

Bernardite, a new thallium arsenic sulphosalt from Allchar, Macedonia, with a determination of the crystal structure

J. PAŠAVA

Ustredni ústav geologický, CS-118 21 Praha, Czechoslovakia

F. PERTLIK

Institut fuer Mineralogie und Kristallographie, Universitaet Wien, A-1010 Wien, Austria

E. F. STUMPFL

Institut fuer Mineralogie und Petrologie, Montanuniversitaet, A-8700 Leoben, Austria

AND

J. ZEMANN

Institut fuer Mineralogie und Kristallographie, Universitaet Wien, A-1010 Wien, Austria

Abstract

The new mineral bernardite has been identified on one specimen from Allchar, Macedonia, Yugoslavia, together with orpiment and realgar. It forms black crystals, the size of which may exceed 1 mm. The streak is deep red; on an arbitrarily oriented section $R(589\text{ nm})$ ranges from 23.8 to 24.7% in air, from 10.2 to 11.6% in oil. Microprobe analyses together with an X-ray structure analysis suggest the ideal formula TlAs_5S_8 , with a possible replacement of As by Sb up to 15 wt. %. Monoclinic; a 15.647(4), b 8.038(3), c 10.750(3) Å, β 91.27(3)°; space group $P2_1/c$; $Z = 4$; $R = 0.049$, $wR = 0.036$ for 2410 reflections. The atomic arrangement consists of a 3-dimensional As_5S_8 framework with eight-coordinated Tl in its holes. The mineral is named for Doc. Dr Jan H. Bernard, Prague, Czechoslovakia.

KEYWORDS: bernardite, new mineral, thallium sulpharsenite, Allchar, Macedonia, TlAs_5S_8 .

Introduction

THE AS-Sb-Tl deposit of Allchar (other spellings Allshar and Alshar) in the south of Macedonia, Yugoslavia, is world-famous for its thallium minerals. It is the type locality of the well known species lorandite, TlAsS_2 , and vrbaitite, $\text{Tl}_4\text{Hg}_3\text{As}_8\text{Sb}_2\text{S}_{20}$ (formula according to Caye *et al.*, 1967, and Ohmasa and Nowacki, 1971). Within the last few decades the following new minerals were first described from this locality: raguinite, TlFeS_2 (Laurent *et al.*, 1969); picotpaulite, TlFe_2S_3 (Johan *et al.*, 1970); parapierrrotite, TlSb_5S_8 (Johan *et al.*, 1975); rebulite, $\text{Tl}_5\text{As}_8\text{Sb}_5\text{S}_{22}$ (Balić-Žunić *et al.*, 1982); simonite, $\text{TlHgAs}_3\text{S}_6$ (Engel *et al.*, 1982); and an unnamed mineral with composition Tl_3AsS_4 (El Goresy and Pavićević, 1988; Pavićević and El Goresy, 1988).

This paper adds to this list the monoclinic mineral bernardite with the ideal formula TlAs_5S_8 , and presents also its crystal structure. The species and the name were approved by the Commission on New Minerals and Mineral Names, IMA. For a preliminary note see Pašava *et al.* (1988).

Occurrence and general description

Bernardite was found on only one of numerous specimens that were collected by a group of Czech geologists in 1975 and 1976 at the late-Tertiary hydrothermal metasomatic deposit of Allchar, Southern Macedonia, Yugoslavia. For literature on the deposit the reader is referred to Pavlović and Arsenijević (1956), Ivanov (1965, 1986), Jančević (1960, 1982, 1988) and Pavićević (1988). The bernardite-bearing specimen evidently originated in the As-Tl-rich zone of the deposit which

is poor in Sb and which is characteristic for the central part of the southern zone of the ore district (Ivanov, 1965). Its position in the general mineral sequence is unclear: quartz, opal, bravoite, pyrite–arsenopyrite, gold–melnikovite, marcasite–stibnite–vrbaita, lorandite–realgar–orpiment–barite, sulphur, followed by oxidation products (cf. Ivanov, 1965). Bernardite might have formed with the other thallium minerals.

The mineral occurs with realgar and orpiment. It forms black, thick tabular crystals, usually ≤ 1 mm in size, but the largest crystal had dimensions of ca. $4 \times 3 \times 1.5$ mm. The surface of the crystals is only in part well developed, and is commonly corroded.

The name was given in honour of Docent Dr Jan H. Bernard, a metallogenist, ore-deposit geologist, and mineralogist of the Geological Survey of Czechoslovakia, Prague, who first recognized the new mineral and drew our attention to it.

Holotype specimens have been deposited with the mineral collections of the Národní Museum in Prague and of the Naturhistorisches Museum in Vienna. The grains used for the reflectance measurements and for the X-ray work will be kept in the collection of the Institut fuer Mineralogie und Kristallographie der Universitaet Wien.

