

MINERALOGICAL DATA ON SALZBURGITE AND PAARITE, TWO NEW MEMBERS OF THE BISMUTHINITE–AIKINITE SERIES

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ABSTRACT

Salzburgite, $\text{Cu}_{1.6}\text{Pb}_{1.6}\text{Bi}_{6.4}\text{S}_{12}$, with a 4.007(1), b 44.81(1), c 11.513(3) Å, space group $Pmc2_1$, $Z = 4$, and paarite, $\text{Cu}_{1.7}\text{Pb}_{1.7}\text{Bi}_{6.3}\text{S}_{12}$, with a 4.0070(6), b 55.998(8), c 11.512(2) Å, space group $Pm\bar{c}n$, $Z = 5$, are two new Cu–Pb–Bi sulfosalts, found in quartz veins of the Felbertal scheelite deposit, Salzburg Province, Austria. Both occur as rare elongate homogeneous crystals, up to 0.3 mm long and 0.1 mm in diameter, and as lamellae in exsolution pairs. The associated minerals are: bismuthinite derivatives in the range bismuthinite–krupkaite, Ag-bearing lillianite, makovickyite, pavonite, cosalite, cannizzarite, tetradymite, native bismuth, chalcopyrite and pyrite. Salzburgite and paarite are opaque, with a metallic luster and a greyish black streak. In reflected light, they have a greyish white color with distinct anisotropy and perceptible birefractance in air and oil, without internal reflections. Reflectance data are supplied. Microhardness VHN_{50-100} is in the range 2.04–2.46 kg/mm². The average composition of salzburgite is: Cu 4.65, Fe 0.05, Pb 15.97, Bi 61.58, S 17.79, total 100.04 wt.%, from which an empirical formula $\text{Cu}_{1.60}\text{Pb}_{1.64}\text{Bi}_{6.38}\text{S}_{11.97}$ (on the basis of $\text{Bi} + [(\text{Pb} + \text{Cu})/2] = 8$ atoms) can be derived. The calculated density is 6.904 g/cm³. The strongest eight lines in the calculated X-ray powder pattern [d in Å(hkl)] are: 4.015(57)(082), 3.631(100)(043), 3.586(55)(141), 3.552(86)(0.12.1), 3.156(57)(142), 3.136(93)(181), 2.836(94)(182) and 2.560(43)(084). The average composition of paarite is: Cu 4.79, Fe 0.08, Pb 16.74, Bi 60.76, S 17.83, total 100.2 wt.%, from which an empirical formula $\text{Cu}_{1.66}\text{Pb}_{1.71}\text{Bi}_{6.31}\text{S}_{12.03}$ (on the same basis) can be derived. The calculated density is 6.944 g/cm³. The strongest eight lines in the calculated X-ray powder pattern are: 4.014(56)(0.10.2), 3.630(100)(053), 3.585(55)(141), 3.551(85)(0.15.1), 3.155(57)(152), 3.136(92)(1.10.1), 2.836(93)(1.10.2) and 2.560(41)(0.10.4). Salzburgite and paarite are new superstructures of the bismuthinite–aikinite series with a periodicity of order equal to a four-fold, and five-fold multiple, respectively, of the bismuthinite substructure motif.

Keywords: salzburgite, paarite, sulfosalts, new mineral species, bismuthinite–aikinite series, Felbertal, Austria.

SOMMAIRE

Nous décrivons la salzburgite, $\text{Cu}_{1.6}\text{Pb}_{1.6}\text{Bi}_{6.4}\text{S}_{12}$, a 4.007(1), b 44.81(1), c 11.513(3) Å, groupe spatial $Pmc2_1$, $Z = 4$, et la paarite, $\text{Cu}_{1.7}\text{Pb}_{1.7}\text{Bi}_{6.3}\text{S}_{12}$, a 4.0070(6), b 55.998(8), c 11.512(2) Å, groupe spatial $Pm\bar{c}n$, $Z = 5$, deux nouvelles espèces de sulfosalts de Cu–Pb–Bi découvertes dans des veines de quartz à Felbertal, gisement de scheelite, province de Salzburg, en Autriche. On les trouve en rares cristaux allongés homogènes, atteignant une longueur de 0.3 mm et un diamètre de 0.1 mm, et en lamelles d'exsolution dans un hôte. Leurs sont associés: dérivés de bismuthinite dans l'intervalle bismuthinite–krupkaite, lillianite argentifère, makovickyite, pavonite, cosalite, cannizzarite, tétradymite, bismuth natif, chalcopyrite et pyrite. La salzburgite et la paarite sont opaques, avec un éclat métallique et un rayure noir grisâtre. En lumière réfléchie, elles sont blanc grisâtre avec une anisotropie distincte et une biréfractance perceptible dans l'air et dans l'huile, sans réflexions internes. Nous fournissons les données sur la réflectance. La microdureté VHN_{50-100} est dans l'intervalle 2.04–2.46 kg/mm². La composition moyenne de la salzburgite est: Cu 4.65, Fe 0.05, Pb 15.97, Bi 61.58, S 17.79, pour un total de 100.04% (poids), menant à la formule empirique $\text{Cu}_{1.60}\text{Pb}_{1.64}\text{Bi}_{6.38}\text{S}_{11.97}$ (sur une base de $\text{Bi} + [(\text{Pb} + \text{Cu})/2] = 8$ atomes). La densité calculée est 6.904 g/cm³. Les huit raies les plus intenses du spectre de diffraction calculé, méthode des poudres [d en Å(hkl)] sont: 4.015(57)(082), 3.631(100)(043), 3.586(55)(141), 3.552(86)(0.12.1), 3.156(57)(142), 3.136(93)(181), 2.836(94)(182) et 2.560(43)(084). La composition moyenne de la paarite est: Cu 4.79, Fe 0.08, Pb 16.74, Bi 60.76, S 17.83, pour un total de 100.2%, menant à la formule empirique $\text{Cu}_{1.66}\text{Pb}_{1.71}\text{Bi}_{6.31}\text{S}_{12.03}$ (sur la même base). La densité calculée est 6.944 g/cm³. Les huit raies les plus intenses du spectre de diffraction calculé, méthode des poudres, sont: 4.014(56)(0.10.2), 3.630(100)(053), 3.585(55)(141), 3.551(85)(0.15.1), 3.155(57)(152), 3.136(92)(1.10.1),

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2.836(93)(1.10.2) et 2.560(41)(0.10.4). La salzburgite et la paarite présentent de nouvelles surstructures de la série bismuthinite–aikinite avec une périodicité de mise en ordre de quatre et cinq, respectivement, du motif substructural de la bismuthinite.

