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SILICATE MINERAL ASSEMBLAGES AND THEIR RELATIONSHIP TO SULFIDE MINERALIZATION, PINOS ALTOS MINERAL DEPOSIT, NEW MEXICO

by

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Abstract

The Exxon Company, U.S.A. Pinos Altos skarn-associated mineral deposit is favorably situated in southwestern New Mexico near the Central and Tyrone mining districts and lies in a broad structural uplift that contains a complex sequence of Laramide intrusions. The mineral deposits of the Pinos Altos district are within and around the Pinos Altos quartz monzonite stock, which is emplaced into a thick section of Paleozoic strata and Cretaceous sedimentary and volcanic rocks.

Historic production in the district came from numerous northeast-trending metalized fissure veins and from limestone replacement bodies west of the stock. Metal zoning is exhibited in these veins and replacements, with copper predominant over zinc, lead, and silver in the northern part of the district. Moreover, the intensity of calc-silicate alteration in the replacements increases northward. Thus mineral and alteration zoning suggested that copper-rich skarn mineralization might be found in reactive Paleozoic strata at depth adjacent to the north end of the Pinos Altos stock.

Drilling adjacent to the north end of the Pinos Altos stock has intercepted copper-zinc-silver sulfide mineralization in calc-silicated Paleozoic strata. Chalcopyrite, sphalerite, pyrite, magnetite, specular hematite, and a variety of silver sulfides and sulfosalts are interstitial to the calc-silicates. Sulfide and iron oxide minerals are zoned with respect to the stock—wall-rock contact. Magnetite-chalcopyrite occurs close to the stock and gives way outwards to chalcopyrite-sphalerite and then to pyrite-sphalerite.

Most of the mineralization occurs in three principal zones in the impure limestones of the Pennsylvanian Magdalena Group. Three alteration stages are discernible. The first is an essentially isochemical thermal metamorphic stage. The second is a metasomatic episode in which iron, silica, sulfur, and base metals were added to the wall rocks forming a massive garnet-quartz-calcite skarn with minor amounts of iron oxides and base-metal sulfides. Major sulfide deposition began late in this metasomatic stage and continued into the subsequent retrograde alteration stage—the third alteration event. This retrograde or silicate-destructive phase probably took place in the presence of a hydrous fluid as temperature decreased.

Introduction

The Exxon Company, U.S.A., mineral prospect at Pinos Altos, New Mexico, was a direct outgrowth of a study of old mining districts, which was undertaken in 1971 to establish exploration priorities among the various New Mexico mining areas. The study consisted of a survey of available literature and Exxon reports to determine mineral and structural trends and district habits that might help locate as yet undiscovered ore deposits. Pinos Altos ranked high in this survey.