Physical and chemical characteristics

Our specimen of bernaldite was not suitable for investigation on the optical goniometer because the crystal faces were dull, and in part corroded and/or striated. However, the indexing of the forms of a relatively large, loose crystal (dimensions ~ 1 mm \times 3 mm \times 3 mm) could be effected on a Stoe four-circle X-ray diffractometer. To this end, the cell parameters and the orientation of the grain relative to the internal coordinate system were determined by routine methods. After that, each face was brought into a position parallel to the optical axis of the goniometer by the driving device. This allowed a preliminary determination of the Miller indices. For confirmation, the crystal was automatically turned into the position with the lattice plane corresponding to the indices exactly parallel to the optical axis of the device, and the coincidence was checked by observation with the microscope. Although this procedure is definitely less accurate than optical goniometry, the indices of the forms could be determined unequivocally. Respective to the cell parameters (see below, Table 3, corresponding to $a:1:c = 1.947:1:1.337$, $\beta = 91.27^\circ$) the prominent forms are $\{100\}$, $\{012\}$ and $\{210\}$; subordinate forms are $\{201\}$, $\{201\}$ and $\{010\}$.

No cleavage was observed; the fracture is sub-

Table 1. Minimum (R_1) and maximum (R_2) reflectance values in percent, measured on an arbitrarily oriented section in air and in oil. Standard deviations: < 0.10 .

λ (nm)	N_{oil}	R_1	R_2	im_{R_1}	im_{R_2}
400	1.5363	29.6	32.3	15.3	17.9
420	1.5320	28.9	31.8	14.6	17.6
440	1.5290	28.1	31.3	14.0	17.1
460	1.5262	27.4	30.6	13.3	16.5
480	1.5240	26.8	29.9	12.8	15.8
500	1.5224	26.0	28.9	12.2	14.9
520	1.5210	25.4	27.8	11.7	14.1
540	1.5196	25.0	26.7	11.3	13.3
560	1.5182	24.5	25.8	10.8	12.6
580	1.5168	24.0	25.1	10.4	11.9
600	1.5153	23.6	24.4	10.1	11.3
620	1.5139	23.3	23.9	9.8	10.8
640	1.5125	23.1	23.4	9.5	10.4
660	1.5112	22.9	23.0	9.3	10.0
680	1.5099	22.8	22.8	9.2	9.8
700	1.5085	22.8	22.5	9.1	9.7
470	1.5245	27.1	30.3	13.1	16.1
546	1.5192	24.9	26.5	11.1	13.2
589	1.5160	23.8	24.7	10.2	11.6
650	1.5118	23.0	23.2	9.4	10.2

conchoidal to uneven. The Mohs' hardness is approximately 2. The density of the loose crystal mentioned above was measured using a Berman microbalance. The mean value of several determinations was $D_m = 4.5(1) \text{ g cm}^{-3}$. This is $\sim 10\%$ higher than the theoretical density calculated from the formula TlAs_5S_8 , i.e. $D_x = 4.11 \text{ g cm}^{-3}$ (Cf. Table 3), and also higher than the density calculated from the bernaldite with highest Sb content found by us (cf. Table 2), corresponding approximately to the formula $\text{TlAs}_4\text{SbS}_8$, which led to $D_x = 4.34 \text{ g cm}^{-3}$. A possible explanation for our experimental result would be that the crystal used contained inclusions of another mineral with higher density, e.g. lorandite.

Only one grain could be used for reflectance work. Minimum and maximum values were measured with polarized light in air and in oil on a carefully polished, but arbitrarily oriented, section from 400 to 700 nm in steps of 20 nm. The results, together with those for the four recommended wavelengths of the Commission on ore Mineralogy (COM) of the IMA, are given in Table 1. The reflectance standards used were (W, Ti)C and SiC, and immersion measurements were made with a liquid conforming to DIN 58884.

The chemical composition was determined by

Table 2. Six microprobe point-analyses of one grain of bernardite (weight-%).

	1	2	3	4	5	6	TlAs ₅ S ₈
Tl	23.3	23.4	22.0	22.7	22.5	22.8	24.46
As	43.7	43.4	35.7	35.2	35.7	36.4	44.84
Sb	0.1	0.4	9.3	10.4	10.2	10.0	-
S	31.5	32.6	31.1	29.8	29.9	31.8	30.70
	98.6	99.8	98.1	98.1	98.3	101.0	100.00

Operating conditions: 25 kV excitation voltage, 10 nA specimen current. Lines used: Tl-L α , As-K α and S-K α . Standards: natural lorandite for Tl, As, and S; natural stibnite for Sb.

electron-microprobe analysis, using natural lorandite and stibnite as standards. Due to the lack of material, only six point analyses on one grain were made; the results are given in Table 2. The formulae derived from the analytical results vary approximately between $\text{Tl}(\text{As}_{1-x}\text{Sb}_x)_5\text{S}_8$ and $\text{Tl}(\text{As}_{1-x}\text{Sb}_x)_5\text{S}_9$, with $0.0 \leq x \leq 0.15$. As the structure determination clearly corresponds to the first formula, we consider this to be the correct one. According to our analyses, the ratio Sb/As is not constant throughout the investigated grain; the experimental values of x cluster around 0.0 and 0.14.

