Belendorffite, a new copper amalgam dimorphous with kolymite

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With 1 figure and 3 tables in the text

Abstract: Belendorffite, a new copper amalgam from the Moschellandsberg silver–mercury deposit in Rhineland-Pfalz, FRG, is described. The mineral is associated with native mercury, its colour is silvery white with a yellowish tint. Belendorffite is rhombohedral (pseudo-cubic) with unit cell dimensions of $a_0 = 9.4082$ Å, $a = 90.472°$, $Z = 4$, space group R3m. The five strongest lines of the powder diffraction pattern are 2.983(80), 2.966(80), 2.523(100), 2.227(100) and 2.208(100) Å. The density is 13.2 g/cm³. Reflectance data in air and oil are tabulated. Color values in air relative to CIE illuminant C are Y = 72.5 %, $\lambda_d = 578$ nm, $P_e = 4.1$ %. Microprobe analyses reveal an average composition of Cu = 25.61 wt.%, Hg = 74.06 wt.%, resulting in a formula of Cu_7Hg_6. Belendorffite is dimorphous with kolymite.

Introduction

Kolymite, a copper amalgam with the formula Cu_7Hg_6, was first described by MARKOVA et al. (1980) as an intergrowth with native copper in an antimony ore from Krokhalin, basis of Kolym River, Magadin region, USSR. In 1989, a second and third occurrence of kolymite were reported by CIPRIANI & MAZZETTI (1989), who identified the mineral during a study of museum specimens in two samples labeled silver amalgam. Kolymite grains were associated with moschellandsbergite and native mercury in a sample from Mexico and with moschellandsbergite and silver in a sample from Nevada, USA. The X-ray powder pattern of kolymite from USSR (MARKOVA et al., 1980; JCPDS file # 33-470) and Mexico (CIPRIANI & MAZZETTI, 1989) indicate cubic symmetry for both specimens and unit cell dimensions of 9.418 Å and 9.414 Å, respectively.

Experimental investigations in the system copper–mercury were published by different authors who concluded, that only one intermediate phase exists in the system, the formula of which is given as Cu_7Hg_6 (SCHOSZBERGER, 1935; LIHL, 1953; LINDAHL et al., 1968; LUGSCHNEIDER & JANGG, 1971; CHAKRABARTI

& LAUGHLIN, 1985). Two types of powder patterns were published for this intermediate phase indicating cubic symmetry with $a_0 = 9.406$ Å (SCHOSZ-BERGER, 1935; JCPDS file # 4-0811) or rhombohedrally distorted, pseudo-cubic symmetry with $a_0 = 9.4067$ Å, $\alpha = 90.413°$ (LINDAHL et al., 1968; JCPDS file # 22-241). The crystal structure of the pseudo-cubic phase is described by LINDAHL & WESTMAN (1969) as an ordered version of the Cu_5Cd_8 structure type.

According to the fact, that the powder pattern of the cubic phase of SCHOSZ-BERGER (1935) is almost identical with the pattern of natural cubic Cu_7Hg_6, kolymite, the literature data strongly indicate that Cu_7Hg_6 is dimorphous. This presumption is confirmed by the observation of a second natural copper amalgam having a composition of Cu_7Hg_6, which will be described in the present paper as the new mineral belendorffite.

In 1987, a globular nodule was submitted for investigation to one of the authors by the mineral collector KLAUS BELENDORFF of Münster, Hesse, FRG. The sample came from collection F. KRANTZ of Bonn, FRG, and was labeled landsbergite from Moschellandsberg, Rhineland-Pfalz, FRG. Mr. BELENDORFF suggested that the specimen was mislabeled and asked to identify the mineral. Chemical and crystallographic examinations finally led to the conclusion, that the specimen consisted of a rhombohedral copper amalgam, which is dimorphous with kolymite. Mineralogical data of this mineral named belendorffite were submitted to the IMA Commission on New Minerals and Mineral Names. The species and name have been approved by the Commission.

Type material is preserved in the collection of the Institut für Mineralogie, Ruhr-Universität, Bochum, FRG.

According to recent inquiries, the sample of belendorffite was received from the Krantz collection by exchange and, most probably, was stored in the Krantz stock already in the last century. During this period, similar appearing specimens of landsbergite up to some 100 grams in weight from the Moschellandsberg silver – mercury deposit were preserved in public and private mineral collections. In the area of the Moschellandsberg, silver- and mercury-bearing minerals were mined since the middle ages, mainly native mercury, cinnabar as well as silver- and mercury-containing varieties of the tetrahedrite group. In addition, the Moschellandsberg deposit is type locality for landsbergite, schachnerite and paraschachnerite (DREYER, 1973; NOTTES, 1983; HEIDTKE, 1984). It is also worth mentioning, that a copper-bearing amalgam was quoted by NOTTES (1983) from Moschellandsberg.

