BENJAMINITE, A NEW SULPHOSALT MINERAL OF THE KLAPROTHOLITE GROUP.

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INTRODUCTION.

The present description pertains to a mineral from near Round Mountain, Nye County, Nev., which occurs in a quartz vein with molybdenite, mica, and minor amounts of other minerals. Upon analysis this has been found to be an argentiferous sulphobismuthite of lead and copper differing in ratios from any known mineral. For this new mineral the name proposed is benjaminite, in honor of Dr. Marcus Benjamin of the United States National Museum.

The specimens first examined were sent to the United States Geological Survey some years ago, where they were incorporated in a series of bismuth ores by Frank L. Hess and forwarded to the National Museum. It was not known who sent them in and the only information regarding them was contained in a label reading "Aikinite Mining Co., Round Mountain, Nevada." It was concluded from the name of the mining company that the mineral had been identified as aikinite and that it was a characteristic mineral of the deposit. Nothing further could be learned about the mineral or the mine, however, until an inquiry was addressed to H. G. Clinton, of Manhattan, Nev. Fortunately Mr. Clinton was familiar with the mine, its geology, history, and mineralogy, and was able to visit the locality and to supply an additional very fine specimen of the benjaminite, especially welcome since the original small lot had been almost entirely used up in the several analyses, as well as specimens of the associated minerals. It developed from this correspondence that the material originally received at the Geological Survey had also come from Mr. Clinton. The writer takes this opportunity to acknowledge his obligation to Mr. Clinton for his generosity and his thorough knowledge of the region. The following is quoted from his letter:

> The Aikinite Mining Co. has been out of existence for years but they were operating the Outlaw Mine some 12 miles north of here [Manhattan] at the head of Mariposa Canyon.
>
> The mineral [benjaminite] occurs in large and small bunches and blotches in a dense white quartz, near the southern contact of a rock locally called pegmatite, but described by J. M. Hill as a soda-granite, and an intrusive rhyolite. I have

had assays of 300 ounces in silver from the mineral. I have also noted large flakes of molybdenite associated with it, but all that was ever mined has been carried away.

I note that you have only a few fragments of the mineral left so I am sending my specimen, which is the finest I have yet seen. I hope to get more. I am sending also all the other minerals associated with it, including three or four colors of material that leach out of the ledge, also a small piece of the soda granite. Close to this Outlaw tunnel is a deposit of cinnabar with values in free gold.

Three miles east on the same contact is another bismuth-silver deposit, the bismuth here being in the form of carbonate. Three miles west is a deposit of the molybdenite like the sample sent.

ASSOCIATED MINERALS.

The minerals occurring in the specimens with the benjaminite are quartz, chalcopyrite, pyrite, covellite, muscovite, molybdenite, and fluorite.

The quartz is coarsely crystalline white vein quartz which forms the gangue of the other minerals. As seen in thin section under the

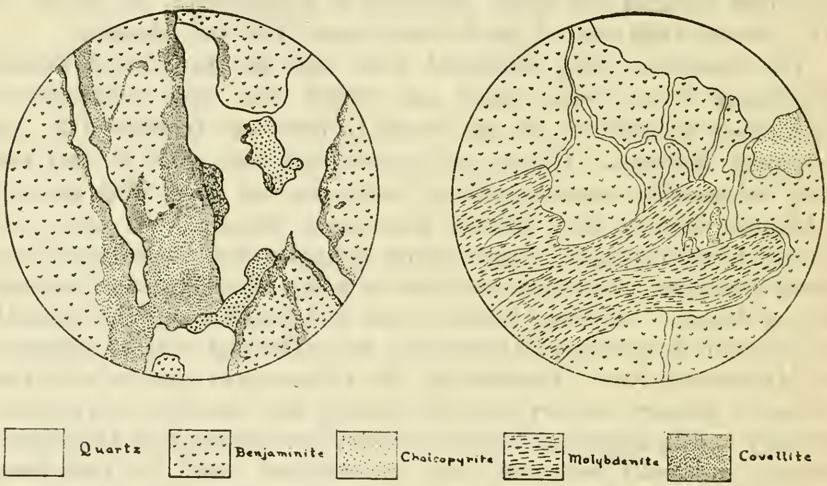

FIG. 1.—SKETCH OF POLISHED SURFACE OF BENJAMINITE SHOWING RELATION OF BENJAMINITE TO QUARTZ AND CHALCOPYRITE AND REPLACEMENT OF CHALCOPYRITE AND BENJAMINITE BY COVELLITE.
FIG. 2.—SKETCH OF POLISHED SURFACE SHOWING RELATIONS OF BENJAMINITE, MOLYBDENITE CHALCOPYRITE, AND QUARTZ.

