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Geology Of Copper-Lead-Zinc-Turquoise Deposits, Southern Part Of The Cerrillos Mining District, Santa Fe County, New Mexico

William G. Gustafson

GEOLOGY OF COPPER-LEAD-ZINC-TURQUOIS DEPOSITS, SOUTHERN PART OF THE CERRILLOS MINING DISTRICT, SANTA FE COUNTY, NEW MEXICO

By

William G. Gustafson

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ABSTRACT

The southern part of the Cerrillos mining district is underlain by a sequence of igneous rocks which have been altered and mineralized. The rocks are intrusive equivalents of the Oligocene (?) Espinaso Volcanics. Four stages of intrusion are recognized. A hornblende monzonite porphyry stock was emplaced during stage T_1. Several small hornblende-augite monzonite stocks intruded stage T_1 rocks during stages T_2 and T_3. During stage T_4, stocks of augite-biotite monzonite, hornblende-biotite monzonite porphyry, and andesine-augite-biotite monzonite porphyry were intruded into the older igneous rocks. The stage T_1, T_2, and T_3 stocks are flanked by sills and laccoliths.

Three sets of near-vertical fractures are the major structural features. The trends strike northeasterly, north, and northwesterly.

Mining operations in the area probably date from A.D. 950, when Indians quarried Mount Chalchihuitl for turquois. Later, but prior to 1680, the Spanish extracted silver from the Mina del Tiro. More recently there was mining of both turquois and sulfides. The main period of activity was from the 1880's to about 1900. Since then only sporadic attempts at mining have been made. Since 1909 the district has produced about $420,000 worth of gold, silver, copper, lead, and zinc.

Vein deposits occur in several of the fractures trending northeasterly. Galena and sphalerite are the major ore minerals.

There is also one known disseminated mineral deposit in the area. It consists of chalcopyrite veinlets in fractured stage T_1 monzonite porphyry. Malachite, azurite, and "copper pitch" replace chalcopyrite near the surface.

Alteration takes the form of propylitization, argillization, and supergene copper mineralization. Propylitization affects only rocks older than stage T_4 and is therefore presumed to be the result of pervasive, but relatively weak, hydrothermal activity. Argillization has converted rocks to quartz, kaolinite, and other clays. However, the areas affected are widespread but individually not very large. Argillized areas have both hypogene and supergene mineralization associated with them, and their exact origin is in doubt.

Turquois is the most prominent supergene mineral. It occurs, at shallow depths, in nearly all argillized areas. Fractures of all three major structural trends are very evident in turquois deposits, and the turquois usually forms thin, discontinuous veinlets in these and other cracks.

INTRODUCTION

Purpose, Scope and Methods

The following is a description of hypogene mineralization, wallrock alteration, and supergene mineralization in the vicinity of the turquois deposits of Mount Chalchihuitl, a small hill in the southern part of the Cerrillos mining district, Santa Fe County, New Mexico. Altered areas, galena-sphalerite veins, and fractures within one mile of Mount Chalchihuitl were mapped on 1:17,000 aerial photographs and transferred to a 1:24,000 geologic map (Fig. 4). Several days were spent checking Disbrow's map (1957, plate 1), and a few changes were made, particularly the addition of a small stock in sec. 8, T. 14 N., R. 8 E. Ore minerals were collected on mine dumps because most underground workings were not accessible.

About 30 days during the last six months of 1962 were spent mapping and collecting samples. Laboratory studies were started in October, 1962, and completed in March, 1963. Analysis of vein mineralization was aided by polished sections. Examination of alteration and disseminated mineralization required the use of thin sections, grain mounts, X-ray diffraction, and differential thermal analysis.

Location and Accessibility

Access to Mount Chalchihuitl is by a poorly maintained mine road originating in the village of Cerrillos, 2.5 miles to the south. Cerrillos is on the main line of the Santa Fe Railroad and on State Highway 10, a paved road. Albuquerque is 45 miles to the south, and Santa Fe is 15 miles to the northeast (Fig. 4).

Geography

The Cerrillos ("little hills") are a cluster of hills covering about 10 square miles. Relief is up to 1,000 feet. The climate is semi-arid. Vegetation consists of cactus, desert grass, and sparsely distributed pinon and juniper. Intermittent drainage is generally radial from the center of the group of hills.

Previous Studies

The long history of mining in the Cerrillos caused a number of the earlier papers on the area. Reports by Blake (1858), Silliman (1881), and Clarke and Diller (1887) dealt with occurrences of turquois. Jones (1904, p. 29-33) and Lindgren (Lindgren, Graton, and Gordon, 1910) reported on mining activity. Johnson (1904) dealt with the geology in a comprehensive manner.

