As_2

Sample	Anal.	Weight per cent										Atomic proportions†										
No.	No.	Pd	Pt	Au	Ag	Ni	Cu	As	Te	Sb	Total	Pd	Pt	Au	Ag	Ni	Cu	Σ	As	Te	Sb	Σ
P-14-17	1	3.5	-	94.1	3.5	-	-	-	-	-	101.1	D.24	-	3.52	0.24	-	-	4.00	-	-	-	-
P-14-17	2	4.1	-	93.1	4.0	-	-	-	-	-	1D1.2	0.28	-	3.45	0.27	-	-	4.00	-	-	-	-
P-14-17	3	2.8	-	93.1	5.0	-	-	-	-	-	100.9	0.19	-	3.47	0.34	-	-	4.00	-	-	-	-
P-14-17	4**	73.4	0.43	nd*	nd	0.23	nd	24.2	0.54	0.04	9B.84	2.02	0.01	-	-	0.01	-	2.04	0.95	0.01	<0.01	0.96
P-14-17	5**	76.2	nd	nd	nd	0.61	nd	19.8	0.46	0.29	97.36	7.90	-	-	-	0.11	-	8.01	2.92	0.04	0.03	2.99
Composite	6**	79.2	nd	nd	nd	-	nd	20.8	0.26	nd	100.26	8.00	-	-	-	-	-	8.00	2.98	0.02	-	3.00
Composite	7**	78.3	nd	nd	nd	-	0.13	20.8	0.06	nd	99.29	7.97	-	-	-	-	0.02	7.99	3.01	<0.01	-	3.01
Composite	8**	69.3	nd	B.0	nd	-	0.32	21.0	0.04	nd	98.66	4.66	-	0.29	-	-	0.04	4.99	2.01	<0.01	-	2.01

* nd = not detected; ** Hg, Bi, Sn sought but nd. Unnamed Pd_5As_2 (No. 8) occurred as a lenticular inclusion 14x38μm in stillwaterite (No. 7).
† Palladian gold calculated for 4 atoms; palladoarsenide for 3 atoms; stillwaterite for 11 atoms and unnamed Pd_5As_2 for 7 atoms.

Stillwater Complex (Cabri and Laflamme, 1974)[10] and the same or slightly more Ag. The melonite has less bismuth and has a palladium content comparable with melonites from Sudbury-area deposits[7], but seems to have the highest Pt content so far reported (Table 6).

Various metallic impurities such as brass, tungsten, iron, zinc and Ni-Cr(Fe) alloys were encountered in the polished sections. It is considered that these originate from drilling, comminution and other forms of treatment to which the samples had been subjected. A careful search for chromite proved negative, only Ni-Cr (Fe) alloys being found. It is therefore likely that all the Cr reported in chemical analyses was due to these alloys (Table 2).