X-ray crystallography and structure determination

Preliminary photographic single-crystal X-ray work showed that bernardite is monoclinic with space group $P2_1/c$. The crystallographic constants as obtained by a least-squares refinement of the Bragg angles of 56 reflections ($18^\circ < \theta < 23^\circ$), carefully measured on a four-circle X-ray diffractometer, are presented in Table 3.

The structure was determined from nearly 4000 single crystal reflections by direct methods and least-squares refinement; details are given in Table 3. Complex neutral-atomic scattering factors (Cromer and Waber, 1974) were used in all calculations. Table 4 presents the atomic coordinates and the anisotropic displacement parameters (Brock, 1984; Fischer and Tillmanns, 1988); the latter do not show unusual values. The average value of the ratio (longest axis)/(shortest axis) of the r.m.s. displacement ellipsoids is 1.3(2), the largest value results for As(1) with 1.8. In a final difference Fourier synthesis, the largest residual peaks had a height of approximately one tenth of that of the S atoms. They occur mainly

near to As(1), but the height never exceeded 10% of a sulphur atom.

Lists of observed and calculated structure amplitudes have been deposited at the Institut fuer Mineralogie und Kristallographie der Universitaet Wien, and with the Mineralogy Library, British Museum (Natural History).

Discussion of the crystal structure

Important interatomic distances and bond angles are compiled in Table 5. Fig. 1 presents the projection of the structure parallel to [010], and Fig. 2 gives a detail in projection parallel to [001]. The atomic arrangement is characterized by an $[\text{As}_5\text{S}_8]$ framework with the Tl atom housed in a large hole.

The atom As(2) to As(5) form pyramidal AsS_3 groups with each three S atoms ($\text{As-S} = 2.25\text{--}2.35$ Å, $\text{S-As-S} = 91.5\text{--}99.8^\circ$). A fourth S neighbour follows with $\text{As-S} \geq 3.09$ Å. For As(1) the situation is somewhat less clear: the bond lengths in the AsS_3 pyramid vary more strongly than for the other four As atoms, namely from 2.22 to 2.51 Å, and a fourth S neighbour has only $\text{As-S} = 2.99$ Å. Thereby, a tendency to a one-sided four-coordination is indicated. A coordination to four S atoms would be more usual for Sb(III). As the chemical analyses of bernardite show Sb contents up to 10 wt.% (Table 2), it seems important to note that for the As(1) atom the r.m.s. anisotropic displacements as obtained from the least-squares refinement—neglecting any possible replacement of As by Sb—are not conspicuously small and, therefore, do not indicate a concentration of Sb on this position. A similar large spread of bond lengths in an AsS_3 pyramid as observed by us for As(1) is only rarely reported in the literature (e.g. Edenharter, 1976), and apparently only for structures in which not all minor details could be determined with high precision.

The atoms S(2) and S(4) to S(8) are clearly bonded to two As atoms. When considering As(1) as three-coordinated ($\text{As-S} = 2.22\text{--}2.51$ Å) also S(3) is bonded to two As atoms, but S(1) only to one. If one considers for As(1) only the two neighbours with $\text{As-S} = 2.22$ and 2.35 Å, both S(1) and S(3) are bonded to only one As atom. And if one takes the extreme position to include also $\text{As(1)-S(1')} = 2.99$ Å into the system of chemical bonds—and thereby considering As(1) to be four-coordinated—both S(1) and S(3) are bonded to two As atoms.

The Tl atom is coordinated to eight S atoms with $\text{Tl-S} = 3.05\text{--}3.54$ Å, then follows one As atom with $\text{Tl-As} = 3.66$ Å and further S atoms with $\text{Tl-S} \geq 3.75$ Å. The coordination is some-

Table 3. Crystal data and experimental conditions for bernardite.

