The Canadian Mineralogist
Vol. 40, pp. 473-479 (2002)

COARSE-GRAINED CABRIITE FROM NORIL'SK, RUSSIA

GRAHAM C. WILSON§

IsoTrace Laboratory, University of Toronto, 60 St. George Street, Toronto, Ontario M5S 1A7, Canada

JOHN C. RUCKLIDGE

IsoTrace Laboratory, University of Toronto, 60 St. George Street, Toronto, Ontario M5S 1A7, and Department of Geology, University of Toronto, 22 Russell Street, Toronto, Ontario M5S 3B1, Canada

CLAUDIO CERMIGNANI

Department of Geology, University of Toronto, 22 Russell Street, Toronto, Ontario M5S 3B1, Canada

ABSTRACT

Cabriite, ideally Pd_2SnCu, has been reported from five localities worldwide, and was first described in the Noril'sk–Talnakh mining district of northwestern Russia. We summarize previous research on cabriite and provide an additional description. A relatively coarse (0.50 × 0.35 mm) roundish oval grain of cabriite was found in a sulfide–PGM (platinum-group mineral) concentrate from the Noril'sk district. It is surrounded by cubanite and chalcopyrite, which are cut by minor veinlets of galena and flanked by coarse (mm-scale) crystals of sperrylite. The cabriite itself is rather homogeneous, 10 analyses revealing Pt and Sb as the only significant minor elements. It contains on average 4.87 wt.% Pt and 0.82% Sb, and its formula is $(Pd_{1.92}Pt_{0.10})(Sn_{0.95}Sb_{0.03})Cu_{0.99}$. The Pt apparently substitutes for Pd, and Sb to a lesser extent for Sn. The cabriite contains minute (1–6 μm) rounded blebs of a Pt–Sb–Bi phase, bismuthian geversite, $Pt(Sb,As,Bi)_2$, with Sb > Bi and minimal As. Associated phases (cubanite, chalcopyrite, sperrylite) are also rather pure and homogeneous, with the exceptions of talnakhite and cubanite exsolved from chalcopyrite and the compositional diversity of abundant Au–Ag alloy. Thus the cabriite has a partial rim of native silver (<1 wt.% Au), indistinguishable from silver that infills a brittle fracture in the margin of adjacent coarse sperrylite, yet quite distinct from nearby coarse zoned aurian silver (1.5–24 wt.% Au). Textural features of the sample are compared to published data, affirming a late-stage origin for cabriite and associated Au–Ag alloy.

Keywords: platinum-group minerals, mineral chemistry, electron-microprobe analysis, cabriite, sperrylite, cubanite, talnakhite, chalcopyrite, native silver, Au–Ag alloy, Noril'sk–Talnakh, Russia.

SOMMAIRE

La cabriite, dont la composition idéale est Pd_2SnCu, n'a été signalée qu'à cinq endroits au monde depuis sa découverte dans le camp minier de Noril'sk–Talnakh, dans le nord-ouest de la Russie. Nous résumons les découvertes antérieures à propos de la cabriite, et nous fournissons une description additionnelle d'un cristal relativement grossier (0.50 × 0.35 mm) de forme ovale, découvert dans un concentré de sulfures et de minéraux du groupe du platine provenant du district de Noril'sk. Ce grain est entouré de cubanite et de chalcopyrite, recoupées par des veinules éparses de galène et, en bordure, des cristaux millimétriques de sperrylite. Le grain de cabriite est sensiblement homogène, les résultats de dix analyses démontrant que le Pt et le Sb sont les seuls éléments mineurs d'importance. La cabriite contient, en moyenne, 4.87% de Pt et 0.82% de Sb (base pondérale). Sa formule est $(Pd_{1.92}Pt_{0.10})(Sn_{0.95}Sb_{0.03})Cu_{0.99}$. Le Pt occupe le site Pd, et le Sb remplace le Sn, quoiqu'à un degré moindre. La cabriite contient de très petits domaines (1–6 μm) arrondis de géversite bismuthifère, $Pt(Sb,As,Bi)_2$, ayant Sb > Bi, et contenant l'arsenic en très petites quantités. Lui sont associés cubanite, chalcopyrite, et sperrylite, qui sont aussi assez pures et homogènes; la talnakhite et la cubanite exsolvées de la chalcopyrite sont moins homogènes, et l'alliage Au–Ag, abondant, est assez variable dans sa composition. Le grain de cabriite possède un liseré partiel d'argent natif (<1% Au, en poids), non distinguable de l'argent qui remplit une fracture cassante à la bordure du crystal adjacent de sperrylite, mais assez distinct de l'argent aurifère avoisinant à grain grossier (1.5–24% Au, par poids). Les relations texturales de l'échantillon, comparées aux descriptions déjà dans la littérature, confirment la formation tardive de la cabriite et de l'alliage associé à Au–Ag.

(Traduit par la Rédaction)

Mots-clés: minéraux du groupe du platine, composition, analyses à la microsonde électronique, cabriite, sperrylite, cubanite, talnakhite, chalcopyrite, argent natif, alliage Au–Ag, Noril'sk–Talnakh, Russie.