Description and physical properties

The sample of belendorffite consisted of a globular nodule weighing originally 6.1 grams. The surface was blackish-brown due to an oxidation skin. The color of a freshly prepared sample is silvery. The mineral shows metallic lustre, the streak is silvery. The only associated mineral is mercury.

The density of the sample was determined by hydrostatic weighing as $13.2(1)\,g/cm^3$. The calculated density is $13.15\,g/cm^3$.

Polished sections were prepared on lead laps using diamond sprays. In the final stage $\frac{1}{4}\,\mu m$ diamond powder on cloth was used. Due to the low hardness of the mineral it was extremely difficult to obtain good polish. The mineral tarnishes rapidly beginning at fine scratches. Two days after polish only a mat yellow surface is left.

A LEITZ microhardness tester was used to measure Vickers-hardness. The observed indentations were perfect but nevertheless two distinctly different mean values of hardness could be measured reproducibly near both ends of a range between $VHN_{25} = 45$ and $VHN_{25} = 206$, with an average value calculated to $VHN_{25} = 125$.

Table 1. Reflectance data and color values relative to CIE illuminant C for belendorffite.

λ [nm]	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700
R[%]	66.2	67.0	67.6	68.3	69.2	70.1	71.0	71.9	72.8	73.4	74.1	74.7	75.3	76.0	76.4	76.9
^{im}R[%]	57.8	58.2	58.6	59.0	59.6	60.3	61.2	62.0	63.0	63.5	64.2	64.8	65.5	66.1	66.5	67.1

air: x = 0.318 y = 0.324 Y = 72.5%   oil: x = 0.318 y = 0.323 Y = 62.7%
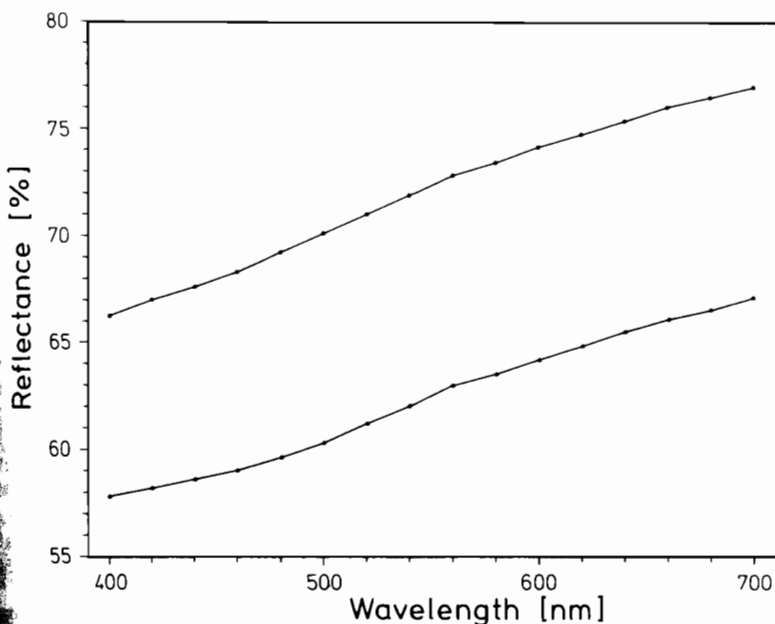λ_d = 578 nm P_e = 4.1% λ_d = 579 nm P_e = 4.1%

1. Spectral reflectance of belendorffite in air (upper curve) and immersion oil (lower curve).

Table 2. X-ray powder diffraction pattern of belendorffite (Moschellandsberg) and synthetic Cu_7Hg_6 (after LINDAHL et al., 1968).