a = 15.647(4) Å	Stoe four-circle diffractometer
b = 8.038(3) Å	program system STRUCSY on an ECLIPSE S 140
c = 10.750(3) Å	crystal size: 0.04 x 0.08 x 0.08 mm ³
β = 91.2713°	graphite-monochromatized MoKα radiation
V = 1351.7 Å ³	2θ/ω-scan mode with a step width of 0.035°
room temperature	steps/reflection: 50 × (α ₁ , α ₂) splitting
space group P2 ₁ /c-C _{2h} ⁵	time/step: 0.5 to 1.5 sec
Z = 4 {TlAs ₅ S ₈ }	range of data: 2° < 2θ < 60°
F(000) = 1496.0	range of h k l: h, ±k, ±l
M _r = 835.49	3 standard reflections
D _x = 4.105 g·cm ⁻³	measuring interval: 2 h
μ(MoKα) ~ 245 cm ⁻¹	intensity variation: 2 %
λ(MoKα) = 0.71073 Å	measured reflections: 7984
no of variables: 128	unique reflections: 3946
R/wR = 0.049/0.036	R _{int} (∑(I- I)/∑I) : 0.063
w = (σ(F _o)) ⁻²	reflections with F _o > 3σ(F _o): 2410
max Δ/σ < 10 ⁻³	secondary extinction g: 7(1)×10 ⁻⁷ *

* Zachariassen (1967)

Table 4. Atomic parameters for bernardite with e.s.d.'s in parentheses. $ATF = \exp[-2\pi^2 \sum_{i=1}^3 \sum_{j=1}^3 U_{ij} h_i h_j a_i^* a_j^*]$

Atom	x	y	z	U ₁₁	U ₂₂	U ₃₃	U ₁₂	U ₁₃	U ₂₃
Tl	0.27798(4)	0.15448(7)	0.82965(5)	0.0433(3)	0.0308(3)	0.0353(3)	-0.0001(3)	-0.0012(2)	-0.0038(2)
As(1)	0.5531(1)	0.6694(2)	0.9003(1)	0.0329(7)	0.0336(7)	0.0279(6)	0.0165(6)	0.0050(5)	0.0049(6)
As(2)	0.0654(1)	0.4545(1)	0.8825(1)	0.0187(6)	0.0215(6)	0.0245(5)	-0.0004(5)	0.0016(5)	-0.0009(5)
As(3)	0.2626(1)	0.6342(1)	0.9401(1)	0.0238(6)	0.0176(6)	0.0236(5)	-0.0026(5)	-0.0015(5)	0.0006(4)
As(4)	0.5783(1)	0.1216(1)	0.8859(1)	0.0227(6)	0.0191(6)	0.0231(5)	-0.0025(5)	-0.0001(5)	0.0006(5)
As(5)	0.8894(1)	0.2148(1)	0.8626(1)	0.0255(6)	0.0234(6)	0.0225(6)	-0.0010(5)	0.0007(5)	-0.0005(5)
S(1)	0.4276(2)	0.1105(4)	0.3997(3)	0.0338(18)	0.0249(15)	0.0255(14)	-0.0017(13)	-0.0004(13)	-0.0053(12)
S(2)	0.5628(2)	0.1451(3)	0.0955(3)	0.0225(14)	0.0205(13)	0.0253(13)	0.0015(13)	0.0009(11)	-0.0014(12)
S(3)	0.3364(2)	0.1051(4)	0.0998(3)	0.0263(16)	0.0193(13)	0.0310(15)	0.0013(12)	0.0016(13)	-0.0010(12)
S(4)	0.0328(2)	0.1809(4)	0.8886(3)	0.0208(15)	0.0215(14)	0.0455(18)	-0.0018(12)	0.0026(14)	0.0005(13)
S(5)	0.1816(2)	0.4148(3)	0.0118(3)	0.0323(17)	0.0199(13)	0.0257(14)	-0.0058(13)	-0.0050(13)	0.0032(12)
S(6)	0.1320(2)	0.4494(4)	0.6979(3)	0.0453(21)	0.0305(16)	0.0279(16)	0.0152(16)	0.0122(15)	0.0066(13)
S(7)	0.8475(2)	0.3294(4)	0.5614(2)	0.0309(16)	0.0246(14)	0.0215(13)	-0.0030(13)	0.0010(12)	-0.0015(12)
S(8)	0.6860(2)	0.1778(4)	0.3639(2)	0.0272(16)	0.0239(15)	0.0214(13)	0.0066(13)	-0.0017(12)	-0.0028(12)

what one-sided, and this tendency becomes especially clear when considering only the four nearest S neighbours with Tl-S = 3.05–3.28 Å (Fig. 3). The smallest Tl-S bond length, i.e. Tl-S(3) = 3.05 Å, is somewhat short in comparison with the majority of such contacts reported in the literature. But it is not an isolated result: comparable values were found, e.g. in Tl₃VS₄ (Vlasse and Fournes, 1978), rebulite, Tl₅As₈Sb₅S₂₂ (Balić-Žunić *et al.*, 1982), and lorandite, TlAsS₂ (Fleet, 1973); in lorandite, the shortest Tl-S contact measures only 2.96(3) Å. The TlS₈ polyhedra have

no edges or faces in common, but from a purely geometrical point of view they are connected via S(3) atoms to chains parallel [001]. Three of the S-S edges belong also to AsS₃ pyramids. The stereochemical behaviour of Tl, evidently in the monovalent oxidation state, corresponds to general experience, e.g. Nowacki *et al.* (1982).

