THE PGE-SULFIDE OFFSET MINERALIZATION OF THE
KILVENJÄRVI-BLOCK (PORTIMO COMPLEX), NE-FENNOSCANDIAN SHIELD —
MINERALOGICAL AND TEXTURAL INVESTIGATIONS

by

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Abstract

The Portimo Complex forms part of a series of early Paleoproterozoic layered intrusive complexes starting from the Swedish/Finish border in the southwest and extending into Karelia, Russia in the northeast. The intrusions have crystallized at around 2.4 Ga in the Archean gneissic basement and were then split up into several blocks, the Kilvenjärvi Block as part of the Portimo Complex, forming one of them. Many of the intrusions are located close to each other, thus forming igneous complexes which were probably connected by dykes or intermediate magma chambers at the time of emplacement.

Continental rifting is supposed to be responsible for the igneous, intrusive event, and the intrusions were already partly eroded before being overlain by Proterozoic sediments. Several metamorphic events affected the intrusions in different ways after crystallization.

The intrusions host a large number and diversity of Platinum group element (PGE) deposits among them the offset deposit is the most peculiar one. The offset deposit occurs within the Archean granite-gneiss basement below the Kilvenjärvi Block.

In summer 1997 three drill cores (KNN6, KNN46, KNN48) through the offset deposit, kindly provided by Outokumpu Oy and the Geological Survey of Finland (Rovaniemi section), were investigated in detail and sampled. The study forms part of a research project funded by the Austrian National Research Foundation and was carried out at the Institut für Geowissenschaften (Mineralogie-Petrologie), University of Leoben, Austria. Fifty polished thin sections have been prepared from selected samples, for microscopic investigation in transmitted and reflected light. Mineralchemical data were obtained by microprobe analysis (ARL-SEMQ electron microprobe, equipped with a Link System energy-dispersive analyser). Fluid inclusion investigations were carried out on double-sided polished sections, microthermometry was done using a Fluid, Inc., convective-style heating and freezing stage.

The offset deposit is characterized by a sulfide mineralization and Platinum group minerals (PGM) including Pd-Pt-bismuthotellurides, subordinately Pd-Pt-stannides, -antimonides and -arsenides. Total PGE concentrations lie in the range of 20 ppm to up to more than 100 ppm. The PGM plus the sulfide mineralization form irregular lenses, stocks, veins, and disseminations in the basement. The sulfides are dominated by Cu-Fe-Ni sulfides which are divided into a "primary", and a "secondary" assemblage, the latter is subdivided into two stages.

Geological Setting

An early Paleoproterozoic mafic intrusion belt, about 2440 Ma in age, crosses the northeastern Fennoscandian Shield from Sweden via Finland into Russia. The intrusions in Finland are concentrated in two areas: the discontinuous Tornio-Näränkävaara intrusion belt which crosses northern Finland at the latitude of the northern end of the Gulf of Bothnia, and the Koitelainen intrusion in central Finish Lapland. The Näränkävaara intrusion belt features the Tornio Intrusion, the Kemi and Penikat intrusions, and the Portimo and Koillismaa layered igneous complexes (ALAPIETI et al., 1990).
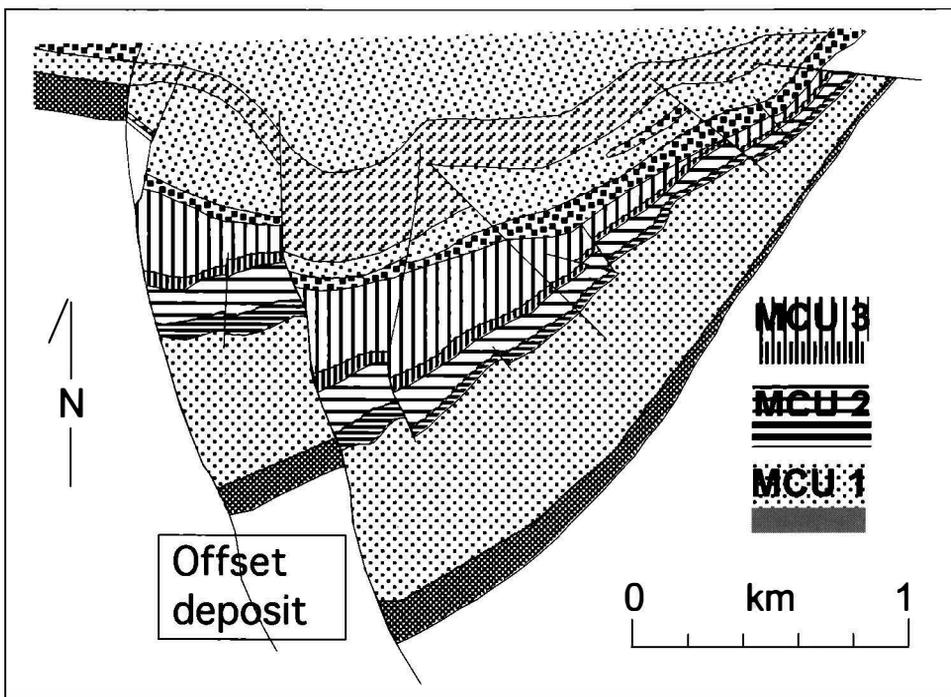