W. C. Stoll mapped and described the mines in 1945, and A. E. Disbrow mapped and described the general geology of the

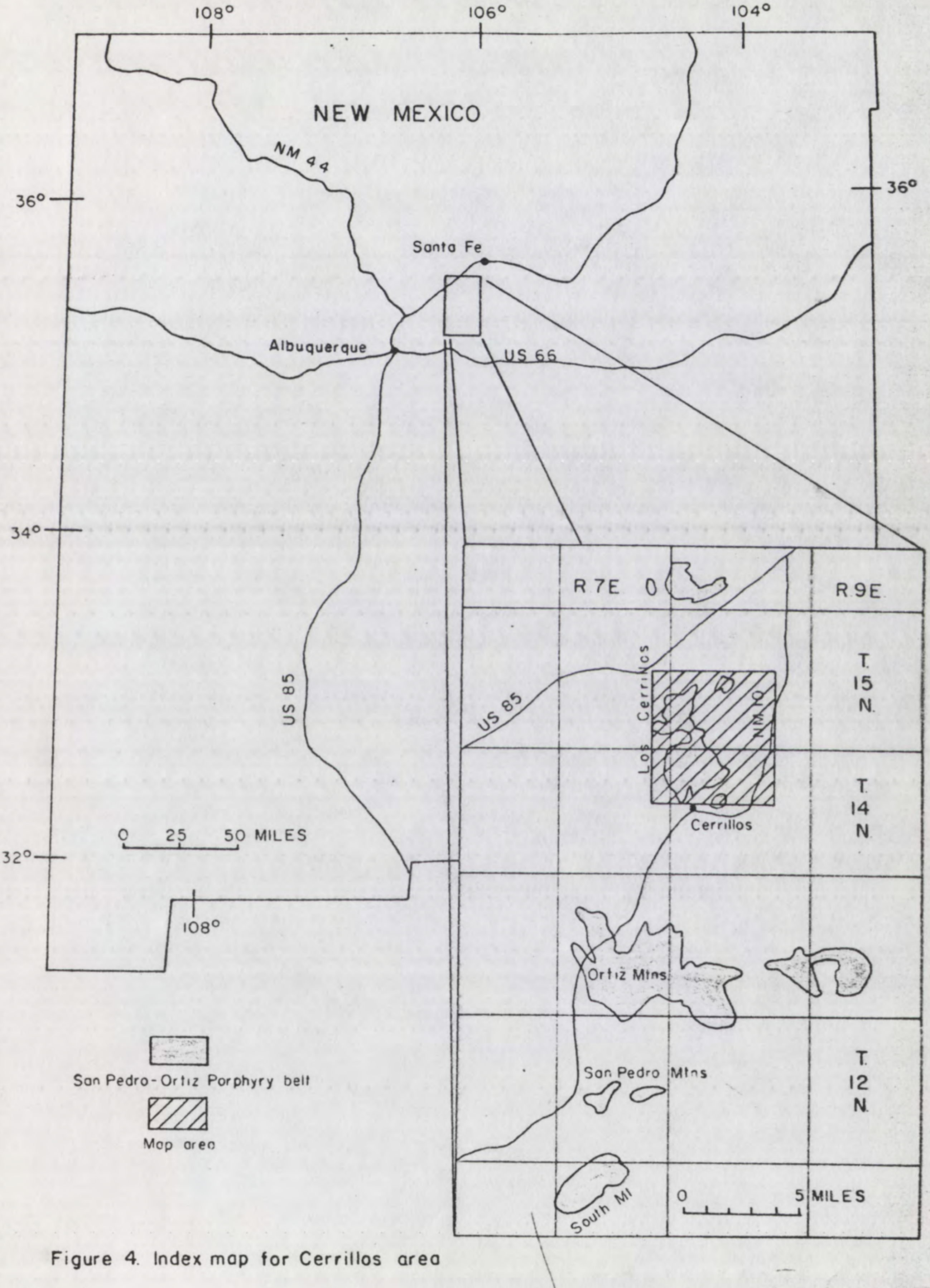

Figure 4. Index map for Cerrillos area

area in 1953. These efforts were published as a single report (Disbrow and Stoll, 1957).

Acknowledgments

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GENERAL GEOLOGY

Regional Setting

Stratigraphy

Monzonite stocks and laccoliths forming the core of the Cerrillos have intruded sedimentary rocks ranging in age from Pennsylvanian to Eocene. The aggregate thickness of this section is about 10,000 feet, and the upper 4,000 feet, all Cretaceous and Tertiary, crop out on the flanks of the Cerrillos.

Associated with the stocks are the Espinaso Volcanics, probably of Oligocene age (Disbrow and Stoll, 1957, p. 24). They consist of latite tuffs, tuff-breccias, and flows overlying and flanking the intrusive rocks.

Rocks younger than the Espinaso Volcanics crop out east and north of the Cerrillos. They consist of 200-700 feet of mafic flows, a few small dikes and plugs, and about 1,200 feet of continental clastic rocks of the Santa Fe Group. Table 1 is a summary of stratigraphy in the Cerrillos area.

Regional Structure

The Cerrillos are the northernmost igneous complex in the Ortiz porphyry belt, a north-trending group of monzonite stocks, sills, and laccoliths forming a belt 20 miles long. The porphyry belt is bounded on the west by the Rio Grande depression and on the east by the Estancia basin.

Intrusions in the Cerrillos domed the overlying sediments. Sedimentary rocks flanking the core of the Cerrillos often have steep dips away from the center of the hills. Most of the laccoliths were emplaced in Mancos Shale. Younger igneous rocks intruded older stocks and laccoliths so that the Cerrillos as a whole consist of multiple intrusions of four distinct stages.

Mount Chalchihuitl Area

Intrusive Rocks

The structure and lithology of intrusive rocks forming the core of the Cerrillos are summarized in Table 2. Johnson (1904, p. 56) believed that the intrusives were laccolithic. Later work by Stearns (1953, p. 436) and Disbrow (Disbrow and Stoll, 1957, p. 34) indicated that major intrusives are stocks with tongue laccoliths, dikes, and sills radiating from them. The rocks were emplaced during four stages separated in time. The stages were numbered T_1 through T_4 by Disbrow and Stoll (1957, p. 34).

Intrusions in the southern part of the Cerrillos formed stocks, dikes, and pipes. A stage T_1 hornblende monzonite porphyry stock, which was intruded by younger rocks, is the largest body (Fig. 1). An irregular, elongate augite-biotite monzonite stock of stage T_4 crops out through the central part of the area and underlies Grand Central Mountain and Franklin

Hill. Two smaller stocks of stage T_4 were emplaced along the southern periphery of the augite-biotite monzonite stock. One, just south of Franklin Hill, is an andesine-augite-biotite monzonite porphyry with conspicuous andesine phenocrysts 3-10 mm long. A group of dikes of the same composition radiate south and southeast from the stock. The other stock, not mapped by Disbrow and Stoll, is in sec. 8, T. 14 N., R. 8 E. about midway between the Mina del Tiro and Grand Central mine (Fig. 1). It is a roughly circular body of hornblende-biotite monzonite porphyry. Microscopically the rock is distinctly porphyritic. An unaltered sample has the following composition:

	Percent	Grain Size (mm)
Phenocrysts		
Andesine (An_{30-40}), subhedral laths, sometimes zoned	40	2-4
Hornblende, subhedral, green grains	10	0.5-2
Orthoclase, subhedral grains	7-8	3-8
Biotite, anhedral, brown	5	0.5
Magnetite, anhedral, rounded grains	2-3	0.25-0.5
Groundmass		
Quartz, orthoclase, magnetite grains	35	0.01-0.02

A disseminated copper deposit has been found in rocks adjacent to the stock, but the stock proper is barren of hypogene mineralization.

Table 1

GENERALIZED STRATIGRAPHIC COLUMN FOR THE CERRILLOS AREA

AGE	STRATIGRAPHIC UNIT	THICKNESS (Feet)	LITHOLOGY
Recent	Alluvium	0-50	Soil, sand, gravel, and talus.
Recent (?)	Cuerbio Basalt	10-35	Basalt flows and pyroclastic rocks.
Pleistocene (?)	Santa Fe Group Ancha Fm.	0-350	Stream deposits of sand and gravel, tuff, and loess.
		Unconformity	
Miocene	Abiquiu Fm.	800+	Lacustrine, tuffaceous sandstone and clay with minor limestone.
	Cieneguilla Limburgite	200-700	Limburgite, intrusive, extrusive, and pyroclastic, with minor amounts of sand, clay, and limestone.
		Unconformity	
Oligocene (?)	Espinaso Volcanics	2000+	Latite flows, pyroclastic, and intrusive rocks.
		Unconformity	
Eocene	Galisteo Fm.	1,200-3,000	River channel, floodplain and lacustrine deposits of sandstone, conglomerate and variegated clay.
		Unconformity	

AGE	STRATIGRAPHIC UNIT	THICKNESS (Feet)	LITHOLOGY
Cretaceous	Mesaverde Fm.	0-765	Continental and marine sandstone, shale and coal.
	Mancos Shale	2,350	Drab to dark gray, marine siltstone with interbedded limestone and sandstone.
	Dakota Fm.	50-100	Continental and marine, white, quartzose, cross-bedded sandstone with minor amounts of shale.
		Unconformity	
Jurassic	Morrison Fm.	850	Floodplain deposits of quartzose sandstone and variegated mudstone and siltstone.
	Todilto Limestone	86	Gypsum and limestone.
	Entrada Sandstone	80	Sandstone.
		Unconformity	
Triassic	Chinle Fm.	600+	Red sandstone, shale, and limestone conglomerate.
		Unconformity	
Permian	San Andres Fm.	260	Limestone and sandstone.
	Yeso Fm.	400-500	Light red sandstone, siltstone, and shale, with minor amounts of limestone.

AGE	STRATIGRAPHIC UNIT	THICKNESS (Feet)	LITHOLOGY
	Abo Fm.	900+	Red sandstone, siltstone and shale.
Pennsylvanian	Madera Limestone	1200+	Limestone and shale, with minor amounts of sandstone.
	Sandia Fm.	200±	Sandstone, shale, conglomerate, with minor amounts of limestone.
		Unconformity	
Precambrian			Quartzite, gneiss, schist, and granite.