The general features of the atomic arrangement in bernardite agree with what one might expect on the basis of known arsenic sulphosalt structures, and in a closer comparison of thallium arsenic sulphosalt structures (Nowacki, 1969;

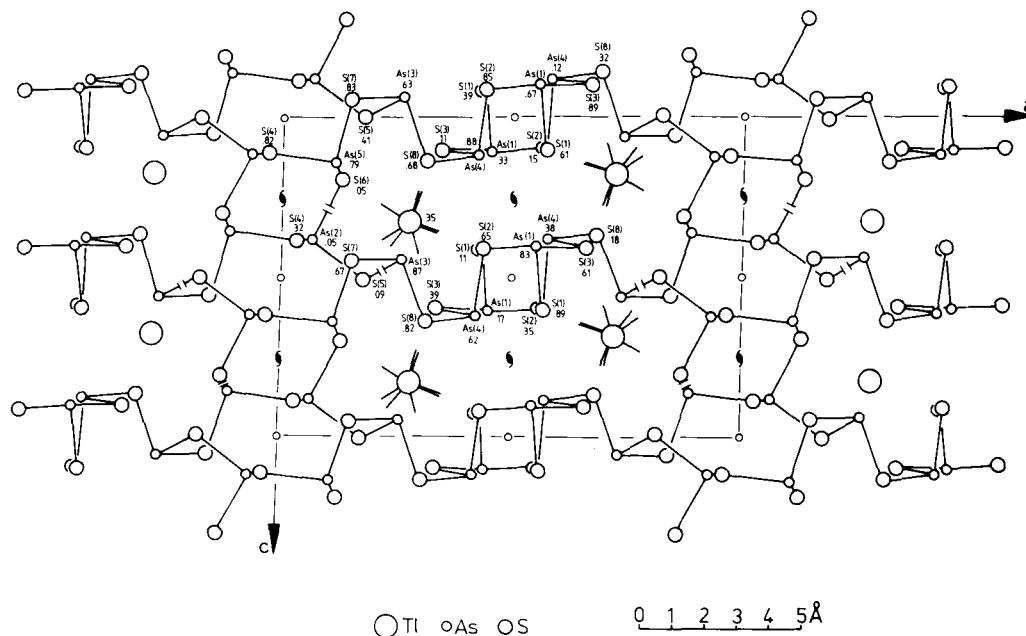


Fig. 1. Projection of the crystal structure of bernardite parallel to [010].

Takéuchi and Sadanaga, 1969; Edenharter, 1976; Nowacki *et al.*, 1982; see also Balić-Žunić and Šćavničar, 1985, 1988). In the classification of Nowacki (1969) bernardite belongs to class $V.a_3$ ($1 < S/As < 2$; AsS_3 pyramids condensed to infinite nets).

Bernardite, $TlAs_5S_8$, is neither isotypic nor homeotypic with pierrotite, $TlAs_5Sb_3S_8$ (Engel *et al.*, 1983), or parapierrotite $TlSb_5S_8$ (Engel, 1980), in spite of the similarity in chemical formulae. This is evidently a consequence of the different sizes of As(III) and Sb(III), as well as of the stronger tendency of As(III) to form clear-cut AsS_3 pyramids as compared with the stereochemical behaviour of Sb(III).

The relationship between the structures of bernardite and hutchinsonite, $TlPbAs_5S_9$ (Takéuchi *et al.*, 1965) is of considerable interest, although their chemical formulae differ significantly. To derive the structure of hutchinsonite from that of bernardite, one has to proceed as follows: (1) cut the structure of bernardite along $(a/2, y, z)$ into slices of thickness d_{100} ($\sim a$), thereby breaking the As(1)–S(2) bonds; (2) pull these slices slightly apart and arrange them mutually not as in bernardite, but rather by glide planes parallel (100) with translation direction b —thereby the lattice constant a will be doubled, and the space group becomes $Pbca$; (3) complete the coordination of

As(1) to an AsS_3 pyramid by a ninth S atom in the formula, with y coordinate near to 0.25 of the new cell; and (4) add the Pb atom appropriately, again with $y \sim 0.25$ of the new cell. The relationship is clearly seen by comparing our Fig. 1 with Fig. 10 of the paper by Takéuchi *et al.* (1965).

