

## NEW OCCURRENCES AND DATA FOR JALPAITE

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## ABSTRACT

Jalpaite of ideal composition  $\text{Ag}_3\text{CuS}_2$  is tetragonal, space group  $I4_1/amd$  with  $a=8.633$ ,  $c=11.743 \text{ \AA}$  and  $Z=8$ . Jalpaite is probably much more common than the literature would suggest. Jalpaite is sectile but fractures into subconchoidal fragments or splinters and the majority of specimens locally show a chalcocpyrite-like tarnish.

Jalpaite, from Silver Plume, Colorado, is  $\text{Ag}_{2.0}\text{Cu}_{1.0}\text{S}_{2.0}$ . However, an additional analysis on a specimen from Boulder County, Colorado and older published analyses indicate slight copper deficiency. Previous studies of synthetic jalpaite suggest a solid solution field to at least  $\text{Ag}_{3.1}\text{Cu}_{0.9}\text{S}_{2.0}$ . The measured density of Silver Plume material,  $6.82 \pm 0.01 \text{ gm/cm}^3$ , agrees with the calculated density of 6.827 for the composition  $\text{Ag}_3\text{CuS}_2$ . The calculated density for  $\text{Ag}_{3.1}\text{Cu}_{0.9}\text{S}_{2.0}$  is 6.920 (based on the same cell dimensions) which suggests that the jalpaite composition may be roughly determined by measurement of the density.

Measurements of the Vickers microhardness and reflectivity of jalpaite in polished section as well as observation of color and etch reactions do not show any clear distinction from acanthite. The X-ray powder patterns of natural jalpaite, which are essentially the same as synthetic  $\text{Ag}_{3.1}\text{Cu}_{0.9}\text{S}_{2.0}$ , distinguish the two.

## INTRODUCTION

First described by Breithaupt in 1858, the mineral jalpaite has had a checkered history. Its formula has been variously written and its existence as a distinct species has, at times, been discredited. However, with no particular difficulty, five different specimens, three almost fist-sized, were verified as jalpaite. It is the authors' belief that jalpaite may actually be quite common.

Breithaupt indicated its formula as  $\text{Ag}_3\text{CuS}_2$  based on chemical analysis. His analysis was remarkably close to those of Bertrand (1872) and Kalb and Bendig (1924) as well as the determinations made in the present study. However, with the publication of *Dana's System of Mineralogy*, Volume I (Palache, Berman and Forndel, 1944), jalpaite was listed as a variety of argentite. Discredit of jalpaite as a separate species was based mainly on the work of Schwartz (1935) who studied the minerals of the argentite-stromeyerite-chalcocite group. Later, Suhr (1955), Djurle (1958) and Skinner (1966), all working with artificial systems, definitely verified the existence of jalpaite as a tetragonal mineral along the pseudobinary  $\text{Ag}_2\text{S-Cu}_2\text{S}$ . Both Djurle and Skinner indicated that the composition was probably  $\text{Ag}_{1.55}\text{Cu}_{0.45}\text{S}$ . Descriptions of natural occurrences of jalpaite are rare in the recent literature. Claringfull (1954) described jalpaite in a paper presented to the Mineralogical Society of London, but unfortunately only an abstract has been published.

## OCCURRENCE AND DESCRIPTION OF THE SPECIMENS

The specimen that began the present study was generously loaned by Mr. Richard Rizzardi of Silver Plume, Colorado, for an exact identification. It measured originally  $6 \times 6 \times 3$  cm and was composed of 80 percent jalpaite in coarse masses with the remainder of the specimen composed of galena, honey-yellow sphalerite and pyrite. Microscopically the galena and sphalerite occur as rounded masses up to about 5 mm in diameter cut infrequently by veinlets of jalpaite, but more generally occur as rounded islands in it. Isolated masses of mckinstryite up to about 3 mm long, often with a very fine rim or hood of covellite, are scattered through the specimen, but nowhere is the mckinstryite in significant quantity.