Table 2

SUMMARY OF LITHOLOGY AND STRUCTURE OF ESPINASO VOLCANICS AND ASSOCIATED INTRUSIVE ROCKS IN THE CERRILLOS
(After Disbrow and Stoll, 1957)

VOLCANIC ROCKS	INTRUSIVE ROCKS	MORPHOLOGY OF INTRUSIVE ROCKS
	Igneous stage T_1	
No extrusive rocks during this period.	Hornblende monzonite porphyry.	Large stock forms core of the Cerrillos. Associated dikes, laccoliths and sills commonly intrude Mancos shale. Surface not breached by igneous rocks. Intrusion formed a symmetrical domal uplift.
Unconformity		
	Igneous stage T_2	
Red hornblende-augite latite porphyry flows, tuff, and tuff-breccia. $300\pm$ feet.	Hornblende-augite monzonite porphyry.	Small intrusions into hornblende monzonite porphyry. Not readily distinguished from rocks of periods T_1 and T_3.
Unconformity		
	Igneous stage T_3	
Gray and pink hornblende-augite latite porphyry tuff, tuff-breccia, and flow breccia. 1,370+ feet.	Hornblende-augite monzonite porphyry.	Small intrusions into hornblende monzonite porphyry.

VOLCANIC ROCKS	INTRUSIVE ROCKS	MORPHOLOGY OF INTRUSIVE ROCKS
Contact covered		
	Igneous stage T_4	
Gray and red-brown augite-latite porphyry tuff, tuff-breccia, and volcanic conglomerate, thickness indeterminate.	Ti_4. Augite-biotite syenite or trachyte porphyry.	Mainly stocks; some sills, laccoliths and dikes. Larger intrusions are in or adjacent to older stocks. Deformation during emplacement less than for intrusive rocks of preceding periods.
	Ti_4a. Andesine-augite-biotite monzonite porphyry.	
	Ti_4b. Augite-biotite monzonite porphyry.	
	Ti_4c. Augite-biotite monzonite.	
	Ti_4d. Coarse grained hornblende-biotite monzonite porphyry.	

The circular body of rock at Mount Chalchihuitl is a stage T_4 brecciated volcanic vent (Fig. 2). Although the rocks are intensely argillized and silicified, the brecciated character has been preserved in most places. The rocks consist of subangular to subrounded fragments in a tuffaceous matrix. The textures of the fragments resemble textures of monzonites in the Cerrillos. Size limits for fragments are difficult to establish because of partial obliteration of boundaries by alteration. Included fragments seem to be of at least two, possibly three, rock types, distinguished by differences in size of feldspar phenocrysts. Some fragments have feldspar phenocrysts 2-5 mm long, other fragments have them .3-1.0 mm, still others show no signs of conspicuous phenocrysts. The volcanic breccia intrudes hornblende monzonite porphyry of stage T_1 and augite-biotite monzonite of stage T_4, suggesting that it is contemporaneous with or younger than stage T_4 eruptive rocks. Although the configuration of the vent at depth is unknown, a slanted hole drilled by Bear Creek Mining Company at Mount Chalchihuitl remained in volcanic breccia to a vertical depth of 141 feet (J. G. Wargo, 1963, personal communication).

Geologic Structure

Two nearly perpendicular fracture sets cut igneous rocks in the southern part of the Cerrillos. One strikes northeast, the other northwest. Both have near vertical dips. Individual fractures are seldom traceable for more than a few hundred feet. Slickensides, thin gouge zones, and fault breccias are common, but directions and amounts of displacement are unknown. Fractures of both trends serve as loci of alteration, but sulfide mineralization is largely confined to fractures trending northeast.

MINERAL DEPOSITS

History of Mining

Mining operations in the southern part of the Cerrillos preceded Spanish colonization of the area by several hundred years. Turquois deposits at Mount Chalchihuitl were probably exploited by Indians as early as A.D. 950 (Northrop, 1959, p. 350). The large open pit on the west side of Mount Chalchihuitl was probably developed first, because substantial amounts of rock could be quarried by digging away the hillside. Considering the primitive tools available, the amount of material removed from the pit is impressive. A reconstruction of the original surface at the quarry suggests that not less than 500,000 cubic feet or 30,000-50,000 tons of rock were quarried from the pit. The date at which operations at Mount Chalchihuitl ended is uncertain. Blake (1858, p. 229) reported that the pit had been long abandoned at the time of his visit, and Silliman (1881, p. 69) speculated that the Pueblo Revolt of 1680 was triggered by the deaths of Indians caught in a landslide at the pit. Although pottery and stone hammers were found in the pit (Silliman, 1881, p. 69; Johnson, 1904, p. 88), there are no reports of Spanish implements. It may well be that the bulk of quarrying operations were carried out prior to the Spanish occupation, or at least without Spanish supervision.

The Mina del Tiro (Tierra), a lead-zinc-silver mine in the southern part of the Cerrillos, is probably one of the oldest lode mines in the United States. Jones (1904, p. 30) thought it antedated the Ortiz and Santa Rita operations by at least a century; the work was probably performed for Jesuits prior to 1680. Workings now buried were still open at the time of his visit. Entry was by a 150-foot incline connected to a 100-foot vertical shaft, and 300 feet of drifts connected a series of chambers and stopes.

A flurry of activity in the Cerrillos was touched off by the rediscovery of sulfide mineralization in 1879. Two towns, Carbonateville and Bonanza City, were staked out in the 1880's; and in 1902 a two-stack smelter for copper and lead was constructed at Cerrillos (Jones, 1904, p. 29-31). The smelter never operated steadily, partly because of difficulties in treating lead-zinc ores from the district (Jones, 1904, p. 31), and partly because of limited production from the mines. Johnson (1904, p. 92) reported that by 1902 Carbonateville and Bonanza City were in ruins, and mining operations were limited to summer prospecting and small operations. Some ore was coming from the Grand Central and Cash Entry mines.

At about the same time there was also renewed interest in turquois. As early as 1881, Silliman (1881, p. 67) reported efforts by D. C. Hyde to reopen Mount Chalchihuitl. However, most of the turquois produced around the turn of the century was probably from Turquois Hill, about three miles north of Mount Chalchihuitl (Kunz, 1901, p. 767).

Although a wide range of figures have been quoted for the value of turquois produced from 1890-1900, it seems likely that the $2,000,000 cited by Kunz (1901, p. 767) is nearer the true value for uncut turquois than are the larger estimates. Otero (1899, p. 159) reported $1,550,000 as the official figure for turquois production for the years 1891-1896.

Production of turquois was drastically reduced after 1900. Sterrett (1912, p. 1070) reported that by 1911 operations at the "Tiffany" mine at Turquois Hill had been suspended for several years. Most of the production in the early 1900's probably came from Michael O'Neil's mine three-quarters of a mile southeast of Mount Chalchihuitl (Sterrett, 1912, p. 1069).

Intermittent lode mining has continued in the Cerrillos over the past half century, but none of the mines in the southern part of the Cerrillos have a record of more than two years continuous production. The total value of gold, silver, copper, lead, and zinc production for the period 1909 to 1957 is $422,743 (Elston, 1961, p. 45-46). Only a fraction of this was produced in the southern part of the Cerrillos. The latest effort to exploit the southern part of the Cerrillos was an exploration program by Bear Creek Mining Company in 1959 (Wargo, 1963, p. 296). Their target was a disseminated copper deposit; but since the company has made no effort to exploit their holdings, it would appear that the deposit was not economically attractive.

Veins

Mina del Tiro

The Mina del Tiro is in the NW 1/4, sec. 8, T. 14 N., R. 8 E. It is about one mile southwest of the Grand Central mine and is the southernmost mine in the Cerrillos with a recorded history of production.

