

Original paper

The Hg–Pd–Te system: phase relations involving temagamite and a new ternary phase

Milan DRÁBEK^{1†}, Anna VYMAZALOVÁ^{1*}, František LAUFEK¹, Marek TUHÝ^{1,2}¹ Czech Geological Survey, Klárov 3, 118 21 Prague 1, Czech Republic; anna.vymazalova@geology.cz² Institute of Geochemistry, Mineralogy and Mineral Resources, Faculty of Science, Charles University, Albertov 6, 128 43 Prague 2, Czech Republic

* Corresponding author

† Deceased



Phase relations in the Hg–Pd–Te system were studied at 350 °C using the silica glass tube method. The following binary phases were confirmed to be stable at 350 °C: PdHg (potarite), HgTe (coloradoite), Pd₁₃Te₃, Pd₂₀Te₇ (keithconnite), Pd₇Te₃, Pd₉Te₄ (telluropalladinite), Pd₃Te₂, PdTe (kotulskite), and PdTe₂ (merenskyite). Kotulskite (PdTe) dissolves up to 8 at. % Hg at 350 °C. Other palladium tellurides do not dissolve Hg. Two ternary phases were proved to be stable in the system at 350 °C: Pd₃HgTe₃ (temagamite) and a new phase Pd₄HgTe₃. The Pd₄HgTe₃ phase is orthorhombic, *Pnma* space group with unit-cell parameters $a = 13.1520(2)$, $b = 11.6879(2)$, $c = 4.25758(5)$ Å, $V = 654.480(5)$ Å³ and $Z = 4$. The Pd₄HgTe₃ phase can be viewed as a ternary ordered variant of the Hg-bearing kotulskite. Synthetic temagamite forms stable assemblages with several phases representing minerals merenskyite and coloradoite, coloradoite and potarite, merenskyite and kotulskite, phase Pd₄HgTe₃ and kotulskite *s.s.*, and phase Pd₄HgTe₃ and potarite. The occurrence of temagamite and its associations indicate the formation of mineralization below 570 °C. The new phase Pd₄HgTe₃ forms stable associations with synthetic analogs of temagamite and potarite, potarite and telluropalladinite, telluropalladinite and kotulskite *s.s.*, temagamite and kotulskite *s.s.* The phase Pd₄HgTe₃ can be expected to be found in such associations under natural conditions.

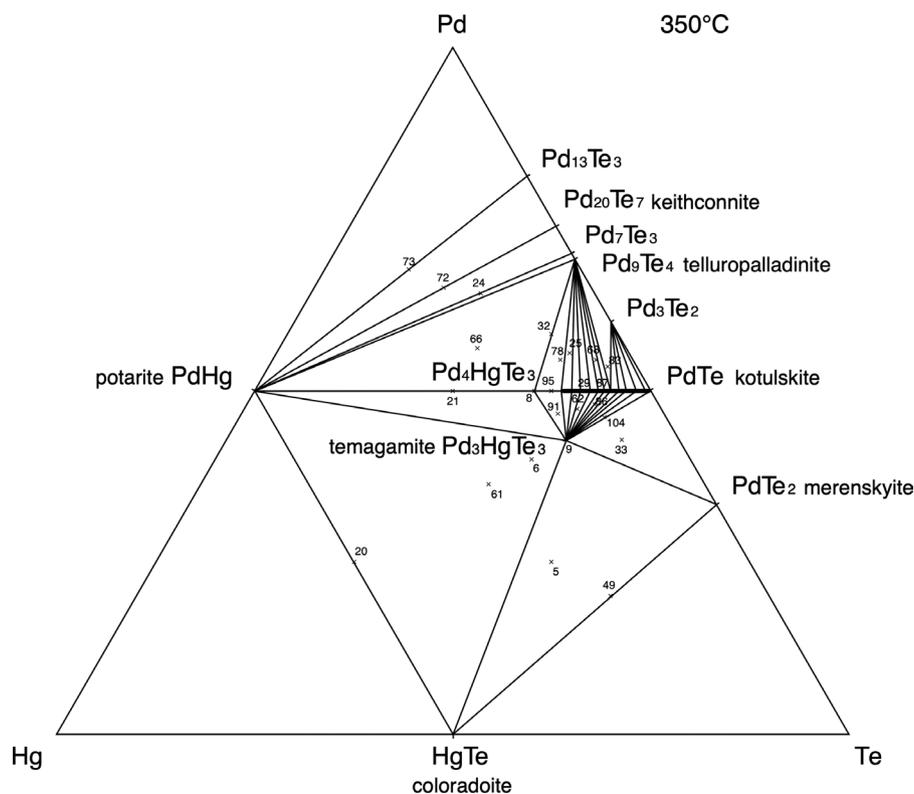
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1. Introduction

