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If not obvious	
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Issued May 17, 1912

# THE MINERALS OF TONOPAH, NEVADA

BY

ARTHUR S. EAKLE

ROBERT R. COATS

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ARTHUR S. EAKLE

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## GENESIS OF THE MINERALS

Some of the minerals occurring with the silver deposit at Tonopah were mentioned by Spurr<sup>1</sup> in his paper on the geology of the district and by Burgess<sup>2</sup> in his discussion of the origin of

<sup>1</sup> Spurr, J. E., Geology of the Tonopah Mining District, Nevada, U. S. Geol. Surv., Prof. paper no. 42, 1903.

<sup>2</sup> Burgess, J. A., The Halogen Salts of Silver and Associated Minerals at Tonopah, Nevada, Econ. Geol., vol. 6, p. 13, 1911.



the silver haloids. The latter author collected a good suite of the minerals found in the veins and sent them to the writer for further study and report, and it is from a study of this material that the following notes on the minerals have been prepared.

*Origin of the deposits.*—The silver deposits occur in a trachyte which Spurr first designated as "earlier andesite," and were formed by ascending solutions carrying the sulphides and the gold and depositing them at a period immediately following the eruption. The typical ore consists of a gangue of massive white quartz and white feldspar containing blotches and bands of finely granular, black silver minerals, small amounts of pyrite, chalcopyrite, galena, and sphalerite, and occasionally free gold. The dark silver bands are mainly argentite, with which are intimately mixed polybasite and perhaps stephanite and tetrahedrite. An analysis of the primary sulphide concentrates of the Montana-Tonopah mine, made by Hillebrand and quoted by Spurr, indicates that the simple sulphide, argentite, predominates, but has probably mixed with it small amounts of silver sulphantimonites and sulpharsenites and some selenide of silver, or of lead and silver. These sulphide minerals are all primary constituents of the veins, yet most if not all of them also occur secondary, and some of the crystals in the cavities of the gangue are doubtless of a later generation.

*Oxidation of the veins.*—The deposits at Tonopah lie in an arid region and, like most desert deposits of sulphide minerals, have their oxidized zones characterized by a variety of rare secondary minerals not found where simple hydration only is possible. This is due to the fact that surface waters penetrating to the vein matter below and bringing about its alteration become charged with salts leached from the overlying and adjacent strata, and complex oxidation with less usual mineral precipitations result. The descending solutions which brought about the main oxidation of the silver minerals at Tonopah contained the alkali bromide and iodide as well as the much more abundant chloride, and the complexity of the depositing solutions is evidenced by the coatings of haloids, phosphates, arsenates, manganates, and sulphates which line the walls of fissures and cavities in the gangue.

*The origin of the silver haloids.*—The most important secondary minerals in the zone of oxidation are the three silver salts, cerargyrite, embolite, and iodyrite. They have undoubtedly crystallized out of descending solutions which obtained their chlorides, bromides, and iodides from superficial deposits impregnated with the alkaline salts, and their general arrangement, as stated by Burgess, is in three zones with cerargyrite above, embolite intermediate, and iodyrite below. Since iodyrite is much less soluble in water than cerargyrite, this order of crystallization may appear reversed, but in reality it is the natural order of occurrence when the silver salts have been deposited from mixed solutions such as undoubtedly obtained at Tonopah.

The formation of good crystals of these difficultly soluble salts generally indicates a slow growth by gradual evaporation of very weak solutions, but the degree of solubility and of concentration before crystallization depends upon the solvent, and crystals may not form until the excess of certain salts have first been removed.

In the cerargyrite zone the crystals are quite perfectly formed and have evidently grown from solutions dilute enough to prevent the previous precipitation of manganese and iron hydrates. While the oxides of iron and manganese may be abundant in this zone, their formation from the solutions was independent of, and later than, the formation of the cerargyrite.

In the embolite zone the crystals are in general imperfectly formed and segregated into bunches. They characteristically rest upon coatings of psilomelane and limonite which have been previously deposited from the solutions and therefore indicate a growth from more concentrated solutions.

In the iodyrite zone the imperfectly formed crystals have grown rather rapidly from solutions concentrated sufficiently to precipitate previously psilomelane, flaky hematite and flaky jarosite in abundant coatings and masses. The evidence points strongly to the conclusion that the crystallization of the iodyrite depended upon the prior or simultaneous precipitation of these iron and manganese minerals.

It is manifestly impossible to form more than an approximate idea of the character of the oxidizing solutions. The waters contained essentially chlorides, bromides, iodides, carbonates, and



sulphates of the alkalis, leached from the surface material and, acting on the abundant pyrite and manganese minerals of the rocks, they became charged with iron and manganese salts. Probably more or less free acid and free gas were formed in the mixed solutions, and the decomposing and oxidizing effect of these solutions on the sulphides of the veins and on the gangue must have been comparatively rapid. The solutions which percolated downward through the ore body were essentially sulphated waters of the alkalis, iron, manganese, and silver, with potassium and sodium chlorides, bromides, and iodides.

