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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TO ACCOMPANY MAP GQ-1391

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GEOLOGIC MAP OF THE HAYDEN QUADRANGLE, PINAL AND GILA COUNTIES, ARIZONA

By Norman G. Banks and Medora H. Krieger

GENERAL GEOLOGY

The main physiographic feature of the Hayden quadrangle is the Dripping Spring Mountains, which trend northwest-southeast through the center of the map area and consist of Precambrian, Paleozoic, and Cretaceous rocks that are intruded by a wide variety of Cretaceous and Tertiary dikes and sills. The range is bounded on the north by the Dripping Spring Valley and on the south by the Gila River Valley. Both valleys were depositional basins for thick colluvial and lake sediments of Miocene age. Oligocene sediments have been exposed by faulting and erosion in the Gila River Valley but not in the Dripping Spring Valley. Complexly faulted Precambrian rocks crop out in the southwest corner of the quadrangle.

The oldest rock exposed in the quadrangle is the Ruin Granite of Precambrian Y age. It is unconformably overlain by Precambrian Y sedimentary and volcanic rocks of the Apache Group and the Troy Quartzite, which were deposited mainly in shallow marine environments; significant disconformities exist in this section. These Precambrian rocks are intruded by Precambrian Y diabase sills and dikes. Faulting accompanying intrusion of the sills did not appreciably tilt the large blocks of intruded sedimentary rock. Topographic relief developed by the intrusion and faulting during the Precambrian was greatly subdued but not entirely removed by erosion prior to Middle and Late Cambrian deposition of the Bolsa Quartzite and Abrigo Formation in shallow marine waters. Erosion and probable nondeposition during Ordovician, Silurian, and Early Devonian time removed only part of the relief remaining after deposition of the Cambrian sedimentary rocks; this resulted in a variable lithology and thickness for the Late Devonian Martin Formation. Slight tilting and faulting occurred during the long interval of early Paleozoic erosion. Dominance of stromatolitic structures and sublithographic dolomite in the Martin Formation suggests that it was deposited primarily near, or in, the intertidal zone. The overlying Upper Devonian Percha Shale (Schumacher and others, 1976) was deposited in a deeper marine environment.

The overlying Mississippian Escabrosa Limestone is locally slightly clastic and does not contain age-diagnostic fossils in its basal few meters, but above this interval, Osagean fossils have been identified (A. K. Armstrong, written commun., 1973), suggesting that a measurable period of erosion occurred in latest Devonian and earliest Mississippian time. Perceptible tilting did not occur during this erosional interval. Dominance of micritic and fine-grained limestone in the lower half of the Escabrosa Limestone suggests that it was deposited in relatively quiet, perhaps deep marine waters; bioclastic debris is much more abundant in the upper part of the formation, which suggests a comparatively more turbulent, perhaps shallower, marine environment during its deposition. Incomplete dolomitization occurs locally in both the basal and upper beds of the formation; dominance of saccharoidal dolomite and bleached and recrystallized chert in the basal dolomite beds suggests that the required magnesium solutions had a hydrothermal source, whereas sublithographic dolomite and pristine chert in the upper beds suggest that the upper incomplete dolomitization occurred by seepage reflux, perhaps from Pennsylvanian seawater. Silification and local solution brecciation of the uppermost beds (deposited in Meramecian time; A. K. Armstrong, written commun., 1973) occurred during late Mississippian or earliest Pennsylvanian erosion but was not accompanied by tilting or faulting.

The erosion produced topographic relief on the Escabrosa Limestone and a varied lithology and thickness in the basal parts of the overlying sedimentary rocks, which contain no age-diagnostic macrofossils or fusulinids. S. B. Keith (oral commun., 1975) reports Late Mississippian conodonts for these basal beds. Overlying beds of the Naco Limestone were deposited during Morrowan (A. K. Armstrong, written commun., 1973) and perhaps through earliest Permian (Peterson and Swanson, 1956) time in a marine environment that fluctuated between conditions favorable to shale deposition and conditions favorable to deposition of chert-bearing carbonates. The Permian parts of these sedimentary rocks, if deposited in the quadrangle, were removed by erosion prior to deposition of the Late Cretaceous basaltic Williamson Canyon Volcanics. During this erosional period or during eruption of the volcanic rocks, olivine basalt locally intruded the Paleozoic section, preferentially forming sills a few meters to tens of meters thick at specific horizons of the Abrigo and Martin Formations and the Escabrosa and Naco Limestones.

Eruption of the Williamson Canyon Volcanics was dominated by explosive activity. As indicated by megabreccia slides of Naco Limestone and older rocks in the volcanic pile in sec. 13, T. 4 S., R. 15 E., it also must have been accompanied or preceded by folding and faulting, perhaps along some of the major north-striking and north-west-striking faults used earlier for access by the Precambrian diabase. Deposition of the volcanic rocks was followed, and perhaps in part accompanied, by the development of a large number of generally east-striking faults, fissure faults, and generally northwest-oriented folds, by intrusion of dikes and sills of andesitic to quartz latitic rock, and only locally by development of intrusive breccias and pebble dikes. Field relations and correlation of petrologically identical rocks in this quadrangle with those in adjoining quadrangles suggest that deposition of the major sulfide ore bodies in the quadrangle occurred after most of these intrusive rocks were emplaced, or about 60 m.y. ago (Banks and others, 1972; Banks and Stuckless, 1973).

Tilting of the layered strata and movement on the major north-striking faults and on some of the east-west-striking faults recurred after deposition of ore but prior to deposition of the thick Oligocene and Miocene sedimentary formations—the San Manuel Formation, the Big Dome Formation, and the deposits in the Dripping Spring Valley. On some of these faults, movement and tilting of strata also occurred during, between, and after deposition of the Tertiary formations in the Gila River Valley.

Post-Miocene events recorded in the rocks of the quadrangle include erosion, faulting, development and then dissection of several pediment surfaces; deposition of several thin clastic units; deposition of travertine along some faults; and development of present drainage and accompanying older and younger alluvial deposits.

STRUCTURE

Geologic structure in the Dripping Spring Mountains is dominated by an intricately patterned fault mosaic superimposed on a gently dipping sequence of rocks that have been arched into a broad, open anticline, plunging to the southeast (see also Eastlick, 1968). This general structure can be further classified into (1) the major northwest-southeast-oriented anticline, (2) minor folds with axial planes also oriented generally northwest-southeast, (3) four major north-south fault systems, (4) two major northwest-southeast-trending fault systems parallel to and near the Miocene sedimentary basins, and (5) many faults oriented 0°-35° north and south of east-west. Tilting of adjacent fault blocks during the faulting resulted in the extremely complex geologic relations of the range; the east-westerly faults provided the major channelways for emplacement of the Laramide igneous rocks.

From west to east across the quadrangle, the major north-south fault systems are the Cowboy, Kelly Springs, Keystone, and O'Carroll faults. The occurrence of Precambrian diabase sills at different stratigraphic horizons across the first three of these fault systems suggests that they were active during emplacement of the diabase, but data neither determine nor negate Precambrian movement on the O'Carroll fault. Combined Precambrian to post-Laramide normal displacement on these north-south fault systems locally is slightly more than 900 m, but individual strands typically show less normal displacement, and total displacement along each system varies along strike. For example, the greatest stratigraphic displacements on the Kelly Springs and O'Carroll faults occur near the north edge of the range, whereas those along the Keystone and Cowboy faults occur near the south edge. One or more strands of each fault system are cut by the Laramide dikes, whereas others cut the dikes, indicating that although major displacements occurred along the fault systems after deposition of the Williamson Canyon Volcanics and prior to intrusion of Laramide dikes, some strands had continued or recurrent activity after intrusion of the Laramide dikes. Some apparent strike-slip displacements along the fault systems are indicated by offset of individual dikes and dike sets, but their magnitudes are variable. For example, an intrusive breccia is offset in an apparent left-lateral direction by the Cowboy fault system near the north edge of the quadrangle. North of this breccia, a distinctive rhyodacite dike cropping out along the quadrangle boundary is also offset left laterally 600 m into the El Capitan Mountain quadrangle. Just south of the breccia, another distinctive dike is offset approximately 500 m, but in sec. 7, T. 4 S., R. 15 E., although Laramide dikes are cut by various fault strands. lateral offset is negligible. Apparent lateral offset of Laramide dikes also progressively decreased southward along the Kelly fault system and northward along the Keystone fault system. Although strands of the O'Carroll fault cut some of the dikes, lateral displacement is neither large nor consistent. At least part of the apparent lateral displacement along the north-south fault systems may reflect tilting of the blocks between them.

Faults are most closely spaced near the intersections between the major north-south fault systems and the two major northwest-southeast fault systems that bound the Dripping Spring Mountains on the northeast and southwest. The northwest-southeast range-front faults were active both prior to and after emplacement of the Laramide dikes, and in the Sonora quadrangle, at least one of the range-front faults moved during emplacement of the Precambrian diabase (Metz and Rose, 1966; Cornwall and others, 1971). These major fault zones may have resulted from a right-lateral shear couple along the range-front faults with complementary movement along the north-south faults. However, large lateral movement on the range-front faults is not compatible with slight offset of Laramide dikes and Precambrian contacts across the Gila River - Mineral Creek Valley (Cornwall, Brooks, and Phillips, 1971). East of the town of Hayden the range-front fault on the southwest side of the mountains displaces the Miocene Big Dome Formation, but significant post-Miocene displacement did not occur on this fault north of Keystone Canyon or along the range-front fault north of the mountains.

Displacement along the many faults oriented 0°-35° north and south of east-west are much smaller than the major north-south-striking and range-front faults discussed above, and many are fissure fractures with little or no displacement. Most of these east-westerly faults apparently developed during Laramide time because many are both parallel to and intruded by the Laramide dikes. Thus, both the major and minor fault systems, and the minor northwest-southeast-oriented folds whose hinge regions were intruded by Laramide dikes, had major development during Laramide time. These structures therefore provided ground preparation for fluid (magma and hydrothermal) access during the time that sulfide ore bodies developed in this and the adjacent quadrangles, and interpretation of the stress responsible for their formation is of potential economic interest.

The thin east-westerly dikes did not have enough thermal energy to stope their way through at least 600 m of carbonate rocks in the exposed section, and they do not show evidence of calcium-magnesium assimilation (no pyroxene). They likewise show only rare evidence of forceful intrusion. Thus, their abundance, lateral continuity, and narrowness suggest that they were most likely intruded in a tectonic environment involving northwest-southeast extension or tension. This condition could have resulted from generally northwest-southeast directed right-lateral tectonic shearing or approximately east-directed compression. However, the left lateral offset of the Laramide dikes on the major north-south faults is not compatiable with right lateral movement on the range-front faults, and east-west compression is supported by the observed northwesterly folds and the general anticlinal character of the Dripping Spring Mountains. It also is suggested on a more

regional scale
sulfide ve
Ariz

regional scale by similar orientation of dikes and sulfide veinlets in nearby quadrangles and elsewhere in Arizona (Cornwall and others, 1971; Cornwall and Krieger, 1975a, b; Krieger, 1974a, b; Willden, 1964; Rehrig and Heidrick, 1972) and by northwest-striking thrust faults to the southwest (Krieger, 1974c). This approximately east-directed compression might have originated in movement of lithospheric plates in Laramide time. Because each dike set in the Hayden quadrangle has its own particular northeast and northwest orientations that are not matched exactly by those of the next younger dike set, the orientation of regional stress probably fluctuated with time during Laramide igneous and structural activity. Thus, both dikes and sulfide veinlets may occupy tensional features, and exploration basinward along projections of the most extensive dike swarms, which indicate potentially favorable channelways for deep fluid sources, could be profitable. Alternatively, because the sulfide veinlets cut the Laramide rocks, the sulfide-bearing fluids might have traveled still another set of fractures oriented east-westerly but not necessarily on or parallel to the particular set of dikes on which a deposit might center. Thus, if all the Laramide sulfide deposits in the quadrangle developed at approximately the same time, the zone of major fluid access might have extended N. 80° W. from Christmas mine through the New Year, Chilito, and 79 mines, which suggests possible exploration ground N. 80° W. of 79 mine and N. 100° E. of Christmas mine. It is noteworthy that N. 80° W. of the 79 mine in Miocene alluvial deposits are manganese oxide-barite-jasperoid deposits (presumably hot springs deposits) that carry base metal anomalies and, as expected, that base metal anomalies in the bedrock parallel the zone occupied by the major known sulfide deposits rather than any particular dike swarm (N. G. Banks and R. D. Dockter, unpub. data).

Only a small part of the Tortilla Mountains occurs in the Hayden quadrangle (southwest corner). The structure of complexly faulted bedrock in this part of the quadrangle is discussed by Krieger (1974c).