Fig. 1

Geological map of the Kilvenjärvi block of the Narkaus intrusion and its surroundings.
MCU is an abbreviation for megacyclic unit (HUHTELIN et al., 1989).

World wide igneous activity, caused by a continental rifting (PIIRAINEN et al., 1974; GORBATSCHEV & GAAL, 1987; GAAL, 1990; TURCHENKO et al., 1991), was responsible for the emplacement of the early Proterozoic layered intrusions in Fennoscandia, and three metamorphic events affected the intrusions in different ways since their crystallization; the last deformation and metamorphism was associated with the Svecofennian orogenic event (1900–1800 ma). These tectonic events have broken up the intrusions into a number of tilted blocks, as they are presented today.

The Portimo Layered Complex as part of the Näränkävaara intrusion belt comprises two intrusions, the Suhanko-Konttijärvi intrusion and the Narkaus intrusion, the latter includes the Kilvenjärvi block with three megacyclic units (Fig. 1).

The Narkaus intrusion is located stratigraphically within late Archean granitoids or at the upper contact to the overlying Proterozoic supracrustal sequence of tholeiitic volcanics, subvolcanic sills and sedimentary rocks. The uppermost parts of the intrusions are considered to have been eroded before the emplacement of the Proterozoic volcanics and sediments. The Narkaus intrusion comprises several PGE and base metal sulphide mineralizations within the megacyclic units, and the offset-type mineralization in the footwall rocks, whereby the Kilvenjärvi offset mineralization is the most peculiar one.

Kilvenjärvi offset mineralization

The Kilvenjärvi offset mineralization comprises irregular massive Cu-Fe sulfides (chalcopyrite with minor pyrrhotite and pyrite) and chalcopyrite-dominant disseminations within Archean granite and granitic gneiss alternating with units of mica-rich gneiss, garnet-rich gneiss and amphibolite.

Both, massive and disseminated sulfide horizons show considerable concentrations of PGE, with total PGE contents lying in the range of 20 ppm to up to more than 100 ppm (THALHAMMER et al., 1998). The mineralization can be divided roughly into three types on the amount of sulfides and the PGE content of the sulfide fraction, i.e. massive-sulfide-PGE-type, disseminated-sulfide-PGE-type, and PGE-type with only trace amounts of associated sulfides.

The platinum group element plus sulfide mineralization forms irregular lenses, stocks, veins, and disseminations in the basement. The sulfides are dominated by Cu-Fe-Ni sulfides and include in decreasing abundance chalcopyrite, pyrrhotite, pyrite, pentlandite, violarite, millerite, marcasite, sphalerite, and subordinately molybdenite, arsenides, bornite and argentian pentlandite. Chalcopyrite-pyrrhotite-pentlandite-pyrite form a typical mineral assemblage which is considered "primary"

Chalcopyrite:
Chalcopyrite represents the dominating sulfide of the offset deposit, in the investigated drill cores. It occurs as medium- to coarse-grained, anhedral grains, forming aggregates. Microprobe analyses revealed a sulfur-to-metal ratio of 1:1. Locally chalcopyrite seems to have intruded the gneiss host rock, which is displayed by pseudomorphs of chalcopyrite after silicate (probably biotite and feldspar) and it occurs as dispersed inclusions in plagioclase. Chalcopyrite is supposed to be part of both, the primary and the secondary sulfide assemblage.

Pyrrhotite:

Anhedral, granular masses of pyrrhotite show triple junction boundaries with chalcopyrite and pentlandite; reaction rims are lacking. The "flame" structure of pentlandite within pyrrhotite, which is rather often observed, results from chrystallographically oriented exsolution of pentlandite from an originally formed nickel-bearing pyrrhotite. Pyrrhotite also occurs as exsolution patches and of worm-like shape within chalcopyrite. The majority of pyrrhotites analysed show Fe-contents of 46 at% and Ni-contents ranging between 0.09 and 0.54 at%.

