

## KEITHCONNITE, TELLUROPALLADINITE AND OTHER Pd-Pt TELLURIDES FROM THE STILLWATER COMPLEX, MONTANA\*

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### ABSTRACT

Keithconnite,  $\text{Pd}_{3-x}\text{Te}$  ( $0.14 < x < 0.43$ ), and telluropalladinite,  $\text{Pd}_6\text{Te}_4$ , are new minerals from the Stillwater complex, Montana. Under reflected light the color of keithconnite depends on associated minerals: it is cream where isolated, dull cream with a brownish tint with kotulskite and grey next to telluropalladinite. Bireflectance is not detectable in white light, and anisotropism varies from moderate to strong. Reflectance ranges from 44.1% at 470 nm to 51.1% at 650 nm.  $VHN_{15} = 410$  (394-424). Keithconnite crystallizes in space group  $R\bar{3}$ , with hexagonal axes  $a$  11.45(1),  $c$  11.40(1) Å: its strongest powder-diffraction lines are 2.26(10)(214), 2.16(9)(140), 1.32(3)(345), 0.8850(3)(2.10.1), 0.7908(4)(758). Telluropalladinite is cream-colored under reflected light, with a yellowish tint where associated with keithconnite. No bireflectance is detectable in air; it was observed for one grain in oil. Anisotropy is moderate in air and enhanced in oil. Reflectance ranges from 42.5% at 470 nm to 53.1% at 650 nm.  $VHN_{15} = 388$  (376-399). Telluropalladinite is monoclinic, space group  $P2_1/c$  with  $a$  7.45(1),  $b$  13.94(2),  $c$  8.82(2) Å,  $\beta$  91.9°,  $Z = 4$ , and with strongest diffraction lines 2.237(10)(152), 2.133(3)(302), 2.094(4)(322), 1.979(3)(341), 1.403(3)(531), 1.306(5)(2.10.0). Synthetic  $\text{Pd}_6\text{Te}_4$  yields an equivalent powder pattern and has  $D_{\text{meas}} = 10.25$ ,  $D_{\text{calc}} = 10.62$  g/cm<sup>3</sup>. Low-bismuth kotulskite, merenskyite and moncheite from the same samples represent the lowest Bi contents reported for these tellurides: 1.2% for kotulskite, 0.53% for merenskyite, and 0.17% for moncheite.

### SOMMAIRE

La keithconnite,  $\text{Pd}_{3-x}\text{Te}$  ( $0.14 < x < 0.43$ ), et la telluropalladinite,  $\text{Pd}_6\text{Te}_4$  sont deux nouveaux minéraux qui se trouvent dans des échantillons provenant du complexe Stillwater du Montana. En lumière réfléchie, la keithconnite change de couleur suivant le minéral contigu: de couleur crème lorsque isolée, elle passe au crème terne à nuance

brunâtre près de la kotulskite et au gris contre la telluropalladinite. Nulle biréfectance n'est détectable en lumière blanche: l'anisotropie varie de modérée à forte. Le pouvoir réflecteur varie de 44.1% (470 nm) à 51.1% (650 nm).  $VHN_{15} = 410$  (394-424). La keithconnite est rhomboédrique, de groupe spatial  $R\bar{3}$ , avec  $a$  11.45(1),  $c$  11.40(1) Å dans le repère hexagonal. Raies de diffraction X les plus intenses: 2.26(10)(214), 2.16(9)(140), 1.32(3)(345), 0.8850(3)(2.10.1), 0.7908(4)(758). La telluropalladinite est de couleur crème en lumière réfléchie, de nuance jaunâtre en contact avec la keithconnite. Nulle biréfectance n'est décelée dans l'air; observable dans l'huile, on l'a observée sur un grain seulement. L'anisotropie, modérée dans l'air, est renforcée dans l'huile. Le pouvoir réflecteur varie de 42.5% (470 nm) à 53.1% (650 nm).  $VHN_{15} = 388$  (376-399). La telluropalladinite est monoclinique, de groupe spatial  $P2_1/c$  avec  $a$  7.45(1),  $b$  13.94(2),  $c$  8.82(2) Å,  $\beta$  91.9°,  $Z = 4$ . Raies de diffraction X les plus intenses: 2.237(10)(152), 2.133(3)(302), 2.094(4)(322), 1.979(3)(341), 1.403(3)(531), 1.306(5)(2.10.0). Le produit de synthèse  $\text{Pd}_6\text{Te}_4$  possède un diagramme de poudre équivalent;  $D(\text{mes.}) = 10.25$ ,  $D(\text{calc.}) = 10.62$ . Certaines variétés de kotulskite, merenskyite et moncheite, trouvées dans les mêmes échantillons, sont les plus pauvres en bismuth que l'on connaisse: 1.2% Bi pour la kotulskite, 0.53% pour la merenskyite, et 0.17% pour la moncheite.

