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Mineralogy of PGE in the Mafic-Ultramafic Massifs of the Kola Region*

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With 2 Figures

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Summary

During the last few years nearly 50 minerals and unnamed platinum-group element (PGE) phases have been identified by the authors in nickel-bearing mafic-ultramafic massifs of the Kola region. About 20 established PGE minerals have been found whilst more than 20 previously undescribed and unnamed PGE phases can be reported. In addition high concentrations of these elements in sulfarsenides of the cobaltite-gersdorffite series have been established. The PGE phases form tiny (5–70 μm, seldom larger) mono- and polymineral inclusions in the main sulfides of the nickel-copper mineralization; at the contacts with silicates and within the silicates themselves. The details of the composition of platinum mineralization in various massifs, its formation under magmatic and hydrothermal conditions and wide isomorphism in certain groups of minerals have been established. Specific features of PGE mineralization of the region as a whole are: the predominance of bismuth tellurides and arsenides of palladium and platinum, a highly subordinated role of their sulphides and higher concentrations of several PGE in sulfarsenides.

Zusammenfassung

Platingruppen-Minerale in den mafischen-ultramafischen Intrusionen der Kola Region

In den vergangenen Jahren wurden etwa 50 z.T. noch unbekannte Minerale von Platingruppen-Elementen (PGE) in Ni-führenden mafisch-ultramafischen Gesteinen der Kola Region bestimmt (ca. 20 bereits bakannte und mehr also 20 bisher nicht beschriebene bzw. noch unbenannte PGE-Minerale). Außerdem wurden hohe Konzentrationen dieser Elemente in Sulfarseniden der Cobaltit-Gersdorffit-Reihe nachgewiesen.

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Die PGE-Minerale kommen als mono- und polymineralische Einschlüsse in den Sulfiden der Ni–Cu-Mineralisation, am Kontakt der Sulfide zu den Silikaten und in den Silikaten selbst vor. Details über die PGE-Mineralisation in verschiedenen Gebieten, ihre Bildung unter magmatischen und hydrothermalen Bedingungen und die Isomorphiebeziehungen innerhalb bestimmter Mineralgruppen werden dargestellt.

Spezifische Eigenheiten der PGE-Mineralisation dieser Region sind: Das Vorherrschen von wismutvtelluriden, sowie von Pd- und Pt-Arseniden, die untergeordnete Rolle von Pd- und Pt-Sulfiden und erhöhte Gehalte bestimmter PGE in den Sulfarseniden.

Introduction

There is scarce information about platinum mineralization in deposits of the Kola Peninsula. The reason for this is that no special investigations have so far been conducted on the mineralogy and geochemistry of PGE. This has now been done during a study of the nickel-copper ores of the region. The occurrences are basically confined to the Monchegorsk pluton, to its rich vein ores and copper (chalcopyrite) veinlet-disseminated mineralization (*Genkin* et al., 1963; *Yushko-Zakharova* et al., 1970).

A considerable amount of PGE minerals previously unknown in the region as well as cobaltite-gersdorffite with a high concentration of PGE have been identified by the authors following publication of the report on mineralogy of nickel-copper ores of the Kola Peninsula (*Yakovlev* et al., 1981).

At present more than 40 independent PGE mineral species and their varieties have been identified in this area. The minerals have been found in mafic-ultramafic massifs of five types (Fig. 1): peridotite-pyroxenite-gabbro-norite rhythmically layered intrusives (Moncha, Fedorova-Pansky tundras, Oulanka, etc.), gabbro-hyperbasite (Karikyavr, etc.), gabbro-wherlite (Pechenga ore field), hyperbasite (Allarechka) and gabbro-lherzolite-websterite (Lovno). All the massifs are nickel-bearing with associated deposits of nickel-copper sulphide ores.

The location of mafic-ultamafic massifs in the region, their structure, composition and the localization of ore mineralization have been discussed in several papers (e.g. *Belkov*, 1985; *Papunen* and *Gorbunov*, 1985).

The most diverse PGE mineralization has been revealed in layered peridotite-pyroxenite-gabbro-norite massifs (Table 1); in other types the number of PGE minerals is small (*Yakovlev* et al., 1981; *Grokhovskaya* et al., 1989, etc.).