(Traduit par la Rédaction)

Mots-clés: salzburgite, paarite, sulfosel, nouvelles espèces minérales, série bismuthinite–aikinite, Felbertal, Autriche.

INTRODUCTION

Detailed electron-microprobe and single-crystal X-ray-diffraction investigations of the sulfosalt material from the scheelite deposit of Felbertal, Hohe Tauern, Austria, have yielded two new members of the bismuthinite–aikinite series of ordered derivatives of the high-temperature $\text{Bi}_2\text{S}_3\text{--CuPbBiS}_3$ solid-solution series. Both minerals occur as independent grains and as lamellae in composite exsolution-induced intergrowths. The chemical compositions and crystal structures of these phases were determined first, as proof that they were new, independent minerals; collection of the relevant mineralogical data required additional efforts. As a result, their concise chemistry and unit-cell data were tabulated by Topa *et al.* (2002a); their structures were published by Topa *et al.* (2000) and Makovicky *et al.* (2001). The present contribution completes the mineralogical definition of these two minerals.

MODE OF OCCURRENCE

The scheelite deposit of Felbertal (Höll & Schenk 1987) is located in the Hohe Tauern, about 10 km south of the town of Mittersill, Salzburg province, in Austria. The scheelite ore is hosted by a sequence of metabasalts, metagabbros and orthogneisses accompanied by Variscan granites (Eichhorn *et al.* 2000). The deposit consists of two parts, or so-called “ore fields”. Paarite and salzburgite occur in the Western Ore Field, which consists of several distinct orebodies (K1–K8), mined underground.

Scheelite formed in three distinct generations (Höll 1975); it is associated with Be minerals, fluorite, and a variety of sulfides and sulfosalts. Dominant sulfides are pyrrhotite, pyrite, chalcopyrite, and members of the molybdenite–tungstenite solid solution. A spectrum of minor sulfides and Sn–W minerals occur as well (Höll 1975). Sulfosalts occur as lens-shaped nests, fine layers of grains and crystals, as well as irregular aggregates in bodies, veins and layers of quartz in amphibolites, gneisses and scheelite ore. Galenobismutite, cosalite, members of the bismuthinite–aikinite series of homeotypes, members of the lillianite-, pavonite-, junoitite- and cuprobismutite homologous series, cannizzarite, eclarite, selected Te minerals and native bismuth are abundant (Topa *et al.* 2002a).

The mineralization process that formed the ore and sulfosalt assemblage is considered to be a product of Variscan magmatic events; it was subsequently

subjected to the Alpine prograde metamorphism of the upper greenschist – lower amphibolite facies, followed by retrograde recrystallization. Formation of native Bi clearly postdates the growth of sulfides (Topa *et al.* 2002a). Additional data on the Felbertal deposit are summarized in Topa (2001). Both sulfosalts described here are found in associations relatively poor in copper: the associated minerals are other sulfosalts in the range gladite–krupkaite, the gustavite–lillianite solid solution, pavonite and makovickyite, traces of cosalite, cannizzarite, tetradymite, native Bi, chalcopyrite, and pyrite, all hosted in quartz.

PHYSICAL PROPERTIES

Paarite, present in larger amounts than *salzburgite*, permitted the determination of more physical properties. Both minerals form rare, elongate crystals, up to 0.2 mm in length for the former, 0.3 mm for the latter. Both are light grey, opaque with metallic luster, and brittle with an uneven fracture. Perfect $\{0kl\}$ cleavage could be observed for paarite. With a VHN load of 50 g (12 indentations on four grains), a mean value of microhardness of 204 kg/mm² was observed (range 170–228); with a load of 100 g (14 micro-indentations on four grains), these values are 246 kg/mm² (range 195–286). A Mohs hardness of 3.3–3.6 was calculated from the micro-indentation data. No microhardness data could be obtained from salzburgite owing to the scarcity of suitable crystals. Density calculated from the single-crystal data is 6.944 g/cm³ for paarite and 6.904 g/cm³ for salzburgite.

In reflected light, *paarite* is white with a creamy tint, with bireflectance perceptible in air and moderate in oil. It shows weak pleochroism in white and creamy tints, enhanced in oil. Internal reflections are absent; anisotropy is distinct in air and strong in oil. *Salzburgite* is greyish white, with similar properties, but pleochroism was not observed in the material available. Reflectance of both phases was evaluated in air, using a WTiC standard; the observed R_{\min} and R_{\max} values are given in Table 1. Reflectance values increase with decreasing wavelength in the visible spectrum. The increase is slightly steeper for salzburgite; both R_{\max} curves show a small plateau in the broad region of 540 nm. The differences between the two minerals may be due primarily to the orientation of the available grains rather than to the differences in structure and chemistry. This assumption is confirmed by a comparison with the spectra of gladite and krupkaite in Figure 1.