### INTRODUCTION

Mineralogical studies of rock samples and heavy mineral concentrates from the Banded and Upper zones of the Stillwater complex, Montana, have revealed rich and diverse assemblages of platinum-group minerals (PGM). Some findings have been reported in a series of papers: on the native alloys (Cabri & Laflamme 1974, Cabri & Feather 1975), on some platinum-group arsenides (Cabri *et al.* 1975, 1977), on two palladium-bismuth-arsenic minerals (Cabri *et al.* 1976) and on the platinum-palladium sulfides (Cabri *et al.* 1978). This paper describes the new minerals keithconnite and telluropalladinite, as well as three other

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PG-tellurides. The geology, sample locations and previous work are described or referred to in the aforementioned publications; Conn (1979) described the exploration for and the location of the zones of Pt-Pd-bearing mineralization.

#### NOMENCLATURE AND PRESERVATION OF TYPE MATERIAL

The mineral  $Pd_{3-x}Te$  and the name keithconnite were approved by the Commission on New Minerals and Mineral Names, I.M.A. The mineral is named for Mr. H. Keith Conn, General Technical Manager, Johns-Manville Corporation, whose geological insight and perseverance were largely responsible for the discovery of Pt-Pd mineralization in the Upper and Banded parts of the Stillwater complex, Montana. Polished sections with grains of cotype material, whose analyses are given in Table 2, have been deposited as follows: no. 8 in the U.S. National Museum, Smithsonian Institution (144957), Washington, D.C., no. 10 in the Systematic Reference Series of the National Mineral Collection, Geological Survey of Canada (12187), Ottawa, and no. 9 in the Royal Ontario Museum (M35867), Toronto. Number 11 is preserved in the Crystal Structure Laboratory, CANMET, mounted on a glass fibre.

The mineral  $Pd_6Te_4$  and the name telluropalladinite, after its composition, were approved by the Commission on New Minerals and Mineral Names, I.M.A. Polished sections with grains of cotype material, whose analyses are given in Table 2, have been deposited as follows: no. 1 in the U.S. National Museum, Smithsonian Institution (144958), Washington, D.C., no. 3 in the Systematic Reference Series of the Geological Survey of Canada (12188), Ottawa, and no. 4 in the Royal Ontario Museum (M35867), Toronto. Numbers 2, 5, 6 and 7 are mounted on glass fibres in the Crystal Structure Laboratory, CANMET.

#### ANALYTICAL PROCEDURES

Sample preparation methods and the determination of reflectance, micro-indentation hardness, X-ray and microanalytical data are described in Cabri & Laflamme (1974). In addition, X-ray powder diffraction data for synthetic phases were obtained with a 114.6 mm Debye-Scherrer camera on samples mounted