Rhythmically layered massifs are among the largest mafic-ultramafic intrusives of the region. They contain disseminated sulphide mineralization in the form of "hanging" horizons and veinlet-disseminated mineralization in the bottom part of the intrusives and, sometimes, veins of massive sulphide ores (Monchegorsk pluton).

The northern zone has a north-west trend and includes the massifs of Pansky and Fedorova tundra, Monchegorsk and Monchetundra, Ulita, Generalsky mountain and several smaller massifs. The southern zone has an east-west trend and embraces massifs of the Oulanka group (Lukkulaisvaara, Tsypringa, Kivakka). The continuation of this zone to the west into Finland is known as the Koillismaa-Kemi zone.

Massifs of the Karikyavr group are located in the north-eastern gneiss framework of the Pechenga structure and within the northern zone of the development of layered intrusives. They are clearly differentiated from gabbro to lherzolites and dunites. Sulphide mineralization is concentrated in peridotites in lower parts of the

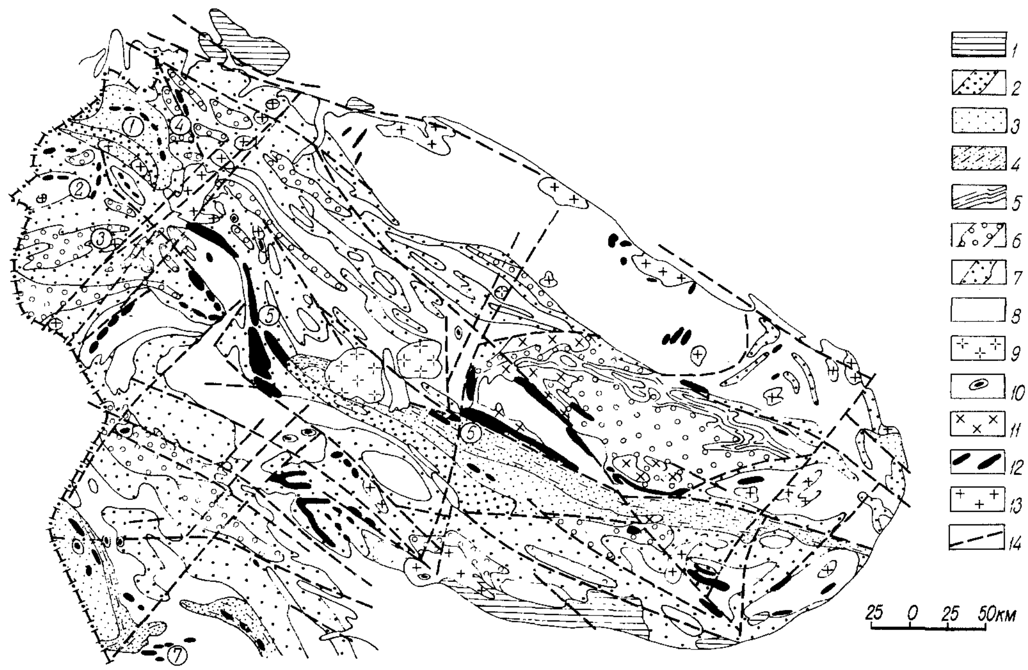

Fig. 1. Geological map of the Kola Peninsula (after *Yakovlev* et al., 1981). *1* Rifes terrigenous complex (sandstones, conglomerates, schists); *2–4* Karelian volcanogenic-sedimentary complex (*2* South-Pechenga and Tominga series; *3* Pechenga and Varzuga series; *4* Strelna series); *5–7* Kola Belomorian amphibolite-gneiss crystalline schist complex (*5* Keivy schist series; *6* Lebyazhka, Voronyetundra series and their analogs; 7 Vochelambino, Olenegorsk, Annam series, and their analogs); *8* Oldest complex of primary sialic crust (plagiogranites, tonalites, plagiogneisses); *9–13* Intrusive formations (*9* nepheline alkaline syenites; *10* alkaline gabbroids; *11* alkaline granitoids; *12* mafic and ultramafic rocks; *13* granitoids); *14* most important fractures. Circled numbers: nickel areas (*1* Pechenga; *2* Allarechka; *3* Lovnoozero; *4* East-Pechenga (Karikjavr, Generalskaya etc.); *5* Monchegorsk (Monchepluton, Monchetundra, Ostrovskoe etc.); *6* Fedorova-Pansky tundras; 7 Oulanka (Lukkulaisvaara, Kivakka, Tsipringa etc.)

succession; it includes disseminated and schlieren-shaped segregations and rarely occurs as "hanging" horizons in the middle part, as well as in the form of small lenses of breccia-shaped ores in the host gneisses.