The vein is in a sheeted zone in hornblende monzonite porphyry of stage T_1. It strikes N. 45° E., dips 70°-80° NW, and is exposed in prospects and discontinuous outcrops for a distance of about 1,500 feet. Linked veinlets of quartz and limonite in a zone 4-8 feet wide comprise the vein at the surface. The sheeted zone and a few feet of wallrock on either side are argillized and silicified. The argillized rock grades into propylitized hornblende monzonite porphyry. There is no change in the character of the propylitization as the vein is approached.

The ore shoot mined from the Mina del Tiro has been described by Disbrow and Stoll (1957, p. 62-63). At the 90-foot level it is exposed for 55 feet along the strike. Here the vein is a lens of vuggy quartz, up to 5 feet wide, containing streaks, veinlets, and disseminations of sulfides. The vein is on the footwall of a breccia zone 5-6 feet thick and consisting of barren wallrock.

The following minerals have been identified from samples taken from the Mina del Tiro dump:

Hypogene minerals:

Barite . . . . $BaSO_4$

Bornite. . . . . . . Cu_5FeS_4

Chalcopyrite . . . . $CuFeS_2$

Galena . . . . PbS

Pyrite . . . . FeS_2

Quartz . . . . SiO_2

Sphalerite . . . . ZnS

Supergene minerals:

Chalcocite . . . . Cu_2S

Covellite. . . . . . CuS

Wulfenite. . . . . . $PbMoO_4$

Barite is a minor constituent of the deposit. It occurs as masses in the quartz lens that range from a few centimeters across up to hand-specimen size. Where associated with ore minerals, it is veined by them. Under the microscope one may see that it was crushed, then veined and replaced by sulfides, particularly chalcopyrite.

Bornite is exceedingly sparse in this deposit. It occurs as an occasional grain in quartz and is always rimmed by chalcocite or covellite.

Chalcopyrite is the least abundant of the ore minerals and is probably not present in economic concentrations. It is most commonly observed as veinlets cutting pyrite and replacing pyrite grains. Less commonly it is disseminated in quartz as anhedral grains about 0.1 mm in diameter. It also occurs as minute blebs in galena. This is interpreted to be the result of exsolution. In a few instances small, irregular patches of chalcopyrite, which resemble remnants of larger masses, are found contained in sphalerite. In one unusual specimen chalcopyrite veinlets and stringers, fractured and irregular in distribution, serve as a host for rounded anhedral grains and blebs of galena. Fractured sphalerite grains are adjacent to and enclosed by chalcopyrite.

Galena is one of the principal ore minerals. Its common habit is as disseminated grains 2-4 mm across and as elongate granular stringers and bands. In places individual crystals and clusters of crystals partially fill vugs lined with quartz. Galena less commonly occurs as veinlets cutting pyrite or sphalerite.

Pyrite is not particularly abundant relative to the other sulfides, but its spatial distribution is considerably greater. It is disseminated throughout the vein as angular, equigranular, commonly subhedral or euhedral grains about 0.1 mm in diameter. In many instances pyrite is partly replaced, particularly by chalcopyrite, which veins it. Pyrite is the only sulfide found outside the quartz vein. It is as abundant in the adjacent wallrock as it is in the vein and is found in rocks far enough from the vein so that they have not been affected by argillization and silicification. In the wallrock it occurs as fine-grained disseminations, stringers, and thin coatings on fractures.

Quartz is the common gangue mineral and constitutes the principal mineral in the ore shoot. The quartz is white and crystalline, with grains 0.3-1.0 mm across, and tightly interlocked between vugs. The quartz grains are generally euhedral or subhedral, and distinct crystals are easily seen in hand specimen. Although the vein-wallrock boundary is sharply defined in terms of textures, the wallrock immediately adjacent to the vein is almost completely saturated with quartz, much of it granular, although it is finer grained than that in the vein. Where sulfides have filled vugs, the quartz crystals terminating in the sulfides are usually bounded by sharp, clean crystal faces if the sulfide is galena, but exhibit corroded edges where the sulfide is sphalerite.

Sphalerite is the other principal ore mineral. Its occurrence is much the same as galena. It is disseminated in quartz as individual grains 0.2-1.0 mm across and in roughly equidimensional masses up to 5 or 6 mm in diameter. Less commonly it occurs as veinlets cutting pyrite or, occasionally, galena. Most sphalerite is very light brown or yellow. Some specimens have a distinct green tinge. The light color is usually taken as an indication of very low iron content.

Chalcocite and covellite occur in very minor amounts. Both form veinlets cutting other sulfides, especially galena.

Wulfenite is a minor but conspicuous mineral in several specimens. It occurs as scattered, euhedral, prismatic crystals up to 3 or 4 mm long. The crystals grow on quartz and sulfides and usually project into a vug.

Grand Central Mine

The Grand Central mine is in the SE 1/4, sec. 5, T. 14 N., R. 8 E. The vein is just east of Mount Chalchihuitl. It strikes N. 30° E. and is discontinuously exposed in prospects and outcrops for about 1,500 feet. The vein is similar to the one at the Mina del Tiro as it appears at the surface. It is in a sheeted zone 4-8 feet wide containing linked veinlets of quartz and limonite. The wallrock is stage T_1 hornblende monzonite porphyry and stage T_4 augite-biotite monzonite porphyry. Where the vein is in hornblende monzonite porphyry, there is a narrow zone of argillization up to 1 or 2 feet beyond the vein. Where the vein is in augite-biotite monzonite porphyry, the wallrock adjacent to the vein is unaltered.

The host for sulfide mineralization is brecciated wallrock, which is veined and saturated with quartz. The following minerals have been identified from samples of the Grand Central dump.

Barite	$BaSO_4$
Galena	PbS
Gold	Au
Magnetite. . . .	Fe_3O_4
Pyrite	FeS_2
Quartz	SiO_2
Sphalerite . . .	ZnS

Barite occurs as euhedral blades 1.0 mm across and 3-7 mm long, and as long patches of euhedral grains. Several of the blades have cut completely across sulfide grains, particularly pyrite and chacopyrite.

Galena occurs as disseminated grains a few millimeters in diameter and in parallel, poorly defined veinlets. Galena and sphalerite generally do not occur together; samples of hand-specimen size are mainly one or the other. Galena fills vugs in quartz and often replaces it; sphalerite does not.

Magnetite in association with quartz, pyrite, and chalcopyrite has been observed in samples which, although fractured and mineralized, are considerably less affected by argillization than samples of the vein. The fresh appearance of these rocks suggests that they were close to but not actually part of the vein. The magnetite is present as anhedral grains a few millimeters across, and as small veinlets cutting wallrock.

Pyrite is a widespread but minor constituent. It is disseminated through the vein and adjacent walls. It nearly always occurs as individual grains, many euhedral in cross-section, 0.2-3.0 mm across. The coarser grains tend to occur in the most silicified parts of the vein. Some pyrite fills interstices in quartz. Much of the pyrite has been brecciated, then veined by one of the other sulfides, and by quartz and barite.

Quartz veins and replaces brecciated rocks in the vein. It is vuggy and coarse grained. Many grains are euhedral in cross section.

Sphalerite forms masses up to 2 cm across. It is partly replaced by limonite, and individual grains have corroded boundaries. This gives the sphalerite a brecciated appearance, which is actually due to replacement, not crushing.

A single flake of gold was seen in one polished section. It was an anhedral grain, about 0.1 mm in diameter, occupying the boundary between quartz and chalcopyrite.

