Geology of the Christmas Copper Mine, Gila County Arizona

By NELS P. PETERSON *and* ROGER W. SWANSON

A CONTRIBUTION TO ECONOMIC GEOLOGY

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An exploration of the ore deposits, in mine workings and by diamond drilling

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GEOLOGY OF THE CHRISTMAS COPPER MINE GILA COUNTY, ARIZONA

By Nels P. Peterson and Roger W. Swanson

ABSTRACT

The Christmas copper mine is in the Banner mining district, Gila County, Arizona. It is 8 miles north of Winkelman and 22 miles south of Globe. The mine was opened in 1905; to the end of 1943 it had produced about 55,340,000 pounds of copper. In 1946 it was operated under lease. The ore is high-lime fluxing ore, required by the smelter at Hayden. The ore produced during 1942 averaged 2.16 percent copper, but it contained no other metals paid for by the smelter.

The mineral deposits are in a thick series of gently dipping Paleozoic limestones that range in age from Devonian to Permian(?). Overlying the limestones with only slight discordance is a thick sequence of Cretaceous(?) volcanic rocks, mainly andesitic tuffs, breccias, and flows. A small quartz diorite stock has been intruded into the limestones and volcanic rocks. The Christmas fault cuts northwestward through the limestones, lavas, and the quartz diorite intrusive. The eastern part of the area has been depressed, bringing the lavas in contact with the limestones, which crop out west of the fault.

The mineral deposits are of the contact metamorphic or pyrometasomatic type. Chalcopyrite is the most abundant ore mineral, but variable amounts of bornite, chalcocite, and oxidized copper minerals are generally present. The gangue is chiefly garnet, quartz, magnetite, and unreplaced limestone. The factors that controlled the localization of the ore minerals are: (1) proximity to the limestone-quartz diorite contact, (2) favorable character of certain limestone beds, (3) garnetization of the limestone, and (4) postgarnetization fracturing.

The past production of the mine came mainly from ore bodies in the Naco limestone of Pennsylvania and Permian(?) age. A few small ore bodies have been mined from the Escabrosa limestone of Mississippian age. Other deposits of ore grade have been discovered by a drilling project carried on by the Bureau of Mines. Deep drilling below the bottom level (770-foot level) of the mine also disclosed mineralized limestone in the lower part of the Martin limestone of Devonian age. The ore in the Naco occurs in flat tabular bodies which are replacements of certain favorable limestone beds close to their contact with the quartz diorite. The ore is confined to 11 distinct beds, which are consistently mineralized wherever they occur in favorable relationship to the contact. They constitute a zone about 425 feet thick of interbedded limestones and shale. The deposits in the Escabrosa are thick irregular bodies that lie against the contact.

The deposits in the Martin limestone are known only from drill holes, and little can be determined concerning their size or shape.

INTRODUCTION

The Christmas copper mine is in the Banner mining district, Gila County, Ariz. It is 8 miles north of Winkelman and about 22 miles south of Globe (fig. 50) and is accessible from either town via State

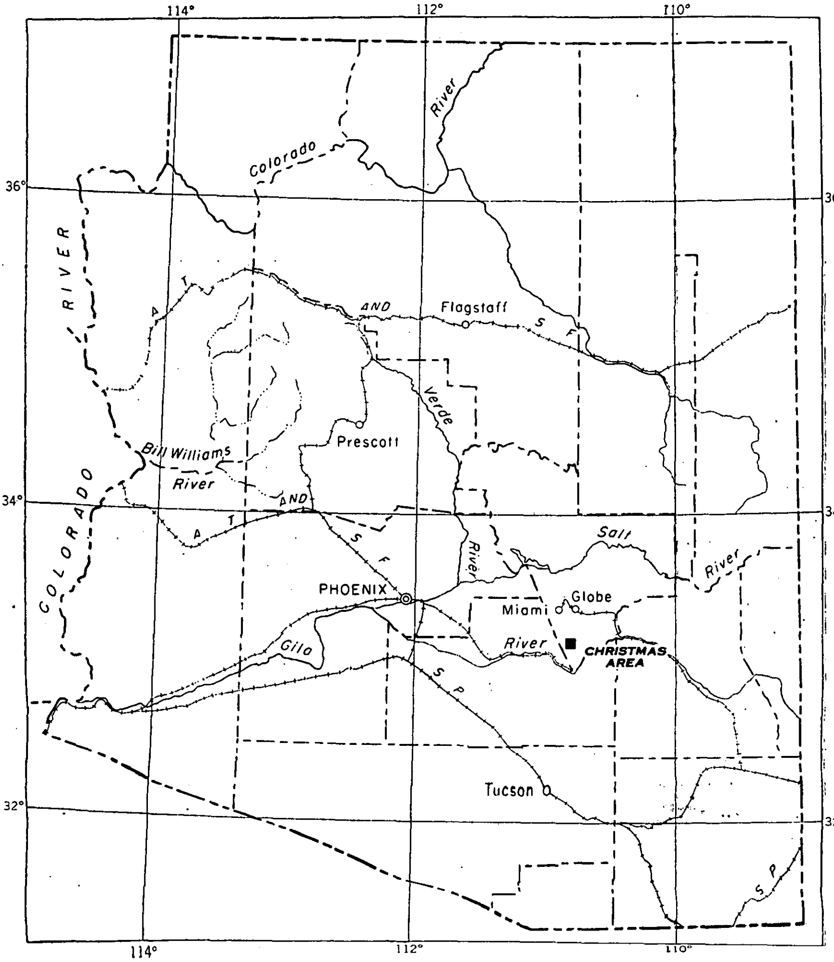

FIGURE 50.—Index map of Arizona showing location of the Christmas area.

Highway 77, a graded gravel road. A branch line of the Southern Pacific R. R. has its terminus a mile east of the camp and gives easy access to the American Smelting and Refining Co. smelter at Hayden, 9 miles by rail from the loading station.