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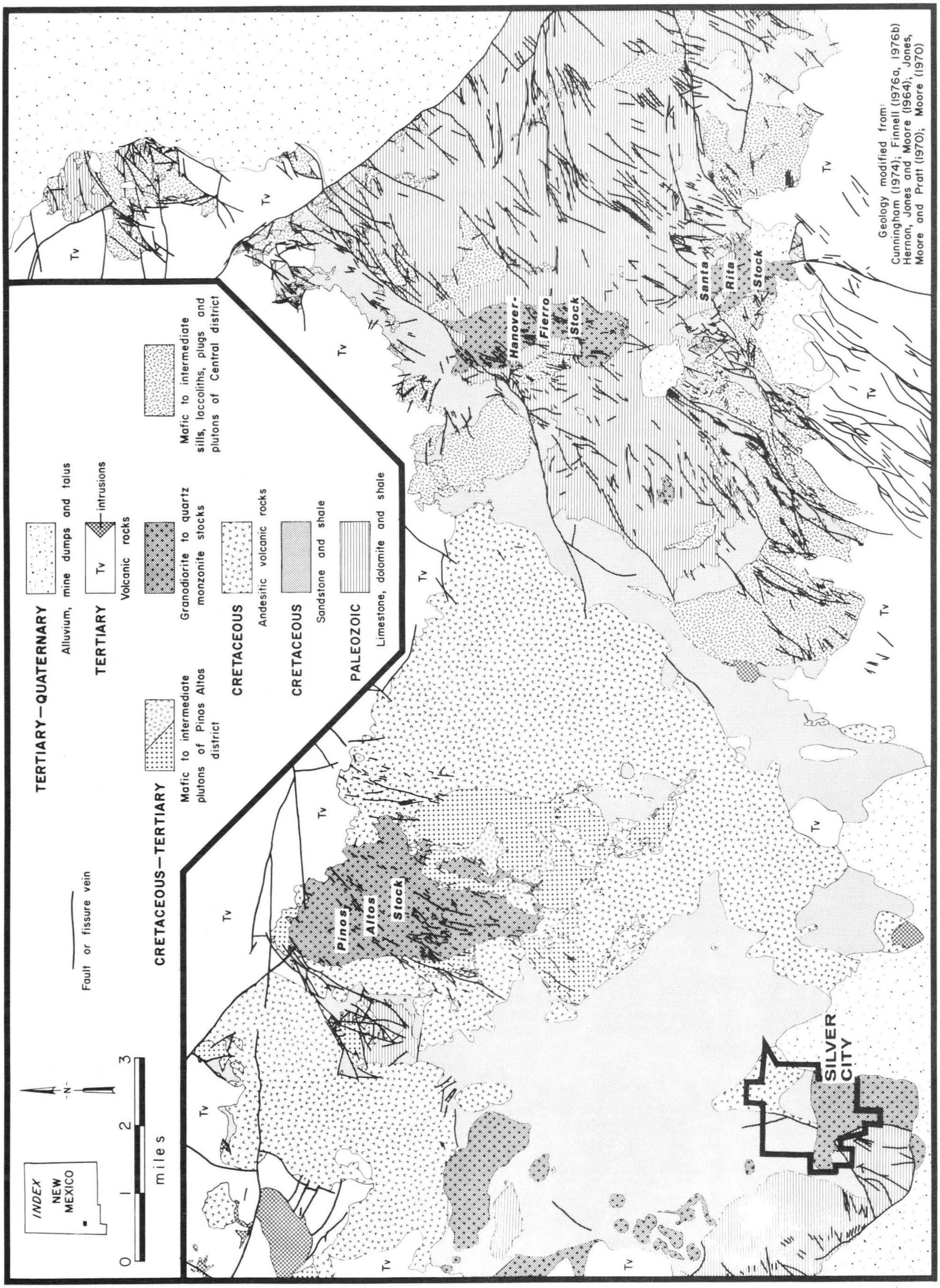

Geology modified from: Cunningham (1974); Finnell (1976a, 1976b) Hernon, Jones and Moore (1964); Jones, Moore and Pratt (1970); Moore (1970)

Fig. 1. Generalized geologic map of the Silver City mining region

Geologic Setting and Exploration History

The Pinos Altos prospect is located about eight miles north of Silver City, New Mexico (Fig. 1). The district is favorably situated in a metallized region, including the Central mining district 10 miles to the east and the Tyrone district 18 miles to the southwest. The area covered in Figure 1 is termed the Silver City mining region following the usage of Jones, Case, and Pratt (1964). The region is a broad structural uplift that contains a complex sequence of differentiated Laramide igneous rocks. The diversity of rock types is evident in mapping by Hernon, Jones, and Moore (1964) and by Jones, Moore, and Pratt (1970), who show seventeen different Laramide intrusive rock types in the area. Several medium-grained, multiple-phase granodiorite to quartz monzonite porphyry stocks occur in this region, most of which have associated base and precious metal mineralization. The stocks at Santa Rita, Hanover-Fierro, and Pinos Altos are perhaps the more well known of these metallized intrusions.

Late Cretaceous andesitic volcanic rocks similar to those commonly associated with southwestern porphyry copper deposits cover a large part of the area, particularly around the Pinos Altos district. The volcanic rocks overlie unconformably either Upper Cretaceous clastic rocks of the Beartooth Quartzite or Colorado Formation or Paleozoic carbonate strata. These sedimentary and volcanic rocks (Table 1) are the hosts for many of the Laramide intrusions and much of the mineralization in the region.

The Pinos Altos intrusive complex consists of a variety of mafic to intermediate intrusions peripheral to the Pinos Altos stock, a later multiple-phase mass of quartz monzonite (Fig. 2). Rocks of the complex are fresh to moderately chloritized and contain at most only a few tenths of a percent pyrite. McDowell (1971) reported potassium-argon dates of 72.6 + 2.2 m.y. and 69.1 ± 2.1 m.y. on hornblende collected near the center of the Pinos Altos stock. These values are in close agreement with a less precise potassium-argon value of 68 ± 8 m.y. that Exxon obtained through Dr. J. A. S. Adams of Rice University.