TABLE 6. ELECTRON PROBE ANALYSES OF KOTULSKITE, MERENSKYITE, MONCHEITE AND MELONITE

Sample No.	Anal. No.	Weight per cent Pd	Pt	Ni	Te	Bi	Sb	Total	Atomic proportions* Pd	Pt	Ni	Σ	Te	Bi	Sb	Σ
Composite	1	43.4	nd**	nd	46.8	9.2	0.26	99.66	0.99	-	-	0.99	0.89	0.11	<.01	1.00
Composite	2	44.8	nd	0.09	51.3	4.2	0.23	100.62	0.99	-	<0.01	0.99	0.95	0.05	<.01	1.00
Composite	3	44.7	nd	0.18	50.6	5.0	0.19	100.67	0.99	-	0.01	1.00	0.94	0.06	<.01	1.00
P-14-11	4	44.4	0.34	0.08	50.4	5.2	nd	100.42	1.00	<0.01	<0.01	1.00	0.94	0.06	-	1.00
P-14-11	5	45.9	0.48	0.12	53.1	1.5	nd	101.10	1.00	0.01	<0.01	1.01	0.97	0.02	-	0.99
P-14-17	6	45.0	nd	0.05	52.9	1.6	nd	99.55	1.00	-	<0.01	1.00	0.98	0.02	-	1.00
P-14-17	7	44.3	nd	0.09	53.5	1.5	nd	99.39	0.97	-	<0.01	0.97	1.01	0.02	-	1.03
P-14-17	8	44.7	nd	0.10	52.9	2.0	nd	99.70	0.98	-	<0.01	0.98	0.99	0.02	-	1.01
P-14-17	9	44.6	nd	0.06	51.0	4.8	nd	100.46	0.99	-	<0.01	0.99	0.95	0.05	-	1.00
J.M.F.	10	24.2	7.2	0.04	65.4	3.8	-	100.64	0.86	0.14	<0.01	1.00	1.93	0.07	-	2.00
J.M.F.	11	28.7	0.29	0.03	64.0	6.6	-	99.62	1.01	<0.01	<0.01	1.01	1.87	0.12	-	1.99
J.M.F.	12	28.5	0.26	0.03	64.3	6.4	-	99.49	1.00	<0.01	<0.01	1.00	1.88	0.11	-	1.99
P-14-11	13	28.3	0.97	0.14	69.0	1.4	-	99.81	0.97	0.02	0.01	1.00	1.97	0.02	-	1.99
P-14-11	14	27.6	1.7	nd	68.4	1.6	-	99.3	0.96	0.03	-	0.99	1.98	0.03	-	2.01
P-14-11	15	23.5	4.3	1.5	64.8	3.3	-	97.4	0.84	0.08	0.10	1.02	1.92	0.06	-	1.98
P-14-17	16	28.6	nd	0.39	69.3	1.1	-	99.39	0.98	-	0.02	1.00	1.98	0.02	-	2.00
P-14-17	17	28.6	nd	0.14	63.0	7.8	-	99.54	1.01	-	<0.01	1.01	1.85	0.14	-	1.99
P-14-17	18	29.5	nd	0.14	68.9	1.6	-	100.14	1.01	-	<0.01	1.01	1.96	0.03	-	1.99
P-14-11	19	1.4	40.7	0.09	55.3	0.75	-	98.24	0.95	0.06	0.01	1.02	1.97	0.01	-	1.98
P-14-11	20	0.80	41.7	0.25	56.9	nd	-	99.65	0.96	0.03	0.02	1.01	1.99	-	-	1.99
P-14-11	21	6.7	10.6	8.9	68.1	4.8	nd	99.1	0.23	0.20	0.55	0.98	1.94	0.08	-	2.02

* Kotulskite calculated for 2 atoms, merenskyite, moncheite and melonite calculated for 3 atoms.
** nd = not detected.

The platinum-group minerals (PGM)

General observations

One hundred and forty-nine discrete grains of platinum-group minerals were identified, their approximate size range and distribution amongst other minerals being given in Table 7. The approximate frequency of these PGM are: braggite series [(Pd,Pt)S] ≥ kotulskite (PdTe) > isomertieite ($Pd_{11}As_2Sb_2$) > merenskyite ($PdTe_2$) > sperrylite ($PtAs_2$) > moncheite ($PtTe_2$). Stillwaterite (Pd_8As_3), palladoarsenide (Pd_2As) and unnamed Pd_5As_2 are much rarer. An additional 20-odd grains of merenskyite found in sample J.M.F. are not included above because the sample was small and not representative.

TABLE 7. NUMBER, SIZE RANGE AND DISTRIBUTION OF PGM

PGM	pn	po	cp	py	si	ml	PGM	mag	free	total	Size range**
braggite series	18*	-	1	-	12	-	-	2	-	33	5X7 to 105X155
kotulskite	10	2	3	1	8	-	8	-	-	32	2X6 to 150X155
isomertieite	-	-	4	-	12	1	1	-	4	22	6X6 to 145X245
merenskyite	8	3	4	2	3	-	-	-	-	20	5X5 to 45X65
sperrylite	8	1	-	-	3	-	6	-	-	18	5X5 to 55X110
moncheite	6	-	1	-	3	-	5	-	-	15	4X6 to 70X100
stillwaterite	-	-	-	-	-	-	2	-	-	2	25X45 to 25X245
palladoarsenide	2	-	-	-	-	-	-	-	1	3	17X22 to 55X245
(Au,Ag,Pd)	-	-	-	-	3	-	-	-	-	3	70X105 to 125X300
Pd_5As_2	-	-	-	-	-	-	1	-	-	1	14X38
	52	6	13	3	44	1	23	2	5	149	

pn = pentlandite, po = pyrrhotite, cp = chalcopyrite, py = pyrite, si = silicate, ml = millerite, mag = magnetite.
* Number of discrete grains included in pentlandite; ** approximate dimensions in μm.