belendorffite				synthetic Cu_7Hg_6		
$d_{obs.}$	$d_{calc.}$	h k l	I/I_1	$d_{obs.}$	h k l	I/I_1
6.682	6.680	$\bar{1}$ 1 0	60	6.66	$\bar{1}$ 1 0/1 1 0	50
6.628	6.625	1 1 0	40			
3.862	3.857	$\bar{2}$ 1 1	10	3.84	2 1 $\bar{1}$	10
3.311	3.312	2 2 0	60	3.31	2 2 0	50
2.983	2.982	$\bar{1}$ 3 0	80	2.981	$\bar{3}$ 1 0	80
2.966	2.968	1 3 0	80	2.967	3 1 0	80
2.722	2.723	$\bar{2}$ 2 2	60	2.721	$\bar{2}$ 2 2	50
2.693	2.693	2 2 2	60	2.696	2 2 2	50
2.523	2.525	$\bar{3}$ 2 1	100	2.520	3 $\bar{2}$ 1	100
	2.522	$\bar{2}$ 3 1				
2.497	2.498	2 3 1	60	2.499	3 2 1	50
2.350	2.352	0 4 0	40	2.351	4 0 0	50
2.227	2.227	$\bar{3}$ 3 0	100	2.226	$\bar{3}$ 3 0/$\bar{4}$ 1 1	100
	2.225	$\bar{4}$ 1 1				
2.221	2.218	$\bar{1}$ 4 1	100	2.218	4 $\bar{1}$ 1	100
2.208	2.208	1 4 1	100	2.209	4 1 1/3 3 0	100
2.099	2.097	2 4 0	10			
2.013	2.012	$\bar{3}$ 3 2	60	2.011	$\bar{3}$ 3 2	50
2.008	2.008	$\bar{3}$ $\bar{3}$ 2	10			
1.9285	1.9283	$\bar{4}$ 2 2	40	1.9280	$\bar{4}$ 2 2	< 10
1.9082	1.9071	2 4 2	10			
1.8521	1.8527	$\bar{4}$ 3 1	10			
	1.8515	$\bar{3}$ 4 1				
1.8479	1.8479	$\bar{1}$ 5 0	10			
1.8426	1.8420	1 5 0	40			
1.8343	1.8339	3 4 1	40	1.8361	4 3 1	< 10
1.7234	1.7238	$\bar{5}$ 2 1	20			
1.7165	1.7161	$\bar{5}$ $\bar{2}$ 1	10			
1.7091	1.7095	2 5 1	40	1.7104	5 2 1	20
1.6165	1.6169	$\bar{3}$ 4 1	40	1.6162	4 $\bar{3}$ 3	20
1.6067	1.6075	3 5 0	10			
1.5998	1.6005	3 4 3	10			
1.5678	1.5679	0 6 0	60	1.5676	4 4 $\bar{2}$/6 0 0	50
1.5561	1.5565	4 4 2	40	1.5577	4 4 2	10
1.5294	1.5298	$\bar{6}$ 1 1	60	1.5291	$\bar{6}$ 1 1	50
1.5215	1.5218	1 6 1	60	1.5229	6 1 1	50
1.4912	1.4911	$\bar{2}$ 6 0	20	1.4910	$\bar{6}$ 2 0	10
1.4834	1.4838	2 6 0	20	1.4853	6 2 0	10
1.4575	1.4577	$\bar{5}$ 4 1	40	1.4571	$\bar{5}$ 4 1	10
	1.4574	4 4 3				
1.4484	1.4485	$\bar{5}$ $\bar{4}$ 1	20	1.4502	5 4 $\bar{1}$	10
1.4237	1.4239	3 5 3	60	1.4231	$\bar{6}$ 2 2	50
	1.4236	$\bar{6}$ 2 2				
1.3920	1.3924	$\bar{6}$ 3 1	60	1.3910	$\bar{6}$ 3 1/6 $\bar{3}$ 1	50
1.3618	1.3616	$\bar{4}$ 4 4	60	1.3611	$\bar{4}$ 4 4	50
1.3360	1.3360	$\bar{5}$ 5 0	60	1.3355	$\bar{5}$ 5 0	50

Table 2 (Continued).

belendorffite				synthetic Cu₇Hg₆		
$d_{obs.}$	$d_{calc.}$	h k l	I/I₁	$d_{obs.}$	h k l	I/I₁
	1.3358	3 6 2				
1.2998	1.2996	4 6 0	20	1.3005	6 4 0	20
1.2850	1.2854	4 6 1	10			
	1.2852	5̄ 5 2				
1.2819	1.2820	2̄ 7 1	60	1.2817	7 2̄ 1/6 3̄ 3	50
1.2742	1.2757	2 7 1	20			
1.2718	1.2714	5 5 2	40			
1.2621	1.2624	6̄ 4 2	10			
1.2565	1.2564	6̄ 4̄ 2	20	1.2560	6 4 2̄	< 10
1.2334	1.2360	4 5 4	10			
	1.2316	3 7 0				
1.1996	1.1998	6̄ 5 1	20			
	1.1996	5 6 0				
	1.1994	5̄ 6 1				
1.1970	1.1968	3̄ 7 2	20	1.1964	7 3̄ 2	< 10
1.1918	1.1917	6̄ 5̄ 1	10	1.1916	6 5 1̄	< 10
1.1625	1.1627	4 7 0	10			
	1.1625	7̄ 4 1				
1.1554	1.1555	7̄ 4̄ 1	40	1.1556	8 1 1	< 10
1.1527	1.1523	4 7 1	10			
1.1456	1.1453	6̄ 4 4	10			
1.1434	1.1430	2̄ 8 0	20	1.1429	8 2 0	< 10
1.1289	1.1290	2 8 1	20	1.1276	6 5̄ 3	< 10
	1.1289	6̄ 5 3				
1.1130	1.1133	6̄ 6 0	20			
1.1040	1.1041	6 6 0	20			
	1.1041	3̄ 8 0				
1.0893	1.0893	5 7 0	10			
	1.0893	5̄ 5 5				
1.0838	1.0835	7̄ 5̄ 1	10			
	1.0834	6̄ 6 2				

The mineral is completely opaque. In reflected plane-polarized light it shows a bright white color with a yellowish tint. Bireflectance and pleochroism are absent. Very weak uncolored anisotropy can be observed. There is no complete extinction using exactly crossed polarizers. Microscopic examinations in air and immersion oil did not reveal remarkable differences.