Pentlandite:

Pentlandite forms three distinct textures: 1) granular, polycrystalline veinlets, 2) massive in association with pyrrhotite and chalcopyrite, and 3) oriented lamellae and "flames" within pyrrhotite. The first type of pentlandite occupies irregular spaces between chalcopyrite and pyrrhotite, leading to a veinlet-texture; the massive type is commonly inhomogeneous caused by tiny inclusions of pyrrhotite that locally look like a fine network (1–3 μm scale). These islands and inclusions of pyrrhotite probably represent isochemical exsolution during cooling.
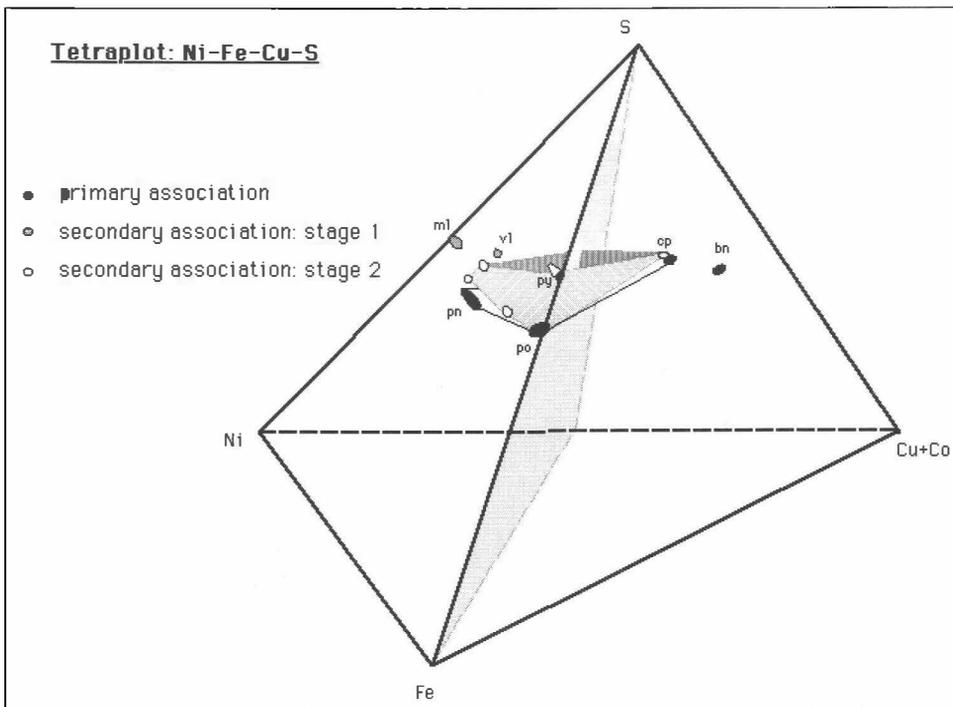

Fig. 2

Primary and Secondary sulfide mineralization of the Kilvenjärvi offset deposit illustrated in the tetraplot Cu(Co)-Fe-Ni-S. The secondary assemblage is further separated into two stages of mineralization.
bo = bornite, cp = chalcopyrite, ml = millerite, pn = pentlandite, po = pyrrhotite, py = pyrite, vl = violarite.
Black symbols show primary sulfide minerals, grey symbols show secondary sulfide minerals, clearly first stage, open symbols show secondary sulfide minerals, second stage suggested.

132

Pyrite:

Pyrite is supposed to be part of both, the primary and the secondary sulfide assemblage. The two pyrite generations are distinguished on the basis of textural and compositional criterias. Pyrite occuring as euhedral cubes and anhedral crystalline masses, showing a characteristic zonation represents the first, "primary" generation .The zonation is defined microscopically by a whitish "normal" pyrite core and a pinkish rim, which varies in Ni-, Co- and Cu-content (Ni in the range of up to 7 at%, Co and Cu up to 0.5 at%), and show sharp contacts to the "normal" pyrite core. The pyrite core shows Ni-contents less than 0.6 at%, but locally hosts spots of Ni-rich pyrite.

This "primary" sulfide assemblage is replaced in variable intensity by secondary, mostly low-temperature minerals such as violarite, millerite, pyrite, marcasite, argentian pentlandite, chalcopyrite, bravoite and sphalerite. Replacement may be almost complete, so that relics only of the primary sulfide assemblage are preserved. The "secondary" sulfide assemblage is subdivided into two stages: Violarite ± millerite ± chalcopyrite represent the first stage of replacement of the primary sulfide paragenesis, which is considered as violarization. Progressive replacement (stage 2) is characterized by pyrite ± marcasite, i. e. pyritization (see also Fig. 2).

