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MIESSIITE, $Pd_{11}Te_2Se_2$, A NEW MINERAL SPECIES FROM MIESSIJOKI, FINNISH LAPLAND, FINLAND

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Abstract

Miessiite, a new mineral species of ideal composition $Pd_{11}Te_2Se_2$, is cubic, space group *Fd*3*m* (#227), *a* 12.448(2) Å, *V* 1929.0 (4) Å^3, *Z* = 8. The strongest six lines of the X-ray powder-diffraction pattern [*d* in Å(I)(*hkl*)] are: 2.395(80)(511,333), 2.197(100)(440), 1.875(25)(622), 1.555(25)(800), 1.305(25)(931) and 1.271(30)(844). The mineral was discovered in a platinum-group-mineral (PGM) placer sample taken from the Miessijoki river, Lemmenjoki area, Inari Commune, Finnish Lapland, Finland. Associated PGM and other heavy minerals include stillwaterite, isomertieite, mertieite-II, cooperite, braggite, kotulskite, vincentite, tantalite, thorianite, pyrite, magnetite, chromite, and isoferroplatinum with inclusions of laurite and Os–Ir–Ru alloy. Miessiite is black with a metallic luster. The fragments are malleable and silvery grey in color. The average micro-indentation hardness VHN_{100} is 362 (n = 4) and corresponds to a Mohs hardness of 2–2½. Under reflected plane-polarized light, the mineral is isotropic with a light grey color in comparison with the associated PGM grains. Measured values of reflectance are tabulated, obtained in air and in oil for a single grain. The reflectance values in air for the standard COM wavelengths are: 48.88 (470 nm), 51.63 (546 nm), 53.91 (589 nm) and 56.82% (650 nm). *D* (calc) is 10.94 g/cm^3 (for the empirical formula and unit-cell parameter refined from powder data). The electron-microprobe analyses yielded (wt.%) Pd 75.17, Se 9.61, Te 17.06, total of 101.84 wt.%, which corresponds to $Pd_{11.02}\,Te_{2.09}\,Se_{1.90}$, based 15 atoms. The mineral is named after the locality, the Miessi river (in Saami language, *Miessijohka*).

Keywords: miessiite, new mineral species, palladium telluride selenide, X-ray data, electron-microprobe data, reflectance data, Miessijoki River, Lemmenjoki area, Finnish Lapland, Finland.

Sommaire

La miessiite, nouvelle espèce minérale ayant la composition idéale $Pd_{11}Te_2Se_2$, est cubique, groupe spatial *Fd*3*m* (#227), *a* 12.448(2) Å, *V* 1929.0 (4) Å^3, *Z* = 8. Les six raies les plus intenses du spectre de diffraction X [*d* en Å(I)(*hkl*)] sont: 2.395(80)(511,333), 2.197(100)(440), 1.875(25)(622), 1.555(25)(800), 1.305(25)(931) et 1.271(30)(844). Nous avons découvert le minéral dans un échantillon alluvionnaire enrichi en minéraux du groupe du platine, pris de la rivière Miessijoki, région de Lemmenjoki, commune d'Inari, en Lapponie finlandaise, en Finlande. Lui son associés stillwaterite, isomertieïte, mertieïte-II, cooperite, braggite, kotulskite, vincentite, tantalite, thorianite, pyrite, magnétite, chromite, et isoferroplatine avec inclusions de laurite et d'un alliage Os–Ir–Ru. La miessiite est noire avec un éclat métallique. Les fragments sont malléables et gris argenté. La dureté

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moyenne, mesurée par évaluation de micro-indentations VHN_{100}, est 362 (n = 4) et correspond à une dureté de Mohs de 2–2½. En lumière polarisée réfléchie, le minéral est isotrope et gris pâle en comparaison des grains de minéraux du groupe du platine associés. Nous présentons les valeurs de réflectance dans l'huile et dans l'air, mesurées sur un seul grain. Les valeurs de réflectance dans l'air pour les longueurs d'onde standard COM sont: 48.88 (470 nm), 51.63 (546 nm), 53.91 (589 nm) et 56.82% (650 nm). La densité, calculée à partir de la formule empirique et du paramètre réticulaire affiné (données de diffraction sur poudre), est 10.94 g/cm^3. Les analyses effectuées avec une microsonde électronique ont donné: Pd 75.17, Se 9.61, Te 17.06, pour un total de 101.84% (poids), ce qui correspond à $Pd_{11.02}Te_{2.09}Se_{1.90}$, sur une base de 15 atomes. Le nom rappelle le lieu de découverte, la rivière Miessi (en langue Saami, *Miessijohka*).