CHEMICAL DATA

Electron-microprobe analyses were performed using a JEOL JXA-8600 apparatus, controlled by a LINK-*eXL* system, with on-line ZAF correction procedure. Acceleration voltage was 25 kV, beam current 30 nA; selected analytical wavelengths and standards were: $\text{CuK}\alpha$ and $\text{FeK}\alpha$ (natural chalcopyrite), $\text{BiL}\alpha$ and $\text{SK}\alpha$

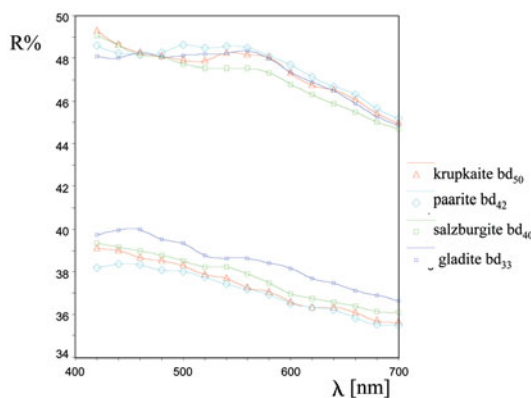


FIG. 1. Reflectance data (R_{\max} and R_{\min}) in air for salzburgite (larger squares), paarite (diamonds), gladite (smaller squares) and krupkaite (triangles).

TABLE 1. REFLECTANCE DATA IN AIR FOR SALZBURGITE AND PAARITE

λ (nm)	salzburgite		paarite	
	R1 %	R2 %	R1 %	R2 %
400	40.47	50.58	38.50	48.74
420	39.40	49.05	38.18	48.58
440	39.18	48.67	38.36	48.24
460	38.97	48.07	38.32	48.16
470	39.15	48.36	38.27	48.23
480	38.75	48.05	38.07	48.26
500	38.57	47.76	38.02	48.61
520	38.15	47.54	37.74	48.48
540	38.22	47.54	37.42	48.56
546	38.26	47.65	37.34	48.56
560	37.85	47.52	37.18	48.50
580	37.46	47.39	36.93	48.09
589	37.23	47.14	36.75	47.90
600	36.94	46.79	36.51	47.68
620	36.71	46.29	36.32	47.13
640	36.50	45.86	36.20	46.69
650	36.55	45.71	36.00	46.53
660	36.37	45.48	35.82	46.32
680	36.16	44.93	35.51	45.65
700	36.08	44.68	35.48	45.21

(synthetic bismuthinite) and $\text{PbL}\alpha$ (galena); no other element with $Z > 11$ was detected.

Composition estimates for both phases are given in Tables 2 and 3. Data for crystals confirmed by single-crystal X-ray diffraction are indicated in bold italics. Analysis of the crystals used for crystal-structure analysis resulted in the empirical formulae $\text{Cu}_{1.66}\text{Pb}_{1.71}\text{Bi}_{6.32}\text{S}_{11.99}$ for paarite (No. 4 in Table 3) and $\text{Cu}_{1.60}\text{Pb}_{1.64}\text{Bi}_{6.38}\text{S}_{11.97}$ for salzburgite (No. 13 in Table 2). These formulae are based on the calculation scheme for cations $\text{Bi} + [(\text{Pb} + \text{Cu})/2] = 8$ atoms. Simplified formulae are $\text{Cu}_{1.7}\text{Pb}_{1.7}\text{Bi}_{6.3}\text{S}_{12}$ for paarite and $\text{Cu}_{1.6}\text{Pb}_{1.6}\text{Bi}_{6.4}\text{S}_{12}$ for salzburgite. The minor differences in composition are real; they are connected with the fact that paarite is a five-fold superstructure, whereas salzburgite is a four-fold superstructure. The structure determinations (Topa *et al.* 2000, Makovicky *et al.* 2001) show that these compositions cannot automatically be reduced to the simple formulae hitherto assumed for all members of the bismuthinite-aikinite series (*e.g.*, Mumme *et al.* 1976, Žák 1980). Paarite is closer to such an ideal composition, whereas salzburgite appears to require a set of partly occupied Cu sites for its stability (Topa *et al.* 2000). The position of salzburgite and paarite in the $\text{Cu}_2\text{S}-\text{Pb}_2\text{S}_2-\text{Bi}_2\text{S}_3$ system is illustrated in Figure 2.

CRYSTALLOGRAPHY

The scarcity of pure material led to single-crystal X-ray-diffraction studies of both phases, and calculation of the theoretical X-ray powder-diffraction patterns based on the respective structures (Topa *et al.* 2000, Makovicky *et al.* 2001). Both minerals are orthorhombic; the four-fold superstructure of salzburgite has the space group $Pmc2_1$, whereas the five-fold superstructure of paarite has the space group $Pm\bar{c}n$. The program and conditions used in calculating the theoretical patterns (Tables 4, 5) were as follows: Powder cell 2.3 software (Kraus & Nolze 1999), Debye-Scherrer configuration, $\text{CuK}\alpha$ radiation, fixed slit, no anomalous dispersion, and structure data from the published descriptions of the structures; isotropic displacement factors.

The unit cell of salzburgite, a four-fold supercell of the Bi_2S_3 cell, contains eight Me_4S_6 ribbons in an *n*-glide-related herringbone arrangement. Two of these are Bi_4S_6 "bismuthinite-like" ribbons, and six are $\text{CuPbBi}_3\text{S}_6$ "krupkaite-like" ribbons (Fig. 3a). This scheme is complicated by the presence of two partially occupied (10%) tetrahedral Cu sites, resulting in a statistical presence of a few aikinite-like ribbons in the structure (Topa *et al.* 2000).

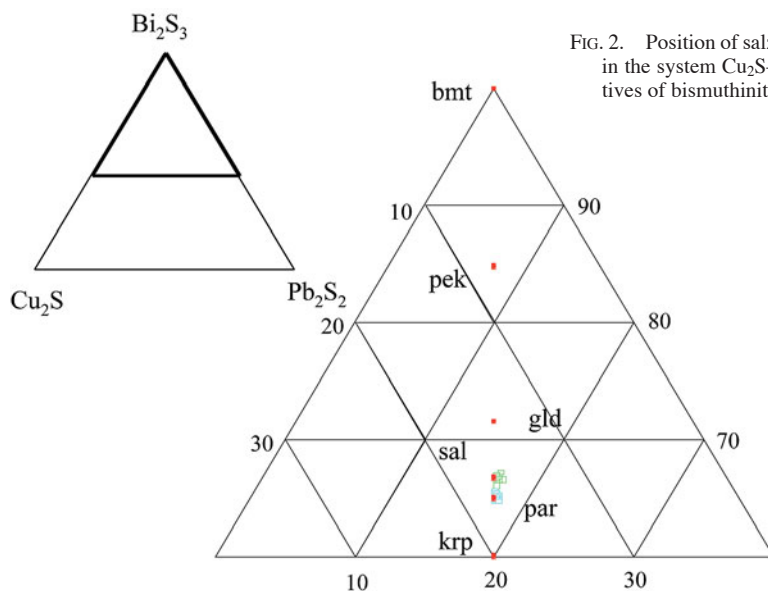


FIG. 2. Position of salzburgite (green) and paarite (turquoise) in the system $\text{Cu}_2\text{S}-\text{Pb}_2\text{S}_2-\text{Bi}_2\text{S}_3$ (in at. %). Other derivatives of bismuthinite are shown in red.