§ *E-mail address*: turnstone@heydon.com

Historical Introduction

Cabriite, of ideal formula Pd_2SnCu, was formally described and named by Evstigneeva & Genkin (1983). It has been described at only five localities worldwide (the Noril'sk–Talnakh ore district, the Bushveld, Duluth and Muskox complexes, and Thetford Mines), accounting for the limited number of citations in English-language publications. The Noril'sk–Talnakh ore junction remains the principal locality for cabriite: all English-language references known to the authors are cited in the present note; additional material is available in Russian, including early Russian observations from Noril'sk (Razin *et al.* 1975, Cabri 1981; see also Cabri 1976, 1984), which predate its acceptance as a mineral species in 1983. Linguistic limitations prevent us from reviewing the original literature in detail, but the scope of the predominant Russian studies of Noril'sk minerals and orebodies can be found in the text and bibliographies of Yushko-Zahkarova *et al.* (1970), Razin *et al.* (1975), Genkin *et al.* (1982), Distler *et al.* (1988, 1993), and Duzhikov *et al.* (1992).

For the record, there are 17 primary references on cabriite to which we have access, excluding standard mineral catalogues; in addition to the ones already mentioned, these are: Corrivaux & Laflamme (1989, 1990), Sluzhenikin (1991), Rudashevsky & Avdontsev (1992), Rudashevsky *et al.* (1992), Criddle & Stanley (1993), Barnes & Francis (1995), Saini-Eidukat *et al.* (1996), McSwiggen (1998) and Barkov *et al.* (2000a, b).

The Type-Locality Cabriite

Cabriite was first described in detail from the Oktabr'sky deposit in the Noril'sk–Talnakh camp; it forms 200 μm grains associated with sperrylite and other PGM, talnakhite, cubanite, magnetite and other ore minerals (Evstigneeva & Genkin 1983). Cassiterite may occur with cabriite in galena–chalcopyrite vein-ores, with or without other Sn-rich phases such as stannite (Evstigneeva & Genkin 1983).

The (Cu,Pd)-rich nature of certain zones and styles of mineralization at Noril'sk has been described in detail (see, for example, Razin *et al.* 1975, Genkin *et al.* 1982, Distler *et al.* 1993, Naldrett *et al.* 1996, Naldrett & Lightfoot 1999, and references therein). The occurrence of Pd_2SnCu as a discrete phase had been suggested in the 1970s by Russian investigators of the Noril'sk–Talnakh district, as summarized by Cabri (1981, p. 183, 186). Most convincing was unknown mineral UN1973–13, forming anhedral grains typically 40–80 μm in size, usually polysynthetically twinned, with Cu sulfides and magnetite, other PGM, Au–Ag alloys, valleriite, galena and sphalerite. Sluzhenikin (1991) noted that relatively S-poor Noril'sk ores contain a range of PGM including tetraferroplatinum (PtFe) as well as taimyrite, cabriite and other phases rich in Pd ± Pt, Cu ± Sn, Pb ± Bi.

Razin *et al.* (1975) provided a detailed review of the distribution and mineralogy of the PGE in the Noril'sk–Talnakh district, and described associations of PGM diagnostic of the various types of ores. Massive Cu ores and associated Cu veins are dominated by intermetallic phases of Pd–Cu–Pt–Sn and Pd–Pb–Bi compositions. In the Cu-rich southwestern part of the Talnakh deposit, PGM commonly occur as intergrowths of three or four, and as many as nine precious-metal species, including native gold and silver. PGM containing Sn and Pb are seen early in the paragenesis, whereas arsenides such as sperrylite are late. Sperrylite (Razin *et al*. 1975, p. 48) forms single crystals up to 4 mm in size, averaging 15–20 μm, and occurs in intergrowths with other PGM. Cabriite occurs as grains 2 μm to 4 mm in size, averaging 40–80 μm, and in intergrowths 10 μm to 6 mm wide, averaging 100–200 μm. The cabriite is associated with chalcopyrite, talnakhite, magnetite and gangue, valleriite, galena and sphalerite, and with other PGM plus Ag-bearing auricupride (cubic Cu_3Au), native silver and aurian silver.

The Sample

The material described here is a coarsely crushed concentrate with numerous lustrous millimetric angular crystals of sperrylite of variable habit in bronze-colored sulfides. Talnakh is famed for extremely coarse sperrylite (see, for example, the aforementioned Russian literature, and also Wilson *et al.* 2000, p. 32). The cabriite (Fig. 1) was found in a polished mount revealing a complex assemblage of Cu sulfides and precious-metal minerals. The sample was obtained by the first author as reference material ("sperrylite in Cu sulfides from Noril'sk", GCW sample 1571) from mineral dealer David New in October 1993.