The alkali chlorides predominated over the bromides and iodides in the upper zone of oxidation and it is safe to say that chlorine was greatly in excess of bromine or iodine in this zone. The dilute solutions moved slowly downward through main channels and narrow fissures, thoroughly saturating portions of the vein, leaching out the potash of the feldspar and converting the silver sulphides to sulphates. With sufficient silver present the evaporation in this zone would have caused the precipitation of the main deposit of the cerargyrite even if the bromide and iodide of silver had also been thrown out previously or with it. These two haloids, however, would not have existed in the alkali chloride solution but would have been completely transposed into cerargyrite, while the bromine and iodine would have been absorbed in the cold solutions and carried down possibly as sodium and potassium salts.

The solutions passing downward became more concentrated in bulk, stronger relatively in bromine, iodine, and alkalis, and at the same time depleted in chlorides, until a stage was reached where the almost constant associate and natural successor of cerargyrite, the double salt embolite, crystallized. Bromine and chlorine are alike and usually accompany and replace each other, so that cerargyrite and embolite are typically associated. As the chlorine diminished in the solutions, bromine replaced it in cerargyrite as shown by tests, and probably a gradation from cerargyrite to embolite occurs in the mines. The embolite zone represents a proportionate increase of bromine to chlorine in the solutions, yet sufficient chlorine was still present to prevent the formation of bromyrite and to form considerable cerargyrite in

this zone and some in the lower zone. The embolite is typically deposited in bunches of imperfect crystals on layers of psilomelane, and the occurrence suggests the possibility that the bromide was soluble in the excess of the alkali-manganese sulphates and could not form readily as embolite until some of the sodium and potash was removed with the manganese by evaporation. No analyses have been made of the manganese oxides, but doubtless they contain considerable potash and sodium, since these two alkalis were abundant in the solutions. It is well known that the silver haloids are soluble in the alkali chlorides, bromides, and iodides, the alkali carbonates, and probably in the alkali sulphates, so that the general tendency of alkaline solutions is to dissolve the silver salts. Cerargyrite crystallized in the upper zones because of the predominance of chlorine in dilute solutions of the alkalis, although the solubility of the chloride was raised; but in the embolite zone the solutions had become more concentrated and at the same time considerably stronger in the alkalis, especially potash from the leaching of the orthoclase, and neither the cerargyrite, the iodyrite, nor the embolite of this zone crystallized until the hydrate of manganese was thrown down, carrying the restraining alkalis.

The solutions percolating downward carried small amounts of chlorine and bromine and most of the iodine in the form of alkali salts of these elements. They also contained large amounts of potassium, iron, and manganese derived from the veins, and in the final evaporation of the waters, abundant coatings of psilomelane, flaky precipitated hematite and platy crystals of jarosite were formed. The wobbly crystals of iodyrite and smaller bunches of embolite are in general perched upon these coatings or crystallized with them, and the evidence seems conclusive that the iodyrite was soluble in the concentrated solutions and did not crystallize until after the hydrates of iron and of manganese had been precipitated or had begun to form. What kept the iodyrite from forming was probably the strong solutions of potassium and sodium sulphates, and it was not until the alkalis had been removed in the formation of the jarosite and psilomelane that the silver iodide could crystallize. Iodyrite is decomposed by strong solutions of potassium or sodium sul-



phate and also slowly by ferric sulphate and presumably by manganic sulphate, so its solubility may have been due to a combination of these salts.

The three zones probably represent the action of long standing solutions on the silver minerals of each zone and what silver was carried below was in the form of silver sulphate and not as haloids. The bromine and iodine were presumably carried down as alkali salts. The oxidation of the deposit may have been long continuous or at successive intervals, but it seems to the writer that a basin must have formerly existed above the deposit in which the salts accumulated, and that a body of water from this basin penetrated to the ore below carrying these salts.

In the passage of the solutions downward pools were doubtless formed in the ore body, which gave rise to rich pockets of the haloids. The occurrence of some of the iodyrite crystals suggests also that they were formed by fumes of free iodine acting on the silver. Doubtless free iodine was formed by the decomposition of the iodide or iodate in the concentrated hot solutions, and it must have formed if free acid was present.

*The hydrous secondary minerals.*—The secondary minerals derived by the alteration of the metallic and basic constituents of the deposits are characteristically present in the form of coatings on the walls of cavities and fissures. The coatings are either in very thin, minutely crystalline, drusy layers or they form minute botryoidal groupings. Most of them are brilliantly lustrous but the crystals are generally unmeasurable.

The hydrous manganese oxide is present in soft velvety layers of impure material and in hard mammillary shells of psilomelane. Much of it may have been derived from the alteration of manganese tungstate which appears to be one of the older minerals of the vein. Manganese hydroxides carrying the alkalies undoubtedly played an important part in the formation and crystallization of the silver haloids and in its association with these it was, in general, deposited first and forms the layers upon which the crystals rest.

The soluble phosphate, arsenate, and sulphate occur in the lower or iodyrite zone of oxidation. They have necessarily been crystallized from more concentrated solutions, while at the same time they antedate the formation of much of the iodyrite.

The few carbonates are of probably more recent formation than those minerals derived by the general oxidation of the deposit.