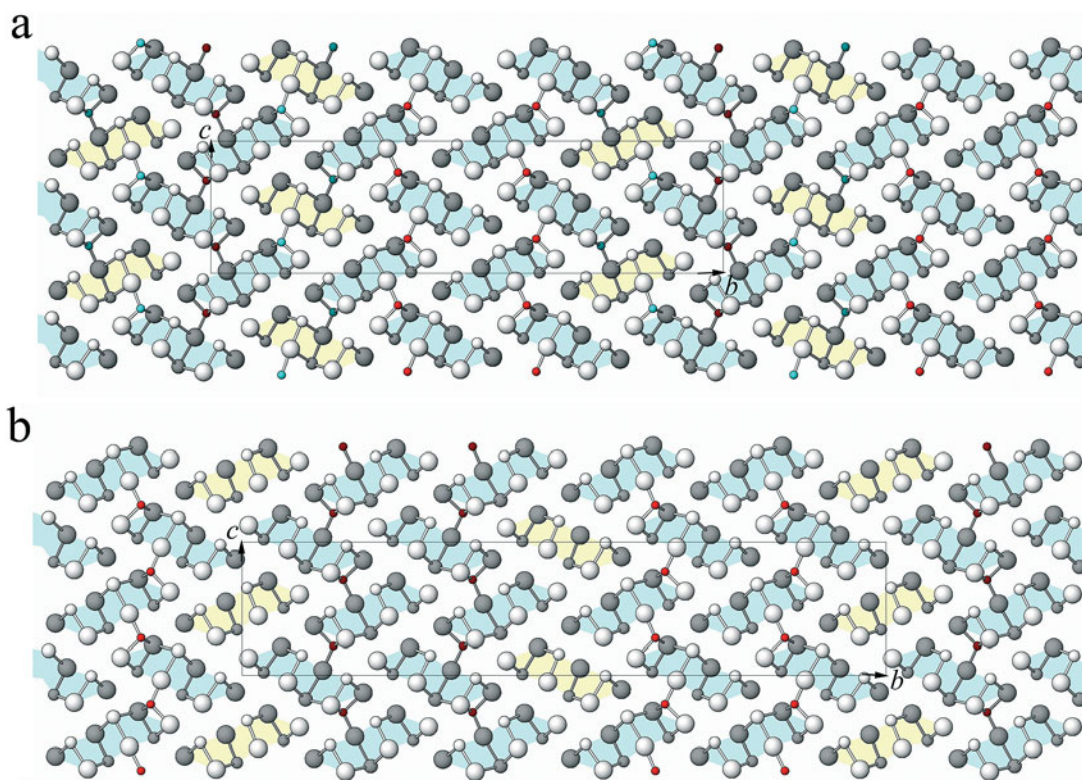


FIG. 3. The crystal structures of (a) salzburgite and (b) paarite. Atoms in the order of decreasing size: S, Pb, Bi and Cu. Light and dark atoms are at two levels, $\frac{1}{2}a$ apart. Bismuthinite-like ribbons are yellow, krupkaite-like ribbons are blue. Fully occupied Cu positions are indicated in red, partially occupied Cu sites in blue.

TABLE 2. CHEMICAL COMPOSITION OF SALZBURGITE FROM FELBERTAL, AUSTRIA

No.	Sample	Cu	Fe	Pb	Bi	S	Total	n_{aik}	n_k	Δn_{aik}	ch	ev	Pb/Cu
1	FE-97/3b-22	4.54	0.07	15.63	61.85	17.79	99.88	39.64	79.28	0.40	0.07	0.29	1.02
2	FE-97/3a-45	4.54	0.09	15.91	61.83	17.97	100.33	39.90	79.80	0.61	-0.11	-0.46	1.03
3	FE-97/3a-13a	4.69	0.00	15.71	62.66	18.04	101.11	39.94	79.88	0.54	-0.01	-0.04	1.03
4	FE-97/3a-18	4.70	0.00	15.63	62.52	17.80	100.66	39.96	79.92	0.39	0.25	1.05	1.02
5	FE-97/3-P211	4.68	0.00	15.67	62.47	17.80	100.62	39.96	79.92	0.52	0.25	1.05	1.03
6	FE97/3-sg3b	4.62	0.00	15.64	61.97	17.82	100.05	39.98	79.97	0.75	0.04	0.17	1.04
7	FE97/3-sg3a	4.64	0.00	15.49	61.75	17.82	99.70	40.00	79.99	0.49	-0.05	-0.21	1.03
8	FE-97/3a-10a	4.71	0.00	15.75	62.71	17.90	101.07	40.01	80.02	0.53	0.20	0.84	1.03
9	FE97/3-sg2	4.65	0.00	15.47	61.70	17.87	99.69	40.06	80.11	0.39	-0.14	-0.58	1.02
10	FE-97/3-sg26	4.64	0.00	15.47	61.53	17.89	99.53	40.12	80.24	0.43	-0.22	-0.91	1.02
11	FE-97/3b-23	4.62	0.05	15.99	62.07	17.73	100.46	40.20	80.39	0.75	0.29	1.22	1.04
12	FE-97/3b-1	4.62	0.05	16.06	61.89	17.81	100.44	40.38	80.76	0.83	0.15	0.63	1.04
13	FE-97/3b-21*	4.65	0.05	15.97	61.58	17.79	100.04	40.52	81.04	0.58	0.08	0.33	1.03
14	FE-97/3a-13	4.77	0.00	15.79	61.89	18.11	100.57	40.71	81.41	0.29	-0.29	-1.19	1.01
15	FE-97/3b-23	4.68	0.05	16.11	61.65	17.80	100.30	40.75	81.51	0.58	0.13	0.54	1.03
16	FE-97/3a-20	4.81	0.00	16.15	62.07	17.83	100.86	41.10	82.21	0.61	0.22	0.92	1.03
17	"bd41"-gr2*	4.72	0.06	16.31	61.54	17.90	100.52	41.13	82.27	0.62	0.02	0.08	1.03
18	FE-97/3b-4'd	4.73	0.06	16.23	61.27	17.81	100.10	41.21	82.42	0.51	0.04	0.17	1.02
19	FE-97/3a-40	4.70	0.07	16.35	61.20	18.01	100.34	41.27	82.54	0.64	-0.23	-0.95	1.03

