

ADAMITE FROM THE OJUELA MINE,  
MAPIMI, MEXICO\*

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WITH NOTES ON THE OCCURRENCE BY  
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ABSTRACT

Adamite of unusually pure composition is described from a new locality, the Ojuela mine at Mapimi, Durango, Mexico. A chemical analysis is given together with measurements of the morphological axial ratio ( $a:b:c=0.9753:1:0.7055$ ), the unit cell dimensions ( $a_0=8.30$ ,  $b_0=8.51$ ,  $c_0=6.04$  Å), the specific gravity (4.435) and optical constants ( $X=1.722$ ,  $Y=1.742$ ,  $Z=1.763$ ,  $2V$  (meas.)  $88^\circ \pm 2^\circ$ ). Analysis gave ZnO 56.78, As<sub>2</sub>O<sub>5</sub> 38.96, SiO<sub>2</sub> 0.26, H<sub>2</sub>O 3.53; total 99.53. Spectrographic analysis also revealed Cu ( $\sim 0.1$ ), Pb ( $\sim 0.1$ ), Fe (0.01–0.1), Mg (0.01–0.1), Al ( $\sim 0.01$ ), Ca ( $\sim 0.01$ ), Ag (0.001–0.01) and Ga ( $\sim 0.001$ ).

CRYSTALLOGRAPHY

Most of the crystals of Mapimi adamite occur merged together as radiating crusts or as fan-shaped rosettes on a matrix of limonite. A few

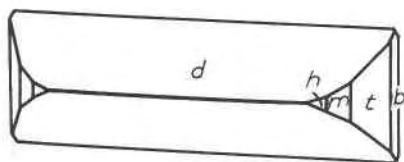


FIG. 1. Adamite crystal from Mapimi showing all the forms observed.

single-crystals, however, were found. The crystals are elongated parallel to [010]. Most crystals were attached at one end of the  $b$ -axis; only three doubly terminated crystals could be found. These indicated holohedral symmetry. A test for piezoelectricity by the cathode-ray oscilloscope method gave negative results. The crystals range in size from  $\frac{1}{2}$  mm. to 8 mm. along [010].

The crystals are rather simple in habit. The form  $d\{101\}$  is dominant and is truncated by  $t\{120\}$  and  $m\{110\}$ . On some crystals the prism  $h\{210\}$  occurs, but only as very small faces which gave poor signals during goniometric measurement, and  $b\{010\}$  was observed in several instances. The faces in the [010] zone are highly striated parallel to [010], producing a train of signals which made accurate measurements impos-

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sible. A somewhat idealized drawing showing all of the forms observed is given in Fig. 1.

Although a great number of crystals were carefully examined, only nine of the very best of these were selected for measurement (Table 1).

TABLE 1. ADAMITE: MEASURED AND CALCULATED ANGLES

Forms	No. of Xls	No. of Meas.	Size	Quality*	Measured Range		Weighted Mean		Calculated	
					$\phi_2$	$\rho_2$	$\phi_2$	$\rho_2$	$\phi_2$	$\rho_2$
<i>b</i> 010	1	1	VS	C	—	—	—	0°00'	—	0°00'
<i>t</i> 120	9	18	M	B	—	26°52'–27°33'	0°00'	27 08½	0°00'	27 08½
<i>m</i> 110	9	18	S	D	—	45°11'–46 32'	0 00	45 44	0 00	45 43
<i>h</i> 210	9	14	VS	E	—	63 42'–64 14'	0 00	64 01	0 00	64 00½
<i>d</i> 101	9	36	L	B	53°22'–54°59'	—	54 07	90 00	54 07	90 00

\* A equals first quality.

The linear elements derived from these measurements ( $a:b:c=0.9753:1:0.7056$ ) are identical with those derived from x-ray Weissenberg measurements on the same crystals ( $a:b:c=0.9753:1:0.7055$ ).

A number of other investigators have reported elements for adamite from other localities and these are listed in Table 2.