Massifs of gabbro-wherlite are concentrated in the Pechenga-Varzuga structure, a metallogenic zone of rift origin, stretching from north-west to south-east across the entire peninsula. Ore-bearing massifs are located in the north-western part of the zone (Pechenga structure) and its northern gneiss framework (Nyasyukka dykes); the former are found in association with economic deposits of various ore types, the latter only with disseminated mineralization.

Massifs of hyperbasite and gabbro-lherzolite-websterite are of small size and concentrate as NW-trending narrow zones or belts coinciding with the general strike of large structures of amphibolite-gneiss (Kola-Belomorian) Archean complexes which are evidently relicts of ancient greenstone belts.

Age relationships of these magmatic complexes have not yet been clearly defined. Reliable age determination is only available for the layered intrusives (about 2.45 Ga) and gabbro-wherlites (1.8–1.9 Ga; *Pushkarev*, 1989).

Table 1. *Platinum-group minerals in mafic-ultramafic massifs of the Kola region*

	Mineral	Formula	Oulanka	Pansky	Moncha	Karikyavr	Pechenga	Allarechka	Lovno
1	2	3	4	5	6	7	8	9	10
1	Iridosmine	(Os, Ir)			+				
2	Pd-gold*	(Au, Pd)		+					
3	Atokite	$(Pd, Cu, Pt)_3Sn$					+		
4	Taimyrite*	$(Pd, Cu)_3Sn$	+						
5	Stannopalladinite	Pd_3Sn_2			+				
6	Niggliite	PtSn			+				
7	Tulameenite*	Pt_2CuFe	+						
8	(unnamed)*	$Pd_2(Sn, Sb)$	+						
9	Cooperite*	PtS		+					
10	Vysotskite*	(Pd, Ni)S		+	+				
11	Braggite*	(Pt, Ni, Pd)S	+	+	+				
12	(unnamed)*	$Pd_2(Cu, Ag)_2S_3$	+						
13	(unnamed)	$Pd_5(Cu, Fe)_3SnTe_2S_2$	+						
14	Kotulskite	PdTe	+	+	+				
15	Sb-kotulskite*	(Pd, Pt)(Te, Bi, Sb)	+	+					
16	Sobolevskite*	(Pd, Ni)(Bi, Te)		+					
17	Pd-melonite*	$(Ni, Pd)(Te, Bi)_2$					+	+	+
18	Ni-merenskyite	$(Pd, Ni)(Te, Bi)_2$					+		
19	Merenskyite	$Pd(Te, Bi)_2$	+	+	+	+	+		
20	Moncheite	(Pt, Pd)(Te, Bi, S)	+	+	+			+	
21	Michenerite	PdBiTe		+	+	+	+	+	
22	Sb-michenerite	Pd(Bi, Sb)Te					+		
23	(unnamed)	$PdBiTe_2$			+				
24	(unnamed)*	Pd_8Te_3	+						
25	(unnamed)*	$(Pt, Pd, Ni)_3Te_4$							+
26	Froodite(?)	$PdBi_2$				+			
27	Sopcheite	$Ag_4Pd_3Te_4$	+	+	+				
28	(unnamed)*	Pd_6AgTe_4	+						
29	Telargpalite	$(Pd, Ag, Pb)_4Te$	+						
30	Stillwaterite*	Pd_8As_3	+						
31	Palladoarsenide*	Pd_2As	+						
32	Majakite*	(Pd, Ni)As	+						
33	Sperrylite	$PtAs_2$	+	+	+	+	+	+	
34	Omeiite	$OsAs_2$				+			
35	Osarsite	$(Os, Ru)(As, S)_2$				+			
36	Irarsite	(Ir, Rh, Pt)AsS	+			+			
37	Hollingworthite	(Rh, Pt, Pd)AsS	+			+			
38	(unnamed)*	$PtAs_2S_2$	+						
39	(unnamed)	$(Fe, Pt)(As, S)_2$				+			
40	Mertieite*	Pd_8Sb_3	+						
41	Isomertieite*	$Pd_{11}As_2(Sb, Te)_2$	+						
42	(unnamed)	RuAsTe				+			
43	(unnamed)	$(Ru, Os)(As, Te)_2$				+			
44	Rh-cobaltite	(Co, Rh, Ni)AsS	+			+			
45	Ru-cob.*	(Co, Ru, Ni)AsS				+			
46	Rh–Ir–Ru–Os–cob.	(Co, Ni, Rh, Ru, Ir, Os)AsS				+	+		
47	Rh–Pt–Ir–cob.*	(Co, Ni, Fe, Rh, Pt, Ir)AsS		+					
48	Rh–Te–cob.	(Co, Ni, Fe, Rh)(As, Te)S				+			
49	Os–Rh–Ru–gersd.	(Ni, Co, Fe, Os, Rh, Ru)AsS				+			