The existence of several platinum-group minerals (PGM) containing Hg has prompted studies of PGM systems containing Hg. The systems Pd–Hg–Se and Pt–Hg–Se were studied by Drábek et al. (2012) and (2014), respectively. However, the system Hg–Pd–Te has not been studied to date. Apart from the native elements, six binary minerals and one ternary mineral belong to the Hg–Pd–Te system: kotulskite (PdTe), merenskyite (PdTe₂), telluropalladinite (Pd₉Te₄), keithconnite (Pd₂₀Te₇), potarite (PdHg), coloradoite (HgTe) and temagamite (Pd₃HgTe₃). Minerals belonging to the system Hg–Pd–Te are plotted in Fig. 1.

Fig. 1 Isothermal section for the Hg–Pd–Te system at 350 °C.



In this contribution, we present the phase relations in the system Hg–Pd–Te at 350 °C and predict possible, stable assemblages under natural conditions. We explore the mineralogical implications of our findings. A new ternary phase, Pd₄HgTe₃, is described in the ternary system.

2. Previous experiments

2.1. The system Pd–Te

Experimentally, this system has been studied by a number of researchers (e.g., Medvedeva et al. 1961; Kim 1986; Kim et al. 1990; Kelm et al. 1990; Vymazalová and Drábek 2010). Recently, Vymazalová et al. (2015) revised the system and confirmed the following binary phases to be stable at 350 °C: Pd₁₃Te₃, Pd₂₀Te₇, Pd₇Te₃, Pd₉Te₄, Pd₃Te₂, PdTe and PdTe₂.

2.2. The system Hg–Te

Phase relations with the system Hg–Te were studied by Sharma et al. (1995). Only one binary phase, HgTe, is stable in the system. It melts at 671 °C.

2.3. The system Pd–Hg

Phase relations within the system Pd–Hg were described by Guminski (1990). Three phases are stable in the system: PdHg, Pd₂Hg₅ (stable up to 238 °C) and the low-temperature phase PdHg₄ (stable below 90 °C). Palladium dissolves up to 13.8 at. % Hg (Terada and Cagle 1961).

2.4. The system Pd–Hg–Te

Phase relations in the ternary system Pd–Hg–Te have not been studied to date. Cabri et al. (1973) studied the thermal stability of temagamite Pd₃HgTe₃ by a differential thermal analysis (DTA). At 496–472 °C, there was a significant loss of Hg to the vapor phase. Endothermic peaks at 570–573 °C were interpreted as peritectic reaction Pd₃HgTe₃ → PdTe + Hg. The endothermic reaction at 670 °C was interpreted by Cabri et al. (1973) as congruent melting of PdTe. The crystal structure of synthetic temagamite was described by Laufek et al. (2016).

3. Experimental techniques

The experiments were performed using the silica-glass tube technique (Kullerud 1971).

Charges of about 50 to 300 mg were weighed out from pure elements. Starting reagents were palladium granules (Aldrich, 99.99 % Pd), Te ingot (Aldrich, 99.999 % Te) and mercury (Lachema, 99.999 % Hg). The experiments were performed at 350 °C. The syntheses show satisfactory reaction kinetics at this temperature. The charges were heated for several weeks to months to approach the equilibrium. During the duration of the experiment, the charges were repeatedly re-ground (1–3 times) under acetone after quenching and re-heated at the target temperature. After the heating, the tubes with experimental products were quenched in cold water.

The reaction products were examined by reflected-light microscopy, X-ray powder diffraction, and an electron microprobe. The X-ray powder diffraction data were collected

Tab. 1 Results of selected experimental runs in the system Hg–Pd–Te at 350 °C (based on EMPA and XRD data).

