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PARAGENESIS OF THE ORES OF THE PALOMAS (HERMOSA) DISTRICT, SOUTHWESTERN NEW MEXICO

By

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H E N R Y   L .   J I C H A ,   J R .

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ABSTRACT

Low temperature lead-zinc-silver mineralization of Tertiary age characterizes the Palomas Mining District in the western part of Sierra County, in southwestern New Mexico. The ore occurs in fissure veins and replacement bodies in Paleozoic limestones and dolomitic limestones. Structural control of ore deposition has been exerted by fractures or shaly horizons. The principal hypogene minerals are galena, sphalerite, chalcopyrite, and argentite. Associated minerals are pyrite, polybasite, and tetrahedrite. The gangue consists mainly of talc, with associated calcite, quartz, barite, and clay minerals. Supergene minerals include covellite, native silver, limonite, carbonates of lead, zinc, and copper, silver halides, and a little vanadinite, descloizite. and pyromorphite.

Talc, which occurs both as vein filling and in wall-rock alteration, is thought to have been formed by the action of silica-bearing hypogene solutions. Little transportation appears to have taken place during the early stages of oxidation, as evidenced by the intimate association of hypogene and supergene silver minerals. The mineralization is believed to have been brought about by alkaline hydrothermal solutions whose origin is 'in

doubt, but may be connected with the sources of Tertiary volcanic activity in the area. An unusual feature of the deposits is the occurrence of talc as the chief gangue mineral.

INTRODUCTION

IN the summer of 1952 an examination and mapping project in the Palomas Mining District was begun by Dr. Richard H. Jahns and the author, under the auspices of the New Mexico Bureau of Mines and Mineral Resources. Pre-
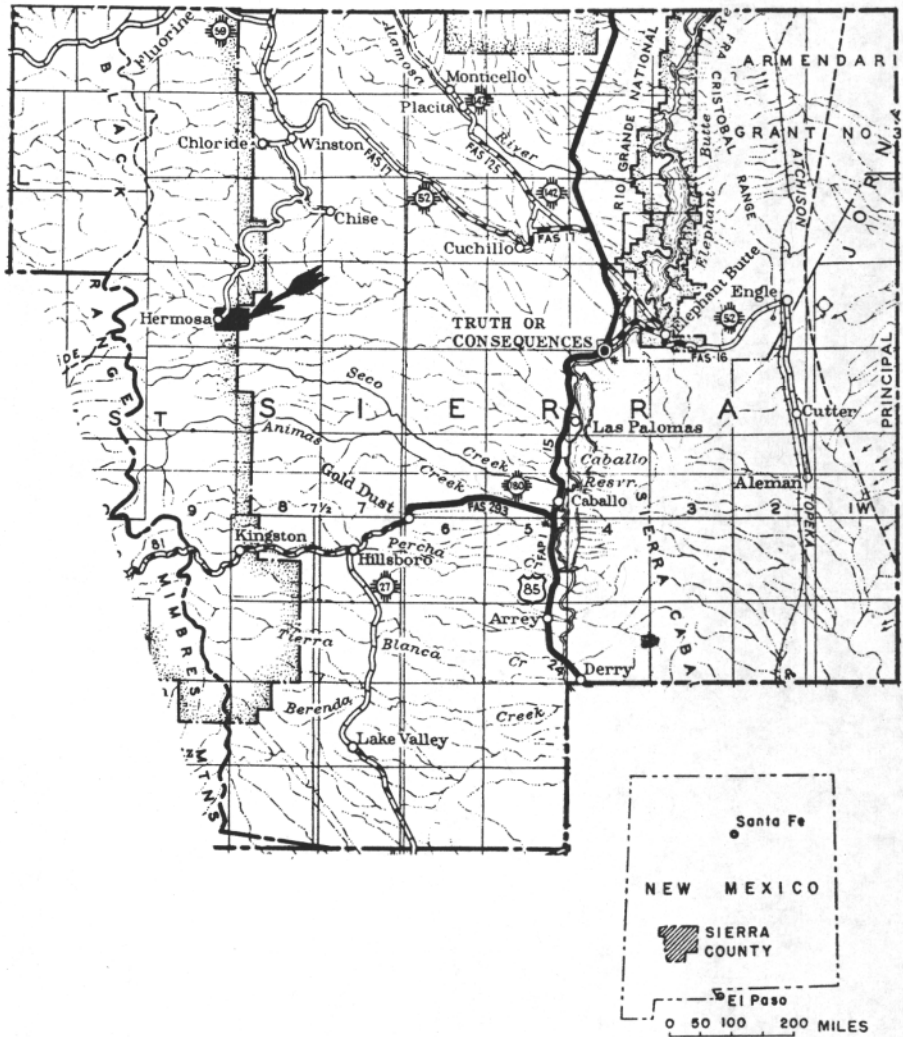
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FIG. 1.   Index map of Sierra County, showing location of the Palomas Mining District (arrow).

vious work in the area was done by Gordon (2)[2] and Harley (8), but no detailed study of the geology and mineralogy was made. During the course of detailed mapping of the mines of the district, a suite of ore specimens was obtained for laboratory examination. The purpose of this paper is to present the data obtained in the laboratory examination of the ore specimens, together with some conclusions as to the origin and mode of emplacement of the deposits which were arrived at on the basis of these data.

Acknowledgments.—The author wishes to acknowledge the help and cooperation of Dr. Richard H. Jahns and Alfred M iesch in the search for mineral specimens suitable for study. Messrs. George Koepke and H. B. Jones, who were operating the Nana mine under lease, kindly provided ore specimens from that mine as mining progressed during the fall and winter of 1952.

Dr. Jahns kindly read the manuscript critically and offered many useful suggestions.

Location.—The Palomas Mining District is located on the eastern slope of the Black Range, in T. 13 S., R. 8 W., near Hermosa in Sierra County, New Mexico (Fig. 1) an area of many mining districts in earlier days.

GENERAL GEOLOGY

The Hermosa area, which includes the Palomas Mining District, is in the upthrown block of a north-south trending horst. In this upthrown block mainly Paleozoic sediments are exposed. The east fault separates the Paleozoic sediments from the Tertiary (?) Palomas gravels. The west fault is in Tertiary latitic volcanics, part of which have been preserved in the upthrown block. The main part of the Palomas district is located in a relatively small faulted domal structure in the Paleozoic rocks of the upthrown block exposed in Palomas Canyon.

The sedimentary formations exposed in the Palomas district include the Montoya, Valmont, Fusselman, Onate, Percha, Lake Valley, Kelly, Magdalena, and Abo formations. They range in age from Ordovician through Permian. The sediments are in places unconformably overlain by Tertiary latitic volcanics which include flows, flow breccias, and tuffs.