MINERAL DEPOSITS

Some of the metallization and alteration associated with the Christmas deposit, owned by Inspiration Consolidated Copper Co., occurs at the east-central edge of the quadrangle in secs. 19, and 30, T. 4 S., R. 15 E. (unsurveyed). From discovery through 1974, the deposit produced 279,250,300 pounds of copper (J. T. Eastlick, written commun., 1975), first in surface and underground mining of replacement beds in the Martin Formation, and the Escabrosa and Naco Limestones and later by open-pit mining, part of which includes stockwork mineralization. More detailed descriptions of the deposit are found in Eastlick (1968), Willden (1964), Peterson and Swanson (1956), and Ross (1925).

About 3 km northwest of the Christmas deposit in SW cor. sec. 13 and NW cor. sec. 24, T. 4 S., R. 15 E., is Santa Montica Camp (originally the Premier mining group reported by Ross, 1925). About 400 m of adits and drifts have been made in the area, and about $70,000 worth of gold was reportedly produced from one of the main workings (J. T. Eastlick, written commun., 1975). The gold occurs as native gold in thin seams with iron and manganese oxides. The copper mineralization occurs as oxidized veins and replacement ore bodies immediately adjacent to the veins. At the surface, these veins are mostly jasper or spongy quartz, heavily stained with hematite, jarosite, and goethite; some veins show one or more of the following: manganese oxides, cerussite, anglesite, galena, copper carbonates, wulfenite, vanadinite, and hemimorphite.

The New Year mine, about 2.5 km N. 80° W. of Christmas mine, produced about 1,000 tons of lead ore and about 50 tons of zinc ore according to Ross (1925); there are four or more shafts including the Curtain shaft (reportedly 100 m deep, J. T. Eastlick, written commun., 1975), several adits, many prospect pits, and other surface workings. Alteration minerals in igneous rocks of the area include quartz-sericite, kaolinite, and propylitic minerals (epidote, chlorite, carbonate), and carbonate rocks have been variably converted to skarn. Eastlick (1968) reports galena, anglesite, cerussite, and hemimorphite as the major ore minerals.

About 1.5 km N. 80° W. of New Year mine is the Chilito mine (Kennecott Copper Corp.), a small- to medium-sized stockwork-vein-disseminated porphyry copper deposit presently (1975) worked under contract to provide silica flux for the Kennecott Copper Corp. smelter at Hayden. Alteration minerals include hydrothermal biotite, quartz-sericite, epidote, chlorite, and carbonate minerals. Hypogene chalcopyrite, pyrite, molybdenite, and anhydrite are present in the relatively unoxidized parts; at least $200,000 of supergene chalcocite ore was produced from the Schneider claims prior to 1913 (Ransome, 1923) in secondarily enriched pyrite in replaced beds of the Mescal Limestone west of the present open pit. Chilito produced about $1¼ million worth of ore during World War I (Eastlick, 1968).

Mineralization probably associated with Chilito encouraged development of small producing mines 1 km northeast (Apex or San Bernardo Jr. mine), and also east, southeast (Lavell mines), and south (London-Arizona mine) of Chilito along the east side of Schneider Canyon. Most of this mining activity focused on the upper beds of the Abrigo Formation and on the O'Carroll bed (local name) in the Martin Formation. The largest producer was the London-Arizona mine (about $1 million; Eastlick, 1968). The Lavell mines are said to have produced about $10,000 worth of gold ore (Ransome, 1923); the Apex mine produced about $20,000 worth of gold from oxidized lead ore and also some high-grade gold ore (Ross, 1925); and the London-Arizona produced at least 15,000 tons of ore averaging 4.5 percent copper. Minerals associated with these deposits include chalcopyrite, pyrite, pyrrhotite, copper carbonates, cuprite, chalcocite, cerussite, galena, wulfenite, native gold, andradite, specularite, quartz, idocrase, magnetite, serpentine, and anhydrite.

A few small adits and prospect pits that probably shipped no ore occur within 1 km to the northwest and southwest of Chilito mine. A little over 1 km southwest of London-Arizona mine, some workings in the upper Abrigo Formation and lower Martin Formation may have produced a few carloads of ore (probably gold) from oxidized veins and replacement bodies; the Hogvall prospect (Ross, 1925) is among these workings.

The 79 mine, in the approximate center of the quadrangle, was discovered in 1879 and worked intermittently through the 1950's. Production prior to 1947 was about 110,000 tons of mixed oxide and sulfide ore valued at between $3 million and $4 million (Kiersch, 1947). The ore came from vein and bedding replacement ore primarily in the Martin Formation and Naco Limestone (Eastlick, 1968; Keith, 1972). In addition to surface workings, the mine includes the main incline, seven levels, and over 3,000 m of tunnels and stopes (Keith, 1972). Near the surface is oxidized galena ore with cerussite, anglesite, sphalerite, chalcopyrite, descloizite, vanadinite, wulfenite, hematite, and some pyrite and copper carbonates. The zinc content of the ore increases with depth (Eastlick, 1968). The ore deposits at the mine are discussed in detail by Kiersch (1947), and a more complete list of minerals present in the mine is presented by Keith (1972). Many prospect pits, small shafts, and adits are scattered in sec. 21 and along its border with sec. 22, T. 4 S., R. 15 E., to the north of the main 79 mine workings.

Along Keystone Canyon, 1½ km south of 79 mine, are the Regan Camp prospects. Kiersch (1947) reported that several carloads of oxidized lead ore were produced from the irregular and scattered workings, mostly in replacement ore bodies and veins along a fault cutting Naco Limestone, south of Keystone Canyon. In addition to the oxidized galena ore, wulfenite, vanadinite, and copper carbonates occur on the prospect dumps. Similar minerals and also manganese oxides occur on the dump of the Overland mine near SE cor. sec. 28, T. 4 S., R. 15 E.; this mine consists of a main shaft and probably a few short tunnels that may have produced one or two carloads of oxidized lead ore.

Just north of the quadrangle is the Barbarosa mine, reported by Ransome (1923) to have produced $2,000–$3,000 worth of gold by dry washing alluvium deposited on Troy Quartzite on gully slopes. Associated workings occur in this quadrangle in and east of sec. 36, T. 3 S., R. 14 E. The gold most likely came from vein and replacement ore in the overlying Abrigo Formation and Martin Formation. Several prospects in Mescal Limestone, south of the Barbarosa mine in this quadrangle, show oxidized lead-zinc minerals.

Extensive jasperoid-barite reefs and associated crosscutting manganese oxide and carbonate veins and bedding replacement bodies occur in the Miocene Big Dome Formation in an area of over a square mile centered in NW cor. sec. 19, T. 4 S., R. 15 E. Both the jasperoid-barite and manganese-carbonate mineralization extends into nearby older rocks. The strongest veining is oriented northwest-southeast. The mineralization carries base metal and vanadium-tungsten anomalies, and copper staining was observed at several localities (N. G. Banks and R. D. Dockter, unpub. data). Prospecting of the deposit has been extensive, but it is estimated that less than 1,000 tons of high-grade manganese ore has been shipped from the properties. High-grade manganese ore is better developed in the southeast part of the deposit relative to the northwest part. The geologic location, colloform banding of the jasperoid and manganese, mineralogy, open vugs, and a mercury-antimony anomaly favor a hot-spring origin for the deposit. Its position westward along the projection of a chain of Laramide sulfide deposits suggests that remobilized Laramide sulfides might account for the base metal anomaly.

About ½ km northeast of Kelly Springs are several prospects and minor shafts with oxidized galena, sphalerite, smithsonite, and minor amounts of copper carbonate. Silver concentrations of 1,100 ppm were detected in a sample of lead-rich rock from the dump of one prospect.

Scattered prospects on generally weak shows of mineralization are peripheral to each of the mining localities described above. Mineral showings in addition to those described above occur east of Hayden on the north and south sides of the Gila River and also along epidote alteration zones in the volcanic rocks southwest of the Christmas mine.

ACKNOWLEDGMENTS

The writers are very grateful to the Inspiration Consolidated Copper Co., particularly Chief Geologist, John T. Eastlick, for access to its properties, drill hole information for the 79, London-Arizona, and New Year mines, and for maps, history, and production of workings between the Christmas and Chilito mines. The management and geologic staff of Kennecott Copper Corp., Ray Mines Division, in particular Neil A. Gambell, Charles H. Phillips, Donald S. Fountain, and Steven A. Hoelscher, were equally helpful with similar information concerning the jasperoid-manganese deposit south of Steamboat Mountain and the Chilito properties. Bernardo and Connie Velasco provided friendship and access to and information about their properties north of Chilito mine. We are also grateful for the access granted us by the several ranchers in and near the quadrangle, particularly to Walter and Wynonna Barrup who provided a site and facilities for one season's base camp.

Augustus K. Armstrong provided us with his unpublished fossil and stratigraphic data from the Escabrosa and Naco Limestones and also correlated several fossil collections from the Naco Limestone with his sections. Randolph A. Koski provided some thin sections from the Williamson Canyon Volcanics.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qd MINE DUMP – Waste from open-pit mining operations

Qal ALLUVIUM – Gravel, sand, and silt deposits in stream channels and on young low-lying terraces along streams

Qt TALUS – Accumulations of large to small angular blocks at or near the base of cliffs and steep slopes

Qls LANDSLIDE DEPOSITS – Several slides of Naco Limestone in sections 35 and 36, T. 4 S., R. 15 E., and one coherent slide block and accompanying debris along the Gila River (Sec. 12, T. 5 S., R. 15 E.)

Qtr TRAVERTINE – Calcium carbonate deposits occurring along faults in Steamboat Wash (secs. 1 and 12, T. 4 S., R. 14 E.) and east of Hayden townsite

Qp SOIL AND GRAVEL VENEER (0–8 m) – Reddish-brown soil and gravel with subangular to subrounded pebble to boulder clasts from older rocks. Deposited on terrace surfaces of several ages along the Gila River Valley, Dripping Spring Wash, and major drainages out of the Dripping Spring Mountains. Limestone clasts are rare even where deposits overlie carbonate rocks or limestone conglomerate

Qog OLDER GRAVELS (0–15 m) – Grayish to yellowish-white carbonate-cemented gravels and conglomerates deposited along but at higher levels than present channels, streams, and washes. Clasts are subrounded pebbles, cobbles, and small boulders of older rocks exposed along adjacent drainage. Includes deposits of several ages

QTv VEINS – Red jasperoid-barite-manganese oxide and manganese oxide-calcite veins and replacement bodies with local base metal anomalies

DEPOSITS IN DRIPPING SPRING VALLEY (0–>460 m) – Interfingering alluvial and lakebed deposits exposed in the Dripping Spring Valley; age unknown, tentatively correlated with Big Dome Formation on the basis of lithology but part might be as young as Quiburis Formation (Miocene or Pliocene age) of San Pedro Valley

Tgv CONGLOMERATE (0–>150 m) – Facies dominated by angular to subangular pebble- to boulder-size clasts of Williamson Canyon Volcanics and Cretaceous and Tertiary intrusive rocks. Matrix is greenish gray, sand size, and composed mainly of decomposed volcanic and intrusive rocks. Induration is poor to slight

Tg CONGLOMERATE (0–>460 m) – Conglomerate facies with subangular to subrounded clasts representing all pre-Miocene rocks in proportions and size that vary with proximity to and composition of the adjacent bedrock exposures. Matrix of silt- to small-pebble-size material (varying with composition of adjacent bedrock) is well cemented, particularly near bedrock, and is light olive gray to light tans and browns. Poorly sorted and bedded near bedrock; moderately well sorted and bedded in transitional facies with lakebed facies

Tl CLAY, SILT, AND SAND (0–unknown but at least 300 m) – Lakebed facies; interbedded clay, silt, and fine sand. Clay-rich beds, locally with lenses and veins of gypsum, are most abundant near and south of SE cor. sec. 35, T. 3 S., R. 15 E. The clay-rich beds, probably representing the center of the depositional basin, are orange pink to very pale brown and grade southwestward and northeastward into grayish beds containing progressively more silt and then progressively more sand; beds of freshwater limestone are present and become increasingly abundant on the east side of the basin. Interbedded tuffs (<3 m) are most apparent north of Dripping Spring Wash; alteration of the tuffs is variable; glass shards in one tuff have a refractive index slightly greater than 1.495

BIG DOME FORMATION (0–> 460 m) – An alluvial deposit having four facies in this quadrangle (see also Krieger and others, 1974; Cornwall and Krieger, 1975a) and two interbedded tuffs, one of which gives K-Ar ages of 14 m.y. (biotite) and 17 m.y. (hornblende) (Cornwall and others, 1971; Banks and others, 1972)