1) Cu_{1.57}Pb_{1.60}Bi_{6.41}S_{11.97}
 2) Cu_{1.57}Pb_{1.62}Bi_{6.40}S_{12.07}
 3) Cu_{1.58}Pb_{1.62}Bi_{6.40}S_{12.01}
 4) Cu_{1.58}Pb_{1.61}Bi_{6.40}S_{11.88}
 5) Cu_{1.58}Pb_{1.62}Bi_{6.40}S_{11.89}
 6) Cu_{1.57}Pb_{1.62}Bi_{6.40}S_{11.99}

7) Cu_{1.58}Pb_{1.62}Bi_{6.40}S_{12.04}
 8) Cu_{1.58}Pb_{1.62}Bi_{6.40}S_{11.91}
 9) Cu_{1.59}Pb_{1.62}Bi_{6.40}S_{12.08}
 10) Cu_{1.59}Pb_{1.62}Bi_{6.40}S_{12.12}
 11) Cu_{1.58}Pb_{1.64}Bi_{6.39}S_{11.87}
 12) Cu_{1.58}Pb_{1.65}Bi_{6.38}S_{11.94}

13) Cu_{1.60}Pb_{1.64}Bi_{6.38}S_{11.97}
 14) Cu_{1.62}Pb_{1.64}Bi_{6.37}S_{12.15}
 15) Cu_{1.61}Pb_{1.65}Bi_{6.37}S_{11.95}
 16) Cu_{1.62}Pb_{1.67}Bi_{6.36}S_{11.90}
 17) Cu_{1.62}Pb_{1.67}Bi_{6.35}S_{12.00}
 18) Cu_{1.63}Pb_{1.67}Bi_{6.35}S_{11.99}
 19) Cu_{1.63}Pb_{1.68}Bi_{6.35}S_{12.13}

Notes: n_{aik} indicates the percentage of the aikinite component, CuPbBi₃S₆, in the analyzed phase when considered as an intermediate member of the Bi₂S₃-CuPbBi₃S₆ solid-solution series; the uncertainty of this estimate, based on the Pb/Cu ratio deviating from 1, is Δn_{aik} . n_k indicates the percentage of the krupkaite component, CuPbBi₃S₆ (*i.e.*, the ideal percentage of krupkaite-like ribbons besides the bismuthinite-like ribbons in the structure). ch and ev express the absolute and relative error in the charge balance based on the sums of cation and anion charges. * indicates the crystals used for single-crystal structural investigation.

The unit cell of paarite, a five-fold supercell of the Bi₂S₃ cell, has ten *Me*₄S₆ ribbons distributed as two Bi₂S₃ ribbons and eight CuPbBi₃S₆ ribbons (Fig. 3b). No partially occupied Cu sites were located in the structure determination (Makovicky *et al.* 2001), but this was done on a sample from the lower end of the composition range of paarite shown in Table 3.

In an alternative description, with reference to the structures of gladite CuPbBi₅S₉ (a three-fold superstructure) and krupkaite CuPbBi₃S₆ (a one-fold structure) by Topa *et al.* (2002b), which respectively have 1.5 and one subcell wide structure intervals between the adjacent (010) planes of occupied Cu coordination tetrahedra, the structures of our phases can be described as ordered sequences of such "structure modules". They can be denoted as "G" and "K", respectively (Ferraris *et al.* 2004). Salzbergite displays the sequence GGK, whereas paarite displays the sequence GK.

In addition to forming independent columnar aggregates, these minerals appear as exsolution lamellae in two-component aggregates formed by decomposition of intermediate compositions of the aikinite-bismuthinite series (Fig. 4). Salzbergite participates in krupkaite-salzbergite and gladite-salzbergite intergrowths, whereas paarite especially appears in paarite-krupkaite intergrowths, although the paarite-gladite intergrowths are known as well, as was also confirmed by X-ray single-crystal studies. Pre-exsolution bulk compositions lie anywhere between 40 and 47 mol.% of the aikinite component. These exsolution-induced products and their chemical development toward the most stable associations have been treated in detail by Topa *et al.* (2002a). In this process, the assemblage paarite-krupkaite is first replaced by the pair salzbergite-krupkaite and, during the final step, by the most stable association, gladite-krupkaite. So far, the Felbertal deposit appears

to be the only confirmed occurrence of these two metastable, higher-entropy minerals; they escaped the effects of re-equilibration because they are encased in a quartz host in metamorphic rocks.