The Christmas area is a part of the Christmas 15-minute quadrangle, which was mapped by the U. S. Geological Survey in 1915. The mine is a mile west of the Gila River, in a steep-walled tributary gulch at the southeastern end of the Dripping Spring Mountains. The topography is rugged; altitudes range from 2,100 feet above sea level at the river to 4,200 feet on the crest of canyon walls within a distance of 2 miles. The collar of the main shaft is at 3,040 feet.

In normal times about 40,000 gallons of water per day is pumped from the mine workings, but during wet seasons it is commonly necessary to pump twice this amount in order to keep pace with the inflow. At the present time all water for domestic and mining purposes is obtained from the mine. When a concentrator was in operation, water for metallurgical use was pumped from shallow wells near the Gila River. Electric power is supplied by the San Carlos Irrigation Project from a 66,000-volt transmission line, which crosses the property near the main shaft.

The exploration project at Christmas was carried on cooperatively by the Geological Survey and U. S. Bureau of Mines. Mr. O. M. Bishop, Engineer for the Bureau of Mines, examined the property and in his report of June 6, 1942 recommended that six holes be drilled from the 800 level of the mine. The Bureau of Mines began drilling in September 1942, and the Survey investigations began a month later. Since any ore bodies discovered below the 800 level would be inaccessible until a deeper level could be developed, the Bureau and Survey decided to explore from higher levels where resulting benefits could be more quickly realized. Drilling from the upper levels was begun early in 1943.

The field work for this report was completed by the end of June 1943. R. W. Swanson remained until the completion of the Bureau of Mines project in January 1944.

A supplementary diamond drilling project to explore for new ore bodies below the 800 level of the mine was begun by the Bureau of Mines in September 1945 and completed in January 1947.

ACKNOWLEDGMENTS

The base maps of the underground workings used in this report were supplied by the operators. Sam Knight, lessee, and Frank P. Knight, mine superintendent, gave the writers every possible assistance and made available all existing records, maps, and engineering data pertaining to the property. Unfortunately many maps and records had been lost in a fire that destroyed the engineering office in 1931. We are also indebted to Mr. L. C. Marshall and Mr. Stanton L. Tainter, project engineers for the Bureau of Mines.

All except the most recent underground workings were mapped by Guy N. Bjorge, Harrison Schmitt, S. H. Sherman, and others. The writers made full use of all previous work and remapped the geology of all workings and stopes that are still accessible.

PREVIOUS WORK

The only published work on the Christmas area is by C. P. Ross, entitled "Ore deposits of the Saddle Mountain and Banner mining districts, Ariz." (U. S. Geol. Survey Bull. 771), published in 1925.

HISTORY

The original mineral claims that include the Christmas deposit were located about 1880 by Dennis O'Brien and William Tweed, who sold or optioned them to Phelps-Dodge Co. The locations proved to be on the San Carlos Indian Reservation and were declared invalid. In December 1902, the portion of the reservation that includes the deposits was restored to the public domain by Executive Order, and the claims were relocated on Christmas Eve by G. B. Chittenden.

Phelps-Dodge Co. filed suit to recover the property without success, and the Saddle Mountain Mining Co. was organized to hold and operate the claims. A small copper smelter, erected in 1905, was operated until the spring of 1907, when the company failed. The Gila Copper Sulphide Co. was organized in 1909 to take over the assets of the old company. Capital necessary to resume operation could not be raised until April 1915, when a contract was made with American Smelting and Refining Co. under which that company assumed management and advanced funds to develop the property. Production of copper ore began in February 1916; and by the end of the year, the loan had been repaid. American Smelting and Refining Co. continued to operate the property until January 1919. In the meantime, certain bonds fell due and were defaulted. A receiver was appointed, who operated the mine until it was shut down in April 1921.

In 1925, Mineral Products Co., a corporation controlled by the Iron Cap Copper Co., bought a controlling interest in the Gila Copper Sulphide Co. which was then reorganized as the Christmas Copper Co. The mine was reopened, and in 1925 a 500-ton concentrator was moved from the Iron Cap mine in the Globe-Miami district and erected at Christmas. To 1932 about 321,000 tons of ore had been treated by flotation. The Christmas Copper Co. became bankrupt and was reorganized as the Christmas Copper Corp. in 1936. The mine was reopened in 1937 but was closed again in March of the following year owing to the low price of copper.

Mining was resumed in 1939, and the property has been operated under lease since that date by the Sam Knight Mining Lease, Inc., producing high-lime fluxing ore. Shipments have been limited to the amount of flux required by the Hayden smelter for treating the copper concentrate from the mine at Ray. The ore shipped during 1942 averaged 2.16 percent copper and about 30 percent lime. No other metals were paid for by the smelter. The operation has been economically possible only because of low transportation costs and because the premium paid for lime more than offsets the treatment charge.

PRODUCTION

The Christmas mine has produced mainly copper, though records covering the period 1905 to 1933 also show production of $160,000 in gold and $150,000 in silver (Elsing and Heineman, 1936, p. 92). Since the mine was reopened in 1937 the smelter has not paid for gold and silver. The copper production of the Christmas mine to the end of 1943 is shown in the accompanying table.

Copper production of the Christmas mine, 1905–43

Year	Ore (tons)	Copper (pounds)	Value
1905–33	1,079,855	[1] 48,300,000	[1] $8,990,000
1937	29,692	[2] 1,225,982	148,344
1938	6,098	275,303	26,980
1939	24,790	889,698	92,529
1940	25,871	1,030,381	116,433
1941	35,791	1,308,156	154,362
1942	39,837	1,400,852	169,503
1943	27,030	906,926	117,900
Total	1,268,964	55,337,298	$9,816,051

[1] Elsing, M. J., and Heineman, R. E. S., Arizona metal production: Ariz. Bur. Mines Bull. 140, p. 92, 1936.
[2] Pounds of copper paid for by the smelter. Production figures from 1937 to 1943 furnished by lessee. Published with permission.

The relation of the periods during which the mine was operated to the average yearly price of copper is illustrated in figure 51.