Tbg CONGLOMERATE (0–>300 m) – Facies dominated by subangular pebble- to boulder-size clasts of Ruin Granite and variable amounts of other pre-Miocene rocks; few clasts of Miocene Apache Leap Tuff (Peterson, 1969) and Paleozoic limestone except near boundary with sandstone and conglomerate facies. Matrix is pale-yellowish-brown to yellowish-gray sand-size material derived from decomposed and abraded granite. The clast/matrix ratio generally decreases northeastward. Beds are poorly indurated, bedded, and sorted. Shallow channeling is common. The main source area for this facies was to the west or south

Tbs SANDSTONE AND INTERBEDDED CONGLOMERATE (0–300 m) – Facies with arkosic, poorly indurated sandstone and interbedded conglomerate. The clasts consist of variable amounts of all pre-Miocene rocks. Matrix of the conglomerate is arkosic, calcareous, and sand sized. Large well-rounded clasts of Apache Leap Tuff (derived from northwest of the quadrangle) are common and locally abundant; conglomerate beds with limestone clasts dominant are abundant in basal beds. Facies occupies approximate center of the Big Dome Formation depositional basin

Tbl CONGLOMERATE (0–>460 m) – Facies dominated by subrounded pebble- to boulder-size clasts of Paleozoic limestone and variable, mostly minor, amounts of other pre-Miocene rocks. Matrix is light-gray, calcareous, and well-indurated sand- to granule-size material derived mostly from disintegration of Precambrian and Paleozoic sedimentary rocks

Tbv CONGLOMERATE (0–>400 m) – Facies dominated by angular to subangular pebble- to boulder-size clasts of Williamson Canyon Volcanics with locally abundant clasts of Cretaceous and Tertiary intrusive rocks. Clasts of Precambrian and Paleozoic sedimentary rocks are present but are subordinate in amount, especially close to bedrock outcrops. Clasts become smaller and less abundant relative to matrix southwestward from the bedrock contact. Matrix is greenish gray, sand size, and composed mainly of disintegrated volcanic and intrusive rocks. Induration is poor. Contains a few thin, highly altered white tuff beds that include clinoptilolite, a zeolite

Tblt LAPILLI TUFF (9 m) – Series of beds of thinly laminated to massive, white to tan, rhyolitic tuff, tuffaceous sandstone, and pumice lapilli tuff and interbedded sandstone and conglomerate lenses. Some shards and pumice lapilli are altered to clay minerals; glass in unaltered shards is rhyolitic (refractive index of 1.496). The lapilli are white (altered) or light gray (unaltered) and generally are 1–4 mm in diameter, although they are as much as 3 cm in diameter in middle bed where they are closely packed. Exposed in the SW¼ sec. 12, T. 4 S., R. 14 E.; widely exposed in adjacent Kearney quadrangle (Cornwall and Krieger, 1975a)

Tbq1 QUARTZ LATITE ASH-FLOW TUFF (6 m) – Nonwelded to partly welded ash-flow tuff; pinkish

57. Geology of the Christmas Mine and Vicinity, Banner Mining District, Arizona

JOHN T. EASTLICK*

Contents

Illustrations

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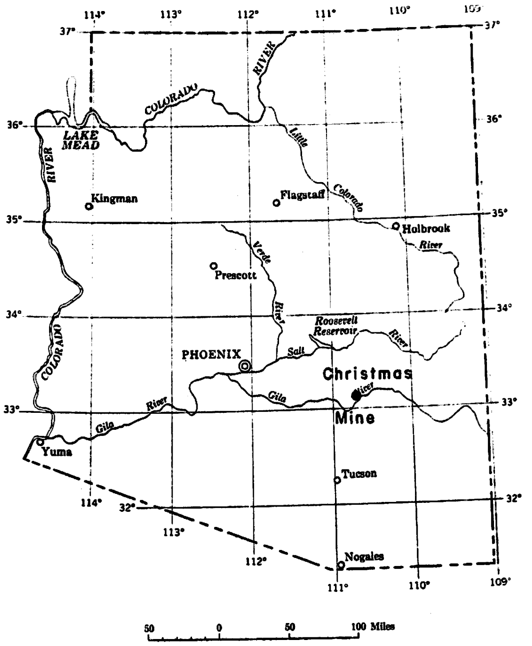
* Inspiration Consolidated Copper Company, Inspiration, Arizona.

Tables



ABSTRACT

The Banner mining district is about 70 miles northeast of Tucson in the southern part of Gila County, Arizona. Production from the district, valued at about $26 million, is chiefly from copper-silver-lead zinc ores.

The stratigraphic section consists of Precambrian conglomerates, quartzites, dolomites, and limestones, Cambrian quartzites; Devonian limestones; dolomites, and shales; Mississippian limestones; Pennsylvanian limestones and shales; and Cretaceous volcanic and sedimentary rocks. Deformation of these rocks presumably started near the end of the Cretaceous, and extended into the late Tertiary. The sedimentary rocks were folded, faulted, and intruded by fine grained diorite, quartz mica diorite, and dacite porphyry.

At least four distinct stages of mineralization are recognized. In the first stage of contact metamorphism and the second stage of hydrothermal alteration, favorable zones were prepared for ore deposition. Metallization occurred in three of the mineralizing stages. Magnetite, pyrite, and hematite were deposited near the end of the second stage of hydrothermal alteration. The third stage included the main deposition of sphalerite, chalcopyrite, bornite, and galena. In the fourth and final stage, minor amounts of sulfide minerals were deposited with a late anhydrite and quartz gangue.

The ore deposits in the form of veins and veinlets, pipes, irregular massive replacements, and bedded replacements are localized by the extent and distribution of metamorphic and hydrothermal alteration, by the proximity to the intrusive contacts, and by the effects of structural development.

Oxidized ores of copper, lead, and zinc constituted the principal production of the district prior to 1940, but, for the most part, supergene enrichment was of minor economic importance.

The ore bodies of the district are in the mesothermal class of deposits, occurring as normal metasomatic replacement and vein types.

INTRODUCTION

The Banner mining district is in the southern part of Gila County, Arizona, about 70 miles northeast of Tucson and 100 miles east of Phoenix. Nearby major mines include those at Ray and Superior, respectively 16 and 27 miles to the northwest; those in the Globe-Miami district, 25 miles to the north; and those at San Manuel, 26 miles to the south.

Hayden and Winkelman, the only towns in the district, are located about one mile apart at the southern end of the district. For livelihood, these towns depend largely on the operations of the copper-treating facilities of the Kennecott Copper Corporation and the American Smelting and Refining Company. They also serve as centers for an extensive cattle raising and farming industry. State Highway 77 connects the district with Tucson, 70 miles to the south, and with Globe, 25 miles to the north. Westward from Winkelman, State Highway 177 extends to Superior where it joins U.S. Highway 60-70. Secondary roads from the main highways lead to the various mines and prospects in the district.

A branch of the Southern Pacific Railroad connects Winkelman and Hayden with the main line of the system at Florence, Arizona.

HISTORY AND PRODUCTION

Most of the ore deposits in the Banner mining district were discovered in the late 1870's and early 1880's, but little ore was produced until after 1900. In the early years of production, the isolated location of the district, together with unstable economic conditions, contributed to the difficulty of maintaining a steady or profitable operation for any length of time.

The total value of mineral production from the district to 1964 is about $26 million. Copper is the principal metal produced, followed by lead and zinc. Gold ore has been mined from the several places, and both gold and silver are recovered as by-products from the copper, lead, and zinc ores. Minor amounts of vanadium have also been found in several prospects. Most of the copper ore deposits are uniform in grade, averaging between 1 to 4 per cent of copper, but local occurrences of oxidized ore containing up to 18 per cent copper were mined in the past. The greater portion of the lead came from bodies of oxidized lead ore that were generally of high-quality, containing from 22 to 24 per cent lead and from 4 to 5 ounces of silver per ton. Production of zinc was mainly from sulfide ores, but several shipments of high-grade zinc carbonate ore are recorded. The gold ore found was rich, but the bodies were small and pockety.

The Christmas mine is the largest in the district and is the only mine operating at the present. Discovered in 1880, the mine is credited with a total production through 1963 of 2,370,700 tons of ore that yielded 89,354,300 pounds of copper. Inspiration Consolidated Copper Company owns and operates the mine as its Christmas Division.

Notable amounts of ore have been produced from other mines in the district. Total production from the Seventy-Nine mine is valued between $3 to $4 million (2, p. 66). The Chilito mine is credited with a production of $1,250,000 during World War I, and the London-Arizona mine has a recorded production of $1,050,000 between 1912 and 1928 (4, p. 359, 368).

TABLE I. Gold, Silver, Copper, Lead, and Zinc Production in the Banner Mining District 1905–1963

Years	Gold	Silver	Copper	Lead	Zinc	Value
	(Ounces)	(Ounces)	(Pounds)	(Pounds)	(Pounds)	(Dollars)
1905–1949[1]	22,689	702,786	68,973,911	34,284,199	4,593,733	$15,877,996
1950[2]	257	6,130	1,352,200	59,200	2,500	304,148
1951	256	10,932	1,658,600	128,000	20,000	446,019
1952	149	7,720	1,359,400	63,100	51,500	359,920
1953	110	4,215	1,252,000	8,500	—	368,102
1954	152	5,153	1,465,400	—	—	442,277
1955	—	129	70,000	12,000	1,788	28,052
1956	3	293	241,400	—	—	102,965
1957	2	522	365,200	34,300	—	115,372
1958[3]	—	—	254,559	—	—	43,833
1959[4]	—	—	1,121,398	—	—	302,349
1960	—	—	334,794	—	—	151,669
1961	—	—	331,016	—	—	82,920
1962	—	—	4,465,319	—	—	1,654,337
1963	—	—	20,232,893	—	—	6,272,197

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[1] Data for the years 1905–1949 compiled by J. W. Anthony from Minerals Resources of the U.S. and U.S. Minerals Yearbooks; published by Arizona Bureau of Mines as totals for district, Bulletin No. 158, 1951, p. 66.

[2] Data for the years 1950–1957 taken from U.S. Bureau of Mines Minerals Yearbooks.

[3] Production figures from 1958 to 1963 furnished by G. Wainright, lessee of Chilito mine. Pounds of copper paid for by smelter. Published with permission.

[4] Production figures for years 1959, 1962, and 1963 include copper, gold, and silver produced by the Christmas mine. Adjusted from net smelter returns. Published with permission.

Production statistics for the Banner mining district for the years 1905 through 1963 are listed below in Table I.

PHYSIOGRAPHIC HISTORY AND PRESENT TOPOGRAPHY

The Banner mining district is in the southeastern part of the Dripping Springs Mountains, a northwest-trending fault-block mountain range, aligned with the Pinal Mountains to the northeast and with the Tortilla Mountains to the southwest. Structural valleys separating these ranges are deeply filled with lacustrine and fluviatile deposits.

Drainage patterns are strongly reflective of a complex fault system. Strong fault zones with northwesterly trends show evidence of recent movement along the flanks of the range, and other major faults with northerly alignment form prominent drainage features in the O'Carroll, Chocolate, and Keystone Canyons. Further geomorphic influences were provided by the smaller subsidiary faults and fractures, and by the character of the different rock formations.

The highest point in the district is Tam O'Shanter Peak at an altitude of 4639 feet above sea level. The lowest point is near Winkelman on the Gila River at an elevation of about 1950 feet. The mountainous area is rough and rugged with the surface dissected by many steep-sided gulches and canyons. Generally the higher points are capped by the harder, more resistant sedimentary formations, forming cliffs where the drainage has cut through into the softer beds below. Few flat upland areas remain.

The Gila River forms the southeastern boundary of the district, its channel cutting deeply into volcanic and sedimentary rocks. The river bed ranges from a few hundred feet wide in its narrowest parts to more than a thousand feet in width at its confluence with the larger tributaries of the area.

GEOLOGIC HISTORY

Stratigraphic Column

The southern part of the Dripping Springs Range is comprised of tilted, folded, and faulted blocks of sedimentary and volcanic rocks. Rock units range in age from Precambrian through Cretaceous, exceeding 6000 feet in total thickness.

Pre-Cretaceous sedimentary rocks, with the exception of the thick basal Cambrian and Precambrian quartzites, are largely of marine origin, consisting of limestone, dolomite, and shale.

The Cretaceous sequence include pyroclastic deposits and flows of basalt and andesite. Sedimentary beds occur at several places in the section but little is known of their extent or exact stratigraphic position.

The Precambrian Apache Group is intruded by sills and irregular bodies of diabase. In turn, all of the rocks of Cretaceous and older age are intruded by sills, plugs, dikes, and stocks of diorite and quartz-mica diorite and by dikes of later age of dacite, andesite, and basalt. Details of stratigraphy, thickness and character of the rocks exposed throughout the district are summarized in Table II.