Northwesterly and northeasterly trending faults display a braided structural fabric characteristic of metallized porphyry districts. This fault pattern coupled with northeasterly trending dikes and fissure veins indicates pronounced northwest-southeast extension. Numerous northeasterly trending metallized fissure veins are exposed in the Pinos Altos stock and in the Cretaceous wall rocks (Fig. 2), and

Table 1. Generalized premineral stratigraphic section in the Silver City mining region

AGE	FORMATION		DOMINANT LITHOLOGY	APPROXIMATE THICKNESS (FT.)	CHARACTER AS HOST FOR MINERALIZATION
Cretaceous	Andesitic volcanic rocks		Flows, breccia and tuff	300-1000	Poor
Cretaceous	Colorado Formation		Sandstones and shale	300-2200	Poor
	Beartooth Quartzite		Orthoquartzite sandstone, some conglomerate	60-140	Poor; calcareous beds permissive
Permian	Abo Formation		Red shale, partly calcareous	0-265	Fair to excellent for deposits in thermal metamorphic skarn
Pennsylvanian	Magdalena Group	Syrena Formation	Argillaceous silty limestone, calcareous siltstone, shale	0-390	Good to excellent for deposits in thermal metamorphic skarn
		Oswaldo Formation	Limestone, calcareous siltstone, shale	450-490	Excellent for metasomatic replacements
Mississippian	Lake Valley Limestone		Limestone, partly cherty and argillaceous	300-480	Excellent for metasomatic replacements
Devonian	Percha Shale		Shale, upper member calcareous	350-430	Poor
Silurian	Fusselman Dolomite		Dolomite	200-300	Poor; permissive for small metasomatic replacements
Ordovician	Montoya Dolomite		Dolomite and limestone with chert	200-350	Poor; permissive for small metasomatic replacements
	El Paso Limestone		Silty dolomite and limestone	520	Fair for metasomatic replacements; good for deposits in thermal metamorphic skarn
Cambrian-Ordovician	Bliss Formation		Sandstone and shale	190	Poor
Precambrian			Granite		Poor