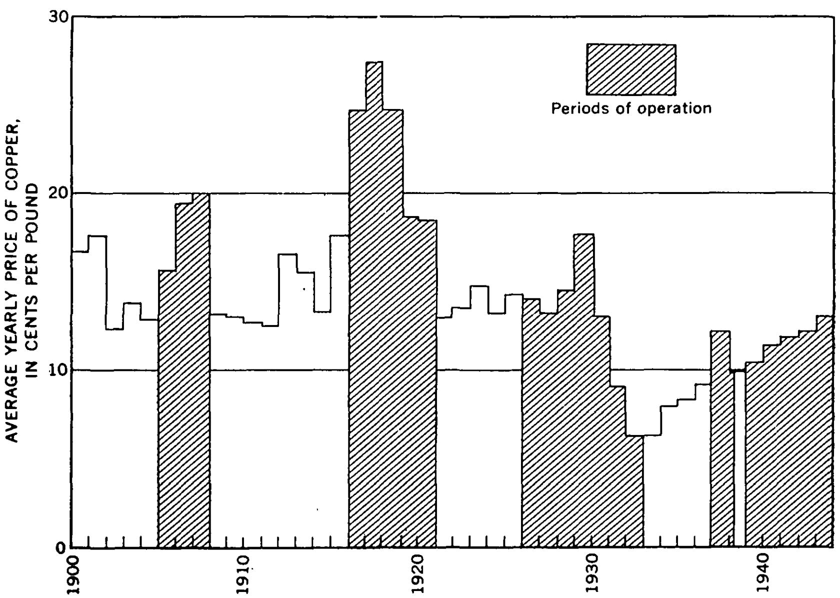

FIGURE 51.—Relation of periods of operation of the Christmas mine to the price of copper.

DESCRIPTION OF THE MINE WORKINGS

The Christmas mine was developed from 5 shafts, of which only No. 3 and parts of the Christmas shaft are now accessible. No. 3, which is the main working shaft, is vertical and has 3 compartments; two are equipped with cages, and the third serves as manway and pipe compartment. This shaft begins in diorite near the west end of the main mass, and at 635 feet below the collar it crosses the south contact and continues in limestone to the bottom, which is at 908 feet. The main levels are at 95, 200, 275, 375, 500, 635, and 770 feet below the collar and are generally referred to as the 100, 200, 300, 400, 500, 600, and 800 levels respectively. The mine is drained to the 800 level, which is about 280 feet above the bed of the Gila River a mile to the east. The composite level map (pl. 34) shows the arrangement of the levels and stopes around the borders of the diorite intrusive.

The 100 level is no longer accessible from No. 3 shaft, but the parts of the level that are still open can be reached through stopes which connect with the surface. The level was originally developed from No. 1 shaft and later connected with No. 3.

The 200 level is developed only on the south side of the diorite where it extends for 1,800 feet along the south contact. Only a small part of the level that lies west of the shaft is now accessible.

The 300 level (pl. 35) is extensively developed on both sides of the intrusive. The north-side workings can be entered either from the shaft or by an adit in the old Hackberry workings, which connects with the surface in the gulch at the northwest edge of the settlement. The east end of the south-side workings connects with the surface by way of the Track tunnel, which is an adit in the Old Christmas workings about 10 feet above the level. Nearly all the stoping along the north contact was on or above the 300 level; only a few stopes are below the level, and these are in the lower part of the Las Novias beds.[1] The south-side workings extend for 2,000 feet along the contact where limestone beds above and below the level have been extensively mined. Practically all the drifts and crosscuts under the stoped area on the south side are now caved.

The 400 level (pl. 36) has about the same extent as the level above. North of the shaft the level is near the top of a thick diorite sill. One drift, No. 410, follows close to the north contact as far as the Christmas fault. South of the intrusive the beds along the contact have been extensively mined above the level; some of the lower stopes are a few feet below it. This level serves as the main haulageway for the mine. All the ore now being mined is either hoisted or transferred through raises to the 400 level and trammed out of the mine through an adit at the east end.

[1] Local names applied to beds in the mining area are given on plate 42.

The station at the 500 level is caved and bulkheaded so that workings cannot be entered from the shaft. North of the shaft the development was mainly in diorite, and the workings are entirely inaccessible except for a short section of drift at the bottom of raise 501 A. The level south of the shaft has been abandoned and is in poor condition and partly flooded. The only means of entry is through raise 512 A near the east end of the level.

The 600 (635-foot) level consists of about 1,200 feet of drifting which cuts across several fingers of diorite at the west end of the main mass. The ground is heavy, the timbering is in poor repair, and much of the level is unsafe. The south contact cuts through the shaft at the level, and about 400 feet of drift is in the limestone south of the contact.

The 800 (770-foot) or bottom level was also developed mainly at the west end of the intrusive, where the diorite splits into a number of dikelike fingers (pl. 37). The diorite dikes and the limestone between them are fractured and contain much clay gouge which makes the ground very heavy, especially before it is thoroughly drained and dried out. The stopes on the 800 level were heavy and required square-set timber support.

GEOLOGY

The Christmas mine is in the southwestern part of the Christmas quadrangle about one-half mile east of the western boundary. The areal geology of the part of the Banner mining district that lies within the Christmas quadrangle was mapped by C. P. Ross (1925, pl. 1) of the U. S. Geological Survey in 1922 and that of the adjacent Ray quadrangle, which includes the remainder of the Banner district, was mapped by F. L. Ransome (1923) in 1910 and 1911. A more detailed geologic map of the mine area is shown on plate 33.

The mineral deposits are in a thick series of Paleozoic limestones that dip gently toward the southeast. Overlying the limestones with only slight discordance is a thick sequence of volcanic rocks that are mainly andesitic tuffs, breccias, and flows. A small quartz diorite stock has been intruded into the limestones and volcanic rocks. The Christmas fault cuts northwestward through the limestones, lavas, and the quartz diorite intrusive. The eastern part of the area has been depressed, bringing the lavas in contact with the limestones that crop out west of the fault. The ore bodies are replacements of certain favorable limestone beds by copper minerals and occur close to the limestone-quartz diorite contact. All the known ore bodies are in the higher block, west of the Christmas fault.