Run No	Starting composition (at. %)			Phase assemblages at 350 °C
	Pd	Hg	Te	
5	25	25	50	Pd ₃ HgTe ₃ + HgTe + PdTe ₂
6	40	20	40	Pd ₃ HgTe ₃ + HgTe + PdHg
20	25	50	25	PdHg + HgTe
21	50	25	25	PdHg + Pd ₄ HgTe ₃
24	64.28	14.29	21.43	PdHg + Pd ₄ Te ₄
25	55.55	7.41	37.04	Pd ₉ Te ₄ + Pd(Te,Hg) <i>s.s.</i>
29	50	8.33	41.67	Pd(Te,Hg) <i>s.s.</i>
32	58.33	8.33	33.34	Pd ₉ Te ₄ + Pd ₄ HgTe ₃
33	37.5	18.75	43.75	Pd ₃ HgTe ₃ + PdTe + PdTe ₂
49	20	20	60	HgTe + PdTe ₂
61	36.36	27.27	36.36	Pd ₃ HgTe ₃ + HgTe + PdHg
62	47.37	10.53	42.11	Pd ₃ HgTe ₃ + Pd(Te,Hg) <i>s.s.</i>
66	56.25	18.75	25	PdHg + Pd ₄ HgTe ₃ + Pd ₉ Te ₄
68	54.55	2.55	40.91	Pd ₉ Te ₄ + Pd(Te,Hg) <i>s.s.</i>
72	65.12	18.6	16.28	PdHg + Pd ₂₀ Te ₇
73	67.57	21.62	10.81	PdHg + Pd ₁₃ Te ₃
78	54.55	9.09	36.36	Pd ₉ Te ₄ + Pd(Te,Hg) <i>s.s.</i>
83	53.71	3.57	42.72	Pd ₉ Te ₄ + Pd(Te,Hg) <i>s.s.</i>
86	48	8	44	Pd ₃ HgTe ₃ + Pd(Te,Hg) <i>s.s.</i>
87	50	6.25	43.75	Pd(Te,Hg) <i>s.s.</i>
91	46.67	13.33	40	Pd ₄ HgTe ₃ + Pd ₃ HgTe ₃ + Pd(Te,Hg) <i>s.s.</i>
95	50	12.5	37.5	Pd ₄ HgTe ₃ + Pd(Te,Hg) <i>s.s.</i>
104	46.15	7.69	46.15	Pd ₃ HgTe ₃ + PdTe
H8	50	12.5	37.5	Pd ₄ HgTe ₃
H9	42.86	14.29	42.86	Pd ₃ HgTe ₃

on a Bruker D8 diffractometer using CuK α radiation and Lynx-Eye XE detector. The data were collected in the 2 θ range 4–80°, with a step of 0.015°. The data were evaluated utilizing the HighScore (PANalytical 2011) software. The crystal structure of a new ternary phase Pd₄HgTe₃ (see below) was solved from powder X-ray diffraction data.

Chemical analyses were performed with a CAMECA SX100 microanalyzer in a wavelength-dispersion mode. Concentrations were quantified using PdL α , AgL β and TeL α and HgM α . Pure elements Pd and Te, and cinnabar were used as standards. The excitation voltage was 15 kV, with a beam current of 10 nA and beam focus 1–2 μ m. Within each synthetic product, several different grains were analyzed.

4. Results

In total, 85 experimental runs were performed in the system Hg–Pd–Te. Representative runs are summarized in Tab. 1. The stable binary compounds at 350 °C are: HgTe (analogue of coloradoite), PdHg (analogue of potarite), Pd₁₃Te₃, Pd₂₀Te₇ (analogue of keithconnite), Pd₇Te₃, Pd₉Te₄ (analogue of telluropalladinite), Pd₃Te₂, PdTe (analogue of kotulskite), and PdTe₂ (analogue of merenskyite). The PdTe phase, the analog of kotulskite, forms an extensive solid solution dissolving up to 8 at. % Hg at 350 °C because Hg substitutes for Te in the crystal structure. Other binary Pd-tellurides do not dissolve Hg.

In the Hg–Pd–Te system, there are two ternary phases stable at 350 °C: Pd₃HgTe₃ phase, the analog of temagamite, and a new phase Pd₄HgTe₃. The EMPA data of ternary phases are summarized in Tab. 2.