TABLE 2. REPORTED MORPHOLOGICAL ELEMENTS OF ADAMITE

Investigator	Locality	Axial Ratio
1. Des Cloizeau (1878)	Chañarcillo, Chile	$a:b:c=0.9733:1:0.7158$
2. Aloisi (1909)	Mte. Valerio, Italy	$a:b:c=0.9736:1:0.7013$
3. Staples (1935)	Gold Hill, Utah	$a:b:c=0.9742:1:0.7095$
4. Mrose (1948)	Mapimi, Mexico	$a:b:c=0.9753:1:0.7055$
5. Rosický (1910)	Thasos, Turkey	$a:b:c=0.9764:1:0.7049$
6. Ungemach (1921)	Laurium, Greece	$a:b:c=0.9770:1:0.7124$
7. Des Cloizeau and Lacroix (1910)	Laurium, Greece	$a:b:c=0.9784:1:0.7117$
8. Kukharenko (1939)	Northwestern Balkhash region (lilac variety)	$a:b:c=0.9787:1:0.7128$
9. Palache (priv. comm.; 1921)	Laurium, Greece	$a:b:c=0.9812:1:0.7108$
10. Laspeyres (1878)	Laurium (emerald-green; cuprian)	$a:b:c=0.9958:1:0.6848$
	Laurium (colorless)	$a:b:c=0.9958:1:0.7176$
11. Murdoch (1936)	Chloride Cliff, Calif. (colorless)	$a:b:c=0.996 :1:0.718$

The wide variation observed appears to be due largely to the poor quality of the measured crystals. In part, however, the differences may be due to variation in chemical composition such as substitution of Cu or Co for Zn or of  $(PO_4)$  for  $(AsO_4)$ , but no definite correlations could be

established. Laspeyres (1878) has shown that the angles of the adamite crystals from Laurium vary measurably with the presence of Cu in substitution for Zn. The arithmetical average of the linear elements reported, after eliminating those of Laspeyres (1878), Murdoch (1936) and Des Cloizeau (1878), which are relatively far out of line with the others, is  $a:b:c=0.9769:1:0.7086$ . An angle-table for the forms observed on the Mapimi crystals calculated for these elements is given in Table 3.

TABLE 3. ADAMITE: ANGLE TABLE

Orthorhombic; dipyramidal— $2/m\ 2/m\ 2/m$						
$a:b:c=0.9769:1:0.7086$ ; $p_0:q_0:r_0=0.7254:0.7086:1$						
$q_1:r_1:p_1=0.9769:1.3786:1$ ; $r_2:p_2:q_2=1.4112:1.0236:1$						
Forms:	$\phi$	$\rho=C$	$\phi_1$	$\rho_1=A$	$\phi_2$	$\rho_2=B$
<i>b</i> 010	0°00'	90°00'	90°00'	90°00'	—	0°00'
<i>t</i> 120	27 06½	90 00	90 00	62 53½	0°00'	27 06½
<i>m</i> 110	45 40½	90 00	90 00	44 19½	0 00	45 40½
<i>h</i> 210	63 58	90 00	90 00	26 02	0 00	63 58
<i>d</i> 101	90 00	35 57½	0 00	54 02½	54 02½	90 00

## PHYSICAL PROPERTIES

Cleavage {101} good. The {010} cleavage reported by Staples (1935) on crystals from Gold Hill, Utah, was not observed. Fracture uneven. Brittle. Hardness  $3\frac{1}{2}$ .  $G.=4.435\pm 0.005$  (an average of measurements of 8 different crystals on the microbalance); 4.435 (calculated). The specific gravity found for the Mapimi adamite, which is essentially pure  $Zn_2(AsO_4)OH$  is comparable to the values 4.475 and 4.484 reported by de Schulten (1903) for the pure artificial compound and by Rošický (1910) for pure adamite from Thasos, Turkey. Lower values, ranging between 4.319 and 4.35, have been found for material containing Cu, Co or Fe' in substitution for Zn. Luster vitreous. Small crystals on the specimens are nearly colorless, while the larger crystals are greenish-yellow; all are transparent. The Mapimi adamite fluoresces a bright lemon yellow with a pale lemon yellow phosphorescence in short-wave ultraviolet radiation; a much weaker reaction is given in long-wave ultraviolet and in  $x$ -rays (pale bluish-green). Specimens from other localities react variously. A blue-green Laurium specimen gave a weak greenish fluorescence in both long- and short-wave ultraviolet; bluish-green, in  $x$ -rays. Negative results were obtained with a colorless specimen from Laurium, a blue-green specimen from Gold Hill, Utah, cobaltian material from Cap Garonne, France, and Tsumeb, Africa, and with cuprian material from Tsumeb.