* Minerals found by the authors since 1981.

Distribution of the PGE Minerals in Mafite-Ultramafites

Platinum-group minerals described from the Kola region belong to the following classification groups: native metals and intermetallides, sulphides, tellurides and bismuth tellurides, arsenides and sulfarsenides (Table 1). Minerals of palladium and platinum predominate in all the groups; the rest of the PGE, as a rule, occurs as admixtures and more seldom form independent minerals—in groups of native minerals, arsenides and sulfarsenides. High concentrations of some PGE are characteristic of Co, Ni, Fe sulfarsenides.

Several groups of minerals show a tendency for development in certain intrusive complexes. Thus, platinum and palladium sulphides have only been revealed in layered massifs; arsenides and sulfarsenides, especially of rare PGE, as well as their stibio- and tellurarsenides occur in the intrusives of Oulanka and Kirikyavr.

Intermetallides and native metals occur more frequently. Pd and Pt tellurides

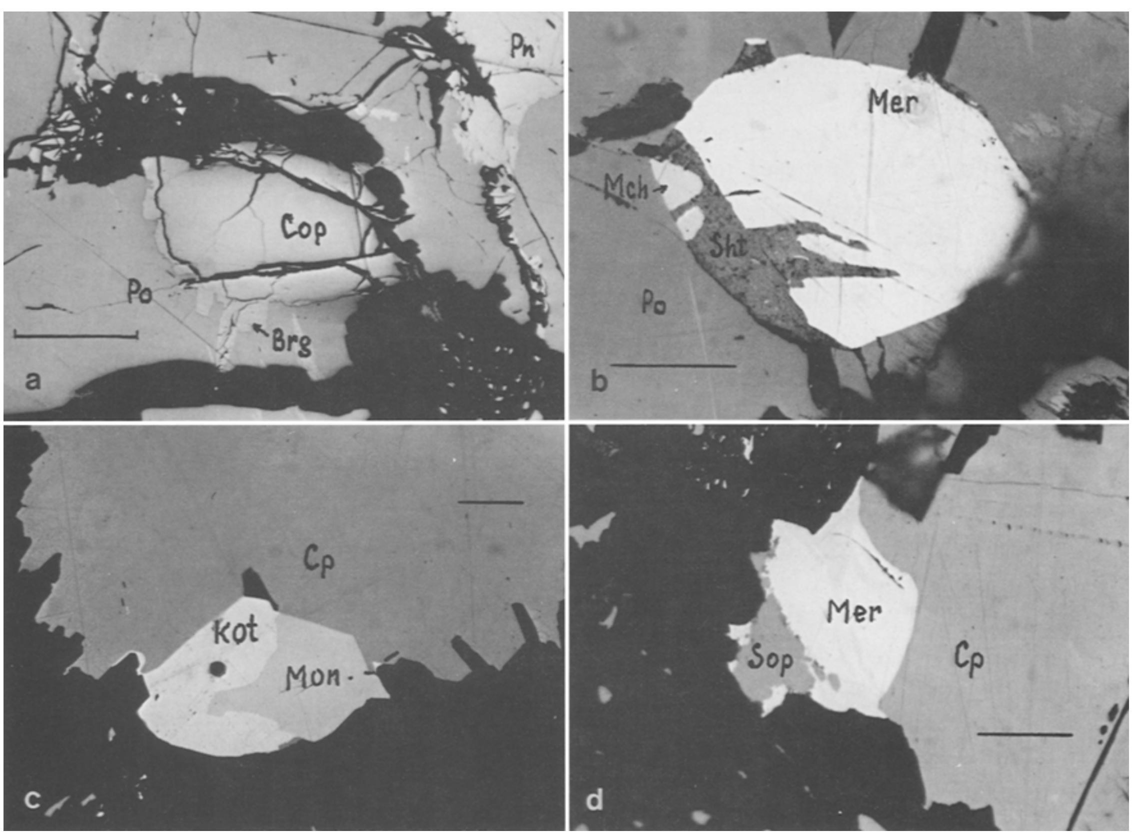

Fig. 2. Platinum-group minerals of the Fedorova-Pansky massif. a) Cooperite (*Cop*) and braggite (*Brg*) in the massive ore (schlieren) of the marginal zone; *Po* pyrrhotite, *Pn* pentlandite, black = silicates. b) Merenskyite (*Mer*), stützite (*Sht*) and michenerite (*Mch*) in the veined ore of the norite zone; *Po* pyrrhotite, black = silicates. c) Kotulskite (*Kot*) and moncheite (*Mon*) in the disseminated ore of the "hanging" horizon: *Cp* chalcopyrite. d) Sopcheite (*Sop*) and merenskyite (*Mer*) in the disseminated ore of the "hanging" horizon. Scale bar = 50 μm

and bismuth-tellurides are also widely distributed. They have been found in all mafic-ultramafic massifs though they are more fully represented in the rhythmically-layered massifs.