STRUCTURE

The strata of the Dripping Springs Mountains form a complexly faulted, asymmetrical, southeasterly plunging anticlinal structure. Other principal structural features include a well-defined east-west belt of intrusive stocks, dikes, and sills, and a series of strong north to northwesterly striking faults.

Sedimentary beds along the northern side of the range have generally south to southeasterly dips of 10° to 30° and along the southwest side are tilted to the southwest with dips ranging between 20° and 40°. Superimposed along both sides of the range are numerous small folds and flexures. Compressive stresses are further reflected by local rolls in the bedding minor thrust faults, and slips along the bedding planes.

There are undoubtedly several different periods of faulting that occurred from pre-Devonian through Tertiary time. The existence of early zones of crustal weakness are shown by the several sets of generally east-west-trending intrusive dikes of quartz latite, quartz mica diorite porphyry, breccia, dacite porphyry, and andesite (Figure 1). It is probable that these bodies intruded, in part, along previous existing structures, and it is evident that later post-diorite, pre-mineral, and post-mineral faulting followed the same trends. The faults of this east-west group strike from N65°E to N70°W and dip from 50°N to 60°S.

Another system of pre-mineral faults strike approximately N15°E to N50°E and dip generally 50° to 65° northwest. Other pre-mineral structures include a complementary group with northwest trends.

Along the trend of the east-west dikes, sev-

TABLE II. Generalized Stratigraphic Section, Showing Igneous and Sedimentary Rocks in the Banner Mining District

Series	Formation	Thickness (in feet)	Character
Recent	Alluvium	100±	Gravel, sand, silt, clay, talus, and fanglomerate
Unconformity			
Tertiary	Gila Conglomerate	900±	Interbedded conglomerate, basalt, gravel, sand, sandstone, and gypsum, consisting of steam channel alluvium and lakebeds.
Unconformity			
Tertiary	Dikes		Narrow, generally N5°–25°W—trending olivine basalt dikes.
	Dikes		Hornblende andesite dikes trend generally N50°–60°E to east-west.
	Dikes		Dacite porphyry dikes—trend generally east-west, intruding diorite bodies and sedimentary rocks.
	Breccia dikes		Narrow dikelike bodies of injection breccia with quartzite and shale fragments in a matrix of comminuted quartz or diorite.
	Stocks, plugs, dikes, and sills		Intrusive bodies of quartz hornblende diorite, quartz biotite diorite, quartz monzonite porphyry, and granite porphyry.
Cretaceous and/or Tertiary	Siliceous dikes and irregular masses		Irregular silicious dikes consisting of microcrystalline quartz and feldspar. Quartz mica diorite intrudes these bodies.
	Stocks, plugs, dikes, and sills		Fine grained diorite
Unconformity			
Cretaceous	Unnamed	2000'–3000' 5'–10'	Andesite, basalt, and pyroclastic rocks with intercalated shale and limestone 5' to 10' conglomerate at the base of andesites near Christmas. Thickens to +1000' to the souhteast into a sedimentary sequence of conglomerate, siltstone, sandstone, and shale.
Unconformity			
Pennsylvanian	Naco Limestone (Upper member)	400±	Thick-bedded, light to dark gray crystalline limesotne wtih local chert nodules and thin shaly layers, containing abundant fusilinids.
	(Middle member)	500±	Thin to medium beds of limestone and shale, locally cherty, with abundant fossil fragments of crinoids, brachipods, and horn corals.
	(Lower member)	100±	Two beds of granular quartzite separated by thick bedded, gray, crystalline limestone in the upper 60 feet; fine to coarse grained crystalline limestone below with 5 feet of dark shale at the base.
Mississippian	Escabrosa Limestone	550±	Massive light gray, fine to coarse grained crystalline limestone; locally thin-bedded and cherty in the upper part.

Table II. Generalized Stratigraphic Section, Showing Igneous and Sedimentary Rocks in the Banner Mining District (Continued)

Series	Formation	Thickness (in feet)	Character
Devonian	Martin Limestone (Upper member)	65±	Thin-bedded shaly limestone, argillaceous and calcareous shales.
	(Middle member)	170±	Massive, light gray, fine grained crystalline limestone with thin quartzite beds in the upper part.
	O'Carroll bed	30±	Thin-bedded dolomite with interbedded limestone, shaoe, and shaly limestone at the base.
Unconformity			
Cambrian	Undivided	500	Calcareous and argillaceous quartzites with thin shales and limestone layers in the upper part; granuar quartzite with thin shale partings; angular conglomerate at the bottom.
Unconformity			
Precambrian	Troy Quartzite	900	Hard, dense quartzite and sandstone; pebble conglomerate at the base. Reassigned to Precambrian by Krieger (5).
Unconformity			
Precambrian (Apache Group)	Flow	50–75	Vesicular and amygdaloidal basalt
	Sills and irregular bodies		Diabase of several textural and compositional variations; intrudes all the rocks below the Troy formation.
	Mescal Limestone	250±	Sandy dolomites, cherty limestone, and marble
	Dripping Springs formation (Upper member)	75±	Tan to gray, fine grained, feldspathic quartzite; generally medium thick-bedded.
	(Middle member)	150±	Interbedded red-brown to gray quartzite and red shale
	(Lower member)	100±	Medium to thick bedded, gray to tan quartzite
	(Barnes Conglomerate member)	15–50	Well-rounded pebbles of quartzite and quartz in a matrix of arkosic sand. Reduced to rank of member. (Willden, 7, p. E 12)
	Pioneer Shale or Formation	200±	Reddish-brown to purplish shales, siltstones, and sandy silstotnes; characterized by numerous small oval greenish-gray spots.
	Scanlon Conglomerate	5–10	Well-rounded pebbles of quartzite and quartz in a matrix of arkosic sand. Reduced to rank of member (Willden, 7, p. E 12).
Unconformity			
Precambrian	Irregular bodies		Red to red-brown, coarse grained quartz monzonite; igneous rock similar in character and composition intrudes schist in the Tortilla Mountains to the south and in the Pinal Mountains to the north.

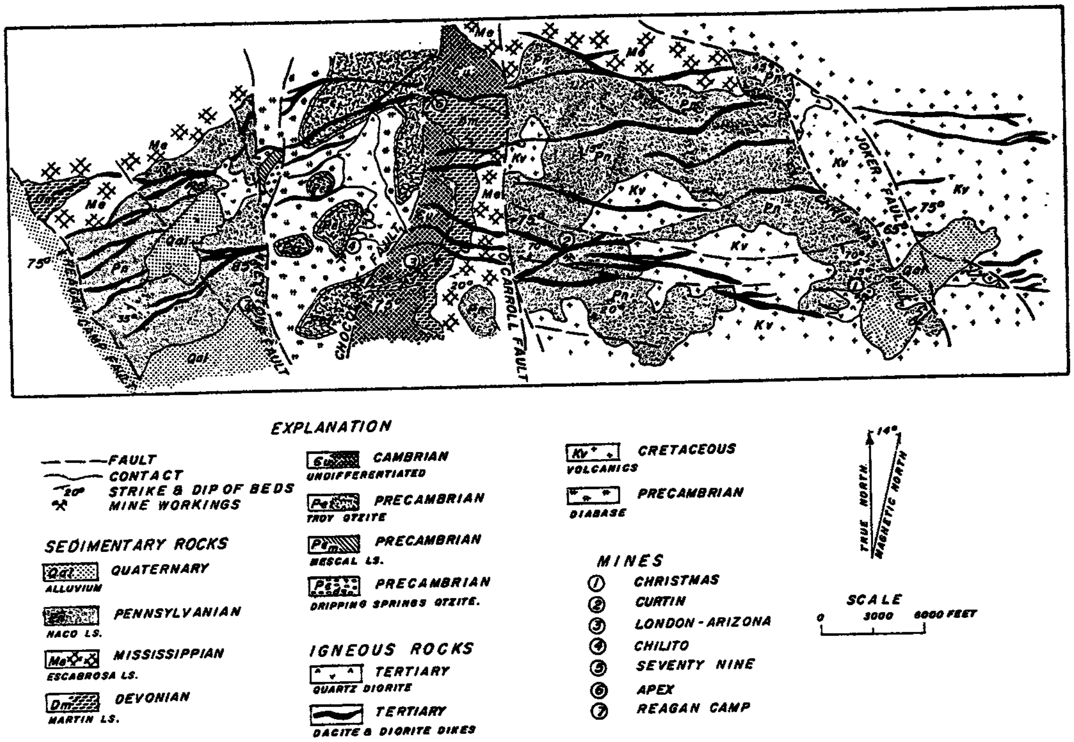


FIG. 1. *Generalized Geologic Map of Part of the Banner Mining District, Arizona.*

eral small stocks are exposed in the areas of the principal mines (Figure 1). The largest silicic intrusive body in the district is exposed north of the Christmas area, intruding the Cretaceous volcanics and extending to the northeast under the Tertiary gravels at the edge of the Dripping Springs Wash.

At the Christmas mine, the main quartz-mica diorite body is cut and offset by the Christmas-Joker fault zone. The surface outcrop forms an irregular elliptically-shaped mass, measuring approximately 4000 by 2000 feet with the long axis trending about N70°E. The west end narrows into several dikes with marked westerly trends. Four separate pre-mineral intrusive stages are recognized at Christmas. Coarse-grained quartz-mica diorite porphyry intrudes earlier fine-grained diorite and siliceous bodies, and later east-west trending dacite porphyry dikes invade and cut the coarser textured diorite.

Other small stocks occur at the Seventy-Nine and Chilito mines. At the Seventy-Nine mine, the outcrop of the stock is largely covered by alluvium, and its size can only be approximated. The northeast end is well-exposed and scattered surface exposures indicate its dimensions to be about 3000 feet by 1000 feet with the long axis trending about N65°E. Later dikes of pre-mineral quartz porphyry and post-mineral basalt intrude the main intrusive body.

The intrusive body at the Chilito mine, in contrast with the other dioritic stocks in the area, trends about due north along its long axis, forming an oval-shaped outcrop approximately 3800 feet by 1000 feet in the largest dimensions. Several dikes of dacite porphyry intrude the main body of quartz-mica diorite.

The major north-northwest-trending faults divide the Dripping Springs Mountains into several linear blocks. Along the northeast side of the range, the Christmas-Joker fault is traceable for about 7.5 miles and its continuation to the northwest is suggested by physiographic evidence. At the Christmas mine, Cretaceous volcanics are displaced downward into contact with the Naco formation of the footwall block (Figure 2). Further to the north, Gila conglomerate, showing evidence of recent movement, is in fault contact with the older Paleozoic rocks. Total displacement along the Christmas-Joker fault zone is indicated to be more than 2500 feet with a normal downthrow to the northeast.

Along the southwest side of the range to the west of the Seventy-Nine mine, another northwest-striking fault zone, known as the

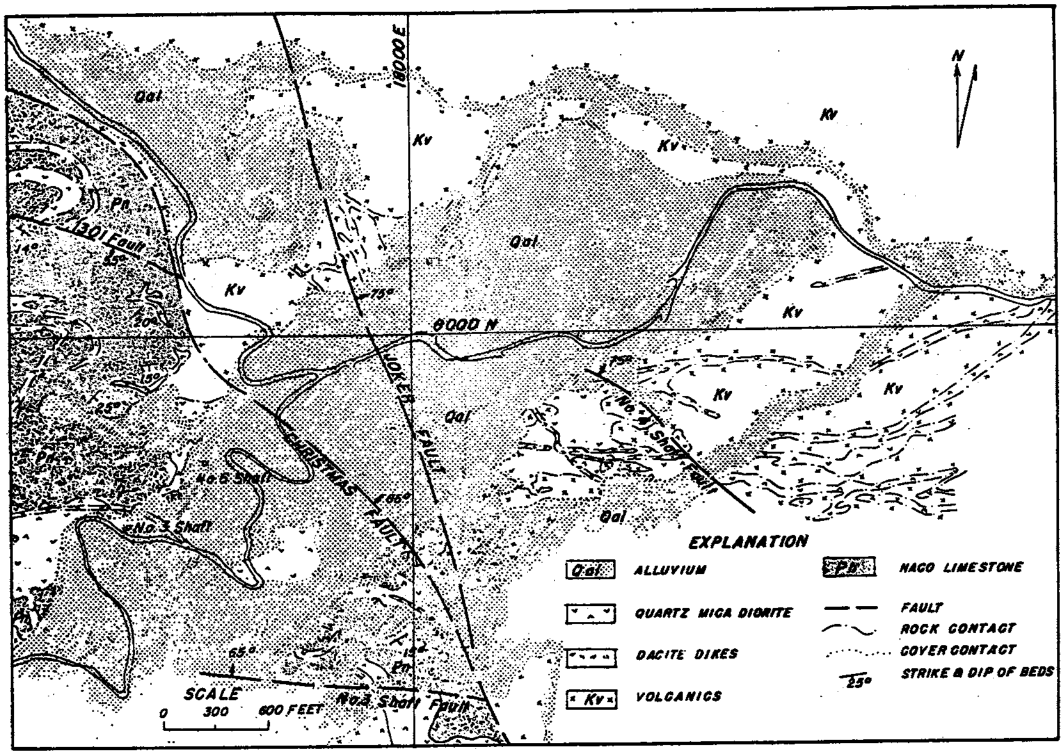


FIG. 2. *Surface Geology, Christmas Mine, Arizona.*

Reagan Camp fault, is exposed. Movement is normal, with a downthrown block moving to the southwest.