TABLE 4. COMPARISON OF SOME PHYSICAL AND CHEMICAL PROPERTIES OF ADAMITE FROM SEVERAL LOCALITIES

Observer: Mapimi (Mrose, 1948)	Tsumeb, S.W. Africa (Mrose, 1948) (cuprian)	Gold Hill, Utah (Staples, 1935)	Chloride Cliff, Calif. (Murdoch, 1936)	Laurium (Larsen, 1921) (Larsen, 1934)	Northwestern Balkhash Region, (Kukharenko, 1939)
greenish-yellow	sea-green	nearly colorless to pale honey yellow	colorless	nearly colorless	lilac
(+); partly (-)	(-); partly (+)	(+)	(+)	(-)	colorless and greenish (-)
1.722 ± 0.003	1.742 ± 0.006	1.711 ± 0.003	1.720	1.708 ± 0.003	1.710
1.742 ± 0.003	1.768 ± 0.006	1.732 ± 0.003	1.740	1.708 ± 0.003	1.713
1.763 ± 0.003	1.773 ± 0.006	1.756 ± 0.003	1.745 ±	1.744 ± 0.003	1.735
X = a, Z = b	X = a, Z = b	X = a, Z = b		1.738 ± 0.003	1.758
r < r <sub>0</sub> , strong	r > r <sub>0</sub> , strong	r < r <sub>0</sub> , strong		X = a, Z = b	
				r > r <sub>0</sub> , strong	
	nearly colorless				pink
	bluish green				pale rose
	yellow green				colorless
	10°-20°		90° ±		86° ±
	23°28'	87°17'			88° ±
					78°54'
					82°31'
					84°11'
2V (meas.)	87°-90°				
2V (calc.)	89°37'				

## OPTICAL PROPERTIES

The optical properties of the Mapimi adamite are cited in Table 4 in comparison with those reported on material from other localities. The wide variation in the indices of refraction is due to variation in the chemical composition of the crystals, as is clearly shown by comparison of the data on the cuprian and cobaltian material from Tsumeb, but since chemical analyses are lacking in most instances the nature of the relationship is not clear.

## X-RAY STUDY

A selected single-crystal of the Mapimi adamite was studied by the Weissenberg *x*-ray method. The unit cell dimensions, given in Table 5, are in close agreement with those obtained by Strunz (1936) and Kokkoros (1937) on adamite from Thasos and Laurium. The Weissenberg films exhibited orthorhombic centro-symmetry. If the crystal class is

TABLE 5. UNIT CELL DIMENSIONS OF ADAMITE

	1 Adamite (Mapimi) (Mrose, 1948)	2 Adamite (Thasos) (Strunz, 1936)	3 Adamite (Laurium) (Kokkoros, 1937)
$a_0$	$8.30 \pm 0.02$	8.32	8.31
$b_0$	$8.51 \pm 0.02$	8.54	8.51
$c_0$	$6.04 \pm 0.02$	6.08	6.06
$a_0:b_0:c_0$	0.975:1:0.706	0.974:1:0.712	0.977:1:0.712
$a_0/c_0$	1.38	1.37	1.37
$V_0$	427	431	429
Space group	<i>Pnmm</i>	<i>Pnmm</i>	<i>Pnmm</i>

taken to be dipyramidal, as is indicated by the form development (summarized by Ungemach (1921)) and by the absence of piezoelectricity, the space group is established by the diffraction effects as *Pnmm* in conformance with that earlier reported.