MINERAL NAMES AND TYPE MATERIAL

Paarite is named after Werner Hermann Paar (b. 1942), Professor of Mineralogy at the University of

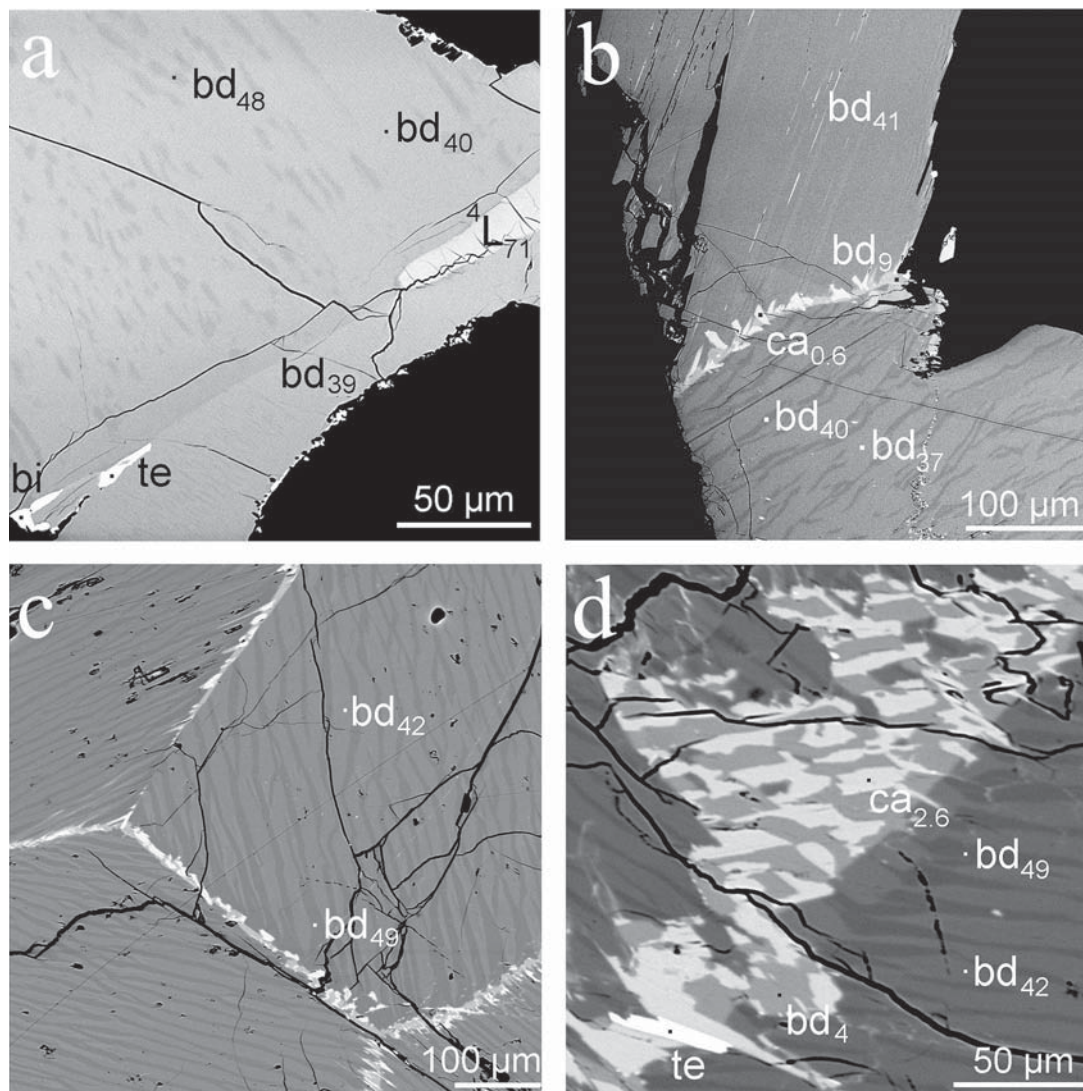


FIG. 4. a. A lamella of copper-oversubstituted gladite (bd_{39}) (the subscript indicates the n_{aik} value, explained in the caption to Table 2) with incipient exsolution; above it is a large crystal of salzburgite (bd_{40}) with lamellae of krupkaite (bd_{48}). Grains of native bismuth, Bi telluride and gustavite are indicated. b. Above: a crystal of salzburgite (bd_{41}) with several exsolution-induced lamellae; below: exsolution intergrowth of oversubstituted gladite (bd_{37}) with salzburgite (bd_{40}). A replacement intergrowth of Ag-poor cannizzarite ($ca_{0.6}$) and cupro-plumbian bismuthinite (bd_9) developed at the grain junction. c. A mosaic of large grains of a low-Cu bismuthinite derivative, decomposed into an intergrowth of paarite (bd_{42}) and krupkaite (bd_{49}). Replacement aggregates composed of cupro-plumbian bismuthinite (light grey) and cannizzarite (white) are developed along grain boundaries. d. Graphic intergrowth of cannizzarite ($ca_{2.6}$) and bismuthinite developed between grains of a bismuthinite derivative, exsolved into paarite (bd_{42}) - krupkaite (bd_{49}) intergrowths. Note the substantial lamellae of krupkaite close to the boundary of the light-colored, low-Cu intergrowth, indicating a Bi-rich zone predating the exsolution. a-d: Back-scattered electron images, material from Felbertal, Austria.