Between these two northwest-striking faults are a series of strong north-trending faults. From east to west, these include the O'Carroll, the Chocolate, and the Keystone faults. All have normal movement. The O'Carroll and the Chocolate faults dip to the east with displacements of about 1200 feet and 1400 feet, respectively. The Keystone fault dips west with a total displacement of over 2000 feet. Displacements along the major north to northwest fault zones appear to be largely post-mineral, evidently the result of late structural adjustment of the gravity type.

Numerous narrow post-mineral olivine basalt dikes represent the youngest stage of igneous intrusion. These steeply-dipping dikes trend generally north to northwest, paralleling the strike of the regional block-faulting pattern.

Age of Mineralization

The sequence of geologic events leading up to the period of ore deposition is well-established. The hypogene ore deposits are younger than the fine grained diorite, the siliceous bodies, the quartz-mica diorite porphyry, and the dacite porphyry. They are older than hornblende andesite and the olivine basalt. Two separate periods—that of hydrothermal alteration and that of ore deposition—are recognized between the dacite and andesite intrusions. Both of these periods appear to have a close genetic relationship to structural events following the emplacement of the dacite porphyry dikes.

Recently, an age determination of biotite from the quartz-mica diorite intrusive in the Christmas mine was dated at 62 million years (6, p. D4). This would indicate an early Tertiary age for the emplacement of the quartz-mica diorite stocks. It is probable that the time span between the intrusion of the quartz diorite and the deposition of the ore was, geologically speaking, short. This would place the period of ore deposition also in the early Tertiary.

ECONOMIC GEOLOGY—PRIMARY ORE

Forms of Ore Bodies

The ore deposits of the Banner district occur in four structural types. These are: (1) bedded replacement in certain stratigraphic horizons;

(2) irregular massive replacements along the edges of intrusive contacts; (3) pipe-like replacements at the intersections of shear and fracture zones; and (4) vein deposits along fissures.

Bedded Replacement Deposits The bedded deposits form the largest of the ore bodies and are the most common type in the district. Notable examples of these tabular deposits occur in Naco and Devonian limestones at the Christmas mine, in the lower Devonian strata at the London-Arizona mine, in the Naco limestone at the Seventy-Nine mine, and in the Mescal limestone at the Chilito mine.

The most persistent ore-bearing bed is the lower twenty to thirty feet of the limestone Devonian Martin, locally known as the O'Carroll bed. At the Christmas mine, mineralization in the Martin limestone extends from above the 1300 level on the north side of the intrusive contact to below the 1600 level on the south side (Figure 3). Along the north contact zone, the mineralized zone is exposed for 2200 feet along strike and for 1100 feet at its widest part up-dip along the bedding. The mineralized deposit on the south side is about 3300 feet in strike length along the intrusive contact, extending approximately 1400 feet down-dip. Generally, the mineralization is thickest adjacent to the main intrusive mass, although thicker sections sometimes occur along premineral fissure zones and near the contacts of the smaller dioritic dikes. Heights vary between 55 to 80 feet in the thicker portions of the ore body to about 10 feet in thickness at the outer extremities.

At the London-Arizona mine, the lower Devonian ore body is well-exposed for about 3000 feet along the east and southeast side of Chocolate Canyon. Here the deposit has been stoped in the better mineralized zones for 150 to 200 feet down-dip along the bedding throughout a thickness of 10 to 30 feet. This mineralized bed is in the hanging-wall (east) block of the Chocolate fault, approximately 2000 feet to the southeast of the Chilito quartz-mica diorite stock. The exposures of the London-Arizona ore deposit probably represent the outer peripheral zone of a major ore body with the portions towards the main intrusive contact being eroded away.

At the Christmas mine, the ore deposits in the Naco outcrop at the surface on both sides of the main quartz mica diorite intrusive mass, extending to below the 600 level at the north contact and to below the 800 level on the south side. At least six different stratigraphic zones are recognized, each of which is comprised of two or more distinct mineralized beds. These mineralized zones, constituting a total section of about 700 feet, are known locally as the Pinnacle, the "J," the "K," the "L," the Los Novias, and the "M" series. The individual beds that comprise these series are described in detail by Peterson and Swanson (3, p. 365–368). These range between 6 and 60 feet in thickness, with mineralization in certain beds extending laterally from 50 to 400 feet away from the central intrusive mass. Generally the pure limestones were more receptive to mineralization than the impure limestone beds, although both rock types are the hosts to important ore bodies. Shales, hornfels, and fine-grained diorite sills usually separate the different mineralized beds, and these, in places, are sufficiently mineralized to constitute ore.

To the east in the hanging-wall side of the Christmas fault (Figure 2) the Naco beds are displaced downward approximately 1300 feet relative to those in the footwall block. Along the north side of the contact, the topmost Pinnacle bed is found just below the 800 level, and part of the Los Novias series is exposed on the 1300 level. The upper mineralized portion of the "M" series is on the 1600 level. Within each of the fault blocks, faulting, igneous intrusion, and metamorphism complicate the geological picture. Identification of the various units that comprise the Naco section have been in doubt in many cases, and it has been only recently that many of the geological problems have been solved.

The bedded ore deposits in the Naco sediments at the Seventy-Nine mine (Figure 1), as described by Kiersch (2, p. 73, 74) are much smaller in extent than those at Christmas. Two of the larger bedded ore bodies—the Discovery ore body which outcrops at the surface and the Massive Pyrite ore body which is exposed between the 5th and 6th levels—average about 50 feet in thickness and generally extend only 200 to 300 feet laterally along the strike of the bedding. Mineralization in these bodies selectively replaces fractured, thin-bedded, calcareous shales and limestones, following along the dip of the beds for several hundred feet. At least five other bedded zones were locally well enough mineralized to be mined as shipping-grade ore.

At the Chilito mine (Figure 1), ore was mined from several beds in the Mescal formation, the most important of which is just below the base of the Troy Quartzite. Ross (1, p. 63) describes the occurrence of the ore as discontinuous replacement deposits; however, extensive intrusion of diabase together with

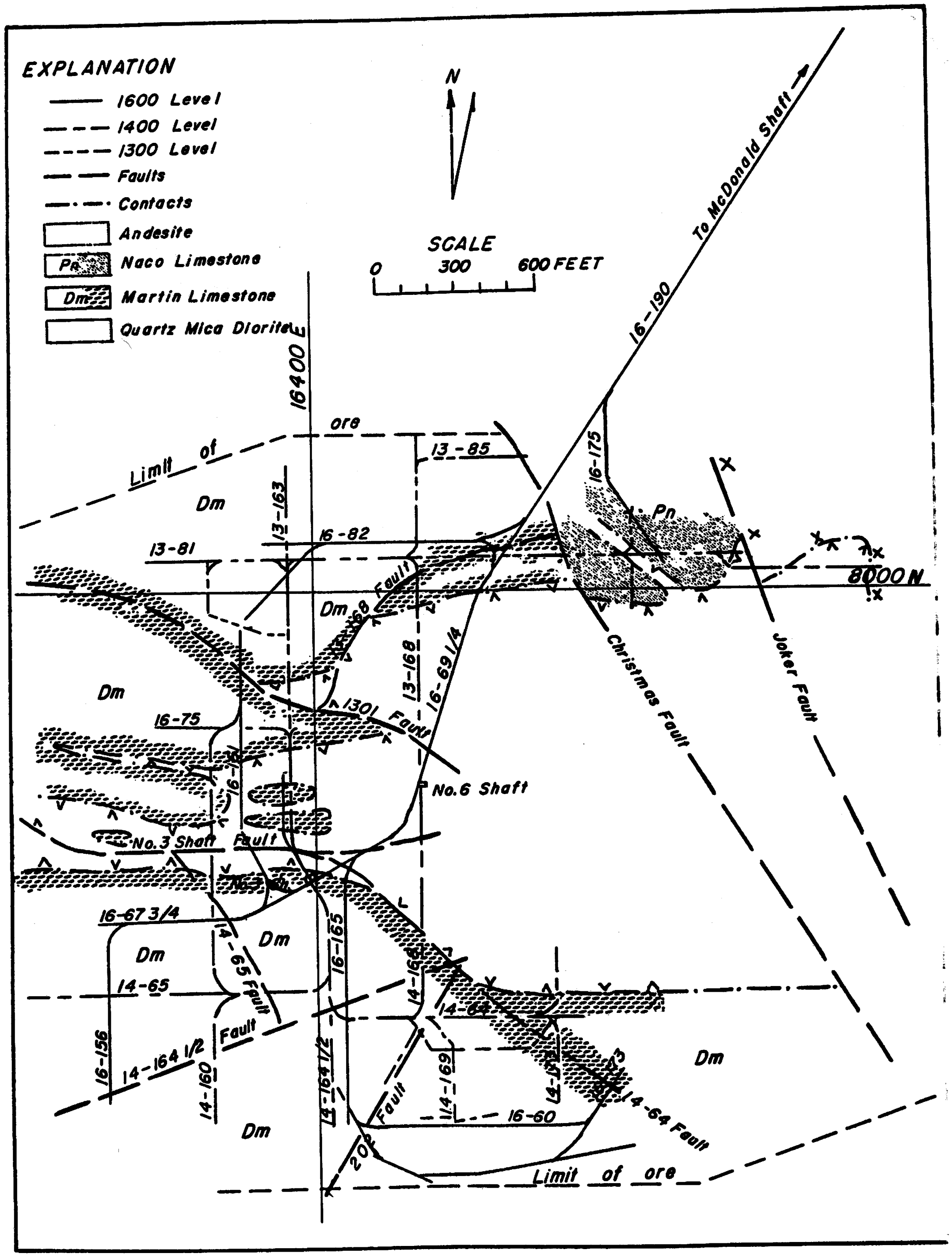


FIG. 3. *Composite Map of Lower Levels, Christmas Mine, Arizona. Symbols for Tertiary quartz diorite and Cretaceous volcanics (andesite) are those used in Figures 1 and 2.*

faulting complicates the geology of the area. Most of the mine workings are now caved, and little is known about the extent of the ore bodies. There is little doubt, however, that the ore bodies at the Chilito and the London-Arizona mines are parts of the same deposit.

IRREGULAR REPLACEMENT ORE BODIES In the district, the only important irregular replacement ore deposits are at the Christmas mine in the upper and lower parts of the Escabrosa limestone.

The characteristics of these deposits are shown by the ore bodies developed in the upper part of the Escabrosa on and below the 800 level. The largest of these ore bodies occur as massive, irregular replacements adjacent to the north and south intrusive borders. Along the north side of the intrusive, the ore zone roughly parallels the contact for at least 1200 feet, averaging about 75 feet wide and 150 feet in height. A similar mineralized zone is developed along 1500 feet of the south side of the intrusive. Here, the vertical dimension averages about 300 feet in height, with an horizontal thickness of 100 feet away from the contact. Other large deposits are found in blocks of limestones completely surrounded by quartz-mica diorite and in limestone embayments between westerly projecting dikes.

The vertical extent of mineralization is limited by thick diorite sills at the top and bottom of the ore section. Laterally away from the intrusive contacts, the ore bodies usually terminate against marbleized limestone.

Little is known of the extent of the ore deposits in the lower part of the Escabrosa. The few diamond-drill-hole penetrations through these mineralized zones indicate ore with the same general characteristics as that in the upper part of the formation.

PIPE-LIKE ORE DEPOSITS Recent work at Christmas proves the existence of several pipe or chimney ore bodies in the hanging wall of the Joker fault zone (Figure 2). These mineralized pipes occur within the main quartz-mica diorite mass adjacent to the andesite-intrusive contact zone. The ore bodies extending from above the 800 level to below the 1300 level rake steeply to the northeast along the intersection of a series of N20°E trending fissures with a N80° to 85°W striking shear zone. Generally, these bodies are small, with an average cross sectional area of about 60 feet by 40 feet. The long axes of the pipes parallel the strikes of the northeast fissure zones with mineralization narrowing into veins and veinlets to the northeast. Surrounding these pipe-like ore bodies is a halo of weaker mineralization formed by a stockwork of numerous irregular veinlets of quartz and sulfide mineral.