The spacing data obtained from a powder photograph of the Mapimi material are listed in Table 6. Photographs of the adamite pattern and of the isostructural species olivenite,  $\text{Cu}_2(\text{AsO}_4)(\text{OH})$ , and libethenite,  $\text{Cu}_2(\text{PO}_4)(\text{OH})$ , are given by Richmond (1940). Powder photographs taken of unanalyzed cobaltian and cuprian adamite from Tsumeb were found to differ very slightly in the relative spacing of the lines from that of the Mapimi material and to have very slightly smaller cells.

## CHEMISTRY

A chemical analysis of the Mapimi adamite, cited in column 2 of Table 7, proves it to be essentially pure  $\text{Zn}_2(\text{AsO}_4)(\text{OH})$ . A semi-quantitative

TABLE 6. X-RAY POWDER DATA ON ANALYZED ADAMITE FROM MAPIMI  
Copper radiation, nickel filter

No.	<i>I</i>	<i>d</i> (meas.)	No.	<i>I</i>	<i>d</i> (meas.)	No.	<i>I</i>	<i>d</i> (meas.)
1	6	5.944	13	5	2.422	25	3	1.658
2	0.5	5.479	14	4	2.359	26	1	1.622
3	9	4.897	15	1	2.072	27	8	1.608
4	6	4.242	16	1	2.016	28	3	1.581
5	4	3.782	17	3	1.958	29	3	1.570
6	2	3.058	18	2	1.912	30	4	1.511
7	9	2.967	19	2	1.888	31	4	1.483
8	8	2.698	20	1	1.851	32	0.5	1.462
9	4	2.641	21	1	1.811	33	0.5	1.434
10	3	2.582	22	1	1.778	34	0.5	1.408
11	3	2.524	23	1	1.738	35	1	1.395
12	10	2.448	24	2	1.708	36	1	1.377

TABLE 7. CHEMICAL ANALYSES OF ADAMITE

	1	2	3	4	5	6
ZnO	56.77	56.78	31.85	49.11	54.32	54.90
CuO			23.45	1.75		tr.
CoO			0.52	5.16		
FeO					1.48	
MnO						0.11
Rare earths						0.39
As <sub>2</sub> O <sub>5</sub>	40.09	38.96	39.85	39.24	39.95	39.80
H <sub>2</sub> O	3.14	3.53	3.68	4.25	4.55	3.45
Rem.		0.26				0.69
Total	100.00	99.53	100.22	99.51	100.30	99.34
G.		4.435		4.352	4.338	4.319

1. Zn<sub>2</sub>(AsO<sub>4</sub>)(OH). 2. Mapimi, Mexico. McClean analyst, 1947. Rem. is SiO<sub>2</sub>. 3. Cap Garonne, France (cuprian adamite). Pisani (1870). 4. Cap Garonne, France (cobaltian adamite). Damour (1868). 5. Chañarcillo, Chile. Friedel (1866). 6. Balkhash region, USSR. Rem. is SiO<sub>2</sub>. Kukharenko (1939).

spectrographic analysis, however, shows that other elements are present in significant amounts: Cu~0.1, Pb~0.1, Fe 0.01–0.1, Mg 0.01–0.1, Al~0.01, Ca~0.01, Ag 0.001–0.01, Ga~0.001.

Of the 11 analyses of adamite reported in the literature,<sup>1</sup> only that of the material from Thasos, Turkey, is comparable in purity to the Mapimi mineral. The axial ratio and specific gravity of the crystals from these two localities also are more closely related to each other than to material

<sup>1</sup> Ten analyses in Doelter (1918); with a more recent analysis by Kukharenko (1939).

from other localities. The other reported analyses of adamite all show various amounts of Cu, Co or Fe'' in substitutional solid solution, and small amounts of Mn'' and rare-earths also have been reported. Substitution of P for As has not been reported although this occurs in some related minerals, notably conichalcite,  $\text{CaCu}(\text{AsO}_4)(\text{OH})$ . The analyses showing the maximum amounts of these substituting elements so far reported are cited in Table 7, and the atomic ratios of the cations corresponding to these analyses are given below. Sufficient data are not at hand to permit a definitive statement of the relation between

cuprian adamite (analysis 3) Cu:Zn=1:1.33

cobaltian adamite (analysis 4) Co:Zn=1:8.8

ferroan adamite (analysis 5) Fe:Zn=1:32.4

the variation in composition and the concomitant variation in optical properties and specific gravity.