Spectral reflectance measurements in air and immersion oil were performed using a LEITZ ORTHOPLAN microscope combined with a photometer similar to that described by BERNHARDT (1987).

A ZEISS WTiC-standard was used for measurements in air and in immersion oil (DIN 58.884) as well as a plane-glass reflector with 20× objectives (effective numerical apertures: 0.2).

The reflectance data and color values relative to CIE illuminant C are summarized in Table 1 with the spectra shown in Fig. 1.

X-ray crystallography

The X-ray powder diffraction pattern of belendorffite is almost identical with the pattern of the synthetic, rhombohedrally distorted, pseudo-cubic Cu_7Hg_6 (Table 2) of LINDAHL et al. (1968), but differs distinctly from the pattern of kolymite (MARKOVA et al., 1980; CIPRIANI & MAZZETTI, 1989) and synthetic kolymite (SCHOSZBERGER, 1935). Using the data of LINDAHL et al. (1968) and LINDAHL & WESTMAN (1969), the powder pattern of belendorffite (Guinier camera, $CuK\alpha_1$-radiation, intensities visually estimated) was indexed as given in Table 2. The refined unit cell dimensions were calculated as $a_0 = 9.4082(4)$ Å, $a = 90.472(5)°$, $V = 832.67$ Å^3. According to LINDAHL & WESTMAN (1969), the space group of synthetic belendorffite is R3m. The rhombohedral unit cell contains 52 atoms (28 Cu and 24 Hg atoms), i.e. four formula units. The crystal structure is related to gamma brass and may be described as an ordered version of the Cu_5Cd_8 structure type, with Hg in one sixfold and two threefold positions in the primitive unit of the body-centered cell. The structure is related to that derived by SCHOSZBERGER (1935) for cubic Cu_7Hg_6 by an interchange of Cu and Hg between distinct positions.

Chemistry

The analyses were performed with an CAMECA CAMEBAX electron microprobe. As standards analyzed natural HgS and pure copper were used. The measured radiations were $Hg-L\alpha$ and $Cu-K\alpha$ at an acceleration voltage of 20 kV. The data were corrected by using the PAP-procedure of POUCHOU & PICHOIR (1984). As the mineral decomposes very rapidly under the electron beam, a beam current of only five nA (measured on a faraday cup) was used. In addition, the beam was slightly unfocused and scanned over an area of 10×10 μm. Sample and standards were measured under identical conditions.

Table 3. Microprobe analyses of belendorffite (in wt.%; atomic proportions are normalized to Cu + Hg = 13).

No.	1	2	3	4	5	6	7	8	9	10
Hg	73.52	75.14	74.32	73.85	74.00	72.89	73.41	75.09	74.22	74.12
Cu	25.88	24.37	25.88	25.83	25.29	26.91	26.07	24.89	25.41	25.53
Σ	99.40	99.51	100.20	99.68	99.29	99.80	99.48	99.98	99.63	99.65

	microprobe analyses			atomic proportions		
	mean	range	theor.	mean	range	theor.
Hg	74.06	72.89 75.14	73.01	6.22	6.00 6.42	6
Cu	25.61	24.37 26.91	26.99	6.78	6.57 6.99	7
Σ	99.67	99.29 100.20	100.00			

Ten microprobe analyses were obtained on the sample, which are summarized in Table 3. The measured mean composition of Cu = 25.61 wt.% and Hg = 74.06 wt.% is very close to the theoretical composition of Cu_7Hg_6, which requires Cu = 26.99 wt.% and Hg = 73.01 wt.%.

Wet chemical analyses with part of the nodule weighing about one gram using the ICP-method revealed a slightly different composition of Hg = 80.2 wt.% and Cu = 19.5 wt.% (average of three analyses). These results proof that the sample also contained some native mercury closely intergrown with belendorffite.

Direct comparison with kolymite type material

In the course of the approval procedure of belendorffite by the IMA Commission a direct comparison of both minerals, especially of the Guinier powder diffraction patterns of both phases seemed desirable. However, the authors as well as the chairman of the IMA Commission were unable to receive any type material or X-ray diffraction photograph of kolymite from Russian colleagues.

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