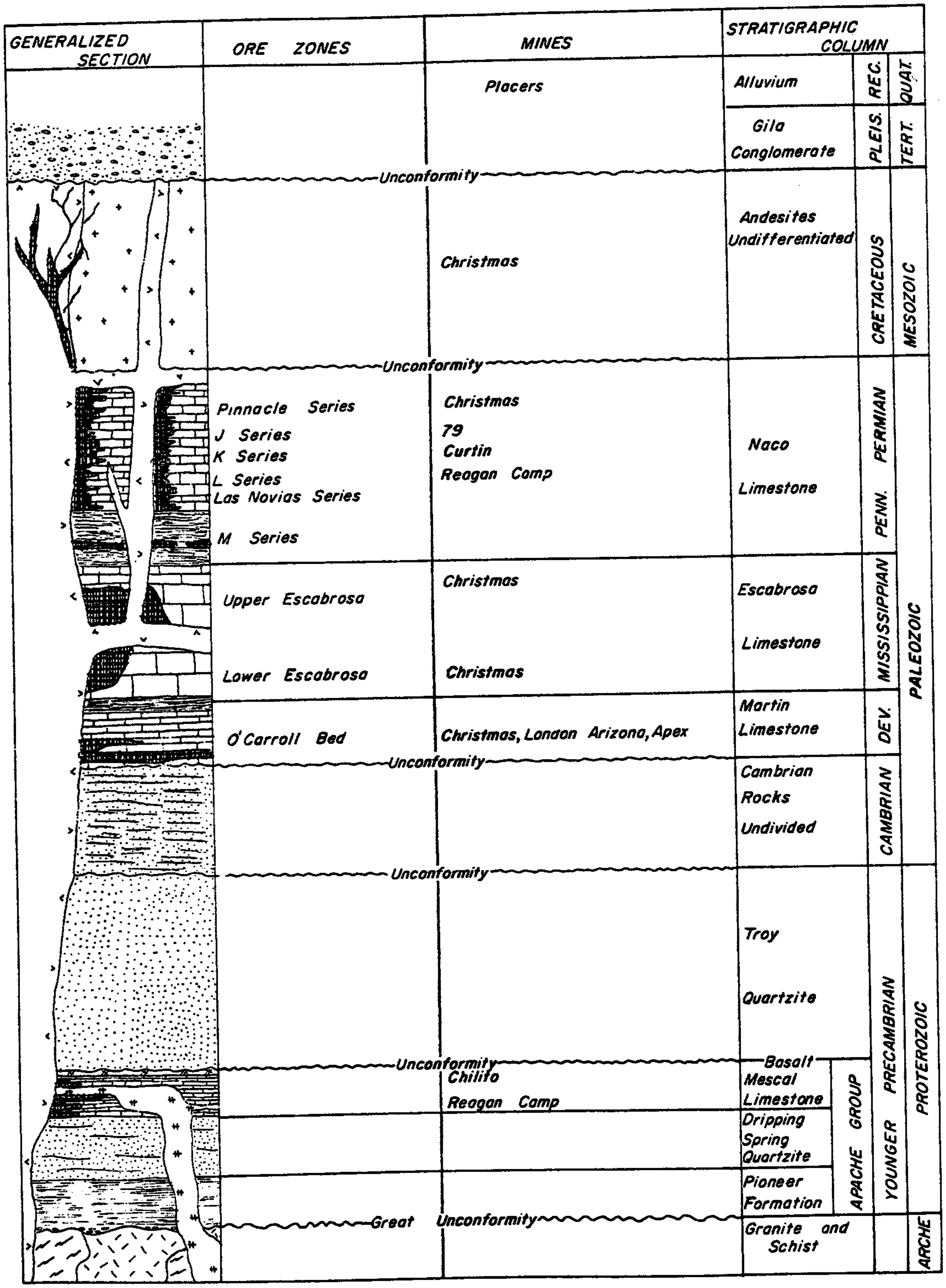
Other pipe-like replacement deposits form the main ore body or ore bodies of many of the smaller mines and prospects in the district. Commonly these bodies occur at the intersections of the east-west-striking pre-mineral faults with northeast-trending fracture and shear zones. Usually, where the pipes crosscut bedded sediments, some control of ore deposition by stratification can be observed.

VEIN DEPOSITS Vein deposits are common throughout the district, but most are too narrow or discontinuous to be mineable for more than short distances. Ore deposition is localized along two different sets of faults, one set occurring as the east-west-trending faults and the other as N15° to N55°E faults. The most notable of the vein deposits occur at the Seventy-Nine and Apex mines (Figure 2). At the Seventy-Nine mine, discontinuous vein deposits were mined along the strike of a N80°E-trending dike of quartz prophyry. In another generally east-west-trending vein at the Apex mine, the ore occurs along a steeply dipping fracture zone in the Martin limestone. Ore was mined from a body about 300 feet in length, about 15 feet in height, and from a few inches to several feet in width (1, p. 64).

Two N20°E striking vein deposits at the Christmas mine, which give promise to be economically important, are exposed in the hanging wall of the Joker fault on the 1300 level (Figure 3). The veins have not been developed to any lateral or vertical extent, but both veins average good assay grades for over 15 feet in width. These veins, together with the pipe-like ore bodies previously described, form part of a larger mineralized area consisting of a stockwork of fractures into which quartz and sulfide minerals have been introduced. The area has not been studied in detail, but it is interesting to note that this mineralization is similar in character to many of the porphyry copper deposits. The occurrence of several breccia dikes in the area, although not an exclusive characteristic of the prophyry coppers, show a common bond with many of them.

Stratigraphic Relations of the Ore Bodies

Within the Banner district certain formations are more favorable for ore deposition than others. In general, the formations that



ORE ZONES	MINES	STRATIGRAPHIC COLUMN		
	Placers	Alluvium	REC.	QUAT.
		Gila Conglomerate	PLEIS.	TERT.
Unconformity				
	Christmas	Andesites Undifferentiated	CRETACEOUS	MESOZOIC
Unconformity				
Pinnacle Series J Series K Series L Series Las Novias Series M Series	Christmas 79 Curtin Reagan Camp	Naco Limestone	PERMIAN PENN.	PALEOZOIC
Upper Escabrosa Lower Escabrosa	Christmas Christmas	Escabrosa Limestone	MISSISSIPPIAN	
O'Carroll Bed	Christmas, London Arizona, Apex	Martin Limestone	DEV.	
Unconformity				
		Cambrian Rocks Undivided	CAMBRIAN	
Unconformity				
		Troy Quartzite	YOUNGER PRECAMBRIAN	PROTEROZOIC
Unconformity		Basalt		
	Chilito Reagan Camp	Mescal Limestone	APACHE GROUP	
		Dripping Spring Quartzite		
		Pioneer Formation		
Great Unconformity				
		Granite and Schist		ARCHE

FIG. 4. *Correlation of Major Rock Units and Ore Zones, Banner Mining District, Arizona.*

are comprised of limestone, dolomite, and calcareous shale are most favorable. Quartzite, conglomerates, and hornfels are unfavorable. The relationship of the ore zones to the major rock units are shown on Figure 4.

Ore deposits at the Christmas mine occur in altered dolomites of the lower and middle units of the Martin limestone of Devonian age, in the massive limestones in the upper and lower parts of the Escabrosa limestone of Mississippian age, and in the thin-bedded limestones of the Naco limestone of Pennsylvanian age. Other deposits are stratigraphically associated with Cretaceous volcanic rocks. The Curtin and Seventy-Nine mines are in the middle member of Pennsylvanian limestones. The London-Arizona and the Apex mines are in the thin-bedded dolomites of Devonian age. The oldest of the mineralized beds is in the Mescal formation of Precambrian age at the Chilito mine.

Mineralogy of the Deposits

On a district-wide scale, mineralization within the separate mine areas demonstrates a general zonal distribution, probably reflecting an overall variance in temperature at the time of ore deposition. The Chilito-London-Arizona and the Christmas areas seem to represent central zones of copper mineralization. Surrounding these areas are other mineralized deposits containing a lower temperature assemblage of minerals such as galena, sphalerite, and gold.

The major economic hypogene ore minerals of the Banner district are chalcopyrite, bornite, sphalerite, and galena. Other primary minerals of lesser importance include chalcocite, covellite, cubanite, molybdenite, gold, and silver. Pyrite, magnetite, pyrrhotite, and hematite are the most abundant and widely distributed metallic minerals.

Within the Christmas mine, the various rocks have been altered and mineralized to different extents, with each stratigraphic sequence showing a characteristic mineral assemblage and a well-defined pattern of zoning. In general, the ores of the upper stratigraphic horizons contain less iron, but with depth, magnetite and iron sulfide minerals become increasingly abundant.

In the Cretaceous section, the upper part of the pipe-like ore bodies, exposed to the east of the Joker fault on the 800 level, are composed of a central core of quartz, bornite, chalcopyrite, and chalcocite. Surrounding these bodies is a halo of weaker mineralization consisting of a stockwork of numerous veinlets of quartz, chalcopyrite, and bornite. Laterally away from the central zone of mineralization, pyrite becomes more plentiful. The lower parts of these bodies have not been exposed, but cores from diamond-drill intersections show some increase in primary chalcocite with depth.

The quartz-mica diorite around these pipe-like bodies appears to be silicified; however, thin section studies show no appreciable additions of silica. Actually the rock has undergone extensive hydrothermal alteration and recrystallization, resulting in the formation of abundant secondary quartz and orthoclase along with some sericite and clay. A few fragments of altered diorite are found within the pipes; these appear to be literally "soaked in quartz."

The widespread extent and distribution of mineralization in the quartz-mica diorite and in the surrounding andesite has many features common to the porphyry-copper deposits. Although rock alteration is comparatively mild, the development of large amounts of secondary biotite in the andesite and the alteration of the diorite into an aggregate of sericite and secondary quartz seem to fit the normal porphyry-type alteration.

Secondary enrichment in the Cretaceous section appears to be of minor importance. Some leaching and redeposition of copper minerals are localized along fracture and fault zones, but in places primary sulfides can be found at the surface. Secondary ore minerals include chalcocite, cuprite, melaconite-tenorite, native copper, and chrysocolla.

To the west of the Christmas fault zone (in its footwall) along the north and south sides of the main intrusive mass, bedded deposits in limestones of Pennsylvanian age outcrop at the surface and are exposed in the mine workings on the 300, 400, 500, and 600 levels. In the hanging wall of the Christmas fault, down-dropped extensions of these beds are found along the north contact zone on the 800, the 1300, and the 1600 levels. Primary mineralization in these bedded replacement deposits consists mainly of magnetite and pyrite near the intrusive mass, grading laterally into an intermediate zone of chalcopyrite and bornite, and into an outer zone of chalcopyrite, pyrite, sphalerite, and minor galena. Generally the individual ore-bearing beds average from 6 to 60 feet in thickness, with the thicker sections adjacent to the intrusive contacts. Gangue minerals are largely grossularite and andradite garnet with lesser amounts of quartz, idocrase, epidote, and wollastonite. Some clays, serpentine, and chlorite, resulting from hydrothermal alteration, are apparent near the intrusive contacts. Generally, in the outer zone, the lime-silicate minerals decrease, and marble becomes predominant.

Production from the Naco beds above the 300 level was mostly from oxidized and partly oxidized ores. Supergene enrichment was evidently of minor importance, although local concentrations of chalcocite, copper carbonates, and native copper are found along some fracture zones. Oxidation along the Christmas and Joker fault zones extend down to the 1600 level. Supergene ore minerals are chalcocite, cuprite, tenorite, malachite, azurite, dioptase, brochantite, and chalcanthite.

Lower in the sedimentary series, the irregular replacement ore bodies in the massive Escabrosa limestones exhibit their own distinctive mineral assemblage. The gangue minerals consist of garnet, marble, clays, chlorite, diopside, and tremolite. The clay minerals, together with tremolite, diopside, and chlorite, predominate near the intrusive contacts, grading into garnet and tremolite in the intermediate zone, and into garnet-marble to marble in the outer extremities. Where the ore bodies are completely surrounded by diorite, a central core of weakly mineralized marble or garnet-marble will usually be present.

Principal metallic minerals include magnetite, pyrite, chalcopyrite, bornite, and sphalerite, and there are some small amounts of specularite, molybdenite, and galena. Magnetite, pyrite, and chalcopyrite generally predominate adjacent to the intrusive contacts with sphalerite, specularite, and galena localized at the outer edges.