TABLE 1. SYNTHETIC STANDARDS AND X-RAY LINES USED FOR ELECTRON-PROBE ANALYSES OF Pd-Pt TELLURIDES

x-ray line	keithconnite <sup>†</sup>	kotulskite	moncheite	merenskyite
PdL $\alpha$	Pd <sub>3</sub> Te <sub>4</sub>	PdTe	PdBiTe	Pd <sub>0.9</sub> Ni <sub>0.1</sub> Te <sub>1.9</sub>
PtL $\alpha$	PtSn	PtTe <sub>2</sub>	PtTe <sub>2</sub>	PtTe <sub>2</sub>
NiK $\alpha$	-	Ni****	Ni	Pd <sub>0.9</sub> Ni <sub>0.1</sub> Te <sub>1.9</sub>
TeL $\alpha$	Pd <sub>3</sub> Te <sub>4</sub>	PdTe	PtTe <sub>2</sub>	Pd <sub>0.9</sub> Ni <sub>0.1</sub> Te <sub>1.9</sub>
BiL $\alpha$	Bi	PdBiTe	PdBiTe	PdBiTe
SbL $\alpha$	Pd <sub>5</sub> As <sub>1.5</sub> Sb <sub>0.5</sub> *	-	-	-
SnL $\alpha$	PtSn	-	-	-
PbM $\alpha$	Pd <sub>3</sub> Pb**	Pd <sub>3</sub> Pb	-	-
AsL $\alpha$	InAs***	-	-	-
HgL $\alpha$	Pd <sub>3</sub> HgTe <sub>3</sub>	-	-	-

<sup>†</sup> and telluropalladinite; \* or Pd<sub>5</sub>Sb<sub>3</sub>; \*\* or PbS; \*\*\* or Pd<sub>5</sub>As<sub>1.5</sub>Sb<sub>0.5</sub>; \*\*\*\* or Pd<sub>0.9</sub>Ni<sub>0.1</sub>Te<sub>1.9</sub>.

in a 0.2 mm quartz capillary, as well as with a Guinier-type focusing camera. The X-ray lines and synthetic standards for microprobe analyses are described in Table 1. Syntheses were made using weighed amounts of high-purity elements in evacuated quartz tubes and heated to the appropriate temperatures in furnaces. Various grinding, pelletizing and annealing operations were performed to assure complete reaction and homogeneity.

#### RESULTS

##### Keithconnite $Pd_{3-x}Te$

Four grains of keithconnite have been found; their size in cross-section ranges from 22x38 to 145x220  $\mu$ m. It is associated with kotulskite, telluropalladinite and magnetite but is also

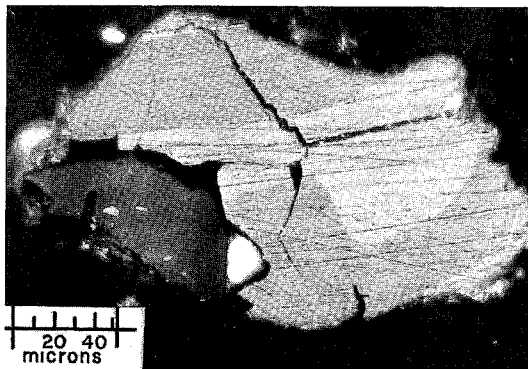


FIG. 1. Keithconnite (darker grey) intergrown with telluropalladinite and with attached magnetite (left). Analyses 9 and 4, respectively, Table 2; R.O.M. No. M35867.

TABLE 2. ELECTRON PROBE ANALYSES OF TELLUROPALLADINITE AND KEITHCONNITE

No.	weight percent									atomic proportions								ΣTe
	Pd	Te	As	Bi	Sn	Sb	Pb	Hg	TOTAL	Pd	Te	As	Bi	Sn	Sb	Pb	Hg	
<b>Telluropalladinite</b>																		
1	64.9	33.9	0.18	0.89	n.d.	n.d.	0.30	n.d.	100.17	8.97	3.91	0.04	0.06	-	-	0.02	-	4.03
2†	65.4	34.1	0.33	0.15	0.07	0.12	n.d.	n.d.	100.17	8.99	3.91	0.07	0.01	0.01	0.01	-	-	4.01
3	64.8	32.2	0.51	2.2	n.d.	n.d.	n.d.	n.d.	99.71	9.01	3.73	0.10	0.16	-	-	-	-	3.99
4	64.7*	31.6	0.61	1.8	n.d.	n.d.	n.d.	0.06	98.82	9.06	3.69	0.12	0.13	-	-	-	<0.01	3.94
5†	64.9	31.4	0.68	2.6	n.d.	n.d.	n.d.	n.d.	99.58	9.04	3.65	0.13	0.18	-	-	-	-	3.96
6†	65.1	33.2	0.63	1.0	n.d.	n.d.	n.d.	n.d.	99.93	8.99	3.82	0.12	0.07	-	-	-	-	4.01
7†	64.6	33.5	0.10	1.5	n.d.	n.d.	n.d.	n.d.	99.70	8.99	3.89	0.02	0.10	-	-	-	-	4.01
<b>Keithconnite</b>																		
8	68.7	29.1	n.d.	1.0	n.d.	n.d.	1.6	n.d.	100.4	18.79	6.64	-	0.14	-	-	0.22	-	7.00
9	68.4**	28.5	0.16	0.54	0.08	n.d.	0.94	0.37	99.02	19.14	6.65	0.06	0.08	0.02	-	0.14	0.05	7.00
10	71.0	14.2	6.7	0.96	5.0	1.4	n.d.	n.d.	99.26	18.04	3.01	2.42	0.12	1.14	0.31	-	-	7.00
11†	68.4	26.3	n.d.	n.d.	4.5	0.23	n.d.	n.d.	99.43	18.30	5.87	-	-	1.08	0.05	-	-	7.00