GENERAL RELATIONS OF THE ORES

The ores of the Palomas district occur principally as thin shoots, stringers, and pockets along subsidiary fractures of small displacements associated with the major faults in the domal uplift that is exposed in Palomas Canyon. Some mineralization was also observed at the intersections of minor fractures and of minor fractures and bedding-plane slips. The largest part of the mineralization occurs in Ordovician and Silurian dolomites and dolomitic limestones under the shaly base of the Devonian Onate formation. Locally small replacement bodies of ore occur in higher formations. In general, the ore bodies are small, yielding from a few to a few hundred tons of high-grade ore, and from two to ten times as much low-grade ore. At places the ores are vuggy ; more

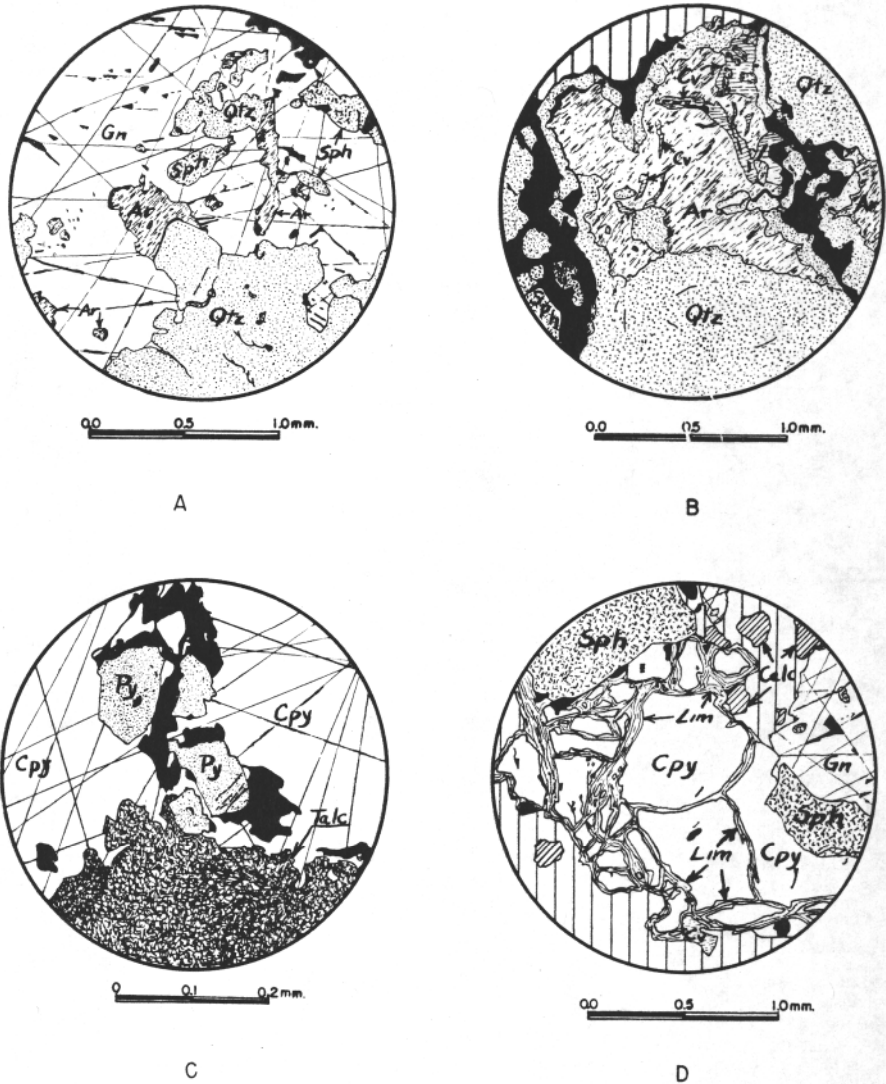2 Numbers in parentheses refer to References at end of paper.

FIG. 2. Camera lucida drawings: A. Quartz (Qtz) and sphalerite (Sph) re-
placed by galena (Gn) and all replaced by argentite (Ar). Black areas are holes.
B. Argentite (Ar) replaced quartz (Qtz) and is itself replaced by covellite (Cv).
Black spaces are holes. Vertical ruling is mounting medium. C. Pyrite (Py) re-
placed by chalcopyrite (Cpy) and both replaced by talc. Black areas are holes.
D. Chalcopyrite (Cpy) replaced by limonite (Lim) and covellite (Cv). Original
texture shows chalcopyrite replaced sphalerite (Sph) and sphalerite replaced by
galena. Some late calcite (Calc). Mounting medium (vertical ruling). Black
areas are holes.

commonly they are fairly tight. The sulfide minerals are largely galena and sphalerite. Small amounts of chalcopyrite, pyrite, tetrahedrite, pyrargyrite, polybasite, and argentite are also present. Gangue minerals include calcite, quartz, barite, talc, and montmorillonite.

Wall-rock alteration is evidenced mainly by the formation of talc. Most of the high-grade ore bodies are surrounded by a "skin" of talc, commonly mixed with calcite. This "skin" ranges in thickness from $1/8$-inch to 3 inches, and averages about $3/4$-inch. The talc "skin" commonly breaks free of the unaltered wall-rock. Talc is also commonly present in areas where pyrite is the only sulfide present. Relatively large volumes of talc, which varies in color from white through yellow to almost black, commonly accompany metallization
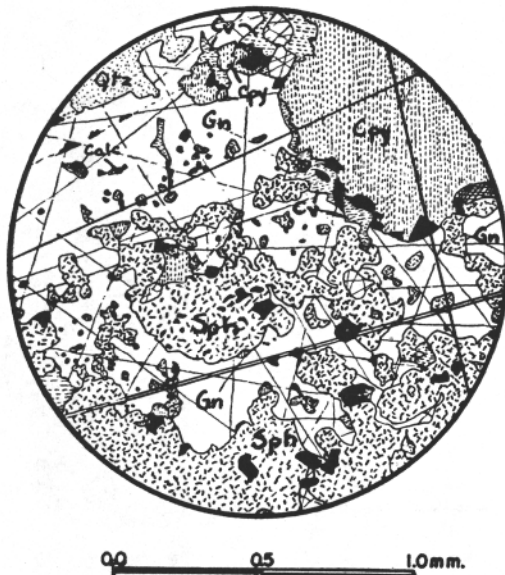

Fig. 3. Sphalerite (Sph) and quartz (Qtz) replaced by chalcopyrite (Cpy) and galena (Gn). Covellite (Cv) shows that some secondary sulfide enrichment has taken place. Late calcite (Calc) also present. Black areas are holes. Camera lucida drawing.

of all grades. "Skin" talc is yellowish or creamy white, with more or less iron stain. Fault and fracture openings also contain some talc, part of which is almost certainly replacement of the dolomitic gouge. Some of the dolomite and dolomitic limestone near ore shoots is replaced by talc, which is partly disseminated and also occurs as layers around blocks of unmineralized dolomite. These bands show Liesegang-like rings (Fig. 9) that apparently developed from the outside inward; the centers are unreplaced masses of original dolomite.