microscope it forms broad interlocking crystals which contain numerous fluid inclusions which are visible with the higher powers of the microscope. Some of the largest of these contain bubbles and the smaller are aligned into strings. A later introduction of quartz took place filling numerous very fine fractures in the older quartz, and especially in the sulphides. These later quartz seams are especially conspicuous in polished surfaces of the sulphides under the microscope and are indicated in the drawing (fig. 2).

Muscovite is common in the quartz as scales and aggregates of scales. The individual crystals range up to 1 cm. in diameter and are in part hexagonal in outline. In color the mica varies from pale green to white or pale brown and much of it has a more or less pearly luster. It is probably all of the margarodite variety of muscovite, low in potash and correspondingly high in basic hydrogen. Optically it is negative with the acute bisectrix perpendicular to the plates, 2E estimated at 60° to 70°, $\alpha = 1.562$, $\beta = 1.597$, $\gamma = 1.602$, $r > v$ weak. Other specimens from the mine consist entirely of masses of scales of mica, some of which contain scattered crystals of fluorite an rare masses of benjaminite.

Pyrite occurs as cubic crystals which are rare in intimate association with the benjaminite. Other quartz specimens which contain no benjaminite show cubic crystals up to 3 cm. in diameter isolated in the quartz which also contains mica. The pyrite crystals are greatly shattered and show distinct cubic cleavage.

Molybdenite occurs as a graphitic slickensided smear on fractures and also as foliated scales and small rosettes of scales. It is occasionally interleaved with mica. Some of the rosettes reach a diameter of 5 mm. Occasionally these have a sharp hexagonal outline and are made up of six triangular sectors with a twinning line down the center and striation on either side like the A structure of mica. As seen in polished sections the molybdenite is older than the benjaminite and its folia have been contorted, separated, and bent by the later fractures, although the cracks do not cross the folia but pass around their ends. The relations of the molybdenite to the other minerals are shown in the drawings (figs. 2 and 3).

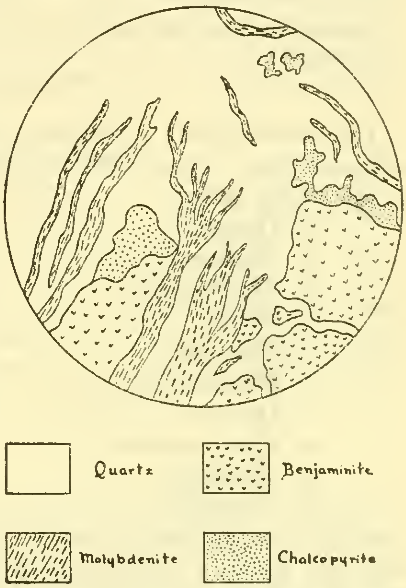

Fig 3.—Sketch of Polished Surface Showing Relations of Benjaminite, Molybdenite, Chalcopyrite and Quartz.

Fluorite occurs especially as isolated crystals in the granular masses of mica where it forms crystals up to 4 cm. in maximum size. The color varies from deep purple to purplish red, yellow and colorless. In the mica fluorite occurred in the same specimen with benjaminite but only one specimen shows fluorite in quartz and this does not contain any benjaminite. The fluorite forms a skeleton cube apparently developing by metasomatic replacement of the quartz.

Chalcopyrite occurs only as minute, almost microscopic, grains and was introduced with the late quartz which fills fine cracks in the benjaminite. It forms grains isolated in the quartz and small areas grown on the benjaminite or apparently, in some cases, replacing the benjaminite. This mineral is mainly clearly later than the benjaminite although a very little may be contemporaneous with it. The relations of the chalcopyrite are shown in figures 1, 2, and 3.