TABLE 3. CHEMICAL COMPOSITION OF PAARITE FROM FELBERTAL, AUSTRIA

No.	Sample	Cu	Fe	Pb	Bi	S	Total	n_{calc}	n_k	Δn_{calc}	ch	ev	Pb/Cu
1	FE-97/3a-15a	4.89	0.00	16.31	61.56	17.92	100.68	41.82	83.64	0.45	0.01	0.04	1.02
2	FE-97/3-sg97b	4.85	0.00	16.15	60.76	17.77	99.53	41.95	83.89	0.42	-0.09	-0.37	1.02
3	FE-97/3a-23matr	4.92	0.00	16.44	61.60	17.80	100.76	42.01	84.02	0.53	0.22	0.92	1.03
4	FE-97/3-sg56*	4.79	0.08	16.74	60.76	17.83	100.20	42.18	84.36	0.58	-0.05	-0.21	1.03
5	FE-97/3-sg20	4.89	0.00	16.29	60.43	17.95	99.56	42.40	84.80	0.45	-0.39	-1.60	1.02
6	FE-97/3-sg2	4.93	0.08	16.52	60.63	17.83	99.98	42.48	84.95	-0.17	-0.03	-0.12	0.99
7	FE97/3-sg9a	4.95	0.04	16.58	61.03	18.07	100.67	42.49	84.97	0.20	-0.25	-1.03	1.01
8	FE-97/3-sg110	4.91	0.00	16.37	60.54	17.88	99.70	42.49	84.98	0.47	-0.24	-0.99	1.02
9	FE-97/3-sg100	4.87	0.00	16.39	60.28	17.73	99.26	42.50	84.99	0.68	-0.12	-0.50	1.03
10	FE-97/3-sg62*	4.85	0.08	16.71	60.35	17.87	99.86	42.57	85.13	0.37	-0.16	-0.66	1.02
11	FE97/3-sg3c-m	4.97	0.00	16.32	60.39	17.79	99.47	42.72	85.44	0.14	-0.15	-0.62	1.01
12	FE-97/3-sg374.96	0.00	16.53	60.58	17.61	99.68	42.79	85.57	0.47	0.19	0.80	1.02	

1) $\text{Cu}_{1.65}\text{Pb}_{1.69}\text{Bi}_{6.33}\text{S}_{12.00}$ 5) $\text{Cu}_{1.68}\text{Pb}_{1.71}\text{Bi}_{6.30}\text{S}_{12.21}$ 9) $\text{Cu}_{1.67}\text{Pb}_{1.73}\text{Bi}_{6.30}\text{S}_{12.07}$
2) $\text{Cu}_{1.66}\text{Pb}_{1.69}\text{Bi}_{6.32}\text{S}_{12.05}$ 6) $\text{Cu}_{1.71}\text{Pb}_{1.69}\text{Bi}_{6.30}\text{S}_{12.01}$ 10) $\text{Cu}_{1.69}\text{Pb}_{1.72}\text{Bi}_{6.30}\text{S}_{12.09}$
3) $\text{Cu}_{1.66}\text{Pb}_{1.70}\text{Bi}_{6.32}\text{S}_{11.90}$ 7) $\text{Cu}_{1.69}\text{Pb}_{1.71}\text{Bi}_{6.30}\text{S}_{12.13}$ 11) $\text{Cu}_{1.70}\text{Pb}_{1.71}\text{Bi}_{6.29}\text{S}_{12.08}$
4) $\text{Cu}_{1.66}\text{Pb}_{1.71}\text{Bi}_{6.31}\text{S}_{12.03}$ 8) $\text{Cu}_{1.68}\text{Pb}_{1.72}\text{Bi}_{6.30}\text{S}_{12.13}$ 12) $\text{Cu}_{1.69}\text{Pb}_{1.73}\text{Bi}_{6.29}\text{S}_{11.92}$

Compositions are expressed in wt. %.

TABLE 4. CALCULATED POWDER-DIFFRACTION DATA FOR SALZBURGITE

<i>h</i>	<i>k</i>	<i>l</i>	<i>d</i>	<i>I</i>	<i>h</i>	<i>k</i>	<i>l</i>	<i>d</i>	<i>I</i>	<i>h</i>	<i>k</i>	<i>l</i>	<i>d</i>	<i>I</i>	<i>h</i>	<i>k</i>	<i>l</i>	<i>d</i>	<i>I</i>
0	4	1	8.03	3.1	0	0	4	2.878	3.7	0	15	4	2.073	1.1	1	16	4	1.7947	1.2
0	0	2	5.76	16.7	1	8	2	2.836	93.5	1	17	2	2.057	1.2	1	11	5	1.7928	1.8
0	0	2	5.76	16.7	0	16	0	2.801	3.6	1	15	3	2.032	1.4	2	8	2	1.7928	10.1
0	8	0	5.60	3.2	1	12	0	2.732	21.2	0	16	4	2.007	3.5	1	21	2	1.7902	1.8
0	3	2	5.37	1.6	0	16	1	2.721	3.4	2	0	0	2.004	37.2	0	24	2	1.7761	2.4
0	4	2	5.12	20.2	0	12	3	2.676	1.4	1	12	4	1.9815	1.2	0	25	1	1.7712	1.2
0	11	0	4.07	3.5	1	12	1	2.658	36.7	1	16	3	1.9701	36.5	0	20	4	1.7681	1.3
0	8	2	4.015	57.3	0	7	4	2.625	2.9	1	4	5	1.9656	8.0	1	12	5	1.7607	11.3
0	11	1	3.841	3.9	0	8	4	2.560	42.9	0	12	5	1.9600	10.5	2	4	3	1.7543	20.4
1	4	0	3.773	29.0	0	16	2	2.519	15.7	1	20	0	1.9557	16.2	1	23	0	1.7522	1.3
0	9	2	3.766	1.5	0	9	4	2.492	2.0	1	5	5	1.9488	1.2	2	12	1	1.7452	18.9
0	3	3	3.717	3.3	1	8	3	2.484	21.5	0	20	3	1.9350	22.2	1	20	3	1.7425	3.6
0	4	3	3.631	100	1	12	2	2.468	1.6	1	20	1	1.9281	3.1	1	0	6	1.7307	10.4
1	4	1	3.586	55.3	1	0	4	2.338	23.8	0	0	6	1.9189	9.8	1	4	6	1.7104	4.5
0	12	1	3.552	85.8	1	1	4	2.335	4.0	0	1	6	1.9171	1.5	0	12	6	1.7068	2.0
0	5	3	3.528	1.4	1	4	4	2.289	30.2	1	17	3	1.9101	1.1	2	8	3	1.6931	1.9
0	13	0	3.447	4.0	0	12	4	2.280	2.9	1	7	5	1.9060	1.2	2	12	2	1.6880	1.8
0	7	3	3.292	1.7	0	16	3	2.262	3.2	2	0	2	1.8924	1.7	1	24	1	1.6745	3.1
1	0	2	3.289	18.9	1	16	1	2.251	21.5	0	4	6	1.8913	1.2	1	8	6	1.6536	1.8
1	1	2	3.280	3.1	1	12	3	2.226	6.0	1	8	5	1.8807	8.8	2	0	4	1.6445	1.1
1	3	2	3.212	1.4	1	15	2	2.211	4.2	0	24	0	1.8672	7.9	0	27	1	1.6427	1.3
0	8	3	3.166	8.6	0	20	1	2.199	3.5	2	4	2	1.8659	2.1	2	16	0	1.6296	1.1
1	4	2	3.156	56.9	0	17	3	2.173	2.1	1	20	2	1.8518	1.6	1	16	5	1.6258	3.9
1	8	1	3.136	92.9	1	17	1	2.163	1.9	0	24	1	1.8431	1.3	1	25	1	1.6200	1.3
0	12	2	3.133	7.2	1	8	4	2.157	9.3	0	7	6	1.8381	1.0	2	16	1	1.6135	1.2
1	5	2	3.088	2.2	1	16	2	2.132	15.0	0	19	4	1.8243	1.3	0	8	7	1.5781	1.0
0	9	3	3.040	1.7	0	8	5	2.130	7.9	0	8	6	1.8153	1.2	2	8	4	1.5779	14.7
1	9	1	3.013	2.3	0	20	2	2.088	4.3	1	19	3	1.7963	1.7	1	12	6	1.5703	1.9