## DESCRIPTION OF THE MINERALS

### NATIVE ELEMENTS: GOLD AND SILVER

*Gold.*—Free gold occurs as small flakes and grains in the narrow black bands of argentite, on the borders of small, irregular veins and seams of quartz, mostly in the vicinity of the Valley View vein. Arborescent groupings of deformed octahedrons and rhombic dodecahedrons have occasionally been found in some of the mines. Gold occurs in very limited quantities in rich silver ore, the general ratio of gold to silver being about 1 to 90. The metal appears to have been deposited originally with the silver minerals, either as visible particles or later made visible through the decomposition of the silver minerals containing it. No tellurides have been found in the district and no traces of tellurium in the concentrates, but its near relation selenium is present in over two per cent, as shown by Hillebrand's analysis. It is probably a constituent of polybasite or tetrahedrite, or forms a silver selenide rather than a gold selenide.

*Silver.*—Wires, films, and spongy masses of metallic silver are frequently found accompanying the various silver minerals, especially in the vugs where these are better crystallized. The wires are generally attached to argentite, polybasite, tetrahedrite, or pyrargyrite, and the metal is evidently a reduction product. Some of the polybasite crystals have their surfaces honeycombed and the small cellular cavities filled with minute capillary silver. Wire silver is prominent in the Belmont mine and one quartz specimen from the 1000-foot level charged with platy tetrahedrite has a fine wire coating.

### SULPHIDES: ARGENTITE, GALENA, CINNABAR, PYRITE, CHALCOPYRITE AND SPHALERITE

*Argentite.*—The chief mineral of the Tonopah veins is argentite, but the sulphide is intermixed with the sulphosalt, polybasite, and possibly stephanite. The mineral is both primary and



secondary and the better crystallized masses in the gangue vugs are probably largely secondary. The common reticulated and arborescent shapes occasionally show the octahedron or cubo-octahedron, very much distorted.

*Galena*.—Rich sulphide ore containing a high percentage of gold often has galena disseminated through it accompanied by pyrite and chalcopyrite. Galena is found at all depths, and in the lower workings of some of the barren or low-grade veins it is associated with sphalerite and chalcopyrite.

*Cinnabar*.—Minute patches and thin streaks of the red mercury sulphide are visible in some of the gangue of the West End mine. The mineral is very scarce in the veins and has only been observed in this mine.

*Pyrite*.—The country rock and wall rock of the deposits contain much pyrite, but its scarcity in the vein-matter has been commented upon by Spurr. It is held to be largely secondary, but some of that is undoubtedly primary which is so intimately associated with the fine granular black silver bands. Many of the crystals of polybasite when broken show small particles of pyrite and chalcopyrite as inclusions.

*Chalcopyrite*.—Limited amounts of chalcopyrite are seen in all parts of the veins, usually in very fine grains, and it is a common inclusion in the polybasite crystals. It is the source of the few secondary copper salts in the oxide zone.

*Sphalerite*.—Brown sphalerite is very limited in its occurrence in the veins. It is found with galena, chalcopyrite, and traces of silver, below the 900-foot level of the Mizpah shaft.

#### SULPHANTIMONITES: POLYBASITE, STEPHANITE?, PYRARGYRITE, AND TETRAHEDRITE

*Polybasite*.—The brittle black sulphantimonite of silver, accompanying the argentite as one of the primary minerals of the veins, is chiefly polybasite. Platy crystals occur in the quartz cavities and seams, some of them with very brilliant faces. When broken they show a characteristic cherry-red color like pyrargyrite. The crystals are thin basal plates with their edge-faces horizontally striated, and they consist mainly of a broad base with narrow faces of the pyramid  $p$  (111), the prism  $m$  (110),

and the brachypinacoid  $b$  (010). A few crystals had in addition the form  $r$  (112), and one showed a good face of a new form  $o$  (443). The typical habit of the crystals is seen in figure 1, plate 1.

	Measured	Calculated
(110) : (1 $\bar{1}$ 0)	60°08'	60°10'
(110) : (010)	30 00	29 55
(001) : (111)	61 15	61 14
(001) : (112)	42 14	42 19
(001) : (443)	67 46	67 38

*Stephanite*.—Whether stephanite is mixed with the polybasite in the black silver bands is practically impossible to determine. All of the crystals of the brittle black silver occurring in the cavities of the specimens examined are polybasite, so the presence of stephanite was not proved.

*Pyrargyrite*.—The dark ruby silver is generally found as a fissure-filling in the quartz, often intergrown with argentite and polybasite, and accompanied by wires of native silver. Most of the mineral appears granular in the quartz, in the characteristic dark gray bands with reddish cast. Small dark-red crystals have been formed in some of the cavities, consisting of the simple combination of second order prism  $a$  (11 $\bar{2}$ 0), base  $c$  (0001), and rhombohedron  $r$  (10 $\bar{1}$ 1).

	Measured	Calculated
(21 $\bar{1}$ 0) : (11 $\bar{2}$ 0)	60°02'	60°00'
(0001) : (10 $\bar{1}$ 1)	42 18	42 28

*Tetrahedrite*.—Thick tabular plates of tetrahedrite in the gangue of quartz and feldspar, with wires of native silver, occur in a specimen from the Belmont mine.

#### HALOIDS: CERARGERITE, EMBOLITE, AND IODYRITE

*Cerargerite*.—The chloride of silver is the most abundant member of the haloids in the deposits. It occurs throughout the zone of oxidation, but is principally found in the upper portion of the zone. Waxy coatings of the mineral cover several square feet in area and minute crystals are abundantly disseminated in the soft kaolinized feldspar, and in the small cavities of the quartz. The coatings and crystals have a very brilliant adamantine to waxy luster, and most are of a translucent pale gray color.