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#### NOTES ON THE OCCURRENCE

The Ojuela Mine is located at the base of the northeast escarpment of the Sierra de Mapimi, about five miles southeast of the town of Mapimi, Durango. It is one of Mexico's largest mines, and one may spend weeks travelling underground without revisiting the same spot. The mine has been worked to shallow depths for rich secondary silver ores since 1600. In 1893 it was converted into an enormous lead-silver property by the American Metals Company and almost four million tons of ore, assaying on the average 3.7 grams gold, 462 grams silver and 14.9 per cent lead have since been mined. Large scale operations ceased a decade ago in the face of mounting drainage difficulties and depletion of reserves, and work is now carried forward by a mining cooperative.

The Ojuela deposit is a limestone replacement, typical of northern Mexico (Hayward (1931) and Foshag (1934)). Mineralization is controlled by a system of fractures and favors certain dolomitic horizons. Unlike other similar deposits the Ojuela Mine shows signs of igneous activity in its lower workings, small pegmatite veins being present. Enormous caves and pipes, widely separated by barren limestone, contain the principal ore bodies.

In general, the mineralogy of the Ojuela Mine resembles that of Tintic, Utah; most of the species of one locality are represented at the other, although copper minerals occur less abundantly at Ojuela. Primary mineralization emplaced extensive sulfide bodies composed chiefly of arsenopyrite, pyrite, sphalerite and argentiferous galena. Calcite, quartz, fluorite and limonite are the important gangue minerals. A wide variety of minerals resulted from intensive oxidation, among them the arsenates for which the locality is noted. Unfortunately, many of the rarer arsenates, including carminite, scorodite, arseniosiderite, and dussertite have been encountered only sparingly in dump material. A detailed description of these minerals has been given by Foshag (1937).

In June, 1946, the writers had the good fortune to discover a remarkable pocket of adamite in a small manway of the Las Palomas ore body, just above the 11th level. Enroute to a stope containing fine specimens of wulfenite and green mimetite, our lamps fell upon a pocket in the limestone. We saw a miniature grotto, some four feet in diameter and as many deep, its interior carved into fantastic shapes and the entire surface covered with smoothly undulating waves of sparkling yellow crystals; it was a glorious sight, as though we were gazing upon a mineral specimen of unimaginable splendor! Although we could hardly credit our good luck, we set miners to work immediately and obtained some extraordinary specimens. The largest weighed 75 pounds underground, and was almost 3 feet square; it exhibited a continuous crust of green crystals about  $\frac{1}{4}$  inch in size resting on a matrix of brown limonite. This specimen, after being trimmed in shape, now rests in the U. S. National Museum. Two other notable specimens are contained in the Harvard collection.

Crystals of adamite from this pocket range up to 5/16" in length. The color varies from water-white through yellow-green (the predominant color) to a pale bluish-yellow. Smaller pockets of adamite subsequently found in the immediate vicinity contain crystals of a paler yellow color. In addition to the adamite found underground a few specimens were collected from surface dumps near the Norte and America No. 1 shafts. These specimens were of poor quality but occasionally exhibited a pinkish color and were sometimes on a matrix of arseniosiderite, while the matrix of the adamite found underground was merely limonite or limestone.

The particular pocket of adamite which we discovered appears to have resulted from a combination of favorable conditions. It seems likely that descending solutions were zinc-rich, as hemimorphite, occurring in large crystals reminiscent of those found at Santa Eulalia, Chihuahua, is abundant in the Palomas ore body between the 11th and 12th levels; although no hemimorphite was found associated with the adamite, smith-



sonite was sparingly present. The adamite pocket occurred in an elbow of the Las Palomas ore chimney and solutions entering this pocket would tend to stagnate, permitting undisturbed alteration and the growth of large crystals.