In the deeper levels of the Christmas mine, the lower Martin limestones and dolomites are extensively replaced by anhydrite and antigorite. These alteration products are interbedded with layers and lenses of other gangue minerals which include chondrodite, diopside, tremolite, actinolite, sericite, and chlorite. Several narrow veins of hedenbergite, barite, magnetite, and feldspar and numerous small veinlets of anhydrite, gypsum, brucite, and zoisite occur throughout the deposit, representing a late state in mineralizing activity.

Zonal arrangements of the gangue minerals have not been studied in any detail, but, in general, three zones are recognized. They are: (1) a near-contact zone of anhydrite, chondrodite, and antigorite; (2) a central zone of anhydrite, antigorite, and tremolite-actinolite; and (3) an outer zone of antigorite, sericite-chlorite, anhydrite, and gypsum.

The metallic minerals are predominately magnetite, pyrite, pyrrhotite, chalcopyrite, bornite, and sphalerite, with lesser amounts of hematite, molybdenite, galena, chalcocite, covellite, and cubanite. Magnetite occurs throughout the mineralized stone, forming from 15 to 25 per cent of the total mineral content. The later sulfide mineralization demonstrates a well-defined zoning, both in laterally and vertically. In the thicker sections, the footwall and hanging wall show a marked decrease in bornite grading away from the central zone, with pyrite, sphalerite, and local galena becoming more plentiful towards the edges. Laterally away from the central intrusive mass, the mineralization grades from a pyrite-chalcopyrite zone to a chalcopyrite-bornite intermediate zone to a pyrrhotite-pyrite-sphalerite-chalcopyrite outer zone.

In the London-Arizona workings, most of the ore in the lower Martin formation was enriched, containing local concentrations of chalcocite, cuprite, malachite, azurite, brochantite, and chalcanthite. Hypogene minerals still in evidence are magnetite, pyrite, chalcopyrite, and pyrrhotite in a gangue of serpentine and anhydrite.

The ore bodies in the Mescal limestone at the Chilito mine were largely oxidized, but some pyritic material enriched by a supergene chalcocite was found (1, p. 63). Recently, low-grade oxidized copper ore in the Troy Quartzite was mined and shipped as smelter flux.

The positions of the lead-zinc ore bodies at the Seventy-Nine and Curtin mines relative to the copper deposits of the Christmas and Chilito mines suggest that there is a zonal arrangement along the east-west trending fault and dike systems. Zoning is further indicated by the lead-gold ore deposits to the northwest at the Apex and Santa Monica mines, and by the silver-gold-lead-zinc deposits to the southeast across the Gila River in the Saddle Mountain district.

The ore deposits at the Seventy-Nine mine are described in detail by Kiersch (2, p. 77–78). Near-surface deposits consisted mainly of oxidized ores of lead. Some azurite, malachite, brochantite, and chalcanthite occurs throughout the oxidized zone, but nowhere are they abundant enough to constitute copper ore. Hypogene metallic minerals are pyrite, sphalerite, argentiferous galena, chalcopyrite, and hematite. Gangue minerals include quartz, garnet, argillic material, and kaolin. With depth the sulfide ores show an increase in the zinc-to-lead content, and pyrite becomes more plentiful in the deeper levels.

The ore bodies at the Curtin mine are almost completely oxidized. Some residual galena and pyrite remain, but oxidized ore minerals—anglesite, cerussite, and hemimorphite—predominate along with lesser amounts of plumbojarosite, mottramite, and smithsonite. The gangue contains quartz, garnet, and kaolin.

Wall-Rock Alteration

Most of the rocks in the region were altered to some extent by processes related to plutonic intrusion and to later mineralizing activity. The wall-rock alteration has not been studied in any detail, but, in comparison with other major ore deposits in central Arizona, the effects are relatively mild.

Hydrothermal alteration in the andesites around the Christmas ore deposit reflects the extent of the mineralizing solutions. Near the central intrusive mass, large amounts of fine grained secondary biotite together with numerous veinlets of quartz typically flood the andesites. Away from the deposit, a peripheral alteration zone, characterized by irregular patches and abundant veinlets of epidote, extends over a mile from the ore body.

Near the intrusive borders, the quartz-mica diorite has been conspicuously and selectively altered. The original rock-forming minerals have undergone hydrothermal alteration and recrystallization to form large amounts of secondary quartz and orthoclase together with some calcite, clay, and sericite. This stage of alteration appears to be earlier than the main period of ore deposition, possibly occuring in conjunction with the extensive hydrothermal alteration of the lower Devonian beds.

There is no doubt that most of the silication in the Naco and Escabrosa limestones and the silicification of the Naco and Devonian shales are due to contact metamorphism. In the upper limestones, many of the earlier metamorphic products are much in evidence; although, near the intrusive contacts, later hydrothermal action has altered some of the original constituents to clay, serpentine, and chlorite.

Petrographic work indicates that the hornfels alteration of the Naco and Upper Devonian shales represents metamorphism of calcareous argillites with recrystallization of quartz. There is no evidence of the introduction of silica.

Alteration of the lower Devonian dolomites and dolomitic limestones is extensive, evidently the result of contact metamorphism followed by later hydrothermal activity related to ore deposition. Original metamorphic products include chondrodite, tremolite, marble, and possible pyroxene minerals. Later hydrothermal alteration converted part of the chondrodite and all of the pyroxene (?) to antigorite and probably at the same time altered the interstitial calcite in the marble to anhydrite. No remnant of carbonate is found within the mineralized zone. Most of the magnetite and hematite appear to have been deposited during this period.

Above the mineralized deposit, the beds are almost completely dolomitized and numerous irregular veinlets and apophyses of serpentine, anhydrite, and magnetite extend into the hanging wall. The footwall quartzite on the other hand contains much calcareous and argillaceous material. The diversity of alteration affecting the two adjacent rock types is surprisingly great.

Mineralization in the lower Devonian beds at the London-Arizona mine consists largely of secondary minerals of copper in association with magnetite, serpentine, anhydrite, and gypsum. Similarly, as at Christmas, very little carbonate remains within the mineralized zone.

In many of the other mines in the district, secondary mineralization also masks much of the original characteristics of the rocks, but some forms of hydrothermal alteration are apparent. Near the intrusive contacts at the Curtin mine, many of the shales and shaly limestone beds are strongly kaolinized. Kaolinization of the quartz-mica diorite is also evident along the contact zones, with local occurrences of sericite and serpentine.

At the Seventy-Nine mine, Kiersch (2, p. 76) describes an argillized material, evidently of hydrothermal origin, that is associated with the better mineralized portions of the discontinuous vein deposits.

Paragenesis

The paragenesis of the principal ore and gangue minerals of the lower Devonian ores is shown diagrammatically in Figure 5. The paragenetic sequence is based on a preliminary thin-section study by Dennis P. Cox, formerly of The Anaconda Company, and on a later polished-section study by Wilson McCurry, a graduate student at the Arizona State University. The author, however, assumes all responsibility for interpretation of the data provided.

The mineralization is divided into an earlier metamorphic stage, a hydrothermal alteration stage, a main sulfide mineralization stage, and

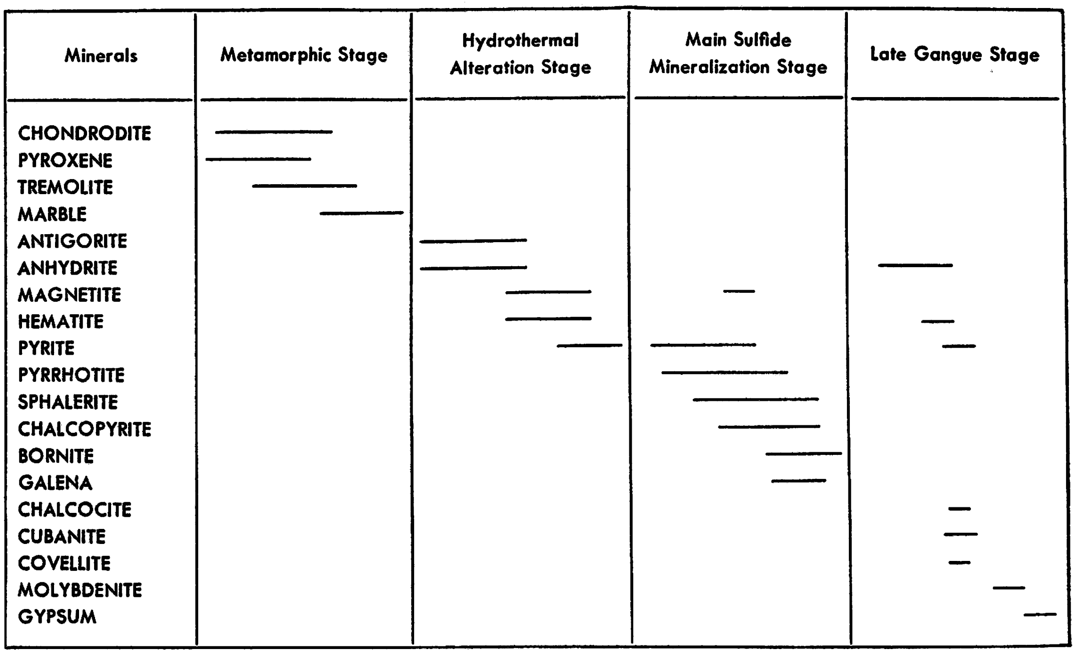


FIG. 5. *Paragenesis of Mineralization and Alteration in the Lower Part of the Martin Formation.*

a late gangue stage. There evidently were considerable time intervals between the metamorphic stage and the start of the hydrothermal alteration stage, and between the end of the hydrothermal alteration stage and the start of the sulfide mineralization stage. It is probable, however, that once the sulfide mineralization started, it took place over several intervening structural events in a nearly continuous sequence.

The initial hydrothermal solutions must have been rich in sulfur and iron. In the lower Devonian beds, the early metamorphic products were extensively altered to anhydrite and antigorite, and abundant amounts of magnetite, with some hematite. The age of antigorite relative to anhydrite is not known. Chondrodite is replaced by antigorite, and anhydrite and chondrodite commonly occur together. Anhydrite is sometimes surrounded by antigorite, and, in many instances, they occur together along mutual boundaries. They are probably essentially contemporaneous. Magnetite and hematite are later than antigorite and anhydrite.

Pyrite is the earliest sulfide mineral. It veins magnetite and hematite and is disseminated in grains throughout antigorite and anhydrite. Pyrite occurs as relicts in sphalerite, chalcopyrite, and pyrrhotite. Pyrrhotite is veined and replaced by chalcopyrite and sphalerite. Chalcopyrite occurs as oriented blebs in sphalerite, probably through unmixing. Bornite veins and replaces sphalerite and chalcopyrite, but, in some instances, blades of chalcopyrite and chalcocite show exsolution intergrowths along the chrystallographic planes of bornite (McCurry, written communication, 1964). Galena is interstitial to sphalerite and chalcopyrite, possibly in part replacing them.

Late veinlets of anhydrite and gypsum cut all the above minerals. Associated with the later anhydrite veinlets, chalcocite and covellite selectively replace bornite, and cubanite occurs as parallel laths in chalcopyrite. Also in conjunction with this stage, pyrrhotite is sometimes altered to pyrite, to magnetite, and to hematite. Molybdenite is late and is commonly introduced with a late anhydrite gangue. Coarse calcite and botryoidal marcasite are the latest minerals, and at the present are still being locally deposited from hot waters along open fractures.

No detailed mineralogical study has been made of the ore deposits in the Escabrosa and Naco limestones. However, the stages of mineralization that are present in the lower Devonian beds are readily recognizable, even though different mineral assemblages prevail.

In the pipe-like ore bodies in the hanging wall of the Joker fault, at least three periods of sulfide mineralization are apparent. In the first stage, quartz, bornite, and chalcopyrite appear to have been deposited at the same time; much of the quartz, however, was probably formed earlier during the hydrothermal alteration stage. In the second period, steep veinlets of quartz, containing disseminations of magnetite, chalcopyrite, bornite, and pyrite, cut the earlier mineralization. Later bornite and chalcopyrite vein the minerals of both earlier periods.

The paragenetic sequence of hypogene minerals from the lower levels of the Seventy-Nine mine is discussed by Kiersch (2, p. 77–78). Pyrite is commonly associated with specular hematite in some bodies and was the earliest sulfide mineral formed. Deposition of pyrite and hematite, corresponding to the deposition of magnetite in the hydrothermal alteration stage at Christmas, ceased before the next stage of sulfide mineralization began. In this stage, sphalerite is early, containing numerous small blebs of chalcopyrite. Galena veins the sphalerite, and, in some instances, forms mutual boundaries with chalcopyrite. Galena and chalcopyrite are regarded as essentially contemporaneous. Quartz, representing the late gangue stage, cuts and replaces the sulfide ores.