The nature and relative abundance of PGM vary considerably among samples. The distribution and relative abundance of the principal PGM are as follows:

Composite	:	kotulskite > sperrylite.
P-14-7	:	braggite series only.
P-14-8	:	moncheite > braggite series > kotulskite > merenskyite > sperrylite.
P-14-11	:	merenskyite > moncheite > kotulskite > braggite series, sperrylite.
P-14-17	:	braggite series > kotulskite > merenskyite > sperrylite.
P-23	:	isomertieite > sperrylite.

The preponderance of palladium minerals over platinum minerals confirms the low Pt:(Pt+Pd) ratios obtained by assays (Table 2). The sample with the lowest S:(S+Cu+Ni) ratio (P-23, Table 2) contains only the arseno-antimonide of palladium (isomertieite) and platinum diarsenide (sperrylite) in contrast to the more common tellurides and sulphides of Pd-Pt found in the other samples.

Braggite series, (Pd,Pt)S

Braggite, ideally (Pt,Pd)S, and vysotskite, ideally PdS, are nickeloan members of an isomorphous solid-solution series (Pd,Pt)S known as the braggite series[(4)]. Analysis of 12 randomly selected grains indicates that braggite and vysotskite occur in equal proportions (Table 8). As noted previously[(4)],

TABLE 8. ELECTRON PROBE ANALYSES OF BRAGGITE-VYSOTSKITE

Sample No.	Anal. No.	Weight per cent Pt	Pd	Ni	S	Total	Atomic proportions Pt	Pd	Ni	ΣM	S	Mineral*
P-14-11	1	28.3	42.3	8.2	21.7	100.5	0.21	0.59	0.20	1.00	1.00	B
P-14-17	2	41.6	33.3	5.8	20.7	101.4	0.34	0.49	0.15	0.98	1.02	B
P-14-17	3	3.9	65.8	6.9	24.4	101.0	0.03	0.B2	0.15	1.00	1.00	V
P-14-17	4	9.4(0.9-16.9)	59.8(53.5-66.6)	7.6	24.1(23.5-24.9)	100.9	0.06	0.75	0.17	0.98	1.01	V
P-14-17	5	30.7(29.0-31.B)	41.2(40.4-42.4)	6.8	21.9	100.6	0.23	0.5B	0.17	0.98	1.02	B
P-14-17	6	27.2(25.8-29.2)	44.2	6.8	22.0	100.2	0.21	0.61	0.17	0.99	1.01	B
P-14-17	7	29.5(17.3-35.6)	42.9(38.5-54.8)	5.4	21.6(21.1-23.1)	99.4	0.23	0.61	0.14	0.98	1.02	B
P-14-17	8	13.7(6.2-20.9)	57.9(51.6-63.4)	6.6(6.2-7.4)	23.B(23.0-24.4)	102.0	0.10	0.74	0.15	0.99	1.01	B
P-14-17	9	11.1(6.5-15.1)	58.9(54.9-61.9)	6.7	24.0(23.7-24.1)	100.7	0.08	0.75	0.15	0.98	1.02	V
P-14-17	10	3.7	63.0	B.5	24.3	99.5	0.03	0.78	0.19	1.00	1.00	V
P-14-7	11†	2.0	69.5	3.9	23.7	99.1	0.01	0.89	0.09	0.99	1.01	V
P-14-7	12	6.3(3.4-11.2)	62.5(58.8-64.7)	6.8(6.6-7.4)	24.0(23.5-24.2)	99.6	0.04	0.79	0.16	0.99	1.01	V

* B = braggite, V = vysotskite. † grain X-rayed. Bi and Sb were sought for, but not detected.

members of the braggite series tend to be compositionally non-homogeneous and this was also found to be true for 7 of the 12 grains analyzed. These 12 analyses are plotted on Fig. 11 for comparison with analyses of braggite-series minerals from Montana, U.S.A., Transvaal, South Africa, and Noril'sk area, U.S.S.R. Though braggite and vysotskite are optically similar, they are readily distinguished from the common sulphides (Fig. 4).