All the samples collected from the Grand Central dump were at least partly modified by supergene processes. Many samples had significant amounts of fine-grained quartz, limonite, hematite, and manganese oxides associated with them. Mixtures of these minerals were observed corroding and replacing hydrothermal minerals, especially barite and sphalerite.

Paragenesis

The sequence of mineral deposition was essentially the same in both of the veins examined. Coarse-grained quartz was the first mineral. It was followed by disseminated pyrite, some of which, in contrast to younger minerals, was brecciated. After the brecciation chalcopyrite, galena, and sphalerite were deposited with substantial overlap. Chalcopyrite is usually older, as evidenced by veinlets of galena and sphalerite that cut it. However, small rounded blebs of chalcopyrite in both galena and sphalerite are interpreted as due to exsolution. The relationship of galena to sphalerite is completely ambiguous. Each veins the other and each partly replaces the other. For the most part the two, when together, exhibit mutual boundaries which are indicative of contemporaneous deposition. Minor quantities of barite followed galena and sphalerite. Several barite blades cut and replace individual galena grains. Barite also veined and replaced quartz.

A few samples taken from the Mina del Tiro dump show a post-barite stage of sulfide deposition in narrow zones of shearing that occurred after the deposition of barite. Following brecciation of quartz and barite in shear zones, chalcopyrite, galena, and sphalerite were deposited. Sphalerite, present in minor amounts, is oldest and is veined by chalcopyrite and galena. Chalcopyrite occurs as stringers and veinlets in the gangue. It serves as the host mineral for much of the galena which occurs as exsolved blebs.

A late stage of quartz deposition is seen in both veins. In samples from the Mina del Tiro, drusy quartz coats sphalerite and galena. In samples from the Grand Central mine, quartz coats sulfides, but it also veins galena, sphalerite, and barite. Its exact position in the paragenetic sequence is not perfectly clear, but it is cleaner and coarser than supergene quartz associated with limonitic oxidation products, and on this basis is considered hypogene.

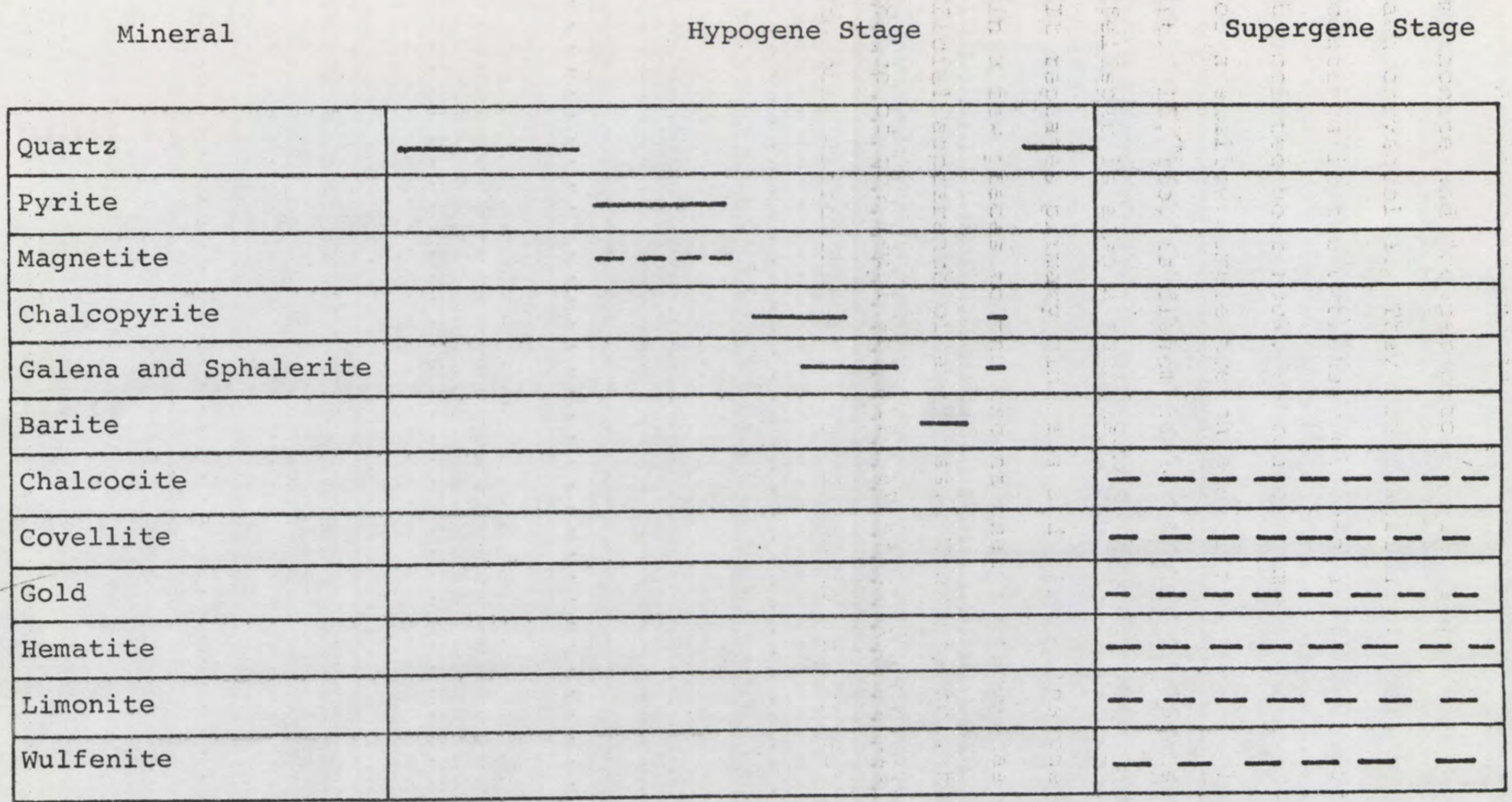
The paragenesis of bornite and magnetite could not be determined. The few bornite grains seen are anhedral and rimmed by chalcocite and covellite. The bornite is spatially associated with sulfides of the first stage of deposition in samples from the Mina del Tiro. It has been arbitrarily assigned the same position as chalcopyrite. Magnetite, which is spatially associated with sulfides in rocks adjacent to the vein, occurs as individual grains. There is no cutting of magnetite by sulfides and no cutting of sulfides by magnetite. Magnetite is assigned the same age as pyrite because of their close spatial relationship and their similar mode of deposition as interstial filling in granular quartz.

Secondary enrichment is almost negligible. Chalcocite and covellite rim and vein older sulfides in a few instances, but replacement is uncommon. Supergene processes have resulted in the deposition of minor amounts of gold, some wulfenite, and a gossan of quartz, iron oxides, manganese oxides, gypsum, and a number of clay minerals, all of which are attacking and replacing sulfides.

Disseminated Bodies

A disseminated copper deposit crops out in sections 5 and 8, T. 14 N., R. 8 E. It is midway between the Mina del Tiro and Grand Central mine.

Mineralization is in a zone of intense brecciation which encircles a small stage T_4 (Fig. 1) stock. The mineralization observed occupies only a portion of the brecciated area. It is concentrated along the south and west margins of the stock in an arcuate zone 2,500 feet long and up to 500 feet wide. The stock inside the brecciated zone is barren.



Note: Solid lines indicate relative period and length of deposition.
Dotted lines indicate that relative period and length of deposition is uncertain.

Figure 5. Paragenesis of vein minerals in the southern Cerrillos.

