

## BENJAMINITE — A RE-EXAMINATION OF THE TYPE MATERIAL

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### ABSTRACT

Benjaminite from the type locality of Nye County, Nevada consists mainly of two phases intergrown as parallel lamellae measuring up to about 10  $\mu\text{m}$  in width. Because the first reciprocal layer normal to  $b[010] = 8.12\text{\AA}$  is too weak to resolve, the true cells cannot be established. The sub-cells of the phases have in common the cell dimensions  $a' = 13.39$ ,  $b' = 4.06\text{\AA}$ , the diffraction symbol  $C^{**}$ , and the cell contents  $\text{Pb}_{2x}(\text{Ag,Cu})_{6-x}(\text{Bi,Pb})_{14-x}\text{S}_{24}$  in which  $\text{Pb} + (\text{Ag,Cu}) + \text{Bi} = 20$  and  $x$  is 0 in one cell and 2 in the other. The more abundant sub-cell has  $c' = 20.21\text{\AA}$  and  $\beta = 103^\circ 27'$  and has been identified with the phase  $(\text{Ag,Cu})_8(\text{Bi,Pb})_{14}\text{S}_{24}$ ,  $D(\text{calc}) = 6.68 \text{ g/cm}^3$ . The other sub-cell has  $c' = 19.71\text{\AA}$ ,  $\beta = 90^\circ 07'$  and is identified with the phase  $\text{Pb}_4(\text{Ag,Cu})_4(\text{Bi,Pb})_{12}\text{S}_{24}$ ,  $D(\text{calc}) = 6.94 \text{ g/cm}^3$ . A third minor phase has relatively more Cu and less Bi than the two main phases but the grains are too small and sparse for satisfactory analysis.

Shannon's (1925) analyses, on which the species was founded, fall between the values for the benjaminite phases and aikinite which is abundant on Shannon's type specimens and which was not recognized by him.

It is proposed to reserve the name benjaminite for the more abundant phase —  $2[(\text{Ag,Cu})_8(\text{Bi,Pb})_7\text{S}_{12}]$  with  $a' = 13.39$ ,  $b' = 4.06$ ,  $c' = 20.21\text{\AA}$ ,  $\beta = 103^\circ 27'$ ,  $D(\text{calc}) = 6.68 \text{ g/cm}^3$  and space group  $C2/m$ .

### RÉSUMÉ

La benjaminite provenant de la localit  type de Nye County, Nevada consiste principalement de deux phases enchev tr es sous forme de lamelles parall les mesurant jusqu'  10  $\mu\text{m}$  de largeur. A cause de la premi re couche inverse normale    $b[010] = 8.12\text{\AA}$  qui est trop faible   r soudre, les vraies mailles ne peuvent  tre  tablies. Les sous-mailles des phases ont en commun les dimensions de maille  $a' = 13.39$ ,  $b' = 4.06\text{\AA}$ , le symbole de diffraction  $C^{**}$  et les contenus  $\text{Pb}_{2x}(\text{Ag,Cu})_{6-x}(\text{Bi,Pb})_{14-x}\text{S}_{24}$  de la maille dans laquelle  $\text{Pb} + (\text{Ag,Cu}) + \text{Bi} = 20$  et  $x$  est 0 dans une maille et 2 dans l'autre. La sous-maille la plus abondante a  $c' = 20.21\text{\AA}$  et  $\beta = 103^\circ 27'$  et a  t  identifi e avec la phase  $(\text{Ag,Cu})_8(\text{Bi,Pb})_{14}\text{S}_{24}$ ,  $D(\text{calc}) = 6.68 \text{ g/cm}^3$ . L'autre sous-maille a  $c' = 19.71\text{\AA}$ ,  $\beta = 90^\circ 07'$  et est identifi e avec la phase  $\text{Pb}_4(\text{Ag,Cu})_4(\text{Bi,Pb})_{12}\text{S}_{24}$ ,  $D(\text{calc}) = 6.94 \text{ g/cm}^3$ .

Une troisi me phase mineure qui a relativement plus de Cu et moins de Bi que les deux principales phases a cependant des grains trop petits et trop  pars pour des analyses satisfaisantes.

Les analyses de Shannon (1925), desquelles l'esp ce a  t  cr e e, se trouvent entre les valeurs des phases de la benjaminite et de l'aikinite, laquelle abonde parmi les sp cimens types de Shannon et laquelle il n'a pas reconnue.

Il est propos e de r server le nom de benjaminite pour la phase la plus abondante —  $2[(\text{Ag,Cu})_8(\text{Bi,Pb})_7\text{S}_{12}]$  avec  $a' = 13.39$ ,  $b' = 4.06$ ,  $c' = 20.21\text{\AA}$ ,  $\beta = 103^\circ 27'$ ,  $D(\text{calc}) = 6.68 \text{ g/cm}^3$  et un groupe spatial  $C2/m$ .