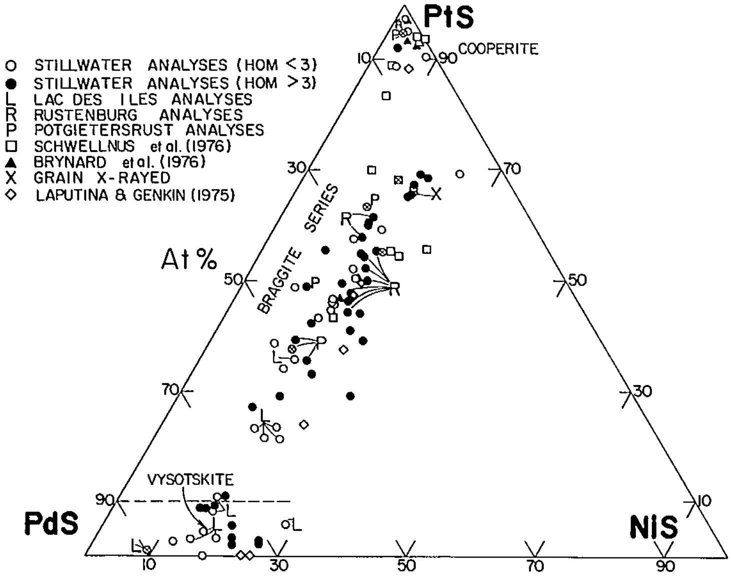

Fig. 11 Cooperite, braggite and vysotskite analyses plotted in the PtS-PdS-NiS composition triangle - after Cabri et al. (1978)[4].

Kotulskite, PdTe

Nine of the 32 kotulskite grains found were quantitatively analyzed (Table 6). The analyses indicate little or no replacement of Pd by Pt or Ni and of Te by Sb. Replacement of Te by Bi ranges from 1.5 to 9.2 wt % Bi. Such replacements have been reported for kotulskite from the Stillwater Complex, Montana by Cabri et al. (1979)[11]. Some mineral assemblages involving kotulskite are illustrated in Fig. 5, 6, 7 and 8.

Isomertieite, $Pd_{11}Sb_2As_2$

Eight of 22 isomertieite grains were analysed quantitatively (Table 9). The problems in analyzing this mineral are discussed by Cabri[3]. The analyses show minor substitution of Au for Pd and Te for Sb. This rather rare mineral has been found previously only in heavy mineral concentrates from Itabira, Minas Gerais, Brazil (Clark et al.,1974) (12) and thus the Lac des Iles occurrence is the first recorded from massive crystalline rocks of igneous origin (Fig. 8).

TABLE 9. ELECTRON PROBE ANALYSES OF ISOMERTIEITE

Anal.	Weight per cent						Atomic proportions						
No.	Pd	Au	Sb	Te	As	Total	Pd	Au	ΣPd	Sb	Te	ΣSb	As
1	74.0	0.30	15.4	0.20	9.5	99.40	10.96	0.02	10.98	1.99	0.03	2.02	2.00
2	74.3	0.13	13.9	1.5	9.4	99.23	11.02	0.01	11.03	1.80	0.19	1.99	1.98
3	74.4	0.33	14.0	1.6	9.4	99.73	10.99	0.03	11.02	1.81	0.20	2.01	1.97
4	74.5	tr.*	13.5	2.6	9.4	100.0	10.98	<0.01	10.98	1.74	0.32	2.06	1.96
5	73.8	0.74	15.3	0.25	9.4	99.49	10.95	0.06	11.01	1.98	0.03	2.01	1.98
6	74.2	0.35	13.9	1.8	9.5	99.75	10.96	0.03	10.99	1.80	0.22	2.02	1.99
7	73.9	0.56	13.8	2.2	9.4	99.86	10.93	0.05	10.98	1.78	0.27	2.05	1.97
8**	74.2	0.06	13.3	2.5	9.3	99.36	11.00	<0.01	11.00	1.72	0.32	2.04	1.96

* tr = trace, <0.04 wt.%. Atomic proportions, calculated on a total of 15 atoms. ** Grain x-rayed.

Merenskyite, $PdTe_2$

The 9 grains of merenskyite analyzed quantitatively (Table 6) are not very different from merenskyites found elsewhere. The grains typically have little or no replacement of Pd by Pt or Ni and minor replacement of Te by Bi (Table 6).