Some coatings incline toward a green color and seem to grade into embolite. The crystals are very minute in size and form perfect cubes with generally the octahedron. Some are distorted into prismatic shapes and others are twisted and curved and show evidences of having been formed from dripping solutions.

Spurr<sup>2</sup> cites the occurrence of cerargyrite as an inclusion in primary argentite and advances the possibility of the formation of the hornsilver by the solvent action of the same solutions which deposited the original sulphides. It is possible and even probable that some chlorine was present in the original ascending solutions and that some cerargyrite may have been formed, but it appears undoubted that surface waters brought in the bulk of the chloride and accomplished the main oxidation of the deposit.

*Embolite*.—The chloro-bromide is not so abundant as the simple chloride or iodide, and it is chiefly found intermediate between the two. It occurs in bunches and groups of green, imperfectly formed crystals, often implanted on psilomelane. The crystals are highly deformed cubes and octahedrons, with sometimes the rhombic dodecahedron.

In the crystallization of the cerargyrite considerable bromine was taken up, so the amount of embolite present in the mines does not represent the original quantity of bromine carried in the solutions.

*Iodyrite*.—Bromine so generally accompanies chlorine that embolite is a characteristic associate of cerargyrite in deposits containing important amounts of the latter. Iodine on the other hand is very rare, and the Tonopah deposit is quite exceptional in having iodyrite in a comparatively large quantity. The iodide is mostly confined to the lower depths of the oxidized zone. It is present as small loose crystals in the cavities and fissures of the veins, and as brilliant crystalline crusts and coatings on the walls of fissures. One of the largest pockets of loose crystals was found in the Valley View vein, a few feet above the 500-foot level. It contained a host of deep yellow crystals mixed with small fragments of stalaetitic and conchoidal psilomelane. The crystals also occur characteristically with flaky brown and yellow

jarosite. The later crystallization of the iodyrite is evidenced by its deposition on layers of the iron sulphate and on other secondary minerals lining the fissures.

The crystals are mainly of a bright sulphur-yellow color, but some incline to greenish yellow, and others are tarnished bronze-brown. The brilliant crystals after exposure to light gradually become cloudy and opaque. The best crystals for measurement occur isolated in quartz cavities, generally perched on drusy quartz.

Iodyrite possesses considerable crystallographic importance because it is one of the few known representatives of the dihexagonal-pyramidal, or hemimorphic, class of symmetry, and many of the Tonopah crystals show this hemimorphic character quite prominently. With very few exceptions the crystals are simple combinations of the unit prism ( $10\bar{1}0$ ), base ( $0001$ ), and steep pyramid ( $20\bar{2}1$ ). The prism is terminated on the upper or positive end, according to the usual orientation, by narrow faces of ( $20\bar{2}1$ ) and a broad base, and on the lower or negative end by ( $20\bar{2}\bar{1}$ ), often without a lower base, as a characteristic habit. The few other forms are very rare and were observed only once or twice in a lot of several hundred crystals examined. Leaving out all doubtful forms, which were many on account of imperfections, the forms determined were:

$c$ ( $0001$ )	$i$ ( $20\bar{2}1$ )	$u$ ( $40\bar{4}1$ )
$m$ ( $10\bar{1}0$ )	$r$ ( $10\bar{1}1$ )	$\bar{i}$ ( $20\bar{2}\bar{1}$ )
$a$ ( $11\bar{2}0$ )	$f$ ( $30\bar{3}1$ )	$\bar{c}$ ( $000\bar{1}$ )

One crystal showed narrow faces of the second order prism ( $11\bar{2}0$ ). Several had the unit pyramid ( $10\bar{1}1$ ) as very narrow faces. The steeper pyramids ( $30\bar{3}1$ ) and ( $40\bar{4}1$ ) were each observed on two crystals. The only negative pyramidal termination was ( $20\bar{2}\bar{1}$ ).

The four forms ( $0001$ ), ( $10\bar{1}0$ ), ( $20\bar{2}1$ ), and ( $20\bar{2}\bar{1}$ ) make up the crystals and the habit or type is governed by the size and predominance of these forms. Few of the crystals are simple because of the alternating growth of prism and pyramid. Successive alternations of these two forms have produced horizontally striated, furrowed, stepped, and tapered crystals which make measurements very poor. A fact also observed was

<sup>2</sup> *Loc. cit.*



that the alternations were not rigidly parallel in many cases, and that even the interfacial angles were sometimes distorted. One of the best crystals which gave sharp signals measured  $(0001) : (20\bar{2}1) = 58^\circ 43'$  and  $(0001) : (\bar{2}021) = 64^\circ 12'$ , with angles lying between these for the adjacent readings. Similar variations were noticed on other crystals, and it seems probable that the oscillations in the growth, combined with a slight sectility of the mineral, have caused a deformation of the angles. Some of the prisms have their negative ends terminated by good faces of the steep pyramid and small base, but the lower end is rather characteristically drawn out into a long, wobbly and curved, tapering pyramid. Many of the crystals, especially the larger ones, are mere shells or hollow prisms with irregular cavities.