(Traduit par le journal)

### INTRODUCTION

Benjaminite is a poorly-defined mineral founded by Shannon (1925) on the basis of four chemical analyses performed on a mixture of minerals from near Round Mountain, Nye County, Nevada. Presently the name owes its claim to represent a distinct species to the unit-cell parameters and  $x$ -ray powder data derived by the writer (Nuffield 1953) from a mineral associated with abundant aikinite on Shannon's type material (U.S. National Museum specimen 95058). Although the powder patterns of benjaminite and pavonite,  $\text{AgBi}_3\text{S}_5$ , were described as having only subtle differences (Nuffield 1954), distinction between the two species has been attempted almost invariably by the  $x$ -ray powder method supported only by electron microprobe analyses on material often intimately intergrown with chemically-similar minerals. As a consequence, doubt has arisen about the authenticity of benjaminite and the mineral has been considered to be identical with pavonite or to be a mixture of aikinite and pavonite. In this paper the writer reports on a re-examination of the crystal which gave the original structural data and on a study of additional material from the type locality using instruments and methods that were not available at the time of the first study. The new data confirm the distinction between pavonite and benjaminite, but reveal that the latter mineral is more complex than anticipated.

## RECENT STUDY

The original rotation and Weissenberg films were obtained by rotating the crystal about a set of fine striations in the plane of a face or cleavage. The rotation photograph gave the period  $8.12\text{\AA}$  but the first layer was too weak to resolve. Resolution of the zero and second layers revealed a monoclinic sub-cell with  $a' = 13.34$ ,  $b' = 4.06$ ,  $c' = 20.25\text{\AA}$ ,  $\beta = 104^\circ$ , space group  $C2/m$ . The striations were assumed to be due to twinning and to be responsible for additional reflections lying on the Weissenberg festoons.

In this study the same layers, using the same

crystal, were resolved on precession films (Fig. 1). The crystal is seen to consist of two crystallographically-aligned phases which manifest themselves as pairs of reflections along reciprocal rows parallel to  $[001]^*$ . The additional reflections noted previously correspond to the open circles in Figure 2 and represent one of the phases. Because the first layer line ( $b = 8.12\text{\AA}$ ) could not be resolved, at least one of the cells is a sub-cell. The parameters of the cells are given in Table 1. One cell (#1 of Table 1) is the sub-cell originally proposed for benjaminite and on the basis of intensity, is the more abundant. The other cell is geometrically orthogonal within the accuracy of measurement,