(Traduit par la Rédaction)

Mots-clés: miessiite, nouvelle espèce minérale, tellurure et séléniure de palladium, données de diffraction X, données de microsonde électronique, données de réflectance, rivière Miessijoki, région de Lemmenjoki, Lapponie finlandaise, Finlande.

INTRODUCTION

The new mineral species miessiite, ideally $Pd_{11}Te_2Se_2$, was recently discovered in a polished section made of a sample of heavy minerals in a placer concentrate from the Miessi River, Lemmenjoki area, Finnish Lapland, Finland. One grain of miessiite, measuring 483 × 522 μm in size, was found with an electron microprobe at the University of Hamburg in a polished section prepared by the late Mr. Yrjö Vuorelainen (1922–1988). He had collected and analyzed placer PGM nuggets in the early 1980s from the Miessijoki area (Törnroos & Vuorelainen 1987, Törnroos *et al.* 1996). The mineral is named after the locality, the Miessi River (in Saami, *Miessijohka*, where *johka* means river and *Miessi* means a reindeer calf). The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, IMA (2006–013). The miessiite-bearing polished section is preserved in the Finnish Museum of Natural History, Geological Museum, University of Helsinki, Helsinki, Finland, under collection sample number D3004.

THE TYPE LOCALITY

The mineral was discovered along with placer gold and PGM nuggets from the Miessijoki River in the Lemmenjoki area, Inari commune, Finnish Lapland, Finland (Fig. 1). The discovery locality is located at longitude 25°21'N and latitude 68°25'E. The placer gold and PGM nuggets were recovered from glaciofluvial river gravels, sands, terraces, poorly sorted sandy till and weathered bedrock (Saarnisto *et al.* 1991). The PGM exist as individual grains or as inclusions in larger PGM

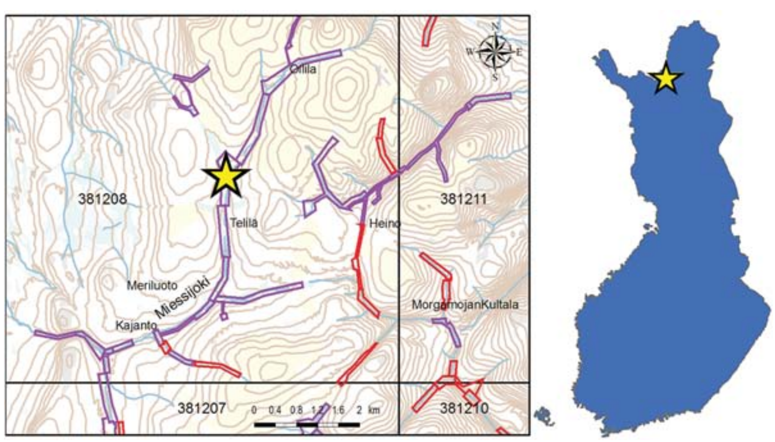

FIG. 1. Map showing the discovery location (yellow star) of a miessiite-bearing nugget in the Miessijohka (Miessijoki) river, a tributary of the Lemmenjoki River, Finland. The red areas along rivers are gold claims, and the blue stippled areas are mining concessions. Map by Geological Survey of Finland, Active Map Explorer ©.

grains (Kojonen *et al.* 2005, 2006). The bedrock in the area is Proterozoic granulite *ca.* 2 Ga old (Meriläinen 1976, Tuisku & Huhma 2003) containing granitic pegmatite and quartz–carbonate veins and mafic–ultramafic gabbro–pyroxenite intrusions. The granulite complex of northern Finnish Lapland forms an arc that extends north–south from the Norwegian border and intersects the Russian border in an east–west direction. This arc is bordered in the southwest by greenstones, mica schists and gneisses. The heavy minerals found in the black placer sands include magnetite, ilmenite, Cr–Fe spinel, hematite, columbite–tantalite, tapiolite, garnet, monazite, zircon, pyrite, rutile, uraninite–thorianite, galena, Pb–Sn alloy and wolframite. Of the sulfides, only pyrite has been preserved in the placers, but inclusions of pyrrhotite, pentlandite, chalcopyrite, cubanite, cobaltite–gersdorffite and molybdenite have been found in native gold and PGM nuggets (Saarnisto *et al.* 1991, Törnroos *et al.* 1996).