Another slightly larger similar specimen was subsequently made available for study by Mr. Rizzardi. Both of these specimens certainly came from the Payrock Mine in Silver Plume, Clear Creek County, Colorado, and were mined about 1895–1898. Unfortunately, the Payrock Mine is now closed and inaccessible but it was a major producer in the Silver Plume area. Spurr, Garey and Ball (1908) ascribe about \$2,000,000 in total production to the Payrock Mine with by far the greater part of the value being in silver. Eckel (1961) noted that jalpaite (as a variety of argentite) had been previously observed from the Payrock Mine and he cites the results of an unpublished analysis that show 13.4 percent copper and traces of lead and iron.

Four other specimens of jalpaite were found in the Colorado School of Mines reference collection with no difficulty. The largest, almost fist-sized, consists of at least 60 percent jalpaite. The remainder of this specimen is composed of striking nodules and irregular masses up to about 2 cm in maximum dimension with a thin irregular rim of granular chalcopyrite and a core of finely intergrown jalpaite and pearceite. The exact location of this specimen is not known but the label reads: "Boulder County, Colorado, mine of E. C. Hite (from Randall collection)."

A smaller, approximately equidimensional specimen about 2 cm in diameter from Tepic, Mexico, also proved to be jalpaite although labeled "argentite." The specimen consists of rounded laths of jalpaite with a large 1 cm crystal of chalcopyrite perched on it. The crystals are too deformed to allow determination of the crystallography. Because of its relatively small size, no work has been done on this specimen beyond certain identification of the jalpaite by an X-ray powder photograph.

Another specimen, about  $4 \times 4 \times 3$  cm, is totally unlike any of the others and is similar in appearance to a porous sinter. The jalpaite is present as a loose aggregate with 30 percent voids, major quartz and pyrite and minor chalcopyrite and polybasite (?). The specimen presents a dull, rough sooty-black surface. Even when fractured, the surfaces retain

much the same appearance although speckled with scattered shiny pyrite and quartz grains. In polished section, the sulfides are intimately intergrown with no obvious order of deposition. There is no location listed for this specimen.

The last specimen of jalpaite recognized was found accidentally in the Colorado School of Mines collection during routine identification work. Its label reads: "Galena (argentiferous), Geyser Mine, Silver Cliff, Custer County, Colorado." The specimen measures  $6 \times 3.5 \times 1.5$  cm and consists of about 60 percent jalpaite replacing galena. The jalpaite occurs as rounded masses and islands in the galena with minor chalcopyrite, polybasite, pyrite and sphalerite. The hand specimen also shows a rough banding with one prominent band of galena about 4 mm thick and more irregular bands of jalpaite up to about 1 cm thick broken by random masses of fine-grained galena.

#### PROPERTIES

Jalpaite is a light metallic-gray color on freshly-fractured surfaces and shows conchoidal fractures with a tendency to break into irregular splinters (especially the Boulder County specimen). The Silver Plume and Boulder County specimens in particular and the others to a lesser degree display a peculiar surface tarnish. The greater part of the surface of these specimens shows a lustrous dark-gray tarnish but locally, the tarnish is iridescent with prominent yellow and yellow-orange that almost resembles chalcopyrite. Although some of the specimens are known to be quite old, there is almost no development of the dull black coating common to some other silver-bearing minerals. Jalpaite is slightly less sectile than acanthite.

Skinner (1966) has remarked that where jalpaite and acanthite occur separately they may be quite difficult to distinguish in polished section. After observing verified jalpaite in polished section, there is no doubt that the distinction is not easy even under conditions where both minerals are present. At least part of the problem is the difficulty in polishing both jalpaite and acanthite. A variety of polishing methods was tried but none produced even a relatively scratch-free surface.

One apparent distinction between acanthite and jalpaite in the material studied is that the irregular grain boundaries and twin planes of the acanthite can be distinguished quite readily in polarized light under an ore microscope. But even on the best polished jalpaite surfaces, the grain boundaries were at best poorly defined and diffused. However, both under orthoscopic and conoscopic conditions jalpaite is anisotropic.

*Etch reactions.* The etch reactions for all three specimens of jalpaite tested were essentially the same:

HNO <sub>3</sub> :	Dark gray to light brown halo which does not entirely wash off but remains a very light brown and may be overlooked.
HCl:	Develops an iridescent halo which does not wash off may or may not produce a light gray stain.
KCN:	Develops a light gray stain which brings out scratches. No halo.
FeCl <sub>3</sub> :	Quickly develops an iridescent stain which does not rub off. No halo.
KOH:	Negative
HgCl <sub>2</sub> :	Develops a light brown halo which may not be easily noticed, but does not wash off. Quickly stains iridescent.