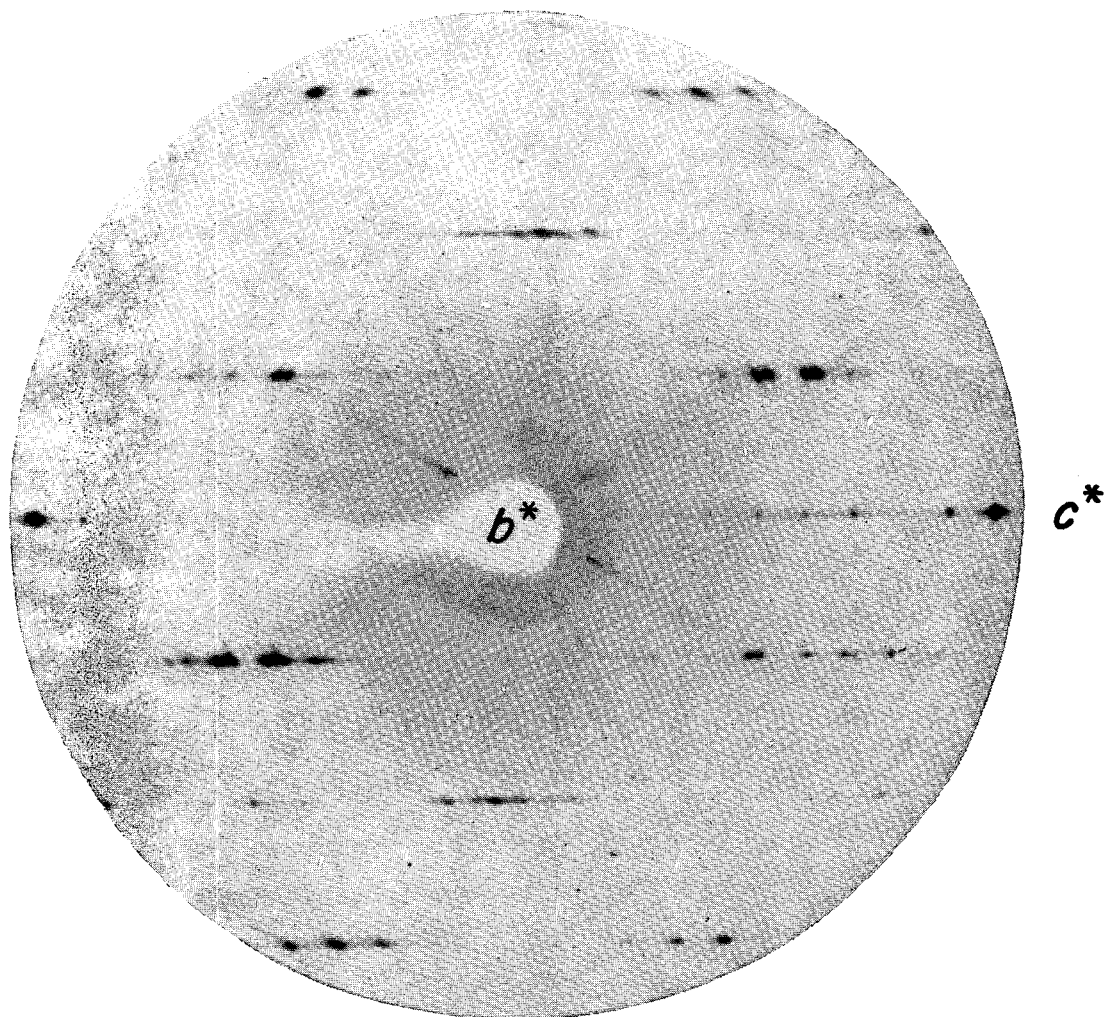


FIG. 1. Zero-layer precession film of the type benjaminite crystal from Nye County, Nevada (USNM 95058), with  $[010]$  as precession axis, showing two sets of lattice points on reciprocal rows parallel to  $[001]^*$ .  $\text{CuK}\alpha$  radiation.

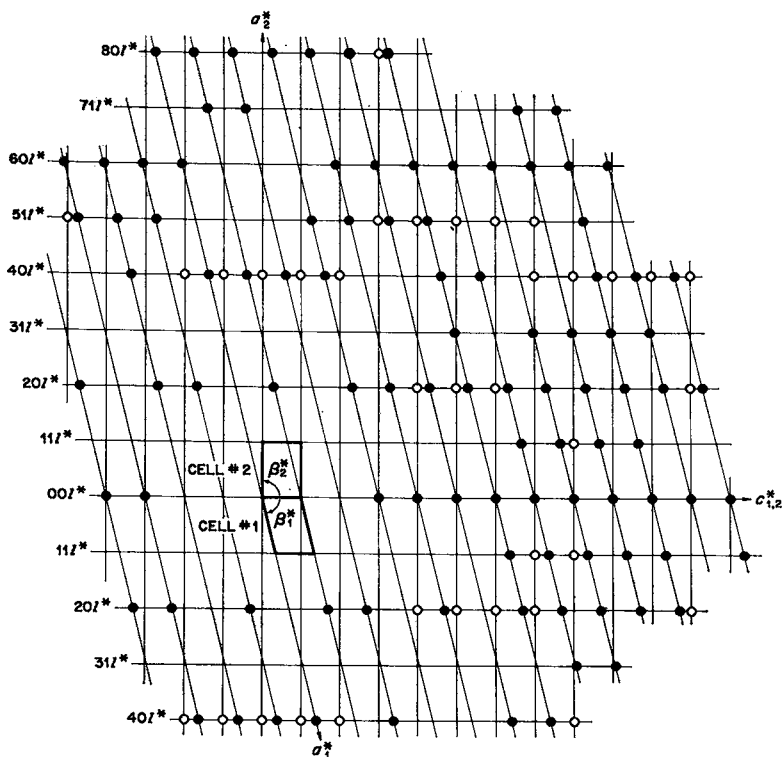


FIG. 2. Reciprocal points from precession photographs of the zero and the first strong reciprocal layer normal to  $b[010]$ . Filled circles — cell #1, open circles — cell #2. The two sub-cells are intergrown with  $\bar{b}^*_1 = b^*_2$  and  $c^*_1 = c^*_2$ . Type crystal (USNM 95058).

but both cells have monoclinic diffraction symmetry. The  $a$  and  $b$  axes are identical and coincide in direction in the intergrowth. The striations mark the (001) bounding planes between components of the two phases. The volumes of the two cells are practically identical at  $1070 \pm 2\text{\AA}^3$ .