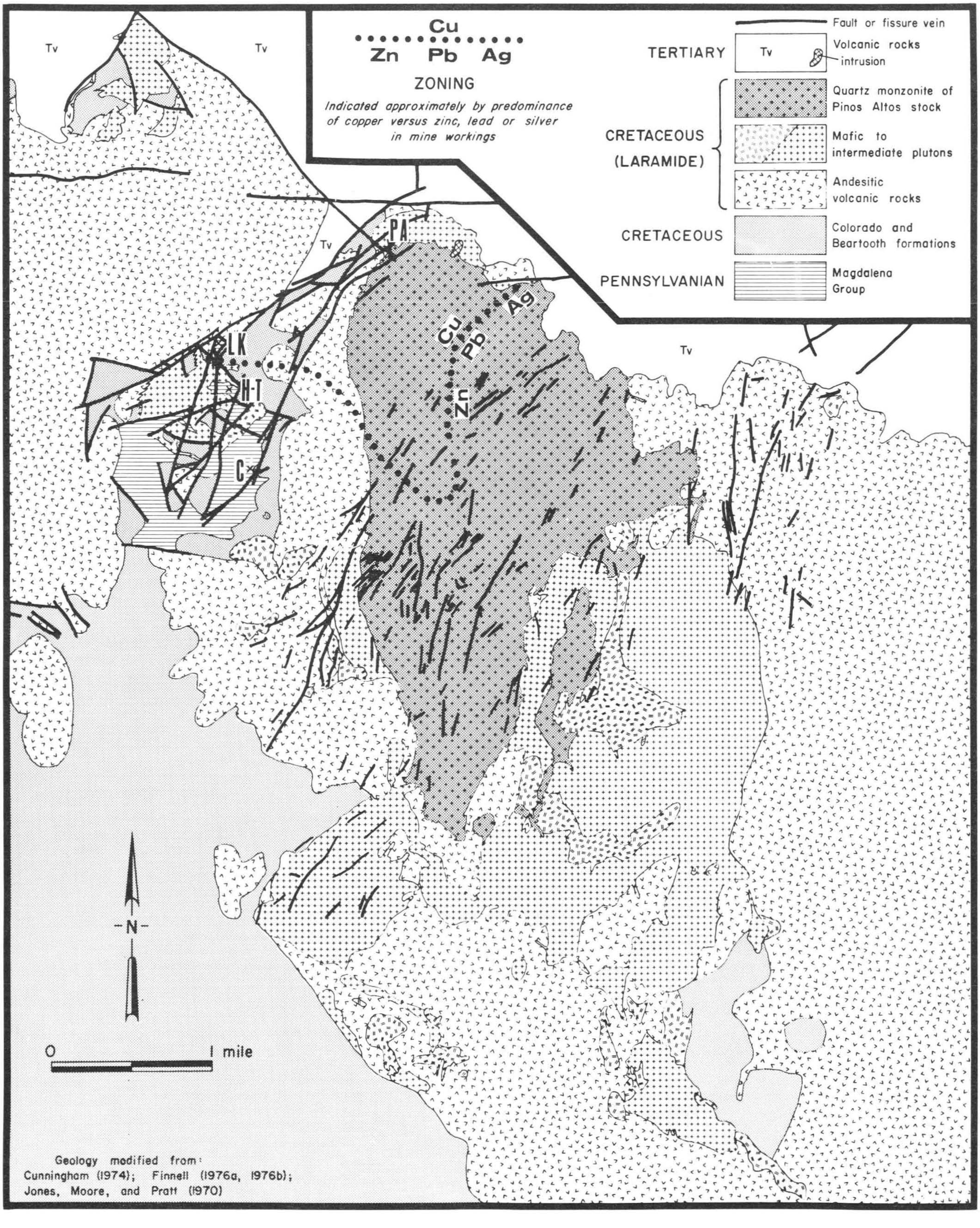

Fig. 2. Geologic map of Pinos Altos district. Abbreviations west of Pinos Altos stock refer to localities discussed in text: C, Cleveland mine; H-T, Houston-Thomas mine; LK, Lady Katherine prospect; PA, Pinos Altos prospect.

many mine workings exploited these veins. Visible mineralization on the dumps of these workings include both hypogene and supergene sulfides and oxides of copper, zinc, silver, and lead. Many of the veins in the Pinos Altos district have produced significant amounts of gold. Quartz-pyrite is the common gangue in the veins which characteristically have sericitic selvages. Zoning is indicated by abundant copper mineralization at the north end of the stock and by a strong partial halo of zinc-lead-silver across the middle and south end of the intrusive complex (Fig. 2). Sparse molybdenite occurs in some northeasterly trending quartz veins in the north-central part of the stock.

Most of the historic production in the district came from replacement and skarn deposits in Pennsylvanian Magdalena Group limestone exposed west of the Pinos Altos stock. The greatest production came from the Cleveland mine (C on Fig. 2), which produced zinc and lead from replacement deposits; judging from rock on the dump, the host is weakly chloritized marble from the Magdalena Group. Lesser production came from the Houston-Thomas mine (H-T) area to the north, but these workings produced some copper as well as lead and zinc. The Magdalena limestone in the Houston-Thomas workings contains actinolite as well as abundant chlorite. The northernmost block of limestone west of the stock occurs at the Lady Katherine prospect (LK), where chalcopyrite and minor sphalerite occur with pyrite along fissure veins in the Magdalena. Here, the Magdalena is altered to a relatively high temperature skarn assemblage of garnet, diopside, actinolite and calcite.

Thus, observations at the old workings indicate metal and alteration zoning about a source to the north where the permissive Paleozoic carbonate strata are covered by Cretaceous clastic rocks and andesitic volcanic rocks. In this area, hematitic goethite occurs along fractures in an upthrown block of the Colorado Formation. The sandstone is nonreactive and therefore not obviously altered, but vuggy quartz thinly coats sparse fractures. In addition, small adits, shafts, and prospect pits occur along fissure veins, which contain feeble to modest copper mineralization.

Cretaceous andesites in this area are weakly propylitized but are not obviously more altered than andesites elsewhere along the periphery of the stock. Thermal metamorphism has converted the andesite to a hornfels in the vicinity of the Pinos Altos stock.