The imperfect character of most of the crystals renders good measurements impossible, and readings were obtained which correspond to various new and improbable forms. These crystals have been described by Kraus and Cook,<sup>4</sup> who give several new forms. From the nature of the crystals these new forms would need to be substantiated by further observations of them. As shown above, considerable variation in the angle between the base and pyramid may exist and their forms  $(70\bar{7}4)$ ,  $(70\bar{7}3)$ , and  $(15.0.\bar{1}5.8)$  seem to be striated gradations into, or imperfect readings of, the form  $(20\bar{2}1)$ . The angle  $(0001) : (20\bar{2}1) = 62^\circ 10'$ , and their angles for these forms show a variation of  $-3^\circ 23'$  to  $+3^\circ 23'$ , as seen from their measurements:

$$\begin{aligned}(0001) : (70\bar{7}4) &= 58^\circ 47' \\ (0001) : (70\bar{7}3) &= 65^\circ 33' \\ (00010) : (15.0.\bar{1}5.8) &= 60^\circ 32'\end{aligned}$$

With good crystals there might be no question about the validity of these new forms, but on the Tonopah crystals their existence is very doubtful. Their new form  $(90\bar{9}2)$  may be the known form  $(40\bar{4}1)$ . The angle  $(0001) : (40\bar{4}1)$  is  $75^\circ 12'$  and the writer obtained measurements varying from  $74^\circ 55'$  to  $76^\circ 40'$  for a form which is probably  $(40\bar{4}1)$ , although the latter angle yields more closely the indices  $(90\bar{9}2)$ .

<sup>4</sup> Kraus and Cook, Iodyrite from Tonopah, Nevada, Amer. Journ. Sci., vol. 27, p. 210, 1909.

The best readings obtained for the several forms observed gave as averages:

	Measured	Calculated
$(0001) : (10\bar{1}1)$	$43^\circ 27'$	$43^\circ 25'$
$(0001) : (20\bar{2}1)$	$62^\circ 13'$	$62^\circ 09'$
$(0001) : (30\bar{3}1)$	$70^\circ 31'$	$70^\circ 36'$
$(0001) : (40\bar{4}1)$	$75^\circ 52'$	$75^\circ 12'$
$(10\bar{1}0) : (11\bar{2}0)$	$30^\circ 00'$	$30^\circ 00'$

Twinning is on the usual twinning-plane  $(30\bar{3}4)$ , but not many of the crystals are twinned, comparatively. The twinned crystals are generally flattened parallel to the prism faces in the same zone with the twinning-plane.

Some of the characteristic types of the crystals are illustrated in figures 2 and 3 of plate 1.

OXIDES: QUARTZ, OPAL, CUPRITE, HEMATITE, LIMONITE, MANGANITE, PYROLUSITE, PSILOMELANE, AND WAD

*Quartz*.—Massive white quartz constitutes the chief part of the gangue. The fine granular silver minerals are always in it, and the best of the crystals occur in its cavities and fissures. Many of the cavities of the veins have been produced by the alteration and leaching out of the feldspathic portion of the gangue, and these pockets are often lined with a secondary deposit of drusy quartz and quartz crystals, which are sometimes corroded and stained yellowish brown. Trigonal development of the quartz terminations are common, but none occur with trapezohedrons.

*Opal*.—In the Valley View vein a small amount of clear colloidal silica has solidified into colorless hyalite and this has spread as a thin coating over minute crystals of white apatite, giving them a glassy glaze. The opal has taken up crystals of yellow iodyrite and other fragments in its flow and it is one of the latest secondary formations.

*Cuprite*.—A few small masses of the red copper oxide have been encountered in the oxidized zone, which have their source originally in the chalcopyrite.

*Hematite and Limonite*.—Naturally the common iron oxides would be plentiful in the weathered zone as impure earthy



masses and stains, from the decomposition of the pyrite and wolframite and former iron-bearing minerals. Dark-red earthy masses with seams of brown jarosite are found in association with the iodyrite. The yellowish stains of limonite color much of the quartz, especially in those cavities and crevices where the fibrous caoxenite occurs.

*Manganite, Pyrolusite, Psilomelane, and Wad.*—The black oxides of manganese are very abundant in the zone of oxidation, and their close association with the several silver haloids is significant of their influence in the crystallization of the latter. Manganite is present in some of the pockets as long, slender, vertically striated rods. Pyrolusite is finely fibrous and forms coatings along the walls of some of the fissures. A felty variety is seen on some of the specimens. Psilomelane is the common manganese mineral of the mines. It is generally in botryoidal and small mammillary masses, and the embolite and iodyrite are often deposited on them. Some of the pockets of the gangue contain broken fragments of psilomelane mixed with loose crystals of iodyrite. Manganese is present also in soft, velvety coatings, with quite impure mixtures, and may be classed as wad. Brown jarosite crystals are generally implanted on such black coatings.