Electron-Microprobe Analysis

Ideally, stoichiometric cabriite contains 53.87 wt.% Pd plus 30.05% Sn and 16.08% Cu. Initial examination of the crystal selected for study with energy-dispersion electron-probe microanalysis (EDS EPM) indicated a mineral rich in Pd and Cu, with other rare minerals in a matrix dominated by Cu–Fe sulfides. A wavelength-dispersion (WDS) scan using the Cameca SX–50 microprobe at the Department of Geology, University of Toronto, confirmed the major elements and possible overlaps. The cabriite was analyzed for nine elements with a focused (1–2 μm) electron beam at an accelerating voltage of 20 kV, and a current of 30 nA. Reference materials were chalcopyrite (Cu, Fe and S), pentlandite (Ni), and CANMET materials PtSn (Cabri–476, niggliite, for Pt and Sn) and $Pd_5(As,Sb)_2$ (Cabri–346, isomertieite, for Pd, As, Sb). $L\alpha$ lines were measured for Pd, Sn, Sb (PET crystal) and Pt (LiF crystal), and $K\alpha$ lines were employed for the other elements on two

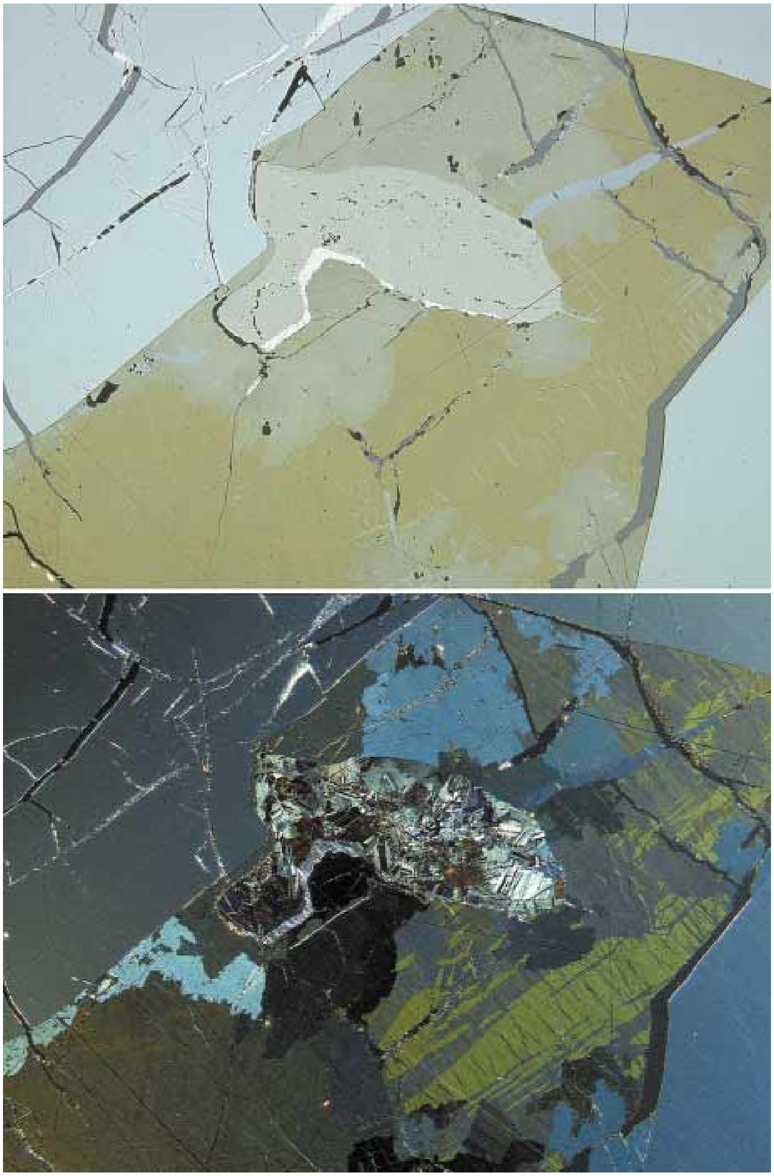

FIG. 1. Photomicrograph showing the ovoid grain of cabriite with a partial rim of native silver in a matrix of proximal brownish cubanite, with sparing contact to tawny chalcopyrite, which contains minor exsolution-induced blebs of Ni-bearing talnakhite. The Cu–Fe sulfides are cut by a thin galena-filled fracture (upper right quadrant). The assemblage is surrounded on three sides by coarse, millimetric crystals of sperrylite. Also adjacent to sperrylite; anhedral wisps of galena (bottom left) and wedge-shaped native silver (upper left). The cabriite contains a fine speckling of minute PGM (geversite) inclusions. Magnification 80×, width of field of view 1.2 mm, as seen in plane-polarized (above) and cross-polarized (below) reflected light.

LiF crystals (except for S, PET). The microprobe data are presented in Table 1.