The reflections on the precession films occur in clusters on the reciprocal rows parallel to  $[001]^*$ , suggesting the presence of a superlattice that is common to the two phases. When the reflections in each cluster are merged, the result is an approximately hexagonal array with the dimensions  $a = 7.7$ ,  $c = 4.06\text{\AA}$ .

As a final check on the original structural data, an x-ray "powder" pattern was obtained from the type crystal mounted in a Gandolfi camera. The  $d$ -spacings measured on the film agree well with the published powder data (Nuffield 1953; Berry & Thompson 1962) and confirm that the data are representative of the type crystal. Table 2 gives the published low- $2\theta$  powder data for benjaminite indexed in terms of the parameters of the two sub-cells. Satis-

factory indexing of the  $d$ -spacings larger than  $2.9\text{\AA}$  requires the presence of both sub-cells.

The comparison of powder data in Table 3 points up the similarities between the patterns of aikinite, benjaminite and pavonite. The table also emphasizes the differences and shows, if additional evidence is needed, that the benjaminite pattern cannot be a mixture of the other two patterns.

The sub-cells of benjaminite are unique. The unit cell of pavonite,  $a$  13.35,  $b$  4.03,  $c$  16.34 $\text{\AA}$ ,  $\beta$   $94\frac{1}{2}^\circ$  (Nuffield 1954) which has been confirmed by Karup-Møller (1972), has  $a$ - and  $b$ -periods that are almost identical with the corresponding periods in the benjaminite sub-cells, but the  $c$  periods and the  $\beta$  angles are distinctly different and give no reason to believe, as has been implied, that the species are members of a series. Benjaminite bears a close resemblance to gustavite (Karup-Møller 1970). Like benjaminite, gustavite includes a component, phase X, in parallel crystallographic alignment and the cells have two dimensions in common. Gustavite and its component have orthorhombic symmetry, but

TABLE 1. THE TWO SUB-CELLS IN THE TYPE CRYSTAL OF BENJAMINITE\*

Cell No.	a'	b'	c'	β	Volume	Space Group
1	13.39	4.06	20.21 Å	103° 27'	1068.3 Å <sup>3</sup>	C2/m
2	13.39	4.06	19.71	90° 07'	1071.5	C2/m

\* U.S.N.M. specimen 95058, Nye County, Nevada.

TABLE 2. THE LOW-2θ X-RAY POWDER LINES OF BENJAMINITE

Nuffield (1953)		Berry & Thompson (1962)		Cell No. 1	Cell No. 2
<i>I</i>	<i>d</i> <sub>meas.</sub>	<i>I</i>	<i>d</i> <sub>meas.</sub>	<i>hkl</i>	<i>d</i> <sub>calc.</sub>
7	3.47 Å	9	3.51 Å	112	3.52 Å
		1	3.40		205̄ 3.40 Å
					205 3.39
		½	3.30		40T̄ 3.30
					401 3.30
					006 3.28
½	3.18	½	3.19		402̄ 3.17
					402 3.17
½	2.95	½	2.95	312̄ 2.97	31T̄ 2.97
				310 2.97	311 2.97
				114 2.95	206̄ 2.95
					206 2.95
10	2.82	10	2.83	207̄ 2.83	007 2.82
				007 2.81	
				510 2.19	009 2.19
				009 2.18	512 2.18
1	2.18	1	2.18	604̄ 2.18	512 2.18
				600 2.17	602̄ 2.18
					602 2.18
				406 2.08	209̄ 2.08
				318̄ 2.06	118 2.08
				512 2.06	209 2.08
½	2.07	1	2.07		118 2.08
					317 2.06
				516̄ 2.01	022 1.988
				118 2.01	022̄ 1.988
6	2.00	6	1.998	022 1.988	408̄ 1.986
				022̄ 1.988	408 1.982

Ni filtered Cu radiation; λ = 1.5418 Å

Cell No. 1: a' 13.39, b' 4.06, c' 20.21 Å, β 103° 27'

Cell No. 2: a' 13.39, b' 4.06, c' 19.71 Å, β 90° 07'

TABLE 3. COMPARISON OF THE X-RAY POWDER DATA FOR AIKINITE, BENJAMINITE AND PAVONITE\*

Aikinite**		Benjaminite		Pavonite**	
<i>I</i>	<i>d</i> (Å)	<i>I</i>	<i>d</i> (Å)	<i>I</i>	<i>d</i> (Å)
10	3.68			6	3.58
6	3.59	9	3.47	6	3.44
		1	3.40		
		½	3.30	6	3.33
8	3.19	½	3.19		
		½	2.95		
7	2.88				
		10	2.83	10	2.84
5	2.59				
		1	2.18		
		1	2.07		
4	1.989	6	1.998	7	2.01

\*All data taken from Berry & Thompson (1962).