Covellite occurs in minute amount as a later replacement, along cracks, of both chalcopyrite and benjaminite, preferring the latter. The field showing the greatest amount of this mineral is that shown in Figure 1. The amount of covellite present in the analyzed material was so exceedingly small that it could not have any effect on the analytic results.

Chalcocite was seen as a few rare and very minute areas replacing covellite.

PARAGENESIS.

The minerals may be arranged in the following paragenetic order although there is some doubt as to the mutual age relations of some of the earlier ones.

1. Quartz.
2. Muscovite.
3. Molybdenite.
4. Pyrite.
5. Fluorite.
6. Benjaminite.
7. Quartz.
8. Chalcopyrite.
9. Covellite.
10. Chalcocite.

While a considerable time gap may have intervened between the first five and the second five of these minerals it is most probable that the whole series belongs to a single genetic sequence although the covellite and chalcocite may be products of downward secondary enrichment. The benjaminite, a silver-bismuth ore mineral, is thus a constituent of a vein characterized by mica, molybdenite, and fluorite, minerals typical of high temperature veins of pegmatitic affiliations. Such a silver deposit is more or less unique.

GENERAL DESCRIPTION OF BENJAMINITE.

The benjaminite is the only abundant metallic mineral in the ore and carries the silver for which the mine was explored. It forms irregular masses up to 5 cm. in maximum diameter which have clearly developed along fractures in the quartz, apparently by replacement. The benjaminite contains some pyrite although many masses are free from it and it all contains fine grains of chalcopyrite developed along later minute quartz filled cracks. The color on fresh fracture is medium gray and the luster is metallic with a greasy appearance. At first glance the mineral suggets massive tetrahedrite. It has a moderately good cleavage in one direction, somewhat interrupted by the later cracks. The masses are coarse equigranular and the mineral shows no tendency to platy, fibrous or prismatic form. Cleavage surfaces indicate the crystals to reach a maximum size of 15 mm. in the masses. Upon exposure the cleavage surface remains bright or becomes slightly yellow while in another direction the grains tarnish coppery red and in a third direction they become dull lead gray. Granular aggregates which have been exposed for some time look like a mixture of three minerals and the nondescript appearance is heightened by the quartz filled cracks, minute chalcopyrite grains and scattered pyrite and molybdenite. The streak is dull lead gray and only assumes a barely perceptible reddish gray tinge with long rubbing. The mineral scratches calcite but with difficulty and its hardness is thus about 3.3 to 3.5.

PYROGNOSTICS, ETC.

Benjaminite is soluble in hot concentrated nitric or hydrochloric acid and the solution gives the usual qualitative reactions for silver, copper, bismuth, and lead. Alone on charcoal it yields sulphurous fumes but is not reduced. With potassium iodide-sulphur mixture the usual conspicuous bismuth coating is obtained. In the closed tube it gives only a ring of sulphur and in the open tube only sulphur dioxide without the formation of any sublimate.

MICROSCOPIC PROPERTIES.

In polished sections under the metallographic microscope the benjaminite is medium gray, the color being about that of the average tetrahedrite. Examined with polarizing reflecting apparatus the mineral is found to be uniformly and very decidedly anisotropic but it exhibits no color pleochroism. When the surface is treated with the standard microchemical reagents hydrochloric acid, ferric chloride, mercuric chloride, and potassium hydroxide give negative results. With reagent nitric acid the surface effervesces and blackens and the fumes tarnish brown. These properties, according to Davy and Farnham's scheme, would identify the mineral as aikinite, thus seemingly substantiating the qualitative identification.

ANALYSES AND COMPOSITION.