n.d. = not detected; \* + 0.05 wt.% Pt; \*\* + 0.03 wt.% Pt. † = grains X-rayed. All grains are from sample 789 T-1-1 except Nos. 1 and 8 which are from sample 1824-PP-20. Sample locations described by Cabri *et al.* (1978).

found as a free grain in the heavy-mineral concentrates. In polished section with white light its color is dependent on the associated minerals. Where free, keithconnite is cream; with kotulskite it is dull cream with a brownish tint; it is grey if adjacent to telluropalladinite (Fig. 1). Bireflectance in air is not detectable to the human eye. Anisotropism varies from moderate (grey to extinction) to strong (bluish-grey to extinction). With the analyzer set at 2° off extinction, the colors go from extinction to dark brown. In oil some grains appear more anisotropic and some have brownish tones. Reflectances in air in % (av. of 3 measurements on grain no. 8, Table 2) are: 470 nm 44.1, 42.2; 546 nm 46.4, 43.7; 589 nm 48.2, 45.5; 650 nm 51.1, 48.5. Micro-indentation hardness for five indentations on the same grain gave  $VHN_{15} = 410$  (394–424).

The elucidation of an ideal formula for keithconnite proved to be fraught with difficulties. We believed, initially, that a 5:2 stoichiometry was indicated by our early synthesis experiments, and that the apparent nonstoichiometry was a reflection of difficult analyses, as is often the case for PGM (Cabri 1978). Thus, a generalized formula of  $Pd_{5+x}Te_{2-x}$  was proposed and approved by the I.M.A. Commission on New Minerals and Mineral Names. Other stoichiometries such as 8:3 and 20:7 were considered, but none was completely satisfactory for all four analyses. The electron-probe analyses given in Table 2 were calculated on the basis of 7 Te atoms, *i.e.*,  $\frac{1}{3}[21(Pd_{3-x}Te)]$ . This manner of calculating a formula for keithconnite was chosen because of the crystallographic similarities noted below and for comparison with the composition of telluropalladinite.

Keithconnite was found to be rhombohedral, space group  $R\bar{3}$ , by single-crystal precession; an X-ray powder-diffraction pattern (Table

TABLE 3. X-RAY POWDER DIFFRACTION DATA FOR KEITHCONNITE

$I$	$d_{meas}$	$d_{calc}$	$hkl$	$I$	$d_{meas}$	$d_{calc}$	$hkl$
1	2.74	2.740	104	2	1.27	1.268	354
1	2.49	2.494	033	1	1.20	1.203	535
10	2.26	2.269	214	1	1.18	1.183	039
2	2.22	2.222	015	1	1.077	1.080	176
9	2.16	2.164	140	1	1.039	1.040	283
1	1.87	1.873	502	1	0.9269	0.9255	663
1	1.65	1.647	036	1	0.8939	0.8960	1.5.11
1	1.56	1.566	244	3	0.8850	0.8878	2.10.1
1	1.51	1.510	514	2	0.8675	0.8667	485
1	1.44	1.448	425	2	0.8378	0.8366	5.3.11
2	1.40	1.406	351	2	0.8117	0.8118	0.1.14
2	1.37	1.375	072	4	0.7908	0.7904	758
3	1.32	1.326	345				

57.3 mm Gandolfi camera; Ni-filtered Cu radiation,  $\lambda=1.5405\text{\AA}$ . Analysis no. 11, Table 2. Values of  $d_{calc}$  are based on refinement using cell parameters known to three decimal places.