From the above it can be seen that the etch reactions for jalpaite appear quite similar to those given for argentite by Short (1940) and Uytendogaardt (1951); however, the reactions given for jalpaite by Uytendogaardt appear to be incorrect. The only difference in the etch tests between jalpaite and argentite (or acanthite) would appear to be a more positive reaction to HNO<sub>3</sub>. The jalpaite studied always gave a very light persistent halo and stain whereas both Short and Uytendogaardt noted that the HNO<sub>3</sub> halo for argentite did not persist and the reaction was often negative. A test on a surface of acanthite from Cobalt, Ontario, gave a negative reaction to HNO<sub>3</sub>. While etch reactions are occasionally subject to uncertain results and this reaction is not particularly distinctive, the reaction to HNO<sub>3</sub> appears to offer one of the few easily used tests to distinguish jalpaite from acanthite in polished section.

*Color.* Jalpaite shows the following colors against some other minerals in white light. The mckinstryite, polybasite-pearceite and galena occurred in natural association; the acanthite and chalcocite were placed in contact in preparing the mounts:

	<i>Air</i>	<i>Oil</i>
Acanthite	Colors about the same shade of gray; may appear as a shade of green to some. Reflectivity same or slightly higher than jalpaite but greatly influenced by polish.	as air
Chalcocite	Jalpaite appears light yellow-brown against the light blue of chalcocite. Reflectivity of chalcocite noticeably higher.	as air
Galena	Galena is a distinctly lighter gray and jalpaite may have a slight greenish tinge against it.	as air
Mckinstryite	Very light blue against jalpaite in all positions. Distinctly bireflectant with reflectivity varying above and below jalpaite.	as air, but a distinct shade of blue against jalpaite.
Polybasite-pearceite	Slightly higher reflectivity and a light shade of pink against jalpaite.	as air

*Reflectivity.* The reflectivity data for jalpaite are presented with some reservation. The specimens used were never satisfactorily polished and the reproducibility of the measurements was poor. Because the jalpaite could not be well polished, reflectivity measurements by photoelectric devices were considered inappropriate. The Hallimond visual microphotometer was used for all measurements; the accuracy and use of this instrument has been discussed by Leonard (1960).

An estimate of the accuracy indicates that the "best" orange light values may vary by  $\pm 1$  percent on well polished material. The variation noted undoubtedly includes the effect of bireflectance, but its variation was obscured by the much larger variations due to polishing. The information given in Table 1 is taken from specimens with a relatively good

TABLE 1. REFLECTIVITY OF JALPAITE

Filter <sup>a</sup>	Air	Oil
Green	32½	17½
Orange	30	15½
Red	27½	13½

<sup>a</sup> See Leonard and Vlisidis (1961) Table 5 for details of filters.

polish. The values tended to increase during the course of the work as more care was taken and technique was improved. It must be emphasized that even with what appeared to be carefully polished surfaces, lower values often resulted. One surface that appeared well polished produced a quite reproducible series of measurements of from 23–25 percent in orange light over the entire surface but repolishing gave much higher values.

The relative position for the red, green and orange values in air and in oil are more precise. They are based on three series of measurements in oil and in air at single locations on the polished surfaces, only the filters and objectives being changed. The precision of these values is probably within 1/2 percent. All the values were adjusted to what appeared to be the best orange light value in air and any particular value in the table is undoubtedly subject to the variations noted for the orange light value of air.

The reflectivity values obtained for this paper for jalpaite closely approximate those given by Ramdohr (1960) for acanthite. Since no acanthite was apparently present with any of the jalpaite, two surfaces were prepared which placed verified jalpaite from Silver Plume and Boulder

County, Colorado against acanthite from Silver Plume, Colorado, and Cobalt, Ontario. With the best polish, there was no definite distinction in reflectivity. Along most of the contacts, jalpaite generally did appear to have slightly lower reflectivity but the reverse relation also occurred. In view of this, it is not surprising that Schwartz (1935) could not isolate jalpaite as a separate species in polished section.