ROCKS AND STRATIGRAPHY

The sedimentary formations of the Christmas area are well exposed on Tornado Peak (pl. 38) about 2½ miles west of the mine, and in a section a mile north of the mine (pl. 39). At Tornado Peak, the Troy quartzite of Cambrian age is the oldest rock exposed. It is overlain by 185 feet of fine-grained argillaceous quartzite containing a few thin beds of coarser grained iron-stained quartzite. These quartzites are probably also of Cambrian age and equivalent to the Santa Catalina formation of Stoyanow (1936, p. 476).

The Devonian system is represented by 340 feet of Martin limestone. There is a thin quartzite member at the bottom, which is overlain by about 30 feet of dolomitic limestone that is thin-bedded and shaly in the lower part. This member is mineralized in the vicinity of Tornado Peak and in the Christmas mine and is known locally as the O'Carroll bed. The middle part of the Martin at Tornado Peak is thin- to medium-bedded limestone about 180 feet thick. Many of the thicker beds are marble and are in part dolomitic. The upper part of the Martin is a bed of olive-gray argillite 65 feet thick overlain by soft thin-bedded shaly limestone. The argillite is the metamorphosed equivalent of the fissile calcareous shale that is commonly the top member of the Martin limestone.

The thick series of Carboniferous limestones that overlie the Martin was named Tornado limestone by Ransome (1919, p. 47). In the Bisbee quadrangle, Ransome (1904, p. 42–44) subdivided the Carboniferous formations into the Escabrosa limestone of Mississippian age and the Naco limestone of Pennsylvanian and Permian ages. The use of these names has been extended to designate limestones of similar ages throughout southeastern Arizona.

The Escabrosa on Tornado Peak is 550 feet thick and consists largely of pure crystalline limestone; some beds are composed almost entirely of crinoid fragments, a few beds are dolomitic, and some contain abundant nodules of chert.

The upper 380 feet of the Tornado Peak section is Naco limestone. It is separated from the Escabrosa by a thin bed of chert conglomerate and shale. The Naco is made up of thin to medium beds of nearly pure gray limestone, separated by thin layers of calcareous shale.

A section of younger beds, which appears to be a continuation of part of the Tornado Peak section, is exposed one mile north of the mine (pl. 39). The middle part of this section contains about 300 feet of alternating thin beds of limestone and shale, which is the only part of the section that is comparable with the most extensively mineralized beds in the upper levels of the Christmas mine. M. L. Thompson (personal communication) states that fusulinids collected from the uppermost beds of this section are characteristic of the transition zone between rocks of Pennsylvanian and Permian ages. An abundant fauna of dwarf gastropods also suggests that the beds at the top of this section are possibly of Permian age. Beds containing similar fusulinids and gastropods crop out just under the lavas west of No. 3 shaft; therefore the Naco limestone is considered to be of Pennsylvanian and Permian (?) ages in the Christmas mine area.

The total thickness of Naco limestone represented in these two sections is probably a little more than 1,000 feet, and the total thickness of Carboniferous rocks is about 1,550 feet. Thus, if the productive ore bodies of the Christmas mine are in the upper third quarter of the Naco limestone, as appears to be the case, the top of the Escabrosa is approximately at the bottom level of the mine (800 level), and 550 feet of Escabrosa and 300 feet of Martin limestone could be expected below that level. Deep drilling below the 800 level has roughly confirmed this estimate; however, the formation members that can be identified in drill cores appear to be considerably thinner than in the measured section on Tornado Peak. The thinning may be partly the result of shrinkage attending the metamorphism of the rocks, but the Martin limestone and its various members are known to differ greatly in thickness from place to place. Furthermore, owing to the intense alteration of the limestones and the limited exposures in the mine workings, the top of the Escabrosa cannot be determined accurately.

Only the upper part of the Naco limestone crops out in the vicinity of the mine. In general, the exposures are poor, and the limestone is so completely altered by recrystallization and garnetization that beds cannot be correlated from one place to another.

The Paleozoic limestones are overlain by a thick sequence of volcanic rocks—mainly andesitic tuffs, flow breccias, and flows—which form the high ridges north, south, and west of the camp. These volcanic rocks are brown, brownish black, or dark gray and are generally fine grained. Ross (1925, p. 11–14) regards them to be of Cretaceous age. The lower part of the volcanic series contains gray hornblende porphyry which may be either flows or intruded sills. Other bodies of similar hornblende porphyry form sills within the uppermost limestones near their contact with the andesitic rocks.

The volcanic rocks are so poorly bedded and so widely covered by talus that a satisfactory section cannot be measured, but, judging from the development in No. 4 shaft (pl. 40), their thickness must be at least 2,000 feet. They appear to be nearly conformable with the limestone strata. In places contact metamorphism has affected the andesites, causing the formation of abundant epidote and small amounts of pyrite; but they are not known to be ore bearing in the Christmas area.

Several varieties of dioritic intrusive rock occur in the Christmas area, all of which are assumed to be facies of the same magma. The most common type, which constitutes the main intrusive mass, is a quartz-mica diorite porphyry containing phenocrysts of quartz, feldspar, and biotite in a fine-grained gray groundmass. Other facies are not porphyritic and show wide variation in grain size. The coarser varieties are usually light colored, whereas the fine-grained rocks are dark. The petrographic character of the rocks has been adequately described by Ross (1925, p. 20–21) and Ransome (1919, p. 64–66). Some of the sills and smaller dikes contain hornblende with or without biotite.

Several narrow dikes of fine-grained brownish-black andesite or basalt are exposed in the mine workings. They cut at random through the ore bodies, altered limestone, and other rocks with no apparent alteration or change in character. They are younger than the quartz diorite and the mineralization. Some dikes trend northeast, others nearly north. One particularly persistent dike, 2 to 4 feet wide, follows the limestone-quartz diorite contact on the north side of the main intrusive (pls. 35 and 36).

Most of the area surrounding the mine is underlain by thick deposits of talus and alluvium that accumulated in the bottom of the main gulch. Much of this detrital material is partly consolidated and was designated by Ross (1925, p. 18) as older alluvium. It is a poorly sorted aggregate of coarse gravel and subangular to rounded boulders of the older rocks, more or less firmly cemented by caliche. The more recent alluvium is unconsolidated slope wash and talus derived mainly from the andesitic rocks and older alluvium. The two types of alluvium are not differentiated on plate 33.