Undefined Ni-Fe-S phases partly replace pentlandite, still showing the inheritance of octahedral shrinkage cracks from pentlandite. The Ni-Fe-S phases have a metal to sulfur ratio of nearly 1:1 (Tab. 1). Ni- and Fe- contents vary strongly, and hence, two types can be distinguished: a Ni-dominated and a Fe-dominated group. Probably this difference is a result of variable Ni:Fe ratios of precursor pentlandite.

Oxide mineral phases (as magnetite or chromite) are practically lacking at the base of the intrusion; only a few grains of ilmenite and rutile could be observed locally.

Table 1

Electron microprobe analyses of undefined Ni-Fe-S phases in at.%.

Sample	Fe	Cu	S	Co	NI
48/7/5/1	21.62	1.41	48.29	0.12	28.56
6/2/1/2	17.95	0.45	50.99	0.95	29.66
46/5/5/x2a	23.64	5.77	52.23	0.63	17.73
46/5/10/2	13.41	0.13	58.85	10.36	17.25
46/11/1/4	22.46	0	48.57	0.21	28.76
46/11/4/4	22.66	0	48.9	0.31	28.13
46/14a/3/2	22.93	0.07	50.09	0.04	26.87
46/14a/7/4	22.3	0.08	52.46	0.02	25.14
46/14a/11/1a	23.62	0	48.53	0	27.85
46/14a/6pn	23.74	0	49.84	0.06	26.36
46/14b/1/x	25.28	4.09	49.68	0.02	20.93
46/14b/8/4	23.85	0	49.02	0	27.13
46/14b/10/2	21.95	0	52.84	0.24	24.97
6/2/2/1	16.84	0	51.71	1.37	30.08
6/2/5/2	17.72	0	49.58	0.93	31.77
6/2/5/6	23.07	0	49.39	0.03	27.51
6/3a/2/6	20.81	0.14	51.97	1.25	25.83
6/3b/3/5	21.2	0	49.92	1.86	27.02
6/3b/1/8	19.91	0.6	57.11	1.6	20.78
6/3b/5/4	23.5	0	48.21	0.46	27.83
6/3b/6/3d	23.73	0	52.45	0.57	23.25
6/3b/2/7	23.08	5.59	50.47	1.22	19.64
6/3c/1/4	23.61	3.56	48.19	0.94	23.7
6/3d/2/8	22.61	0	48.27	0.23	28.89
6/3d/5/1	23.11	0	48.99	0.77	27.13
6/3d/6/1d	35.31	0	53.12	0.72	10.85
6/3d/6/1	24.91	0	48.66	0.74	25.69
6/3d/7/2i	25.02	0	48.28	0.8	25.9
6/3d/8/1	23.57	0	48.97	1.74	25.72
6/5/4/1	18.81	0	49.31	0.48	31.4

Sample	Bi	Pd (Pt)	Te	Total	PGM
6/3d/2/1	47,06	22,2	28,81	98,07	mi
6/3d/2/1a	41,92	35,92	21,04	98,88	ko
6/3d/2/2	42,62	35,67	20,3	98,59	ko
6/3d/2/3	42,62	38,09	20,64	101,35	ko
6/3d/2/5	0,24	30,12	68,22	98,58	mer
6/3d/2/10	39,83	36,28	13,78	89,89	ko?
6/3d/2/9	0,25	30,48	69,92	100,65	mer
6/3d/2/11	46,27	24,24	28,71	99,22	mi
6/3d/2/13	43,97	36,87	20,22	101,06	ko
6/3d/5/1	28,35	23,99	48,28	100,62	mi
6/3d/5/2	47,4	23,25	28,44	99,09	mi
6/3d/5/3a	46,64	28,38	23,45	98,47	ko
6/3d/5/3b	46,65	22,84	27,94	97,43	mi
6/3d/5/6	44,12	36,62	19,12	99,86	ko
6/3d/5/10	9,22	29,14	43,33	81,69	ko
6/3a/3/6	42,75	39,43	20,18	102,36	ko
6/3a/3/8	41,87	38,31	21,6	101,78	ko
6/3a/3/9	37,66	40,24	22,12	100,02	ko
6/3a/3/2	44,46	37,14	18,37	99,97	ko
6/3a/3/1d1	46,19	24,88	28,73	99,8	mi
6/3b/4a	46,9	24,5	28,3	99,7	mi
6/3b/7b	42,31	38,69	20,02	101,02	ko
6/3b/3	46,12	24,78	28,33	99,23	mi
6/3a/1/5	40	38,26	21,3	99,56	ko
6/3a/1/4	41,63	41,49	21,7	104,82	ko
46/10/5/1	54,32	34,02	10,34	98,68	ko
46/5/10/1	55,85	35,17	9,67	100,69	ko
46/5/10/6a	52,03	35,79	13,47	101,29	ko
46/5/10/6b	49,71	23,61	26,32	99,64	ko
46/5/2b/2a	54,88	33,51	11,9	100,29	ko
46/5/2/2b	54,7	33,53	9,09	97,32	ko
46/5/2/9	54,64	33,91	9,01	97,56	ko
48/7/3/B1	34,15	39,67	26,89	100,71	ko