Mineral Chemistry

Ten analyses were made across the cabriite crystal, from the core to within 20 μm of the margins: we found no sign of zoning. The cabriite grain contains 50.07–51.37 wt.% Pd, 27.93–28.26% Sn, 15.46–15.68% Cu, 3.86–6.01% Pt and 0.42–0.96% Sb, and erratic traces of As (≤0.20%) and Ni (≤0.14%). The mean composition is close to 50.7% Pd, 28.1% Sn and 15.5% Cu, with 4.9% Pt and 0.8% Sb. Expressed as a percentage of the mean, the standard deviations for Sn and Cu are 0.4%, and for Pt, 0.8%. The Cu content is particularly constant (mean 15.56 ± 0.12%, $2\sigma_{n-1}$, $n = 10$). Some published compositions of cabriite include high Pt values, up to 13.8% (Rudashevsky *et al.* 1992), 7.1% (Evstigneeva & Genkin 1983) and 6.6% (Barnes & Francis 1995). The principal variation in composition appears to be the substitution of Pt for Pd (Fig. 2). Back-scattered-electron imaging of cabriite reveals tiny (0.5 to 6 μm) roundish inclusions of very high mean atomic number: a semiquantitative analysis yields 40% Pt, 40% Sb and (by difference) 20% Bi, consistent with bismuthian geversite, essentially $Pt(Sb,Bi)_2$. The literature indicates that a range of PGM commonly occur with cabriite, including such phases as geversite and froodite ($PdBi_2$). Published results of cabriite analyses indicate as much as 0.5–2% Ag (Evstigneeva & Genkin 1983) and, in some cases, minor amounts of other elements, such as Fe and Ni. The grain illustrated is relatively close to the ideal composition, although the mineral may, in a wider context, show solid solution toward a related phase, taimyrite, $Pd_9Cu_3Sn_4$ (Barkov *et al.* 2000a, b).

Analyses of the adjacent sperrylite and the host minerals, granular cubanite and chalcopyrite, indicate homogeneity in each of these minerals (exclusive of exsolution features, such as fine lamellae of talnakhite and cubanite in chalcopyrite). The exsolved cubanite is more anisotropic than its chalcopyrite host, and up to 1000 × 125 μm in section. The coarse, subhedral crystals of sperrylite, up to 4.5 mm in diameter, display a thin, smooth rim around an interior mottled on a scale of 2–10 μm (Fig. 1). This unusual texture is a polishing artifact, as suspected from the constancy of the microprobe data and lack of obvious precedents (*cf.* Ramdohr 1980). Re-polishing removed the pockmarked surface and restored the usual smooth appearance of sperrylite (*cf.* Fig. 1 and the cover of this issue, from a photo taken subsequent to re-polishing).

EDS spectra indicate that the partial rim on cabriite is nearly pure native silver, whereas the 40-μm-wide grey veinlet in Figure 1 is confirmed as galena (a series of WDS EPM analyses along this veinlet did not reveal any rare elements in the Pb sulfide, thus Se content is below the nominal detection-limit of 0.15 wt.%). WDS analysis of the Au–Ag alloy in the sample reveals striking chemical diversity within an essentially pure bimetallic alloy of variable fineness, expressed using weight percent values as 1000 × [Au/(Au + Ag)]. The sickle-shaped rim on cabriite and the wedge-shaped fracture-