STRUCTURE

The limestone strata in the vicinity of the mine have a general southeastward dip of about 10°, but local dips may vary considerably from the general trend, particularly near igneous contacts. The Cretaceous(?) volcanic rocks are too poorly bedded to show their true attitude, but they appear to be nearly conformable with the underlying limestone.

The limestones and volcanic rocks in the mine area have been intruded by a small stock of quartz diorite. The outcrop of the stock is largely obscured by alluvium and talus, hence its boundaries at the surface can be only approximately determined. The west end and part of the south contact are well exposed in the mine workings. In plan, the stock is roughly elliptical with its long axis trending about N. 60° E. Its dimensions are about 1,500 by 3,000 feet. The Christmas fault cuts northwestward across the central part of the stock, and the block east of the fault has been relatively depressed, which brings the volcanic rocks against the limestones west of the fault.

At the west end, the quartz diorite mass fringes out into a number of narrow dikes that dip steeply toward the north (pls. 35 and 36). The same is true of the east end, where several dikes extend into the volcanic rocks beyond the main mass. This dike structure at the ends of the body suggests that the quartz diorite was intruded along a system of east-striking fractures, probably at their intersection with the Christmas fault. The fact that the outcrop of the quartz diorite shows very little lateral offset at the fault suggests that some, if not most, of the displacement occurred before the intrusion. It is uncertain that any appreciable displacement occurred along the east-striking fractures. The location of the base of the Martin limestone, as determined by drill holes 23D and 24B (pl. 41) on opposite sides of the quartz diorite body, indicates a smaller angle of dip than the assumed regional dip, but the difference is not large enough to justify any estimate of possible displacement. The bedding in the narrow blocks between the dikes shows little if any change from the normal attitude of the limestone strata.

Between the surface and the 500 level of the mine, the south contact is fairly regular with only a few major apophyses, mostly on or below the 400 level. It strikes about N. 75° W. and dips 45°–75° NE. The contact is generally sharp and is marked by clay gouge and minor slip planes; but in a few places it is serrated by many small, discontinuous sills pushed out between the limestone beds. These sills are especially prominent in sections having a large proportion of interbedded shale which the magma has partly or wholly assimilated. Local flexures and minor thrust faults are common. The beds are commonly bent downward against the quartz diorite and show small rolls or wrinkles parallel to the contact; but in 512A stope on the 500 level, they are bent sharply upward against the contact.

Fractures and sheeted zones, either in the limestone or quartz diorite or both, are generally parallel to the contact. Cross fractures, many of which are mineralized, probably served as feeder channels for the copper-bearing solutions. Sills pushed out between the bedding planes caused displacement on certain fractures by lifting the overlying beds. Where this occurred, the sills end abruptly against vertical or steeply dipping faults. Many of the minor diplacements of the beds are believed to have been caused in this way.

Except for a few short workings from the old Hackberry shaft, which are now caved, the Christmas mine is entirely within the upthrown or footwall block west of the Christmas fault. The only exploration of any consequence in the down-thrown block was by means of No. 4 shaft which was sunk in the volcanic rocks about 1,600 feet northeast of the Christmas fault. The purpose of this shaft, according to report, was at least partly to explore for the limestone below the volcanic rocks. From a level 500 feet below the collar of the shaft (pl. 40), a vertical drill hole was put down 1,085 feet. According to the available records, the shaft and drill hole cut 1,585 feet of andesite and quartz diorite. The drill hole passed out of andesite into quartz diorite at 1,375 feet below the shaft collar, but undoubtedly this point does not represent the lower limit of the volcanic rocks.

Ross (1925, p. 22) regards the Christmas fault as a segment of a major fault zone that can be traced northwestward and southeastward from the mine for a total distance of 7½ miles. The displacement took place along a system of nearly parallel breaks which in places forms a zone more than 100 feet wide. This zone can be seen underground in the Hackberry workings on the north contact (pls. 35 and 41, sec. E–E′), where the mineralized beds are cut off by the fault, and also at the extreme northeast end of the 400 level (pl. 36). That at least part of the displacement was later than the intrusion and the copper mineralization is shown by blocks of quartz diorite and ore that occur in the fault zone where it is crossed by the 300 level adit. The total displacement on the Christmas fault cannot be determined, but from the evidence depicted on section C–C′ (pl. 40) the vertical throw along the fault zone can safely be assumed as at least 1,770 feet.

The outcrops east of the fault are so poor that little can be determined concerning the underlying structure except that the andesite-quartz diorite contact is very irregular. The interfingered quartz diorite and andesite cut by the shaft and tributary workings are badly faulted and fractured, and the ground is said to be so heavy that mine openings are difficult to maintain.

Below the 500 level, the quartz diorite mass seems to expand laterally; its contact with the limestone becomes very irregular, particularly below the 800 level. There are many irregular, dikelike apophyses and countless large and small discontinuous sills that extend out into the adjacent limestone. Development on the 600 and 800 levels indicates the presence of a thick, probably very irregular, sill-like body that extends for some distance along the south contact. It is probably the counterpart of this sill that forms the floor of the limestone in the broad bay on the northwest side of the stock (pls. 35, 36, and 41). Drill holes sunk to explore the south contact below the 800 level show many alternating intersections of quartz diorite and altered limestone, and no definite location for the contact could be determined. On the north side of the intrusive, drilling showed such complex relationships as to defy attempts to interpret the structure or to correlate from one hole to another with any reasonable degree of certainty. There are some blocks of limestone that appear to be completely engulfed by the quartz diorite. These complex intrusive relationships appear to coincide roughly with the zone in which the quartz diorite intrudes the thick pure crystalline limestone beds of the Escabrosa.

MINERAL DEPOSITS

The mineral deposits of the Christmas area are all of the contact metamorphic or pyrometasomatic type. The ore bodies are replacements of limestone around the borders of the quartz diorite stock (pls. 34–37, 41).