At and near the surface the ore minerals are dominantly malachite and "copper pitch", with lesser amounts of azurite and chrysocolla. They are distributed as thin veinlets and coatings in the extremely close-spaced fractures of the brecciated host rock. A random sample taken from the bottom of a shallow sample trench has remnants of chalcopyrite in it. It, too, is disseminated as small veinlets. Potassium feldspar is also a secondary mineral in the brecciated zone. It replaces primary minerals and also veins the host rock; in a few places to the extent that the rock has the superficial appearance of a gneiss. There is not, however, any trace of the usual argillic alteration minerals so common to most disseminated copper deposits in the Southwest.

ALTERATION

Propylitization

Propylitization is the formation of aggregates of chlorite, magnetite, epidote, and biotite in major proportions in igneous rocks. Associated with these minerals are minor amounts of quartz, common clays including kaolinite, uralite, sericite, and calcite. In the southern Cerrillos this type of alteration has affected all of the intrusive rocks older than igneous stage T_4. The mineralogy of the various alteration types present in the Cerrillos is summarized in Table 3.

The rocks that have been propylitized are porphyritic monzonites and quartz monzonites. They consist of phenocrysts set in a groundmass of quartz, feldspar, and magnetite. The phenocrysts are on the order of 1.0 mm in length and constitute 25 to 75 percent of the total rock. One-half to three-fourths of the phenocrysts are andesine; the remainder are hornblende, augite, and biotite. Of these hornblende is the major constituent, biotite of a primary nature occurs in some samples as a trace constituent, and augite rather than hornblende is present in a few samples. The propylitic alteration has given these rocks a distinct, greenish cast.

The extent to which propylitization has affected the rocks is reflected in changes in the proportion of various groups of minerals present as alteration products. Rocks

Sample Number	Primary Minerals								Secondary Minerals														Alteration Class
	Quartz	Feldspar	Hornblende	Augite	Biotite	Magnetite	Apatite		Chlorite	Magnetite	Biotite	Epidote	Silica	Sericite	Uralite	Kaolinite	Carbonate	Clay	Limonite	Hematite	Tourmaline	Turquois	
1c	m	M			t	m	t		M	M		M	s					t	t				Propylitic-intermediate
2	Alteration complete															M	m	t	m	m			Argillic-kaolinitic
2b						m	t		s	s	s							M	m	m			Argillic-propylitic
3a	Alteration complete													s		M	t		s	s			Argillic-kaolinitic
3b	m					m	t		M	M	m	m	s					m					Propylitic-chloritic
4		m								m			m	m		t	m	M		m			Argillic-kaolinitic
5b	m					s	t		M	M	t	m	s					m	m	m			Propylitic-chloritic
8a	m								t		t		M					m	m	m			Argillic-silicic
11	m												M	t		t		s	m	m			Argillic-silicic
11a	m									s			M		s			m					Argillic-silicic
16	Alteration complete												M		m			m	m	m			Argillic-silicic
21	s	M				s							M							s			Fresh rock-incipient silicification
21a	M	M	t										m		t			M		m			Fresh rock-incipient argillization
21b	s	M	t		m		t																Fresh rock-quartz-biotite monzonite
23a		M		m	m	m	t																Fresh rock-augite-biotite monzonite
23b		M			t				s	s		m	s					s					Propylitic-intermediate
23c	m								m	M		s						M					Propylitic-epidotized
27	t	M	m		t	m	t						t										Fresh rock-hornblende-biotite monzonite
29a	Alteration complete									m				m		M		m			t	t	Argillic-kaolinitic
135a	Alteration complete								t	m		t		s		M							Argillic-kaolinitic
138	Alteration complete									m			s	s		M					t		Argillic-kaolinitic
139	m									m			M	m		M		m			t		Argillic-kaolinitic & silicic
152d					m				s	m		m	s			s		s					Argillic-propylitic

Key

M Major constituent	s Significant constituent
m Minor constituent	t Trace constituent

Table 3. Mineral analyses of rocks in the southern Cerrillos

only slightly affected have nearly fresh plagioclase phenocrysts; quartz phenocrysts, if present, exhibit sharp boundaries. Remnants of the ferromagnesian minerals are present, and the outlines of former phenocrysts are readily distinguished. The characteristic alteration minerals are chlorite, green biotite, and magnetite, all confined to the area occupied by altered phenocrysts.

Most of the propylitized rocks examined exhibit an intermediate stage of alteration. Alteration of the feldspar phenocrysts to clays has advanced to the extent that the composition of most cannot be determined, and the phenocryst outlines become somewhat blurred. Chlorite, magnetite, and fine-grained quartz are dominant, and the amount of secondary biotite decreases. Secondary quartz veinlets and chlorite-magnetite veinlets cut across both groundmass and phenocrysts. The outlines of former ferromagnesian phenocrysts become blurred and in some cases are so indistinct that it is impossible to determine whether a chlorite-magnetite aggregate is the site of a former phenocryst or not.

In advanced stages of propylitization the feldspars are completely altered to clays, although their outlines can still be seen. The dominant propylitic minerals are magnetite and epidote. Epidote and magnetite aggregates replace ferromagnesian phenocrysts and form veinlets. Disseminated magnetite constitutes a substantial part of the matrix. Chlorite, a dominant mineral in less intensely altered specimens, occurs only as a minor constituent in zones of intense alteration. The porphyritic texture of the original rock is still apparent, but the outlines of phenocrysts is extremely blurred and irregular in the clearest cases and very nearly obliterated in the others.

The term propylite was first used by Baron von Richthofen in describing igneous rocks of the Washoe District (Comstock Lode), Nevada. It was recognized by Becker (1882, p. 81-90) that the distinctive character of the rocks called propylites is due to alteration in which hornblende, augite, and biotite break down and abundant chlorite forms.

It is widely agreed that propylitic alteration is of hydrothermal origin (Lovering, et al., 1949, p. 16), and most workers rank it as a less intense form of alteration than argillization or intense silification. In many instances propylitization is zonally distributed between fresh and argillized rocks as at Santa Rita, New Mexico, (Kerr, et al., 1950, p. 310, 319) and Castle Dome, Arizona, (Peterson, Gilbert, and Quick, 1946, p. 826) and is usually older than the more intense hydrothermal phases.

The pervasive propylitization of igneous rocks older than stage T_4 and its complete absence in stage T_4 rocks make the alteration older than the consolidation of stage T_4 intrusives. The propylitization is therefore older than argillization, which affects both stage T_4 and older rocks.

Ascribing propylitization to hydrothermal activity is so general an assertion that it is not very satisfactory. Nevertheless, it is difficult to make a more explicit statement. Differences in propylitization over the entire area of stage T_1 rocks are so slight as to preclude the identification of specific conduits along which hydrothermal solutions might have moved. The most intensely altered specimens bear no clear relationship to any obvious structural features. This suggests that the differences in degree of alteration are more apparent than real in the sense that they represent very local differences in chemical response. The differences in intensity, although observable, are of no great magnitude.

The possibility of the propylitization being supergene is precluded by the appearance of propylitized rocks taken from the dumps of the mines. They contain fresh, disseminated pyrite, a mineral too susceptible to weathering and oxidation to have survived in a near-surface environment.

Argillization

Argillization is the formation of quartz, sericite, and clays, in this case mostly kaolinite. Argillized rocks can be recognized by their bleached appearance. The three largest areas of alteration are at Mount Chalchihuitl, in the valley between Mount McKenzie and Grand Central Mountain, and directly south of Franklin Hill (Fig. 1). There are also numerous, isolated patches of argillized rocks, up to a few thousand square feet in areal extent, which are scattered throughout the area. Narrow envelopes of argillization also enclose the veins in the area.