Platinum-group minerals (PGM)

The PGE mineralogy of the offset deposit is characterized by Pd-Pt-bis-muthotellurides (like michenerite, kotulskite and merenskyite), subordinately Pd-Pt-stannides, -antimonides and -arsenides.

The platinum-group minerals are associated with metamorphic silicates (chlorite, biotite, amphiboles, garnet), and sulfides (predominantly with sulfides of the "secondary" sulfide assemblage which is considered as violarization). Locally PGM grains fill fractures in metamorphic silicates or occur interstital to chlorite, biotite, and amphibole; their shapes are mostly anhedral.

Table 2

*Electron microprobe analyses of Pd(Pt)-bismuthotellurides in wt%. ko= kotulskite, mi = michenerite, me = merenskyite*

The Pd-Bi-Te phases are either in the kotulskite-sobolevskite solid solution series [Pd(Te-Bi)$_{1-2}$] or michenerite (PdBiTe). HOFFMAN & MCLEAN (1976) report a melting point of michenerite at 501 ± 3°C, based on experimental study. At this temperature michenerite melts incongruently producing first Bi-rich kotulskite and liquid, and with increasing temperature the Bi content of the kotulskite decreases. Finally, pure kotulskite melts congruently at 720°C (BERLINGCOURT et al., 1981).

Fig. 3 illustrates the compositional characteristics of PGM from the offset deposit in the system Pd-Bi-Te (Tab. 2). Kotuslkite is characterized by high Bi-contents, indicating crystallization temperatures below 720°C.

According to an experimental investigation of phase relations in the Pd-Bi-Te system by HOFFMAN & MCLEAN (1976), the solid solution between merenskyite and kotulskite is complete beween 575 ± 10°C and 710 ± 10°C, but the extend of the solid-solution field at lower temperatures has not been defined. A solid solution series between kotulskite and merenskyite cannot be observed in Fig. 3, which probably again indicates low-temperature formation.

Fig. 3

Chemical composition (in wt%) of the Pd-Te-Bi phases in the Pd-Bi-Te diagram.
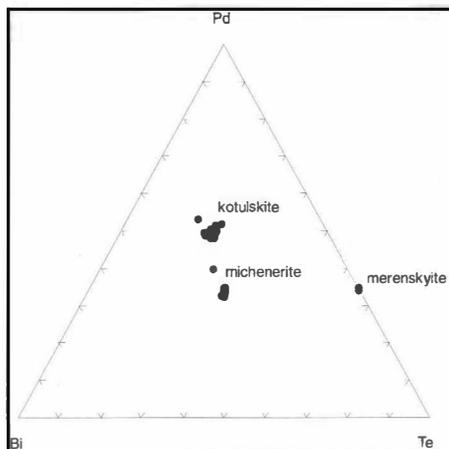
Conclusions

The Kilvenjärvi offset deposit comprises chalcopyrite-dominated base metal sulphides of massive and disseminated type. Two generations of sulfide associations can be distinguished, a primary association of chalcopyrite-pyrrhotite-pentlandite-pyrite-(bornite) and a secondary association. The primary sulfide association is considered of magmatic origin, having been introduced into the already metamorphosed Archean granite-gneiss host rock, closely related with the intrusion of the Portimo Complex. The secondary association represents the result of a post-magmatic, low temperature metasomatic event, and can be divided into:

a) the result of violarization, characterized by violarite, millerite and possible PGM, and

b) the result of pyritization evidenced by the appearance of Ni-rich pyrite, bravoite, marcasite, secondary pyrrhotite and chalcopyrite.

The PGE mineralogy of the offset deposit is characterized by Pd-Pt-bismuthotellurides, subordinately Pd-Pt-stannides, -antimonides and -arsenides. PGM are often closely associated with the violarite-millerite-chalcopyrite secondary assemblage, as well as with secondary silicates such as chlorite, biotite and tremolitic amphiboles. This suggests that PGM have been formed during violarization, and that replacement of primary sulfides was driven by circulating metasomatic fluids.

High Bi-contents of kotulskite indicate a temperature below 500°C for the formation of PGM.

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