The scope of this investigation did not permit a detailed mineralogical study of the ore, and the following discussion of the minerals is based on a rather superficial megascopic examination of the ore and gangue. A few of the gangue minerals were identified by microscopic examination of oil immersions. The principal metallic minerals of the primary ore are pyrite, chalcopyrite, bornite, magnetite, and specular hematite. Small amounts of sphalerite and galena are commonly present, and molybdenite occurs in a few places, mainly on the upper levels. At the time the mill was operated, the ore was not assayed for molybdenum. Pyrite and magnetite are abundant close to the contacts and in the ore in the narrow blocks of limestone between the quartz diorite dikes at the west end of the intrusive body. Magnetite becomes increasingly abundant with depth, and much of the ore found on the 800 level and below contains so much magnetite that it completely masks the primary copper minerals. Practically all the ore that has been mined above the 800 level is partly oxidized and contains more or less chalcocite, covellite, cuprite, native copper, and copper carbonates.

The gangue of the ore is mainly green and brown garnet, idocrase, epidote, quartz, unreplaced limestone, and generally some clay and chlorite. Diopside and tremolite are prominent gangue minerals in the ore that replaced the dolomitic limestone in the lower part of the Martin. A little anhydrite occurs in some of the ore from the deeper levels. Chert bands and nodules in the limestone are replaced by wollastonite in the altered zone. In recent years the ore has carried from 23 to 31 percent CaO, which makes a desirable flux for smelting copper concentrates.

A typical analysis of the ore is as follows:

Gold	0.005 oz. per ton.	Alumina	1.7 percent.
Silver	0.23 oz. per ton.	Sulfur	3.6 percent.
Copper	2.04 percent.	Iron	12.8 percent.
Silica	33.2 percent.	Lime	28.2 percent.

GEOLOGIC CONTROLS OF THE MINERALIZATION

There are four prerequisites for the localization of ore bodies in the Christmas mine. The first and most important of these is proximity to the limestone-quartz diorite contact; the second is the favorable character of certain limestone beds; the third is garnetization of the favorable beds; and the fourth is faulting and fracturing that followed garnetization.

The main channels of the mineralizing solutions appear to have been along the contacts between the limestone and the quartz diorite, and most of the ore bodies are in the limestone close to the borders of the main quartz diorite mass or along the walls of dikes that extend outward from the main mass. In some places, particularly in the large bay of limestone at the west end of the intrusive shown on plate 35, the mineralizing solutions followed minor faults and fractures and replaced beds that are a considerable distance from the contact. The distance to which metallization extends depends largely on the extent of garnetization and the presence of post-garnetization fractures. In some places, especially along the walls of dikes, ore may lie directly against the quartz diorite, but along the main contacts there is generally a zone of low-grade material between the ore bodies and the quartz diorite. Since the contact is not usually exposed in the stopes, the width of this zone is uncertain, but probably it rarely exceeds 25 feet.

Precisely what characteristic of the limestone beds determines the difference in susceptibility to replacement is not clear, but the selection of certain definite beds by the mineralizing solutions is very consistent. Originally, most of the ore-bearing beds were relatively pure limestone, but many of the unmineralized beds are pure also. A few of the consistently mineralized beds are impure and cherty, but generally the ore in them is not as good as that in the purer beds. The outstanding characteristic of the ore beds is that they are relatively thin units which occur in a series of alternating shale and limestone.

Garnetization of the limestone is an important prerequisite of metallization. Garnetized beds are not always ore bearing, but beds that have not been garnetized are nowhere sufficiently metallized to constitute ore. The ore bodies occur only where the contact alteration was sufficiently intense to produce abundant garnet in the limestone beds, and the size of the ore bodies is limited by the width of the altered zone.

The width of the garnet zone differs considerably from place to place. Its extent was influenced by faults and fractures that preceded or accompanied the intrusion of the quartz diorite. Where fracturing occurred, the solutions or gases that caused the alteration were able to permeate to greater distances from the contact. The fractures that preceded the garnetization have been largely obscured and healed by alteration and recrystallization of the limestone but in places can still be recognized.

Fracturing that followed garnetization had a far greater influence on the localization of ore bodies than the earlier fractures. In some places, garnetized rock has been mineralized where no fracturing is apparent, but in most stopes it is quite apparent that the shape of the ore bodies was governed by the fracture pattern. Irregularities in the outlines of the stopes occur as the result of fractures that have permitted mineralizing solutions to permeate farther into the garnetized limestone than elsewhere. Similar irregularities may have been caused, however, by the garnetization pattern, which in turn was governed by the pregarnetization fractures. The ore does not extend beyond the limits of the garnet rock regardless of the pattern of subsequent fracturing. The effect of fracturing on the thickness of the ore is not so marked, because most of the ore bodies are bounded top and bottom by shale beds which appear to have been nearly impermeable to the copper-bearing solutions.

ORE BODIES IN THE NACO LIMESTONE

Practically all the past production of the mine has been from ore bodies in the Naco limestone. On the north side of the quartz diorite body, the ore occurs in 9 distinct beds that constitute a zone about 300 feet thick. These mineralized beds are known locally as the Las Novias, 250, 235, 220, 205, Johnny, 85, 50, and Upper Copper Knob—named or numbered after the original stope in each bed (pl. 42). The bottom of this zone is a little below the 300 level; the upper beds crop out in the canyon north of No. 3 shaft. Other beds higher in the section are mineralized along the south side of the intrusive body.

The Las Novias beds at the bottom of the zone are three or possibly four massive beds that behave more or less as a unit. This group of beds is 60 feet thick and is bounded at both top and bottom by persistent shale beds. Thin shale partings commonly occur between the beds in the lower part of the group, but as a rule they are not persistent and not always clear enough to be recognized. In places the entire group is mineralized, but generally only one or two beds are sufficiently rich in copper to constitute ore. Where adjacent beds are mineralized, they are mined as one stope, but usually the stopes are one above the other and are separated by floors of waste or low-grade material. The floor plans of a tier of stopes may show little or no similarity in size and shape.

The Las Novias beds on the north side of the quartz diorite are especially susceptible to replacement and are usually mineralized wherever they occur in favorable relationship to the contact. The ore is reported to have carried from 3 to 4 percent copper, which is considerably more than the average for the mine. Because of the great thickness of the beds, they have undoubtedly produced more ore than all the other north-side beds combined.