\*\*Strongest lines only.

TABLE 4. GUSTAVITE AND ITS EXSOLVED COMPONENT (after Karup-Møller 1970)

	Gustavite	Phase X
a	13.548 Å	13.548 Å
b	19.449	20.0
c	4.105	4.105
Volume	1081.6 Å <sup>3</sup>	1112.3 Å <sup>3</sup>
Diffraction symbol	bb**	bb**
Composition	Pb <sub>6</sub> Ag <sub>3</sub> Bi <sub>11</sub> S <sub>24</sub> or PbAgBi <sub>3</sub> S <sub>6</sub> *	Pb <sub>8</sub> Ag <sub>2</sub> Bi <sub>10</sub> S <sub>24</sub>
Density (calc.)	7.11 <sup>†</sup> or 6.96	7.06 <sup>†</sup>

\*Karup-Møller (1972) for gustavite from Colorado.

†Given as 7.01 and 6.98 respectively, by Karup-Møller.

the cell dimensions (Table 4) are otherwise remarkably similar to the dimensions of benjaminite.

ELECTRON MICROPROBE ANALYSES

Electron microprobe analyses were performed on a Royal Ontario Museum specimen (ROM M13805) labelled benjaminite, Manhattan, Nevada. Manhattan is within 10 miles of Round Mountain. Aikinite, identified by Debye-Scherrer diffraction patterns, is abundant on the specimen but a portion gives x-ray powder data which are in excellent agreement with the published data for benjaminite. A polished fragment of this material was used for the analyses. A wavelength scan revealed the presence of only Cu, Ag, Pb, Bi and S.

Examination of the polished section with an oil immersion lens at magnification in excess of 1000X shows a third phase (Fig. 3). It occurs as oriented short lath-like bodies, lighter in colour than the main phases. The laths comprise less than 5 per cent of the mass of benjaminite and, therefore, cannot be detected by x-ray diffraction.

The two main phases are readily apparent in Pb and Cu distribution photographs (Fig. 4). The phases occur as alternating lamellae with a maximum width of about 10 μm. Traverses across the lamellae show that one of the phases is higher in Cu and Pb and lower in Ag and Bi

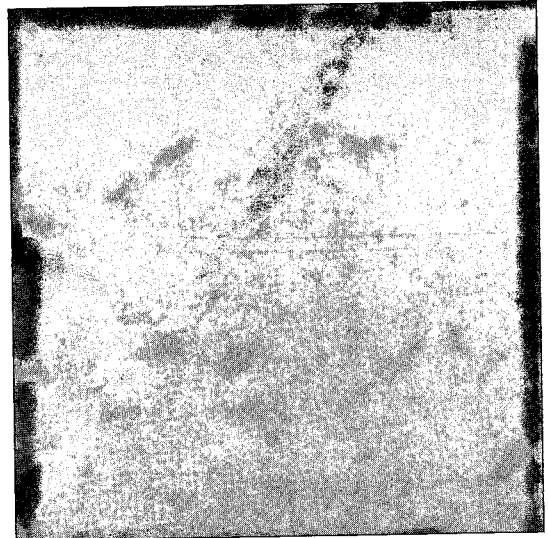


FIG. 3. Photomicrograph of the high-Cu/low-Bi "third" phase (light colour) in benjaminite, Royal Ontario Museum specimen M13805 from Manhattan, Nevada. Magnification 1500X.

than the other. The third phase is high in Cu and low in Bi, relative to the main phases, but the individual laths are too small to analyze.

Analyses were made at ten different locations in the section, at points giving reasonably constant values over an area sufficiently large to ensure minimum contamination from adjacent lamellae. The results of the analyses, six of the high-Pb phase and four of the other, are given in Table 5. Each value represents the average of repeated determinations at the location. Except for Cu, the individual values of the atomic ratios are reasonably constant in each of the two sets. The considerable variation in Cu values is probably due, in large part, to contamination by the high-Cu "third" phase and in smaller part, by chalcopyrite. However, Cu is a minor constituent in each phase and therefore the variation has a minor effect on deducing the cell contents. S is insufficient to balance the metals — S values obtained in the presence of the heavy metallic elements are commonly in error — and consequently, the metal values are high relative to S.