*Microhardness.* The Vickers hardness of jalpaite varies within surprisingly narrow limits, 22.8–29.7, with an average value of 25.6 from 70 separate measurements. Generally the Boulder County surfaces average about 2 units higher than the Silver Plume material, but the range was about the same. Nine different polished surfaces from three specimens were used and individual measurements were randomly taken across the surfaces. A Leitz-Durimet hardness apparatus with a 100-gram load was used. At least part of the variation is due to differences in polishing. In any one set of 10–15 measurements made on different surfaces, but polished at the same time and in the same manner, it was common to have a maximum spread of under four units. The shape of the indentations in the jalpaite varied greatly. Some displays the regular pyramidal shape of the indenter, but more often the sides of the indentation were S-shaped and many appeared highly distorted. However, no measurements were discarded because of distortion nor was the specimen leveled other than in attempt to achieve parallelism of the base and surface of the mounts during preparation. All of the polished sections prepared for this study were mounted in cold-setting plastic, but a few had previously been prepared in a bakelite mounting press. These were included in the measurements as well. In addition, there were variations in the polishing procedure from complete had polishing to rather hard pressure on machine driven laps at high speed.

The only published data for the hardness of jalpaite are those given by Young and Millman (1964) which were gathered with the same machine and load. Their range of values from 23–55 appears too large. Possibly their measurements included some mckinstryite, which at the time had not been identified as a separate species (Skinner, Jambor and Ross, 1966). There was insufficient room on the mckinstryite present in available Silver Plume specimens to make more than six measurements. However, these indicate a Vickers hardness of  $60 \pm 2$ . The shape of the indentation in the mckinstryite was also very characteristic as compared to jalpaite. Mckinstryite showed a conjugate set of *en echelon* fractures, often with off sets, at the border of the indentations.

The data for the Vickers hardness of jalpaite do not offer a distinction from acanthite (or argentite) with which it is most likely to be confused.

Young and Millman (1964) indicate an average Vickers hardness of 21 for acanthite and Bowie and Taylor (1958) give an average value of 24 for argentite (both undoubtedly referring to monoclinic  $\text{Ag}_2\text{S}$  at room temperature). In addition, a check of the instrument used in this study on acanthite gave values well within the range determined for jalpaite.

#### COMPOSITION

The Silver Plume and Boulder County, Colorado, specimens were analyzed for silver and copper by wet chemistry. The results are given in Table 2. Silver was determined by the Volhard method and the copper by iodine titration as outlined in any general quantitative analysis text. There was no difficulty in obtaining 1:1000 accuracy for silver and 1:5000 accuracy for copper in standardizing titration solutions. However, the precision of the jalpaite analyses was well below the standardization accuracy and the discrepancy is ascribed to the difficulty in obtaining pure samples for analysis. The samples were picked and examined carefully under a binocular microscope; however, approximately one-third of the values were discarded. There is no statistical justification for these discards except that they were widely erratic. The precision of the remaining values would appear to justify the accuracy of the values given in Table 2. Sulphur was computed by difference and no other major elements were observed in a semiquantitative spectrographic analysis of the minerals.

Within the accuracy of the analyses, there seems to be little doubt that the Silver Plume jalpaite corresponds to the composition  $\text{Ag}_3\text{CuS}_2$ . The Boulder County material, in contrast, appears to be slightly copper deficient. The previous analyses of Breithaupt (1858), Bertrand (1872) and Kalb and Bendig (1924) also appear to approach  $\text{Ag}_3\text{CuS}_2$  closely, especially with respect to silver content.

The discrepancy between these analyses and the  $\text{Ag}_{1.55}\text{Cu}_{0.45}\text{S}$  composition found in the work of Skinner (1966) and Djurle (1958) cannot be fully explained. The differences in these compositions appear to be much too great to be fully explained by analytical errors. There may well be a solid solution field that tends toward copper deficiency from the "ideal" formula,  $\text{Ag}_3\text{CuS}_2$ . A similar solid solution field was indicated for stromeyerite by Suhr (1955) and Djurle (1958). The formula was not simply  $\text{AgCuS}$  but was, in actuality,  $\text{Ag}_{1-x}\text{Cu}_{1+x}\text{S}$  (with  $0 \leq x \leq 0.1$ , Skinner (1966)).