Concluding remarks

As a consequence of the extremely small amount of bernardite available for our investigation and, as it was decided not to damage the two 'large' crystals, it has not been possible to devote satisfactory attention to certain aspects of its mineralogy, such as optical properties and variation in Sb content. In addition, a structure determination on a grain of exactly known chemical composition has not proved possible. These supplementary investigations have to wait until more bernardite material becomes available. Another consequence of the scarcity of the material is that we cannot give empirical X-ray powder data. Instead, Table 6 presents the theoretical powder data as derived from our single-crystal structure determination.

$TlAs_5S_8$ has, so far, not been synthesized in the laboratory (Klaes, 1984, 1987; Sobott, 1984;

Table 5. Tl-S distances (Å) in the coordination of the Tl atoms and As-S distances (Å), bond angles (°) and S-S distances (Å) in the coordination of the As atoms.

Tl-S(1) = 3.088(3)		Tl-S(5) = 3.259(2)
Tl-S(2) = 3.544(2)		Tl-S(6) = 3.563(3)
Tl-S(3) = 3.051(2)		Tl-S(7) = 3.487(3)
Tl-S(3') = 3.282(2)		Tl-S(8) = 3.439(2)
As(1)-S(1) = 2.216(3)	[S(1)-As(1)-S(1')] = 85.2(2)	3.567(6)
As(1)-S(1') = 2.986(3)	S(1)-As(1)-S(2) = 101.9(1)	3.546(4)
As(1)-S(2) = 2.349(3)	S(1)-As(1)-S(3) = 94.4(1)	3.468(4)
As(1)-S(3) = 2.505(3)	[S(1')-As(1)-S(2)] = 88.3(1)	3.714(4)
	[S(1')-As(1)-S(3)] = 177.5(2.0)	5.490(4)
	S(2)-As(1)-S(3) = 94.3(1)	3.559(4)
As(2)-S(4) = 2.259(3)	S(4)-As(2)-S(5) = 91.4(1)	3.251(4)
As(2)-S(5) = 2.286(3)	S(4)-As(2)-S(6) = 96.7(1)	3.377(4)
As(2)-S(6) = 2.262(3)	S(5)-As(2)-S(6) = 98.9(1)	3.456(4)
As(3)-S(5) = 2.314(3)	S(5)-As(3)-S(7) = 96.0(1)	3.452(4)
As(3)-S(7) = 2.331(3)	S(5)-As(3)-S(8) = 89.7(1)	3.229(4)
As(3)-S(8) = 2.267(2)	S(7)-As(3)-S(8) = 98.6(1)	3.485(4)
As(4)-S(2) = 2.279(2)	[S(2)-As(4)-S(2')] = 84.4(1)	3.654(6)
As(4)-S(2') = 3.088(3)	S(2)-As(4)-S(3) = 94.3(1)	3.330(4)
As(4)-S(3) = 2.262(3)	S(2)-As(4)-S(8) = 97.8(1)	3.486(4)
As(4)-S(8) = 2.347(3)	[S(2')-As(4)-S(3)] = 81.8(1)	3.559(4)
	[S(2')-As(4)-S(8)] = 177.9(2.4)	5.434(4)
	S(3)-As(4)-S(8) = 97.9(1)	3.476(4)
As(5)-S(4) = 2.271(3)	S(4)-As(5)-S(6) = 93.6(1)	3.297(5)
As(5)-S(6) = 2.253(3)	S(4)-As(5)-S(7) = 99.8(1)	3.478(4)
As(5)-S(7) = 2.276(2)	S(6)-As(5)-S(7) = 94.6(1)	3.428(4)

* Common S-S edges of the TlS_8 polyhedron and AsS_3 pyramids

Note: E.s.d.'s in parentheses. Limits: Tl-S < 3.66 Å (= shortest Tl-As contact), As-S < 3.10 Å. The limit for As-S is rather arbitrary as the next larger bond length is As-S = 3.20 Å. Values in the As configuration with As-S = 2.99 and 3.09 Å in square brackets.

Table 6. X-ray powder data of bernardite. Calculated from the crystal structure, Debye-Scherrer geometry; $CuK\alpha$ radiation. Reflections with normalized $I_{calc} < 3$ omitted; $d_{hkl} > 1.70$ Å.