TABLE 1. ELECTRON-MICROPROBE DATA: PGM AND SULFIDES

Point	Fe	Cu	Sn	Ni	Pt	Pd	Sb	As	S	Total
					Cabriite					
cab-01	-	15.46	28.09	-	4.75	50.95	0.89	-	-	100.14
cab-02	-	15.48	28.26	-	5.10	50.58	0.81	-	-	100.23
cab-03	-	15.58	27.98	-	5.52	50.27	0.84	-	-	100.19
cab-04	-	15.68	28.15	-	4.40	51.04	0.78	-	-	100.05
cab-05	-	15.53	28.07	-	3.86	51.37	0.85	-	-	99.67
cab-06	-	15.60	28.09	-	5.10	50.70	0.85	0.20	-	100.54
cab-07	-	15.49	27.93	-	5.03	50.36	0.90	-	-	99.71
cab-08	-	15.63	28.14	-	4.19	51.15	0.96	-	-	100.07
cab-09	-	15.55	28.02	0.14	4.70	50.71	0.94	-	-	100.05
cab-10	-	15.57	28.22	-	6.01	50.07	0.42	-	-	100.29
					Cabriite: atomic percent					
cab-01	-	24.55	23.89	-	2.46	48.33	0.74	-	-	99.97
cab-02	-	24.57	24.00	-	2.63	47.93	0.67	-	-	99.80
cab-03	-	24.75	23.81	-	2.86	47.71	0.70	-	-	99.83
cab-04	-	24.81	23.85	-	2.27	48.23	0.64	-	-	99.80
cab-05	-	24.61	23.81	-	1.99	48.62	0.70	-	-	99.73
cab-06	-	24.65	23.77	-	2.63	47.85	0.70	0.27	-	99.87
cab-07	-	24.65	23.79	-	2.61	47.85	0.75	-	-	99.65
cab-08	-	24.72	23.83	-	2.16	48.33	0.79	-	-	99.83
cab-09	-	24.65	23.78	0.23	2.43	48.00	0.78	-	-	99.87
cab-10	-	24.77	24.04	-	3.12	47.58	0.35	-	-	99.86
					Sperrylite					
spe-11	-	-	-	-	57.04	-	-	42.39	0.18	99.61
spe-12	-	-	-	-	56.99	-	-	41.35	0.16	98.50
spe-13	-	-	-	-	56.81	-	0.09	41.19	0.17	98.26
spe-14	-	-	-	-	56.66	-	0.11	41.19	0.39	98.36
spe-15	-	-	-	-	56.85	-	0.07	40.50	0.44	97.79
					Cubanite					
cub-16	40.59	23.72	-	-	-	-	-	-	35.55	99.86
cub-18	40.73	23.55	-	0.12	-	-	-	-	35.38	99.78
cub-19	40.00	23.34	-	-	0.40	-	-	0.43	35.66	99.84
cub-20	40.52	23.80	-	-	-	-	-	-	35.42	99.74
					Chalcopyrite					
ccp-22	30.29	34.71	-	0.27	-	-	-	-	34.64	99.91
ccp-23	30.16	34.89	-	0.28	-	-	-	-	34.37	99.70
ccp-25	30.46	34.57	-	0.24	-	-	-	-	34.37	99.64
ccp-28	30.60	34.70	n.a.	0.32	n.a.	n.a.	n.a.	n.a.	34.66	100.27
ccp-29	30.65	34.76	n.a.	0.21	n.a.	n.a.	n.a.	n.a.	34.47	100.09
					Talnakhite					
tal-24	29.15	36.84	-	0.81	-	-	-	-	32.97	99.76
tal-30	29.11	36.70	n.a.	0.72	n.a.	n.a.	n.a.	n.a.	32.68	99.21
tal-31	29.91	35.51	n.a.	0.41	n.a.	n.a.	n.a.	n.a.	33.95	99.78
tal-32	29.43	36.08	n.a.	0.60	n.a.	n.a.	n.a.	n.a.	33.51	99.62
					Estimated MDLs					
	0.083	0.157	0.172	0.100	0.258	0.339	0.068	0.141	0.145	

All values in weight percent, except for the estimate of atomic proportions in cabriite. Routine, conservative 3σ (99%) minimum detection-limits (MDLs) are indicated: relatively high values for Pd, for example, reflect short counting times on peak and background. Analysis cub-19, of the cubanite re-entrant between sperrylite and cabriite, has probably gathered some Pt and As signal from the nearby $PtAs_2$. n.a.: not analyzed.

TABLE 2. REFLECTANCE DATA: CABRIITE

nm	R_2%	R_1%	R_2%	R_1%	nm	R_2%	R_1%	R_2%	R_1%
400	40.23	40.54	40.11	40.47	560	49.53	46.82	49.16	46.44
420	40.87	41.42	40.91	41.36	580	51.28	47.94	50.90	47.69
440	41.79	41.80	41.47	41.87	590	52.28	48.76	51.81	48.44
460	42.73	42.25	42.52	42.12	600	53.34	49.51	53.02	49.26
470	43.41	42.70	43.07	42.59	620	55.67	51.44	55.22	51.16
480	44.11	43.15	43.93	42.88	640	58.07	53.57	57.65	53.11
500	45.49	44.03	45.18	43.74	650	59.34	54.58	58.89	54.28
520	46.81	44.84	46.44	44.59	660	60.79	55.81	60.15	55.44
540	48.20	45.84	47.89	45.54	680	63.03	58.20	62.60	57.56
550	48.89	46.36	48.56	46.06	700	66.17	60.79	64.52	60.15

Two pairs of spectra determined in air with a Zeiss MPM 800 microscope spectrophotometer. Reflectance standard used: WTiC (Zeiss 314). 50× objective, effective N.A. 0.28. Each spectrum is an average of five scans. Target diameter: 10 μm.

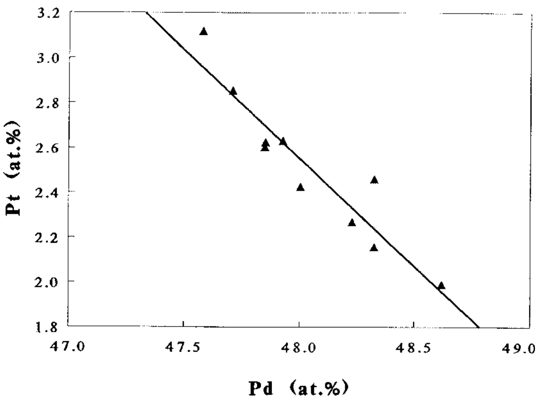

FIG. 2. Plot of Pt *versus* Pd contents for ten points on the cabriite grain. The data indicate 1:1 atomic substitution of Pt for predominant Pd (a mass ratio of 1.83 parts Pt per 1 part Pd).