The PGM associated with miessiite are stillwaterite, isomertieite, mertieite-II, cooperite, braggite, kotulskite, vincentite, and isoferroplatinum with inclusions of laurite and Os–Ir–Ru alloy. The sources of the placer gold, PGM and columbite–tantalite–tapiolite series minerals are still enigmatic, but the most probable sources are the quartz–carbonate veins, mafic–ultramafic intrusions and complex granitic pegmatites, respectively. The area where the placers occur belongs currently to the Lemmenjoki National Park, and no modern exploration is allowed.

Material and Methods of Investigation

Miessiite was identified in a polished specimen prepared from PGM nuggets obtained during gold panning. Usually, the PGM grains are not recognized by prospectors, and they consequently remain in the residual heavy black sand, whereas the grains of visible gold are picked out from the concentrate. However, appreciable amounts of fine-grained gold, PGM and other heavy minerals remain in the black sand. After removing magnetic minerals and gangue from the black sands and sieving to various grain-size classes, the PGM may be picked out under a stereo microscope. In the case of the miessiite-bearing concentrate, the grains were mounted in epoxy and analyzed systematically in rows with a Cameca SX–100 electron microprobe at the University of Hamburg. The micro-indentation hardness was measured with a Leitz Durimet tester. The X-ray powder-diffraction data were obtained using a 114.6 mm Debye–Scherrer powder camera with Ni-filtered Cu$K\alpha$ radiation. The reflectance values were measured using a Zeiss MPM microphotometer and Zeiss standard WTiC Nr 326. The measurements were repeated 50 times every 20 nm, both in air and using standard immersion oil. The light source of the Zeiss microscope was 100 W halogen, diaphragm 0.15, measuring objective 16×, and the area of measurement 5 μm in diameter.

Optical, Physical, Crystallographic and Chemical Properties

Optical properties

Megascopically, miessiite is opaque with a metallic luster and is quite malleable. Under plane-polarized reflected light in air, miessiite is light grey and isotropic. The grain shows a subidiomorphic cubic morphology (Fig. 2). In the back-scattered electron images (Fig. 2), the grain is chemically homogeneous. Under oil immersion, the mineral has a pinkish grey color. Reflectance measurements were made every 20 nm from 400 to 700 nm (Fig. 3). The values for the COM standard wavelengths 470, 546, 589 and 650 nm were calculated. The mean of 50 replicate measurements at each wavelength is reported in Table 1. The measurements were made in both air and in oil with a 16× objective. The calculated ICE color values and the dominant wavelength also are given in Table 1.

TABLE 1. REFLECTANCE AND COLOR VALUES FOR MIESSIITE AND ISOMERTIEITE

Miessiite

Wavelength	R% in air	R% in oil	Wavelength	R% in air	R% in oil
400 nm	44.3	22.6	560 nm	52.2	32.45
420	45.65	23.6	580	53.3	33.2
440	47.6	26.5	589 (COM)	53.9	33.7
460	48.65	28.7	600	54.6	34.35
470 (COM)	48.9	29.5	620	55.7	35.1
480	49.1	30.2	640	56.5	36.1
500	49.6	30.8	650 (COM)	56.8	36.65
520	50.3	30.5	660	57.1	37.2
540	51.4	31.2	680	57.55	37.8
546 (COM)	51.6	31.6	700	58.3	38.4

CIE color values, illuminant C; x: 0.322 (air), 0.329 (oil); y: 0.325 (air), 0.344 (oil); Y: 53.2 (air), 32.4 (oil); λd: 582 nm (air), 579 nm (oil); P_e %: 5.9 (air), 9.9 (oil). The index of refraction of the immersion oil is 1.5147 at 590 nm. Standard WTiC, sample Miessi 3–75 (Fig. 2).