Sperrylite, $PtAs_2$

Sperrylite is common in many Cu-Ni deposits. Some of the sperrylite grains from the Stillwater Complex, Montana, were reported by Cabri et al.(1975) (13) to contain minor Rh. Schwellnus et al.(1976) (14) found minor Os in one sperrylite from the Merensky reef, and Feather (1976) (15) reported minor Ir, Os and Rh in some sperrylites from the Au-U Witwatersrand conglomerates. The sperrylite in the Lac des Iles samples, however, was not analyzed quantitatively (Fig. 6).

Moncheite, $PtTe_2$

The two grains of moncheite analyzed quantitatively have the lowest Bi contents reported to date (Table 6). Minor replacements of Pd or Ni for Pt are common. Moncheite inclusions in kotulskite are frequent (Fig. 6 and 7).

Stillwaterite, Pd_8As_3, palladoarsenide, Pd_2As and unnamed Pd_5As_2

Stillwaterite, palladoarsenide and an unnamed Pd_5As_2 had been reported to occur in samples from the Stillwater Complex, Montana[(13)]. The analyses of these three minerals from Lac des Iles (Table 5) show substitutions similar to those reported for the Stillwater minerals. As at Stillwater, the unnamed mineral is also found included in stillwaterite and has a high gold content (Fig. 9). Of particular note is that these are only the second world occurrence of stillwaterite and the third of unnamed Pd_5As_2. Unnamed Pd_5As_2 has been reported as a secondary mineral in sedimentary rocks (Zechstein) from Poland by Kucha (1975)[(16)].

DISTRIBUTION OF METAL VALUES

It is not possible to arrive at a satisfactory distribution of metal values by applying chemical analyses to the minerals (Table 2). It is difficult, if not impossible, to apportion nickel among the various nickel-bearing minerals, such as pentlandite (∿36%), millerite (∿65%), siegenite and violarite (∿33%), pyrite (∿0.5%), pyrrhotite (∿0.5%), nickeline (∿44%), gersdorffite (∿35%) and the numerous minerals with minor and variable nickel contents such as cobaltite, arsenopyrite, loellingite, skutterudite, and the PGM. However, if it is assumed that the samples contain equal quantities of pentlandite, pyrrhotite and pyrite, then 3% of the total nickel is attributable to pyrite and pyrrhotite. By assuming that all the other nickel-bearing minerals account for a maximum of 2% Ni, then the remaining 95% of total Ni is attributable to pentlandite. All the Cu, on the other hand, may be assigned to chalcopyrite (35.5% Cu, 35.0% S). The following calculations, based on these assumptions, illustrate the problems in arriving at a metal balance (Table 10).

TABLE 10. METAL DISTRIBUTIONS

	Analyses			In cp		In pn		In py + pn
Sample	Cu%	Ni%	S%	Cu%	S%	Ni%	S%	%S
P-14-7	0.05	0.07	0.07	0.05	0.051	0.066	0.019*	insufficient
P-14-8	0.14	0.23	0.36	0.14	0.142	0.218	0.202	only 0.016
P-14-11	0.47	0.48	1.19	0.47	0.476	0.456	0.423	0.291
P-14-17	0.30	0.29	0.74	0.30	0.304	0.275	0.256	0.190
P-23	0.03	0.07	0.02	0.03	**	none?		none?

*Insufficient, need 0.062% S for all the pn. **Insufficient, need 0.03% S for all the cp.

In many cases, there is insufficient sulphur to account for all the pentlandite, pyrite, pyrrhotite and, in one case, even for the chalcopyrite. Changing the relative proportions of pyrite, pentlandite and pyrrhotite will not affect the apparent deficiency in sulphur in P-23 and will not significantly affect the rest of the calculations. For example, doubling the previous estimate of pyrite and pyrrhotite results in a total of 0.061% S needed for pentlandite in sample P-14-7, still much more than is available (0.019%), after allowing for chalcopyrite.

The pentlandite has been shown to contain an average of 0.19% Pd in solid solution. If the weight per cent of pentlandite present could be established with any degree of confidence, it would be possible to calculate the total palladium content in pentlandite, the balance could then be assigned to discrete PGM. The uncertainties in the metal distribution outlined above preclude such calculations.