General Geology of the Mineral Deposit

The geology and zoning suggested that skarn-associated sulfide mineralization might exist in Paleozoic carbonate strata adjacent to the north end of the Pinos Altos quartz monzonite stock; the permissive strata are covered by Cretaceous clastic sediments, Cretaceous andesites, and postmineral mid-Tertiary sediments and volcanic rocks (Fig. 2). Exxon's drilling program to test this target began in 1973 and delimited copper-zinc-silver sulfide mineralization in calc-silicated Paleozoic carbonate strata. Most mineralization occurs in the Pennsylvanian Magdalena Group, but some mineralization also occurs in the Mississippian Lake Valley Limestone and in the lower Paleozoic formations. (Table 1). The Paleozoic strata are essentially flat-lying and separated from the overlying Cretaceous clastic sedimentary rock by a disconformity. In the mineralized area the top of the Paleozoic section ranges from 350 to 1,700 feet beneath the surface.

Mineralization on the west side of the stock occurs in specific zones in the Syrena and Oswaldo Formations which comprise the Magdalena Group. The most extensive, the "upper" mineralized zone, is directly beneath the Cretaceous Beartooth Quartzite (the Permian Abo Formation being locally absent beneath the unconformity at the base of the Beartooth). A second mineralized zone, the "lower" zone, occurs at the contact of the carbonate wall rocks with the Pinos Altos stock. Several mineralized intervals between the upper and lower zones probably follow favorable lithologies in the Magdalena.

Stratigraphy and Skarn Facies

The Syrena Formation is predominantly argillaceous-silty limestone and calcareous siltstone, but it also contains abundant interbedded siltstone and shale; pure carbonate units are uncommon. The lithologic character of the Oswaldo Formation resembles that of the Syrena, but the Oswaldo contains less argillaceous material, more carbonate and more clean limestone units. Thus, the overall calcium carbonate content of the Magdalena Group increases downward. Both the Syrena and Oswaldo characteristically vary in lithology over short lateral and vertical distances.

The Paleozoic strata are subdivided into five basic types of host rock, each of which alters to a distinctive suite of metamorphic and metasomatic minerals (Fig. 3). Most of the mineralization found to date occurs in the argillaceous-silty limestone and calcareous siltstones.

Alteration and mineralization was a continuous process which can be described as occurring in three more or less well-defined stages.

HOST	METAMORPHIC	METASOMATIC	RETROGRADE
LIMESTONE Pure Cherty	MARBLE recrystallized Calcite Wollastonite	Andradite Quartz Calcite	Chlorite Calcite Quartz
ARGILLACEOUS SILTY LIMESTONE and CALCAREOUS SILTSTONE	SKARN OR MARBLE Calcite → Wollastonite Idocrase Grossularite Diopside Talc Tremolite Clinozoisite Pyrite / Pyrrhotite	Magnetite Pyrite Specularite Diopside Wollastonite Hedenbergite Sericite K feldspar Epidote	Clay Actinolite Talc Sericite Epidote Siderite – Ankerite Zeolites Gypsum Pyrite
SILTSTONE	HORNFELS Chlorite → Diopside	Siderite – Ankerite Scapolite	Sphalerite Chalcopyrite
MUDSTONE and SHALE	HORNFELS Chlorite → Biotite → K feldspar Albite Garnet	Chalcopyrite Sphalerite Pyrrhotite Molybdenite	Galena Hematite Magnetite
DOLOMITE Pure Siliceous	MARBLE recrystallized Dolomite Talc → Tremolite → Diopside	Talc Diopside	Talc

Fig. 3. Generalized skarn facies associated with five basic Paleozoic rock types at Pinos Altos. Common minerals are listed in larger type than uncommon minerals. Arrows indicate a temperature-related reaction series between minerals.

The first stage was essentially isochemical or nonadditive thermal metamorphism. A metasomatic stage followed in which abundant quantities of iron, silica, sulfur, and base metals were added to the wall rocks, presumably from the intrusion. Metasomatic replacement, although clearly favoring carbonate sections, was superimposed on nearly all host types except the shales and dolomites. Thermal metamorphism and silica-iron metasomatism are interpreted to have taken place under conditions of rising temperature and are therefore termed prograding events. The third, or retrograde, stage probably took place as temperature waned in the presence of a fluid rich in water. Alteration of previously formed skarn minerals characterized this stage. Deposition of sulfides and iron oxides began during metasomatism and continued into the retrograde stage.