filling in adjacent sperrylite (Fig. 1) are indistinguishable (respective mean fineness, based on five points per target, ranges from 3 to 7 for the rim and from 3 to 9 for the filling, overall mean fineness of 5). In contrast, a large horseshoe-shaped mass of silver-rich alloy was examined on the opposite flank of the sperrylite from the cabriite. The mass, approximately 1.8 mm wide and 0.6 mm thick, is strongly zoned, not from core to rim but from one end to the other, the fineness ranging from 15 to 240 (average 120, $n = 25$). The composition of this alloy is Au-poor relative to typical "electrum", and is termed aurian silver here [grains of alloy near 200 fine have been referred to as "kustelite", *e.g.*, Ramdohr (1980, p. 321), Razin *et al.* (1975)]. Gold–silver alloys appear to be common within (Pd,Sn,Cu)-enriched ores at Noril'sk, which comprise a rich repository of rare minerals such as cabriite and the tatyanaite–taimyrite solid-solution series (Barkov *et al.* 2000a, b).

OPTICAL PROPERTIES

The cabriite grain has a pinkish brown body color, and in crossed polars exhibits crinkly, strongly developed lamellar twinning, with consequently patchy extinction, and strong anisotropy in deep steel-blue to brown tones, with scratches appearing bright near the extinction position, as with many alloys and native metals. The reflectance of the cabriite was measured at the Natural History Museum, London, using a computer-interfaced standard technique (Criddle 1998). The mount was re-polished immediately prior to the measurement. A small area was selected, which appeared relatively unaffected by the ubiquitous polysynthetic twinning in the cabriite. The analyzed area lies within the silver-rimmed prominence visible at the lower left of the grain in Figure 1. A summary of reflectance data for the cabriite in air is presented in Table 2, and the corresponding spectra are plotted in Figure 3. The absolute values are in good agreement (±1–3%) with the two datasets presented by Criddle & Stanley (1993, p. 67-68).

ORE TEXTURES AND ASSOCIATIONS

The small sample is composed of massive sulfide ore dominated by Cu–Fe sulfides (chalcopyrite and lesser cubanite and talnakhite) plus coarse crystals of sperrylite, with minor magnetite and galena, plus accessory pentlandite, cabriite, native silver, aurian silver and geversite, with minor veinlets of magnetite and galena. It appears to be a magmatic sulfide ore, modified by subsequent exsolution, fracturing and veinlet emplacement. A tentative, partial paragenesis, for this sample alone, is as follows, based on general observations of ore textures. The most plausible interpretation involves early segregation of magnetite and Fe + Cu ± Ni sulfides, and later exsolution of additional cubanite and talnakhite lamellae from chalcopyrite. Coarse, locally euhedral but commonly embayed, subhedral sperrylite grew within the Fe–Cu–Ni sulfide matrix, rarely enclosing earlier magnetite but not the sulfides.

The cabriite in Figure 1 closely abuts yet appears not to touch coarser sperrylite: it is an anhedral, L-shaped grain with rounded margins, 550 × 350 μm in size, displaying complex irregular, closely spaced lamellar twinning, patchy extinction, and strong deep steel-blue to brown anisotropy. The uniformity of the microprobe data, coupled with the lack of inclusions other than the discrete blebs of geversite, show no evidence of intergrowth with related phases such as Pd_2Sn (Evstigneeva & Genkin 1983, p. 484). The cabriite postdates its host phases, cubanite and chalcopyrite. The latter exsolved minor lamellae of relatively Cu- and Ni-rich talnakhite, and excess Pt was exsolved from cabriite to form geversite. One flank of the coarse mass of aurian

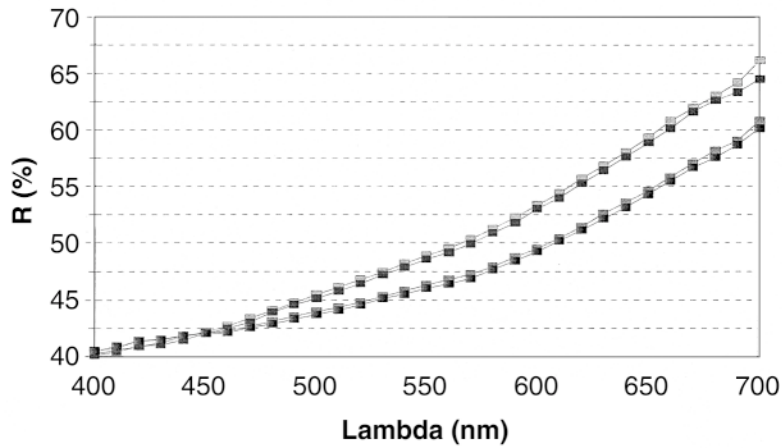

FIG. 3. Reflectance spectra for cabriite, measured in air. See Table 2 for further details.

silver abuts a complex intergrowth of pentlandite, cubanite, galena and chalcopyrite, in which occur small ragged grains of aurian silver: two examples are 75 and 100 fine, suggesting affinity with the coarse silver mass. Silver may in part may have exsolved from earlier sulfide, especially galena. Furthermore, galena adjacent to aurian silver appears to contain 2–6 wt.% Ag in unknown form, perhaps submicroscopic inclusions. A silver peak is clearly visible in EDS spectra of this galena, whereas analyses of the galena veinlet in Figure 1 yield a more normal result, <0.1 wt.% Ag. Finally, discontinuous fracture fillings, veinlets and a rim of nearly pure native silver and galena coated and traversed the earlier minerals. Galena veinlets up to 80 μm wide cut earlier exsolved lamellae of cubanite, and fractures cutting both the galena veining and its Cu sulfide hosts may be lined with magnetite (Fig. 1, upper right corner).