CARBONATES: CALCITE, MANGANOCALCITE, SIDERITE, RHODOCHROSITE, MALACHITE, AND AZURITE

*Calcite.*—The carbonates in the mines are all of later secondary origin. Some good calcites line the crevices near the 200-foot level of the Mizpah vein. They rest upon fibrous malachite and some are bright green from inclusions of the copper carbonate and some have a coating of colorless gypsum. The crystals show an unusual habit. They are steep rhombohedral with curved faces, and the rhombohedron is the rare negative form  $g$  (05 $\bar{5}2$ ). They are somewhat scalenohedral in habit owing to the curvature of the faces, but without obtuse edges. A few of the crystals have in addition the unit rhombohedron  $r$  (10 $\bar{1}1$ ) and the low negative rhombohedron  $e$  (01 $\bar{1}2$ ), both in very narrow faces, as seen in figure 4, plate 1.

The measurements were fairly good, notwithstanding the curvature of the main faces.

	Measured	Calculated
(5502) : (0552)	106°30'	106°44'
(5502) : (0552)	73 16	73 13
(10 $\bar{1}1$ ) : (01 $\bar{1}1$ )	74 51	74 55
(10 $\bar{1}1$ ) : (0552)	53 39	53 39
(10 $\bar{1}1$ ) : (01 $\bar{1}2$ )	37 26	37 27
(0552) : (01 $\bar{1}1$ )	112 15	112 33

*Manganocalcite.*—Specimens of ore taken from the 1000-foot level of the Belmont mine contain crystalline granular patches of a light brown carbonate which turns dark brown when heated and gives a strong reaction for manganese, but no iron. The mineral is chiefly calcium carbonate containing manganese, but the characteristic rose tint is missing. The grains of the mass show some striated and curved faces and only the low rhombohedron (01 $\bar{1}2$ ) can be distinguished.

Siderite is given by Spurr as one of the minerals of the veins but none of the specimens include this carbonate.

*Rhodochrosite.*—The manganese carbonate is of very rare occurrence in the deposit. In the crevices of some of the quartz specimens from the Montana-Tonopah mine a few pale rose crystals of minute size occur singly. They are made up of the steep scalenohedron  $y$  (32 $\bar{5}1$ ) terminated by the base. The faces of the scalenohedron are striated parallel to their basal edges and the base is invariably dull. The crystals are shown in figure 5, plate 1.

	Measured	Calculated
(3251) : (52 $\bar{3}1$ )	45°37'	45°26'
(3251) : (35 $\bar{2}1$ )	70 50	70 47

*Malachite and Azurite.*—Small amounts of both copper carbonates occur as stains and crystalline coatings. The malachite associated with the calcite of the Mizpah vein occurs in delicate acicular groups. The azurite is with much of the malachite as light blue earthy material.

SILICATES: FELDSPAR, KAOLINITE, SERICITE, AND RHODONITE

*Feldspar and Kaolinite.*—The potash feldspar, classed as adularia, is the prominent silicate of the gangue. It is all more



or less altered to pure white, or brownish white, masses and much of it is completely kaolinized to soft white clay. This kaolinization has been brought about by the action of acid or alkali solutions and the soft masses in the upper zone of oxidation are often impregnated with minute crystals of hornsilver.

*Sericite*.—All of the original silicates of the rock were altered by the original ascending solutions and the scant amount of soft pearly sericitic muscovite now in the gangue is of secondary formation.

*Rhodonite*.—The rich silver ore of some of the veins shows pinkish bands of rhodonite included in the quartz. Much of the kaolinized feldspar is stained a pale rose color resembling impure rhodonite.

PHOSPHATES AND ARSENATES: APATITE, PSEUDOMALACHITE,  
WAVELLITE, TURQUOIS, PHARMACOSIDERITE, AND  
CACOXENITE

*Apatite*.—Minute crystals of apatite line the crevices in the Valley View vein, from the 440-foot to the 640-foot levels. The crystals are snow-white and measure about two millimeters in length. They occur as innumerable crystals forming a coating, and have iodyrite crystals implanted upon them. Some of the crystals have been later coated with a glaze of hyalite. The crystals are combinations of the hexagonal prism with upper base and occasionally very narrow faces of the unit pyramid (fig. 6). This apatite has been formed as a purely secondary mineral and gives no test for chlorine or fluorine. It is probably the simple calcium triphosphate.

*Pseudomalachite*.—This rare copper phosphate occurs in small globular incrustations on the quartz in association with rhodonite and hübnerite. The globular forms are of a bright emerald-green color and have a finely fibrous structure resembling malachite.

*Wavellite*.—Little spheres of white wavellite are implanted on specimens of the vein quartz, but they are few in number. Internally they have concentric-radiating, delicately fibrous, structure.

*Turquoise*.—Small amounts of pale green turquoise, fading into white opaque masses, occur in the crevices of the Mizpah vein at the 600-foot level. The mineral is associated with black manganese oxides and kaolinite, and occurs in the vicinity of much iodyrite.

*Pharmacosiderite*.—The rare iron arsenate occurs as a coating on quartz at the 370-foot level of the Montana-Tonopah mine. It is light yellowish green and occurs in distinct cubes, with its tetrahedral symmetry indicated by diagonal striations. A few crystals show small faces of the tetrahedron and narrow faces of the rhombic dodecahedron. Deposited on this arsenate are little botryoidal groups of an undetermined dark-red iron phosphate with iridescent surfaces and light brown altered rims.

*Cacoxenite*.—Radiating tufts of golden yellow and pale yellow cacoxenite occur in the cellular quartz gangue of the Montana-Tonopah mine, about the 500-foot level. The structure of the minerals resembles burrs with short bristles, and the bristles or needles often radiate from a central small circle like spokes from the hub of a wheel. These bunches are typically deposited on drusy quartz which is coated with brownish black velvety layers of manganese oxide, or is colored brown or black by manganese.