3) of grain no. 11 was indexed on a hexagonal cell with  $a$  11.45(1),  $c$  11.40(1)Å. Keithconnite has the same space group as synthetic  $Pd_{20}Te_7$  (Wopersnow & Schubert 1977), whose cell dimensions,  $a$  11.797(1) and  $c$  11.172(2)Å are also similar to those of keithconnite. Synthetic  $Pd_{20}Te_7$  contains 3 formula weights *per* unit cell, *i.e.*, 60 Pd atoms and 21 Te atoms. The structure is essentially hexagonal-close-packed with three vacant sites. Thus, a fully occupied unit cell of dimensions comparable to those of keithconnite would contain 63 Pd atoms and 21 Te atoms, with an atomic ratio of exactly 3:1. The electron-probe analyses of keithconnite suggest additional vacancies, accounting for the Pd deficiencies. Grains 8 and 9 seem to have 6 vacancies, *i.e.*, 57 Pd atoms and 21 Te atoms or 3  $Pd_{19}Te_7$ , and grains 10 and 11 appear to have 9 vacancies, *i.e.*, 54 Pd atoms and 21 Te atoms or 3  $Pd_{18}Te_7$ . Both these compositions are possible with space group  $R\bar{3}$ .

The variations in keithconnite stoichiometry (Table 2) may reflect (a) analytical errors, (b) two compositions  $Pd_{19}Te_7$  and  $Pd_{18}Te_7$ , or (c) a range of compositions including these values. These two ideal compositions have atomic ratios of Pd:Te = 2.714 and 2.571, respectively,

straddling that of  $\text{Pd}_8\text{Te}_3$ , where  $\text{Pd}:\text{Te} = 2.667$ . One factor to be considered is the occurrence of telluropalladinite (anal. 4) adjacent to keithconnite (anal. 9, Fig. 1). This should not occur, ideally, because an 8:3 phase has been determined between  $\text{Pd}_{20}\text{Te}_7$  and  $\text{Pd}_8\text{Te}_4$  in the system Pd-Te (work in progress). Therefore, in view of all these uncertainties, the general formula of  $\text{Pd}_{3-x}\text{Te}$ , with  $0.14 < x < 0.43$  and in which Te also includes minor As, Bi, Sb, Sn and Pb, is proposed for keithconnite until better X-ray data become available.

Further detailed work in the partial system Pd-PdTe, not as yet complete, has revealed many complications regarding phase equilibria and identity of phases. We can report, however, that we have been unable to synthesize keithconnite and that currently available phase-equilibrium diagrams on the system Pd-Te (Medvedeva *et al.* 1961, Elliott 1965) are unreliable and require major modifications.

McCallum *et al.* (1976) and Loucks (1978) report an unidentified weakly anisotropic rosetan mineral "Pd phase B" with an indicated stoichiometry of  $\text{Pd}_3(\text{Te},\text{Bi})_2$ . The mineral contains minor Sb and Pt and 13-15 wt. % Bi. Confirmation of the equivalence of the "Pd phase B" with keithconnite, however, must await an X-ray-diffraction study.