Based on the literature data for the binary sub-systems (particularly for binary Pd–Te system) summarized above and on our experiments within the ternary system, an isothermal condensed phase diagram for 350 °C is presented in Fig. 1. The following univariant assemblages are confirmed to be stable in the system at 350 °C:

Te + merenskyite (PdTe₂) + coloradoite (HgTe)
 merenskyite (PdTe₂) + coloradoite (HgTe) + temagamite (Pd₃HgTe₃)
 temagamite (Pd₃HgTe₃) + coloradoite (HgTe) + potarite (PdHg)
 temagamite (Pd₃HgTe₃) + kotulskite (PdTe) + merenskyite (PdTe₂)
 coloradoite (HgTe) + potarite (PdHg) + Hg
 Pd₄HgTe₃ + temagamite (Pd₃HgTe₃) + potarite (PdHg)

Tab. 2 EMPA data of ternary phases in the Hg–Pd–Te system at 350 °C.

Run no.	n	wt. %				Atoms per formula unit		
		Pd	Hg	Te	Total	Pd	Hg	Te
Pd ₃ HgTe ₃ (temagamite)								
9	3	34.47	21.17	42.86	98.51	2.96	0.97	3.07
Pd ₄ HgTe ₃								
8	5	42.16	19.68	37.40	99.24	4.03	1.00	2.98
91	3	41.94	19.99	37.84	99.77	3.99	1.01	3.00
78	4	41.77	19.87	37.74	99.38	3.99	1.01	3.01
95	4	41.21	19.18	38.86	99.24	3.94	0.97	3.09
66	5	39.75	19.77	39.26	98.79	3.83	1.01	3.16
Pd(Te,Hg) – kotulskite s.s.								
91	9	43.14	12.70	44.22	100.06	0.99	0.16	0.85
83	10	43.94	6.85	49.09	99.88	0.99	0.08	0.93
25	6	39.75	19.77	39.26	98.79	0.98	0.14	0.88

Pd₄HgTe₃ + temagamite (Pd₃HgTe₃) + kotulskite ss Pd(Hg,Te)

Pd₄HgTe₃ + kotulskite ss Pd(Hg,Te) + telluropalladinite (Pd₉Te₄)

Pd₃Te₂ + telluropalladinite (Pd₉Te₄) + kotulskite ss Pd(Hg,Te)

telluropalladinite (Pd₉Te₄) + Pd₄HgTe₃ + potarite (PdHg)

telluropalladinite (Pd₉Te₄) + Pd₇Te₃ + potarite (PdHg)

Pd₇Te₃ + keithconnite (Pd₂₀Te₇) + potarite (PdHg)

keithconnite (Pd₂₀Te₇) + Pd₁₃Te₃ + potarite (PdHg)

Pd₁₃Te₃ + potarite (PdHg) + Pd

4.1. The Pd₃HgTe₃ phase, the analog of temagamite

Temagamite was described by Cabri et al. (1973) from a former copper deposit located on Temagami Island, Ontario, Canada. The crystal structure was solved on its synthetic analog (Pd₃HgTe₃) by Laufek et al. (2016). It is trigonal, space group *P3m1*, with *a* = 7.8211 Å, *c* = 17.281 Å, *V* = 917.8 Å³ and *Z* = 6. It crystallizes in a framework structure based on [PdTe₆] octahedra and [PdTe₄] squares. Synthetic Pd₃HgTe₃ is stable up to 570 °C, as determined by its behavior on heating using DTA followed by an examination of quenched products (Cabri et al. 1973).

4.2. The Pd₄HgTe₃ phase

A newly discovered ternary phase Pd₄HgTe₃ synthesized at 350 °C is compositionally distinct from synthetic Hg-bearing kotulskite and temagamite (Pd₃HgTe₃). The crystal structure of Pd₄HgTe₃ was solved from powder X-ray diffraction data collected in Bragg-Brentano geometry in the angular range of 10–145° of 2 θ . Its diffraction pattern was indexed using the Topas 5 program (Bruker AXS 2014) based on the orthorhombic cell listed in Tab. 3. The crystal structure of this new phase was solved with the

Tab. 3 Powder diffraction data collection and Rietveld analysis of the Pd₄HgTe₃ phase.