Isomertieite

Wavelength	R% in air	R% in oil	Wavelength	R% in air	R% in oil
400 nm	42.8	29.4	560 nm	54.95	42.1
420	43.2	30.0	580	56.2	43.3
440	44.05	31.0	589 (COM)	56.8	43.95
460	45.5	32.4	600	57.35	44.55
470 (COM)	46.4	33.3	620	58.4	45.65
480	47.3	34.3	640	59.2	46.4
500	49.4	36.4	650 (COM)	59.45	46.65
520	51.5	38.5	660	59.7	47.0
540	53.5	40.5	680	60.2	47.45
546 (COM)	54.0	40.9	700	60.7	47.9

CIE color values, illuminant C; x: 0.331 (air), 0.339 (oil); y: 0.337 (air), 0.344 (oil); Y: 54.3 (air), 41.4 (oil); λd: 578 nm (air), 578 nm (oil); P_e %: 11.2 (air), 15.2 (oil). Zeiss immersion oil DIN58,884 at 20°C. Standard WTiC Zeiss, 314, *Quantitative Data File for Ore Minerals* (1993), edited by A.J. Criddle & C.J. Stanley, and published by Chapman & Hall (p. 262).

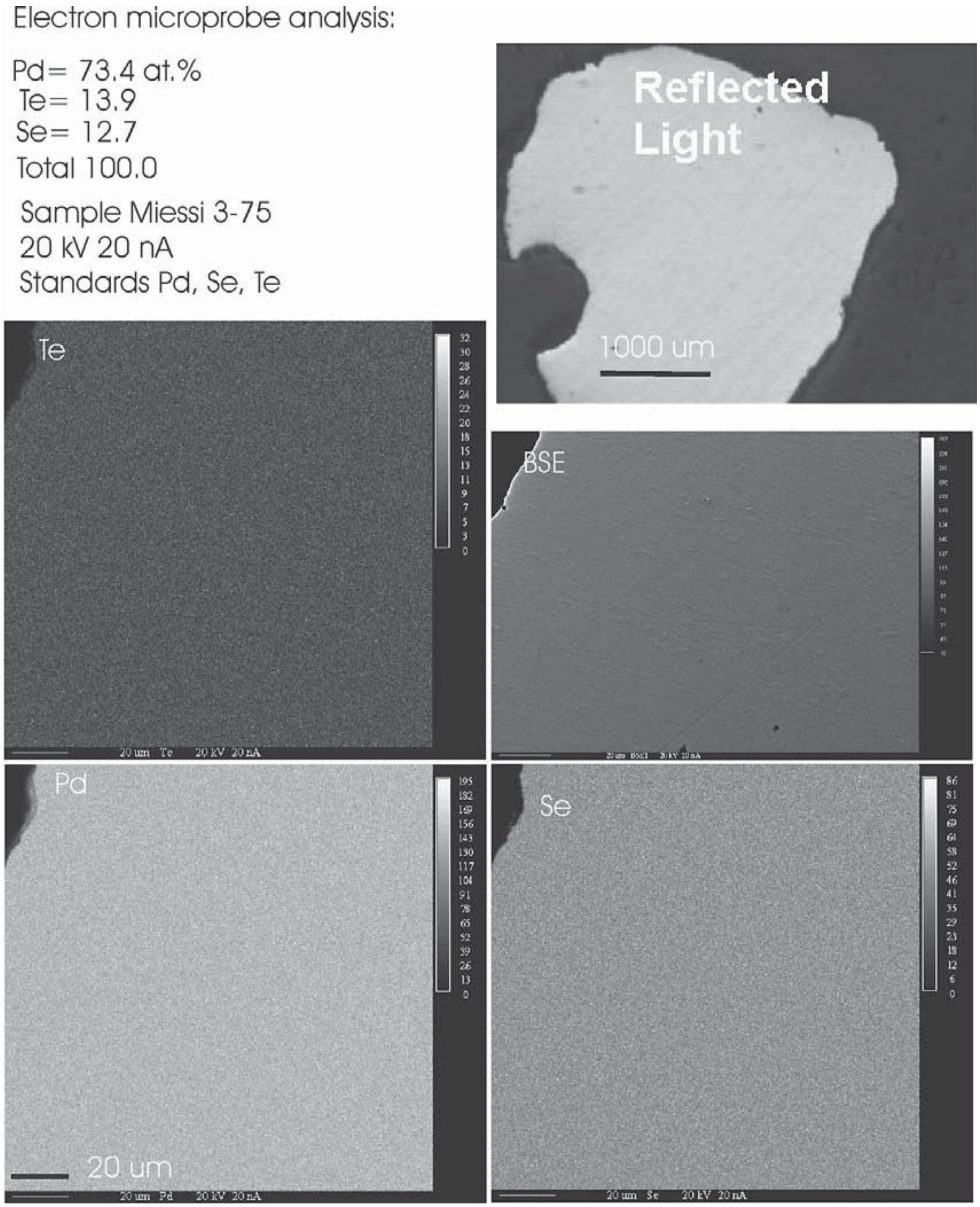

FIG. 2. Optical, back-scattered electron image and element-distribution maps of a miessiite grain.