Thermal Metamorphism—Metamorphic Skarn

Of the three alteration events, the thermal metamorphic episode produced the most varied mineral assemblages (Fig. 3), as a consequence of the compositional variety of original host rock types. In pure limestone and dolomite, for example, thermal metamorphism resulted in the simple recrystallization of the component carbonate. Where silica was available, wollastonite developed in limestone. Metamorphism of argillaceous and silty limestones along with calcareous siltstones produced a variety of minerals including wollastonite, idocrase, grossularite, and diopside. Several other minerals (Fig. 3) are present though not abundant. These metamorphic minerals tend to form selectively in the argillaceous and silty fraction of the rock, where it is in contact with calcite, thus preserving primary sedimentary textures.

Siltstones are converted to two hornfels assemblages: quartz-chlorite formed at relatively low temperatures, and quartz-diopside formed at higher temperatures. Mudstones and shales are metamorphosed to biotite hornfels adjacent to the stock and to chlorite hornfels farther from the stock. The biotite hornfels locally contains sparse amounts of orthoclase and garnet.

Metasomatic Skarn

Metasomatic skarns are superimposed upon and locally obliterate thermal metamorphic skarns. The metasomatic skarns contain relatively few minerals. Andradite, quartz, and calcite comprise the bulk of the rock (Fig. 3) and characterize an assemblage here designated as "garnet skarn." Magnetite, pyrite, specularite, diopside, and base-metal sulfides commonly occur in small amounts. Sparse, minor constituents of the metasomatic skarns include hedenbergite and an iron-bearing wollastonite. Metasomatic garnet skarns generally replace beds en masse but favor pure limestone beds, traveling farther from the intrusion in these more susceptible units (Fig. 4). As a consequence of this selective replacement process, an erratic marble line is developed. Magnetite and hematite are distributed throughout the garnet skarn but generally die out toward the metasomatic front separating the skarn and the unsilicated wall rocks. Sulfides likewise occur sporadically throughout the garnet skarn, and some sphalerite actually occurs in marbles outside of the skarn.

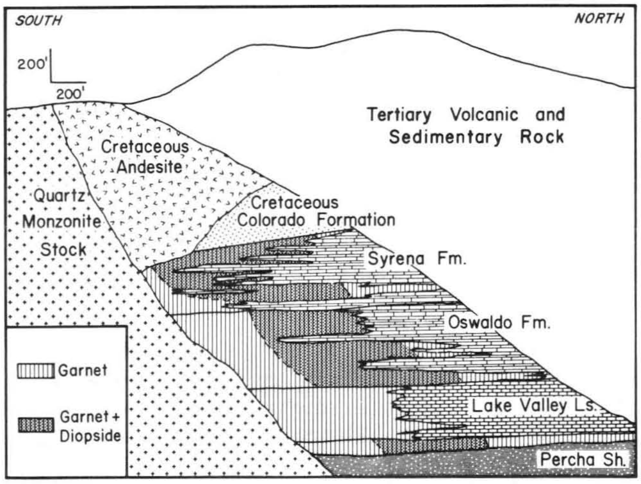

Fig. 4. Schematic section across the north side of the Pinos Altos stock showing the distribution of skarn types.

Diopside in the garnet skarns is relict from prograde thermal metamorphism inasmuch as it occurs only in magnesium-bearing strata of the Magdalena Group and in the Box or upper member of the Percha shale. Diopside is absent in the massive garnet skarns formed from the clean Lake Valley Limestone.

Thus, compositional changes from bed to bed control the degree to which the various strata are affected by thermal metamorphism or metasomatism. The impure carbonates of the Syrena form diopside-bearing metamorphic skarns upon which metasomatic garnet skarns are superimposed. The Oswaldo Formation, with a higher proportion of limestone, forms a massive garnet skarn containing less diopside, and skarns formed in the Lake Valley Limestone are entirely metasomatic garnet skarns (Fig. 4).

Alteration of the lower Paleozoic strata is poorly known. A few holes have penetrated the Ready Pay or lower member of the Percha Shale which is baked to a chlorite-biotite hornfels but is not affected by metasomatism. Talc and diopside, intercepted in Ordovician dolomites near the stock contact, probably developed through additions of silica and water, rather than from isochemical thermal metamorphism.

Retrograde Alteration

Retrograde alteration affected the metasomatic and to a lesser extent, the metamorphic skarns. The minerals produced during this stage are characteristically the hydrous phases—chlorite, clay, actinolite, talc, and sericite (Fig. 3). Calcite, quartz, iron oxides and sulfides also occur in this assemblage. A variety of other minerals is also present, but their distribution is sparse and sporadic.