*Density.* The density of jalpaite was measured with a Berman microbalance and the results are included in Table 2. The unit-cell dimensions used for the calculated density were those derived from a refinement of

TABLE 2. ANALYSES OF JALPAITE, WEIGHT PERCENT

This study <sup>a</sup>				
	Silver Plume, Colorado	Boulder Co., Colorado	Ag <sub>3</sub> CuS <sub>2</sub>	Ag <sub>1.55</sub> Cu <sub>0.45</sub> S
Ag	71.7 ± 0.1 (4)	71.7 ± 0.4 (5)	71.71	73.38
Cu	14.05 ± 0.05 (4)	13.84 ± 0.05 (3)	14.08	12.55
S (by diff.)	14.2 ± 0.1	14.5 ± 0.4	14.21	14.07
	100.0	100.0	100.0	100.0
Density:	$\rho_{\text{meas.}} = 6.82 \pm 0.01$	$\rho_{\text{meas.}} = 6.85 \pm 0.01$	$\rho_{\text{calc.}} = 6.827$	$\rho_{\text{calc.}} = 6.920$
	Jalpa, Mexico (Breithaupt, 1858)	Altai, U.S.S.R. (Kalb & Bendig, 1924)	Buena Esperanza Mine, Tres Puntas Dist., Chile (Bertrand, 1872)	
Ag	71.51	71.73	71.63	
Cu	13.12	14.10	13.06	
S	14.36	16.33	14.02	
Fe	0.79	—	0.57	
	99.78	102.16	99.28	

<sup>a</sup> No. of analyses in parentheses).

X-ray powder photography measurements. The correspondence (within the limits of accuracy of the measurements) between the calculated and measured density of the Silver Plume specimen serves as confirming evidence that the chemical analysis is indeed correct. It is also suggested that the range in the calculated density, 6.827 gm/cm<sup>3</sup> for Ag<sub>3</sub>CuS<sub>2</sub> to 6.920 for Ag<sub>1.55</sub>Su<sub>0.45</sub>S, may serve as a measure of the composition within the range. Certainly more data are needed to construct a curve, but the density of 6.85 gm/cm<sup>3</sup> for the Boulder County specimen, the only other specimen analysed, confirms this idea.

#### UNIT CELL OF JALPAITE

Crystal fragments of Silver Plume jalpaite have been used to determine the unit cell. The unit-cell dimensions determined from precession photographs were then used as an initial input, together with powder film data for the refinement of the cell data by the Evans, Appleman and Handwerker (1963) program. X-ray powder data are given in Table 3 together with the powder data of Djurle (1958) for comparison.

Portions of the Silver Plume material yielded excellent crystal frag-



TABLE 3. X-RAY POWDER DATA FOR JALPAITE, BOULDER COUNTY, COLORADO COMPARED WITH THE  $\alpha$ -PHASE OF DJURLE (1958) OF COMPOSITION  $\text{Ag}_{1.55}\text{Cu}_{0.45}\text{S}^c$ 