SULPHATES: GYPSUM, JAROSITE, AND BARITE

*Gypsum*.—Very little calcium sulphate is seen in association with the specimens examined, and the mines were quite free of calcium compounds which could form this common secondary mineral. Some of the fissure walls are coated with thin layers of colorless selenite, and it occasionally forms a glaze on argentite and on some of the other secondary minerals. Brilliant crystal faces are seen on the coatings but there are no well-defined crystals.

*Jarosite*.—The hydrous sulphate, jarosite, is the most prominent of the secondary minerals precipitated from the solutions. It is characteristic of the lower zone of oxidation and is in close association with the larger part of the iodyrite. It generally occurs in flaky masses and flaky coatings, varying from light ochre-yellow to dark reddish brown. These flakes under the microscope are seen to be basal plates with rhombohedral edges.



Small crystals with bright reflecting faces also occur in the crevices of earthy masses and as a deposition on the black manganese coatings. The crystals are rhombohedrons with the basal planes in about equal development, so their resemblance to octahedrons and to cubes with the tetrahedron is quite marked (fig. 7). Some of them have the rhombohedral faces striated while the base is perfect.

The solutions which precipitated the jarosite contained both the sodium and the potassium sulphates, and it is probable that analyses would show the presence of natrojarosite as well as the normal jarosite and gradations of one into the other. A qualitative analysis made of the yellow flakes shows them to be jarosite but with considerable sodium.

*Barite*.—The sulphate of barium does not occur abundantly in the vein, yet masses of crystals covering several square feet are found on the walls of some of the fissures. The crystals are white and have the common basal-plate habit. Some are half an inch thick and an inch or more wide. The large crystals consist simply of the base  $c$  (001) and prism  $m$  (110), while the smaller ones have also narrow faces of the pyramid  $z$  (111), and brachypinacoid  $b$  (010). Thin layers of hematite or limonite coat many of them. Some of the stout plates are later parallel enlargements of smaller plates and the interior crystal had often the brachypinacoid, not present on the outer or enlarged crystal. Figure 8 illustrates the type of crystals.

	Measured	Calculated
(110) : (110)	78°21'	78°22'
(110) : (010)	50 50	50 49
(001) : (111)	64 24	64 19
(110) : (111)	25 42	25 41

TUNGSTATE AND MOLYBDATE: HÜBNERITE OR WOLFRAMITE, AND WULFENITE

*Hübnerite or Wolframite*.—The manganese tungstate occurs in black platy masses in the compact quartz gangue and in very thin plates in the cavities and seams of the gangue. All of the material contains iron and is to be classed as wolframite rather than as hübnerite. The crystals are tabular parallel to the

orthopinacoid and some of them are exceedingly thin and almost transparent, with a deep red color. They are vertically furrowed and striated and the least touch breaks them into slender rods by the easy clinopinacoidal cleavage. Many of the broad plates have frayed-out ends, while others are terminated by dull bases. The predominating habit shows a broad, striated, front-pinacoid grading into prisms and terminated by a rough base and two small faces of the rear pyramid ( $\bar{1}11$ ), as seen in figure 9. Some of the stouter crystals gave very good readings with the two-circle goniometer, since the striations did not prevent good polar orientation. The prismatic zone was a multiple of narrow striated faces and gave a train of wedges from which only a few could be distinguished as definite forms. Since the crystals are very thin, the pyramidal faces were all small, but mostly very bright. One new pyramid ( $\bar{1}22$ ) occurred on some of the crystals, in good reflecting faces. The forms observed on the crystals and the angles measured and calculated are as follows:

	$c$ (001)	$m$ (110)	$d$ ( $\bar{2}11$ )
	$b$ (010)	$q$ (830)	$o$ ( $\bar{1}11$ )
	$a$ (100)	$h$ (310)	$e$ ( $\bar{1}12$ )
	$r$ (120)	$s$ ( $\bar{1}21$ )	$v$ ( $\bar{1}22$ ) new
	Measured		Calculated
	$\theta$	$\rho$	$\theta$ $\rho$
$m$	$\infty$ 110	49°48'	90°00' 50°27' 90°00'
$q$	$\frac{1}{2}\infty$ 830	72 54	90 00 72 48 90 00
$h$	3 $\infty$ 310	74 40	90 00 74 37 90 00
$r$	$\infty$ 2 120	31 00	90 00 31 12 90 00
$s$	—12 $\bar{1}21$	30 34	63 34 31 00 63 41
$d$	—21 $\bar{2}11$	67 05	66 21 67 29 66 10
$o$	—11 $\bar{1}11$	50 00	54 00 50 14 53 42
$e$	—11 $\bar{1}12$	50 00	34 19 50 01 33 59
$v$	—11 $\bar{1}22$	30 50	45 14 30 48 45 15

*Wulfenite*.—Thin basal plates of wulfenite occur associated with barite and crystals of iodyrite. Twinned crystals of iodyrite have been deposited on the wulfenite plates and are therefore of later generation. The plates are almost colorless and