CONCLUSIONS

The following conclusions must be qualified because of uncertainties resulting from an examination of a limited suite of samples whose relative importance to the mineralization as a whole was not known. Percentages given below are estimates only to indicate the order of magnitude and are not true values.

1. Cu, Ni, Pd, Pt, Ag and Au are the principal metals of potential economic interest.

2. Chalcopyrite ($CuFeS_2$) probably accounts for over 99% of the copper content.

3. Nickel is distributed in many minerals but it is estimated that at least 95% is in pentlandite [$(Fe,Ni)_9S_8$]. Nickel losses may be expected in pyrrhotite ($Fe_{1-X}S$) and in pyrite (FeS_2), which together may account for about 3% of the nickel; another 2% of the Ni may occur in minerals such as millerite (NiS) and siegenite ($CoNi_2S_4$).

4. The braggite-series minerals, (Pd,Pt)S, and kotulskite, (PdTe), are the principal PGM and may account for a large proportion of the Pd and Pt present. Pentlandite, however, contains an average of 0.19% Pd in solid solution and is therefore a significant source of Pd.

5. Native silver accounts for the higher Ag value in sample P-14-7; palladian argentian gold (Au,Ag,Pd) and electrum (Au,Ag) may represent the source of most of the gold and some additional silver.

6. A considerable number of PGM occur as inclusions in silicates and are not liberated at plus 106 μm mesh (150 mesh). The most common PGM except for isomertieite were also frequently closly associated with pentlandite. Potential beneficiation problems may arise because of the very fine-grained pyrite-pentlandite intergrowths noted to occur in some samples.

ACKNOWLEDGEMENTS

The authors acknowledge the technical assistance of P. Carrière for nickel analyses of pyrite and pyrrhotite, R.G. Pinard for the photomicrographs, Y. Bourgoin for mineral separations and polished sections, J.D. MacLeod for drafting, and personnel in the Chemical Laboratory for analyses. S. Kaiman and J.L. Jambor made helpful comments on the manuscript. Gratitude is also expressed to J.P. Sheridan, Toronto, and to J.M. Franklin, Geological Survey of Canada, for samples and for permission to publish results.

REFERENCES

1. Anonymous "Deep hole for Boston Bay at Lac des Iles palladium", North Min; 62:32,27; 1976.

2. Cabri, L.J. and Laflamme, J.H.G. "Ore microscopy of some samples from Lac des Isles, Ontario"; Geol Assoc Can - Mineral Assoc Can; Program Abstr 1:56; 1976.

3. Cabri, L.J. "Determination of ideal formulae for new minerals of the platinum-group"; XIth Inter Miner Assoc Meeting, Abstr 1:147; 1978.

4. Cabri, L.J., Laflamme, J.H.G., Stewart, J.M., Turner, K. and Skinner, B.J. "On cooperite, braggite and vysotskite"; Amer Mineral; 63:832-839; 1978.

5. Dunning, G.R. "The geology and platinum-group mineralization of the Roby zone, Lac des Iles complex, northwestern Ontario"; M.Sc. thesis, Carleton University; 1979.

6. Watkinson, D.H. and Dunning, G. "Geology and platinum-group mineralization, Lac des Iles complex, northwestern Ontario"; Can Mineral; 17:453-462; 1979.

7. Cabri, L.J. and Laflamme, J.H.G. "The mineralogy of the platinum-group elements from some copper-nickel deposits of the Sudbury area, Ontario"; Econ Geol; 71:1159-1195; 1976.

8. Nickel, E.H. "Violarite - a key mineral in the supergene alteration of nickel sulphide ores"; Austral Inst Min & Metall Conference Series No. 2 Papers; Western Australia: 111-116; 1973.

9. Hudson, D.R. and Groves, D.I. "The composition of violarite coexisting with vaesite, pyrite and millerite"; Econ Geol; 69:1335-1340; 1974.

10. Cabri, L.J. and Laflamme, J.H.G. "Rhodium, platinum and gold from the Stillwater Complex"; Can Mineral; 12:399-403; 1974.

11. Cabri, L.J., Rowland, J.F., Laflamme, J.H.G. and Stewart, J.M. "Keithconnite, telluropalladinite and other Pd-Pt tellurides from the Stillwater Complex, Montana"; Can Mineral; 17: 589-594; 1979.