Large amounts of talc are good indications of nearby ore and with few exceptions talc is present where there are high-grade ores. However, talc is also widespread as a minor constituent where ore is sparse or not present.
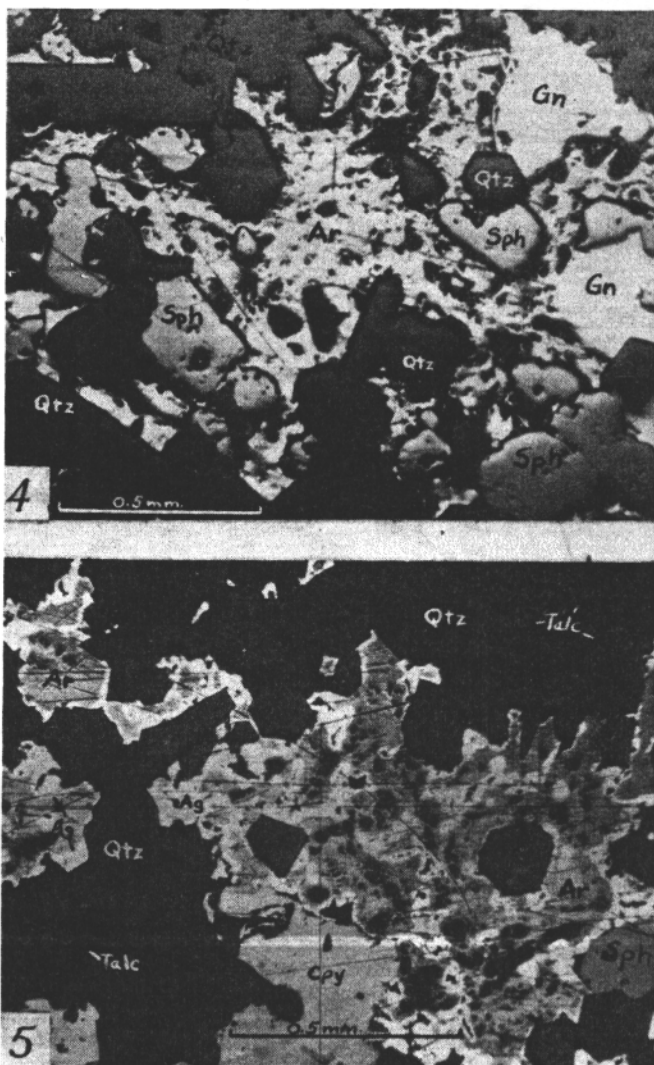
FIG. 4. Vug in crystalline quartz (Qtz) filled with sphalerite (Sph), galena (Gn), and argentite (Ar).

FIG. 5. Vug in crystalline quartz (Qtz) with sphalerite (Sph), chalcopyrite (Cpy), argentite (Ar), and native silver (Ag). Note that silver has replaced argentite peripherally and from holes. This texture is similar to that described by Bastin (1925, p. 54) for pearcite replaced by native siler at Aspen, Colo.

     Some silicification has also occurred. At many places silica partly replaces the dolomitic limestone country rock in association with talc. Less commonly, large masses of quartz form fine-grained crystalline aggregates to the complete exclusion of the country rock. Vugs in these aggregates commonly contain some metallic minerals.

At many places the ores are accompanied by crystalline calcite in rhombs as much as 2 inches on an edge. The calcite is generally closely associated with talc and also fills the openings along many of the larger pre-mineralization faults. Where calcite occurs along bedding-plane slips, it commonly forms the locus of deposition for sulfides.

Many of the high-grade ore deposits occur in the form of nodules or "pillows," up to 18 inches in length and breadth, and 8 inches thick, that are com-

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pletely, or almost completely surrounded by talc in the form of a "skin" described previously. The ore also occurs as fracture fillings and partial replacements accompanied by relatively large volumes of talc. The replacement bodies and fissure-fillings may be of equally high-grade and contain the same minerals as the ore pillows but they are generally surrounded by lower-grade, disseminated ores. The disseminated ores commonly consist of nodules of sulfides, scattered through relatively large masses of talc.

The high-grade ores consist largely of galena and sphalerite with chalcopyrite, argentite, and silver sulfo-salts. The galena, sphalerite, and chalcopyrite are commonly coarse-grained, in crystals as much as 2 cm in diameter. The silver minerals are finer-grained, and generally occur only as small masses scattered throughout the ore. The lower-grade ores rarely contain recognizable silver minerals.

The hypogene ores of the Palomas district have been subjected to extensive supergene alteration, chiefly oxidation, mainly in areas where faulting and solution have opened the primary ores to the ingress of meteoric waters. Surface exposures are, of course, highly altered. Generally, a high degree of oxidation is characteristic only of those portions of the ore deposits exposed to weathering. but some oxidation occurs on almost all levels of the mines. Oxidation in the lower levels is probably due to through-going fractures and faults that appear also to have been channels for the hypogene solutions. A high degree of oxidation is common near fractures that adjoin and parallel the Pelican fault in the Day mine. Many similar localities could be cited.

Small-scale sulfide enrichment is found in most of the ores. In the rich ores, native silver occurs associated with argentite, covellite, and chalcocite. Oxidized ores are commonly of the dry-bone type, being made up largely of lead and zinc carbonates. At some localities copper carbonates, brochantite, cuprite, and limonite are accessories. In one area, the ores are largely lead and zinc carbonate in a boxwork structure, accompanied by vanadinite, descloizite, mimetite, pyromorphite, wulfenite, and some quartz. The accessory minerals form crystal sheafs and crusts on the cerrusite boxwork.

MINERALOGY

Thirty-eight mineral species have been identified during the present investigation. Five species which were not found in the present suite have been reported to occur (14). Of the thirty-eight minerals identified, fifteen have not been previously reported. A list of the mineral species of the Palomas district is given in Table 1.

GENERAL RELATIONS OF THE MINERALS

Gangue Minerals.—Calcite occurs in three forms : (1), As large milky white rhombs commonly closely associated with talc, which in some places localizes sulfides, mainly sphalerite and galena, and also is found along barren fault planes. (2) Similar calcite occurs with some of the sphalerite in contact with the earlier calcite, or as growths on the earlier calcite and sphalerite ; sphalerite occurs only on the earlier calcite whereas galena occurs on both. (3) Clear calcite occurring as vug and fracture fillings in the ores with a complex crystal form of rhombs modified by scalenohedrons, and commonly associated with yellow or black talc ; the fourth variety similar to the third, but is clouded with specks of limonite.