In all mafic-ultramafic massifs, PGE mineralization is associated with sulphide nickel-copper mineralization and, as a rule, with the richer ores. Thus, vein ores in the Monchegorsk pluton are greatly enriched in PGM minerals, though they are also common in veinlet-disseminated ores and rare in "hanging" horizons of poor disseminated mineralization. In massifs of other types these minerals are concentrated in rich disseminated, breccia-form and massive ores. In the Pansky-Fedorova tundra and Lukkulaisvaara massifs the concentration of these minerals, however, cannot be correlated with the sulfide content; they uniformly occur in all sulfide-bearing horizons.

The PGE minerals ubiquitously form tiny (5–70 μm, seldom larger) inclusions in sulfides (chalcopyrite, pyrrhotite, pentlandite, sometimes bornite, pyrite, etc.), also at contacts of sulphides with silicates (Fig. 2) and sometimes in silicates (pyroxenes, amphiboles, micas) or in oxides (magnetite). Inclusions generally have an irregular form which is not seldom drop-like; some minerals are characterized by idiomorphic individuals (sperrylite, sulfarsenides, etc.). Monomineralic segregations predominate; intergrowths of 2–3 PGE minerals are rare and mostly occur in layered intrusions.

In most nickel-copper deposits and occurrences the PGE minerals are part of the magmatic parageneses, mainly of the final stages of the magmatic process. An association with tellurides of Pb, Bi, Ag, Au and Ni is peculiar to the majority of these parageneses. Their structural relationships testify that they formed coevally. The amount of PGE minerals markedly increases with an increase in the copper content of the ores. Noteworthy in this respect is their concentration in predominantly chalcopyrite (sometimes bornite-chalcopyrite) schlieren and veins of pegmatoid plagiopyroxenites (the Oulanka intrusives), sulfide veins and veinlet-disseminated ores (Monchegorsk) as well as in peculiar carbonate-sulfide, vein-shaped, isolated mineralization (Allarechka). Evidently this reflects the tendency common to all magmatic deposits of accumulating trace elements in residual portions of the melt with high concentrations of volatile components. At early magmatic stages the PGE as a rule do not form independent minerals but are incorporated in monosulfides of Fe, Ni, and Co as an isomorphic admixture (*Distler*, 1980; *Genkin* et al., 1981; *Distler* et al., 1988).