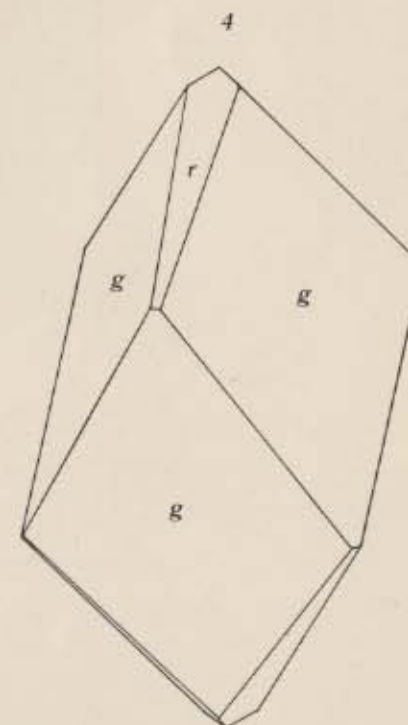
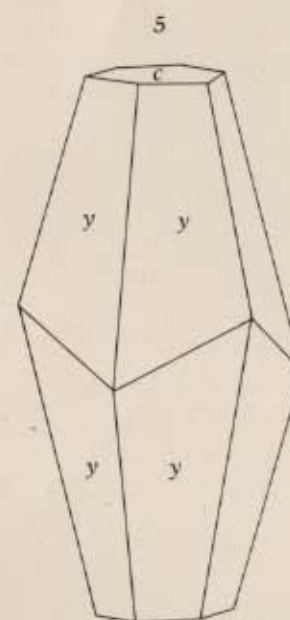
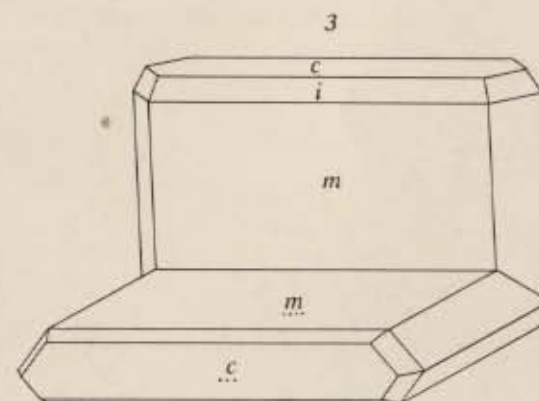
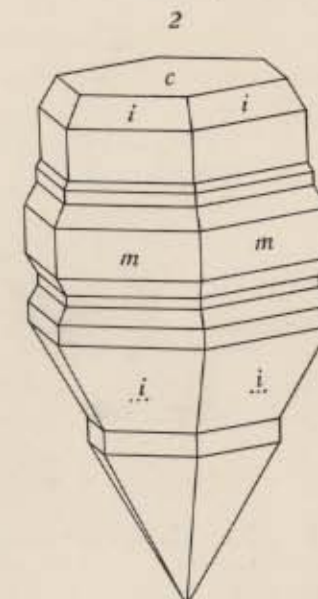


are very thin compared to their lateral dimensions (fig. 10). The forms and angles measured and calculated are as follows:

	<i>c</i> (001)	
	<i>e</i> (101)	
	<i>u</i> (102)	
	Measured	Calculated
(001) : (101)	57°31'	57°37'
(001) : (102)	37°56'	38°15'

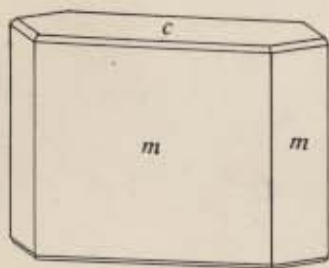
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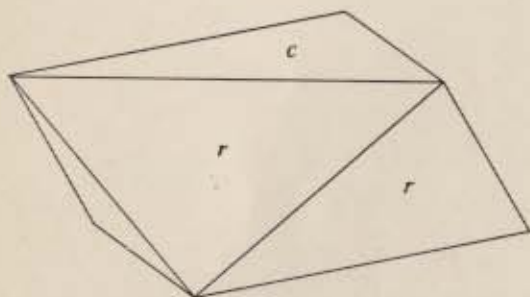
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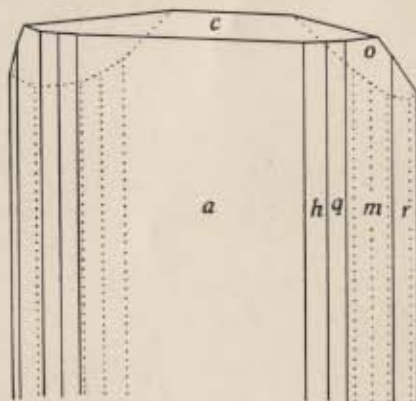
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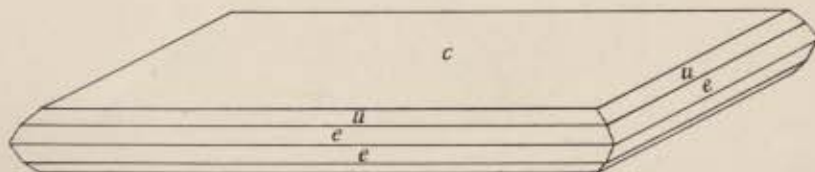
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