Razin *et al.* (1975, p. 22) noted the presence of veinlets of the Au-poor alloy (aurian silver) and valleriite that corroded all the Pt- and Pd-bearing PGM species. They identified these late veinlets as most probably marking the end of the PGE-bearing paragenesis in the ores at Talnakh.

The mineralogy of the sample is in broad accord with past descriptions of massive sulfides of the Noril'sk–Talnakh camp, and with other occurrences as noted below. Barnes & Francis (1995) analyzed a 0.5-mm grain of cabriite hosted by cubanite, in a cubanite–chalcopyrite association from a massive sulfide lens in the eastern marginal zone of the Muskox complex. Corrivaux & Laflamme (1989, 1990) discovered fine-grained (≤10 μm) Rh- and Sb-rich cabriite in the chromitites of Thetford Mines, as well as a probable Rh analogue, Rh_2SnCu: these Pd- and Rh-rich minerals appear to have formed at a late stage, during serpentinization. A relatively late origin also is indicated for cabriite in the dunite pipes of the Bushveld complex (Rudashevsky & Avdontsev 1992, Rudashevsky *et al.* 1992) in which the rare mineral occurs in a late assemblage, at least partly as micrometric inclusions in tetraferroplatinum. Saini-Eidukat *et al.* (1996) noted that massive pentlandite – cubanite – chalcopyrite ore at Noril'sk may contain PGM such as froodite and cabriite with native silver and the Fe hydroxychloride hibbingite. The latter is also found at the Duluth complex, where McSwiggen (1998) noted both froodite and cabriite in disseminated Ni–Cu sulfide ores of the Minnamax deposit.

In conclusion, the properties of cabriite presented here affirm past observations of this rare PGM species. The cabriite and closely associated minerals, such as gold–silver alloys, are a late-stage assemblage that post-dates the host magmatic sulfides.

ACKNOWLEDGEMENTS

This note was prepared in honor of Louis J. Cabri on the occasion of his retirement from CANMET: the project is modest, but the subject matter and methodology are surely appropriate! Special thanks are due to Alan Criddle and Chris Stanley (Natural History Museum, London) for reflectance measurements and digital photography of the cabriite grain. This discussion was improved by the attentions of two anonymous referees, guest Associate Editor G. Garuti and R.F. Martin.

REFERENCES

BARKOV, A.Y., MARTIN, R.F., POIRIER, G., TARKIAN, M., PAKHOMOVSKII, Y.A. & MEN'SHIKOV, Y.P. (2000a): Tatyanaite, a new platinum-group mineral, the Pt analogue of taimyrite, from the Noril'sk complex (northern Siberia, Russia). *Eur. J. Mineral.* **12**, 391-396.

________, ________, ________ & YAKOVLEV, Y.N. (2000b): The taimyrite – tatyanaite series and zoning in intermetallic compounds of Pt, Pd, Cu, and Sn from Noril'sk, Siberia, Russia. *Can. Mineral.* **38**, 599-609.

BARNES, S.-J. & FRANCIS, D. (1995): The distribution of platinum-group elements, nickel, copper, and gold in the Muskox layered intrusion, Northwest Territories, Canada. *Econ. Geol.* **90**, 135-154.

CABRI, L.J. (1976): New mineral names: fifteen new minerals from the Talnakh deposit. *Am. Mineral.* **61**, 179-182.

________ (1981): Unnamed platinum-group minerals. *In* Platinum-Group Elements: Mineralogy, Geology and Recovery (L.J. Cabri, ed.). *Can. Inst. Mining Metall., Spec. Publ.* **23**, 175-195.

________ (1984): New mineral names. *Am. Mineral.* **69**, 1190.

CORRIVAUX, L. & LAFLAMME, J.H.G. (1989): Minéralogie des éléments du groupe du platine dans les chromitites du complex ophiolitique de Thetford Mines. *Geol. Assoc. Can. – Mineral. Assoc. Can., Program Abstr.* **14**, A48.

________ & ________ (1990): Minéralogie des éléments du groupe du platine dans les chromitites de l'ophiolite de Thetford Mines, Quebec. *Can. Mineral.* **28**, 579-595.

CRIDDLE, A.J. (1998): Ore microscopy and photometry (1890–1998). *In* Modern Approaches to Ore and Environmental Mineralogy (L.J. Cabri & D.J. Vaughan, eds.). *Mineral. Assoc. Can., Short Course* **27**, 1-74.