12. Clark, A.M., Criddle, A.J. and Fejer, E.E. "Palladium arsenide-antimonides from Itabira, Minas Gerais, Brazil"; Mineral Mag; 39:528-543; 1974.

13. Cabri, L.J., Laflamme, J.H.G., Stewart, J.M., Rowland, J.F. and Chen, T.T. "New data on some palladium arsenides and tellurides"; Can Mineral; 13:321-335; 1975.

14. Schwellnus, J.S.I., Hiemstra, S.A. and Gasparrini, E. "The Merensky reef at the Atok Platinum mine and its environs"; Econ Geol; 71:249-260; 1976.

15. Feather, C.E. "Mineralogy of platinum-group minerals in the Witwatersrand, South Africa"; Econ Geol; 71:1399-1428; 1976.

16. Kucha, H. "Preliminary report on the occurrence of palladium minerals in Zechstein rocks of the Fore-Sudetic monocline"; Mineralogica Polonica; 6:87-91; 1975.

/tab

CANMET REPORTS

Recent CANMET reports presently available or soon to be released through Printing and Publishing, Supply and Services Canada (addresses on inside front cover), or from CANMET Publications Office, 555 Booth Street, Ottawa, Ontario, K1A 0G1:

Les récents rapports de CANMET, qui sont présentement disponibles ou qui le seront bientôt peuvent être obtenus de la direction de l'Imprimerie et de l'Edition, Approvisionnements et Services Canada (adresses au verso de la page couverture), ou du Bureau de Vente et distribution de CANMET, 555 rue Booth, Ottawa, Ontario, K1A 0G1:

78-1 Summary of research contracts - 1977; compiled by D.C. Misener; Cat. no. M38-13/78-1, ISBN 0-660-10218-8; Price: $1.25 Canada, $1.50 other countries.

78-17 A case study for contracting out; G. Bartlett and D.F. Coates; Cat. no. M38-13/78-17, ISBN 0-660-10128-9; Price: $1.00 Canada, $1.20 other countries.

78-18 Catalogue of CANMET publications 1977/78 - Catalogue des publications de CANMET; Cat. no. M38-13/78-18, ISBN 0-660-50361-1; Price: $6.00 Canada, $7.20 other countries.

78-23 Image analysis study of mill products from batch tests on Brunswick Mining and Smelting mill tailings; W. Petruk; Cat. no. M38-13/78-23, ISBN 0-660-10238-2; Price: $1.25 Canada, $1.50 other countries.

78-24 Development of a simulated catalyst aging technique; J.F. Kriz and M. Ternan; Cat. no. M38-13/78-24, ISBN 0-660-10191-2; Price: $1.25 Canada, $1.50 other countries.

78-28 Canadian base metal mining in the 1970's; D.G.F. Hedley; Cat. no. M38-13/78-28, ISBN 0-660-10242-0; Price: $1.25 Canada, $1.50 other countries.

79-3 Soil samples SO-1, SO-2, SO-3 and SO-4 - Certified reference materials; W.S. Bowman, G.H. Faye, R. Sutarno, J.A. McKeague and H. Kodame; Cat. no. M38-13/79-3, ISBN 0-660-10257-9; Price: $1.75 Canada, $2.10 other countries.

79-4 Uranium ore BR-5 - Certified reference material; G.H. Faye, W.S. Bowman and R. Sutarno; Cat. no. M38-13/79-4, ISBN 0-660-10271-4; Price: $1.25 Canada, $1.50 other countries.

79-7 Analysis directory of Canadian commercial coal - Supplement 3; T.E. Tibbetts, W.J. Montgomery and D.K. Faurschou; Cat. no. M38-13/79-7, ISBN 0-660-10256-0; Price: $4.00 Canada, $4.80 other countries.

79-12 Energy cascades in Canada; A.C.S. Hayden and T.D. Brown; Cat. no. M38-13/79-12, ISBN 0-660-10243-9; Price: $1.75 Canada, $2.10 other countries.

78-12F Revue de CANMET 77/78; (also available in English) Cat. no. M38-13/78-12F, ISBN 0-660-90235-4; Price: $2.25 Canada, $2.70 other countries.