#### Telluropalladinite $\text{Pd}_8\text{Te}_4$

In addition to a single intergrowth with keithconnite and magnetite (Table 2, no. 4), seven grains of a second new palladium telluride (telluropalladinite) were also found, as free grains in the concentrates. Telluropalladinite grains range in cross-section from  $27 \times 27$  to  $55 \times 100$  microns. In polished section, with white light, telluropalladinite is cream-colored with a yellowish tint discernible in the grain associated with keithconnite. Bireflectance is not detectable to the human eye in air but was observed for one grain in oil. Telluropalladinite has moderate (grey to extinction) to strong (light brownish-grey to extinction) anisotropy. In oil all the grains are strongly anisotropic. Reflectance was measured in air on three grains (including nos. 2, 4 in Table 2) and the average values in % are: 470 nm 45.2, 42.5; 546 nm 47.7, 45.4; 589 nm 49.5, 47.4; 650 nm 53.1, 51.9. Micro-indentation hardness for grain no. 4 gives  $VHN_{15} = 388$  (376-399) for five indentations;  $VHN_{15} = 302$  (296-308) for another grain.

Electron-probe analyses are given in Table 2

TABLE 4. X-RAY POWDER DIFFRACTION DATA FOR  $\text{Pd}_8\text{Te}_4$  AND TELLUROPALLADINITE

synthetic $\text{Pd}_8\text{Te}_4$				telluropalladinite		
I	dmeas	dcalc	hkl	I	dmeas	dcalc
<1	3.6	3.599	210			
1	3.36	3.372	211			
1/2	3.25	3.241	041	1/2	3.24	3.24
1/2	2.784	2.783	231			
4	2.722	2.718	113	1	2.717	2.713
1	2.661	2.658	113			
7	2.543	2.545	240	2	2.543	2.546
3	2.483	2.483	300			
1/2	2.426	2.430	241			
1/2	2.339	2.339	133	1/2	2.336	2.337
4	2.276*	2.279	321			
4	2.247*	2.246	061			
10	2.237	2.236	152	10	2.237	2.236
5B	2.196	2.197	302	1/2	2.193	2.195
6	2.134	2.134	302	3	2.133	2.133
6	2.094	2.095	322	4	2.094	2.094
1	2.040	2.040	322	1/2	2.043	2.040
5	1.985	1.983	341	3	1.979	1.983
6	1.961	1.960	341	3	1.964	1.960
1/2	1.915	1.916	261	1/2	1.917	1.917
1	1.877	1.876	171	1	1.876	1.877
3	1.861	1.861	323	1	1.856	1.859
1	1.802	1.804	323			
1/2	1.687	1.686	422	1/2	1.685	1.685
2	1.582	1.581	324	1/2	1.584	1.580
1	1.546	1.548	450	1/2	1.542	1.549
3	1.456	1.456	372	2	1.453	1.456
4B	1.394	1.394	531	3	1.403	1.394
2B	1.357	1.356	046	1	1.354	1.354
1/2	1.335	1.337	444			
8B	1.305	1.305	2.10.0	5	1.306	1.306
3	1.245	1.245	1.10.3	2	1.247	1.245
1	1.233	1.232	166	1/2	1.230	1.230
2B	1.218	1.218	127			
2B	1.189	1.188	622	1/2	1.191	1.188
1B	0.9105	0.9101	684	1	0.9111	0.9101
2B	0.9017	0.9016	2.15.0			
3B	0.8896	0.8896	823	1B	0.8850	0.8893
1	0.8833	0.8835	850	1B	0.8833	0.8835
1B	0.8750	0.8752	783	1B	0.8781	0.8751
2B	0.8654	0.8656	6.11.2	1B	0.8652	0.8659
1B	0.8557	0.8556	577	1B	0.8544	0.8550

Both patterns with Ni-filtered Cu radiation,  $\lambda = 1.5405 \text{ \AA}$  except for asterisk reflections measured from another 114.6 mm film exposed to Fe-filtered Co radiation,  $\lambda = 1.7889 \text{ \AA}$ . Synthetic  $\text{Pd}_8\text{Te}_4$  with a 114.6 mm Debye-Scherrer camera. Telluropalladinite, grains 5 & 6, with a 57.3 mm Gandolfi camera. B= broad; dcalc. are based on refinement using cell parameters of three decimal places.