Data collection	
Radiation type, source	X-ray, CuK _α
Generator settings	40 kV, 30 mA
Range in 2θ (°)	10–145
Step size (°)	0.015
Crystal data	
Space group	<i>Pnma</i> (No. 62)
Unit-cell content	Pd ₄ HgTe ₃ , Z = 4
Unit-cell parameters (Å)	<i>a</i> = 13.1520(2) <i>b</i> = 11.6879(2) <i>c</i> = 4.25758(5)
Unit-cell volume (Å ³)	654.480(5)
Rietveld analysis	
No. of reflections	689
No. of structural parameters	13
Crystallite size (nm)	169(1)
<i>R</i> _{Bragg}	0.0487
<i>R</i> _p	0.0631
<i>R</i> _{wp}	0.0809

charge flipping program Superflip (Palatinus and Chapuis 2007) and subsequently refined by the Rietveld method with the Topas 5 program (Bruker AXS 2014). The final cycles involved refinement of unit-cell parameters, atomic coordinates, isotropic displacement parameter, isotropic size and strain. The background was determined

Tab 4. Atomic positions (space group *Pnma*) and isotropic displacement parameters for synthetic Pd₄HgTe₃. The isotropic displacement parameter (*B*_{iso}) was constrained to be equal for all atoms.

Atom	Wyckoff letter	<i>x</i>	<i>y</i>	<i>z</i>	<i>B</i> _{iso} [Å ²]
Pd(1)	8 <i>d</i>	0.1848(1)	0.1228(1)	0.0012(6)	0.256(7)
Pd(2)	4 <i>a</i>	0	0	0	0.256(7)
Pd(3)	4 <i>c</i>	0.3852(1)	1/4	0.0058(9)	0.256(7)
Hg(1)	4 <i>c</i>	0.2517(1)	1/4	0.5026(6)	0.256(7)
Te(1)	4 <i>c</i>	0.0111(1)	1/4	0.001(1)	0.256(7)
Te(2)	8 <i>d</i>	0.3672(1)	0.0177(1)	0.0012(8)	0.256(7)

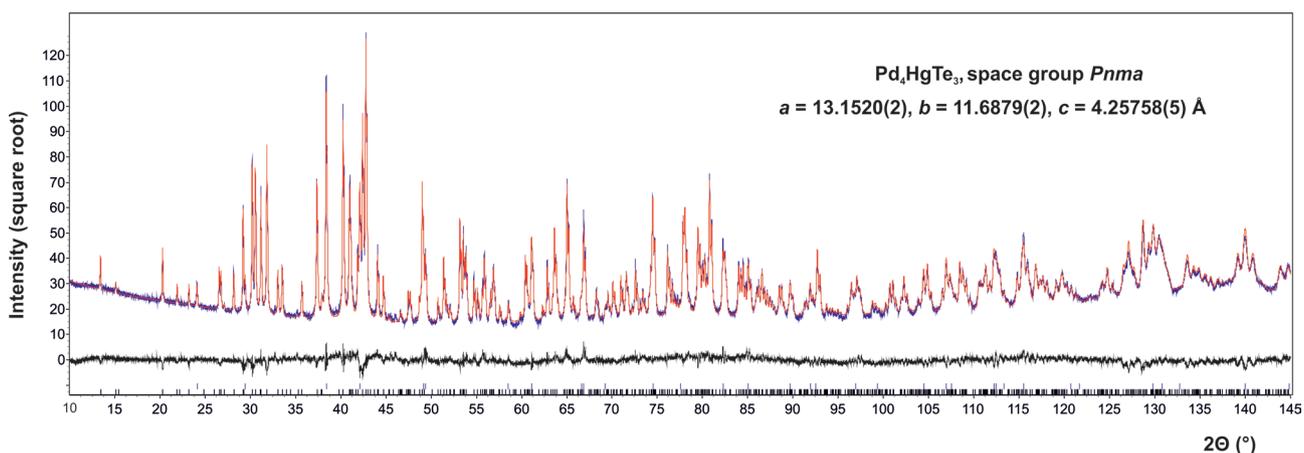
employing a Chebyshev polynomial function of the 5th order. The final cycles of refinements converged to the agreements factor: *R*_{Bragg} = 0.0487 and *R*_{wp} = 0.0809. The crystal structure data and fractional coordinates are given in Tabs 3 and 4, respectively. Fig. 2 shows the final Rietveld plot.

The crystal structure of Pd₄HgTe₃ contains three Pd, two Te and one Hg sites. As is indicated in Fig. 3, Pd(1) and Pd(3) atoms show distorted octahedral coordination by four Te and two Hg atoms forming [PdHg₂Te₄] polyhedra with Hg atoms at *cis*-position to each other, Pd(2) atoms form distorted [PdTe₆] octahedra. The Pd–Te bonds fall within the range of 2.69 to 2.92 Å, while Pd–Hg distances are from 2.72 to 2.76 Å. The distorted octahedra share their edges and faces forming a three-dimensional network. The structure contains a system of Pd–Pd bonds (2.82–3.025 Å) across the shared octahedral faces (Fig. 3).