TABLE 1

MINERALS OF THE PALOMAS DISTRICT

*Anglesite	$PbCO_3$	Gypsum	$CaSO_4 \cdot 2H_2O$
*Argentite	Ag_2S	Hematite	Fe_2O_3
*Azurite	$Cu_3(CO_3)_2(OH)_2$	Lepidocrocite	$FeO(OH)$
Barite	$BaSO_4$	*Limonite	Hydrated ferric oxides
*Bornite	Cu_5FeS_4	*Malachite	$Cu_2CO_3(OH)_2$
Brochantite (?)	$Cu_4SO_4(OH)_6$	Manganite	$MnO(OH)$
†*Bromyrite	$AgBr$	†*Marcasite	FeS_2
*Calcite	$CaCO_3$	†*Miargyrite	$Ag_2Sb_2S_4$
†*Cerargyrite	$AgCl$	Mimetite	$Pb_5(AsO_4, PO_4)_3Cl$
*Cerussite	$PbCO_3$	Polybasite	$Ag_{16}Sb_2S_{11}$
*Chalcocite	Cu_2S	*Pyrargyrite	Ag_3SbS_3
Chrysocolla	$CuSiO_3 \cdot 2H_2O$	*Pyrite	FeS_2
*Chalcopyrite	$CuFeS_2$	Pyromorphite	$Pb_5(PO_4, AsO_4)_3Cl$
*Covellite	CuS	*Quartz	SiO_2
Cuprite (rare)	CuO	*Silver	Ag
Descloizite	$(Pb, Zn, Cu)_2(OH)VO_4$	*Smithsonite	$ZnCO_3$
†*Embolite	$Ag(Cl, Br)$	*Sphalerite	ZnS
Epsomite	$MgSO_4 \cdot 7H_2O$	*Talc	$Mg_3(Si_2O_5)_2(OH)_2$
*Galena	PbS	*Tetrahedrite	$5Cu_2S \cdot 2(Cu, Fe)S \cdot 2Sb_2S_3$
*Gold	Au	Vanadinite	$Pb_5Cl(VO_4)_3$
Goethite	$HFeO_2$	*Wulfenite	$PbMoO_4$

* indicates that mineral has been previously reported as occurring in the Palomas district.
†* indicates that mineral has been mentioned as occurring in the Palomas district but is not found in the present suite.
(?) indicates that the identification of this mineral is in doubt.

Quartz occurs in the ores in three forms : (1) as vuggy, crystalline aggregates which commonly contain small but valuable amounts of sulfides (Figs. 4, 5) both as complete fillings and as thin coatings on the quartz crystals ; the contained sulfides include sphalerite, tetrahedrite, galena, and argentite, and talc. Some botryoidal quartz occurs as veinlets in sphalerite, and a third form occurs exclusively with the secondary ores, as vugs and crystalline crusts in and on such minerals as cerussite, vanadinite, and pyromorphite ; many of the crystals are clouded with specks of limonite.

Barite occurring as yellowish translucent tabular crystals from 1 to 2 cm long is a common constituent of oxidized ores and is also found in association with pyrargyrite and polybasite, which form crystal incrustations on it.

Sulfide Minerals.—Pyrite is rare. It occurs with talc or in association with chalcopyrite, which commonly completely surrounds it. *Marcasite* has

been reported to occur in the ores as incrustations on galena (14, p. 209), but was not seen in the ores examined.

Sphalerite is generally present in the high-grade sulfide ores in lesser quantity than galena. It is light to dark amber in color, and occurs as discrete crystals with dodecahedral form and as crystalline crusts. On weathered sur-
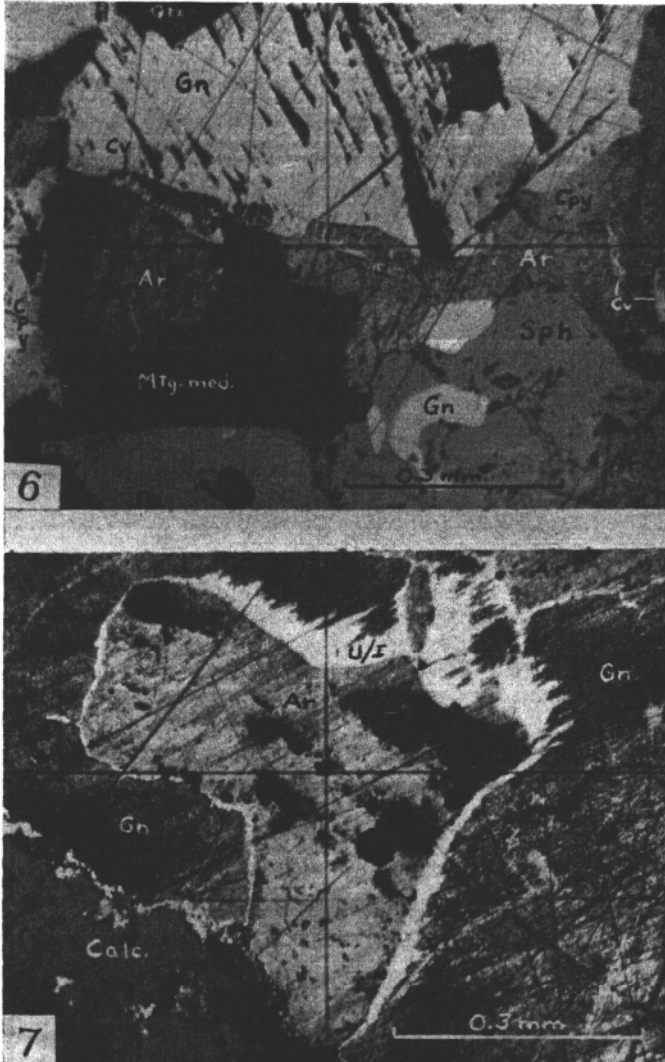

Fig. 6. Galena (Gn) and argentite (Ar) replaced sphalerite (Sph), quartz (Qtz) and chalcopyrite (Cpy). Light streaks in argentite are covellite (Cv). Flat gray is mounting medium (Mtg. Med.).

Fig. 7. Argentite (Ar) in galena (Gn) etched dark with hydrogen peroxide to show border of unidentified mineral (U/I) in galena around argentite. Calcite (Calc) at lower left.

faces the crystals are generally dark gray with a submetallic luster, and appear to have been slightly oxidized. Under the microscope it is seen to contain numerous inclusions of chalcopyrite, with some tetrahedrite and galena. The more important relations are embayment and veining of sphalerite, which also occupies cleavages in the calcite ; sphalerite also occurs as crusts on vuggy quartz.

Tetrahedrite occurs sparsely in the ores, mainly as small blebs and masses in sphalerite to the exclusion of all other minerals. It is most abundant in the ores of the Palomas Chief mine, and is associated with sphalerite or with argentite, being embayed by the latter.