The remaining eight beds of the productive zone range from 6 to 12 feet in thickness. They are separated by prominent shale partings that make up from one-third to one-half of the total section.

The 250 and 205 beds were the next most productive beds on the north side of the intrusive body. They are relatively pure limestones and, like the Las Novias, contained ore of superior grade.

The 220 and 235 beds are rather impure limestones, in part shaly and cherty. They are not consistently mineralized, but under favorable conditions they have been host to ore bodies which are generally below the average in copper content.

The Johnny bed is above the 205 bed and is separated from it by 47 feet of interbedded shale and thin flaggy limestone. Generally only the lower 6 feet of the bed is ore, but in some places the upper part of the bed is sufficiently mineralized to make ore.

The stopes in the 85 and 50 beds on the north side of the quartz diorite are not extensive, mainly because those parts of the beds that were within the limits of mineralization have been largely removed by erosion. The Johnny, 85, 50, and Upper Copper Knob beds crop out in the canyon north of No. 3 shaft. Little is known concerning the extent of the Upper Copper Knob ore because it was mined from an opencut that is now partly concealed by a dump. According to report, the ore averaged 2.8 percent copper. Erosion has removed all the other favorable beds on the north side of the quartz diorite that were close enough to the contact to have been reached by the copper-bearing solutions.

The ore bodies conform with the bedding of the limestone and consist of a series of flat or gently dipping tabular bodies that extend outward from the margins of the quartz diorite stock (pl. 41). The average width of all the stopes along the south contact is about 53 feet, but mineralized rock of ore grade commonly extends as much as 150 feet from the limestone-quartz diorite contact. The distance to which ore extends depends largely on the extent of garnetization and the presence of postgarnetization fractures. The formation of the lime silicates preceded the deposition of the metallic minerals and appears to have been a prerequisite of metallization.

Because the ore bodies in the Naco limestone are confined to a certain group of limestone beds, a method was sought whereby these favorable beds could be identified throughout the mine and particularly on the south side of the quartz diorite body. The individual limestone beds appeared to possess no unique characteristics by which they could be recognized with any degree of certainty, especially where they had been affected by such extreme and variable degrees of alteration as prevail in those parts of the mine in which the beds are mineralized. However, regardless of the state of alteration, the shale partings can usually be distinguished from the limestone, and the pattern presented by the interbedded series of limestone and shale appeared to be distinctive enough to serve as a means of correlation.

A section was first measured in 321A and 346A raises where the longest continuous sequence of beds is exposed (pl. 41, sec. D–D′). Then sections were measured in all the accessible raises on the north side of the quartz diorite body. In some of these sections, beds that could be traced laterally through the mine workings or that could be definitely identified served as markers. The measured sections were then plotted to a common scale and pieced together into a composite master section which extended from the 400 level to the highest stopes on the north side (pl. 42). No accessible raises could be found in which satisfactory sections could be measured below the 400 level.

Comparison of sections that are known to be equivalent shows that the general pattern of the limestone and shale sequence is reasonably consistent within the limits of the mine area. Although some of the minor shale bands are not persistent, the more prominent shale beds carry through but commonly show considerable variation in thickness from place to place. The pattern is complicated by the presence of many quartz diorite sills, some of which have been intruded between the limestone strata, generally at the shale partings, whereas others appear to have formed by granitization of shale beds and grade laterally into shale. It is often difficult to distinguish between the highly metamorphosed shale beds and the fine-grained intruded sills. Some of the variations in the measured sections may be due to this difficulty, but undoubtedly some are caused by different shrinkage of the beds resulting from different degrees of metamorphism. Furthermore, not all limestone-shale contacts are sharp; some are gradational from shale to limy shale to limestone. Thus in highly altered beds some blending takes place, which may result in minor discrepancies in thickness measurements of individual beds. However, the comparison of equivalent sections in various parts of the mine has shown the degree of conformity that could be expected.

Sections were then measured in all accessible raises in the workings south of the diorite intrusive. Another section was compiled, partly from underground measurements and partly from surface mapping, of the Old Christmas workings at the extreme east end of the mine. When the north and south sections were compared, they presented in part different patterns, but showed reasonably clear overlap between the lower part of the south sections and the upper part of the north sections. On the basis of this overlap, the 530A stope (pl. 43) is believed to be in the Johnny bed. The massive 39-foot J bed along the south contact is believed to be the same as the Upper Copper Knob bed on the north side, and the ore-bearing series is increased to 11 beds by the addition of the OX–14 and OX–15 beds. Other stratigraphically higher beds have been mined on the south side of the quartz diorite, but, as in most of the underlying beds, the stopes are caved and no data concerning them can be obtained except from incomplete mine records. Thus the Johnny is the lowest bed in the series to be consistently stoped south of the diorite, and therefore the 205, 220, 235, 250, and Las Novias series of beds lie below; that is, between the 400 and 600 levels. On the basis of this interpretation it appeared reasonable to assume that these beds were mineralized and probably contain ore bodies. Subsequent diamond drilling by the Bureau of Mines proved this assumption to be justified (pl. 43).

ORE BODIES IN THE ESCABROSA AND MARTIN LIMESTONES

Several small ore bodies have been found by development on the 800 level, and others have been discovered by drilling below the level. The ore bodies replace the massive or thick-bedded Escabrosa limestone. In contrast with the flat, tabular deposits in the Naco limestone, those in the Escabrosa that have been mined or sufficiently developed to reveal their shape are thick, irregular bodies that lie like a shell against the contact. Others are replacements of narrow slivers of limestone between dikes or small blocks that may be completely engulfed by the quartz diorite. Some bodies are known only from drill-hole intersection, hence little can be discovered concerning their shape or size.