The ternary Pd₄HgTe₃ phase can be viewed as a ternary ordered variant of the Hg-bearing kotulskite with an ordered distribution of Te and Hg atoms. Both structures are based on distorted hexagonal close-packed atoms of Te and Hg where Pd atoms occupy all available octahedral sites. While PdTe shows almost regular [PdTe₆] octahedra (neglecting a slight compression along the *c*-axis), the corresponding octahedra in the Pd₄HgTe₃ structure are quite distorted, leading to a different system of Pd–Pd bonds in both structures (Fig. 3). The chemical composition of the Pd₄HgTe₃ phase can be alternatively expressed as PdHg_{0.25}Te_{0.75}, which also directly indicates its relationship to the Hg-bearing kotulskite Pd(Hg,Te).

It is interesting to note that at elevated temperatures (above 500 °C), the Pd₄HgTe₃ phase

can be alternatively expressed as PdHg_{0.25}Te_{0.75}, which also directly indicates its relationship to the Hg-bearing kotulskite Pd(Hg,Te).

**Fig. 2** The final Rietveld plot for the synthetic phase Pd₄HgTe₃. The upper diffraction trace corresponds to a composition with 11 wt. % HgPd, the lower corresponds to Pd₄HgTe₃.

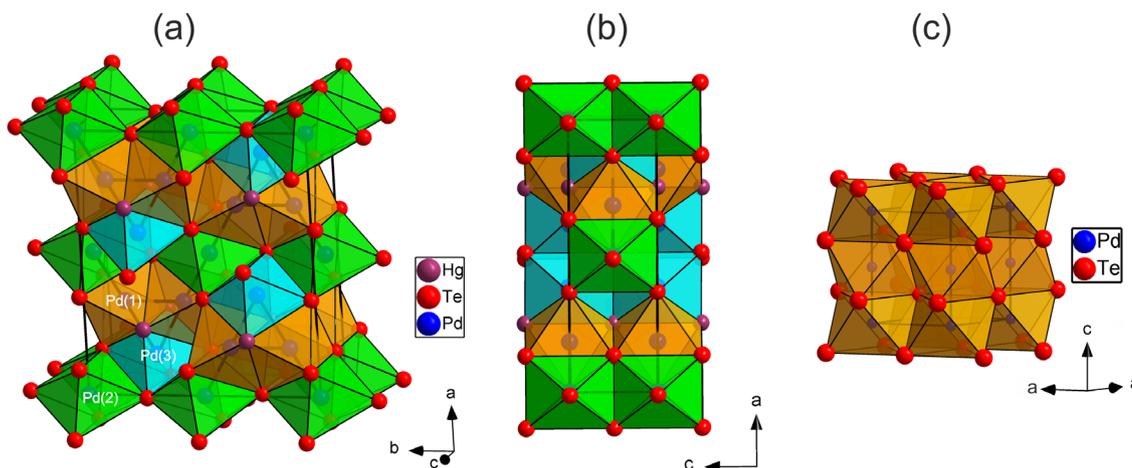


Fig. 3 Polyhedral representation of (a, b) crystal structure of Pd_4HgTe_3 phase emphasising the $[\text{Pd}(1)\text{Hg}_2\text{Te}_4]$, $[\text{Pd}(2)\text{Te}_6]$ and $[\text{Pd}(3)\text{Hg}_2\text{Te}_4]$ octahedra. The system of Pd–Pd bonds across shared octahedral faces is shown. (c) Crystal structure of PdTe for comparison.

transforms to a hexagonal kotulskite-based structure with $P6_3/mmc$ symmetry.

The strongest seven lines in observed XRD pattern of Pd_4HgTe_3 phase are: [d in Å, (hkl /intensity)] 2.1111 (341/100), 2.1285 (002/52), 2.2374 (501/60), 2.4034 (331/30), 2.8076 (131, 43), 2.9213 (040, 38) and 2.9547 (311, 39). It should be noted that the powder XRD pattern of Pd_4HgTe_3 differs considerably from those of Hg bearing-PdTe and temagamite (Pd_3HgTe_3), which makes all phases clearly distinguishable by XRD.