The specimens were at first labeled aikinite and the mineral not only gives the qualitative reactions of aikinite but greatly resembles the aikinite from Beresov, Siberia in the Museum collections. The analysis was at first undertaken as of aikinite from a new locality and was temporarily discontinued owing to the inhomogeneous appearance of the material. A specimen was then polished and examined carefully by modern metallographic methods and, avoiding molybdenite and the scattered large grains of pyrite, was found to be homogeneous except for the small percentage of chalcopyrite. Four analyses were made in all on separate specimens, each of which was carefully selected and studied metallographically. In analysis 1 the presence of silver was not suspected and it was weighed with the copper. In analysis 2, made a year later, a large error was made by inadvertently filtering off a large part of the lead and weighing it in the form of sulphate, with the quartz. The value for lead in this analysis was adopted arbitrarily from the mean relation of lead to bismuth in the other three and the insoluble matter and sulphur were corrected in accordance. The results are given here because the determinations of copper, silver, and bismuth are of value. The analyses were made at intervals over three years and with variously modified procedures. Each analyzed sample was a thin slice which had been polished and examined metallographically and selected free from pyrite and with a minimum of molybdenite. These were crushed and screened to pass 100-mesh screens, the dust removed, and the quartz floated out by a gravity separation with methylene iodide. The quartz present in exceedingly thin veinlets yielded mixed grains so that the samples could not be entirely freed from quartz. The small chalcopyrite grains associated with the quartz could not be avoided although in one case they were largely removed magnetically. The results of the analyses are stated in detail, separately, below.

Analysis 1 of benjaminite.

Constituent.	Original.	Deductions.	Net.	Recalculated.
Quartz	13.46	13.46	----------	----------
Lead	20.77	----------	20.77	26.87
Copper } Silver }	8.17	1.92	6.25	8.09
Iron	1.69	1.69	----------	----------
Bismuth	38.36	----------	38.36	49.63
Molybdenum	.60	.60	----------	----------
Sulphur	14.26	2.35	11.91	15.41
Total	97.31	20.02	77.29	100.00

The impurities deducted are the insoluble quartz and molybdenite equivalent to the total molybdenum and chalcopyrite equivalent to the total iron. These amount to quartz 13.46 per cent, molybdenite 1 per cent, and chalcopyrite 5.56 per cent.

The results of analysis 2, recalculated as above noted, are as follows:

Analysis 2 of benjaminite (recalculated).

Constituent.	Original.	Deductions.	Net.	Recalculated.
Quartz	12. 83	12. 83		
Lead	18. 53		18. 53	23. 95
Copper	4. 07	1. 85	2. 22	2. 87
Silver	3. 24		3. 24	4. 19
Iron	1. 63	1. 63		
Bismuth	41. 64		41. 64	53. 83
Molybdenum	. 46	. 46		
Sulphur	13. 92	2. 19	11. 73	15. 16
Total	96. 32	18. 96	77. 36	100. 00

The deducted impurities are quartz 12.83 per cent, molybdenite 0.77 per cent and chalcopyrite 5.36 per cent.

Analysis 3 is the most dependable analysis of the four since the material was not only well selected but the method most suited for the several separations had been determined by the previous work. The powder used for analysis was, moreover, treated to a magnetic separation whereby a large part and possibly all of the chalcopyrite was removed. Although the iron found is considered below to be present as admixed chalcopyrite which is deducted, it is possible that the amount found in this analysis is essential to the benjaminite occurring as an isomorphous replacement of the lead. This would not affect the formula below derived but would rather tend to support it by bringing the analytical results into closer agreement with the calculated percentages. The analysis is as follows:

Analysis 3 of benjaminite.

Constituent.	Original.	Deductions.	Net.	Recalculated.
Quartz	8. 86	8. 86		
Lead	21. 70		21. 70	25. 25
Copper	6. 65	. 65	6. 00	6. 98
Silver	2. 78		2. 78	3. 23
Iron	. 58	. 58		
Bismuth	41. 45		41. 45	48. 24
Molybdenum	1. 30	1. 30		
Sulphur	15. 53	1. 53	14. 00	16. 30
Total	98. 85	12. 92	85. 93	100. 00

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The deductions amount to quartz 8.86 per cent, molybdenite 2.17 per cent and chalcopyrite 1.91 per cent.

The fourth analysis, made as a final check on the preceding three was on a powder from which the chalcopyrite had not been removed magnetically. It gave the following results:

Analysis 4 of benjaminite.

Constituent.	Original.	Deductions.	Net.	Recalculated.
Quartz	10. 00	10. 00		
Lead	19. 98		19. 98	24. 70
Copper	5. 00	1. 59	3. 41	4. 22
Silver	2. 52		2. 52	3. 11
Iron	1. 40	1. 40		
Bismuth	41. 62		41. 62	51. 45
Molybdenum	1. 34	1. 34		
Sulphur	(15. 87)	2. 51	13. 36	16. 52
Total	97. 73	16. 84	80. 89	100. 00

The recalculated percentages for the several analyses of the benaminite are collected and averaged in the following table:

Average and comparison of recalculated analyses.