Jalpaite			$\alpha$ -phase of Djurle (1968)		
<i>hkl</i>	$d_{\text{calc}}$	$d_{\text{obs}}$	I	$d_{\text{obs}}$	I
101	6.958	6.953	4	6.916	w
200	4.317	4.298	6	4.318	m
211	3.668	3.666	2	3.668	w
103	3.56	2.567	2	3.564	w
202	2.478	3.462	2	2.484	w
		3.407 <sup>a</sup>	$\frac{1}{2}$	3.484	w
		3.084 <sup>b</sup>	$\frac{1}{2}$		
220	3.052	3.053 <sup>a</sup>	$\frac{1}{2}$		
004	2.936	2.961(?)	1		
301	2.795	2.794	9	2.805	st
213	2.749	2.740	8	2.755	st
		2.585(?)	$\frac{1}{2}$		
312	2.476	2.475	5	2.483	m
204	2.428	2.422	8	2.433	st
321	2.346	2.345	10	2.354	st
303	2.319	2.311	3	2.327	w
105	2.266	2.268	5	2.270	w
400	2.158	1.158	4	2.166	w
224	2.116	2.114	7	2.122	m
		2.087 <sup>a</sup>	$\frac{1}{2}$		
215	2.007	2.006	6	2.013	w
332	1.923	1.922	4	1.932	vw
116	1.864	1.863	1	1.866	vw
206	1.783	1.783	2		
404	1.739	1.739	4	1.745	w
431	1.708	1.707	1	1.715	vw
325	1.677	1.677	$\frac{1}{2}$	1.679	vw
433	1.580	1.580	1	1.588	vw
415	1.563	1.563	2	1.568	vw
440	1.526	1.524	$\frac{1}{2}$		
523	1.484	1.483	3	1.490	w
008	1.468	1.468	$\frac{1}{2}$	1.472	vw
406	1.450	1.450	$\frac{1}{2}$		
532	1.436	1.436	4	1.433	w
336	1.411	1.412	2	1.415	w
435	1.391	1.391	2	1.396	w

<sup>a</sup> Only on Silver Plume pattern.

<sup>b</sup> Only on Boulder County pattern.

<sup>c</sup> The pattern of jalpaite from Silver Plume, Colorado is essentially the same as the Boulder Co. specimen except as noted.  $d_{\text{calc}}$  for a tetragonal cell,  $a = 8.633 \pm 0.0008 \text{ \AA}$ ,  $c = 11.743 \pm 0.001 \text{ \AA}$ , space group =  $I4_1/amd$ . Intensities are relative intensities by visual estimate. Measurements made with  $\text{Cu}(K\alpha)$  radiation.

TABLE 3. (Continued)

Jalpaite			$\alpha$ -phase of Djurle (1968)		
<i>hkl</i>	<i>d</i> <sub>calc</sub>	<i>d</i> <sub>obs</sub>	I	<i>d</i> <sub>obs</sub>	I
426	1.374	1.375	1	1.377	vw
620	1.365	1.363	$\frac{1}{2}$		
444	1.354	1.352	1		
525	1.324	1.325	3	1.328	w
516	1.280	1.280	1	1.285	vw
633	1.223	1.223	$\frac{1}{2}$		
437	1.203	1.206	$\frac{1}{2}$		
309	1.188	1.190	1	1.189	vw
536	1.181	1.181	$\frac{1}{2}$		
329	1.146	1.147	1	1.147	vw
723	1.135	1.135	$\frac{1}{2}$		
800	1.079	1.080	$\frac{1}{2}$		
1011	1.060	1.060	$\frac{1}{2}$		
538	1.042	1.043	$\frac{1}{2}$		
804	1.013	1.013	$\frac{1}{2}$		
3011	1.001	1.001	1		

ments. Precession photographs of the *hk0*, *hk1*, *hk2*, *0kl*, *1kl* levels were taken for space group determination as well as unit cell measurements. The unit-cell dimensions and space group information are given in Table 4.

The unit cell contains 8 [Ag<sub>3</sub>CuS<sub>2</sub>] which is compatible with space group requirements and the structure of jalpaite is being determined in order to compare the Ag-Cu distribution with that of other minerals in the Ag-Cu-S system. The single crystal investigation confirms the tetragonal system and unit cell dimensions of jalpaite originally presented by Djurle (1958).

#### GEOLOGIC RELATIONS

Jalpaite from Silver Plume and Boulder County, Colorado probably formed at some temperature below 117°C, as suggested by the size and homogeneity of the material. Skinner (1966) points out that above that temperature jalpaite forms a body centered cubic mineral with a large compositional field. Upon cooling, the higher temperature form decomposes into a mixture of acanthite, mckinstryite or jalpaite unless the high temperature form had exactly the composition of jalpaite, a highly fortuitous situation. It is probable that the higher temperature phase would separate into fairly fine-grained intergrowths. Skinner (1966) presents a photograph indicating an exsolution of jalpaite in acanthite to

illustrate formation above 117°C. However, the large masses of jalpaite found at Silver Plume and at the Boulder County locality probably formed below 117°C from solutions that formed one dominant mineral to the exclusion of acanthite or mckinstryite.