In order to explore the south contact, the Bureau of Mines selected a drilling site at the east end of 808 drift on the 800 level (pl. 37). The eastern part of the drift is in quartz diorite which was believed to be a thick sill. It was uncertain whether the main contact was to the north or to the south of the drilling site. A vertical hole (23A) drilled by the Bureau of Mines showed quartz diorite to a depth of 200 feet (pl. 41, sec. F–F′). A hole (23B) inclined 45° from the horizontal was then drilled southward. It passed through quartz diorite for 323 feet, beyond which it showed alternating intersections of quartz diorite and garnetized limestone that contained from 0.5 to 2.5 percent copper. The last 15 feet of the hole was in unmineralized white marble. Apparently the hole had passed through the sill-like body but was too far south of the main contact to find mineralized limestone.

A third hole (23D) was drilled at a steeper angle, 57° from the horizontal. It passed through 480 feet of quartz diorite into hornfels and altered limestone. The last 30 feet of the hole is in quartzite that apparently is the basal part of the Martin and probably includes some of the upper beds of the Cambrian system. The hornfels undoubtedly represents the shale at the top of the Martin limestone. Directly below the quartz diorite, the hole intersected 110 feet of altered limestone—probably in the lower part of the Escabrosa—that averaged 2.48 percent copper, and 133 feet of limestone a little above the quartzite that averaged 2.37 percent copper. The lower mineralized limestone contained abundant diopside and tremolite and is the metamorphosed equivalent of the dolomitic limestone in the lower part of the Martin.

The sill-like apophysis of quartz diorite appears to coincide roughly with the position of the Escabrosa limestone, and it probably continues eastward along the contact to the Christmas fault. Its structure suggests that it splits up into thin sills that probably pinch out a few hundred feet to the south. If so, the limestone along the south edge is likely to be mineralized and may contain ore bodies. The thickness of the stratigraphic section indicates that the quartz diorite comprising this projection stoped its way into the limestone and was not intruded between the beds.

The only available drilling site from which exploration of the north contact could be attempted was at the north end of the 817 drift on the 800 level (pl. 37). The last 125 feet of this drift is in quartz diorite which previous drilling had proved to be a thin sill. The intrusive relationships in this general locality are very complex, and there was no clue as to the direction in which the main contact might be found.

A vertical hole (24B) intersected a small body of altered limestone directly below the sill (pl. 41) and about 436 feet of quartz diorite. At a depth of 506 feet it passed from quartz diorite into Martin limestone, and at a depth of 650 feet into quartzite. Except for two thin sills of hornblende porphyry, it continued in quartzite for 130 feet to a total depth of 781 feet. The upper part of this quartzite probably is the basal part of the Martin, but the remainder undoubtedly is of Cambrian age. The lower part of the limestone contains abundant diopside and tremolite as in drill hole 23D. It is slightly mineralized, and a segment of core 57 feet long averaged 1.54 percent copper.

Another hole (24E) drilled from the same site was directed N. 25° W. and inclined about 68° from horizontal. The drill passed through 118 feet of well-mineralized limestone under the sill and 215 feet of quartz diorite. It entered limestone at 360 feet and quartzite at 652 feet from the collar and penetrated about 50 feet of Escabrosa limestone and the entire section of Martin limestone. A segment of core 41 feet long in the Escabrosa averaged 2.85 percent copper, and another 65 feet long in the lower part of the Martin averaged a little more than 2 percent copper.

A third drill hole (24D) in the same vertical plane as the other two but inclined 30° from horizontal passed out of the main quartz diorite body into unmineralized white marble at 392 feet from the collar. All three drill holes apparently intersected the main north contact which, in the plane of the drill holes, dips southward 30° to 50°; however, it is uncertain that the plane is normal to the contact, and the dip may be considerably steeper. In the plane of the drill holes, the north contact on the 300 and 400 levels is about 250 feet south of its position in hole 24D, hence the north side of the stock also appears to have a bulge along the zone in which the quartz diorite intrudes the Escabrosa limestone.

Drill holes 24A, 24C, 24D, and 24E intersected ore of superior grade in what appears to be an inclusion of limestone just below the drilling site. Development work preparatory to its extraction is under way.

The ore bodies that have been found on and below the 800 level prove that the Escabrosa limestone is a favorable host rock. These ore bodies are much thicker than those in the Naco, but probably do not extend as far away from the contact. The known ore bodies are all either in the upper or lower part of the formation; the contact between the quartz diorite and the middle part is beyond the reach of the present mine workings and has not been explored.

The mineralized Escabrosa limestone is soft and granular and contains a large amount of clay. It is very incompetent, and mine workings in it are difficult to maintain, especially if the ground is wet.

The three drill holes that penetrated the Martin all found the thin-bedded, shaly, and dolomitic limestone in the lower part of the formation to be well mineralized. This zone is extensively mineralized and contained many small ore bodies on the London-Arizona and other properties, 2 miles west of Christmas where it is known as the O'Carroll ore bed.

The 800 level is developed only at the west end of the quartz diorite where the intrusive body breaks up into narrow dikes. If, as on the upper levels of the mine, the contact becomes more regular toward the east, larger and more continuous ore bodies can reasonably be expected. At the east, the limestones are cut off by the Christmas fault; but because the fault dips northeast, the eastward extent of the contacts increases with depth.

OXIDATION AND ENRICHMENT

According to report, oxidation of sulfides was nearly complete in some of the ore bodies mined above the 300 level, especially those that cropped out. The ore now being mined, as well as that developed by Bureau of Mines drilling along the south contact, is partly oxidized.

From 1928 to 1932, when the mill was in operation, most of the ore came from the south stopes and was partly oxidized, but satisfactory recovery was accomplished by flotation preceded by sulfide filming.

The structure and composition of the Christmas ore bodies are unfavorable for enrichment by supergene processes. The flat-lying ore bodies are relatively thin and are separated by barren limestone and shale beds which are nearly impervious and prevent downward circulation of groundwater except along fractures. In all the ore bodies which can now be observed, sufficient unreplaced limestone remains in the gangue to prevent the transportation of copper for more than a few feet. That some migration of copper did take place is shown by masses of chalcocite and native copper found in some stopes. The enrichment accomplished was of no economic importance, as it took place entirely within beds too thin to be mined selectively. Some oxidation has occurred at the deepest level reached by the drill holes, but this is of no economic significance except insofar as it would affect mill recovery by flotation.

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