for seven grains, calculated on the basis of 13 atoms. The analysis of an eighth grain is not given because it represented an earlier analysis done prior to synthesis of suitable standards. This grain, unfortunately, was lost during attempts at extraction for X-ray analysis. The ideal formula corresponds to  $\text{Pd}_8\text{Te}_4$  with minor substitutions of Pt for Pd and As, Bi, Sn, Sb, Pb and Hg for Te. The mineral corresponds to synthetic  $\text{Pd}_8\text{Te}_4$  of Matkovič & Schubert (1978), who reported the phase to be monoclinic with  $a$  7.458(1),  $b$  13.938(1),  $c$  8.839(1) Å,  $\beta$  91.97(1)°, space group  $P2_1/c$ . We have confirmed the results of Matkovič & Schubert by synthesis of  $\text{Pd}_8\text{Te}_4$  with  $a$  7.456(6),  $b$  13.936(5),  $c$  8.842(9),  $\beta$  91.94°. Telluropalladinite has  $a$  7.45(1),  $b$  13.95(2),  $c$  8.82(2) Å,  $\beta$  91.9° and its powder pattern compares well with that of synthetic  $\text{Pd}_8\text{Te}_4$  (Table 4). Calculated density for telluropalladinite (average compositions for grains 5 & 6) with  $Z = 4$  is 10.68 g/cm<sup>3</sup>. The measured density for synthetic  $\text{Pd}_8\text{Te}_4$  of 10.25

TABLE 5. ELECTRON PROBE ANALYSES OF KOTULSKITE, MERENSKYITE AND MONCHEITE

No.	weight percent							atomic proportions***							
	Pd	Pt	Ni	Te	Bi	Pb	Total	Pd	Pt	Ni	Σ	Te	Bi	Pb	Σ
1*	44.7	nd	0.04	49.4	2.6	2.7	99.44	1.01	-	<.01	1.01	0.93	.03	.03	0.99
2*	44.8	0.13	0.03	51.9	2.4	0.5	99.76	1.00	<.01	<.01	1.00	0.96	.03	.01	1.00
3 †	44.8	nd	0.08	53.4	1.2	-	99.48	1.00	<.01	<.01	1.00	0.99	.01	-	1.00
4***	28.9	0.46	0.11	69.0	0.53	-	99.00	0.99	.01	1.01	1.98	.01	-	-	1.99
5	nd	43.0	nd	55.0	0.63	-	99.63	-	1.00	-	1.00	1.99	.01	-	2.00
6	5.3	35.1	nd	59.4	0.17	-	99.97	0.21	0.78	-	0.99	2.01	<.01	-	2.01
7	nd	43.4	nd	54.2	2.6	-	100.2	-	1.01	-	1.01	1.93	.06	-	1.99
8**	nd	43.2	nd	54.6	1.6	-	99.4	-	1.01	-	1.01	1.95	.04	-	1.99
9***	nd	43.2	nd	54.8	1.4	-	99.4	-	1.01	-	1.01	1.96	.03	-	1.99

nd=not detected; \*As, Sb nd; \*\*Sb nd; \*\*\*Kotulskite calculated for 2 atoms, merenskyite and moncheite calculated for 3 atoms. Grains 1, 2, 5, 6 from sample 1824-PP-20; grains 3, 4 from sample 1; grain 7 from sample 2; grain 8 from sample 3; and grain 9 from sample 4. All samples come from the West Fork adit of the property worked by Johns-Manville Corporation and are described in Cabri *et al.* (1978) except for sample 3, which is from the olivine column referred to as "MPT". †-grain x-rayed.

g/cm<sup>3</sup> (Berman balance with toluene) compares well with a calculated density of 10.62 g/cm<sup>3</sup>.

### Other Pd-Pt tellurides

Kotulskite (PdTe), merenskyite (PdTe<sub>2</sub>) and moncheite (PtTe<sub>2</sub>) also occur in these samples. Moncheite is the most common PG-telluride found in the sulfide concentrate from the bulk sample (1824-PP-20) and, for the PGM, is next in abundance to the PG-sulfides braggite and vysotskite (Cabri *et al.* 1978). Kotulskite is less common and merenskyite is rare.

It is now well established that all three minerals are stoichiometric and equivalent to the ideal synthetic end-members PdTe, PdTe<sub>2</sub> and PtTe<sub>2</sub>. Analyses reported in the literature for these three tellurides, however, usually contain significant quantities of Bi substituting for Te. Though Bi-rich grains occur in our samples, Bi-poor grains are also present and representative analyses for these are given in Table 5. These analyses record the lowest Bi contents found to date in these tellurides and document the first occurrence of Pb in kotulskite.