Chalcopyrite and bornite are not quantitatively important. Chalcopyrite is common in the high-grade silver ores of the district, and is generally regarded as an indication of silver. In polished sections it is seen as tiny rods and blebs in sphalerite, along cleavages or peripheral. Some blebs lead into veinlets of chalcopyrite in the same plane of weakness. In partly oxidized ores, the chalcopyrite is partly replaced by covellite and chalcocite, and limonite is a common associate (Fig. 2D). The chalcopyrite is embayed by galena and argentite, and it in turn embays galena. Some bornite is associated with chalcopyrite.

Galena is quantitatively the chief sulfide mineral. It occurs mostly as cubes modified by octahedrons, and as dodecahedrons. Some anhedral galena appears to have inherited its shape from pre-existing minerals. Some fine-grained "steel" galena occurs at bends in fractures that cut across the ore bodies ; near such fractures some galena has curved cleavages as much as 40 degrees from the normal trend of the cleavage line.

A specimen of galena from the Nana mine was analyzed spectrographically. No bismuth or antimony were found. The limits of detection of these elements were five parts per million and two hundred parts per million, respectively. The lack of antimony in the galena is particularly interesting in view of the presence of small amounts of antimony minerals (tetrahedrite and polybasite) in the ores. Silver is present in this particular galena to the extent of 0.1 percent. It has been shown (17, p. 305) that galena can contain this much silver without giving visible evidence of the silver content, even on etching with hydrogen peroxide. Etching on a polished surface of the sample has shown that the silver is present in a non-etching mineral tentatively identified as a lead-silver sulfide that occurs as veinlets in and peripheral coatings on galena. This mineral has been described by Bastin and Laney (1, p. 21-23) and also by Petersen (16, p. 493).

Traces of Fe, Mg, Ti, Al, Mn, and Cu were also found. Of these elements, Wasserstein (22) has found that Fe, Ti, and Mn may substitute in very small amounts for Pb in the galena lattice. Other elements listed by him are Sn, Cd, Sr, and V, none of which have been found to occur in this galena. The presence of Mg, Al, and Cu may be ascribed to minor contamination of the sample.

Harley (8, p. 94) has described cubes of supergene galena in cavities, but the author has found no evidence of supergene galena.
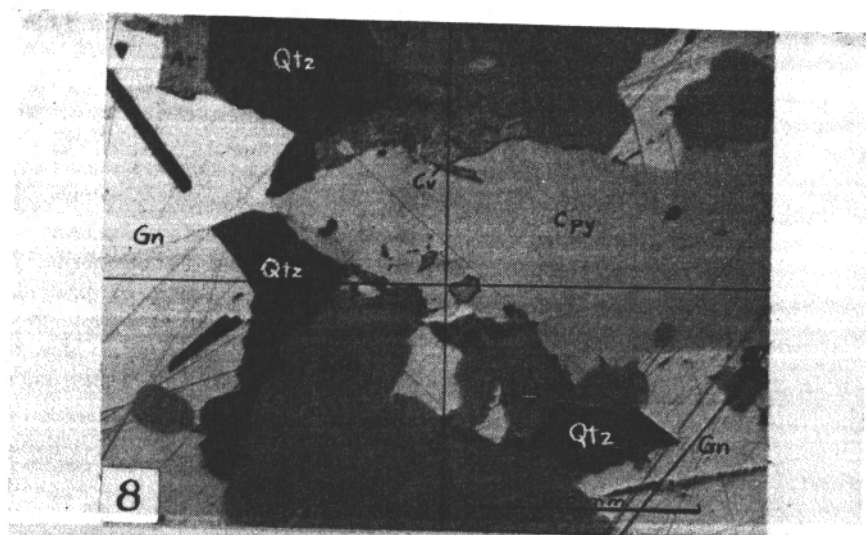
FIG. 8.   Sphalerite (Sph) replaced quartz (Qtz), chalcopyrite (Cpy) replaced sphalerite and quartz; galena (Gn) replaced sphalerite, quartz, and chalcopyrite; argentite (Ar) replaced all previous minerals, and covellite (Cv) replaced argentite.
FIG. 9.   Dolomite (dark gray, center) replaced by talc which shows Liesegang-like rings.   Dolomite is replaced from outside of block inward.

Covellite and chalcocite are both found in the ores of the Palomas District. Covellite occurs as small microscopic veinlets and as bladed masses, and as rims around chalcopyrite, or as veinlets in argentite. In the more highly enriched ores covellite generally is present to the exclusion of most or all of the argentite. Chalcocite is scattered through the enriched portions of the ores

in somewhat larger amounts than covellite. For the most part it is in intimate association with covellite.

An *undetermined mineral* is indicated by etching galena with hydrogen peroxide, which in places brings out a minor, but persistent difference in parts of the crystals. In the silver-poor ores, cleavages and cleavage intersections in many crystals show rims and blebs of a mineral which has not been identified specifically, but which does not etch with hydrogen peroxide. This mineral is identical in all other properties to galena, except that it commonly exhibits some resistance to the action of nitric acid but after a short period, not over 30 seconds, it etches in a manner similar to galena. Bastin (1, p. 21-23) has described this same mineral, which occurs at Tonopah, and came to the conclusion that it is probably a double sulfide of silver and lead. That this is a strong possibility is shown in the relations between argentite and galena. The rims of this intermediate mineral are much wider in the vicinity of such contacts than where little or no argentite is found. No mineral other than galena shows rims and veinlets of the undetermined mineral.
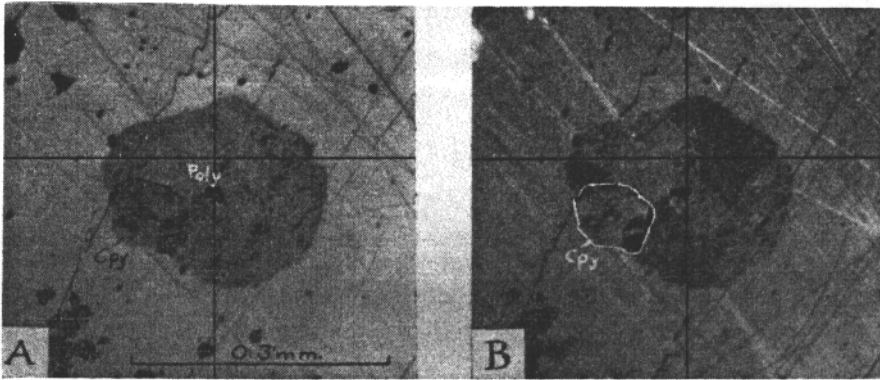

FIG. 10.   A. Polybasite (Poly) and chalcopyrite (Cpy) in galena.   B. Same as A, crossed nicols.   Note anisotropism of polybasite, which shows crystal to be twinned.