In some massifs a dependence of the PGE mineral parageneses on the composition of sulfide associations has been established. Thus, in the Lukkulaisvaara massif the rocks with pyrrhotite-pentlandite-chalcopyrite and pentlandite-chalcopyrite associations mostly contain PGE arsenides and sulfarsenides (sperrylite, mertieite, isomertieite, majakite, stillwaterite, etc.), whereas in the schlierens of plagiopyroxenites with chalcosite-bornite-pentlandite-chalcopyrite or chalcosite-bornite-magnetite, PGE sulfides and tellurides (braggite, moncheite, kotulskite, telargpalite etc.) are predominant.

Platinum-group mineral distribution in the nickel-copper ores is also affected by the degree of metamorphism of the ores. Generally it results in the redistribution of the PGE (particularly, from primary monosulfides) and in the formation of arsenides and sulfarsenides of PGE as well as of the minerals of cobaltite-gersdorffite series with elevated concentrations of rare PGE (Rh, Ru, Os and Ir).

Specific Features of Chemical Composition of Minerals

The composition of platinum minerals of the Kola region varies widely, both in different types of mafite-ultramafites and in separate massifs (Table 2)* . The most significant variations occur in tellurides and bismuth tellurides. In nickel-copper ores of the Kola region, pseudohexogonal (trigonal) merenskyite and moncheite and cubic michenerite have been identified. Isomorphism among Pt and Pd, and Te and Bi in these series is generally known (*Cabri* and *Laflamme*, 1976; *Genkin* et al., 1981; *Hoffman* and *MacLean*, 1976; *Yakovlev* and *Pakhomovsky*, 1982, etc.). The occurrence of Ni-merenskyite and Pd-melonite as well as the data concerning the change of their chemical composition (Table 2) show that the limits of isomorphic replacement at the expense of nickel are considerably larger than previously thought. It is also possible to consider Pd-melonite-merenskyite-moncheite as a single series.

The composition of michenerite is variable, too. According to published data the contents of the main components are (atomic %) 11.70–24.56 Pd, 0.26–10.00 Pt, 28.10–38.00 Te, 38.62–50.00 Bi. The results reported here fall within this range.

Sulfarsenides of Fe, Co and Ni containing almost all the PGE (Table 2) also show compositional variations. However, the solubility of the latter is limited and does not exceed 20% total PGE. Palladium occurs extremely rarely and in small amounts. It has been identified only in Rh-cobaltite from the Oulanka area. It is noteworthy that the solubility of Fe, Ni and Co is also limited and does not exceed 20% either; the admixture of Fe and Ni is more common whereas Co is rare (though its content in hollingworthite of the Karikyavr massif reaches 6.73%). The total content of PGE in sulfarsenides of Fe, Ni and Co reflects, to some extent, the temperature conditions of their formation: PGE concentration in cobaltite of the Pechenga mafite-ultramafites, metamorphosed under conditions of greenschist facies is considerably lower than in cobaltite of the Karikyavr massifs, metamorphosed under conditions of an amphibolite facies or in cobaltites and gersdorffites of layered intrusives in magmatic parageneses. The ratio of certain platinum metals in sulfarsenides of Fe, Co and Ni from different massifs varies greatly.

The composition of PGE sulfides is also variable but to a lesser degree. In addition to Pt and Pd, they always contain small amounts of the other platinum-group metals and a larger proportion of Ni and Fe and, in one case, of Bi. A limited number of analyses suggests a higher content of Pd in braggite of the Monchegorsk region as compared to braggite of the Fedorova-Pansky tundras and Oulanka intrusives (Table 2).

Conclusions

In the Kola region platinum-group minerals are most common in rhythmically-layered intrusives of the peridotite-pyroxenite-gabbronorite as well as in gabbro-hyperbasite massifs. The amount of these minerals in mafite-ultramafites of other groups is small, and they belong to the category of rare minerals. Over the last few years a considerable number of platinum-group minerals as well as sulfar-senides of Fe, Co and Ni with a higher content of PGE have been identified in the massifs

* For details on analytical methods and standards used see *Gorkhovskaya* et al. (1989).