The merenskyite analysis in Table 5 shows less Bi than the low-Bi analyses (1.8%) reported by Watkinson *et al.* (1978). The X-ray powder diffraction pattern (Table 6) has better resolution than the pattern of bismuthian merenskyite (six indexed reflections) initially reported by Kingston (1965) but is not as well

TABLE 6. X-RAY POWDER DIFFRACTION DATA FOR MERENSKYITE

I	d <sub>meas</sub>	d <sub>calc</sub>	hkl	I	d <sub>meas</sub>	d <sub>calc</sub>	hkl
10	2.880	2.879	101	1	1.162	1.161	300
7	2.058	2.061	102	4	1.078	1.079	114
9	2.011	2.011	110	1	1.034	1.030	204
2	1.711	1.704	003	2	0.9814	0.9812	105
8	1.648	1.648	201	2	0.9495	0.9495	311
5	1.578	1.580	112	1	0.9036	0.9039	312
3	1.529	1.531	103	1	0.8830	0.8819	205
3	1.435	1.439	202	3B	0.8593	0.8596	304
6	1.272	1.278	211	2B	0.8279	0.8278	106
1	1.220	1.218	203	2B	0.8086	0.8077	215
1	1.171	1.170	212	3B	0.7911	0.7904	224

57.3 mm Gandolfi camera, Ni-filtered Cu radiation, λ=1.5405 Å. Analysis No. 4 in Table 5. B=broad.

TABLE 7. X-RAY POWDER DIFFRACTION DATA FOR MONCHEITE

I	d <sub>meas</sub>	d <sub>calc</sub>	hkl	I	d <sub>meas</sub>	d <sub>calc</sub>	hkl
3	5.22	5.22	001	6	1.092	1.094	114
10	2.895	2.897	101	4	1.049	1.050	213
7	2.089	2.089	102	1	1.004	1.005	220
6	2.010	2.011	110	3	1.000	1.000	105
2	1.880	1.877	111	3	0.9877	0.9876	221
1	1.737	1.740	003	1	0.9665	0.9663	303
5	1.651	1.652	201	3	0.9498	0.9502	311
5	1.555	1.556	103	3	0.9266	0.9267	311
5	1.447	1.449	202	4	0.8958	0.8956	205
1	1.314	1.316	113	5	0.8681	0.8676	304
1	1.304	1.305	004	1	0.8586	0.8591	401
5	1.275	1.276	211	6	0.8452	0.8448	313
3	1.229	1.231	203	2	0.8265	0.8262	402
5	1.173	1.175	212	6	0.8163	0.8162	215
1	1.159	1.161	300	4B	0.7973	0.7967	224
3	1.134	1.133	301	3B	0.7904	0.7901	321

57.3 mm Gandolfi camera, Ni-filtered Cu radiation, λ=1.5405 Å. Analysis No. 9, Table 5.

resolved as the pattern for synthetic PdTe<sub>2</sub> by V.B. Compton (PDF 18-955) taken with a 114.6 mm camera. Loucks (1978) refers to a "Pd phase C" with the stoichiometry of merenskyite having low Bi contents (0.86, 1.58, 4.66%) but occurring intergrown with bismuthian merenskyite. This mineral is cream-colored, has lower reflectivity than the associated bismuthian merenskyite and weaker anisotropy. The identity of "Pd phase C" must await X-ray diffraction data.

The low-Bi kotulskite grains are too small for extraction and confirmation by X-ray diffraction but a Bi-poor moncheite (no. 9, Table 5) was found to have hexagonal axes *a* 4.033 (3), *c* 5.220(7) Å, in good agreement with *a* 4.0259, *c* 5.2209 Å (PDF 18-977) for synthetic PtTe<sub>2</sub> reported by Grønvold *et al.* (1960). The pattern of this moncheite is given in Table 7 because it is more complete than that reported by Genkin *et al.* (1963) and reproduced in PDF 15-392.

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