#### THE CHEMICAL COMPOSITION OF THE SUB-CELLS

Table 6, column 1, shows the averages of the atomic ratios and the range of the variations. The calculated densities of the known Ag-Cu-Bi and Pb-Ag-Cu-Bi sulphosalts fall in the range 6.75 to 7.25 g/cm<sup>3</sup>. It is reasonable to expect that the main benjaminite phases should have similar densities. In converting the atomic ratios to numbers of atoms in the sub-

TABLE 5. ELECTRON MICROPROBE ANALYSES OF BENJAMINITE\*

	High-Pb Phase						Low-Pb Phase					
Weight percentages:												
Cu	3.55	1.76	0.18	0.20	3.61	3.71	0.63	0.68	0.64	3.83		
Ag	7.72	7.55	7.67	7.15	5.20	6.32	12.91	12.57	12.96	11.81		
Pb	22.64	21.00	22.44	22.39	23.06	23.35	3.32	3.91	3.91	3.62		
Bi	51.55	54.44	55.03	55.23	51.79	51.99	65.65	65.11	65.13	64.34		
S	15.14	14.93	15.32	16.30	15.96	16.02	16.30	16.10	16.43	16.73		
Totals	100.59	99.65	100.65	101.27	99.63	101.38	98.81	98.37	99.07	100.32		
Atomic ratios**:												
Cu	56	28	3	3	57	58	10	10	10	60		
Ag	71	70	70	65	48	58	121	118	121	109		
Pb	109	102	108	107	112	111	16	19	19	17		
Bi	245	261	262	261	249	245	318	317	315	307		
S	469	467	475	502	500	493	514	510	517	520		

\*Analyst: O.M. Malik. Data reduction effected with EMPADR VII (Rucklidge & Gasparri 1969).

\*\* (Wt. percentage summed to 100%) X 10<sup>3</sup>/atomic wt.

TABLE 6. ATOMIC CONTENTS OF THE BENJAMINITE SUB-CELLS

	High-Pb Phase			Low-Pb Phase		
	1	2	3	1	2	3
Cu	34	1.53	23	1.04		
Ag	98 ± 30	2.89	118	5.32		
Pb	108	4.87	4	0.81		
Bi	362 ± 8	16.33	12	14.17		
S	254	11.46	314	23.28		
	484	21.84	24	516		34

1. Average of the atomic ratios in Table 5. 2. Atoms in the sub-cell: atomic ratio X wt. of the sub-cell (= volume X density/1.66 = 1070 Å<sup>3</sup> X 7.0 g cm<sup>3</sup>/1.66). 3. Idealized cell contents.

cells, a value of 7.0 in the middle of the range and the average, 1070 Å<sup>3</sup>, of the cell volumes were used in the calculations to obtain the values in column 2. The idealized cell contents deduced from column 2 and listed in column 3 take account of the experience that Cu commonly substitutes for Ag, that Pb and Bi are frequently not completely ordered in the Pb-Bi sulphosalts, and that the equipoint ranks common to space groups with the diffraction sym-

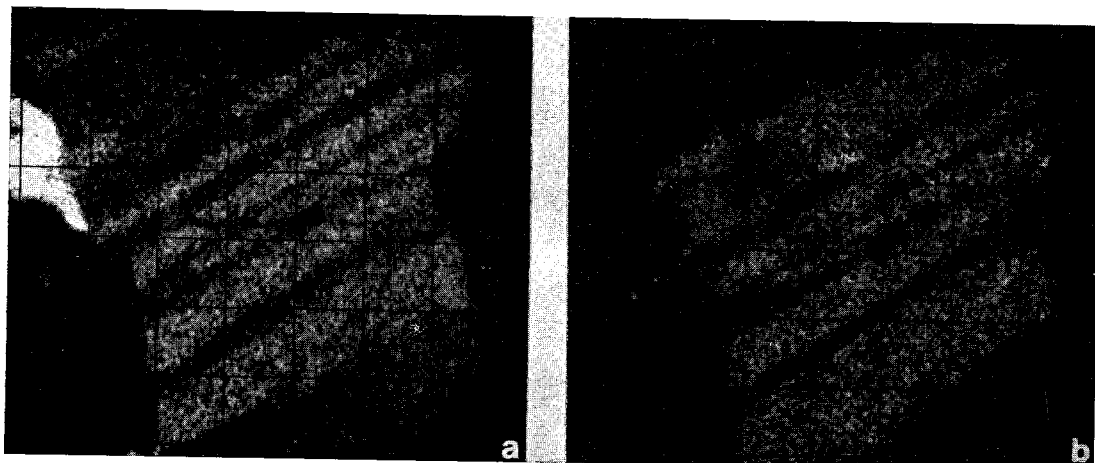


FIG. 4. X-ray distribution photographs: (a)CuKa. (b)PbMa. The high-intensity area in (a) is due to a grain of chalcopyrite. The photographs illustrate the lamellar intergrowth of the two main benjaminite phases. Same section as in Figure 3. Grid size 2.6 μm.