Table 2. *Chemical composition (weight %) of PGE-minerals in the Kola region*

	Mineral	Pd	Pt	Ag	Au	Sn	Fe	Ni	Cu	S	Te	Bi	Sb	Sum	District
1	Pd-gold	3.01		1.38	94.08				0.77					99.24	Pansky
2	Taimyrite	59.28	3.89			26.33	0.66		7.27	0.44	0.37			98.24	Oulanka
3	Tulameenite	0.73	76.77				10.05		11.88					99.43	Oulanka
4	$Pd_2(Sn, Sb)$	63.56	0.16	0.93		16.43				0.24	0.60	0.25	16.55	98.80	Oulanka
5	Cooperite		78.38				1.21	0.23		16.32		2.67		98.81	Pansky
6	Vysotskite	58.44		5.23				10.84		24.13				98.83	Pansky
7	Vysotskite	55.87	15.71					6.62		22.74				100.94	Moncha
8	Braggite	20.52	60.09					2.35		16.46				99.42	Moncha
9	Braggite		71.91				0.23	7.35		18.01		1.07		98.85	Pansky
10	Braggite	3.15	69.54	0.09			0.13	8.31		18.31				99.53	Oulanka
11	$Pd_2(Cu, Ag)_2S_3$	45.58		9.57				0.18	22.73	19.92				97.98	Oulanka
12	Kotulskite	40.84		3.24			0.24	0.20			49.56	4.90	0.35	99.33	Pansky
13	Kotulskite	44.81	1.00								52.23	1.33	0.25	99.62	Oulanka
14	Sb-kotulskite	39.77	0.71								36.29	18.39	7.47	102.63	Oulanka
15	Sobolevskite	26.42	0.53	3.38			0.72	2.82			20.08	46.06		100.01	Pansky
16	Pd-melonite	7.71						12.69			67.68	11.52		99.60	Allarechka
17	Merenskyite	13.78	17.13	1.08			0.33	0.17			49.44	18.10		100.03	Pansky
18	Merenskyite	21.14	4.65					1.81		0.13	57.48	14.84		100.05	Moncha
19	Merenskyite	29.00								0.15	63.85	6.59		99.59	Oulanka
20	Moncheite	0.08	46.68				0.09	0.03			53.10	2.93	0.31	100.22	Pansky
21	Moncheite	1.64	38.93	0.94			0.84	0.19	0.66	0.99	53.11	2.88		100.18	Oulanka
22	Moncheite	4.23	31.40	0.48			0.25	0.55	0.19		39.69	23.72	0.21	100.72	Allarechka
23	Michenerite	23.95	0.89							0.17	33.28	42.27		100.56	Moncha
24	Michenerite	21.73	0.55	2.35			0.31	0.43			30.71	43.24		99.32	Pansky
25	Michenerite	21.36	2.60								32.86	43.90		100.72	Allarechka

Table 2 (continued)

	Mineral	Pd	Pt	Rh	Ag	Cu	Fe	Ni	Co	S	As	Te	Bi	Sb	Sum	District
26	Pd_8Te_3	61.60	0.62		4.41							32.76			99.39	Oulanka
27	$(Pt,Pd,Ni)_3Te_4$	7.73	26.96				0.14	6.47	0.13			55.89	3.51		100.83	Lovno
28	Sopcheite	25.61			34.31		0.40	0.03				41.03			101.38	Pansky
29	Sopcheite	24.33	0.20		35.41					0.09		40.81		0.17	101.08	Oulanka
30	Pd_6AgTe_4	52.12			7.86							40.39			100.37	Oulanka
31	Telargpalite	38.41	0.29		28.40	0.56		0.08		0.29	0.37	20.19	1.00		99.05	Oulanka
32	Stillwaterite	74.22	0.32			3.20		0.85		0.22	20.20				99.01	Oulanka
33	Palladoarsenide	73.05				0.29	0.53	0.38	0.23		22.34		0.08	0.51	97.41	Oulanka
34	Majakite	45.71						24.76			30.50			0.16	101.13	Oulanka
35	Sperrylite		56.36				0.45				41.98		0.66		99.71	Pansky
36	Sperrylite		56.62			0.13	0.06	0.01			43.28				100.10	Allarechka
37	Hollingworthite	4.90	13.74	33.24						14.08	30.86				100.05	Oulanka
38	$PtAs_2S_2$		41.40					0.19		24.14	28.76	0.23	2.71	0.26	97.69	Oulanka
39	Mertieite	70.19	0.07	0.04	0.18	0.12	0.75	0.07		0.36	2.23	0.15	0.85	25.62	100.63	Oulanka
40	Isomertieite	76.77	1.00								9.48	2.56	0.18	12.22	102.21	Oulanka
41	Ru-cobaltite			0.45			3.67	9.32	23.09	20.10	43.48				101.91	Karikyavr
42	Rh–Ru–Ir–Os–cob.	0.27	0.01	2.29			3.67	6.20	23.01	19.65	44.53				101.72	Pechenga
43	Rh–Pt–Ir–cob.		1.77	4.02			6.16	8.18	15.73	19.10	43.91				100.33	Pansky