________ & STANLEY, C.J., eds. (1993): *Quantitative Data File for Ore Minerals* (third edition). Chapman & Hall, London, U.K.

DISTLER, V.V., DYUZHIKOV, O.A. & GENKIN, A.D. (1993): The Talnakh ore field: a copper – nickel – platinum giant. *Geology of Ore Deposits* **35**, 1-13 (in Russ.).

________, GROKHOVSKAYA, T.L., SLUZHENIKIN, S.F., FILIMONOVA, A.A. & LAPUTINA, I.P. (1988): Distribution, mineral composition and zoning of copper–nickel ores. *In* Petrology of Sulphide Magmatic Ore Formation (I.D. Ryabchikov, ed.). Nauka, Moscow, Russia (in Russ.).

DUZHIKOV, O.A., DISTLER, V.V., STRUNIN, B.M., MKRTYCHYAN, A.K., SHERMAN, M.L., SLUZHENIKIN, S.S. & LURYE, A.M., eds. (1992): *Geology and Metallogeny of Sulfide Deposits, Noril'sk Region, U.S.S.R. Soc. Econ. Geol., Spec. Publ.* **1**.

EVSTIGNEEVA, T.L. & GENKIN, A.D. (1983): Cabriite, Pd_2SnCu, a new species in the mineral group of palladium, tin and copper compounds. *Can. Mineral.* **21**, 481-487.

GENKIN, A.D., DISTLER, V.V., GLADYSHEV, G.D., FILIMONOVA, A.A., EVSTIGNEEVA, T.L., KOVALENKER, V.A., LAPUTINA, I.P., SMIRNOV, A.V. & GROKHOVSKAYA, T.L. (1982): *Copper– Nickel Sulphide Ores of the Noril'sk Deposits*. English translation of Russian (1981) original: CANMET report MRP/MSL **82-90(LS)**.

MCSWIGGEN, P.L. (1998): Electron microprobe study of the Pt–Pd and related mineralization in the Minnamax/Babbitt Cu–Ni deposit. *Inst. Lake Superior Geology, Ann. Meet.* **44**(1), 88 (abstr.).

NALDRETT, A.J., FEDORENKO, V.A., ASIF, M., SHUSHEN, L., KUNILOV, V.E., STEKHIN, A.I., LIGHTFOOT, P.C. & GORBACHEV, N.S. (1996): Controls on the composition of Ni–Cu sulfide deposits as illustrated by those at Noril'sk, Siberia. *Econ. Geol.* **91**, 751-773.

________ & LIGHTFOOT, P.C. (1999): Ni–Cu–PGE deposits of the Noril'sk region, Siberia: their formation in conduits for flood basalt volcanism. *In* Dynamic Processes in Magmatic Ore Deposits and their Application to Mineral Exploration (R.R. Keays, C.M. Lesher, P.C. Lightfoot & C.E.G. Farrow, eds.). *Geol. Assoc. Can., Short Course* **13**, 195-249.

RAMDOHR, P. (1980): *The Ore Minerals and their Intergrowths* (second ed.). Pergamon Press, New York, N.Y.

RAZIN, L.V., BEGIZOV, V.D. & MESHCHANKINA, V.I. (1975): Data on mineralogy of platinum metals in Talnakh deposit. *Int. Geol. Rev.* **17**, 6-56.

RUDASHEVSKY, N.S. & AVDONTSEV, S.N. (1992): Petrology and platinum group minerals (PGM) of the Mooihoek and Onverwacht pipes, Bushveld complex. Int. Geol. Congress, 29^{th} (Kyoto), 723 (abstr.).

________, ________ & DNEPROVSKAYA, M.B. (1992): Evolution of PGE mineralization in hortonolitic dunites of the Mooihoek and Onverwacht pipes, Bushveld complex. *Mineral. Petrol.* **47**, 37-54.

SAINI-EIDUKAT, B., RUDASHEVSKY, N.S. & POLOZOV, A.G. (1996): Occurrence of hibbingite in the Duluth complex, Minnesota, and in the Noril'sk complex and Korshunovskoe iron ore deposit, Russia. *Inst. Lake Superior Geology, Ann. Meet*. **42**(1), 53-54 (abstr.).

SLUZHENIKIN, S.F. (1991): Evolution of PGM associations during the postmagmatic stage of the ore forming process in Noril'sk region. *Sixth Int. Platinum Symp*. (*Perth*), *Programme and Abstr*., 47-48.

WILSON, W.E., VAN PELT, H. & VAN PELT, E. (2000): The Joseph A. Freilich collection. *Mineral. Rec.* **31**, 1-80.

YUSHKO-ZAKHAROVA, O.Y., BYKOV, V.P., KULAGOV, E.A., AVDONIN, A.S., CHERNYAYEV, L.A. & YURKINA, K.V. (1970): Isomorphism in the platinum metals. *Geochem. Int.* **7**, 788-796.

Received July 13, 2000, revised manuscript accepted June 24, 2001.