## REFERENCES

- ALOISI, P., Adamina di Monte Valerio (Campiglia Marittima): *Riv. di Miner. e Crist.*, **39**, 58–64 (1909).
- DAMOUR, A., Sur un arséniate de zinc naturel provenant du Cap Garonne (department du Var): *Compt. rend.*, **62**, 1124–1129 (1868).
- DANA, E. S., *System of Mineralogy*, 6th ed., 786–787, John Wiley & Sons, Inc., New York (1892).
- DES CLOIZEAU, A., Adamine du Laurium: *Bull. soc. min.*, **1**, 30–31 (1878).
- DOELTER, C., *Handbuch der Mineral-chemie*, **3**, [1], 695–697 (1918).
- FOSHAG, W. F., Carminite and associated minerals from Mapimi, Mexico: *Am. Mineral.*, **22**, 474–484 (1937).
- FOSHAG, W. F., The ore deposits of Los Lamentos, Chihuahua, Mexico: *Econ. Geol.*, **29**, 330–345 (1934).
- FRIEDEL, C., Sur l'adamine, nouvelle espèce minérale: *Compt. rend.*, **62**, 692–695 (1866).
- HAYWARD, M. W., AND TRIPLETT, W. H., Occurrence of lead-zinc ores in dolomitic limestones in northern Mexico: *A.I.M.E. Technical Publication No. 442* (1931).
- HINTZE, C., Adamin  $\text{AsO}_4\text{Zn}(\text{ZnOH})$ : *Handb. der Min.*, **1**, [4A], 643–649 (1933).
- KOKKOROS, P., Über die Struktur von Adamin: *Zeits. Krist.*, **96**, 417–435 (1937).
- KUKHARENKO, A., Adamite from the Gulshad Deposit (northwestern Balkash region): *Mém. Soc. Russe Min.*, **68**, ser. 2, 589–600 (1939).
- LACROIX, A., Adamite: *Minéralogie de la France et de ses Colonies*, **4**, 424–427 (1910).
- LASPEYRES, H., Adamin-Krystalle von Laurium: *Zeits. Krist.*, **2**, 147–153 (1878).
- LINDGREN, W., *Mineral Deposits*, 4th ed., 598, McGraw-Hill Book Co., Inc., New York (1933).
- MURDOCH, J., Adamite from Chloride Cliff, California: *Am. Mineral.*, **21**, 811–813 (1936).
- PISANI, F., Sur les minéraux trouvés dans la mine de cuivre du Cap Garonne (Var). Adamine: *Compt. rend.*, **70**, 1001–1004 (1870).
- RICHMOND, W., Crystal chemistry of the phosphates, arsenates and vanadates of the type  $\text{A}_2\text{XO}_4(\text{Z})$ : *Am. Mineral.*, **25**, 441–479 (1940).
- ROSICKÝ, V., Adamin von Thasos in der Türkei: *Bulletin international de l'Académie des Sciences de Bohême*, 1–8 (1908); *Zeits. Kri.*, **48**, 656–660 (1910).
- DE SCHULTEN, A., Reproduction artificielle de la kœttigite et de l'adamine: *Bull. soc. min.*, **26**, 93–95 (1903).
- STAPLES, L., Adamite from Gold Hill, Tooele Co., Utah: *Am. Mineral.*, **20**, 371–376 (1935).
- STRUNZ, H., Vergleichende röntgenographische und morphologische Untersuchung von Andalusit  $(\text{AlO})\text{AlSiO}_3$ , Libethenit  $(\text{CuOH})\text{CuPO}_4$  und Adamin  $(\text{ZnOH})\text{ZnAsO}_4$ : *Zeits. Krist.*, **94**, 60–74 (1936).
- UNGEMACH, H., Sur l'adamite: *Bull. soc. min.*, **44**, 122–128 (1921).