Notes: the blanks in columns mean that an element was not analysed. Totals include an.4 – 0.08 As, an.6 – 0.19 Co, an.9 and 35 – 0.28 and 0.26Hg, an.29 – 0.07 Sn, an.31 – 9.47 Pb, an.37 and 42 – 3.23 and 0.69 Ir, an.41, 42 – 1.65 and 0.31 Ru respectively, 0.15 and 1.09 Os, an.43 – 1.17 Ir, 0.29 Os. Analytical conditions: MS-46, conventional technique (*Grokhovskaya* et al., 1989), analysts *Ya. A. Pakhomovsky*, *S. A. Rezhenova*, *A. I. Lednev*, *I. P. Laputina*. The table contains only the authors' data.

of the first two groups. As a result the total number of these minerals now exceeds 40. This fact permits consideration of the Kola region as a new PGE province.

The layered intrusives of the Kola province, as compared to other regions of the world, are characterized by platinum-group minerals which are predominantly tellurides and bismuth tellurides as well as arsenides and sulfarsenides. By contrast in the largest stratified complexes (Bushveld, Stillwater) PGE sulfides, Pt–Fe alloys and sperrylite prevail (*Kingston* and *El-Dosuky*, 1982; *Kinloch*, 1982; *Page* et al., 1976; *Talkington* and *Lipin*, 1986; *Volborth* et al., 1986, etc.).

Much closer to the mineralization in the Kola layered intrusives is the composition of platinum-group minerals in nickel-copper deposits of the Sudbury Complex: there tellurides and bismuth tellurides of Pd and Pt as well as sperrylite predominate (*Cabri* and *Laflamme*, 1976).

In layered intrusives of Northern Finland (Penikat, Konttijärvi, Koillismaa, etc.) the PGM of sulfide-bearing horizons as a whole have much in common with the Oulanka group massifs, although the proportion of certain mineral groups, the number of mineral species and their composition vary within a wide range (*Alapieti* and *Lahtinen*, 1986; *Lahtinen* et al., 1989; *Vuorelainen* et al., 1982). But in the layered massifs of the Kola region no analogues of the SJ platinum-group mineralization, a chromite-bearing horizon in the Penikat massif, have been identified (*Lahtinen* et al., 1989; *Halkoaho* et al., 1989). In nickel-bearing massifs of the other formations, except for that of gabbro-hyperbasites (Karikyavr), the platinum-group mineralization is similar in the Kola region and in Finland: it is represented by a small number of minerals, with bismuth tellurides of palladium and platinum and sperrylite being predominant (*Häkli* et al., 1976; *Yakovlev* et al., 1981).

The chemical composition of the main groups of platinum-group minerals of the Kola region are practically analogous to those in other regions. Wider limits of isomorphic replacement in the series of pseudohexogonal (trigonal) Pd and Pt bismuth tellurides established earlier in this region (*Yakovlev* and *Pakhomovsky*, 1982) have been confirmed by studies elsewhere (*Garuti* and *Rinaldi*, 1988). Sulfarsenides of Fe, Co and Ni with high PGE contents including rare PGE are an exception.

In the layered intrusives and massifs of gabbro-hyperbasites and gabbro-wherlites, new discoveries are expected to reveal the rare minerals. Thus, the main details of the PGE mineralization in these complexes is already understood and it is these features that define the "mineralogical character" of the Kola platinum-metal province.

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