l_{calc}	d_{calc} (Å) h k l	l_{calc}	d_{calc} (Å) h k l
37	15.73 1 0 0	8	2.99 2 2 -2
27	7.86 2 0 0	8	2.76 3 2 -2
11	7.18 1 1 0	17	2.74 3 2 2
13	5.98 1 1 -1	59	2.68 { 0 0 4 0 2 3
19	5.63 2 1 0	11	2.65 { 1 3 0 1 0 -4
24	5.10 1 0 -2	19	2.64 1 2 -3
10	5.05 1 0 2	6	2.63 1 2 3
6	5.01 2 1 1	7	2.61 0 3 1
24	4.96 2 1 1	30	2.57 1 3 1
65	4.46 0 1 2	25	2.55 { 2 0 -4 3 1 0
32	4.40 { 2 0 2 3 1 0	27	2.54 0 1 4
74	4.28 1 1 2	25	2.43 2 1 -4
61	4.09 3 1 -1	7	2.41 2 1 4
23	4.05 3 1 1	9	4.03 0 2 0
9	4.03 0 2 0	22	2.40 { 3 0 -4 3 2 -3
10	3.86 2 1 2	30	2.37 3 2 3
63	3.78 { 0 2 1 3 0 -2	5	2.34 3 3 -1
55	3.72 3 0 2	4	2.28 3 1 4
21	3.67 1 2 1	13	2.15 0 3 3
5	3.59 2 2 0	8	2.07 { 0 1 5 2 3 3
54	3.42 3 1 -2	14	2.02 0 4 0
19	3.41 2 2 -1	14	2.00 1 4 0
6	3.40 2 2 1	9	1.99 3 3 -3
20	3.27 0 1 3	11	1.98 0 4 1
8	3.21 1 1 -3	5	1.94 3 1 -5
3	3.19 1 1 3	6	1.92 3 1 5
65	3.07 3 2 -1	8	1.77 3 4 2
100	3.06 3 2 1	7	1.74 2 0 6
10	3.03 2 1 -3	10	1.73 1 1 6
27	3.00 2 1 3		

Sobott *et al.*, 1987). Further work in the Sb- and Tl-poor part of the Tl-As-Sb-S system is urgently required to learn whether or not a low Sb content is essential for the stabilization of the bernardite structure.

Acknowledgements

Our thanks go to Doc. Dr J. H. Bernard, Praha, who drew our attention to this new mineral and who put the working material at our disposal, and to Prof. Dr E. Mackovicky, København, who suggested the structural relationship between bernardite and hutchinsonite. Dr E. Libowitzky, Wien, helped in the optical measurements, and Drs J. E. Chisholm and A. J.

Criddle, London, made useful suggestions for improvements in the manuscript.

References

- Balić-Zunić, T. and Ščavničar, S. (1985) *Mineralogija*, Godišnjak JAM 1, 35-47.
 ——— (1988) *Nucl. Instr. Meth. Phys. Research A271*, 304-7.
 ——— and Engel, P. (1982) *Z. Kristallogr.* **160**, 109-25.
 Brock, C. P. (1984) *ACA Newsletter* **15** [2], No. 5, 14.
 Caye, R., Picot, P., Pierrot, R. and Permingeat, F. (1967) *Bull. Soc. fr. Minéral. Cristallogr.* **90**, 185-91.
 Cromer, D. T. and Waber, J. T. (1974) In *International*

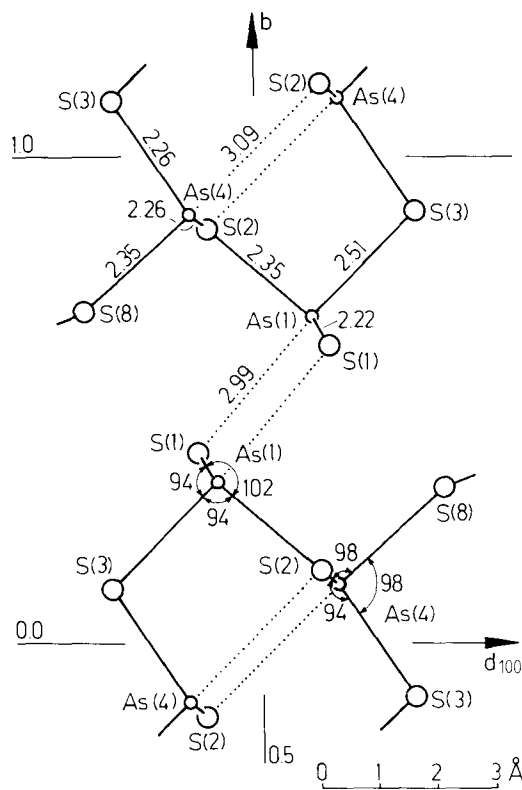


FIG. 2. Detail of the crystal structure of bernardite near $(\frac{1}{2}, y, \frac{1}{2})$ projected parallel to $[001]$. Forth-shortest As(1)–S and As(4)–S contacts dotted.