5. Discussion

Among platinum-group minerals, the only known Pt- and Pd-dominant minerals containing Hg as an essential element are atheneite ($\text{Pd}_2\text{As}_{0.75}\text{Hg}_{0.25}$), jacutingaite (Pt_2HgSe_3), potarite (PdHg), temagamite (Pd_3HgTe_3), tilkerodeite (Pd_2HgSe_3), and tischendorfite ($\text{Pd}_8\text{Hg}_3\text{Se}_9$). There are two ternary phases (Pd_3HgTe_3 and Pd_4HgTe_3) in the Hg–Pd–Te system and they do not show any exact selenium counterparts in the systems Pt–Hg–Se (Drábek et al. 2012) and Pd–Hg–Se (Drábek et al. 2014). A phase with the composition “ Pd_6HgTe_4 ” reported by Grokhovskaya et al. (2012) from the South Sopcha Massif, Monchegorsk Complex was not experimentally confirmed, as well as minerals with possible compositions of “ Pd_2Hg_3 ” and “ Pd_3Hg_2 ” reported by Volchenko et al. (1975) and Yong and Seccombe (1993), respectively.

The extent of the Hg–Te substitution in the synthetic analog of kotulskite PdTe (up to 8 at. % Hg) is remarkable since it contrasts with the PdSe phase where no Hg substitution was found (Drábek et al. 2014). This might be related to the different covalent size of Se, Te and Hg atoms and differences in their crystal structures, i.e., $[\text{PdTe}_6]$ octahedra versus $[\text{PdSe}_4]$ squares in PdTe and PdSe, respectively (Ijjaali and Ibers 2001), and a

strong preference of Pt to form Pt–Se bond over Pt–Hg in square-planar coordination. For the Pd selenides, only palladseite $\text{Pd}_{17}\text{Se}_{15}$ dissolves a limited amount of Hg, i.e., up to 4.15 at. % (Drábek et al. 2014). However, Hg in Hg-bearing palladseite occupies a new site and does not substitute for Se (Laufek et al. 2021).

6. Conclusions

We have elucidated the phase relations in the Hg–Pd–Te system at 350 °C. Two ternary phases were found to be stable at the system at 350 °C: Pd_3HgTe_3 (temagamite) and a new phase Pd_4HgTe_3 .

The Pd_4HgTe_3 phase is orthorhombic with unit-cell parameters $a = 13.1520(2)$, $b = 11.6879(2)$, $c = 4.25758(5)$ Å, $V = 654.480(5)$ Å³ and $Z = 4$. This phase can be viewed as a ternary ordered variant of Hg-bearing kotulskite with an ordered distribution of Te and Hg atoms.

The PdTe phase, the analog of kotulskite forms a limited Pd(Te,Hg) solid-solution by dissolving up to 8 at. % Hg at 350 °C. Other binary Pd-tellurides dissolve negligible quantities of Hg.

Synthetic temagamite (Pd_3HgTe_3) forms stable assemblages with several phases representing the minerals merenskyite (PdTe_2) and coloradoite (HgTe), coloradoite (HgTe) and potarite (PdHg), merenskyite (PdTe_2) and kotulskite (PdTe), Pd_4HgTe_3 and kotulskite *s.s.*, and Pd_4HgTe_3 and potarite. The occurrence of temagamite and its associations are in line with the formation of mineralization below 570 °C determined by Cabri et al. (1973).

The new Pd_4HgTe_3 phase forms stable associations with synthetic analogs of minerals temagamite (Pd_3HgTe_3) and potarite (PdHg), potarite (PdHg) and telluropalladinite (Pd_9Te_4), telluropalladinite (Pd_9Te_4) and kotulskite *s.s.*, temagamite (Pd_3HgTe_3) and kotulskite *s.s.*

The phase Pd₄HgTe₃ might be found in nature in such associations.

Mineral assemblages defined in this study are relevant to magmatic Cu–Ni–PGE mineral deposits associated with mafic and ultramafic igneous rocks. In particular, those associations where Pd-tellurides and temagamite are known to occur, as in deposits like the Temagami deposit, Ontario, the Raglan Ni–Cu–(PGE) deposit, Quebec in Canada; deposits in the Kola Peninsula in Russia or in Merensky Reef in South Africa. The new ternary phase determined in this study can also be expected in association with low-temperature hydrothermally modified primary PGM.