Factors Controlling Form and Location of Ore Bodies

The principal ore deposits of the district are in altered carbonate rocks near the contacts with silicic intrusive bodies. Other smaller ore bodies occur in the vicinity of the contact zones within these intrusive bodies. Ore mineralization is directly proportional to the extent of metamorphism and hydrothermal alteration. These, in turn, are functions of proximity to the intrusive contact, of the characteristics of various rocks, and of certain structural controls.

ALTERATION CONTROL The distribution and extent of alteration by metamorphic and hydrothermal processes directly influenced the localization of ore bodies. At Christmas, ore minerals selectively replaced the hydrothermally altered dolomites of the lower Martin formation and the garnetized limestones of the Escabrosa and Naco formations. Within all these formations, the thicker portions of the ore bodies are adjacent to the intrusive contacts where the intensity of metamorphism and hydrothermal alteration were greatest.

Ore bodies in the Chilito and London-Arizona area are in hydrothermally altered dolomites and limestone of the Precambrian Mescal and the Devonian Martin formations. The thicknesses of these deposits are limited by the vertical extents of the altered zones.

Generally, in the smaller mines of the district, the most striking feature is the small extent of alteration in the sediments surrounding the intrusive bodies. Ore bodies in these areas are commonly localized in the altered zones near or adjacent to the intrusive contacts.

STRUCTURAL CONTROLS At least three sets of fault and fracture systems can be distinguished, all of which appear to have been developed prior to the period of mineralization. These systems include steep east-west faults, steep northeast faults, and steep northwest faults.

The most prominent of these systems are faults transverse to the regional trend of folding. This group, generally referred to as the east-westers, strike between N65°E and N70° and dip 70°S to 50°N. Original displacements along these zones served to localize the emplacement of the earlier fine-grained dioritic and aplitic bodies, and the later intrusions of quartz-mica diorite and dacite porphyry. Recurrent movements along these zones, both before and after mineralization, are clearly demonstrated.

The east-west system must have been developed as strike-slip faulting complementary to the trend of regional compression, but well-defined slicken-sides give evidence that most of the recent post-mineral movement was normal.

Persistent northeast shear zones strike N15° to 55°E and dip from 50°NW to 65°SW. The relationship of these structures to the east-westers is not clear. In some instances, they appear as tension fractures in conjunction with the east-west faulting, but, for some of them, a later age is indicated by northeast-striking hornblende andesite dikes which crosscut the earlier diorite porphyry.

The northwest faults and fractures form a separate, well-defined system with N5° to 40°W trends. The northwesters are later than the other groups, appearing in many instances as tension shears between the northeast and eastwest faults. Later post-mineral movement along the major northwest faults evidently followed these earlier zones of weakness.

Zones of alteration and mineralization, associated with east-west faulting, are traceable for approximately 6 miles across the district through the Christmas, Chilito, and London-Arizona, and Seventy-Nine areas (Figure 1).

The east-west faults, in addition to providing channels for the hydrothermal and mineralizing solutions, also influenced ore deposition at their intersections with favorable beds and with other structures. In a few occurrences, they form strongly mineralized veins.

The northeasters are most intensely mineralized at their intersections with the east-westers, forming several pipe-like ore deposits. These bodies commonly occur near an intrusive contact in either an altered sedimentary or intrusive rock. In most instances, however, the northeast system (together with the north-west fissures) form, at their intersections with favorable beds, the loci for sulfide mineralization.

The bedding characteristics of the carbonate rocks which comprise each formation played an important role in influencing the thickness and lateral extent of ore deposition. Flat-dipping, tabular deposits are commonly formed in the thin-bedded calcareous rocks of the Naco and Martin formations. In contrast, ore bodies in the massive Escabrosa limestones have a limited horizontal extent away from the intrusive contacts.

The importance of folding in ore localization appears to be minor; where a fold yielded to compressive stresses, however, thrust faulting and flat-dipping shears at low angles to the bedding provided for the lateral distribution of hydrothermal solutions. These fractures were later instrumental in localizing ore along the bedding between the steeper structures.

INTRUSIVE CONTACT CONTROL The quartz-mica diorite stocks and related intrusive bodies had a direct effect in the localization of ore deposits. The rocks surrounding these intrusive bodies were extensively fractured, faulted, and metamorphosed. Hydrothermal solutions, evidently ascending along fault and fracture zones near their intersections with intrusive contacts, subjected the metamorphosed rocks to various degrees of metasomatic alteration. Later ore solutions, undoubtedly traveling along the same channelways, formed the replacement ore bodies in favorably prepared areas.

Figure 6 illustrates the localization of ore near the contact of the Christmas stock. Ore fluids, probably ascended along the contacts, formed the thicker portions of the ore bodies adjacent to the main intrusive mass. The decrease in the intensity of ore mineralization outward from the intrusive contact zones and inward toward the interior of the stock presents direct evidence of intrusive-contact control. Furthermore, the zonal arrangement of ore minerals within each of the ore deposits throughout the stratigraphic section stresses the probability that the ore solutions must have been directed along restricted conduits before being introduced into the various zones favorable to ore deposition.

Vertical chimneys of ore in the Curtin mine workings were localized near the intrusive dike contacts, and mineralization decreases in intensity away from these pipe-like bodies. Other examples of intrusive-contact control are demonstrated by the ore bodies along and within the North dike area at the Seventy-Nine mine. Here, the intrusive rock has been fractured, hydrothermally altered, and extensively mineralized.

ECONOMIC GEOLOGY—SECONDARY ORE

In the Banner district, oxidized and secondary enriched ores constituted most of the production prior to 1940. The principal minerals developed during oxidation of the primary ores were hydrous iron oxides, malachite, azurite, cuprite, tenorite, dioptase, chalcocite, native copper, anglesite, cerussite, and hemimorphite. Small amounts of manganese oxide, chalcanthite, covellite, turquoise, hydrozincite, and plumbojarosite are generally present in certain oxided zones, and local occurrences of mottramite, vanadanite, wulfenite, smithsonite, and brochantite have been reported in various workings.

At the Christmas mine, secondary enrichment was poorly developed. Most of the ore mined above the 300 level was partly oxidized, with some enrichment by secondary chalcocite and native copper. Except along certain fracture zones, the structure and composition of the Naco limestones are not favorable for the widespread migration of copper, and the topography of the area encourages the rapid runoff of surface waters. Oxidation is deepest and best developed along fracture and fault zones, extending to a maximum depth of 1400 feet below the surface along the Christmas and Joker faults. East of the Joker fault, sparse iron oxides and primary sulfides are found in the andesites at the surface, indicating that the possibility of finding any significant enriched zones in the Cretaceous section is small.

The ore mined in the Chilito and London-Arizona areas was largely oxidized, with some enrichment by supergene chalcocite (1, p. 62–63). In the stopes that are now accessible, particularly in the London-Arizona workings, mining apparently was selective in the higher-grade portions of the copper mineralization.

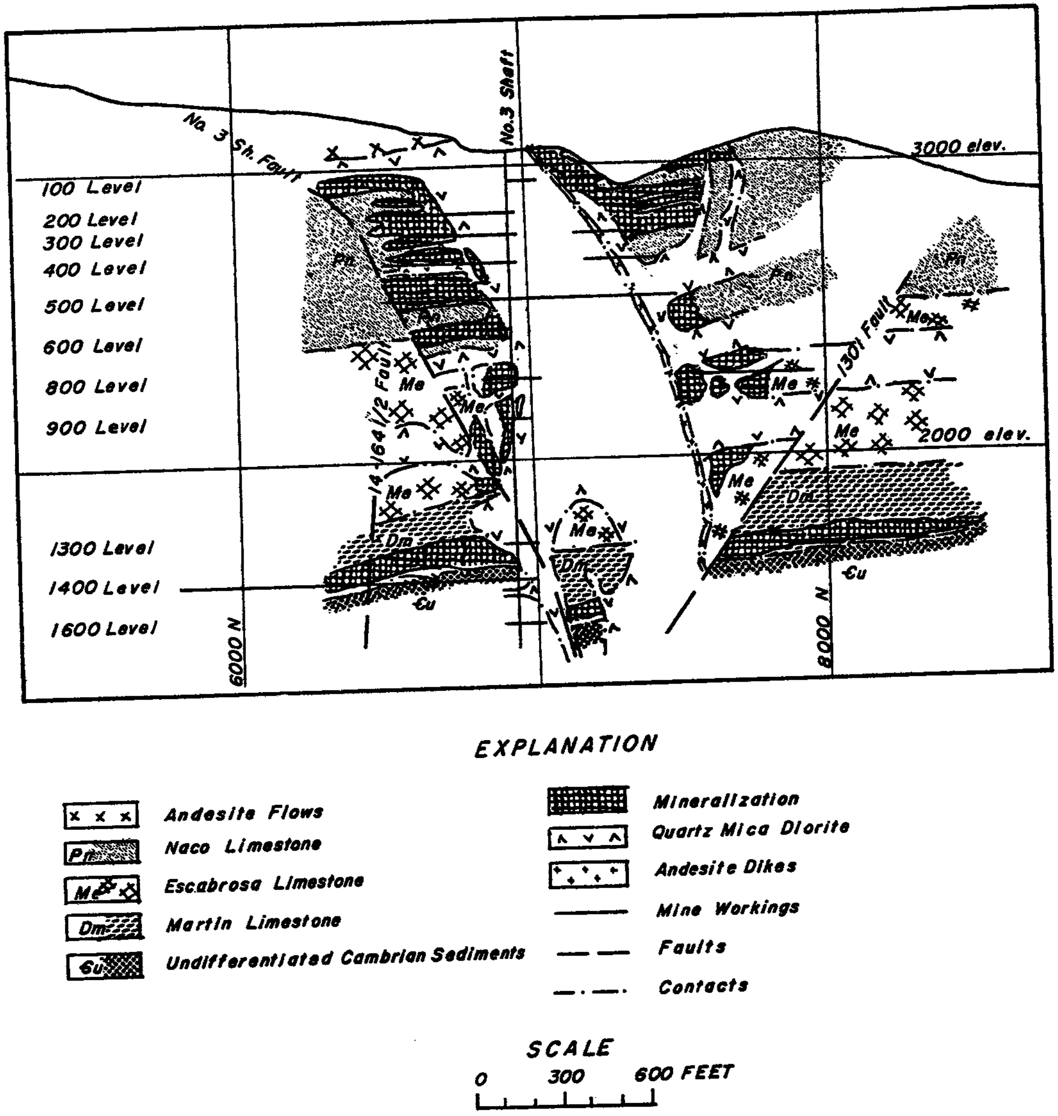


FIG. 6. *North-South Section 16400 E., looking west, Christmas Mine, Arizona.*

Structure evidently was the dominant factor in the localization of these enriched zones.

Oxidation and supergene enrichment at the Seventy-Nine mine is briefly discussed by Kiersch (2, p. 79). Here the oxidized zone generally extends to about the 6th level, approximately 400 feet below the surface; however, along the North dike and within certain fracture zones, oxidation penetrates to below the 6th level. Generally, the oxide-sulfide boundaries are gradational in both horizontal and vertical directions, although abundant relict galena was reported in the upper stopes (1, p. 66). Zinc minerals in the oxide zone have been largely removed.

Elsewhere in the district, structure appears to be the most important factor in the localization of secondary mineralization, but in some deposits the rock composition played an important part. At the Curtin mine, the pipe-like ore bodies are almost completely oxidized, with little relict galena remaining. However, one of the most striking features here is that there was little apparent migration of the zinc. Evidently restricted circulation of the ground water, together with unreplaced limestone in the gangue, prevented the transportation of zinc away from the area.

ORE GENESIS—CONCLUSIONS

The ore deposits of the Banner district show the inter-relationship of intrusive activity, metamorphism, hydrothermal alteration, and metallization. Within the district, the intrusive sequence is fine-grained diorite, quartz-mica diorite porphyry, dacite porphyry, hornblende andesite, and olivine basalt. Hydrothermal alteration and ore deposition, in separate and distinct stages, are late in the intrusive sequence, occurring between the dacitic and andesitic intrusions.

The mineralogy of the deposits is not unique, but distinctive mineralogical features within different geologic environments are well-illustrated, particularly at the Christmas mine. Here, ore deposits in the forms of stockworks of veinlets and veins, contact pipes, irregular massive replacements, and bedded replacements are localized by certain alteration effects and by structural developments that predate the period of ore deposition.

Throughout the district, the proximity of the intrusive contacts, the extent of metamorphism and hydrothermal alteration, and the intensity of pre-mineral fracturing are the dominant controls on the localization of the ore bodies. The widespread distribution of minerals characteristic of intermediate temperatures, places these deposits in the mesothermal class. While the mineral associations of these deposits are suggestive of a contact metasomatic or pyrometasomatic type, their character is clearly demonstrated to be that of normal replacement deposits.

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