Constituent.	1	2	3	4	Average.
Lead	26. 87	23. 95	25. 25	24. 70	25. 18
Copper	} 8. 09	2. 87	6. 98	4. 22	4. 69
Silver		4. 19	3. 23	3. 11	3. 51
Bismuth	49. 63	53. 83	48. 24	51. 45	50. 78
Sulphur	15. 41	15. 16	16. 30	16. 52	15. 84
Total	100. 00	100. 00	100. 00	100. 00	100. 00

The average column from the above table gives the ratios of the following table:

Ratios of average analyses.

Constituent.	Per cent.	Ratios.		
Lead	25. 18	0. 122	0. 061×2	1. 04×2
Copper	4. 69	. 074 }	. 053×2	. 90×2
Silver	3. 51	. 032 }		
Bismuth	50. 78	. 250	. 062×4	1. 05×4
Sulphur	15. 84	. 494	. 055×9	. 93×9
Total	100. 00			

The above ratios indicate the formula for the mineral to be $Pb_2(Ag, Cu)_2Bi_4S_9$ or $2PbS.(Cu, Ag)_2S.2Bi_2S_3$. The average of the analyses is below repeated in comparison with the theoretical percentages and with several related minerals.

Comparison of benjaminite with other minerals.

Constituent.	Analysis.	Theory.	Aikinite.	Cosalite.	Galen-obismutite.
Lead	25. 18	24. 50	36. 0	41. 8	27. 5
Copper	4. 69	5. 01	11. 0	----------	----------
Silver	3. 51	4. 25	----------	----------	----------
Bismuth	50. 78	49. 18	36. 2	42. 0	55. 4
Sulphur	15. 84	17. 06	16. 8	16. 2	17. 1
Total	100. 00	100. 00	100. 00	100. 00	100. 0

The low summation of the benjaminite analyses deserves comment as do the low sulphur determinations. In each analysis a single small portion only of the powdered and purified mineral was available. Sulphur had to be determined in an aliquot small portion of the solution used for general analysis, a procedure which tends to give low results both from loss of some sulphur on solution in acid, probably as hydrogen sulphide, and by incomplete precipitation by barium chloride. The results for this constituent are consequently only approximate and may be 1 per cent low in each case.

The low summation is in part due to this cause and in part to hygroscopic or absorbed substances in the fine powder, particularly methylene iodide used for the gravity separation which seems to adhere to the surfaces of the grains. The absence of zinc, manganese, tin, antimony, arsenic, and other probable metals was definitely determined.

The mineral seems unquestionably distinct from any established species. The nearest approach to the composition found in the literature is in certain cupriferous and argentiferous cosalites quoted in Dana. Cosalite is a lead mineral, the composition of which is definitely established and, while the lead is probably susceptible of replacement by metals of like valence, including cupric copper, cupric sulphide is relatively rare as a constituent of the sulpho-salt minerals and the copper commonly occurs in the cuprous form isomorphous with silver. The non-isomorphism of metals of unlike valence in minerals of this class is now widely recognized[1] and these analyses of "cosalite" which show amounts of silver and copper in excess of 1 or 2 per cent are doubtless other minerals or mechanical mixtures and required to be reexamined by modern methods.

The benjaminite falls in the 3:2 division, klaprotholite group of Wherry and Foshag.[2] The members of this group now are as follows:

Klaprotholite	$3Cu_2S$	$2Bi_2S_3$
Schirmerite	$2Ag_2S.\ PbS$	$2Bi_2S_3$
Rathite	$3PbS$	$2As_2S_3$
Benjaminite	$2PbS.\ (Cu, Ag)_2S$	$2Bi_2S_3$

[1] William F. Foshag. The isomorphic relations of the sulphosalts of lead, silver and copper. Amer. Journ. Sci., vol. 1, pp. 444–446, 1921.

[2] Edgar T. Wherry and William F. Foshag. A new classification of the sulfo-salt minerals. Journ. Wash. Acad. Sci., vol. 11, pp. 1–8, 1921.

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