Argillized rocks fall conveniently into three categories.

Two categories represent initial stages of argillization. The third category represents an advanced stage.

One of the initial categories contains rocks that have been previously subjected to propylitization. These rocks, although bleached in appearance, still contain traces of minerals characteristic of propylitization. Patches and veinlets of chlorite, magnetite, and epidote make up minor assemblages in these rocks. The major minerals, however, are clays and quartz due to argillization. They vein and replace feldspar phenocrysts. In samples where argillization is incipient, minor amounts of sericite and uralite are present. In more intensely altered specimens, alteration of the original groundmass has proceeded to the extent that kaolinite is recognizable as an alteration product under the microscope.

The other initial category contains rocks which were not propylitized prior to argillization. Secondary quartz is the characteristic alteration mineral. In a sample representing an incipient stage, the primary minerals are mostly fresh. Alteration forms fine-grained quartz veinlets across andesine phenocrysts. In samples where alteration is further advanced, fine-grained quartz occurs as aggregates replacing phenocrysts. There is minor secondary biotite and uralite replacing ferromagnesians. Patches of sericite and calcite occur in traces, and minor amounts of clay occur, mostly as a replacement of feldspar phenocrysts.

The third category is an intense stage of argillization. In most cases primary textures are totally obliterated.

Kaolinite is the dominant mineral, and laths of it 0.1-0.2 mm long develop a conspicuous orthogonal network. Sericite is widely scattered in small patches, and irregular grains and aggregates of tourmaline occur in trace amounts. Fine-grained magnetite, not apparent in hand specimens, is disseminated in minor amounts throughout all of the samples. Argillized rocks at Mount Chalchihuitl also contain veinlets of tourmaline and magnetite in an envelope of quartz.

Supergene Mineralization

General Features

Supergene minerals in the southern part of the Cerrillos are predominantly turquois, malachite, azurite, chrysocolla, and "copper pitch". Turquois is found in almost every patch of argillized rocks. The most conspicuous deposit is at Mount Chalchihuitl (Fig. 2). Several smaller deposits are scattered in argillized areas in sections 8 and 9, T. 14 N., R. 8 E. south of Franklin Hill. There are sparse amounts of turquois in scattered prospects between Grand Central Mountain and Mount McKenzie. Malachite, azurite, and "copper pitch" occur in the disseminated copper deposit between the Mina del Tiro and Grand Central mine. Malachite and azurite also coat fractures in a limburgite dike of Miocene age which crops out east of Franklin Hill. Chrysocolla is a very minor mineral in the southern Cerrillos. It is found in small amounts associated with malachite and azurite.

Turquois

One of the largest and best exposed turquois deposits is at Mount Chalchihuitl. It is in an argillized breccia pipe approximately 400 feet in diameter. Turquois occurs in an L-shaped area. Each leg of the area is 50-57 feet wide and about 200 feet long. One leg trends northeast, the other northwest. Turquois has been mined from two quarries, one at the northwest corner of the turquois zone, the other along its eastern side (Fig. 2), and from a tunnel and several small stopes driven from the east quarry into the center of the deposit (Fig. 3). Turquois coats and fills narrow fractures, and is disseminated as small nodules in wallrock. The thickness of the resulting veinlets ranges from a paint-thin coating up to about 1/8 inch. The nodules are small, and few exceed 1/4 inch in diameter.

Much of the turquois and all of the vein minerals are localized in one of three conspicuous fracture systems cutting the breccia pipe. The fractures strike northwest, north, and northeast, and all are steeply dipping (Figs. 2 and 3). Quartz-magnetite-tourmaline veinlets fill narrow fractures on all three trends. Turquois cuts some of these veinlets. One northeast-trending fracture is filled by a quartz and breccia vein which is saturated with limonite. A small amount of turquois is disseminated in the vein. The north-trending fractures are shear zones, up to one foot wide, containing the remnants of quartz veins. The veins are vuggy and also contain limonitic minerals typical of gossans.

Siliceous boxworks have a rectangular pattern resembling galena cleavage which suggests the former presence of sulfides. There is turquois in the shear zones as disseminated nodules and as veinlets in the numerous, closely spaced fractures. However, those parts of the shear zones containing quartz veins are nearly barren of turquois.

The origin of turquois at Cerrillos has long been debated. Clarke and Diller (1881, p. 42) observed turquois as veinlets with a fibrous structure perpendicular to the vein walls. They argued that a fibrous habit was typical of apatite and therefore turquois was pseudomorphous after apatite. Johnson (1904, p. 198-199) observed turquois with radial fibrous and spherulitic structures. Thin sections studied by the author substantiate Johnson's observations. There are no remnants of apatite in turquois; neither does the habit of turquois suggest that turquois is a pseudomorph. Neither Clarke and Diller nor Johnson was specific about the exact origin of turquois. Johnson (1904, p. 200) recognized that turquois was secondary, but he implied that it was contemporaneous with hydrothermal wallrock alteration because of its association with tourmaline and hydrothermal alteration. A supergene origin for turquois in the southern part of the Cerrillos is indicated by the following:

1. Veins associated with turquois deposits have been leached by descending water. None of the primary metallic vein minerals remain.
2. Malachite, azurite, anglesite, and limonite, all

supergene, are associated with turquois. Southeast of Franklin Hill, malachite, azurite, and turquois are all deposited as fillings in narrow fractures in wallrock. Limonite is a common associate of turquois.

3. Fractures containing veinlets of turquois cut across hypogene minerals and structures. This relationship is clear where veinlets of quartz, tourmaline, and magnetite are cut by younger fractures which were later filled with turquois.
4. Turquois deposits are surface and near-surface phenomena. At Mount Chalchihuitl turquois occurs at the outcrop. Prospect pits and workings in the southern part of the Cerrillos have exposed turquois at depths of about 100 feet. Drilling of the Mount Chalchihuitl deposits, however, has failed to detect the mineral at depth (J. G. Wargo, 1963, personal communication).

Laboratory evidence tending to substantiate a supergene hypothesis was reported by Paige (1912, p. 382-392) in conjunction with an investigation of the turquois deposits in the Burro Mountains of New Mexico. In the primary zone apatite and cupriferous pyrite (Paige's terminology) are present in altered wallrock consisting of quartz, sericite, and chloritic minerals. No turquois is present. This is in sharp contrast to the similarly altered rocks at the surface which contain turquois, but no pyrite or apatite.

Paige concluded that the necessary copper and phosphorus were derived from the cupriferous pyrite and apatite, but only in the weathering zone, as both minerals are stable in the hydrothermal primary zone and soluble under oxidizing, acidic conditions. Paige's laboratory experiments validated these conclusions. A sulfate solution containing copper, aluminum, and phosphate simulated the solution obtained from oxidizing conditions in a weathering pyritic copper deposit. The solution was neutralized, simulating downward percolation. As the solution approached neutral pH, from the acid end, copper aluminum phosphates were the first compounds to precipitate.

Sterrett's report (1911, p. 779-782) on the turquois deposits of the western United States offers further substantiation of a supergene origin. The deposits are monotonously similar, suggesting that all formed in the same way. They are all in or near argillized or sericitized rocks of granitic or monzonitic composition. All are near-surface deposits, a condition indicative of supergene formation.

The previously cited evidence for the Cerrillos is consistent with a supergene model but does not conclusively rule out alternatives. However, Sterrett's work is a strong case for a single, supergene origin for all turquois deposits. This, coupled with Paige's demonstration, indicates that a supergene mode of formation is most likely in the Cerrillos.