It is also known that at least two other minerals along the  $\text{Ag}_2\text{S}-\text{Cu}_2\text{S}$  join occur in relatively large masses at Silver Plume. One large specimen from the Payrock Mine proved to be almost entirely chalcocite with a few grains of pyrite and polybasite. In addition, acanthite masses and groups of cubic and octahedral pseudomorphs after argentite are commonly encountered from the Silver Plume vicinity. In at least one mine, small octahedral (?) crystals of acanthite (after argentite?), together with wire silver growing on them, can be found in vugs as much as 50 meters below the present surface. Numerous other examples of acanthite from Silver Plume have been verified. Some weigh up to one-half pound and apparently all lack significant associated jalpaite. In view of these relatively large masses of acanthite, chalcocite and jalpaite at Silver Plume, there appears to be some basic chemical control that has separated these minerals. The temperature of formation of the Silver Plume jalpaite suggests that this is a supergene process.

With one minor exception, the mineral assemblages noted in all of the specimens examined are in accord with the tie-lines of Djurle's (1958) diagram of the  $\text{Ag}-\text{Cu}-\text{S}$  system. The only exception is one thin veinlet of digenite about 10 microns thick on a single surface from Silver Plume. No acanthite was noted with any jalpaite although it is a stable associate of jalpaite. Covellite, in small amounts, was found commonly in all the material examined in polished section.

Neither chalcocite nor stromeyerite were seen in any of the sections with jalpaite. They are not expected to be stable associates although both are often mentioned as appearing in similar types of deposits (see

TABLE 4. UNIT-CELL DATA FOR JALPAITE,  $\text{Ag}_3\text{CuS}_2$ . ALL SINGLE CRYSTAL DATA WERE OBTAINED FROM SILVER PLUME, COLORADO MATERIAL

Unit-cell dimensions		Space group data
Precession	Refined	
$a = 8.634 \pm 0.005$	$8.633 \pm 0.001$	$hkl: h+k+l=2n$
$c = 11.770 \pm 0.03$	$11.743 \pm 0.001$	$hk0: h=2n; k=2n$
$\rho_{\text{obs.}} = 6.820 \pm .010$		$hhl: 2h+l=4n (l=2n)$
		Space group: $I4_1/amd$
$\rho_{\text{calc.}} = 6.827$		
$Z = 8$		

the discussion in Skinner, 1966, for some of the inconsistencies in identification of the natural assemblages). It is interesting to note, that chalcopyrite and polybasite or pearceite were found in at least minor amounts in all of the material examined to the exclusion of other copper-iron sulphides or other silver-bearing sulphosalts. At present no significance can be attached to this.

If the assumption is made that jalpaite does have a solid solution field from  $\text{Ag}_3\text{CuS}_2$  to at least  $\text{Ag}_{1.55}\text{Cu}_{0.45}\text{S}$ , specific minerals along the  $\text{Ag}_2\text{S}$ - $\text{Cu}_2\text{S}$  tie might tend to be found with one either the former or latter of the end compositions. Thus, acanthite may be found naturally associated with copper deficient jalpaite and mckinstryite with jalpaite of the ideal composition,  $\text{Ag}_3\text{CuS}_2$ . The former case cannot be demonstrated, but mckinstryite certainly does accompany  $\text{Ag}_3\text{CuS}_2$  in the Silver Plume material. In addition, the Boulder County specimen, which is in an intermediate position in the postulated solid solution field, does not contain either acanthite or mckinstryite.

NOTE ADDED IN PROOF: In a recent publication Johan [Johan, Z. (1967) Etude de la jalpaite,  $\text{Ag}_{1.55}\text{Cu}_{0.45}\text{S}$ . *Acta Univ. Carolinae-Geol. No. 2*, 113-122] investigated naturally occurring jalpaite from Bohutin near Přebram, Czechoslovakia by powder X-ray methods, polished section and a chemical analysis of a jalpaite-acanthite mixture.

Jalpaite has also been observed recently in samples obtained from the dump of the American Eagle mine near Montezuma, Colorado, in association with covellite (T. Botinelly, U. S. Geological Survey, personal communication).

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