Reflections with $I_{\text{calc}} < 1.0$ have been omitted.

TABLE 5. CALCULATED POWDER-DIFFRACTION DATA FOR PAARITE

<i>h k l</i>	<i>d</i>	<i>I</i>	<i>h k l</i>	<i>d</i>	<i>I</i>	<i>h k l</i>	<i>d</i>	<i>I</i>	<i>h k l</i>	<i>d</i>	<i>I</i>
0 5 1	8.03	3.0	110 2	2.836	92.6	121 2	2.071	1.6	210 2	1.7926	8.9
0 0 2	5.76	16.0	020 0	2.800	3.7	019 4	2.059	1.0	114 5	1.7862	1.8
010 0	5.60	2.9	0 5 4	2.788	1.1	119 3	2.019	1.8	124 3	1.7849	1.6
0 4 2	5.32	2.4	115 0	2.731	19.8	020 4	2.007	3.1	031 1	1.7846	1.2
0 5 2	5.12	19.3	020 1	2.721	3.3	2 0 0	2.004	34.5	030 2	1.7756	2.0
010 2	4.01	56.3	015 3	2.676	1.2	115 4	1.9812	1.2	115 5	1.7605	9.5
014 0	4.000	5.0	115 1	2.658	36.4	1 4 5	1.9764	1.0	2 5 3	1.7541	18.0
011 2	3.813	1.5	0 9 4	2.612	3.7	120 3	1.9697	32.0	215 1	1.7449	16.5
014 1	3.778	4.6	010 4	2.560	40.6	1 5 5	1.9654	7.0	125 3	1.7421	3.0
1 5 0	3.773	28.1	114 2	2.540	1.1	015 5	1.9597	9.5	129 0	1.7395	1.2
0 4 3	3.701	4.3	020 2	2.518	15.6	125 0	1.9552	14.7	1 0 6	1.7306	8.9
0 5 3	3.630	100.0	011 4	2.505	2.8	1 6 5	1.9522	1.4	1 5 6	1.7103	3.8
1 5 1	3.585	55.3	110 3	2.484	20.2	025 3	1.9345	19.9	015 6	1.7065	1.8
015 1	3.551	84.7	115 2	2.468	1.7	125 1	1.9276	2.7	210 3	1.6929	1.5
0 6 3	3.549	1.7	1 0 4	2.338	21.7	121 3	1.9216	1.3	215 2	1.6878	1.5
016 0	3.500	4.9	1 1 4	2.336	5.0	0 0 6	1.9187	8.5	130 1	1.6740	2.5
1 0 2	3.289	18.1	1 5 4	2.288	28.1	0 1 6	1.9176	1.6	110 6	1.6534	1.6
1 1 2	3.283	4.3	015 4	2.279	2.7	124 2	1.9030	1.0	2 0 4	1.6443	1.0
0 9 3	3.266	2.1	020 3	2.262	2.8	1 9 5	1.9009	1.3	034 1	1.6304	1.3
1 9 1	3.233	1.2	120 1	2.251	20.3	2 0 2	1.8922	1.4	131 1	1.6302	1.2
1 4 2	3.202	1.8	115 3	2.225	6.0	0 5 6	1.8912	0.9	220 0	1.6293	1.0
010 3	3.166	7.8	025 1	2.199	3.2	110 5	1.8804	7.7	120 5	1.6255	3.5
1 5 2	3.155	57.2	119 2	2.195	4.9	030 0	1.8666	7.1	220 1	1.6133	1.0
110 1	3.136	92.4	021 3	2.190	2.1	2 5 2	1.8657	1.8	2 9 4	1.5897	1.0
015 2	3.132	7.1	121 1	2.180	1.8	125 2	1.8513	1.3	210 4	1.5777	12.2
1 6 2	3.102	2.7	110 4	2.157	8.7	0 9 6	1.8335	1.1	115 6	1.5701	1.4
011 3	3.064	2.0	120 2	2.132	13.4	024 4	1.8125	1.4	220 2	1.5677	4.7
111 1	3.037	2.9	010 5	2.130	7.2	126 2	1.8018	1.8	030 4	1.5661	2.3
0 0 4	2.878	3.8	025 2	2.087	4.0	120 4	1.7944	1.2	035 2	1.5415	2.8

Salzburg, for his contributions to ore mineralogy. He was the first to recognize the potential of the sulfosalt mineralization of the Austrian Alps, and especially of the Felbertal tungsten deposit. *Salzburgite* is named after the province of Salzburg in the Republic of Austria, in which the Felbertal deposit is located. Holotype samples have been deposited at the Geological Museum of the University of Copenhagen (Denmark) and in the reference collection of the Mineralogical Institute, University of Salzburg.

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