Physical properties

A grain measuring 483 × 522 μm was mounted in epoxy. It is very soft but allowed for perfect micro-indentations made with a 100-g load and a 10-s measurement time. Four successful measurements of VHN gave a range of values, 348–370, and a mean of value 362 kg/mm^2, corresponding to a Mohs hardness of 2–2½. The calculated density, 10.94 g/cm^3, is based on the average empirical formula derived from the results of electron-microprobe analyses and the unit-cell parameter refined from the X-ray powder-diffraction data.

X-ray crystallography

A small fragment of miessiite, dug out from the edge of the only known grain in the polished section, was studied by single-crystal precession methods employing unfiltered Mo radiation. The fragment was mounted such that (110*) is parallel to the dial axis; the following levels were collected: *hk*0 → *hk*3 for 110* ^ *c**. Precession films indicate cubic symmetry, with a measured unit-cell parameter *a* of 12.56 Å. Systematic absences dictate a *F*-centered lattice with *Fd*3*m* (#227) or *Fd*3 (#203) as permissible space-groups. The soft,

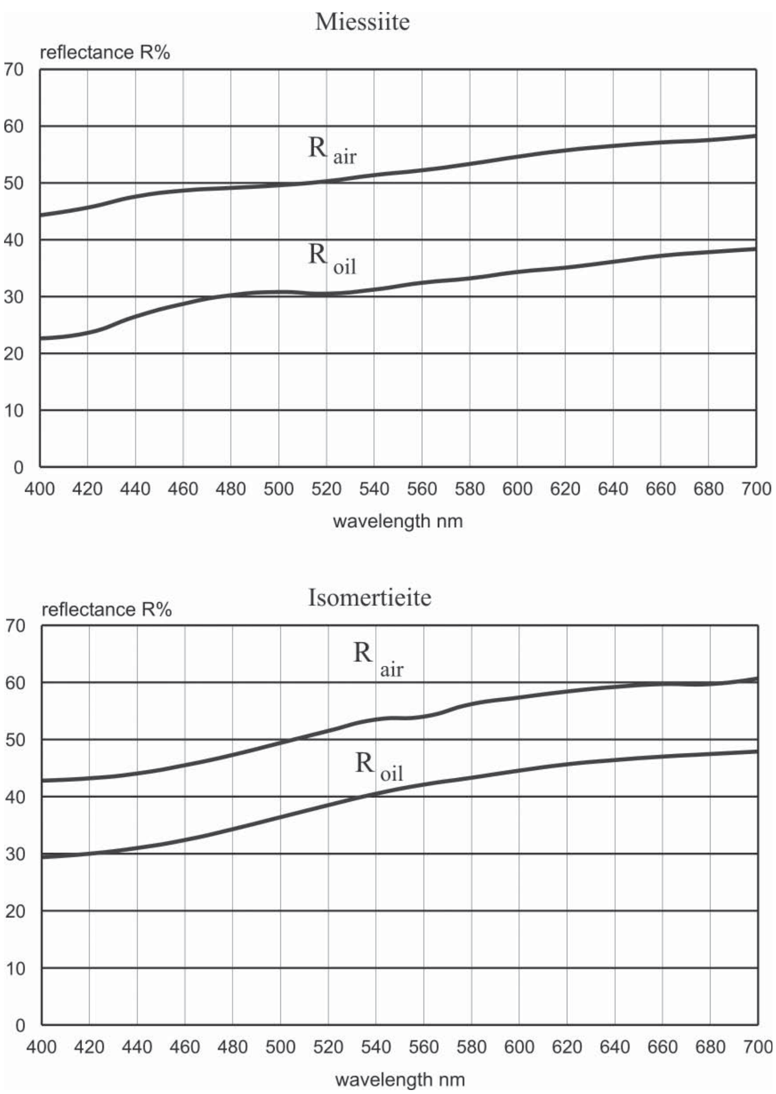

FIG. 3. The reflectance curves of miessiite and isomertieite in air and oil in the range 400–700 nm.

malleable nature of the mineral produced nodes on the precession films, which are streaked and stretched and certainly indicate that this particular fragment is not suitable for crystal-structure analysis.