APPENDIX I

Thin section descriptions

Samples 21b, 23a, 27

Quartz-hornblende-biotite monzonite

Minerals:

Essential: Orthoclase, partly corroded, and plagioclase.

Varietal: Quartz, hornblende, partly chloritized, and biotite.

Accessory: Magnetite, apatite, and perthite.

Texture: Hypiodiomorphic, medium grained.

Remarks: Plagioclase of sample 27 is cut by minor quartz veinlets. Sample 23a contains augite instead of hornblende and is a quartz-augite-biotite monzonite.

Samples 1c, 3b, 5b, 23b, 23c

Propylitized monzonite porphyry (Stage T_1 hornblende monzonite porphyry)

Minerals:

Essential: Orthoclase in fine-grained groundmass, and plagioclase (An_{26-34}), partly altered.

Varietal: Hornblende and augite, completely altered.

Accessory: Quartz and magnetite.

Alteration: Chlorite and magnetite replace hornblende. Quartz and epidote occur as scattered veinlets. Kaolinite and unidentified clays partly replace plagioclase. Biotite and carbonate minerals occur as scattered patches.

Texture: Porphyritic.

Samples 2b, 4, 21a, 152

Argillized propylitized monzonite porphyry (Stage T_2 hornblende monzonite porphyry)

Minerals:

Essential: Altered plagioclase phenocrysts and fine-grained orthoclase (?).

Varietal: Altered hornblende and corroded quartz phenocrysts.

Alteration: Two alteration phases are present.

1. Propylitization: Magnetite, chlorite or uralite, biotite, and quartz aggregates replace hornblende. Epidote occurs as veinlets.
2. Argillization: Quartz veins the groundmass and cuts across plagioclase phenocrysts. Kaolinite and unidentified clays replace groundmass and feldspar phenocrysts.

Texture: Porphyritic.

Remarks: Samples taken from bleached areas in propylitized rocks. Field relations indicate rocks were first propylitized, then argillized.

Samples 8, 11, 16, 21

Silicified hornblende monzonite porphyry (Stage T_1)

Minerals:

Primary: Completely destroyed.

Alteration: Clays, uralite, carbonate minerals, biotite, and minor chlorite after hornblende (?) phenocrysts. Sericite and fine-grained quartz as veinlets and patches dominate sample.

Remarks: Silicification is apparently superimposed on propylitization. Significant amounts of propylitic minerals remain, suggesting that silicification is an incipient stage in the argillization process.

Samples 2, 3a, 29a, 135, 138, 139

Argillized igneous rocks

Remarks: Rocks are all characterized by a predominance of kaolin, often forming an orthogonal network. In hand specimen the rocks exhibit pronounced bleaching. Under the microscope they are seen to be mixtures of kaolinite, quartz, magnetite, and sericite. Epidote, iron hydroxides, biotite, tourmaline, and turquois appear in some samples in trace amounts. Textures are nearly obliterated in most cases, although former phenocryst outlines are still apparent in a few instances.

APPENDIX II

Polished section descriptions

Sample No. M-1

Ore Minerals: Galena, sphalerite, chalcopyrite.

Gangue: Quartz, pyrite, silicified wallrock (barren).

Textures: Specimen is a vuggy, crystalline quartz vein containing disseminated sulfides. Galena and sphalerite fill vugs. Irregular pyrite grains occur as inclusions in galena and sphalerite, and in interstices between quartz grains. Galena and chalcopyrite vein pyrite.

Paragenesis:
1. Quartz is older than all sulfides.
2. Pyrite is older than galena and sphalerite.

Sample No. M-2

Ore Minerals: Galena, sphalerite, chalcopyrite.

Gangue: Quartz, pyrite.

Textures: A crystalline, porous, slightly vuggy quartz matrix contains disseminated sulfides. Sulfides fill vugs and interstices and to a very limited extent replace quartz. Pyrite is brecciated and veined by galena, sphalerite, and chalcopyrite. Minor chalcopyrite is exsolved from galena as small blebs.

Paragenesis:
1. Quartz is older than all sulfides.
2. Pyrite is older than galena, sphalerite, and chalcopyrite.
3. Chalcopyrite and galena overlap.

Sample No. M-3

Ore Minerals: Galena, sphalerite, chalcopyrite, covellite, chalcocite.

Gangue: Quartz, silicified wallrock (barren).

Textures: Banded vein of sulfides and quartz. Pyrite is disseminated in quartz. Galena, sphalerite, and chalcopyrite form narrow bands in vein and replace galena and chalcopyrite. Brecciated pyrite is veined by galena, sphalerite, and chalcopyrite.

Paragenesis:
1. Quartz is older than all sulfides.
2. Pyrite is older than other sulfides.
3. Chalcocite and covellite are younger than galena and chalcopyrite.

Sample No. M-4

Ore Minerals: Galena, sphalerite, chalcopyrite, chalcocite.

Gangue: Quartz, pyrite.

Textures: Vuggy quartz matrix contains disseminated masses and grains of sulfides. Pyrite occurs as fine grains in quartz and sulfides. It is brecciated and veined by galena, sphalerite, and chalcopyrite. Quartz is replaced by galena and sphalerite. Chalcocite replaces galena as an advancing wave.

Paragenesis:

1. Quartz is older than galena, sphalerite, and chalcopyrite.
2. Pyrite is older than other sulfides.
3. Chalcocite is younger than galena.

Sample No. M-5

Ore Minerals: Chalcopyrite, galena, sphalerite.

Gangue: Quartz, barite.

Textures: Veinlets of chalcopyrite in vuggy quartz and barite. Quartz and barite are brecciated and replaced by sulfides, especially chalcopyrite. Sulfides vein each other to extent that paragenetic sequence is ambiguous. Texture indicates deposition of sulfides followed by movement and remobilization.

Paragenesis: 1. Quartz and barite are older than remobilized sulfides.

Sample No. GC-1

Ore Minerals: Galena, sphalerite, chalcopyrite.

Gangue: Quartz, barite, pyrite, limonite, hematite.

Textures: Vuggy quartz and barite, both brecciated, form a matrix between veins and disseminated masses of sulfides. Barite veins quartz and cuts individual galena crystals. Vugs in quartz are filled with sulfides. Pyrite and chalcopyrite are brecciated and veined by other sulfides and barite. A late stage of quartz veins all other minerals.

Paragenesis:

1. Quartz as an early stage precedes all other minerals.
2. Pyrite is older than all other sulfides and barite.
3. Chalcopyrite is older than galena and sphalerite.
4. Barite is younger than galena and chalcopyrite.
5. Quartz as a late stage veins barite.
6. Limonite and hematite as fine-grained components saturate openings in sample.

Sample No. GC-2

Ore Minerals: Galena, sphalerite, chalcopyrite, gold.

Gangue: Quartz, limonite, brecciated and silicified wallrock.

Texture: Weathering processes have affected the sample to the point where primary textures are not clear. Sphalerite, galena, and pyrite are corroded remnants in a matrix of silica, limonite and wallrock. A single flake of gold 0.1 mm across occurs in the limonitic matrix.

Paragenesis:
1. Pyrite older than galena.
2. Some chalcopyrite older than sphalerite and galena.

Sample No. GC-3

Ore Minerals: Sphalerite, galena, chalcopyrite.

Gangue: Silicified wallrock, pyrite, quartz.

Textures: Brecciated, silicified wallrock contains disseminated sulfides. Quartz fills interstices in wallrock. Brecciated pyrite veined by quartz.

Paragenesis: 1. Pyrite is older than quartz.

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