- Tables for X-ray Crystallography IV* (Ibers, J. A. and Hamilton, W. C., eds.) The Kynoch Press: Birmingham.
- Edenharter, A. (1976) *Schweiz. Mineral. Petrogr. Mitt.* **56**, 195–217.
- El Goresy, A. and Pavićević, M. K. (1988) *Naturwiss.* **75**, 37–9.
- Engel, P. (1980) *Z. Kristallogr.* **151**, 203–16.
- Nowacki, W., Balić-Zunić, T. and Ščavničar, S. (1982) *Ibid.* **161**, 159–66.
- Gostojić, M. and Nowacki, W. (1983) *Ibid.* **165**, 209–15.
- Fischer, R. X. and Tillmanns, E. (1988) *Acta Crystallogr.* **C44**, 775–6.
- Fleet, M. E. (1973) *Z. Kristallogr.* **138**, 147–60.
- Ivanov, T. (1965) *Problems of Postmagmatic Ore Deposition*, Vol. II, 186–91. Geol. Surv. Czechoslovakia.
- (1986) *Proc. Workshop Feasibility solar neutrino detection with ^{205}Pb by geochem. and accel. mass. spectroscop. measurements*. GSI-86-9 Report, 1–6.
- Jankovič, S. (1960) *Neues Jahrb. Mineral. Abh.* **94**, 506–38.
- (1982) Yugoslavia. In *Mineral Deposits of Europe*, Vol. 2: *Southeast Europe* (Dunning, F. W., Mykura,

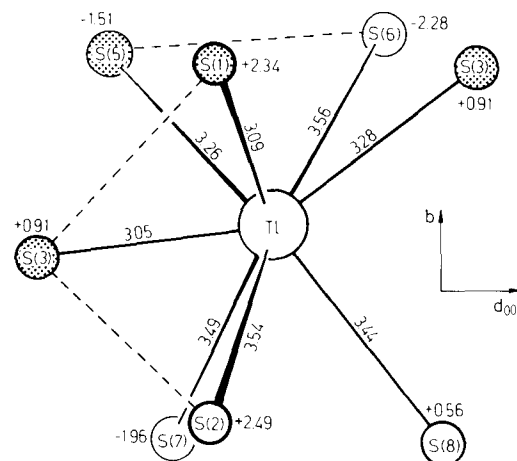


FIG. 3. TlS_8 polyhedron in projection parallel $[100]$. The numbers at the atoms give their height in Å relative to that of the Tl atom. Common edges with AsS_3 pyramids are indicated by broken lines. The four nearest S atoms are dotted.

- W. and Slater, D., eds.), 143–202 (especially p. 185).
- (1988) *Nucl. Instr. Meth. Phys. Res.* **A271**, 286
- Johan, Z., Pierrot, R., Schubnel, H.-J. and Permingeat, F. (1970) *Bull. Soc. fr. Minéral. Cristallogr.* **93**, 545–9.
- Picot, P., Hak, J. and Kvaček, M. (1975) *Tscherm. Mineral. Petrogr. Mitt.* **22**, 200–10.
- Klaes, R. (1984) *Neues Jahrb. Mineral. Abh.* **150**, 59–61.
- (1987) *Experimentelle Untersuchungen an komplexen Thalliumsulfiden, unter besonderer Berücksichtigung von Thallium-Silber-Sulfosalzen*. Inaugural-Diss. Universität Heidelberg.
- Laurent, Y., Picot, P., Pierrot, R., Permingeat, F. and Ivanov, T. (1969) *Bull. Soc. fr. Minéral. Cristallogr.* **92**, 38–48.
- Nowacki, W. (1969) *Schweiz. Mineral. Petrogr. Mitt.* **49**, 109–56.
- Edenharter, A., Engel, P., Gostojić, M. and Nagl, A. (1982) *Ore Genesis. The State of the Art* (Amstutz G. C. et al., eds.) Springer: Berlin-Heidelberg-New York, 689–704.
- Ohmura, M. and Nowacki, W. (1971) *Z. Kristallogr.* **134**, 360–80.
- Pašava, J., Pertlik, F., Stumpfl, E. F., and Zemann, J. (1988) *Fortschr. Mineralogie* **66**, Beih. 1, 117.
- Pavićević, M. K. (1988) *Nucl. Instr. Meth. Phys. Res.* **A271**, 287–96.
- and El Goresy, A. (1988) *Ibid.* **A271**, 297–300.
- Pavlović, V. and Arsenijević, M. (1956) *Bull. Inst. Géol. République Macédonienne* **5**, 297–301.
- Sobott, R. J. G. (1984) *Neues Jahrb. Mineral. Abh.* **150**, 54–9.
- Klaes, R. and Moh, G. H. (1987) *Chem. Erde* **47**, 195–218.
- Takéuchi, Y. and Sadanaga, R. (1969) *Z. Kristallogr.* **130**, 346–68.

- Ghose, S. and Nowacki, W. (1965) *Ibid.* **121**, 321–48.
Zachariasen, W. H. (1967) *Acta Crystallogr.*, **23**, 558–64.
- Vlasse, M. and Fournes, L. (1978) *Compt. Rend. Acad. Sci. Paris*, **287**, Sér. C, 47–9. [Manuscript received 28 December 1988; revised 1 June 1989]