The refined unit-cell parameter a 12.448(2) Å, V 1929.0(4) Å^3, $Z = 8$, is based on the d values of 16 X-ray powder lines between 2.541 and 1.198 Å for which unambiguous indexing was possible. All possible reflections down to 1.198 Å were visually examined on single-crystal precession films. A fully indexed X-ray powder pattern obtained with a 114.6 mm Debye–Scherrer camera is presented in Table 2. The powder pattern of miessiite is virtually identical to that of isomertieite (laboratory standard), if one takes into account line shifts due to differences in unit-cell dimension; arc intensities are virtually identical for both phases. This certainly supports our contention that miessiite is the Te–Se analogue of isomertieite, and that by analogy, the correct space-group for miessiite is *Fd*3*m* (#227). The PSC (Pearson Symbol Code) is *cF* 120, and assuming that *Fd*3*m* is the correct space-group, it does not have a known prototype structure. The mineral falls within group 2.AC.15 of the Strunz Mineralogical Tables (Strunz & Nickel 2001).

TABLE 2. X-RAY POWDER-DIFFRACTION DATA FOR MIESSIITE AND ISOMERTIEITE

Miessiite

	I est.	*d* meas.	*d* calc.	*hkl*		I est.	*d* meas.	*d* calc.	*hkl*
	5	7.196	7.187	111	*	20	1.467	1.467	660, 822
	5	3.739	3.753	311	*	15	1.437	1.437	555
	5	3.612	3.593	222	*	20	1.427	1.428	662
	5	2.844	2.856	331		5	1.393	1.392	840
*	20	2.543	2.541	422		3	1.367	1.366	911, 753
*	80	2.395	2.396	511, 333	*	20	1.358	1.358	842
*	100	2.197	2.201	440		3	1.327	1.327	664
*	20	2.072	2.075	442	*	25	1.305	1.305	931
	10	1.966	1.968	620	*	30	1.271	1.271	844
	5	1.901	1.898	533	*	20	1.252	1.251	933, 771, 755
*	25	1.875	1.877	622		5	1.221	1.221	$\underline{10}$20, 862
	5	1.741	1.743	711, 551	*	20	1.204	1.203	773, 951
*	20	1.620	1.621	553	*	20	1.198	1.198	$\underline{10}$22
*	25	1.555	1.556	800					

114.6 mm Debye–Scherrer powder camera using Ni-filtered Cu radiation (λ Cu$K\alpha_1$ = 1.54178 Å). Intensities estimated visually. Not corrected for shrinkage, and no internal standard was used. *: lines used for unit-cell refinement. Indexed on a cell with a = 12.448(2) Å. Values of d are expressed in Å.

Isomertieite $Pd_5(As_{0.5}Sb_{0.5})_{\Sigma 2}$

I calc.	*d* meas.	*hkl*	I calc.	*d* meas.	*hkl*
25	7.0899	111	22	1.447	822
9	3.7026	311	10	1.4180	555
10	3.5449	222	5	1.4086	662
4	2.8172	331	1	1.3479	840
19	2.5066	422	1	1.3399	911
52	2.3633	511	1	1.3399	842
100	2.1708	440	1	1.3091	664
19	2.0467	442	8	1.2873	931
20	1.9416	620	27	1.2533	844
12	1.8727	533	13	1.2342	771
41	1.8513	622	2	1.2042	$\underline{10}$20
8	1.7195	551	8	1.1872	773
5	1.6410	642	14	1.1816	$\underline{10}$22
5	1.5350	800			

Pd 73.01, As 10.28, Sb 16.71 wt.%; Shi, N., Ma, Z., Zhang, N. & Ding, X. (1978): *Kexue Tongbao* **23**, 499. Calculated from ICSD using POWD–12++, PDF #00-026-0833, a 12.28 Å, V 1851.8 Å^3, Z = 16; Last modification dated 01/29/2005. Cu radiation (Cu$K\alpha$ = 1.54056 Å). Values of d are expressed in Å.