Silver Minerals.—Polybasite is rare, having been found only in a few specimens of rich ore from the Nana mine where it occurs as small blebs and veinlets in galena (Fig. 10). It cuts across the galena cleavages in places ; in other places it follows the cleavages. In one specimen small crystals of polybasite occur on barite. Microscopic examination shows the mineral to be greengray, somewhat lighter than argentite and slightly darker and greener than tetrahedrite, with a hardness of C —. It is strongly anisotropic, the colors being yellowish-green, grayish-purple, and brown (Fig. 10). Though no discernible internal reflection has been found, the optical properties and etch tests agree with those given for polybasite (20, p. 126a).

Pyrargyrite is seen in the richer ores as small irregular grains commonly associated with and embaying chalcopyrite, blue-gray, slightly harder than galena, and anisotropic in shades of gray. The mineral reacts to etch tests

in a manner which suggests that it is pyrargyrite (20, p. 127). However, its identification is tentative. Some hand specimens contain crystals identified as pyrargyrite in association with polybasite on barite.

Miargyrite was reported from the Palomas district by Jones (10, p. 343), but none was found in the ores examined.

Argentite occurs sparsely throughout the richer ores as small blebs, veinlets, and thin films in sphalerite and galena, commonly along the cleavage. Chalcopyrite and tetrahedrite are also found as associates of argentite, which usually embays rather than forms veinlets in these minerals. The contact between argentite and galena characteristically shows rims of a mineral which is thought to be a double sulfide of lead and silver. In one specimen, argentite

Paragenetic Sequence of the Hypogene Ores

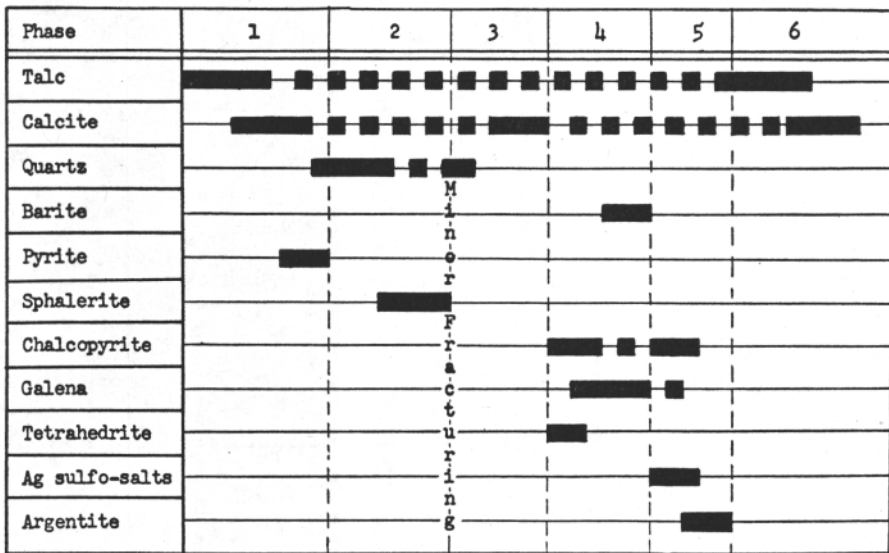| Phase	1	2	3	4	5	6
Talc						
Calcite						
Quartz						
Barite						
Pyrite						
Sphalerite						
Chalcopyrite						
Galena						
Tetrahedrite						
Ag sulfo-salts						
Argentite						

Fig. 11. Paragenetic sequence of the hypogene ores.

occurs as aggregates of small crystals that show twinning. Such argentite is reported to have formed at temperature above 179° C (17, p. 317). Argentite occurs in vugs in some places, in association with native silver (Fig. 5). Similar occurrences have been reported from the Comstock lode (2, p. 53). Another common associate of argentite is covellite, which embays or forms vein-lets in argentite. In a few areas the argentite forms rims around masses of covellite.

Native silver is rather rare and is found only in the more highly enriched of the argentite-bearing sulfide-talc ores, where it occurs as flakes, wires and small arborescent masses associated with argentite, as well as in tiny blebs and veinlets in and around argentite (Fig. 5) or covellite ; in places it is in small isolated masses in talc.

Silver halides, notably cerargyrite, embolite, and bromyrite, have been reported from the Palomas district (8, p. 94), but the author was unable to find any, probably because the high-grade oxidized ores of silver were stoped out at an early date.

The ratio of silver to gold is several thousand to one ; the gold content is minute, but some free gold has been reported in the oxidized ores by Harley (8, p. 94).

Oxidized minerals. Malachite and *azurite* are found as films, stains, and crusts on most oxidized ores that contained copper sulfides ; cuprite and chrysocolla are also present and brochantite has been identified tentatively. Most of these minerals are found in association with cerussite, smithsonite, and limonite, and in some of the dry-bone ores.

Cerussite and *limonite* are the most common products of oxidation. Cerussite generally occurs as aggregates of small crystals that may form a box work indicating the shape of the parent galena crystals. Cerussite is commonly associated with limonite, which forms a thin coating on the boxwork of cerussite crystals. It is one of the main constituents of the oxidized ores. It also occurs as a white coating on some of the more highly oxidized sulfide ores of the Nana mine, and on oxidized ores from other mines. The cerussite contains small amounts of copper and zinc. *Anglesite* is only rarely found as an oxidation product of galena. In some of the oxidized ores where sulfides remain, it forms thin films on galena crystal surfaces and cleavages.

Smithsonite is fairly abundant in the low-grade oxidized ore, forming the well-known dry-bone type. A few crusts of smithsonite are also found associated with the more varied mineral assemblage found in one area in the district.

Phosphates, vanadates, and arsenates, including vanadinite, descloizite, pyromorphite, mimetite, and wulfenite, occur in the highly oxidized ores from a mine in the Wolford group. These minerals are associated with the more common cerussite, smithsonite, calcite, limonite, and basic copper carbonates. The ores are very vuggy and some of the minerals have developed into crystals as large as 1 cm in length and 1 to 2 mm in diameter. *Vanadinite* occurs in two closely allied forms : (1) as large (1 cm by 2 mm) well-terminated prismatic crystals of deep orange-brown color, and (2) as tiny bunches of straw-yellow acicular crystals. *Descloizite* (probably cuprodescloizite) occurs as bunches of tiny yellow acicular crystals, difficult to distinguish from vanadinite of similar form except by chemical tests, and more commonly as a crust of shiny, black, acicular crystals on limonite-cerussite boxwork. Microchemical tests indicate the presence of copper. *Pyromorphite* occurs as white to almost colorless, subtransparent to translucent crystals about 1 cm long in association with descloizite, cerussite, limonite, and quartz. *Mirnetite* occurs as small greenish prisms in association with pyromorphite. *Wulfenite* occurs in small amounts as incrustations in fractures associated with the more highly oxidized ores.