bol  $C^{**}$  have values of 4 and 2. The generalized cell contents are clearly

high-Pb phase:  $4[Pb(Ag,Cu)(Bi,Pb)_3S_6]$

low-Pb phase:  $2[(Ag,Cu)_3(Bi,Pb)_7S_{12}]$

Several preliminary analyses, giving an estimate of the average composition of benjaminite in the section, indicate that the high-Pb phase is less abundant than the other and is, therefore, represented by cell #2 in Table 1. The calculated density of this phase for a cell content of  $4[Pb(Ag_{0.67}Cu_{0.33})Bi_3S_6]$  (which approximates the values in column 2) and the appropriate cell volume  $1071.5\text{\AA}^3$ , is  $6.94\text{ g/cm}^3$ . The composition of this phase is practically identical with the composition derived by Karup-Møller (1972) for gusatvite occurrences in Colorado (Table 4). The calculated density of the low-Pb phase for the cell contents  $2[(Ag_{0.83}Cu_{0.17})_3Bi_7S_{12}]$  (representative of the averages in column 2) and the cell volume  $1068.3\text{\AA}^3$ , corresponding to cell # 1, is  $6.68$ . This phase is close to pavonite in composition.

Table 7 compares the theoretical compositions of the various minerals pertinent to this study. It is understandable, in view of the compositions of the benjaminite phases, that microprobe analyses of benjaminite from the type locality have been interrupted as mixtures of aikinite and pavonite (e.g., Karup-Møller 1972, p. 32). Analytical results that fall between the values for the two benjaminite phases are evidently inadvertent composite analyses of the phases. Shannon's (1925) analyses lie between the values for the benjaminite phases and aikinite which is abundant on his specimens and which was not recognized by him.

TABLE 7. WEIGHT PERCENTAGES --- A COMPARISON

	1	2	3	4	5
Cu	11.03	5.08	1.87	1.51	---
Ag	---	4.20	6.46	12.50	12.05
Pb	35.98	24.43	18.50	---	---
Bi	36.29	49.28	55.99	68.08	70.04
S	16.70	17.01	17.18	17.91	17.91
	100.00	100.00	100.00	100.00	100.00

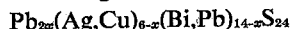
1.  $PbCuBiS_3$  (aikinite). 2.  $Pb_2(Cu_{0.67}Ag_{0.33})_2Bi_4S_9$  (proposed by Shannon for benjaminite). 3.  $Pb(Ag_{0.67}Cu_{0.33})Bi_3S_6$  (high-Pb benjaminite phase). 4.  $(Ag_{0.83}Cu_{0.17})_3Bi_7S_{12}$  (low-Pb benjaminite phase). 5.  $AgBi_3S_5$  (pavonite).

TABLE 8. THEORETICAL SERIES:  $Pb_{2x}(Ag,Cu)_{6-x}(Bi,Pb)_{14-x}S_{24}$   
IN WHICH  $x = 0$  to 6 and  $Pb + (Ag,Cu) + Bi = 20$

Pb	(Ag,Cu)	(Bi,Pb)	
12	0	8	
10	1	9	
8	2	10	gustavite phase X, Greenland
6	3	11	gustavite, Greenland
4	4	12	high-Pb benjaminite phase; gustavite from Colorado
2	5	13	
0	6	14	low-Pb benjaminite phase

Pavonite, gustavite, and the low-Pb benjaminite phase cannot be distinguished satisfactorily by chemical analyses without supporting definitive x-ray diffraction data. The chemical similarity of these compounds emphasizes the need for a comprehensive approach in the study of ore minerals.

The atomic arrangements in the benjaminite phases are evidently closely related and therefore it is reasonable to assume that the cell contents of the phases should be expressible by a single general formula. The phases have in common the conditions that  $Pb + (Ag,Cu) + Bi = 20$  and  $S = 24$  and their compositions are related by the chemical transition  $2Pb^{2+} \rightleftharpoons Ag^+ + Bi^{3+}$ . The general formula



in which  $x = 0$  or 2, accounts for these various characteristics in the two phases. The compositions of all compounds, both known and theoretical, that conform to this formula are collected in Table 8. The table includes two compounds —  $Pb_{12}(Bi,Pb)_8S_{24}$  and  $Pb_8(Ag,Cu)_2(Bi,Pb)_{10}S_{24}$  — additional to the benjaminite phases, which satisfy the benjaminite equipoint restriction and presumably, therefore, may be found to occur with a benjaminite-type structure. The second compound is chemically identical with the gustavite phase X. Three of the compounds in the table, namely those with  $x = 1, 3$  and 5, are not compatible with the benjaminite equipoint restriction.