Chemical composition

Quantitative electron-microprobe analyses of miessiite were performed with a Cameca SX–100 electron microprobe, with an operating voltage of 20 kV, a beam current of 20 nA, and a beam-spot diameter of 1 μm. We used as standards the elements Se, Pd and Te. A TAP analyzing crystal was used for Se$L\alpha$, and a PET analyzing crystal was used for Pd$L\alpha$, and Te$L\beta$. Counting on times peaks were 20 s, with 10 s for the background. The electron-microprobe data for miessiite are given in Table 3.

The average results of 16 analyses yield Pd 75.17, Te 17.06, Se 9.61, for a total of 101.84 wt.%, corresponding to $Pd_{11.02}Te_{2.09}Se_{1.90}$ (Table 3) based on a 15 atoms per formula unit. The idealized formula is $Pd_{11}Te_2Se_2$, which requires Pd 73.91, Te 16.11, Se 9.97, total 100.00 wt.%.

Discussion

Miessiite, characterized as a new mineral species, is ideally $Pd_{11}Te_2Se_2$. In the binary system Se–Te, the (Se,Te) compound is stable below 221°C and 449.57°C, which represent the melting points of Se and Te, respectively (Ghosh *et al.* 1994). In the system Pd–Se, there is an eutectic point for the compound $Pd_{34}Se_{11}$ at 385°C. According to experimental results, Se replaces Te in the Pd–*B*–Te compounds (El-Boragy & Schubert 1971), where *B* stands for Sb, As, Bi, and Se. No experimental results have been found for the synthetic $Pd_{11}Te_2Se_2$, but replacing half of the Se atoms by Te in the phase $Pd_{34}Se_{11}$ would lead to a formula $Pd_{34}Se_{5.5}Te_{5.5}$, which is close to the composition of miessiite multiplied by three ($Pd_{33}Te_6Se_6$). The increase of Te replacing Se

TABLE 3. ELECTRON-MICROPROBE DATA FOR MIESSIITE

	Average n = 16	Range	Standard deviation	Microprobe standard
Pd wt.%	75.17	74.41 - 75.56	0.29	Pd
Te	17.06	16.78 - 17.39	0.19	Te
Se	9.61	9.49 - 9.73	0.06	Se
Total	101.84	100.87 - 102.33	0.36	

Cameca SX–100 electron microprobe, accelerating voltage 20 kV, beam current 20 nA, beam diameter 1 μm. Empirical formula: $Pd_{11.02}Te_{2.09}Se_{1.90}$, calculated on basis of 15 atoms per formula unit.

probably makes the upper temperature of stability higher, close to 400°C.

Miessiite is isostructural with isomertieite $Pd_{11}Sb_2As_2$. The reflectance values of miessiite in air are higher in the low-wavelength area but about the same as those of isomertieite in high-wavelength area. The reflectance values of miessiite in oil are lower than those of isomertieite (Table 1, Fig. 3). The average VHN of miessiite, 362 kg/mm^2, is lower than the VHN of isomertieite, 592 kg/mm^2. The *d* values are slightly shifted from those of isomertieite. The lattice constant *a* is 12.56 Å for miessiite and 12.28 Å for isomertieite. Based on the atomic radius of Sb (161 pm), Te (137 pm), As (121 pm) and Se (117 pm), it is reasonable to assume that Te replaces Sb and Se replaces As in the structure of miessiite, in comparison with that of isomertieite. Miessiite, isomertieite, mertieite-II, vincentite and stillwaterite belong to group 2.AC, "Alloys of metalloids with platinum-group elements" in the Strunz Mineralogical Tables (Strunz & Nickel 2001).

The empirical formula, based on the average results of 16 electron-microprobe analyses and fifteen atoms per formula unit, is $Pd_{11.02}Te_{2.09}Se_{1.90}$. Miessiite is not the only Pd–Se compound in the area; grains of palladseite, $Pd_{17}Se_{15}$, have been discovered in the Puskuoja River about 3 km southeast from Miessijoki. It is probable that the Pd selenide, selenotelluride and arsenobismuthide nuggets were not transported over a great distance; their source must be a nearby mafic–ultramafic intrusion in the host granulite. Miessiite, like many associated PGE-bearing tellurides and antimonides, is rather soft, and would not endure long transport and mechanical abrasion in the glaciofluvial processes.

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