Iron and Manganese Oxides. Limonite is one of the most common constituents of oxidation. It is generally orange-brown to yellow-brown and sub-crystalline to earthy. In polished section it can easily be seen to be made up

of lepidocrocite and goethite. In the less-oxidized ores, limonite shows a layered growth and the minerals alternate. They are distinguished from each other under the microscope by the fact that lepidocrocite is lighter in color and has a bright red internal reflection as compared to the darker colored goethite, which has a brown internal reflection. Both show pleochroism, but lepidocrocite is more highly pleochroic. The distinction is made easily only when both minerals are present. In hand specimen, with low-power magnification, lepidocrocite is found to form red, translucent botryoidal crusts associated with brown, less well-crystallized goethite.

Hematite is found in some parts of the district as a fine red powder coating bedding surfaces in mineralized areas.

Small bunches of dark brown spots and tiny dark brown nodules occur in association with limonite in many of the oxidized ores have been found to contain manganese. The mineral represented is thought to be manganite, from its physical properties and association with limonite.

Other Minerals.—Gypsum occurs as vug fillings in many of the harder ores that have been subjected to supergene alteration. It also occurs in some of the softer, talcy ores as discrete crystals and aggregates. Gypsum is also found in large porous masses of fibrous crystals in some of the moderately oxidized portions of the deposits. *Epsomite* occurs in some of the mine workings which are now dry but were once filled with water. *KaoUnite* is present in the gangue of the ores where supergene action has taken place. Its common association is with the talc masses around the ores.

PARAGENESIS

With the exception of some argentite and all covellite and chalcocite, all of the sulfide minerals are considered to be hypogene. In addition, the gangue minerals talc, barite, calcite, and quartz are also hypogene, though the last two also occur as supergene minerals.

The primary mineralization sequence in the Palomas district is shown in Figure 11. Much of the faulting antedates the mineralization but most of the mineralized fault zones show evidence of post-mineralization movement. The mineralization proper occurred with little apparent discontinuity, but has been divided into several phases for convenience in reference and description.

The first phase was marked by the formation of white talc and large rhombs of milky white calcite. This was followed by the deposition of small amounts of pyrite. In the second phase crystalline quartz was formed. Sphalerite was introduced slightly later. Minor fracturing took place at the end of this phase. In the third phase of mineralization minor botryoidal quartz and some additional milky calcite were added. The calcite of this phase commonly occurs as secondary growths on calcite rhombs of the first phase. The fourth phase consists largely of sulfide minerals. Tetrahedrite and chalcopyrite were deposited contemporaneously, closely followed by galena and small amounts of barite. Galena was contemporaneous with a large part of the chalcopyrite. Phase five is marked by the introduction of sulfosalts of silver, mainly polybasite ; these were followed by argentite, the last hypogene sulfide deposited.

Some chalcopyrite is thought to have accompanied the silver minerals. The closing phase of the mineralization is a second talc and calcite phase. However, the calcite of this phase is clear and is in the form of rhombs modified by scalenohedron faces. The talc is pale yellow to cream-colored and waxy. It forms late veinlets in the sulfides and at some places also forms large envelopes around the sulfides.

The above generalized sequence does not appear to have been followed exactly throughout the district, though the exceptions are mainly matters of degree. Some of the ores are poor in silver and contain few visible silver minerals. In such ores the late carbonate and talc phase is also poorly represented. This may indicate blocking of the late hypogene solutions from the ores by fracture-filling. The presence of silver minerals and chalcopyrite is thought to indicate comparatively greater permeability of the ores that contain large amounts of these minerals to the late hypogene solutions. The hypogene ores that contain large amounts of argentite and chalcopyrite are generally vuggy or else they are enclosed in masses of a fairly porous talc. Where the ores are "tight" there is not much argentite and chalcopyrite. At other places the carbonate and quartz of phase three are not prominent.

Talc appears to have been formed throughout most of the period of mineralization, and hence its formation was contemporaneous with the sulfide deposition. The contemporaneity of the talc formation with sulfide deposition in the ore "pillows" is almost unquestionable, as indicated by the almost constant association of the talc with the sulfides and the mutual consistency of the variation in the size of the sulfide masses and their associated talc deposits. Though talc formed throughout the mineralization sequence, the two major epochs of talc formation are recognized because talc was one of the chief minerals formed in those parts of the mineralization sequence.

Chalcopyrite is all later than sphalerite in the paragenetic sequence, in spite of some relations that might indicate unmixing. The general irregularity of distribution of the inclusions of chalcopyrite in sphalerite, and their accompaniment by veinlets and other encroaching grains of chalcopyrite is evidence for this conclusion.

Argentite is considered to be mostly hypogene. It encroaches on most minerals of the primary sequence in a manner that suggests hypogene replacement, coupled with the presence of some argentite that must have formed over 179° C. In addition, supergene minerals are found to encroach upon and form veinlets in most argentite. Some argentite is thought to be supergene, as it forms encroaching rims on supergene covellite. No detailed paragenetic sequence has been established for the supergene ores. The location of most of the ores above the present water table favors oxidation over sulfide enrichment, and indeed, oxidation is the most prominent form of supergene activity. Sulfide enrichment has gone on in these ores only on a much smaller scale. This fact points to a rapid lowering of the water table and subsequent exposure of the ores to oxidation, probably resulting from the rapid downcutting of Palomas Creek. However, small bodies of perched water exist, and the percolation of meteoric waters in other areas is extremely restricted. The perched water and lack of easy access of meteoric waters to oxygen may account for a large

part of the supergene sulfide deposition. That sulfide enrichment may occur as part of an incomplete oxidation process has been brought out by Lindgren (12, p. 164). Where ore occurs below water level, sulfide enrichment is undoubtedly also going on.

A rough summary of supergene alteration might be as follows : The early stages of alteration are marked by the formation of covellite, chalcocite, native silver, and some limonite. Galena may have cleavage films of anglesite. In later stages, when oxidation predominated, sphalerite was dissolved and some smithsonite formed. Cerussite, gypsum, limonite, and copper carbonates were formed as well as minor wulfenite. Some relict galena generally remained. Silver halides were formed. In the most advanced stages of alteration, minerals such as hematite, vanadinite, descloizite, pyromorphite, mimetite, chrysocolla, brochantite, and cuprite were formed on cerussite, smithsonite, and limonite. Most of the silver was leached out. This synthesis follows closely the evidence provided by known localities of occurrence of the various types of ore mentioned.

FORMATION OF TALC

The problem of the origin of the talc associated with the Palomas ores has been studied in some detail.

Insoluble residue studies have shown the content of insolubles in unaltered dolomites and dolomitic limestones of the Palomas district to be relatively minor. The general figures for the lower Paleozoic formations are between 3 and 9 percent by weight, excluding chert of chert nodules. Differential thermal studies of these residues show that their clay content is small. There were some indications of the presence of illite and possibly montmorillonite. X-ray studies tend to confirm these indications.