The various compositions which have been proposed for gustavite and its exsolved component, phase X, also conform to the general formula for the benjaminite phases as might be expected from a comparison of Tables 1 and 4. Table 8 calls attention to the incompatibility of the composition  $Pb_8(Ag,Cu)_2Bi_{11}S_{24}$  proposed by Karup-Møller (1970) for gustavite from Greenland, with the diffraction symbol  $Bb^{**}$ . The equipoints in the space groups represented by this symbol have ranks of 16, 8 and 4. Unless the gustavite structure accommodates an unusual degree of disorder of the metals, the composition of the phase, or its symmetry, is in error.

### THE RE-DEFINITION OF BENJAMINITE

Benjaminite was first defined in terms of a chemical composition (Shannon 1925) which has been shown in this paper to be invalid. The mineral was characterized by the present writer (Nuffield 1953) with a monoclinic sub-cell which agrees with sub-cell # 1 (Table 1). The

sub-cell has been found to have the contents  $2[(\text{Ag,Cu})_3(\text{Bi,Pb})_7\text{S}_{12}]$  and is the most abundant phase in the type crystal. Although the type crystal contains two additional phases, it is reasonable to restrict use of the name benjaminite to this (low-Pb) phase. The published structural data associated with the name then remain unchanged, except for minor refinement, and the status of the species is improved by the addition of chemical data. This definition of benjaminite has received the approval of the Commission on New Minerals and Mineral Names, IMA.

Sub-cell # 2, with the cell contents  $4[\text{Pb}(\text{Ag,Cu})(\text{Bi,Pb})_3\text{S}_6]$ , is structurally related to the sub-cell of benjaminite but must be regarded as a distinct and new species in the present definition of minerals. However, in view of the difficulty experienced in establishing the validity of benjaminite, it is the intention to delay naming the new species until its existence has been confirmed in another laboratory or from another locality.

#### REPORTED OCCURRENCES OF BENJAMINITE FROM OTHER LOCALITIES

A number of occurrences of minerals resembling benjaminite and/or pavonite has been reported in the literature.

Mintser (1967) obtained three microprobe analyses on material from Adrasman, central Asia, which agree well with the formula  $\text{Pb}_{27}(\text{Cu,Ag})_2\text{Bi}_4\text{S}_9$  derived by Shannon (1925) in the original study of benjaminite. Mintser's *x*-ray powder diffraction data were not in good agreement with the data published for benjaminite, however, or in fact, with any *x*-ray data obtained from the Nye County, Nevada locality. Borodaev & Mozgowa (1971) found by electron microprobe analysis that the grains in Mintser's sample were not homogeneous but consisted of intergrowths of berryite with small amounts of matildite and lindströmite. They showed that Mintser's *x*-ray data agreed well with the data for berryite.

Shadlun *et al.* (1969) described a sulphbismuthide, associated with aikinite, from the Dzhida district. The grains ranged from 0.01 to 0.5 mm in size and most exhibited a fine platy structure resembling polysynthetic twinning. Without this structure, the grains could not be distinguished optically from aikinite. Except for some differences in intensities, the *x*-ray powder data agree well with the data for pavonite and for synthetic  $(\text{Cu,Ag})_2\text{Bi}_4\text{S}_7$ , less well with the benjaminite data. The average of five mi-

croprobe analyses gave Bi 65, S 25, Cu 6, Ag 3, sum 99%, leading to the formula  $(\text{Cu,Ag})_{1.5}\text{Bi}_3\text{S}_{7.5}$  compared with  $\text{AgBi}_3\text{S}_7$  for pavonite, or to  $(\text{Cu,Ag})_{3.0}\text{Bi}_7\text{S}_{17.5}$  compared with  $(\text{Ag,Cu})_3\text{Bi}_7\text{S}_{12}$  for the low-Pb benjaminite phase. The variation in Ag from 1 to 5% and Cu from 5 to 11% suggested to the authors that the platy structure represented a regular alternation of two phases, differing in Ag and Cu content but not optically or by *x*-rays. This material is probably either a Cu-bearing pavonite or low-Pb benjaminite. A positive identification evidently depends on obtaining single-crystal *x*-ray data.

Lur'ye *et al.* (1971) reported on a sulphbismuthide from the Kaptarkhan ore deposit, East Karamazar in Central Asia. The mineral occurs as bladed segregations intimately associated with secondary Bi, Cu and Ag minerals. The *x*-ray powder data consist of 15 lines which agree only approximately and about equally well with both pavonite and benjaminite. The average of two microprobe analyses of material admittedly intergrown with secondary minerals gave the composition  $\text{Pb}(\text{Cu}_{0.7}\text{Ag}_{1.5})\text{Bi}_{4.6}\text{S}_{7.6}$ . The intergrowths are evidently on too fine a scale to provide good microprobe data and to permit *x*-ray single-crystal study.

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