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References

- BRUKER AXS (2014) Topas 5, computing program, Bruker AXS GmbH, Karlsruhe, Germany.
- CABRI LJ, LAFLAMME GJH, STEWART JM (1973) Temagamite, a new palladium-mercury telluride from the Temagami copper deposit, Ontario, Canada. *Canad Mineral* 12: 193–198
- DRÁBEK M, VYMAZALOVÁ A, CABRAL AR (2012) The Hg–Pt–Se system at 400 °C: Phase relations involving jacutingaite. *Canad Mineral* 50: 441–446
- DRÁBEK M, VYMAZALOVÁ A, LAUFEK F (2014) The system Hg–Pd–Se at 400 °C: Phase relations involving tischendorfite and other ternary phases. *Canad Mineral* 52: 763–768
- GROKHOVSKAYA TL, IVANCHENKO VN, KARIMOVA OV, GRIBOEDOVA IG, SAMOSHNIKOVA LA (2012) Geology, mineralogy, and genesis of PGE mineralization in the South Sopcha Massif, Monchegorsk Complex, Russia. *Geol Ore Deposits* 54: 347–369
- GUMINSKI C (1990) The Hg–Pd (Mercury–Palladium) system. *Bull Alloy Phase Diagr*, 11: 22–26
- IJJAALI I, IBERS, JA (2001) Crystal structure of palladium selenide, PdSe. *Z Kristallogr – New Cryst Struct* 216: 485–486
- KELM M, GORTZEN A, KLEYKAMP H, PENTINGHAUS H (1990) On the constitution of the Pd–Te system up to 28 at. % Te. *J Less-Common Meta* 166: 125–133
- KIM WS (1986) Two synthetic phases, Pd₁₇e₄, and Pd₇Te₃ and new phase relations of the Pd–Te system. *J Geol Soc Korea* 22: 145–160
- KIM WS, CHAO G, CABRI LJ (1990) Phase relations in the Pd–Te system. *J Less-Common Meta* 162: 61–74
- KULLERUD G (1971) Experimental techniques in dry sulfide research. In: ULMER G (ed) *Research Techniques for High Pressure and High Temperature*. Springer-Verlag, New York, pp 288–315
- LAUFEK F, VYMAZALOVÁ A, DRÁBEK M, DUŠEK M, NAVRÁTIL J, ČERNOŠKOVÁ E (2016) The crystal structure of Pd₃HgTe₃, the synthetic analogue of temagamite. *Eur J Mineral* 79: 1831–1832
- LAUFEK F, VYMAZALOVÁ A, TUHÝ M (2021) Ag, Cu, Hg, Pt, Sb, As and Te substitutions in the synthetic analogue of palladseite, Pd₁₇Se₁₅: an experimental mineralogical study. *J Geosci* 66: 205–213
- MEDVEDEVA ZS, KLOCHKO MA, KUZNETSOV VG, ANDREEVA SN (1961) Equilibrium diagram of the palladium-tellurium system. *Zh Neorg Khim* 6: 1737–1739 [in Russian]
- PALATINUS L, CHAPUIS G (2007) SUPERFLIP – a computer program for the solution of crystal structures by charge flipping in arbitrary dimensions. *J Appl Cryst* 41: 786–790
- PANALYTICAL BC (2011) HighScore 3.0c, Almelo, The Netherlands.
- SHARMA RC, CHANG YA, GUMINSKY C (1995) The Hg–Te (Mercury tellurium) system. *J Phase Equilib* 16: 338–347
- TERADA K, CAGLE FW (1961) The solid solution of mercury in palladium. *Acta Crystallogr* 14: 1299
- VOLCHENKO YUA, NECHEUKHIN VM, RADYGIN AI, SANDLER GA (1975) A new type of PGE mineralization in ultramafics of fold belts. *Dokl Akad Nauk SSSR* 224(1): 182–185
- Vymazalová A, Drábek M (2010) The system Pd–Sn–Te at 400 °C and mineralogical applications. I. The binary phases. *Canad Mineral* 48: 1041–1050
- VYMAZALOVÁ A, LAUFEK F, KRISTAVCHUK AV, CHAREEV DA, DRÁBEK M (2015) The system Ag–Pd–Te: phase relations and mineral assemblages. *Mineral Mag* 79: 1813–1832
- YONG K, SECCOMBE PK (1993) Platinum-group minerals in the chromitites of the Great Serpentine Belt, NSW, Australia. *Mineral Petrol* 47:263–286