The formation of talc is thought to have resulted from the introduction of hot alkaline siliceous solutions into the dolomitic country rock and may have taken place as 'follows :

$$4SiO_2 + FI_2O + 6 (Ca, Mg)CO_3 \quad Mg_3(Si_2O_5)_2(OH)_2 + 3CaCO_3 + 3CO_2$$

This same process is thought to have taken place during the formation of talc deposits in dolomitic limestones and marbles (5 ; 11, p. 434). As talc occurs in large amounts only where the country rock is highly dolomitic and is found only sparingly in deposits associated with the Mississippian and Pennsylvanian rocks, which are dominantly high-calcium limestones, such an hypothesis seems probable. Shaly layers that have been altered in part to talc also contain a high proportion of dolomite in their unaltered state. Some of the "hypogene" calcite is thought to be a by-product of the formation of talc from the magnesia in the dolomites and dolomitic limestones. The almost constant association of talc with unaltered primary sulfides is an important factor in the assumption that the talc is hypogene in origin. Ross and Hendricks (19, p. 71) indicate that talc may be formed under hydrothermal conditions at temperatures of about 350° C in alkaline environments. The experiments of Bowen and Tuttle (4) corroborate these indications.

Part of the silica for the formation of talc and for deposition of free quartz may have been derived from chert in the dolomites and dolomitic limestones under and surrounding the ore deposits. Evidence for this tentative conclusion is found in the fact that at many places in the mineralized areas the cherts of the Montoya formation are largely replaced by calcite. It is thought probable that this replacement was accomplished by hypogene solutions. The silica thus liberated may have taken part in the formation of talc.

The presence of kaolinite in some samples of partly oxidized ore may be attributed to the action of supergene sulfate waters (18, p. 174). Kaolirtite generally forms in acid environments (19. p. 23) which are incompatible with the alkaline environment necessary for the formation of talc.

An analysis of a specimen of slightly oxidized ore is given in Table 2. Recalculation of the figures to mol fractions and development of the possible

TABLE 2

ANALYSIS OF SLIGHTLY OXIDIZED ORE FROM THE NANA MINE, PALOMAS DISTRICT

Constituent	Percent	Probable minerals*	
Ag	1.84	Argentite	—Ag_2S
Cu	3.29	Native silver	—Ag
Pb	52.89	Chalcopyrite	—$CuFeS_2$
Fe	1.85	Covellite	—CuS
Zn	0.82	Galena	—PbS
S	10.17	Sphalerite	—ZnS
		Cerussite	—$PbCO_3$
SiO_2	20.37	Anglesite(?)	—$PbSO_4$
TiO_2	0.13	Quartz	—SiO_2
Al_2O_3	1.22	Kaolinite	—$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
CaO	0.00	Talc	—$Mg_3Si_4O_{10}(OH)_2$
MgO	4.19	Manganite	—MnO(OH)
MnO	0.47	Goethite	—$HFeO_2$
P_2O_5	0.00	Leipdocrocite	—FeO(OH)
SO_4	0.03		
CO_2	0.97		
H_2O	2.33		
Total	99.53		

* All of these minerals with the exception of kaolinite, manganite, and anglesite have been identified in polished sections of this specimen. The clay mineral was identified by X-ray diffraction methods. Assays show that this specimen contains some gold.
Analysis by H. B. Wiik.

mineral content by a process similar to the development of the norm of an igneous rock indicates that there should be talc and some kaolinite in the ore as well as free quartz. The presence of talc and kaolinite has been confirmed by X-ray diffraction patterns.

NATURE, AGE, AND ORIGIN OF THE MINERALIZING SOLUTIONS

The mineralization is thought to have been accomplished by moderate- to low-temperature alkaline solutions. As has been previously stated, the formation of talc by introduction of silica into magnesian limestones requires alkaline conditions. Inasmuch as talc was formed throughout the mineralization

sequence, alkaline conditions probably prevailed throughout the entire period of mineralization. The low-temperature nature of the deposit is evidenced in the mineral suite as well as the general restriction of the deposits to fissure fillings with only minor replacement. It should be noted that the low-temperature mineralization in the Palomas district is in direct contrast to the high-temperature silicate mineralization found in the Cuchillo Mountains to the north and east of Winston (9).

The age of the mineralization is mid-Tertiary (probably Miocene). Mineralized and altered dikes similar in composition to the late Tertiary latitic volcanics in the surrounding region occur in the district. The mineralized zone also extends into some of the volcanics that overlap the sediments in one of the mineralized areas. The source of the mineralizing solutions has not been definitely established, but may be related to the igneous activity that took place in the region in late Tertiary time. There is no conclusive evidence of intrusives other than a few mineralized latitic dikes in the area.

Assuming that conditions have not changed markedly since the beginning of the major epoch of supergene enrichment, the following characteristics of supergene solutions are postulated. The supergene solutions were probably restricted in their flow. The present rate of circulation is very low. This low rate of circulation suggests poor access to oxygen. The waters were also probably not very acid, as suggested by the carbonate gangue. Formation of such minerals as covellite, chalcocite, native silver, and argentite under supergene conditions suggests that where such alteration occurs the solutions contained copper sulfate, silver sulfate, and ferrous sulfate. In an oxygen-poor environment, little ferric sulfate would be formed. Where ferric sulfate was formed by reduction of silver sulfate to silver, hydrolysis would yield an acid solution, which on contact with the carbonate wall rock should yield ferric hydroxide, gypsum or epsomite, and carbon dioxide. Limonite, gypsum, and epsomite have all been found in areas of such supergene alteration. Similar occurrences have been described by Bastin (2, p. 96-97). Most of the equations for these reactions have been given by Emmons (6).

SUMMARY AND CONCLUSIONS

The ore deposits of the Palomas district are examples of low-temperature lead-zinc-silver mineralization in Paleozoic limestones and dolomitic limestones. The main hypogene sulfides are galena, sphalerite, chalcopyrite, and argentite, with some pyrite, tetrahedrite, and polybasite. The gangue includes calcite, quartz, talc, and montmorillonite. An unusual feature of this deposit is the predominance of talc in the gangue and well-rock alteration. The,talc is thought to have been formed by the action of siliceous solutions on the &AOmitic wall-rock. Supergene action in the district has yielded a typical suite of oxidation products of lead, copper, iron, zinc, and silver sulfides, including limonite, cerussite, smithsonite, copper carbonates, silver halides, and also such minerals as vanadinite, descloizite, mimetite, pyromorphite, and wulfenite. Small scale sulfide enrichment is evidenced by the presence of covellite and chalcocite. The mineralization was probably introduced by hydrothermal

solutions of alkaline nature, as evidenced by the presence of talc and mont-morillonite in the gangue. The mineralization is late Tertiary in age. The source of the hydrothermal solutions is in doubt, but may have been associated with the source of volcanic activity in the area.

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