Mineral assemblages characterized as retrograde either replace earlier formed metamorphic and metasomatic minerals or occur interstitially to metasomatic skarn minerals. Retrograde alteration affects prograde skarns to varying degrees from slight alteration of the edges to complete replacement of the silicate grains.

Sulfide Distribution and Paragenesis

Copper-zinc-silver-iron sulfides and iron oxides are interstitial to the calc-silicates, and the sulfides may or may not be found with associated retrograde alteration minerals. For example, the upper zone contains extensive retrograde alteration products associated with mineralization, whereas in the lower zone, sulfides and iron oxides occur in generally unaltered prograde metasomatic skarn. Mineralization typically occurs with retrograde alteration in pervasive stockwork fractures.

Sulfide and iron oxide minerals in the upper zone are apparently zoned with respect to the stock–wall rock contact. Figure 5 illustrates the typical mineral zoning and paragenesis observed. Magnetite was deposited early; it is abundant near the stock but diminishes abruptly outward. With time and with increasing distance from the stock, chalcopyrite and pyrite become the major iron-bearing phases reaching successive peaks and then declining. Later sphalerite and galena are the predominant sulfide minerals in the distal parts of the mineralized zones. The volume of sulfides increases outward, reaching a maximum in the pyrite-chalcopyrite-sphalerite zone, and then decreasing.

Mineral distribution in the lower mineral zone differs in several respects from that in the upper zone. The lower zone generally contains smaller bodies of higher grade chalcopyrite mineralization. In addition, detectable chalcopyrite is present over a much broader area in the lower zone. Furthermore, magnetite is more abundant in the lower zone, whereas pyrite is less abundant in the lower zone than in the upper zone.

The paragenetic sequence (Fig. 6) is essentially the same in all zones. Prograde calc-silicate formation was followed by iron oxides and a wide variety of copper, zinc, silver, lead, and bismuth sulfides. Although much of the sulfide deposition accompanied the silicate-destructive retrograde event, significant mineralization does occur without obvious retrograde effects on associated silicates.

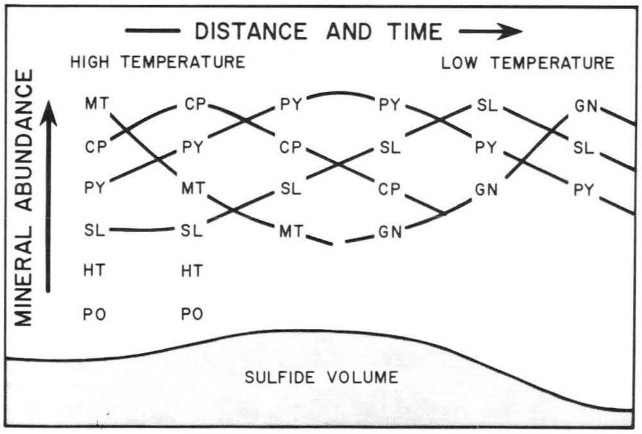

Fig. 5. Schematic sulfide-oxide zoning sequence at Pinos Altos as a function of time and distance from the Pinos Altos stock

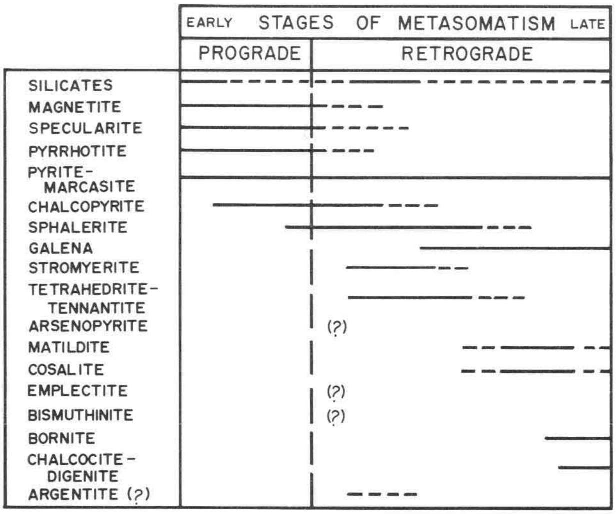

Fig. 6. Generalized paragenetic sequence for ore zones at Pinos Altos. The minerals arsenopyrite, emplectite, and bismuthinite have been definitely identified, but their position in the paragenetic sequence is uncertain. A mineral tentatively identified as argentite occurs early in the paragentic sequence. (Mineral identifications by A. L. Kidwell, Exxon Production Research Co.)

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